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A NOVEL APPROACH FOR POST-TENSIONED IN BUILDING STRUCTURE

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ABSTRACT

One of the more important improvements in the fields of structural engineering and construction. Referring particularly to post tensioning applications, it is generally recognized how it opens the possibility to improve economy, structural behavior and aesthetic aspects in concrete solutions. As in modern days post tensioning has been most economical method when compared to the RCC works. The project discusses the activity of using post tensioning in slabs and beams in buildings. This method is quite used in the construction of shopping malls, theatres and multistory structures.

In spite of the simplicity of its basic concepts and well known advantages, the application extent of post-tensioning solutions cannot be considered harmonized in the different areas and structural applications. In fact, for various reasons, it appears that the potential offered by prestressing is far from being exploited, especially in building structures field. In many cases where post-tensioning would provide a superior solution, it happens after all that a more conventional non-prestressed solution is often selected.

Post-tensioned slabs are a preferred method for industrial, commercial and residential floor slab construction**.** The increasingly extensive use of this method is due to its advantages and its nature of easy application to a wide variety of structure geometry and design solutions. The use of post-tensioned floor slabs and reinforced concrete core walls has become increasingly popular in high-rise construction.

Economics of the post-tensioning slab system are discussed including relative material contents, speed of construction, and factors affecting the cost of post-tensioning. Finally, a

discussion on the flexibility of post-tensioned building structures in terms of future uses, new floor penetrations and demolition is presented.

INTRODUCTION

When Eugene Freyssinet developed and patented the technique of prestressing concrete in 1928 he little realized the applications to which his invention would be put in future years. Spectacular growth in the use of prestressed concrete took place after the Second World War with the material used to repair and reconstruct bridges in Europe. It is now an accepted Civil Engineering construction material.

The A.C.I. Committee on Prestressed Concrete gives one of the most apt descriptions of post tensioned concrete.

`Prestressed Concrete is concrete in which there have been introduced internal forces of such magnitude and distribution that the forces resulting from given external loadings are counteracted to a desirable degree'.

In post-tensioning we obtain several distinct advantages: -

a) Designers have the opportunity to impart forces internally to the concrete structure to counteract and balance loads sustained by the structure thereby enabling design optimization.

b) Designers can utilize the advantage of the compressive strength of concrete while circumventing its inherent weakness in tension.

c) Post-tensioned concrete combines and optimizes today's very high strength concretes and steel to result in a practical and efficient structural system.

The first post-tensioned buildings were erected in the USA in the 1950’s using unbonded post tensioning. Some post-tensioned structures were built in Europe quite early on but the real development took place in Australia and the USA. Joint efforts by prestressing companies, researchers and design engineers in these early stages resulted in standards and recommendations which assisted in promoting the widespread use of this form of construction in Australia, the USA and throughout the Asian region.

Extensive research in these countries, as well as in Europe more recently, has greatly expanded the knowledge available on such structures and now forms the basis for standards and codes of practice in these countries.

Since the introduction of post-tensioning to buildings, a great deal of experience has been gained as to which type of building has floors most suited to this method of construction. Many

Engineers and Builders can identify at a glance whether the advantages of post-tensioning can be utilized in any particular situation.

Current architecture in India continues to place emphasis on the necessity of providing large uninterrupted floor space, flexibility of internal layout, versatility of use and freedom of movement. All of these are facilitated by the use of post-tensioning in the construction of concrete floor slabs, giving large clear spans, fewer columns and supports, and reduced floor thickness.

Post-tensioning in buildings can be loosely divided into two categories. The first application is for specialized structural elements such as raft foundations, transfer plates, transfer beams, tie beams and the like. For large multi-strand tendons used in these elements, 15.2 mm diameter seven wire strands are preferred.

1. ADVANTAGES OF POST-TENSIONED FLOORS

The primary advantages of post-tensioned floors over conventional reinforced concrete in-situ floors may be summarized as follows:

a. Longer Spans

Longer spans can be used reducing the number of columns. This results in larger, column free floor areas which greatly increase the flexibility of use for the structure and can result in higher rental returns.

b. Overall Structural Cost

The total cost of materials, labour and formwork required to construct a floor is reduced for spans greater than 7 meters, thereby providing superior economy.

c. Reduced Floor to Floor Height

For the same imposed load, thinner slabs can be used. The reduced section depths allow minimum building height with resultant savings in facade costs. Alternatively, for taller buildings it can allow more floors to be constructed within the original building envelope.

d. Deflection Free Slabs

Undesirable deflections under service loads can be virtually eliminated.

e. Waterproof Slabs

Post-tensioned slabs can be designed to be crack free and therefore waterproof slabs are possible. Achievement of this objective depends upon careful design, detailing and construction. The choice of concrete mix and curing methods along with quality workmanship also plays a key role.

f. Early Formwork Stripping

The earlier stripping of formwork and reduced back propping requirements enable faster construction cycles and quick re-use of formwork. This increase in speed of construction is explained further in the next section on economics.

g. Materials Handling

The reduced material quantities in concrete and reinforcement greatly benefit on-site carnage requirements. The strength of post-tensioning strand is approximately 4 times that of conventional reinforcement. Therefore the total weight of reinforcing material is greatly reduced.

h. Column and Footing Design

The reduced floor dead loads may be utilized in more economical design of the reinforced concrete columns and footings. In multi-storey buildings, reduced column sizes may increase the floor net let table area.

These advantages can result in significant savings in overall costs. There are also some situations where the height of the building is limited, in which the reduced storey height has allowed additional storey's to be constructed within the building envelope.

2. BONDED OR UNBONDED TENDON SYSTEMS

Post-tensioned floors can be constructed using either bonded or unbonded tendons. The relative merits of the two techniques are subject to debate. The following points may be made in favour of each.

a) Bonded system

For a bonded system the post-tensioned strands are installed in galvanized steel or plastic ducts that are cast into the concrete section at the required profile and form a voided path through which the strands can be installed.

The ducts can be either circular- or oval-shaped and can vary in size to accommodate a varying number of steel strands within each duct. At the ends a combined anchorage casting is provided which anchors all of the strands within the duct. The anchorage transfers the force from the stressing jack into the concrete. Once the strands have been stressed the void around the strands is filled with a cementitious grout, which fully bonds the strands to the concrete. The duct and the strands contained within are collectively called a tendon.

Bonded systems.

The main features of a bonded system are summarized below.

1. There is less reliance on the anchorages once the duct has been grouted.
2. The full strength of the strand can be utilized at the ultimate limit state (due to strain compatibility with the concrete) and hence there is generally a lower requirement for the use of unstressed reinforcement.
3. The prestressing tendons can contribute to the concrete shear capacity.
4. Due to the concentrated arrangement of the strands within the ducts a high force can be applied to a small concrete section.
5. Accidental damage to a tendon results in a local loss of the prestress force only and does not affect the full length of the tendon.

b) Unbonded system

In an unbonded system the individual steel strands are encapsulated in a polyurethane sheath and the voids between the sheath and the strand are filled with rust-inhibiting grease.

The sheath and grease are applied under factory conditions and the completed tendon is electronically tested to ensure that the process has been carried out successfully. The individual tendons are anchored at each end with anchorage castings.

The tendons are cast into the concrete section and are jacked to apply the required prestress force once the concrete has achieved the required strength.

Un bonded Tendon systems.

The main features of an unbounded system are summarized below.

1. The tendon can be prefabricated off site.
2. The installation process on site can be quicker due to prefabrication and the reduced site operations.
3. The smaller tendon diameter and reduced cover requirements allow the eccentricity from the neutral axis to be increased thus resulting in a lower force requirement.
4. The tendons are flexible and can be curved easily in the horizontal direction to accommodate curved buildings or divert around openings in the slab.
5. The force loss due to friction is lower than for bonded tendons due to the action of the grease.
6. The force in an unbonded tendon does not increase significantly above that of the prestressing load.

7. The ultimate flexural capacity of sections with unbounded tendons is less than that with bonded tendons but much greater deflections will take place before yielding of the steel.
8. Tendons can be replaced (usually with a smaller diameter).
9. **A** broken tendon cause's prestress to be lost for the full length of that tendon.
10. Careful attention is required in design to ensure against progressive collapse.

Why a bonded system?

This is another question that arises. Why do we use bonded tendons? Well there are a number of advantages; higher flexural capacity, good flexural crack distribution, good corrosion protection and flexibility for later cutting of penetrations and easier demolition.

However there are some disadvantages such as an additional operation for grouting and a more labour intensive installation.

However, the main reason why bonded tendons are preferred relates to the overall cost of the structure and not just of the post-tensioning. With unbonded tendons it is usual to have a layer of conventional reinforcement for crack control.

Using bonded tendons there is no such requirement and therefore the overall price of bonded post-tensioning and associated reinforcement is less than for bonded tendons. For unbonded tendons the post-tensioning price may be less, but the overall cost of reinforcing materials is greater.

3. MATERIALS

Post-tensioned floors use all the materials required in a reinforced concrete floor-formwork, rod reinforcement and concrete- and, additionally, they use high tensile steel strand and the hardware specific to post-tensioning.

As a material, rod reinforcement in post-tensioned floors is exactly same as that in reinforced concrete in every respect. The normal high tensile steel, as used in rod reinforcement, has a yield stress of 460 N/mm^2 and a modulus of elasticity of 200 KN/mm^2. It has a poisons ratio of 0.3 and a coefficient of thermal expansion of 12.5 x 10^{-6} per degree centigrade. The strength of high tensioned steel is affected by rise in temperature, dropping from 100% at 300 degree centigrade to only 5% at 800 degree centigrade.

The technology for the production, compaction and curing of concrete is well understood and is not discussed here. Only the properties of concrete which are important for post-tensioning are considered.

Normal dense concrete, 2400 kg/m^3 density, is more common in post-tensioning. Light weight concrete, however, has certain advantages in the right circumstances. Both are dealt with in separate sections.

The properties of two concretes are quite different and it is not a good practice to use the two side by side; there may be problems from differential movement and the difference in their module of elasticity, shrinkage and creep.

a) FORMWORK

In a post-tensioned floor, the vertical edge boards of the form work need to have holes drilled through for the tendons to pass at live anchorages. During stressing, the concrete undergoes a slight reduction in length due to axial component of the pre stress. Though trapping of formwork between any down stands is not a serious problem, the design of formwork should recognize the possibility. During stressing, the post-tensioned slab lifts off the formwork, so that there is a re-distribution of its weight. This may impose heavier loads on parts of the formwork than those due to the weight of wet concrete. In other respects, the formwork for a post-tensioned floor is similar to that for a reinforced concrete floor.Each live anchorage is set in a recess, or anchorage pocket, in the slab edge. The pocket is formed using proprietary plastic formers supplied by the specialist pre stressing hardware supplier. The formers are removed when the formwork is stripped. Expanded polystyrene blocks have sometimes used for this purpose but, in the authors experience they are often difficult to remove afterwards and pieces of polystyrene are left in the anchorage pocket. Attempts to remove these by burning causes heating of the anchorage and the strand at a critical point and use of chemicals may have a detrimental effect on concrete or steel.

Economical Design

Of course, the economics of post-tensioned buildings is heavily dictated by the design of the structure. The designer has a role to play in the minimization of material quantities, the selection of the most economical structural system, and the simplification of the detailing allowing for ease and speed of installation. A few design considerations are briefly mentioned below.

a) Partial Prestressing

The advent of what is commonly termed partial prestressing has had a significant effect on the quantity of post-tensioning installed into building structures. Tensile cracking is allowed to occur, with crack control being provided by the bonded tendons and/or supplementary reinforcement. A cracked section analysis needs to be carried out to determine the cracked moment of inertia for use in deflection calculations as well as the steel stresses to confirm adequate crack control. The availability of computer software to carry out these calculations has meant that more often than not the amount of post tensioning is selected to satisfy deflection criteria.

b) Selection of Column Grid

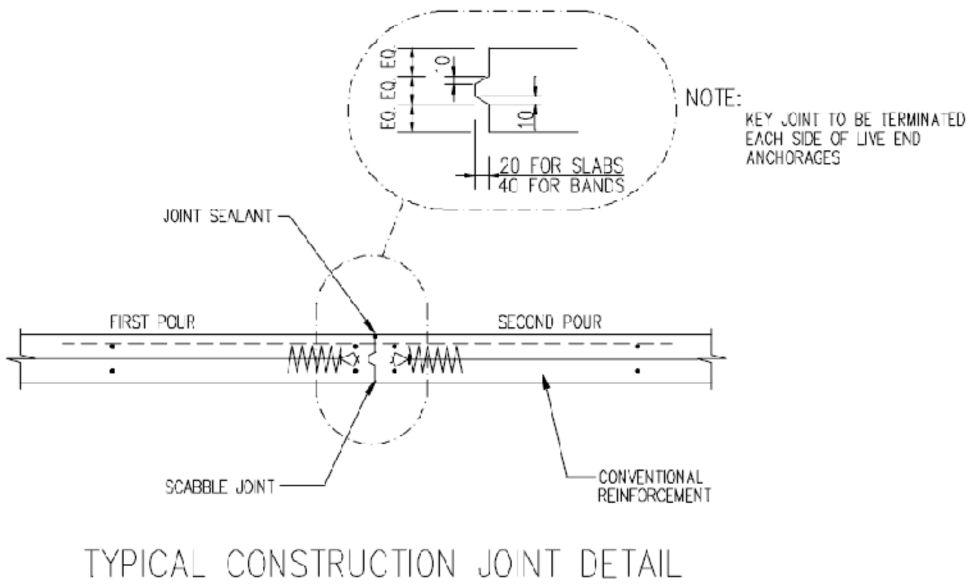
A column grid spacing of between 8 and 10 meters for car parks, shopping centers and offices usually results in the most economical structure while maintaining architectural requirements.

c) Formwork Layout

Formwork layout should be selected to enable quick fabrication with a minimum of form ply cutting. Widths of beams should be standardized in consultation with the main contractor and importantly, the width of the slab between bands should be selected as a multiple of 1200 mm to suit the standard formwork sheet widths.

d) Construction Joint Treatment

As mentioned previously the detail at the construction joint will play a significant role in the economics of the floor system. Post-tensioning couplers should be avoided due to their cost and slow installation. Construction joints should be stitched with conventional reinforcement as shown in figure below.



'Stitched' construction joint detail.

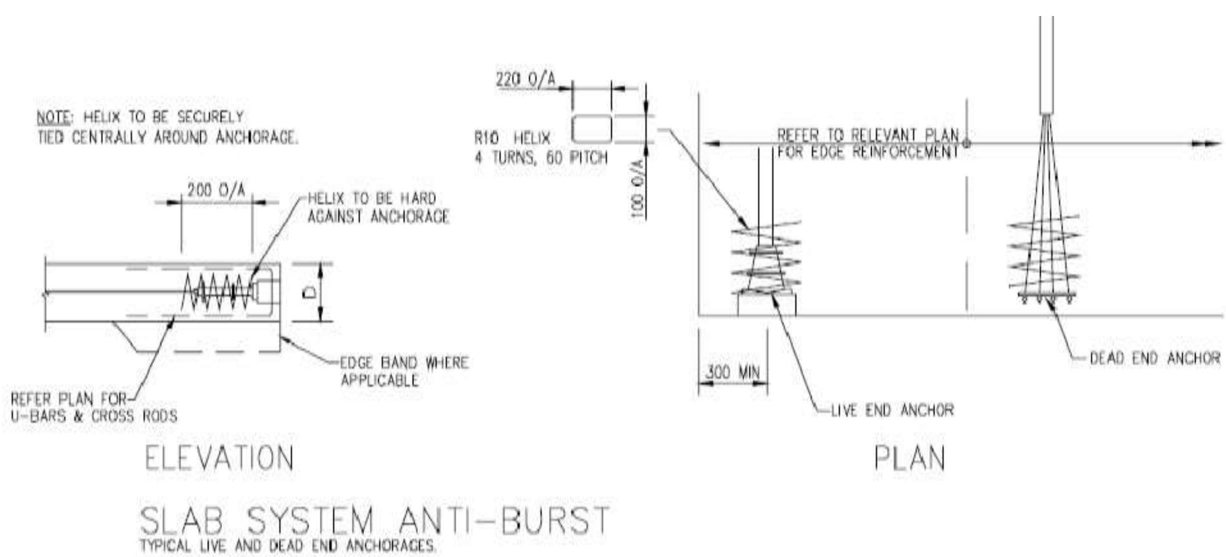
Note that the amount of reinforcement required keeping a construction joint closed (say a crack width of 0.2 mm as for reinforced concrete) depends highly on the restraint of the overall frame. If the frame is very flexible, or alternatively if the construction joint is adjacent to very stiff elements such as core walls, then the amount of reinforcement required is quite low. On the other hand, if the frame is very stiff, large quantities of reinforcement will be required at which point an expansion joint should be positioned rather than a construction joint.

e) Simplicity In Detailing

As with all methods of construction the speed of installation is highly dependent upon the quality of the structural detailing. The designer needs to understand the installation process and be conscious of how their decisions on detailing affect all parties concerned on site. Detailing should be standardized and as simple as possible to understand. Congested areas should be carefully assessed and, as appropriate, large scale drawings and details produced.

f) Anchorage Reinforcement

Standardization of anchorage reinforcement is important. For the slab system, helical reinforcement is preferred by the main contractor due to the speed and ease of installation. It must be noted that by providing a single helix around an anchorage is not adequate since tensile forces are also generated between anchorages. It is usual to detail u-bars plus longitudinal reinforcement along the perimeter to control these forces and to reinforce the un-tensioned area between anchorages.



g) L/D Ratios

Choosing the right L/D ratio for the structural system and applied loading is important. Choosing a high L/D ratio may minimize the amount of concrete, but will increase the amount of post-tensioning and/or reinforcement required, and perhaps cause increased vibration. Choosing a low L/D ratio in order to minimize post-tensioning may not secure the expected result due to minimum reinforcement rules and adequate residual compression levels to ensure shrinkage cracking is controlled.

h) Load Balancing

The selection of the load to be balanced by the post-tensioning tendons is an important factor in the economics of post-tensioned systems. One of the major advantages of post-tensioning is to reduce the long-term deflection of the structure; however selection of too high a load to balance may incur prestressing costs reducing the economy of the prestressed solution. A combination of a lower level of 'balanced load' and the addition of normal reinforcement at peak moment regions will prove to be a more economical solution in most applications. Table below is a guide to the amount of load to balance under a range of building uses.

Occupancy of building	Partitions and Other Superimposed Dead Load kPa	Live Load kPa	Load to Balance kPa
Car Parks	Nil	2.5	(0.7-0.85)SW
Shopping Centres	0.0 - 2.0	5.0	(0.85-1.0)SW
Residential (check transfer carefully)	2.0 - 4.0	1.5	SW + 30% of partition load
Office Buildings	0.5 - 1.0	3.0	(0.8-0.95)SW
Storage	Nil	2.4 kPa / m height	SW + 20% LL

Note: SW denotes self weight, LL denotes live load.

Table 8. General level of load to be balanced by post-tensioning tendons to give an economic structure.

i) Terminate Tendons Wherever Possible

Often the amount of post-tensioning required within a member varies across its length. 1For example, end bays usually require a greater level of prestress to control deflections than internal bays. Terminating the post-tensioning once it is not required can be achieved by either terminating whole tendons or terminating individual strands using a ‘short dead end’.

j) The Use of Finite Element Analysis for Selected Projects

With the advent of sophisticated finite element analysis programs that are relatively easy to use, significant economy can be gained for selected projects. The types of structures benefiting from FEA methods are residential flat plate construction with an irregular supporting column grid and transfer structures such as transfer plates and raft foundations.

We find that the use of FEA methods for these types of structures allow for a better determination of structural load paths and enables the designer to detail and drape the post tensioning tendons to better reflect the slab bending moments. This is what leads to economy.

CONCLUSION

In conclusion it is worthy to reinforce a few key points.

There is a definite trend towards 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. Post-tensioning is an economical way of achieving these larger spans. For spans 7.5 meters and over, post-tensioning will certainly be economic and, as the spans increase, so do the savings.

The most significant factor affecting the cost of slab system post-tensioning is the tendon length. Other factors create a scatter of results leading to an upper and lower bound. Not with standing this, it is always advisable to obtain budget prices from a post-tensioning supplier.

The main structural schemes available are the flat plate, flat slab and banded slab, with the latter generally leading to the most cost-efficient structure. However, other factors such as floor to floor heights, services, etc., must be taken into account in the selection of the floor structure. For high rise construction and highly repetitive floor plates, the use of more specialized structural schemes is appropriate with emphasis on systems formwork.

It is not uncommon for post-tensioning to be rejected in certain types of building project due to a perceived lack of flexibility. However, tendons are usually spaced sufficiently far apart to allow penetrations of reasonable size to be made later, without cutting through the tendons.
Should it be necessary to cut tendons this can easily be achieved using well established methods.

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