POST TENSIONING IN BUILDING STRUCTURES

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ABSTRACT

The development of prestressing technology has 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 solution. As in modern days post tensioning has been most economical method when compared to the RCC works. The project discuss the activities of using post tensioning in slabs and beams in buildings. This method is quite used in he constructions of shopping malls, theaters and multistory structures.

Post tensioned slabs are 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 applications to a wide variety of structure geometry and design solutions. It is popular in high rise construction. Finally a discussion on the flexibility of post tension building structures in terms of future uses, new floor penetrations and demolition is presented.

1. INTRODUCTION

1.1 GENERAL

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 posttensioned 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 unbounded posttioning. 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 Australia 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 applications 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, 12.7 mm diameter seven wire strands are preferred.

1.2 BONDED AND BONDED TENDON SYSTEM

Pre-tensioned concrete is a variant of prestressed concrete where the tendons are tensioned prior to the concrete being cast. The concrete bonds to the tendons as it cures, following which the end-anchoring of the tendons is released, and the tendon tension forces are transferred to the concrete as compression by static friction.

Pre-tensioning is a common prefabrication technique, where the resulting concrete element is manufactured remotely from the final structure location and transported to site once cured. It requires strong, stable end-anchoring points between which the tendons are stretched. These anchorages form the ends of a "casting bed" which may be many times the length of the concrete element being fabricated. This allows multiple elements to be constructed end-on-end in the one pre-tensioning operation, allowing significant productivity benefits and economies of scale to be realized for this method of construction.

The amount of bond (or adhesion) achievable between the freshly set concrete and the surface of the tendons is critical to the pre-tensioning process, as it determines when the tendon anchorages can be safely released. Higher bond strength in early-age concrete allows more economical fabrication as it speeds production. To promote this, pre-tensioned tendons are usually composed of isolated single wires or strands, as this provides a greater surface area for bond action than bundled strand tendons.

Unlike those of post-tensioned concrete, the tendons of pre-tensioned concrete elements generally form straight lines between end-anchorages. Where "profiled" or "harped" tendon are required, one or more intermediate deviators are located between the ends of the tendon to hold the tendon to the desired non-linear alignment during tensioning. Such deviators usually act against substantial forces, and hence require a robust casting bed foundation system.

Straight tendons are typically used in "linear" precast elements such as shallow beams, hollow-core planks and slabs, whereas profiled tendons are more commonly found in deeper precast bridge beams and girders.

Pre-tensioned concrete is most commonly used for the fabrication of structural beams, floor slabs, hollow-core planks, balconies, lintels, driven piles, water tanks and concrete pipes.

Post-tensioned concrete

Fig-1: Tendon Anchorage

Four-piece "lock-off" wedges are visible holding each strand Post-tensioned concrete is a variant of prestressed concrete where the tendons are tensioned after the surrounding concrete structure has been cast.

The tendons are not placed in direct contact with the concrete, but are encapsulated within a protective sleeve or duct which is either cast into the concrete structure or placed adjacent to it. At each end of a tendon is an anchorage assembly firmly fixed to the surrounding concrete. Once the concrete has been cast and set, the tendons are tensioned ("stressed") by pulling the tendon ends through the anchorages while pressing against the concrete. The large forces required to tension the tendons result in a significant permanent compression being applied to the concrete once the tendon is "locked-off" at the anchorage. The method of locking the tendon-ends to the anchorage is dependent upon the tendon composition, with the most common systems being "button-head" anchoring (for wire tendons), split-wedge anchoring (for strand tendons), and threaded anchoring (for bar tendons).

Balanced-cantilever bridge under construction. Each added segment is supported by post-tensioned tendons.
Tendon encapsulation systems are constructed from plastic or galvanized steel materials, and are classified into two main types: those where the tendon element is subsequently bonded to the surrounding concrete by internal grouting of the duct after stressing (bonded post-tensioning); and those where the tendon element is permanently deboned from the surrounding concrete, usually by means of a greased sheath over the tendon strands (unbonded post-tensioning)

Casting the tendon ducts/sleeves into the concrete before any tensioning occurs allows them to be readily "profiled" to any desired shape including incorporating vertical and/or horizontal curvature. When the tendons are tensioned, this profiling result in reaction forces being imparted onto the hardened concrete, and these can be beneficially used to counter any loadings subsequently applied to the structure.

1.3 Objectives of the work

Based on the complete analysis of the literature, the post tensioning in building structures in slabs, beams, grouts, anchorages etc in construction field.

As a result the scope of the present investigation is summarized below.

- To minimize the impact on the environment and avoids disruption to water or road traffic below.
- To study overall structural cost and reduced materials handling at sight.
- Usage of Post-tensioned rock and soil anchors in tunneling and slope stabilization and as tie-backs for excavations. Post-tensioning can also be used to produce virtually crack-free concrete for water-tanks.
- To study longer span and reduce column and footing sizes in post tensioning structures.

2. REVIEW OF LITERATURE

Hans-Rudolf Ganz. et al., (2008) represents some recent developments and trends in materials used for prestressed concrete. In particular, ultra-high performance concrete is introduced. After a review of developments in post-tensioning systems some new damping devices are presented which are used for bridge and building structures. Finally, a few specific applications with significant potential for the next years are given. These include post-tensioned buildings, slabs-on-ground, precast segmental bridges, extradosed bridges, and concrete containment and storage structures.

Larry Krauser et al., (2006) presented that post-tensioning can be used for repairs, modification and strengthening of reinforced concrete and post-tensioned structures. The article describes some of the commonly used techniques and precautions for detensioning tendons, repairs and re-stressing of tendons. The article gives guidance to practicing engineers and contractors on techniques that can be used to create new openings in existing posttensioned structures. The article also explores techniques for the strengthening of existing structures by external post-tensioning.

Iverson, JK Hawkins, NM et al., (1994) the paper titled “Performance of precast/prestressed building structures during Northridge earthquake”. Observations are reported of the performance in the January 17, 1994 Northridge, California, earthquake of buildings in which precast/prestressed concrete components were utilized. Ground motions recorded during the earthquake are discussed in relation to fault movements, observed responses at building sites, and prevailing building code design requirements. The results of field observations of parking garages, cladding for buildings and foundations for residences are reviewed. It is concluded that, with the exception of buildings in the immediate vicinity of the epicenter, engineered structures, including those with precast/prestressed concrete components, generally performed well. Parking garages, particularly those with large plan areas, did not perform as well as other types of...
buildings. The greatest damage was in collector elements funneling lateral forces to the vertical elements of the lateral load resisting system and in the columns of gravity load carrying systems that were not intended to be part of seismic resisting system. No damage was observed to cladding due either to inadequacies of the precast components or their connections to the building's structural system.

Dion Marriott, Stefano Pampanin, Alessandro Palermo et al., (2008) Quasi-static and pseudo-dynamic testing of unbonded post-tensioned rocking bridge piers with external replaceable dissipaters It has been well documented that following a major earthquake a substantial percentage of economic loss results from downtime of essential lifelines in and out of major urban centres. This has thus led to an improvement of both performance-based seismic design philosophies and to the development of cost-effective seismic structural systems capable of guaranteeing a high level of protection, low structural damage and reduced downtime after a design-level seismic event. An example of such technology is the development of unbonded post-tensioned techniques in combination with rocking–dissipating connections. In this contribution, further advances in the development of high-performance seismic-resistant bridge piers are achieved through the experimental validation of unbonded post-tensioned bridge piers with external, fully replaceable, mild steel hysteretic dissipaters. The experimental response of three 1 : 3 scale unbonded, post-tensioned cantilever bridge piers, subjected to quasi-static and pseudo-dynamic loading protocols, are presented and compared with an equivalently reinforced monolithic benchmark. Minimal physical damage is observed for the post-tensioned systems, which exhibit very stable energy dissipation and re-centering properties.

Wight, R., Green, M., and Erki, M. et al., (2001) presented a paper entitled “Prestressed FRP Sheets for Post strengthening Reinforced Concrete Beams”. Four large-scale reinforced concrete beams were constructed and tested to investigate the effectiveness of external post strengthening with prestressed fiber reinforced polymer (FRP) sheets. One of the beams served as a control specimen, another was strengthened with nonprestressed carbon FRP sheets, and the remaining two were strengthened with prestressed carbon FRP sheets. Presented is a method of prestressing multiple layers of the carbon fiber sheets during the application process and the experimental and analytical behavior of the beams under quasi-static loading. Comparisons are made between the control beam, the beam reinforced with nonprestressed carbon FRP sheets, and the beams strengthened with prestressed sheets. Serviceability and ultimate conditions are considered in the theoretical prediction of beam behavior, including the effects of multiple layer prestressing and external loading. The bonding of prestressed FRP sheets to the tensile face of concrete beams improved both the serviceability and the ultimate behavior of the reinforced concrete beams.

3. MATERIAL AND DIMENSIONS:

The preferred slab system for building works in Australia is the well proven bonded tendon which contains between 2 and 5, 12.7 mm diameter seven wire prestressing strands with an ultimate tensile strength of 184 KN, housed in oval ducting. The strands are anchored in flat fan shaped anchorages and stressed mono-strand (that is, one at a time) using light weight jacking equipment. Figure shows the cast iron anchorage guide, stressing block, reusable recess former and wedges. Minimum slab thickness for adequate edge distance, cover to anti-burst reinforcement and the like is 130mm for 2 strands, 140mm for 3 strands and 150mm for 4 and 5 strands.

Why use 12.7mm diameter strands?

A question that arises from time to time is why we use 12.7mm diameter strands for building works, when on face value 15.2mm diameter strands appears more cost effective. The first answer is that 12.7mm has a high strength per unit weight when compared to 15.2mm, which leads to a reduced cost. Secondly,
and more importantly from an installation viewpoint, it allows greater flexibility in choosing the tendon we want to use. This is mainly due to the recommended maximum tendon spacing being limited to 8 to 10 times the slab thickness.

The addition of a single 12.7mm strand in a tendon leads to a relatively small increase in overall tonnage and therefore cost, and allows for better customization of the design. Of course there are times when 15.2mm strand should be used. This occurs when the tendon already contains the full 5 strands in a duct and the tendon spacing is not at the maximum allowed. In our experience this occurs in less than 10% of structures. If this is the case, we should substitute 15.2mm diameter strands and increase the tendon spacing. This leads to reduction in the number of whole tendons and a subsequent reduction in anchorage costs and labor costs since less whole tendons have to be installed. As noted earlier, 15.2mm diameter should also be used for specialized structural elements and large civil engineering applications, where the aim is to use as few whole tendons as possible.

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 amore 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.

3.1 Post-Tensioned Buildings – Advantages

Post-tensioned concrete slabs in buildings have many advantages over reinforced concrete slabs and other structural systems for both single and multi-level structures. Some of the main advantages are described below.

1. 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.

2. 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.

3. 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.

4. Deflection Free Slabs

Undesirable deflections under service loads can be virtually eliminated.

5. 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 play a key role.

6. 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.

7. Materials Handling

The reduced material quantities in concrete and reinforcement greatly benefit on-site craneage 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.

8. 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,
4. RESULTS AND DISCUSSION

4.1 Economics

When is Post-tensioning Cost Effective?

The relative economics of post-tensioning versus other forms of construction vary according to the individual requirements of each case. In any basic comparison between post-tensioned and reinforced concrete one must consider the relative quantities of materials including formwork, concrete, reinforcement and posttensioning. Other factors such as speed of construction, foundation costs, etc., must also be given consideration.

There is not always sufficient time or budget to carry out comparative feasibility studies for all structural solutions. There are however, some useful guidelines which can be employed when considering post-tensioned alternatives. As can be seen from figure 7 below, post-tensioned should be considered as a possible economic alternative for most structures when spans exceed 7.0 meters.

Fig-4: Cost Comparison - Reinforced Vs Post-Tensioned Flat Slab.

The graph illustrates two main points. Firstly, how with increasing span the difference in cost between reinforced and post-tensioned concrete flat slabs also increases. Secondly, using an index of one for a 7.0 m span how the cost will vary for other spans. For example, a posttensioned 10.0 m span will cost approximately 20% more than a post-tensioned 7.0 m span. In general, for spans in excess of 8.0 meters, savings in excess of $10 per square meter should be regularly attained in a direct cost comparison with reinforced concrete slabs.

4.2 Speed of Construction

Economics and construction speed are heavily linked in today’s building construction environment. The speed of construction of a multi storey building is foremost in achieving economic building construction.

The key factor in the speed of construction of a post-tensioned framed building is expedient use and re-use of formwork. Post-tensioning allows for the early recovery of formwork by early stressing of tendons. Slab system tendons are usually stressed at the following minimum compressive strengths:

- Initial stress of slab tendons 24 hours after the pour of concrete for control of early shrinkage stresses at a minimum concrete strength of 7MPa.
- Final stressing of the slab system tendons may occur when the concrete has attained 22MPa based on site cured cylinders in accordance with clause 19.6.2.8 of AS3600.

A typical floor cycle for a multi storey office development is shown below in figure 8. This building has a floor area of approximately 1000 m2 and is divided into two pours per floor by a construction joint. It is normal to use two full sets of formwork in this type of construction.

Fig-5: Typical 5 Day Construction Cycle.

4.3 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.

1. 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.

2. 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.

3. 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.

4. 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 10 below.

Fig-6. Stitched Construction Joint Detail

Note that the amount of reinforcement required to keep 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.

5. 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.

6. 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.
7. 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 minimise 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 minimise post-tensioning may not secure the expected result due to minimum reinforcement rules and adequate residual compression levels to ensure shrinkage cracking is controlled.

8. 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 1 is a guide to the amount of load to balance under a range of building uses.

Table 1: General Level of Load To Be Balanced By Post-Tensioning Tendons To Give An Economic Structure.

<table>
<thead>
<tr>
<th>Occupancy of building</th>
<th>Partitions and Other Superimposed Dead Load kPa</th>
<th>Live Load kPa</th>
<th>Load to Balance kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car Parks</td>
<td>Nil</td>
<td>2.0</td>
<td>(0.7-0.85)SW</td>
</tr>
<tr>
<td>Shopping Centres</td>
<td>0.0 - 2.0</td>
<td>5.0</td>
<td>(0.85-1.0)SW</td>
</tr>
<tr>
<td>Residential (shock transfer certify)</td>
<td>2.0 - 4.0</td>
<td>1.5</td>
<td>(0.85-1.0)SW</td>
</tr>
<tr>
<td>Office Buildings</td>
<td>0.5 - 1.0</td>
<td>3.0</td>
<td>SW = 30% of load</td>
</tr>
<tr>
<td>Storage</td>
<td>Nil</td>
<td>2.4 kPa/m * height</td>
<td>SW = 30% LL</td>
</tr>
</tbody>
</table>

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

9. Terminate Tendons Wherever Possible

Often the amount of post-tensioning required within a member varies across its length. For 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’

10. 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.

4.4 STRUCTURAL SYSTEMS:

The three most common floor systems used for building structures such as offices, shopping centres and carparks are the flat plate, flat slab and banded slab. For high rise construction a fourth system is widely used which consists of band beams at relatively close spacing spanning from the building perimeter to the service core. Although economy of each of these depends primarily on the span and applied load, it is generally true to say that a band...
beam scheme is cheaper than a flat slab which in turn is cheaper than a flat plate.

To illustrate this analysis was carried out on a structural scheme for each of the three systems to show the percentage cost of each structural component. The schemes were based on a column grid of 8.5 m and imposed load of 5 kPa. A total relative cost figure, also shown, is obtained by multiplying each structural element by its cost rate. This rate varies from country to country, but the trend will remain unchanged.

Table-2: Floor Systems Spans

<table>
<thead>
<tr>
<th>FLOOR SYSTEM</th>
<th>Flat Plate</th>
<th>Flat Slab</th>
<th>Banded Slab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>25</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Post-tensioning</td>
<td>26</td>
<td>23</td>
<td>20</td>
</tr>
<tr>
<td>Formwork</td>
<td>43</td>
<td>47</td>
<td>48</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Relative total cost</td>
<td>1</td>
<td>0.97</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Post-tensioning is not limited to simple flat slabs and the range of structural types which can be economically stressed is almost limitless. Some of the most common floor systems are presented below along with recommended concrete sizes and span to depth ratios. Note that the span to depth ratios given depend on the element being an internal bay, end bay or simple span. Fig-8 explains the differences.

![Fig-8: Examples of Single Spans, End Spans, And Internal Spans.](image)

1. Flat Plate

This system is commonly used in Sydney for high rise residential construction where the span is usually 7 to 8 meters. The most attractive feature of this floor system is its flush soffit which requires simple formwork and greatly simplifies construction. The depth of a flat plate is often dictated by shear requirements. Thinner slabs or longer spans can be constructed if column capitals or shear heads are employed. Used Where spans are similar both directions

Economic Span Range 7.0 to 9.0 m
Imposed Loads Up to 7.5

2. Flat Slab

A widely used system today for many reasons - flat soffit, simple formwork and ease of construction, as well as flexibility for locating services. The economical span range over a flat plate is increase by the addition of drop panels. The drop panels increase the flexural stiffness of the floor as well as improving its punching shear strength. This system provides the thinnest floors and can lead to height reductions and substantial savings in facade costs. Used Where spans are similar both directions

Economic Span Range Up to 13.0 m
Imposed Loads Up to 10.0 kPa

3. Banded Slab

This system is used for structures where spans in one direction are predominant. It is also a very common system due to minimum material costs as well as relatively simple formwork. In most circumstances the width of the band beam is chosen to suit the standard sizes of the formwork. The sides of the band can be either square, or tapered for a more attractive result. The band beam has a relatively wide, shallow cross section which reduces the overall depth of the floor while permitting longer spans. This
concrete section simplifies the formwork and permits services to easily pass under the beams. The post-tensioned tendons are not interwoven leading to fast installation and decreased cycle time. The band beam system has another advantage which is not widely appreciated. In most circumstances depending on the actual geometry of the cross section the beam can be considered as a two way slab for fire rating and shear design. This enables considerable economies to be achieved in both post-tensioning and reinforcement quantities.

Used Span predominant in one direction

Economic Span Range Band Beam: 8.0 to 15.0 m
Slab: 6.0 to 10.0 m
Imposed Loads Up to 15.0 kPa

4. High Rise Banded Slab

This system has gained favour over the past 10 to 15 years for high rise construction and consists of band beams at relatively close centers spanning between a perimeter beam and the service core. The system suits system formwork due to the amount of re-use in high rise construction. Services may either pass under the shallow bands or, alternatively, pass under service ‘notches’ in the band soffit. For clear slab spans in excess of 4.5m the use of post-tensioning is economical perpendicular to the bands and assist in reducing the weight of slab carried by the bands.

Used long span high rise construction

Economic Span Range Band Beam: 9.0 to 15.0 m
Imposed Loads Up to 7.5 kPa

4.5 DESIGNING POST-TENSIONED SLABS FOR FUTURE OPENINGS

1. Locating post-tensioning tendons

For post-tensioned slabs and beams where tendon positions may not be readily identifiable, soffit marking can be employed. Prior to casting the slab, stainless steel staples are use to secure the ducts to the formwork. When the formwork is struck, the position of the tendons is obvious, especially if the staple lines have been linked by painted lines. Alternatively, chalk lines can be marked on the slab top surface to aid in the locating of posttensioning tendons. This procedure will assist in locating openings away from tendons.

2. Structural systems in post-tensioned concrete

a) Band Beam and Slab

For rectangular grids the band beam and slab solution may be appropriate. This is the system typically used for shopping centres and carparks due to the economic benefit and relative insensitivity to floor height restrictions. Normally band beams span in the long direction and impose the same constraints on hole placement as would a steel or reinforced concrete beam. However, small hydraulic type penetrations (approximately 150 mm diameter) can usually be accommodated without the need for remedial action. The slabs however, are usually quite lightly prestressed with tendons in one direction only at approximately 1500 mm centres. Reasonable size openings or large slots are therefore easy to
accommodate without the need to cut post-tensioning tendons.

b) Flat Slabs and Flat Plates

For structures requiring minimum floor to floor height and regular grids the two-way posttensioned flat slab is usually the most cost effective solution. The normal installation procedure would concentrate the tendons into ‘column strips' along the column grids at approximately 600 mm centers with tendons away from the column strip at approximately 1400 mm centers. Consequently small holes for services could be located without the need to cut tendons. Using this structural system it is possible to leave the central panel as traditionally reinforced and designed as a ‘soft zone' to easily accommodate large openings. The cost penalty for the extra reinforcement required would need to be offset against the perceived benefits.

c) Ribbed and Waffle Slab

Larger grids or heavier loads may dictate the introduction of ribs spanning either one-way or two-way (waffle) depending upon the aspect ratio of the grid. Rib spacing for post-tensioned slabs are generally larger than for reinforced concrete, being typically 1.2 to 1.5 metres. Consequently small to moderate holes can easily be cut through the topping slab without disturbing the ribs. Indeed with tendons confined to the ribs their location is readily identifiable, assisting in the siting of the openings.

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. Notwithstanding 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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