

Post Tensioned Concrete Floors

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Abstract

: Deals with the construction of concrete building structures incorporating post-tensioned concept. It is suitable for use by architects, contract managers and quantity surveyors who may wish to gain an understanding of the principles without going into the mathematical aspects of the design process, as well as structural engineers requiring detailed design guidance.

Keyword(s): Light Weight, Concrete Floors, Formwork, Metal Work, Expansion Joints

Practical Experience on Construction of Post Tensioned Concrete Floors at B+G+1 Shopping Mall Project for M/s. Union Cooperative Society at Al Barsha District of United Arab Emirates

General Introduction:

The project was a B+G+1 (Basement +Ground +First) shopping mall construction having approximately 800,000 Sq.ft for M/s. Union Cooperative Society – Dubai. Basement floor was constructed on the isolated footings combined with a raft foundation having a floor area of 208072 Sq.ft. Part of the ground floor was consisted of a post tensioned (PT) slab and other part was on the slab on grade.

Purpose of the Study: In Sri Lankan construction industry, the term “stressed concrete” is mainly popular in beam designs which are used in bridges. That is also with pre stressing concrete concept in which the strands are stressed prior to do the concrete. We mainly design slabs with conventional type and provide reinforcement as per the code BS 8110. But in post tensioned design, there are additional few things to be added to the design and knowledge of conventional cast in-situ concrete design is sufficient to understand the basics of the PT design. No prior knowledge of post tensioning is required.

This report deals with the practical situation of the construction of post tensioned floors which enable engineers to make the most effective use of the material properties of concrete. No much mathematical calculations with the theory behind the PT slabs are shown in this paper and discuss only the concept of post tensioned concrete floor construction which has been consistently growing in recent years with the aid of drawings and photos.

Conclusion: When the design of PT slab is done properly against the conventional concrete slab; it can contribute significantly to the economy and aesthetic qualities of the building. As a result, PT floors have found widespread use in office buildings, shopping malls and apartment constructions etc. In my project, PT slabs were for shopping mall and it was mandatory to have a bigger clear span for the car park and shop area. Therefore it was economical and convenient to design the slabs with post tensioning method in order satisfy the end user’s requirement. The techniques, structural behavior and design are very simple and very similar to the conventional RC structures. Only thing, there were much provision to go for long spans between each direction columns due to the special advantage of stressing. That is due to the high span/depth ratio in PT floors. It is between 20 and 25 for RC floors whereas the same is between 30 and 40 for PT floors. Normally PT designs are not done for the slabs with the span under 6.0m. In my project, the span between the columns along longer direction of the building was 8.6m and the same was 11.2m along shorter direction of the building.

1.0 Post Tensioning Techniques

1.1 Post Tensioning Techniques

Post tensioning is a technique of pre loading the concrete in a manner which eliminates or reduces the tensile stresses that are induced by the dead and live loads. High strength steel ropes called “strands” inside the metal duct (“tendon”) arranged to pass through the concrete floor. When the concrete is

hardened, each set of strands is gripped in the jaws of hydraulic jack and stretched to a pre determined force. Stressing procedure will be fully described in a later chapter with the details.

The terms which are mostly used in the post tensioning slab constructions are strands, tendons, anchorages etc. “Anchorage” is a device which locks the strand in order to ease the stressing and cast inside the concrete. This will induce a compressive stress in the concrete and later strand is held permanently by this anchorage.

1.2 Post Tensioned Concrete Floors and Cast in-situ RC Floors

Post tensioning offers some very useful technical and economic advantages over cast in-situ RC, particularly for long spans. Reinforced concrete technology is widely available and is well understood.

The main advantages of post tensioned floors over conventional RC in-situ floors are summarized as follows.

1. Increased clear span
2. Thinner slabs
3. Lighter structures -
4. Reduced shrinkage cracking – PT keeps the concrete in compression, which control the shrinkage cracking and reduces the possibility of opening up of construction joints.
5. Reduced deflection – The upward force exerted by a curved tendon acts against the applied loads. Therefore the deflection of the floor is lower.
6. Rapid construction
7. Better water tightness – The tensile stresses in a PT member is smaller than the equivalent member of RC.
8. Less work
9. Fewer construction joints – larger area of a floor can be cast in one time
10. Reduced scaffolding cost

These advantages can result in significant saving in overall cost for the construction of slabs. There are few disadvantages also when decide to go for post tension slab constructions as mention follows.

1. Needs the services of trained operatives for installation which involves additional trade on site
2. Additional site works required – holes to be drilled in the side shutter and anchorage blocks to be fixed to the formwork
3. Risk while stressing where applied load is reversed
4. Special materials required such as anchorages, ducts and strands which have to specially procured and stored on site
5. Special equipments needed such as stressing jacks and grout pumps which need to be stored and moved from one position to another

2.0 Post tensioning design and site activities

2.1 Post tensioning design:

As I mentioned earlier, the shopping mall consisting of basement, ground, first and roof in which the basement floor is constructed with reinforced concrete. Other slabs were designed to construct by post tensioning which was designed by an approved PT designer. PT slabs were designed in accordance to BS 8110/1997 and the slab loadings were as follows.

	Super Imposed D.L (KPa)		Super Imposed L.L (KPa)		Floor Finish and Services (KPa)	Super Imposed L.L (KPa)
	Shops	Car Park	Shops	Car Park		
Ground Floor	5	2	5	4		
First Floor	5		5			
Roof Floor					3.5	3.5

Table 1: Slab loading considered in design of the structure

The design was carried out with combination of both RC part and PT part. Reinforcement, concrete and PT strand properties were taken in to account at the time of designing the slabs to satisfy the above loads. PT floors use all the materials required in RC floor constructions such as r/f, concrete and additionally we used high tensile steel strand and the hardware which was specific to post tensioning. The properties of used materials are as follows.

Concrete: Reinforced concrete shall have a minimum 28 day cube crushing strength of 40 N/mm² with minimum cement content of 380 Kg/m³ and maximum water/cement ratio shall be 0.42

Reinforcement: All reinforcing steel bars shall be deformed hard grade steel having a minimum yield strength of 460 N/mm²

Strands: Low-relaxation stress relieved supra-strand

12.7mm with min. breaking load of $F_{pu} = 184$ KN

12.7mm with min. breaking load of $F_{pu} = 260$ KN

These strand runs inside a metal duct called tendon.

2.2 Site Activities:

Before discussing the site activities, it is better to have an idea of following equipments which used for post tensioning works.

- Stressing Jack and Pump
- Strand Threading Machine
- Strand Cutters
- Grout Mixer and Pump

Site activities in post tensioning floor is not much differ from the conventional type of floors but some additional works will be there throughout the operation.

2.2.1 Scaffolding and Formwork

Once the PT design drawings were approved by the consultant, these drawings were sent to scaffolding sub contractor for the design of scaffolding arrangement to proceed with the formwork. Scaffolding sub contractor was submitted the scaffolding layout with the details for consultant approval and issued to the site for the execution of the said work. Formwork was carried out on the scaffolding frame with the side shutters and PT requires holes to be drilled in the side shutters for the tendons to project through and the anchorage blocks need to be attached to the formwork. Also the scaffolding platform about a metre in width was extended in order to access the live anchorages at floor edges for the strands stressing purpose.

2.3 Post Tensioning Site Works

After formwork completes, the reinforcement work started and bottom reinforcement lay as per approved drawing. Then the PT works started by drawing tendons on both directions of the slab according to the tendon layout given in the approved PT drawing. The tendons follow a smooth parabolic profile between high and low points as per the heights mentioned in the drawing and provided chairs at maximum 1000mm centre to centre to support the tendon. Strands support or end at the edges as per the anchorage types described below with the locations where use such anchorages.

Anchorage is device which fixed to the vertical board comes with the casting, barrel, wedge, polystyrene recess former and the spiral reinforcement bent according to the type of the anchorage with different size of r/f bar and no of turns mentioned in the drawing.

2.3.1 Anchorage Types

- a. Pan end anchorage:** This type of anchorage was used where the reinforcement of the slab is continuing but there is gap between the concrete. In our site, pan end anchorages provided at the expansion joint as shown in the picture below.



Figure 1: Practical usage of the Pan End Anchorage at site

- b. **Live end anchorage:** The anchorage is in direct contact with the concrete and is the component which transfers the stressing force to the concrete. In our site live end anchorages were near pour strip and the places where free end is exposed to stress the tendon.



Figure 2: Practical usage of the Live End Anchorage at site

- c. **Dead End Anchorage:** This type of anchorage is provided at tendon end where the access is not required any operation like stressing after concreting the slab so that the anchorage assembly is cast inside the concrete.



Figure 3: Practical usage of the Dead End Anchorage at site

In the project, the slab areas were big and introduced expansion joints along shorter and longer direction of the building. Ground floor itself had around 18000 m² of floor area and there was an expansion joint along longer side of the building and 2 joints along shorter direction. Since the area is big, floor was divided into parts at the expansion joints and introduced pour strips along shorter side of the building in order to ease the post tension ground floor slab construction. Pour strips were on the both directions of the building for the first floor since the slab area was around 26000 m² and cannot stress the strands with higher distance. Two slabs on both sides of the pour strip to be cast at one time since the tendons of the slabs can be stressed from the same pour strip.

2.3.2 Pour Strip

Pour strips are specific to post-tensioned slab constructions and are located at the mid span or quarter point of the bay. Bays are decided by the PT designer with the available expansion joints on the slab. In my case there were 6 bays in both GF 6 bays in the FF slab. The slabs on each side of the pour strip have to be completely separate when the tendons are stressed to provide the crack control benefit. For that the reinforcement must be discontinued across a pour strip and it can be concreted only after 28 days from the slab concrete.

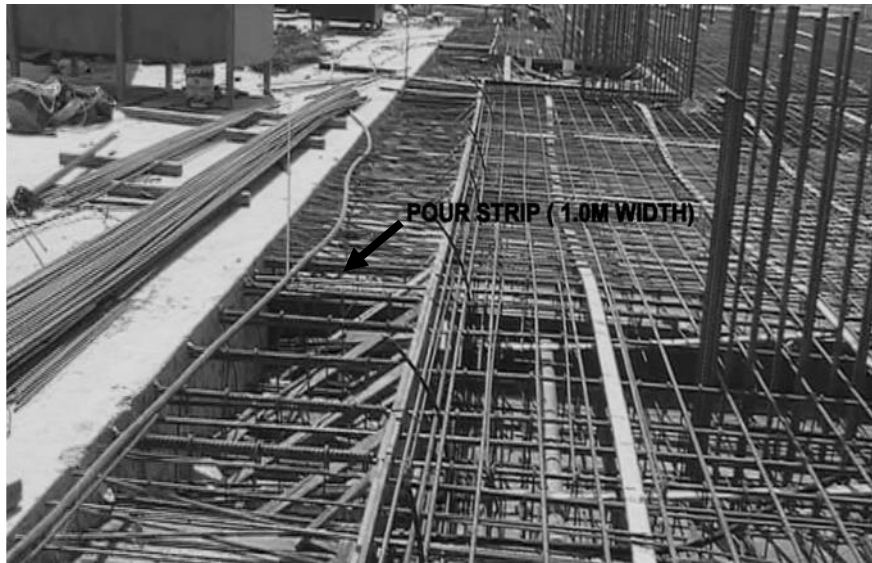


Figure 4: Pour strip construction at site

2.3.3 Sequence in post tensioned slab construction:

The post tensioned slabs were constructed in my site according to the following sequence.

1. Design and drawing approval for both PT and Scaffolding
2. Scaffolding and formwork for the selected pour
3. Side shutter for the slab edges and make provisions for the insertion of live anchorages
4. Insert the strands to the tendon as per the number mention in the PT drawing for the particular pour.
5. Mark the tendon layout in red on the formwork in order to have the marking in the soffit slab for the information where the tendon after the concrete. This will allow us to do any drilling of the slab for MEP or any other requirement in future without damaging the tendon.

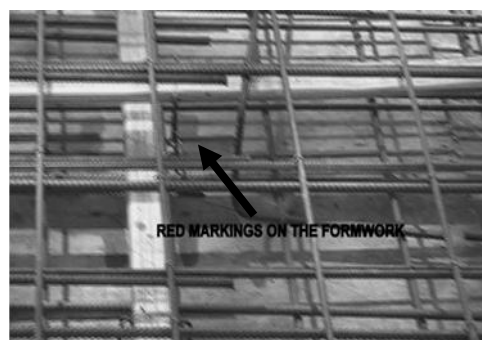


Figure 5: Red markings on the formwork

6. Lay the bottom r/f of the slab and beams as per the r/f details given by the PT designer and provide MEP conduits on the slab and cut openings where necessary.

7. Fix the Polystyrene recess former, casting, barrel with the wedge to the vertical side board where live anchorages are provided and insert spiral to the tendon with the no. of turns as per the detail given by the PT designer.
8. Fix the tendons to the anchorage points and lay the tendons according to the tendon profile mention in the drawing. Make sure to maintain the straight direction of the tendon and maximum allowable diversion of the tendon is $1/20$. For the dead anchorages, one end of the strands should be crimped and other end to be a pan end or live end as per the design. For the pan end, first fix the pan made out of wooden with Polystyrene recess former, casting, barrel with the wedge and spiral. Then take the strands to the inside of the pan which comes from the other end.

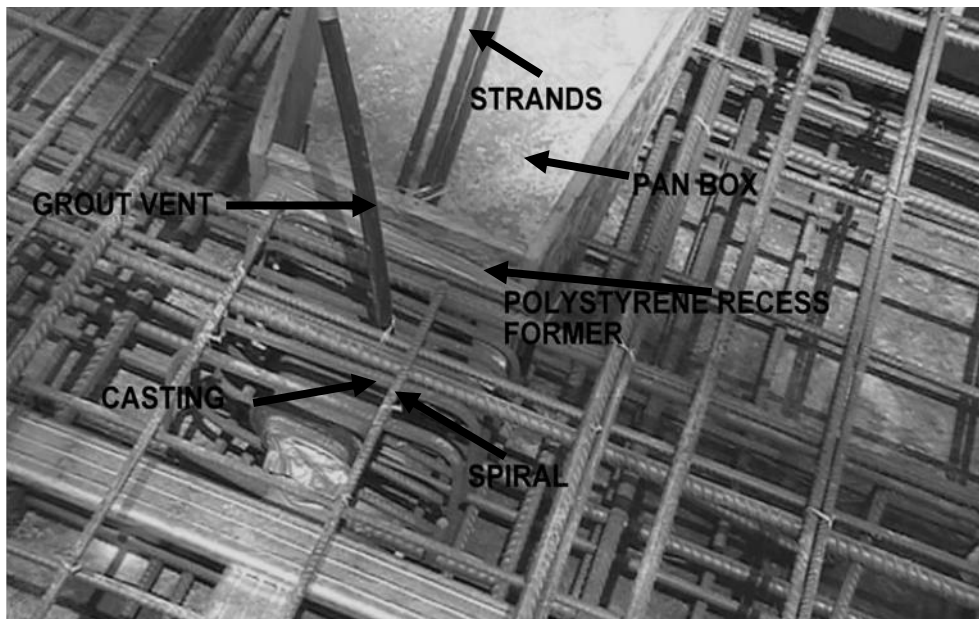


Figure 6: Accessories of the Anchorage

9. Fix the grout vent to the specific locations along the tendon.



Figure 7: Fixing of Grout Vent

10. Lay the top r/f of the slab with extra r/f provided at the pan end anchorages and openings where mentioned in the MEP drawings coordinated with PT design.
11. Arrange inspection with consultant after completion of r/f and PT works.
12. Pour concrete with special care for the tendons and grout vent providing planks on blocks across slab bands for access and adequate restraint of concrete pump lines and placing on stools or timber blocks above ducts.

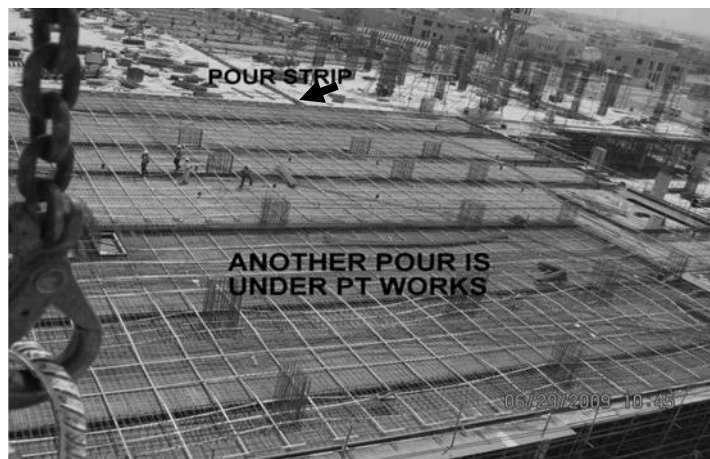


Figure 8: Parallel slabs under PT works and pour strip

13. After 2 days of concrete, start initial stressing based on the compressive strength results of the cubes.

2.3.4 Stressing Procedure and Sequence

The stressing of tendons was started after the concrete cube strength gained for 2 and 4 days with the values mentioned in the following table.

Day	Required F_{cu} (MPa)	
1		Take 6 cubes at the time of concrete from each $50m^3$ for 2 nd , 4 th and 28 th day tests. Commence curing and continue until stressing completes.
2	8	Each strand in slab cables shall be stressed to 25% of final jacking force
4	28	Stress all strands in slab and beams to final jacking force which is not to exceed 75% of breaking load (F_{cu})

Figure 9: Strength of concrete required to proceed with the stressing

2.3.4.1 Stressing Procedure:

Stand away from the jack while the stressing is in progress.

1. Provide pressure force calibration curves, jack gauges and force extension curves for strands.
2. Remove slack then mark strand to stress up to $0.75 F_{pu}$ ensuring to not to exceed the final jacking force of $0.75 F_{pu}$. The stressing jack with the pump is shown in the picture

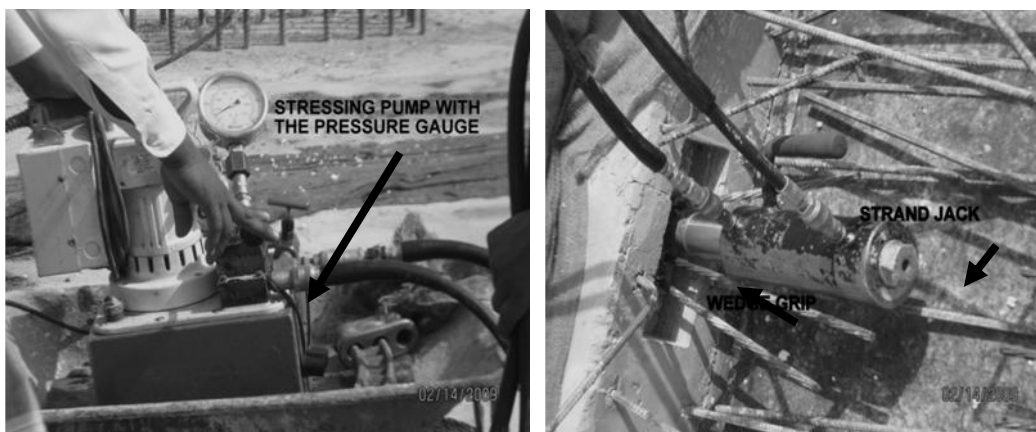


Figure 10: Usage of equipments to stress the tendons

3. Record total extension for each strand at each end

2.3.4.2 Stressing Sequence:

1. The stressing sequence for the strands which are straight in plan



Strand No. 4 3 1 2 5

Figure 11: Stressing sequence for the strands which are straight in plan



Strand No. 5 4 3 2 1

Figure 12: Stressing sequence for the strands which are curved in plan

2. In general, beam strands stress first and then the slab strands.
3. Stressing sequence may only continue when concrete strength at that stage has been achieved. Otherwise PT designer's advice should be taken.
4. When the stressing completes the PT designer is analyzed the extension of the strands and check whether those are in the allowable limits and submit to the consultant approval to proceed with the tendon grouting.
5. Start grouting tendons by the grout pump on completion of final stressing in order to bond the strands to the structure as well as ensuring the corrosion protection.
6. After grouting, the strands are trimmed at the wedge grip and the pockets for anchorage filled with a well vibrated stiff concrete mix.
Grout should be of high fluidity and cohesion when plastic, have low shrinkage when hardening and have adequate strength when hard. The compressive cubic strength for 100mm cubes should not be less than 35 N/mm^2 at 28 days with water/cement ratio not greater than 0.44.

2.4 Back Propping

Back propping of the slab and beams was carried out to ensure the ongoing construction loads to be safely carried from the level above. The soffit shutter was removed once all the tendons have received the final stressing loads and beams to be propped using 2 props every 2.5m along the span and slab was propped at maximum spacing of 3.0m in each direction as follows.



Figure 13: Back propping of the slab to do the slab casting above this level

Back propping was carried out through two levels below the current construction level and only removed at the lowest level when more than two levels are back propped.

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