Back cover photos

main — Post-tensioned balconies, The Criterion, Piccadilly

right — Post-tensioned floors, Advanced Technology Centre, University of Warwick

centre — Ground bearing slab for Waitrose, Bracknell

left — Stressing unbonded tendons at The Chimes Shopping Centre, Uxbridge



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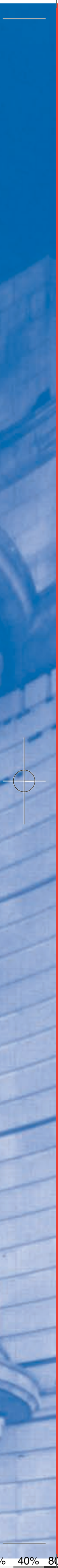
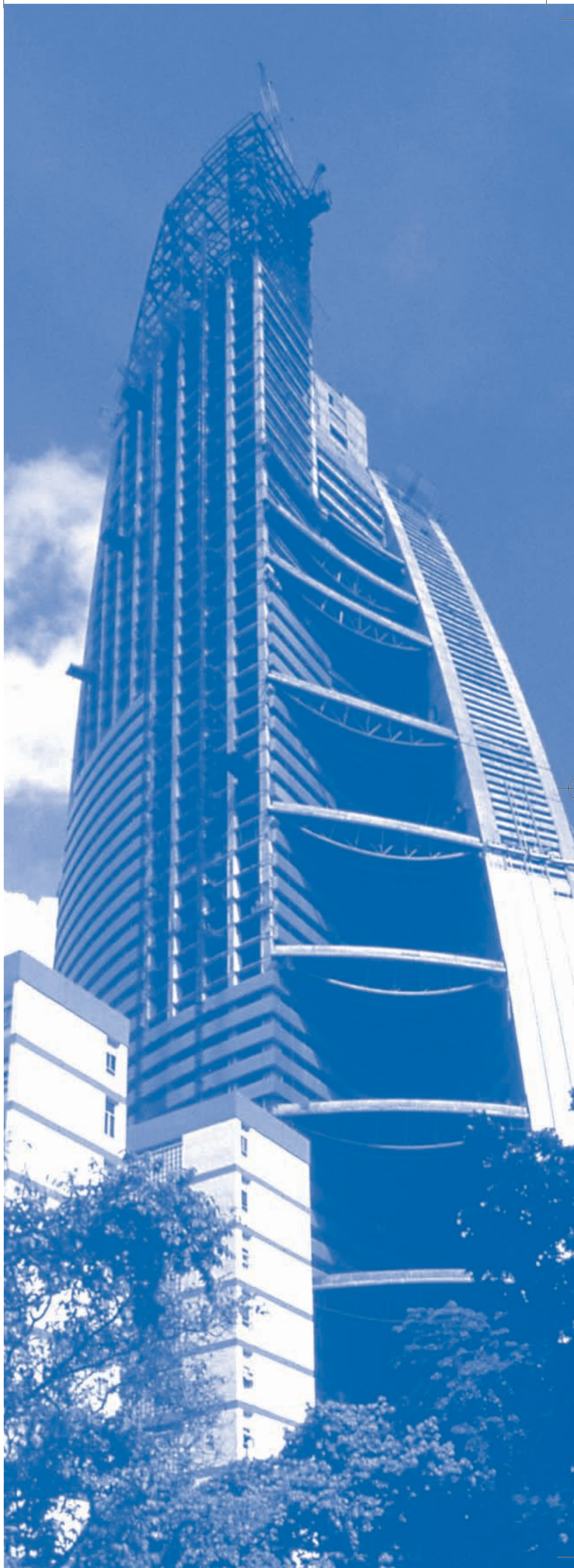


# Slabstress

## Post-tensioning systems for buildings

freyssinet



# Slabstress

1

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4

1. Multi-storey car park, Lakeside Shopping Centre
2. Storage facility, Bracknell
3. Jervis Shopping Centre, Dublin
4. The Chimes, Uxbridge

Front cover photos

main Telekom Tower, Kuala Lumpur

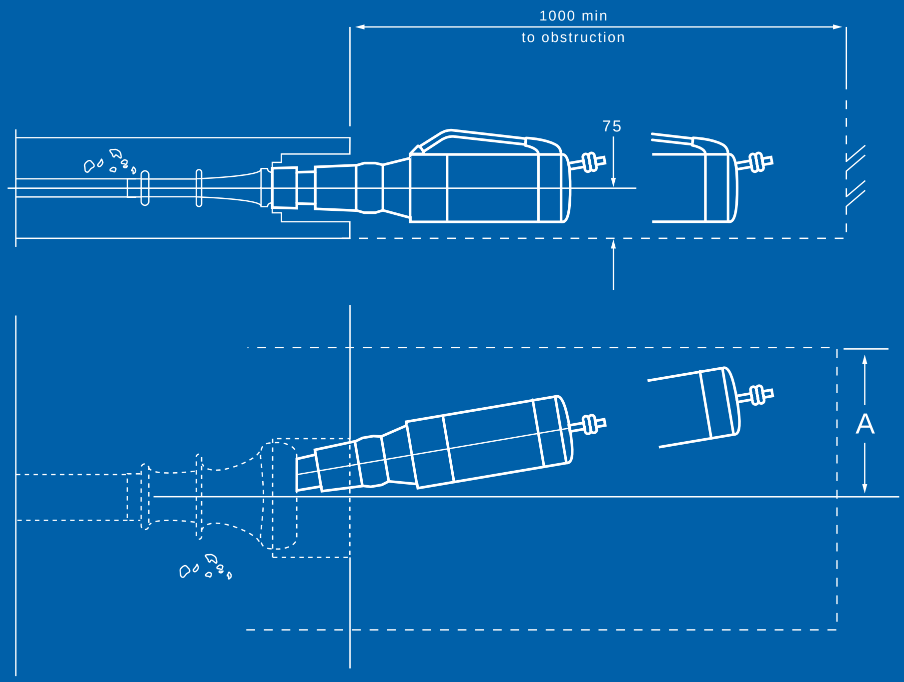
inset Unbonded live end anchorage

# Construction details

### Stressing access requirements

Note: Refer to Freyssinet if these clearances cannot be provided.

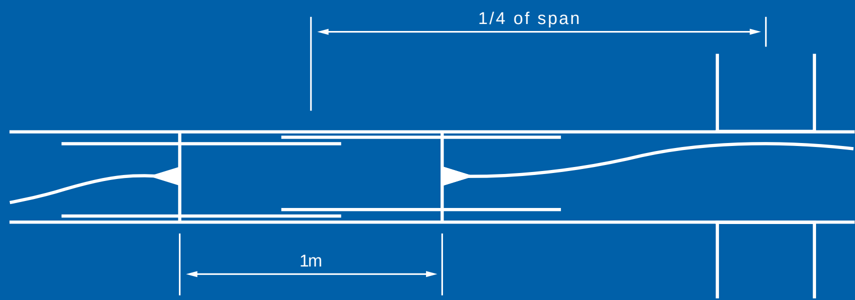
| Anchorage | A |
|---|---|
| 1SL15 | 75 |
| 4S15 | 350 |
| 5S15 | 450 |



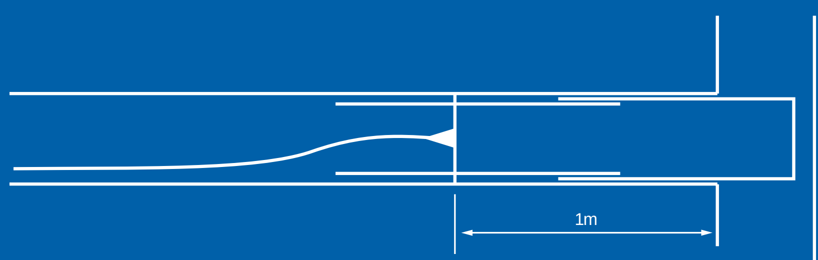

### Release details

When a post-tensioned slab is stressed, it needs to be able to shorten. Columns are normally sufficiently flexible not to be a problem but if two or more stiff cores exist, then it is often necessary to incorporate a temporary release. Some typical details are sketched below.

A 1m wide reinforced concrete infill strip, mid-way between the cores, allows stressing access and release (until concreted).




A 1m wide reinforced concrete infill strip temporarily separates the slab from the wall. This detail is useful for stressing access and release at retaining walls.




1. 1SL15 live end
2. 1SL15 dead end
3. Intermediate anchor
4. Unbonded tendons at Broadway, Maidenhead

1

2

3

4

# Slabs on grade

### Ground bearing slabs

- Economic for slabs subject to heavy loadings, particularly on poor ground
- Enables pouring of large areas, saving in both joints and construction time
- Elimination of substantial foundations for slabs on poor subgrade
- Allows reduction in slab thickness, particularly for raft slabs
- Free of cracks and hence resistant to penetration of moisture and aggressive chemicals
- The joint and crack-free slabs are capable of meeting the severe loading and flatness criteria of modern high stacking systems with the minimum of maintenance.

Post-tensioned slabs on grade are frequently used for:

- High tolerance floors in high bay warehouses
- Sports halls
- Pharmaceutical and chemical factories
- Airport aprons

### Slabs on piles

Combines the strength and deflection benefits of suspended post-tensioned slabs with the crack and joint-free benefits of slabs on grade.

# Strand types

The table below gives the main characteristics of the most common strands which may be used with the Slabstress range. The strand types comply with BS 5896: 1980.

### Table 7: Acceptable strand types

| Strand type | Nominal Tensile Strength $N/mm^2$ | Nominal Diameter mm | Nominal Steel Area $mm^2$ | Nominal Mass kg/m | Minimum Breaking Strength kN | 0.1% Proof Load kN |
|---|---|---|---|---|---|---|
| 12.9 Super | 1860 | 12.9 | 100 | 0.785 | 186 | 158 |
| 12.7 Drawn | 1860 | 12.7 | 112 | 0.89 | 209 | 178 |
| 15.7 Super | 1770 | 15.7 | 150 | 1.18 | 265 | 225 |
| 15.7 Euro* | 1860 | 15.7 | 150 | 1.18 | 279 | 237 |
| 15.2 Drawn | 1820 | 15.2 | 165 | 1.295 | 300 | 255 |

*Strictly speaking this now common strand type is 15.7 super strand made from higher grade (1860) material. It is commonly referred to as Euro strand and complies generally with BS 5896: 1980.

All sizes are available as bonded or unbonded strand.

Other strand types/sizes may be acceptable. Please refer to Freyssinet Limited for clarification.

# Future alterations

### Holes in slabs

Tendons are usually spaced sufficiently far apart to allow holes of reasonable size to be made later, without cutting through the tendons. Where larger openings are required it may be necessary to cut tendons. When cutting holes the effect on the slab should be assessed by a qualified engineer beforehand.

Usually bonded tendons can be cut with traditional methods. There will be a loss of force local to the cut and so trimmer beams around the hole may be necessary.

When an unbonded tendon is cut it will de-tension along its whole length. It will need to be re-stressed, usually from the face of the new hole. Freyssinet have successfully achieved this on several projects.

It is possible to design slabs with ‘soft’ zones where future penetrations can be cut without difficulty.

### Demolition

In the case of post-tensioned structures using bonded tendons, demolition can be carried out using techniques similar to those used to demolish reinforced concrete structures. Whilst tendons are made from high tensile strand there is considerably less steel to cut and generally concrete sections will be thinner than comparable reinforced concrete structures.

In the case of transfer slabs or beams which have been progressively stressed, extra precautions must be taken to avoid upward bursting of concrete as the self weight of the structure above is progressively removed.

The cutting of unbonded tendons may result in the dramatic collapse of a structure, but properly considered can be used to advantage, enabling rapid demolition of large areas as the force in the supporting tendons is released.

# Introduction

When Eugene Freyssinet developed and patented the technique of prestressing concrete in 1928, he little realised the applications to which his invention would be put in future years. Freyssinet introduced the concept of post-tensioned buildings to the UK in the 1970s with the launch of the Slabstress system. Since then thousands of square metres of suspended and ground bearing slabs have been completed utilising the system for projects as diverse as:

- Offices
- Car parks
- Schools and universities
- Shopping centres
- Reservoirs
- High bay distribution warehouses
- Sports halls
- Pharmaceutical and chemical facilities
- Places of worship
- Apartment buildings
- Airports

## Technical assistance

Freyssinet have an in-house design department staffed by qualified engineers with experience in post-tensioned building design. This team is happy to assist clients, architects, engineers and contractors with:

- Scheme design
- Budget estimate
- Detailed design
- Vibration analysis of floor plates
- Working (shop) drawings
- Provision of method statements, specifications and risk assessments.

## Site service

Freyssinet offer a full supply and installation service including:

- Supply of post-tensioning materials
- Supply of reinforcement
- Installation of post-tensioning and reinforcement
- Stressing
- Cutting off tendon surplus
- Grouting
- Forming and concreting slabs on grade.

## Quality assurance

Freyssinet is a quality assured company to BS EN ISO9001: 2000. Design, manufacture and site works are strictly controlled to ensure optimum efficiency and premium quality. Additionally, Freyssinet is registered under the CARES post-tensioning scheme. Anchorages are tested in accordance with BS4447 "The performance of prestressing anchorages for post-tensioned construction" to ensure safe and reliable operation.

1. The Criterion, Piccadilly
2. The Broadway, Maidenhead

1

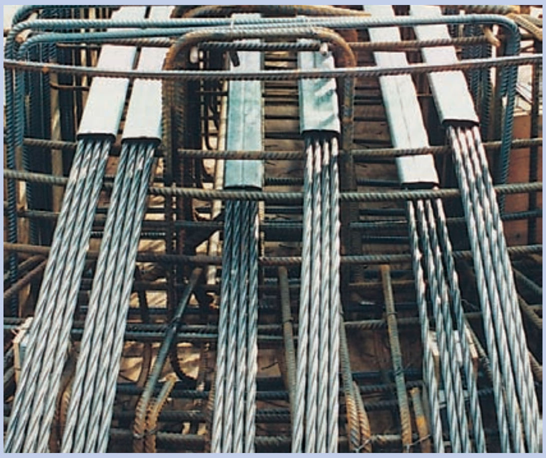


2

1. 4S15 live end
2. 4S15 bulb dead end
3. Bonded tendons at The Criterion
4. Lakeside, Thurrock

1

2



3

4

# The unbonded system

The unbonded system consists of individually greased and plastic coated strands. The grease inhibits corrosion and prevents bond between the sheath and the strand. Slabstress unbonded anchorages are suitable for strands produced to most internationally acceptable standards. Refer to Table 7 for commonly used sizes. Unbonded tendons have the following features:

- Often require conventional reinforcement to assist with controlling crack widths and supplementing the ultimate resistance
- Much more flexible than bonded tendons. Easily diverted around openings and other obstructions
- Each strand is individually anchored, allowing anchors to be fanned out if necessary to avoid obstructions
- Lower friction than bonded tendons
- Quick to install as there is no duct to fix or grout to inject.

## Live (stressing) anchorage

The anchorage consists of a high strength iron casting with a tapered hole to take the gripping wedges. There is a tight-fitting sealing sleeve at the back and a screwed-on plastic grease cap at the front to fully seal and protect the wedges.

Easy fixing to the shuttering is obtained by a plastic mandrel, which is screwed to the casting and holds a re-usable plastic recess form in position by means of a locking nut at the outside of the form. A 45mm hole is required in the shutter to fix the anchorage assembly.

The striking procedure involves removing the nut and shuttering and rotating the mandrel by means of a hand tool which fits into it. This rotation unscrews the mandrel from the casting and automatically releases the recess form.

The anchorage is designed for 15mm strand up to 300 kN UTS, but can be adapted to take 13mm strand. Unbonded system design parameters for both 13mm and 15mm options are given below.

| | Unbonded |
|---|---|
| Wobble factor k | 0.0030/m |
| Friction factor $\mu$ | 0.06 |
| Wedge pull-in | 6mm |

The re-usable recess form is designed to give adequate cover and allows the strand to be cut by means of a disc cutter. The pocket should be filled with a dry-packed sand/cement mortar after the grease cap has been filled with grease and fixed.

## Unbonded dead end anchorage

The dead end anchorages are usually fitted to prefabricated tendons in the factory and are similar to the stressing anchorage. The mandrel, nut and recess former are not necessary.

## Unbonded intermediate anchorage

These anchorages are used when it is necessary to stress part of a tendon in advance of the total length. This occurs in stage construction to facilitate formwork removal or prevent shrinkage cracking.

The anchorage consists of a slotted bearing plate and a tapered barrel which receives the gripping wedges. The barrel is usually placed in its approximate position during tendon fabrication and the slotted plate and wedges fitted on site. The plate has two nail holes for fixing to a stop-end shutter.

If stressing is required at an intermediate anchorage, 400mm of the plastic sheathing on the jacking side of the plate should be removed temporarily and an open throat GEMI jack used for the stressing.

## Corrosion protection

Unbonded strand comes pre-greased and plastic coated to FIP recommendations. The Slabstress unbonded anchorages are fully encapsulated against corrosion by means of a sealing sleeve that fits snugly against the strand, and a screw-on grease-filled cap that covers the strand and jaws. These features are true of both the live *and* dead ends.

**Quick guide to scheme design**

These rules can be used to provide an initial idea of an economic post-tensioned solution at feasibility stage.

1. Select structure type using Figures 1-5 and Table 1.
2. For two-way structures, that is a square or roughly square grid, select a structure type from Figures 1-4. For rectangular grids, that is an aspect ratio of more than 1.5, select from Figure 4 or 5.
3. Select member sizes from Table 1.
4. Contact Freyssinet to confirm the scheme and provide a budget price.
5. Refer to (inside back page) **Construction details** for practical advice.

A useful rule of thumb is to reduce the depth of a reinforced concrete design by 25% to obtain the equivalent post-tensioned scheme sizes.

# Advantages of post-tensioning

**Longer spans**
- Fewer columns – spans up to 50% longer
- More lettable area

**Flexibility**
- Greater freedom with internal layout
- Easier to replace or reposition partitions

**Thinner slabs**
- Reduced building height – planning gain
- Reduced cladding area
- Incorporate more floors into a fixed building height
- Reduced weight – savings in foundations
- Reduced excavation when substructure floors or transfer slabs are post-tensioned

**Performance**
- Complete monolithic frame
- Resistance to cracking and water seepage
- Excellent deflection control

**Services access**
- The thin floors, often with flat soffits, allow efficient and economic services design

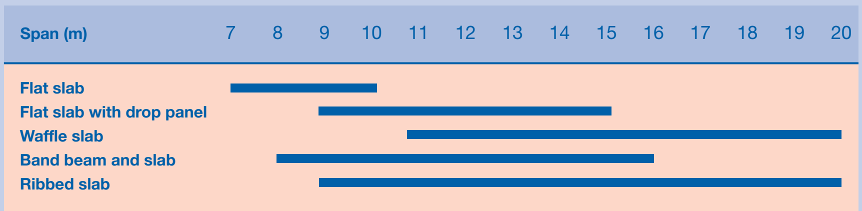
**Construction benefits**
- Simple formwork increases speed
- Early form striking reduces cost
- Less steel and concrete to install
- Less material to store on site and lift to the working level

## Table 1: Typical span to depth ratios for post-tensioned floors

These ratios are for multiple spans. For single spans add 15% to the depth.

| | Total imposed load (kN/m$^2$) | Span to depth ratio | | Typical member details |
|---|---|---|---|---|
| **Flat slab** | 2.5 | 40 | | The addition of column caps (typically 700mm square by 200mm deep) can assist economy. |
| | 5.0 | 36 | | |
| **Flat slab with drop panel** | 2.5 | 45 | | Drop panel total width is 1/3 of the span, its overall depth is 75% more than slab depth. |
| | 5.0 | 40 | | |
| **Waffle slab** | 2.5 | 30 | | Ribs usually at 900-1500mm centres. |
| | 5.0 | 27 | | |
| **Continuous band beam** | | **Slab** | **Beam** | Band beam width is 1/5 of its span. Usually the slab spans the shorter grid to reduce concrete volume. |
| | 2.5 | 45 | 30 | |
| | 5.0 | 40 | 25 | |
| **Ribbed slab** | | **Slab** | **Beam** | Band beam width is 1/5 of its span. Usually ribs span the longer grid to produce a common soffit (ribs and beam the same depth). Ribs usually at 900-1500mm centres. |
| | 2.5 | 30 | 30 | |
| | 5.0 | 27 | 25 | |

## Table 2: Typical economic spans for post-tensioned floors



# Structural solutions

Modern post-tensioning techniques produce thinner floors or larger spans that need fewer supporting columns. An advantage of thinner floors in tall buildings is that often more storeys can be incorporated into a building height, than if the structure were constructed using reinforced concrete. Large, uninterrupted floor spaces produce a building with increased versatility because the space can be adapted to suit the needs of different types of occupier. Prestressed concrete produces lighter structural members, resulting in reduced loadings being transferred to the foundations, with potential savings in construction costs.

The post-tensioning process is a highly economical way (see Figure 6) of designing the floors and roofs of buildings such as multi-storey offices and apartments, warehouses, car parks, shopping centres, reservoirs, hospitals and schools.

## Slab system

The action of the prestressing tendon in a floor slab is to develop an uplift force to counteract the downward thrust of the imposed loads, with the result of little deflection in the finished floor. The need to pre-camber formwork, as is often the case in construction of long floor spans, is usually eliminated.

The diagrams below illustrate some of the typical post-tensioned floor systems and their applications.

### Figure 1: Flat slab or plate

This type of slab is generally used in apartment blocks, office buildings, car parks, hotels, etc, where spans are similar in both directions. Its construction is easy with very simple formwork and it allows considerable flexibility for locating building services.

### Figure 2: Flat slab with drop panel

The introduction of a drop panel at the column improves shear resistance and increases the stiffness of the floor whilst maintaining the ease of construction of the flat slab.

### Figure 3: Waffle slab

A very stiff structure, it is recommended for heavy loads spanning up to 20 metres, such as industrial buildings and airport terminals.

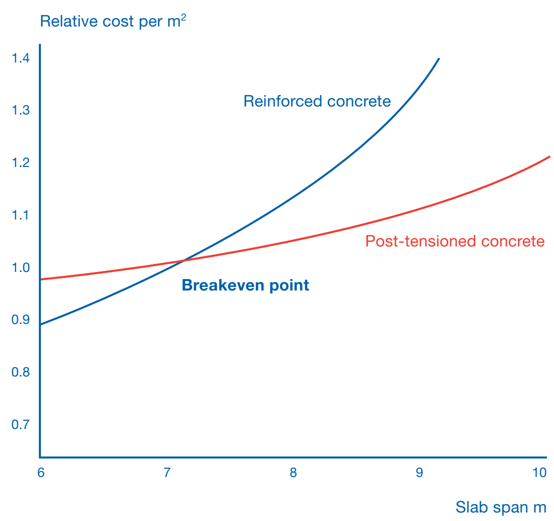
### Figure 4: Band beam and slab

Used in structures where spans are predominantly in one direction. The continuous band beam is relatively wide and shallow, reducing the overall depth of the floor while permitting longer spans, with a one way spanning slab between the beams.

### Figure 5: Ribbed slab

A very competitive system when considering concrete volume and dead weight of the structure. Introducing ribs reduces the quantity of concrete and reinforcement and hence the weight of the floor. The formwork is more complicated but the use of a modular system will overcome this problem.

### Figure 6: Cost comparison Reinforced vs post-tensioned concrete slab



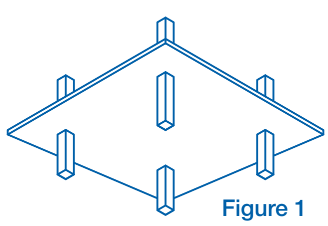



Figure 1

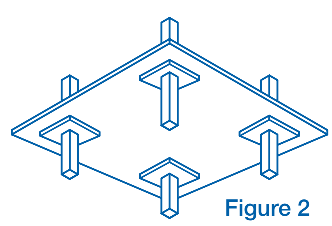


Figure 2

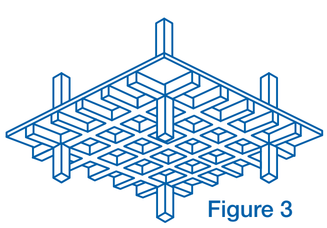


Figure 3

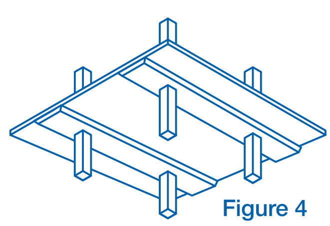


Figure 4

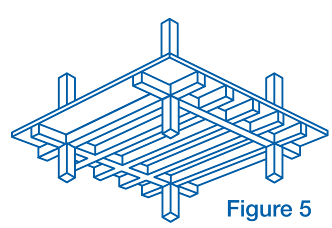


Figure 5

System details under flap

## Table 5: The range of unbonded tendons using 13 or 15mm strands

| Tendon reference | No. of strands | Strand type | Total ultimate tensile strength kN | 80% UTS | 60% UTS | Transfer strength of concrete N/mm$^2$ |
|---|---|---|---|---|---|---|
| 1S13 | 1 | 12.9 Super | 186 | 148.8 | 111.6 | 25 |
| 1S13D | 1 | 12.7 Drawn | 209 | 167.2 | 125.4 | 25 |
| 1SL15 | 1 | 15.7 Super | 265 | 212.0 | 159.0 | 25 |
| 1SL15E | 1 | 15.7 Euro | 279 | 223.2 | 167.4 | 25 |
| 1SL15D | 1 | 15.2 Drawn | 300 | 240.0 | 180.0 | 25 |

Notes: Transfer strength is the minimum cube strength of the concrete at the time of applying full stressing load.

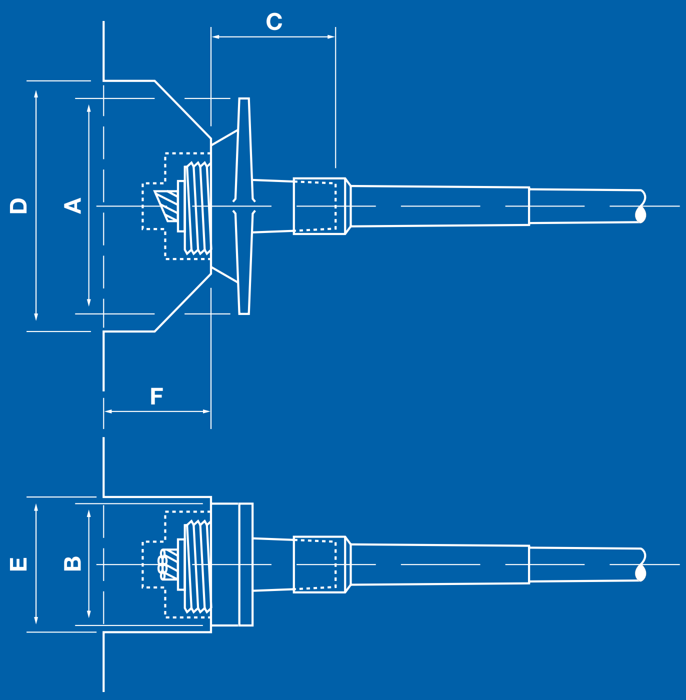
Tendons are usually stressed to 80% UTS.

After tendon losses due to friction, shrinkage, creep, elastic shortening etc, the average prestress is often close to 60% UTS.

## Table 6: Anchorage sizes – unbonded system

| | Anchor | | | Pocket | | |
|---|---|---|---|---|---|---|
| **Anchor ref.** | **Width** | **Depth** | **Length** | **Width** | **Depth** | **Length** |
| **Dimension** | **A** | **B** | **C** | **D** | **E** | **F** |
| 1SL15 | 130 | 70 | 65 | 150 | 75 | 67 |

Note: All systems use the 1SL15 anchorage.




Left:
University College Cork, flat slab and waffle slab stressed with unbonded tendons

Below:
Jervis Shopping Centre, Dublin

# The bonded system

The bonded system comprises up to five strands that are contained within an oval duct which, after stressing, is injected with cement grout. The grout provides both bond to the structure and corrosion protection to the strands. The duct is easily profiled about its weaker axis and its flat cross section allows maximum use to be made of the available concrete section in design. Slabstress bonded anchorages are suitable for strands produced to most internationally acceptable standards. Refer to Table 7 for commonly used sizes. Bonded tendons have the following features:

- Higher ultimate strength than unbonded
- The anchorage is less critical, long-term, as force is transferred to the structure via bond
- As several strands share a common anchorage, the total anchorage size is less; good for congested areas
- Safer during hole-cutting or demolition as high energy release is prevented by bond.

## Live (stressing) anchorage

The anchorage consists of a cast iron bearing plate/guide and a high strength, cast iron anchor block which contains tapered holes to take the gripping wedges.

At the time of casting the concrete, the guide is fixed to the side shutter with a single bolt and separated from the shutter by a polystyrene recess form. The bolt hole in the guide later doubles as a grout inlet point or alternatively a grout inlet point can be provided at the top of the guide.

After the bolt, shutter and recess form are removed, the anchor block and wedges can be assembled to the guide for stressing. Any number of strands from one to five can be stressed independently, allowing a high degree of flexibility for partial or stage stressing. Note that the 5S15 anchorage uses five separate barrels against a common guide, in place of the usual block.

The anchorage is designed and tested for a minimum concrete transfer strength of 25 $N/mm^2$, see Table 3. Bonded system design parameters for both 13mm and 15mm options are given below.

| | Bonded |
|---|---|
| Wobble factor k | 0.0030/m |
| Friction factor $\mu$ | 0.20 |
| Wedge pull-in | 6mm |

After stressing, the strands are cropped by a disc cutter to within 20mm of the wedges and a dry packed, sand/cement mortar infill applied to the void. The grout inlet tube, threaded into the original fixing hole, must be placed prior to the mortar application.

## Bulb dead end anchorage

The end of each strand is distorted into a bulb using a jack. Load is transferred to the concrete by the bulbs and via bond with the strand. The end of the duct is sealed to prevent grout ingress.

## Corrosion protection

Freyssinet Limited were at the forefront of development of the improved grouting technique for bridges specified in TR47 and were the first company to gain CARES accreditation for stressing and grouting internal bonded tendons. If a fully encapsulated tendon is required then plastic ducting should be used with live and blind dead end anchorages complete with caps. This system can be pressure tested prior to concreting to verify correct assembly. Plastic duct is not necessarily available for all tendon sizes and Freyssinet should be consulted in this matter. Plastic ducting is more expensive than the standard galvanised steel and would normally only be of interest in very severe exposure conditions.

System details under flap

## Table 3: The range of bonded tendons using 13 or 15mm strands

| Tendon reference | No. of strands | Strand type | Total ultimate tensile strength kN | 80% UTS | 60% UTS | Transfer strength of concrete $N/mm^2$ |
|---|---|---|---|---|---|---|
| 4S13 | 4 | 12.9 Super | 744 | 595 | 446 | 25 |
| 4S13D | 4 | 12.7 Drawn | 836 | 669 | 502 | 25 |
| 4S15 | 4 | 15.7 Super | 1060 | 848 | 636 | 25 |
| 4S15E | 4 | 15.7 Euro | 1116 | 893 | 670 | 28 |
| 4S15D | 4 | 15.2 Drawn | 1200 | 960 | 720 | 33 |
| 5S13 | 5 | 12.9 Super | 930 | 744 | 558 | 25 |
| 5S15 | 5 | 15.7 Super | 1325 | 1060 | 795 | 25 |

**Notes:** Transfer strength is the minimum cube strength of the concrete at the time of applying full stressing load.

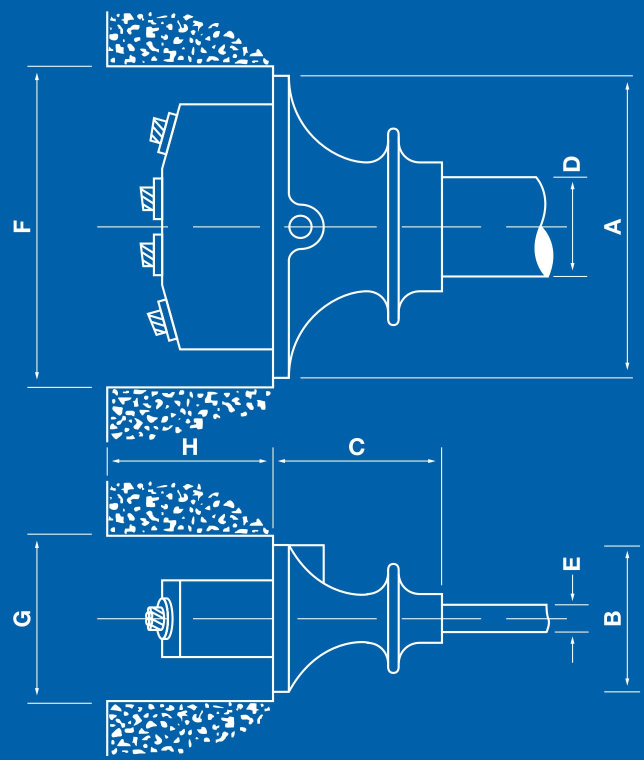
Tendons are usually stressed to 80% UTS.

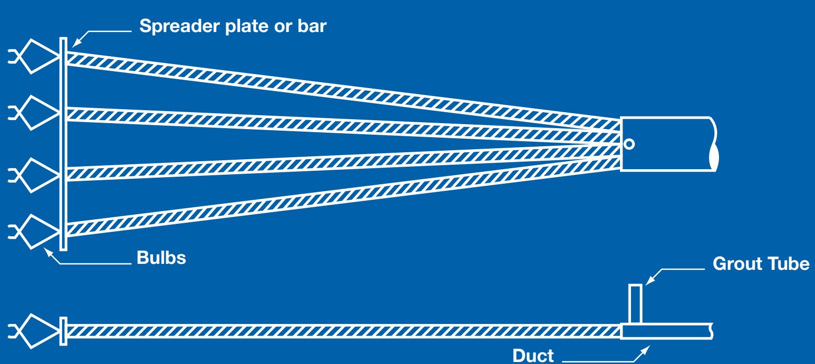
After tendon losses due to friction, shrinkage, creep, elastic shortening etc, the average prestress is often close to 60% UTS.

## Table 4: Anchorage sizes – bonded system

| | Anchor | | | Duct | | Pocket | | |
|---|---|---|---|---|---|---|---|---|
| **Anchor ref.** | **Width** | **Depth** | **Length** | **Width** | **Depth** | **Width** | **Depth** | **Length** |
| **Dimension** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** |
| 4S13 | 195 | 85 | 95 | 75 | 20 | 215 | 90 | 90 |
| 4S15 | 230 | 100 | 110 | 75 | 20 | 230 | 110 | 120 |
| 5S13 | 220 | 75 | 215 | 70 | 19 | 260 | 100 | 100 |
| 5S15 | 260 | 80 | 270 | 90 | 19 | 360 | 100 | 100 |

**Note:** 4S13D uses the 4S13 anchorage. 4S15E and 4S15D use the 4S15 anchorage.




Post-tensioned warehouse ground slab