



The **Concrete** Centre™

Post-tensioned Concrete Floors



A GUIDE TO DESIGN AND CONSTRUCTION

Contents

- 1 Development of Post-tensioned Floors
- 2 Principles of Post-tensioned Floors
- 3 Benefits of Post-tensioned Floors
- 6 Structural Forms
 - 7 PT Flat Slab
 - 8 PT Ribbed and Waffle Slabs
 - 9 PT Beam and Slab
- 10 Design Theory
- 12 Design Considerations
- 15 Construction Considerations
- 16 Cost Comparisons
 - 16 Commercial Buildings
 - 18 Hospitals
 - 19 Schools
- 20 End of Life
- 21 Summary
- 21 References

INTRODUCTION

In the UK, the use of post-tensioned (PT) concrete floors in buildings is now commonplace. Post-tensioned floor slabs are also widely used in multi-storey construction overseas, particularly in North America, Australia and the Middle East. In California it is the primary choice for concrete floors.

In the UK, typical applications have been:

- Offices
- Apartment buildings
- Car parks
- Shopping centres
- Hospitals
- Transfer beams.

The purpose of this publication is to widen the understanding of post-tensioned floor construction and show the considerable benefits and opportunities it offers to developers, architects, engineers and contractors. These benefits include:

- Minimum storey heights
- Minimum number of columns
- Rapid construction
- Economy
- Maximum design flexibility
- Optimum clear spans
- Joint-free, crack-free construction
- Controlled deflections.

This publication also aims to dispel the myths about post-tensioned concrete slabs and answers frequently asked questions by showing that:

- The design is not necessarily complicated.
- PT floors are compatible with fast-track construction.
- PT floors do not require the use of high-strength concrete.
- The formwork does not carry any of the prestressing forces.
- PT floors can be demolished safely.
- Local failure does not lead to total collapse.
- Holes can be cut in slabs at a later date.

A more detailed guide to the design of PT floors can be found in The Concrete Society Technical Report TR43 *Post-tensioned Concrete Floors: Design Handbook* [1].

Cardinal Place, London. Courtesy of Freyssinet.



Cover pictures:

Main: Post tensioning at Paradise Street, Liverpool – a mixed use development of retail and car parking. Courtesy of Conforce.

Inset: Bridgewater Place, Leeds.

– a mixed use development of 32 storeys. Courtesy of Bridgewater Place Ltd and Structural Systems UK Ltd.

DEVELOPMENT OF POST-TENSIONED FLOORS

The 'pre' in pre-stressing describes the stress applied before any normal loads are applied. The 'post' in post-tensioned refers to the strands being tensioned after the concrete has been cast and gained sufficient strength to be compressed in an equal and opposite reaction to the tensioning of the strands.

The practice of prestressing can be traced back as far as 440BC, when the Greeks reduced bending stresses and tensions in the hulls of their fighting galleys by prestressing them with tensioned ropes.

One of the simplest examples of prestressing is that of trying to lift a row of books as illustrated in Figure 1 below. To lift the books it is necessary to push them together, i.e. to apply a precompression to the row. This increases the resistance to slip between the books so that they can be lifted.

In the 19th century, several engineers tried to develop prestressing techniques without success. The invention of prestressed concrete is accredited to Eugene Freyssinet who developed the first practical post-tensioning system in 1939. Systems were developed around the use of multi-wire tendons

located in large ducts cast into the concrete section, and fixed at each end by anchorages. They were stressed by jacking from either one or both ends, and then the tendons were grouted within the duct. This is generally referred to as a bonded system as the grouting bonds the tendon along the length of the section.

The bonding is similar to the way in which bars are bonded in reinforced concrete. After grouting is complete there is no longer any reliance on the anchorage to transfer the precompression into the section.

Applications in buildings have always existed in the design of large span beams supporting heavy loadings, but these systems were not suitable for prestressing floor slabs, which cannot accommodate either the large ducts or anchorages.

During the 1960s, in the US, unbonded systems were developed. These rely on the anchorages to transfer the forces between the strand and the concrete throughout the life of the structure.

More versatile bonded systems suitable for floor slabs were developed in Australia. Bonded systems became popular in the UK in the 1990s. In the UK, bonded construction is now widely used; having approximately 90% of the PT suspended floor market.

Both bonded and unbonded systems are suitable for floor slabs and a comparison of the techniques is given in the section on Design Considerations (page 14).

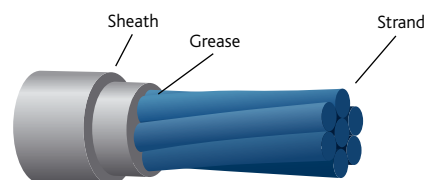
Unbonded system before pouring concrete.
Courtesy of Balvac.



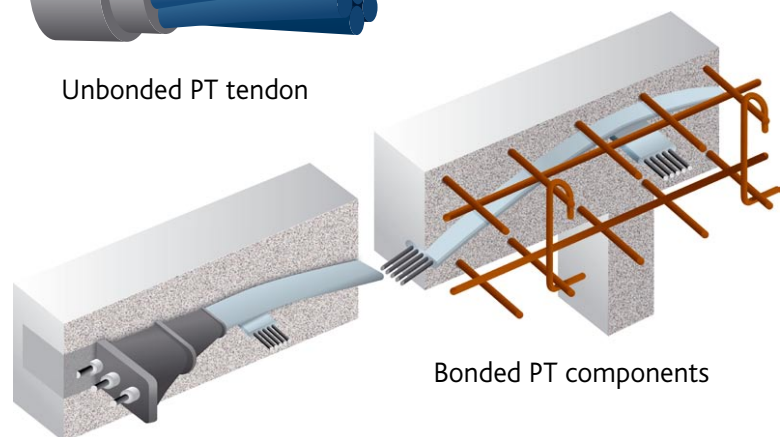
FIGURE 1: LIFTING A ROW OF BOOKS



Bonded system before pouring concrete.
Courtesy of Freyssinet.



Unbonded PT tendon



Bonded PT components

PRINCIPLES OF POST-TENSIONED FLOORS

Concrete has a low tensile strength but is strong in compression. By pre-compressing a concrete element, so that when flexing under applied loads it still remains in compression, a more efficient design for the structure can be achieved. The basic principles of prestressed concrete are given in Figure 2.

Under an applied load, a prestressed element will bend, reducing the built-in compression stresses; when the load is removed, the prestressing force causes the element to return to its original condition, illustrating the resilience of prestressed concrete. Furthermore, tests have shown that a virtually unlimited number of such reversals of the loading can be carried out without affecting the element's ability to carry its working load or impairing its ultimate load capacity. In other words prestressing endows the element with a high degree of resistance to fatigue.

If the tensile stresses due to load do not exceed the prestress, the concrete will not crack in the tension zone. If the working load is exceeded and the tensile stresses overcome the prestress, cracks will appear. Depending on the environment it may be acceptable to have some cracking. However, even after an element has been loaded to beyond its working load, and well towards its ultimate capacity, removal of the load results in closing of the cracks and they will not reappear under working load.

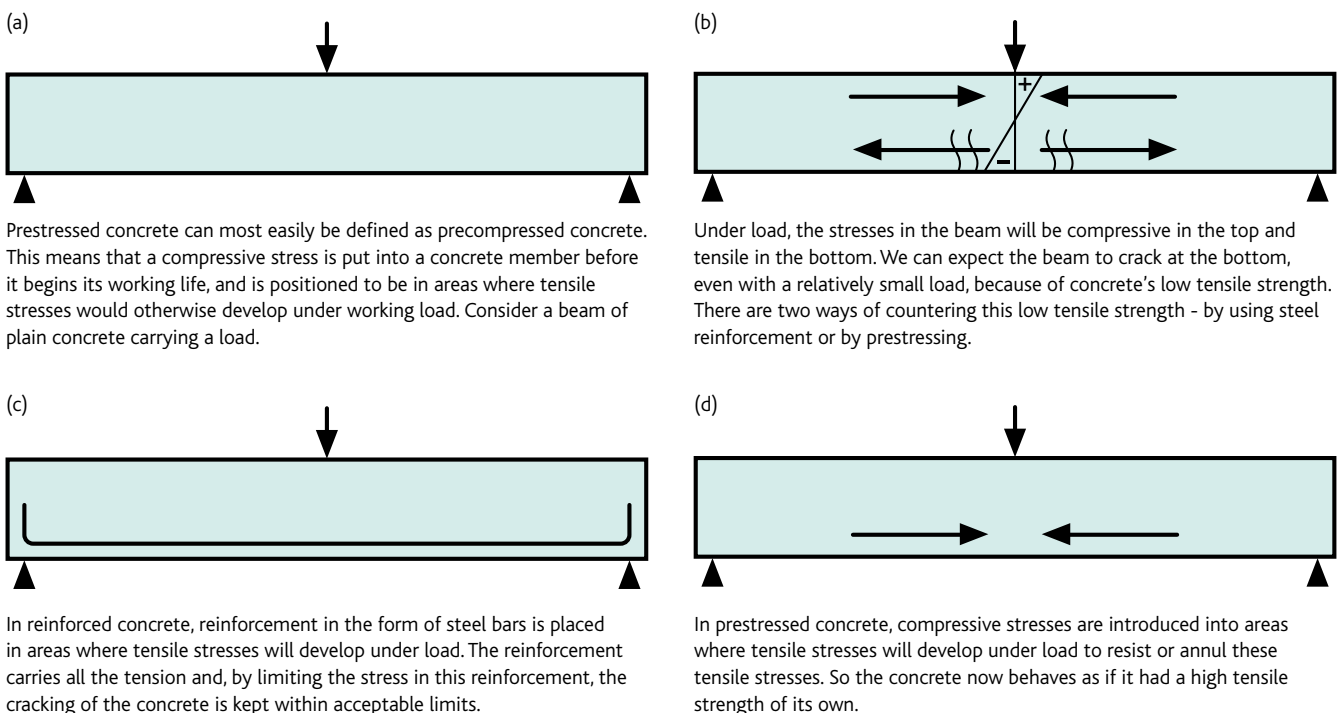
There are two methods of applying prestress to a concrete member. These are:

- Post-tensioning - where the concrete is placed around sheaths or ducts containing unstressed tendons. Once the concrete has gained sufficient strength the tendons are stressed against the concrete and locked off by special anchor grips, known as split wedges. In this system, all tendon forces are transmitted directly to the concrete. Since no stresses are applied to the formwork, conventional formwork may be used.
- Pre-tensioning - where the concrete is placed around previously stressed tendons. As the concrete hardens, it grips the stressed tendons and when it has obtained sufficient strength the tendons are released, thus transferring the forces to the concrete. Considerable force is required to stress the tendons, so pre-tensioning is principally used for precast concrete where the forces can be restrained by fixed abutments located at each end of the stressing bed, or carried by specially stiffened moulds.

Table 1: Post-tensioning terms

Term	Definition
Anchorage	Device to lock the strand at a pre-determined tensile force, which induces compressive stress in the concrete.
Dead-end anchorage	An anchorage where no jacking takes place.
Duct	Metal or plastic tube through which the strand is passed for the bonded system.
Eccentricity	Distance between the centroid of the concrete section and the centre of the strand.
Live anchorage	The anchorage at the jacking end of the strand. Both ends of the strand can be live.
Profile	Geometric shape of the tendon in elevation, often parabolic.
Sheath	Plastic extrusion moulded directly to the strand. A layer of grease between the strand and the sheath prevents bonding.
Strands	High strength steel reinforcement.
Tendon	One or more strands in a common duct or sheath.

FIGURE 2: PRINCIPLES OF PRESTRESSING



BENEFITS OF POST-TENSIONED FLOORS

Post-tensioning concrete increases the many benefits associated with a concrete framed building. This section is intended to explain these benefits. The economics of a project are often the main driver and a separate section is devoted to this topic on pages 16 to 19.

Design benefits

Long spans

One key advantage of PT concrete is that it can economically span further than reinforced concrete. PT slabs can be used to economically span distances of up to 25m between columns. The benefits of the long spans are:

- Reduction in the number of columns
- Reduction in the number of foundations
- Increased flexibility for internal planning
- Maximisation of the available letting space of a floor.

Minimum floor thickness

PT concrete gives the minimum structural thickness of any solution for typical spans and loads. This has several benefits:

- Minimising the self-weight of the structure
- Reducing foundation loads
- Minimising the overall height of the building (see Figure 3)
- Reducing cost of cladding
- Reducing vertical runs of services.

Flexibility

Flexibility of layout can be achieved as PT concrete can cope with irregular grids and unusual geometry, including curves.

Aesthetics

Internal fair-faced concrete can be both aesthetically pleasing and durable, ensuring buildings keep looking good with little maintenance.

In addition, by exposing the floor soffit, concrete's thermal mass properties can help to reduce the temperature of the working environment and save energy.

Servicing benefits

Distribution of services

Mechanical and electrical services are an expensive and programme-critical element in construction, with significant maintenance and replacement issues. M&E contractors can often quote an additional cost for horizontal services distribution below a profiled slab, of up to 15%. PT concrete floors generally have a flat soffit which provides a zone for services distribution free of any downstand beams. This reduces design team coordination effort and risk of errors. It also allows flexibility in design and adaptability in use. A flat soffit permits maximum off-site fabrication of services, higher quality work and quicker installation.

Openings

PT concrete floors can accommodate openings without too much difficulty. Smaller holes seldom present problems as they may be readily formed between tendons, which are often spaced at well over one metre centres.

Larger openings can be formed by diverting the tendons around them.

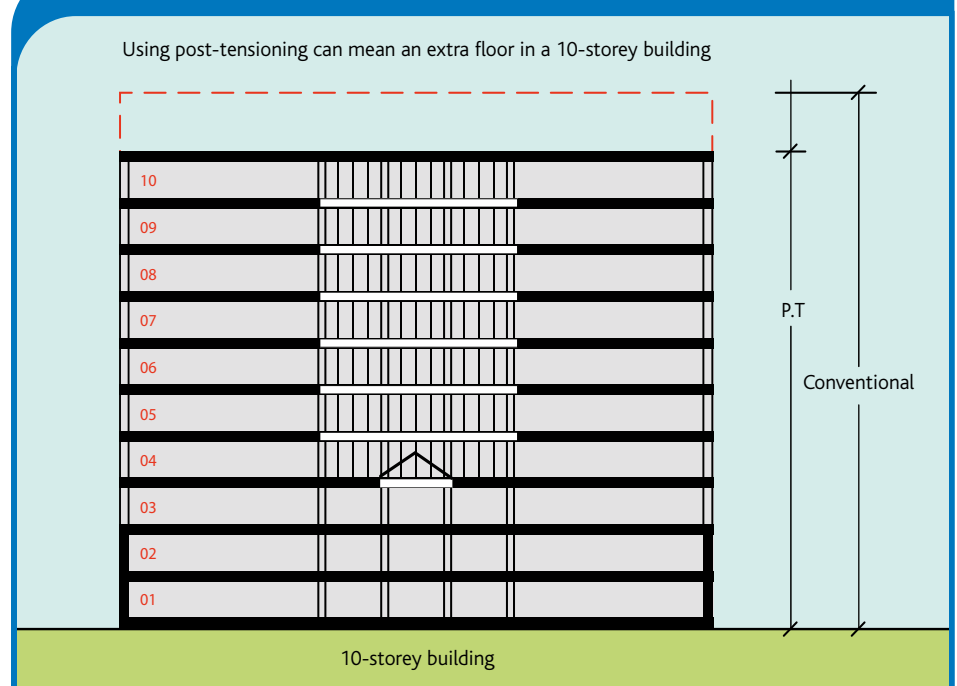
Openings can also be formed adjacent to the face of columns, although this can increase the punching shear reinforcement requirements.

The positions of the tendons can be marked on the slab's soffit and topside to aid identification for future openings. Alternatively, tendons can be located using C.A.T cable detection equipment.

PT floors have the following advantages:

- Economic
- Minimum floor thickness
- Long spans
- Rapid construction
- Minimal use of materials
- Flexibility of layout
- Adaptability
- Inherent fire protection

FIGURE 3: PT CONCRETE FLOORS CAN SIGNIFICANTLY REDUCE BUILDING HEIGHT



Construction benefits

Speed of construction

PT concrete is highly compatible with fast programme construction as there can be rapid mobilisation at the start of the project. Just like reinforced concrete, sophisticated, modern formwork systems are available to reduce floor construction cycle times. Modern formwork systems have markedly increased construction rates. It is now common to achieve 500m² per week per crane. Post-tensioning reduces reinforcement congestion, which speeds up the fixing time and makes placing of concrete easier.

Large area pours

PT slabs are thinner than reinforced concrete slabs and so a larger area can be poured for the same volume of concrete. Large area pours reduce the number of pours and increase construction speed and efficiency. With bonded PT floors, when the concrete has reached a strength of typically 12.5 N/mm², part of the prestressing force is usually applied to control shrinkage cracking and thus further aid larger area pours. It may be possible to avoid two-stage stressing if there is sufficient passively stressed reinforcement to control shrinkage cracking, such as in unbonded floors.

Programme

Speed of construction of the frame is one consideration in the programme, but the effect of the choice of material on the whole project programme is also important.

Concrete provides a safe working platform and semi-internal conditions, allowing services installation and follow-on trades to commence early in the programme, while flexibility allows accommodation of design changes later in the process.

Reduced crantage

PT slabs are thinner and use less reinforcement than reinforced concrete slabs, so this reduces the 'hook' time required for the frame construction.

Performance benefits

Deflection

Deflection is often a governing design criteria, especially where long spans are used. To some extent the deflection of the slab can be controlled by varying the prestress. Increasing the prestress can decrease the deflection, albeit with a cost implication.

Vibration control

For PT concrete buildings, vibration criteria for most uses are covered without any change to the normal design. For some uses, such as laboratories or hospitals, additional measures may be needed, but these are significantly less than for other materials. In an independent study [2] into the vibration performance of hospital floors, it was found that concrete required less modification to meet the vibration criteria. Figure 4 shows the increases in construction depth needed to upgrade a floor designed for office loading to meet hospital vibration criteria for night wards and operating theatres.

Crack-free

Crack-free construction can be provided by designing the whole slab to be in compression under normal working loads. (However, it is normal to adopt a partially prestressed solution and allow cracks widths up to 0.2mm.)

For crack-free construction appropriate details may also be incorporated to reduce the effects of restraint, which may otherwise lead to cracking (see section on restraint on page 12). This crack-free construction is often exploited in car parks where concrete surfaces are exposed to an aggressive environment.

Fire protection

Inherent fire resistance means concrete structures generally do not require additional fire protection. This reduces time, costs, use of a separate trade and ongoing maintenance for applied fire protection.

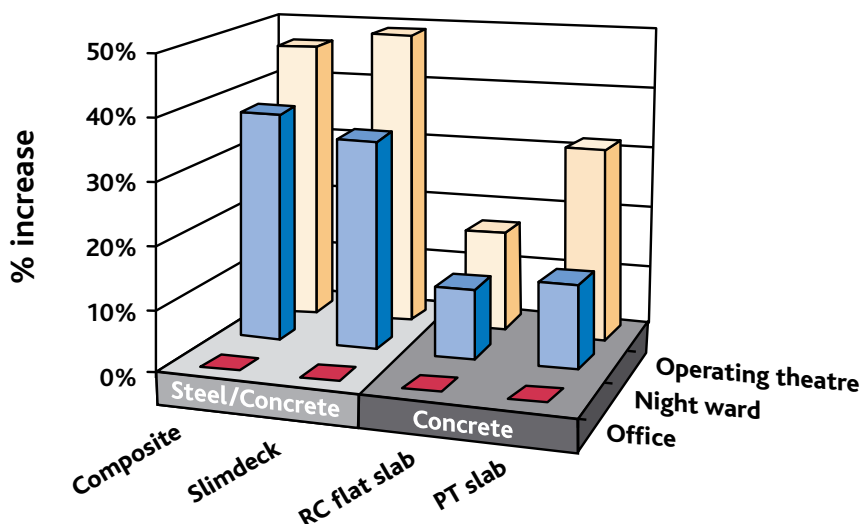
Acoustics

Additional finishings to floors are often required to meet the requirements of Approved Document E. The inherent mass of concrete means additional finishings are minimised or even eliminated. Independent testing of 250mm thick concrete floors in a block of student accommodation gave results exceeding requirements by more than 5dB for both airborne and impact sound insulation [3]. Further acoustic test results are available at www.concretecentre.com.

Air-tightness

Part L of the Building Regulations requires precompletion pressure testing. Failing these tests means a time consuming process of inspecting joints and interfaces, resealing where necessary. Concrete edge details are simpler to seal, with less failure risk. Some contractors have switched to concrete frames on this criterion alone.

FIGURE 4: VIBRATION CONTROL - INCREASE IN FLOOR THICKNESS FOR HOSPITAL WARDS AND THEATRES COMPARED TO OFFICE SPACES



Operational benefits

Robustness and vandal resistance

Concrete is, by its nature, very robust and is capable of being designed to withstand explosions. It is also capable of resisting accidental damage and vandalism.

Durability

A well detailed concrete floor is expected to have a long life and require very little maintenance. It should easily be able to achieve a 60-year design life and, with careful attention to detail, should be able to achieve a 120-year life, even in aggressive environments.

Adaptability

Markets and working practices are constantly changing, so it makes sense to consider a material that can accommodate changing needs or be adapted with minimum effort. A PT concrete floor can easily be adapted during its life. Holes can be cut through slabs relatively simply, and there are methods to strengthen the frame if required (see section on alterations on page 20).

Partitions

Sealing and fire stopping at partition heads is simplest with flat soffits. Significant savings of up to 10% of the partitions package can be made compared to the equivalent dry lining package abutting a profiled soffit with downstands. This can represent up to 4% of the frame cost, and a significant reduction in programme length.

Minimal maintenance

Unlike other materials, concrete does not need any toxic coatings or paint to protect it against deterioration or fire. Properly designed and installed concrete is maintenance free.

Sustainable benefits

The environmental impacts of developments are increasingly considered during design. PT concrete has many environmental benefits in construction, and, most importantly, during use.

Local materials

The constituent parts of concrete (water, cement and aggregate) are all readily and locally available to any construction site, minimising the impact of transporting raw materials.

Reduced use of materials

PT is an efficient structural form, which minimises the use of concrete and uses high-grade steel for the tendons. This has the dual benefit of reducing the use of raw materials and reducing the number of vehicle movements to transport the materials.

Thermal mass

A concrete structure has high thermal mass. Exposed soffits allow fabric energy storage (FES), regulating temperature swings. This can reduce initial plant costs and ongoing operational costs, while converting plant space to usable space. With the outlook of increasingly hot summers, it makes long-term sense to choose a material that reduces the requirement for energy intensive, high maintenance air-conditioning.

Recycling

Concrete can be specified with recycled aggregate and, at the end of its life, both the concrete and steel tendons from demolished PT floors are 100% recyclable.

Concrete mix

Modern concretes generally contain cement replacements which lower the embodied CO₂ and use by-products from other industries. Care should be exercised to balance the environmental benefits of cement replacements with their slower strength gain, which delays the initial prestress. Visit www.sustainableconcrete.org.uk to compare alternative mix constituents.

A bonded PT slab before casting concrete at Cambridge Grand Arcade shopping centre. The final concrete mix used was 40% ground granulated blast furnace slag (ggbs), bringing considerable sustainability benefits. Courtesy of Civil and Marine.



There are three main structural forms used in the UK:

- Solid flat slab
- Ribbed slab
- Band beam and slab

STRUCTURAL FORMS

The economic range for PT floors is 6m to 20m, depending on the structural form used. The shorter limit is based on the practical minimum economic depth of PT slab being 200mm.

There are three main structural forms used in the UK:

- Solid flat slab
- Ribbed slab
- Band beam and slab

The solid flat slab is economic for spans between 6m and 13m, which makes it suitable as an alternative for many current frame options (see Figure 5 below). Further details on flat slabs are given on page 7. For longer spans, ribbed slabs or band beams are more economic and are described on pages 8 and 9.

Figure 6 provides typical span-to-depth for PT floors. More detailed guidance on sizing PT floors can be found in The Concrete Centre's guide *Economic Concrete Frame Elements* [4].

FIGURE 5: TYPICAL ECONOMIC SPAN RANGES

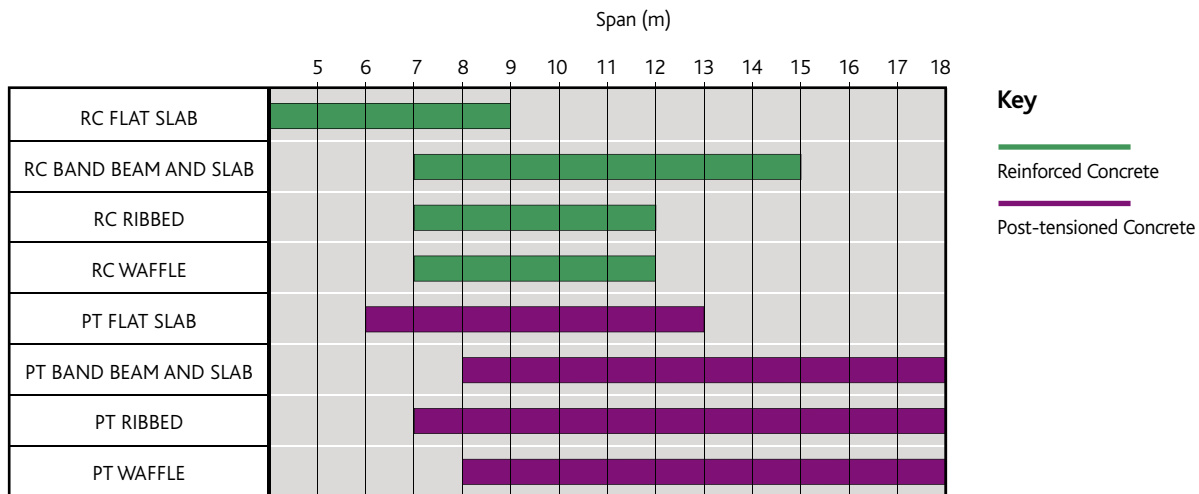
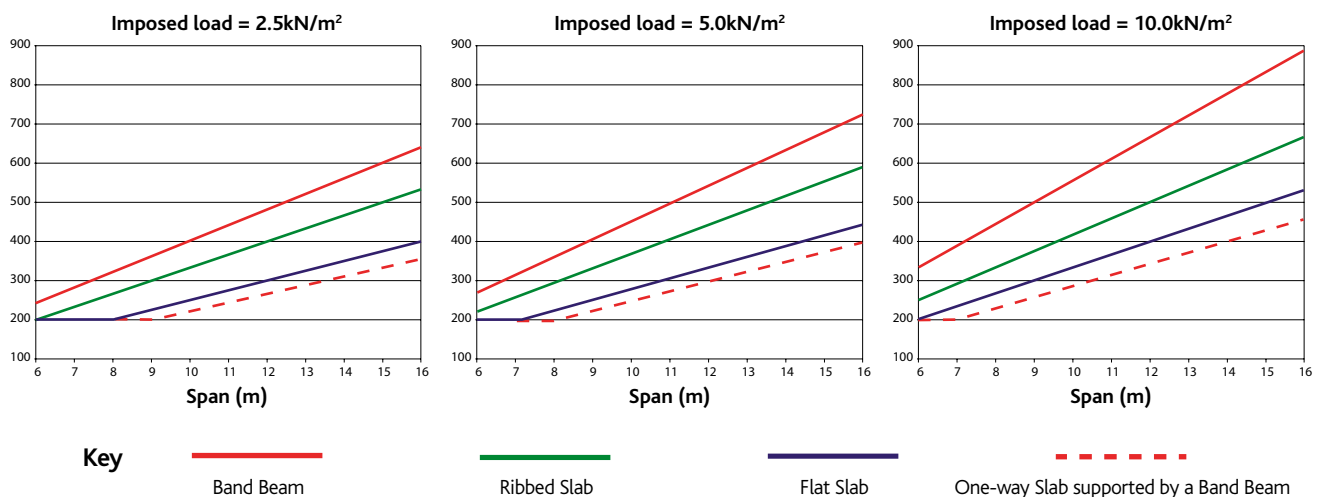


FIGURE 6: SPAN TO DEPTH RATIOS FOR PT FLOORS



PT FLAT SLAB

An efficient post-tensioned design can be achieved with a solid flat slab which is ideally suited to multi-storey construction where there is a regular column grid.

Points to Note

Design

The depth of a flat slab is usually controlled by deflection requirements or by the punching shear capacity around the column.

Post-tensioning improves the control of deflections and enhances shear capacity. Shear reinforcement can be provided by links, shear rails or steel cruciforms.

Flat slabs may be designed using the equivalent frame method, finite element analysis programmes or yield line analysis. Guidance is available from The Concrete Centre [5,6].

Construction

Construction of flat slabs is one of the quickest methods available. Table forms can be used; these are becoming more lightweight so that larger areas can be constructed on one table form, with formwork lifted by crane or, for craneless construction, by hoist. Table forms should be used as repetitively as possible to gain most advantage of the construction method. Downstand beams should be avoided wherever possible as forming beams significantly slows construction. Edge beams need not be used for most cladding loads.

Economics

Flat slabs are particularly appropriate for areas where tops of partitions need to be sealed to the slab soffit for acoustic or fire reasons. It is often the reason that flat slabs are considered to be faster and more economic than other forms of construction, as partition heads do not need to be cut around downstand beams or ribs.

Flat slabs can be designed with a good surface finish to the soffit, allowing exposed soffits to be used. This allows exploitation of the building's thermal mass in the design of heating, ventilation and cooling (HVAC) requirements, increasing energy efficiency, and reducing energy consumption in use.

Speed on site

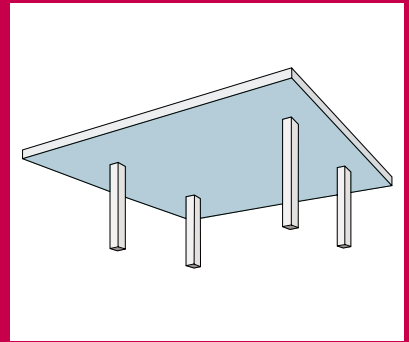
Speed of construction will vary from project to project, but a useful guide is approximately 500m²/crane/week. Once the final prestress is applied the formwork can be struck.

Mechanical and electrical services

Flat slabs provide the most flexible arrangements for services distribution as services do not have to divert around structural elements.

Holes through the slab close to the column head affect the design shear perimeter of the column head. Holes next to the column should ideally be small and limited to two. These should be on opposite sides rather than on adjacent sides of the column. It is worth setting out rules for the size and location of these holes early in the design stage to allow coordination.

Large service holes should be located away from the column strips and column heads in the centre of the bays. Again, location and size of any holes should be agreed early in the design.



Flat slab

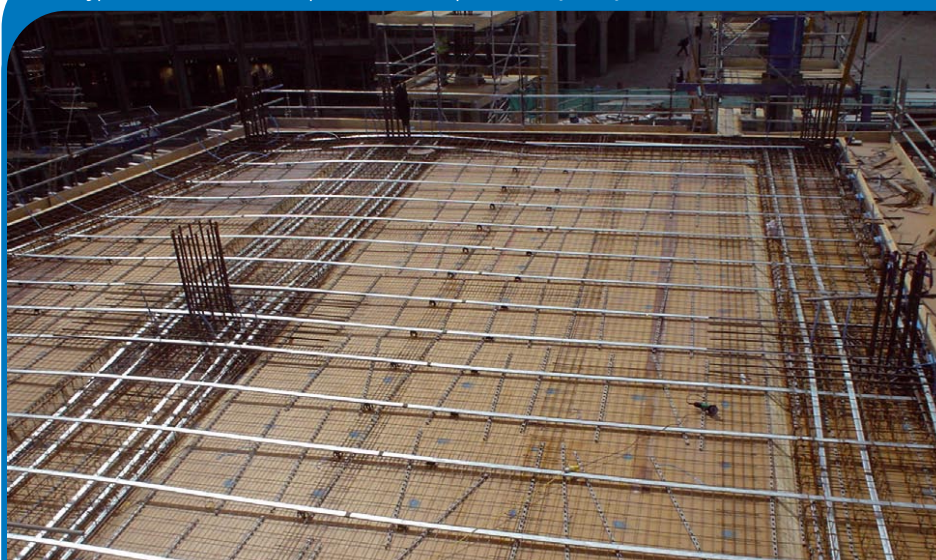
Markets:

- ✓ Residential
- ✓ Commercial
- ✓ Hospitals
- ✓ Laboratories
- ✓ Hotels
- ✓ Schools

Benefits:

- ✓ Cost
- ✓ Speed
- ✓ Flexibility
- ✓ Sound control
- ✓ Fire resistance
- ✓ Robustness
- ✓ Thermal mass
- ✓ Durable finishes

A typical bonded PT flat slab prior to concrete pour. Courtesy of Freyssinet.



PT RIBBED AND WAFFLE SLABS

For longer spans the weight of a solid slab adds to both the frame and foundation costs. By using a ribbed slab, which reduces the self-weight, large spans can be economically constructed. These provide a very good slab where vibration is an issue, such as laboratories and hospitals.

The one-way spanning ribbed slab provides a very adaptable structure able to accommodate openings. Ribbed slabs are made up of beams running between columns with narrow ribs spanning in the orthogonal direction. A thin topping slab completes the system.

For large two-way spans, waffle slabs give a very material-efficient option capable of supporting high loads. Waffle slabs tend to be deeper than the equivalent ribbed slab. Waffle slabs have a thin topping slab and narrow ribs spanning in both directions between column heads or band beams. The column heads are the same depth as the ribs. The major drawback with post-tensioning waffle slabs is that it is necessary to 'weave' the pre-stressing tendons.

Points to Note

Design

Waffle slabs work best with a square grid. Ribbed slabs should be orientated so that the ribs span the longer distance, and the band beams the shorter distance. The most economic layout is an aspect ratio of 4:3.

Construction

Both waffle and ribbed slabs are constructed using table forms with moulds positioned on the table forms. Speed of construction depends on repetition, so that the moulds on the table forms do not need to be re-positioned.

Exposed finishes

Ribbed and waffle slabs can provide a good surface finish to the soffit, allowing exposed soffits to be used in the final building. This allows the use of the thermal mass of the building in the design of the HVAC requirements, particularly as the soffit surface area of the slab is greater than a flat slab, increasing the building's energy efficiency.

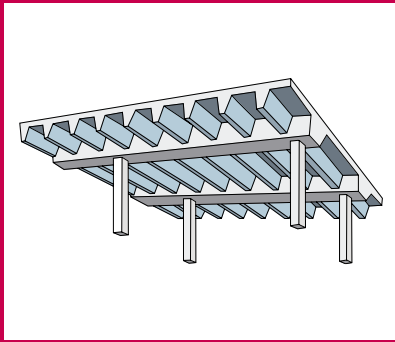
Speed on site

This is a slower form of construction than flat slabs. The use of table forms offers the fastest solution.

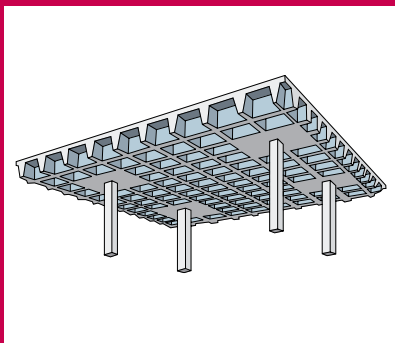
Where partitions need to be sealed acoustically or for fire, up to the soffit, ribbed and waffle slabs take longer on site. Lightweight floor blocks can be placed between the concrete ribs to act as permanent formwork, which give a flat soffit, although these take away some of the benefits of the lighter weight slab design. If partition locations are known, the moulds may be omitted on these lines.

Mechanical and electrical services

Holes should be located between ribs where possible. If the holes are greater than the space between ribs, then the holes should be trimmed with similar depth ribs. Post construction holes can be located between the ribs.



Ribbed slab



Waffle slab

Markets:

- ✓ Vibration critical projects
- ✓ Hospitals
- ✓ Laboratories

Benefits:

- ✓ Flexible
- ✓ Relatively light, therefore less foundation costs
- ✓ Speed
- ✓ Fairly slim floor depths
- ✓ Robustness
- ✓ Excellent vibration characteristics
- ✓ Thermal mass
- ✓ Good services integration
- ✓ Durable finishes
- ✓ Fire resistance

PT BEAM AND SLAB

Beam and slab construction involves the use of one or two way spanning slabs onto beams spanning in one or two directions. The beams can be wide and flat or narrow and deep, depending on the structure's requirements. Beams tend to span between columns or walls and can be simply supported or continuous.

This form of construction is commonly used for irregular grids and long spans, where flat slabs may be less suitable. It is also used for transferring loads from columns and walls or from heavy point loads to columns or walls below.

It is also a popular method for providing a 15.6m clear span for a standard car park configuration with a band beam spanning 15.6m and a one-way slab spanning 7.2m or 7.5m.

Points to Note

Design

The beams will usually be designed to be PT, whereas the slabs can be designed with conventional reinforcement if the spans are relatively short.

Construction

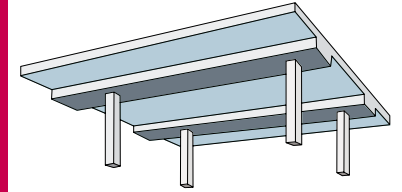
Using a band beam rather than a deep beam simplifies the formwork.

Slabs tend to be lightly reinforced and can normally be reinforced with standard mesh.

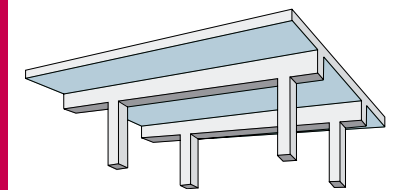
Mechanical and electrical services

Wide band beams can have less effect on the horizontal distribution of the M&E services than deep beams which tend to be more difficult to negotiate, particularly if spanning in both directions. Any holes put into the web of the beam to ease the passage of the services must be coordinated.

Vertical distribution of services can be located anywhere in the slab zone, but holes through beams need to be designed into the structure at an early stage.



Band beam and slab



Deep beam and slab

A typical PT beam and slab under construction. Courtesy of Freyssinet.



Markets:

- ✓ Transfer structures
- ✓ Heavily loaded slabs
- ✓ Very long spans

Benefits:

- ✓ Flexible
- ✓ Sound control
- ✓ Fire resistance
- ✓ Robustness
- ✓ Thermal mass

DESIGN THEORY

Recommendations for the design of prestressed concrete are given in Eurocode 2, part 1-1 [7]. Design methods for post-tensioned flat slabs are relatively straightforward, and detailed guidance, based on Eurocode 2, is available in The Concrete Society Technical Report 43 [1].

At the serviceability condition the concrete section is checked at all positions to ensure that both the compressive and tensile stresses lie within the acceptable limits given in the Codes of Practice. Stresses are checked in the concrete section at the initial condition when the prestress is applied, and at serviceability conditions when calculations are made to determine the deflections and crack widths for various load combinations.

At the ultimate limit state the pre-compression in the section is ignored and checks are made to ensure that the section has sufficient moment capacity. Shear stresses are also checked at the ultimate limit state in a similar manner to that for reinforced concrete design, although the benefit of the prestress across the shear plane may be taken into account.

At the serviceability limit state, a prestressed slab is generally always in compression and therefore flexure cracking is uncommon. This allows the accurate prediction of deflections as the properties of the uncracked concrete section are easily

determined. Deflections can therefore be estimated, and limited to specific values rather than purely controlling the span-to-depth ratio of the slab, as in reinforced concrete design.

In carrying out the above checks, extensive use can be made of computer software either to provide accurate models of the structure, taking into account the affect of other elements and to enable different load combinations to be applied, or to carry out both the structural analysis and prestress design.

There are currently three software programs which are widely used, but other programs also exist. They either use the finite element method to analyse the whole floor or design strips to analyse bay widths running across the floor plan in each direction.

The basic principles of prestressed concrete design can be simply understood by considering the stress distribution in a concrete section under the action of externally applied forces or loads. It is not intended here to provide a detailed explanation of the theory of prestressed concrete design.

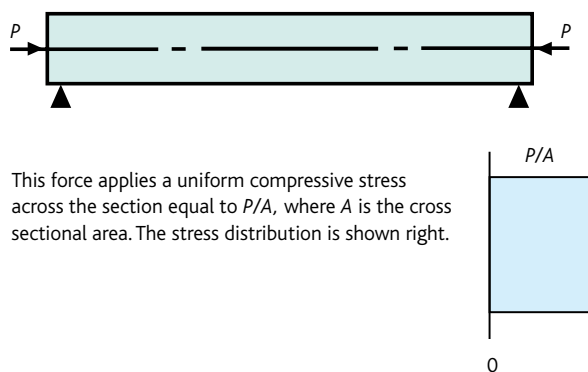
Figure 7 illustrates the simplicity of the basic theory. In essence, the design process for serviceability entails the checking of the stress distribution under the combined action of both the prestress and applied loads, at all positions along the beam, in order to ensure that both the compressive and tensile stress are kept within the limits stated in design standards.

PT beams and slabs are usually designed to maximise the benefit of the continuity provided by adjacent spans. In this situation 'secondary' effects should be considered in the design. The secondary effects are not necessarily adverse and an experienced designer can use them to refine a design.

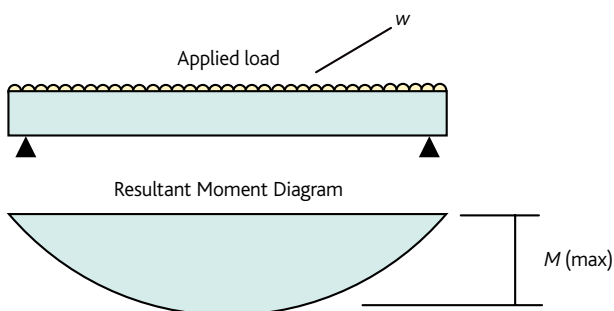
In the majority of prestressed slabs it will be necessary to add reinforcement, either to control cracking or to supplement the capacity of the tendons at the ultimate load condition.

FIGURE 7: PRINCIPLES OF PRESTRESSED DESIGN

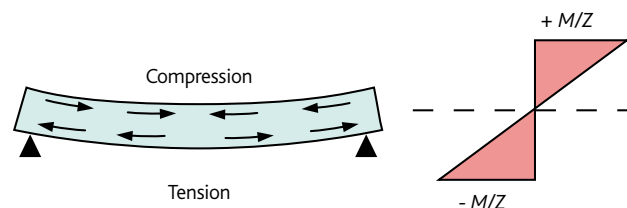
a) Consider a beam with a force P applied at each end along the beams' centre line.



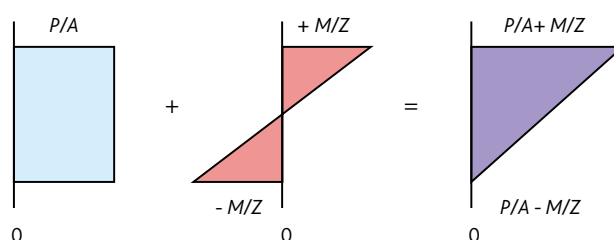
b) Consider next a vertical load w applied along the beam and the corresponding bending moment diagram applied to this alone.



c) The stress distribution from the flexure of the beam is calculated from M/Z where M is the bending moment and Z the section modulus. By considering the deflected shape of the beam it can be seen that the bottom surface will be in tension. The corresponding stress diagram can be drawn.



d) Concrete is strong in compression but not in tension. Only small tensile stresses can be applied before cracks that limit the effectiveness of the section will occur. By combining the stress distributions from the applied precompression and the applied loading it can be seen there is no longer any tension, assuming the magnitude of P has been chosen correctly.



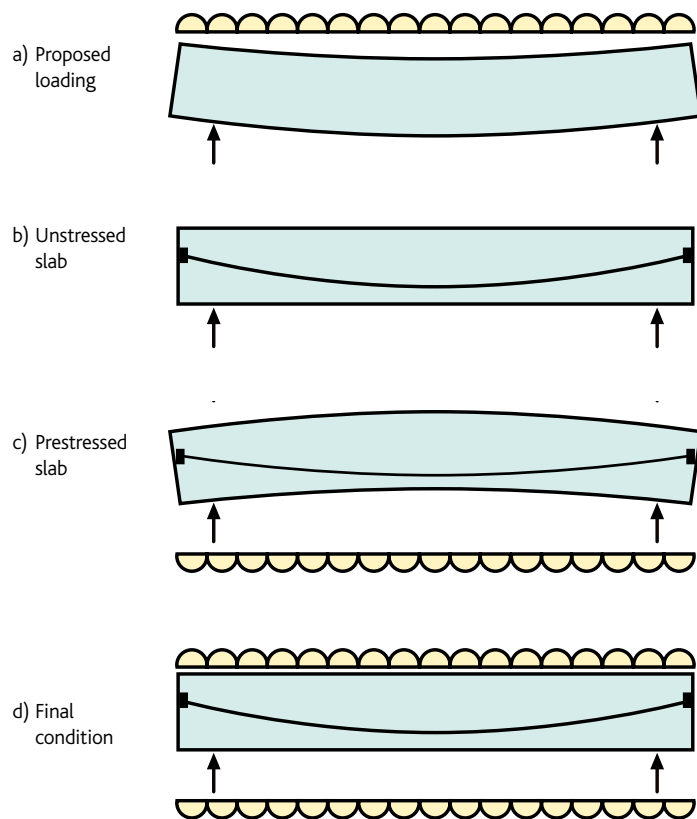
Load balancing

The technique known as 'load balancing' offers the designer a powerful tool. In this, forces exerted by the prestressing tendons are modelled as equivalent upward forces on the slab. These forces are then proportioned to balance the applied downwards forces (see Figure 8). By balancing a chosen percentage of the applied loading it is possible to control deflections and also make the most efficient use of the slab depth.

In order to use the load balancing technique, the prestressing tendons must be set to follow profiles that reflect the bending moment envelope from the applied loadings. Generally parabolic profiles are used. In the case of flat soffit slabs these are achieved by the use of supporting reinforcing bars placed on proprietary chairs.

In post-tensioned concrete floors, the load balancing technique can enable the optimum depth to be achieved for any given span. The final thickness of the slab, as with reinforced concrete flat slabs, may also be controlled by the punching shear around the column.

FIGURE 8: LOAD BALANCING TECHNIQUE



Tendons draped to reflect the bending moment profile. Courtesy of Freyssinet.



Restraint of the slab by shear walls should be considered at the early stages of a project to avoid movement joints or time-consuming construction details.

DESIGN CONSIDERATIONS

Restraint

At the early stages of a project using post-tensioned floors, care must be taken to avoid the problems of restraint. This is where the free movement in the length of the slab under the prestress forces is restrained, for example by the unfavourable positioning of shear walls or lift cores (see Figure 9).

All concrete elements shrink due to drying and early thermal effects but, in addition, prestressing causes elastic shortening and ongoing shrinkage due to creep. Stiff vertical members such as stability walls restrain the floor slab from shrinking, which prevents the prestress from developing and thus reduces the strength of the floor.

Where the restraining walls are in a favourable arrangement and the floor is in an internal environment, the maximum length of the floor without movement joints can be up to 50m. However, full consideration should be given to the effects of shrinkage due to drying, early thermal effects, elastic shortening and creep in the design.

Where the walls are unfavourably arranged then a calculation of the effects of movement should be carried out and suitable measures taken to overcome them. This could involve:

- Using infill strips which are usually cast around 28 days after the remainder of the floor, to allow initial shrinkage to occur (see Figure 10).
- Increasing the quantity of conventional reinforcement, to control the cracking.
- Using temporary release details (see Figure 11).
- Reducing the stiffness of the restraining elements.

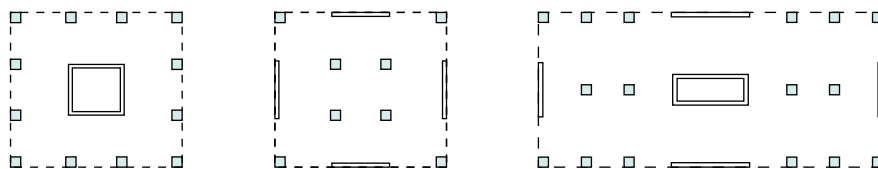
The effect of the floor shortening on the columns should also be considered in their design as this may increase their design moments.

Design to prevent disproportionate collapse

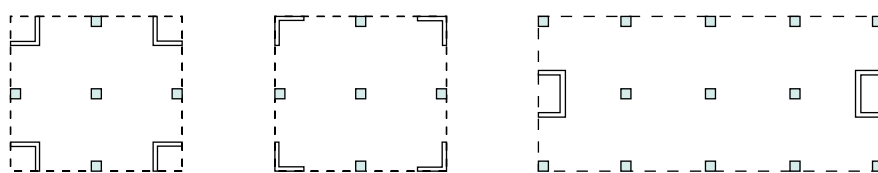
PT floor systems are usually designed to resist disproportionate collapse through detailing of the tendons and reinforcement.

In bonded systems the tendons can be considered to act as horizontal ties. In unbonded systems, the tendons cannot be relied on and the conventional reinforcement acts as the horizontal ties.

FIGURE 9: TYPICAL FLOOR LAYOUTS



a) Favourable layout of restraining walls (low restraint)



b) Unfavourable layout of restraining walls (high restraint)

FIGURE 10: TYPICAL INFILL STRIP

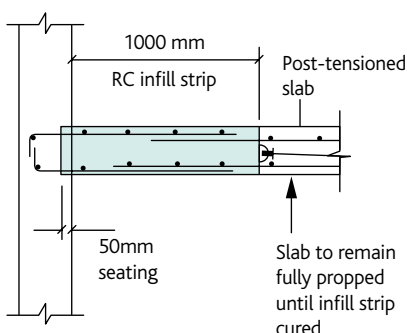
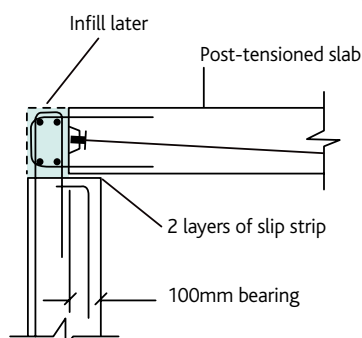


FIGURE 11: TEMPORARY RELEASE DETAIL



Holes and tendon layout

A particular design feature of post-tensioned slabs is that the distribution of tendons on plan within the slab does not significantly effect its ultimate strength. There is some effect on strength and shear capacity, but this is generally small. This allows an even prestress in each direction of a flat slab to be achieved with a number of tendon layouts (see Figure 12).

This offers considerable design flexibility to allow for penetrations and subsequent openings, and the adoption of differing slab profiles, from solid slabs through to ribbed and waffle construction.

Layout (a) of Figure 12 shows the layout of tendons banded over a line of columns in one direction and evenly distributed in the other direction. This layout can be used for solid slabs, ribbed slabs, or band beam and slab floors. It offers the advantages that holes through the slab can be easily accommodated and readily positioned at the construction stage.

Layout (b) shows the tendons banded in one direction, and a combination of banding and even distribution in the other direction. This does not provide quite the same flexibility in positioning of holes, but offers increased shear capacity around column heads. Again, this layout can be used for both solid and ribbed slabs and banded beam construction.

Layout (c) shows banded and distributed tendons in both directions and is logically suitable for waffle flat slabs, but may be employed for other slabs, depending on design requirements. The disadvantage of this layout is that it requires 'weaving' of the tendons.

Holes through post-tensioned slabs can be accommodated easily if they are identified at the design stage. Small holes (less than 300mm x 300mm) can generally be positioned anywhere on the slab, between tendons, without any special requirements. Larger holes 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. In ribbed slabs, holes can be readily incorporated between ribs or, for larger holes, by amending rib spacings or by stopping-off ribs and transferring forces to the adjoining ribs.

With flat slabs it is possible to locate holes adjacent to faces of columns. It is important to note that this significantly reduces the punching shear capacity.

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 (see page 20). A better approach is to identify at the design stage zones where further penetrations may be placed. These zones can then be clearly marked on the soffit and top side of the slab.

FIGURE 12: COMMON LAYOUT OF TENDONS

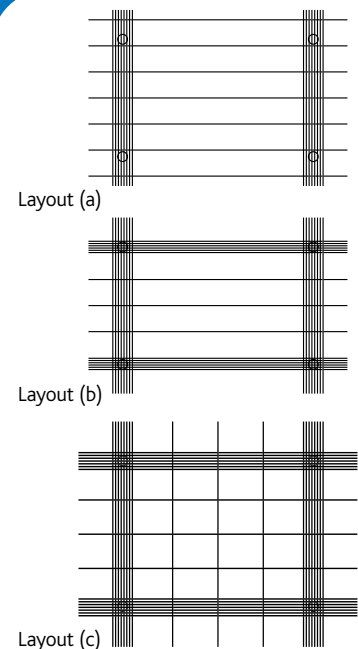


FIGURE 13: DETAILING OF TENDONS AROUND AN OPENING

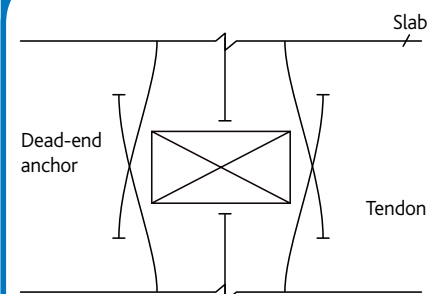
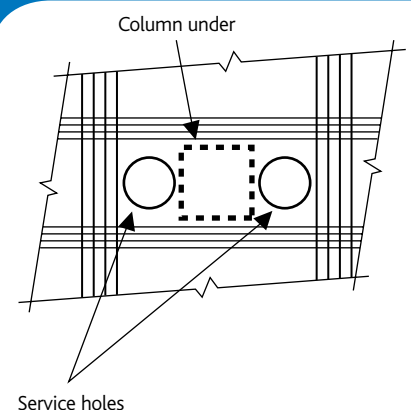
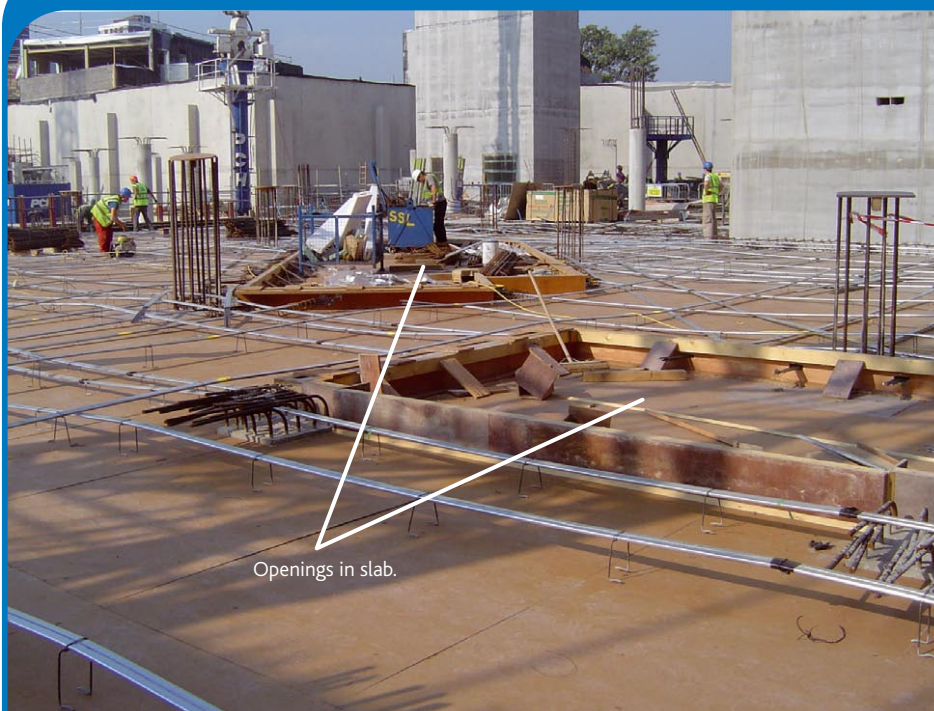


FIGURE 14: LAYOUT OF TENDONS TO ALLOW SERVICES TO BE PLACED CLOSE TO COLUMN FACE



Large openings can be formed. Courtesy of Structural Systems.



Bonded or unbonded?

Post-tensioned floors may be bonded, unbonded or a combination of both.

With the bonded system the prestressing tendons run through small continuous flattened ducts which are grouted after the tendons are stressed, creating bond between the concrete and tendons.

The ducts are formed from spirally-wound or seam-folded galvanised metal strip. The limit on the curvature or profile that can be achieved with the prestressing tendons is dependent on the flexibility of the ducts.

In an unbonded system the tendon is not grouted and remains free to move independently of the concrete. This has no effect on the serviceability design or performance of a structure under normal working conditions. It does, however, change both the design theory and structural performance at the ultimate limit state.

Table 2 summarises the main differences between the two systems. The greater resistance to accidental damage of bonded construction is often an important consideration.

Table 2: Comparison of PT systems

Bonded	Unbonded
- Localises the effect of accidental damage - Develops higher ultimate strength - Does not depend on the anchorages after grouting - Can be demolished in the same way as reinforced concrete structures	- Reduced covers to strand - Reduced prestressing force - Tendons can be pre-fabricated leading to faster construction - Tendons can be deflected around obstructions more easily - Greater eccentricity of the strand - Grouting not required

Concrete

PT slabs do not require particularly high strength concrete and often class C32/40 concrete is used. For speed of construction the concrete should have high early strength. This allows initial prestress to be carried out as early as possible, usually after 24 hours to prevent cracking. Final stressing can take place after three days, allowing striking of formwork.

Durability

The concrete should be specified in accordance with BS 8500 to ensure good durability. For most building structures with an internal environment this is not an onerous requirement. However, external structures, and in particular car parks, require more attention to detail to ensure good corrosion resistance.

Cover

As with reinforced concrete, cover is chosen to meet the following requirements:

- Corrosion resistance (BS 8500)
- Bond (Eurocode 2, Part 1-1 [7])
- Fire (Eurocode 2, Part 1-2 [8])

Further guidance can be found in *How to design concrete structures using Eurocode 2* (Getting Started section) [9].

Procurement

PT slabs can be procured using the same routes as any other concrete slab. The post-tensioning specialist is usually sub-contracted to the concrete frame contractor. As post-tensioning has been increasingly used since the mid 1990s the concrete frame contractors are now familiar with the technique.

It is important that the PT system is supplied and installed by a suitably experienced company. An industry accreditation scheme is run by UK CARES and the status of a particular company can be found at www.ukcares.com. It is recommended that specifications require CARES approved PT suppliers and installers to be used.

In the UK the PT specialist is often made responsible for the design of the floor and detailing the strand and anchorages. In the US, and increasingly in the UK, the consulting engineer undertakes the design.

Whichever route is adopted on a project, it is important to be clear from the outset where the responsibilities lie. Both BS 8110 and Eurocodes highlight the need for a sole engineer to take responsibility for the overall design, ensuring that any design carried out by others is compatible with the design of the remainder of the structure.

Specification

It is recommended that the model specification for bonded and unbonded post-tensioned floors is used. This is published by UK CARES and is available from www.ukcares.com. This should be referenced from the concrete specification by adding a suitable clause.

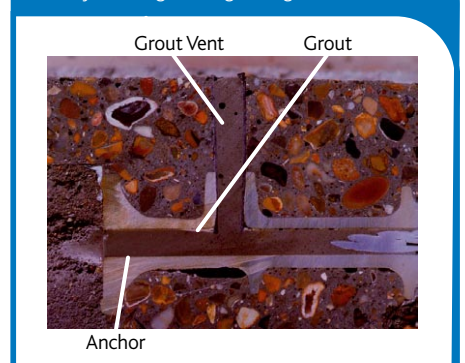
A bonded live anchorage.



An unbonded anchorage. Courtesy of Balvac.



Section through a bonded live anchorage. Courtesy of Strongforce Engineering.



CONSTRUCTION CONSIDERATIONS

Sequence of installation

A typical construction sequence is as follows:

- 1 Install soffit and edge formwork
- 2 Fix bottom reinforcement
- 3 Fix live anchorages to edge forms
- 4 Install tendons
- 5 Tape joints in ducts and thread the strands (bonded only)
- 6 Fix tendon support bars to specified heights (1m centres)
- 7 Fix top steel
- 8 Fix punching shear reinforcement

Construction joints

There are three types of construction joint that can be used between areas of slab; these are shown in Figure 14. 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 or reducing the need for perimeter access from formwork or scaffolding.

Construction joint with no stressing (Figure 15a)

The slab is cast in bays and stressed when all the bays are complete. For large slab areas, control of restraint stresses may be necessary and ideally the next pour should be carried out on the following day.

Construction joint with intermediate stressing (Figure 15b)

On completion of the first pour containing embedded bearing plates, intermediate anchorages or couplers are fixed to allow the tendons to be stressed. After casting of the adjacent pour, the remainder of the tendon is stressed. It is sometimes necessary to leave a pocket around the intermediate anchorage to allow the wedges that anchor the tendons during the first stage of stressing to move during the second stage of stressing. This option is most suitable for use with unbonded tendons.

Infill or closure strips (Figure 15c)

The slabs on either side of the strip are poured and stressed, and the strip is infilled after allowing time for temperature stresses to dissipate and some shrinkage and creep to take place.

Pour size/joints

Large pour areas are possible in post-tensioned slabs, and the application of an early initial prestress, at a concrete strength of typically 12.5 N/mm^2 , can help to control restraint stresses. There are economical limits on the length of tendons used in a slab. Typically these are 35m for tendons stressed from one end only and 70m for tendons stressed from both ends.

The slab can be divided into appropriate areas by the use of stop ends and, where necessary, bearing plates are positioned over the unbonded tendons to allow for intermediate stressing.

Concreting

Care must be taken when concreting to prevent operatives displacing tendons or crushing the ducts in bonded construction.

Good compaction of the concrete is always important, but it is particularly so around anchorages because of the high local stresses in these areas.

Stressing

Ideally after 24 hours, when the concrete has attained a strength of typically 12.5 N/mm^2 , initial stressing of tendons to about 25% of their final jacking force is carried out. (The actual concrete strength and tendon force will vary depending on loadings, slab type and other requirements.) This controls restraint stresses and may also enable the slab to be self-supporting so that formwork can be removed.

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 three to five days, when the concrete has attained its design strength, the remaining stress is applied to the tendons.

The extension of each tendon under load is recorded and compared against the calculated value. Provided that it falls within an acceptable tolerance, the tendon is then trimmed. With an unbonded system, a greased cap is placed over the recessed anchor and the remaining void dry-packed. With a bonded system the anchor recess is simply dry-packed and the tendon grouted.

Back propping

When designing the formwork systems for multi-storey construction, the use of back-props, through more than one floor to support the floor under construction, should be considered.

Slab soffit marking

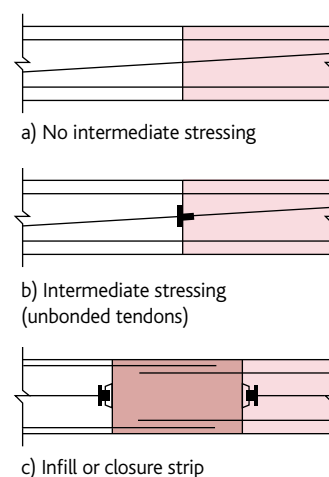
Various methods exist for marking the slab soffit to identify where groups of tendons are fixed. The most common is to use paint markings, usually on the soffit. Alternatively a thin ply sheet may be laid between the tendons to give a physical demarcation. This enables areas for small holes and fixings to be drilled after completion, safe in the knowledge that tendons will not be damaged.

The position and maximum depth of fixings should be agreed and clearly conveyed to follow-on trades.

PT slab being cast. The slab is lightly reinforced. Courtesy of Structural Systems.



FIGURE 15: CONSTRUCTION JOINTS



The choice of structural frame may also affect the cost of:

- Cladding
- Partitions
- Services
- Preliminaries
- Foundations

It may also impact on the nett lettable area.

COST COMPARISONS

The frame is the key structural element of any building. Frame choice and design can have an influential role in the performance of the final building, and importantly, also influence people using the building.

The cost of the frame alone should not dictate frame choice. Many issues should be considered when choosing the optimum solution. The Concrete Centre commissioned a series of cost model studies [10,11,12] to compare the cost of various structural frames for a variety of different buildings. All the buildings were designed, costed and programmed by independent consultants. Selected information for a community hospital, a secondary school and an office in central London is presented here.

All the studies showed that the choice of frame had an influence on the cost of other elements of the building which should be considered at the early stages of a project. Whole life costs should also be considered. Concrete has inherent benefits – such as fabric energy storage (thermal mass), fire resistance and sound insulation – which mean that concrete buildings tend to have lower operating costs and lower maintenance requirements. This is an important consideration, particularly for owner-occupiers and PFI consortia.

Commercial Buildings

For this building configuration, post-tensioned and reinforced concrete were found to be the lowest cost options.

The commercial cost model study included a six-storey office building in central London. The building included some retail areas at ground floor level to reflect current trends.

Six short span options were developed including a PT flat slab and a RC flat slab. The PT option is shown in

Figure 16. Two long span options were also included which included PT band beams and slab (see Figure 17).

A programming exercise was carried out and this established that both the post-tensioned options could be constructed one week faster than either a reinforced (RC) flat slab or a steel frame with long span composite cellular beams.

The study compared the cost of the various options and found the cost for the PT flat slab option was just 0.1% more expensive than the lowest cost option – a RC flat slab (see Table 3). It also found that, of the two long span options, PT band beams had the lowest building cost and the premium for the long spans was 2.2%.

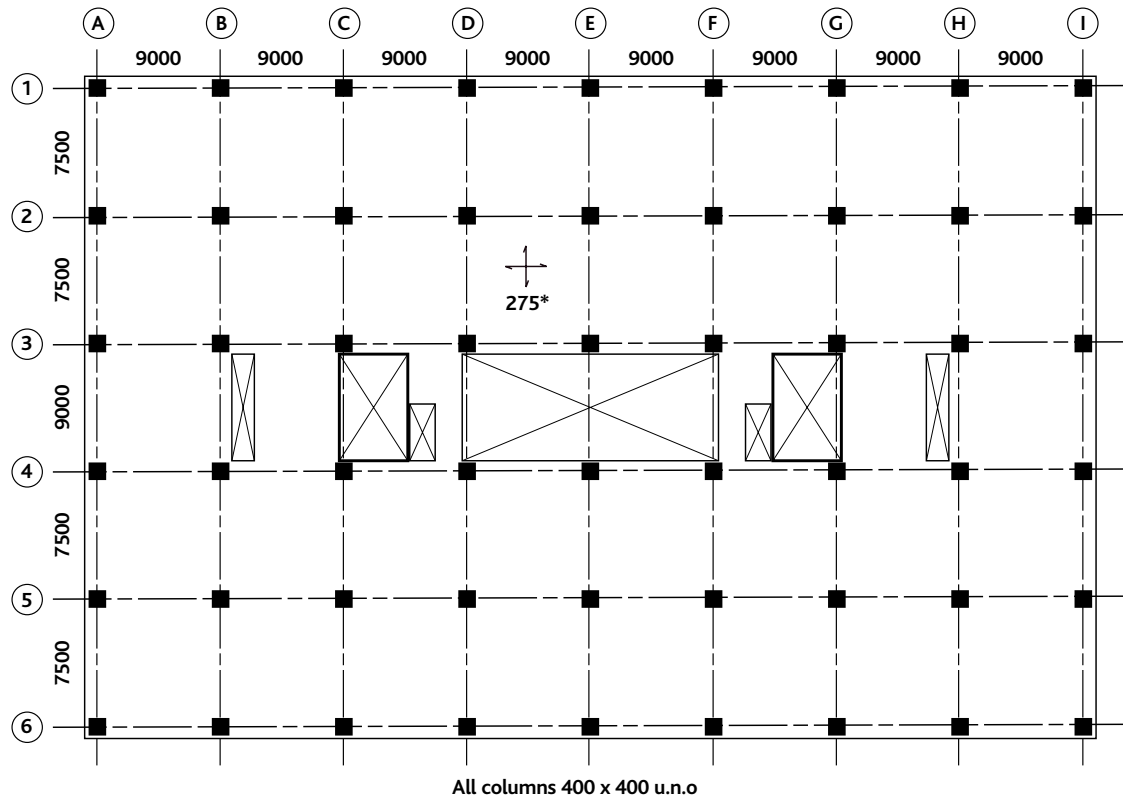
More analysis of the frame and upper floor costs for the short span options showed that formwork costs were similar. The concrete costs were lower for a PT flat slab, but reinforcement costs were higher.

Full details of the study are available from *Cost Model Study - Commercial Buildings* [10].

Table 3: Elemental costs compared for office building

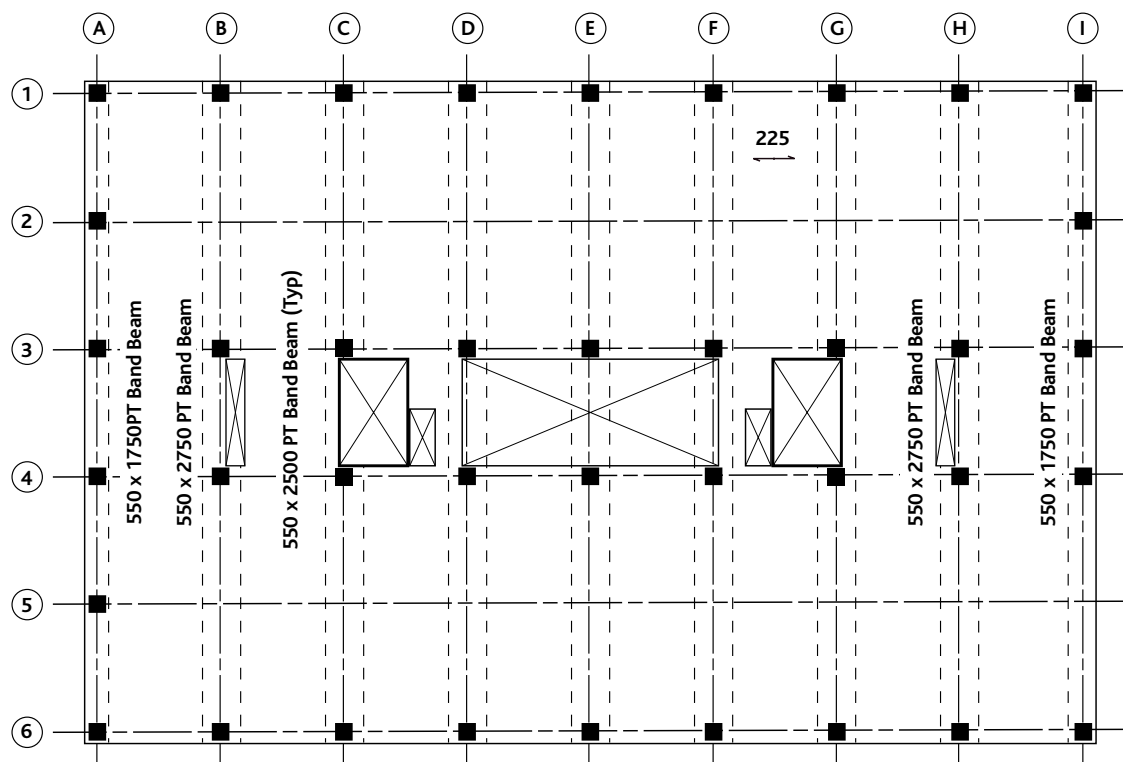
Element	Short Span Options				Long Span Options			
	Flat Slab		PT Flat Slab		PT Band Beams		Composite	
	£/m ²	%	£/m ²	%	£/m ²	%	£/m ²	%
Substructures	54	3.2%	53	3.1%	55	3.2%	52	3.0%
Frame & Upper Floors	110	6.6%	122	7.3%	135	7.9%	134	7.7%
Roof	33	2.0%	33	2.0%	33	1.9%	33	1.9%
Stairs	8	0.5%	8	0.5%	8	0.5%	8	0.5%
External Cladding	361	21.5%	355	21.1%	369	21.5%	362	21.0%
Internal Planning	18	1.1%	18	1.1%	18	1.1%	22	1.3%
Wall Finishes	14	0.8%	14	0.8%	14	0.8%	15	0.9%
Floor Finishes	71	4.2%	71	4.2%	71	4.1%	71	4.1%
Ceiling Finishes	43	2.5%	43	2.5%	43	2.5%	43	2.5%
Fittings	8	0.5%	8	0.5%	8	0.5%	8	0.5%
Sanitary	50	3.0%	50	3.0%	50	2.9%	50	2.9%
Mechanical	276	16.5%	276	16.4%	276	16.0%	281	16.3%
Electrical	163	9.7%	163	9.7%	163	9.5%	166	9.6%
Lifts	36	2.2%	36	2.2%	36	2.1%	36	2.1%
Builders Work	37	2.2%	37	2.2%	37	2.1%	37	2.1%
Preliminaries	203	12.1%	201	12.0%	99	5.7%	97	5.7%
Contingency	96	5.7%	96	5.7%	201	11.7%	203	11.8%
Overheads & Profits	95	5.7%	95	5.7%	97	5.7%	97	5.7%
Total	£1,676		£1,678		£1,713		£1,715	

FIGURE 16: PT FLAT SLAB FOR A TYPICAL CENTRAL LONDON OFFICE BUILDING (SHORT SPAN)



*This is a slab thickness used for scheme design. Specialist contractors have advised that a 250mm thick slab would be proposed in a competitive situation.

FIGURE 17: PT BAND BEAMS FOR A TYPICAL CENTRAL LONDON OFFICE BUILDING (LONG SPAN)



Hospitals

For the hospital configuration examined in the study post-tensioning was the lowest cost option.

The hospital buildings cost model study included a local hospital and a district hospital. Both consisted of a number of wards, identical to the structural arrangement shown in Figure 18. The local hospital had four wards plus entrance areas, while the district hospital had wards spread over three storeys plus entrance areas and corridors.

The whole building costs for six structural options were assessed for these types of hospital. The costs for two of these options for a local hospital, a RC flat slab and PT flat slab, are compared in Table 4. This shows that the PT flat slab would have lower cost than a building using a RC flat slab. The saving comes not only from the frame cost, but also the reduction in foundation cost because the frame is lighter. The building is lower and therefore the cladding cost is also reduced.

Further detail on the frame cost indicates that there is a premium to pay for reinforcement in a post-tensioned slab, but that there is a saving in the volume of concrete.

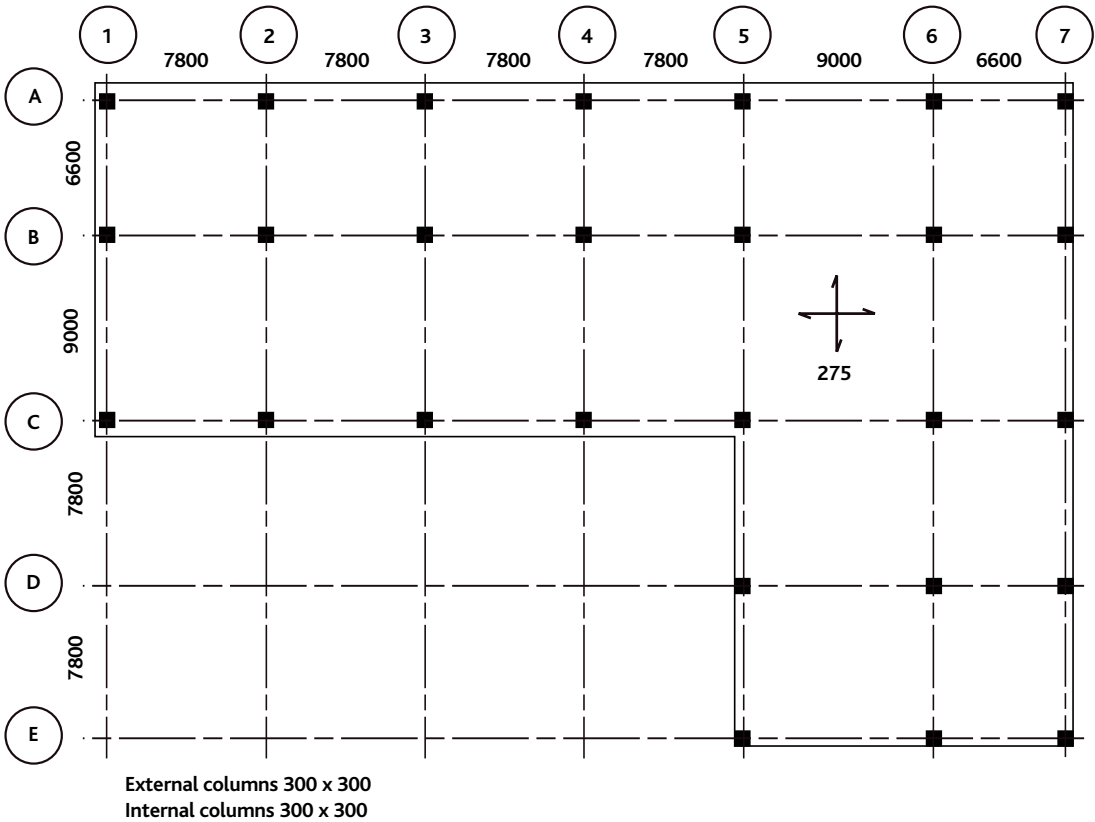
The PT and RC flat slab options were designed to meet vibration criteria for a ward with minimal additional materials.

Full details of the study are available from *Cost Model Study - Hospital Buildings* [11].

Table 4: Elemental costs for local hospital compared

Element	Flat Slab		PT Flat Slab	
	£/m ²	%	£/m ²	%
Substructure	74	3.9	71	3.8
Frame & Upper Floors	130	6.9	121	6.5
Roof	93	4.9	93	5.0
Stairs	8	0.4	8	0.4
External Cladding	157	8.3	155	8.3
External Windows & Doors	22	1.2	22	1.2
Internal Planning	92	4.9	92	4.9
Wall Finishes	21	1.1	20	1.1
Floor Finishes	48	2.5	48	2.6
Ceiling Finishes	28	1.5	28	1.5
Fittings	210	11.1	210	11.2
Sanitary	23	1.2	23	1.2
Mechanical	250	13.2	250	13.3
Electrical	193	10.2	193	10.3
Lifts	53	2.9	53	2.9
BWIC	47	2.5	47	2.5
Contingency	109	5.7	108	5.7
Prelims	227	12.0	227	12.1
Overheads & profit	107	5.7	106	5.7
Total	1,892	100	1,875	100

FIGURE 18: PT FLAT SLAB FOR A SINGLE WARD



Schools

For the school design examined in the study post-tensioning was found to be the lowest cost option.

The educational cost model study focused on a secondary school on a redeveloped school site. The school was a mixture of two-storeys, three-storeys and some double height spaces. Six structural options were developed, including a RC flat slab and a PT flat slab. Details for part of the PT option are shown in Figure 19. The remainder of the two- and three-storey areas in the school are of a similar nature. For this study it was decided that roofs for all the options would be constructed in a similar way.

The programme prepared (by a contractor) showed that the PT flat slab would give the shortest overall construction time; the frame would be constructed in just eight weeks.

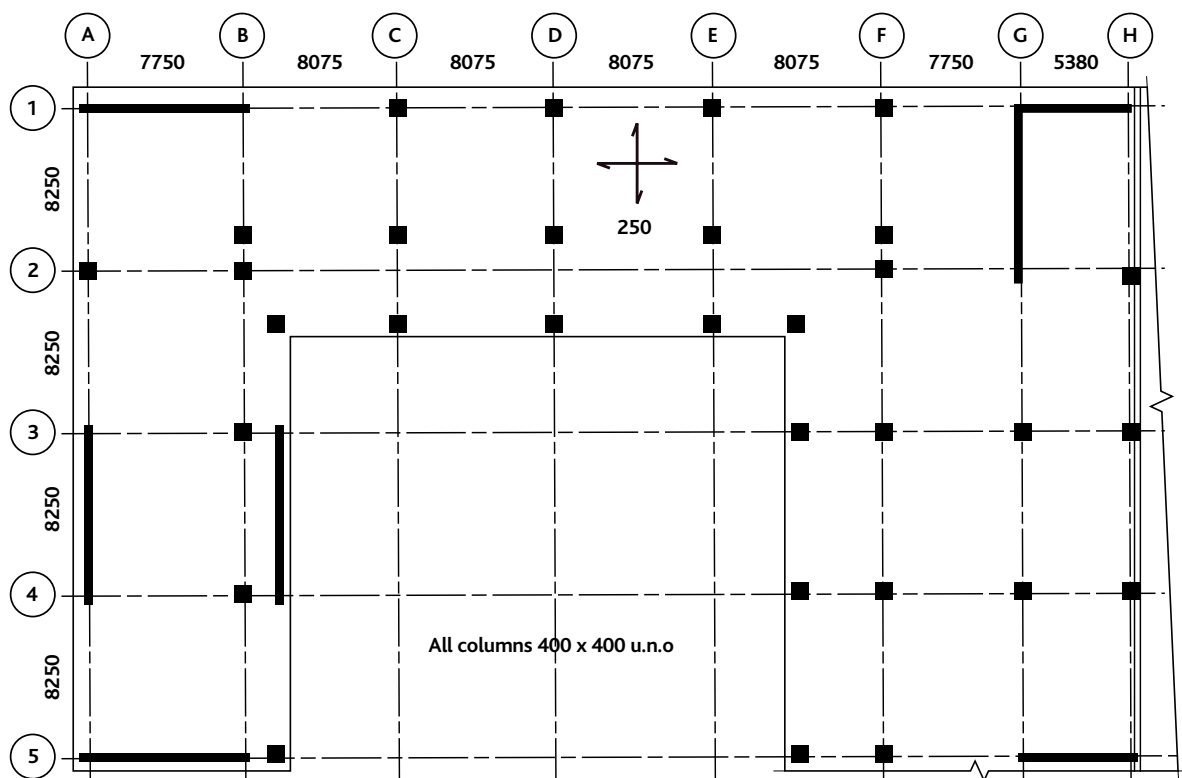
The cost comparisons show that the PT flat slab would give the lowest cost of all six options and a comparison against a RC flat slab is shown in Table 5.

Full details of the study are available from *Cost Model Study - School Buildings* [12].

Table 5: Elemental costs school building compared

Element	Flat Slab		PT Flat Slab	
	£/m ²	%	£/m ²	%
Substructures	68	3.7%	66	3.6%
Frame & Upper Floors	117	6.4%	113	6.2%
Roof	88	4.8%	88	4.8%
Stairs	7	0.4%	7	0.4%
External Cladding	149	8.2%	147	8.1%
External Windows & Doors	21	1.1%	20	1.1%
Internal Planning	88	4.8%	88	4.8%
Wall Finishes	21	1.1%	20	1.1%
Floor Finishes	46	2.5%	46	2.5%
Ceiling Finishes	27	1.5%	27	1.5%
Fittings	200	10.9%	200	11.0%
Sanitary	21	1.2%	21	1.2%
Mechanical	237	13.0%	237	13.0%
Electrical	183	10.0%	183	10.1%
Lifts	19	1.0%	19	1.0%
Builders Work	45	2.5%	45	2.5%
Contingency	100	5.5%	99	5.5%
Preliminaries	394	21.5%	394	21.6%
Overheads & Profit	84	5.7%	82	5.7%
Total	£1,488		£1,459	

FIGURE 19: PT FLAT SLAB FOR PART OF A SECONDARY SCHOOL



END OF LIFE

Demolition

There is only a very small additional risk associated with the demolition of a post-tensioned structure. The demolition methods are similar to those used for reinforced concrete (RC) structures, with some modifications as noted below.

Prestressing tendons are made of extremely tough high-strength steel and are therefore difficult to sever. In contrast, separating the steel and concrete is slightly simpler than for RC structures because there is less steel.

A bonded slab should not require any significant changes of approach to an RC slab. If percussion methods are used, the breaking up of the concrete around the ducts will release the prestressing forces locally in the same way as tension is released from reinforcement in an RC slab. Using cutting methods will have a similar effect.

For unbonded slabs, the approach is often to prop the floor and then release the tension in the tendons by either:

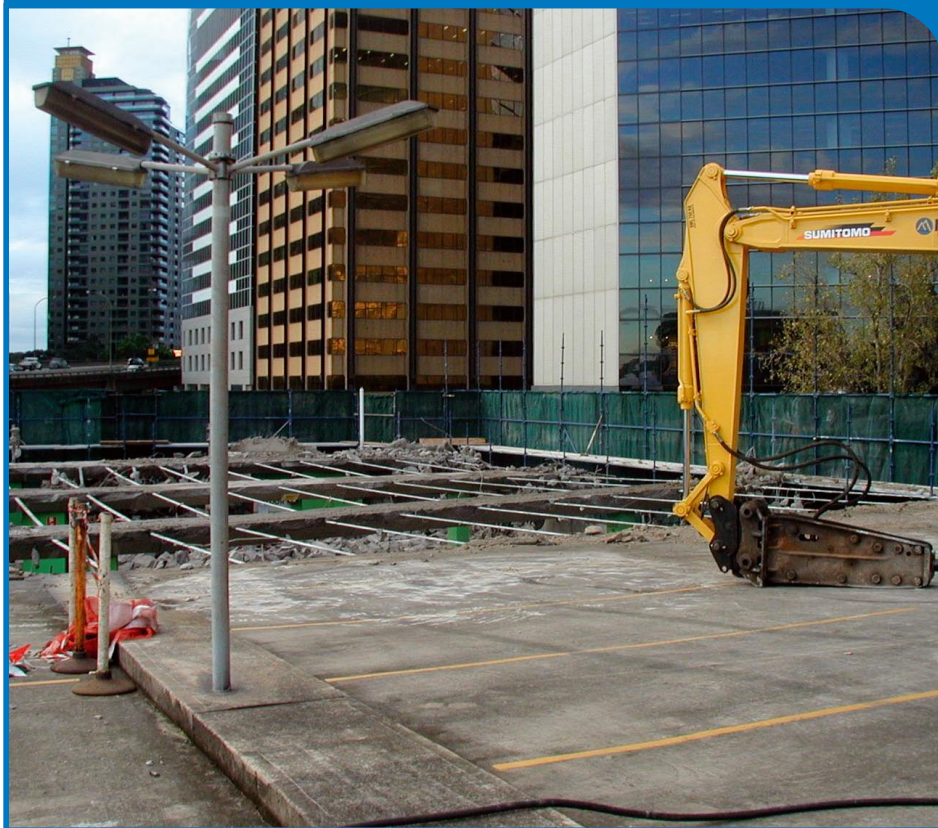
- Heating the wedges until the tendon slip occurs
- Breaking out the concrete behind the anchorage until detensioning occurs
- De-tensioning the tendon, using jacks
- Cutting through the strands at high points, whilst protecting around anchorages.

It has been shown by testing and from experiences on-site that anchorages and/or dry packing are not ejected from the slab edge at high velocity. This is due to the friction between strand and the sheath which dissipates.

More detailed guidance can be found in *Demolition and hole cutting in post tensioned concrete buildings* [13].

Demolition of transfer structures should be treated with due consideration. The forces involved are significantly higher than for a single floor slab and the prestressing forces may have been increased as additional floors were constructed. Provided the demolition method takes account of these issues, the risks can be identified and managed.

Demolition of PT bonded slab using conventional demolition equipment. Courtesy of Freyssinet.



Alterations

As with demolition, structural alterations are no more difficult than for other construction forms, and can be easier to adapt. This means that the benefits of existing post-tensioned floor construction can be used when altering existing buildings (e.g. redundant office space being reused for residential accommodation).

When it comes to minor alterations, PT slabs are often easier to work with than other structural forms. They derive their tensile strength from high strength steel tendons which are often spaced at well over 1m centres. Depending on the specific circumstances, the concrete can generally be cut out between the strands without the need for strengthening. This could potentially be an opening of 1m square, or perhaps even larger. An experienced structural engineer should always be employed to check the effects of the proposed alterations.

More substantial alterations can also be undertaken using tried and tested techniques. Procedures vary slightly depending on whether the PT slab has bonded or unbonded tendons. Currently, bonded tendons are used for the vast majority of new PT construction in the UK. In this system the steel strand is bonded via the grout and duct to the concrete, so that any cut through the tendon has a local effect only. At a bond length away the tensile strength is unaffected.

A typical procedure for bonded tendons would be as follows:

- 1 Mark the tendon positions.
- 2 Using appropriate equipment for the type and size of project, demolish the concrete between tendons, taking care to avoid damage to the tendons.
- 3 Remove the concrete, leaving the tendons.
- 4 Cut the tendons to length for the new layout.
- 5 Cast new concrete.

Experience has shown there is no explosive release of energy when the concrete is broken out because the concrete is broken out in relatively small areas. For major refurbishment projects new tendons and anchorages can be installed to work in combination with the existing post-tensioning.

Many of the older PT slabs in the UK were constructed using unbonded tendons, and the techniques for altering these are similar, but require slightly more planning and possibly disruption. This is because unbonded construction relies on the anchorages at either end to transmit forces between the slab and tendons so cutting the tendon releases the tension throughout its length. Therefore, before breaking out any concrete, the slab must be propped throughout the length of the strand to be cut, and then de-tensioning of the strand should be carried out. The same procedure detailed for a bonded system can then be adopted except that the severed unbonded tendons should be restressed using new anchorages cast into the edge of the opening.

SUMMARY

- Post tensioned concrete slabs are a tried and tested form of construction in use throughout the world with many example projects in the UK.
- There are many benefits to be gained from using post-tensioned construction:
 - Minimum floor thickness
 - Long spans
 - Rapid speed of construction
 - Flexibility of layout
 - Flat soffit
 - Minimum use of materials
 - Cost-effective
- There are a number of slab types that can be used to suit individual projects.
- As with all structural solutions, there are a number of considerations to be aware of and, for PT, restraint of the slab should be considered at the early stage of a project.
- Demolition and alterations of PT slabs should not be seen as being more difficult than with any other type of design; they all require planning and detailed consideration. There is also plenty of experience of this type of work amongst UK sub-contractors.

REFERENCES

To download or access many of these publications, visit www.concretecentre.com/publications.
Case studies on post-tensioning can be found at the website of the Post-tensioning Association
- www.post-tensioning.co.uk

1. Technical Report no. 43: Post-tensioned Concrete Floors Design Handbook (second edition), The Concrete Society, 2005
2. Hospital Floor Vibration Study – comparison of possible floor structures with respect to NHS vibration criteria, Arup, 2004. Download from www.concretecentre.com
3. PE Jones, Site Airborne and Impact Sound Insulation Measurements Between Rooms in Student Accommodation at Colman House, University of East Anglia, Norwich (Acoustic Test Report no. 04091), 2004. Download from www.concretecentre.com (within Acoustic Performance section)
4. Economic Concrete Frame Elements (Second Edition), CCIP-025, The Concrete Centre, due 2008
5. How to design reinforced concrete flat slabs using Finite Element Analysis, The Concrete Centre, 2006
6. Practical Yield Line Design, The Concrete Centre, 2004
7. BS EN1992-1-1, Eurocode 2: Design of Concrete Structures. General Rules and rules for building, British Standards Institution, 2004
8. BS EN1992-1-2, Eurocode 2: Design of Concrete Structures. General Rules – structural fire design, British Standards Institution, 2004
9. How to Design Concrete Structures using Eurocode 2, CCIP-06, The Concrete Centre, 2007
10. Cost Model Study - Commercial Buildings, CCIP-010, The Concrete Centre, 2007
11. Cost Model Study - Hospital Buildings, CCIP-012, The Concrete Centre, due 2008
12. Cost Model Study - School Buildings, CCIP-011, The Concrete Centre, 2008
13. K Bennett, Demolition and Hole Cutting in Post Tensioned Concrete Buildings, Engineering Technical Press, 1999, Download from www.post-tensioning.co.uk

The entire concrete industry in your office

The Concrete Centre provides continuing professional development at your fingertips. A wide range of presentations, all of which are CPD-certified with approved learning outcomes, are free of charge and can be delivered in your office by our expert team of regional engineers.

For more information visit
www.concretecentre.com/cpd

If you have a general enquiry relating to the design, use and performance of concrete, please contact our national helpline on 0845 812 0000



The **Concrete Centre**™

Advice is free and available Monday to Friday from 8am to 6pm.
Call 0845 812 0000
Email helpline@concretecentre.com

CI/SfB				
UDC				

Spectrum development, Manchester. At 13-storeys high, this development reduced its overall height by specifying post-tensioned concrete floors.



The Concrete Centre™

The Concrete Centre,
Riverside House,
4 Meadows Business Park,
Station Approach, Blackwater,
Camberley, Surrey GU17 9AB

National Helpline
Call 0845 812 0000
Email helpline@concretecentre.com

Ref. TCC/03/33
ISBN 978-1-904818-59-5
First published 2008
© The Concrete Centre 2008

All advice or information from The Concrete Centre is intended for those who will evaluate the significance and limitations of its contents and take responsibility for its use and application. No liability (including that for negligence) for any loss resulting from such advice or information is accepted. Readers should note that all publications from The Concrete Centre are subject to revision from time to time and should therefore ensure that they are in possession of the latest version.



www.concretecentre.com

