

APPLICATION OF POST TENSIONS IN HIGH RISE BUILDING CONSTRUCTION IN SRI LANKA

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Abstract: The world is changing; the economy is changing; and Architectural practice is changing. Therefore, there is a definite trend towards the irregular shapes with large spans in buildings due to the fact that there is now more emphasis on providing large uninterrupted floor space which can result in higher rental returns. Today the building industry is taking the next step in concrete technologies by introducing post-tension systems to slab construction with the use of system formwork and high strength concrete. Post-tensioned concrete has proven to be a preferred method of construction for commercial and office buildings, residential apartments, high-rise condominiums, parking structures, and mixed-use facilities such as hotels and entertainments. The main benefits over conventionally reinforced concrete being its ability to span greater distances without resorting to thick slabs and beams (and the consequent loss of head height), reduce deflection and cracking, Reduction in overall building mass, which is important in zones of high seismicity and superior performance of diaphragm action at building irregularities. There are also some associated labour and time savings. The objective of this paper is to introduce the post tension slab system to Sri Lankan construction industry. This study will discuss the benefits of having post tension in building industry, challenges encounter in PT designs and quality controlling process during construction.

Keywords: high rise; parking structures; span; deflection and cracking; building mass; seismicity; diaphragm action; PT slabs;

1. Introduction

Over the last 20 years, many buildings with post-tensioned floor slabs have been successfully constructed in the USA, Middle East, South East Asia, with corresponding increases in both steelwork prices and delivery times due to rapid growth in global economy. However, with the rapid growth of industry, the demands for labour force and constructions time play a major role at cost of construction. As a result of economic growth in Sri Lanka, above factors generate significant interest in post tensioned floor constructions. Pre tension and Post tensioning Systems have been available in Sri Lanka since 1960s but, it was limited to pre-cast, pre tensioned / post tension beams and slab elements in bridge and slab constructions.

Post-tensioned floors are totally of cast in-situ concrete. They can be designed as two-

way or one way spanning flat slabs, one-way spanning ribbed slabs, waffle or as banded beam & slabs. There are a number of publications that highlight the suitability of in-situ reinforced concrete frames for both economy and speed of construction in high-rise buildings. Post-tensioned concrete will not always be the most suitable, but it should be properly evaluated while considering other most familiar techniques. However, Engineers have a sole responsibility to overview all available construction methods to their clients.

The benefits of the post tension slab systems could be categorized as follows.

- Rapid construction with minimal labour requirement
- Minimum storey heights by satisfying Construction, servicing and operational requirements
- Architectural Flexibility

- Design and Performance
- Joint and crack-free construction
- Optimum clear spans with Controlled deflections.

Post tension flat slab floor systems, maximizes the ceiling zone available for horizontal services, minimizes the self-weight and foundation loads, and keeps down the overall height of the building. Thus, minimum story height is achieved. As a result, the story height of a building with post tension slab system can be less than that of a steel-framed or conventional RC building by as much as 300 mm per floor. This can give an extra story in a ten-story building. Alternatively, it minimizes the exterior surface area to be enclosed, as well as the vertical runs of mechanical and electrical systems. The reduced building volume will save on cladding costs and may reduce running costs of HVAC systems. Further to this, Rapid construction is readily achieved in multi-story buildings as pre-stressing leads to less congested slab construction (having minimal labour requirement) and early stressing enables forms to be stripped quickly and moved to the next floor. Introduction of system formwork (table forms or equivalent) will further speed the construction cycle.

Structural flexibility of the design and detailing can cope with irregular grids leaving more freedom to architectural designs, and services as tendons (with the use of corrugated flat ducts, Figure 09) can easily be deflected horizontally to suit the building's geometry or curves at the openings.

In PT design, the depth of flat slab is usually controlled by deflection requirements, by the punching shear capacity around the column or by the tensile stress on top and bottom surface of the floor slab. Further, Post-tensioning improves control of deflections (by volume balance due to tendon profile) and enhances shear capacity mainly due to pre compression (P/A) and vertical component of pre stressing force by curvature of the tendons. Future flexibility is provided as knockout zones can be

identified for future service penetrations. Further, Appropriate details may also be incorporated to reduce the effects of restraint, which may otherwise lead to cracking (Figure 05-07). Crack-free construction is often exploited in car parks, water tanks etc. where, concrete surfaces exposed to an aggressive environment.

Having considered all above aspects Post tension floor slab construction will produce cost effective solutions to Sri Lankan construction industry. The objective of this publication is to introduce the post tension slab systems to Sri Lankan construction industry. This study will discuss the benefits to both the developers and designer of having post tension in building industry, challenges encountered in PT designs and quality controlling process during construction.

2. Challenges of post-tensioning in Sri Lankan construction industry

For most multi-story buildings there are several suitable concrete floor framing systems, e.g. conventional RC floors, steel composite floor systems, post tension floors and precast pre tension floor systems. For spans greater than 6.0 m or where building floor arrangement is highly irregular, post-tension slabs start to become cost-effective. It can be used alone or combined with reinforced concrete to provide a competitive cost effective solution to a variety of available in-situ concrete floor systems.

In the past, Sri Lankan construction industry basically followed the conventional RC systems with conventional formwork systems for any type of building construction except in few projects where pre cast pre tension floor beams; steel composite floor systems and system formwork were used. Pre cast pre tension systems were highly promoted during the period of 1960-2000 with the pioneering efforts of Dr A. N. S Kulasinghe [16-17]. Though it was cheaper, it was not practical for high-rise building where complicated loading behaviours to be considered and also due to construction difficulties (storage and handling). Even though concept of post

tension is almost similar with the pre tension, it took decades to introduce post tension systems to Sri Lanka due to unavailability of specialized sub-contractors, confusions with pre tension systems, myths about post tension, unavailability of cost comparisons and lack of exposure to international codes such as ACI318[1,2], Technical report 43[3] etc.

As most of the clients, contractor's wants to know the cost saving rather than time saving. Cost comparison was done considering height gain, concrete, formwork, reinforcement, architectural finishes (ceiling, painting and facade etc.) and additional revenue. Following case studies will show the cost benefits to the client.

Case Study 1

As a first step of major expectations, author got a rare chance to introduce the post tension floor systems to the Sri Lankan construction industry through Platinum tower project where there were lots of constraints making conventional reinforced floor systems highly uneconomical. General guidelines were available in several reports [2, 3] and cost comparison and initial estimations are shown in Table 1 and Figure 01.

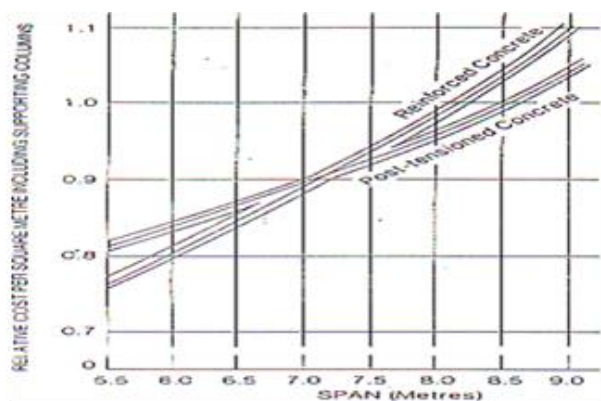


Figure 01: Cost comparison

Platinum tower project is a more specific project. It has been casted up to its 4th floor and left along for few decades. Ground & first floor is been functioned for several years and rest of the partly constructed floor were occupied with unauthorized slum people. With the higher economic demand

Table 01: Initial estimation of slab thickness

Section type	Total imposed loading (kN/m ²)	Span/depth ratios 6m ≤ L ≤ 13m	
Solid flat slab	2.5	40*/45**	
	5.0	36*/40**	
	10.0	30*/36**	
Slab with drop panels	2.5	44*/48**	
	5.0	40*/45**	
	10.0	34*/40	
Slab with band beams*	2.5	45*/48**	25*/35**
	5.0	40*/45**	22*/30**
	10.0	35*/40**	18*/25**
Slab with long span beam	2.5	45*/48**	20*/25**
	5.0	40*/45**	16*/20**
	10.0	35*/40**	13*/15**

in country, Developer wanted to start the rest of building up to 17th floors. To achieve the developer's expectations, consultant has to investigate the overall building stability and structural adequacy of structural elements been constructed and left along for decades. With the rigorous investigations and analysis done by consultant, it was found that, existing columns has to strengthen and existing raft foundations could bear about 300kN/m² of allowable soil bearing pressure. In additions to structural requirements, to achieve the developers required number of apartments and required circulations with in apartments, few of existing columns have to terminate at the 5th floor and slab has to project 2-3m outside the column grid making 2-3m cantilever projections at either sides of the floor slab.

Having considering all constraints, author had done a cost comparison with the use of authors' past experience and presented it to the client. Specific details are tabulated in Table 2-4.

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Table 02: Cost comparison of Platinum Tower, Colombo 03

Description	Costing of Platinum Tower Project /(RS/m2)						% saving		
	Concrete	Reinf	Form work	PT	Cladding	Partition	Total	w.r.t Total cost of a floor	w.r.t cost of slab only
PT Flat Slab	6001	7204	1333	1080	5167	2180	22729	17	18
RC Flat Slab	7185	11934	1342		5250	2180	27891	-1	-7
Conventional	5640	11230	2276		6000	2405	27532		-2

Table 03: Weight Comparison of Platinum Tower, Colombo 03

Slab Option	weight of slab/kg	weight of partitions	Total Weight/kg	% mass increase
PT Flat Slab	259350	80085	610035	-18
RC Flat Slab	341250	132240	757620	2
Conventional	257503	174387	744658	

Case Study 2

Araliya Green City is a Hotel projects in the heart of the Nuwaraeliya. It has a basement, ground and 5 stories hotel with a roof top swimming pool supported on pile foundation. As this is in the heart of Nuwaraeliya, there was height limitation and this restricts the client investment. And other basic information's of the building are 200 Number of hotel room including suites, 2 and 3 bed room hotel rooms in a 19100m2 of floor area.

During the soil investigation, it was found that, underneath sub soil conditions is too weak and depth to rock is varying from 25-60m. Client had a very stringer time target to complete the project before New Year 2017. Therefore, there was need of high tech solutions in constructions.

As client was not getting facilities from contractor and also not familiar with the PT works and highly QA/QC procedures, initially, cost benefits, time savings and labour demand was explained in details to convince client. With the greater effort, project structural works was completed with 10-day cycle.

Following tables (Table 4 and 6) illustrate the cost benefits gain through PT works.

Table 05 Comparison of Material quantities

Project description	Location	Type of usage	Num of stories	Range of span (m)	Loading (kN/m2)	Type of slab	geometry (mm)		PT option		RC Option		comparison/ (%)
							slab thick	Beam thick	Reinf Qt/ m3	Cost/ (\$/m2)	Reinf Qt/ m2	Cost/ (\$/m2)	
Athenae Tower	Thailand	Office	37	9-11	3	1.7	250		5.2	34	27.3		
Athenae Residency		Residential	45	8-9	2	1.7*	250		4.1	40	26.5		
Ideal24 Tower		Residential	41	7.6-10	4	2*	250		4.2	40	26.8		
River side garden Marina		Residential	37	9-10	2	2.5*	250		5.6	35	28.8		
Fullerton Tower		Residential	38	10.4	2	3.6	250		6.8	40	34		
Palm Tower		Residential	56	5-7	2	4.5	240		3.2	36	21.9	29	43.5
Dubai Tower		Mixed dev	33	5-8	2	5	250		3.8	36	24.1	32	48
KG Tower		Residential	45	5-8	2	3.5	240-220		3.6	31	20.3	28	42
ABC Tower (3 Towers)		Residential	37	8-9	2	3.5	220		4.7	35	24.7		
Salem Bin Tower (3 Towers)		Residential	32	5-6.5	2	3.5	200		3.3	22	15.8	34	51
Al Nahda Tower	UAE	Mixed dev	34	6-9	2	7	240		4.8	26	22.8		
Ali Salem Tower		Mixed dev	14	7.5-8.6	2	5.5	230		5.8	30	26.6		
Al Jumairi Building		Residential	15	7.8-8.8	2	5.5	250		3.8	30	21.9		
Danar Buhairah Tower		Residential	45	6-10	2	4.5	225-260		7.1	35	31.7		
Staff Hostels		Hostels	9	6.5-7.5	2	4.5	225		4.2	32	22.6		
U M H	Qatar	Hospital	9	9-20	2-10	9-3.5	250	800	7.3	42	36.2		
Building		Parking	2	9	5	2	250		5.3	35	28		
Oval car park													

* partition loads considered separately as line loads

Table 04: Cost comparison of Araliya Green city, Nuwaraeliya

Description	Costing of Araliya Green City /(RS/m2)						% saving		
	Concrete	Reinf	Form work	PT	Celling	Partition	Total	w.r.t Total cost of a floor	w.r.t cost of slab only
PT Flat Slab	4877	4217	1338	1558	2250	2873	17113	22	17
RC Flat Slab	6230	13442	1353		2250	2895	26170	-19	-46
Conventional	4041	8191	2195		4500	3142	22069		-28

Table 06: Weight Comparison of Araliya Green city, Nuwaraeliya

Slab Option	weight of slab/kg	weight of partitions	Total Weight/kg	% mass increase
PT Flat Slab	240000	306680	1148180	-32
RC Flat Slab	387000	315700	1529763	-8
Conventional	756000	348848	1656323	

3. Constructions sequence and QA/QC requirements followed in Sri Lanka

Many of the major specialist contractors have experience with post-tensioned construction, and are aware of how it differs from using reinforced concrete and the benefits it offer. Those less familiar contractors may worry as there is definitely a learning curve to be climbed in the early stages of a project. However, experience shows that once in their stride, all contractors can achieve exceptional floor cycles with post-tensioned construction. Author believes that it will be followed in Sri Lankan construction industry as well with the qualified major local contractors

There are guidelines to be followed during construction of Post tension slab systems and they will be forwarded to the main contractor in a document called method statement [14] for post tension works. It will basically follow the following steps in a sequential manner.

- Fixing of bottom mat reinforcement.
- Preparation of dead ends (Figure 02).
- Fixing of pocket formers with live end anchors for live ends (stressing ends) to the side bored at a given height (most probably centre of the slab (Figure 03).
- Laying of ducts as per the tendon lay out.
- Fixing of tendon support bars to specified heights as per shop drawings (typically at 1m spacing, Figure 06, 09, 10).
- Fixing of top mat steel, additional reinforcement specified in general notes and column head reinforcements (Figure 11).

- Sealing the joints using mastic seal tape wrapping around the joints and undergo the inspections.
- Inspection, concreting and preparing test cubes
- Testing of concrete test cubes and start stressing as per guide lines in method statement
- Form work removal and back propping.

As Sri Lankan construction industry is premature in post-tension slab constructions, therefore, there are lots of practical difficulties expected to encounter during the period of PT installations to removal of form works of the floor slab. Following sections are the few of the areas where contractor and designer must put their due considerations and follow up with QA QC procedures.



Figure 02: Preparation of dead end anchorage



Figure 03: Fixing of pocket formers

3.1 Tendon arrangements and Opening in Slabs

A particular design feature of post-tensioned slabs is that the distribution of tendons on plan within the slab. There is some effect on strength and shear capacity, but this is generally small. This allows an even pre stress in each direction of a flat slab to be achieved with a number of tendon layouts. Most Commonly used options are shown in Figure 04a, b,c and authors' recommended layout [ACI318. R18.12.4] is in Figure 05. This offers considerable design flexibility to allow for penetrations and subsequent openings, and the adoption of

differing slab profiles, e.g. from solid slabs through to ribbed and waffle construction.

Holes through pre stressed slabs can be accommodated easily if they are identified at the design stage. Small penetrations (less than 300 mm x 300 mm) can generally be positioned anywhere on the slab, between tendons, without any special requirements. Larger slab penetrations are accommodated by locally displacing the continuous tendons around the hole. It is good detailing practice to overlap any stopped off (or 'dead-ended') tendons towards the corners of the holes in order to eliminate any cracking at the corners. Holes are more difficult to accommodate once the slab has been cast. They can, however, be carefully cut if the tendon positions have been accurately recorded or can be identified. A better approach is to identify the possible zones where further penetrations may be required at the design stage itself. These zones can then be clearly marked on the soffit of the slab.

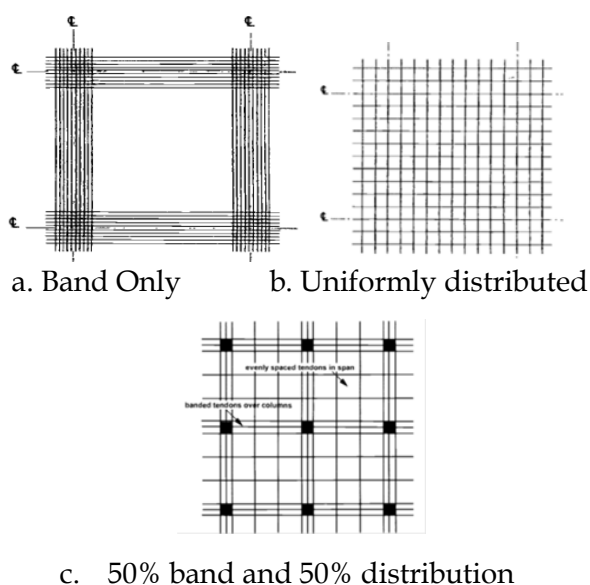


Figure 04 a,b,c: Possible Tendon arrangements - Technical report 43 [3]

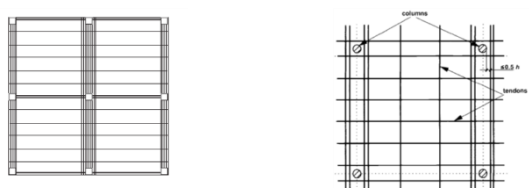


Figure 05: Band and distribution arrangement of tendons-ACI 318[2] & Technical report 43 [3]

3.2 Installation of tendons

To enhance the laying of tendons, contractor/ designer has to submit a method statement along with shop drawing for each and every tendon (Figure 06, 07). Contractor has to make sure that, given method statement is followed perfectly to overcome unwanted delays by readjustment of tendons and removal of reinforcements etc. Most probably, practical difficulties encounter over the column heads or mid spans where band and distribution tendons are crossing each other.

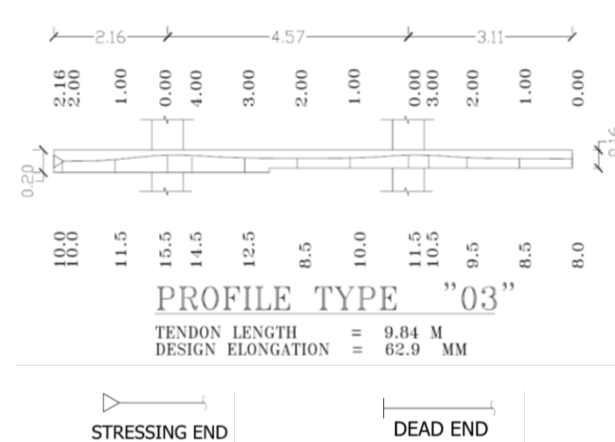
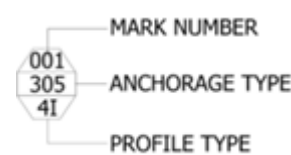


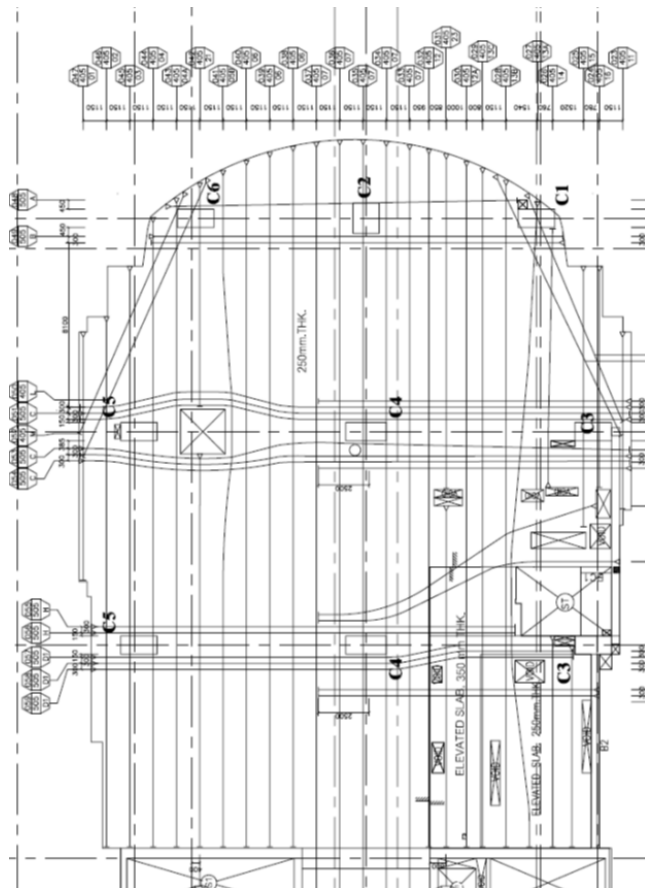
Figure 06: Tendon shop Drawings

3.3 Provisions for construction joints (to control restrain effects)

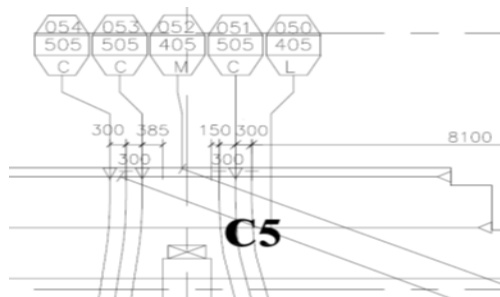
There are three types of construction joints (closure strips, wall infill strips or temporary release) that can be used between areas of slab. When used they are typically positioned in the vicinity of a quarter or third points of the span. The most commonly used joint is the infill or closure strip, as this is an ideal method of resolving problems of restraint, and it also provides inboard access for stressing, removing the need for perimeter access from formwork or scaffolding. Concreting in bays were introduced in Platinum Tower project in Sri Lanka to overcome difficulties arise due to lack of scaffoldings for formwork supports



a. Tendon marking



Tendon layout



b. Detailing of tendons

Figure 07 a,b,c: Tendon Layout and detail Drawings

and concreting difficulties during peak hours and at the night and also to control the restrain effects of the central core. Further, to eliminate the restrain effects at the unfavourable wall locations, temporary wall infill or column block out had to be introduced. However, in another project (Colombo tower Figure 13, 15) closer strip along the rigid central core up to level 7 was proposed to eliminate the restrain effects and gain the easy access for stressing of tendons. Following quality measures should

be whenever required in the construction of closure strips.



Figure 08 Insert tendons into ducts

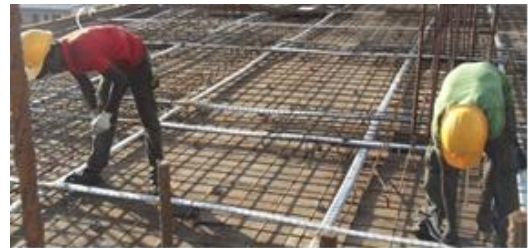


Figure 09 adjusting the tendon profiles



Figure 10 Fixing of bursting reinforcements



Figure 11: Arrangement of additional reinforcements at the opening

- Retain shoring until concrete in closure strip reaches specified concrete strength
- Closure strip to be filled with non-shrink concrete
- Roughen, clean joints and wet prior to placing concrete
- Eliminate accidental misalignment between edges of slabs that are to be joined with a closure strip. Use

mechanical methods such as jacking if necessary

- Provide waterproofing membrane if required for water tightness
- If closure strip will be in an aggressive environment, seal anchorage pockets as per the project specifications and caulk joint all the way around with flexible sealant
- Contractor shall note, that there are special shoring conditions on either side of the closure strip, especially for multi-story structures

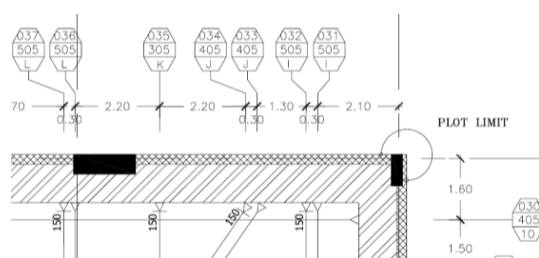


Figure 13: Closure Strip details

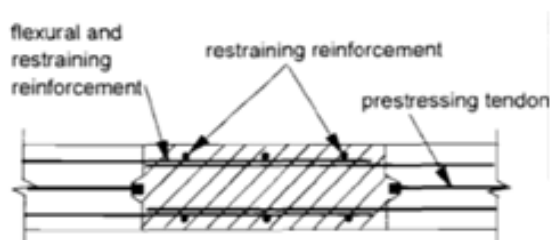


Figure 14: Closure Strip within slab

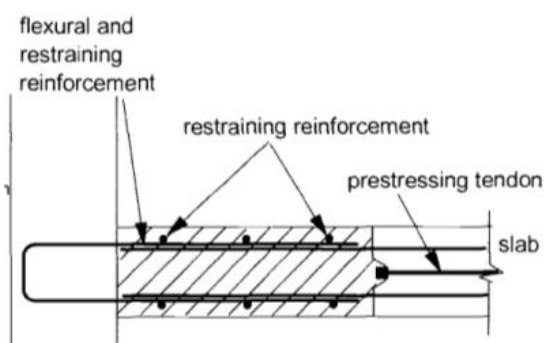


Figure 15: Closure Strip at wall slab junction

3.4 Placing un-tension reinforcements

Laying of un-tension reinforcement should be done as per method statement to minimize the repetitive works. Normal practice is to lay the bottom layer first. And after installing the tendons in place, lay the top reinforcement as per reinforcement layout and general notes.

3.5 Concrete placing, curing and maximum pour size of concrete

While concreting is in progress, Care must be taken to prevent displacing of tendons and blockage of ducts (pass compress air into the ducts through one of vent pipe to insure that there is no concrete leakage into the ducts), although it is easier than concreting of conventional reinforced slab as there is no reinforcement congestion. However, both the placing and curing of the concrete is similar to that of a reinforced slab. Concrete cubes are taken and cured close to the slab to enable the strength gain of the concrete to be monitored. The cubes are taken during the pour and crushed at daily intervals to monitor the strength gain of the concrete. Large pour areas are possible in post-tensioned slabs, as the application of an early initial pre stress (partial pre stressing), at a concrete strength of typically 12.5 N/mm² (if needed only), can help to control restraint stresses due to early thermal and shrinkage (most probably due to high wind and use of high strength concrete). There are economical limits on the length of tendons used in a slab, and these can be used as a guide to estimate the maximum pour size. Typically these are 35 m for tendons stressed from one end only and 70 m for tendons stressed from both ends.

3.6 Stressing, back propping and grouting

The tendon is stressed with a hydraulic jack and the resulting force is locked into the tendon by means of a split wedge located in the barrel of the recessed anchor. At about 4 days after concreting, after achieving 28N/mm² cube strength, (The concrete strength and tendon force will vary depending on post tension system), slab can be fully stressed in a sequence manner given in method statement, enabling the slab to be self-supporting so that formwork can be removed. While stressing is in progress, hydraulic jack is locked to predetermined force (typically 15 Tons) and resultant elongations is checked with computed elongation indicated in shop drawings (Figure 06). Care should be taken while stressing the tendons, where expected

elongations could not be achieved (expected elongations is well below or above with the achieved elongation for the corresponding the jacking force). Fortunately, so far in Sri Lanka, none of the tendons were broken/slip/blocked during the stressing (this gives an evidence that it is easily increased the jacking force up to 80% in the near future as used in other countries and ACI318.18.5.1). After Applying the pre stressing forces, close observations is required at the jacking ends for few days to ensure seating of the pre stressing tendons. It is recommended that, as soon as the formwork has been removed a secondary propping system (if required) is used until the next slab is fully stressed. However, this will be included in initial design checks/ pre stress transfer condition on the frame by taking account of the reduced concrete strength during the design process.



Figure 16: Stressing in progress

In the bonding systems, durability of PT strands, bonding between PT strand and concrete/ ducts is achieved by grouts. As bonding systems do not allow provisions for maintenance of PT strands, grouting play a major role. These grouts has a high water cementious material ratio (>0.45), resulting in low strength and high shrinkage. There is a tendency for the solids to settle, leaving a layer of water on the top. Therefore, special ingredients or treatments are needed to improve these characteristics [6]. In order to assure the quality, following proper inspection, procedures and testing (listed in table 7, 8) are essential.

Table 7 performance specification of grouts

Grout Performance characteristics	Test Method	Acceptance Criteria
Bleed and Segregation of grout	Inclined Tube test and Wick - Induced Bleed test	Bleed water $<0.3\%$ Air void $<0.3\%$ Segregation :No significant segregation visible to the naked eye Of Original Grout Volume Initial Flow time <25 Seconds
Flow Time of grout	Flow cone according to EN 445	Change of flow time in 45 minutes <3 Seconds variation Of density $<5\%$
Sedimentation of grout	Sedimentation test	
Corrosiveness of grout	Chemical analysis of grout by qualified laboratory	Chloride content $<0.1\%$ Of Cement weight
Toxicity of grout	Declaration of materiala or chemical analysis by qualified laboratory	Grout shall not contain toxic materials
Strength of grout	Test According to EN 445	Compressive strength at 7 days >30 MPa
Volume Change of grout	Test According to EN 445	Volume Change At 24 Hours -0.5% to $+1.1\%$ Of original grout volume
Setting time of grout	Measurement of heat of hydration by qualified laboratory	Start Of Setting >3 hours Declaration of start ,Peak ,end of setting
Water/Cement ratio Of grout	Weight measurement of constituents including liquid in admixtures	Declaration Of water /cement ratio of grout
Density Of grout	Volume and weight measurement of grout	Declaration of density of grout
Frost Resistance of	Testing by	Declaration of frost

Table 8 Code provisions and testing for Grouts

Property	EN 447	PTI	Test Method/Specimen
Flowability	≤ 25 seconds	11 to 30 seconds	Flow cone($\varnothing 10$ or 12.7mm)
Volume change	1% to +5%	0% to +0.1%	Plastic cylinder(100-200mm high)
Bleed	$\leq 2\%$	0%	Plastic cylinder(100-200mm high)
Strength	at 7 days ≥ 27 MPa	≥ 21 MPa	Cube or cylinder(50-100mm)
	at 28 days ≥ 30 MPa	≥ 35 MPa	

4. Conclusions

In the recent past, First Building in Sri Lanka (Platinum 1) with the application of Post Tension was done successfully with expected time targets and cost. During the first few floors were casted; there was a time to learn about the QA/QC procedures and detailing which were not familiar to Sri Lankan contractors. All ways contractors' first priority was for reinforcements, but in PT slabs it is for tendons. With greater effort, the contractor was successfully trained to achieve the specific targets. Today, there are few projects already completed with the post tension slabs and few of other buildings are yet to incorporate the technology. However, Post Tension Flat slab constructions were done by specialist subcontractors in overseas countries.

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