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ACCOUNTING OF WATER FOOTPRINT IN SUBSTRUCTURE IN A TYPICAL MULTISTOREY CONCRETE BUILDING

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Abstract: In last few decades, the building construction sector of India has become an important indicator of the development as it contributes a fair amount in GDP (gross domestic product) of nation. The fast growing construction consumes huge amount of natural resources such as, soil, water, woods, and by developing proper accounting method of consumption of these resources, the goal of sustainable construction can be achieved. This paper attempts to develop an empirical method of accounting of water footprint in construction of substructure (or foundation) in a multistorey concrete building. A substructure is the most important element of a multistorey building which connects it to the ground, and transfer loads from the structure to the ground. Water footprint attributed to substructure is the quantity of fresh water required for its various construction processes and supporting activities. The paper presents a case study on raft type, shallow substructures of three multistorey residential buildings of India to develop the method of accounting of water footprint. The results shows, total water footprint in construction of substructure in the case study buildings were accounted in the range of 7.71 – 36.10 litres per square meter of gross construction area. It also imputed from the results that water footprint consumption in concrete preparation has highest proportion, may be due to utilization of huge volume of concrete mix in construction of substructure. In addition, the paper also points out on some efficient reduction strategies of water footprint consumption to develop sustainable built environment.

Keywords: construction water; sustainable built environment; sustainable construction; water footprint.

1. Introduction

Fast growing population leads industrialization and urbanisation which adversely affects the quality and quantity of natural resources like soil, water, woods and natural materials. Water is a basic requirement for sustaining the life; therefore, the availability of good quality or fresh water is of great concern since it has finite resource and finding fresh water is a global issue for many countries and many others may face the same problem in the near future. Approximately 0.1 % water is fresh water usable for animal and human beings out of total available earth's water of 2.5% [1].

India is the country which receives average annual rainfall of 1.160 meter greater than the world's average rainfall of 1.110 meter [2]. Despite this, it is one of the highest consumers of water due to fast growing urban developments, such as, construction of buildings, highways, bridges etc.

In past few decades, the building construction sector of India has become an important indicator of the development as it contributes a fair amount in GDP of nation. A building is an assembly of various products and processes which consumes a large quantity of water during building's life cycle. The demand of fresh water or good quality water required for these products and processes is termed as water footprint.

The water needs of a building classify into two parts: direct water and indirect/embodied water. Direct water is the water used for on-site construction activities, and domestically consumed by humans involved in on-site activities of a building. However, indirect water includes the amount of water consumed for off-site activities, such as, extraction of raw material, manufacturing of construction products/materials used for construction & maintenance, production of fuel utilized for transportation, manufacturing of construction equipment & machines, production of products & foods utilized by labor/resident/staff, and domestically consumed by humans involved in off-site activities [3]. The indirect water of a building shares a larger portion as compared to the direct water in the total water consumption [6]. However, as the fresh water resources are depleting, the less quantity of direct water footprint may become more significant, especially in the developing country like India.

This paper focuses on development of an empirical method of accounting of water footprint in construction of substructure in a multistorey concrete building. A substructure is the most important element of a multistorey building which connects it to the ground, and transfer loads from the structure to the ground. Water footprint involved in substructure is the quantity of fresh water required for its construction processes and supporting activities. To achieve the goal of sustainable construction, accountability of this water footprint is necessary. The paper includes a case study on raft type, shallow substructures of three multistorey buildings of India to develop the method of accounting of water footprint.

2. Previous studies

The water footprint concept is evolved by A. Y. Hoekstra and defined as an indicator of the fresh water or good quality water consumption for manufacturing products and rendering the services to a person or a nation [4] and also referred to the locality where water is demanded or needed [5].

A very limited number of studies have considered water footprint in buildings [6]. Most of the existing studies of the water requirements associated with the production or provision of other goods and services have focused on the water required for energy [7] and food production [8]. However, there are some studies available for buildings but these focuses on embodied water in buildings [6] since it involves major proportion of water, but at yet, no study has analyzed the water footprint in construction phase of buildings. This study attempts to determine significance of water footprint in construction phase of building by providing a method of accounting of water footprint in construction of substructure in the multistorey concrete building.

3. Accounting of water footprint: a case study of Indian multistorey concrete buildings

3.1Description of the case study buildings

Three multistorey residential concrete buildings was chosen as the case study for analysis are representative of many of new multistorey buildings currently built across Jaipur in the state of Rajasthan, India. The detailed descriptions of the case study buildings are provided in table 1.

Table 01. Physical description of the case study buildings

Description	Building 1	Building 2	Building 3
Study period	December' 2013 to May' 2016	December' 2013 to May' 2016	December' 2013 to May' 2016
Location coordinates	Latitude 26.91° N Longitude 75.78° E	Latitude 26.91° N Longitude 75.78° E	Latitude 26.91° N Longitude 75.78° E
No. of floors	Stilt +9	Stilt +7	Stilt +18
Elevation per floor	4.27 m	4.27 m	3.96 m
Floor area	1769.25 m^2	538.84 m^2	1254.2 m^2
Structure	Reinforced concrete	Reinforced concrete	Reinforced concrete

3.2 Description of substructure of the case study buildings

A substructure (or, more commonly, foundation) is the element of an architectural structure which connects it to the ground, and transfers loads from the structure to the ground. Substructures are generally considered either shallow or deep type [9].

Shallow substructures, often called footings, are usually embedded into soil at certain depth. One common type is the raft substructure (sometimes known as mat foundations) is a large concrete slab which can support a number of columns and walls. The slab is spread out under the entire building or at least a large part of it which lowers the contact pressure compared to the traditionally used strip or trench substructures.

Raft substructures can be constructed near the ground surface, or at the bottom of basements. In multistorey buildings, these substructures can have several meters thickness, with extensive reinforcing to ensure relatively uniform load transfer.

A deep substructure is used to transfer the load of a structure down through the upper weak layer of topsoil to the stronger layer of subsoil below. There are different types of deep substructures including impact driven piles, drilled shafts, caissons, helical piles, geo-piers and earth stabilized columns [10].

In this case study of three residential multistorey buildings, buildings has raft type, shallow substructures divided in two parts; lower part is PCC (plain cement concrete) to provide proper level and smoothness to surface, and upper part is footing having greater thickness and capable to transfer structure load in to ground. The detailed description of the substructures of the case study buildings are provided in table 2.

3.3 Accounting of water footprint

The goal of study aims to develop a method of accounting of water footprint in construction of substructure in the case study buildings, which involves various construction processes with supporting activities where water consumed, such as, excavation, concrete preparation, and curing work as shown below in figure 1. Further, these processes are necessarily involves the support of labor & site staff, as well as equipment & machines.

Table 2: Description of substructure of the case study buildings

Description	Building 1	Building 2	Building 3
Type of substructure	Raft	Raft	Raft
Substructure level from ground level	3.438 m	3.353 m	5.030 m
Surface area of substructure	1769.2 m^2	538.8 m^2	1254.2 m^2
Thickness of PCC	0.15 m	0.15 m	0.15 m
Thickness of footing	0.61 m	0.61 m	0.61 m
Grade of concrete used	M 25	M 25	M 25
Type of cement used	OPC 43, OPC 53	OPC 43, OPC 53	OPC 43, OPC 53
Type of sand used	Zone 3	Zone 3	Zone 3

(OPC = Ordinary Portland Cement; PCC = Plain Cement Concrete)

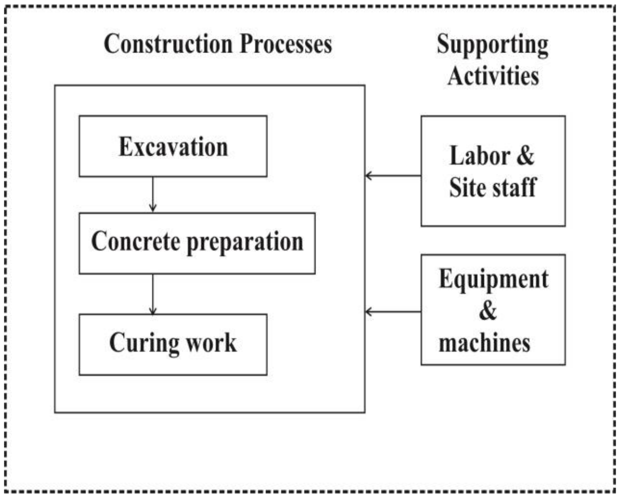

Fig.01. Processes and supporting activities involved in construction of substructure

The water quantity needed for excavation work as well as dust suppression work is termed as "water footprint for excavation

($WF_{Excavation}$)" and depends on surface area of substructure and depth of excavation. Concrete mix can be prepared on site as well import from nearest RMC (ready mixed concrete) plant. The requirement of water to prepare concrete mix is referred as "water footprint for concrete preparation ($WF_{Concrete.prep}$)" which is a function of surface area of substructure, depth of PCC & footing, water-cement ratio, and ambient temperature which affects the slump of concrete transported from RMC plant. The "water footprint for curing (WF_{Curing})" is the amount of water utilized in curing of PCC and footing and is a function of pipe water flow, frequency of curing in a day, and number of days curing done.

The construction processes described above in figure 1 are necessarily supported by labor & site staffs that employed on construction site at the time of construction of substructure and consume water domestically, and termed as "water footprint for labor & site staff ($WF_{Labor\&staff}$)." Equipment & machines, such as, excavator, bulldozer, and vibrators are also supports construction processes and for cleaning these equipment & machines water is utilized which is referred as "water footprint for equipment & machines ($WF_{Equipment/machines}$)."

The total water footprint in litre per square meter of gross construction area in substructure ($WF_{Substructure}$) is summation of water footprints involves in the above processes and activities shown in figure 1 and represented by following equation (1).

$$WF_{Substructure} = WF_{Excavation} + WF_{Concrete.prep} + WF_{Curing} + WF_{Labor\&staff} + WF_{Equipment/machines} \quad (1)$$

The following table 3 presents the input values required in above equation (1) for accounting of water footprint in substructure of the case study buildings.

Table 03. Input values for accounting of water footprint in substructure of the case study buildings

Inputs	Unit	Values
Flow of pipe	Litres/hour	705 – 1490
Frequency of curing (for PCC & footing both)	Hours/day	3 – 6.5
Curing period (for PCC & footing both)	Days	1 – 8
Labor & site staff involved	Nos./square meter of substructure construction	13 – 24
Water quantity Domestically consumed by a person	Litres/capita/day	22 – 68

4. Results and Discussions

This section outlines the results of the accounting of water footprint in substructures and presented in figures 2, 4 and 6 of the case study buildings over the study period of December' 2013 to May' 2016. The total water footprint in construction of substructure in all three case study buildings was accounted in the range of 7.71 – 36.10 litres per square meter of gross construction area. This result is an indicative result which shows the average range of water footprint consumption in substructure per square meter of gross construction and can be applicable to whole study area. It has very wide range due to large variations in construction practices, variation in skill of labors, and availability of resources in the case study buildings. Figure 2 represents water footprint results of building 1. It shows, total water footprint in construction of substructure of building 1 was 15.19 – 26.22 litres per square meter of gross construction area.

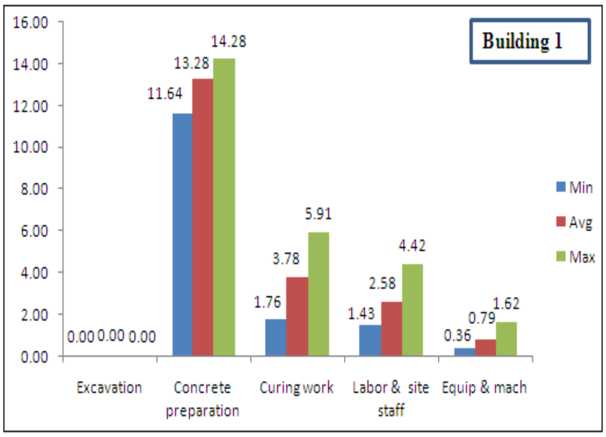

Fig. 02. Water footprint results (in litre/m² of gross construction area) for building 1

The results presented in above figure 2 of building 1 have maximum water footprint consumption in preparation of concrete mix, when compare to other construction activities. Following figure 3 shows that the average water footprint proportion for concrete preparation was 65% that of 18% for curing work in construction of substructure of building 1. However, water consumed domestically by labor & site staff has also considerable ratio of 13%.

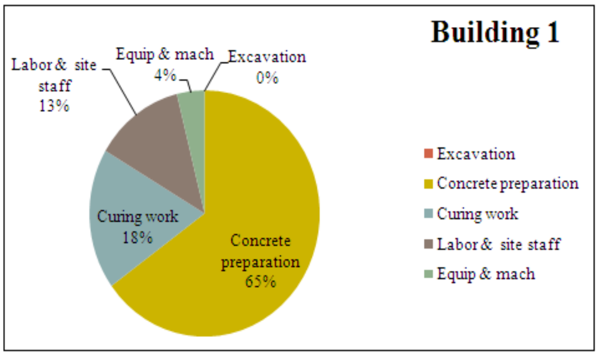

Fig. 03: Average water footprints (% distribution in activities) for the case study of building 1

The following figure 4 shows; total water footprint in construction of substructure of building 2 was 19.59 – 36.10 litres per square meter of gross construction area.

Following figure 5 shows that the average water footprint proportion for concrete preparation was 57% that of 29% for curing work in construction of substructure of building 2. However, proportion of curing water is less than to concrete mix water, but it is considerable amount which was not in substructure of building 1.

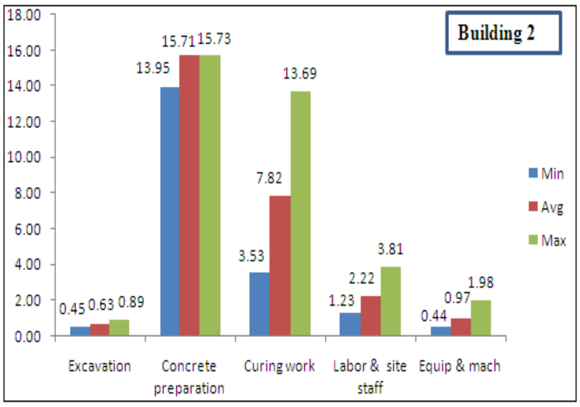

Fig. 04. Water footprint results (in litre/m² of gross construction area) for building 2

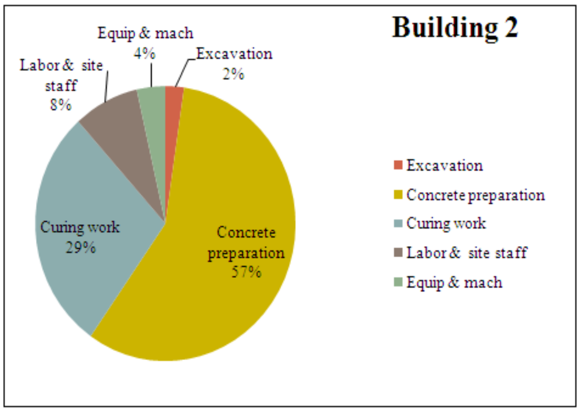

Fig. 05. Average water footprints (% distribution in activities) for the case study of building 2

The below figure 6 shows total water footprint in construction of substructure of building 3 was 7.71 – 15.79 litres per square meter of gross construction area.

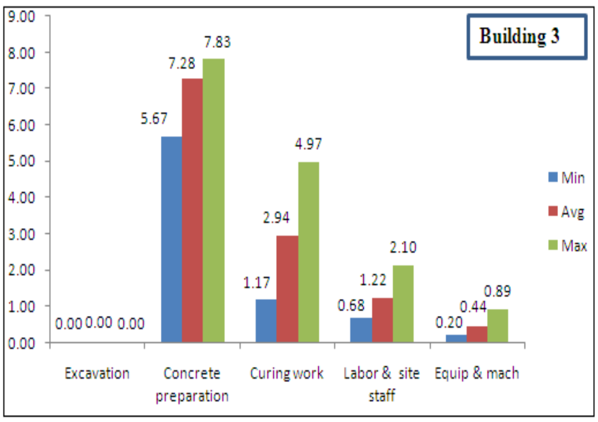

Fig. 06. Water footprint results (in litre/m² of gross construction area) for building 3

The following figure 7 shows that the average water footprint proportion for concrete preparation was 61% that of 25% for curing work in construction of substructure of building 3. These results are almost similar to results of building 2 shown in figure 5.

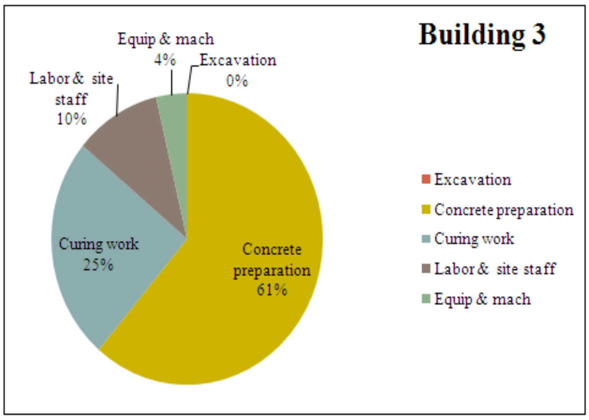

Fig. 07. Average water footprints (% distribution in activities) for the case study of building 3

The results shown in above figures 3, 5 and 7 of the case study buildings are comparable, in which consumption of water footprint in concrete preparation has highest proportion, and it may be due to utilization of huge volume of concrete mix in construction of substructure.

5. Conclusions

Water is a vital resource for functioning of ecosystems, human survivals and for many economic activities. The availability of fresh water and its management is a great concern. A water footprint indicates the total water requirement of a nation and also shows an impact of water consumption on the natural habitat and water environment.

Water footprint is an important dimension for sustainable development. Sustainable development focuses on optimizing the water footprint consumption for the long term future sustenance. The sustainable approach of water usage in building includes the impact of water use on water scarcity as well as on the environment and it can be met by accounting of water footprint. Water footprint for buildings can be classified as direct and indirect water footprint. Most of the studies on building water footprint focuses on indirect water since it have a significant portion. However, accounting of direct water footprint for the construction phase of building is generally unknown since it thought of less significant with respect the total water footprint. However, as the fresh water resources are depleting, the less quantity of direct water footprint may become more significant.

A building is an assembly of various products and processes which consumes a large quantity of water during building's life cycle. This paper focuses on water consumption in construction of substructure of multi-storey concrete building. A substructure is the most important element of a building which connects it to the ground, and transfer loads from the structure to the ground. Water footprint involved in substructure is the quantity of fresh water required for its construction. The paper presents a case study on raft type, shallow substructures of three multi-storey buildings of India to develop the method of accounting of water footprint. The results shows, total water footprint in construction of substructure in the case study buildings was accounted in the range of 7.71 – 36.10 litres per square meter of gross construction area. This result is an indicative result which shows the average range of water footprint consumption in substructure per square meter of gross construction and can be applicable to whole study area. It has very wide range due to large variations in construction practices, variation in skill of labors, and availability of resources in the case study buildings. It also imputed from the results that consumption of water footprint in concrete preparation has highest proportion, and it may be due to utilization of huge volume of concrete mix in construction of substructure.

To develop sustainable built environment, consumption of water footprint should be reduced by providing various measures, such as, proper construction practices, appropriate curing methods and explore potential to replace fresh water by treated waste water.

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Apart from us this paper will certainly be immense importance for those who are interesting to know about this subject. We hope they will find it comprehensible.

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