Proceedings of the Session on

Construction Management and Tall Building and Urban Habitat

6th International Conference on

Structural Engineering and Construction Management 2015

Kandy, Sri Lanka

11th to 13th December 2015

Abstracts of 6th International Conference on Structural Engineering and Construction Management 2015

Vision

Promoting innovative research for tomorrow's development

Mission

To meet experts, colleagues and friends in the field and to exchange findings, concepts and ideas on research for the development of a sustainable world

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Preface

It is with great pleasure that we present the Proceedings of the 6th International Conference on Structural Engineering and Construction Management (ICSECM 2015). This is the sixth conference consecutively organized following the 1st International Conference on Sustainable Built Environment in 2010, 2nd International Conference on Structural Engineering and Construction Management in 2011, 3rd International Conference on Sustainable Built Environment in 2012, 4th International Conference on Structural Engineering and Construction Management in 2013 and the 5th International Conference on Sustainable Built Environment in 2014, keeping its tradition of adhering to engineering excellence.

Taking a step forward from the last four events, the coverage of specialty areas of this conference has been diversified. This book contains the abstracts of research papers from ten different sub specialties in Construction Management, Construction Materials and Systems, Structural Health Monitoring, Structural and Solid Mechanics, Earthquake Engineering, Fatigue Damage of Materials, Water Safety, Hydraulic Structures, Tall Building and Urban Habitat and MSW and Landfill Management. We expect that all these abstracts will be presented in parallel sessions from 11th to 13th December 2015.

We would like to express our appreciation to all keynote lecturers for their invaluable contribution for the development of a sustainable world. We are very much grateful to the authors for contributing research papers of high quality. The research papers of these abstracts in the publication have been peer-reviewed. The enormous work carried out by the reviewers is gratefully appreciated. We are also pleased to acknowledge the advice and assistance provided by the members of the international advisory committee, members of the editorial committee along with many others who volunteered to assist to make this very significant event a success. Finally, we acknowledge the financial sponsorship provided by many organizations that has been extremely helpful in successfully organizing this international conference.

It is the earnest wish of the editors that this book of abstracts and volumes of proceedings would be used by the research community and practicing engineers who are directly or indirectly involved in studies related to Construction Management.

Editorial Committee

6th International Conference on Structural Engineering and Construction Management 2015

11th December 2015.

Message from Conference Chairmen

It is a pleasure for us to welcome all the participants to the 6th International Conference on Structural Engineering and Construction Management 2015 in Kandy, Sri Lanka. We, the co-chairs would gratefully like to mention the previous successful conferences, the 1st International Conference on Sustainable Built Environment 2010, 2nd International Conference on Structural Engineering and Construction Management 2011, 3rd International Conference on Sustainable Built Environment 2012, 4th International Conference on Structural Engineering and Construction Management 2013 and the 5th International Conference on Sustainable Built Environment in 2014, all held in Kandy, Sri Lanka.

The theme selected for the conference - Structural Engineering and Construction Management- is extremely relevant for today's world. With the vision of promoting innovative research for tomorrow's development, we organize this conference as a meeting place of talents, knowledge and dedication. Therefore, we trust that the conference will produce great ideas from a variety of research and exchange the knowledge of experts, colleagues and friends who are working for the world's sustainable development.

The conference focuses on ten different sub topics in Structural Engineering and Construction Management: Construction Management, Construction Materials and Systems, Structural Health Monitoring, Structural and Solid Mechanics, Earthquake Engineering, Fatigue Damage of Materials, Water Safety, Hydraulic Structures, Tall Building and Urban Habitat and MSW and Landfill Management. The proceedings of the conference are peer reviewed. The full papers are published in five volumes in paper format with a book of abstracts.

The host city of the conference, Kandy, is a world heritage city famous for its unique architecture, culture, natural beauty and climate. We hope that you will enjoy your time in Kandy during the conference.

We, the conference co-chairs express our sincere thanks to our guests, keynote speakers, authors, members of the international advisory committee, members of the editorial committee financial sponsors and many others who volunteered to assist to make this very significant event a success.

Prof. Ranjith Dissanayake
Prof. S.M.A. Nanayakkara
Prof. Priyan Mendis
Prof. Janaka Ruwanpura
Dr. Y.G.S. De Silva
Eng. Shiromal Fernando

Co-chairs

6th International Conference on Structural Engineering and Construction Management 2015
11th December 2015.

Message from
Dean, Faculty of Engineering, University of Peradeniya.

I am glad to submit this message for the Sixth International Conference on Structural Engineering and Construction Management (ICSECM-2015), which is a continuation of the efforts of the organizers to share knowledge and research in the sectors. This time too, the conference is held in historic city of Kandy, in Sri Lanka.

The ICSECM - 2015 is organized as a joint effort of a number of professionals, and a number of institutions; including Engineering Faculties of Peradeniya, Moratuwa and Ruhuna Universities in Sri Lanka. The topic covered and the keynotes delivered by professionals in the field add more depth to the objectives and outcomes of the conference.

I take this opportunity to thank the organizers for their commitment and persistent effort to make the conference a success. These events facilitate a forum for many young undergraduate and postgraduate students to receive a good initial exposure to present their work, and for some few, to get a flavor of organizing events of global importance.

I believe that the organizers of ICSECM-2015 will continue their dialog of bringing concerned professionals from diverse fields, from different parts of the worlds, into the discussion forum of ICSECM.

I wish the conference a great success.

Prof. Leelananda Rajapaksha

Dean,
Faculty of Engineering,
University of Peradeniya,
Peradeniya,
Sri Lanka.

Table of Contents

SECM/15/1
A STUDY OF EXPERIMENT IN ARCHITECTURE WITH REFERENCE TO PERSONALISED HOUSES
Neesha Silva and Prasad Botejue

SECM/15/4
IDENTIFICATION OF SIGNIFICANT FACTORS INFLUENCING PERFORMANCE OF ROAD CONSTRUCTION INDUSTRY USING FACTOR ANALYSIS
S. B. Wijekoon

SECM/15/11
TEMPORARY SUBSTRUCTURE FORCES DURING BRIDGE SLIDE: IMPACT OF SLIDING FRICTION AND SUBSTRUCTURE ALIGNMENT
U. Attanayake, O. Ridvanoglu and H. Aktan

SECM/15/29
THE SIGNIFICANCE OF BUILDING INFORMATION MODELLING TO THE QUANTITY SURVEYING PRACTICES IN THE UAE CONSTRUCTION INDUSTRY
M. R. Rimas Muhammad

SECM/15/60
ASSESSMENT ON DEFECTS OCCURENCE AND REWORK COSTS IN HOUSING CONSTRUCTION SECTOR IN SRI LANKA
B. M. Y. Dahanayake and T. Ramachandra

SECM/15/81
ANALYSIS OF FACTORS CONTRIBUTING CIVIL ENGINEERING PROJECT DELAYS IN SRI LANKA
M. Kesavan, N. N. Gobidan and P. B. G. Dissanayake

SECM/15/82
THE CHALLENGES AND OBSTACLES OF POST-DISASTER ROAD INFRASTRUCTURE RECONSTRUCTION IN THE PRE-CONSTRUCTION PHASE
E. Hayat, D. Amaratunga and C. Malalgoda

SECM/15/88
STUDY ON THE IMPACT OF ACCIDENTS ON CONSTRUCTION PROJECTS
W.A. Asanka and M. Ranasinghe

SECM/15/103
THIRD REVOLUTION DIGITAL TECHNOLOGY IN DISASTER EARLY WARNING
K. De Silva, D. Amaratunga and R. Haigh

SECM/15/117
BUILDING INFORMATION MODELLING IN PRACTICE: LEARNING FROM THE IMPLEMENTATION OF BIM IN A HOUSING PROJECT IN THE NETHERLANDS
A.A. Aibinu

SECM/15/129
IMPORTANCE OF QUALITY FOR CONSTRUCTION PROJECT SUCCESS
H. Mallawaarachchi and S. Senaratne

SECM/15/132
ADOPTION AND SCOPE OF BUILDING INFORMATION MODELLING (BIM) IN CONSTRUCTION INDUSTRY OF PAKISTAN
A. Adil and A. Fatima

SECM/15/142
APPORTIONMENT AND RANKING OF RISK ELEMENTS IN CONSTRUCTION INDUSTRY OF SRI LANKA-CONTRACTORS' PERSPECTIVE
D.A.R. Dolage and A.L.U.P. Wijesekara

SECM/15/145
INVESTIGATION ON WHOLE BODY VIBRATION EXPOSURES IN WORKERS IN CONSTRUCTION INDUSTRY
Madhushanka J.G.N, Subashi De Silva G.H.M.J and De Silve G.S.Y

SECM/15/148
INVESTIGATION ON HAND ARM VIBRATION EXPOSURES IN WORKERS IN CONSTRUCTION INDUSTRY
R.M.K.S Karunarathna, Subashi De Silva and Sudhira De Silva

SECM/15/149
INVESTIGATION ON CHARACTERISTICS OF NOISE INDUCED BY CONSTRUCTION TRAFFIC
B Thirukumaran, Subashi De Silva and Sudhira De Silva

SECM/15/151
INVESTIGATION ON IMPROVEMENT OF LOW COST NERD SLAB SYSTEM
B.G.V. Sanjaya, W.M.S. Srilal, W.W.P.K. Perera, H.P. Sooriyaarachchi and J.M.R.S. Appuhamy

SECM/15/167
BIM SOFTWARE FRAMEWORK FOR PREFABRICATED CONSTRUCTION: CASE STUDY DEMONSTRATING BIM IMPLEMENTATION ON A MODULAR HOUSE
T. Samarasinghe, P. Mendis, T. Ngo and W.J.B.S. Fernando

SECM/15/171
STRATEGIES FOR PLANNING MOULD FREE AIR CONDITIONED BUILDINGS IN TROPICAL CLIMATES
K.K.G.K.D. Kariyawasm

SECM/15/174
PERFORMANCE OF SAND CEMENT BLOCK PRODUCED WITH PARTIAL REPLACEMENT OF CEMENT BY RICE HUSK ASH
D.S.R.S.S Gunawardhana and J.C.P.H.Gamage

SECM/15/175
BEHAVIOUR OF CONCRETE PRODUCED WITH CEMENT AND RICE HUSK ASH
M.A.Abdullah and J.C.P.H.Gamage

SECM/15/178
Structural Feasibility of a Pre-Cast Building System
P.L.N. Fernando and C. Jayasinghe

SECM/15/71
FACILITIES MANAGEMENT APPROACHES FOR SUSTAINABILITY
N.H.C. Manjula, D.M.P.P. Dissanayake and P.A.D. Rajini

SECM/15/168
STRUCTURAL FEASIBILITY OF VERY-HIGH STRENGTH CONCRETE (100 – 150 MPA) FOR TALL BUILDINGS
K.B.K. Shanaka, P. Mendis, T. Ngo, W.J.B.S. Fernando and B. Waduge

SECM/15/169
FIRE SPALLING OF CONCRETE MEMBERS
M. Hedayati, P. A. Mendis, M. Sofi and T. Ngo

SECM/15/172
WIND DESIGN OF SLENDER TALL BUILDINGS: CFD APPROACH
D. Mohotti, K. Danushka and P. Mendis

SECM/15/001

A Study of Experiment in Architecture with Reference to Personalised Houses

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Abstract: This research is an enquiry into architectural design and construction. It is an examination on how architects experiment and innovate. Research identifies 'design intervention' as the critical and profound feature common to Sri Lankan architecture. Having established that, the question arises as to 'why' this 'richness' has not extended into interventions with building materials and technology? This leads to two key hypotheses; "Architects are not sufficiently involved in experimenting with building material and technology" and "the limited experimenting is due to cost issues".

The research looks at the architecture of personalised houses designed by Chartered Architects in Sri Lanka. This sector receives the most active contribution from the professionals but the approaches are confined to a limited set of practice conventions. Therefore, this segment of the industry is identified as the most appropriate the carry tout the research.

The research is carried out according to a theoretical framework formulated in relation to materials and technology. The study investigates the effects of 'cost' in relation to experiment and attempts to establish the notion of 'experiment' in architectural design process and practice in Sri Lanka.

Keywords: Experiment in Architecture, Materials and Technology, Building Process, Conventions, Cost

1. Introduction

This study is about experimenting in architecture. Experimenting is important to any field. It is the same for architecture. Architecture is a process where the end product or the final outcome is a 'built product'. This 'product' is made using materials and technology. Experimenting is stepping aside the convention and attempting to go beyond, deviate or innovate in practice. In architecture, experimenting leads to;

- Bring economic benefits to the building industry
- Expand existing knowledge and add new knowledge to the industry and its practices
- Innovate, develop materials and technologies
- Satisfy academic, intellectual curiosity and research.

Building construction is a heavily cost driven industry and any attempt to deviate from the standard modes of practice will have considerable cost implications. This situation seems to have restricted experiment and innovation by the architect. The study intends to investigate into this condition and find out what key factors define the scope of their practices in terms of engaging in experiment.

2. Background to the study

"Buildings are not achievements in individual entities. Social development, social cultural Infrastructure, Technical system, Material Investigation, Labour Training has become act of Flexible creative synthesis that brings problems and solutions..." [1](Pathiraja, M, 2014).

The above statement indicates how architecture becomes a product of social, economic and material process. According to ANC Arquitectos, it is a process that combines aesthetic and social issues with economy of means, tectonic research and sensory comfort.

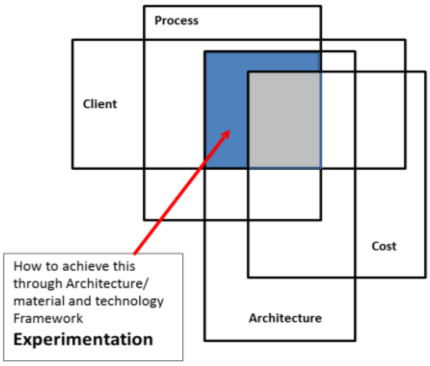

Figure 1: Building Process Framework

The scope of experiment in architecture is a matter of the behaviour of the process, the client and the cost. This framework (Figure 1) provides the scope and limitations of experiment. The research intended to investigate the following in relation to architecture;

1. Investigate the Experimental approach to architecture
2. Investigate what is meant by architectural experiment in material and technology.
3. Find out the architectural community's perception about architectural experiment.
4. Find out about time – cost implications in Architectural Experiment.
5. To find out what are the advantages and benefits of experimenting?
6. To find answers to what makes architects' practice experiment.

3. Methodology

This study is carried out 'combining qualitative and quantitative data to best understand and explain a research problem' [2] (Creswell, 2002, p. 59) and therefore follows a 'Mixed Method Research' procedure.

The following methods were used to gather information and data for this study.

1. Pilot survey
2. Survey on published architectural work
3. Selection of case studies and Interviews
4. Findings and Data analysis

The study will conclude by summarising the findings of the survey and answering the key questions.

4. Significance of the study

The research acknowledges that experimenting is fundamentally to the advancement of the practice and the profession. It is also noted that there is limited research done within the field in relation to the research area. Hence, the research intends to gather knowledge into experiment in architecture.

The lack of awareness of the significance of the research area may also lead to vast amount of valuable knowledge 'getting lost' in practice and such may be noted as a loss of opportunities. Raising awareness of the significance of experimenting as well as the benefits of doing the same may encourage and promote initiatives in that direction.

4.1. Scope and limitations

The main scope of this study is to inquire in to approaches in experimenting in architecture in Sri Lanka. This inquiry focuses on experiment in materials and technology within architectural field. The inquiry extends into finding out the nature of such experimentation. The study also attempts to find;

- The Perception about experimenting among architects.
- Implications of experimenting with materials and technology in architecture.
- Find out the approaches, into experiment in architecture in Sri Lanka.
- Implications on cost and plan of work in experimenting.

The experimenting approach and undertakings, carried out on personalized house projects by the local architects will be the focus of this study. However, the study is not looking at specific detailed experiments for their technical and architectural value. The study will enquire about the intentions, will recognize and record such attempts that have been made.
The key limitations of the study are;

- The study does not consider 'Designing' as a form of 'experiment' in Architecture.
- The samples of projects are limited to published personalised houses in Sri Lanka.
- The case studies are selected from the above-published samples and based on data gathered from survey.
- Experimental architects are selected according to architects' judgment and word survey.
- Case studies are limited to three projects.
- The aspect of experiment is taken, as the focus but not the actual experiment.

- The aspect of ‘cost’ is taken as a key determinant in experiment in architecture, but the actual monitory costs of projects are not considered.
- The implications on fee and architects’ plan of work are noted but the effects are not quantified.

5. Experiment in architecture.

The research investigates implications in architecture in relation to experiment by looking at;

- Modes of interventions and the types of outcomes
- Where such interventions take place
- The significance of studying such interventions in experimental housing designed and supervised by individual practitioners.

5.1 Interventions of experiment n personalised houses.

To research about experiment in Architecture, this study focuses on personalized house sector in Sri Lanka. As the available published information indicate, it is believed that at this segment of the market is where the architects have experienced the least amount of commercial pressure and as a result to have enjoyed most amount of ‘design freedom’ as opposed to other types of projects. This design freedom, intimate and informal relationship with the client that most architects have enjoyed while working in this sector, has given them the best opportunity to experiment and speculate. Without a specific survey, such assumptions may be difficult to establish but this study intends to justify these assumptions based on its findings.

The glorification of the architectural product as a function of scenographic communication – as opposed to a system of socio-technical production – has certainly had a detrimental impact in those countries considered as developing in terms of socio-economic capabilities… [1](Pathiraja, M, 2014, p. 31)
The research highlights the important efforts in experimenting hidden within the projects published, selected on the basis of current readers’ expectations on the basis of the obvious ‘seductive picturesque quality’. In depth, nature of such attempts and achievements in experiment may get its due recognition through the textual and image analysis that.

“The current professional architectural education in Sri Lanka steeped in a cultural framework that is, at best, context-selective, impinging on a specific narrative celebrating the picturesque alongside nostalgic representation of traditional building products and processes that reflect aspirations of high craftsmanship.” [1](Pathiraja, M, 2014, p. 34)

6. Field surveys and case studies.

The research reflects how certain architects have managed to engage in experiment in architecture within the current system and important features of their experience.

The research is carried out in four main stages.

1. Pilot survey and questionnaire
2. Survey on published architectural work
3. Selection of case studies and Interviews
4. Findings and Data analysis

7. Research outcomes.

The standard design process as given in RIBA plan of work was considered against case studies to observe any variations due to mode of operation. The outcomes are shown in figure 2, 3 and 4.

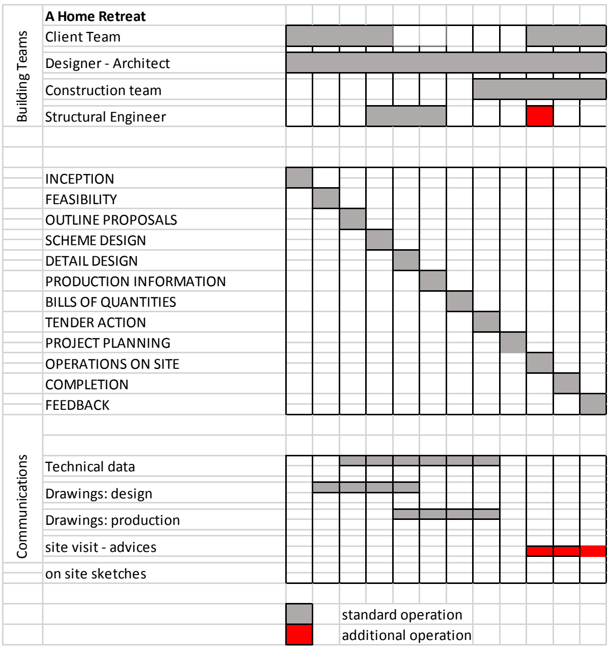

Figure 2: Case study 01 – Relationship between RIBA plan of work and the involvement of the building team and the methods of communication

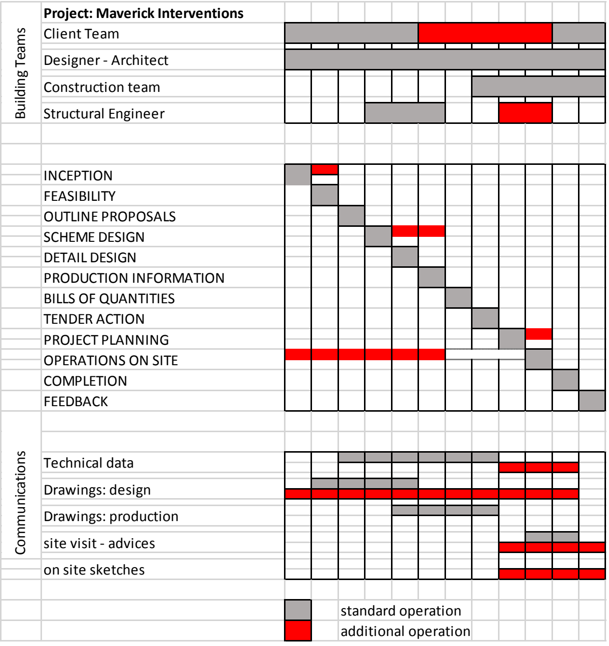

Figure 3: Case study 02 – Relationship between RIBA plan of work and the involvement of the building team and the methods of communication

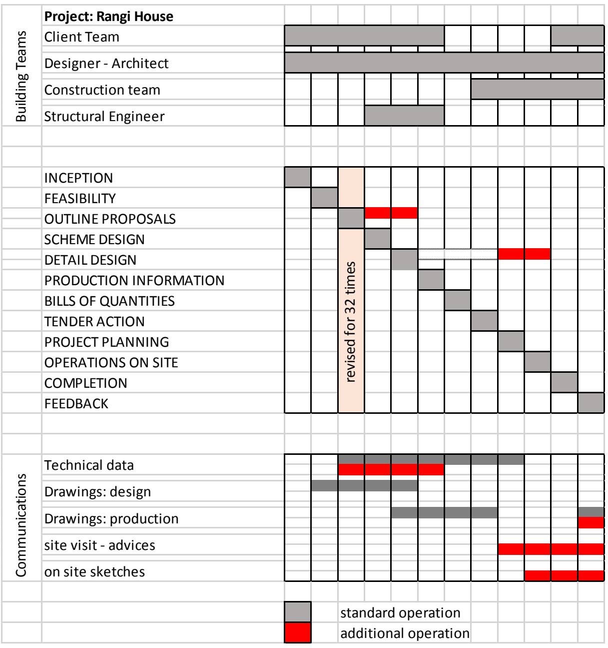

Figure 4: Case study 03 – Relationship between RIBA plan of work and the involvement of the building team and the methods of communication

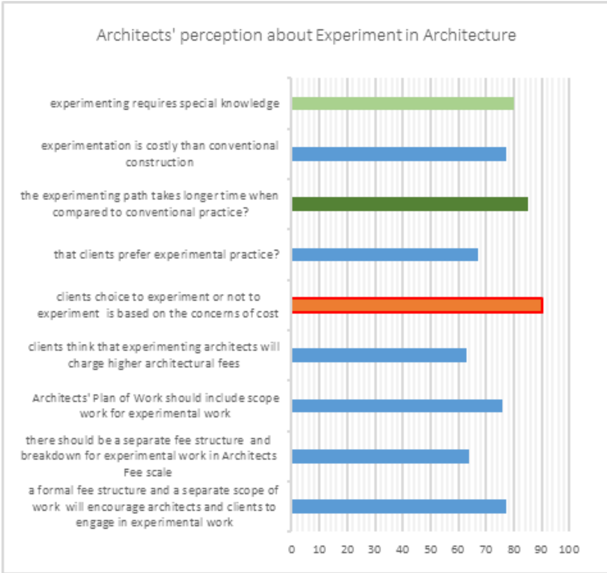

Figure 5: Architects' perception about Experiment in Architecture

The architectural practice in Sri Lanka is based on the SLIA (Sri Lanka Institute of Architects) Plan of Work which is modelled on the RIBA (Royal Institute of British Architects) Plan of work. The cost distribution of the professional services fee is based on the stages of the plan of work. (Figure 5)

This fee distribution allows minimal provision for architects to engage in any experiment work. This condition is reflected in the additional works carried out in the case studies.

With the results obtained from the questionnaire, it was possible to make further analysis about the architects who participated in the survey. Majority of the respondents were individual practitioners (Figure 6)

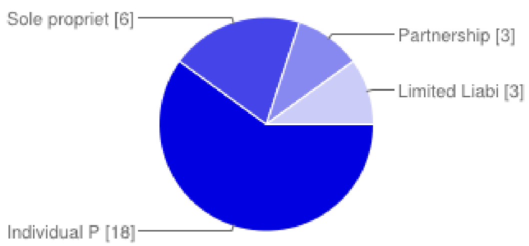

Figure 6: practice type of the respondents

Table 1: practice type of the respondents in percentage

Individual Practice	58.1%
Sole proprietorship	19.4%
Partnership	9.7%
Limited Liability	9.7%

The preference for experiment from the 30 architects who participated in the questionnaire survey, the majority expressed they were already involved in some form of experiment (figure 7) but did not follow a formal approach. Hence, they stressed the importance of developing an approach that will lead to success in experimentation that can be followed by all.

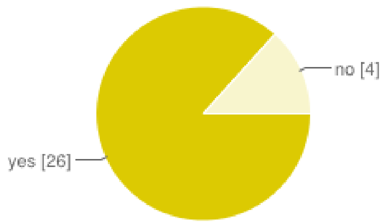

Figure 7: Involvement in Experiment

Table 2: Involvement in Experiment in percentage

yes	83.9%
no	12.9%

8. Conclusion

The research findings answered key research questions and reviewed the effect on the architects Plan of Work against experiment mode of architecture. The final analysis of the study clearly showed that majority of surveyed architects believed that they 'did experiment' in practice. This was clearly reflected with the questionnaire survey findings where 83% of architects claimed that they do experiment and only 17 % claimed that did not experiment. This finding was based on their own perception of their work practice.

From the case studies, two out of three architects (67%) stated that they were experimenting and the remaining architect (33%) claimed that whatever he did, he did not consider that as experiment.

Therefore, in conclusion, it can be noted that on contrary to the claim in the hypotheses, 'that architects do not experiment' majority of architects believed that they did experiment in materials and technology.

The analysis of the image survey, carried out on the published projects however revealed that majority of architects continued to operate within conventional use of materials and technologies Confirming the claim that made by the research question. However, it can be concluded that image survey was carried out with limitations as compared that of questionnaire survey and the case study survey.

From the questionnaire survey findings it can be concluded that majority of architects believed that that experimenting was beneficial to the practitioners and to the profession. The majority who took the questionnaire survey indicated that cost and time as the key challenges and factors that discouraged experimentation. However, this finding was comprehensively disputed by the case study interviews. Those architects concluded that 'cost' was key determinant to engage in experimentation and the extension of time was not as critical as perceived. The gains on cost effectiveness seemed have off set the difficulties of time extensions incurred due to experiment.

The findings of the case studies indicated the considerable changes and variations to the standard, Architects Plan of Work, in relation to experimenting. However, most of these variations in architects extended scope and engagement occurred within the conventional building programme. The case study survey justified that extended involvement as an essential feature to the success of any experimental intervention although it was not supplemented with additional professional fee. It may be concluded that architects were aware of these facts from the inception of the projects and they continued to engage in experimenting without any monetary reward.

The findings of the study further indicated that experiment in architecture might be encouraged where cost limitations are critical. The experimental case studies justified this fact and established that greater cost benefits can be achieved with experiments, although these projects may require additional time to complete.

The case studies gave valuable insight to salient factors specific to experiment. These findings indicated that, for successful experimenting and to encourage experimenting, certain simple methods can bring positive outcomes. The study findings are concluded with the following list of ten key propositions to achieve a successful approach to experiment in architecture;

1. Develop a plan of work and a fee scale that can facilitate experiment in architecture
2. Carry out background studies
3. Keep the records
4. Before implementation, discuss ideas with the engineer and the builder
5. Educate the client about what you are going to do as ‘experiment’
6. Pre-plan alternatives in case of an un-successful experiment
7. Pre-think about the maintenance process
8. Educate the client about the maintenance
9. Get feedback from the client
10. Execute the improvements immediately

Acknowledgement

The authors like to acknowledge the valuable contribution made by the Chartered Architects and other personnel who participated in the field survey, interviews and case studies in the research.

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SECM/15/004

Identification of Significant Factors Influencing Performance of Road Construction Industry Using Factor Analysis

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Abstract: This study is aimed at identifying the significant factors affecting the performance of road construction projects in Sri Lanka using factor analysis. Data collected using a questionnaire distributed among thirty engineers working in the road construction industry in Sri Lanka who represent the engineer and the contractor organizations. A list of 130 factors influencing performance of road construction industry have been identified & included in the questionnaire and all thirty engineers responded and returned the questionnaire. Participants were requested to allocate marks from 1-5 (1-very poor influence; 2-poor influence; 3-average influence; 4-high influence; 5-very high influence) to each factor according to their knowledge.

Factors influencing performance of the road construction contracts have been ranked based on average score initially. Significant factors influencing the performance have been identified using factor analysis and they were: conducting progress review meetings and site inspections at appropriate intervals; previous experience of the construction team working on similar project; effective monitoring and feedback by the construction manager; availability of skilled construction labour; engineer's ability to analyze contractor's claims fair and reasonable manner; making payment for Interim Payment Certificates within reasonable time (2 weeks); quick response by the contractor to employers and engineer's requests and instructions; certification of the Interim Payment Certificates by the engineer within a reasonable time (2 weeks) and timely submission of the Interim Payment Certificates by the contractor.

Keywords: Construction, Factor Analysis, Industry, Performance, Roads.

1. Introduction

Road Development is an important component of the economic development in Sri Lanka. Although respective Governments have recognized the importance of improving the road network in the country aiming rapid economic growth which is the top priority of the Government. Accordingly, number of road improvements projects have been planned and some of them are in progress. However, it is learned that the majority of these road projects do not perform as expected especially within time, cost and quality standards due to various factors. This study is aimed at identifying the significant factors influencing the performance of road projects using factor analysis.

2. Literature review

Industry related factors influenced performance of road construction industry were: Uniqueness of construction projects; varied locations; adverse weather and seasonality; dependence on the economy; size of the firm; research and development programs; construction codes, regulations & laws and labour related factors were: high percentage of labour cost; supply - demand characteristics; learning; risk of accidents; work rules and worker motivation [1]. Four management related factors influence construction productivity identified were: planning; resource utilization; information system; and selection of human resources [2].

Non-availability of material and tools, equipment breakdown, repeat work, changing craftsmen, interference, absenteeism, supervision delays, overcrowding, changing foreman, and working overtime have been identified as factors influencing construction productivity in different countries [3], [4], [5].

Construction equipment, materials, tools and consumables, engineering drawings management, direction and coordination, project management, training, craft worker qualifications, superintendent competency and foreman competency are affecting construction labour productivity. Communicating with the supervisors, pay and monetary bonus, training on skills, safety and health influence performance of the construction works [6].

Another important factor influencing the construction productivity and performance is subcontracting. It has become a standard practice implemented by the contractors for project execution. Sub -contracting allows the contractor to have less number of permanent staff and it allows the contractor to downsize the organization. Thereby ensure better handling of the unstable market conditions. When sub - contracting is introduced, there can be an institutional gap between the contractor's staff and sub - contractor's staff and this will lead to disturb the teamwork at sites [7].

It is observed that the fleet of machinery currently deployed in the Sri Lankan construction industry is fairly old and susceptible to frequent breakdowns, and also belongs to various makes and models. As a result, their preventive maintenance and repairs have become complicated. Also the contractors are reluctant to invest on new machinery due to the high cost of capital and also due to the risk of continuity of construction works. Due to these reasons, the contractors are preferred to hire machinery [8].

Some difficulties and constraints faced by the contractors during construction identified were: shortcomings in the market and business environment in which they operate; shortcomings of the clients and consultants and personal shortcomings of the contractor. The other two important factors for effective training for improved performance were: skill upgrading of workmen and upgrading of management skills of contractors [9].

Unanticipated conditions on a construction project result in a significant loss of productivity. Some of the factors that may affect are: adverse weather; scheduled overtime and material shortages [10].

Construction performance can be improved by scheduling construction activities realistically, planning them proactively, motivating workers, and establishing effective project coordination communication mechanisms [11].

Change orders and timing of change orders have adverse effects on the labour productivity in construction [12]. Competitive environment has a great influence on the contractor's performance [13].

3. Data Collection and analysis

A well-designed questionnaire including 130 factors influencing the performance of the road construction industry has been prepared using the factors identified in the previous studies and they were distributed among selected 40 engineers representing engineer and contractor organizations. Thirty engineers have responded and returned the questionnaire with comments. The participants were requested to allocate scores from 1-5 (1-very poor influence; 2-poor influence; 3-average influence; 4-high influence; 5-very high influence) to each factor according to their knowledge. Thirty six factors obtained average score of 4.00 and above are listed Table 1.0 [14].

Average score of the responses are varying from 4.57 to 2.77. Factors obtained average score of 4.00 and above (80% of the maximum score) have been selected for the factor analysis initially and there are 36 such factors. IDM SPSS (Statistical Package for Social Studies) Software Version 22 was used for factor analysis and initial run was conducted with the 36 factors. Factor analysis result of this run indicated that the matrix is not positive definite. In order to make the matrix positive definite the number of factors selected should be less than the number of responses. Therefore 27 factors up to the average score of 4.07 were selected and the second factor analysis run was conducted and the result indicated that this run was satisfactory.

As a first step to perform factor analysis, the adequacy of the survey data was examined by conducting the Kaiser-Meyer-Oklin (KMO) test and Bartlett's test of specificity [15]. The KMO statistics very between 0-1 and recommended bare minimum value of KMO for a satisfactory factor analysis is greater than 0.50 [16]. In this analysis KMO value obtained for the selected 27 factors is 0.577, which is more than 0.5 and hence, considered acceptable. The Bartlett's test of sphericity was 737.907 with an associated probability of 0.000 (less than 0.001), suggested that the population correlation matrix is not an identity matrix. The results of these tests show that the sample data appropriate for factor analysis. During the factor analysis seven principle components with eigenvalues greater than 1 are extracted. Component matrix after varimax rotation using factor analysis and the rotation sums of squared loadings carried out for the questionnaire survey of the Sri Lankan industry are given in Table 2.0 and Table 3.0 respectively.

Table 1.0 - Factors Scored more than 4.0

Number After Ranking	Original No. Allocated	Description of the Factor
1	28	Making the payment for IPCs within a reasonable time (2 weeks)
2	12	Certification of the IPCs by the engineer within a reasonable time (2 weeks)
3	38	Timely issue of instructions by the engineer
4	80	Good working relationship with the employer, engineer & the contractor
5	49	Construction manager's ability to manage people at work
6	85	Timely submission of IPCs by the contractor
7	45	Contractor's ability to prepare timely, accurate and complete IPC
8	117	Availability of skill construction labour
9	2	Employer's ability to provide agreed / required resources (funds, land, etc.) throughout the project duration
10	113	Availability of the required number of plant & equipment
11	116	Technical ability & construction knowledge of contractor's staff
12	11	Discuss with the employer, the engineer & the contractor on construction issues and constraints at a regular intervals
13	112	Condition/reliability of the construction plant & equipment
14	14	Leadership qualities of the engineer
15	15	Authority to take day-to-day decisions by the engineer or his assistants
16	22	Effective monitoring and feedback by the construction manager
17	51	Having very good contract administration knowledge and experience by the engineer
18	72	Previous experience of the construction team working on similar project
19	17	Engineer's technical ability
20	5	Selection of a construction manager with proven track record at the start of the construction work
21	37	Conducting progress review meetings and site inspections at appropriate intervals
22	128	Head office support to site staff during construction
23	36	Engineer's qualifications and experience
24	6	Providing effective assistance to the construction team to take decisions as required on time
25	9	Allowing the engineer to take decisions and supporting such decisions by the employer
26	50	Engineer's ability to analyse contractor's claims fair and reasonable manner
27	105	Quick response by the contractor to employer's / engineer's requests / instructions
28	63	Adequacy and accuracy in contractor's planning on operations, resources & funds
29	109	Contractor's commitment to complete the project within the original or agreed time period
30	110	Availability of specified construction materials
31	21	Understanding of the responsibilities by various members of the construction team
32	25	Academic and professional qualifications of the engineer
33	77	Effective monitoring of plant & equipment utilization
34	119	Knowledge & skill of the construction supervisors
35	126	Contractor's knowledge on construction methods

Table 2.0 Component Matrix after Varimax Rotation (Questionnaire Survey Sri Lankan Industry)

Factors		Factor loading 1	2	3	4	5	6	7	Variance explained (%)
Group 01:									41.405
72	Previous experience of the construction team working on similar project	0.826							
105	Quick response by the contractor to employer's / engineer's requests / instructions	0.782							
85	Timely submission of IPCs by the contractor	0.759							
45	Contractor's ability to prepare timely, accurate and complete IPC	0.696							
22	Effective monitoring and feedback by the construction manager	0.682							
80	Good working relationship with the employer, engineer & the contractor	0.439							
Group 02:									8.588
28	Making the payment for IPCs within a reasonable time (2 weeks)		0.792						
12	Certification of the IPCs by the engineer within a reasonable time (2 weeks)		0.779						
5	Selection of a construction manager with proven track record at the start of the construction work		0.680						
2	Employer's ability to provide agreed / required resources (funds, land, etc.) throughout the project duration		0.661						
49	Construction manager's ability to manage people at work		0.527						
112	Condition/reliability of the construction plant & equipment		0.498						
Group 03:									5.753
15	Authority to take day-to-day decisions by the engineer or his assistants			0.744					
9	Allowing the engineer to take decisions and supporting such decisions by the employer			0.601					
6	Providing effective assistance to the construction team to take decisions as required on time			0.573					
128	Head office support to site staff during construction			0.535					
Group 04:									5.493
117	Availability of skill construction labour				0.812				
113	Availability of the required number of plant & equipment				0.694				
11	Discuss with the employer, the engineer & the contractor on construction issues and constraints at a regular intervals				0.598				
116	Technical ability & construction knowledge of contractor's staff				0.446				
Group 05:									5.041
14	Leadership qualities of the engineer					0.701			
51	Having very good contract administration knowledge and experience by the engineer					0.711			
36	Engineer's qualifications and experience					0.645			
Group 06:									4.556
17	Effective monitoring and feedback by the construction manager						0.817		
50	Engineer's ability to analyse contractor's claims fair and reasonable manner						0.812		
Group 07:									3.766
37	Conducting progress review meetings and site inspections at appropriate intervals							0.830	
38	Timely issue of instructions by the engineer							0.585	
								Total variance explained (%)	**80.602**

Table 3.0 – Rotation Sums of Squared Loadings

Component	Eigenvalues	% of Variance	Cumulative %
1	12.799	47.405	47.405
2	2.319	8.588	55.993
3	1.553	5.753	61.746
4	1.483	5.493	67.239
5	1.361	5.041	72.28
6	1.23	4.556	76.836
7	1.017	3.766	80.602

4. Conclusion

According to the results in Table 2.0, seven components extracted account for 80.602% of the variance and Group 1 accounts for 41.405% of the total variance with six factors. Group 2 accounts for 8.588% of the total variance with six factors. Group 3, Group 4, Group 5, Group 6 and Group 7 accounts for total variances of 5.753%, 5.493%, 5.041%, 4.556% and 3.766% respectively. Factors which have earned loading more than 0.75 were considered as significant factors and they are listed below with the loading each factor received:

1. Conducting progress review meetings and site inspections at appropriate intervals (0.830)
2. Previous experience of the construction team working on similar projects (0.826)
3. Effective monitoring and feedback by the construction manager (0.817)
4. Availability of skilled construction labour (0.812)
5. Engineer’s ability to analyse contractor’s claims fair and reasonable manner (0.812)
6. Making payment for IPCs within reasonable time (2 weeks) (0.792)
7. Quick response by the contractor to employer’s and engineer’s requests and instructions (0.782)
8. Certification of the IPCs by the engineer within a reasonable time (2 weeks) (0.779)
9. Timely submission of the IPCs by the contractor (0.759)

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Temporary Substructure Forces during Bridge Slide: Impact of Sliding Friction and Substructure Alignment

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Abstract: Slide-in Bridge Construction (SIBC) is different from the conventional bridge construction because of the activity required to move the bridge to final position following construction. Moving activity requires bridge to be on a temporary support structure, resting on a sliding system such as bearings suitable for sliding, and a system of force actuation for pushing or pulling the bridge. Two SIBC projects were recently completed in Michigan, USA. SIBC being new to the bridge community, substructure forces that are developed during slides are best estimated. Hence, one of the Michigan projects was selected and slide operation was simulated using dynamic explicit finite element analysis techniques. This article presents use of dynamic explicit finite element analysis for evaluating temporary substructure forces during bridge slide. Further the analysis results are used to explain the impact of unequal friction at sliding surfaces and differential alignment of the temporary supports on substructure forces and bridge superstructure movement. Typically, bridge superstructures are slid in place using force-controlled systems. Analysis was performed using force-controlled and displacement-controlled methods. Then, the analysis results are used to explain the benefits of using displacement-controlled methods with force monitoring to slide a bridge rather than employing a force-controlled method.

Keywords: Accelerated Bridge Construction (ABC), Dynamic Explicit Simulation, Finite Element Analysis, Parametric Analysis, Slide-In Bridge Construction

1. Introduction

The Slide-in Bridge Construction (SIBC) is performed by supporting a new superstructure on sliding girders and pulling them, or by installing sliding surfaces to a new superstructure itself and pushing it. Two SIBC projects were completed in Michigan [0, 0]. During both projects, new superstructures were moved by applying forces and monitoring displacements. Displacement was monitored visually by construction personal, and the moving operation was temporarily stopped every time the bridge superstructure was off the alignment by a magnitude specified in the project special provisions. This process caused many challenges to the contractor for maintaining bridge alignment.

In order to demonstrate the impact of using force control and displacement control sliding, differential friction at the sliding surfaces, and differential alignment of the temporary substructure, sliding of the US-131 NB Bridge over 3 Mile Road in Michigan, USA, was simulated. This article presents the simulation model, temporary structure forces developed during slide, challenges with maintaining bridge alignment with differential friction under force or displacement-controlled slide, and recommendation to overcome some of the challenges experienced during SIBC.

2. Sliding friction

Friction at the sliding surface plays an important role in SIBC. Static and kinetic friction coefficients are used to calculate the required pull or push forces to slide a bridge as well as to design temporary and permanent substructure. Identifying and evaluating the parameters that affect static and kinetic friction coefficients and the decay rate from static to kinetic friction is important to properly design a slide system. According to the classical isotropic Coulomb friction model shown in Eq. 1, the friction at a given time can be calculated knowing the static and kinetic friction coefficients as well as the exponential decay rate [0].

$$\mu = \mu_k + (\mu_s - \mu_k)e^{d_c \dot{\gamma}_{eq}}$$
(1)

where, μ_k and μ_s are the kinetic and static friction coefficients, d_c is a decay coefficient, and γ_{eq} is the slip rate.

As shown in Figure 1, a typical sliding surface used in SIBC is formed by placing a stainless steel shoe on a set of neoprene bearing pads with Polytetrafluoroethylene (PTFE) layers (PTFE is commonly known as *Teflon*). Hence, the interface between a sliding shoe and PTFE layers form the sliding surface. Friction at PTFE-stainless steel sliding surfaces depends on sliding velocity, normal pressure, PTFE composition, steel sliding surface roughness, surface treatment (lubricants), temperature, and the angle between the surface polishing of steel and sliding direction [0].

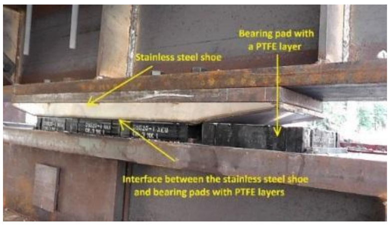


Figure 1: A stainless steel sliding shoe and neoprene bearing pads with PTFE layers

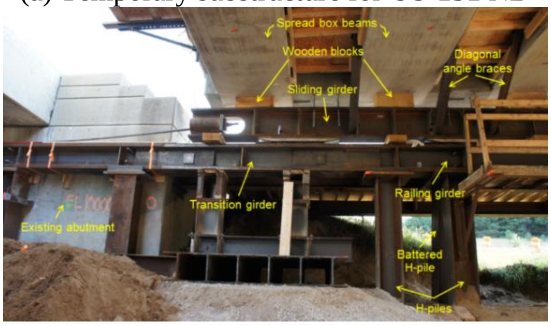
Kinetic friction decreases with an increase in normal pressure and use of lubrication [0]. Published data in many resources was reviewed [0 - 0]. In summary, static and kinetic friction coefficients range from 4% to 15% and from 1% to 6%, respectively. Unfortunately, references do not explicitly document the type of PTFE and the conditions under which the data was recorded. Kinetic friction coefficients given in the jacking plans for Michigan slide projects [0] and SHRP 2 R04 [0] are primarily from the AASHTO LRFD [0] for dimpled lubricated PTFE pads with less than 1 ksi (6895 kPa) normal pressure. Considering the data given in [0 – 0 and 0 - 0], static friction of 10% and a kinetic friction coefficient range of 2% - 5% are selected for the analysis.

3. Simulation of SIBC

3.1 US-131 NB Bridge construction

The US-131 NB over 3 Mile Road SIBC project was considered as a case-study. The new superstructure was built on temporary substructures located outside of the existing alignment of the bridge, but adjacent to the old structure (Figure 2a). Temporary substructure at each abutment location consisted of HP14×73 driven piles, HP14×73 columns, a railing girder, a transition girder, and a sliding girder. Each temporary substructure consisted of 8 vertically driven H-piles and 4 battered H-piles. At alternate pile locations, battered piles were added to provide lateral stiffness to the substructure. At those locations, a short HP14×73 section was welded on top as an extension to provide lateral restraint to the superstructure during construction. Spread box beams of the replacement structure were supported by wooden blocks on the sliding girder (Figure 2b). Neoprene bearing pads with PTFE layers were placed next to each other along the railing girder to form the sliding surface. Two post-tensioning jacks with a maximum stroke of 2 in. (50 mm) and a capacity of 110 ton (978.6 kN) were mounted to pull the superstructure (Figure 2c). Both jacks were powered by a single hydraulic pump. During the pulling operation the pressure was kept equal on both jacks and adjusted manually as needed. Due to limited stroke of the jacks, bridge superstructure was moved by performing a series of discrete pulls instead of pulling the bridge continuously to the final position (Figure 2d).

(a) Temporary substructure for US-131 NB



(b) New superstructure on the sliding girder

(c) Sliding girder being pulled

(d) Repositioning a jack after completing a pull

Figure 2: Replacing US-131 NB bridge superstructure using SIBC

The new superstructure geometry on the temporary structure is shown in Figure 3. The railing girder at abutment B was located at a higher elevation than the railing girder at abutment A.

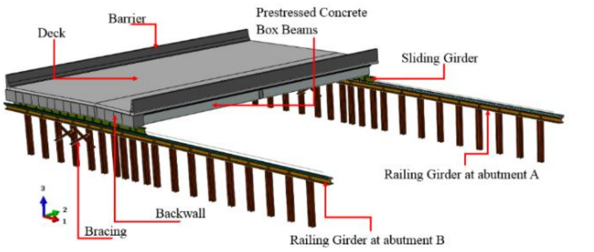


Figure 3: Isometric view of new superstructure on temporary substructure

3.2 Scope of sliding simulation

The scope simulation is shown in Figure 4. The primary objective is to evaluate the impact of interface friction and railing girder alignment on superstructure movement and stresses/stress resultants developed in the temporary structures due to continuous and discrete sliding under displacement and force control methods.

For displacement or force control sliding, railing girders at abutment A and B are positioned at the same alignment or at different alignments (as per the bridge plans, abutment B railing girder was at 0.31 ft (9.4cm) above the railing girder at abutment A). Equal and unequal friction at the sliding surfaces was also considered. With continuous sliding, the superstructure is slid from beginning to end without a pause. Discrete sliding is simulated by pulling the superstructure and allowing it to stop due to frictional forces; a representation of a typical slide.

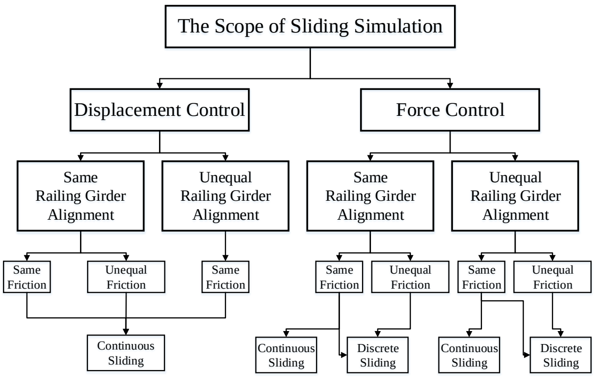
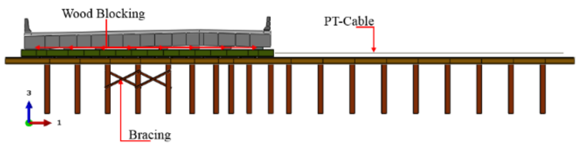


Figure 4: Scope of sliding simulation

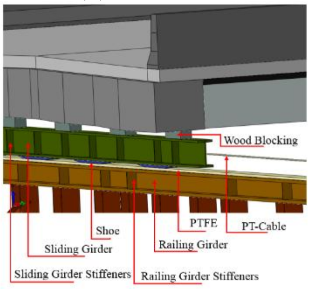
3.3 Finite element model (FEM) parameters

3.3.1 Geometry

The US-131 NB bridge geometry and the temporary structure and sliding mechanism details are closely replicated (Figure 3 and Figure 5).



(a) Side view



(b) Sliding and railing girder details

Figure 5: Superstructure, temporary structure, and sliding mechanism detail

3.3.2 Normal pressure and friction

As discussed in section 2, static friction of 10% and a kinetic friction coefficient range of 2% - 5% are selected for the analysis. Decay rate depends on static friction, kinetic friction, and sliding velocity. Considering the total length of slide and the slide duration of US-131 over 3 Mile Road project, sliding velocity of 2 in/min (5 cm/min) was calculated. Since the sliding process consisted of a collection of successive discrete sliding events, much higher peak velocities are expected. Further, with experience, it is possible to achieve a peak slide velocity of at least two to three times the velocities that were calculated from the first two SIBC projects in Michigan. Hence, it is reasonable to expect a sliding velocity of 6 in/min (15.2 cm/min) (i.e., 0.1 in/sec) or greater during a discrete event.

As shown in Figure 4, continuous and discrete slide events are simulated. Continuous slide simulation represents a single event during which the bridge is pulled 62.5 ft (19 m) (from start to the end) without a pause. After performing exploratory analyses of sliding events, it is decided to use a sliding velocity of 10 in/sec (25 cm/sec). This decision is made mainly considering the complexity of the analysis model in the presence of a large number of contact surfaces, analysis duration, and space required for storing analysis data during each step of calculation. Using velocities higher than the velocities documented in the field do not affect frictional forces developed at the PTFE – steel interface. This is mainly because the Coulomb friction model is used with user defined static and kinetic friction coefficients and a decay rate. However, using higher velocities may affect the dynamic forces developed in the system when sliding stops. This will be discussed with discrete slide analysis results. For continuous analysis, decay rate is defined to achieve 5% friction when the velocity reaches 10 in/sec (25.4 m/sec), resulting in a decay rate of 0.4105.

Analysis is also performed with unequal friction at two railing girders. In this case, the static friction is maintained at the same, and the kinetic friction of 2% and 5% is defined for the railing girder at abutments A and B, respectively. These values represent an extreme case of unequal friction on sliding girders.

3.2.3 FE Discretization of the model

The railing girder is supported on extended piles or columns, and represent the behaviour of a multi-span continuous beam under moving loads. Because of the girder deflection profile under moving loads, it is expected to have a non-uniform load distribution among the sliding shoes; thus unequal frictional forces between sliding shoes. When unbalanced forces are developed at each sliding girder, there is a possibility for superstructure to yaw.

Since the primary focus is on the interface friction forces, bridge movement, and stress resultants on temporary structures, the bridge superstructure is discretised into a coarse mesh. The members of the temporary substructures, sliding shoes, and the railing girders are discretised into elements with aspect ratios that are suitable for stress calculation.

The contact pair option in Abaqus [0] is used to define the interaction at the interface between the polished stainless steel shoe and the PTFE pads. Multi-point constraint option is used to define the connection between the pulling rods and the sliding girder.

Extended pile and column ends at the ground level are constrained for translations and rotations simulating fixed supports. While one end of the pulling rod is connected to the sliding girder, the other end is constrained for all the degrees of freedoms, except for the translation in direction 1 (i.e., the slide direction shown in Figure 5).

3.2.4 Loads and prescribed displacements

Self-weight of all the components is applied using the *DLOAD command in Abaqus. In order to suppress the dynamics that are not naturally occurring in the system, self-weight is applied as a gradually increasing load using the *AMPLITUDE command. For consistent units, the gravitational acceleration is defined as 386 in/s^2 (9.81 m/s^2).

For displacement control models, a displacement is defined at the free end of the pulling rod. The magnitude of the prescribed displacement is equal to the total slide distance. For force control models, pulling force is defined at the free end of the pulling rod. The total frictional force of 144 kips (640 kN) is calculated based on the nominal stress at each sliding shoe and the static friction coefficient of 10%. However, it is necessary to apply a pulling force that is slightly greater than the estimated total frictional force. Hence, a gradually increasing pulling force with a maximum of 85 kips (378 kN) is applied to each rod.

The force control method is used to simulate a discrete slide event. In this case, the applied force is gradually increased until the sliding structure reaches a predefined velocity. At that time, the force is removed, and the superstructure is allowed to slide until it is stopped due to frictional resistance.

4 Results

4.1 Continuous slide

Continuous sliding simulations were performed under displacement and force control methods. In displacement control, the structure was pulled gradually, starting from a resting position, until the sliding velocity reached 10 in/sec. After that, a constant velocity of 10 in/sec (25.4 cm/sec) was maintained. As a result, both sliding girders slid uniformly along the railing girders, irrespective of the frictional forces developed at the PTFE-steel interface.

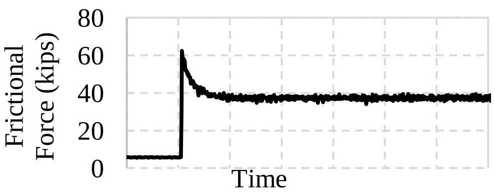
Under force control sliding, the structure is expected to slide when the applied force exceeds the resisting force of 72 kips (320 kN). In the analysis described herein, the pulling force was gradually applied to each sliding rail using a ramp function. Hence, the force was gradually increased to 85 kips (378 kN) and maintained at that level until bridge slid 62.5 ft (19 m).

4.1.1 Frictional forces

Frictional forces developed under the displacement control sliding method are presented in Figure 6a. As soon as the sliding initiates, there is a sudden increase in the frictional force. As the velocity increases, the frictional force decreases due to a reduction in the coefficient of friction as per the defined decay rate. With a constant sliding velocity, the frictional force becomes a constant.

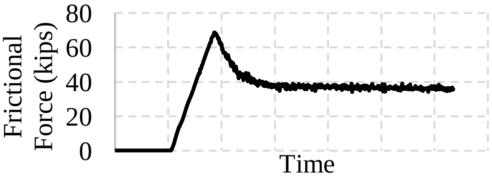
Frictional forces developed during force control sliding are presented in Figure 6b. The frictional force is linearly proportional to the applied force until the applied force equals the static frictional force. As the velocity increases, the frictional force decreases in proportion to the defined decay rate. Once the friction reaches kinetic friction, frictional force remains constant during the rest of the move.

The static friction coefficient at each sliding surface is specified as 10%. The vertical force acting on each temporary structure is 720 kips (3200 kN). Hence, the expected total frictional force on each temporary structure at the onset of sliding, and in the direction of sliding, is 72 kips (320 kN) (i.e., 0.1×720). At the onset of sliding under displacement, the maximum total frictional force observed on each temporary structure in the direction of sliding is 65 kips (289 kN). Similarly, the maximum total frictional force observed on each temporary structure under force control is 69 kips (307 kN). The maximum value is an instantaneous value and, in both cases, the observed forces are more than 90% of the expected value, and within the acceptable limits for numerical simulations. The difference is due to a numerical error with force being calculated at each time increment. The time increment used in the calculations is less than 10^{-5} seconds.



(1 kip = 4.4482 kN)

(a) Displacement control sliding



(1 kip = 4.4482 kN)

(b) Force control sliding

Figure 6: Frictional force at Steel-PTFE interface

As shown in Figure 6, when the velocity is equal or greater than 10 in/sec, the frictional forces developed at each rail are 36 kips (160 kN), same as the expected kinetic friction (i.e., 0.05 ×720 kips). The expected value is calculated through numerical simulations because the kinetic friction remains at a constant value over a time during steady state sliding.

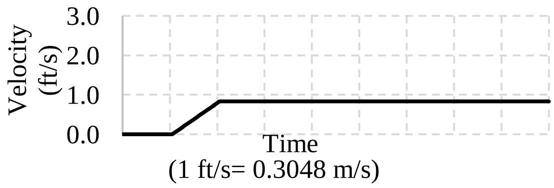
In order to account for the friction variation between sliding surfaces, the railing girder at abutments A and B are assigned kinematic friction coefficients of 2% and 5%, respectively. Both temporary structures are assigned the same static friction coefficient of 10%; hence, it is expected to have the same maximum frictional force acting on both temporary structures. Forces acting on each structure at the onset of sliding are slightly different. As the velocity increases and reaches steady state sliding velocity of 10 in/sec, the forces are decreased to 15 kips (67 kN) and 36 kips (160 kN) for temporary structures at abutments A and B, respectively. Even with unequal friction, under displacement control, the sliding progresses in alignment without any drift to the transverse direction. Unequal friction simulations under force control was not performed for continuous slide. Under force control, even a small difference in friction will drift the structure to the transverse direction. For a continuous slide, since the sliding distance is greater, performing unequal friction simulation without transverse restraint under force control method will move the sliding girder off the alignment making the system unstable. Hence, only discrete slide was simulated under force control with unequal friction and the results are presented in the following section 4.2.

4.1.2 Forces on temporary structure

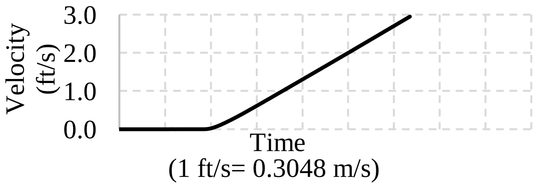
Forces generated at the sliding surfaces are the horizontal forces that are transmitted to the temporary structure. The normal forces at the sliding surface and the temporary structure self-weight represent the vertical reactions at the temporary structure supports. In design, the vertical loads are calculated from the dead loads. The horizontal load is calculated from static friction and the normal force acting on the sliding surface. Sliding can also generate dynamic loads.

The analysis results are useful to understand the structural response and the nature of forces that are developed during a bridge slide. Figure 7 shows the variation of superstructure velocity and reaction forces developed in the temporary structure under displacement and force control sliding. The horizontal reaction expected at the temporary structure under static friction is 72 kips (320 kN). Due to the acceleration introduced into the system at the onset of sliding under displacement control, the horizontal forces greater than 100 kips (444.82 kN) are developed. As per the displacement control analysis parameters used in this analysis, an impact factor of 1.53 (i.e., 110 kips/72 kips) is calculated. The application of well controlled slower displacement rates (i.e., velocities) at the beginning of a slide can reduce these dynamic forces.

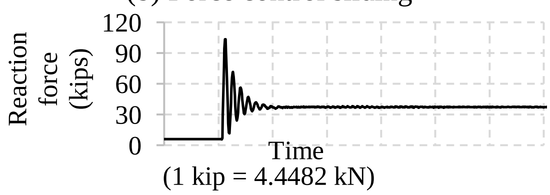
In displacement control sliding simulation, the rate of displacement (i.e., velocity) is increased from zero to 0.833 ft/s (0.26 m/sec) (i.e., 10 in/sec) within a short duration, and it is maintained at a constant rate afterwards (Figure 7a). The change in the rate of displacement resulted in an acceleration that amplified the inertia forces acting on the superstructure. However, under force control sliding simulation, initial motion of the bridge superstructure is slow, and the rate of change of velocity is quadratic until achieving a linear profile (Figure 7b). Because of the small acceleration at the beginning of the motion, dynamic effects are not significant. Sliding structure dynamics affected the vertical reactions, too. However, the amplifications are less than 2% and 1% in displacement and force control sliding, respectively.



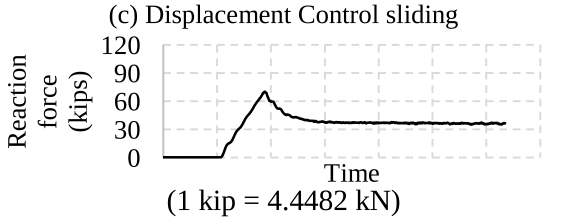
(a) Displacement control sliding



(b) Force control sliding



(c) Displacement Control sliding



(d) Force Control sliding

Figure 7: Variation of velocity and temporary structure's horizontal reaction in the sliding direction for displacement and force control sliding

4.1.3 Unequal railing girder alignment

Slide simulation was performed with an unequal railing girder alignment. During this simulation, a uniform friction on both railing girders was maintained. Simulation was performed using displacement and force control methods. The alignment difference between abutments was 0.31 ft (9.45 cm) which is equivalent to a 0.4% grade of the superstructure. Displacement control continuous slide resulted in a 0.75 in (1.9 cm) transverse drift towards abutment A. This is less than the 1 in. (2.54 cm) tolerance specified in project special provisions. Since same friction was maintained on both railing girders, frictional forces acting on each temporary structure remained the same. Under force control simulation no significant transverse movement was observed.

4.2 Discrete slide

Pulling or pushing of a bridge superstructure is not a continuous operation. The superstructure is pulled or pushed up to a certain distance depending on the stroke capacity of the jacks. The impact of this pulling or pushing process on the sliding process, as well as on the temporary structure, was of an interest.

Under force control sliding, the structure is expected to start sliding as soon as the pulling force overcomes the resisting force of 72 kips (320 kN). The pulling force was gradually increased to 85 kips (378 kN) and maintained at that level until the velocity reached to 10 in/s. At that time, the force was removed and allowed the structure to slide for a while under inertia and frictional forces. The following four cases were considered for discrete sliding:

Case I:
- Both railing girders are at the same elevation.
- Equal friction occurs on both girders (10% static and 5% kinetic).

Case II:
- Unequal railing girder alignment (railing girder at abutment B is raised 0.31 ft above the railing girder at abutment A).
- Equal friction occurs on both girders (10% static and 5% kinetic).

Case III:
- Both railing girders are at the same elevation.

- Unequal kinetic friction occurs on railing girders (10% static on both, and 2% and 5% kinetic friction on railing girder at abutment A and B respectively).

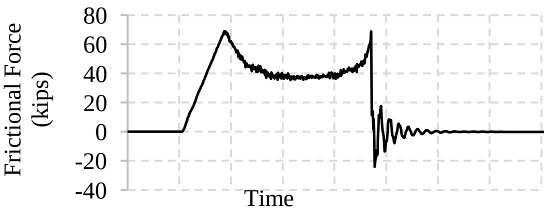
Case IV:

- Unequal railing girder alignment (railing girder at abutment B is raised 0.31 ft (9.4 cm) above the railing girder at abutment A).
- Unequal kinetic friction occurs on railing girders (10% static on both, and 2% and 5% kinetic friction on railing girder at abutments A and B respectively).

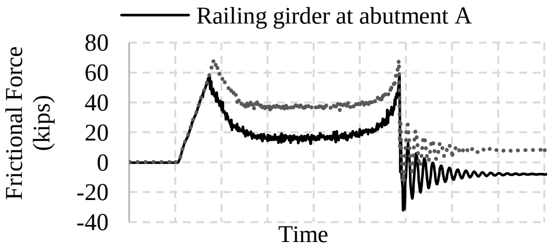
Out of the four simulation cases listed above, only Case I and Case III were included for further analysis. According to preliminary analysis, unequal railing girder alignment does not have significant effects on the simulation results. This is mainly due to the limited slide distance under discrete sliding. The difference between Case I and III is the friction coefficients of railing girders. Case I incorporates equal friction while Case III includes unequal friction on girders.

4.2.1 Sliding frictional forces

Initially, the frictional forces follow the same trend and pattern that was observed during continuous sliding under force control. As shown in Figure 8a, frictional force was gradually increased up to 69 kips (307 kN). Once the motion started, velocity was increased, and frictional force was reduced to 38 kips (169 kN), following the decay rate defined in the friction model. After the pulling force was removed, the velocity was gradually reduced and the frictional forces started to increase in proportion to the decay rate defined in the friction model. By the time the structure sliding seized, frictional forces reached the maximum, the static value. At this moment, dynamic forces were developed in the structure. Similar behaviour was observed when kinetic friction of 2% and 5% were assigned to abutment A and B (Figure 8b). The maximum dynamic frictional force of 32 (142 kN) kips was observed.



(1 kip = 4.4482 kN)
(a) Case I



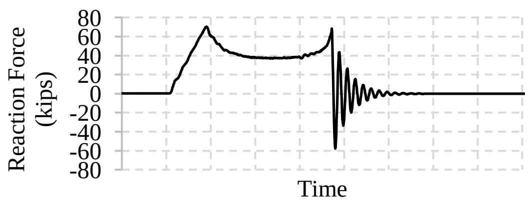
(1 kip = 4.4482 kN)
(b) Case III

Figure 8: Frictional force developed under discrete sliding

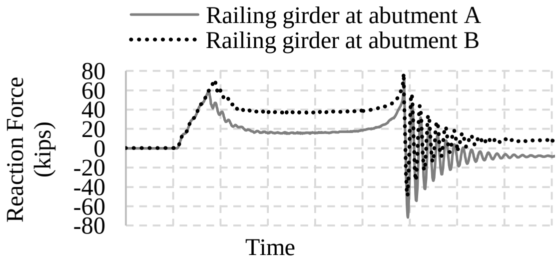
Due to unequal friction, bridge superstructure drifted to transverse direction and engaged with the restraint provided in the model. One inch (25.4 mm) tolerance was maintained between sliding girder and the restraint. As soon as the structure engaged with the restraint, it bounced back and drifted again to engage with the transverse restraint. This movement was repeated and the superstructure started sliding against the restraint provided in the system. Analysis results demonstrate the need for providing transverse restraint even if the railing girders are at the same alignment.

4.2.2 Forces on temporary structure

Figure 9 shows the temporary structure's horizontal reactions, in the direction of sliding, with respect to time. Analysis cases are (a) equal railing girder alignment with equal friction and (b) equal railing girder alignment with unequal friction. As shown in Figure 9, once the superstructure sliding was seized, dynamic forces were developed at the supports. The maximum amplitude of the dynamic force was about 72 kips (267 kN). The frictional dynamic force amplitude at the sliding surface ranged between 24 kips (107 kN) and 32 kips (142 kN) (Figure 8). However, due to the inertia forces developed in the substructure, horizontal reactions at the temporary structure supports were amplified. Yet, the damping characteristics of the structural system was adequate to control the response.



(a) Case I



(b) Case III

Figure 9: Temporary structure reactions in the sliding direction

4.2.3 Unequal railing girder alignment

Unequal railing girder alignment of 0.31 ft (9.4 cm) did not generate a noticeable drift. One reason for this can be the limited sliding distance of about 9 ft during this discrete event. Analysis results of unequal railing girder alignment models closely represented the observations discussed in the previous section.

5 Summary, Conclusion and Recommendations

The US-131 over 3 mile (1.6 km) Road Bridge slide-in processes was simulated. The primary objective was to evaluate the impact of interface friction and railing girder alignment on superstructure movement and stresses or stress resultants developed in the temporary structures due to continuous and discrete sliding under displacement and force control methods.

The following conclusions are derived based on the analysis results presented in this article:

1. Dynamic explicit analysis is a versatile tool to simulate bridge slide operations and to evaluate the impact of parameters that affect the sliding process.
2. As a result of unequal friction, the superstructure drifts in the direction transverse to the direction of sliding. Hence, providing a lateral restraint is important to keep the bridge aligned with the slide direction, irrespective of the railing girder alignment differences.
3. Unequal railing girder alignment does not generate a significant drift in continuous sliding. Under displacement control, the superstructure drift under 0.4% grade was less than 1.0 in. (2.54 cm), and within the movement tolerances specified for the project. Drifting is not observed during discrete sliding. Hence, unequal friction has a greater influence than the railing girder alignment on the transverse drift of the superstructure.
4. During discrete sliding, considerably large fluctuations in horizontal reactions, in the direction of slide, were documented at the temporary structure supports. This is a result of the inertia forces developed in the system due to substructure self-weight. Still these dynamic forces are smaller than the static frictional forces. Further, the damping characteristics of the structural system was adequate to control the response. Hence, use of the horizontal forces due to static friction is adequate for design of temporary substructures. However, the structural system dynamic characteristics needs to be studied to evaluate potential for resonance.
5. Implementation of the displacement control sliding method allows sliding the superstructure without transverse drift, irrespective of the difference in friction of the sliding surfaces. To define accurate and controlled displacement and force targets during the move operation, a servo controller is required. The inclusion of the servo controller requires the use of electronics and most likely a field computer. The advantage of using a servo controller is the ability to establish force, displacement, or combined targets for the movement of the piston. To prevent uncontrolled force built-up, the servo system can be programmed with force limits so that in unforeseen situations, such as the move being restrained, the movement will stop when force limits are reached.

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The significance of Building Information Modelling to the Quantity Surveying practices in the UAE Construction Industry

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Abstract: Quantity surveying is a significant discipline in the construction industry. Building Information Modelling (BIM) was defined at early stages as the development of Computer Aided Design (CAD). BIM has been developed and it has the potential to revolutionise construction process in the way how buildings are designed, analysed, constructed and managed. Several disciplines including quantity surveying profession are being extensively impacted by the emergence of BIM. The quantity surveyors' roles in construction include a wide range of services. BIM offers numerous advantages to the quantity surveying practices. However, BIM adoption level in quantity surveying practice is comparatively less due to some of its current limitations and challenges. The aim of this paper is to investigate the effectiveness of BIM adoption in quantity surveying practices in the UAE. The secondary data was collected through a critical literature review and whilst empirical data was collected through semi-structured interview and online questionnaire survey among the quantity surveyors in the UAE. It is highly recommended that the implementation of BIM in quantity surveying practices in the UAE is beneficial and would generate great opportunities for the development of the construction industry. It is also suggested that the uptake of BIM is more effective to survive in the competitive construction market.

Keywords: BIM, Quantity Surveying Practices, UAE Construction Industry

1. Introduction

The construction industry, unlike other industries, is widely acknowledged for its special characteristic which is unique. Meantime it has been criticised for conservative [13]. Another feature of the construction industry is information intensive due to the construction of complexity buildings [4]. The construction industry plays a major role in driving economies of a country. Not only it contributes to the country's economy but an innovative and efficient construction industry causes to create a stable global economy in macro level [17]. However, the industry has been blamed for notoriously conventional and for relatively slow adoption of changes. In particular, data transfer among project stakeholders is time consuming [6]. The construction industry has remained slow in the adoption of innovative technologies although it has been proved with strong evidence that the information technology (IT) has a positive impact in the project performance [14]. New technologies provide several benefits to the industry by increasing the opportunities. Technology in a simple form refers to improvement in soft and hard methodologies [13]. IT applications provide the platform for the improvements in design and project monitoring. This has lowered the project cost and improved accuracy, speed and safety. Consequently, more benefits such as solution for uncertainties in a construction project and dispute resolution have been expected from an advanced form of IT [22].

Quantity surveying is a significant discipline in the construction industry. Measurement or quantification is a basic capability expected from the quantity surveyor. Quantity surveyors largely involve in quantities take-off and preparation of bill of quantities [1]. Measurement is derived from coordinate data which is usually in the form of design or construction drawings. The invention of computer aided drawings (CAD) has impacted the way in which the quantities are taken off and the bills of quantities are prepared. The bills of quantities are prepared using the data generated from CAD. Whilst this concept has been realised in the research environment the challenges and the opportunities have been started to be addressed. This led to cast the base for building information modelling (BIM). Therefore, BIM was defined at early stages as the development of CAD [13]. BIM has been developed and it has the potential to revolutionise several disciplines including quantity surveying profession considerably.

1.1 BIM Definition

The basic concept of building information modelling is developed and described by many authors. BIM concept was described elaborately in the report written by Thompson & Miner in 2007. When all relevant data for an entire project are stored in a central point by various disciplines in order to enable all the stakeholders to exchange their engineering and business knowledge including time and cost parameters, then the project could be managed and executed in a virtual environment [21]. This process allows many stakeholders to be involved at an early stage and improved coordination by real time collaboration and therefore, the project can be benefitted in several ways. The resulting model serves as a source of data which can be extracted and analysed according to the requirements [2].

BIM is defined in a simple way as "the digital representation of the building process to facilitate exchange and interoperability of information in digital format" [6]. BIM is not only a digital representation but it also involves with the creation of virtual models of buildings and assists in identifying all possible construction related problems and other implications through simulation at an early stage before physical construction commences [7]. BIM is defined in an effective way as the process of producing digital database containing all relevant information for lifecycle of a project and is expressed in an interoperable way to create, engineer, estimate, illustrate and construct a project [19].

In another short form and multi-disciplinary perspective, BIM is defined as a 'collaborative project oriented method' which produces many building models and allows all the project stakeholders to communicate and exchange data during modelling process [20]. The communication and data exchange among stakeholders occur at all the stages of project lifecycle and therefore, the project could be possibly free from many types of design based defects. This process also eliminates unnecessary variations which occur during construction phase due to design failures. The application of BIM is not limited only for design and construction phase of a project but it assists in facility management also [15].

BIM deals with all required information related to the project in terms of its design, planning, construction and operation [3]. BIM extends its information even to cover the buildings' physical and functional characteristics in the operation phase [11]. Physical characteristics include all the properties information such as function, shape, dimension and material [10].

1.2 Different levels of BIM

The gradual development of Building Information Modelling is demonstrated in a three dimensional digital representation. Level-1 deals with traditional two dimensional design process of drawings but level-2 enhances the design into 3D modelling. In contrast to 2D drawings where sets of lines and areas are illustrated through soft and hard intelligent features, data related to each object are stored by means of BIM in level-2. BIM is matured in level-2 where various professionals particularly designers involve collaboratively and they are able to model real life situations before construction commences [13]. Level-3 is considered to be more advance with the integration of 4D and 5D which are time and cost parameters respectively. Level-3 represents the most complex BIM with fully integration of all relevant information for the whole lifecycle of the project [8]. Figure 1.1 displays the maturity diagram of BIM at different levels.

This paper mainly deals with two variables which are BIM and quantity surveying practices in United Arab Emirates (UAE). The research seeks to correlate between these two variables.

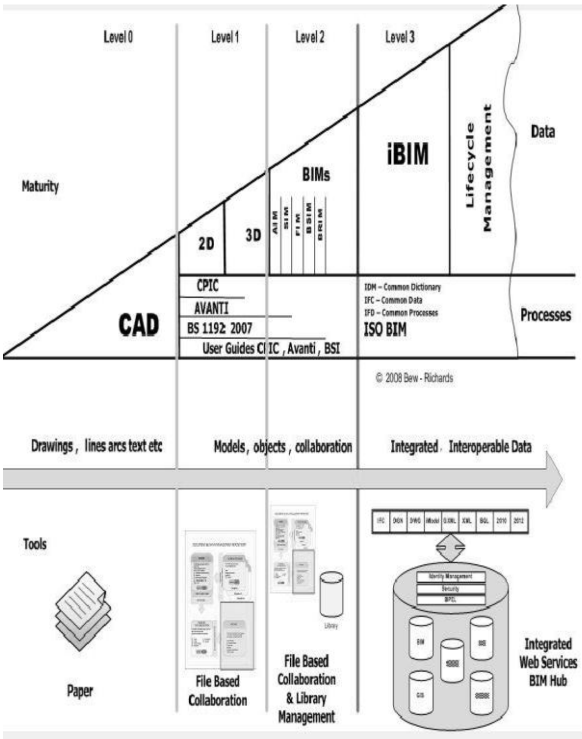

Figure 1.1: BIM maturity levels (Department for Business Innovation & Skills- BIS, 2011)

1.3 Problem statement

BIM provides substantial benefits to any construction project and supports overall project processes. As a result, all the stakeholders are benefitted through improved project performances. Similarly, BIM offers numerous advantages to the quantity surveying practices as well [16]. However, BIM adoption level in quantity surveying practice is comparatively less due to some of its challenges [23].

Legal issues and cultural issues are well known challenges in BIM application [12]. UAE is not exempted from these challenges. Copyrights of design and data, ownership, sharing of responsibilities among project participants are few examples of legal issues [2]. Human and cultural issues are considered as largest barriers for BIM adoption. Professionals do not show willingness to change from traditional practice to new procedures mostly because they feel comfortable with their present roles [25]. As far as BIM application is concerned it deals with substantial amount of changes to the traditional quantity surveying practices [4]. Therefore, these concerns have caused the quantity surveying professional reluctance to change their current roles to BIM enabled practices.

Besides the challenges as described above, there is insufficient evidence to show the benefits of BIM application in terms of financial aspects. This applies in BIM enabled quantity surveying practices too. Quantity surveyors are behind in adoption of BIM into their practices not only due to the above mentioned challenges but also due to lack of awareness and being unsure of its application [23].

Based on all the facts and arguments stated above, it triggers a need for the research to know whether the adoption of BIM in quantity surveying practices is effective.

1.4 Aim of the research

The aim of the research is "to explore the effectiveness of Building Information Modelling in Quantity Surveying practices in the UAE Construction Industry".

1.4 Research objectives

The following objectives are established in order to achieve the aim within the allocated time frame of the research study:

1. To critically review on what "Building Information Modelling" means in the construction sector.
2. To review on quantity surveying practices in UAE construction industry.
3. To investigate the awareness of Building Information Modelling among quantity surveyors in the construction sector in UAE.
4. To explore the benefits of Building Information Modelling in quantity surveying practices in UAE.
5. To identify the challenges of Building Information Modelling in quantity surveying practices in UAE.
6. To make recommendations to the Quantity Surveyors on the usage of Building Information Modelling in UAE.

2. Research methodology

The aim was established to reflect the working title in a simple and narrowed area of work. Initially the aim was developed as a research question and converted into a conjectural statement of the relationship between BIM and quantity surveying practices. The established aim attempts to discover some truths which are perceived by many quantity surveyors. BIM is perceived to be more beneficial in quantity surveying practices. The topic area relates to the positivist theoretical perspective and the research is designed as a deductive approach. The study seeks to explore information regarding BIM in relation with quantity surveying practices hence, the research falls under the category of exploratory studies. The data required for the research was medium level of rigour. Based on these categorizations survey approach was selected as the most suitable research strategy for this study. There are two subdivisions of survey strategy which are analytical and descriptive surveys. Since the research deals with deductive approach with an emphasis on reliability of systematically collected data for the correct generalization of results through statistical control of variables, analytical survey is chosen. Further, the sample size is relatively big, geographically dispersed and it deals with relationship between two variables only thus, it justifies the selection of analytical survey [5].

The sampling method used in this study, which is the selection of precise and random samples in order to standardize error free data, shows the strengths of survey strategy over the other competing strategy like case study where generalizability of the results is limited to only certain principles.

As far as research techniques are concerned questionnaire survey method is chosen for this research study. Questionnaire survey was constructed to investigate the correlation levels between BIM and quantity surveying practices. Focussed interview was also designed only to seek expert opinion but the questionnaire survey was adopted as the main technique for this research study. Structured interview approach has many advantages over the other techniques. The researcher is able to ensure the validity of data through conducting interviews personally. The researcher himself administers the questions and clarifies the doubts of interviewees at the same time. Repeatability and consistency are the other strengths of the structured interview techniques [9]. Even though interview has distinguished advantages, the questionnaire survey was selected as the technique because of the large size of representative sample which is widespread all over the country. Therefore, conducting interviews with each individual with prior appointment would consume more time or it might become impossible. Further, it is expensive too. In order to avoid errors in data large representative sample is selected for the questionnaire survey [5]. Another advantage of questionnaire survey is that the data can be validated up to certain extent if similar questionnaires were used before to draw the similar data. Questionnaire was disseminated online in order to save time for both researcher and the participants.

2.1 Practical implementation of the chosen strategy

Two types of information such as secondary and empirical data were approached to acquire information for the research study, particularly BIM in quantity surveying practices. The secondary data was obtained through academic literature and related study material. Even though the secondary data offers required information about research study up to certain extent, the primary data is still required to reinforce the secondary data and to achieve research aim and objectives successfully. The primary data was collected in two ways which were semi-structured interviews as a mode of seeking expert opinion and online questionnaire survey. Five experts were selected for conducting interview. The research population is the professional quantity surveyors of all categories, who practise in UAE. The sampling frame of the research study was 600 professional quantity surveyors and the targeted representative sample was 100 quantity surveyors. Based on recent research studies carried out by both post graduate students and the university lecturers it was found that the response rate of the participants for similar studies in UAE was less and resulted in between 20% to 25% [18]. Considering this fact and risk of high volume of non-responses, 600 professional quantity surveyors were chosen as the sampling frame and at least 100 responses were expected. The quantity surveyors were divided into five categories based on the type of organizations where they were employed. The categories consisted of quantity surveyors who work for client, developer, consultant, constructor and sub-contractor. The sampling frame was selected in such a way that the quantity surveyors from all of these categories were included. The purpose of this categorization and the wise selection of sampling frame were to represent the wider population properly and to generalize the survey results accurately. The categorization process also served the purpose of ensuring the relevance and validity of responses.

2.1.1 Focussed interview

A focussed semi structured interviews were conducted with the pre-selected quantity surveyors who were experts on BIM and employed within UAE. Only five experts were targeted for the interview. The purpose of conducting these interviews was to obtain professional insight about the research subject and the UAE Construction Industry. The acquired information was much useful to refine the questionnaire by eliminating ambiguous contents and simplifying. The interviewees were qualified based on their level of industry experiences and total number of projects where BIM was adopted. The expert quantity surveyors were chosen from different disciplines such as project manager, contract manager, commercial manager, cost manager and procurement manager.

2.1.2 Questionnaire survey

Questionnaires were disseminated online among the professional quantity surveyors from different organizations in UAE through their e-mails in order to form the second part of the primary data. The online software tool called 'surveymonkey' was used to dispense the questionnaires and to receive the responses from the respondents. The online questionnaire survey was carried out at a particular time period in order to control the extraneous variables by holding them constant that is, the research was not focussed on the implication of BIM in quantity surveying practices in different periods of time.

2.2 Data collection

The data received from respondents were summarized and stored in a spread sheet for each question separately. All the information received from the respondents was stored digitally in a standardised format. All relevant ethical issues regarding the protection and maintaining the confidentiality of the data are fulfilled during data collection period. The late responses from the participants were not taken into consideration.

2.3 Data Analysis

Data from each question was analysed and discussed separately. Some of data were derived through combining the responses of few questions and the same data were analysed to get more insights from the research study. Both qualitative and quantitative approaches were used to analyse the data because the questions were from both types. The data for few questions were converted from qualitative to quantitative and analysed by adopting weighted average method. Statistical measures such as mean and standard deviation were used to analyse the data. Bar charts were used for the effective comparison of the results. In addition, software tool for data analysis such as 'surveymonkey' was adopted.

3. Survey results and analysis

3.1 Focussed interview

The experts were approached for conducting face-to-face interview. The advantages, challenges and drivers of BIM in relation with quantity surveying practices, which were found through critical literature review, were discussed with interviewees. All the interviewees agreed that these advantages, challenges and drivers which are experienced in BIM technological advanced countries like USA and UK, are applicable in UAE too. Some advanced applications of BIM in quantity surveying practices were pointed out by interviewees, which are cost and schedule performance analysis softwares. Draft questionnaire was refined with additional information from experts. Some of literature findings and questionnaire detail were emphasized through interviewees' opinions. Without contradicting all the experts agreed that the quantity surveying practices would be benefitted by adopting BIM and strongly suggested the significance of the benefits of its adoption.

3.2 Questionnaire

Total of 74 responses were obtained through online questionnaire survey. Even though the target representative sample was 100 the current sample size is only 74. However, the sample comprises of all types of quantity surveyors from various organizations. Therefore, generalization of the research findings is effective. The majority of respondents are well experienced. The results show that nearly 42% of the respondents have 6 to 10 years of experience and another 42% of the participants have more than ten years of experience approximately. Therefore, total of 84% of the respondents have more than five years of valuable industry experience. As a result, the information offered by the respondents would be rich. This is a good indication that the analysis of the data obtained from respondents would provide valid and effective results.

3.3 Quantity surveying practices in UAE

As far as current practices of quantity surveyors in UAE are considered all types of QS roles are exercised as per the data obtained through online questionnaire survey. All quantity surveying roles such as measurement and quantification, Preliminary estimates, Feasibility studies, Cost planning, Preparation of BOQ, Advise on procurement method and contractor selection, Tender analysis, Construction contract practices, Financial management, Valuation of claims and variation, Project management, value management, Management contracting, facilities management, Development appraisal, Taxation & grants and construction dispute resolution are offered as answers by the respondents. This indicates that all types of quantity surveying roles are being practiced in UAE. It is found that basic and core practices of quantity surveyors hit high percentages but advanced competencies of quantity surveyors such as construction project management, value management, facilities management, management contracting, arbitration and other dispute resolution, insolvency, insurance, property investment funding, taxation allowances and grants, and research methodologies and techniques are practised at lower level.

Table 3.1 provides the distribution percentages of various types of quantity surveying profession in UAE. It could be noticed that the senior levels of quantity surveyors contribute to 19% approximately whereas other levels such as junior and middle range cover 81% of the total population of the quantity surveyors in UAE. However, these percentages do not match with the percentages of different competency level of quantity surveying practices as discussed earlier. For an instance, the average percentage of advanced competency level is 10% approximately whereas the senior professionals are 19% of the quantity surveying community in the UAE Construction Sector. One of the reasons is suggested that some of senior level quantity surveyors who are contract manager, commercial manager and cost manager practise core competencies of quantity surveying profession.

Table 3.1**:** Distribution of various types of quantity surveying profession

Question - Please indicate your current profession	
Answer Options	**Response Percentage**
Contract Manager	6.8%
Commercial Manager	6.8%
Cost Manager	5.5%
Quantity Surveyor	76.7%
Estimator	4.1%
Total	**100.0%**

3.4 Awareness of BIM among quantity surveyors in UAE

The awareness of BIM among the professional quantity surveyors in UAE sounds well based on the results of empirical survey conducted. Figure 3.1 illustrates the levels of understanding about BIM by quantity surveyors who practise in UAE. The respondents were given four options such as ‘excellent’, ‘good’, ‘poor’ and ‘no idea’ in order for them to show their understanding regarding BIM. Majority of the respondents, approximately 65.7%, understand BIM well however, only 31.4% of the quantity surveyors agree that the BIM is practised in their current organizations as revealed by survey results and as depicted in Figure 3.2.

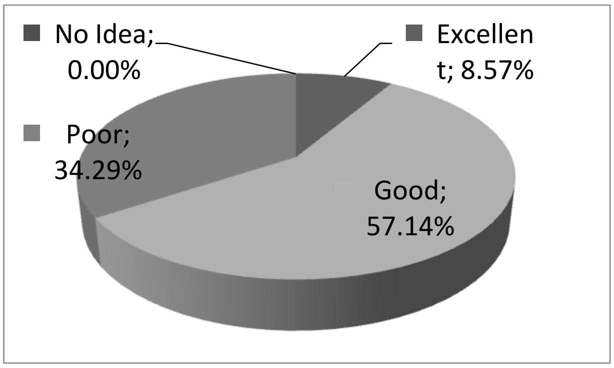

Figure 3.1: Understanding about BIM among QS in UAE

It is apparent that the quantity surveyors practise BIM within their scope when their organizations adopt BIM into their projects. Accordingly, the information contained in Figure 3.2 is reasonably considered that the quantity surveyors practise BIM when their answer is ‘yes’ for the status of BIM practice in their firms. Although 65.7% of the professional quantity surveyors have better knowledge about BIM less than half of that population practise BIM in their organizations.

The gap between the awareness and the usage is an indication that there are prevailing constraints such as client demand, lack of standard and lack of technology use in the adoption of BIM. Also this is a clear indication that the construction projects where professionals practise BIM is very less in UAE.

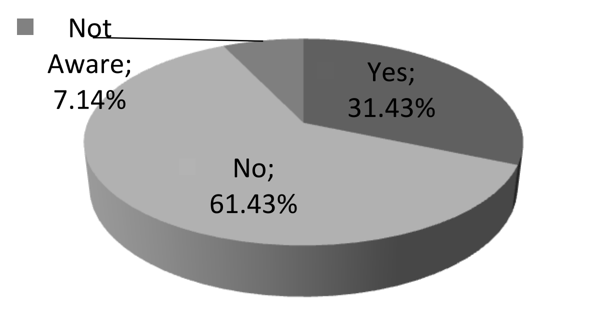

Figure 3.2: Respondents answers on the status of BIM practice in their organizations

3.5 Advantages of BIM in QS practices in UAE

Table 3.2 displays different types of BIM benefits which are experienced by the quantity surveyors.

Table 3.2**:** Ratings of QS related BIM applications in UAE

BIM Benefits	Response %
3D coordination	57.14%
Visualization	57.14%
Automated quantities take-off	42.86%
Cost estimation using related software	39.29%
BOQ preparation using related software	32.14%
Computer aided construction planning	28.57%
Performance analysis using software	25.00%
Computer aided construction management	21.43%
Lifecycle costing using software	10.71%

The results show 3D coordination and visualization applications are being used by majority of the respondents whereas software for lifecycle costing is being practised comparatively very less. The finding depicts that main benefit of 5D BIM is visualization of the building because it is connected with many other benefits such as bulk checking device for manual measurement, efficient data extraction for estimating, producing schedules of quantities, rapid identification and costing of design changes. Finally, all these benefits lead to have commercial advantage over competitors. It also explains that there is a lack of interest among practitioners in usage of BIM for its expanded applications such as lifecycle cost estimates.

3.6 Challenges of BIM's adoption in QS practices in UAE

The survey results describe the respondents ranking on barriers for BIM adoption in quantity surveying practices. This shows that the lack of experience and knowledge are the most effective barriers whereas lack of confidence with automation is ranked as the least effective barrier in adoption of BIM in quantity surveying practices. The effectiveness of the barriers diminishes as the rank increases from 1 till 6. Therefore the middle which is 3.5 reflects the average (mean).

It could be identified that the lack of experience and knowledge, lack of awareness of BIM's benefits and lack of client demand are more effective obstacles which fall less than 3.5 as average rating whereas resistance to change from traditional practices, investment expenses and lack of confidence with automation are less effective barriers comparatively since they take average ratings more than 3.5. However, the hindrances such as lack of experience and knowledge, lack of awareness of BIM's benefits and lack of confidence with automation are focussed more since these factors deviate exceptionally towards either sides of effectiveness from the average (mean) compared to others. Hence, the said first two hindrances are considered as very strong barriers while the third one is very weak for the adoption of BIM in quantity surveying practices in UAE.

Lack of confidence with automation is cited by the respondents as the least obstacle. This is clearly evidenced by Dubai Mall Project which is one of the iconic projects and world largest shopping mall. The automation function used for the construction of Dubai Mall has saved over 700 man-months, which in other words the automation resulted in increase of efficiency by 86% and an overall savings of 7 Million US Dollars. Therefore, it is strongly suggested that the effect of these magnificent savings has resulted in increasing the confidence level in BIM's automation function among quantity surveyors in UAE.

3.7 Effectiveness of BIM's adoption in QS practices in UAE

Table 3.3 provides the ratings of quantity surveyors regarding their overall opinions in relation with BIM enabled quantity surveying practices. The listed options are the essential requirements in quantity surveying practices. Majority of the respondents agree that BIM improves these benefits to quantity surveying practices. However, considerable percentage of respondents disagree the statements that adoption of BIM would offer increased accuracy and increased reliability. In overall more than 90% of the respondents agree each of the statement in relation with the adoption of BIM. The data shows a clear and robust indication that the adoption of BIM is very beneficial to the quantity surveying practices in UAE. This statement is further supported by the data shown in Table 3.4.

Table 3.3: Rating the overall opinions of respondents regarding BIM enabled QS practices

BIM Benefits	Strongly agree	Agree	Dis-agree	Strongly dis-agree
More cost savings in the long run	28 (44.4%)	33 (52.4%)	2 (3.2%)	0 (0.0%)
Time savings	28 (45.9%)	32 (52.5%)	1 (1.6%)	0 (0.0%)
Increase accuracy	26 (41.9%)	31 (50.0%)	5 (8.1%)	0 (0.0%)
Increase reliability	25 (40.3%)	31 (50.0%)	5 (8.1%)	1 (1.6%)

According to the survey results which is tabulated in Table 3.4, approximately 97% of the quantity surveyors show their positive attitudes towards uptake of BIM in quantity surveying practices in UAE. In overall point of respondents view, implementation of BIM in quantity surveying practices in UAE is highly recommended and more effective to survive in the competitive construction market.

Table 3.4: Rating the opinions of respondents regarding the implementation of BIM in QS practices

Question 15 – Would you recommend the implementation of BIM in quantity surveying practices?	
Answer Options	**Response Percentage**
Yes	96.7%
No	1.7%
No idea	1.6%

4. Conclusions and Recommendations

The rich information acquired through the research study reflects positive attitudes of majority of the quantity surveyors in UAE, towards the benefits of BIM and its implementation regardless the small percentage of BIM's awareness level. The interviewees showed their consent on the uptake of BIM in quantity surveying practices and strongly suggested the significance of the benefits of its adoption.

Concluding all the literature collections of BIM in construction, it is examined that there is no unifying definition which covers all the aspects of BIM. As BIM continues to evolve and being developed over time, many theoretical concepts are frequently drawn from different perspectives. However, BIM can be defined including almost all of its aspects, as "the process and technology for producing, managing and sharing physical and functional data of a facility in a collaborative environment using digital representative models throughout project lifecycle processes [24]. All the data in BIM environment should be shared or exchanged in an interoperable way.

All types of quantity surveying disciplines as found in the literature are practised in UAE. However, the practised percentage differs from one to another. Basic and core competency levels of quantity surveying roles are practised from 19% to 76% approximately but advanced level practices found to be very less comparatively. Only value management role in advanced competency level is practised 34% approximately and the others fall within the range from 1% to 19% only in UAE. However, these percentages do not correspond with the distribution of various types of quantity surveyors. It is suggested as one of the reasons, that the managerial level quantity surveyors practise core level disciplines too.

The awareness level of BIM among UAE quantity surveyors sounds well. The majority of the respondents show their consents regarding excellent and good understanding of BIM. Approximately 66% of the population have good knowledge about BIM whereas 31% of the quantity surveyors only practise currently. One of the reasons for the difference between these percentages can be suggested as the hindrances for uptake of BIM.

3D coordination and visualization applications of BIM are widely adopted in quantity surveying practices in UAE. Visualization leads to many other benefits of BIM in quantity surveying practices. BIM software for lifecycle cost estimate is practised comparatively very less due to lack of enthusiasm among quantity surveyors in UAE. It is found that majority of the quantity surveyors in UAE agree the significance of all the benefits which are available in the literature.

All the barriers and challenges identified in secondary data are agreed by majority of the quantity surveyors as effective hindrances for the adoption of BIM in quantity surveying practices in UAE. Lack of experience and knowledge of BIM and lack of awareness of its benefits are found to be the most effective barriers whilst lack of confidence with automation of BIM is ranked as the least obstacle. The confidence level has increased based on the benefits achieved from BIM based Dubai Mall construction. All the listed challenges are highly effective in uptake of BIM. Legal concern of copyright of BIM data is ranked as the least effective challenge as per the survey results and other recent research findings strengthen the statement. In mean time, the identified drivers and solutions are highly recommended by majority of the practitioners as important for overcoming the challenges.

By critically analysing all the above discussed survey findings and the survey results obtained for respondents' overall opinions and recommendation, it is highly recommended that the implementation of BIM in quantity surveying practices in UAE is beneficial and utilization of great opportunities. It is also suggested that the uptake of BIM is more effective to survive in the competitive construction market. All the recent research findings strengthen these recommendations.

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ASSESSMENT ON DEFECTS OCCURENCE AND REWORK COSTS IN HOUSING CONSTRUCTION SECTOR IN SRI LANKA

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Abstract: Defects in building construction are considered to be one of the recurring problems in the construction industry. It has adverse effects on project performance, building performance, and client or end-user satisfaction. The lack of focus on defects leads to negative impacts on cost, duration and resources of projects. Defects may generate controversies among parties involved, not only affecting ongoing construction but also during its operation. Rework cost is another effect of defects, absorbs a significant share ranging from 0.5% to 3.7% of total project costs. This research therefore investigates the most frequent defects and rework cost involved in rectifying the defects in residential buildings in Sri Lanka. A questionnaire survey and subsequent interviews to be carried out together with a detailed analysis of documents will be employed to address research focus. 47 housing projects which exposed to defects were studied. Findings of the study indicates that defects such as bulging of columns, beams and slabs, verticality issues of masonry walls, cracks in plastering and painting, defects in doors and windows are more likely to occur in residential buildings in Sri Lanka. The mean total rework cost as a percentage of the cumulative work done value was found to be 0.92%. For a mean total rework cost of 0.92%, the likelihood that a project exceeds is 37%. Finally, the study proposes strategies such as proper documentation, proper coordination of works and uplift the attitude towards reporting the defects of lower level staff would help practitioners to minimise the defects in building construction in Sri Lanka.

Keywords: Defects, Housing construction, Rework costs, Sri Lanka.

1. Introduction

Building defects and failures are very common phenomena in any kind of construction; either building or civil engineering. Building defects arise through inappropriate or poor design, specification and construction as well as to insufficient attention given to building maintenance. Building defects can be the result of design errors by professionals, a manufacturing flaw, defective materials, improper use or installation of materials, not conforming to the design by the contractor, or any combination of the above [3]. Ransom [17] stresses that the defects in many of the buildings not only due to lack of knowledge but also by non-application and misapplication of knowledge.

On a similar note Ojo and Ijatuyi [14] explains that, defective construction refers to works which fall short of complying with specified descriptions or requirements of a construction contract, especially any drawings or specifications, together with any implied terms and conditions as to its quality, workmanship, durability, aesthetics, performance or design.

1.1 Objectives

With this notion in mind, the objectives of the research are to;

- Identify and differentiate types of defects
- Identify the frequency of occurrence of identified defects
- Analyse the rework cost related to defects

The research identifies most defects occurring elements, frequency of defects pertaining to those elements, probability of rework costs for rectification of defects of residential buildings in the course of construction and defect liability period. For the purposes of this research, rework is defined as 'the unnecessary effort of redoing a process or activity that was incorrectly implemented at the first time'.

2. Definition of defects and different terminologies used in the construction environment

The term 'defect' has been defined differently by researchers. It means the shortcomings in the design and construction practices for some of them, while to others; it implies the inadequacies that arise from normal wear and tear. Olanrewaju and Idrus [15] indicates that design and construction defects are those that are caused due to wrong methods of construction, poor materials and bad labour practices. “A defect is a shortfall in performance occurring at any time in the life of the product, element or building in which it occurs (BRE Digest 268). It is also a departure from design requirements where these were not themselves at fault” [6, p.49]. However, Table 1 shows that there has been recent increase in research on defects in the house building sector.

Table 1: Definitions of defects in various contexts ([19], p.86)

Context of definition	Definition	Literature Sources
Wider construction environment	Wider construction at any time in the life of the environment.	BRE (1990)
Wider construction	Non-fulfilment of intended usage environment requirements.	Josephson and Hammarlund (1999)
House building environment	Failing or shortcoming in function, performance, statutory or user requirements of a building that manifests itself within the structure, fabric services and other facilities of the building.	Ilozor, et al.(2004)
Wider construction environment	Part of work which is not in accordance with the work's information.	NEC (2005)
House building environment	A final product that does not meet the required quality.	Kim, et al (2007)
House building environment	A component has a shortcoming and no longer fulfils its intended function.	Georgiou (2010)
House building environment	Breach of any mandatory requirement by builder or anyone employed by or acting for the builder.	NHBC (2011)
House building environment	Something that is unfinished, or an imperfection that is inadequate or causes failure.	Beattie (2011)

Another term that is commonly used is rework. Rework may be defined as the process by which an item is made to conform to the original requirement by completion or correction [4]. Alternatively, rework is doing something at least one extra time due to non-conformance to requirements [5]. A broader definition of rework is unnecessary effort of redoing a process or activity that was incorrectly done the first time [11]. However, Hwang, Thomas, Haas, and Caldas [7] emphasis that all these definitions share a common theme which is to redo work due to non-conformance with requirements or the occurrence of a defect.

2.1 Types of defects

Othman, Jaafar, Harun, and Ibrahim. [16] identifies, building defects can be categorized into two which are patent and latent defects. Patent defects are ‘obvious’ defects while latent defects are hidden and become apparent at a later date. A patent defect could be something that is visually obvious, for example, the omission of mastic seal in the required areas around a shower or bath unit. Patent defects can be identified during construction’s inspection and during Defect Liability Period (DLP) contrast to latent defect that will occur after the building is occupied [8].

Such patent defects are often recorded in snagging or defect lists at the time of practical completion. Latent defects may include those defects that, while not obvious at practical completion, become obvious soon after. If defects become patent during the defects rectification period, most standard form construction contracts contain mechanisms for rectifying them.

2.2 Causes of defects

Ahzahar et. al. [3], have identified contributory factors for defects within the Malaysian construction industry as;

- Faulty Design
- Faulty Construction
- Building Type and Change in Use
- Climatic Conditions
- Lack of Supervision

These factors can be the root causes for many different defects in different ways. Following are origins of defects identified as shown in Table 2 and how they may manifest in a building in general. It lists out the common roots for which results ultimately to spread into number of defects.

Table 2: Origins of defects ([18], p.61)

Origins of defects	Examples of defects
Material failure or component failure	Deterioration of finishes such as paint
	Sulphate attack of ordinary Portland cement in walls and floors
	Metal fatigue in fixings
	Spalling of clay brickwork
	Failure of bitumen felt roofing
Workmanship failure	Joint seals
	DPC laps
	Manufacturing faults
	Absence or incorrect use of fixings and restraints
Design failure	Tolerance faults
	Material combinations and aggressive effects
	Difficult weatherproofing details
	Insufficient sizing of structural elements
External agencies	Impact damage from vehicles
	Vandalism
	Arson
Wear and tear	Natural degradation of materials

Besides those technical aspects, Ågren [2] stated, the causes of defects as lack of documentation, standardisation, knowledge and motivation. Communication issues and insufficient resources have also been eminent. Although concepts are usually related to organisational factors, these studies have been carried out on an operational level, for example, the lack of communication between two individuals and a lack of resources for a given construction task.

3. Rework cost and significance of defects in building construction industry

Rework refers to non-achievement of quality standards within the construction industry. Rework as defined by Love and Li [12] as the unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time. The impact of rework on construction organisation is significant. It can adversely affect an individual's, organisation's and project's performance and productivity [10]. Abdul-Rahman [1] agrees that an organisation's reputation and its profit margin can be affected because the cost of redoing a project that is not up to standard is high. The need to reduce costs and at the same time improve quality standards is mutually supportive for any project. If the building process must achieve the principle of doing things right the first time and every time, it should be appreciated that the occurrence of defects has a price.
To perform rational defect prevention, it is necessary to have knowledge about defects, their causes and associated costs [9]. Previous research efforts have revealed that the rework cost could be result as 5 % to as high as 23 % of the contract value ([13]; [9]).

4. Research Methodology

A quantitative approach was used as the main research approach to obtain the frequency of defect

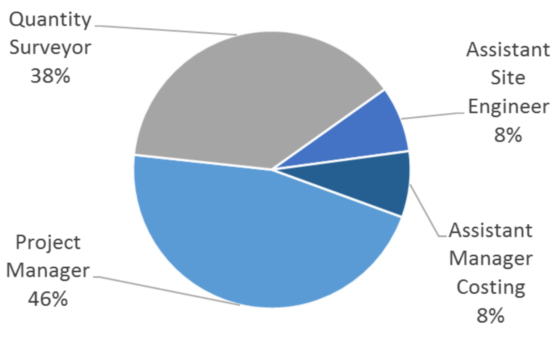
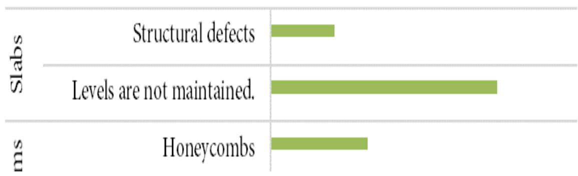


Figure 1: Respondents by profession

occurrence and observe the behaviour of the total rework costs associated with defects. A questionnaire survey along with interviews and document survey was implemented to improve the reliability of the data obtained. The questionnaire had four major focuses: general profile of the project which had defects, types of defects together with their frequency, root causes of the defects and rework costs associated with them. The respondents were asked to consider their experience in projects where they had defects and answer the questions given under the above four areas. In addition, participants were given the list of defects identified in the literature. Where it deviates from the literature findings participants were given the freedom to indicate their own options.
The study sample was selected based on snowball sampling method as there was tendency of the participants were reluctant to furnish some of the confidential information. Respondents included Project Managers, Quantity Surveyors, Assistant Site Engineers and Assistant Manager in costing. The research participants had 5 to 20 years of work experiences in building construction.

For the data analysis, details were obtained from housing projects situated in Western and Southern provinces carried out by different contractors.
Data were collected from construction firms which have C3 to C7 grading and registered with Construction Industry Development Authority (CIDA) in Sri Lanka. Figure 1 provides a breakdown of the respondents based on their professions: projects managers (46%), quantity surveyors (38%), assistant site engineer (8%) and assistant manager costing (8%). Response rate of the data collection is 100% as each and every data collection was personally attended. During the data collection, a detailed questionnaire along with a semi-structured interview was carried out to improve the reliability of the data.



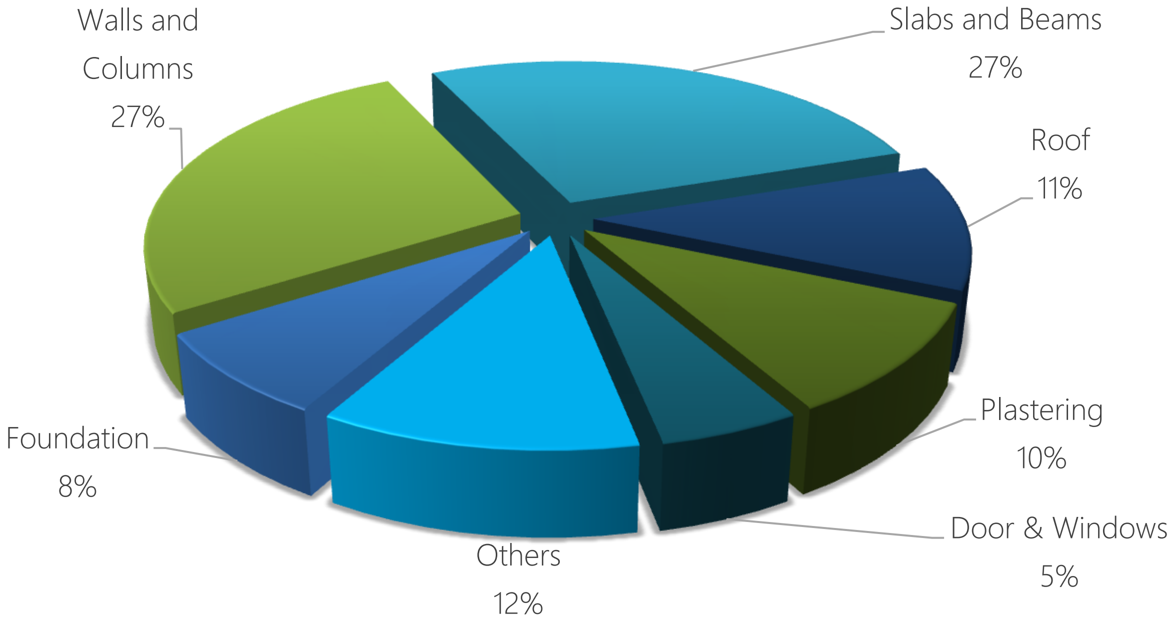


Figure 2: Frequency of occurrence of defects pertaining to elements

4.1 Data analysis procedure

Quantitative data collected from the questionnaire and document survey where required were encoded using the Statistical Package for the Social Science (SPSS) v.20 and results were analysed using both descriptive and inferential statistics. Additionally, EasyFit Professional 5.6 were used to analyse the probability of distribution of rework costs.

5. Research findings and discussion

Defects and Contribution factors for defects

The questionnaire asked participants to provide details on a current project or any past projects where defects have occurred during the course of construction and the defect liability period. Likert scale 5-part type questions (1-Less occurred, 5-Mostly occurred) were asked on each defects listed out in the questionnaire which was identified through literature survey and preliminary survey. According to the data collected, defects were identified under following elements. Figure 2 depicts the frequencies of defects occurrence pertaining to a particular element group. Most of the defects occurred in the elements of slabs, beams and columns as an account of 54% of total defects. Where others category has been introduced by including the elements in which the frequencies reported below 5%. Others category can be elaborated as follows;

- Painting defects 4%
- Plumbing defects 4%
- Floor finishes defects 3%
- Waterproofing defects 1%

Nature of the defects occurred in the concrete works are shown in the Figure 3. Most of the defects such as alignment issues and bulging of columns, beams and slabs are due to inadequate formwork supplied and lack of supervision of the responsible parties. In general practise honeycombs are not recognised as defects unless otherwise it will create a structural issue. Deep honeycombs are considered as defects in the industry practitioners and generally they are rectified with specialized sub-contractors.

Roof defects which is of 11% are due to the leakage of the ridge and the fading of paint of the valance boards and other components. All of the roof defects pertaining to water leakages have been reported during the defects liability period.

Cracks formation of the plaster due to chemical reactions of substances and inadequate curing is the third most occurring defect in the residential buildings pertaining 10% of the whole. Sometimes these cracks have emerged after the painting was done, so therefore it affects the painting as well. Foundation defects have been identified during the construction and they account to design defects most of the time and only at one scenario has been reported due to bad workmanship under the study.

Door and windows defects are reported due to unmatching of sizes due to carpenter's erroneous production and usage of not properly seasoned timber.

Table 3: Descriptive statistics of total rework costs

Statistic	Value	Percentile	Value
Sample Size	47	Min	0.049
Range	3.646	5%	0.0956
Mean	0.91791	10%	0.122
Variance	0.73983	25% (Q1)	0.214
Std. Deviation	0.86013	50% (Median)	0.583
Coeff. of Variation	0.93705	75% (Q3)	1.292
Std. Error	0.12546	90%	2.2286
Skewness	1.3163	95%	2.7658
Excess Kurtosis	1.3442	Max	3.695

Figure 3: Types of defects occurred in the concrete works

Defects in floor finishes accounting to 5% are occurred due to poor workmanship and the chipping of the tiles and terrazzo due to careless handling of equipment and poor organizing of work sequence.

Rework costs

Table 3 presents the descriptive statistics for the total rework costs used in determining the probability of rework in the sampled project. The mean total rework cost as a percentage of the original contract sum was revealed to be 0.91% and the standard deviation was 0.86%. The data indicate that the total rework costs ranged from 0.05% to 3.7%. Evidently, the total costs of rework vary considerably among projects. Love [10] argued that the degree of variability in the estimates specified by the respondents suggests that many respondents may be unsure about the actual costs of rework incurred in the projects.

The following steps were adopted to determine the probability of rework. First, the probability density functions (PDFs) were developed using EasyFit Professional 5.6 software. The PDF is a mathematical expression that analyses a continuous random variable and defines the shape of the distribution. The 'best fit' probability distribution was examined using Kolmogorov-Smirnov and Anderson-Darling goodness-of-fit tests.

- Kolmogorov-Smirnov statistic (D): Based on the largest vertical difference between the theoretical and empirical CDF (Cumulative Distribution Function)

- Anderson-Darling statistic (A^2): A general test to compare the fit of an observed CDF to an expected CDF. The test provides more weight to a distributions tails than the Kolmogorov-Smirnov test.

As observed from Table 4, the results of the goodness-of- fit tests revealed that generalised Exponential distribution provided the best fit for the dataset for total rework costs. The histogram presented in Figure 4, depicts probability distribution function for rework costs based upon the distribution parameters. For instance, Figure 4 shows that likelihood that a project will exceed a mean total rework cost of 0.92% is 37%.

Table 4: Goodness-of-fit details for total rework costs

Kolmogorov-Smirnov					
Sample Size	47				
Statistic	0.072				
P-Value	0.953				
Rank	3				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.153	0.175	0.194	0.217	0.233
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	47				
Statistic	0.356				
Rank	1				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.380	1.929	2.502	3.289	3.907
Reject?	No	No	No	No	No

6. Conclusions

The research presented the types of defects and its frequency of occurrence during the course of construction and throughout the defect liability period. Required data from 47 housing projects were obtained through questionnaire survey along with interviews and document survey.

Research has uncovered most occurring defects types during construction and throughout the defect liability period. Considering the findings presented in this research, approximately 54% of the defects have been recorded in the concrete works during the structure construction. Most of the roof defects are due to water leakages and they were only reported within the defect liability period. As an overview, contribution factors for defects have been identified as lack of supervision, unfavourable working conditions, design errors, poor coordination of works, construction materials and poor workmanship. However, it was revealed that there was a lacking procedure in documentation and proper management of defects of most of the sites from the interviews conducted. As identified in the research, organizational practices have more influence on this aspect, as being some have established quality objectives to control defects and some have not had much consideration on defects.

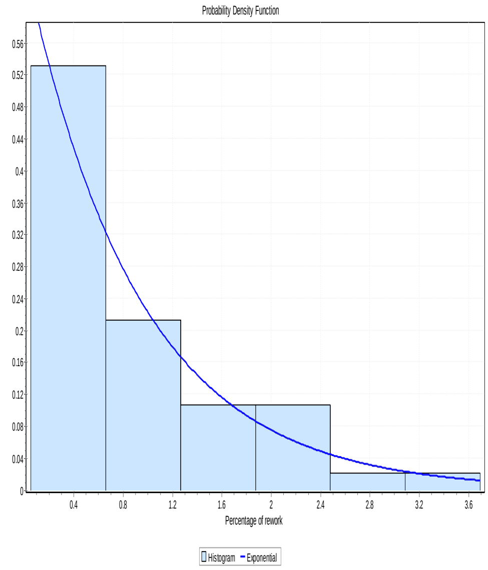


Figure 4: An exponential histogram of rework

The analysis of rework costs revealed that, the total rework costs as a percentage of the total work done value varies from 0.5% to 3.7%. During the statistical analysis, using Kolmogorov-Smirnov statistic and Anderson-Darling statistic, it has been observed the distribution of rework costs follows general Exponential distribution. The mean total rework cost as a percentage of the cumulative work done value was found to be 0.92%. For a mean total rework cost of 0.92%, the likelihood that a project exceeds is 37%.

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Analysis of Factors Contributing Civil Engineering Project Delays in Sri Lanka

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Abstract: A construction project is commonly acknowledged as a successful project when the aim of the project is achieved in terms of predetermined objectives of completing the project on time, within budget and to the required quality standard. Delay in the completion of a construction project can be a major problem for contractors, consultants as well as for clients. These delays lead to costly disputes and adverse relationships amongst project participants. Projects can be delayed due to large number of reasons. The reasons are related to various types of uncertainties associated with activities during the construction process or during the planning and design stages. Therefore a comprehensive survey was carried out to identify the critical factors that cause the delays in Sri Lankan construction projects. From in-depth literature studies, 52 causes of delay were identified. Questionnaire survey was carried out among 107 selected construction projects in Sri Lanka. The findings show that the delay in Sri Lankan construction projects is mostly originated by labour, followed by contractor and client, while external related causes are less important. This paper also explores and provides some recommendations to reduce the impact of delays on civil engineering projects in Sri Lanka.

Keywords: Construction delays, Delay causes, Sri Lankan project delays, Delay factors, Sri Lankan construction industries

1. Introduction

One of the most important problems that may occur in civil construction projects is delays. The significance of these delays vary considerably from project to project. Any disruptions to the project objectives will certainly contribute to project delays with its specified adverse effects on project objectives. The causes for construction project delays are client related causes, contractor related causes, consultant related causes, material related causes, labour related causes, equipment related causes and external causes.

2. Literature review

Several researchers have studied about the causes of the construction project delays in different countries. The findings of such studies have been reviewed for this research.

Assaf and Al-Hejji (2006) studied the causes of delay in large building construction projects in Saudi Arabia. There were 73 factors that cause construction delays were found and categorized into 9 groups. Some of the most important causes of delay included approval of shop drawings, delays in contractors' payment by owners, design changes by owners, cash problems during construction, the slowness of the owners' decision-making process, design errors, excessive bureaucracy in project-owner organization, labour shortages and inadequate labour skills.

Frimpong et al (2001) had carried out the research on finding out delay causes in ground water construction projects in 2001 in Ghana as a case study. The objective was to study and evaluate the factors that contribute to delay and cost overrun in ground water constructions. There were 26 factors affecting construction delays identified from the previous observations their relative importance index were determined. Monthly payment difficulties from agencies, poor contractor management, planning and scheduling deficiencies, material procurement and poor technical performance were identified as major causes of delays. Identifying appropriate funding levels of the projects at planning stage, introducing training programmes to improve managerial skills of the contractors and introducing effective material procurement systems were suggested as mitigation activities.

Alaghbari et al (1999) carried out a research to identify the causes of delays in building construction projects in Malaysia using the survey. Financial difficulties and economic problems (client), Financial problems (contractor), Supervision too late and slowness in making decision (consultant), Slow to give instructions (consultant), Lack of materials on market (external), Poor site management (contractor), Construction mistakes and defective work (contractor), Delay in delivery of material to site (contractor), Slowness in making decisions (Owner), Lack of consultant experience (consultant) and Incomplete documents (consultant) are the factors of delay were categorized and ranked according to contractor, owner and consultant separately.

Chan and Kumaraswamy (1997) did a survey to assess the relative importance of 20 potential delay factors in Hong Kong construction projects and five key factors were found, such as poor risk management and supervision, unforeseen site conditions, slow decision making, client-initiated variations, and work variations. However, Al-Momani (2000) in a research on construction delays in 130 public projects in Jordan found that weather, site conditions, late deliveries, economic conditions and increase in quantity are the critical factors which cause construction delays in Jordan construction industry.

Assaf *et al.* (1995) identified 56 main causes of delay in large building construction projects in Saudi Arabia and calculated their relative importance. Based on the contractors surveyed the most important delay factors were preparation and approval of shop drawings, delays in contractor's progress, payment by owners and design changes.

3. Objectives

The following objectives are developed to achieve the aim of the research.

- To identify the causes of delays in civil engineering construction industry in Sri Lanka.
- To study the differences in ideas of the three main stakeholders including clients, contractors and consultants.
- To identify the significant factors that cause delays in Sri Lankan construction projects.

4. Methodology

To understand the current status of project delays in Sri Lankan construction industry, the data collection was carried out through a questionnaire survey and a series of interviews. Preliminary survey was carried out through interviews and discussions to finalize the questionnaire.

The questionnaire survey included 107 nos. Sri Lankan construction projects such as building, road/highway, water supply and irrigation. The questionnaire was divided into two main parts. Part one includes the details of the respondents and organizations in order to get the information about the respondent's details and organization as well. Part two includes the factors that cause construction project delays in Sri Lankan construction industry. This part is comprised of seven categories such as client, contractor, consultant, materials, equipment, labour and external factors.

The questions were based on the Liker's scale of five ordinal measures from 1 to 5 (very low effect to very high effect) according to level of contributing.

The collected data was analyzed using MS Excel. This data analysis was used to determine the relative importance of the various factors that contribute to causes of construction project delays. The following steps were followed in the analysis of data:

- Relative Importance Index (RII) was calculated.

$$RII = \frac{\sum w_i x_i}{\sum x_i}$$

  Where:
  i - Response category index
  w_i - Weight assigned to i^{th} response (1, 2, 3, 4, 5 respectively)
  x_i - Frequency of the i^{th} response given as percentage of the total responses for each factor

- The factors were ranked in each category based on their Relative Importance Index (RII)

According to Assaf and Al-Hejji (2006) spearman's rank correlation is a non-parametric test. Correlation is a relationship measure among different parties or factors and the strength and direction of the relationship. This method mainly used to show the degree of agreement between the different parties. The correlation coefficient varies between +1 and -1, where +1 implies a perfect positive relationship (agreement), while -1 results from a perfect negative relationship (disagreement). The value near to zero indicates little or no correlation. In this research this correlation is used to find out the degree of agreement between parties. This correlation is computed by the following formula:

$$r_s{}^{J} = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

Where:

$r_s{}^{J}$ - Spearman rank correlation coefficient between two parties

d - difference between ranks assigned to variables for each cause

n - number of pairs of rank

5. Data analysis & results

All the causes of delays were ranked based on their Relative Importance Index as shown below.

Table 1: Ranking of client related causes of delays

Causes	RII	Rank
Delay in progress payments	3.27	1
Change orders by owner during construction	3.01	2
Slowness in the decision making process	3.00	3
Suspension of work by owner	2.98	4
Delay to furnish and deliver the site	2.93	5
Delay in approving shop drawing and sample	2.90	6
Late in revising and approving design documents	2.83	7
Poor communication and coordination	2.78	8
Conflicts between joint-ownership of the project	2.59	9

Table 2: Ranking of contractor related causes of delays

Causes	RII	Rank
Conflicts in sub-contractors schedule during execution of project	3.27	1
Difficulties in financing project	3.21	2
Frequent change of sub-contractors	3.18	3
Delays in sub-contractor’s work	3.13	4
Rework due to errors during construction	3.13	4
Poor communication and coordination	3.08	6
Ineffective planning and scheduling of project	3.01	7
Inadequate contractor’s work	2.94	8
Implementation of improper construction methods	2.90	9
Conflicts between contractor and other parties	2.87	10
Poor qualification of the contractor's technical staff	2.75	11
Delays in site mobilization	2.59	12

Table 3: Ranking of consultant related causes of delays

Causes	RII	Rank
Delay in approving major changes in the scope of work	3.03	1
Insufficient data collection and survey before design	3.00	2
Delays in producing design documents	2.92	3
Non-use of advanced engineering design software	2.92	3
Poor communication and coordination	2.91	5

Unclear and inadequate details in drawings	2.83	6
Mistakes and discrepancies in design documents	2.73	7
Inadequate experience of consultant	2.71	8

Table 4: Ranking of material related causes of delays

Causes	RII	Rank
Delay in material delivery	3.07	1
Late procurement of materials	2.89	2
Delay in manufacturing special building materials	2.88	3
Shortage of construction materials in market	2.82	4
Changes in material types during construction	2.77	5
Damage of sorted material while they are needed urgently	2.73	6

Table 5: Ranking of labour related causes of delays

Causes	RII	Rank
Shortage of labours	3.20	1
Low productivity level of labours	3.14	2
Personal conflicts among labours	3.02	3
Working permit of labours	2.79	4

Table 6: Ranking of equipment related causes of delays

Causes	RII	Rank
Lack of high technology	2.97	1
Shortage of equipment	2.92	2
Equipment breakdowns	2.91	3
Low productivity and efficiency of equipment	2.81	4
Low level of equipment operator's skill	2.71	5

Table 7: Ranking of external causes of delays

Causes	RII	Rank
Weather effect on construction activities	3.22	1
Effects on subsurface and ground conditions	3.08	2
Traffic control and restriction at job site	2.94	3
Delay in obtaining permits from municipality	2.91	4
Delay in providing services from utilities	2.73	5
Delay in performing final inspection and certification	2.72	6
Changes in government regulations and laws	2.64	7
Accident during construction	2.40	8

Delay affecting factors were ranked based on their Relative Importance Index shown below.

Table 8: Ranking of delay affecting factors

Related Factors	RII	Rank
Labour	3.04	1
Contractor	2.99	2
Client	2.92	3
Consultant	2.90	4
Equipment	2.86	5
Material	2.86	6
External	2.83	7

Ranking of the factors associated with degree of severity by clients, consultants and contractors are shown in Table 9, Table 10 and Table 11. Table 9 and Table 11 present that both client and contractor specified that labour related causes as sources of delay. However, consultant indicated that contractor related causes mostly contribute to construction delays. The combined results shown in Table 8 present that delay in civil engineering construction projects in Sri Lanka is mostly originated by labour, followed by contractor and client, while external related causes are less important.

Table 9: Ranking of delay affecting factors by client

Related Factors	RII	Rank
Labour	3.08	1
Contractor	2.99	2
Client	2.90	3
Equipment	2.83	4
Consultant	2.75	5
Material	2.68	6
External	2.60	7

Table 10: Ranking of delay affecting factors by consultant

Related Factors	RII	Rank
Contractor	3.03	1
Material	2.95	2
Labour	2.92	3
Consultant	2.90	4
Equipment	2.86	5
Client	2.78	6
External	2.70	7

Table 11: Ranking of delay affecting factors by contractor

Related Factors	RII	Rank
Labour	3.22	1
External	3.13	2
Consultant	3.09	3
Material	3.02	4
Client	3.02	4
Contractor	2.98	6
Equipment	2.90	7

Table 12: Summary of ranking of delay affecting factors

Factors	Ranking by			Overall Rank
	Client	Consultant	Contractor	
Client	3	6	4	4
Contractor	2	1	6	2
Consultant	5	4	3	6
Material	6	2	4	3
Labour	1	3	1	1
Equipment	4	5	7	5
External	7	7	2	7

The Spearman's rank correlation coefficient is applied to measure the degree of agreement or disagreement associated with the importance ranking of each two stakeholders for a single factor of delay, while ignoring the ranking of the third party. The results indicate 37.5% of degree of agreement (positive relationship) is between client and consultant. There is no correlation between client and contractor, and negative relationship between consultant and contractor. The relative agreement between each two parties is shown below.

Table 13: Importance Rank Correlation

Parties	Spearman Rank Correlation Coefficient
Client - Consultant	0.375
Client - Contractor	0.000
Consultant - Contractor	- 0.196

6. Conclusion

Delay in Sri Lankan construction projects is mostly originated by labour, followed by contractor and client, while external related causes are less important. Client and contractor specified that labour related causes as sources of delay. However, consultant indicated that contractor related causes mostly contribute to construction delays. Conflicts in sub-contractors schedule, delay in progress payments, weather effects on construction activities, difficulties in financing project, shortage of labour, frequent change of subcontractors, low productivity level of labour, delays in sub-contractor's work, rework due to errors during construction and effects of subsurface and ground conditions are the top 10 major causes of delay in Sri Lankan construction projects.

7. Recommendation

The tasks such as developing training facilities for labours, motivating labours by establishing acceptable attractive minimum salary scale, introducing productivity based payment system for labours and adopting new types of contracts are recommended to reduce the effects of labour related delay causes.

To minimize and control delays in construction projects, the following issues can be recommended by all parties.

The clients should pay special attention to the following factors:

- Minimize changes in order during construction so as to avoid delays
- Pay progress payment to the contractors on time as it weakens the contractor's ability to finance the work.
- Speed up reviewing and approving of design documents

Consultants should focus on the following points:

- Avoid delays in reviewing and approving design documents
- Build up the knowledge and skills of technical staff
- Improve coordination between parties

The contractors should give more attention to the following factors:

- Improve the knowledge and skills of technical staff
- Manage the financial resources and plan cash flow by utilizing progress payment
- Planning and scheduling the works from start of project and during the work
- Improve site management and supervision to achieve completion of work within specified time

Effective strategic planning, proper project planning and scheduling, collaborative working in construction, effective Site management and supervision, frequent coordination between the parties involved, accurate initial cost estimates, frequent progress meeting, and clear information and communication channels are the minimizing methods suggested. Continuous monitoring, financial controlling, labour management, revising schedule, material/ Equipment controlling and usage of planning softwares are the planning activities proposed to avoid the effects of delays.

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The Challenges and Obstacles of Post-Disaster Road Infrastructure Reconstruction in the Pre-Construction Phase

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Abstracts: Purpose-The reconstruction of road infrastructure in the post-disaster context require different approach when compared with road projects in the normal development context. Disaster recovery projects are seen as having their own unique identity, particularly due to stakeholder issues, resource challenges, capability issues, and even long-term reliability concerns. This paper invites a discussion regarding the challenges and obstacles identified in the reconstruction of road infrastructure in a post-disaster reconstruction setting, and focuses the discussion on the pre-construction phase.

Design/ Methodology/ Approach - The challenges and obstacles presented in this paper are based on the literature and the empirical evidence collected from the research in three case study districts in Aceh, Indonesia. Twenty-eight face-to-face semi-structured interviews were conducted with stakeholders of road infrastructure at the local, provincial and national level, and represented by respondents from the public works, planning agency, disaster management agency, consultant, contractors, and donor agencies. The findings were triangulated with the literature and consulted with five experts in the road infrastructure and disaster reconstruction area.

Findings - The identified challenges and obstacles are divided into three groups of discussion; planning and programming, road design, and procurement. Whilst some of these challenges are not unique to post-disaster context, the scale of the risks had been undermined.

Originality/ value - This paper identifies the challenges and obstacles of a road project in the post-disaster setting from the pre-construction perspective. Identification of these challenges and obstacles may help improve the implementation of post-disaster road infrastructure reconstruction projects in future recovery projects, particularly in the developing world.

Keywords- Road infrastructure, post-disaster reconstruction, project management

1. Introduction

Disaster recovery projects are seen as having their own unique identity, particularly due to significant stakeholder issues (Haigh and Sutton, 2012, Baroudi and R. Rapp, 2014), resource challenges (Chang et al., 2010a, Chang et al., 2010b, Chang et al., 2011, Chang et al., 2012), capability issues (Crawford et al., 2012) and even long-term reliability concerns (Hayes and Hammons, 2000). Moreover, the level of success of a project is often reflected from the performance of three indicators: time, cost and quality. This means that successful project is completed within the specified project period, within budget allocation and as intended quality. However, achieving all success factors in a road construction project is not a straightforward effort. Often, at least one of the factors would be compromised to achieve the other performance indicators. In a disaster recovery, the complexity of road construction project is also intensified by the chaotic environment and the high level of uncertainties associated with the post disaster reconstruction context. In turn, these factors result in challenges that are unique, in context and scale, to post disaster reconstruction of road infrastructure.

In major disasters, transport infrastructure appears to be one of the sectors which suffer the most damages and losses. Bappenas (2005) reported that losses and damages in infrastructure sector accounted for 19.7% of the total estimated losses and damages caused by the earthquake and tsunami in Aceh. In Sri Lanka, losses and damages in roads and transportation due to the tsunami accounted for 22% of the total needs (Asian Development Bank et al., 2005). The tsunami disaster in Aceh in 2004 caused damage to more than 2700 km of roads. Within the four year reconstruction period, more than 3600 km of road were reconstructed by the national government and donor agencies working in the reconstruction of road infrastructure in Aceh (Sihombing, 2009). This paper, which is based on the first author's PhD research in three case study districts in Aceh, is focused on the challenges and obstacles identified in the post-disaster reconstruction of the road infrastructure during the pre-construction phase. The identified challenges and obstacles are grouped into three main categories; planning and programming, road design, and procurement. The planning and programming phase refers to the preparation of blueprint of the overall reconstruction and program coordination. The road design phase refers to the process of designing the road technical specification. The procurement phase accordingly refers to challenges and obstacles identified in the procurement process.

2. Methodology

Twenty-eight face-to-face semi-structured interviews were conducted with the representatives of the road infrastructure stakeholders at the national, provincial and local level. The twenty-eight respondents comprise of eighteen respondents from three case study districts in the west coast area of Aceh province and ten policy makers from the provincial and national level. The basic profile and distribution of the interview respondents is presented in Table 1.

Table 1 – Basic Profile of the Respondents

Institution Types	Total
Public works	**9**
Consultant	**4**
Contractors	**3**
Planning agency	**5**
Disaster management agency	**3**
Donor organisation	**2**
Transport agency	**1**
Secretary of province	**1**
Total	**28**

The respondents for the interviews were selected using a combination of purposive sampling and snowballing method. Semi-structured interviews were conducted in a face-to-face approach. Each of the interviewees was briefed about the objective of the study and was advised to subscribe to the Participant Consent Form. Each interview was conducted for approximately one hour. The interviews were transcribed into NVivo 10, and were coded using multiple stages approach; open coding, axial coding and selective coding process. The data was analysed using content analysis technique with the aid of the same software. The findings of the study were triangulated through consultation with five experts in the subjects of post-disaster reconstruction and road infrastructure management as well as with the literature (the basic profiles of the experts are presented in Table 2).

Table 2 – Profile of respondents for the Expert validation semi-structured interviews

Code	Professional Background
Val01	Academic
Val02	Consultant
Val03	Consultant
Val04	Academic
Val05	Consultant

3. Discussion

This paper identifies challenges and obstacles of road reconstruction project in the pre-construction phase. The following sections will present the discussions according to the project phase.

Planning and programming

The discussion of the challenges and obstacles in planning and programming process covers the preparation of the blueprint for the overall reconstruction of road infrastructure, as well as the coordination of the reconstruction process. The summary of the challenges and obstacles at the planning and programming process is presented in

Table 3.

Table 3 – Challenges and obstacles in the planning and programming process

Project Phase	Challenges and Obstacles
Planning and programming	Fewer aid agencies focused on road infrastructure
	Increased material price
	Project delay
	Blueprint errors
	limited preparation time
	no project prioritisation, inclusion of almost all road networks
	Political pressure
	political pressure affect project location and budget allocation
	Competing donors makes coordinating and project distribution difficult

Hayat and Amaratunga (2011) argue that the reconstruction of road infrastructure in the post-disaster context is immediately challenged by the relatively fewer donor organisations working in the road sector compared with other sector such as housing and livelihood. Even though road infrastructure condition affected the speed and cost of aid distribution and the overall recovery process, very few aid agencies provided sufficient focus and fund allocation for the reconstruction of road infrastructure. Chang et al. (2011) argue that many aid agencies working in the tsunami reconstruction in Aceh undermined the importance of road infrastructure by not including it in their initial recovery plans, which resulted in project delays and increased material price.

Furthermore, the blueprint for the reconstruction of the affected areas was prepared in a very short time (3 months). Accordingly, inaccuracies were found and the blueprint included a number of programs not related to earthquake and tsunami disaster. For instance, almost all national roads and provincial roads were included in the blueprint that it overlapped with those under the responsibility of the Directorate General of Highways and the Aceh administration as part of their regular development programs (Sihombing, 2009). On the other hand, as further explained by Sihombing (2009) there were several most urgent programs excluded from the blueprint, such as the construction of escape airstrips in the remote and strategic locations in Aceh. As a consequence, the disaster reconstruction implementation agency, The Agency for the Rehabilitation and Reconstruction of Aceh Nias (BRR), had to abandon the blueprint and worked based on what they see fit in the actual field condition. Accordingly, in the BRR Mid Term Review report (MTR), adjustments were made in the reconstruction plan, and that the reconstruction projects were grouped into four quadrant of MTR matrix (Subekti, 2009). The MTR matrix is shown in Figure 2

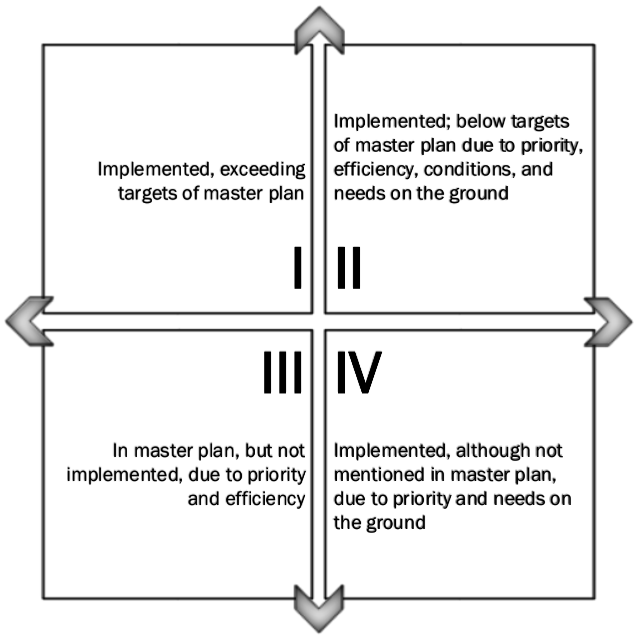

Figure 1 – The four Quadrant of the MTR (Subekti, 2009)

At the programming phase, the study identifies that the distribution of project location and budget allocation was also challenged by the political pressure, conflict of interest, and competition among the donors and stakeholders. It was suggested that political pressure from the parliament member and high-rank officials, for instance, affected the decision-making in determining project location. On the one hand, it was acknowledged that the political pressure to disperse project location was necessary as a means to ensure the distribution of wealth. However, there were cases where such pressure stem from the conflict of interest. As illustrated by CS04

> *"The challenge was that too many road projects were forcefully requested to be done in certain locations… Why do they have to be there? After we did field observations, we found that there was the house of the head of parliament, or it was the Regent's village. That happened." – CS04*

Furthermore, the great number of donors working in the post-disaster reconstruction made coordination and distribution of work areas difficult, particularly when more than one donors interested in working in the same areas and that there were changes of reconstruction coordination authority at the initial reconstruction phase. In the initial period of the reconstruction, Sugiarto (2009) described how the transfer of authority for reconstruction coordination from the National Development Agency to the BRR resulted in a number of projects' postponement, which was due to changes in the reconstruction procurement policy and the reluctance of big donor organisation to coordinate with the BRR for their project implementation. Miscommunication and coordination problem also occurred resulting from the lack of donors' representative offices in Aceh.

With regards to donors' competing interests, Sugiarto (2009) describes a case where the government of Japan insisted to build the whole road network between Banda Aceh, Calang and Meulaboh in the west coast area. However, the request was refused as the road section between Banda Aceh and Calang had been allocated for the USAID. The dispute resulted in project commencement delays, until it was covered by Japan national media and raised the Japanese public's attention.

The reconstruction coordination was also challenged by the various conditions that came with donors' donation. For instance, the Governments of Germany and Japan identified that some of their projects in certain sectors had to be carried out by their own implementing agencies. The disbursement of funds for these projects, even though accounted for in the national budgetary system, were carried out by the particular donors and therefore outside the authority of the coordinating agency, BRR. This scheme was also known as on-budget/ off-treasury projects (Subekti, 2009).

To help with coordination and reporting of project progress, the BRR developed Recovery Aceh-Nias Database (RAND), which registered all projects carried out in Aceh and Nias. The database was accessible for update by the respective NGOs and donor organisations, and was made as one of the requirement for the expatriate personnel to obtain their working permit. In some cases, several NGOs refused to coordinate and report their progress with the BRR by ignoring the need to register and update the RAND database, which affected the overall reconstruction coordination. Consequently, the BRR did not include and acknowledge such projects in the disaster recovery reconstruction progress report. The challenges and obstacles in the planning and programming phase have been discussed in this section. Accordingly, the next section will present issues related to the road design process.

Road design

The summary of challenges and obstacles in the design process is presented in Table 4. Even though the disaster recovery blueprint indicated the list of projects for the post-disaster reconstruction, it did not come with a design plan and inaccuracies were also found. As indicated earlier, the disaster reconstruction resulted in nearly 1000kms more road networks than what was destroyed by the earthquake and tsunami in Aceh. It was suggested that such an extensive number resulted from adopting and implementing the build back better principle where rehabilitation and reconstruction was not only applied to the damaged road section, but also to the connecting network. However, the number was also affected by the inaccuracies of the initial road network length measurement indicated in the blueprint resulting from the limited preparation time as well as the severe condition of the project locations. Accordingly, there were many cases where the project cost escalated and the initial project budget allocation was no longer sufficient to accommodate the actual needs. One of the solutions to deal with the project cost escalation was to reduce the project's scope of work. For instance, many of the World Bank's IRFF road reconstruction projects were long sections of roads that were broken down into smaller packages of road segments. Some packages included the construction of culverts or bridges. Accordingly, to maintain the targeted quality of the road structures within the initial budget ceiling, changes in the scope of works often resulted in the reduction of the road length or the omission of some project items. The latter option may include the deferral of bridge construction into future projects. Consequently, many of the projects resulted in some sections being left with 'untouched' parts at the end of the road segment while some others may have a newly built road with temporary wooden bridges in between. Nevertheless, these gaps were rectified in the next projects.

Table 4 – Challenges and obstacles in the design process

Project Phase	Challenges and Obstacles
Road design	Inaccurate design
	limited time
	harsh working environment
	Land acquisition process
	Customary land title
	Large number of land parcels
	Conflicting donor's policy
	Over-standard design
	prolong maintenance needs
	donors' pride

With regards to planning and design, Sihombing (2009) acknowledges that providing a design plan in an emergency condition was impossible due to the time constraint and pressure to act quickly. Accordingly, a design review concept was adopted by the BRR, which provided only the basic planning concept, tender documents, and the estimated project value, leaving the details of the design to the awarded party. This was meant to accelerate most of the reconstruction projects, and was claimed to be an effective method (Sihombing, 2009). However, road reconstruction required a different approach and obtaining a 'final' design is an urgent priority for the commencement of the land acquisition process. As a result, there were significant delays in the road reconstruction project in Aceh. Some of the main causes of the delay were that road design and implementation plan had not been approved by the time it was needed. Changes to the design and scope of projects are not uncommon in road construction projects, both in the developed and developing countries, which is considered to be one of the most significant causes of project delays (Kaliba et al., 2009). In Aceh, this issue, along with frequent changes to the project scope due to budget thresholds and disagreement over the final road alignment (USAID, 2006) were the additional causes of the project delays.

In many locations, most of the road sections had been submerged under the seawater, requiring changes to the road layout and the need to acquire land. The challenges and obstacles in the land acquisition process are summarised by Hayat and Amaratunga (2011). They describe that the main challenges in the land acquisition process stem from the large number of land parcels to be acquired; more than 3000 land parcels in the west coast alone, and the existence of two types of land title in Indonesia; those formally registered in the national land agency and those acknowledged by the customary law. While anticipated, the significant amount of time and other difficulties related to acquiring land were underestimated (USAID, 2007). In the tsunami affected areas, many landowners and up to 30% of government personnel as well as offices responsible for the land acquisition process had also been victims of the event (BRR and International Partners, 2005, Fitzpatrick, 2006).

Furthermore, at the project level, the study identified that the use of *over-standard* design consequently gives a long-term impact to the local governments who are responsible to provide the maintenance. The *over-standard* design refers to the higher structural quality pavement standard relative to the local governments' experience and common practice at that time. The *over-standard* design is accordingly more expensive to build. Practically, in Aceh, this refers to the Hot Mix Asphalt pavement type. Respondent Val05 suggested that the use of HMA was affected by 'pride competition' between donor organisations which utilised the reconstruction project as a 'display' of their works and aid donation.

Nevertheless, the use of HMA was also supported by the technical and economic rationale, in that the HMA provides better surface quality and durability which may then prolong the future maintenance needs. In turn, it was expected to help reduce the local governments' maintenance backlog problems. Unfortunately, in the long run, the study identified that the wide application of HMA in the reconstruction process resulted in local governments undermining the various advantages and disadvantages of different road types. The local governments are 'abandoning' the idea of having macadam and gravel roads in their districts, for instance, as they used to have prior to the tsunami reconstruction. Consequently, the annual budget allocation in the road sector was focused and channelled for the new road projects with HMA surface or upgrading the existing macadam and gravel roads to HMA, with little attention given to the maintenance needs.

As the challenges and obstacles in the road design process have been presented, the following section will discuss issues identified in the procurement phase.

Procurement

At the pre-construction phase, the procurement process experienced the greatest number of challenges and obstacles. As shown in Table 5, the challenges and obstacles can be grouped into local resources, bid competition, contractor capacity, and regulatory arrangement.

The procurement process was immediately challenged by the lack of personnel capable and legible for organising and administering the procurement process. As stipulated in the Presidential Decree no 80/2003, the procurement personnel must be civil servant with procurement certification. However, the number of civil servants with procurement certification was very limited. Accordingly, to help solve this issue, BRR regularly and frequently provided training and certification test for their personnel, as well as for the local government personnel.

Table 5 – Challenges and obstacles in the procurement process

Project Phase	Challenges and Obstacles
Procurement.	Local resources availability
	limited personnel with procurement capacity and qualification
	Great numbers of project, limited contractors
	Poor contractor capacity
	seasonal contractor with strong political support
	unfamiliarity with international bidding requirements
	external contractors' reluctance to work in Aceh due to conflict and threats
	Bid competition
	threats and corrupt practices
	unfair competition - collusion among AMP owner
	Regulatory arrangement
	involvement of international consultant in the procurement process against national regulation
	Indigenous people protection
	The absence of post-disaster specific exemption

In addition to procurement personnel capacity issue, the reconstruction was also challenged by the limited capacity of the contractors available locally. This condition was affected by the fact that many construction companies and their personnel were affected and killed by the disaster, and that a great number of reconstruction projects took place within a relatively same period of time. Furthermore, after the tsunami, it was identified that there were many new and seasonal contractors competing for the reconstruction projects through political support. Many of the new contractors were arguably lacked both the skills and experience in construction, and however pushed aside contractors with skills and experience but without political backup. Such a condition was illustrated by respondent CS06,

"Now, fishermen becomes contractors, and contractors go fishing (as there are no jobs)"

The CS06 comment's illustrated his view that inexperienced contractors flooded the industry and pushed aside the existing contractors.

Moreover, Aceh was in a prolonged conflict of nearly 30 years before the peace agreement achieved in 2005. However, the security and safety threats remained on the ground, which hindered the opportunity and willingness of external contractor to work in Aceh. To better ensure the security and safety of project implementation, many of the external contractors established partnerships with the local contractors. The partnership between them occurred in the form of joint-operation scheme, as a contractor and supplier, or as a contractor and subcontractors.

The procurement phase was also challenged by the unfamiliarity of the contractors with the international bidding procedure, which frequently resulted in delays and dispute. As the reconstruction of Aceh involved many international donor organisations, certain projects had to refer to the international bidding procedure. Indonesian procurement regulation (Presidential Decree 80/2003) also stipulates that if any conflicting regulations occur between Indonesia and donor regulations in projects that are partially or fully funded under loan or grant schemes, donor regulation would then prevail. Accordingly, problems due to unfamiliarity with certain procedures and requirements inevitably occurred. For instance, in the initial phase of the USAID project, the implementation plan proposed by the Indonesian contractor, PT Wijaya Karya (WIKA), was not approved due to its non-compliance with the US requirement which caused delays to the project commencement (USAID, 2006). This regulation has been since amended a number of times with the latest being the Presidential Regulation no 54/2010 and its second amendment, Presidential Regulation no 70/2012, where conflicting regulation will now need prior negotiation and agreement.

During the post-disaster reconstruction period, the number of reconstruction projects and the growing number of contractors in the affected areas consequently lead to fierce competition between the contractors in winning the projects. This condition consequently resulted in threats and corrupt practices in the procurement process. As previously discussed, joint-operation scheme was adopted by many contractors working in Aceh. Some of the problems resulted from such collaborations were recorded in details by Sihombing (2009), when a contractor who submitted the most expensive bid was adamant about winning the project and turned into a rage when there seemed to be no chance of winning. In another case, Sihombing (2009) highlights a case where a national company lost a procurement tender due to the local partners' lack of experience in the procurement of heavy vehicle equipment, and forcefully tried to justify their bid position. Accordingly, in order to avoid threats from the bid participants who were eager to win, the procurement committee had to work literally out of the public reach by moving the selection process to another city.

Furthermore, in public procurement, corrupt practices may occur in the form of awarding contracts to the best briber instead of based on the best price-quality value. Such practice may result in higher contract value or purchase of unnecessary items (Søreide, 2005), or fraud resulting from discrepancies between amounts paid to suppliers for goods and the quantity of goods delivered (Oxfam, cited in Schultz and Søreide, 2006). Ewins et al. (2006) suggest that corruption risk in the humanitarian action are among others affected by the existing corruption and transparency level, value of relief activities, and the condition of the affected area. With regard to the transparency level, the Transparency International lists Indonesia as the 114 out of the 117 countries surveyed in its 2013 global corruption perception report (Transparency International, 2013).

After the peace agreement, the ex-combatants returned to the community and formed an association, called Aceh Transition Committee (KPA). At the village level, the KPA is called *Sagoe* (corner). To ensure that the project could be implemented well and without disruption, a personal approach and agreement with the *Sagoe* leaders was frequently required. As a result, the KPA members would generally be involved in the project as the contractors' personnel or as the suppliers for the project. Respondent CS10 implicitly revealed that this practice was well-coordinated and well-organised by the KPA at the higher level. He said

> *"Since the 'Sagoe' might have been directed by the KPA regarding the project in their village, the contractors would later need to recruit some of the local KPA members in the project. Whether as a night guard... or if they have a business, might also be as the suppliers. So we share (the works)." – CS10*

Whilst CS10's comment above illustrates how the security and safety issue would affect the implementation of a project on the ground, the influences and pressures from the KPA also affected the project tender process. CS10 further described that he had to coordinate with the KPA and distributed the construction work packages between the KPA members. As CS10 explained

> *"We always coordinated with them (KPA). We explained (to the leaders) so that they could convey the message to their members that we are all 'equal' (together). We would distribute (the projects) in the tender process. So there would be no one saying that I have to win such and such project, or this must be mine. What happened was that we arranged them through the (formal) procedure, through tender." CS10*

Another issue identified was with regards to the requirement of having an Asphalt Mixing Plant (AMP), or supported by an AMP company, for a contractor to participate in a road project tender. Whilst such requirement was necessary to ensure that participating contractors were capable of delivering the project, the study identified that the limited number of AMP in the affected areas resulted in at least two consequences. The first consequence was that the requirement of AMP reduced the opportunity for small contractors to participate in a road project tender. On the one hand, this condition helped filter-out contractors with lack of experience or equipment support. On the other hand, however, such requirement did not necessarily resulted as intended. Many contractors who did not have an AMP were able to participate in the project tender, as long as they were supported by AMP companies. Nevertheless, such a support was normally given under a condition that AMP related works (i.e. road pavement) were carried out by the AMP companies, with a price that could be the same with or more than what was included and allocated by the contractors' in their bid. Whilst the price had been normally agreed upon prior to bid submission, there were cases where the AMP companies changed the price after the contractor win the project. The contractors would then need to compensate their loss from the AMP related works by justifying their project budget and specification of other works, often by reducing the quality. The other consequence of the AMP support requirement was that AMP owners were taking turn in winning a project. Such a practice was locally known as *arisan*, where AMP owners formed collusive collaboration by not providing support to contractors without AMPs and distribute the road projects between themselves by pre-arranging the bid price.

The study also identifies that the reconstruction process was also challenged by the regulatory arrangement, which was not suitable and applicable for the post-disaster condition or conflicted with the donor organisations' regulations. For instance, the

World Bank required the involvement of international consultant in the procurement of their co-funded projects. Such a requirement was not accommodated and allowed in the Indonesian law, as the law did not even allow any non-civil servant personnel involved in the procurement committee (Presidential Decree, 2003). Furthermore, the World Bank also implemented the indigenous people protection policy. This policy required the assurance that people affected by the project would not be disadvantaged. The policy included paying damages or relocation of the affected communities or businesses. Whilst Indonesian law accommodated the need to pay damages to the affected communities through the land acquisition process, the Indonesian law did not recognise paying damages or relocation of affected people which illegally occupied the land. These condition eventually resulted in disputes and project commencement delays. In many cases, problems occurring from the regulatory arrangement were due to the lack of disaster-specific regulations and laws. Regulations and laws which are produced for normal context cannot be simply applied and implemented in the post-disaster reconstruction context, where the actual field condition is affected by the severe site condition, chaotic environment, and the pressure for a speedy recovery. Some of the problems resulting from conflicting regulations were solved through discussion and amendment of regulation and laws. However, many of the issues resulted in disputes and delays, which were often unnecessary and avoidable should disaster-specific regulations were in place.

4. Conclusion

This paper presents a discussion on the various challenges and obstacles identified in the reconstruction of road infrastructure during the pre-construction phase. These challenges and obstacles, separated into three main phases – planning and programming, road design, and procurement, are identified from the literature and empirical evidence collected from semi-structured interviews with twenty-eight respondents in three case study districts in Aceh and five experts in the road infrastructure and post-disaster reconstruction subject. At the planning and programming phase, the issues stem to limited number of aid agencies working in the road sector, error in the blueprint preparation, and political pressure in determining project location and budget allocation. From the road design perspective, the study identifies challenges and obstacles resulting from inaccurate design, the extensive land acquisition process, and the wide application of over-standard design. At the procurement phase, the reconstruction of road infrastructure was challenged by the limited local resources availability, poor contractor capacity and unhealthy competition between contractors, as well as issues resulting from conflicting regulation.

The list of challenges and obstacles identified in this paper is not exhaustive and open for discussion. It is acknowledged that each disaster may pose different challenges to its recovery process. Nevertheless, this paper provides a guidance to assist with the implementation of road infrastructure reconstruction project in the future.

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STUDY ON THE IMPACT OF ACCIDENTS ON CONSTRUCTION PROJECTS

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Abstract: As the construction industry is carried out in hazardous environments, it experiences accidents in different levels of severity, some causing minor and major injuries with even some resulting in fatality. In addition to the human cost involved, it also causes bad publicity to the profession. Worldwide, authorities have tightened up safety standards, which have enhanced the performance in construction sites. However, accidents are still happening and there is a need for further research on this important subject.

From construction organization's point of view, accidents are unexpected events and unplanned costs. Some accidents may change the organizational goals or it could even make the company uncompetitive in the industry. A good understanding of accident forecasting is vital in construction project management. This research explores four questions that arise in accidents in construction sites. Namely, (1) What are the impacts of accidents on construction work? (2) What are the uncertain contributory factors in these accidents? (3) How are human and financial aspects linked to accidents? (4) What are the possible project performance enhancements under uncertainty factors of the accident?

The objectives of this research paper are (i) to investigate construction site accidents to identify the critical causes and effects; and (ii) establish relationship of accidents with additional project cost, additional time, project scope, company reputation, and impact on national safety indexes. While human errors were identified as the main cause for construction accidents, negligence or mistakes can happen due to the uncertain circumstances. Hence, unavoidable accidents have to be expected in the construction industry. The commitment of all humans involved, from the project manager to the labourer towards good practices would enhance the safety performance in construction sites.

Keywords: accidents, accident forecast

1. Introduction

1.1 Background

Accidents are unforeseen events, which cause damages or injuries unintentionally and unexpectedly. In the construction sector, accidents are unavoidable and has higher risk compared to other occupations. Higher fatality rates for construction works around the world have been reported highlighting the industrial crisis due to accidents [1], [2].

However, accidents can be mitigated by establishing proper safety management system (SMS) in construction sites. Authorities have tightened up their safety standards to mitigate accidents but still accidents are happening. As a construction organization, accidents are to be expected. Therefore, forecasting accidents for the future projects would be advantageous for the required pre preparations and budget allocations to minimise the overall damages to the organizations financial stability.

1.2 Objectives

This study explores four key questions; (1) what are the impacts of accidents in construction work? (2) What are the uncertain contributory factors in these accidents? (3) How are the human and financial aspects linked to accidents? (4) What are the possible project performance enhancements under uncertainty factors of the accident?

Hence, the objectives of this study are to (1) investigate construction site accidents to identify critical causes and effects; and (2) establish the relationship of accidents with additional project cost, additional time, project scope, company reputation, and influence on national safety indexes.

2. Literature review

Accidents are a main disadvantage in the construction industry. During the last 20 years in the UK, 27% of fatal and 10% of major injuries were construction related [3]. Statistics of construction related accidents in US and Singapore show highest fatalities in 24-34 age group, 80% of skilled manpower, and 50% of just before or during the tea time [1].

According to the South Australian construction industry, experienced workers have higher potential to cause accidents, while workers employed by small companies are unsecure than larger companies [4].

The reported accidents are only a portion of the incidents that actually happen in construction sites. Some accidents may not be reported due to various reasons, such as geological location, communication difficulties, governmental interference, cultural barriers etc [2].

Different countries have established various legislations to mitigate occupational accidents. In Singapore, Ministry of Manpower (MOM) published Workplace Safety and Health Act in 2006 superseding the former factories act with new enforcements highlighting the reasonable practicable measures to be undertaken by organizations to minimise occupational accidents [http://www.mom.gov.sg/].

However, accidents are still happening, Table 1 is showing the distribution of fatalities in construction sector, Singapore over the years.

Table 1 - Fatality in construction sector, Singapore [http://www.mom.gov.sg/]

year	2006	2007	2008	2009	2010	2011	2012	2013
fatality	24	24	25	31	32	22	26	33

Outcomes of safety related researches have contributed to enhance the safety performance to some extent. For example the Olympic infrastructure development project had award winning safety and health performance through careful planning and leadership [5]. Generally, the accident rates are still higher in the construction industry [1], [2].

3. Research method

The necessary information was collected from online sources in published media and research papers. The collected information was studied to identify the potential causes and effects in the construction industry.

Some of the cost information was taken directly from the case studies and some have been predicted using available data sources.

National safety indexes of Singapore have been taken in to consideration to find the effect of national safety indexes {www.wshc.sg}.

4. Accidents

4.1 General

Accidents cause construction delays, cost overrun and sometimes ruin the reputation of the organization, and losing the confidence among workforce [6] or banning from tendering by government authorities. It can cause dissatisfaction among stakeholders, be uncompetitive when tendering, financial losses due to property damages and penalties from authorities. Further studies need to be launched to investigate this global tragedy.

Emphasizing the importance of the accidents, researchers have modelled the accidents in several ways [7] as,

- Traditional Approaches
  - Sequential Accident Models
  - Epidemiological Accident Models
- Complex Socio-Technical Systems
- Systemic Accident Models
  - Systems Theoretic Approach
  - Cognitive Systems Engineering Approach
  - Rasmussen’s Socio-Technical Framework
  - AcciMap Accident Analysis Technique
  - STAMP Approach
- Formal Methods and Accident Analysis
  - Logic to Support Accident Analysis
  - Probabilistic Models of Causality

Accident causation model is a systematic way of ascertaining the causes of accidents.

Domino theory is the most influential accident causation theory, which was developed by Heinrich [8]. It has five metaphorical dominos, which cause accidents:

- Social Environment and Ancestry
- Fault of Person
- Unsafe Acts or Unsafe Conditions
- Accident
- Injury

Eliminating one of the dominos will prevent accidents.

Heinrich, believes that the human failure is the main reason for accidents by saying “man-failure” [9] and according to the outcome of his study of accident databases, 88% of accidents are due to unsafe act of workers, 10% are due to unsafe condition, 2% are Acts of God [8]. His concept was backed up by several other research works [10], [11].

Though, Heinrich's theory was understandable and perceptible, blaming only to personal is not practical without emphasizing responsibility of the management of the organization [12]. Due to this weakness, domino theory was expanded by introducing management competencies.

Chronologically the expansions for the domino theory are,

- Updated the domino sequence by Bird 1974[13]
- Updated sequence by Adams [14]
- Updated dominoes by Weaver in 1971 [14]

These are some expansions of the management-based concepts to domino theory [14]. Management errors [15], [16] and, task unpredictability and error management [17] in operational and work flow planning have significant effect on accidents.

However, stair step model and multiple causation model were not domino theory, but management based accident causation theories [14]. Multiple causation model expressed that the accident is a result of many factors, causes and sub causes [14].

4.2 Causes and effects

Most accidents in the construction sector can be prevented by deploying proper management system. Human factors are the major causes of accidents but it is not the only reason for all the accidents.

When considering the human factor, negligence is one of the most critical causes which has been identified by several researchers [1], [18], [19] and indirect cause of mental stress [14] is causing considerable effect on construction accidents.

A study in UK found that the factors such as nature of project, method of construction, restrictions at site, project duration, design complexity, subcontracting, procurement system, level of construction contributed to cause accidents [12].

Accident Root Causes Tracing Model (ARCTM) introduces three main root causes [20],

1) Failure to identify unsafe condition prior to the work;
2) proceed with work even after identifying the unsafe condition; and
3) Neglecting the initial unsafe condition and proceeding with work.

4.3 Uncertainties and accidents

Uncertainties are everywhere, unpredictability or lack of knowledge can be taken as uncertain. Unique nature and the unfamiliar environment at the work sites usually create eventual uncertain feelings to construction employees.

Unsafe method, human element, unsafe equipment, job site conditions, management, and the unique nature were concluded as main uncertainties in the research work based on Malaysian construction industry [18].

Management exerts additional pressure on employees to increase the production to catch up delays due to other reasons. This can be a hazardous move which will cause accidents and increases the chances of being injured [21].

Several studies on construction fatalities in Singapore and US have found that the age group (most in 24-34), skill level (20% accidents), education (95%), tea breaks (50% accidents), season (October before the rainy season) are main uncertainties in Singapore and the differences between US are age group (35-44), skill (33% accidents), and has no relationship with the season [1].

Severity of the accidents are increased with the age, experienced workers are involved in more accidents, workers in smaller companies are at higher risk while the medium-sized firms are the safest, and outer suburbs are unsafe than inner suburbs [4].

Contribution of the key factors to accidents are workers (70%), work place issues (49%) equipment shortcomings (56%), material conditions (27%) and risk management (84%) [22]. Education and training, competent personal, Construction management and planning, negligence, personal protection equipment (PPE), availability of regulations and knowledge, enforcement of Safety regulations, unique nature of the industry, Work environment, Machinery/equipment, work method, Supervision and Communication, which are recorded as uncertainties in Kuwait [23], USA [20], [24], and Thailand [25] that cause accidents.

Design and planning stage plays a major role in uncertainty. A study of the accident causation model based on project conceptualisation had uncovered the relationship of the accidents with project concept, design and construction planning. The results shows that the accidents are related to inappropriate, Construction planning (28.8%), Construction control (16.6%), Construction operation (88.0%), Site condition (6.0%), Operative action (29.9%) [26].

4.4 Cost of accidents

Accidents involve additional costs to the employer, individual and to the community to which the person belongs.

Heinrich [8] has divided the total accident cost into direct and indirect cost with the ratio of 1:4. Simonds and Grimaldi [27] proposed insured and uninsured cost arguing that some of direct cost can be considered as indirect. For example, insurance cost is direct due to the financial accounts but it actually contains some extent of uncertainty. However, later studies re-defined the terminology insured and uninsured costs as direct and indirect [28].

Direct cost is the tangible cash involvement in the accident (medical, insurance, compensation, etc..) [29], [30] and the indirect cost is all other costs, which has contribution to the incident or the victim or the costs not covered in the insurance premium [31], [32].

Lost labour, Continuing payments to injured worker after accident, Insurance costs, Damage to equipment or material, Legal costs, loss of other employee time, cost of work delay etc can be taken as indirect costs [8], [29], [31], [33].

Indirect cost is invincible but huge in amount as explained in the Bird's [13] accident cost iceberg [34].

In Singapore building projects, the average accident cost of insured, uninsured and the total are 0.15%, 0.1% and 0.25% of the contract sum of the project respectively [35]. The uninsured cost depends on company size, project size, and the percentage of the work completed by subcontractors. The motivation towards the safety is higher in Singaporean contractors' due to their concern on cost [18] and the higher influence of government involvement.

According to The International Labour Organisation (ILO) [36], global estimates of direct & indirect costs for accidents are USD 2.8 trillion, equivalent to 4% of the annual global GDP [37].

Several countries have developed individual cost models to estimate cost impact of accidents.

4.5 Singapore cost model

WSH Institute (Singapore) has developed economic cost model for accidents with the aid of international collaboration. The advisers from Australia and Finland were engaged in the cost model development since they had previous experiences on this important subject.

Cost modelling has two approaches called, incident approach and prevalence reproach. In the incidence approach, it considers the accidents happening on the reference year only but the prevalence approach considers all up to the given time [38]. Both approaches have been used in the Singapore cost model.

Table 2 summarises the major considerations of the Singapore accident cost model. Similarly, European and Australian accident cost models are given in the Table 3 and Table 4.

Table 2 - Singapore Accident Cost Model [38]

Cost bearer	Cost items
Employers	Staff Turnover Costs Training costs Loss of Output Insurance Premiums Legal costs
Workers	Net loss of future earnings (future earnings less compensations) Additional costs of medical Treatments Rehabilitation costs
Community	Social Payouts Investigation / inspection costs Fatal loss of human capital medical subsidy

Table 3 - British accident cost model [39]

Cost bearer	Cost items
Individuals and their families.	Loss of gross family earnings (-) Medical cost (+) State benefit receipts (+) Income tax and National Insurance saving reduction (+) Insurance receipts, net of legal costs (+) Monetised value of nonfinancial human costs (-) Out of pocket funeral, travel, prescription, home expenses (-) Proportion of individual private health insurance premiums attributable to work related illness/injury (-) Administration of insurance, compensation and benefit claims (-) Insurance company profit margin costs on other insurance products (-)
Employers	Medical cost (-) National Insurance (-) Work reorganisation (-) Recruitment and induction costs for

	replacement staff (-) Insurance premiums (-) Proportion of corporate private health insurance premiums attributable to work related illness/injury (-) Administration of insurance and compensation claims (-) Investigation/prosecution - internal costs + legal costs (-) Fines paid (-)
Government /Community	Medical reimbursements (-) State benefit payments (-) Income tax and National Insurance reduction (-) Loss of profit on economic output individual absent from workforce (-) Treatment and rehabilitation costs (-) Treatment and rehabilitation by private insurance claims (+) Administration of claims (-) Investigation / prosecution costs (-) Fines received (+)

(-) sign indicates losses and (+) indicates the gaining of the particular cost bearer.

Table 4: Australian accident Cost model [40]

Cost bearer	Cost items
Worker	Loss of income Private insurance Legal cost Travelling Medical career costs
Employer	Overtime payments employer excess payments Sick leave staff turnover medial legal fines & penalties investigation costs
Society	compensation or welfare (due to no job) tax losses medical compensations legal cost claim investigation cost travel compensation Career payments

Accident cost of Singapore is SGD 10.45 billion for the year 2011, which can be divided into different cost agents as SGD 5.28 billion (50.5%) for individuals, SGD 2.31 billion (22.1%) for employer, and 2.87 billion (27.4%) for community. Total loss is equivalent to 3.2% GDP, which is considerable amount. Work related accident cost of Australia is given in Table 5 with the comparison to different times and periods.

Table 5 - Comparison of work related accident cost (Australia) [40]

Estimation Period	Worker	Employer	Community	Cost ($ Billions)
2000~01	44%	3%	53%	34.30
2005~06	49%	4%	47%	57.50
2008~08	74%	5%	21%	60.60

According to the records of Work Injury Compensation Department, the compensation payments for different injuries [41] can be summarised as in the Table 6.

Table 6 - Amount of Work Injury Compensation Awarded ($ millions) 2012 to 2014 [41]

		Year		
		2012	2013	2014
Temporary incapability	**cases**	9083	9039	10126
	MC ($millions)	5.02	5.62	6.22
Permanent Incapability (PI)	**cases**	4112	4428	4494
	MC ($ millions)	8.64	9.88	10.96
	PI ($ millions)	51.50	60.70	65.99
Fatal	**cases**	103	115	113
	Death ($millions)	11.50	14.68	14.95

MC-Medical Certificate

The detail direct cost estimation case study is shown in the Table 7 for understanding the cost variation with the industry type.

Table 7 - Accident cost Case studies {www.wshc.sg}

Type of incident	Industry Type	Incident Total Amount (S$)
Collapse of Crane	CL	5,290
Fall From Height	CL	4,236
Fall From Height	CL	3,705
Struck by Falling Objects	GW	900
Caught In or Between Objects	GW	45,180
Stepping On, Striking	H&M	1,670

Against or Struck by Objects		
Exposure to Harmful Substances	L&T	9,875
Fire / Explosion	Mf	29,495
Struck by Falling Objects	Mf	12,565
Contact with Electric Current	M&M	3,201,100
Fall From Height	M&M	225
Fall From Height	W&WM	13,468

CL-Construction and Landscape, GW-General Workplace, H&M-Hospitality and Entertainment, L&T-Logistics and Transport, Mf-Manufacturing, M&M-Metalworking and Manufacturing, and W&WM-Water and Waste Management

Loss of man hours due to occupational accidents are given in the Table 8.

Table 8 - Loss of Man hours due to accidents, Singapore {www.wshc.sg}

Year	Loss of man hours
2009	258,421
2010	239,137
2011	170,366
2012	206,845
2013	274,183
2014	245,987

4.6 Accidents and project scope

Larger the projects, safer the employees, than that of smaller or limited scope projects [42]–[44], a study based on Australian construction industry revealed that small and medium projects (79.5%) has higher risk than larger (20.5%) [4].

The loss of control events cause accidents [45]. Therefore, activities, which contain high-risk incidents or potential to loss control, should be minimised. According to Singapore statistics, top three incidents, which cause major and minor accidents, are given in Table **9**. Proper assessment should be carried out over the project scope to minimise the activities which has higher potential to cause accidents.

Table 9: Incident types

		Top 3 incident types		
2014 Singapore	Major	FFH	STF	CIBO
	Minor	SBMO	STF	SBFO
2013 Singapore	Major	FFH	STF	CIBO,SBFO
	Minor	SBMO	SBFO	STF
2003~13 Australia	Fatal	FFH	SBMO	

FFH-Fall from height, STF-Slips, Trips and Falls, CIBO-Caught In/Between Objects, SBMO-Struck by Moving Objects, SBFO-Struck by Falling Objects

4.7 Safety Enhancements and Project Performance

Project performance is enhanced with the safety improvements. There are several publications highlighting various methodologies about upgrading the safety standards [46]. Safety enhancements should be proposed at the design stage of the project unless the designers have adequate knowledge of the risk identification at design stage [47]

Human resource development has a significant effect on safety enhancements. The highest organizational level influence towards accident is insufficient inspection, the second highest is training and the third is a lack of training plan [48].

Supervisors are key persons in any safety management system as they are the immediate management staff for the workers. Their roles and responsibilities are vital for proper implementation and maintaining of safety [49].

Forming a psychologically safe environment for humans has positive influence on safety enhancements [50]. Achieving this elimination would increase the reliability of the system and enhance the performance of the work flow [51].

Reputation and accident free records can be valued in terms of long term business considerations in larger scale. When implementing the accident prevention measures, Hong Kong construction managers have exhibited their dedication with above average vigour [52].

A recent research has been studied the influencing factors on the SMS to its success, Singapore and Malaysia uses four and twelve influence factors respectively while most of other countries uses eight. Selected five factors (Resources Factor, Management Factor, Personal Factors, HRM/Incentive Factor Relationship) had been used in the study and concluded that personal commitment should be higher to obtain higher remarkable safety performances [53].

Proper planning and monitoring has significant effect on SMS, IT based Safety related practices are found to be effective not only safety but quality of construction as well [54].

A cognitive map based safety system has been proposed to analyse and prevent marine construction accidents. The proposed system could identify and eliminate human errors to enhance awareness [48].

4.8 National Safety Indexes

One consequence of the industrial revolution is consideration of worker's health as labour issue and the workplace safety and health is relatively modern concept [55]. However, in the modern world, countries are more concerned about accident free workplaces.

When comparing the global context, workplace injury rate (injuries per 100,000 workers), accident frequency rate (accidents per 1million Man-hours), accident severity rate (Loss of Man-days per 1million Man-hours) and Occupational decease incidence (occupational deceases per 100,000 workers) can be taken as important factors to determine the effectiveness of local safety standards. The safety of human capital is one of the leading factors to nominate a country as developed [56].

According to the Singapore 2013 data one accident will contribute 12.2% increase in national fatality rate of construction sector (Total work force = 101,900). Some statics of Singapore and Australia are shown in Table **10**.

Table 10: Workplace fatality rate of construction sector

	2011	2012	2013
Singapore (www.wshc.sg)	5.50	5.90	7.00
Australia (www.safeworkaustralia.gov.au)	3.97	3.00	1.85

5. Conclusion

Through the identification of critical causes and effects of construction site accidents, this study established the relationship of accidents with additional project cost, time, scope, company reputation, and their impact on national safety indexes. The study explored the four issues, impacts of accidents, their contributory factors, link between human and financial aspects to accidents and possible performance enhancements under uncertainty factors of the accident to arrive at the conclusion.

While humans were identified as the main cause for construction accidents, negligence or mistakes can happen due to the uncertain circumstances. Hence, unavoidable accidents have to be expected in the construction industry. The commitment of all humans involved, from the project manager to the labourer towards good practices would enhance the safety performance in construction sites.

As future developments, this study will be extended to simulate occurrence of construction site accidents through the development of a model to predict accidents and develop performance enhancements under uncertainty. This development would facilitate decision making under uncertainty that will enhance safety in construction sites.

6. References

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Third Revolution Digital Technology in Disaster Early Warning

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Abstract: Networking societies with electronic based technologies can change social morphology, where key social structures and activities are organized around electronically processed information networks.
The application of information and communications technologies (ICT) has been shown to have a positive impact across the emergency or disaster lifecycle. For example, utility of mobile, internet and social network technology, commercial and amateur radio networks, television and video networks and open access technologies for processing data and distributing information can be highlighted. Early warning is the key function during an emergency. Early warning system is an interrelated set of hazard warning, risk assessment, communication and preparedness activities that enable individuals, communities, businesses and others to take timely action to reduce their risks. Third revolution digital technology with semantic features such as standard protocols can facilitate standard data exchange therefore proactive decision making. As a result, people belong to any given hierarchy can access the information simultaneously and make decisions on their own challenging the traditional power relations. Within this context, this paper attempts to explore the use of third revolution digital technology for improving early warning.

Keywords: Disaster, Digital Technology, Early warning, Tsunami

1. Introduction

This paper attempts to explore disasters in the context of resilience giving more emphasis on preparedness and capacities for early warning. Therefore disaster context, Early Warning Systems (EWs), third revolution digital technology in disaster early warning, research aims and objectives, key findings from the literature on critical phases of EW and third revolution digital technology in disaster Early Warning (EW) as well as how findings of this paper can shape up future research work are sub topic covered under this paper.

1.1 Disaster context

Disaster means a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources [1]. Improved social and organizational factors such as increased wealth, the widespread provision of disaster insurance, the improvement of social networks, increased community engagement and participation, local understanding of risk, improvements of resilience within natural systems can mitigate disasters [2]. In addition, improved resilience in the context of Capacity of a system, community or society potentially exposed to hazards to adopt by resisting or changing to reach and maintain an acceptable level of functioning and structure can mitigate disasters [3].

Social resilience captures the differential social capacity within and between communities. Demographic attributes to social capacity suggests that communities with higher levels of educational equality, and those with fewer elderly, disabled residents, and non-native English speaking residents likely exhibit greater resilience than places without these characteristics. Similarly, communities have high percentages of inhabitants with vehicle access, telephone access, and health insurance also may demonstrate higher levels of disaster resilience [2]. Therefore it can be argued that the resilience is affected by the capacity of communities to reduce risk, to engage local residents in mitigation, to create organizational linkages, and to enhance and protect the social systems within a community [4]. Capacity of the community is a measure of preparedness as the preparedness capacity is the ability to perform functions, solve problems by setting and achieving objectives at individual, organisations, institutions and societies levels [5].

Preparedness means the knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate respond to and recover from the impacts of likely, imminent or current hazard events or conditions [1]. Therefore it is important to address the question of how to improve what the public knows and to motivate them to take actions to prepare for future hazards [6,7]. Effective early warning thus become important as early waning means the provision of information on an emerging dangerous circumstance where that information can enable action in advance to reduce the risks involved specially the life loss. In this paper improving preparedness education with the access to right information on right time will be discussed in the context of early warning such as educating communities making them fully aware of the risk of hazard, the potential for disaster, evacuation routes and practicing evacuation drills for disciplined evacuation. Nevertheless, unless this complete process is monitored on a community-led, sustainable basis ensuring the community ownership as required community capacity will not be sustained [8]. As preparedness education can save lives with empowering individuals and communities, threatened by natural or similar hazards, by acting in sufficient time and an appropriate manner reducing the possibility of personal injury, loss of life and damage to property [9], it can be argued that early warning, preparedness and capacity as key components for resilience.

The effectiveness of preparedness education is increased when verbal and written information is frequently disseminated from multiple sources over multiple communication channels with consistent information regarding what recipients need to know and about actions that they should take [6]. This is very important for early warning saving lives making accurate decisions timely manner. As early warning system can be defined as the set of capacities need to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss [1], early warning system can be viewed as an information system designed to facilitate decision-making. Early warning systems exist for natural geophysical and biological hazards, complex socio-political emergencies, industrial hazards, personal health risks and many other related risks [10]. According to Mileti and Sorensen[11] a warning system means getting information about an impending emergency, communicating that information to those who need it, and facilitating good decisions and timely response by people in danger. Therefore generating and disseminating timely and meaningful warning information can enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss [1].

1.2 Early warning systems

International bodies provide support to national early warning activities and foster the exchange of data and knowledge between individual countries. Support includes advisory information, technical cooperation, policy, organizational support necessary to ensure the development and operational capabilities of national authorities or agencies responsible for early warning practice.

The protection of people from external threats including those derive from natural hazards had been a key role of governments. During past decades many countries had developed and integrated early warning capabilities particularly for meteorological and hydrological events as an important tool for preventing disasters. The need for international coordination of these efforts is well recognized and mainly provided through specialized United Nations agencies responsible for geological hazards, food security, environmental protection and humanitarian response. As a result, The International Decade for Natural Disaster Reduction [9] promoted this concept and raised profile of EW resulted in acknowledgement of its crucial importance in the Yokohama Strategy for a Safer World endorsed at the World conference on Natural Disaster Reduction in 1994. The International Strategy for Disaster Reduction, the successor to the IDNDR, has introduced a stronger focus on vulnerabilities and has emphasized the need to integrate disaster risk reduction into sustainable development. The World Conference on Disaster Reduction (WCDR) in Kobe, Hyogo, Japan, 18-22 January 2005 adopted the Hyogo Framework for Action 2005-2015: building the resilience of nations and communities to disasters in which risk assessment and early warning is one of the five themes of disaster reduction. Specific recommendations include the call for countries to develop people-centred early warning systems. In addition Agenda

21, the multilateral environmental agreements, the Barbodos Plan of Action for Small Island Developing States and the Johannesburg Plan of Implementation can be highlighted as other development frameworks called for actions to strengthen international, national and local initiatives to develop early warning in the context of disaster reduction for sustainable development and poverty reduction. Three international conferences on early warning such as International Conference on Early Warning Systems for the Reduction of Natural Disaster in 1998(EWC'98), Second International Conference on Early Warning- 'integrating natural disaster early warning into public policy' in 2003 (EWC-II) and the Third International Early Warning Programme entitled "effective Early Warning to Reduce Disasters: The Need for More Coherent International Action" was launched at the conference (EWS-III) 26-29 March, 2006 in Bonn, Germany produced a set of internationally agreed guiding principles for effective early warning systems as well as the outline of an international programme on early warning to reduce disasters. All three conferences addressed strengthening EWSs by incorporating EW into policy and development frameworks with a greater emphasis on social factors in EWs and mechanisms sustaining dialogue and collaborative action among key stakeholders [12].

At the third international EW conference held in Bonn, Germany in 2006, ISDR presented their global survey on Early Warning Systems (EWs) highlighting advances in the capacity of agencies in many countries to forecast potentially catastrophic events and implementation of EWSs for a broad range of hazards. In addition, the survey highlighted the variation of advances in EWS in countries and gaps specially in developing countries including Sri Lanka. For many developing countries lack of infrastructure, adequately trained staff and resources were the main gaps identified that to be prioritized. In order to fill such gaps it was recommended to have a globally comprehensive early warning system rooted in existing EW systems and capacities. As a result, in Intergovernmental Coordination Group for Tsunami Early Warning and Mitigation System for the North-Eastern Atlantic, Mediterranean and Connected Sea (ICG/NEAM TWS) meeting that was held in 2007 in Bonn , Germany developing a globally-standardized framework related to alert or warning levels. As a result, factors such as hazard dependent EWS frameworks and variations of EWS frameworks for the same hazard according to the country context were explored. This was further benefited with Kofi Annan' former Secretary –General of the United Nations(2005) demanding for a feasibility of implementing a global early warning system highlighting the devastating impact of Tsunami 2004 claimed more than 200,000 lives due to lack of a Tsunami Warning System in many of the countries affected including Sri Lanka. In addition, EWs has a major contribution to key priority area 2 of the Hyogo Framework for Action 2005-2015: building the resilience of nations and communities to disasters, which was conducted by negotiation among states and organizations at the World Conference on Disaster Reduction (WCDR) in Kobe, Hyogo, Japan, 18-22 January 2005.

As over the last 10 years time disasters have continued adversely impact on well-being and safety of persons, communities and countries claiming over 700 thousand lives, over 1.4 million injured and approximately 23 million homeless affecting more than 1.5 billion people by various ways, other International mechanisms for strategic advice, coordination and partnership development for Disaster Risk Reduction (DRR) had taken steps to improve resilience strengthening DRR frameworks. For example, the Global Platform for Disaster Risk Reduction and the Regional Platforms for Disaster Risk Reduction, the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 that was adopted at the Third United Nations World Conference on Disaster Risk Reduction, held from 14 to 18 March 2015 in Sendai, Miyagi, Japan had been involved in the development of policies and strategies and the advancement of knowledge and mutual learning with special emphasis on preparedness for early warning and response in order to improve resilience [13].

Sendai framework is focused on four priority areas such as understanding disaster risk, strengthening disaster risk governance to manage disaster risk, investing in disaster risk reduction for resilience, enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction. This also highlights that, more dedicated action needs to be focused on tackling underlying disaster risk drivers, such as the consequences of poverty and inequality, climate change and variability, unplanned and rapid urbanization, poor land management and compounding factors such as demographic change, weak institutional arrangements, non-risk-informed policies, lack of regulation and incentives for private disaster risk reduction investment, complex supply chains, limited availability of technology, unsustainable uses of natural resources, declining ecosystems, pandemics and epidemics. Moreover, it is necessary to continue strengthening good governance in disaster risk reduction strategies at the national, regional and global levels and improving preparedness and national coordination for disaster response, rehabilitation and reconstruction and to use post-disaster recovery and reconstruction to "Build Back Better", supported by strengthened modalities of international cooperation. This calls for a broader and a more people-centred preventive approach for disaster risk reduction and improving resilience [13].

This aspect had been highlighted in the Global Assessment Report [14] as well due to following reasons.

- Most catastrophic events have not yet occurred
- Many infrequent but severe hazards simply might not have occurred
- events are never exactly the same, thus basing the risk assessment only on past event might hide unobserved, but yet possible, consequences
- Limitations of providing temporal and spatial information about the event and detailed records of consequences, specially linked with the local severity of the hazard and performance of the buildings.

Source: GAR, 2015

Given the explained background it is understood that, decision makers including people at immediate risk need to know which events and losses can possibly occur, their likelihood and frequencies in advance [14] . This is a critical consideration in early warning saving lives during disasters. Therefore, identifying critical phases/components of EW become crucial.

With reference to existing people centred early warning systems in the world, key components are risk knowledge, monitoring and warning service, dissemination and communication and response capability. Risk knowledge is mainly focus on systematically collecting data and undertaking risk assessments finding out whether hazards and vulnerabilities are well known, what are the patterns and trends in these factors, whether risk maps and data widely available. The second component, monitoring and warning service focuses on developing hazard monitoring and early warning services, finding out whether right parameters are monitored and scientific basis for forecasting and generating accurate and timely warning. Third component dissemination and communication that focus on communicating risk information and early warning, finding out whether warnings reach all those at risk, the risks and the warnings understood and warning information is clear and useable. Forth or the final component of early warning system is the response capacity that focus on building national and community response capabilities finding out whether response plans up to date and tested, local capacities and knowledge made use of and people prepared and ready to react to warnings. In terms of community response capabilities, utilization of exiting communication mechanisms for warning dissemination at grass root level becomes important. For example, use of mobiles for early warning with improved services such as access to internet. Introduction of internet accessible mobiles or SMART phone with the use of third revolution digital technology can be highlighted. Therefore, it is worth exploring application of third revolution digital technology in early warning.

1.3 Third Revolution Digital Technology in Early Warning

Information and Communication Technology can access millions of people within few seconds or even less, found to be a great strength during emergencies for warning communication. For example, geographic information systems that play a key role in alerting communities at immediate risk, the ongoing development of satellite-, wireless-, mobile-, radio- and internet based ICT are EW capacity to expand and grow improving preparedness and resilience. In looking forward with optimism, it is anticipated that, future research might examine the use of promising new ICT as part of the ECWS capacity in Australia, and more broadly around the world [15]

Third revolution digital technology has semantic features such as Standard Protocols that can facilitate standard data exchange. This enables sending the same alert to mobiles and all media stations while providing more intelligent, capable, relevant and responsive interaction than with information technology. Therefore people belong any given hierarchy can access the information simultaneously and make decisions on their own challenging the traditional power relations. Access to information enhances knowledge thereby ability of making the right decision. Access to the right information on risks on right time can save lives enhancing social interactions. Therefore, it is worth understanding how people's emergent roles and their inter-relatedness with one another help to build adaptive capacity and awareness making them better prepared for disasters. This is useful for proactive decision making responding to disasters saving lives and properties as well as reducing other social risks such as robberies [16]. However, this study will only focus on proactive decision making with third revolution digital technology saving lives during disasters.

According to Castells and Cardoso [17], networking societies with electronic based technologies can change social morphology, where key social structures and activities are organized around electronically processed information networks. As a result, operation and outcomes in processes of production, experience, power and culture can be modified. In this regard semantic features emerge from third revolution digital technology can play a vital role. In the environment of the Sematic Web an ontology is a partial conceptualization of a given knowledge domain, shared by a community of users, that has been identified in a formal machine- process able language for the explicit purpose of sharing semantic information across automated systems [18]. This is very useful for first respondents in a disaster situation to make accurate decisions. At present, first responses for an emergency happen via non-hierarchical, uncontrollable social media with instant global distribution of images. This information flow leads to create emergent roles of individuals subverting traditional power relationships in terms of challenging hierarchies and gaining control over decision making. However, critical knowledge and evidence of disaster managing agencies become important to engage with community networks and support people playing a vital catalytic role bridging or linking emergent roles, strengthening disaster preparedness [16]. Thus a closer examination of social relations and characteristics within communication networks is essential conceptualizing the knowledge flow enhancing resilience of the people making them proactive for EW saving lives.

2. Objectives

Objectives of this paper as follows,

- Identify critical phases of effective early warning to enhance community preparedness

- Explore the use of third revolution digital technology to improve early warning

3. Methodology

A literature review was conducted in view of examining critical phases of early waning for improving resilience with special emphasis on early warning preparedness and capacity. In addition, collecting information by visiting technical agencies related to tsunami warning in Sri Lanka such as Dept. of Meteorology (responsible agency for issuing Tsunami warning), Disaster Management Centre (DMC- for disseminating EW) Geological Survey and Mines Bureau (GSMB- earthquake and tsunami information), National Aquatic Resources Research and Development Agency (NARA- ocean monitoring) and discussions with the technical officers responsible for Tsunami warning were carried out. Accordingly, 5 interviews were conducted with tsunami EW focal points of the above agencies in Sri Lanka. In addition, related previous case reports were also reviewed. Analysis of the familiar social context and third revolution digital technology effects in early warning for improving preparedness capacities for disaster resilience, strategies for gaining risk knowledge and use of social support networks were taken into consideration. Analysis of related global, regional and national level assessments and reports was also carried out. Preliminary finding of this paper will support my future research work on developing strategies/roadmap for incorporating third revolution digital technology in early warning.

4. Findings

4.1 Key findings from the literature on critical phases of EW

There are four key components of a people centred EW system such as risk knowledge, monitoring and warning service, dissemination and communication and response capability. These are influence by effective governance, institutional arrangements and good communication practices. Therefore inter linkages of EW components and influencing factors can be interpreted as in below.

Fig 1.Interlinkages among components of people centred EW system and underpinning factors
Source: ISDR platform for the promotion of EW combined with Author's work, 2015

In order to ensure people and communities are warned in advance of impending natural hazard events and facilitate national and regional coordination and information exchange key actors such as International, national and local disaster management agencies, national meteorological and hydrological services, military and civil authorities, media organizations, businesses in vulnerable sectors, community based and grassroots organizations, international and UN agencies such as UNISDR, IFRC, UNDP, UNESCO, UNEP, WMO, OCHA become very important. Simultaneously institutionalization of the decision-making process by enforcing warning dissemination chain through government policy or legislation and empowering relevant authorities become importance. Functions, roles and responsibilities of each actor in the warning dissemination process should be specified in legislation or government policy. For example, meteorological authorities to provide weather messages, health authorities to provide health warnings. It is equally important to define roles and responsibilities of regional or cross border early warning centres including the dissemination of warnings to neighbouring countries. Nevertheless, in order to ensuring last mile EW volunteer network trained and empowered to receive and widely disseminate hazard warnings to remote households and communities become important. In building capacities of the vulnerable people for practicing responding to EW, installation of communication and dissemination equipments and systems tailored to the needs of communities become crucial. For example, radio, television, mobile for those with access; and sirens, warning flags or messengers, runners for remote communities). However, warning communication technology should reach the entire population at immediate risk without any discrimination including floating population. Therefore, use of multiple communication mediums for warning dissemination is essential. Also having two-way and interactive communication systems allowing verification of warnings can make EW system more effective (EWS; A checklist, Third International Conference on EW, 2006). For example having mobile devices with internet access belongs to third revolution digital technology for EW can help people receive risk information as well as ensure two way communications. Therefore, it is worth exploring use of third revolution digital technology within early warning systems.

4.2 Key findings from the literature on Third Revolution Digital Technology in Disaster resilience within the context of early warning system

Earthquake hazard monitoring can be highlight as the very inception of using digital technology for early warning. Computer systems in Phase 1 (Mainframe Era) were used for very dedicated Tsunami Warning System (TWS) functions in early times before 1980. A strong influence of digital technology on TWS architecture became visible in Phase II (Microcomputer Era) with the digitalization of sensor data and the availability of microcomputer systems. Phase III (Internet Era) created the concepts and foundation for the architecture of modern TWS and their basic components which include decision support components, sensor systems and warning components. The standardization processes of component interfaces and the encoding of data were fostered by the development and success of the Internet promoted by the work of standardization organizations such as World Wide Web Consortium (W3C), Organization for the Advancement of Structured Information Standards (OASIS), Open Geospatial Consortium (OGC) and International Organization for Standardization (ISO). The development of ocean-wide warning infrastructures in Phase IV (Ubiquitous Computing Era), as discussed in responsible UNESCO/ IOC bodies, will become technologically feasible to communities at immediate risk in near future. Given the explained background there is a clear shift from domain to ICT expects when looking at the domains driving the development of TWS (Wachter and Uslander, [19]).

The progress of TWS is mainly driven by development activities within specific scientific communities in Phase I and II, e.g. geodesists, physicists and geologists. Within Phase III these developments become more and more integrated in and depending on mainstream ICT evolution resulting from both the increasing system complexity and the progress in standardization. Exploring digital technology developments during the times of phase III and IV For example, cloud computing, integration of Earth Observation (EO) systems, ubiquitous sensing and volunteered geographic information become important to highlight third revolution digital technology as a supporting tool for EW [19].

Third revolution digital technology is a recognized EW aid that links technical agencies with or without agreements/mandates. All global, regional and national EW systems sustain with this digital aid due to its ability to use by millions of people by passing all hierarchies and power relations making effective decisions. Therefore, this can be easily applied linking up with all related stakeholders making EW mechanism effective. For example, Disaster Management Centre in Sri Lanka as the focal point responsible for coordinating and disseminating early warning in Sri Lanka with the relevant technical agencies and Technical Committees ensuring last mile dissemination, links up with the Department of Meteorology (DoM) and National Aquatic Resources Research and Development Agency (NARA), Geological Survey and Mines Bureau (GSMB) 24 x 7 basis with the use of third revolution digital technology such as internet, ubiquitous bandwidth and cloud storage. In addition use Inter Governmental Network (IGN) that connects technical agencies in Sri Lanka. However, even if the DoM is identified as the technical agency mandated for issuing Tsunami (seismic wave) Warning according to the Draft National Emergency Operations Plan Sri Lanka (2015), Ocean Observation Centre (OOC) of NARA with a Tsunami Warning Centre on 24 hr basis and monitoring ocean conditions around Sri Lanka in near real time provides Tsunami verifications to the Disaster Management Centre with the use internet based data exchange. This highlights third revolution digital technological features can connect stakeholders with or without mandate for early warning saving lives of the people at immediate risk.

Department of Meteorological Sri Lanka connects with Pacific Tsunami Warning Centre (PTWC), Japan Meteorological Agency (JMA) and Indian Ocean Tsunami Warning System (IOTWS) to receive tsunami warnings and earthquake bulletins through internet a feature of third revolution digital technology. IOTWS connects with Indian Ocean Regional Tsunami Service Providers such as Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Indian National Centre for Ocean Information Services (INCOIS) and Joint Australian Tsunami Warning Centre (JATWC) operated by the Australian Bureau of Meteorology and Geosciences Australia are able to provide tsunami warnings effectively to the relevant national authorities with the use of third revolution digital technology. This is due to the ability of third revolution digital technology accessing places any time with limited or no access for humans. For example, tsunami monitoring is done with the use of third revolution digital technology as initial capturing of tsunami signs using a recorder on seabed monitors changes in pressure and detect tsunamis. Subsequently, acoustic link transmits data to moored surface buoy and data relayed to satellite and satellite transmits data to ground stations linked with the global and regional tsunami warning networks mentioned before. In this regard, use of cloud computing, integration of Earth Observation (EO) systems, ubiquitous sensing and volunteered geographic information become important. Sensors with self-description capabilities and wireless communication connect with local level additional sensors to form ad-hoc sensor networks resulting higher resolution and lower uncertainty by synthesizing and exchanging their individually observed data for local monitoring.

With reference to ground level EW dissemination in Sri Lanka with the use of third revolution digital technology it is evident that the features such mobile applications have been developed called Disaster Early Warning Network II (DEWN II) for ensuring last mile EW. DEWN is one of the first mass alerting system used for EW in Sri Lanka. This is often deploys Global System for Mobile communication (GSM) technology with outbound messaging via SMS, cell broadcast, mobile app notifications etc. DEWN supports common alerting protocol (CAP) which is an XML based data format for exchanging public warning and emergencies between alerting technologies. DEWN can set priority groups for message broadcasts, regional groups based on requirement and also support media groups to integrate to the alerts via Application Programme Interface (API) [20]. However, it is important to conduct necessary training and awareness programmes as well as establish supporting infrastructure at agency as well as community levels for better familiarisation of such means of communication methods for proactive decision making during disasters saving lives.

In terms of agency capacity building for using third revolution digital technology for responding to disasters, interviewed experts mentioned that, use of General Packet Radio Service (GPRS) is better than Wi-Fi due to less interruption. Wi-Fi is potentially the best and cheapest delivery mode can access with the SMART phone. However, it can be really fast and slow depending on the connection and number of people using that Wi-Fi source. GPRS is one step up from no data signal at all cellular communication system's global system for mobile communication [21]. As most of the EW data exchange among relevant technical agencies happens via Internet in Sri Lanka, Sri Lanka Telecom (SLT) the main telecommunication provider for state sector technical agencies uses Fabre Optic technology providing internet connection to 24x7 operation units/centres for tsunami warning such as, Emergency operation Centre of DMC, National Tsunami Early Warning Centre of DoM, Ocean Observation Centre of NARA, and Seismic Data Analysis and Tsunami Alert Centre of GSMB. However, having necessary infrastructure such as dedicated communication lines with applicable communication protocols ensuring effective data exchange without interruptions had been highlighted by the interviewees for sharing risk knowledge and improving proactive responding. In addition, using satellite communication for EW dissemination and communication to ensure uninterrupted and fast exchange of data for data analysis and issuing warning were also highlighted. Using Google maps marked with vulnerable areas, evacuation routes, evacuation zones, and alternative routes for floating population during a disaster, places for vertical and horizontal evacuation that can be accessed visa SMART phones had been highlighted as useful applications of third revolution digital technology for communities at immediate risk.

5. Conclusions

Given the explained background it is clear that there are four key components of a people centred EW system such as risk knowledge, monitoring and warning service, dissemination and communication and response capability component three "dissemination and communication" using appropriate mechanism tailored to cater the needs of the people is critical for EW decision making saving lives. For example, DEWN II mobile application for SMART phone improve information access therefore decision making as a response capacity of the people at immediate risk. However, it is essential to conduct necessary awareness and trainings, practicing evacuation excises with such communication means and devices such as SMART phones facilitating two way communications. At agency level more preparedness is anticipated by having dedicated communication lines for 24 x 7 operated tsunami warning units of the technical agencies such as DoM, DMC, GSMB and NARA with applicable communication protocols required for sharing risk information for proactive responding. Preliminary finding of this paper such as identification of critical phases of early Warning and exploration of third revolution digital technology in early warning will support my future research work on developing strategies/roadmap for incorporating third revolution digital technology in early warning.

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Building Information Modelling Implementation in Practice: Lessons learned from a housing project in the Netherlands

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Abstract: Real-world implementations of BIM can serve as use cases to demonstrate BIM implementation strategy in practice. This paper presents the findings from a case study of BIM implementation on a housing project in the Netherlands. It describes how BIM approach was used to facilitate the delivery of the project. The benefits and challenges encountered are discussed. The role of BIM process management, BIM activities and key enabling technologies are examined as well as the impact of procurement on BIM implementation. The paper highlights how BIM activities was structured to deliver the project faster (time), cheaper (cost) and better (quality and performance). The analysis is based on project documents and interview with those involved in managing the BIM process. One of the major implications of the findings is that: BIM implementation is a set of interrelated activities and processes. Organisations seeking to work using BIM approach need to actively engage with the process and, in an ongoing basis, learn from their experiences as well as improve based on the lessons learned.

Keywords: Building Information Modelling (BIM), Case study, housing project, BIM implementation.

1. Introduction

The delivery of building and infrastructure projects are generally complex. These projects are often executed in a non-collaborative way. Because of lack of integration and collaboration, project information are often difficult to generate, transmit, reuse, coordinate and so manage thereby leading to inefficiencies, low productivity, delays and project cost blowout and poor value for money outcomes. In addition to that, the accuracy of project information generated and communicated are often less reliable and where reliable they are difficult to access due to lack of team and process integration.

Building Information Modelling (BIM) promises to eliminate the problem associated with the traditional approach to project coordination and management. The drive toward the adoption and implementation of BIM on projects is gaining momentum. In Finland, United Kingdom, Norway, Singapore, and many other countries, BIM has become a mandatory requirement for government projects by a set date. BIM policies and BIM guides has also proliferated globally.

Although there is a lot of talk about the benefits of Building Information Modelling (BIM) as well as growing interest in BIM implementation across architecture, engineering and construction (AEC) industry in many countries, a widespread lack of understanding about how BIM can be implemented in practice remains one of the significant barriers to the widespread adoption of BIM by organizations and on projects. There is anecdotal evidence to suggest that where BIM has been adopted by company, its implementation is still fraught with many difficulties and challenges.

Real-world case example of BIM implementation would provide useful way of understanding the BIM process, benefits, challenges and the implementation in practice. Lessons learned could help others who might wish to implement BIM on their projects.

The purpose of the research reported in this paper was to understand the actual implementation of BIM in practice using a case study. The research is part of a larger study looking at best practices for efficient adoption and effective deployment of BIM. This paper presents some preliminary findings. It describes how BIM approach was used to facilitate the delivery of a housing project in the Netherlands. The benefits and challenges encountered are discussed. The role of BIM process management, BIM activities and key enabling technologies are highlighted.

2. What is BIM?

Building Information Modelling (BIM) can be described as an intelligent model-based process of creating and managing building and infrastructure project information during design, construction and operations phase using three-dimensional, real time, dynamic building modelling software to decrease wasted time and resources. BIM can help integrate project delivery process, the product (the built form or the facility), and people (the supply chain).

BIM facilitates simultaneous work by multiple design disciplines. BIM can eliminate project coordination difficulties and information management problems [1]. It provides a platform for integrated information exchange through a single model. This means that BIM is not just defined by a 3D graphical model; it also includes the capability to transmit and reuse the information embedded in the model. Depending on the data embedded, a model can be 3D graphical model, 4D time model or 5D cost model. With further information stored, BIM can be modelled to include other dimensions such as sustainability aspects (including energy), safety etc. Thus, BIM maturity can be at various levels namely: manual 2D, computer-aided 2D, 3D CAD drawings, intelligent 3D, collaboration which involves sharing of object-based models between two or more disciplines, and integration which involves integration of several multi-disciplinary models using model servers of other network such as cloud computing. GIS information can also be linked to the model. Arguably, when developed and used in its multi-dimensional form, building information model may be referred to as built environment information model. Thus BIM approach offers many promises.

3. BIM benefits and promises

The use of BIM can lead to faster, cheaper and better buildings which are environmentally sustainable. BIM-enabled project delivery can facilitate integration of project team as well as integrate design, construction and operations of a building. BIM can bring cost and time savings on projects because of (a) the high quality of design documentation and well-coordinated project team (b) the ability to facilitate exchange of information between the various design disciplines thereby reduce design errors and omissions with significant reduction in design time (c) the use of BIM to collate the various components of designs authored with BIM tools in order to identify clashes early during the design stage. Information enriched BIM can improve communication between the project team members and can facilitate agile response to project stakeholders' concerns or suggestions during design and construction of facilities. BIM can enable the project team and the owner to visualize the design. Visualization can support design decisions regarding choice of alternative materials, technology and building systems for the facility.

Advanced level of BIM implementation can also help the owner and the design team understand the newly proposed facility in relation to existing facilities, and road network in a precinct, town or city. The impact of the newly proposed facility on neighbourhood infrastructure can be interrogated and potentially improve sustainability of cities and the built environment. BIM information can be used for facility management during operations. For example, upon project completion, the coordinated construction models developed by the builder can become as-built models incorporated with electronic specifications, catalogues, maintenance manuals, testing and commissioning documents that are passed on to the client and facility managers for the purpose of asset operations and maintenance, and later for refurbishment when required.

Despite the promises of BIM, it appears that real-world adoption is still very patchy in many countries and high-level of BIM maturity is still evolving. There is lack of consistent evidence to show that there is widespread adoption of BIM. Case study of real world BIM implementation could help reduce uncertainties around BIM process and its implementation.

4. Research methodology

The research is exploratory using a case study. It made use of qualitative research approach with semi-structured interviews and document review. As part of the larger study, the BIM managers responsible for managing the project were interviewed. In the rest of this paper, the implementation of BIM on the housing project is described and examined.

5. Project description and context

5.1 The Project, the main parties and why BIM was used

The housing project consists of rental apartments for single and two-person households. The complex has nine storeys containing 40 apartments, with five apartments on each floor spread over eight floors. The client (hereafter referred to as 'the owner') is a housing association in partnership with a property development company. The contractor (hereafter referred to as 'the builder') is a design, build, maintain and manage company with over 500million Euros turnover in 2013. The builders are also into property development business. On the project, BIM was not a contractual requirement. The use of BIM was the builders' choice and part of the tender proposal to the owner with the goal of using BIM to help the owner achieve their requirements, the most important being to achieve the lowest 'economic cost'. Thus the value statement is about a better building delivered at the lowest cost. Overall, by using BIM, the builders hoped to eliminate design errors, reduce clashes and deliver the project faster, cheaper and better.

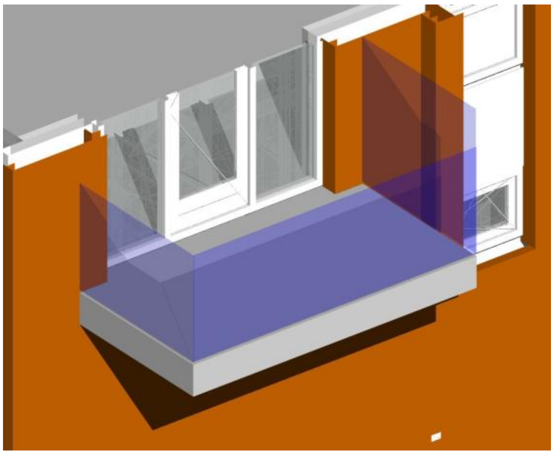

Figure 1: Balcony at LOD 300
(Source: Made available to the author by the interviewee)

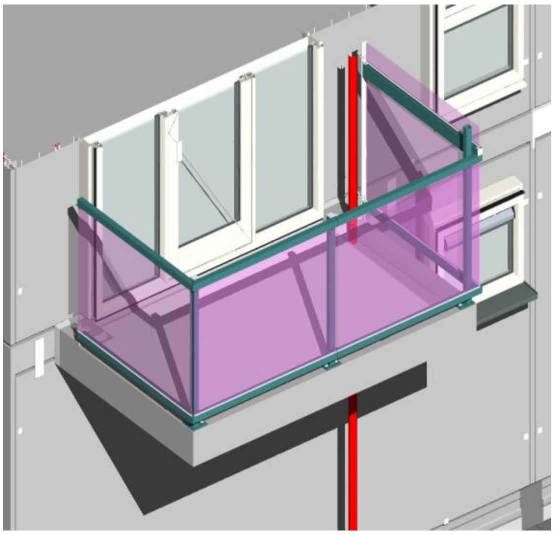

Figure 2: Balcony at LOD 400
(Source: Made available to the author by the interviewee)

5.2 Project organisational structure, roles and responsibilities and the procurement approach

The project delivery method was design and build (D&B) procurement. The designers were engaged by the owners to define the scope of the project whereby the design was developed from conceptual design (LOD100) to schematic design (LOD200) stage. The Level of Development (LOD) describes the dimensional, spatial, quantitative, qualitative, and other data included in a design model [2]. It indicates the level of design information in the design at various stages. For the sake of clarity, Figure 1 and Figure 2 show a balcony in LOD 300 and LOD 400 respectively. Based on the LOD200, the project was tendered and the builder was selected. The designers engaged by the owner to define the project scope at LOD100 and LOD200 were novated to work for the builder after the tender process. Figure 3 shows the project organisational structure.

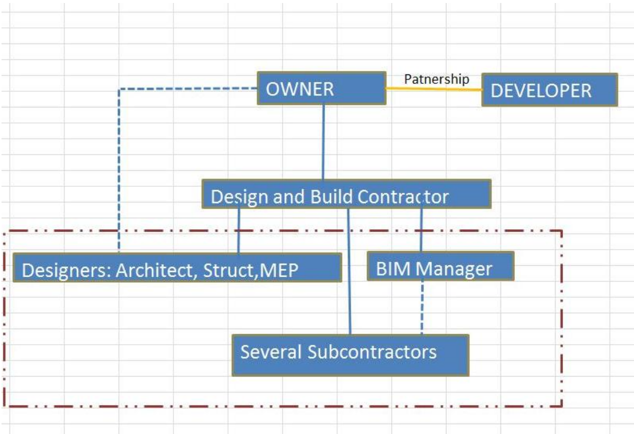

Figure 3: Project organisational structure [Design and Build]

Ideally, the collaborative platform offered by BIM tools and process need to be leveraged by using Integrated Project Delivery (IPD) system [3]. This is because engineering and construction projects delivery process is a social-technical system involving interaction between people and technical aspects. The way interaction occurs between project team members is critical for success. IPD is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction [4]. With BIM and IPD, a project can be defined and coordinated to a much higher level before the commencement of construction on site [5]. Although design and build (D&B) method is not the ideal arena for reaping the full benefit of BIM, the use of D&B on the project do exhibit some features of collaborative and integrated project delivery (IPD).

6. The use of BIM features and integrated project delivery

6.1 Virtual Design and Construction (VDC) method

As recommended by the American Institute of Architects [4], the use BIM and features of IPD, was adopted in what can be referred to as 'Virtual Design and Construction' (VDC). The method integrated the project stakeholders. Models were created by the various designers and participants and the project was built virtually with many design coordination activities and many design revisions. The re-visioning was enabled by the use of 3D models and intelligent computer programs which facilitated information exchange between the parties.

The Centre for Integrated Facility Engineering (CIFE) at Stanford University pioneered the VDC. According to CIFE, VDC is the use of multi-disciplinary performance models of design-construction projects, including the Product (i.e. facilities), Work Processes and Organization of the design - construction - operation in order to support business objectives. With VDC, practitioners can build symbolic models of the project, project organization and process (P-O-P) early before a large commitment of time or money is made to a project. VDC supports the description, explanation, evaluation, prediction, alternative formulation, negotiation and decisions about a project's scope, organization and schedule with virtual methods [6]. The virtual models can be used to simulate the complexities of the construction project delivery as well as identify and analyse the pitfalls that the project team may encounter and how they can be addressed virtually before start of construction work [6]. Thus VDC involves simulation, analysis, visualization, and constructability inputs at the early stage of project development. Forecast of project cash flow can be conducted early with high accuracy. Overall, VDC should reduce project risk and speed up project completion time because key project participants are involved from the earliest practicable moment. The approach can also improve decision-making because of the influx of knowledge and expertise of all key participants.

In this project, the design and build (D&B) procurement overlaid with IPD features allowed the builder to take the advantages of BIM despite BIM not being a contractual requirement. Several subcontractors were engaged early to provide their input into the design.

6.2 BIM managers, MEP engineers and subcontractors roles

The BIM managers were engaged by the builder after the award of the project. They were responsible for managing the BIM process from LOD300, LOD350 to LOD400 phases as well as the calculation of the construction costs at the various stages of the design. They worked with the services engineers i.e. mechanical, electrical and plumbing (MEP), to model the final design of the project (LOD 300). The LOD 300 models form the basis of clash detection, cost calculation, and formed the basis of the subcontractors LOD400 models. The BIM managers worked with several subcontractors to develop the LOD400 prior to working drawings development. The team jointly produced an excellent model for the construction of the complex. It is important to note that the subcontractors were selected based on price and their experience with BIM.

7. BIM management and BIM use

7.1 BIM management process

To ensure the success of BIM implementation, an initial project workshop was conducted. The purpose was to ensure that all the parties understood the project as well as agree to the way of working and how BIM would be used. All parties had to sign the BIM execution document as a part of the contract. Thus the BIM process was supported by BIM protocols and BIM management plan right from the early stage of the workshop. The BIM management plan contains parties' agreements regarding technology, definition of required training levels, BIM goals, process and responsibilities as well as deliverables and timelines etc. After the initial workshop, parties stayed in contact using online project platform. All the parties got the right information at the right time. The BIM activities were structured into six phases with sub activities within each phase as shown in Table 1 to Table 6. During the process, there were several meetings in order to monitor the progress.

7.2 BIM use

BIM was used for the following: clash detection, preparation of working drawings, design visualization, quantities take-off, cost calculation, and exchange of information.

The BIM managers were responsible for the quantity take-off and costing as the design evolved from LOD300 to LOD400. The quantities were automatically extracted from the model therefore more accurate. The quantities also formed basis for developing the construction programme. He programme was separately done and was not live-linked to the model. The federated model was used to produce unambiguous working drawings which formed the basis for actual construction of the building on site. It also made it possible for the parties to visualize and analyse the building prior to construction.

Table 1: Phase 1 of BIM Implementation Activities
(Project document sharing and explanations and BIM specification phase)

Step	Activity
1.1	Transfer of documents to all parties
1.2	Presentation of BIM methodology
1.3	Preparation of the online platform (common data environment for the project)
1.4	Providing the BIM execution plan to all parties
1.5	Verifying and agreeing on the execution plan

Table 2: Phase 2 of BIM Implementation Activities
(Drafting 3D BIM model - LOD 300)

Step	Activity
2.1	Preparation of the 3D architectural and structural models
2.2	Import 3D models (structural) in IFC
2.3	Clash detection (architectual and structural)
2.4	Revising the 3D models (architectual and structural) as result of the clash detection report
2.5	Transfering the cordinated 3D architectual and structural models to MEP engineers
2.6	Preparation 3D MEP models
2.7	Clash detection of 3D architectual and structural models with MEP models
2.8	Revising the 3D models (architectual, structural and MEP) as result of the clash detection report
2.9	Verifying LOD300 models (architectual, structural and MEP)

Table 3: Phase 3 of BIM Implementation Activities
(Preparation of the Budget)

Step	Activity
3.1	Preparation of budget using model based estimating method
3.2	Discuss / review budget
3.3	Establish working budget and possible changes in the design

Table 4: Phase 4 of BIM Implementation Activities
(Drafting 3D BIM model for subcontractors - LOD400

Step	Activity
4.1	Sharing the verifed 3D models (LOD 300) with the subcontractors
4.2	Identifying and clarifying key constraints based on subcontractors input
4.3	Preparation 3D subcontractors models
4.4	Clash detection of 3D modells (architectual, structural, and MEP) with subcontractors models.
4.5	Revising the 3D models of the subcontractors as a result of the clash detection report
4.6	Verifying LOD400 models (with fabrication, assembly and detailing information embeded)

Table 5: Phase 5 of BIM Implementation Activities
(Phase 5: Working drawings)

Step	Activity
5.1	Identifying required information for working drawings
5.2	Establishing the required working drawings
5.3	Processing the possible design changes of subcontractors model into a final LOD400 model
5.4	Preparation working drawings out of LOD400 model
5.5	Control of the working drawings
5.6	Revising the working drawings
5.7	Verifying the working drawings

Table 6: Phase 6 of BIM Implementation Activities
(Phase 6: Overall/general activities during all the phases)

Step	Activity
6.1	Consultation with the owner
6.2	Verifying and recording of all processes
6.3	Collaboration among all the parties involved
6.4	Specific explanation of the BIM methodology by the BIM manager
6.5	Opening abnd mantaining of the project comon data environment.
6.6	Evaluation of the project

8. Information sharing, Technology, and Model coordination

A project website was hosted on the servers of the BIM managers and was used as a common data environment (CDE) and platform for sharing project information. The platform served as a single source of information for the project. Although it was not possible for models to be viewed directly on the platform during the modelling phase, the website served as a platform for gathering, managing and transmitting documents as well as all 3D graphical models and non-graphical data for the project team. This facilitated collaboration between the team members. It also helped avoid duplication and mistakes. All parties were required to upload their updated model every Friday. All project team members used their own software but shared information using IFC (industry foundation classes). About 8 different softwares were used on the projects.

The BIM process involved frequent coordination of 3D models from the various design disciplines and from several subcontractors. Thus the building was virtually built through collaboration between the owner, builder, the BIM manager, the various designers (architectural, structural and services) and several subcontractors. All models were federated by the BIM managers and subjected to clash detection to identify errors and clashes in the models and the process.

9. BIM challenges and how they were resolved

Some of the challenges encountered include: late delivery of documents by the owner, architect and other parties; many changes in the design phase; coordination of many different models due to the number of parties involved including the several subcontractors; exchange of BIM models with IFC (software were not compatible), tight schedule, different expectations from different parties. The BIM maturities and knowledge of the parties are divergent. The initial workshop conducted at the early stage of the project helped secured commitment of all the parties to BIM method. Frequent model coordination helped to detect errors and clashes early.

10. Outcome of BIM use

In this project, parties did not recreate their own information at every phase. Information created at an earlier phase was reused in the subsequent phases. This eliminated inefficiencies by reducing wasted time and effort. For example, the LOD200 model created by the owner's designers at the early stage was used as the basis for LOD300 model produced by builder while the LOD300 model formed the basis for the subcontractors' model (LOD400). Thus the implementation of BIM resulted in federated 3D model (architectural, structural and MEP) at LOD300; and subcontractors model at LOD400) on the basis of which unambiguous drawings, working drawings, design visualization, clash report, cost estimates, planning, document management, were prepared and carried out. It also supported construction works on site.

In terms of design errors, up to 590 clashes between architectural, structural and services elements were identified and resolved prior to construction. 84% of the clashes were detected at the LOD 300 while 16% at LOD400 involving several subcontractors models. Overall, the project time was shortened by 40%. Parties, especially the owner was very satisfied because of the quality of the building delivered. The BIM process on the project provided a good learning experience for all the parties involved.

11. Conclusions

A description of real-world implementation of BIM in a housing project has been presented. BIM implementation is a learning process for adopters. The experience from this project shows that BIM implementation is a set of interrelated activities and processes enabled by digital technology including common data environment (CDE) and collaborative procurement. The role of BIM leader (or BIM manager) as well as the management of the BIM process is critical for successful implementation of BIM. The case study described also suggests that the success of BIM would depend on the BIM maturity and commitment of all parties involved. The use of open BIM where parties can share information about their model while working with their preferred software is crucial.

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Importance of Quality for Construction Project Success

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Abstract: Construction projects are always expected to create a balance between cost, time and quality. It is possible to have high quality and low cost, but at the expense of time, and conversely to have high quality and a fast project, but at a cost. High quality is not always the primary objective for the client; however, it is extremely important to a successful project. An appropriate level of quality could be determined during all phases of the construction project. Specially, construction and commissioning are two critical phases where the project could impact by its operability, availability, reliability, and maintainability of a facility. Ultimately, a facility with a good construction quality program and minimal defects is more likely to have a smooth and trouble free transition into the commissioning and qualification phase of the project. This creates a great potential for quality improvements in construction projects, as the poor quality could negatively effect to project failures. Therefore, the purpose of this research is to investigate the importance of quality for construction project success. Accordingly, quality and related key literature were reviewed and a framework of quality for construction project success was developed.

Keywords: Quality, Construction Projects, Success, Importance

1. Introduction

Attainment of acceptable levels of quality in the construction industry has long been a problem. Great expenditures of time, money and resources, both human and material, are wasted each year because of inefficient or non-existent quality management procedures [1]. During the last decades construction industry has been heavily criticized for its performance and productivity compared to other industries [2].

Poor quality in construction projects is a common phenomenon in the world [3]. Further, [4] stated that the satisfaction of quality level in the construction projects has not been achieved and, it is a serious problem. However, most of the countries have been evolved to implement quality standards to ensure construction quality. Therefore, it is necessary to investigate the importance of quality for construction project success. Hence, the purpose of this research is to determine the importance of quality for construction project success. The framework of quality for construction project success is developed accordingly.

2. Literature Review

2.1 Definitions to Quality

Quality can be defined as meeting the legal, aesthetic and functional requirements of a project. Requirements may be simple or complex, or they may be stated in terms of the end result required or as a detailed description of what is to be done. However, the quality is obtained if the stated requirements are adequate, and if the completed project conforms to the requirements [1]. Some design professionals believe that quality is measured by the aesthetics of the facilities they design. According to [5], this traditional definition of quality is based on such issues as how well a building blends into its surroundings, a building's psychological impacts on its inhabitants, the ability of a landscaping design to match the theme of adjacent structures, and the use of bold new design concepts that capture people's imaginations. Quality can also be defined from the view point of function, by how closely the project conforms to its requirements. The concept of quality management is to ensure efforts to achieve the required level of quality for the product which are well planned and organized. However, in the construction industry, quality can be defined as meeting the requirements of the designer, constructor and regulatory agencies as well as the owner [6].

2.2 Application of quality in construction industry

From the perspective of a construction company, quality management in construction projects should mean maintaining the quality of construction works at the required standard so as to obtain customers' satisfaction that would bring long term competitiveness and business survival for the companies [7]. Further, the adoption of quality in construction industry has been promoted in some literature [8; 9]. The application of ISO standards has received much attention from researchers. ISO certification is nowadays a trend in most industries including construction industry [10].

According to study by [11], for the implementation of quality management in project management, the concepts of quality planning (identification of quality standards), quality assurance (evaluation of overall project performance) and quality control (monitoring of specific project results) in the quality management processes are importance. Among those, quality assurance (QA) and quality control (QC) are mostly used in construction.

The quality control procedure in construction projects is based on tender documents, specifications, working drawings etc., therefore, the pre tender stage quality and standards of the work should be properly maintained. Therefore it is important to maintain quality control of the building projects from the inception of its design stage up to the completion of construction including the maintenance period [12]. Quality Assurance (QA) is a program covering activities necessary to provide quality in the work to meet the project requirements. QA involves establishing project related policies, procedures, standards, training, guidelines, and system necessary to produce quality. QA provides protection against quality problems through early warnings of trouble ahead. Such early warnings play an important role in the prevention of both internal and external problems". On the other hand Quality Control (QC) is the specific implementation of the QA program and related activities. Effective QC reduces the possibility of changes, mistakes and omissions, which in turn result in fewer conflicts and disputes [11]. The design professionals and constructors are responsible for developing an appropriate program for each project to enhance the project quality.

3. Research methodology

Key research papers relating to quality, quality management, quality management procedures in construction industry were reviewed in order to determine the importance of quality for construction project success.

4. Findings and Discussion

4.1 Importance of quality for construction projects

A construction project in its life span goes through different phases. The main phases of a project can be described as: conceptual planning, feasibility study, design, procurement, construction, acceptance, operation and maintenance. Quality is one of the critical factors in the success of construction projects. Quality of construction projects is linked with proper quality management in all the phases of project life cycle. Design and construction are the two important phases of project life cycle which affect the quality outcome of construction projects significantly [2]. Further, quality of construction projects can be regarded as the fulfillment of expectations of the project participants by optimizing their satisfaction. It is because, since the quality outcomes of the projects are not according to required standards, faulty construction takes place. Further, the errors on construction projects occur frequently and can be costly for the contractors and owners of constructed facilities. In fact, 6-15% of construction cost is found to be wasted due to rework of defective components detected late during construction and 5% of construction cost is wasted due to rework of defective components detected during maintenance [13]. Hence, quality has become one of the most important competitive strategic tools which many construction organisations have realized it as a key to develop their building products in supporting the continuing success [14].

4.2 Factors affecting construction project quality

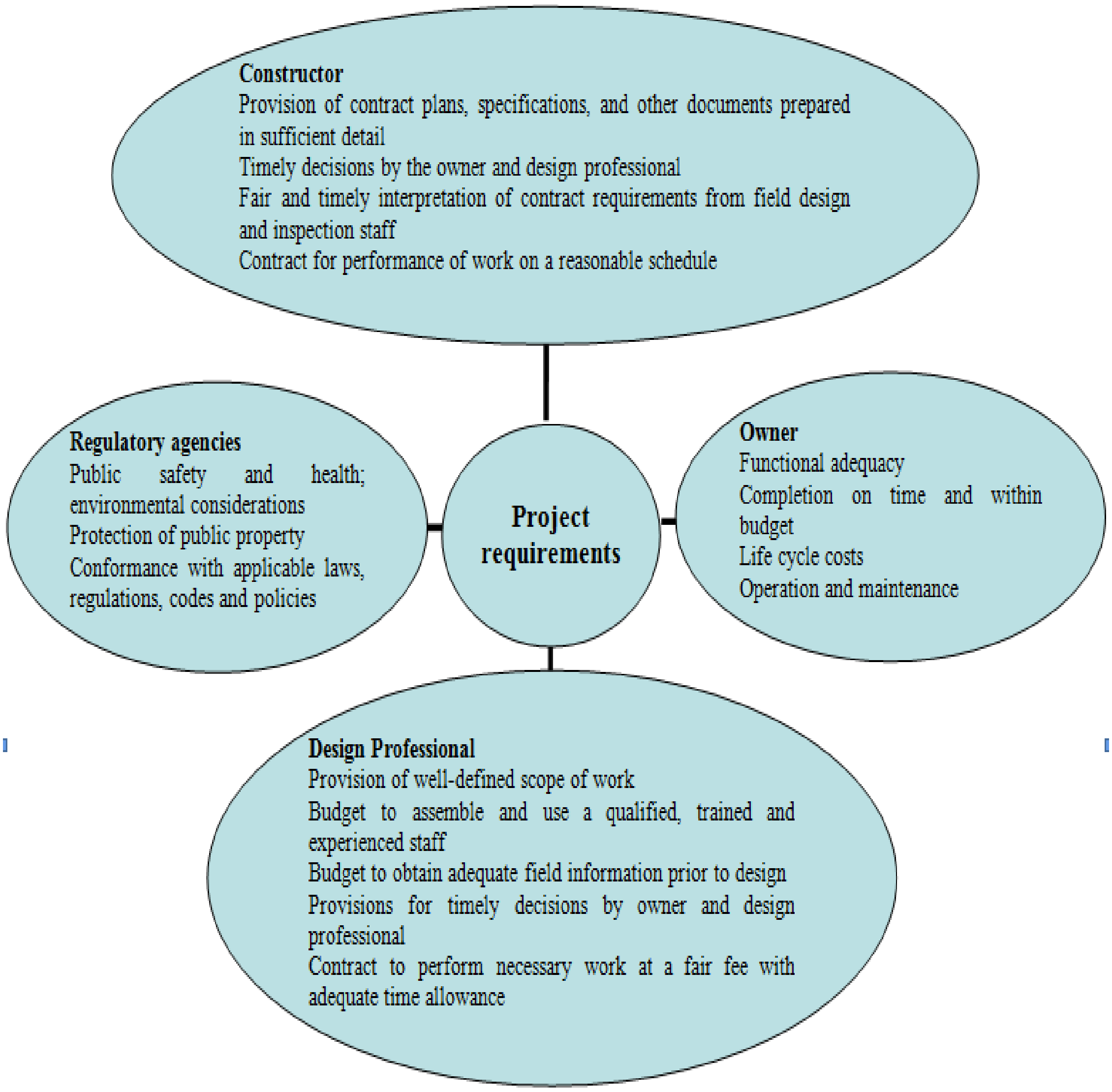

Figure 1: Project requirements
Source: [6]

Establishing project requirements at the project inception stage could affect the quality of completed project. As [1] mentioned that, quality of any construction project is meeting the requirements of the designer, constructor and regulatory agencies as well as the owner. The following Figure 1 illustrates the project requirements of the designer, constructor, regulatory agencies and the owner, that could be meet by enhancing the project quality as found in key literature.

Accordingly, a careful balance between the owner's requirements of the project costs and schedule, desired operating characteristics, materials of construction, etc. and the design professional's need for adequate time and budget to meet those requirements during the design process is essential. Owners balance their requirements against economic considerations and, in some cases, against chance of failure [6]. The design professional is obligated to protect public health and safety in the context of the final completed project.

The constructor is responsible for the means, methods, techniques, sequences, and procedures of construction, as well as safety precautions and programs during the construction process [6; 15]. The completion of project in accordance with the project requirements could be assured by the quality of its construction. Project requirements are the key main factors influencing construction project quality. However, it can be influenced by many factors.

According to a study by [16], management commitment and leadership in construction organizations could affect construction quality. It is because, the poor management practices directly and indirectly lead to decline of construction productivity and ultimately affect on project quality. In construction terms, cost, schedule, and possibly quality goals are established for each project. Project managers are rewarded on the basis of meeting these goals [17]. Further, the quality teams provide companies with the structured environment necessary for successfully implementing and continuously applying the quality in construction [16]. As [16] further stated, extent of teamwork of parties participating in the design phase was found to be the most important factor that affects quality teamwork among parties such as Structural Engineers, Electrical Engineers, Environmental Engineers, Civil Engineers, Architects, and owners is essential to reach the quality goals for design. Further, in the construction phase, extent of teamwork of parties participating in the construction process was found to be very important.

4.3 Cost of poor quality

Construction projects are always expected to create a balance between cost, time and quality. Even though, improving quality is not always the major objective of the project; the poor quality could create cost to organisation. The cost of poor quality refers to the costs associated with providing poor quality product or service. The cost due to failure, appraisal and prevention are three major cost categories that could be directed by poor quality [18]. As [18] further mentioned, failure cost could be occurred as internal and external failures. Internal failure cost includes rework, crap, re-inspection, re-testing, redesign, material review etc whilst external failure cost includes processing customer complaints, customer returns, warranty claims and repair costs, product liability and product recalls. Further, appraisal cost could incur while performing measuring, evaluating, or auditing to assure the quality conformance. These costs include first time inspection, checking, testing, process or service audits, calibration of measuring and test equipment, supplier surveillance, receipt inspection etc. The prevention cost include the costs related to all activities of preventing defects from occurring and to keep appraisal and failure to a minimum, such as, new product review, quality planning, supplier surveys, process reviews, quality improvement teams, education and training etc [14].

Hence, it creates a necessity to enhance the quality of construction projects to lead them towards successful completion. As per the extant literature, adopting quality into building process is therefore utmost important. In construction, failure can result from malfunction on the part of constructor, designer, or even owner. In most cases however, it is the result of a combination of actions by several or all of these parties. According to previous researches, the construction organisation must, therefore, have the ability to deal effectively with all parties involved to make the project success with high project quality. The implementation of quality management plan therefore could start at the project inspection stage and should continue throughout the whole life cycle phases.

Enhancing the quality of drawings, and specifications could be done at the early stages that could affect the quality in design and construction phases and, ultimately the quality of constructed facility. Drawings are the only documents given to the constructor that show the design concept, size and scope of the job. It is critical that drawings and specifications be clear, concise, and uniform. Further, constructability of the design could improve as it affects the quality of design.

The design should be reviewed for effectiveness and compatibility with local requirements, including both the initial construction and post construction operations. Both the initial design constructability and the completed operational design should also be reviewed.

Providing quality training for construction related professionals who have engaged in construction could also effect to enhance project quality. Here, the awareness and training of quality management aspects relating to whole phases is essential. In addition to that, all the parties should be work together as a team in the quality management process to achieve certain quality goals. Partnering arrangements between those parties will enhance the total quality.

The Figure 2 illustrates the importance of enhancing the project quality for construction project success where, the quality drawings, standards, constructability of design, management commitment, training and awareness and the team working of all parties involved in the building process may lead to enhance construction project quality. Accordingly, it may reduce the unnecessary cost of poor quality whilst meeting project requirements by satisfying all the parties involved in the construction process.

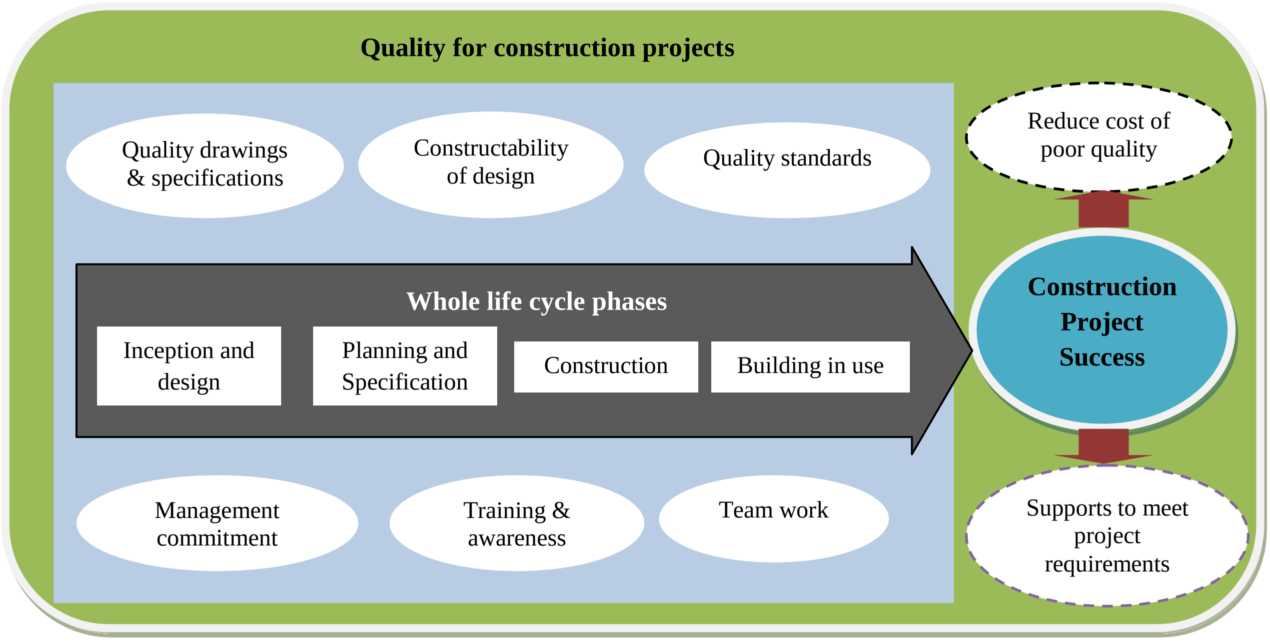

Figure 2: Framework of quality for construction project success

5. Conclusions

Directing a construction project towards quality with low cost and time is a greater concern today. It is because quality is required to meet project requirements of the owners, constructors and other parties involved with a greater satisfaction. Moreover, poor quality could lead to unnecessary cost to the organization where it could create costs due to failure, appraisal and prevention. Hence, it creates a necessity to introduce the concept 'quality' into building process throughout its whole life phases. Implementing proper quality management plan is important at the project inception where, quality drawings, quality standards and constructability of design may lead to enhance the project quality. However, the commitment and the support of the management are important to continue the process. The awareness and training provides a base to collaborate all parties into the process, in which the collaboration of such all parties in quality management process is essential to lead towards construction project success.

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Adoption and Scope of Building Information Modelling (BIM) in Construction Industry of Pakistan

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Abstract: Building Information Modelling "BIM" is becoming a better known established collaboration process in the construction industry. Owners are increasingly requiring BIM services from construction managers all over the world, but the adoption of BIM in building construction industry of Pakistan is very slow. Globally one of the great advantages of BIM is the ability to create an accurate model that is useful throughout the entire life of the building, from initial design through occupancy and operations. The benefits of BIM are evident in its capability.
There are two objective of this research work, first to identify the problems faced in construction management and secondly to identify the barriers in adoption and implementation of BIM in local building construction industry.
The research objectives were achieved through literature review, case studies, and questionnaire. First, the research identified the uses of Building Information Modelling for construction industry, and then identified the problems faced by construction managers in construction management. On the basis of literature review a questionnaire was prepared and surveyed to identify the source of construction management problems in the building construction industry of Pakistan. Then, the project examined the uses and benefits of BIM in the construction of a research facility by minimizing the sources of many identified problems in questionnaire survey. Finally, the project concluded and recommended the ways to increase the use of BIM in building construction industry of Pakistan.

Keywords: BIM, Construction Industry, Construction Management, Labour Productivity

1. Introduction

The construction industry showed progressive reduction of labor productivity in the early 1960s. Meanwhile, the non-agricultural industries, such as the construction industry have increased the productivity of labor. The reduction in labor productivity in the construction sector requires more hours of work per contract dollar amount. This shows that the construction industry is in deficient to developing the concept of labour saving and to save economy.
The role of participants in planning and construction phase is fragmented in traditional construction project delivery approach which is design bid build approach. In other words, it hinders the mutual participation of construction manager or the general contractor during the design phase of the project.
Secondly, the use of traditional and common two-dimensional CAD drawings does not promote a genuine partnership approach. Engineers and architects produce their own fragmented CAD documents for owners and contractors which are usually consist of errors and usually give rise to conflicts of information, which leads to inefficiency in labor productivity. So the construction industry has been under great increasing pressure to improve its practice (LATHAM, 1994; EGAN 1998, HOWELL, 1999). Fragmented nature of construction industry, the problems in communication and coordination between project participant, informal and unstructured learning process, adversarial contractual relationships and lack of customer focus are factors that inhibit the industry performance (COOPER ET AL 2005).
Furthermore, the manufacturing industry workers are paid higher wages than the construction workers. Because of high cost and risk associated with new technology construction firms do not have as much as resources and incentive to invest in research and development. Construction industry is always very slow to adopt new technology due to local constraints and practices even when it is necessary to use new methods and technique then applied for a specific project only. In late 1970's, the first steps was taken towards the use of 3D solid modeling which was very late as compare to manufacturing industry. Because at this time, they were doing all design and analysis of their products on 3D model. In the construction industry, the use of 3D modeling was caught up "by the cost of computing power and later by the

successful widespread adoption of CAD" (Eastman, 2008).

Building Information Modeling (BIM) is one such approach which is now considered as a whole new process and methodology rather than just a technology. Building Information Modeling (BIM) is getting increasingly valuable in construction industry.

Therefore, the basic objective of this research is to study BIM and BIM tools to determine its benefits for construction managers. In this research, the uses of BIM which include 3D coordination, visualization, cost estimation, construction planning and monitoring, prefabrication and record model are discussed in detail. And the source of these common problems of construction managers is identified. Finally a model is proposed to implement BIM as BIM tools has potential to minimize most of these problems.

2. Research Methodology:

Literature Review: Literature review is used to systematically review earlier writings so as to learn more about the subject and other topics which collectively establish the context of this study. The goal was to gain a comprehensive understanding of the Building Information modeling and how the BIM is currently addressing the problems of construction managers in construction industry. It was completed in two phases. Firstly, it was used to gain a comprehensive understanding of BIM, BIM scope for construction managers and its adoption in construction industry. Previously conducted researches were reviewed to obtain knowledge about barriers and challenges which inhibits BIM adoption in industry.

Case Study: A case study approach is adopted to understand the solution of problems related to construction management and how BIM is minimizing the source of these problems.

Survey Questionnaire: Surveys are part of quantitative research and the focus of quantitative research is on objective measures rather than subjective experience. Surveys include cross sectional and longitudinal studies using questionnaires or interviews for data collection with the intent of estimating the characteristics of a large population of interest based on a smaller sample from that population *(RUIKAR, 2004).* Due to the nature of research question, a survey approach was used to obtain primary research data. The reason to select questionnaire is because questionnaire offer several advantages as they are widely distributed and low cost, interviewer bias is eliminated, anonymity of respondents, respondent can answer at leisure. In addition to that, *NAOUM (1998)* described questionnaire as the most popular form of getting primary data from a relatively large number of respondents within a limited time frame.

3. Literature Review:

Building Information Modeling (BIM):

The Building Information Model is primarily a three dimensional digital representation of a building and its intrinsic characteristics. According to the National BIM Standard, Building Information Model is "a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" ("About the National BIM Standard-United States", 2010).

National Institute of Sciences (2007) defines BIM as:

"A BIM or Building information model uses digital technology of last generation to model a computable representation of all the functional and physical characteristics of the facilities and concern information during its life cycle and is intended to be a source of information for the service owner/operator to use and maintain that service during its life cycle."

According to Autodesk (2002), BIMs have three basic characteristics. Create and operate in digital databases for collaboration. To manage the change through these databases in order to make a change in any part of the database is coordinated with all other parts. Capture and preserve the data for reuse by adding industry-specific applications.

The findings of NIBS (2007), MAUNULA (2008)&SUCCAR (2008) that acronym BIM is used in three different ways. BIM can refer three different schools of thought which consider BIM as:

i. A product
ii. An activity/Process
iii. A system , a whole new concept

Problems faced with Construction Management:

In a CAD project, after the hundred percentage construction documentation and addendum and revision information has been turned over to the contractor, construction begins. Before the first scoop of dirt is moved, it is the construction manager responsibility to verify that the immediate information need is adequate and the most recent. Further issues for the project need to be identified and put on a path of resolution for all scopes of work. In theory, this review period for the project allows the construction manager to identify issues and give responsibility to the correct subcontractors. In itself, this is an arduous process.

Analyzing and overlaying CAD files and sheet drawings is time consuming work, it lack in visibility and it is prone to errors and missing information. In reality the construction manager is often cannot juggle managing the project documentation, the trades, the field management, and the construction managers own management team.

Advantages of BIM for Construction Management:

Each professional and user will have a point of view about the benefits of BIM in construction industry especially for construction managers. Their judgment approach or orientation may be different but as whole they are agree that BIM has remarkable effects on construction management.

a. Visualization

Building Information modeling (BIM) is an excellent visualization tool. It can provide a three-dimensional virtual representation of the building. It can help the contesting companies during bidding process because it can provide a better understanding what they have to construct and how it will look like after completion. It is possible due to renderings, walkthrough videos extracted from BIM model by using BIM tools.

b. 3D Coordination

Coordination is very important for a construction manager, especially when dealing with dense urban environment or challenging site. Coordination involves working and communicating with subcontractor, supervisors, materials suppliers, fabricators and equipment suppliers. In addition to juggling the scheduling, managing the budget, sorting through constructability issues, and managing relationship, the construction manager is also responsible who is doing what work on a project. Therefore the coordination efforts in advance of construction will reduce design errors and provide better understating of work ahead of time to be done.

c. Prefabrication

Offsite fabrication required considerable planning and accurate design information. It is becoming more common for contractors to fabricate component offsite to reduce labor cost construction time and better quality control. In offsite fabrication, different component or items can be assembled or fabricate in controlled environment and with greater precision and if any alteration is required then more option are available than site. A ductwork contractor can also use BIM model to installed branches and leave opening where required so that later on diffusers or hood can be installed. Carpenter can also use BIM information to fabricate accurately different size and types of cabinets and wardrobes for different location. Pipe manufactures and plumbers can also have information regarding pipe size, length and location from BIM.

d. Construction Planning and Monitoring

The planning of construction activities or project is basically about its scheduling and sequencing of virtual model to coordinate in time. The progress of construction work can be linked with virtual model to monitor the project schedule and time is introduced as the 4th dimension. To create 4D BIM model, Critical path method (CPM) and line of balance are two common scheduling methods can be used. In critical path method, each and every activity is listed in construction sequence and every activity is linked with another activity. Then time required to complete that activity is assigned on the basis of work break down structure and available resources like money, machinery and manpower.

e. Cost Estimation

Extracting quantities, areas and volume from a 3D model in one of the most useful function BIM technology offers. Cost estimation is basically two step procedure, first is quantity take off from drawings and second is pricing of all items of work. Quantity take off is very laborious and time taking process from 2D drawings and it also has a chance of error in calculation. But it is very easy to take off quantities from 3D BIM model and can be import to a cost database.

f. Record Model

At the end of every project, owner has to deal with a huge amount of documentation with end of project information. In most of the cases owner are not specialized to understand and handle all the construction related information from 2D drawings. So it is better if they have a 3D model of their project. By using BIM tools, after all alteration and as build variations, a record model of BIM can be obtained and handed over to the owner by the construction managers at the end of the project. The recorded model contains all the information of as build and shop drawings from the subcontractors. On the other hand each object properties of the model may also include links for operation and maintenance, submittals and warranty claims and information.

g. Project Cost

By Using BIM, the productivity of design member is increased drastically and more work is done with less resource and people. A small design team will not only reduce the overall cost but also there is less chance for interruptions and miscommunication as fewer minds are working on a project. So by this collaboration is increased. Because the documents are coordinated by the main BIM server or one common data base computer and therefore can be more complete and refine with less error, the cost of various changes at different stages is reduced.

4. BIM Tools

Table 1: Respondent Profile

Product Name	Manufacturer	Primary Function
Revit Structure	Autodesk	3D Structural Modeling and parametric design
Revit Architecture	Autodesk	3D Architectural Modeling and parametric design.
AutoCAD Architecture	Autodesk	3D Architectural Modeling and parametric design
Cadpipe HVAC	AEC design group	3D HVAC Modeling
Cadpipe Commercial Pipe	AEC design group	3D Pipe Modeling
AutoCAD MEP	Autodesk	3D MEP Modeling
AutoCAD Civil 3D	Autodesk	Site Developer
Revit MEP	Autodesk	3D Detailed MEP Modeling

5. Initiating with BIM

BIM is not only a new technology, process or system; there are always some stages, phases and processes behind the technologies. The Building Information Modelling should also be seen as an initiator and founder of significant process improvement in the building industry. This part describes some characteristics, benefits and barriers of the Building Information Modelling.

6. BIM as a Process Changer

BIM not only improves the technology but also changes the process of proceeding with design and build. WALTER claims that: "BIM helps to make a better decisions, it can eliminate the abstraction and coordinates among multiple disciplines, including documentation and design. And BIM can integrate detail design, plans, sections, graphics, and processed data which is not possible to integrate in 2D." On the basis of WALTER's argument, the time that is spent on the design of a facility can be cut into half with half the cost. On the other hand, it will not only save money but that also is to reduce the delivery time of a construction project.

7. Data Analysis and Results

a. Respondent Profiles

A questionnaire is distributed through web based questionnaire survey site and about 210 responses were received. This questionnaire was distributed to construction managers and project managers of CA, CB, C1 and C2 Categories Company of Punjab, Pakistan as define by Pakistan Engineering Council.

Table 2: Respondent Profile

Respondent Profile			
1	Designation/Position in Company	Construction managers	63%
		Project Managers	37 %
2	Construction Experience	More than 4 Year	32%
		More than 7 year	44 %
		More than 10 [[[[year	24%
3	Company Category (As per PEC)	CA	24%
		CB	27%
		C1	19%
		C2	30 %

As shown in respondent profile, about 63 % respondent are working as construction managers and 37 5 are working as project managers. On the basis of their construction experiences, all respondents are divided in to three categories. So 24 % respondent having more than 10 year construction experience, 44 % having more than 7 year construction experience and 32 % having more than 4 year construction experience. These respondents are working in construction companies of different categories which is shown in respondent profile.

a. Respondent Knowledge about BIM/BIM Tools

The figure shows that 51 % respondents have medium level of knowledge about BIM, 9 % have high level of knowledge and 28 % have very low level of BIM knowledge. About 7 % claims that they have no knowledge of BIM. It reflects the present BIM adoption situation in construction industry of Pakistan. Those respondent have very high knowledge of BIM probably have working experience on international project with international consultant and designers.

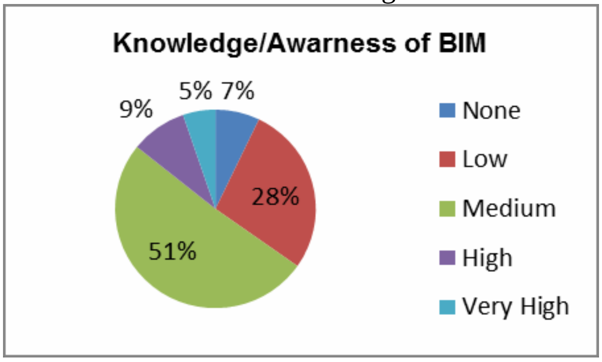

Figure 1: Benchmarking of BIM Knowledge

b. Barrier in BIM Adoption and Implementation

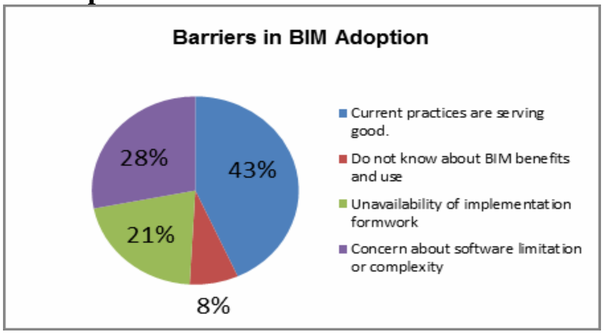

Figure 2: Barriers in BIM Adoption

The figure shows that respondent believe in that current practices are serving best in very high, it is about 43 %. But about 28 % respondents have believe that BIM tools are complex, expensive and not easily available which is a hurdle in BIM adoption. About 21 % respondents claim that every new technology must have an implementation frame work for its adoption in construction industry. It is the common problem with every new technology that people don't know about its uses and benefits.

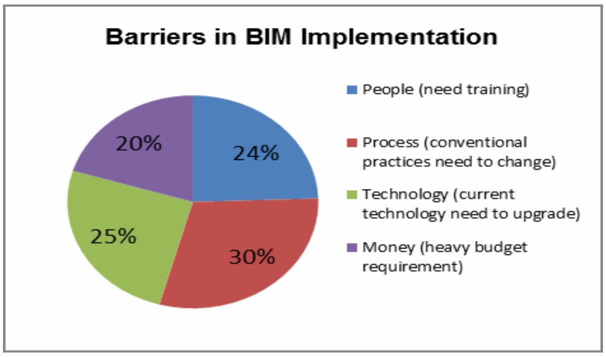

Figure 3: Barriers in BIM Implementation at Company Level

It has been pointed out by 30 % respondents that current practices of construction management need to change and about 24 % and 25 % think that people training and technology up gradation is the barrier in implementing BIM. As all respondent belong to large size construction companies so 2o % believes that money required for up gradation and training is also another barrier.

c. External Constraints in BIM Implementation

Figure shows that the adoption of BIM in construction industry of Pakistan is very slow which is reflecting from response as about 34 % respondents are agreed.

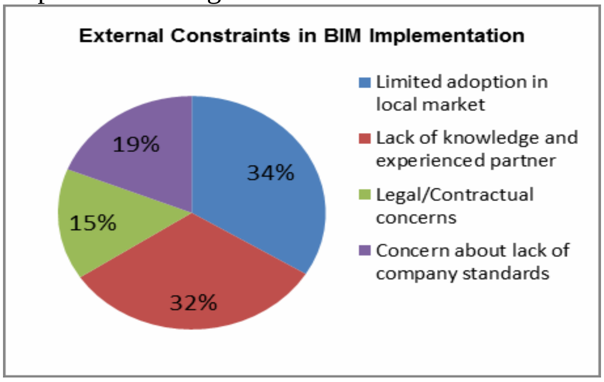

Figure 4: External Constraints in Implementation of BIM

And about 32 % of the respondents believe that lack of knowledge about BIM and unavailability of experienced partner is the main external constraints in the implementation of BIM. So the construction industry of Pakistan need to aware this latest construction management technology and must start with some pilot project. While 19% and 15% are assuming that BIM implementation has external constraints due to lack of company standards and contractual constraints respectively.

d. Problem in Planning and Scheduling

This is revealed from the survey that unavailability of trained staff and interpretability of planning tools with 2D CAD drawing is the main source of problem in planning and scheduling of a project. A small percentage of respondents claim that confusion in construction sequence is creating problem in planning and scheduling.

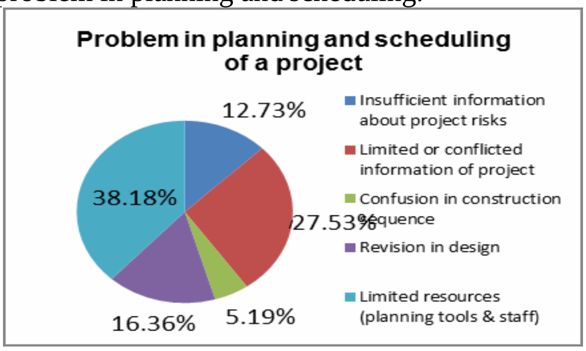

Figure 5: Problem in Planning & Scheduling

e. Problem in Site Coordination

Site coordination refers to the organization of the site, materials, equipment, safety and site security.

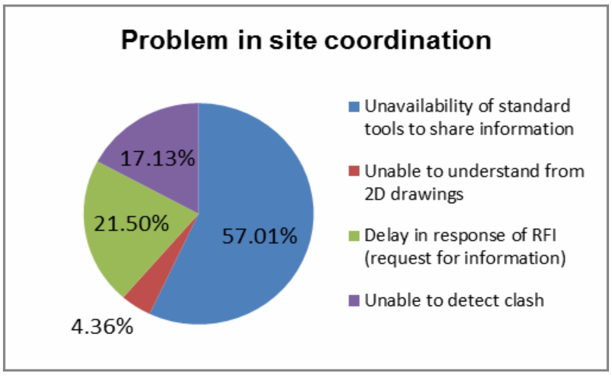

Figure 6: Problem in Site Coordination

Site coordination is very important for smooth running of all construction activity.

f. Problem in Procurement Management

As per site requirement, the construction manager is also responsible to procured required construction items prior to the start of construction activities at site. It is very important for avoiding any delay in construction. The figure shows that delay in procurement is due to low progress of quantity survey department because they have to take off quantities from 2D CAD drawing after coordination between architecture, structure and MEP drawings.

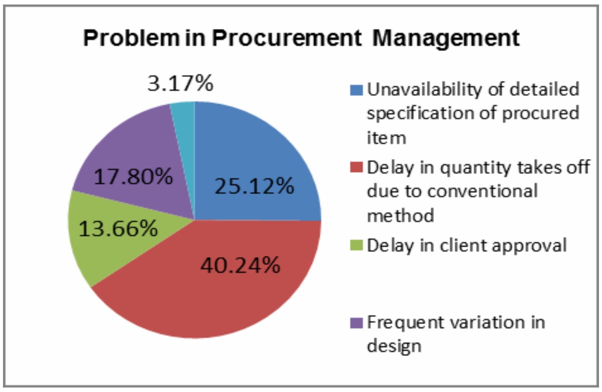

Figure 7: Problem in Procurement Management

g. Problem in Cost Estimation and Quantity Take Off

Cost estimation is consisting of two part, first quantities of all items of work need to calculate accurately and it need to multiply with unit price for cost estimation.

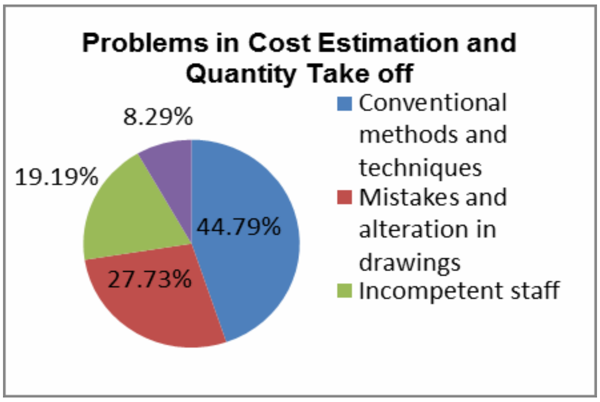

Figure 8: Problem in Cost Estimation and Quantity Take Off

From 2D CAD drawings it is very laborious and time taking and chance of error is always there. The figure shows that conventional methods and tools are creating problems in cost estimation and quantities take off which need to be changed and have to adopt new tools and technologies.

h. Difficulties in Cost Controlling

The construction manager at site is unable to control the overheads due to different reasons like excessive redoing, inappropriate sources allocation, low productivity of labors and machinery and construction delay etc. the figure shows the sources of problem in cost controlling.

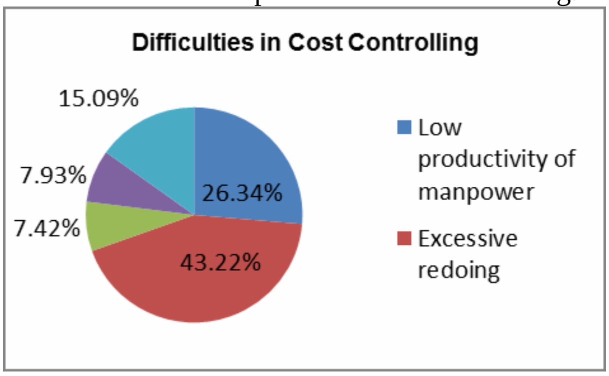

Figure 9: Difficulties in Cost Controlling

i. Problem of Excessive Redoing of Work

Excessive redoing at site is not only the loss of money but also the loss of time. Redoing at site is possible due to many reasons, some of them are avoidable and some are unavoidable. The figure shows the sources of redoing work and respondents experiences about this problem.

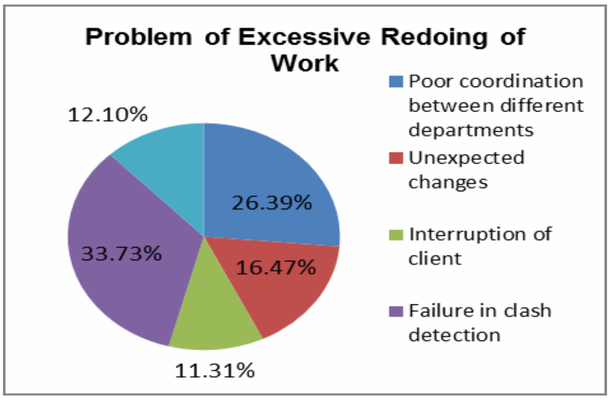

Figure 10: Problem of Excessive Redoing of Work

j. Problem of Low Productivity

The construction managers are facing this problem due to fragmented nature of construction industry. It will results in increase in construction time. This figure shows that improper planning of manpower is the main reason of low productivity.

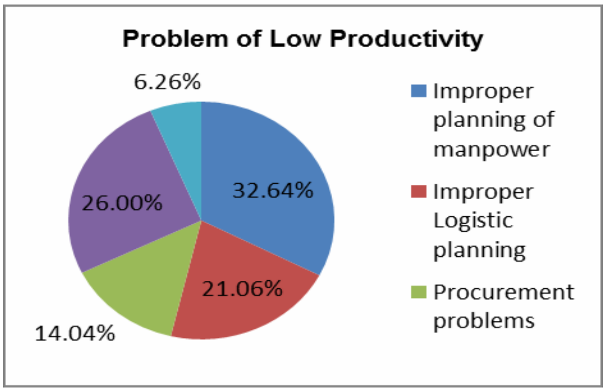

Figure 11: Problem of Low Productivity

k. Increase in Construction Time

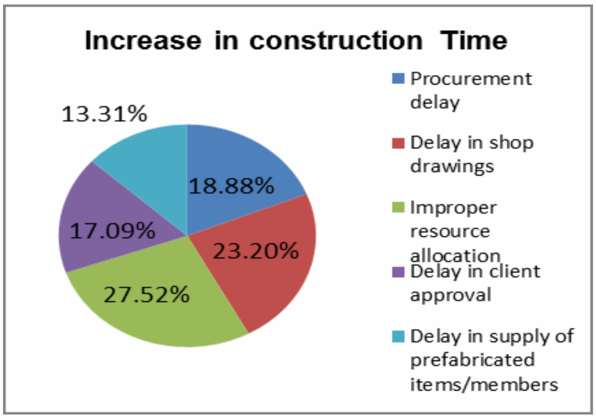

Figure 12: Increase in Construction Time

Construction manager is responsible to complete the project in time as per schedule and assigned budget. Sometime this is not possible to complete the project due to many reasons but construction manager has to minimize the problem which results in increase in construction time.

l. Increase in Project Cost

The owner is always very conscious about the cost of the project. The construction manager is also at stake in construction manager at risk project delivery system. Increase in project cost is the loss of construction manager in CM at risk delivery system. A small percentage of respondents believe that extreme weather condition and activity crushing is the reason to increase in construction cost as shown in figure.

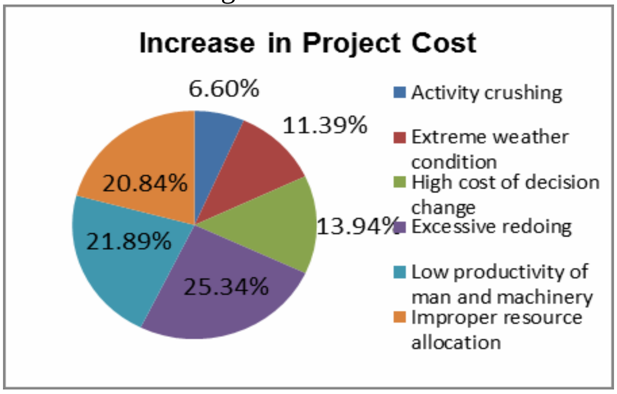

Figure 13: Increase in Project Cost

m. Problem in Facility Management

This phase is usually started after the construction of a project. The figure shows that 42% construction managers have problem in facility management due to limited information for as build drawings especially regarding the service lines. Unavailability of information about building components is also a source of problem in facility management.

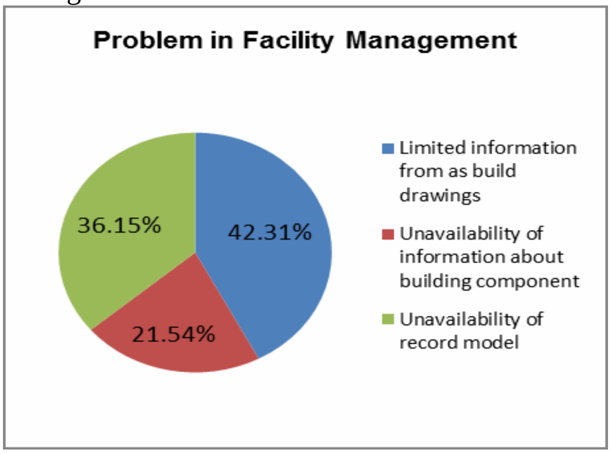

Figure 14: Problem in Facility Management

8. BIM Implementation Model

After gone through literature review and case study, the objective of this research of this study is to make an implementation model of BIM for construction management. This model is implemented it three steps, the first is Initiation, second is Adoption and the last step is Implementation of BIM.

a. Initiation

In the first step of initiation for BIM, the construction management companies have to evaluate the current construction management practices on their ongoing projects. Are they fulfilling the requirement of company and client? If it is not, then need to identify the problems first, then the sources of these problems. They have to take input from field staff even from their subcontractors as well. Some time it is not possible to identify the problems when you are the part of the system. So if feeling difficulties in identifying those problems then the organization may take consultancy.

b. Adoption

After decision has been made by the management for the adoption of BIM, the first step is activate all available resources for achieve target and target is BIM implementation in the construction organization. Allocate fund for the training of staff, hiring of new staff, purchasing of BIM softwares and training of current staff.

c. Implementation of BIM

To start with implementation of BIM project, there must be a **contract** document which clearly defines the responsibilities of project participants. The intention of a contract, especially when geared towards BIM users, is not to point fingers if something goes wrong but rather to clearly define tasks, responsibilities and rights at the onset of a project. In a typical BIM contract, there are three groups of professionals: the owner, the design team (architects and engineers), and the contractors. These groups are professionals who share similar but different rights

and privileges when completing a BIM led construction project. Contracts on a BIM project determine a contractor's ability to influence and collect and share data throughout the project life cycle.

After successful implementation of BIM on pilot project, evaluate BIM benefits and outcomes. If there is any discrepancy in implementation then identify the route cause so that it must not be repeated on next project. Also share the benefits and outcomes of BIM model with all project participants, it will become the source of awareness and information for others to implement BIM model.

9. Conclusion

The results of the research have shown that the adoption of Building Information Modeling is very slow in Pakistan as compare to other neighboring country, like in 2010, Singapore has planned to shift about 80% of their construction industry on Building Information Modeling.

- The majority of construction managers and project managers have medium level of knowledge about BIM and current practices for construction management is claimed to be the barrier in BIM adoption.
- But if any organization is willing to adopt BIM then people and conventional practices are the major internal constraints.
- "Limited adoption in local construction market" is pointed out as one of the major external constraint in BIM adoption and implementation.
- Most of the problems faced in construction managements can be minimized with the help of Building Information Modeling (BIM).
- Owners should demand BIM on their project.
- Large construction organization should come forward to adopt and implement BIM on their projects by dedicating some sources (like money etc.).
- Building Information Modeling should be taught as a course in professional education, and seminar should be conducted on BIM to show success stories which could be a source of information and inspiration to construction organizations.

10. Recommendation

The findings of this study raise some future research questions that should be addressed in the context of the implementation of BIM. First of all, the developed framework has several limitations as it is suggested as a guideline framework, so its validity needs to be tested in practical scenario to form a rigorous methodology for BIM adoption in accordance with project and organisation based BIM implementation.

Secondly, the study has considered BIM implementation within large contracting organisations because current BIM awareness level in market is not very supportive of small and medium enterprise in Pakistan. But it would be interesting to investigate that what difference it will make when implementing BIM in small and medium contractors as it is been claimed that small and medium enterprise have some unique characteristics . Another interest may be discovering the BIM implementation effect on supply chain relationship of large contractors. As BIM adoption will make new bonds in market relations that will disturb the existing relations with clients, suppliers or vendors so intensity of this drift, need to be evaluated.

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Adoption and Scope of Building Information Modelling (BIM) in Construction Industry of Pakistan

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Abstract: Project management is today a current and highly discussed area. How projects within the construction industry are managed has not changed significantly during the last decades. The construction market, the number of different actors and the way that projects are procured today has however changed. This has led to a gap between the managerial view on how construction projects should be conducted today and how they actually are executed. This is reason enough to question this conservative industry and look into what possibilities there might be in the future. The Agile project management approach evolved from the software industry where it has grown and developed through empirical progress.

The objective of the research is to identify and understand the challenges and opportunities confronting the Pakistani construction sector and to investigate ways to implementing the agile approach. The research will identify the changes that are necessary to meet the industry's performance requirements. The Agile approach almost forces the client to increase their participation in the project compared to the situation today. It can also decrease uncertainty and improve risk management.

Keywords: Agile Management, Construction Management, Dynamically complex projects, Traditional Project Management

1. Introduction

"*Project management is today a current area undergoing intensive development.*"

(Tonnquist, 2006, Preface), (Author's translation) Discovering the prime method for overseeing, observing and synchronizing the undertakings is a persistent errand (Tonnquist, 2006). Conforming working systems, expressive parts and imagining the task distinction through new easy to understand administration instruments are instances of how this test can be.met. Today, Project administration frequently upsets the entire association whether it involves a little private association or a greater open corporate.

There are two general techniques that can be utilized to deal with a task (i.e. either an arrangement or procedure methodology) highlighted in customary undertaking administration by Turner (1999) and Boehm (2002). Though this conventional methodology is observed to be valuable for activities with less instabilities, complexities and all around characterized extension (Chin, 2004). The suspicions that dangers and instabilities are unsurprising. (Alleman, 2008) was of late fiercely slated (Atkinson et al, 2006).

The traditional way of handling construction projects is still the same since half a century on which CI relies. Project execution methods have been changed now. The distance between an old and new practices of managing construction projects creates an unease and uncertainty within the industry and its employees. With a specific end goal to examine the probabilities of utilizing an effectively expressed and checked administration approach, which is the point of this proposal, the prime need is to scrutinize the development's conventions industry and take a gander at the future's possibilities.

2. Literature Review

a. Background

There are two general methodologies that can be employed to manage a project (i.e. either a plan or process approach) highlighted in traditional project management by Turner (1999) and Boehm (2002). Contrary to the reality on the ground shows that projects are becoming more complex and the business atmosphere is also changing at unprecedented levels making it difficult to predict project behavior (Rodrigues and Bowers, 1996; Nobeoka and Cusumano, 1997; Hauc and Kovač, 2000; Chin, 2004; Shenhar, 2004; Gallo and Gardiner, 2007; Fernandez and Fernandez, 2009; Papke Shields *et al*, 2009;)

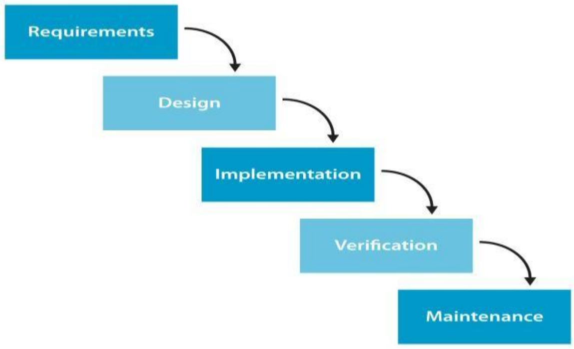
One of the developing project management approaches is agile project management, which provides diversified benefits complex projects to different organizations, however others believe it is applicable on all projects whether complex or not (Chin, 2004; Aguanno, 2004; Cicmil *et al*, 2006; Owen *et al*, 2006; Weinstein, 2009;).

Costly and timely last minute changes that were the prime part of traditional project management has been eliminated by employing agile project management approach that works on iterative process throughout project lifecycle (Schuh, 2005). The above objectives can only be achieved in some projects if organizations are able to adopt agile project management methodologies that are perspective specific and incorporate rigidity and variation within them (Sharifi and Zhang, 2001; Sharifi and Zhang 2000). This is thus as a result of in contrast to traditional project delivery methods that depends on costly additional rework, scope and demand changes as project progresses, dexterous undertaking administration is particularly intended to set up these sudden changes through its significance on planned thinking further as prioritization on task learning.

b. Traditional/Waterfall Management

Several management strategies are used now a days and quite a few of them are old. The brief introduction to one of the traditional management method (TPM) is given below which is known as Waterfall management, as shown in Figure 2.1. This introduction is given to understanding the standard method during which the development business is managed nowadays.

There are different phases during the course of the project life cycle in TPM (Hass, 2007). Controlled planning and methods are important part of this approach. The events are performed in strategic and organized ways. The project's future is assumed to be predictable in order to perform such extensive planning. When a stage is finished it ought not be reexamined. There are obviously both advantages and disadvantages of this methodology. One of the preferences is that it is systematized and simple to take after. It additionally offers accentuation to the customer's significance prerequisites. On the other side it is exceptionally uncommon that a venture can completely take after the grouping as arranged, following the conditions for the most part change with time furthermore it is troublesome for the customer to indicate in detail all necessities toward the begin.



3. Benefits from Implementing Agile Technique

a. Client Contribution

The guideline advantage, with applying Agile, organization in the, setup time of an, improvement endeavor shows up, to be the, client's advantage. Finally, it slips, to the client's joy, and satisfaction with, the completed result so if the client, is relentlessly included, and prepared to make, changes to the thing, while the endeavour is creating, it would lead, to more gainful, endeavours.

The Agile procedure, lets the client think, about the idea, and the objective, and specifically, about the unobtrusive components, and specific responses for the endeavour in the midst of it's empowering.

b. Reduction of Uncertainties in Project

Composed organization, work in cycles that, last from one week, to four weeks. Within these cycles, there are each day, stand-up social affairs, to starting now get, a fast and successful enrolment on the, present day and, the things that, ought to be done, on the next day, produces. Exactly when scrutinizing the respondents, depictions, it is all in all completely like the Agile Strategy. You can set up cycles, for case, 2 weeks and toward the end of each cycle have, evaluated a meeting, an arrangement meeting, at which the headway, is discussed and the late cycle. By then, either another design, meeting to mastermind the, accompanying cycle or two occasions this, be solidified in a lone, meeting of the Evaluation, or Planning held.

c. **Communication**

Questioners frequently needed, to pass the correspondence, by the task, director or outline chief. That is on account of, they have to in, all matters emerging, in the undertaking furthermore on the grounds that it, might be inquiries, that can be replied, rapidly by the administrator himself be invigorated.

d. **Program and Product Backlog**

Period of the system is the serious time. On the off chance that the projects for the ventures analyzed were consummated or not is difficult to say, but rather when they figure out that the time when the most extraordinary, there are great motivations to trust that they have a considerable measure of exertion into it. Then again, they don't hold in a few tasks to the timetable, in spite of the fact that it creates a point by point program. They say it could have been brought on by the absence of interior assets and poor correspondence. This demonstrates the significance of dispersing data and correspondence, as they had a careful system is not ready to impart the accessibility's significance of assets sooner rather than later. The hypothesis of Agile Management clarifies the significance of building up the item build-up or program. A build-up that is always upgraded and actualized gradually in the venture can help more exact calendars.

e. **Initial Phases**

Toward the starting, of a venture, the coordinated, methodology is to adding to, a strong vision for the task, and a very much created, correspondence arrange for, that incorporates the organized gatherings, such that the, undertaking starts to fabricate a strong establishment.

f. **Constant Improvement**

Nimble methodology is, going to get some, an opportunity to get ready for, the future, do a subsequent later, gain from it and afterward they, will enhance later on. The Agile methodology is beneficial, in a manner that a task begin, with just, a portion of the methodologies systems and after that, amid the venture's advancement, either, begin with a few of his techniques, modify ,the utilization cycle were one, in the middle of, evaluated , enhanced and change the procedure that is at present being used, the task empowers the consistent change of effectiveness.

g. **Time management**

Agile approach may be of value in the construction industry, is the way it uses time-management, and with time as the most important factor that cannot be changed. Many construction projects today use time management as well, but it is the specific way in which the agile approach uses the ones who can benefit the construction industry. Through skilful planning at different levels with different time frames, it all boils down to small tasks just take a couple of hours to perform. This gives you a tool to evaluate efficiently, as the project progresses, it lags behind when, or if it is better than expected.

h. **Differences**

Something that needs to be considered is that the agile approach in a way, quite a lot of the way different projects carried out today. For example, the decision-making process will change if you switch to agile management. Some of the authority under which certain decisions will be transferred from the project manager on the project members. This change may not agree with some of the project manager to lose control of the projects. However, this is only a matter of trust, and it takes some getting used to. Hopefully, the project manager, the company will have the best interest in mind and should therefore do what it takes to improve results.

The employees are motivated by giving a proper level of responsibility. The Agile project management handovers part of the decision making to members of the project team from the project manager and according to literature they are dedicated and motivated for the project. This approach can attract anyone because it shows respect and trust

4. Evaluation of KPI's In Construction

a. Overview

APM is proposed as a conceivable administrative thought to manage complex situations in undertakings. One discriminating part of the structure, the KPI, investigates conceivable systems to accomplish deft execution all through task administration. Among all proposed KPIs, this study embraces the five KPIs as recognized by Fei Han (2013) to be more qualified for development ventures. These KPIs were hauled out from both other lithe building controls like coordinated assembling, and existing development related speculations and practice which could have the potential as main impetus to advance dexterity thoughts. These five KPIs are:

"Real time resource monitoring and productivity measurement."
"Self-autonomous work teams with multi-functional crews."
"Short-term planning along with concurrent execution of activities."
"Continuous improvement based on learning organization."
"Information technology integration."

"APM" is a way to deal with overseeing ventures that permits the task to flourish under persistent and eccentric changes. At the point when contrasted with conventional and incline development administration, lithe administration has three noteworthy qualities:

1. It empowers both proactive and receptive reactions to up and coming changes.
2. It requires profoundly agreeable, level and self-persuaded working structures rather than extremely various leveled and successive structures.
3. It is a redundant and incremental procedure in light of nonstop learning and enhancing instead of a quick and streamlined procedure.

In light of the three's criteria qualities, five KPI's specified above are proposed for focusing on postponements and expense invade created by dubious changes, and eventually enhancing general project performance.

5. Research Methodology

a. Introduction

Research methodology demonstrates how the scientists are going to do their study to accomplish and answer research targets (Saunders et al., 2007). The examination was begun with broad writing survey as past studies, exploration papers, books on the subject and few contextual analyses. The strategies for gathering and producing examination information are the poll study and meetings. This exploration is led with an intend to think about for investigating the potential utilization of proposed deft KPIs in development.

b. The Questionnaire

The questionnaire was distributed in hard form as well as it was uploaded through "google Drive" for online filling and submission. Since the online submission through "google drive" is a paper free method, it provides more and speedy responses.

The questionnaire form consisted of two parts. Part I of the questionnaire was designed to make prioritized effect of key performance indicators on project management in construction industry of Pakistan. For this purpose 5 key performance indicators were chosen through extensive literature review and 16 parameters were identified to gauge their internal effects that are explored in part II of questionnaire.

Part II was designed to study the key performance indicators in construction industry of Pakistan. It consisted of five sections. Each section covers factors effecting each KPI.

First section covered general considerations for KPI's in construction industry and their effect based on their priorities. Second section, comprised of 16 questions covered the specific parameters regarding Key performance indicators. The third section consisting of 5 questions explored about some views of construction industry professionals who are implementing agile project management techniques in their projects.

A five-point likert scale, with 1 being very low and 5 being very high, was utilized to judge the performance parameters. All the stakeholders of CI including clients, consultants and contractors/subcontractors are made part of this survey.

c. Agility Framework

To make a system for the administration of coordinated development, an exhaustive survey of the current writing is utilized as a first approach. The writing audit secured the field of administration of the development and additionally spryness in programming improvement and assembling. Since spryness envelops different implications and standards, the first errand was to give a reasonable and particular clarification what it implies deftness in the development and propose a dexterous administration system to take out instability.

Since the light-footed administration idea is as yet rising in development, a theoretical system is regarded fitting as a sort of middle of the road hypothesis that endeavors to associate all parts of exploration hobby. In this manner, diminishing the time may be more like a "critical thinking procedure" beginning from "issue ID" (postponement causes), "improvement arrangements" (hypothetical information/experimental and down to earth) on "assessment of results" and "lessons learned" (acceptance delay lessening systems). In addition, the proposed casing goes about as a guide which gives a consistency by any means "turning points" amid the deferral diminishment forms.

6. Data Collection and Analysis

a. Respondent Profile

The questionnaires were distributed to group of four stakeholders working in project management units with construction professionals and professional consultancy firms in the construction industry of Pakistan and theses firms belongs to different sectors. Tables-1 shows the number of respondents and percentage of returned questionnaires whereas Table-2 shows the number and percentage of responses from different sectors like private, government and semi governments.

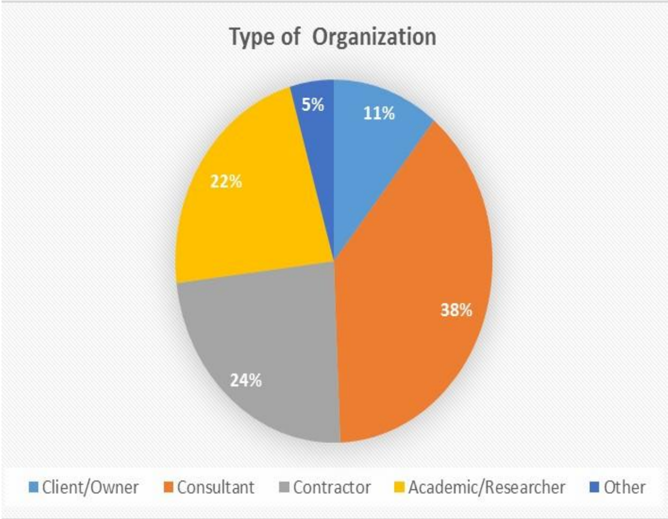


Figure 1 Type of Organization

b. Solicitation Of Key Performance Indicators in Recent Construction Industry Setup

It can be seen from the results that Resource Monitoring and Productivity Measurement is best commonly used KPI in projects.

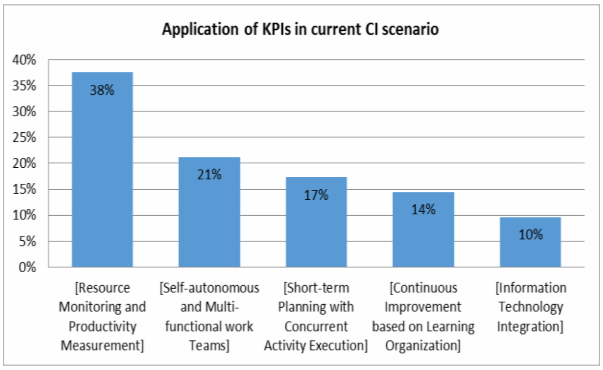


Figure 2: Application of KPIs in current CI scenario

Same pattern will be followed for each KPI and there sub questions. Each question will be dealt separately and result will be shown in form of histograms and pie charts.

c. Analysis of Factors Affecting Key Performance Indicators

1. Resource Monitoring and Productivity Measurement

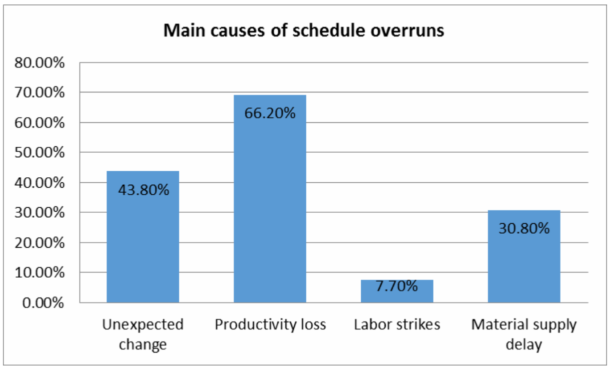


Figure 3 Main causes of schedule overruns

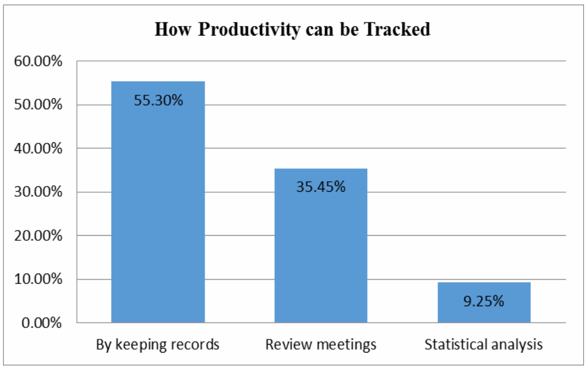


Figure 4 How Productivity can be tracked

It has been found that productivity loss and unexpected change are main grounds for schedule plunders (Lee et al., 2006). Keeping daily records of resources of invested works effectively help to detect the productivity loss and unexpected changes which will effect responsiveness of project performance as shown in Figure. Incessant recording of productivity helps in tracking the alteration of productivity regularly as shown in Figure (Daneshgari, 2010).

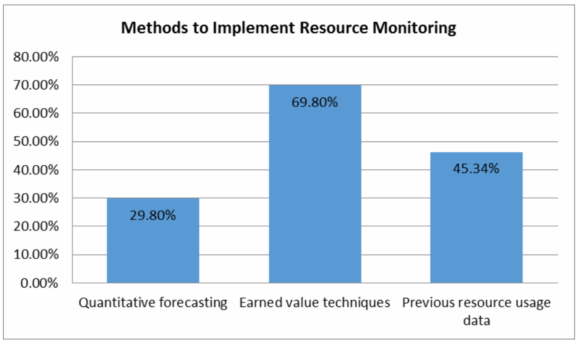


Figure 5 Methods to Implement Resource Monitoring

Resource monitoring has been applied in Earned Value Management (EVM) to provide a quantitative forecasting, of schedule (Nassar et al., 2005), as shown in Figure.

2. Self-autonomous and Multi-functional Work Teams

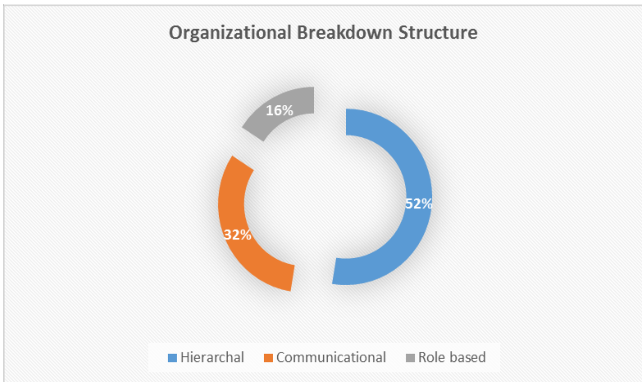


Figure 7: Organizational Breakdown Structure

Being agile should be reflected in organizational breakdown structure. Breaking down traditional hierarchies structures at crew level will provide freedom to the workers ti make their own decisions. The results show that most of the organizations based on hierarchal system. As they give more importance to the system in which members of an organization or society are ranked according to relative status or authority as shown in both figure.

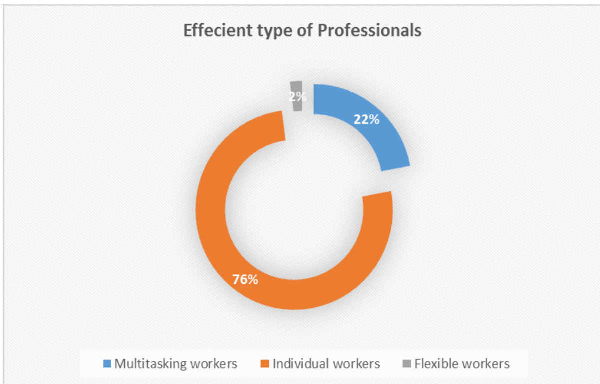


Figure 8: Efficient type of Professionals

3. Short-term Planning with Concurrent Activity Execution

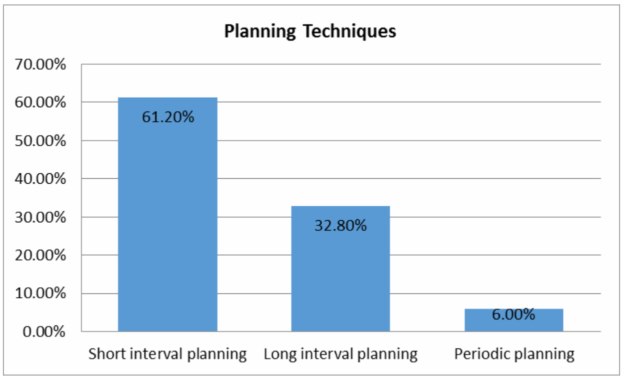
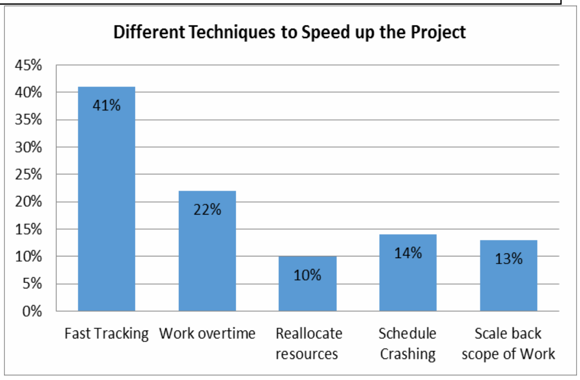


Figure 9 Planning Techniques

Short interim arranging, encourages "without a moment to spare" asset supply approach, hence decreased conceivable defers and enhanced efficiency

Figure 10 Different Techniques to Speed up



the Project

Overlapping activities actually tries making the schedule flexible also called as fast tracking. To speed up the project there are many different methods. Different organizations use different techniques. The results show application of different techniques, for speeding up the project. The most commonly used technique for speeding up the project is fast racking and work over time as shown in Figure.

4. Continuous Improvement based on Learning Organization

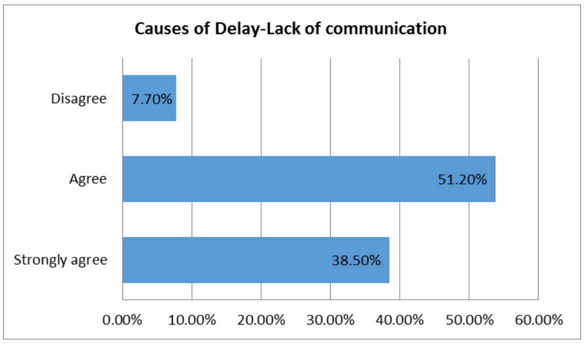


Figure 11 Causes of Delay-Lack of communication

Surveyed result also giving same result that lack of communication is one of the main cause of delay in projects as shown in Figure-4.18

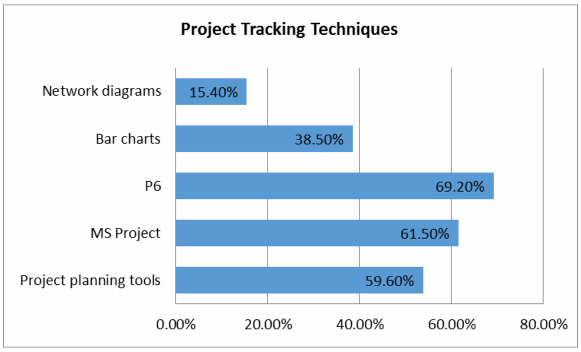


Figure 12 Project Tracking Techniques

Results shows that there are a lot of project tracking techniques out of which the most commonly used techniques are Primavera Ms project and project planning tools (Different organizations use different tools) and 96 bar charts. So there is a range of techniques and tools used by construction industry professional for tracking their projects in order to avoid delays as shown in Figure.

5. Information Technology Integration

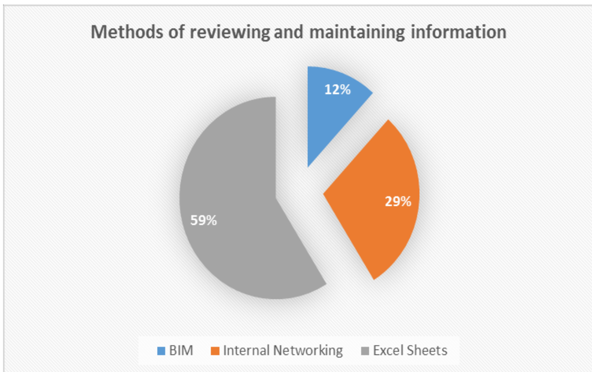


Figure 13 Methods of reviewing and maintaining information

Data innovation has changed the way individuals oversee and actualize the venture development exercises, yet there is still space to coordinate them completely into the regulatory procedure. In light of the steadily changing specialized necessities and administration, empowers experts in the building itself to recognize and programming apparatuses to productively oversee ventures. Adaptability is another advantage when data is transmitted and surveyed by pumping information, Internet and Building Information Modeling (BIM) continuously.

7. Traditional Versus Agile Project Management

Traditional Project Management	Agile Project Management
Focus on process and plan	Focus on people
Focus on developing all parts of the scope first .	Focus on the most important part of the scope first and then proceed to the next.
Regulation of changes is based on rigid Procedures.	Regulation of changes depends on flexible and adaptable procedures.
Members work individually within teams i.e. less collaboration.	Team members collaborate in all aspects.
Order establishment is facilitated by hierarchical organizational structures.	Order is established as a result of continuous and voluntary interaction in complex systems
Increased order is a result of increased control.	Self-organization, interaction and simple rules result in increased order.
Organizations must be rigid and static Hierarchies.	Organizations must be flexible and eliminate unnecessary bureaucracy.
Controlling type of management.	Management role is to facilitate and give support.
Employees are interchangeable 'parts' in the organizational 'machine'	Employees are an important part of the organization whose contribution is necessary.
Customer is mainly involved during requirements gathering and delivery phases	Customer is continuously involved throughout the project lifecycle
The reductionist task breakdown and allocation is necessary for solving problems (e.g. Work Breakdown Structure (WBS) and the Project Breakdown Structure (PBS)).	Iterative approaches to selected tasks with continuous feedback from team members and stakeholders result in valuable incremental progress in a short time.
Projects and risks are adequately predictable and it is possible to manage them through detailed and complex advance planning.	It is impossible to control the future because projects and risks are unpredictable due to uncertainties; therefore there is no need for detailed advance planning.

8. Conclusions

This research work clearly directed towards analyzing and quantifying the KPIs as well as development of conceptual frame work that works in fluid environment of agile project management and aims at reducing delays and cost overruns. Following conclusions are made.

- The major pros by applying "APM" are the increased client involvement because for development of project team client will continually keep in touch with the project throughout its life cycle.
- It has also been prominent that both project management approaches can be applied on the same project at different times.
- Traditional project management approach mainly focus on the rigid and detailed planning, task and sub tasks distributions and preset stakeholder necessities, while the agile project management conform to soft and human side of projects.
- It has been noted that iterative working approach of small independent teams are vital for agile project management system.
- Iterations in project applications and meetings in case of complex projects are more frequent and used as next step for improvement of projects.
- Traditional project management approach focuses on detailed planning which consumes more time while planning is done progressively, in case of agile project management.

Both project management approaches are good.

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SECM/15/142

Apportionment and Ranking of Risk Elements in Construction Industry of Sri Lanka-Contractors' Perspective

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Abstract: This study provides the results of a survey of major contractors engaged in the Sri Lankan construction industry. It is aimed at identifying common risk elements affecting construction industry projects, determining how they are apportioned between the owner and the contractor, and quantifying and ranking their significance. The previous studies provided a list of 52 risk elements and with the help of a pilot study it was reduced to manageable 25 risk elements having a great relevance to the Sri Lankan construction industry. Altogether 72 respondents selected from among major contractors in Sri Lanka (C1 to C4) were involved in the questionnaire survey of the study.

The analysis of the results show that only some risk elements are apportioned more to one party (apportionment of at least 65%) either contractor or owner. *Shortage of labor, materials, tools and equipment (82%), Low productivity of labor and equipment due to complexity of work (78%), Labor disputes & trade union action (76%), Delays due to sub-contractors, suppliers and other bodies (74%), Difficulty to coordinate with sub- contractors (74%), Corruption (70%), Delayed payment by owner (68%),* and *Accidents (66%)* are apportioned more to contractors whereas, D*elay in approvals and permits (70%)*, is apportioned more to the owner than to the contractor. The risk elements were ranked according to their significance and the most significant risk elements are, in descending order of significance are; *Shortage of labor, materials, tools and equipment, inaccurate and incomplete design, Financial failure resulting from owner and contractor, Substandard quality of work.* The results indicate that contractors perceive that risks are apportioned disproportionately more towards them. The implication of this is that naturally contractors tend to quote higher bid prices to cover their potential risks.

Key words: Construction Risks, Risk Management, Sri Lankan Construction industry

1. Introduction

The construction industry is exposed to a lot of predictable and unpredictable risks that could have a greater impact on the productivity, performance, quality and the budget of the project. Risk management is a relatively new discipline in the construction industry of Sri Lanka. However, it is gradually becoming prominent owing to increased construction activity, increased complexity and sophistication in the end products and stiff competition. A better understanding of significance of risks and how they are apportioned is needed to arrive at a realistic bid price.

The main objective of this study is to identify common risk elements affecting construction industry projects, determine how they are apportioned between the owner and the contractor, and quantify and rank their significance.

2. Literature Review

Risk is defined in Webster's dictionary as a chance of injury or damage or loss.The construction industry is increasingly fraught with high levels of risks and uncertainties. Kartam and Kartam (2001) defined risk as the probability of occurrence of some uncertain, unpredictable and even undesirable event(s) that would change the prospects for the profitability on a given investment. Over the past decade, many projects have experienced large variations in cost and/or schedule turning these projects into unsuccessful endeavors (Abdelgawad and Fayek, 2010). Systematic risk management allows the early detection of risks. Therefore, there is no need for contingency plans to cover almost every eventuality (Dawood, 1998).

Yusuwan *et al.* (2008) have explored a number of risks faced by the construction industry, namely political risk, economic risk, technology risk and social risk. These risks having a bearing mainly on the cost and duration of project completion may push up the tender price. Flanagan and Norman (1993) state the construction industry participants (client, consultants and contractors) are heterogeneous having different roles and tasks to perform. In order to survive in a risky environment the participants should show a desire to share risk. This process termed risk apportionment is an important component of risk management. Risk management is a critical part of project management as unmanaged or unmitigated risks are one of the primary causes of project failure (Royer, 2000).

Nummedal *et al*. (1996) suggested a five step procedure for risk management which are; risk identification, risk estimation, risk evaluation, risk response and risk monitoring. Baker *et al.*(1999) have suggested a simple circular procedure fitting these five steps, which is lustrated in Figure 1. The adherence to this procedure will yield a controlled risk environment. The first two steps, namely risk identification and risk estimation jointly forms the process of risk analysis. Risk analysis followed by risk evaluation together forms the risk assessment. Risk response and Risk monitoring constitutes the risk controlling process.

Kartam and Kartam (2001) have conducted a study to identify common risk elements affecting construction industry projects and to assess the degree of risk apportionment between owner and contractor for the Kuwaiti construction industry.
In Sri Lanka, evidently, no study has been carried out on the same aspect.

Figure 1: Steps in Systematic Risk Management

3. Methodology

3.1 Questionnaire Design

The past studies revealed 52 risk elements related to construction industry and with the help of 5 industry experts these risk elements were short listed to manageable 25 risk elements. Their inputs were useful in the questionnaire design, too. In order to ensure obtaining complete and meaningful response to the questionnaire, an interview based questionnaire was conducted with each respondent. This also gave an opportunity to explain the objectives of the study to the respondents.

The main questionnaire consists of three parts. The first part seeks background information of respondents. The second and the third parts contain the same 25 short statements eliciting perceptions on apportionment and significance of risk elements. The layout of the questionnaire is presented in Figure 2.

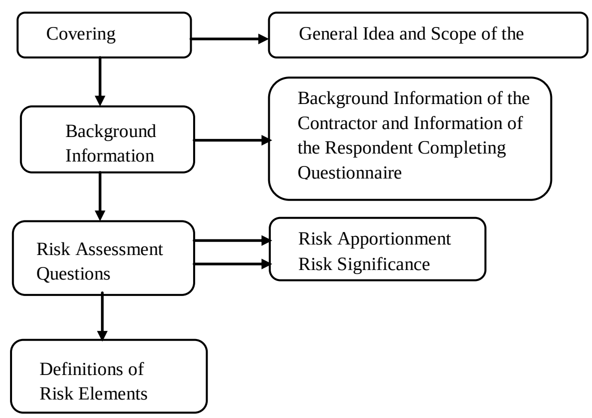

Figure 2: Layout of the Questionnaire

3.2 Sample Selection

Selection of the most suitable sample for the survey from a long list of contractors was a major task in making the research more effective and representative. In order to maintain the precision of study it was decided to consider only the construction contractors for the survey. The contractors for the sample survey were selected from the list obtained from the directory published by ICTAD -2011. Only medium (C4) to large scale construction contractors (C1) working in the Western Province were included in the survey. The questionnaires were distributed to 80 respondents and a response rate of 62.5 per cent was achieved.

3.3 Approach to Analysis

The first part focused on getting information regarding respondent's employers and their experience. The second part of the questionnaire solicits information to evaluate the risk apportionment between contractor and owner. As against each risk element the respondents indicated their perception about how the risk is shared between owner and client. In order to facilitate the respondent to indicate the perceptions on risk apportionment between owner and contractor (as a percentage) five uniform ranges were decided namely; 0-20, 20-40, 40-60, 60-80 and 80-100. The third part is to get contractors' observations and judgements in determining the relative significance of the each risk element.

A Likert-Type Scale ranging from 1 to 5 was adopted to gauge people's perception. Although the degree of significance of a particular risk element could vary from project to project, the questionnaire is expected to elicit a general assessment of the significance of each risk element. Weightings were assigned to different levels of significance as follows;

Most significant - 5 points
More significant - 4 points
Significant - 3 points
Less significant - 2 points
Least significant - 1 points

The principle is that the risk with the highest significance would be assigned with the largest weight. Risk Significance Score (RSS) for each risk element was calculated as follows:

$$RSS= 5X_5 +4X_4 +3X_3 +2X_2 +1X_1$$

Where X_1, X_2 , X_3, X_4 and X_5 denotes number of respondents indicating most significant, more significant, significant, less significant and least significant respectively.

4. Results and Discussion

4.1 Analysis of Sample

Distributions of respondents based on ICTAD grading of the constructing firms where they are employed at are shown in Table 1. The level of experience of respondents is shown in Table 2.

Table 1: Distribution of Respondents

Classification of the Contractor	Number of respondents (Frequency)	Percentage
C1	40	80
C2	08	16
C3	02	04
Lower than C4	00	00
Total respondents (N)	50	100

It was found that 80 per cent of the respondents are from C1 contracting firms (those qualified to undertake projects worth more than Rs 600 million), 16 percent of the respondents are from C2 contracting firms (those qualified to undertake projects worth more than Rs 300 million and less than 600 million).

Table 2: Experience of Respondents

Experience (Years)	Number of respondents	Percentage
1 – 5	06	12
6 – 10	08	16
> 10	36	72
Total respondents (N)	50	100

4.2 Construction Risk Apportionment

The frequencies of responses on the perceptions on the risk apportionment between the owner and the contractor were counted under the five ranges, with respect to each risk element. In order to enable easy interpretation, the number of responses in the ranges 0-20 and 20-40 were amalgamated under the range 0-40. Similarly, responses in the ranges 60-80 and 80-100 were grouped under the range 60-100. The results have been summarized and presented in Table 3. In similar studies by Kangary (1995) in the USA and by Kartam and Kartam (2001) in Kuwait, an apportionment of 70% or beyond to one party is considered as full apportionment to that party. In this study this value was lowered to 60 so that more risks elements can be apportioned to one party. Accordingly, the following risk elements are considered to be fully apportioned to the contractor:

- Shortage of labor, material, tools & equipment
- Low productivity of labor and equipment due to complexity of work
- Labor disputes & trade union action
- Delays due to sub contractors, suppliers and other bodies
- Difficulty to coordinate with sub contractors
- Corruption
- Delayed payment by owner
- Accidents

Beside these, there were other risk elements which are apportioned neither to contractor nor to owner. If the apportionment of a risk element is less than 60 per cent to any party (except for shared elements), it is considered as an 'undecided' apportionment. Risk elements which were categorized as 'undecided' are listed below:

- Issues related to right of way and site access to vehicles
- Unexpected site conditions (soil, underground pipes, etc)
- Unpredictable weather conditions
- Noncompliance of materials to standards and specifications
- Delayed dispute resolutions
- Substandard quality of work
- Financial failure resulting from owner and contractor
- Errors in project program
- Increasing actual quantity of work
- Delayed payment by the owner
- Change to scope, plans and specifications
- Capacity issues of contractor to handle the given job
- Price increase due to inflation

If a risk element is equally apportioned to either part it is considered a 'shared risk'. As such the following risk elements are considered as 'shared risks';

- Scope limitation & insufficient definition of work
- Inaccurate & incomplete design
- Natural disaster & human violence

Beside these, the risk element 'Delay in approvals and permits' is fully apportioned to the owner instead of the contractor.

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4.3 Significant risk elements

Table 4 depicts the summary of both frequencies of different significant levels and RSS of risk elements according to the perceptions of engineers and project managers employed by the contractors. The RSSs and ranks in relation to all risk elements are summarised in Table 4. The figures in parentheses in Table 4 are the ranks of risks based on RSSs. The following six risk elements have RSS greater than 200 and carries ranks from one to six.

- Shortage of labour, materials, tools and equipment
- Inaccurate and incomplete design
- Financial failure resulting from owner and Contractor
- Substandard quality of work
- Lower productivity of labour & equipment due to complexity of work

The most significant risk element (Shortage of labour, materials, tools and equipment) is also the one apportioned most to the contractor.

Table 3: Apportionment of Risk between Owner and Contractor- Percentage

s/n	Risk Elements	Owner (%)			Contractor (%)		
		0-20 & 20-40	40-60	60-80 & 80-100	0-20 & 20-40	40-60	60-80 & 80-100
01	Delays in approvals and permits	8	22	70	70	18	12
02	Issues related to right of way and site access to vehicles	36	22	42	32	36	32
03	Scope limitation & insufficient definition of work	26	40	34	30	36	34
04	Shortage of labour, materials, tools and equipment	80	6	14	6	12	82
05	Lower productivity of labour & equipment due to complexity of work	76	14	10	4	18	78
06	Inaccurate and incomplete design	28	32	40	24	38	38
07	Unexpected site conditions (soil, underground pipes, etc)	34	34	32	26	34	40
08	Unpredictable weather conditions	54	18	28	28	28	44
09	Natural disasters and human violence	34	34	32	22	48	30
10	Noncompliance of materials to standards and specifications	34	30	36	22	30	48
11	Ad-hoc revision in government policies and regulations	26	24	50	40	34	26
12	Labour disputes and trade union actions	84	8	8	10	14	76
13	Accidents	70	22	8	12	22	66
14	Price increases due to inflation	22	26	52	36	30	34
15	Capacity issues of contractor to handle the given job	30	14	56	40	22	38
16	Changes to scope, plans and specifications	18	18	54	44	34	22
17	Delays due to sub contractors, suppliers and other bodies	62	16	22	4	22	74
18	Difficulty to coordinate with subcontractors	66	22	12	0	26	74
19	Delayed dispute resolutions	48	22	30	20	24	56
20	Delayed payments by the owner	48	20	32	18	14	68
21	Substandard quality of work	40	24	36	24	22	54
22	Financial failure resulting from owner and contractor	10	44	46	22	44	34
23	Increasing actual quantities of work	24	26	50	34	44	22
24	Errors in project program	38	22	40	26	22	52
25	Corruption (bribery/theft/burglary and & pilferage)	48	20	32	14	16	70

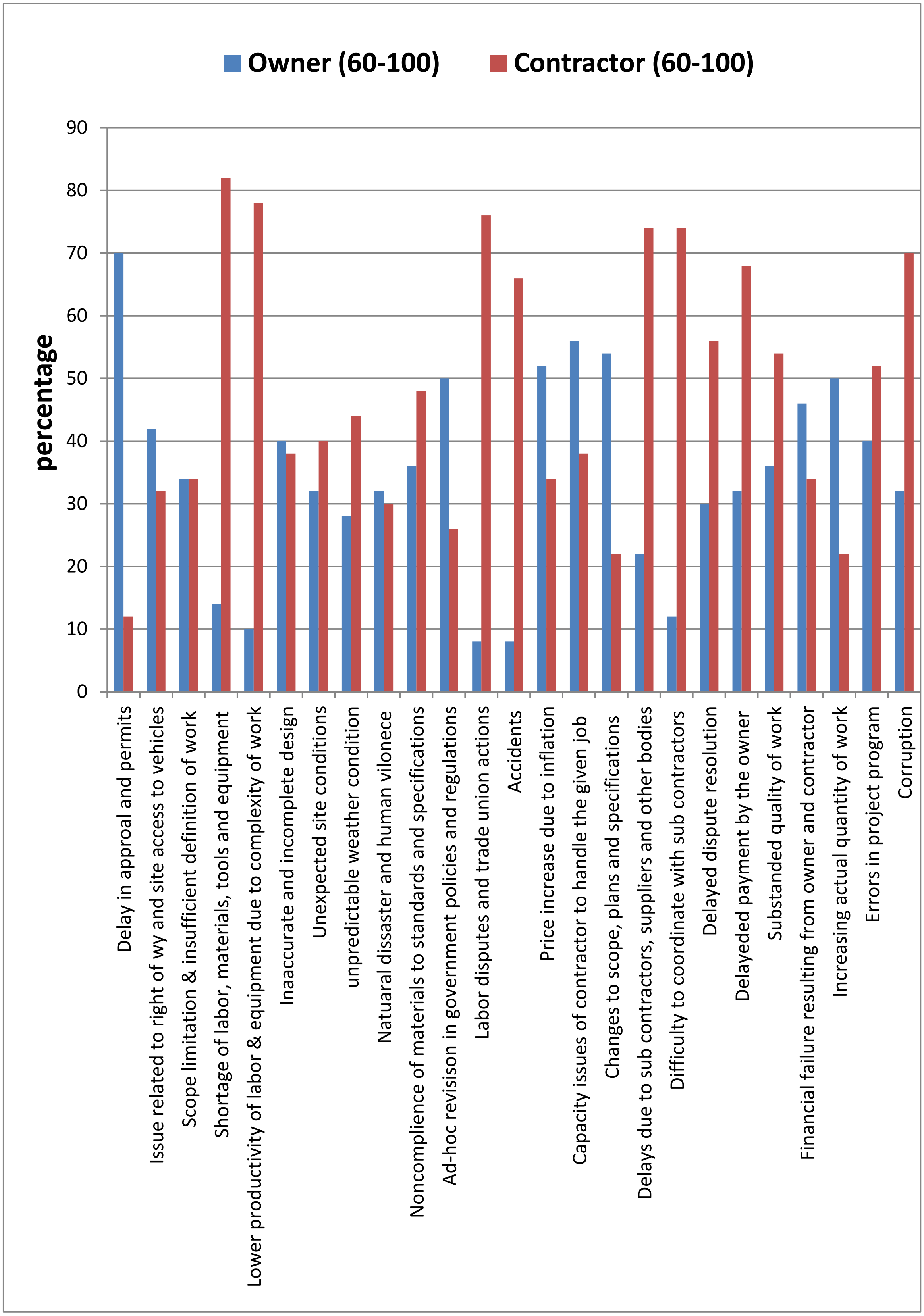

Figure 3: Risk Apportionment between Contractor and Owner

Table 4: Weighted scores of importance of risk elements

s/n	Risk elements	Least Significant (1)	Less Significant (2)	Significant (3)	More Significant (4)	Most Significant (5)	Risk Significance Score and [rank]
01	Delays in approvals and permits	0 (0)	1(2)	16(48)	16(64)	17(85)	199 [06]
02	Issues related to right of way and site access to vehicles	0(0)	1(2)	26(78)	13(52)	10(50)	182 [12]
03	Scope limitation & insufficient definition of work	0(0)	1(2)	24(72)	17(68)	8(40)	182 [12]
04	Shortage of labor, materials, tools and equipment	0(0)	1(2)	6(18)	27(108)	16(80)	208 [01]
05	Lower productivity of labor & eqpt due to complexity of work	0(0)	3(6)	12(36)	30(120)	5(40)	202 [05]
06	Inaccurate and incomplete design	0(0)	1(2)	13(39)	19(76)	18(90)	207[02]
07	Unexpected site conditions (soil, underground pipes, etc)	0(0)	9(18)	23(69)	12(48)	6(30)	165 [18]
08	Unpredictable weather conditions	0(0)	16(32)	22(66)	10(40)	2(10)	148 [23]
09	Natural disasters and human violence	0(0)	20(40)	19(57)	8(32)	3(15)	144 [24]
10	Noncompliance of materials to standards and specifications	0(0)	1(2)	14(42)	22(88)	13(65)	197 [08]
11	Ad-hoc revision in government policies and regulations	2(2)	10(20)	23(69)	21(84)	4(20)	195 [09]
12	Labor disputes and trade union actions	0(0)	17(34)	24(72)	7(28)	2(10)	144 [24]
13	Accidents	1(1)	9(18)	21(63)	11(44)	8(40)	166 [17]
14	Price increases due to inflation	0(0)	10(20)	22(66)	14(56)	4(20)	162 [20]
15	Capacity issues of contractor to handle the given job	0(0)	4(8)	16(48)	21(84)	9(45)	185 [10]
16	Changes to scope, plans and specifications	0(0)	2(4)	19(57)	21(84)	8(40)	185 [10]
17	Delays due to sub contractors, suppliers and other bodies	0(0)	0(0)	23(69)	23(92)	4(20)	181 [14]
18	Difficulty to coordinate with subcontractors	0(0)	8(16)	21(63)	17(68)	4(20)	167 [16]
19	Delayed dispute resolutions	1(1)	8(16)	22(66)	17(68)	2(10)	161 [21]
20	Delayed payments by the owner	0(0)	0(0)	14(42)	19(76)	16(80)	198 [07]
21	Substandard quality of work	0(0)	0(0)	10(30)	26(104)	14(70)	204 [04]
22	Financial failure resulting from owner and contractor	0(0)	1(2)	14(42)	13(52)	22(110)	206 [03]
23	Increasing actual quantities of work	0(0)	12(24)	21(63)	12(48)	5(25)	160[22]
24	Errors in project program	1(1)	9(18)	18(54)	15(60)	7(35)	168 [15]
25	Corruption bribery/theft/ burglary and & pilferage)	1(1)	11(22)	16(48)	17(68)	5(25)	164 [19]

5. Conclusions

Although the number of construction risk elements found in the literature could be well over 50, they can be summarised into 25 manageable risk elements. The results prove that the evaluation of current practice of risk apportionment between contractor and owner is a measurable task. Except for one risk element all risk elements are apportioned to contractors. Only the risk 'a delay in approvals and permits' is apportioned to the owner. It must be stressed that this is the perspective of the engineers' employed by the contractors. Hence, naturally, there could be a tendency for them to believe that risks have been apportioned, unfairly, more to them. Although the technique of interview based surveys minimised the possibility for this, it is prudent to examine the risk element from the perspective of owners of construction projects in future studies.

The risk, 'shortage of labour, materials, tools and equipment' is the most significant risk and also it is the one which is perceived to be most apportioned to the contractor. The study also revealed the next five most significant risks as follows; Inaccurate and incomplete design, Financial failure resulting from owner and Contractor, Substandard quality of work, Lower productivity of labour & equipment due to complexity of work.

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Investigation on Whole Body Vibration exposures of operators of construction vehicles

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Abstract: There is a growing interest in the areas of increased comfort and reduced vibration exposure levels in construction vehicles. It is necessary to understand the level of Whole-Body-Vibration (WBV) exposure since it affects comfort and health performance of humans. Objective of this study is to investigate the exposure levels in operators of construction vehicles. In addition, preventive strategies, which are needed to reduce low back pain problems due to WBV, will be investigated.

Ten operators of vehicles were selected where the vehicles were chosen so that those are vastly used in the construction sector. In this study, it was selected three construction vehicle types: excavators, backhoes and roller vibrators. A questionnaire survey was carried out with each operator regarding their profession, age, working experiences, health and exposure duration. The vibration exposure levels induced on operators bodies were measured using a tri axial vibration meter (SV 106) attached to a seat pad accelerometer. The operator was instructed to sat on seat-pad accelerometer and WBV exposures in three directions (i.e., vertical, fore-and-aft and lateral) were measured. It was found that the vibrational effect on vertical direction is more dominant than the other two directions (i.e., lateral and fore-and-aft). Measured vibration exposure levels were assessed based on recommendations given in ISO 2631:1997 and are presented in the paper.

Keywords: Excavators, backhoes, roller vibrator, Seat pad accelometer, Occupational health, ISO 2631-1 and EU directive 2002/44/EC

1. Introduction

In Sri Lanka, workers employed in construction sectors are frequently exposed to vibration within their career (Vitharana et al, [1]). Operators of construction vehicles are exposed to Whole body vibration (WBV) while in standing posture but more often in seating postures (Subashi et al, [2]). Human body at seated posture shows resonance at about 5 Hz in vertical vibration and about 1-3 Hz in horizontal vibration, and attributed by significant motion of several parts of the human body (Subashi et al, [3]). This indicates that vibration can cause long-term painful damage. Shocks and jolts from driving certain types of vehicles can cause severe back pains. However, workers, are not much aware on risk associated with occupation vibration exposures (Vitharana et al, [4])

Exposure to high levels of WBV can increase risks to health. When the vibration magnitudes are high, the damage can be severe and naturally irreversible. In addition to the magnitude, exposure durations, frequent, resting duration, and the vibration consisting with severe shocks or jolts are the major considerations when studying the risk Associated with vibration exposure (Griffin, et al. [5]).

Continuous exposure to WBV is one of the leading risk factors for the development of low back disorders. WBV can also humble other systems in the body suppressing the operation of the musculoskeletal, cardiopulmonary, metabolic, cardiovascular and gastrointestinal systems (Blood, et al. [6]). Comfort levels of the operators highly depend on the amount of vibration induced as well as long term effects. Unexpected shocks or jolts can also be affected on the operators' concentration and that could be caused on occurring accidents.

Most commonly used orthogonal axis system for the whole-body vibration investigation is, the fore-and-aft direction is defined as the x-axis, vertical direction as the z-axis and lateral direction which is perpendicular to above both axis as the y-axis, rotation around the x-axis called as roll, rotation around the y-axis is called as pitch and rotation around the z-axis is called as yaw (Mansfield, [7], ISO 2631-1 [8]).For the quantitative analysis of the vibration exposure levels, it was required well defined parameters that could be easily measured. In that case Maryanne, [9] suggested few evaluating parameters and among them Root mean square value (RMS) and Vibration dose value (VDV) are ideal for analysing exposure levels with more variations.

Large construction activities in Sri Lanka have been increased during the recent past few years. Hence the site workers have to use new technology as well as new machineries whenever they are engaging with the construction activities. Most probably the vibration is used as an energy conveyer which is useful while doing some specific works such as breaking, drilling and compacting etc. Also vibration is induced due to moving of heavy vehicles and equipment. However the employees may not be aware about the health effects associated with long-term exposure to vibration. As a result, vibration related injuries are neglected in Sri Lanka.

Objective of the present study is to investigate whole body vibration exposure levels of operators of excavators, backhoes and roller vibrators in construction industry.

2. Methodology

Sequence of the study is described with study group, questionnaire survey, instrument that was used to measure exposure levels, measuring procedure of exposure levels and analysis.

2.1. Study group

Ten construction operators were selected as the study group, which consists of three excavator operators, three backhoe operators and four vibrating roller operators. Before conducting the questionnaire survey and measurements, each operator was informed about the questionnaire survey and measuring procedure of exposure levels and what they should be done. Age range of the operators participated in the current study was 20-50 years.

2.2. Questionnaire survey

Prior to the site visits, questionnaire survey forms were prepared according to the instructions published in a previous study (Griffin, et al. [5]). The survey was conducted for each operator to investigate their health levels and current situation of their profession. In addition, their work experience and age were recorded. Questions were asked from each operator by the experimenter and the survey forms were completed.

2.3. Instrument

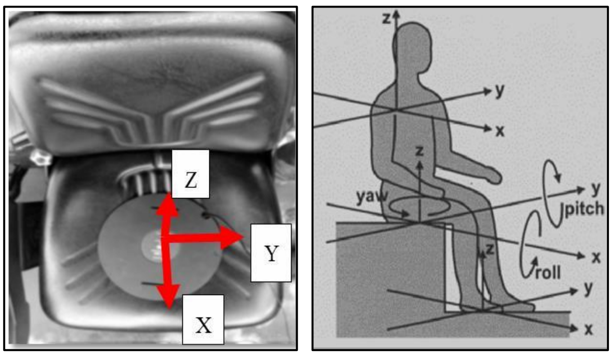
For investigation of vibration exposure levels that transmitted to operator's body, a tri- axial accelerometer was used (Figure 1). The tri axial accelerometer, SVANTEK 106, is a small size instrument and it is very easy to use at construction sites. The SV 106, which is a six-channel human vibration meter and analyser, was used to analyse the vibration exposure levels found in three different directions: vertical, for-and-aft and lateral.

2.4. Measuring exposure levels

Measurements were taken, while operators were engaged in their daily works in the period between 9.00 am to 4.00 pm.

Basic instrumental setup including selection of suitable parameters was installed to the SV 106 before taking any measurement. In order to have a desired measurements from the instrument, start delay time, measurement duration, weighting factors for each axis and repeat duration were initially set under instrumental setup. The measurement duration was decided such a way that at least one typical working cycle should be included in the measurements while minimizing the disturbance of the operators' duty as much as possible.

The sensor of seat pad accelerometer was properly placed on the driver seat as shown in Figure: 1-(a). Three axes indicated on the seat pad should be coincided with the one specified (Figure 1-(b)).



(a) (b)

Figure 1: Seat pad sensor was placed
(a) Seat pad sensor was placed on the seat
(b) Specified axes of vibration

After placing the sensor, operator was instructed to seat on the sensor carefully and operate the vehicle as usual (Figure: 2-a). Measurements were recorded during the operation as shown in the

Figure: 2-b.

(a) (b)

Figure 2: Measuring WBV exposure
(a) Operator was instructed to seat on the sensor
(b) Recording measurement

2.5 Analysis

For each direction, measured vibration with weighting filter, a*w*, was obtained from SV 106 analyser. Vector sum of frequency weighted rms accelerations (or vibration total values), av, were obtained from Equation 1 (ISO 2631-1 [8]).

$$av = \sqrt{(1.4 * aw_x)^2 + (1.4 * aw_y)^2 + aw_z{}^2} \quad (1)$$

Where a_{wx}, a_{wy} and a_{wz} are the frequency weighted rms acceleration in x, y, z orthogonal axes respectively

For each direction, daily vibration exposure of 8 hrs equivalent frequency weighted rms acceleration value was determined by using Equations 2, 3 and 4 ((Griffin, et al. [5]).

$$A_x(8)=1.4*aw_x\sqrt{\frac{T_{EXP}}{T_0}} \quad (2)$$

$$A_Y(8)=1.4*aw_Y\sqrt{\frac{T_{EXP}}{T_0}} \quad (3)$$

$$A_Z(8)=aw_Z\sqrt{\frac{T_{EXP}}{T_0}} \quad (4)$$

Here, T_{EXP} is the duration of exposure to the vibration and T_0 is the reference duration of eight weighting filter) variation of backhoe operator (OP6) for vertical, fore-and-aft and lateral hours. The highest value of $A_x(8)$, $A_y(8)$ and $A_z(8)$ is considered as the daily vibration exposure, and was compared with exposure limits.

Summary of limits associated with different levels of predicted health risk according to the "Health Guidance Caution Zone (HGCZ)" values discussed in ISO 2631-1are given in Table 1.

Table 1: Health risks categorized according to ISO2631-1 with A (8)

ISO 2631-1assessment of adverse health effect	A(8) (ms^{-2} r.m.s)
Below the zone (HGCZ) no health effects observed	<0.45
In the zone (HGCZ) Caution with respect to potential health risks is indicated.	0.45-0.90
Above the zone (HGCZ) health risks are likely.	>0.90

3. Results and Discussion

3.1 Questionnaire survey

Age, experience, exposure duration and health issue of all operators are summarised in Table 2. It seems that age and past experience (number of years exposing to whole body vibration) are the most critical factors that could be affected on the operators' health relative to the others. Among vibrating roller operators, OP1, who has one year experience and age is 23 years does not feel any health issues in his career as an operator. All three backhoe operates were affected by the vibration (Table 2) perhaps, attributed by long term WBV exposures (i.e.,experience of those operators relatively greater)(Table 2). Excavator operator, OP10, has not been affected by any difficulty as well. He is also a relatively young operator with two year experience. Operators, who have been exposed to WBV in several years with fairly older age have been suffered with health issues: 50% of operators have back pain and 30% of operators nave Normal daily tiredness.

3.2. Vibration exposure levels

Figure 3 shows a_w (measured vibration with directions. It can be seen that operator was exposed to number of shocks, although they are not in large magnitude.

Frequency weighted rms value, a_w, for vertical direction is 0.45 ms^{-2}. However, for the fore – and-aft direction and lateral direction, it was 0.28 ms^{-2} and 0.3 ms^{-2}, respectively, which are lesser than the a_w value found for the vertical direction.

Table 2: Age, work experience, exposure duration and health issue of ten operators

Equipment	Operator	Age (year)	Work Experience (years)	Exposure Duration (hours)	Health Issue (regarding operation)
Vibrating roller	OP 1	23	1	6	No
	OP 2	31	8	6	Back Pain
	OP 3	32	5	5	Normal daily tiredness
	OP 4	36	9	6	Back Pain
Backhoes	OP 5	37	10	5	Back Pain
	OP 6	32	10	5	Normal daily tiredness
	OP 7	37	12	5	Normal daily tiredness
Excavator	OP 8	30	6	4	Back Pain
	OP 9	35	15	3	Back Pain
	OP 10	23	2	6	No

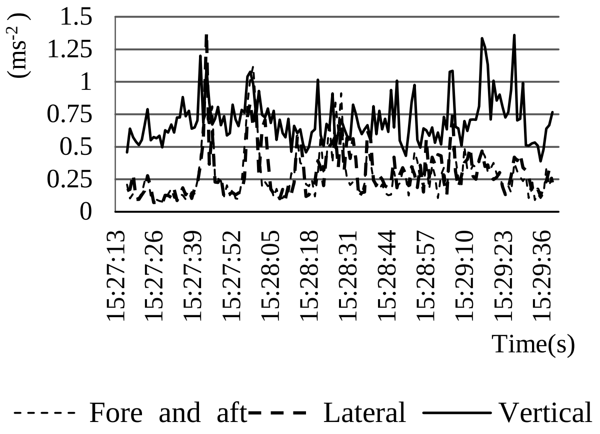


Figure 3: a_w variation for the backhoe, Operator 6,

Table 3: Range of Frequency weighted rms acceleration a_w in three orthogonal directions

Operator	Range of a_w values (ms^{-2})		
	Fore and aft direction	Lateral direction	Vertical direction
Vibrating Roller	0.07-0.21	0.07-0.21	0.44-1.42
Backhoe	0.19-0.59	0.22-0.36	0.29-0.74
Excavator	0.13-0.37	0.09-0.47	0.07-0.94

Range of frequency weighted rms acceleration, a_w, for each type of vehicle is summarized in Table 3. It can be observed that the vibrational effect on vertical direction is more dominant than the other two directions (i.e., lateral and fore and aft).

Vibration total value, a_v, variation with the time of vibration obtained from the same operator (OP6) is shown in Figure 4. Average of this variation is 0.83ms^{-2}.

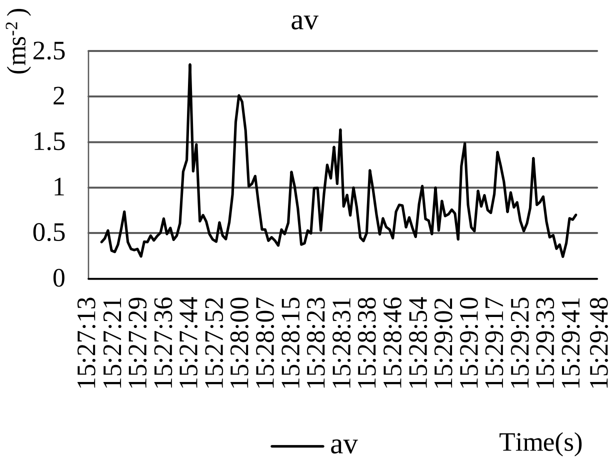


Figure 4: Vibration total value, av variation against to the time for the backhoe operator, OP6

Table 4: Assessment of WBV based on ISO 2631-1(1997)

Equipment	Operator	Exposure Duration (hours)	Vector sum of frequency weighted r.m.s accelerations	Daily exposure A(8) ms^{-2}	Health Risk according ISO 2631-1
Vibrating Roller	OP 1	6	0.83	0.56	In the zone
	OP 2	6	0.90	0.65	In the zone
	OP 3	5	0.49	0.35	Below the zone
	OP 4	6	1.42	1.23	Above the zone
Backhoes	OP 5	5	0.51	0.28	Below the zone
	OP 6	5	0.83	0.43	Below the zone
	OP 7	5	1.15	0.65	In the zone
Excavat Or	OP 8	4	0.24	0.11	Below the zone
	OP 9	3	1.28	0.66	In the zone
	OP10	6	0.91	0.47	In the zone

Vector sum of frequency weighted r.m.s accelerations values of each operator have characteristics which are related to the daily exposure value. Many of the operators are exposed to daily vibration exposure within or above the Health Guidance Caution Zone (HGCZ) (Table 4). One of vibrating roller operator, OP4, is exposed to daily vibration exposure above HGCZ and is in high danger than the other operators. Vibrating roller operator, OP 3, backhoe operators, OP 5, OP6 and excavator operator, OP 8 are exposed to daily exposure, which lies below the caution zone. As mentioned in the ISO 2631-1 health risks on those operators may not be much concerned. Rest of the operators are exposed to daily exposures in the caution zone and there are possible potential to effect on the health levels of those operators. This indicates that an appropriate formalised preventive programme must be set up by the employer to reduce to a minimum the exposure to vibration and attendant risks.

5. Conclusions

It seems that age and past experience (number of years exposing to whole body vibration) are the most critical factors that could be affected on the operators' health in addition to the daily vibration exposure, which could be determined from Whole body vibration measurements

Vibration total value or Vector sum of frequency weighted r.m.s accelerations values of each operator has characteristics which are related to the daily exposure value. According to the ISO 2631:1997, vibrating roller operators have higher potential of facing health effect than other two category discussed in this study. Majority of operators in the study groups are in Health Guidance Caution Zone (HGCZ).

When compare the vibration exposure levels of three axis (i.e. fore and aft, lateral and vertical), it was identified that highest average value always taken by the vertical axis than other two for each three category of vehicles. Therefore to minimize the health risk on the operators, it is desired to damp the vibration that comes in vertical direction.

Acknowledgements

The authors are willing to express their special thanks to everyone including operators who gave the supports and corporation to conduct this research.

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Investigation on Hand Arm Vibration exposures of operators in construction industry

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Abstract: Hand arm vibration syndrome, also known as the white fingere effect, has become one of the most significant diseases seen in construction industry. A long term exposure of arms to high vibration levels causes to the vibration syndromes. Investigation of exposure levels associated with the hand arm vibration is necessary to prevent the white finger syndromes.

Objective of this research is to evaluate the vibration exposure levels which transfer through the human arm to the human body while engaging in civil engineering construction activities. Ten operators in civil engineering construction sites were selected as a study group. A questionnaire survey was conducted with the operators to identify whether they are diagnosed with hand arm vibration syndromes, their experiences and age. Vibration exposure levels transferred through the arms to the human body were measured using a vibration meter (SV 106) with a mounting tri axial accelerometer. It was found that operators were not aware about the vibration related syndromes, although they were exposed to the excessive vibration. Measured exposure levels were evaluated based on the standards.

Keywords: Hand arm vibration White figure effects Exposure levels Tri axial vibration meter

1. Introduction

People always used to build, create, and explore something new which is helpful to have a much easier way and find out the most suitable solution for particular problems. Most of these activities have involved exposure to vibration, with the source comes from power tools, industrial machines, trains, automobiles, etc. In the construction industry, most of major activities such as drilling, breaking, compacting, which are done by using the vibration. Also the apparatus used to build, create, and explore have used more energy, as a result, increased quantities of energy have been dissipated in the form of vibration, some of which has been transmitted to people through human body part that directly touched to the vibrator source. This is caused to some health hazards in the human body (Mansfield, [1]).

Human body vibration can be divided into two main categories: Hand arm vibration (HAV) and the Whole body vibration (WBV). Hand arm vibration is transmitted through the handles or surface of the work piece, via palms, and the fingers into the hands and arms while workers engage with the hand held or manually guided machines. Examples of machines that may cause hand-arm vibration are demolition hammers, drills, hammer drills, angle grinders, chain saws and hand-held circular saws.

Workers, who frequently exposed to this HAV, may suffer from hand arm vibration syndrome (HAVS). The period of time between exposure to HAV and development of symptoms is varied, ranging from months to years (Griffin, [2]). Workers who are exposed to hand arm vibration often suffered with white finger effect, which causes neurological and motor disorders in the hands and fingers (Nakamura et al, [3]). Risk of HAV caused by the use of such equipment is preventable, but once the damage is done it is permanent (Anon, [4]).

It has been reported that there are different corollary about the syndrome, but patients who are having HAVS are most commonly described as having neurological, vascular and musculoskeletal symptoms and signs such as disturbed sensation (numbness, tingling), cold intolerance, episodic finger blanching, pain and weakness in hands and arms (Buhaug, et al. [5]).
Loss of strength in the hand, in the cold and wet, the tips of fingers going white then red and being painful on recovery are the early signs of the white

finger effect. Symptoms of nerve damage include pain, tingling and reduced dexterity, (initially symptoms are intermittent, but it may become heavy, if the worker be exposed to continuous vibration), fingers turn bright red. When rewarming, musculoskeletal complications include reduced grip strength, osteoporosis of the wrist or elbow, and bone cysts.

The orthogonal which belongs to hand arm vibration measurements are based on the head of the third metacarpal. The x-axis is through the palm, the y-axis is across the palm towards the thumb, and the z-axis extends towards the fingers parallel with the back of the hand (Figure 1). Above definition of coordinate system has an advantage that is no confusion regarding axes for palm or power grips or any orientation of the hand (ISO 2631-1 [6])

According to the previous study (Maryanne, [7]),two quantitative analysis parameters, which are Root mean square value (RMS) and Vibration dose value (VDV), were suggested to evaluate the hand arm vibration exposure levels. Furthermore, comparing natural frequency of the human body (human resonant frequency) and the magnitude of the vibration in frequency range is necessary to get the awareness about how significances the vibration exposure levels which transfer to the human body.

Objective of this study is to investigate Hand arm vibration exposure levels of operators in construction industry.

2. Methodology

A questionnaire survey and vibration exposure measurements were conducted simultaneously. Chosen construction sites were visited with the permission of responsible persons. Suitable safety procedures were followed

2.1. Study group

Ten hand arm vibration related machine male operators were selected as a study group. These ten operators consist with two jack hammer operators, four plate compactor operators and four drilling machine operators. Operators, who participated for this study, were within the age range of 20 -40 years.

2.2. Questionnaire survey

Questionnaire survey was conducted for each operator to investigate their health levels and current situation of their profession. In addition, their work experience and age were recorded.

2.3. Instrument

A vibration meter, SVANTEK 106, was used as an instrument to measure the exposure levels of hand arm vibration which transfer to the human body. Vibration meter was calibrated according to ISO 2631-1 and ISO 5349-2 to measure both frequency weighted HAV exposure levels in three orthogonal directions: x axis, y axis and z axis (Figure 1).

2.4. Measuring exposure levels.

Measuring parameters such as start delay time, measurement duration, weighting factors for each axis was set into the vibration meter (SVANTEK 106) before commencement of recording exposure levels. After selecting appropriate operator to measure the exposure levels of the HAV via the vibration meter, the hand sensor was mounted (Figure 2(a)) following defined coordinate system (Figure 1).Operator was instructed to work usually assigned task and vibration exposures were measured (Figure 2(b)). The coordinate system which was indicated on the instrument should exactly follow the above defined coordinate system (Figure 1).

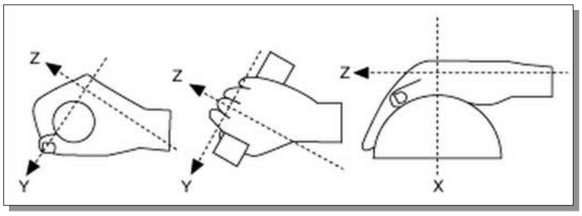

Figure 1: Defined Coordinate system for Hand arm vibration measurements

Figure 2: Measuring procedure of hand arm vibration exposures

(a) Sensor was placed on the hand
(b) Measuring the exposure levels

One operator from each category of equipment was instructed to wear a pair of gloves and let him to work, while the vibration exposures which transfer to his arm with the gloves were measured.

2.5 Analysis

Frequency-weighted hand-transmitted vibration (a_{hw}) for each direction was obtained from SV 106 analyser. Human exposure to hand arm vibration was evaluated by referring the guidelines for measuring and evaluating human exposure (ISO 5349-1(2001) and ISO 5349-2 (2001)). According to the ISO 5349-1 standard recommendations, the most important parameter used to describe the magnitude of the vibrations transmitted to the operator's hands is the root-mean square (rms) frequency-weighted acceleration, expressed in m/s^{-2}. The vibration total value, a_{hv}, or Frequency-weighted acceleration total value was determined as defined in Equation (1)(ISO 5349-1,2 [7]).

$$ah_v = \sqrt{ahw_x^{\ 2} + ahw_y^{\ 2} + ahw_z^{\ 2}} \text{ ---------- } (1)$$

Where ahw_x , ahw_y and ahw_z are frequency-weighted acceleration values for the single axis

Vibration exposure not only depends on the magnitude of the vibration total value, also depends on the duration of the exposure. Total time for which the hands are subjected to vibration during working day (Daily exposure duration) has been expressed in terms of Frequency-weighted acceleration total value as shown in Equation (2) (ISO 5349-1,2 [7]).

$$A(8) = ah_v \sqrt{\frac{T}{T_o}} \text{ ------------ } (2)$$

Where T is the total daily duration of the exposure in seconds, and T_o is the reference duration of 8 hours (28800 s)

HAV daily exposure action value (EAV) of 2.5 ms^{-2} , and HAV daily exposure limit value (EAV) of 5.0 ms^{-2} were considered.

3. Results and Discussion

3.1 Questionnaire survey

Table 1: Age, work experience, exposure duration and health issue of ten operators

Equipment	Operator	Age (year)	Work Experience (years)	Exposure duration (hours)	Health Issue
Jack Hammer	OP 1	45	15	8	Pain and weakness in hands
	OP 2	42	23	8	Numbness
Drilling Machine	OP 3	31	4	6	No
	OP 4	29	6	5	No
	OP 5	35	8	6	No
	OP 6	48	20	6	Pain and weakness in hands
Plate Compactor	OP 7	34	9	8	Normal daily tidiness
	OP 8	42	13	7	tingling
	OP 9	26	2	8	No
	OP 10	40	12	8	Pain and weakness in hands

It seems that operators' age and the working experience affect on the operator's health issues (Table 1). Jack hammer operator, OP1,, who has a 15 years of work experience is affected by the pain and weakness in hands. Jack hammer operator, OP2, who has 23 years of experience, has numbness. Among the drilling machine operators, OP6 has considerable work experience (i.e., 20 years), felt pain and weakness in hands. In addition, plate compacter operator, OP 7, OP 8 and OP 10, felt uncomfortable while operating drilling machine.

3.2. Vibration exposure levels

Frequency-weighted-hand transmitted vibration (a_{hw}) for each direction was obtained from SV 106 analyser. Figure 3 shows frequency-weighted hand-transmitted vibration (a_{hw}) for x, y and z directions of the drilling machine operator, OP3.

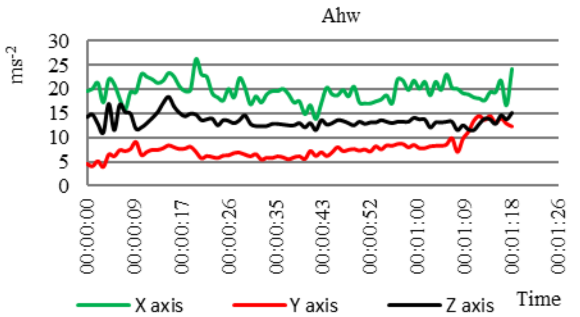

Figure 3: a_w variation of exposure levels of a drilling machine operator, OP3

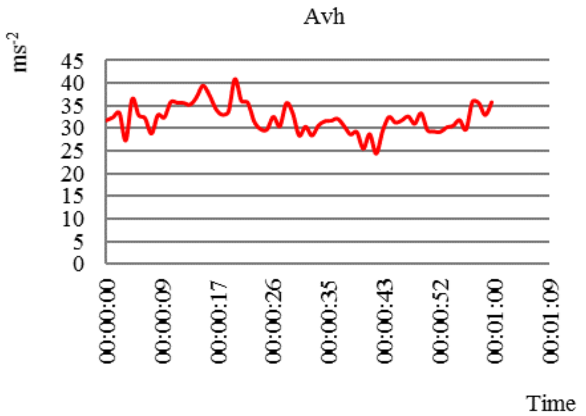

Figure 0: Frequency-weighted acceleration total value for a drilling machine operator, OP3

Frequency-weighted acceleration total value was obtained according to Equation (1) and is shown in Figure 4.

Table 2 summarises Frequency-weighted hand-arm vibration exposures (A_{hw}) for each direction, calculated Frequency-weighted acceleration total value (Ah_v) 8-hour exposure value, A(8) for operators in three different vibratory equipment. Eight-hour energy-equivalent frequency-weighted acceleration, A(8) for OP3,OP4 and OP6 are greater than the exposure limiting values. However, A(8) value of OP5 (2.44 ms^{-2}) is just below the exposure action value (2.5 ms^{-2}).

Table 2: Ahw_x, Ahw_y, Ahw_y, Ahv and A(8) values for all operators

Equipment	Operator	Ahw_x	Ahw_y	Ahw_z	Ah_v	A(8)
Jack Hammer	OP1	4.85	6.63	1.97	13.96	13.96
	OP2	2.11	3.18	9.60	9.86	9.86
Drilling Machine	OP3	7.45	11.18	11.18	24.09	20.86
	OP4	7.21	13.81	6.86	17.03	13.46
	OP5	2.53	1.19	0.32	2.81	2.44
	OP6	8.00	5.76	16.06	22.12	19.15
Plate Compactor	OP7	2.50	5.76	5.76	8.52	8.52
	OP8	6.79	9.87	9.63	15.3	14.38
	OP9	8.91	4.21	18.66	21.01	21.01
	OP10	15.63	15.63	16.08	25.25	25.25

Generally, vibration exposure in *x* axis was greater than the other two directions (Figure 3). It was found that the maximum vibration level induced in *z* axis is 18.66ms-^{2}. For both *y* axis and *x* axis maximum vibration level is 15.63 ms^{-2}. Maximum vibration exposure levels were observed from the plate compactor operators, OP 9 and OP10. It seems that more than 90% of hand arm vibration related equipment generates higher vibration exposure (Table 2) which exceeded the exposure limiting values of legislations: ISO 5349 (2001)

Figure 6 shows the Frequency-weighted acceleration total value (Ahv) work with gloves and the work without wearing the gloves for the operator,OP3.Vibration exposure decreased considerably while working wearing gloves. However, it has been observed that wearing gloves was not practice in civil engineering construction industry, letting operators in health risk.

Figure 5: Glove that used to experiment

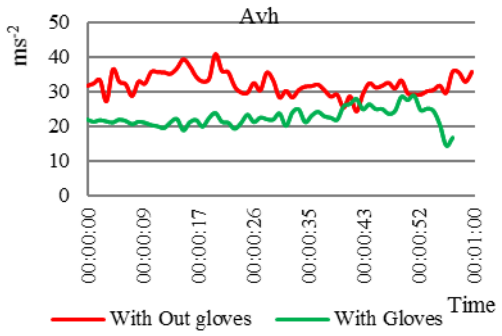

Figure 6: Avh values for with glove and without glove

4. Conclusions

More than 90% of hand arm vibration related equipment generates higher vibration exposure which exceeds the exposure limiting values of legislations: ISO 5349:2001. Majority of operators, who have more work experience and exposure to the higher vibration level, have felt tingling, pain and weaknesses in hand. Vibration exposure level which transfer to the human body decreased considerably while working wearing a pair of gloves.

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SECM/15/149

Investigation on Characteristics of Noise Induced by Construction Traffic

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Abstract: Construction traffic noise continues to grow and it is accompanied by an increasing number of complaints from people exposed to the noise. The historical dimension of noise pollution in urbanized society identified 'noise' as being unwanted or undesirable sound created by construction vehicles that are considered harmful to human health and quality of life. The most important issue is sleep disturbance. However, the assessment of construction traffic noise is highly complex. Objective of this research is to determine the characteristics of noise induced by construction traffic and normal traffic. Sound levels were measured by using Sound level meter (SVAN971) and four channel seismograph at different locations near roads where heavy construction vehicles such as ABC truck, empty truck, roller and motor grader passing through. In order to compare with ambient condition, noise induced by normal vehicles (i.e., car, three-wheeler, van, bus.) was also measured. Most of the construction vehicles induced noise, which are higher than the noise induced by the normal vehicles. Among the normal traffic, three-wheelers produce noise greater than other normal vehicles. It was found that construction traffic induced noise as high as 109 dB ($L(A)_{max}$),79.2 dB ($L(A)_{eq}$). Construction traffic produces noise at relatively low frequencies with high amplitude**.** Low frequency noise can be easily transmitted through structures and it can cause windows and other elements to rattle. The noise with tonal or impulsive characteristics is likely to be more annoying than noise without such characteristics.

Keywords: Construction traffic noise, Environmental impacts, Noise pollution, Sleep disturbance, Noise annoyance

1. Introduction

Environmental noise induced by construction traffic can have significant environmental impacts. The level of construction traffic noise depends on traffic volumes, traffic speeds and percent of heavy trucks on the road. Vehicle noise is a combination of the noises produced by the engine, exhaust, and tires. The loudness of construction traffic noise can also be increased by defective mufflers or other faulty equipment on vehicles. Any condition (such as a steep incline) that causes heavy labouring of motor vehicle engines will also increase traffic noise levels. In addition, there are other more complicated factors that affect the loudness of traffic noise. For example, traffic noise levels are reduced by distance, terrain, vegetation, and natural and manmade obstacles. Construction vehicles can have a very wide footprint and can cause widespread disturbances [1].

In the case of noise, there is a more gradual increase in annoyance with increasing level. Always "average noise level" is the subject of attention because it has been directly linked to noise annoyances caused to residents.

Major effect of environmental noise is sleep disturbance. It may cause primary effects during sleep (e.g. awakening), and secondary effects that can be assessed the day after night time noise exposure. Uninterrupted sleep is a prerequisite for good physiological and mental functioning. For a good night's sleep, the equivalent sound level should not exceed 30 dB (A) for continuous background noise [2]. Sleep disturbances can be reduced by reducing maximum levels of noise in residential areas. Rapid increases in noise would be particular annoying to sleep disturbance to residents living close to the road especially at night time.

It has long been recognized that exposure to levels of noise exceeding safe limits can be detrimental to hearing. However, the World Health Organization (WHO) has recently published new findings linking exposure to excess noise to high blood pressure, strokes, heart attack, feeling irritated and angry, not being able to concentrate, interrupted sleep and hearing related conditions such as tinnitus etc [3].

Noise pollution continues to grow and it is accompanied by an increasing number of complaints from people exposed to the noise. The growth in noise pollution is not sustainable because it involves direct, as well as cumulative, adverse health effects and also adversely affects future generations, and has socio-cultural, aesthetic and economic effects.

2. Objective

Objective of the current study is to determine characteristics of noise induced by construction traffic and normal traffic.

3. Methodology

Noise induced by construction traffic and normal traffics were measured using sound level meter (SVAN 971) and four channel seismograph. Noise levels during the passage of construction traffic were measured at two selected sites: stone crushing and a road construction site. As construction traffic, empty trucks, roller, motor grader and ABC trucks were selected.

In order to compare environmental noise induced by construction traffic with normal traffic, noise induced by normal vehicle was also measured. As normal traffic cars, three-wheelers, vans, and buses were selected.

The sound levels were recorded at 5 m distance from the edge of the roads where heavy construction vehicles passing through. The microphone was kept at 1.5-meter height above ground level. SVAN 971 which has a wide range of measures from 25dB to 140dB, was used to record the continuous sound levels (LAeq). Four channel seismograph was used to record the peak noise levels (LAmax).

4. Results and Discussion

4.1 Evaluation of equivalent noise induced by construction traffic and normal traffic

It was found that A weighted equivalent noise level(LAeq) is 79.2 dB at the road near stone crushing plant. According the guidelines recommended by Central Environmental Authority (CEA) in Sri Lanka (Table 1), equivalent noise level (LAeq) should not exceed 55 dB for low noise areas (within Pradeshiya sabhas) at day time. It was found that the equivalent noise level of 79.2 dB exceeding the CEA guide lines of 55 dB. In addition to the effect of construction traffic, LAeq might be included of a noise component induced by crushing operation. When there is an increase of background noise, there should be an increase in equivalent noise level (LAeq). Normally in the urban areas, these background noises are high due to industrial activities, business activities and public conversations.

Table 1: Maximum permissible noise levels given in CEA guidelines

Area	Day Time	Night Time
Low Noise areas (within Pradeshiya sabha)	55 dB(A)	45 dB(A)
Medium Noise areas (within Municipal Councils or Urban Councils)	63 dB(A)	50 dB(A)
High Noise areas (within Export Processing Zones or Industrial Estates)	70 dB(A)	60 dB(A)
Silent zones (100 meters from the boundary of a courthouse, hospital, public library, school, zoo, sacred area and areas set apart for recreation or environment)	50 dB(A)	45 dB(A)

For example, it can be seen that noise levels of vehicles rapidly increase compared with its background noise (Figure1). Such rapid increases in noise would be particular annoying and sleep disturbance to residents living close to the road ,especially, at night time.

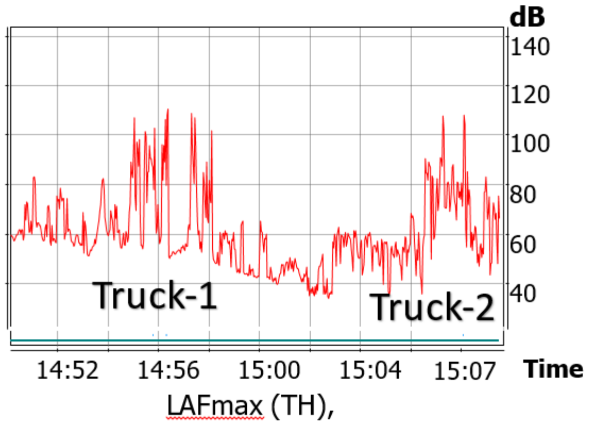

Figure 1: Variation of sound levels when passing a truck

Frequency distribution for a spot time of same kind of trucks are shown in Figures 2 and 3. Truck-1 was loaded by rubble and Truck 2 was unloaded. It can be found that low frequency noises are occurred by both Trucks 1 and 2. However, Truck-2 produces noise in lower frequencies than Truck 1, implying that lighter vehicles produce noise at very low frequencies.

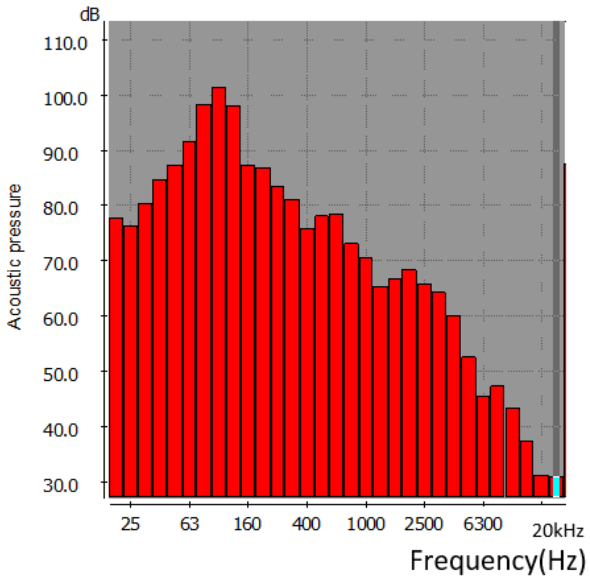

Figure 2 Frequency content of noise induced by Truck-1

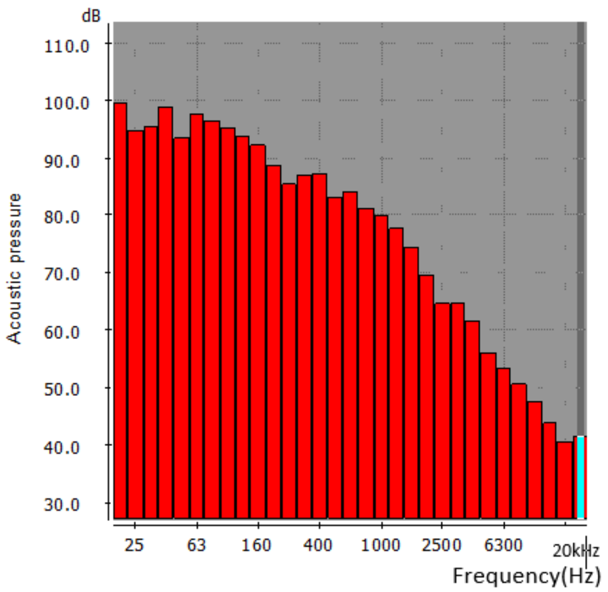

Figure 3 Frequency content of noise induced by Truck-2

4.2 Evaluation of peak noises induced by construction traffic and normal traffic

Figure 4 shows the peak noise levels induced by construction vehicles and normal vehicles. It can be seen that most of the construction vehicles produce greater noise than that induced from the normal vehicles (Figure 4). Loaded trucks produce greater noise of 105dB than noise of 94dB, which induced from unloaded trucks. Roller and motor grader produce noise of 109dB and 107dB, respectively.

Among the normal traffic, three-wheelers produce much noise than the other normal vehicles. And the normal vehicles are producing the noise less than 100dB. According to the WHO guide lines, these LA_{max} values should not exceed 110dB for industrial, commercial, shopping and traffic areas [2].

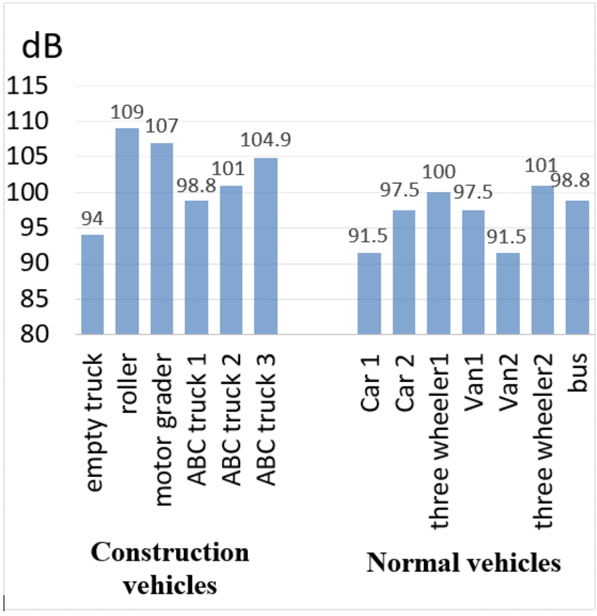

Figure 4: Peak noise levels of construction vehicles and normal vehicles

Sound levels of construction vehicles and normal vehicles are listed in Tables 2 and 3, respectively. Most of the construction vehicles induced noise, which are higher than the noise induced by the normal vehicles. Lighter vehicle induces noise with less amplitude and the heavy vehicle induces noise with high amplitude. It can be observed that the peak noises of vehicles are occurred in the frequency of less than 100Hz. And the lighter vehicles induce the peak noise with very less frequency (car-2Hz and three-wheeler-3.5Hz). Low frequency noise can be easily transmitted through structures and it can cause windows and other elements to rattle [4]**.** Low Frequency Noise (LFN) is not clearly defined but it is generally taken to mean noise below a frequency of about 100 to 150Hz [4].

Table 2: Sound levels of construction vehicles

Construction vehicle type	Peak noise dB(A)max	Frequency (Hz)
Empty truck	94	47.5
Roller	109	34.5
Motor grader	107	71
ABC truck -1	98.8	23
ABC truck- 2	101	52.5
ABC truck- 3	105	92

Table 3: Sound levels of normal vehicles

Normal vehicle type	Peak noise dB(A)max	Frequency (Hz)
Car-1	91.5	2
Car-2	97.5	2
Van-1	97.5	43.5
Van-2	91.5	51.5
Bus	98.8	93.5
Three wheeler-1	100	3.5
Three wheeler-2	101	2

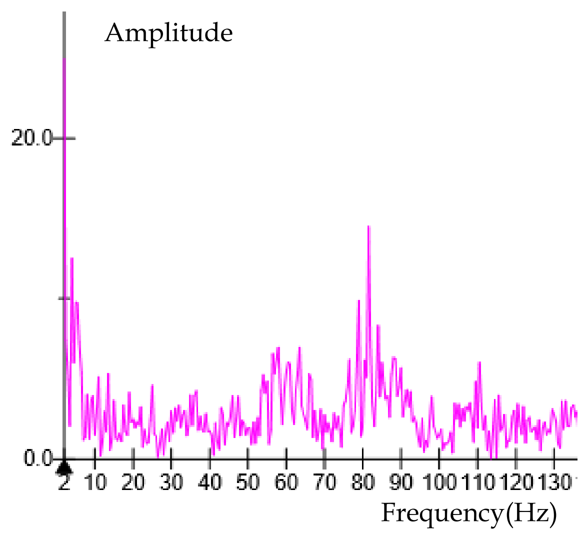

Figure 5: Frequency distribution of peak noise induced by a car

Noise with tonal or impulsive characteristics is likely to be more annoying. Some noise sources are inherently likely to give rise to tonal noise (i.e., vehicle's horn). This tonal noise is more noticeable than normal noise, resulting more annoying. A tonal noise source can normally be identified as shown in Figure 6. If there is a rapid frequency drop or increase greater than or equal to the following values in both adjacent one-third-octave bands: 15dB in low-frequency one-third-octave bands (25Hz to 125Hz), 8dB in middle-frequency bands (160Hz to 400Hz) and 5dB in high-frequency bands (500Hz to 10,000Hz), there should be a tonal noise [4].

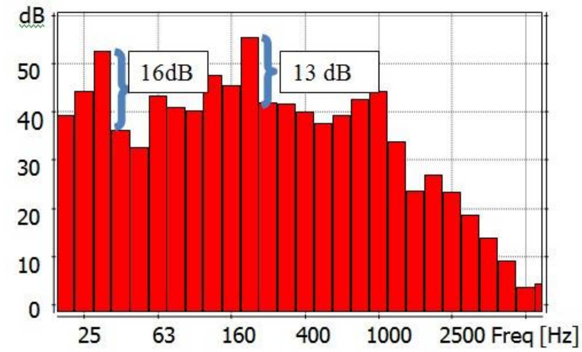

Figure 6: Identification of tonal noise

Some noise has the potential to generate impulsive noise. Normally an impulsive characteristic is determined subjectively as it is clearly audible. For examples, stone crusher that consistently produces an impact noise as when feed the stone to crusher the noise from the dropping of material that causes a short burst of loud sound as the material hits the ground or the noise of heavy hammering.

The traffic noise depends on the number of vehicles, the speeds of the vehicles, and the types of vehicles using the roadway. Generally, the loudness of traffic noise is increased by heavier traffic volume, higher speeds, and greater numbers of medium and heavy trucks. A 10-fold increase in vehicle volume equates to a noise level increase of approximately 10 dBA, or a perceptible doubling in volume [5]. Similarly, an increase in speed from 30 to 65 mph would also equate to a noise level increase of approximately 10 dBA, or a perceptible doubling in noise level (or volume) [5]. One heavy truck at 55 mph contains about the same acoustic energy as approximately 28 cars at that same speed [5]. Given this comparison it is clear that composition of traffic (i.e., the percentages of heavy truck volumes) can have as much (or more) of an effect on final noise levels than volume or speed of traffic.

Noise can be controlled by altering its propagation path through the use of various techniques. Planting of trees along roads and residential areas help in noise reduction. In addition, traffic management can often be the cornerstone to good noise control. Accordingly, some traffic management measures are outlined below.

- Minimize the number of heavy construction vehicles (e.g. roller, excavator) [5]
- Limit the vehicle's speed [5]
- Limit the vehicle volume [5]
- Maintain vehicles in good order, employ the principles of preventive maintenance and undertake reference vehicle noise measurements at defined intervals
- Ensure that noisy vehicles are parked as far as possible from noise sensitive areas
- Switch off idling engines where possible and prevent excessive revving
- Maintain road surfaces in good order
- Ensure that drivers are aware of the potential for noise to cause annoyance/disturbance to local residents (e.g. no unnecessary horn blowing [4].

Construction traffic is identified as one of the main sources of noise, which induced noise great than the normal traffic. Findings of this study may help construction and transportation authorities to regulate construction traffic in several domains: the routes of daily and night lines, the highest acceptable number of vehicles at daytime and at night, and the optimal type of construction vehicles.

5. Conclusions

The construction traffic is a significant predictor for high noise annoyance in an urban area. Most of the construction vehicles induced noise, which are higher than the noise induced by the normal vehicles**.** A-weighted maximum noise level (LAFmax) values are found to be 109 dB for roller, 107 dB for motor grader and 104.9 dB for ABC truck. Construction traffic produces noise at relatively low frequencies with high amplitude**.** Low frequency noise can be easily transmitted through structures and it can cause windows and other elements to rattle. The noise with tonal or impulsive characteristics is likely to be more annoying than noise without such characteristics. Reducing construction traffic noise to the lowest level in residential, areas may be a simple measure to reduce noise annoyance, and to improve general health and quality of life.

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SECM/15/151

Investigation on Improvement of Low Cost NERD Slab System

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Abstract: The NERD center floor slab system was introduced by late Dr. A.N.S. Kulasinghe in early 1987 specially for domestic buildings which are used by middle income families in Sri Lanka. The invention of NERD system directed to identify cost effective slab construction system relative to conventional slab system and also the use of un-propped construction technique and reduction of depth of slab caused to reduce construction time and material required for construction activities. The NERD system consists with 50 mm thick in-situ concrete slab retain on trapezoidal shape pre-stressed beams which are placed by keeping 600 mm interval between each. Although, the concept of NERD system is being widely adapted in domestic building construction exposed beam under the soffit of the slab keeps away people from the use of NERD slab system. Therefore, this research has been given much more advertency to make it as flat soffit slab with the improvement of structural arrangement of the NERD system such a way that changing the shape of pre-stressed beam and thickness of in-situ concrete slab with hollow arrangement to reduce utilized concrete of the slab.

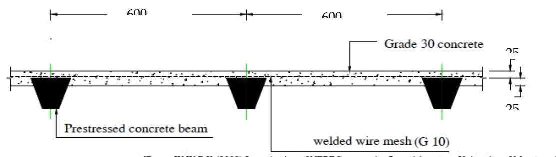
Keywords: Cost, Deflection, Flat soffit, Pre-stressed, Strength

1. Introduction

The use of concrete in structures goes back to period of ancient time. Due to the requirement of people who are using concrete as a construction material, the technology related to concrete has been updating day by day. For instance the precast concrete technology, composite slab system, light weight concrete etc. were introduced based on results of congenial experimental and theoretical investigation to modern construction industry with the use of concrete as a primary construction material.

However, the selections of any type of construction materials depend on many factors; primitive strength, durability, cost for materials etc. But nowadays it is being given much more attention to the reduction of cost and time related to construction practices as vital thing in most circumstances. Therefore, many researchers are trying to introduce cost effective techniques with less construction time period to modern construction industry. As a result of such aresearch, the NERD center floor slab system was introduced by late Dr. A.N.S. Kulasinghe in early 1987. Nowadays the slab system is being widely used in Sri Lanka in the domestic building constructions due to the many advantages over the conventional floor slab system; primitive 30 - 40% cost effectiveness, considerable reduction in weight of the slab, no propping is required for the soffit of slab, saves materials, labour and time, workable bottom space immediately after the concreting etc.

Achieving above advantages have been functioned by changing conventional floor slab system structurally based on supportive conditions of the slab, thickness of the slab, type of reinforcement use in construction practices etc. The NERD slab system consists 50 mm thick in-situ topping retained on trapezoidal pre-stressed concrete beams in 600 mm intervals as shown in Figure 1. While using grade 30 concrete for in-situ topping by placing the gauge 10, 50 mm x 50 mm welded G.I mesh as the reinforcement for slab at the center of slab, grade 40 concrete is being used to cast the pre-stressed beam which contains three numbers of 5 mm high tensile steel wires tensioned to 20 kN each by considering 30% of applied pre-stressing force as effective pre-stressing force.



[Perera W.W.P.K.(2009) Investigation of NERDC composite floor slab system. University of Moratuwa.]

Figure 1: NERD composite slab system

But, generalization of the new system caused to identify required modification for the NERD system. Since it had been identified that use of plywood board to support the fresh concrete in the 50 mm thick slab panel can be replaced by 12.5 mm thick Ferro cement panel as indicated in the Figure 2 below based on proper theoretical and experimental investigation [1].

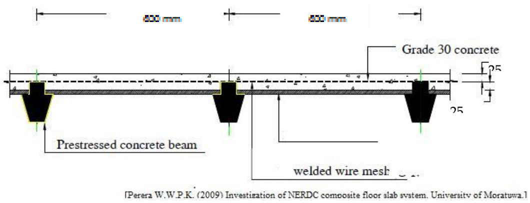


Figure 2: Modified NERD composite slab system

Even though, it has been introduced some modifications on the current NERD system there are some problems with the appearance of the soffit of the slab system. As indicated in Figure 1 and 2, it can be seen exposed beams under the soffit of the slab that create less customer attraction due to inappropriate aesthetic appearance on the soffit of the slab. Therefore, it is vital importance to introduce new system with the flat soffit arrangement for the current NERD system while maintaining 30 % - 40 % cost effectiveness compared with the conventional slab system.

2. Method

2.1. Theoretical analysis

Structural arrangement of current system was changed both in pre-stressed beam and in-situ concrete slab in some extend to design flat soffit arrangement for the current NERD slab. Therefore, the shape of the pre-stressed beam was changed from trapezoidal shape to inverted T beam section while introducing hollow core slab arrangement instead of the 50 mm thick in-situ floor slab in current system. The use of hollow core system guides to improve the fire resistance with excellent deflection and vibration characteristics [2].

However, the anticipated theoretical basis for invention of any kind of new structure is really vital importance and required. Therefore, the theoretical analysis for both pre-stressed beam and composite hollow slab system were done based on recommendation given in BS standards ([[3], [4], [5], [6]). The sectional properties of pre-stressed beam were checked for serviceability limit state and transfer state under the applied dead and imposed load relative to un-propped construction technique. Accordingly the way of beam casting in NERD system, the pre-stressed beams are not being subjected to dead and imposed load during the transfer state. But in the serviceability limit state they are being subjected to the dead load of slab and beam and imposed load. Therefore, modification on the equations of the pre-stressed beam design were done to derive equation given below which are relevant to the NERD system.

$$\frac{M_d}{Z1} + \frac{M_{imax}}{Z1_{comp}} \leq \alpha f_{a,maxt} - f_{a,min} \qquad (1)$$

$$\frac{M_d}{Z2} + \frac{M_{imax}}{Z2_{comp}} \leq f_{a,max} - \alpha f_{a,mint} \qquad (2)$$

Where,

Pi - Initial jacking force
Pj - Effective jacking force
e - Eccentricity of tendons
M_d & M_i - Dead load and imposed on the beam
$Z_{1\&2}$ - Bottom and top sectional properties of beam section
$Z_{1\&2,\ comp}$ - Bottom and top sectional properties of composite section

In the design of in-situ concrete slab, it was realized that the increment of slab thickness is essential to achieve the requirement of the flat soffit arrangement. But, the increment of the slab thickness directly adds additional construction cost for slab system. Therefore, the voided arrangement with cuboids was used to reduce the utilized concrete for the slab.

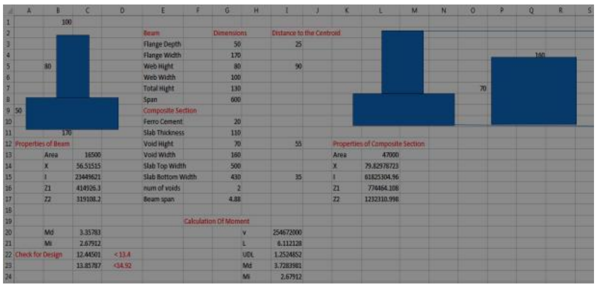


Figure 3: Excel sheet analysis for composite slab

Accordingly above modified equations and the recommendations given in BS 8110, theoretical analysis for composite slab was carried out to identify the beam and slab section for the most economical flat soffit slab arrangement [7]. For the easiness of the analysis it was prepared excel sheet analysis to identify the most suitable beam dimensions, shape and void sizes for different slab thicknesses as shown in the Figure 3. In addition to those variables, the beam span, interval between two beams and types of reinforcement used in slab concrete were considered to optimize existing NERD slab system.

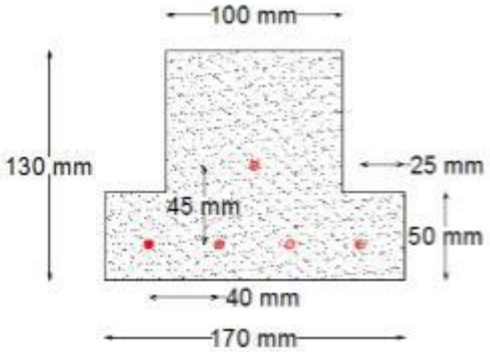


Figure 4: Pre-Stressed Beam

Based on the results of the above analysis, the dimensions and shape of the pre-stressed beam were selected as shown in Figure 4. Suitable eccentricity for tendons and jacking force in the wires in the inverted T beam section were identified based on the result of drawn magnel diagram as shown in Figure 5 [8]. Accordingly, the results of the magnel diagram the eccentricity for the tendon and effective pre-stressed force in the tendons were taken as 29 mm and 72 KN respectively. The tendons in pre-stressed beam were arranged as two layer by keeping 45 mm space between each layer while maintaining 40 mm interval between each tendons in bottom layer as shown in Figure 4.

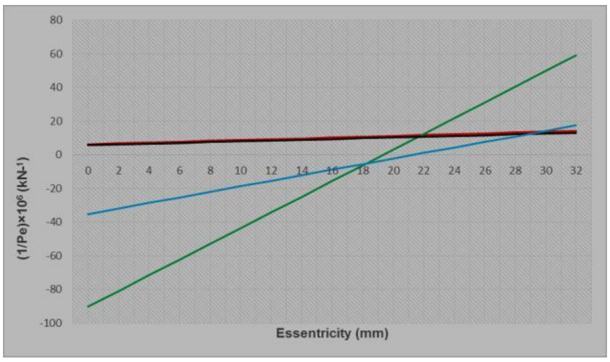


Figure 5: Magnel diagram

Accordingly, results obtained from the Theoretical analysis depth of in-situ concrete slab was taken as 110 mm while placing 20 mm Ferro cement panel to support the fresh concrete in the slab as shown in Figure 6. The sizes of cuboid void placed in the slab panel was maintained as 160 mm × 150 mm × 70 mm while maintaining 40 mm space between each cuboid to place the 6 mm diameter mild steel with the 190 mm space between each bar as the reinforcement for the slab. Improving of composite action between beam and slab was functioned by placing shear links at 225 mm interval along the span of the pre-stressed beam [9].

Table 1: Variation of beam interval with beam span

Beam Span (m)	Beam Interval (mm)	Number of Cuboids: Along the span Direction	Number of Cuboids: Perpendicular to the span direction
≤ 3.05	1200	16	5
3.66	1000	19	4
4.27	800	22	3
4.88	600	25	2

The design of improved slab system was done for the four beam spans as shown in the Table 1 while changing the interval between two beams instead of changing depth of the beam as in current system. And, the number of cuboids in the slab were changed along the span of the slab and perpendicular to the span direction as shown in Table 1 without changing the dimensions, arrangement of the reinforcement and the spaces between cuboids.

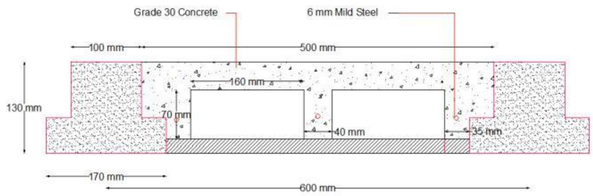


Figure 6: Structural arrangement of the optimized NERD slab

"by the cost of computing power and later by the successful widespread adoption of CAD" (Eastman, 2008).

Building Information Modeling (BIM) is one such approach which is now considered as a whole new process and methodology rather than just a technology. Building Information Modeling (BIM) is getting increasingly valuable in construction industry.

Therefore, the basic objective of this research is to study BIM and BIM tools to determine its benefits for construction managers. In this research, the uses of BIM which include 3D coordination, visualization, cost estimation, construction planning and monitoring, prefabrication and record model are discussed in detail. And the source of these common problems of construction managers is identified. Finally a model is proposed to implement BIM as BIM tools has potential to minimize most of these problems.

1. Research Methodology:

Literature Review: Literature review is used to systematically review earlier writings so as to learn more about the subject and other topics which collectively establish the context of this study. The goal was to gain a comprehensive understanding of the Building Information modeling and how the BIM is currently addressing the problems of construction managers in construction industry. It was completed in two phases. Firstly, it was used to gain a comprehensive understanding of BIM, BIM scope for construction managers and its adoption in construction industry. Previously conducted researches were reviewed to obtain knowledge about barriers and challenges which inhibits BIM adoption in industry.

Case Study: A case study approach is adopted to understand the solution of problems related to construction management and how BIM is minimizing the source of these problems.

Survey Questionnaire: Surveys are part of quantitative research and the focus of quantitative research is on objective measures rather than subjective experience. Surveys include cross sectional and longitudinal studies using questionnaires or interviews for data collection with the intent of estimating the characteristics of a large population of interest based on a smaller sample from that population *(RUIKAR, 2004).* Due to the nature of research question, a survey approach was used to obtain primary research data. The reason to select questionnaire is because questionnaire offer several advantages as they are widely distributed and low cost, interviewer bias is eliminated, anonymity of respondents, respondent can answer at leisure. In addition to that, *NAOUM (1998)* described questionnaire as the most popular form of getting primary data from a relatively large number of respondents within a limited time frame.

1. Literature Review:

Building Information Modeling (BIM):

The Building Information Model is primarily a three dimensional digital representation of a building and its intrinsic characteristics. According to the National BIM Standard, Building Information Model is "a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" ("About the National BIM Standard-United States", 2010). National Institute of Sciences (2007) defines BIM as:

"A BIM or Building information model uses digital technology of last generation to model a computable representation of all the functional and physical characteristics of the facilities and concern information during its life cycle and is intended to be a source of information for the service owner/operator to use and maintain that service during its life cycle."

According to Autodesk (2002), BIMs have three basic characteristics. Create and operate in digital databases for collaboration. To manage the change through these databases in order to make a change in any part of the database is coordinated with all other parts. Capture and preserve the data for reuse by adding industry-specific applications.

The findings of NIBS (2007), MAUNULA (2008)&SUCCAR (2008) that acronym BIM is used in three different ways. BIM can refer three different schools of thought which consider BIM as:

i. A product
ii. An activity/Process
iii. A system , a whole new concept

Problems faced with Construction Management:

In a CAD project, after the hundred percentage construction documentation and addendum and revision information has been turned over to the contractor, construction begins. Before the first scoop of dirt is moved, it is the construction manager responsibility to verify that the immediate information need is adequate and the most recent. Further issues for the project need to be identified and put on a path of resolution for all scopes of work. In theory, this review period for the project allows the construction manager to identify issues and give responsibility to the correct subcontractors. In itself, this is an arduous process.

Analyzing and overlaying CAD files and sheet drawings is time consuming work, it lack in visibility and it is prone to errors and missing information. In reality the construction manager is often cannot juggle managing the project documentation, the trades, the field management, and the construction managers own management team.

Advantages of BIM for Construction Management:

Each professional and user will have a point of view about the benefits of BIM in construction industry especially for construction managers. Their judgment approach or orientation may be different but as whole they are agree that BIM has remarkable effects on construction management.

a. Visualization

Building Information modeling (BIM) is an excellent visualization tool. It can provide a three-dimensional virtual representation of the building. It can help the contesting companies during bidding process because it can provide a better understanding what they have to construct and how it will look like after completion. It is possible due to renderings, walkthrough videos extracted from BIM model by using BIM tools.

b. 3D Coordination

Coordination is very important for a construction manager, especially when dealing with dense urban environment or challenging site. Coordination involves working and communicating with subcontractor, supervisors, materials suppliers, fabricators and equipment suppliers. In addition to juggling the scheduling, managing the budget, sorting through constructability issues, and managing relationship, the construction manager is also responsible who is doing what work on a project. Therefore the coordination efforts in advance of construction will reduce design errors and provide better understating of work ahead of time to be done.

c. Prefabrication

Offsite fabrication required considerable planning and accurate design information. It is becoming more common for contractors to fabricate component offsite to reduce labor cost construction time and better quality control. In offsite fabrication, different component or items can be assembled or fabricate in controlled environment and with greater precision and if any alteration is required then more option are available than site. A ductwork contractor can also use BIM model to installed branches and leave opening where required so that later on diffusers or hood can be girder boundaries. The internal pre-stressing of the upper section of the beam was replaced by external cables arranged over a small-sized mast located atop of the pier of the bridge he proposed (Figure 1).

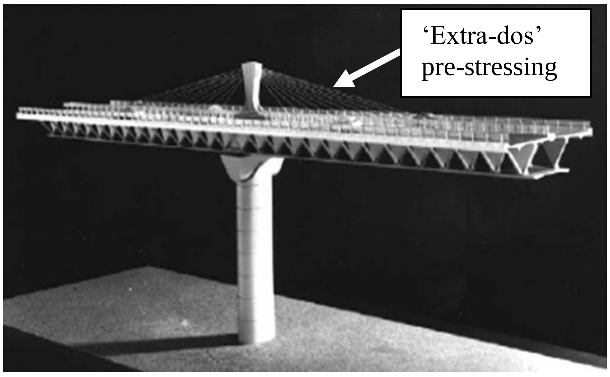


Figure 1: Proposed Viaduct for Arrêt Darré [2]

Since the external pre-stressing arranged by Mathivat was akin to the ‘extra-dos’, which is the upper curve of an arch, this new form of PC bridge was referred to as the ‘Extra-dosed’ type. Extra-dosed PC bridges are a hybrid form of bridge incorporating the structural features of PC girder bridges and those of cable-stayed bridges. While in a cable stayed bridge the vertical load is taken exclusively by the stay cables, in an extra-dosed bridge only a proportion of the vertical load is taken by the external cables (cable stays), while the girder itself takes a significant proportion of the vertical load resulting in larger girder depths than for cable stayed bridges of the same span.

The cable stays of an extra-dosed bridge essentially act as external pre-stressing but with a higher effective eccentricity than for conventional external pre-stressing which lie within the confines of the girder structure, resulting in a reduction of girder size compared to girder bridges of the same span. Due to the cable stays acting as external pre-stressing supporting only a proportion of the live load, the cable stays (external pre-stressing) can be stressed to higher stresses than those allowed in cable-stayed bridges [3] as the cables will be less severely loaded for fatigue considerations. In summary, the structural concept of extra-dosed bridges can be described as a PC box girder bridge with external pre-stressing through stay cables which also carry a portion of the vertical load.

3. General design outline

The proposed extra-dosed bridge is a 3-span structure with a 180m main span and two 100m long side spans. The main span length was determined by the design constraint of the need to avoid locating piers within the river limits. The side span lengths were constrained by the need to avoid locating piers on existing roads and the need to keep sufficient head-room over the said roads. An acceptable ratio of main span to side span length was also required in order to minimise out-of-plane forces on the pylon structure. Hence a main span to side span ratio of 1.8 was chosen. The bridge spans from P19 at station 800m to P22 at station 1180m, with pylons P20 and P21 located at stations 900m and 1080m respectively. This notation will be used throughout this paper. The layout of the proposed bridge with respect to the existing roads and bridge is shown in Figure 2.

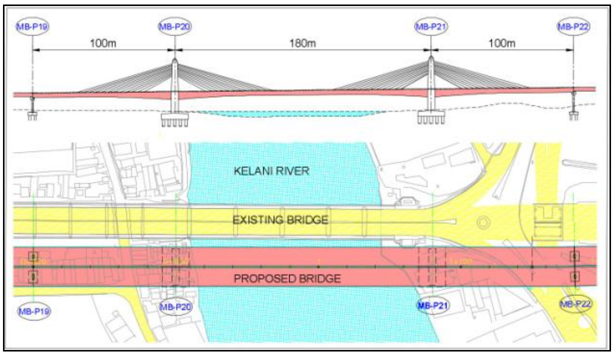


Figure 2: Layout of bridge – plan and elevation

A three cell box girder was chosen as the cross section for the main girder of the bridge. This cross section was chosen based on its high torsional rigidity as well as due to the wide nature of the deck which was designed to support 6 lanes of traffic. The cross sections of the girder at the pylon locations and at mid-span are given in Figure 3.

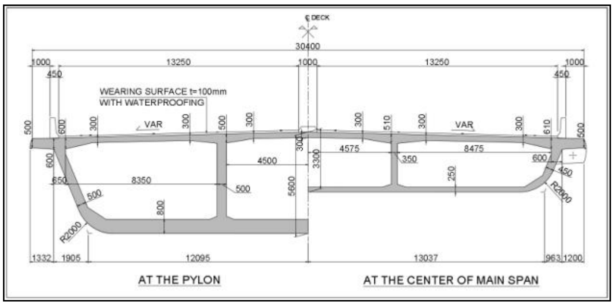


Figure 3: Cross section of main girder

The cross section heights are 5.6m at the pylon locations and 3.3m at mid span and side span ends. As per published literature [3] for extra-dosed bridges, the girder height is usually in the order of L/35~L/45 at the pylon and L/50~L/60 at mid-span, where L is the main span length. For a 180m span this translates into a height of 4~5.1m at the pylon and 3~3.6m at mid-span. A slightly larger value of girder height was chosen for the proposed bridge in order to minimise the size of the stay cables that would be required. In Table 1 typical extra-dosed bridge girder heights are compared to typical values of cable-stayed bridges and PC box girder bridges for the same span.

Table 1: Girder heights for three bridge types

Type of bridge	At pylon	At mid-span
Extra-dosed bridge	L/35 ~ L/45	L/50~L/60
Cable stayed bridge	L/80 ~ L/100 (constant)	
Box girder bridge	L/8 ~ L/16	L/35 ~ L/40

The girder height varies parabolically from 5.6m at the pylon location to 3.3m, 61m either side of the pylon centreline. The girder height is constant from Station 800-839m, for the middle 58m of the main span and also from station 1141-1180m. The top slab is 300mm thick throughout the length of the bridge while the bottom slab thickness and web thickness varies along the length of the bridge as shown in Figure 4.

The girder is supported at the pylon locations and at the end piers on 4 pot bearings each which are located near or directly beneath the web walls. The bearings, which provide no rotational restraint, are fixed in translation in the direction transverse to the bridge axis at all piers, and are free in the longitudinal direction at all piers except at P21.

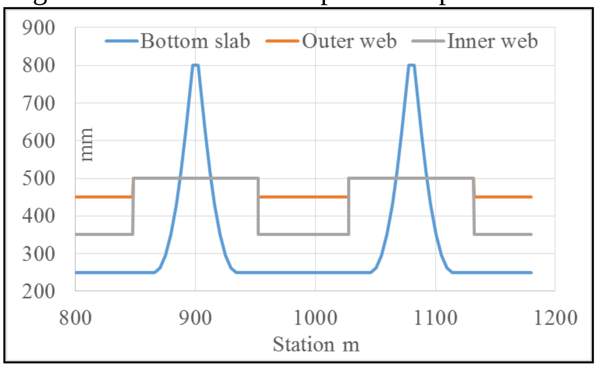


Figure 4: Thickness variation of slabs and webs

Providing longitudinal fixity only at a single pier is not usual in long-span bridge design. This layout was adopted since the design longitudinal load-effects due to wind, temperature and seismic loading in Sri Lanka were relatively minor. The girder is also supported by a system of stay cables emanating from two U-shaped pylons with a twin tower configuration. The twin towers are approximately 20m high above the top surface of the box girder and are inclined 5^0 to the vertical for aesthetic reasons. Each tower supports two planes of stay cables composed of 12 stay cables each. Hence 24 stays emanate out from each pylon. The design resulted in the shortest six cables in each plane being 27 tendon cables while the longest six were 37 tendon cables. The layout of the pylons and stay cables are shown in Figures 5 and 6. The twin towers are rigidly connected to the pylon pier while the connection between the girder and pylon pier is through pot bearings as described.

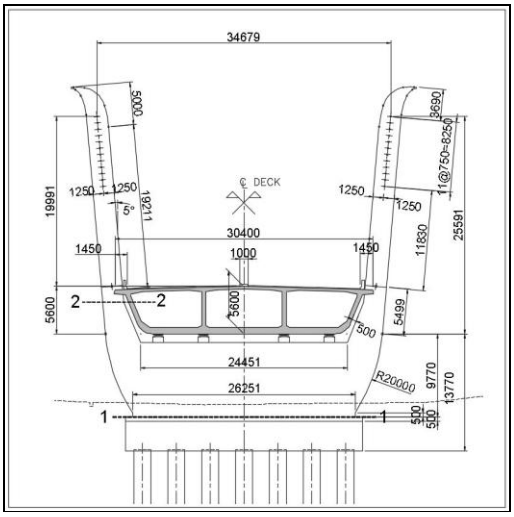


Figure 5: Pylon layout

General design guidance [3] states that for an extra-dosed bridge the tower height above the girder level is of the order of L/8~L/15 which for a 180m span gives a tower height of 12~22.5m. . Hence the tower height of 20m that was chosen falls within the general design guidance. For comparison, a cable–stayed bridge tower would be approximately 36~60m high for the same span. A double plane stay cable arrangement as described was chosen given the need to incorporate a 30.4m wide deck and due to the increase in torsional stiffness a double plane stay arrangement offers. A fan-type arrangement of stay cables was chosen out of the types commonly used (Figure 7).

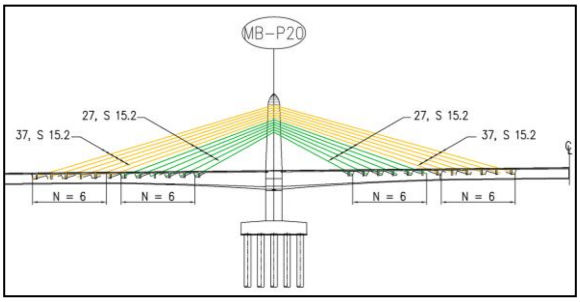


Figure 6: Stay cable layout (P20/P21)

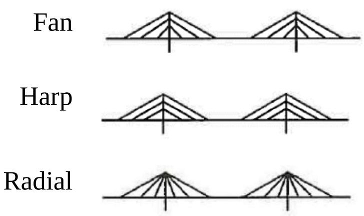


Figure 7: Types of stay cable arrangement

The fan type, which is a hybrid arrangement in between the radial and harp types, utilises cable stays more efficiently than the other types while keeping the sectional forces in the pylon at an acceptable level especially compared to those resulting from the radial type arrangement. The stay cables are located at 4.5m intervals along the suspended length of the girder and spaced at 0.75m intervals at the towers. At the tower a saddle type anchoring system (Figure 8) was chosen since it results in a smaller tower width and smaller spacing of stay cables at the towers than alternative anchorage systems. The 4.5m interval along the girder corresponds to the segment length considered for the girder construction.

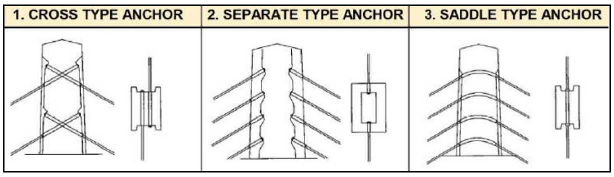


Figure 8: Anchorage systems at pylons

A double tube saddle type tower anchorage system (Figure 9) which allows for the replacement of stay cables was chosen.

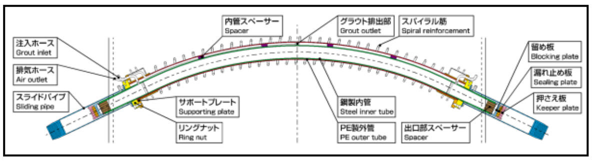


Figure 9: Double-tube saddle anchorage (typical) [4]

Usually, the suspended length of the girder, which is the length supported by stay cables, is of the order of 0.2L. However for this bridge the suspended length was increased to 0.28L, taking into account the deck size as well as to keep the stay cable size to a minimum (Figure 10)

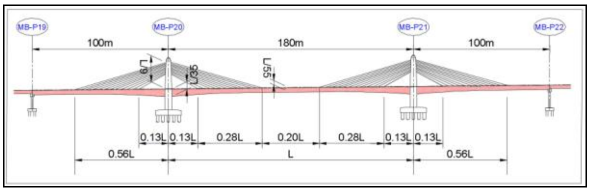


Figure 10: Stay cable layout along the bridge

At the girder level each stay cable is anchored to the girder through anchorages (Figure 11) located on the sides of the bridge deck.

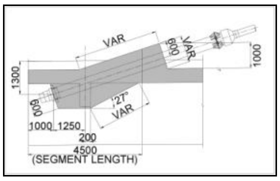


Figure 11: Stay cable anchorage (typical) [4]

The segments of the bridge which contain stay cable anchorages also consist of 400mm thick full width cross beams which are 1750mm high as seen in Figure 12. The structural effect of the cross beams is to improve the load-distribution within the girder cross section of the stay cable forces and to improve the transverse resistance of the girder.

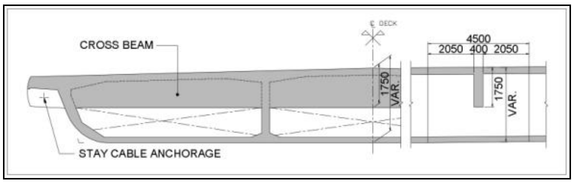


Figure 12: Cross beam layout

Taking into account its excellent corrosion resistance as well as relative ease of construction, epoxy coated and filled (ECF) tendons (Figure 13) will be used for the stay cables of the proposed bridge. In addition to the epoxy coating, the tendon also has a polyethylene (PE) covering and the stay cable itself has a protective PE pipe in which all the tendons are enclosed. ECF tendons also offer superior fretting fatigue resistance compared to other alternatives which is advantageous since the tendons will be susceptible to fretting fatigue due to the saddle type anchorage used at the towers.

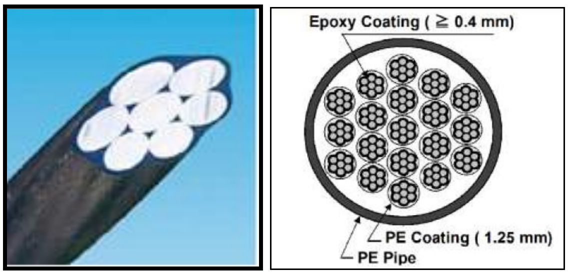


Figure 13: Typical ECF tendon [4] and Stay cable

The sub-surface soil profile at the locations of the proposed piers consist of a thick alluvium layer composed of layers of peat, clay and sand overlaying the bedrock layer. The rock layer consisted of highly to moderately weathered gneiss and was located approximately 25~30m below mean sea level. The allowable bearing capacity for the design of piles socketed in rock was recommended to be 3000kPa together with an ultimate socket friction of ~200kPa. The decision to locate the fixed bearing condition in P20 was made since fixing the girder at P20 resulted in larger lateral forces at P21 (governed by creep and shrinkage effects) and since the ground conditions at P21 were more favourable than at P20.

Table 2: Construction sequence (time in months)

Construction activity	Time
Pile cap, pylon pier and pier head	13
Girder segments without stay cables and part construction of towers	+3.5
Girder segments with stay cables and completion of tower construction	+7.5
Completion of cantilevers	+ 1
Construction of side spans	+ 3
Construction of closure segment at mid span	+1.5
Parapet construction and surfacing	+2

The construction of the proposed extra-dosed bridge will be carried out using the balanced cantilever method with two cantilevers on either side being constructed from each pylon. Table 2 outlines the general planned sequence of construction and approximate timelines. An assumed construction schedule was considered for the structural analysis which is described in the next section.

4. Structural modelling and analysis

The structural modelling for the design of the extra-dosed bridge was done using the CsiBridge2015 analysis software. For the consideration of global effects, a three-dimensional finite element (FE) model consisting of 1-D elements was used. The box girder, pylons, piers and cables were modelled using 1-D frame elements with equivalent stiffness properties. A screen-shot of the finite element model is given in Figure 14.

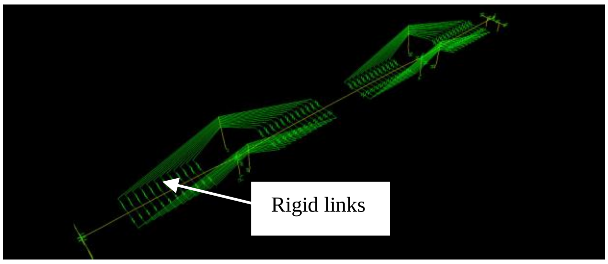


Figure 14: FE analysis model (tendons not shown)

The elements were modelled along the locations of their centroids and the connections between the stay cables and girder were made through rigid links as shown. Since the girder was modelled using frame elements the cross beams were not explicitly modelled. The effects of the cross beams were considered by the use of rigid links as described above. The stay cable anchorage points considered in the model corresponded to their locations in the actual structure. The pylon support foundations were modelled using coupled translational and rotational springs and was updated throughout the analysis to reflect the actual foundation configuration designed. The pot bearings supporting the main girder were modelled using springs with very high translational stiffness with releases specified as appropriate. Hence the connection between the girder elements and the pylon elements in the model was through these spring elements. The 'pier table' of the pylon was modelled by constraining the joints corresponding to the bottom of the pot bearings and the bottom of the towers to act as a rigid body. The stay cables were rigidly connected to the towers at the pylons.
Initially the analysis was done without including the internal pre-stressing tendons within the model. This was done in order to obtain the load-effects of the girder to estimate the required number of internal pre-stressing tendons. The number of internal tendons were then estimated, with an allowance of approximately 2MPa for secondary effects of pre-stressing for the girder. The pre-stressing tendon layout thus designed was then explicitly modelled as elements in the FE model (Figure 15).

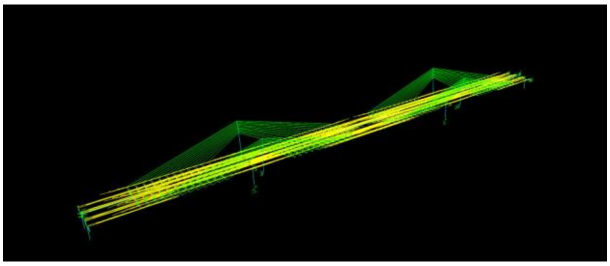


Figure 15: FE model with tendons (in yellow)

The jacking stress for the tendons was specified to be $0.72f_{pu}$. All pre-stress losses were calculated through the software using the following loss parameters. Jacking from both ends was assumed for all internal tendons.

- Friction coefficient 0.3 /rad
- Wobble coefficient 0.004 rad/m
- Wedge draw in 5 mm

The following main loads were considered in the analysis;

1. Dead load and super-dead loads
2. Live loading due to HA and HB loads
3. Wind loading
4. Temperature loading
5. Creep and shrinkage
6. Differential settlement of piers (10mm)
7. Cable and tendon pre-stressing effects
8. Secondary live loading
9. Frictional restraint effects

All loads were considered in accordance with BS5400:2 [5] with traffic loading being taken from BS5400:2(1978). 45 units of HB loading were considered for the analysis. In addition to the aforementioned loads the following special loading conditions were also considered.

1. Sudden loss / replacement of any one stay
2. Replacement of any one bearing

The sudden loss of any one stay was modelled by removing the cable element from the model and re-running the analysis, with equal and opposite forces applied to the girder and tower locations to which the cable was connected to, equal in value to the force in the particular cable at the ULS obtained from the original model (with all load factors set to 1.0). A 1.8 impact factor was applied to take into account dynamic effects. A similar approach was used for the stay and bearing replacement conditions (without the impact factor).

As the bridge will be constructed using the balanced cantilever method a staged analysis was done in order to realistically model dead load effects and effects due to creep and shrinkage. An assumed construction schedule was used for the staged analysis. A 15 day cycle was considered for the construction of girder segments without stay cable anchorages and an 18 day cycle was considered for segments with stay cable anchorages. For each stage, the respective girder segments were added after which the dead load and internal pre-stressing were applied and stay cable pre-stressing applied thereafter where appropriate. During construction of the cantilevers the springs modelling the pot-bearings at the pylons were temporarily assigned to provide full restraint. In reality too, a temporary fixing arrangement will be constructed at the pylon locations to facilitate balanced cantilever construction. When adding the respective segments in the analysis model, segments on either side of the pylon were added at the same time, mimicking the proposed actual construction sequence. Once the cantilever construction was completed, the side-spans were added to the model after which the rotational restraints temporarily assigned to the pylon bearing springs were released. The closure segment at mid-span was then added and the final translational releases were assigned to the bearing-springs, prior to stressing the bottom tendons of the closure segment. The super-dead loads were then added and the effects of long term creep and shrinkage were assessed through time-lapse load-stages which calculated effects up-to 30 years ($T=\infty$) after completion of the bridge (T=0). The creep and shrinkage calculation was done through the software which followed the procedure specified in the CEB-FIP 1990 model code [6]. The creep and shrinkage effects were considered not only for the long term but throughout the construction period. Figure 16 shows a screen-shot of the stage at which the cantilevers emanating out of P20 have been completed.

The effects of all other loads were calculated using the staged analysis model (and associated stiffness) at T=0. The HA and HB live load effects were calculated through influence line analysis using the in-built function of the analysis software. For the wind loading a basic wind speed of 33.5 ms^{-1} was considered [7] while for temperature loading effects, a uniform temperature difference of +/- 7^0C was considered with an installation temperature of 32^0C [8]. A temperature difference +/- 8^0C was considered between steel and concrete elements of the bridge. The re-distribution of load effects due to the change of support fixities was calculated through the software itself. During the staged analysis, the loading from the form traveller was considered as a point load of 160T while a construction live load of 14.6 kN/m on one cantilever and half the load on the other was also considered. The main material parameters considered in the analysis are tabulated in Table 3.

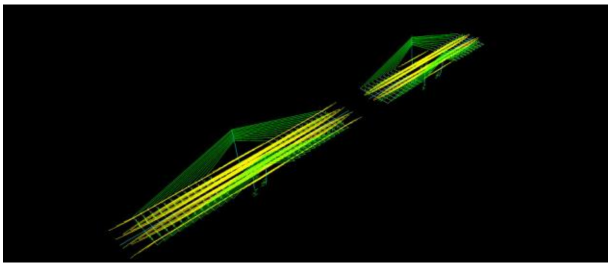


Figure 16: Model at completion of P20 cantilevers

Table 3: Main material parameters considered

Parameter	Value
E (Young's Modulus) of girder (1.15 x 34 – taking into account effect of rebar and tendons) - G50 concrete	39.1 GPa
E of tower - G50 concrete	34 GPa
E of pier (pylon piers included) – G40	31 GPa
E of pre-stressing tendons/cable stays	200 GPa
Shrinkage start date as per [6]	3 days
UTS of tendons f_{pu}	1850 MPa
Relative humidity	70%
Shrinkage coefficient as per [6] β_{sc}	5
Relaxation class as per [6]	2

The full sectional stiffness was considered for the girder elements in the analysis while the sectional stiffness of the pylons and piers were reduced by 50% to account for the fact that these will be cracked at SLS. The same analysis model was used for SLS and ULS, in line with limit state theory. For the stay cables no 'apparent modulus' effects [9] were considered, since even for the longest cable, the change in modulus was negligible.

Initially the analysis was run with all stay cables considered as 27 tendon cables. However it was ascertained that the cable capacity was not sufficient to meet the design criteria upon which the longest six stay cables emanating from each tower was changed to 37 tendon cables. The stay cable pre-stress was applied through the software at each relevant analysis stage as a 'target-force' load-case in which the software increased the strain of the cable until it achieved the specified force. The amount of stay cable pre-stress was initially determined considering the remaining allowable force increase in the cables after the resulting SLS loads in the cables without pre-stress were deducted. Since staged analysis is a type of non-linear analysis, the maximum amount of pre-stress was finalised through iteration.

Creep and shrinkage loss of internal pre-stress was accounted for in the analysis itself as the tendons were modelled explicitly and deformed compatibly with the elements they were embedded to.

5. Detailed design of box girder

Using the load-effects from the global analysis, the SLS and ULS design of the main box girder for longitudinal effects was carried out. The steps described in sections 5.1 to 5.3 were followed in the design. In the longitudinal direction, the main box girder was designed as a Class 2 pre-stressed concrete member as per BS5400-4 [5]. The internal pre-stressing layouts that were designed for the top and bottom slabs of the main box girder are shown in Figures 17a-c. The arrangement is symmetric about the centreline of the girder cross section.

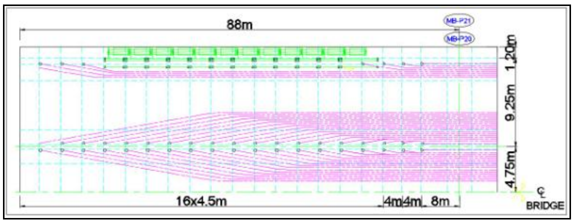


Figure 17a: Top slab pre-stressing (for P20/P21 cantilever spans) – 88 x 15ø15.2mm tendons

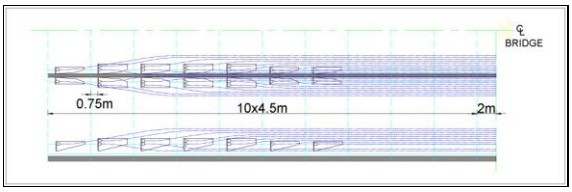


Figure 17b: Bottom slab pre-stressing (mid-span) 66 x 15ø15.2mm tendons

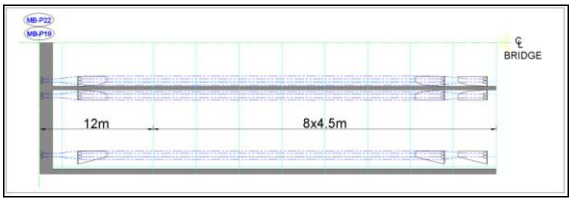


Figure 17c: Bottom slab pre-stressing (side-spans) – 24 x 15ø15.2mm tendons

5.1 Stress check for completed bridge

The extreme fibre stresses of the main girder cross section due to the critical load combinations were calculated for the bridge at and after completion. The resulting stresses were then checked with the relevant stress limitations, which as per BS5400-4 Section 6.3.2 [5] were 2.55 MPa in tension and 20 MPa in compression for grade 50 concrete. The calculated extreme fibre stresses along the bridge are shown in Figure 18. When calculating the stresses, for contributions from the axial forces applied on the girder by the stay cables and internal tendons, a distribution angle of 33^0 was considered [10], since the axial forces are not immediately effective across the whole cross section (Figure 19). This resulted in an effective distribution length behind the anchorage of approximately 7.5m. In the calculation of stresses the contribution from the aforesaid axial forces was only considered effective after this length.

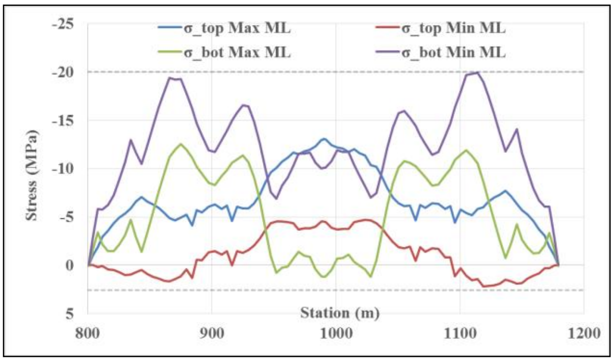


Figure 18: Extreme SLS fibre stresses (T = 0 to ∞) (Tension positive, sagging moment positive)

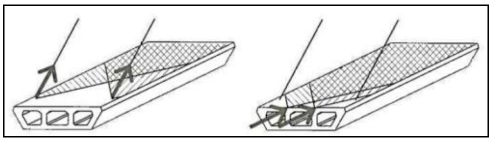


Figure 19: Distribution of applied axial forces

5.2 Stress check during construction

Similar to 5.1, stresses were also calculated for load-effects during construction. It was confirmed that the maximum and minimum stresses during construction were also within the required limits.

5.3 Ultimate capacity checks

In addition to the SLS design, the ULS moment, shear and torsion capacities were also checked. For the longitudinal moment capacity in order to obtain the required capacity above the applied ULS moment it was necessary to design and consider the capacity contributions from the reinforcement of the top and bottom slabs. The longitudinal reinforcement thus designed is tabulated in Table 4. The moment capacity was calculated taking into account the co-existing axial force in the section. Figure 20 shows the variation of maximum and minimum ULS longitudinal moments and the calculated ULS capacities.

Table 4: Slab rebar (top and bottom surfaces)

Slab	Rebar (c/c in mm)	Length along bridge
Top slab	H12@150 c/c	Full length
Bottom slab	H12@150 c/c	P20/21 to P20/21 +/- 12m, P20/21 +/- 54m to +/-90m and side span ends
	H25@150 c/c	P20/21 +/- 12m to +/- 36m
	H20@150 c/c	P20/21 +/- 36m to +/- 54m

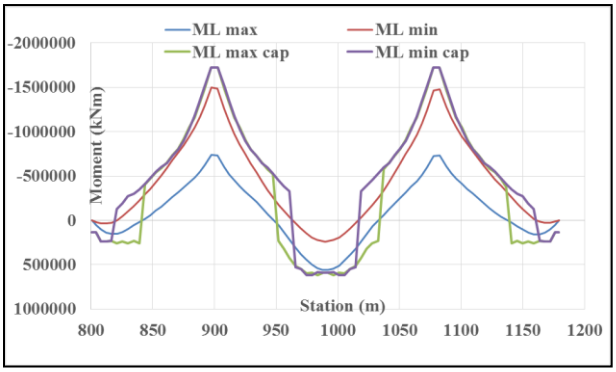


Figure 20: ULS moments and capacities (Sagging moments positive)

The ULS shear and torsion effects were also assessed. The distribution of shear between the outer and inner webs was obtained through an additional finite element model which modelled each web and associated top and bottom slabs as separate elements along with the cross beams. For the outer and inner webs maximum distribution ratios of 0.37 and 0.20 were obtained. These ratios together with the obtained load-effects from the main analysis model was used for ULS shear design of the girder.

5.4 Displacement of girder

The displaced shape of the bridge due to dead and super dead loads (including pre-stress) at the end of creep and shrinkage is shown in Figure 21. A maximum displacement of 423mm (~ L/425) was calculated from the analysis at mid-span. During construction this long term deflection needs to be taken into account in order to ensure that the road alignment of the structure achieves the design requirement in the long term.

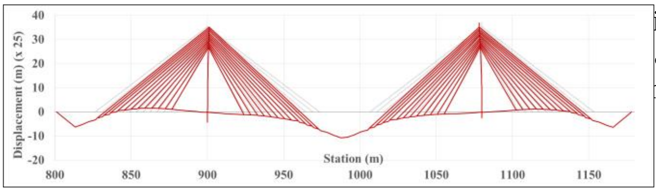


Figure 21: Long term bridge displacement

6. Detailed design of stay cables

The stay cables were designed ensuring that SLS loads in the cables did not exceed $0.6f_{pu}$. For the load-cases of sudden loss of one stay and stay replacement, a stress of $0.65f_{pu}$ was permitted while during construction a maximum stress of $0.7f_{pu}$ was considered permissible. The resulting maximum SLS cable loads for cables emanating from P20 and P21 are shown in Figure 22. Results are presented for cables of one tower of each pylon (as effects are nearly symmetric). As can be seen the maximum cable loads are less than the allowable for all cables. Since the loads in the cables vary due to the live load, fatigue of the cables was also considered. The allowable stress for fatigue is a function of the maximum allowable SLS stress [3] as shown in Figure 23.

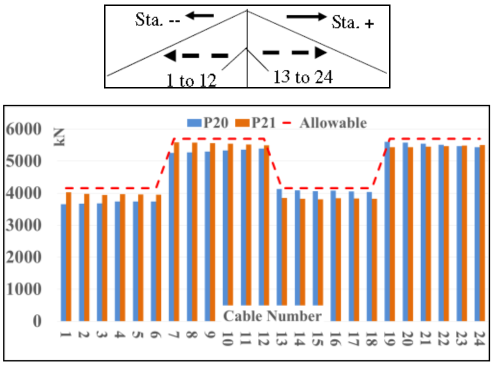


Figure 22: Maximum SLS cable loads (P20/P21)

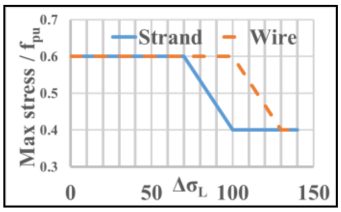


Figure 23: Allowable fatigue stress range ($\Delta\sigma_L$) [3]

For an allowable stress of $0.6f_{pu}$, the allowable stress range is 70 MPa. The calculated cable stress ranges due to live load (HA loading only) are shown in Figure 24. Using HA loading to assess fatigue stress ranges may seem overly conservative. However this method is acceptable ince additional bending stresses induced in the ables near anchorages [11] are not explicitly taken nto account in the analysis.

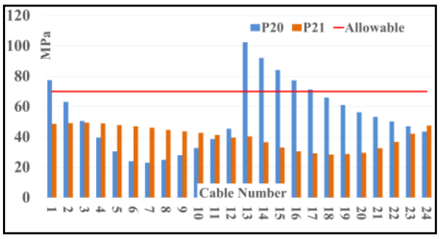


Figure 24: Stay Cable stresses due to HA loading

The shortest five cables of P20 were observed to have stress ranges above the limiting value. This was mitigated by increasing the number of tendons used for these stays. Cable vibrations due to wind/rain will be monitored during construction and damping devices will be designed and installed as required.

7. Detailed design of pylons

The towers of the pylon vary from a 2.5m x 3.5m section at the top to a 2.5m x 5m section at the level of the top of the girder, after which the section increases in width until the level of the 'pier-table', as shown in Figure 25. Below the level of the pier table the pylon 'pier' is a cellular box structure with the typical section as shown in Figure 26. The overall width of the pier varies from 32.71m at level of the bearings to 26.25m at level of the top of the pile cap.

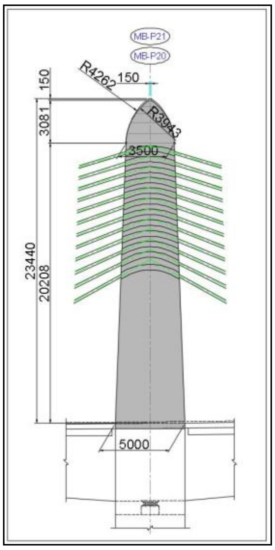


Figure 25: Pylon tower section variation

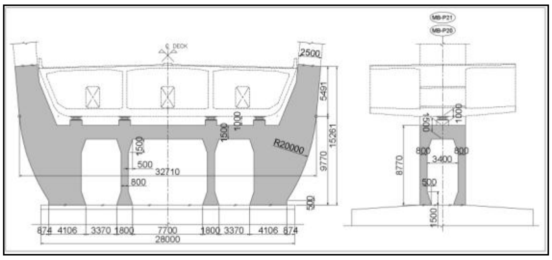


Figure 26: Pylon pier typical cross sections

The tower and pier sections were designed as bi-axially loaded reinforced concrete columns at the ULS and the crack widths were checked at the SLS. The ULS maximum axial force and sectional moments for Sections 1-1 and 2-2 as defined in Figure 5, are given in Table 5 for pylon P20, along with the designed perimeter axial reinforcement. The design of the end piers is not explicitly described in this paper as its design depends on the loadings from the approach bridge as well. However the design philosophy of the piers is the same as that of the pylons.

Table 5: ULS load-effects for pylon P20

Load-effect	Sect 1-1	Sect 2-2
Max compression kN	257606	34818
Min compression kN	185037	53357
Max moment about longitudinal axis	106814	37936
Max moment about transverse axis	501642	120504
Max shear in longitudinal dir.	14955	7365
Max shear in transverse dir.	2944	1998
Max torsion	39439	4
Designed axial rebar	H32@150 mm c/c	H32+H40 @150mm

8. Detailed design of foundations

The designed pile layout for pylons P20 and P21 is shown in Figure 27 while the corresponding pile cap section is shown in Figure 28. 2m diameter piles were considered in the design.

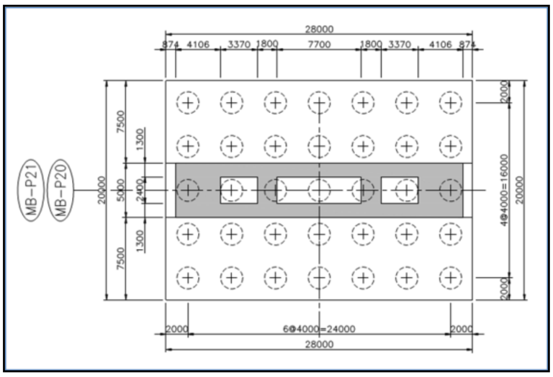


Figure 27: Pile layout of P20/P21 foundations

The design of piles was carried out by using the reactions of the pylon support springs which modelled the effect of the pile foundations in the global analysis model, and applying the said reactions as input loads to a separate finite element model of the pile system. This finite element model is shown in Figure 29.

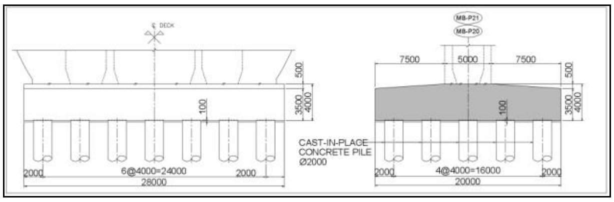


Figure 28: Pile cap dimensions P20/P21

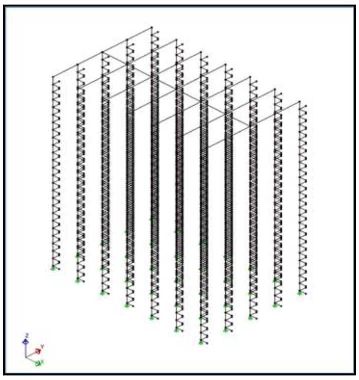


Figure 29 – FE model used for pile design

The top of the piles in the above model was joined together by rigid elements as the 4m high pile cap was considered to be rigid. The piles were supported by springs spaced at 1m intervals which modelled the varying stiffness of the soil layers. The bearing stress from the pile acting on the bearing layer was calculated using the SLS axial force at the bottom of the pile. The pile reinforcement was designed for the ULS condition by considered the pile as a bi-axially loaded reinforced concrete column. The maximum load-effects used for the design of piles in P20 and P21 are tabulated in Table 6. The pile caps of both P20 and P21 pylons are 28m long, 20m wide and 4m high. The pile cap reinforcement was designed based on the moments in the 28m x 4m sections at the face of the pylon pier. This resulted in bottom main reinforcement of 2 x 2H32@150mm c/c. Due to the arrangement of the pylons, the 20m x 4m sections were not critical for the pile cap design.

9. Conclusion and further work

This paper has presented and discussed the detailed design of the main structural elements of the proposed new extra-dosed bridge over the Kelani River, which will be the first of its kind in the country. At the time of writing this paper the detailed design work is ongoing, especially with regard to bearing design, anchorage design and transverse design of the box girder and cross-beams. It is hoped that more details of the design will be the subject of a separate paper in the future.

Table 6: Pile load-effects (kN/kNm)

Load effect	P20	P21
Max SLS axial compression	11618	12122
Max ULS axial compression	15040	15604
Min ULS axial compression	4740	3978
Max ULS moment (moment	1357 (43)	1266 (20)
about ppclr. dir in brackets)	1027 (541)	1122 (603)
Axial rebar	40H25 @ upper part	
	40H20 @ lower part	

Acknowledgement

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CLIMATE CHANGE IMPACT PREDICTION IN UPPER MAHAWELI BASIN

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Abstract: Upper Mahaweli basin is the origination of the main water source of Sri Lanka which is the Mahaweli River. Therefore it is a timely requirement to identify the future climate trends on the basin, to take suitable adaptation strategies. Statistical Downscaling model (SDSM) was used to predict future rainfall patterns of the study area. Observed point rainfall data of ten gauging stations within the study area and Global Climate Model (GCM) data of Hadley Centre Coupled Model, Version 3 (HadCM3) were used for model calibration and validation processes. A representative data set for the study area was generated using Thiessen polygon method from the observed rainfall data of selected gauging stations. Quality of the input data was checked prior to the model calibration. Daily rainfall was forecasted from 1961 to 2099 under A2 (high emission scenario) & B2 (low emission scenario) defined by Intergovernmental Panel on Climate Change (IPCC). Under A2 scenario the total annual rainfall, maximum annual rainfall and annual averaged daily rainfall show an increasing trends and under B2 scenario all the above mentioned parameters show decreasing trends. But the recorded decreasing trends are insignificant.

Keywords: Global Climate Models, Statistical Downscaling model, Emission scenarios

1. Introduction

The climate affects to mankind in a wide variety of ways mainly through precipitation and solar radiation. The climate change phenomenon has become a major concern in modern world due to its adverse effects.Climate change prediction is important to understand accompanied impacts and necessary adaptation to minimize adverse impacts. Simulating the natural atmosphere by using computer models is the main tool that is used for climate prediction.

General Circulation Models or Global Climate Models (GCMs) are mathematical models used to simulate the natural atmosphere. GCM outputs cannot be used directly due to the mismatch in the spatial resolution between GCMs and hydrological models. Then the process of downscaling is required to match those spatial resolutions. In order to understand climate change impacts at basin scale GCMs data are downscaled using standard downscaling methods.

There are two standard downscaling methods namely Dynamical Downscaling (DD) and Statistical Downscaling (SD). Dynamical Downscaling (DD) generates regional scale information using Regional Climate Models (RCM) with coarse GCM data used as boundary conditions and Statistical Downscaling (SD) develops quantitative relationships between large scale atmospheric variables (predictors) and local surface variables (predictands) by using statistical methods [1].

Statistical downscaling methodologies have several practical advantages over dynamical downscaling approaches. In situations where low–cost, rapid assessments of localized climate change impacts are required, statistical downscaling represents the more promising option [2].

Statistical Downscaling model (SDSM) is a combination of Multiple Linear Regression (MLR) and the Stochastic Weather Generator (SWG). Quality control, Transform data, Screen variables, Calibrate model, Weather generator, Summary statics, Frequency analysis, Scenario generator, Compare results and Time series analysis are the key functions of the SDSM model.

SDSM model was used by Dharmarathna [3] to select adaptation measures to sustain rice production in Kurunagala District under the impacts of climate change. Minimum and maximum temperature and rainfall data were downscaled from GCM outputs and the forecasted daily maximum and minimum temperatures showed an increasing trend under both A2 and B2 scenarios while annual rainfall did not show a significant increasing or decreasing trend.

De Silva [4] used the SDSM model to downscale past and future GCM data available at a coarse resolution to the Kelani basin. In this analysis the Kelani basin was divided into two sub basins as lower basin and upper basin. Total annual rainfall was shown an increasing trend for both upper and lower basins under high and low emission scenarios.

2. Study Area and Methodology

The area up to the Polgolla barrage of Mahaweli basin which covers an area of 788 km^2 was selected as the study area. Observed rainfall data of ten gauging stations were used for models calibration and validation. Figure 1 illustrates the study area and selected gauging stations.

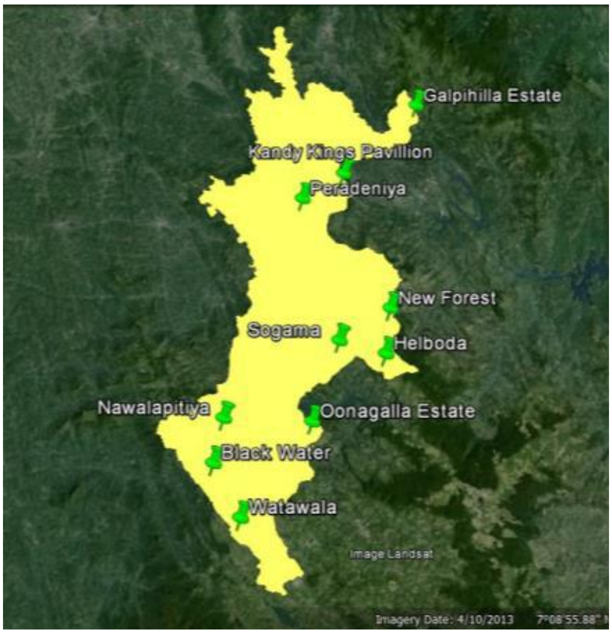

Figure 1: Study area and gauging stations

Observed point rainfall data were spatially distributed over the basin area by Thiessen polygon method and one representative data set for whole study area was generated to feed to the SDSM model.

Statistical Downscaling Model (SDSM) version 4.2.9 was used for climate modelling and rainfall was forecasted up to year 2099 using GCM data**.** GCM data were downloaded from Canadian Climate Scenarios Network [5]. National Centers for Environmental Prediction (NCEP_1961-2001) data set was used to calibrate and validate the model. Then for future rainfall predictions, Hadley Centre Coupled Model, Version 3 (HadCM3) data sets for A2 and B2 scenarios (H3a2a_1961-2099 and H3b2b_1961-2099) were used.

Future forecasts of annual averaged daily rainfall, annual maximum daily rainfall and monthly averaged total precipitations were made under to different emission scenarios namely A2 scenario (high emission case) and B2 scenario (low emission case) of IPCC.

2.1 Model Preparation

Modelling process was set as conditional which assumes an intermediate process between regional forcing and local weather. Forth root transformation was used to convert the skewed rainfall distribution into a normal distribution. The value of variance inflation, which controls the magnitude of variance inflation in downscaled daily weather variables, was set as 18 and the value of bias correction, which compensates for any tendency to over– or under–estimate the mean of conditional processes by the downscaling mode was set as 0.8.

2.2 Model Calibration

Rainfall data from 1971 to 1986 were used for model calibration. The Screening Variable option was used in the choice of appropriate downscaling predictor variables for model calibration. Table 1 illustrates the selected predictor variables among the available 26 variables in SDSM model for the Upper Mahaweli basin.

Table 1: Selected predictor variables for model calibration

Predictor Variable	Description
ncepp_fas.dat	Surface airflow strength
ncepp_zhas.dat	Surface vorticity
ncepp5_fas.dat	500 hPa airflow strength
ncepp5_uas.dat	500 hPa zonal velocity
ncep5_zas.dat	500 hPa vorticity
ncepr850as.dat	850 hPa geopotential height
nceprhumas.dat	Near surface relative humidity
ncepshmas.dat	Surface specific humidity

The simulated values of annual averaged daily rainfall, annual maximum daily rainfall and monthly averaged total precipitations were used to compare with observed rainfall data. Further, the number of dry days of simulated and observed were compared for the above time period. Figure 2 illustrates the comparison done for annual averaged daily rainfall.

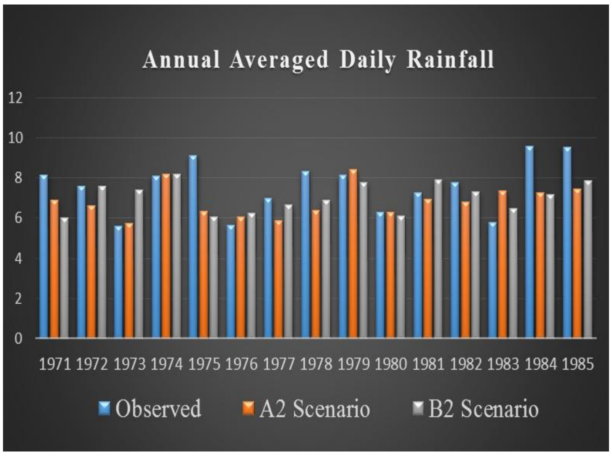

Figure 2: Variation of annual average daily rainfall

The Mean Model Error Percentages (MME %) were calculated to compare the simulated (SR) and observed (OR) rainfall values.

$$MME\ \% = (SR - OR) / OR \times 100\ \% \qquad (1)$$

Figure 3 illustrates the calculated MME percentages for annual averaged daily rainfall under two emission scenarios.

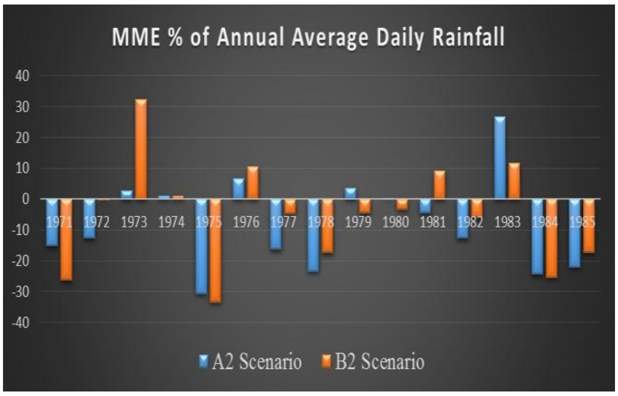

Figure 3: MME% for annual averaged daily rainfall

When calibration period is considered averaged mean model error % values were 13, 13 and 18 for averaged annual daily rainfall, monthly rainfall and number of dry days respectively under A2 emission scenario. Under B2 scenario respective values were 12, 13 and 15.

3.3 Model Validation

Observed rainfall data from year 1986 to 1993 (8 years) were used to validate the model by keeping the same values for variance inflation and bias correction which were used in model calibration stage. Figure 4 shows the comparison between observed and simulated rainfall values for validation period.

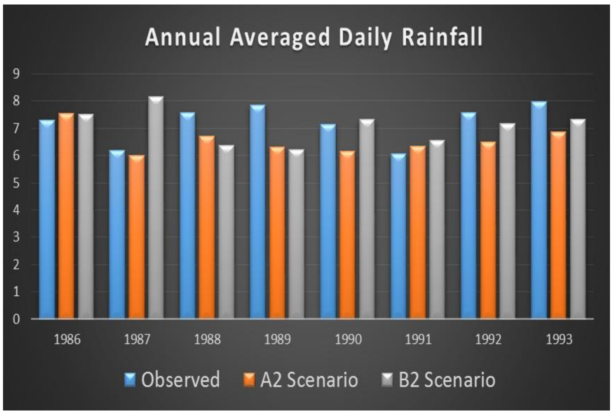

Figure 4: Model validation – Annual averaged daily rainfall

When validation period is considered averaged MME % values were 10, 17 and 10 for averaged annual daily rainfall, monthly rainfall and number of dry days respectively under A2 emission scenario. Under B2 scenario respective values were 12, 13 and 8.

3. Results and Discussion

Calibrated model was used to forecast daily rainfall from 1961 to 2099 under both A2 and B2 scenarios. Following figures illustrate the Time Series Graphs (TSG) derived for annual average daily rainfall, annual total rainfall and annual maximum rainfall under both A2 and B2 scenarios for the study area.

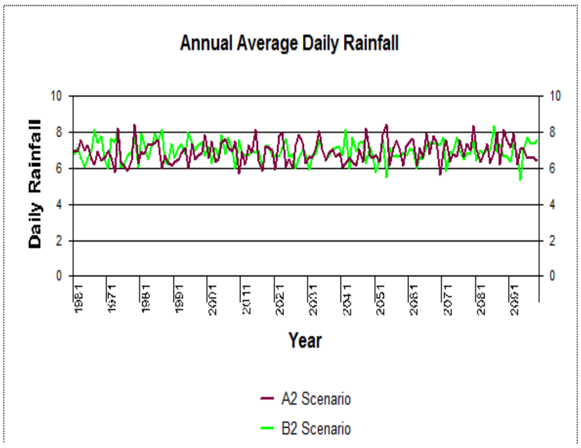

Figure 5: TSG of annual average daily rainfall

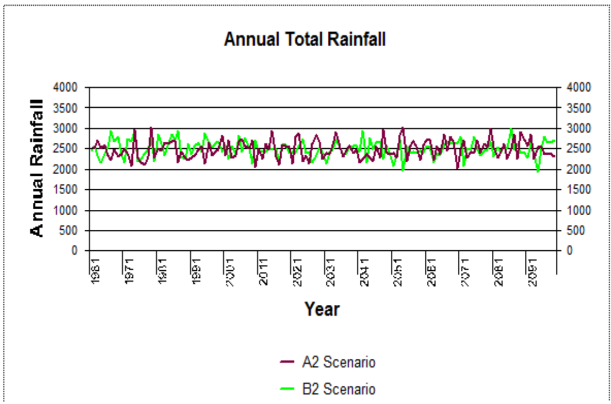

Figure 6: TSG of annual total rainfall

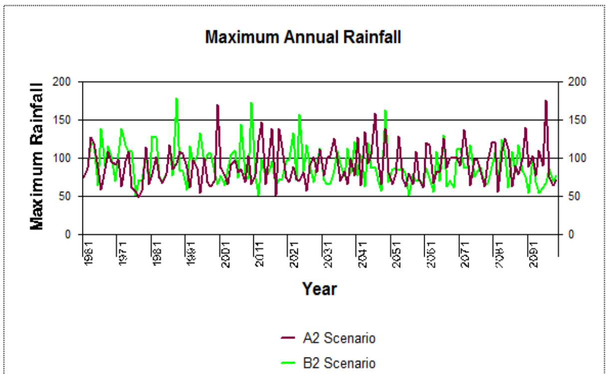

Figure 7: TSG of maximum annual rainfall

Best fit lines for each time series plot under both A2 and B2 scenarios were generated to identify the trend of each variation. Figure 8 and Figure 9 illustrate the best fit lines generated for annual total precipitation under A2 & B2 scenarios.

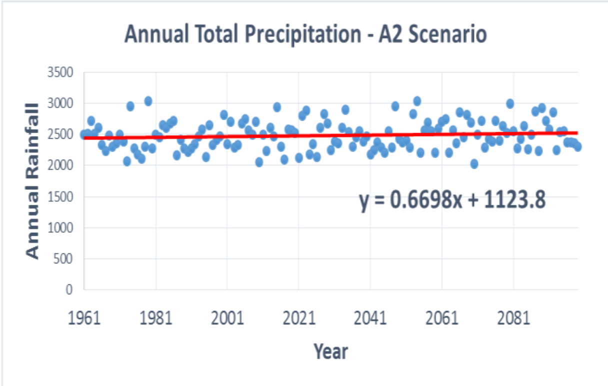

Figure 8: Best fit line for annual total precipitation under A2 scenario

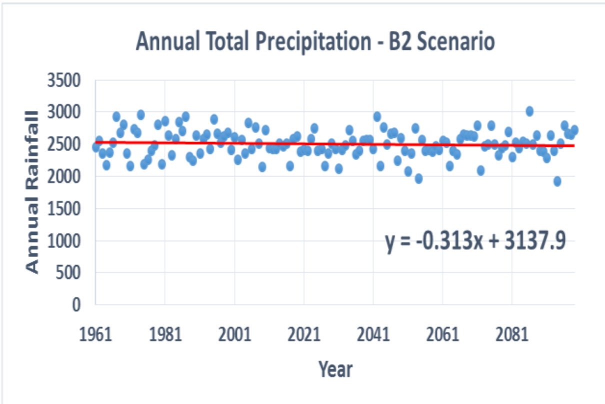

Figure 9: Best fit line for annual total precipitation under B2 scenario

Annual total precipitation, maximum annual rainfall and annual averaged daily rainfall show an increasing trends of 0.7 mm per year, 0.1 mm per year and 0.002 mm per year respectively under A2 scenario. Under B2 scenario all above mentioned parameters illustrate decreasing trends of 0.3 mm per year, 0.15 mm per year and 0.001 mm per year respectively.

4. Conclusions

Annual total precipitation, maximum annual rainfall and annual averaged daily rainfall show increasing trends under A2 scenario and decreasing trends under B2 scenario. But the recorded decreasing trends are insignificant.

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BIM Software Framework for Prefabricated Construction: Case Study Demonstrating BIM Implementation on a Modular House

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Abstract: Building information modeling and prefabrication are concepts that are undergoing intense study in the construction industry. As the technology to implement BIM is commercially available, many industries have started to use BIM in construction related projects. However, BIM implementation can vary significantly according to the nature of the project. Therefore, development of a BIM software framework for a particular industry to meet its requirements is the most efficient way to use Building Information Modeling. This paper will present a BIM software framework developed for prefabricated construction industry and will demonstrate the use of the framework during the design stage of a modular pre-fab house.

Keywords: Building Information Modeling, Prefabrication, BIM Software Framework, Construction

1. Introduction

Prefabricated construction can be considered as an efficient solution to reduce the environmental impact of construction. Building information Modeling (BIM) is an important member of the Prefabrication industry due to its ability to provide an accurate virtual prototype of physical components of the building prior to manufacture at factory. Apart from the design and manufacturing process of building components, BIM will also play an important role during construction and operational stages of a building.

As the technology to implement BIM is readily available with the introduction of 3D building modelling software by industry leaders such as Autodesk, adoption of BIM has increased around the world in the past few years. However, Implementation of BIM varies according to the requirements of a project. Therefore, it is important to use the correct combination of software to create the BIM model for a particular type of construction. BIM software framework demonstrated in this paper will mainly focus on the prefabricated construction industry.

What is Prefab?

Prefabricated construction is defined in this paper as manufacture of complete modular houses, or manufacture of main components in a building in an offsite factory, prior to installation on site.

Prefabrication can be dated back to nineteenth century where it was used by British as a practical strategy to provide shelter to soldiers who were deployed in other countries. It was used as a

There is a significant growth in the prefabricated industry due to the manufacture of prefabricated modular housing. In Australia, with the population growth in 2013/14, 152,000 additional houses were required to be built. However, it has been estimated that there is a short fall of 40,000+ houses compared to the demand (HIA, 2014). In order to cater for the high housing demand, prefabricated housing can be considered as the perfect solution due to its significant improvement in construction time. Prefabricated construction time is 50-60% less than conventional Construction (Rogan, et al., 2013). This time period can be reduced even more by improving the construction sequence in the factory.

Prefabricated construction can vary from complete modular construction to construction of individual building components such as walls, floors, roof trusses etc. The term prefabrication mainly refers to off-site construction, where, factory made components are transported to the building site and assembled to build the complete building. Generally there are three types of prefabricated construction; Modular system, Component system and Hybrid pod system.

Hybrid pod system is where different spaces of the building are manufactured separately in an off-site factory and then transported to the building site for assembly. These pods can be bathroom units, bedrooms, Kitchen and other spaces of the building. This system is mainly used in buildings with many repetitive spaces (i.e.: Apartment Buildings, Office buildings, Hospitals)

Component system is where, different components of the building (i.e.: walls, floors and roof, Duct systems, Piping systems) is manufactured in an off-site factory which can be quickly and efficiently assembled on-site. This system is mainly used in building with less repetitive spaces.

Modular system is where, the complete unit is manufacture at an off-site factory and transported to the site. This system is mainly adopted in prefab housing industry.

According to a study conducted by Queensland University of Technology on 'Profiling the Nature and context of the Australian prefabricated housing industry', the level of prefabrication of complete modular houses is high compared to the level of component based prefabrication (see table I, Steinhardt, et. al., 2013). However, modular prefabrication is not an effective strategy in commercial buildings due to its size limitations. Complete Modular construction is generally limited to the size of a 40-foot shipping container due to transportation difficulties. Therefore, in many cases a combination of modular and component prefabrication strategies are used to overcome the challenges faced during transportation.

What is BIM?

Building information modeling (BIM) can be used as a method of generating and managing information about the building during various stages of its lifecycle (Lee et al., 2006). It can be used as a platform to integrate all key stakeholders during design, construction and operational stages of a project. Although Building information modeling is a concept undergoing intense study at the present time in the AEC (Architectural, Engineering and Construction) industry, it can be dated back nearly thirty years (Laiserin, in Eastman et al., 2011). The concept of BIM is described by Charles M. Eastman in 'The Use of Computers Instead of Drawings in Building Design' published in the AIA journal in 1975.

There are many fields that interact with BIM in a project. They fall under three main categories as Technology, Process and Policy. This concept was originally proposed by (Succar, B 2009) and is presented in figure 1.

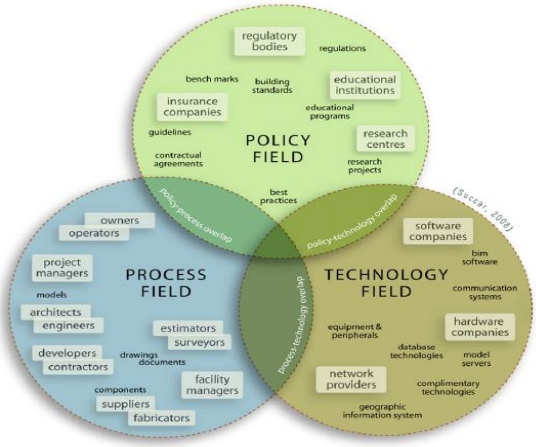

Figure 1: Three interlocking fields of BIM activity
. (Source: Succar, B. 2009)

All the categories have inputs and output to BIM in a project. There are also interactions within and between the categories mentioned in figure 1.

BIM discussed in this paper will be mainly focused on the process - technology overlap shown in figure 1. In other words it will provide a framework of integrating the process and technology fields. Policy category is not in the scope of this paper but will be discussed in the future research.

The visualisation aspect of BIM is mainly considered as a medium of communication between the different fields involved in a particular project and providing logical solutions for problems that might occur during design, construction and maintenance stages of the project. Having a visual model of the finished product will help resolve the problems at early stages of the project. However, BIM is not limited to visualising purposes. BIM can be used to conducted analysis in different disciplines and it can also be used as a construction management tool.

Importance of BIM and Prefabrication for AEC industry

Traditional construction approach often leads to many conflicts between different disciplines during construction stages. This is mainly due to the lack of coordination between these disciplines. In Traditional construction, building services designers, facility management teams and energy consultants are not involved at the initial stages of the project (Mawdesley & Long., 2002).

Generally MEP consultants are introduced to the project when the structure of the building approaches its completion. This results in a very complicated building services design and installation process as engineers will have to use the space provided to install the MEP services. Designers will have to overcome many clashes with the structural design and also with other MEP disciplines. Since the structure of the building is already completed, building services engineers will have to avoid any changes to the structure of the building. However, in many cases where there is no alternative option, changes are made to the structure of the building in order to accommodate the MEP installations. This process can be very costly and time consuming depending on the extent of structural changes required. Construction quality of services is poor in many buildings due to the unplanned installation and space restrictions. Since all disciplines are cramped in one area and are being installed simultaneously by many workers, it will result in poor workmanship and high risk involvement at site.

Poor representation of analysis is also another main drawback of traditional construction. Most of the calculations such as heating and cooling loads, electrical loads and other analysis are done in Microsoft excel or as written calculations. These calculations are not highly accurate and reliable as there can be many human errors. These analysis are not properly documented and due to the complexity of the calculations, they cannot be easily referred to by clients and other building users. Therefore, in many cases these calculations are not used after the completion of the project. Energy analysis, indoor air quality and fire analysis are either ignored or done by separate parties after the construction of the building. In traditional construction, the building is designed to meet the requirements in the standards related to each discipline. This limits the designer's ability to come up with a unique design as often they do not comply with the requirements in relevant standards.

Building Information Modelling (BIM) and prefabricated construction has changed the construction industry from a costly, time consuming and a tedious process to a dynamic, professional, cost and time saving process that is more focused on design and construction of sustainable buildings. There are many benefits for the building services industry from using BIM. Involvement of building services designers from the initial stages of a project is every important in BIM. This will help to develop computation 3 dimensional models that will be used for virtual representations, information storage and analyses in a project. All the information about every element of the model and analyses conducted on the model will be stored in a central location where it can be used for future reference. Significant time and cost savings can be achieved as clash detection can be conducted prior to construction. Integration of all disciplines at the design stage of the project creates the opportunity for prefabricated construction. Many major services such as plant room, chilled water pipes, bathrooms, etc. can be prefabricated at an off-site factory and brought to site for installation. This will reduce the construction time, as most of the testing such as pressure tests and air tightness tests can be done at the factory prior to transportation. Pre-planning of services will result in excellent quality finishes as clashes and other challenges are identified prior to construction stage. Prefabrication of MEP services will reduce the risk of high workforce on site as all discipline will coordinate and produce service modules at the factory and transport it to the construction site.

BIM will create an opportunity for designers to carry out analyses related to building services prior to construction stage in order to get an understanding on how the building will operate after construction. The model can also be used to carry out energy analysis prior to construction, so that energy saving technologies can be introduced during the design stage of the project. This will also help the clients to get an idea on the operational cost of the building. 4D construction simulations can be achieved using software such as Autodesk Navisworks, which will help the project management team as a time line and it will help the health and safety engineers to get a better insight into health and safety challenges that can occur during different stages of construction. Building heating and cooling loads can be calculated using the model rather than using Microsoft excel spread sheets and hand calculations. HVAC duct sizing and pipe sizing can be calculated using the model. Separate reports can be generated for all computational analyses carried out using the model.

Section 2 of the paper will discuss the development of a BIM framework using the software available in the industry and section 3 will demonstrate the use of the BIM framework to create a BIM model of a modular prefabricated house.

2. BIM Software Framework

Due to the wide range of BIM implementation techniques, it is important to develop a BIM software framework based on the requirements of a particular project. However, the framework presented in figure 2 provides a general software framework that can be used in both commercial and residential prefabricated construction projects. All the software used in the framework is commercially available and the interoperability of software was taken into consideration when developing the framework. The software that are not directly compatible with Central BIM model were used as supplementary software to gain the information that can be in the BIM model.

Software used for analyses and development of BIM framework

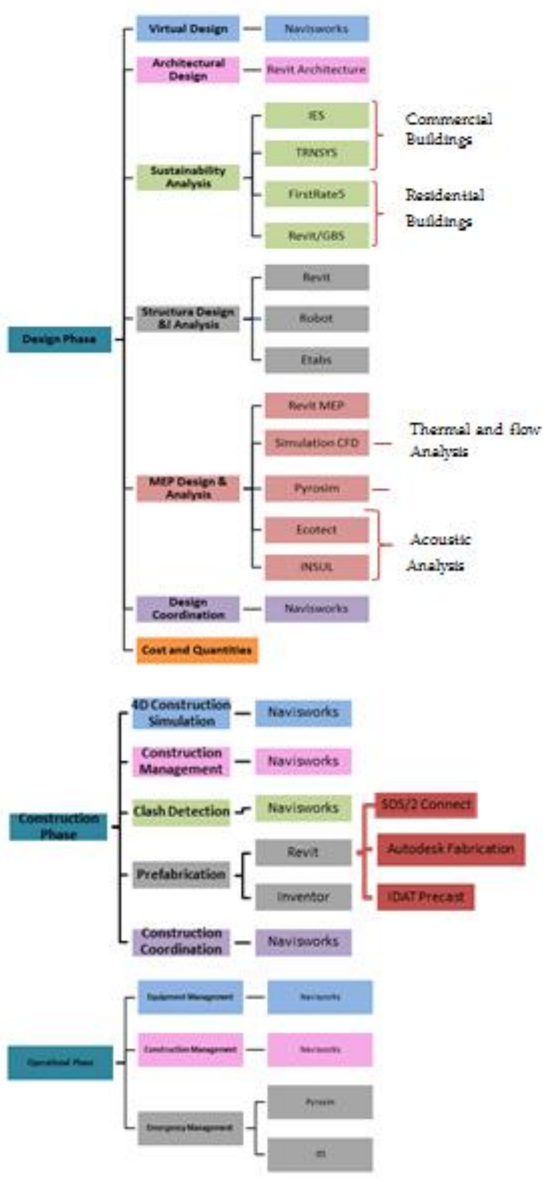

Figure 2: BIM Framework for Prefabricated Construction

Framework for the design stage shown in figure 2 can be used for both conventional construction and phase, SDS/2, IDAT Precast and Autodesk Fabrication will be an important software addition, which will act as supporting tools to generate precise Structural and MEP 3D models for prefabrication at factory.

Case study in section 3 will demonstrate the use of software framework during the design stage of the project.

3. Case-Study (BIM demonstration on Modular House)

The case study project consists of a modular house with two bedrooms, kitchen, Laundry, bathroom, spacious living and dining area. The building is designed to meet the BCA and other relevant standards. It is designed to transport easily and install in a very short period of time. The modular house is designed to be flexible to change in layout. The house is prefabricated as two modules in an off-site factory and is installed on site as one complete modular house. This case study will illustrate the use of different software to conduct analysis and create a complete BIM model that can be used at design, construction and operational stages of the building.

Architectural Design

Three dimensional architectural model was created using Autodesk Revit Architecture. Building materials were assigned as mentioned in table 1. The house was divided into two separate modules for ease of transportation. Main MEP installations were designed to be located on one module to reduce the complications that can arise during the manufacturing and installation of the modules.

Figure 3: Autodesk Revit Architectural model

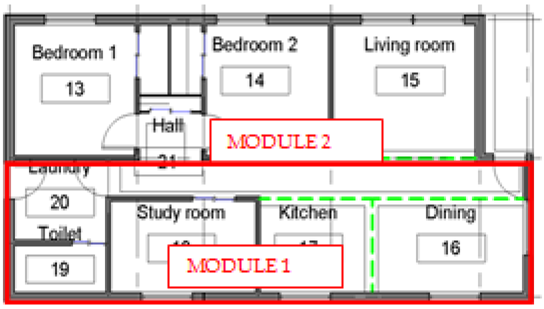

Figure 4: Internal Space separation

Structure and materials

Table 1: Construction Materials

Component	Structure/ Materials
External wall & roof finish	1.6mm PPG Corten steel pre-painted panel, engineered steel structure conforming to ISO/ASTM
Internal wall & ceiling finish	10mm Plasterboard/ Villa Board
Floor finish	15mm FC sheet with vinyl finish
External doors	Sliding aluminium frame external doors
Internal doors	Hollow core timber internal doors
Windows	Aluminium windows with safety glass
Joinery	Laminate MDF cabinets and tops
Plumbing	Copper piping with mains outlet. UPVC sanitary plumbing to outlets
Electrical	All wiring within conduit system Electrical fittings include: Television, phone, data points, light fitting and GPO’s

Building Services Design

Building services is a combination of many disciplines that are required to operate the building after construction. Mechanical, Electrical, Fire engineering, Sustainability and Hydraulics can be considered as main areas of building services. Revit MEP was used with a combination of other software to develop an MEP BIM model for the project. MEP model was linked to the architectural and structural models to create a complete BIM model.

- ***HVAC design***

Two air-conditioning options were modelled on Revit. Option one (Figure 5) is a basic air-conditioning design with a multi-split unit consist of individual indoor units for each air-conditioned area. Option two (Figure 6) is a duct system which serves the air conditioned areas of the house. Duct system is designed with a central duct that runs along the hall area of the house and flexible ducts connecting the inlets to each room. Use of flexible ducts allows the users to change the air-conditioning system if the locations of the rooms need to be changed. Option 2 can be considered as a more architecturally appealing design as there are no indoor units fixed to the walls of the air-conditioned spaces.

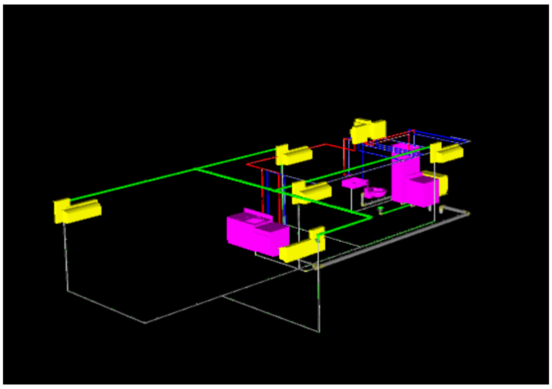

Figure 5: HVAC Option 1

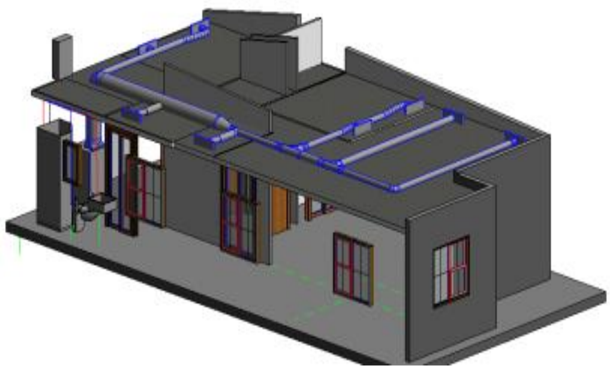

Figure 6: HVAC Option 2

Cooling and Heating load analysis was conducted using IES VE, Revit and FirstRate5 software. Generally for a basic house, a FirstRate5 analysis or a Revit cooling and heating load analysis is sufficient to get an idea of the cooling and heating requirement. However, for a commercial project, it is recommended to use IES VE for load and Energy analysis.

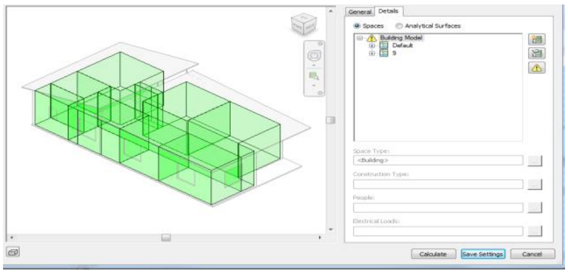

Figure 7: Heating and cooling load on Revit

- ***Thermal Analysis***

Building thermal analysis was conducted using IES VE software. The model created on Revit was imported to IES in order to carryout thermal and energy analysis. Internal room temperature of every room was compared with the outdoor dry bulb temperature in order to get a clear understanding of the thermal performance of the building envelope. Improvements were made to the building envelope in order to achieve an internal air temperature of 18-24^{0}C. The same model was used to gain an understanding of the occupant comfort levels.

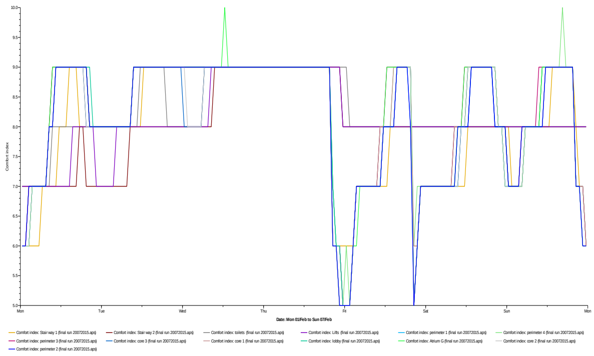
Figure 8: Occupant comfort Index (IES VE)

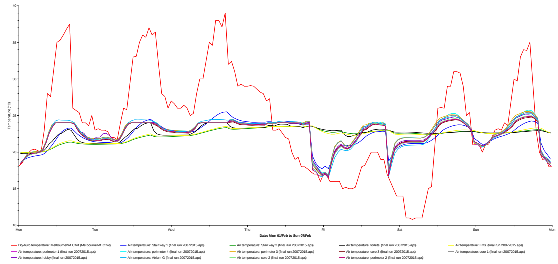
Figure 9: Internal Temperature Analysis (IES VE)

- ***Plumbing Design***

Plumbing design was completed using Autodesk Revit. Three separate plumbing systems were generated for sanitary plumbing, Hot water and cold water in the building. The system was designed in such a way that if required, modular prefabrication can be done separately for the bathroom area. Therefore, Bathroom and other areas have separate plumbing systems for sanitary, ot water and cold water. All piping systems were irected towards the rear of the building for mains utility connections. Pipe pressure loss report can be generated for each system used in the building using Revit.

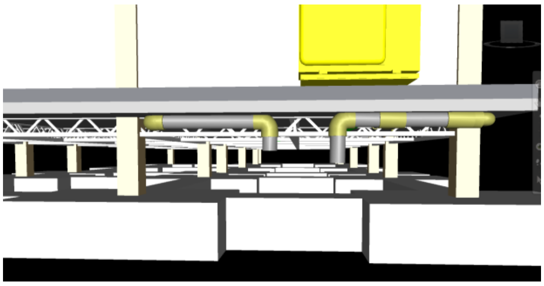
Figure 10: Integrated pluming design (Navisworks)

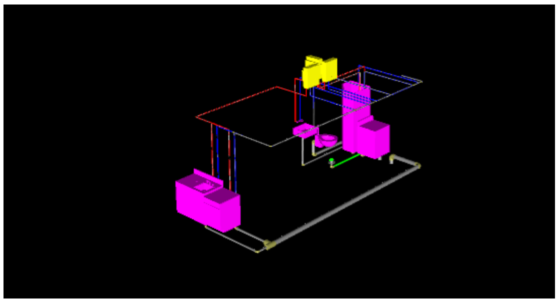
Figure 11: Integrated Bathroom Module (Navisworks)

- ***Electrical Design***

Electrical design was completed using Autodesk Revit. Electrical devices and equipment such as, power outlets, lighting fixtures and panel boards were included in the model. Generally for conventional buildings, wires aren't actually routed in the model and it is left to the contractor on site. However, in prefabricated construction it is important to model the actual conduits and wiring route in the model as the construction process is mostly automated. Electrical load calculations, power and other important details of the electrical system is available on revit and can be genrated as a report.

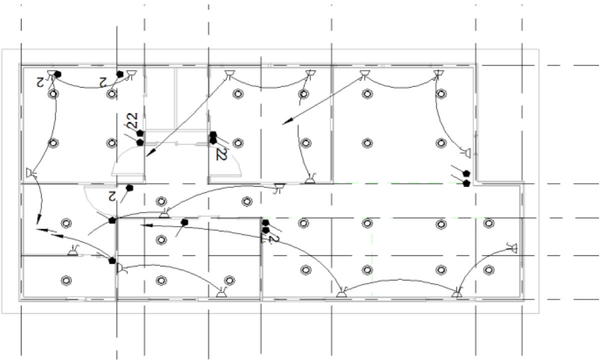

Figure 12: Electrical Circuit Diagram (Revit)

- ***Building Energy Analysis***

Building energy analysis was conducted using Firstrate5, Autodesk Revit (GBS) and IES VE software. Fistrate5 was used as a rating tool to achieve the Australian star energy rating requirements. Generally for a residential project, firstRate5 and Revit (GBS) is sufficient to conduct the required energy analysis. For commercial projects, BIM framework outlined in section 3 of this paper suggest the use of IES VE software. However, in this case study, all three software were used in order to demonstrate the capabilities of each. It was clear from the results that, IES VE provided a more detailed analysis report which can be used to get a clear understanding on the energy usage, thermal comfort, Indoor air quality and daylighting analysis. FirstRate5 and Revit were useful to get a clear star rating for the building.

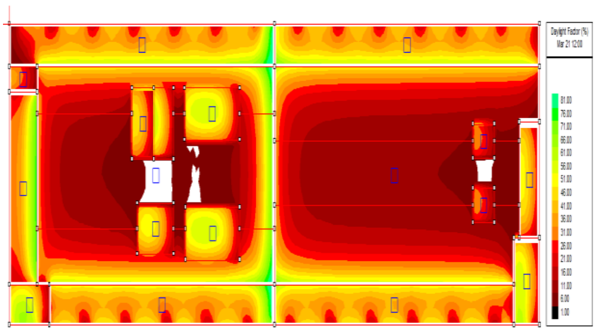

Figure 13: Daylighting analysis (IES VE)

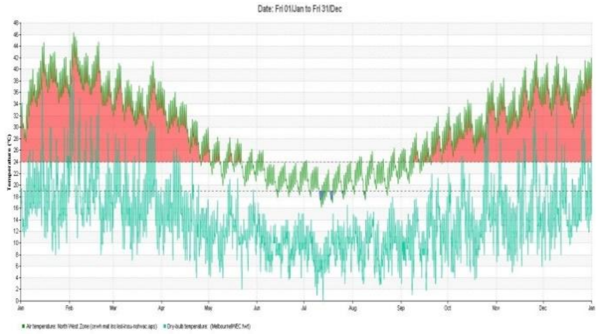

Figure 14: Internal Temperature Analysis (IES VE)

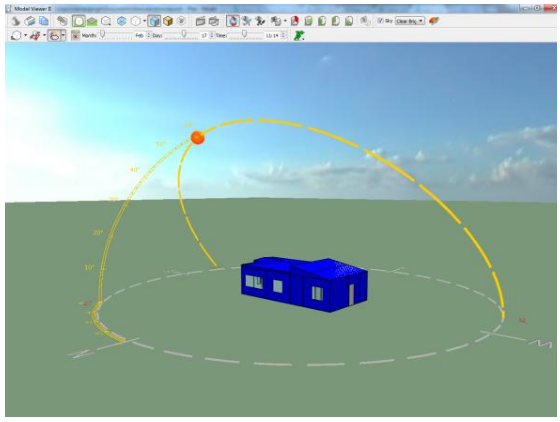

Figure 15: Sun-Path on IESVE

Structural Design

Structural design and analysis was conducted using Autodesk Revit and Autodesk Robot software.

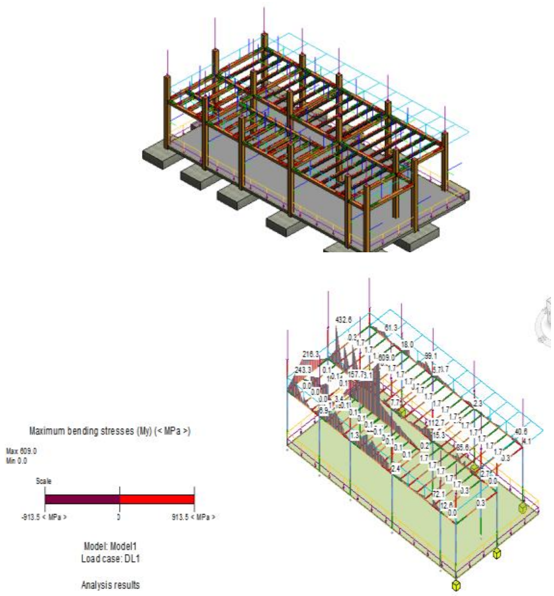

Figure 16: Structural Model developed using Autodesk Revit and Robot

Acoustic analysis

Building acoustic analysis was constructed using INSUL. The software was used to examine the acoustic performance of each building component (i.e. wall panels, floor and ceiling). The software can be used to predict transmission loss, impact sound and rain noise. Trial version of the software was used for demonstration purposes.

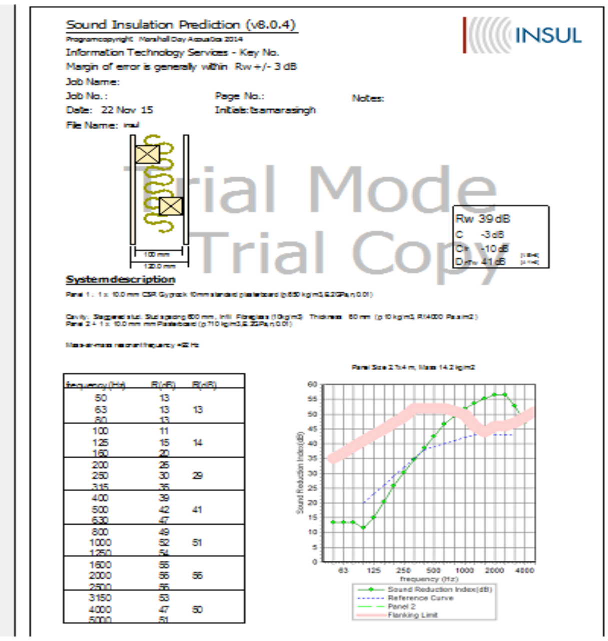

Figure 17: Acoustic report generated on INSU

Model integration to create BIM

All Designs developed on Autodesk Revit were exported to Autodesk Navisworks to create the integrated BIM model. All analysis conducted on different software can be linked to Autodesk Navisworks to create a central BIM model that can be used for clash/interference detection between the disciplines, Quantity surveying, Cost calculations, 4D construction simulations. The model created on Navisworks can be used as a communicational tool within the project during the construction stage.

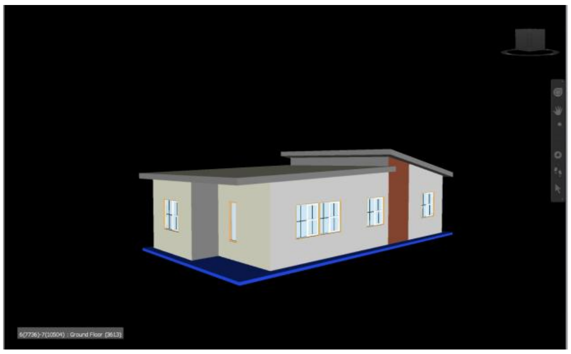

Figure 18: Integrated model on Navisworks

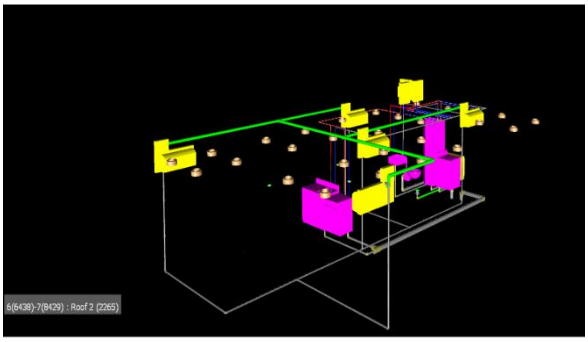

Figure 19: Integrating MEP Models on Navisworks

4D construction simulations and Quantities

Complete integrated BIM model can be used on Navisworks to create 4D construction simulations. Autodesk Navisworks, allows the user to integrate the construction time-lines developed on Microsoft project or Excel to be integrated with the complete 3D models to create a 4D construction simulation. Construction simulation can also include the temporary site constructions and site preparations. This model can be then used to calculate the quantities and costs of the project.

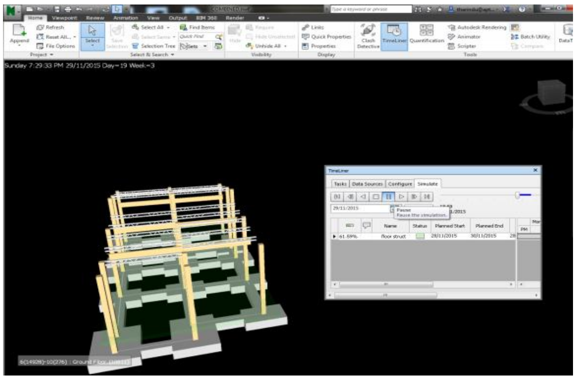

Figure 20: 4D construction simulation on Navisworks

Clash detection and drawing Review

Integrated models can be used to check for clashes in Autodesk Navisworks. Individual fields can be examined to detect clashes with another discipline. Separate view ports can be created for different clashes and comments can be made in the model itself. Navisworks also can generate a complete clash detection report where different parties responsible for providing solutions can be assigned to the task.

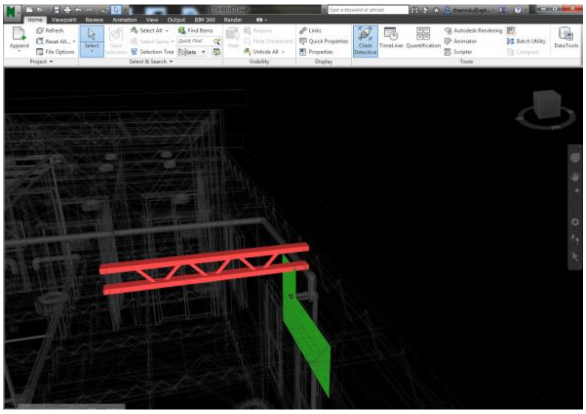

Figure 21: Clash Detection run on

4. Conclusion

BIM framework was developed using the software available in the industry and the case study project was used to demonstrate the use of the BIM framework during the design phase of a prefabricated housing project. Most of the analysis related to residential buildings were demonstrated using the software mentioned in section 3. Fire and evacuation modeling is not demonstrated in the case-study as it is generally conducted for commercial buildings. However, main areas such as, integration of different disciplines, clash detection, 4D construction sequence, thermal and energy analysis were demonstrated using the case study model.

Most of the analysis demonstrated in section 3 of the paper can be implemented on complete module, component basis or hybrid prefab construction. Integration of different disciplines, clash detection and construction sequence can be considered as critical areas in a prefabricated construction project. Software use during the construction phase of the project is not demonstrated in the case study as it will be demonstrated by using a different case study project in the future literature. However, development of a BIM model using the frame work in section 2 can be used in prefab, conventional and hybrid construction approaches to achieve many benefits during the construction life cycle of a building.

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Strategies for Planning Mould Free Air Conditioned Buildings in Tropical Climates

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Abstract: Buildings constructed in tropical climatic conditions must be designed to have a very low carbon foot print that will need the buildings to be used as free running while ensuring adequate thermal comfort with passive means. However, there could be certain instances when the use of active means of thermal comfort like air conditioning will be inevitable due to special requirements. Hospital buildings or buildings with special equipment would need lower indoor temperature like 15 – 18 ^{o}C compared to the ambient temperature in tropical climates. Thus, the growth of mould on the building elements such as walls and floors of the surrounding areas will be inevitable unless special planning provisions have been used with strategically placed buffer zones that will have normal air conditioning which maintains indoors with relatively lower levels of moisture content. Mould created on various building elements can produce spores, air-borne particles and gases which are harmful to the humans and built environments. In order to identify the magnitude and the causes for mould growth, a comprehensive research was carried out with a case study in a hospital building planned without attention to much detail and hence led to a severe growth of mould, where several concerns were raised by the occupants of the building, related to sick building syndrome. This will shed light on special planning precautions that must be taken by the architects and engineers who plan buildings with specially air conditioned spaces in large buildings located in countries with tropical climatic conditions.

Keywords: Mould growth, condensation, air conditioned buildings, air quality

1. Introduction

World Health Organization [1] defines mould as all species of microscopic fungi that grows in the form of multi cellular filaments, called hyphae. Studies conducted in many countries indicate that significant percentage of indoor environment in buildings has shown signs of dampness and mould growth [2] [3] [4] [5] [6] especially in higher scale where low income levels prevail [7] [8]. Fungi are ubiquitous eukaryotic organisms, which may be transported in to buildings by sticking on the surface of materials or active and passive ventilation. Mould growth in building elements is a consequence of an interaction between environmental factors (temperature and humidity), material properties, and the characteristics of mould fungi. [9]

Fungi also need nutrients such as proteins, lipids, and carbohydrates. Fungi can also grow on inert materials like ceramic tiles obtaining nutrients from dust particles and soluble components of water [1]. Indoor fungal growth is mainly due to moisture but other factors such as temperature and nutrients can affect the rate of growth and the production of allergens and metabolites [10]. Mould creates an unpleasant impression and people are always reluctant to enter into such buildings. Indoor mould growth is a severe problem since Bacteria [11] [12] [13] such as Streptomycetes [14] and Viruses [15] can grow in the same areas as moulds grow. Spores which are products of replication of mould and fungal fragments that can stay airborne for long periods of time are prone to be deposited in the respiratory system [16] and respiratory tract [17] which is known to contain harmful allergens [18] and mycotoxins [19]. There is sufficient evidence to suggest the association of mould and building dampness with upper respiratory tract symptoms, Wheeze, Cough, and Asthma by the findings of the Institute of Medicine [2] and other studies conducted in different geographical regions [20] [21] [22] [23]. The study covered in the paper is based on a detailed investigation carried out in a Hospital building in Sri Lanka where mould growth has been a severe problem for the occupants. The extent of mould growth and the related environmental parameters were determined on which the remedial measures were based.

2. The Case Study

The study was carried out in a four storied building, used as a hospital which was constructed in 1997. A temporary roof covers the 4th floor slab of this building. It was reported that frequent repair work in the form of repainting has been carried out on regular basis due to mould growth inside the building. Thus a detailed investigation on mould growth and related air quality parameters was carried out inside building.

The investigation work included the identification of activity spaces of the building, monitoring of thermal and air quality parameters, observing the mould growth and ventilation conditions. The activity spaces were categorized in to four main areas depending on the usage and the ventilation as follows:

- Naturally ventilated areas
- Air conditioned areas
- Specially air conditioned low temperature areas
- Wash rooms

2.1 Mould growth

Figures 1 – 4 show the activity spaces and the extent of mould growth in those spaces which was determined by observation. Since the literature highlights the air quality issues related to mould growth, a comprehensive set of measurements was taken to quantify the concentrations of CO_2, NO_2, VOC, CO, PM2.5, the indoor temperature and relative humidity (RH). These readings were recorded over a period of four days at four different locations. The locations where the readings were taken are indicated in the Figures1 – 4.

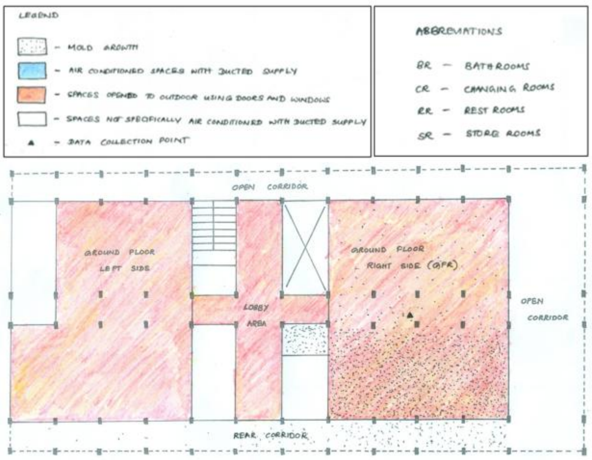

Figure 1: Activity spaces and the extent of mould growth in ground floor

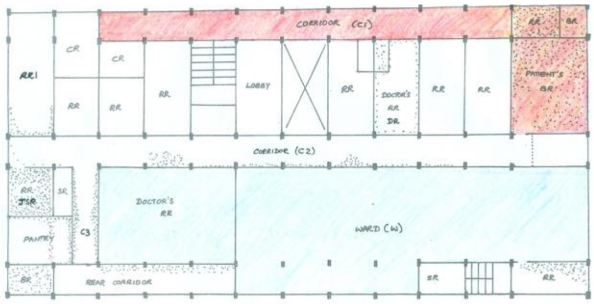

Figure 2: Activity spaces and the extent of mould growth in the first floor

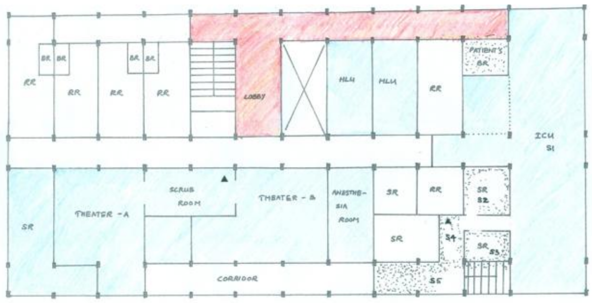

Figure 3: Activity spaces and the extent of mould growth in the second floor

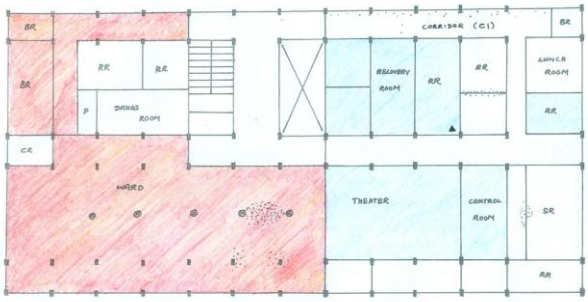

Figure 4: Activity spaces and the extent of mould growth in the third floor

The mould growth could be seen on the ducts, walls, ceilings, pipes, ceiling fans etc. Further to that Mould growth exists even in very important laboratories where critically sick patients are treated. The severity of mould growth in this building is shown in Figure 5 and 6.

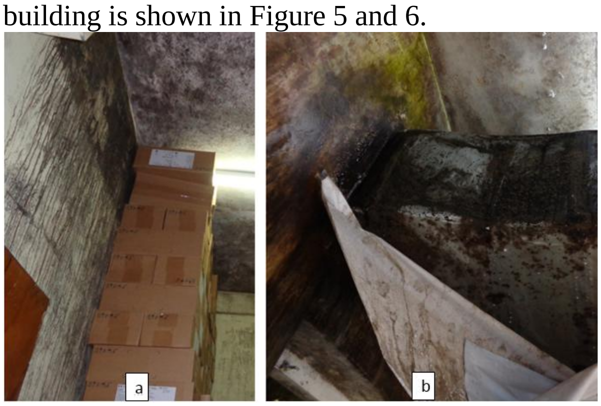

Figure 5: Severe mould growth (a) ICU store room S2 at second floor (b) A duct in S5 at second floor

2.2 Air Quality

In order to monitor the indoor environment air quality parameters CO2, NO2, CO, VOC and PM2.5 were measured at the selected locations in all four floors and compared those with the threshold values indicated in the standards that are shown in Table 1.
The Indoor Air Quality Monitor (IQM60 Environmental Monitor V5.0) was used to measure TVOC (total VOC), CO, CO2, NO2, Temperature and RH (relative humidity) moreover PM2.5 was measured using Haz-Dust Particulate Air Monitor as shown in Figure 6.

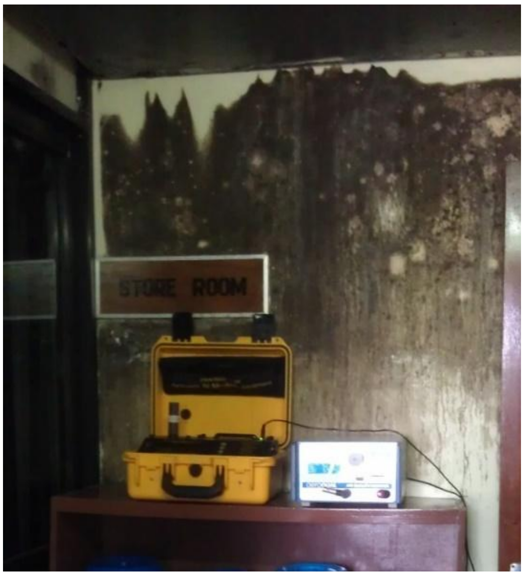

Figure 6: A data collection point at ICU in 2nd Floor

Table 1: Threshold values for indoor air quality (IAQ) pollutants recommended by several organizations

Pollutant Name	Threshold Limit	Organization
CO_2	1000 ppm	ASHRAE [24]
NO_2	0.053 ppm 24-hour mean	ASHRAE [24], US EPA [25]
CO	9 ppm	ASHRAE [24]
VOC	0.75 ppm	OSHA [26]
$PM_{2.5}$	25 $\mu g/m^3$ 24-hour mean	WHO [27]

Air quality parameters were measured in all four floors and the variations for each IAQ parameter showing the most critical values are presented in the paper with possible impacts and causes.

2.2.1 Carbon Dioxide

CO_2 is a colour-less and odour-less gas. Despite the fact that it is non-toxic, if CO_2 concentration is too high, it can be unpleasant and perhaps unhealthy for the building occupants. Indoor Carbon dioxide at levels that are unusually high may cause occupants to feel drowsy, get headaches, or function at lower activity levels. Humans are the main indoor source of carbon dioxide. Indoor CO_2 levels could be an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity [28].

Chart 1shows the variation of the highest CO_2 concentration which has exceeded the recommended threshold of 1000 ppm. This variation was recorded in the Cath lab in the third floor of the building where patients and the medical staff are affected by the adverse effects. Since CO_2 is a direct indication of ventilation, an improved air conditioning system is proposed to supply fresh air to dilute the high CO_2 concentration.

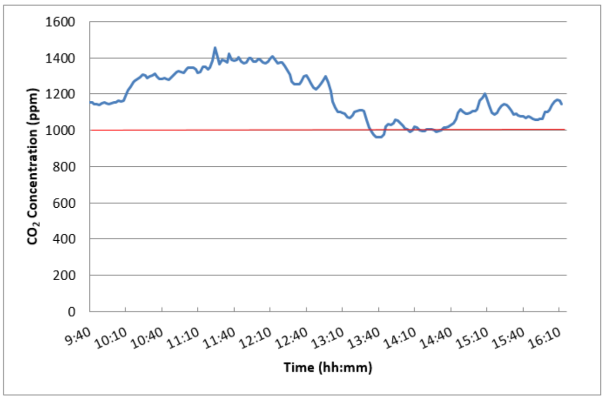

Chart 1: CO_2 Concentration variation in Cath Lab (3rd floor)

2.2.2 Carbon Monoxide

Carbon Monoxide directly interfere with the oxygen carrying red blood cells of the human body, significantly reducing the supply of oxygen to the heart and other organs, by creating a permanent bond with red blood cells called Carboxyhemoglobin. Exposure to CO may contribute to cardiovascular mortality and may also an early cause of heart attacks. Patients with coronary artery disease are considered as most sensitive to CO exposure, with aggravation of angina occurring in patients. Exposure to CO can develop a range of symptoms, such as headaches, weakness, dizziness, nausea, disorientation, confusion and fatigue in healthy people [29], [30].

As shown in Chart 2 Carbon Monoxide was also found to be in excess of the threshold value in the Cath lab located in the third floor which could be due to the activities going on inside the laboratory. Since high CO could cause serious problems for the patients and the staff, proper extraction of toxic gases should be done with a good exhaust system coupled with pumping of fresh air to dilute the higher concentration of CO.

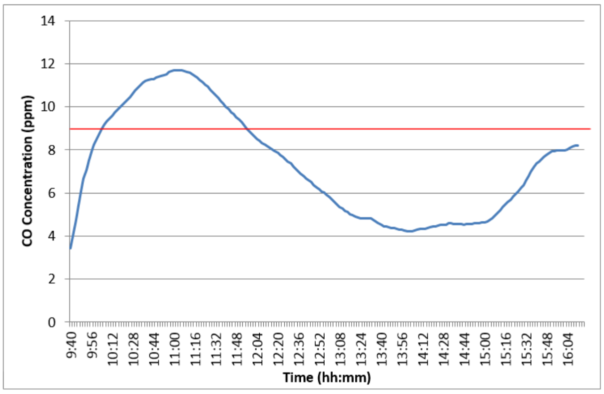

Chart 2: CO Concentration variation in Cath Lab (3rd floor)

In the Cath Lab located at 3rd floor level, the CO2 and CO levels could be high along with VOC from time to time. It is preferable to maintain the CO2 level below 1000 ppm and the threshold value for CO is 9 ppm.

2.2.3 Nitrogen Dioxide

Exposure into NO_2 can cause respiratory problems of various magnitudes depending on the level of exposure. Short term exposure can cause skin and eye irritation whereas long term exposure into NO_2 can affect the lungs, chest, burning sensation, etc. Frequent exposure into high concentrations could lead to increased incidents of acute respiratory illnesses, where the children are the main victims [31]. Chart 3 shows the variation of NO_2 in the 2nd floor ICU.

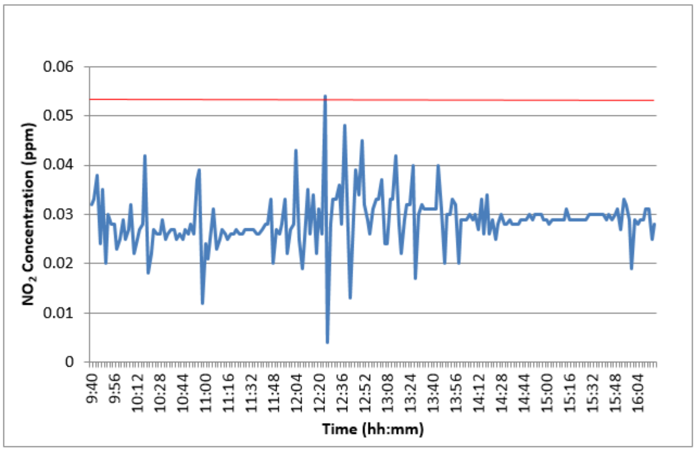

Chart 3: NO_2 Concentration variation in ICU-S4 (2nd floor)

2.2.4 Volatile Organic Compounds

In indoor environments, there can be many different VOC substances in varying concentrations. There are six major classes of VOCs such as aldehydes (formaldehyde), alcohols (ethanol, methanol), aliphatic hydrocarbons (propane, butane, hexane), aromatic hydrocarbons (benzene, toluene, xylene), ketones (acetone) and halogenated hydrocarbons (methyl chloroform, methylene chloride) [1]. Formaldehyde is highly reactive and can irritate body surfaces containing moisture such as eyes and upper respiratory tract. Materials containing formaldehyde release formaldehyde gas into the air. Short term effects include eye, nose, throat and skin irritation, headaches and allergic sensitization. Long term exposure to VOCs can cause carcinogenic effects [32].

The highest values for the VOC were recorded in the ICU of the third floor where lot of chemicals are used for the patient care and cleaning. The medical staff who works there complained of various sick building symptoms which could be linked up with high VOC contents. This can obviously affect the patients as well since most of them are having heart related sicknesses. A properly designed mechanical ventilation system to extract the toxic gases is proposed for the timely dispersion of VOCs. Variation VOC concentration in the 2nd floor ICU is shown in Chart 4.

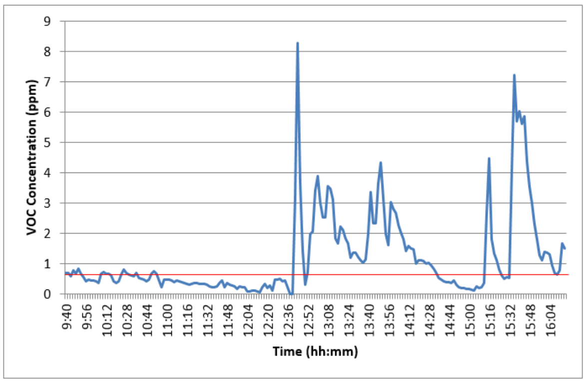

Chart 4: VOC Concentration variation in ICU-S4 (2^{nd} floor)

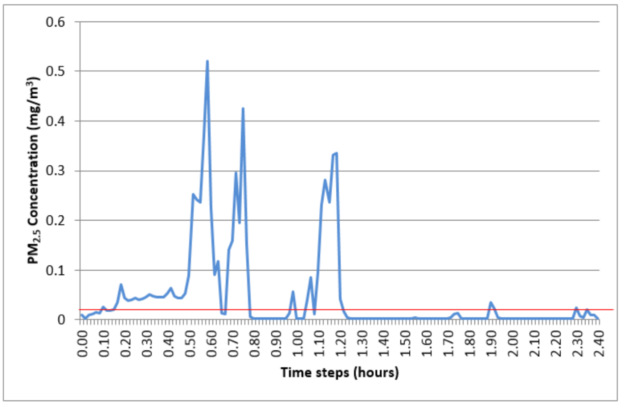

Chart 5: $PM_{2.5}$ Concentration variation in ICU-S4 (2^{nd} floor)

In the Intensive Care Unit (ICU) at the 2nd floor level, CO2, NO2 and CO levels are acceptable. VOC and PM2.5 have indicated many peaks that could be due to the various chemicals used in the ICU. A similar observation was reported in the operation theatre of the 2nd floor as well.

2.2.5. Particulate matter

The particles with an aerodynamic diameter less than or equal to 2.5 micro meters is defined as $PM_{2.5.}$ Particulate matter resulting from combustion can affect the lungs directly.

Smaller particles can create more serious problems since they can penetrate deeper into the lungs and create respiratory problems. The outdoor air which enters into the building can also be a significant source of indoor airborne particulate matter [30], [28], [33]. Variation of Particulate matter in 2^{nd} floor ICU where it was recorded highest is shown in the Chart 5.

2.3 Temperature and humidity

The indoor temperature and the relative humidity values were recorded in all four floors. Four locations were selected in the first floor level to present the temperature differences occurring in the adjacent rooms which will form condensation and resulting mould growth. The locations are Doctor's room (DR), junior staff room (JSR), the rear corridor and the ward. The temperature and RH of the ward were recorded continuously. In Table 2 and Table 3 the temperature and humidity of the ward and the outdoor are given respectively together with the other locations for comparison purposes. For example, in doctors' room (DR), the temperature range is 23^0C – 25^0C. At the same time, the temperature range of the ward was 20^0C – 23^0C and the outdoor temperature was 28^0C – 31^0C. The RH values of Table C.3 can also be compared in the similar manner.

Table 2: Temperature at different locations at first floor

Location	Temperature at selected location (^{0}C)		Temperature within Ward (^{0}C)		Temperature at Outdoor (^{0}C)	
	Mean	Range	Mean	Range	Mean	Range
Doctor's room (DR)	24	23 - 25	21	20 - 23	30	28 – 31
Junior staff room (JSR)	24.5	24.5 - 25	21.5	19 – 22.5	27	26.5 – 27
Rear corridor	25	-	22.5	22.5 - 23	27	27 – 27.5

Table 3: Relative humidity (RH) at different locations of first floor

Location	RH at selected location (^{0}C)		RH within Ward (^{0}C)		RH at Outdoor (^{0}C)	
	Mean	Range	Mean	Range	Mean	Range
Doctor's room (DR)	78	68 - 91	65	52 - 73	64	70 – 78
Junior staff room (JSR)	85	80 - 92	81	79 - 83	81	81 – 84
Rear corridor	87	84 - 88	80	79 - 83	86	84 – 88

2.4 The identified causes for mould growth

The growth of the mould can be isolated to few locations in the building. One notable feature has been the absence of mould growth in areas that can be identified as specially air conditioned with low temperature (SACLT). The very low temperature in these areas means low moisture content in air (as low as 10 – 11g/kg of air) and hence the prevalence of dry conditions along with low due point.

Mould growth has not been very severe in areas that have normal air conditioning as well. The areas that are not air conditioned but located close to SACLT areas have shown severe growth of mould as indicated in Figure 2and 3. This observation indicates that in the naturally ventilated areas adjacent to SACLT areas, the prevalence of extremely low temperatures could lead to condensation on floor slabs and walls. The prolong prevalence of moist environment has promoted the growth of mould.

The temperature of SACLT areas can be as low as 18^{0}C during night time. Since 24 hour air conditioning is provided, the surrounding walls and slabs of these areas can also reach similar temperatures. The moisture content in this location varies between 14 g to 18g per kg of air in general and sometimes reaching even up to 20g/kg of air [34]. When there is 18g/kg, the dew point is 23^{0}C and when it is 14g/kg, the dew point is 19^{0}C. These values can be obtained from the Chart 6(solid line). When the temperature of a surface is above dew point temperature, condensation will not occur. A surface maintaining a temperature lower than the dew point runs the risk of forming moisture.

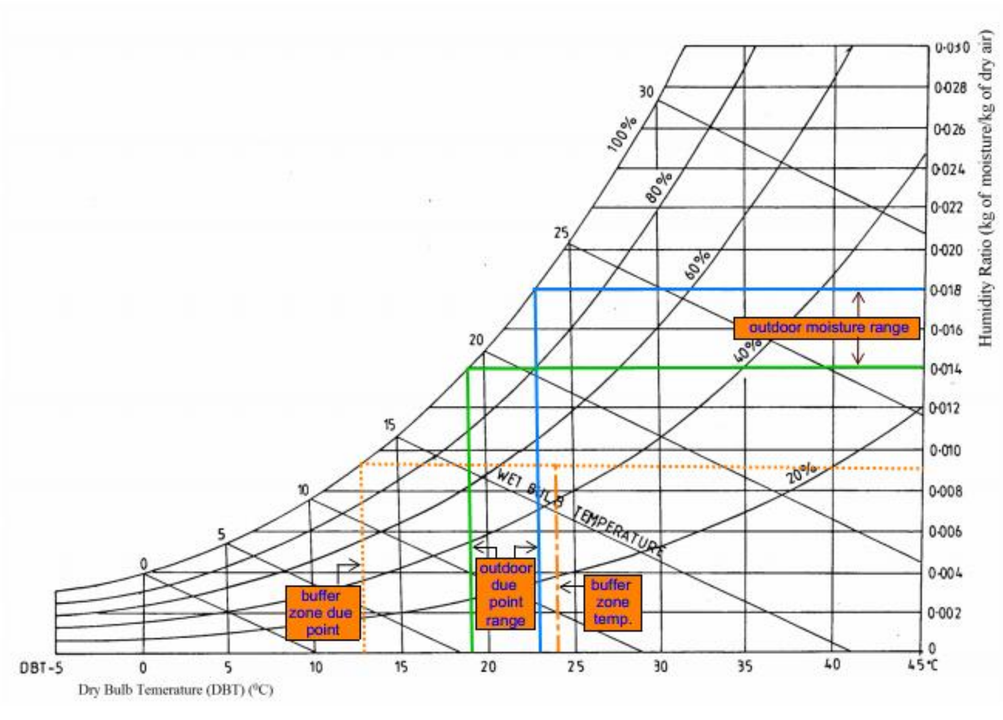

Chart 6: Psychometric chart for outdoor and buffer zone

When the temperature of a surface is exposed to outdoor air is as low as 18^0C, condensation can occur since the dew point of outdoor air could be 19^0C or above in Colombo. However, when the surface temperature is about 24^0C, such a possibility is remote since even with 18g/kg moisture content, the dew point is 23^0C. This is the reason for having mould on some areas as very severe and some other areas as to a lesser extent or no mould problem at all even when under natural ventilation.

2.5 Remedial measures

When the temperature of an air conditioned space is 240C with about 50% RH, as indicated by the broken line in Chart 6, the moisture and the dew point are around 9g/kg and 130C respectively. This indicates that when a normally air conditioned space is next to SACLT area, there is no chance of condensation since the dew point temperature(130C) is less than the lowest likely temperature(180C) that could occur in the slabs and the walls.

The dew point of normal air (outdoor) even with 20g/kg is about 250C. With a more likely maximum of 18g/kg for outdoor air, the dew point is about 230C. When the indoor is maintained at about 240C, the surface temperature of the slabs and walls would be in the range of 240C – 250C. This means that under normal conditions prevailing in Colombo, it is highly unlikely to form moisture except in a few days where the moisture content in outdoor air reaching unusually high values like 20g/kg. Hence, there will not be any prolonged condensation problem when a naturally ventilated area is located next to normally air conditioned area.

This means the solution to the mould growth in the building lies with the formation of buffer zones between SACLT areas and naturally ventilated areas. The buffer zone should be a normally air conditioned area.

3 Conclusion and Recommendations

Mould growth in buildings has been identified to cause building related health problems which could be termed as Sick Building Syndrome. A detailed study covered in this paper highlighted the causes for the mould growth, and remedial measures. Condensation created by the temperature gradient of the adjacent activity spaces of the building, has created dampness in some parts of the building which in turn cause mould growth. The case study has revealed that the activity spaces, adjacent to the spaces with very low temperature were observed with higher magnitude of mould growth. This has resulted degradation of related indoor air quality parameters, VOC, PM2.5 and CO in selected activity spaces. Psychometric chart was used to explain the theoretical background to the condensation occurring. A buffer zone with normally air conditioned space has been recommended as the remedial measure to minimize the condensation which in turn will reduce the mould growth. Moreover, a proper ventilation system with extraction of toxic gases generated by various activities would result better air quality insider the building.

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SECM/15/174

Performance of Sand Cement Block Produced With Partial Replacement of Cement by Rice Husk Ash

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Abstract: The sand cement blocks are cement composites and have been widely used in many countries including Sri Lanka. Rice husk ash (RHA) is a waste material with pozzolanic properties. The use of RHA as a substitute of cement is a sustainable application which solves the problem of its disposal by minimizing the environmental pollution. This paper discusses on the performance of a cellular sand cement block containing rice husk ash through an experimental investigation. The burning temperature of the RHA obtained from power plant is 650°C. Ordinary Portland Cement (OPC) was partially replaced with RHA having different fineness at 5%, 10% and 15% replacement levels to produce sand cement blocks. Particle size of the finer RHA was less than 75 µm. Compressive strength increased up to the 10% cement replacement level only with finer RHA. Replacement percentage beyond the 10% lead to decrease the compressive strength of sand cement block. However, cement replacement with coarser RHA decreased the compressive strength at all the replacement percentages. The density of sand cement block decreased as RHA content increased. Moreover, higher water absorption capacity was observed at higher RHA content.

Keywords: Cement, Compressive strength, Rice husk ash, Sand cement block

1. Introduction

The utilization of rice husk ash as a cement replacement is a new trend in concrete technology as it enhances the properties of concrete and mortar while minimizes the negative environmental impacts. Rice husk is an agro-waste product obtained from the outer covering of rice grains during the milling process. Rice husk contains about 50% cellulose, 25-30% lignin and 15-20% silica (SiO_2) and it constitutes 20% of the 500 million metric tons of rice harvested annually in the word [4].

RHA is used as a partial replacement of cement on structural properties of concrete and mortar, reducing the cost for cement and is produced by the controlled incineration of rice husks to obtain high amount of amorphous silica with low carbon content. Suitable incinerator and grinding method are required for burning and grinding in order to obtain good quality ash [8].More than 90% (in mass) of the RHA which is produced in optimum combustion temperature of 600 °C is made up of amorphous silica [7].Generally, the average particle sizeranges from 5 to 10 µm, and the specific surface area ranges from 20 to 50 m^2/g, depend on the conditions of burning and grinding. However, controlled combustion of rice husks produces good quality ash with higher amount of amorphous silica compared to open field burning which results for the higher amount of unburnt carbon in the ash. Amorphous silica reacts with the $Ca(OH)_2$ produced during the hydration of cement by producing secondary type of calcium silicate hydrate gel which leads to higher strength development of mortar and concrete.RHA is an active pozzolan which improves strength because they are smaller than the cement particles and provide a finer pore structure.

Cement blocks are masonry units generally used for the building construction in Sri Lanka. They are used for load bearing and non-load bearing walls. Therefore, structural performances of blocks should be mainly considered for wall types. There is an increasing interest of using sand cement blocks made with RHA as masonry units in building and minor civil engineering constructions since it reduces the cost for cement used in sand cement block production. The use of RHA in sand cement block also decreases the solar heat gain in buildings and improves the thermal comfort [5]. The RHA based sand cement block shows higher water absorption properties compared to block made with 0% RHA. Moreover, density of sand cement block also decreases with amount of RHA.

Therefore this research is aimed at investigating the effect of partially replacing cement with the RHA having different fineness mainly on the compressive strength, density and water absorption of sand cement block.

2. Experimental Programme

2.1 Materials

For the purpose of this research Ordinary Portland cement complying with BS 12 [3] was used. Rice husk ash was obtained from Bio-energy power plant is shown in Figure 1.

Figure 1: As-received RHA

Sieve analysis was carried out to prepare two RHA samples having different fineness. According to Table 1, Particle size less than 75μm was considered as sample U while particle size between 75-150 μm was considered as sample M.

Table 1: Sample notation of RHA

RHA sample type	Particle size
U	< 75 μm
M	75-150 μm

Locally available natural river sand was used as fine aggregate with maximum aggregate size of 5 mm. Pipe borne water, fit for drinking was used for the manufacturing and curing of sand cement blocks.

2.2 Preparation of blocks

The cellular sand cement block samples having the size of 390mm x 100mm x 195mm were produced by using local block manufacturing machine shownin Figure 2.

Figure 2: Local block manufacturing machine

The cement-sand mix proportion of 1:6 was used to prepare the sand cement block samples. Batching was done by volume. Predetermined material quantities were measured by using a weighing balance. Three cement replacement percentages with RHA by weight (i.e., 5%, 10% and 15%) were used. The constant water/binder ratio of 0.7 was used for the manufacturing all sand cement blocks. Hand mixing was employed throughout the process. The sand cement blocks were prepared with RHA sample U and sample M for each replacement percentage. Figure 3 shows the prepared RHA based sand cement blocks.

Figure 3: RHA based sand cement blocks

2.3 Testing methods

2.3.1 Compressive strength

Crushing machine was used to measure the compressive strength of block samples as shown in Figure 4. Two block samples were tested for each replacement percentage at 28 days and average strength was calculated. Compressive strength values of sand cement blocks made with RHA were compared with the compressive strength of control (0% RHA) block.

Figure 4: Compressive strength testing

2.3.2 Water absorption

Water absorption test was carried out to compare the water absorption behaviour of RHA based sandcement blocks with control block sample. Hence, two block samples from each replacement percentage were first kept in an oven for 24 hours at a temperature of 100^{o}C-105^{o}C and dry weights were measured as shown in Figure 5. Then the block samples were immersed in water for 24 hours and wet weights were measured. Water absorption capacity was determined for each block sample and the average values were calculated.

Figure 5: Weighing of oven dried sample

2.3.3 Density

For each replacement level, weights of two block samples were measured separately in their dry state after keeping in the oven for 24 hours at 100^{o}C-105^{o}C. Then densities of each block were calculated and average value was taken. Thereafter variation of density of blocks for each replacement percentage were compared with the control block sample.

3. Results and Discussion

The variation of compressive strength is shown in Figure 6. The optimum compressive strength was obtained at 10% cement replacement level for U series samples.

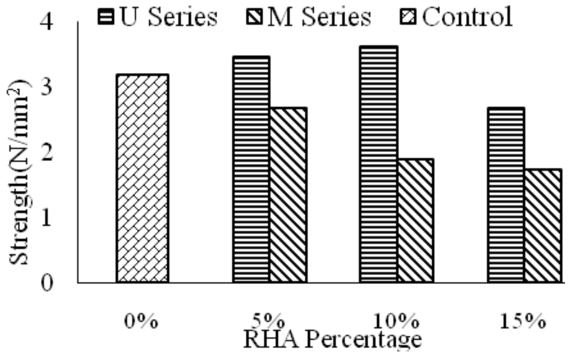

Figure 6: The variation of compressive strength at 28 days

However, 5% replacement level for samples in U series also showed the higher compressive strength than the control sample. These compressive strength values are higher than the specified minimum standard value of 2.8 N/mm^2 according to BS 6073: part 1:1981 [2].It can therefore be concluded that RHA sample U contains higher amorphous silica content than the sample M. Furthermore higher fineness of RHA sample U increases the reactivity of RHA particles resulting the higher compressive strength of blocks in U series.

Water absorption is another focused area of this study. The variation of water absorption is shown in Figure 7.

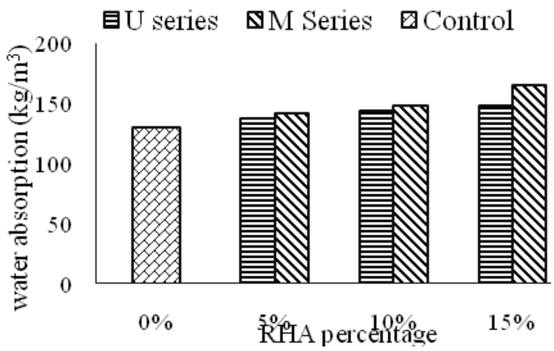

Figure 7: The variation of water absorption

Water absorption increases as the RHA content increases for both U and M samples. However, block made with coarser RHA (sample M) shows the highest water absorption behaviour. All the water absorption capacities are lower than the specified maximum value of 240 kg/m^{3}acccording to SLS: 855[6]. Therefore RHA based block samples show higher durability and resistance to moisture movement.

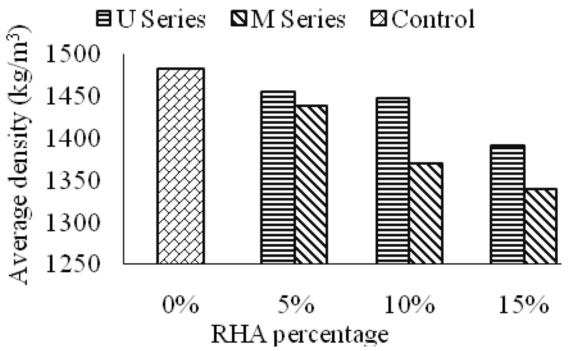

Figure 8: The variation of density

The variation of the density of RHA based sand cement block is shown in Figure 8. Density of RHA based sand cement block decreases as RHA percentage increases. Blocks without RHA show the highest density. This is due to the lower densities of both RHA samples than the density of cement.Lower densities were observed for block samples made with coarser RHA compared to block made with finer (sample U) RHA. It can be concluded that the density of RHA sample U is higher than the density of sample M. However, density values of all block samples are below the BS 2028 [1] minimum limit of 1940 kg/m^3.

4. Conclusions

The rice husk is an agricultural waste material, produced during the rice milling process especially in large scale paddy cultivation areas. The RHA is produced by burning of rice husks and it is identified as a pozzolan. Quality of RHA depends on the burning condition, temperature and grinding methods.

Partial replacement of the ordinary Portland cement with 5% and 10% RHA by mass yields increased strength at 28 days only in the case of block made with RHA having finer particles. Apart from that, 10% is the best percentage to replace the cement with finer RHA in terms of compressive strength.
RHA based sand cement blocks are suitable for external load bearing walls since it has lesser water absorption properties.

Furthermore light weight sand cement blocks can be produced by using this RHA wasted from the power plant. This is an initial approach on sustainable construction.

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Behaviour of Concrete Produced with Cement and Rice Husk Ash

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Abstract: Disposal of rice husk and its ash has been identified as a major problem in areas where rice production is abundance. Cement is an expensive material which plays a major role in the construction industry. This study shows the utilization of Rice Husk Ash (RHA) in concrete by conducting the laboratory experiments. Replacement of cement with RHA enhances both compressive and tensile properties of concrete. For this study, RHA was obtained from Bio-Energy power plant located in Ampara, Sri Lanka. As received RHA was sieved in order to prepare two types of samples with different particle sizes. Enhanced performances of Ordinary Portland Cement (OPC) can be achieved with 10% replacement of OPC by RHA regardless of particle sizes. Moreover, the adverse environmental impacts associated with RHA can also be reduced by utilizing the RHA in cementitious systems.

Keywords: Compressive strength, Concrete, Rice husk ash, Tensile strength

1. Introduction

Rice husk is an agricultural waste that is produced during the rice milling process. Rice husk is widely used as a fuel in several industries such as brick industry, rice mills and power plant industry.These process converts the rice husk into ash. The disposal of rice husk and its ash has been identified as a major problem in areas where rice production is abundance, for example, Ampara district in Sri Lanka. According to theFood and Agriculture Organization of the United Nations [6] database, Sri Lanka produced 4.62 million tons of rice in the year of 2013. However, annual rice production has dramatically increased in last 15 years.

RHA is one of the promising pozzolanic material which can be used in lime-pozzolan mixture and as a replacement material of Portland cement. Pozzolanic reactivity of RHA is influenced by silica content and crystallization phase, particle sizes, large surface area governed by the porous structure of the ash and less amount of carbon content in the ash [8].

However, siliceous and aluminous are pozzolanic materials. Pozzolans have either little or no cementitious material.Addition of RHA into concrete starts the pozzolanic reaction in the presence of Calcium Hydroxide (CH) that obtains from the cement hydration. Calcium Silicate Hydrate (C-S-H) gel is produced by the dissolution-precipitation process at the ordinary temperature. In the presence of moisture, RHA rapidly dissolves in the high pH of Calcium Hydroxide then precipitates the form of C-S-H (secondary) gel which has cementitious property[9].This process leads to producehighly dense and less porous, and it increases the strength of harden concrete against cracking [6].

Several researchers have interested in utilization of waste materials. Most of the studies in various parts of the world illustrate that RHA can be used as a supplementary cementitious material in concrete because of its pozzolanic activity and very high silica content, where rice plant absorbs silica from the soil and assimilates it into its structure during the growth. RHA is a competitive additive to Portland cement because it enhances primary characteristics such as cost reduction, performance, durability, eco-friendly and environmental concerns [7,10].

For the purpose of this research, RHA was obtained from Bio-Energy power plant located in Ampara, SriLanka. As received RHA was sieved in order to prepare two types of ash samples with different particles size.This research investigates the workability, compressive strength and split tensile strength on concreteproduced with cement having partial replacement of RHA.However, tests were conducted on concrete at constant a water/binder ratio and superplasticizer content.

2. Experimental Programme

2.1 Materials

Cement: The Ordinary Portland Cement that compliances with SLS107:2000 which equivalents to BS EN197 was used for this study.

Rice husk ash: RHA which is dark grey in colour was obtained from the biomass power plant in Ampara. Rice husk was burnt at approximately 650°C by continues supply of natural air. As received ash was sieved for 10 minutes. Thereafter, particles passing through 75μm and 150μm sieve sizes were denoted by "P" and "Q" respectively. Both RHA samples showed almost equal bulk densities. The bulk densities of P and Q are 215.8 kg/m^{3}and 215.9kg/m^3 respectively.

Aggregates: Locally available natural river sand was used as fine aggregate. This sand was 100% passed through 5mm sieve size. On the other hand, coarse aggregate was obtained from crushed rock with maximum size of 20mm. Moreover, the water absorption and specific gravity tests were conducted according to BS 812: Part 2 [4] and these properties are shown in Table 1.

Table 1 Properties of Aggregates

Parameter	Fine Aggregate	Coarse Aggregate
Specific gravity	2.60	2.70
Water absorption (% by mass)	0.98	0.45

Chemical admixture:RHEOBUILD®1000 Super plasticizer was used to obtain high workability of the fresh concrete. This water reduces admixture compliances with ASTM C494 type-A&F. It is dark brown, water-soluble and chloride free sulphonated naphthalene. According to the manufacturer's instruction, the dosage was limited to 950ml per 100kg cement.

Water: Potable tap water which comes from pipe supply for the drinking purpose of public was used in this study to make concrete.

2.2 Preparation of concrete

Seven series of samples were prepared including the control mixture. Control mixture was prepared only with the OPC, natural river sand, coarse aggregates and water. The rest of the mixtures were prepared with RHA, which is passing through 75μm and 150μm sieves. Concrete prepared with RHA samples passing 75μm and 150μm sieves are denoted by "P" and "Q" respectively.

For each particle size of RHA, mixtures were produced by replacing OPC with 10%, 12.5% and 15% of RHA by weight. Water/binder ratio was fixed at 0.53 for each and every mixtures. Also fine and coarse aggregates were used in 875 kg/m^3 and 975kg/m^{3}respectively. Notation of mixtures and RHA replacement levels are given in Table 2.

Table 2Mix Design of Control Mixture

Series	Notation	RHA replacement	Cement kg/m^3	RHA kg/m^3
control	C1	0%	360.0	00.0
P	AP	10%	324.0	36.0
P	BP	12.5%	315.0	45.0
P	CP	15%	304.0	54.0
Q	AQ	10%	324.0	36.0
Q	BQ	12.5%	315.0	45.0
Q	CQ	15%	304.0	54.0

After the batching of raw materials coarse and fine aggregates, OPC and RHA were placed in the titling drum mixer .Each mixtures was mixed for 8 minutes duration that included three minutes mixing after adding of water to the concrete. Moreover, the admixture RHEOBUILD® 1000 was dissolved in water before adding it into the concrete to ensure the homogeneous mixing.

2.3 Compressive Strength Test

The test specimens were cast in 150mm cubic mould. The casting process was conducted accordance with BS1881-108-1983 [1]. All the test specimens were cured in water for 28 days.

Figure 1: Compressive strength testing

Compressive strength was measured according to the BS1881-116-1983 [2]as shown in Figure 1. Load was applied continuously at 0.3MPa/s without shocking until the crack propagation.

2.4 Split tensile test

Standard cylinder moulds were used with the diameter and height of 150mm and 300 mm respectively. Test was carried out in accordance with BS 1881-117-1983 [3]as shown in Figure 2. The loading rate was 0.03 MPa/s that was applied continuously without shocking until the crack propagation in the test specimen.

Figure 2 Split tensile test

2.5 Slump test

The slump test was conducted immediately after the completion of mixing process to determine the workability of concrete. Slump Test was conducted according to the BS1881-102-1983as shown in Figure 3.

Figure 3 Measuring the Slump

3. Test results and analysis

3.1 Compressive strength variations

According to Figure 4, P and Q series indicate that the compressive strength increment at 10% replacement level than the control. However, P series test specimens show the highest compressive strength at the age of 28 days. Both P and Q series exhibit the normalized strength of 107% and 105% respectively.

These favourable results show for finer RHA particles which consumes more $Ca(OH)_2$ formed during the hydration of Portland cement and it has high pozzolanic reactivity than the coarser RHA. Also the fine RHA particles improve the particle packing density of the RHA concrete.

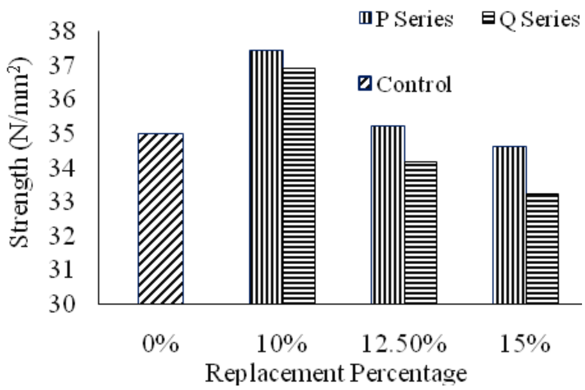

Figure 4 Compressive strength variation at 28 days

3.2 Tensile strength variations

According to Figure 5, the highest tensile strength is obtained for 12.5% cement replacement with RHA at the age of 28 days. Also the strength relevant to 15% replacement level is less than that of 10% replacement level.

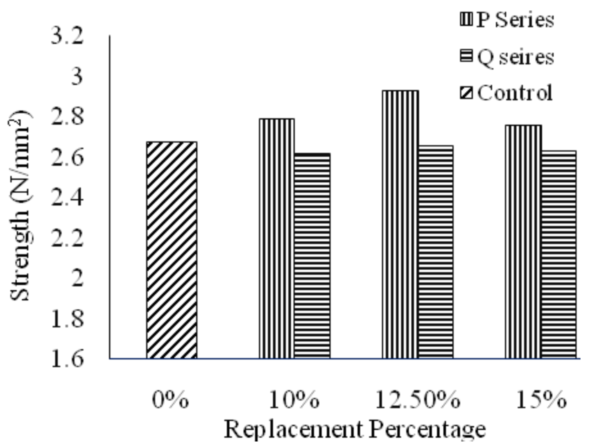

Figure 5

In an overall sense, the finer RHA replaced concrete is stronger than the control concrete. Although, the development in split tensile strength is in very small range, the higher variability in the result due to the senility the fabrication, curing and testing of concrete specimens.

3.3 Slump test

The slump test results are shown in Figure 6.It illustrates thatthe workability of concrete with RHAis low. Moreover, it is observed that slump reduction increases as the RHA percentage increases.Especially, concrete with Q-type RHA has a lower workability than the concrete with P-type RHA. The lowest workability is seen from the concrete with 15% replacement of Q-type RHA and this attributes to the highest water consumption of RHA due to its porous structure.

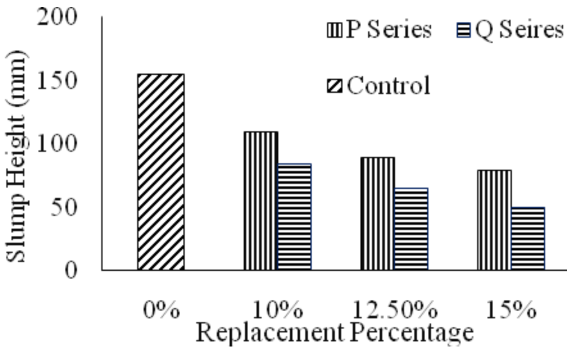

Figure 6 variation of slump height

4. The conclusions drawn from the tests are listed below.

Favourable results were obtained from the compression tests for concrete made with both typesof P (75 µm RHA) and Q (150 µm RHA). Concrete produced with 10% replacement of cement by P-type RHA shows the maximum normalized compressive strength of 107% while concrete with 10.0% replacement of Q-type RHA shows 105% normalized strength. Although P-type RHA replacement level shows a higher split tensile strength than that of the control mix, the maximum split tensile strength is obtained from the concrete produced with 12.5% replacement of cement by P-type RHA.

As a result, it can be concluded that an enhanced performance can be achieved with 10% replacement of cement by RHA regardless of the particle size of RHA.

Test results show that the workability of the concrete with RHA is low. Moreover, it is observed that slump reduction increases as the RHA percentage increases. Especially, concrete made with finer RHA has a lower workability than the concrete made with coarser RHA concrete.

Finally, this study suggests a proper way of disposal for the RHA produced from the Bio-Energy power plant by investigating the suitability of RHA to partially replace the cement. This brings an enormous amount of both environmental and economic benefits to Sri Lanka.

Future research can be carried out with partial replacement of cement with rice husk ash and fly ash in different levels to investigate the improvement of the workability and strength.

Moreover, it is recommended to grind as-received RHA from the power plant in order to produce ultrafine particles and then tests can be conducted to investigate the properties of such RHA replaced cement. Because it is possible to grind RHA in huge concrete plants, where the grinding process is cost effective.

Acknowledgement

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Structural Feasibility of a Pre-Cast Building System

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Abstract: This paper is based on a case study on a model house, which is to be built with slabs, beams and columns, constructed using pre stressed concrete and wall panels constructed out of Expanded Polystyrene. The proposed system is a solution to the fast growing issue of increased demand for housing and buildings and will contribute towards sustainable development with its cost effectiveness and optimized usage of resources. The beams, slabs and columns are pre-stressed in the form of pre-tensioning and Dowell bars are used at the beam-column junctions. As for the wall panels, a mix design would be carried out to identify the optimum cement, fly ash, sand, Expanded Polystyrene proportions. Seismic design has become an integral component in modern day engineering and hence, its implications on a pre-stressed concrete structure and a method to evaluate the feasibility of the proposed system in terms of its ability to withstand the effect due to earthquakes are proposed in the paper.

Keywords: Connections, Expanded Polystyrene, Pre-stressed Concrete, Seismic Design

1. Introduction

Increased demand for housing and buildings has led designers to seek for alternative construction techniques. This is due to the requirement of massive amounts of building material and labour for conventional construction methods, which in fact have already crossed the boundaries of sustainability. In this context, Pre-cast building systems can exhibit a lot of promise with optimized use of material and labour, which in turn would reduce the use of natural resources.

Additionally, given the growing concerns regarding disaster resisting structures due to the recent history of earthquakes in the South East Asia region, these new building systems should be checked for its ability to withstand such disasters.

This research paper is based on a case study carried out for one such initiative, where a model house is to be built with slabs, beams and columns, constructed using pre stressed concrete and wall panels constructed out of Expanded polystyrene. The proposed system will contribute towards sustainable development with its cost effectiveness and optimized usage of resources.

2. Pre-stressed concrete as a pre-cast material

Usage of Pre- stressed concrete as a construction material has been on the rise in Sri Lanka. In fact, increased use of pre-stressed concrete has provided a boom to the pre-cast concrete industry. Simplification of the construction processes (especially at construction sites), along with the obvious savings in terms of time and money and relative ease in quality assurance has led to its widespread use in Sri Lanka.

As far as pre-stressed concrete is concerned, there are two ways of applying the required pre-stress to the concrete, i.e. pre-tensioning and post-tensioning. In both cases, steel wires, strands or cables are used to transfer the pre-stress force to the concrete. This case study focuses on a pre-tensioned system.

At this particular yard, the option of pre-tensioning was chosen due to ease of construction. Generally, post- tensioning would require placing of ducts, which should be carried out accurately. Furthermore, it would also require grouting to provide sufficient bonding between the pre-stressing tendons and concrete. Additionally, unlike in pre-tensioning, special anchoring mechanisms as well as additional helical reinforcement is required at the end regions to counter the transverse tensile stress induced due to large concentrated forces during the jacking process. However, since pre-tensioning is carried out prior to concreting, the aforementioned issues would not occur. Additionally, since the design loading for a house is expected to be relatively low and uniform, a straight tendon profile, as opposed to a curved profile could be maintained. Hence, once all these factors are taken into account, pre-tensioning seems the more convenient, cost effective and feasible option.

3. Pre-Cast Elements

3.1 Beams

Generally, the beams were cast as 150mm x 350mm and the maximum span of a beam was 5 m. The pre-tension force was applied through 8 numbers of 5 mm diameter tendons. In addition, two numbers of T12 bars were used as nominal bottom reinforcement and R6 shear links were placed at 250 mm intervals. The covering to shear links was maintained at 20mm. Grade 40 concrete was used to cast the beams at the yard. A cross section of the beam is illustrated in figure 1 below.

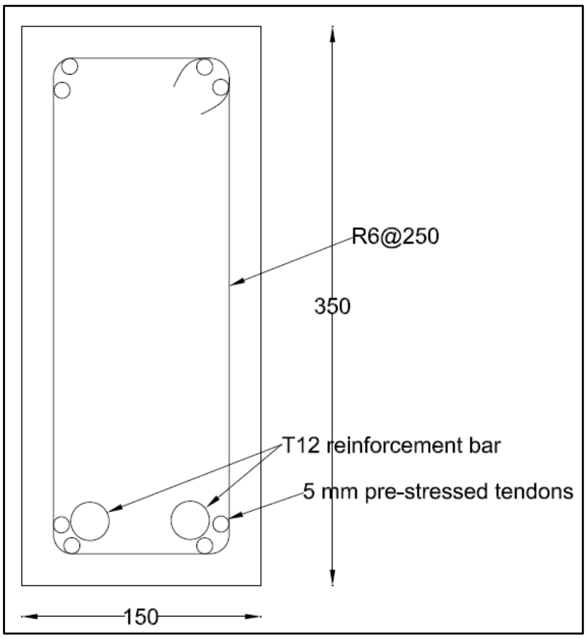

Figure 1: Cross section of a typical beam (all dimensions in mm)

3.2 Slabs

The slabs were produced in two sizes, 6m x 1m and 4m x 1m. However, both these types had a thickness of 75mm. Furthermore, a 45mm thick screed was laid after placing a net of reinforcement of 6mm diameter in the form of a 200mm x 200mm grid (see figure 2). As far as pre-stressing tendons are concerned, the larger slab panels were provided with 16 numbers of pre-stressing tendons, while corresponding number for the smaller panels was 14.

In both the beams and slabs, pre tension force of 2 tons (= 20 kN), were applied to each tendon. The elongation of the steel tendons were monitored and measured to ensure the expected pre- tension force was actually applied.

Figure 2: Reinforcement net on a pre-stressed concrete slab panel before prior to screed concreting

3.3 Columns

The columns were sized as 200mm x 200mm, so as to ensure a bearing of 50mm at each end at beam-column junctions and the columns contained 8 numbers of 5mm diameter pre-stressing tendons.

3.4 Beam-Column Joints

Generally, joints in pre-stressed concrete structures are designed as simply supported, as opposed to the usual practice of fixed joints in reinforced concrete. This would thus eliminate the hogging moments at the joints and therefore render the top reinforcement of beams uncritical. However, this would increase the sagging moments at mid span of beams and hence would require additional pre-stressing to ensure the additional sagging moment is countered through the hogging moment caused due to pre-stressing.

A SAP2000 analysis of a framed structure with 9 bays, each having dimensions of 6m on all sides (see figure 3) was carried out to illustrate the impact of joint conditions on the design moments of a beam. The elements were assigned the properties of concrete and the imposed load was considered as 2kN/m^2. The analysis was carried out for serviceability limit state.

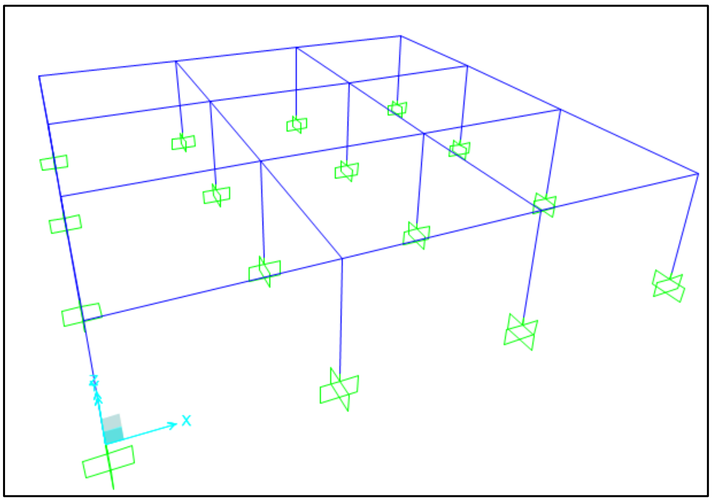

Figure 3: SAP2000 view of the modeled frame

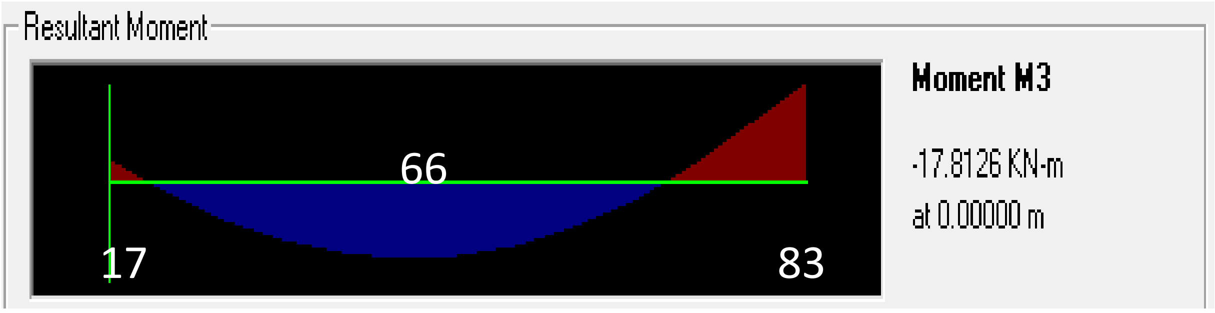

Figure 4: Variation of bending moment for a critical beam under fixed joint connections

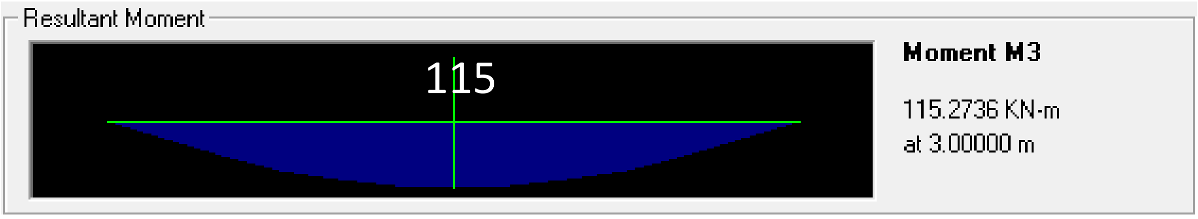

Figure 5: Variation of bending moment for a critical beam under simply supported joint connection

Figure 4 illustrates the variation of bending moment for the beam experiencing the highest hogging moment (83 kNm) and sagging moment (66 kNm) under fixed joint conditions. The variation of bending moments for the same beam, which in fact experiences the greatest sagging moment (115 kNm) under simply supported joint conditions, is illustrated in figure 5.

Although the eventual sagging moment has almost doubled, since providing the required sagging moment capacity is much easier and less expensive due to the effects of pre-stressing, elimination of the relatively high hogging moment is beneficial.

However, achieving continuity at joints is critical during construction. But, constructing connections that achieve continuity at supports is usually complex. In order to achieve connectivity, two numbers of Dowell bars of 20mm diameter were anchored 40mm into the columns using chemical anchoring, to ensure adequate strength at connection joints (see figure 6).

Figure 6: A typical beam-column joint

3.5 Wall panels

The proposed wall panel is to be constructed in the form of Light Weight Compound Sandwich Wall Panel. It consists of two fiber cement boards or calcium silicate boards which act as a reinforcement to the in-filled foam concrete (see figure 7).

Figure 7: View of a wall panel

Foam concrete is a type of lightweight concrete and hence, has the advantages of possessing a high flowability and minimal consumption of aggregate. Additionally, foam concrete has low densities typically ranging from 400 – 1600 kg/m^3 [1]. The foam concrete which is to be used for the proposed wall panel will consist of cement, sand expanded polystyrene and fly ash. It is expected that a certain proportion of cement and sand could be replaced by fly ash and expanded polystyrene respectively (to ensure gaining of adequate strength, albeit at a lower density).

However, the use of foam concrete in structural applications is quite limited due to its low compressive strength [1]. But on the other hand, since these wall panels would not be load bearing walls (since the house is expected to act as a framed structure), a compressive strength sufficient to carry its self-weight would provide a feasible wall panel. Furthermore, the wall panels should be able to withstand the lateral forces, especially due to wind loads and hence, the flexural capacity of the panels would also be critical.

Taking into account the above facts, a mix design would be carried out to identify the optimum mix for the Light Weight Compound Sandwich Wall Panel. The main objectives of the design are to determine the optimum fly ash content to ensure highest compressive and flexural strengths and to determine the optimum replacement percentage of Expanded Polystyrene with Recycled Polystyrene for the identified fly ash content.

Previous research suggests a ratio of 1:1:2 for cement to sand to expanded polystyrene with a water cement ratio of 0.4. However, this is for a density of 1250 kg/m^3 [1]. Meanwhile, for another research with a water cement ratio of 0.65, it was found that the compressive strength had increased with the increasing addition of fly ash. However the flexural strength decreased with the increasing addition of fly ash up to a 9% by weight [2].

As for the proposed test method for the first objective, the fly ash content would be increased from 0 % to 30 % in increments of 5% and for each case, sand will be replaced with polystyrene by 10%, 20% and 30%. The target density of the wall panel is 600kg/m^3.

The testing of compressive strength will be carried out by casting and testing cubes according to BS EN 12390-2: 2009 [3] and the flexural strength will be determined for prismatic moulds using ASTM C348 [4]

As far as the construction of wall panels is concerned, it would be fully automated and hence would reduce the workmanship defects of a typical wall construction.

4. Study on Performance under Earthquake

Seismic design has become an integral component in modern day engineering and hence the feasibility of the proposed system in terms of its ability to withstand the effect due to an earthquake needs to be studied.

Pre stressed concrete elements are expected to remain uncracked for longer periods compared to reinforced concrete elements in the event of cyclic loadings such as earthquakes and hence would contribute more towards an important area of disaster resistant buildings. However, the structural discontinuity, especially at joints, is an area of concern and hence designing and detailing of such joints requires special attention

As far as seismic design is concerned, the restoring force and the energy dissipation capability of a structure are considered critical factors [5]. Hence, these aspects of a pre-stressed concrete structure should be studied and compared and contrasted with other construction technics, in order to identify its feasibility in seismic design.

4.1 Comparison between Reinforced concrete structures and pre-stressed concrete structures

Extensive research, both analytical and experimental has been carried out for reinforced concrete structures and many design and detailing technics are being incorporated into structures. One main drawback in reinforced concrete structures is that although it is possible to enhance the ultimate strength of buildings through increasing the reinforcement ratio and thereby the ability to dissipate energy under cyclic loading, the serviceability, i.e. crack widths of beams and slabs under gravity loading, cannot be improved [6].

On the other hand, a drawback in pre-stressed concrete structures is that, although it enables designers to use longer spans, this could cause the structures to be more flexible and hence the natural period of vibration would be lower. Therefore, this would lead to a smaller design seismic load [6].

However, using of pre-stressed concrete would enable the designers to use higher grades of concrete and hence this would enhance the compressive strength and the elastic modulus of the elements [6].

Previous research has indicated that displacements and inter-storey drifts are generally similar for reinforced concrete and pre-stressed concrete structures. However, it must be noted that the dynamic response of a structure would largely depend on the structural configuration and the ground acceleration [6].

Compared to reinforced concrete frames, pre-stressed concrete frames would exhibit larger ground motions. This could be attributed to the fact that the pre-stressed concrete members usually have higher moments at the commencement of flexural cracking than the reinforced concrete members, and they recover to their original states and respond elastically even after they are loaded up to near their ultimate strengths [6].

In addition, the performance of the beam-column joints can have a large influence on the response of the frame to ground motions, although joint cores are usually assumed to have high rigidity [6]. However, this could be a critical aspect, due to the state of the connections for pre-stressed concrete structures.

As far as seismic design is concerned, the effect of pre-stressing could be advantageous. Prestress introduced into a beam has been shown to improve the shear resistance of beam-column joints. The reason is the biaxial compression in the joint core due to the joint core’s compression in the horizontal direction as well as in the vertical direction due to the axial force on the column. Also, prestressing is considered to increase the diagonal compression strut action in the joint core because the prestress results in a larger neutral axis depth. In addition, prestress can help preserve the rigidity of the joint cores. Stiffness degradation in joints can result in pinched hysteresis loops with reduced energy dissipation [6].

4.2 Analysis Procedure

The behaviour of the proposed system under seismic loads will be analysed using Finite Element Modelling.

The required structural properties of the elements will be tested experimentally. Standard flexural test of ASTM C78 using simple beam with third-point loading will be carried out for the beams and slabs

[7]. Standard Test Methods of Conducting Strength Tests of Panels for Building Construction mentioned in ASTM E72 will be followed to determine the flexural and compressive strengths of the wall panel [8].

The model house will be modelled in SAP2000 incorporating the relevant structural properties and will be analysed for a suitable response spectrum in order to identify the critical results such as base shear, acceleration, deflections and storey drifts.

5. Conclusions

The paper presents a proposed pre-cast building system for a house, with details related to the structural aspects of individual elements of the house. The possibility of replacing a certain proportion of cement by fly ash and sand by Expanded Polystyrene and Recycled Polystyrene is explored by testing samples for compressive and flexural strengths, while targeting a density of 600 kg/m^3.

A finite element analysis of the model house is proposed to determine its behaviour in the event of an earthquake.

Acknowledgement

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ICSECM 2015 - Facilities Management Approaches for Sustainability

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Abstract: In its most general sense sustainability is the capacity to endure. Sustainability has emerged as a result of significant concerns about the unintended social, environmental, and economic consequences of rapid population growth, economic growth and consumption of natural resources. Sustainability depends on three basic pillars; environmental, social and economical sustainability. In order to be sustainable, these three areas of sustainability must be achieved throughout the life cycle of a facility. The facility manager is in a unique position to view the entire process and is often the leader of the only group that has influence over the entire life cycle of a facility. Therefore, the facility manager often becomes the proponent of sustainable and green practices. Armed with the proper approaches, the Facility Manager can create long-lasting value to the organisation by developing, implementing and maintaining sustainable facility practices. Therefore, this study attempts to pinpoint the Facilities Management approaches to achieve and maintain environmental, social and economical sustainability.
A comprehensive literature review was carried out on a broader perspective with the purpose of getting familiarize with the research phenomena. Interview guidelines were developed based on the findings of the literature review. In order to validate and further the literature findings five expert interviews were carried out with experienced industry practitioners.
Research findings revealed that in Sri Lankan context, a Facility Manager's involvement for maintaining sustainability is most crucial in the operational phase of a facility. FM should have a clear view of environmental, social and economical aspects of sustainability. He / She should equally value the three pillars and a balanced approach needs to be taken in order to maintain a facility that is sustainable.

Keywords: Facilities Management, Sustainability, Facilities

1. Introduction

Both sustainability and Facilities Management (FM) are substantial topics trending in the current business environment and have been researched in detail over the past few years. Due to the changing nature of the FM profession, facility managers are increasingly engaged with the evolving sustainability agenda and the development or uptake of sustainability policies within their organisations (Elmualim, 2012).

Increasingly, organisations are concerned with the impact of their business activities on environmental, social and economic sustain-ability, as well as the impact of sustainability issues on their business (Adams and Frost, 2008; Holton et al., 2010; Lindsey, 2011). Study by Elmualim (2012, pp.167-168) revealed that the perception of sustainability, as a matter of benevolence with no direct impact on an organisation's core business strategies, has changed over the years as organisations actively incorporate sustainability principles into their core business strategies. Therefore, sustainability goals of an organisation become of vital importance to achieve success in core business.

The built environment's potential as a significant contributor to achieving sustainability goals is well documented and recognised within the FM profession (Wood, 2006). The role of facility manager has been taken up throughout the design, construction and operation of the built environment, with a function to provide the feedback of knowledge on effective management of the facility (Shah, 2007). Therefore, the facility manager often becomes the proponent of sustainable practices in business organisations. However, FM profession is still blooming in Sri Lankan context and therefore, facility managers' involvement is mainly seen in operational stage. This study thus examines how to adept sustainability approaches within the scope of FM in operational stage.

The paper is structured into four sections. The first section above gave a brief background to the research problem. The next section presents a review of related literature to put the study in a proper perspective. This is followed in Section 3 by methodology. Section 4 discusses the research findings that emanated from analysis while Section 5 presents conclusion, implications for research and practice, and recommendation emanating from research.

2. Literature Review

This section intends to describe the concepts of FM and sustainability both as individual subjects in their own right and how to deliver FM practises in a way that achieves sustainability in built environment.

2.1 Facilities Management

FM emerged over the past decade in response to turbulent change in the business environment (Alexander, 1994). The concept, scope and context of FM are still evolving. Over the years, researchers and practitioners have provided many definitions that help to clarify the objectives and scope of FM. Some definitions cited are tabulated in Table 1.

Table 1: FM definitions

Source	Definition
Becker (1990)	FM is responsible for co-ordinating all efforts related to planning, designing and managing buildings and their systems, equipment and furniture to enhance the organisation's ability to compete successfully in a rapidly changing world.
Barrett (1995)	FM is an integrated approach to operating, maintaining, improving and adapting the buildings and infrastructure of an organisation in order to create an environment that strongly supports the primary objectives of that organisation.
Alexander (1996)	The process by which an organisation delivers and sustains support services in a quality environment to meet strategic needs.
IFMA (2006)	Facilities Management is a practice of coordinating the physical workplace with the people and work of the organisation. It integrates the principles of business administration, architecture and the behavioural and engineering sciences.

As per Table 1, Becker (1990) suggests that FM is only concerned with the hard aspects such as buildings, furniture and equipments. Later definitions, however, include soft aspects such as people, process, environment, health and safety in the responsibilities of FM (Alexander, 1996). Others have taken the definition further by expanding the scope of FM to cover the entire property life cycle of designing, building, financing and operating (Tay and Ooi, 2001). However, regardless their contradictions and limitations, most definitions imply that FM is about managing non-core activities of an organisation in such a way that they will optimally support the core-business objectives.

A research carried out by Global Job Task Analysis (GJTA) (2009) over 62 countries identified 11 core competencies of FM. It is the most comprehensive to date and the first truly global survey and analysis (IFMA, 2014). The core competencies identified are as follows.

- Communication
- Emergency Preparedness and Business Continuity
- **Environmental Stewardship and Sustainability**
- Finance and Business
- Human Factors
- Leadership and Strategy
- Operations and Maintenance
- Project Management
- Quality
- Real Estate and Property Management
- Technology

As per the clarifications made by GJTA (2009 cited IFMA, 2014), sustainability is one of the functions of FM. Further, as discussed in Section 1, sustainability poses a direct impact on an organisation's core business strategies. Thus, sustainability becomes a main concern of facility manager in order to support the core-business objectives of an organisation. This has been also emphasised by Wood (2006) mentioning that the contribution of FM to achieve sustainability is well recognised. Next section discusses the concept of sustainability.

2.2 Sustainability

Sustainability studies continue to attract global attention among researchers (Johannesburg Declaration on Sustainable Development, 2002). In most simple terms sustainability is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987)

Sustainability is also understood as one that is socially just and ethically acceptable. Sustainability has thus been acknowledged as a major normative regulation principle for contemporary society which includes a long-term ethical relationship of present generations with those of the future (Laws et al. 2004, Scholz 2011). Sustainability is an integrative concept which considers environmental, social, and economic aspects as three fundamental dimensions. These three dimensions have been denoted as pillars of sustainability, which reflect that responsible development requires consideration of natural, human, and economic capital or colloquially speaking the planet, people, and profits (Elkington 1997, Kajikawa 2008, Schoolman et al. 2012).

Environmental sustainability is the ability of the environment to support a defined level of environmental quality and natural resource extraction rates indefinitely (Think.org, 2015). Mainly it focuses on an organization's impact on living and non-living natural systems, including ecosystems, land, air and water. Environmental responsibility involves more than compliance with all applicable government regulations or even initiatives such as recycling or energy efficiency (Jamali, 2006). The researcher further stated that it involves a comprehensive approach to a company's operations, products, and facilities that includes assessing business products, processes and services; eliminating waste and emissions; maximizing the efficiency and productivity of all assets and resources; and minimizing practices that might adversely affect the enjoyment of the planet's resources by future generations.

The social aspect of sustainability focuses on balancing the needs of the individual with the needs of the group.

The social dimension centers around the impact of the organisation on the social systems within which it operates. The expectations of diverse groups of internal and external stakeholders as well as interest groups comprising civil society are genuinely considered and skilfully balanced (Jamali, 2006).

It has also been defined as the continuing ability of an organisation to function as a long-term, viable setting for human interaction, communication and cultural development (Yiftachel and Hedgcock, 1993). The social bottom line incorporates issues of public health, community issues, public controversies, skills and education, social justice, workplace safety, working conditions, human rights, equal opportunity, and labor rights (Jamali, 2006).

Economic sustainability is used to define strategies that promote the utilization of socio-economic resources to their best advantage. The idea is to promote the use of those resources in an efficient and responsible way that provides long-term benefits and establishes profitability (frontstream, 2015). According to ICC (2002), the economic dimension refers to financial viability. It encompasses issues of competitiveness, job and market creation and long-term profitability. Economic sustainability is increasingly understood to refer to generating added value in a wider sense, rather than conventional financial accounting. Simply it is about making sure the business makes a profit, but also that business operations do not create social or environmental issues that would harm the long-term success of the company.

Table 2 summarises the basic idea of the three pillars of sustainability

Table 2: Pillars of sustainability

Sources: Knoepfel (2001) and GRI (2003)

Environmental sustainability	*Studying the implications of resource consumption, energy use and the effects of the firm on ecological integrity*
Social sustainability	Maximizing the positive impacts of a firm's operations on broader society
Economical Sustainability	Moving beyond conventional financial accounting by according attention to new measures of wealth such as the human/intellectual capital that firms develop

2.3 Linking Facilities Management into Sustainability

Sustainability has been increasingly quoted over recent years as more organisations jump on the 'triple-bottom-line' bandwagon. With this trend the organisations has moved towards implementing sustainable approaches into their day-to-day operations (Shah, 2007).

As it was mentioned in Section 1, FM is a profession that involves in the four phases of a building life cycle; site and project planning, design and construction, operation and maintenance, refurbishment and demolition. According to Tertiary Education on Facilities

Management Association (TEFMA) (2004), a facility manager could adept sustainability practices in all the four phases (refer Figure 1).

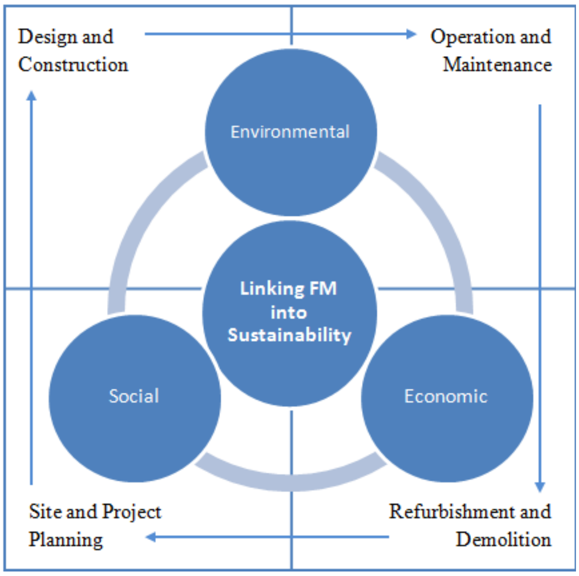

Figure 1: Linking FM into sustainability
(Adapted from TEFMA, 2004)

Built environment is the final product of construction process. The main role of a facility manager thereafter is the conversion of this physical product into a suitable and habitable built environment (Atkin and Brooks, 2002, Kelly et al., 2005, Ventovuori et al., 2007). Built environment has a significant impact on the sustainability agenda as it accounts for nearly 40% of limited natural resources consumed, and 40% of waste and greenhouse gases generated (Chartered Institute of Building, 2004). Further, according to Hodge (2005), cost of maintaining and operating the facility is only topped by the cost of labour of an organization.

FM is a novel profession Sri Lankan context and therefore, still the facility managers' involvement is limited mainly to operational stage. Therefore, sustainable practices that a facility manager can adept in Sri Lanka are found largely in operational phase of a facility.

The approaches those can be adapted to incorporate sustainability into FM practices in Sri Lankan context are discussed in Section 4.

3. Methodology

A comprehensive literature review was carried out on a broader perspective to gain an understanding of how facility managers are adopting sustainability approaches. Interview guidelines were developed based on the findings of the literature review. In order to validate and further the literature findings five expert interviews were carried out with experienced industry practitioners.

Table 3 briefs the profile of the experts interviewed for the data collection.

Table 3: Interviewees' profile

Interviewee	*Designation*	*Experience*
A	Facilities Manager	10 Years
B	Deputy General Manager -Projects	20 Years
C	Facilities Manager	15 Years
D	Facilities Engineer	08 Years
E	Deputy General Manager - Operation	25 Years

Finally, collected data were analysed using content analysis.

4. Research Findings and Analysis

The FM as an industry is complex in its nature. The industry is rapidly expanding with a huge economic as well as environmental impact. Thus, experts viewed that this has created a trend to align FM with sustainability along its three strands, economic, environmental and social.

All the experts are currently involved in sustainable practices in their organisations. According to them, lifecycle cost reduction, legislation requirements, corporate image, pressure from stakeholders, leadership initiative, quality assurance etc. are the driving factors for implementing sustainable practices in their organisations.

All the experts agreed that sustainability must be maintained or practices throughout the project life cycle of a building, while interviewee C pointed out that the most crucial of involvements of a facility manager to sustainability is in the operational stage of the facility. This finding was consistent with the literature findings as well (refer Section 2.3)

In this stage, facility manager has a role in strategic, tactical and operational levels. According to the findings, strategic role involves; getting commitment at all levels of the organisation - this involves evaluating and enhancing the organisation's attitude towards the social, economic, and environmental attitudes of sustainability; developing the sustainability mission, vision and values - this can be achieved by performing the SWOT analysis (strengths, weaknesses, opportunities, threats); and developing goals and objectives to support the sustainability strategy and communicate the strategic plan to all the stakeholders. Experts further reviewed that having a policy documented for sustainability will direct the facility managers towards effective implementation of FM approaches sustainable practices. Experts clarified that such a policy should cover areas like Building disposal, Ethical purchasing, Carbon footprint, Flexible working, Sustainable travel, Specification of sustainable products & services, Targets, measurement and reporting Biodiversity, Health & safety, Energy Management, Waste management & recycling, Biodiversity, Community engagement, Training, Staff productivity etc.

In the tactical level, the processes and procedure those are required in achieving the strategic plan is developed and documented. All the strategic and tactical decisions by organisations to advance the sustainability agenda have to be translated into measurable operational targets which are executed in the operational level.

By reviewing the research findings, it was apparent that the typical FM functions involved in the operational phase are energy management, water efficiency, indoor environment quality, waste management, and space and assets management.

In the vast scope of energy management, to maintain sustainability, a facility manager should pay attention right from choosing the appropriate energy sources, because environmental performance of a building can be significantly improved by choosing the most appropriate energy sources. According to most of the experts, the FM approaches for energy management include frequent monitoring and analysing the amount of energy used by the facilities; adopting energy efficiency measures – e.i. install high-efficacy lamps and fixtures, maximize daylight to reduce the need for electric lighting, rearranging the facility in to lighting zones based on the demands and control lighting accordingly, provide individual controls for lighting where feasible, minimize glare and visual discomfort from electric lighting sources etc.

According to the Expert B and E, careful thought given in the early stages of planning can greatly reduce water consumption and contamination. This will make it easy to ensure water efficiency in the operational stage. Techniques that should be employed for water efficiency are reducing water demand, rainwater harvesting, stormwater management, on-site water reuse, recycling of gray water, water sub metering, waterless or low flow pans and urinals, outdoor water use or appropriate landscape design etc. Further, Expert C stated that in a Facility Manager's plan for water efficiency should include, Initial plan including *purpose and scope, policy and principles, goals and objectives*; Baseline data and performance targets, Water saving measures, Management performance, Performance reporting. Experts further emphasised that water audits should be conducted in regular intervals to identify patterns of consumption. This will help them to identify areas of further improvement of water efficiency.

Indoor Environment Quality (IEQ) is affected by the choices made in the materials selection process. In refurbishments and renovations, the facility manager can go for materials with less volatile organic compounds. Design elements such as daylighting and natural ventilation can also be appropriately used wherever possible to enhance the IEQ. A well maintained indoor environment can affect people of the organisation in a positive manner by creating a healthy, safe and productive environment for the employees of the facility.

According to the experts, a facility manager can apply four main waste management techniques in the operational phase. They are; *Reduce* waste generation, *Reuse* components and materials, and *Recycle* materials to earn additional income, *Recover* energy from suitable materials. In addition, as the last resort, disposal also plays an important role in waste management. To achieve this, a facility manager needs to maintain a safe and environmentally responsible landfill. This can be done by minimising organic waste to landfill. A facility manager might also need to manage hazardous waste wherever necessary, depending on the types of waste the facility associates with. Further, awareness among the staff is vital to successfully manage waste generated in an organisation. Litter and dumping can be reduced through raising awareness.

Space and asset management also has an indirect impact on the pillars of sustainability. According to the experts, in Sri Lankan context, the majority of

FM professionals are yet identify the approaches to manage the space and assets in an organisation in a manner which is sustainable. Experts further suggested that rationalising existing space – minimise space wastage; saving resources in having to provide less new space; reorganising existing space for improved efficiency; rethinking public spaces within the facility; remodelling the usage of spaces (i.e. - sharing parking facilities by the organisations which are located in the same area).

Since FM is still a developing profession in Sri Lanka, it is limited to the few functions discussed above. These functions, when managed properly, can contribute more or less to the three pillars of sustainability.

5. Conclusions

The FM profession has been growing and maturing. Sustainability is an emerging focus of FM today. It addresses sustainable issues during the operation and maintenance of building facilities and the management of support services. A facility manager is a well-rounded and fully educated practitioner in the holistic management of the built environment. The role of the facility manager is to provide the resources and environment in which employees and organisations can be most productive.

Sustainability requires a systems approach to managing a business. FM is a system that supports all other systems. The optimal impacts of sustainability are long term and belong in a strategic plan, and the best facility managers are already linking FM strategy and sustainability tenets to those of the overall entity.

They must develop a holistic view, and knowledge of how an organization works, and how departments interface and interact.

FM been a developing profession in Sri Lanka, it is still restricted to the few functions that are clearly distinguishable among a facility's operational phase. FM approaches for sustainability are considerably limited within the Sri Lankan context. Throughout this study, a number of FM functions that can be practiced in the operational phase with approaches for sustainability have been identified, namely; energy management, water efficiency, indoor environment quality, waste management, and space and assets management.

Integrating FM and sustainability approaches will result in social progress which recognises the needs of everyone, effective protection of the environment, prudent use of natural resources, and maintenance of high and stable levels of economic growth and employment, achieving the three pillars of sustainability.

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ICSECM 2015 - Wind Design of Slender Tall Buildings: CFD Approach

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Abstract: Urbanization has led to the uprising of such buildings in densely populated areas where land availability and prices are a concern in such areas. Where such concerns exist the land must be fully exploited and thus constructions of tall buildings are always found as a solution in such areas. Wind behaviour is a key designing parameter for such building and need to be assessed accurately in the preliminary and secondary design stages. As most of the existing design codes have their own limitations in providing necessary guidelines for the wind designing, such as height limits of the buildings, the existing practice is to conduct wind tunnel tests to determine the wind induced loads on the buildings. However, the cost of the wind tunnel test is comparatively high and conducting wind tunnel tests at preliminary design stage is uneconomical. The rapid growth of Computation Fluid Dynamic (CFD) technique over the last few decades enables Engineers to simulate the wind behaviour around moving objects such as aeroplanes and automobiles. Therefore use of such methodology to predict wind loads on the buildings, especially at the preliminary design stages could be beneficial. This paper discusses a preliminary investigation that carried out on a non-typical 350m tall slender building using CFD approach.

Keywords: Wind loads, Tall buildings, Computational fluid dynamics.

1. Introduction

In the past recent, the construction of tall buildings has become a common featurette around the world. The word skyscraper has been often used for high rise buildings that are generally 150m or more tall. However the terms such as “Tall”, “Super-tall” and “Mega-tall” have been classified by the Council on Tall Buildings and Urban Habitat (CTBUH) for buildings which are 200m, 300m and 600m respectively [1]. These terms have originated because of a massive upsurge of buildings with heights within this range. In the past fifteen years many advances have been made in regions such as Asia and the Middle East (mainly the U.A.E) where super and mega tall structures have been erected. [2].

Urbanization has led to the uprising of such buildings in densely populated areas where land availability and prices are a concern in such areas. Where such concerns exist the land must be fully exploited and thus constructions of these tall buildings are always found in such areas. Furthermore countries such as U.A.E and China which currently claim to have the first and second tallest buildings, , use such structures as tourist attractions, thus bolstering their reputation and economy.

The major concerns in designing of tall buildings are not limited to the resistance of the structural systems to the lateral loads, but also extended to the comfort of the building’s occupants in relation to the wind-induced motion of the buildings.

The current practice is the use wind tunnel tests and relevant standards wind induced pressure and building motion parameters. Australian standard AS/NZS-1170.2 (Standards Australia, 2011), China Code (GB50009:2012), American Code (ASCE7-10:2010), EURO Code (EN1991-1-4:2005) and Japanese Code (AIJ 2004) can be considered as the frequently used standards for such analysis all over the world. AS1170.2, GB50009:2012 and EN1991-1-4:2005 have specified the upper height limits for the building where the relevant codes can be adopted. In addition, for free standing tall buildings the first-mode fundamental frequency shall be larger than 0.2 Hz. Therefore, tall slender buildings outside these limits, the AS-/NZS-1170.2 have recommended using wind tunnel tests as a supplementary technique in order to estimate the wind loads. However, performing wind tunnel tests require considerable resources and it is a time consuming and expensive effort. Therefore, it is worthwhile to look into alternative solutions to replace such experimental procedures.

Application of Computational Fluid Dynamics (CFD) in wind engineering can be considered as an alternative option to the well-known wind tunnel tests procedure. Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. The fundamental basis of almost all CFD problems are the Navier–Stokes equations, which define any single-phase (gas or liquid, but not both) fluid flow. With the advancement of computer capabilities, it is now possible to simulate considerable complex numerical simulations within a feasible time period. One of the main areas of application of CFD in wind engineering is in the environmental aspect. In the past few decades, research on the application of CFD has been conducted extensively in areas such as pedestrian wind comfort and safety, exterior building surface heat transfer, pollutant dispersion around buildings, and natural ventilation of buildings [3]. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. CFD has been used effectively in modelling aerodynamics effect on automotive. Therefore, it has shown a considerable accuracy in simulating atmospheric boundary layer effect. This highlights the possibility of using a similar approach to simulate the wind behaviour around the buildings [4, 5]

There is a considerable research gap exist in this area of interest as there is no significant work has been conducted to validate the results obtain through CFD simulations. Accurate representation of flow separation, turbulent formation are vital for achieving better representation of actual scenario of virtual wind models. In this study advanced Finite element code, ANSYS FLUENT 16 [6] has been used as the solver. Six different turbulence models are available in FLUENT which are incorporated with equations to solve the transported variable, turbulent viscosity, turbulent production and turbulent destruction terms. LES (large Eddy simulation) and K- ε models are the most commonly used turbulent models to represent the wind flow around building domains. There are considerable advantages and disadvantages of these models in terms of using in wind simulations. This paper only presents the results obtained using K- ε model even though the LES and SAS models [7], [8]; [9]; [10] were used in the current research study.

This paper presents the preliminary work done on an ongoing research project to simulate the wind pressure acting on tall slender building. Section 2 of the paper briefly discusses the key design parameters and general effects of wind on buildings. Section 3 describes the modelling process and parameters used in this study. Section 4 presents some results that were obtained and section 5 draws some final conclusions.

2. Wind Flow around Buildings

A tall building concentrates wind at its base (Figure 1 (a). This causes significantly turbulent region in front of the buildings. Similarly when a building is significantly taller than its surroundings it can experience high wind loads and concentrate pedestrian-level winds 1(c). It is also important to understand the flow due to the interaction of adjacent buildings. One of the better alternative to the wind tunnel tests to understand the flow characteristics if virtual wind tunnels using the CFD approach.

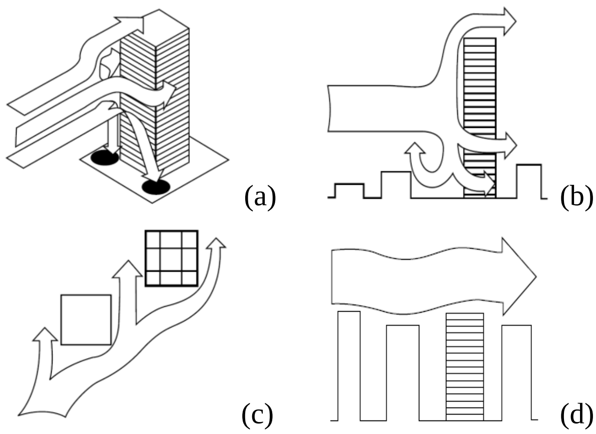

Figure 1: Flow past bluff body

Vortex Shedding

Vortex shedding is an oscillating flow that takes place when fluid such as air flowing past a bluff body such as buildings. The characteristics of the vortex shedding depend on the velocity of the flow, size and shape of the body. The frequency of this vibration is called shedding frequency (f_s) as defined as follows.

$$f_s = \frac{S_r U_\infty}{L} \tag{1}$$

where L is a characteristic length (equal to the diameter D in case of a circular cylinder or tube in cross flow) and U_∞ the freestream velocity.

$$S_r = 0.198\left(1 - \frac{19.7}{R_e}\right) \quad (2)$$

Vortex shedding is significantly important in buildings with cylindrical or similar cross sections. The building consider in this study mainly consists with circular cross sections where vortex shedding have become a critical design parameter.

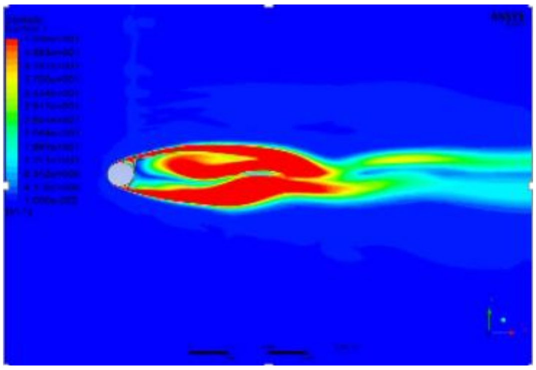

Figure 2: Vortex shedding around cylindrical object

3. Modelling

Figure 3: 350m tall building

The main purpose of this study is to conduct CFD tests for a 350m tall building which is irregular of shape with a base of 38m diameter. Commercial software ANSYS FLUENT v16 used in developing the numerical models.

The method by which a CFD application works can be broken down into three stages namely;

- Pre-Processor
- Solver
- Post-Processor

Domain Size: Choosing an appropriate domain size in important and needs to be large enough to ensure the effects of the boundary walls does not interfere with the final result. For this study a recommended guide is used for the domain size such that the inlet face, the lateral faces and the height of the domain is five times the height of the building (5H). The outlet must is to be located at least 15H away from the building to allow for fully developed flow, as shown in Fig. 4a&b [11].

Quality of the mesh: The generation of mesh for the model is important as the quality of the generated mesh has a direct impact on the credibility of the results. For the domain a hexa mesh is to be used whilst for the layer of the building a tetrahedral mesh is opted due to the incapability of generating hexa meshes on a complex geometry surface. To ensure that the mesh quality is within an acceptable level, the maximum skewness of any element is not to be exceeded a value of 0.85, which is deemed to be good. The number of elements within the mesh is also an important number that needs to be considered. The higher the number of elements the better the accuracy of the solution but longer time it takes for computation. Thus a balance needs to be struck such that a large number of small elements are not employed to gain accuracy which in turn increases time taken to compute but also an adequate number of elements are included such that it would not compromise the accuracy of the results. This was achieved by defining a minimum and maximum element size for the domain and the building surface. The building surface is forced to have a smaller maximum element size to that of the domain and thus this serves as the focal point where elements start to grow. Further to this other methods such as providing a refinement box around the building and in the wake region of the domain to capture features such as vortex formation could also be employed, but for this initial study this was not used.

The following information explains some of the meshing criteria that are imposed on to this model to ensure a high quality mesh generation;

- Building minimum mesh size 0.2m and maximum 0.8m with a growth rate of 20%
- Building mesh growth function defined as a soft function
- Surface mesh function soft with minimum mesh size of 0.2m and maximum mesh size of 30m at a growth rate of 20%
- Rest of the domain with a minimum mesh size of 0.2m and maximum mesh size of 40m at a growth rate of 20%

The domain and the ground surface contain hexa meshes (Fig. 5), however the surface boundary that represents the building, consists of tetrahedral meshing as its complex geometry makes it hard to force hexa meshes to be included on its surface without altering its shape considerably (Fig.6). An inflation layer is defined for the building surface as it is important to capture the nonlinear variation of wind flow when it approaches the building surface ("no slip" wall condition). As mentioned earlier the goal was to obtain a mesh with skewness of less than 0.85. The element with highest skewness was noted to be 0.78 which is very good for the purpose of this analysis.

Turbulent Models: At the solver stage the meshed model is imported and this is where the turbulence model is defined along with any other initial conditions such as wind speed. The manner in which fluids flow is important to understand. Most engineering related problems where the flow of a fluid is concerned the flow is turbulent as opposed to laminar. Laminar generally occur at low velocities such that the flow of fluid can be conceptualized as a streamline and thus each streamline flows parallel to each other in layers. However turbulent flows are completely random and the flow of liquid can be termed as being 'chaotic'. In wind engineering the flow of air is always turbulent therefore the resulting eddies from such a flow are unsteady and occurs in a three dimensional spatial manner. For computer simulations there are various models that can be chosen from and few important ones are listed in table 1. However it must be noted that these are computational turbulent models cannot predict all kinds of turbulent flows and thus each model have its strengths and weaknesses [12]

Table 1: Description of turbulence models

Turbulence Model	Description
Direct Numerical Solutions (DNS)	Numerically solving the Navier-Stokes equations and hence theoretically all turbulent flows can be simulated. Only applicable to simple flow problems where the Reynolds number is relatively low that is, laminar flow [12].
Reynolds-Averaged Navier-Stokes (RANS)	Solves Navier-Stokes equations by either time averaging or ensemble averaging. All turbulence is modelled but large eddies are not resolved. RANS incorporates many types' models where the most prominent modelling tool is the two equation $k - \varepsilon$ model.
Large Eddy Simulations (LES)	Navier-Stokes equation is solved spatially within the domain. Large eddies that are formed are directly solved whilst eddies smaller than the mesh are modelled

At the initial stage of experimentation a steady state RANS model will be used however at a later stage LES simulations and RANS transient analysis can be undertaken to induce effects such as crosswind excitation as it is an important factor in the design of tall buildings [13]. For the solver a steady state RANS k-ε realizable turbulence model was chosen as it requires less computational power and produce accurate results for the needs of this study. Furthermore modified RANS models have been shown to produce good results that are within reasonable deviation limits of those that were recorded in wind tunnel testing [14-16].

Boundary layer profile : For this particular study the use of the wind velocity profile has been derived from the Australian Commentary for the wind code AS 1170.2:2002 known as the Deaves and Harris Model [17]. The wind profile is input into the ANSYS via a Matlab script. The wind profile is as plotted and shown in Fig. 7 and the output from the model depicts this wind profile and as is shown in Fig. 8 at intervals of 10 seconds.

Convergence and Solution: The solution for the CFD simulation is brought about by a step process and hence number of iterations/steps needs to be provided. This is entirely up to the user and the rate of convergence of the solution. For this study we are looking at a convergence for all solutions in the order of 10^{-3} as this is an acceptable value for engineering applications. This whole process is iterative, if the solution does not converge then the user needs to fix the domain size, improve the mesh quality or increase the number of steps and rerun the program until such a convergence is obtained. The Post-processor stage is where the results are observed. In ANSYS visually attractive and meaningful results can be obtained by employing the CFD post processing results tool. Streamlines of air flow, pressures along the building, flow of air as contours on different planes are some of the useful visual outputs that can be obtained. CFD results must always be compared to those that are obtained by wind tunnel experimentation. For this particular building current wind tunnel data is unavailable however there might be a possibility that wind tunnel experimentation for a scaled model to be done in the near future where then results can be compared with. The number of iterations that was used for the solution to converge was kept at 200 whilst first order solver was used. It was required for the solution to converge to 10^{-3} and this was achieved in a mere 36 steps. Such a quick convergence to the solution was due to the size of the domain and the quality of the overall mesh in the domain which provided good continuity of flow throughout the domain.

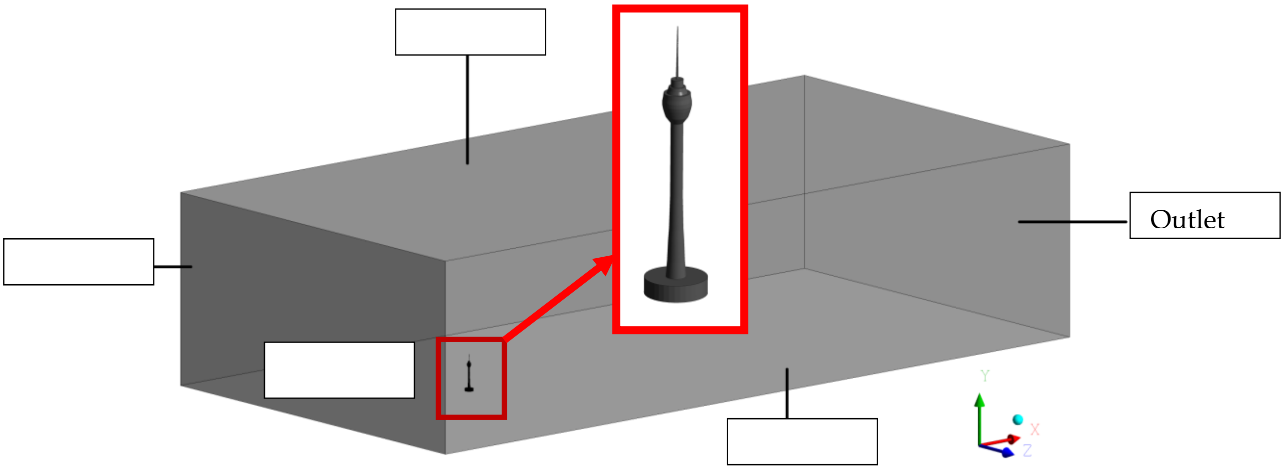

Figure 4a: Virtual wind tunnel

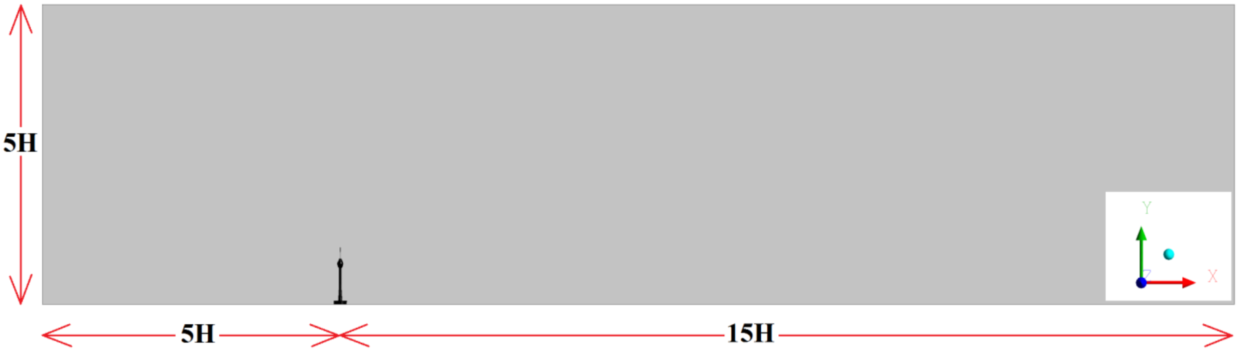

Figure 4b: Dimensions of domain (H: is the height of the building)

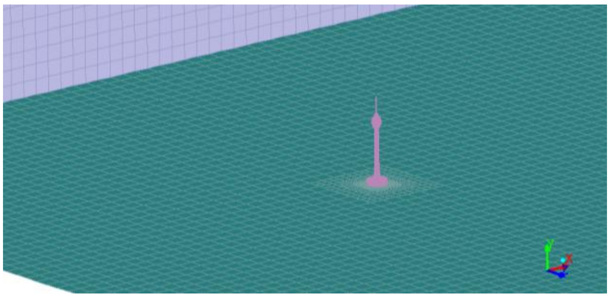

Figure 5: Hexa mesh on ground

Figure 6: Tetrahedral mesh on building surface

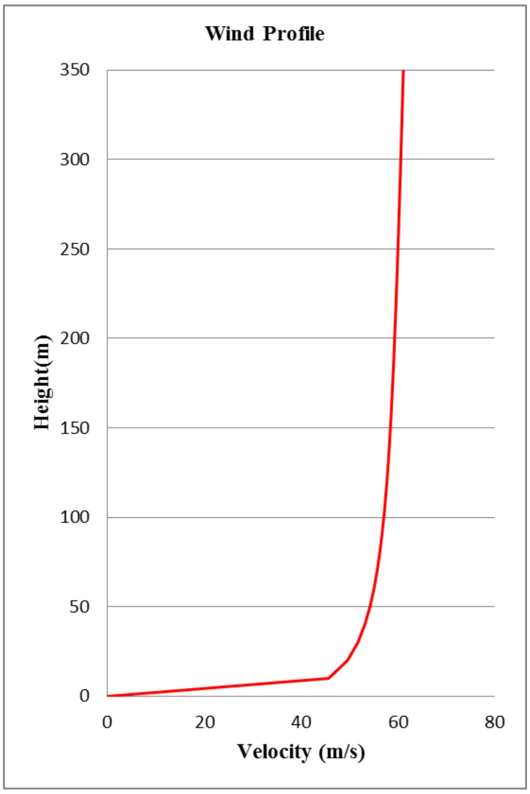

Figure 7: Wind profile along height of domain

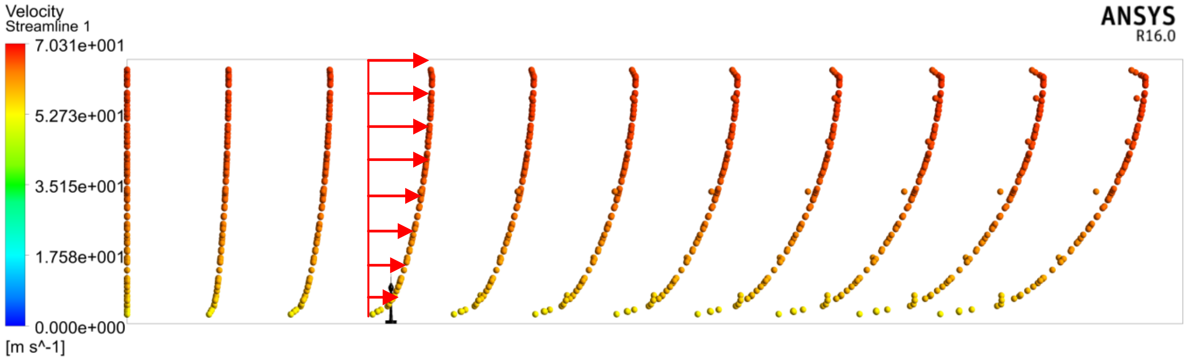

Figure 8: Wind profile in CFD simulation captured at intervals of 10 seconds within the domain

4. Results

The flow of wind around the building in its symmetrical plane is as shown in Fig. 9. The wind approaches the building from the left side and flows around the buildings and leaves on its downstream to the right. It can be seen that the wind significantly retards to a minimum at the face of the building surface and at the wake, it forms a vortex. Furthermore the velocity of the wind approaching the buildings depending on height and location is between the range of 40m/s to 70m/s (according to the wind profile use –terrain category 2: AS1170.2) however at the edges, the speed significantly increases to around 100m/s. This can be depicted from Fig. 10 where the velocity of wind is measured on a horizontal plane at Z=240m above the ground which is, at the bulb of the building. The velocity contour map at a reference height of Z=100m (Fig. 11) above ground show that the acceleration of wind around the building at this point is far less than that which was experienced at Z=240m. This difference was anticipated as the incident velocity at Z= 240m is greater than that at Z=100m also the geometry of the bulb is such that its diameter is larger than that of the stalk of the building thus making the velocity around the building at this level to travel faster.

This result was also observed in previous research conducted by authors Damith et al. [18], where a 600m building of rectangular shape was used to perform the analysis. The behaviour of wind depicted by velocity contour map as shown in Fig. 12 in this study replicates the pattern of the wind flow to that which was obtained for the rectangular building. Furthermore the wind velocity at different levels also show similar patterns of flow development to that observed in Fig. 10 and Fig. 11.

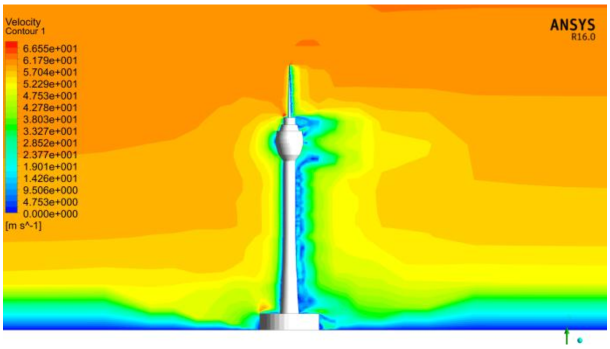

Figure 9: Wind flow around building

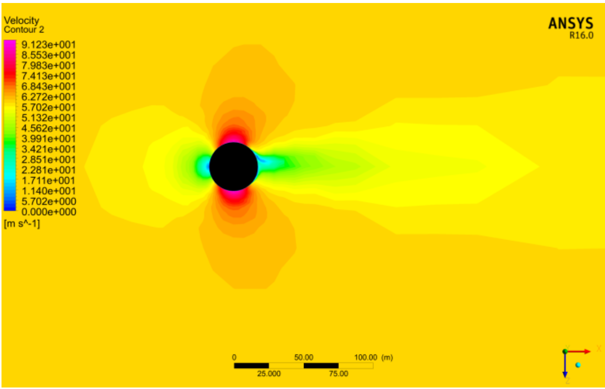

Figure 10: Velocity contour map at Z=240m

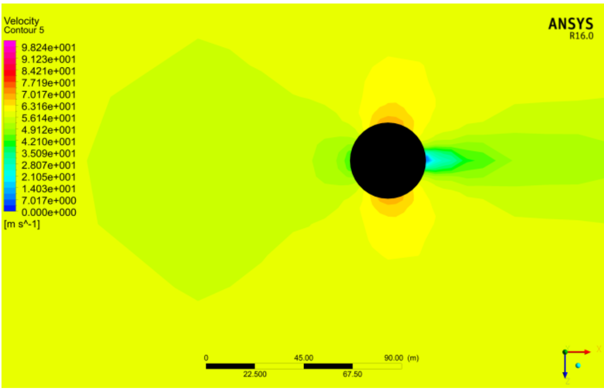

Figure 11: Velocity contour map at Z=100m

Predicting surface pressures accurately is important in the design of tall buildings as it will influence the lateral strength and thus design of the building. Furthermore it also affects the design of facades on the building surface.

The pressure distribution on the face of the building (windward face) where the wind profile directly approaches it is as shown in Fig. 12 and the pressure distribution of leeward face is as shown in Fig. 13. From the pressure contours it can be observed that the on the windward face a positive pressure distribution is observed because of the incident pressure on the face. It must be noted that the pressure increases with the height of the building as it correlates directly to the velocity profile that is incident on the building, which also increases with the height of the building.

On the leeward face the pressures drop and cause suction as shown in Fig. 13 and also on the side of the building, where the flow of wind is greatest, it causes large suction and the pressure significantly drops as shown in Fig. 14.

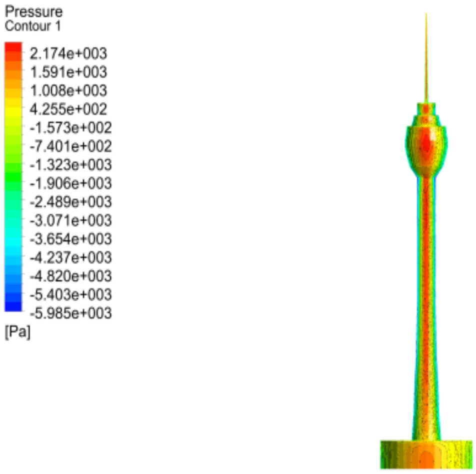

Figure 12: Pressure distribution on windward face

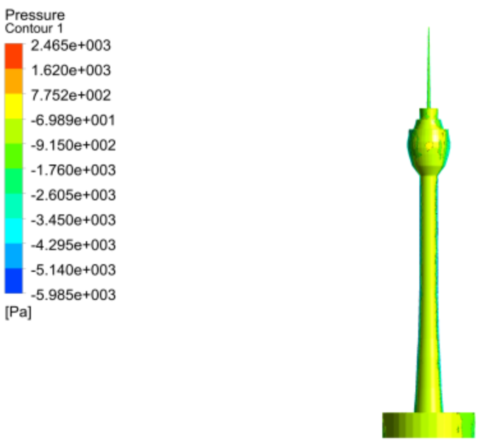

Figure 13: Pressure distribution on leeward face

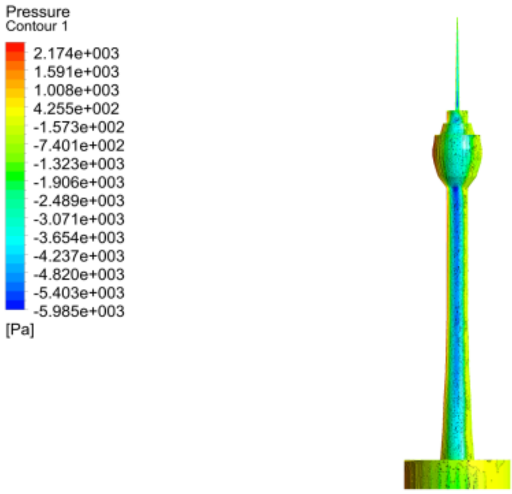

Figure 14: Pressure distribution on side of the building

These results that are obtained in this study are in good agreement with previous studies conducted by different authors where similar results were obtained for tall buildings.

Mean Cp values obtained for the cross section of the tower at 165m is presented in Fig. 14 (Series 6). The results were compared with the predictions from the previous researchers and the Euro code prediction. As it can be seen from Fig. 14, CFD prediction is shown a very good agreement with the experimental and code predicted data for Cp.

5. Conclusion

In the recent past, the application of CFD to analyse the flow of wind and its effects of buildings has greatly been investigated by many authors. Most of the research has been conducted on medium rise buildings whilst only a few has conducted research on buildings that are greater than 200m tall. The importance of the work presented in this paper is unlike previous work done by other authors, the shape of this building is not regular, it is complex in comparison to the conventional rectangular model where various researchers have performed tests.

Currently this paper shows the preliminary work conducted on this complex building to understand the flow of wind around this structure. The results show good correlation to previous work conducted and shows that the application of CFD for this model can be greatly beneficial and is likely to produce credible results that can be used as proof in the future for the design of any tall buildings of unorthodox shapes.

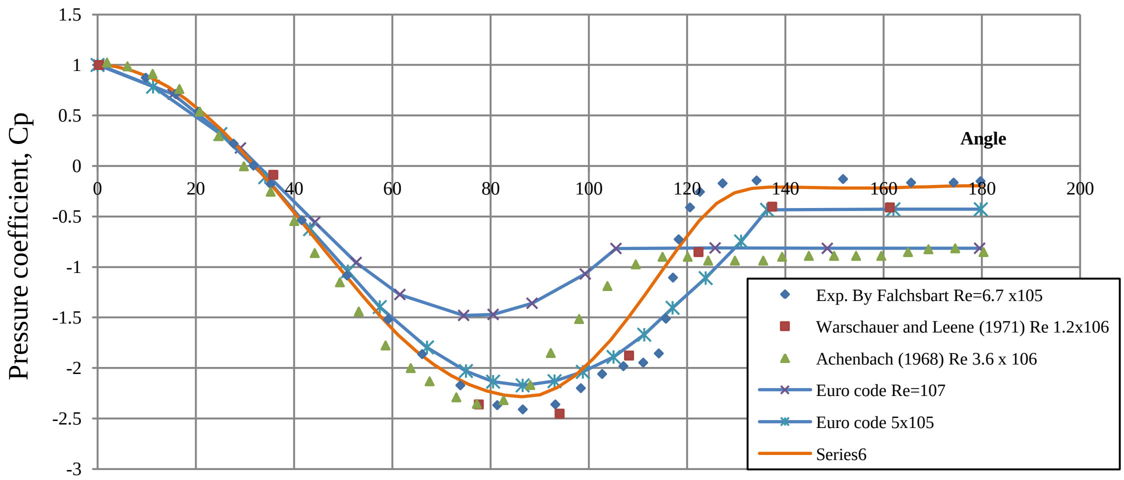

Figure 14: Pressure coefficient, C_p at 165m height

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Fire Spalling of Concrete Members

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Abstract: Thermal instability "spalling" occurs when concrete is exposed to fire. This phenomenon, which happens early after a fire starts (about twenty minutes), is one of the most detrimental effects causing damage to concrete members. It can trigger an immediate degradation of concrete, exposure of steel reinforcements to high temperatures and then eventually can cause failure of the concrete members during or after a fire by decreasing the residual mechanical properties and durability of the structure. In spite of many experimental and numerical studies, the real mechanism of spalling is still not well established. Hence, more comprehensive studies on simulating the behaviour of concrete members exposed to fire to investigate the real physics involved and the affecting factors on this phenomenon are currently lacking. The current study at University of Melbourne is attempted to fill this gap. The lack of understanding of the origin of fire spalling is mainly due to the erratic nature of this phenomenon and inhomogeneity of the concrete structures. To establish a more clear view of the phenomenon further investigation is needed. This paper reports the latest findings on fire spalling behaviour of concrete members and shows the deficiencies of the current experimental work and knowledge.

Keywords: fire, spalling, concrete, influencing factors

1. Introduction

"Spalling" can be defined as a thermal instability that occurs when concrete is exposed to fire [1]. Experimental results indicate that by exposing fire to the surface of a concrete member, some micro cracks generate on the surface. By continuing the heating process the cracks develop and some pieces of concrete from the exposed surface dislodge or even fail in an explosive manner. The dislodgement of concrete pieces during a fire is called fire spalling. Referring to spalling, in addition to material loss, reduction of concrete cover, decrease in the cross-section of the concrete member, and exposure of reinforcement to fire might happen [2,3]. Since steel reinforcement has a low yield point, the exposure and sudden increase in the temperature reduces the durability and lead to yielding. As a result, the integrity and the bearing capacity of the structural elements decline and in some circumstances, even structural failure has been reported [4,5].

General studies on fire spalling go back to 1940s and specific attention was paid on this phenomenon after 1996, when the fire spalling happened in three European tunnels.

In spite of many implemented studies, researchers have not yet achieved a consensus agreement on the relative contribution of the influencing factors on the fire spalling phenomenon. Also, no certain results have led to unique established safety code and design guidance for fire spalling [6]. The gap that has been reported is due to the erratic nature of spalling phenomenon. Other functions include non-homogenous structure of concrete material, large number of factors that influence spalling and their interdependency.

Weak understanding of the origin of fire spalling in concrete members can bring about the following problems:

- It slows down the developments on technological solutions to mitigate the magnitude of spalling and embeds achieving predictive calculation of the risk of this phenomenon;
- Due to increasing usage of high strength concrete (HSC) susceptible to higher risk of fire spalling in many engineering applications, it has become a major challenge for concrete designers [7].

The main objective of this study is to present a comprehensive report on research progress which is aimed at contributing to understanding of the origin of fire spalling in concrete members.

2. Reviewing codes and guidelines with special focus on fire spalling

In this section, only two standards are reviewed as other major codes such as American Code, ACI318 do not cover spalling behaviour in concrete.

2.1. Australian guidelines: AS3600, Concrete Structures Standard (2014) [8]

Section 5 of the Commentary to the Concrete Structures Standard discusses design criteria to improve general fire performance of structures such as fire resistance period, fire resistance level, fire-separating function, insulation and integrity of reinforced and pre-stressed concrete members including beams, slabs, columns and walls. To enhance the fire resistance of concrete members tabulated data including the dimensions of the members are suggested. This code commentary was written by Prof. Priyan Mendis, who is a member of the code committee.

In this part some general observations on spalling behaviour of concrete members is mentioned as follows:

"The tendency for spalling is high when

- the element is made of HSC rather than normal strength concrete (NSC);
- the cover to the reinforcement is increased, especially more than about 40 mm
- the moisture content of the concrete is high
- the temperature rise of the fire is rapid and concrete is subjected to a high thermal gradient
- the concrete is subjected to compressive stress; or
- when concrete is subjected to a hydrocarbon fire compared to a standard fire."

In AS3600, referring to the experimental results, adding Polypropylene fibres (PP) with a dosage of 1.2 kg/m^3 and 6 mm length is recommended to reduce the magnitude of spalling.

2.2. European guidelines (2004)

2.2.1. Eurocode -1 [9]

Eurocode-1 presents standard fire curves, which are designed on the basis of real fire experiences to show a more accurate estimate of fire severity using time-temperature curves. These curves are used in testing, analysis and designing to simulate the behaviour of building elements exposed to fire in both experimental and numerical analysis. Referring to different reasons causing a fire, specific time-temperature curves are introduced. The major fire curves are plotted graphically in Figure 1 and described mathematically as follows.

- Standard fires

The fire curve is the most popular fire curve for predicting the fire resistance of building elements. Most standards around the world follow this time-temperature relationship. Mathematically, the fire curve is defined via the following equation:

$$T = T_0 + 345\log_{10}(8t+1) \qquad (1)$$

Where t is time (minutes), T_0 is ambient temperature (degrees centigrade) and T is Temperature (degrees centigrade).

- Hydrocarbon Fire

The hydrocarbon fire curve is applicable where petroleum fires might occur. This type of fire is defined as follows:

$$T = T_0 + 1080(1 - 0.325e^{-0.167t} - 0.675e^{-2.5t}) \qquad (2)$$

Where t is time in minutes, T_0 is ambient temperature (°C) and T is Temperature (°C). In hydrocarbon fire curve the temperature rise is significantly more rapid when compared to a standard fire.

- External Fire Curve

The external fire curve, which is defined via the following equation, presents the time-temperature relationship for members outside the fire compartment. External member is defined as "structural member located outside the building that may be exposed to fire through openings in the building enclosure"

$$T = T_0 + 660(1 - 0.687e^{-0.32t} - 0.313e^{-3.8t}) \qquad (3)$$

Where t is time in minutes, T_0 is ambient temperature (°C) and T is Temperature (°C).

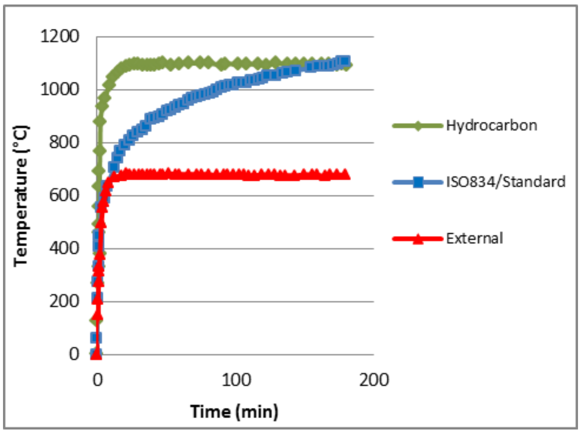

Figure 1: Fire curves used for design of structural members

2.2.2. **Eurocode-2** [10]

Eurocode-2 is a European standard that presents features of the thermal and mechanical properties of concrete and reinforcing steel bars when they are exposed to fire. The main aim of this code is to prevent integrity failure, insulation failure and thermal radiation in concrete members exposed to fire by measuring parameters such as integrity, insulation and load bearing of the exposed members. This code deals specifically with explosive spalling (section4.5 for NSC and section 6.2 for HSC). For NSC with moisture content higher than 3% by weight, assessment of moisture content, type of aggregate, permeability of concrete and heating rate is suggested. In case of HSC the following methods are suggested: using a reinforcement mesh with a nominal cover of 15 mm, using a type of concrete that experimental studies have shown that no spalling will happen for it, using protective layers and using more than 2 Kg/m^3 of PP fibres in the concrete mix

3. Preventive strategies of concrete fire spalling

To mitigate fire spalling in concrete members, researchers have considered some factors influencing this phenomenon.

3.1. Addition of Polypropylene fibres in concrete mix

Many experimental studies claim that using PP fibres could decrease and in some circumstances cancel the fire spalling of the concrete members [6,8,9]. Microscopic study on the behaviour of PP fibres in concrete shows that by exposing concrete to fire, these fibres start to expand, melt, and then shrink at around 170° [13]. The void spaces occur in the concrete referring to melting of PP fibres can be considered as weak points inside concrete. Increasing the heat causes cracks at the edges of the voids. These cracks act as micro gateways around fibres, from which water vapour can pass through by the aid of either capillary forces or the pressure difference. Hence the vapour pressure built-up in the concrete and then the magnitude of spalling could be reduced [3].

Jansson [14] also reported that due to the behaviour of PP fibres in concrete during a fire some additional void spaces are produced in the concrete, which may decrease the durability of the member at first steps of exposing to fire. These voids may be converted in to micro cracks and may become places for stress concentration inside the concrete at temperatures up to 175°C [15]. Therefore, using PP fibres could have some disadvantages on workability of the concrete. Utilizing optimum amount of PP fibres in concrete mix to improve the spalling behaviour as well as durability of concrete members is the matter of importance in this area.

3.2. Reducing water content

To improve the fire spalling performance, pre-drying the concrete is suggested [3,16]. Euro code also suggests decreasing the amount of free water in concrete to less than 3% by weight to reduce the amount of vapour inside concrete at high temperatures. On the other hand, some researchers have reported the occurrence of fire spalling in concretes with low water content [16] . In addition, it was also claimed that even bounded water in high strength concrete could be enough to cause severe spalling [17].

To improve the concrete behaviour in terms of moisture content, efforts need to be made on finding out the optimum amount of moisture, the moisture distribution in different types of concrete and the effect of saturated water inside concrete members on fire performance of concrete [17].

3.3. Utilizing thermal barrier

Referring to some problems that addition of PP fibres could cause, including reduction of mechanical residual strength of concrete exposed to fire, utilizing external thermal barrier or using them in combination of the fibres is suggested [15,16]. Some researchers [5,17] believe that thermal barrier, blocking the heat transfer to the concrete structure, is the most effective but expensive way to improve the fire spalling behaviour of HSC.

4. Experiments

To investigate the effect of the main governing factors on spalling behaviour of concrete walls, experimental analyses have been implemented on NSC and HSC specimens exposed to fire in a furnace. The specifications of the specimens are shown in Tables 1 and 2.
Figure 2 shows a schematic view of a wall specimen exposed to fire. As can be seen, hydraulic jack impose line load on top of the wall. Some sensors are also located on the surface of the wall to measure the temperature and displacements of different parts of the wall. The fire performance of each specimen could be seen through windows located on the furnace.

After testing, the specimens were cooled over two days. Following this, the depth of spalling on the wall surface exposed to fire was measured using a hard net, which is a hard wood panel (1200×2400mm) drilled with net holes (20×20mm net). The depth of spalling was measured via these holes.

Table 1: Concrete mixes (1m^3)

Component	NSC	HSC
Cement PC50 (kg)	320	600
Aggregate (kg)	828 (size 10-20 mm)	1029 (size: 5-10 mm)
Elkem Microsilica Fume (kg)		70
Sand (kg)	925	586
Water (litre)	189	140
Superplasticizer Glenium 51		8.5
Water/Binder Ratio	0.59	0.235
Slum (mm)	17.65	18.92
Initial moisture (%)	8.4	5.7

Table 2: Fire resistance test details of concrete wall specimens

	NSC	HSC
Dimension (meter)	2.4 (H) ×1.5 (W)× 0.15 (D)	2.4 (H) × 1.5 (W)× 0.15 (D)
Compressive strength of concrete	30-32 MPa	80-85 MPa
Type of fire	standard	Standard /hydrocarbon
Applied Load using hydraulic jacks	485 KN (eccentricity:10 mm)	485 KN (eccentricity:10 mm)
Reinforcements Strength	400MPa	400MPa
No and size of longitudinal steel	8Y16-300	8Y16-300
No and size of lateral steel	8Y14-300	8Y14-300
Concrete cover	25mm	25mm

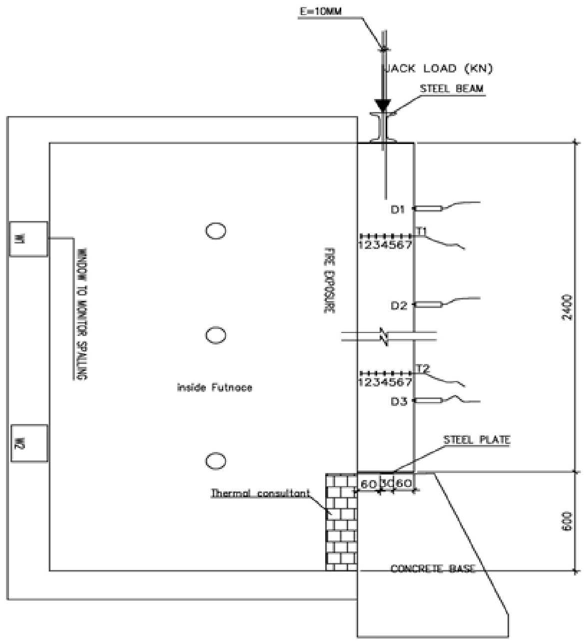

Figure 2: Section of the wall specimen set up in the furnace [21]

5. Results and discussion

Figures 3-5 show the effect of the influencing factors on fire spalling behaviour of concrete walls.

5.1. The effect of concrete porosity on fire spalling

Experimental results comparing fire behaviour of NSC and HSC exposed to standard fire indicate that spalling depth in HSC is larger comparing with NSC (Figure 3) due to the low porosity of HSC.
One of the main reasons affecting the spalling behaviour of concrete is the vapour pressure generated in the pores of a concrete with low gas permeability during fire. By increasing the temperature, water in the pores evaporates and then

solves in free water until the pores become fully saturated. At this stage, pores cannot contain water and vapour at the same time, which cause the pressure inside them to increase considerably. When the pressure surpasses the tensile strength of concrete, spalling happens. Hence it seems that low permeability of concrete impedes internal pressure to escape from concrete and could increase the spalling risk [22]. This could be the reason that HSC materials are more susceptible to spalling than NSC.

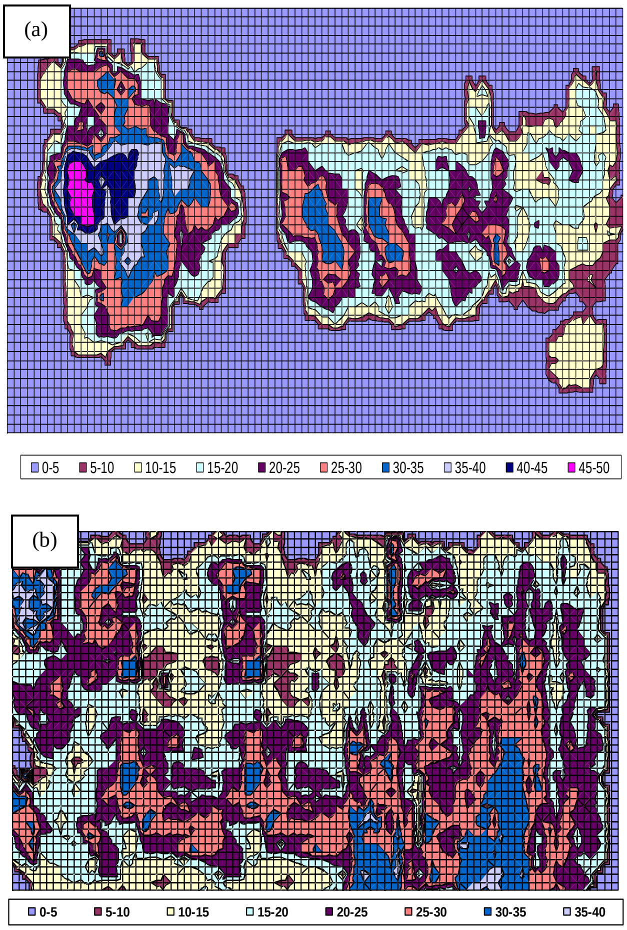

Figure 3: Comparing the spalling depth of (a) NSC and (b) HSC

5.2. The effect of thermal stress and type of fire on fire spalling

Rapid heating gives rise to both temperature and moisture gradient, which leads to higher build-up of pore pressure and tensile stress and then larger spalling [3,20]. Figure 4 shows the experimental results comparing the effect of exposure of hydrocarbon fire with standard fire on spalling depth of HSC. The results indicate that hydrocarbon fire with rapid rise of temperature imposes more thermal gradient and thermal stress, resulted in significant explosive spalling in HSC wall.

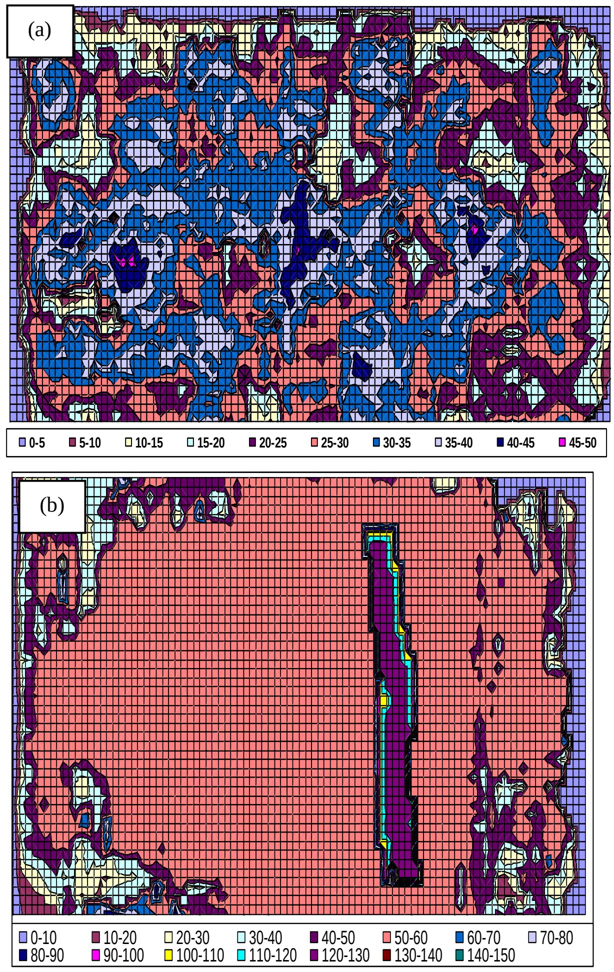

Figure 4: Comparing the effect of type of fire on spalling; (a) Standard Fire, (b) Hydrocarbon fire

5.3. Effect of adding PP fibres in concrete mix on fire spalling

Figure 5 shows the effect of adding PP fibres to HSC mix. As expected, the surface of the HSC without PP fibres is much higher degraded than the one with these fibres. Melting the fibres at high temperatures generates some voids inside the concrete. These voids could act as get ways for the internal vapour pressure. Therefore, reduction of the vapour pressure can mitigate the magnitude of spalling.

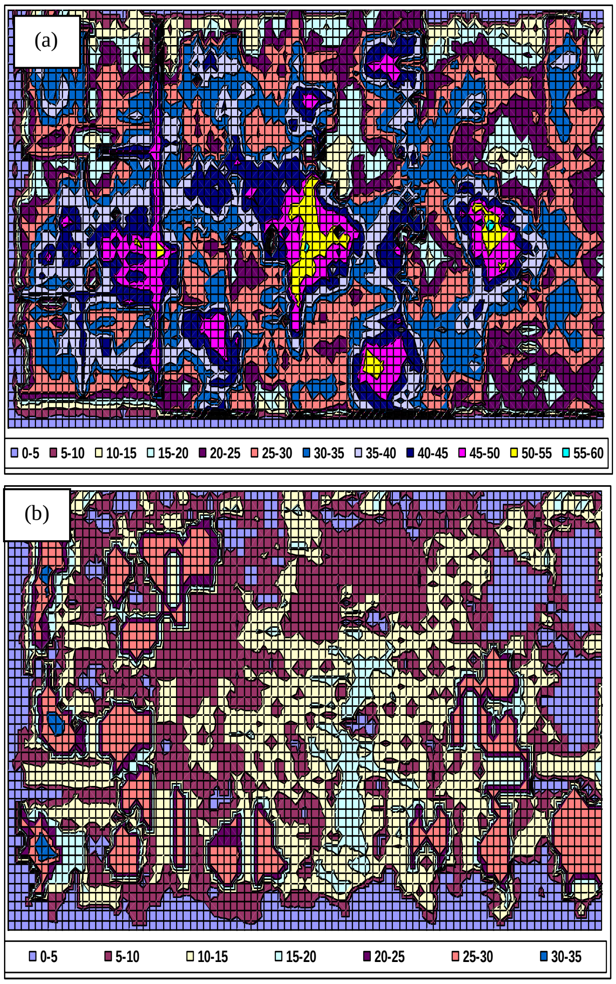

Figure 5: Comparing the effect of adding PP fibres (a) HSC without PP fibres, (b) HSC adding PP fibres

6. Conclusion

Reviewing the previous studies shows that the exact origin of the concrete fire spalling and the physics involved is not yet understood. Continuity of fires, increasing usage of HSC in construction and the susceptibility of these materials to explosive spalling have necessitated more investigations in this area [6]. Since now some influencing factors on the magnitude of fire spalling of concrete and some prevention methods have been found out; which are not comprehensive. To simulate the spalling behaviour of concrete members and figure out the real mechanism of this phenomenon, a comprehensive research program is currently underway at the University of Melbourne.

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