High tension: An introduction to specifying post-tensioned slabs

Jenny Burridge explores the benefits and relative costs of one of the most efficient forms of construction

Post-tensioning is now widely used as an efficient way of designing floor slabs in concrete-framed buildings. It is a way of putting a pre-compression into the concrete, in this case after it has been cast. This means that when the slab is working under normal vertical loads, spanning between columns, the tension that would result in the concrete from bending forces is significantly reduced by the pre-compression. Since the tensile strength of concrete is only about 10% of its compressive strength, this makes it work much more efficiently.

In the simplest form of post-tensioning, the concrete is prestressed by putting high-strength tendons in ducts through the slab and tensioning the tendons with a jack when the concrete has gained sufficient strength. The tendons are usually draped within the depth of the concrete, putting an additional bending moment into the span, which balances the bending moment from the vertical loads.

With the requirement for much greater material efficiency, post-tensioning is now being used much more frequently on projects. Post-tensioned (PT) slabs are one of the most efficient forms of construction, as they enable the two main construction materials to work in the most efficient way. Significant savings can be made in comparison with conventional reinforced concrete, equating to about 20% of the concrete and 50% of the steel in a flat slab.

Figures 1 and 2 provide engineers with a guide to the sizing and rates that will be required for typical flat slabs – a guide that has been agreed by specialist designers.

FIGURE 1: SPAN-TO-DEPTH RATIOS AND RATES FOR POST-TENSIONED FLAT SLABS

Multiple spans (m)	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0
Overall depth (mm)									
Imposed load: 2.5kN/m^2	200	200	215	240	275	310	340	390	475
IL: 5.0kN/m^2	200	210	240	270	300	325	370	400	500
IL: 7.5kN/m^2	200	235	270	300	340	375	410	500	
IL: 10.0kN/m^2	200	275	310	350	390	440	500		
Tendons (kg/m^2)									
IL: 2.5kN/m^2	3.5	3.8	4.4	5.1	5.7	6.9	7.6	9.2	10.1
IL: 5.0kN/m^2	4.0	4.6	5.3	6.3	7.1	8.4	9.3	10.8	11.2
IL: 7.5kN/m^2	4.6	5.6	6.3	7.3	8.4	9.6	10.4	11.6	
IL: 10.0kN/m^2	5.4	6.9	7.8	8.6	9.7	10.7	11.7		
Mesh and loose rebar (kg/m^2)									
IL: 2.5kN/m^2	14	14	14	15	16	19	20	24	25
IL: 5.0kN/m^2	14	14	15	16	17	19	21	25	26
IL: 7.5kN/m^2	15	15	16	17	19	23	24	27	
IL: 10.0kN/m^2	16	17	18	19	23	24	26		

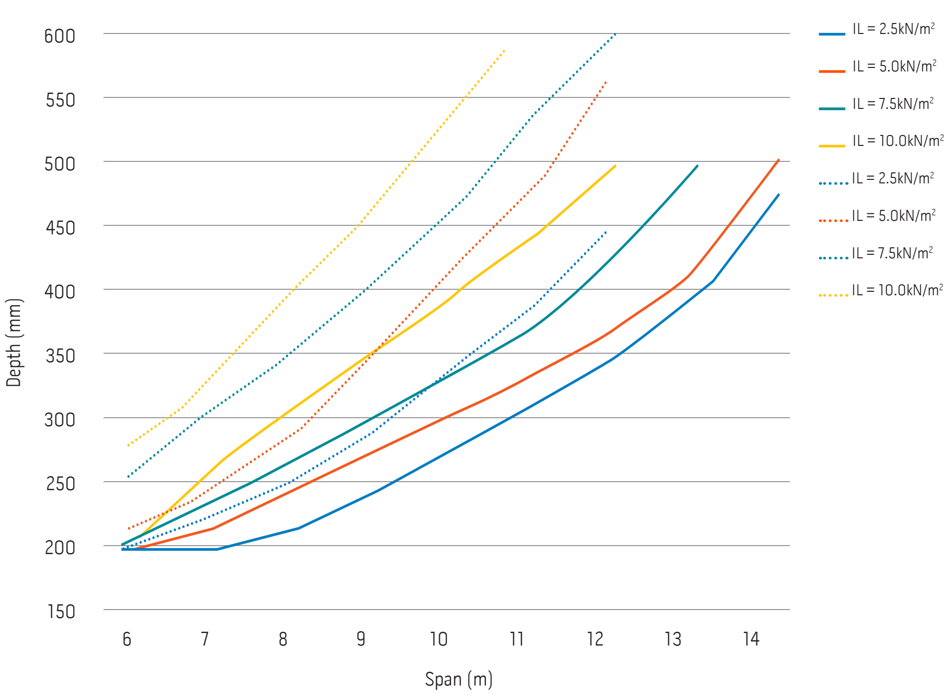
Notes on table

1. These values are mid-range for the options available. It is possible to have slimmer slabs with more tendons
2. A depth limit of 200mm has been adopted as this is standard within the industry and gives a fire resistance of up to four hours
3. The mesh and loose rebar rates include an allowance for anti-burst reinforcement around the anchorages, bottom mesh, edge reinforcement, punching shear links, top mesh for slabs of >375mm for constructors to walk on, pour strips between areas of post-tensioning, construction joints, small amounts of trimming reinforcement around holes. It does not include upstands, beams, core connections or couplers
4. Exposure class XC1 assumed. This covers internal concrete, but not concrete for a car park, for example. If higher exposure classes are required then higher rates would be necessary. Eurocode 2 requires that for XD and XS exposure classes bonded tendons should lie within concrete in compression under the frequent load combination
5. Tendons are assumed to be 12.9mm or 15.7mm Superstrand (A_{ps} = 100mm^2 or 150mm^2, f_{pk} = 1,860MPa.) Either can be used, but one or other should be chosen, rather than both, on the same project
6. Concrete is assumed to be C32/40 with $f_{ck(t)}$ at transfer of 20.8MPa
7. A superimposed dead load of 1.5kN/m^2 is assumed with a perimeter load of 10kN/m
8. Design is in accordance with Eurocode 2 (BS EN 1992-1-1 and BS EN 1992-1-2) and Concrete Society Technical Report TR43, Post-tensioned concrete floors Design handbook
9. Panels are assumed to be square with three bays in each direction.

ABOVE RIGHT At the Newfoundland tower in Canary Wharf, London, the overall slab depth was reduced by about 17%, with a 75% saving in the amount of steel

Photo: Nigel Bowles / Alamy Stock

FIGURE 2: SPAN-TO-DEPTH RATIOS, SHOWN AS A GRAPH



Benefits

Because they are more efficient, PT slabs are thinner than conventionally reinforced equivalents, and smaller floor-to-floor heights can be achieved without losing anything from floor-to-ceiling heights. This produces either lower buildings, with a consequent saving on the cladding materials, services and internal finishes, or enables a greater number of floors to be accommodated within a tall building. For example, Allford Hall Monaghan Morris' tower at 240 Blackfriars Road in London (overleaf) was able to include two additional storeys within the same building height.

The reduction in steel means that PT floors are also quicker to build than conventional in-situ reinforced concrete slabs, because the time taken to fix the reinforcement is significantly less. The fixing and stressing of the tendons are additional work items, but overall the programme is less.

In order to take advantage of the programme savings associated with post-tensioning, the

POST-TENSIONING CAN RESULT IN SAVINGS OF ABOUT 20% OF THE CONCRETE AND 50% OF THE STEEL IN A FLAT SLAB

ABOVE High-strength tendons draped within a floor slab, waiting for the concrete to be poured at the Newfoundland tower, London

RIGHT At 240 Blackfriars Road in London, the use of PT slabs enabled architect AHMM to add two storeys without increasing the building height

Photos: Timothy Soar; Praeter Engineering

concrete has to have early strength gain so that the tendons can be stressed shortly after it has been cast. The concrete for PT slabs has therefore traditionally been specified with a high proportion of Portland cement (CEM 1). However, 50% ground-granulated blast-furnace slag (GGBS) or 40% fly ash mixes have also been successfully used to lower embodied carbon in buildings. The use of high levels of replacement cements is an issue if the concrete is cast during winter.

The increased use of PT slabs in tall buildings was demonstrated by the Post-Tensioning Association (PTA) project award for 2019. Three of the shortlisted projects were high-rise residential buildings where post-tensioning had been used to increase the number of storeys for a given building height and to speed up the construction programme. The award was won by Praeter Engineering for the Newfoundland tower at London's Canary Wharf, where the overall slab depth was reduced by about 17%, with a 75% saving in the amount of steel. The reduced size of the concrete elements led to smaller columns and a reduction in the size of the piled raft foundation.

Rates

The detailed design of post-tensioning is frequently done by specialists, but the engineer for the frame can complete a concept design to size the slab and estimate the number of tendons and amount of reinforcement using standard rates.

Since post-tensioning has become more mainstream, the design of PT slabs has become even more efficient. The Concrete Centre book, Economic Concrete Framed Elements, contains tables for PT slabs and beams. The specialist designers within the PTA have found that the book gives higher rates for tendons with lower rates of conventional reinforcement than would normally be the case. The numbers in the tables have therefore been revised (see Figure 1), with the result that PT becomes more cost-effective.

One of the benefits of post-tensioning is that it is very flexible in the design. The deflection of the slab can be counterbalanced with greater levels of pre-compression or a slightly deeper slab. The drape of the tendon can be modified to give the most economic or efficient solution. PT systems are also very efficient for long cantilevers, as the pre-tension helps to control deflecton.

Figure 1 (previous page) gives a good starting point for a scheme design of a PT flat slab, the most common use of PT in the UK; figure 2 presents this information as a graph.

The PTA has produced a model specification for the procurement of the design of PT floors from specialist designers: Model Specification for the Design and Performance of Post-tensioned Concrete Floors in Building Structures. It also provides useful guidance on the considerations for designers when designing PT slabs. A free download is available at concretecentre.com.

For further information, see Post-tensioned Concrete Floors, published by The Concrete Centre