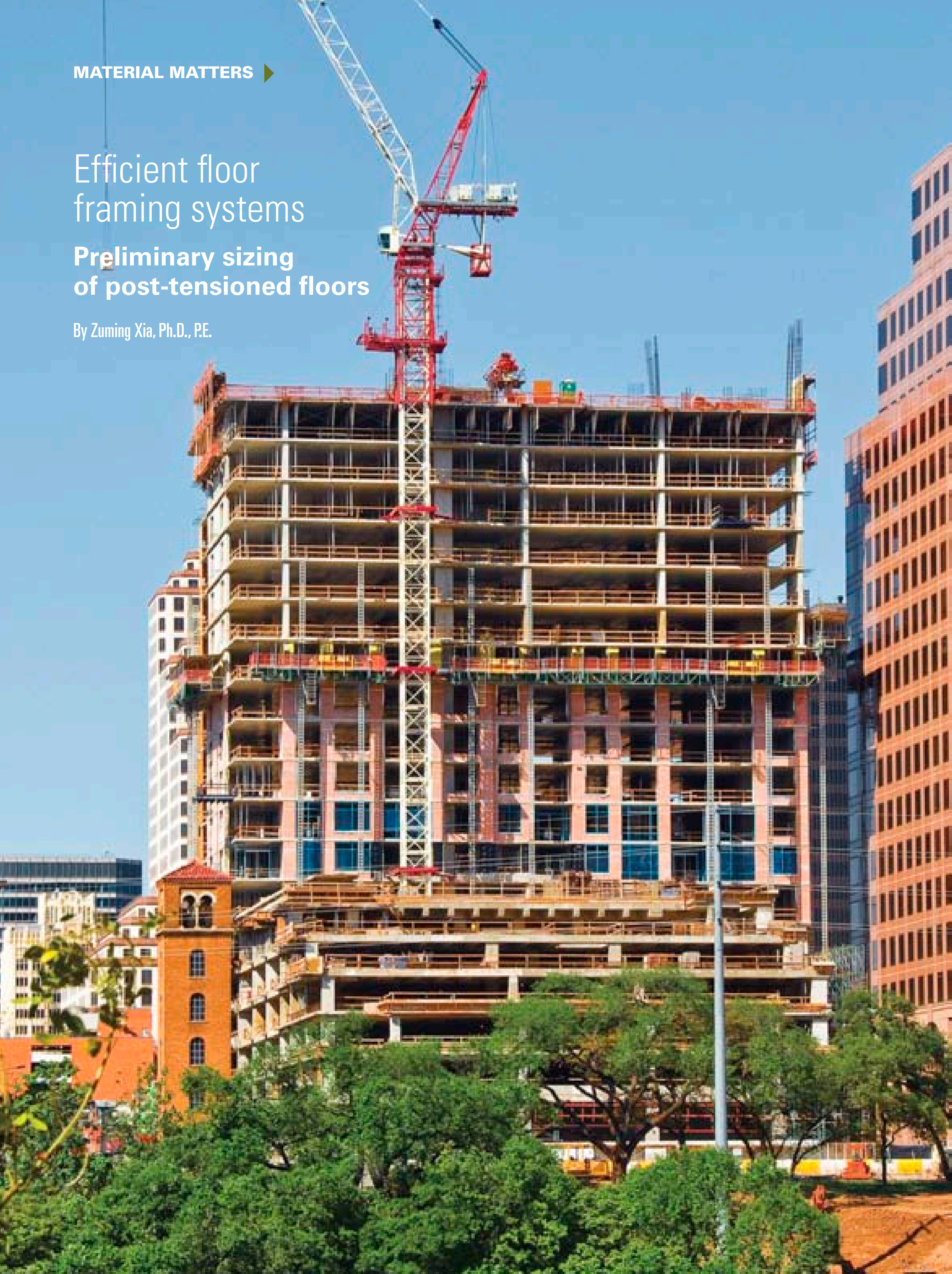
Efficient floor framing systems

Preliminary sizing of post-tensioned floors

By Zuming Xia, Ph.D., P.E.



When designing for thinner floors, using post-tensioning to resist loads and deflections provides a more optimal solution than conventionally reinforced floors. This fact is primarily due to the load-balancing effect of the draped post-tensioned tendons.

How it works — When considered together, uniform and banded tendons act like a net stretched from all four edges of the slab; see Figure 1. This "net" exerts the load-balancing forces on the concrete. In the span, the forces caused by the uniform and banded tendons act on the concrete to oppose gravity; see Figure 2.

Where the tendon curvature is inverted (such as over the grid lines between the columns), the forces in the uniform tendons act downward, inserting concentrated loads on the banded tendons (which typically run along the grid lines). These concentrated forces are balanced by the upward-acting forces from the banded tendons that, in turn, apply downward-acting forces on the columns.

As a follow-up to "Floor framing system selection: Applications of post-tensioning in buildings," by John Crigler printed in the August issue of **Structural Engineer**, this article offers tips for starting post-tensioned designs with more accuracy.

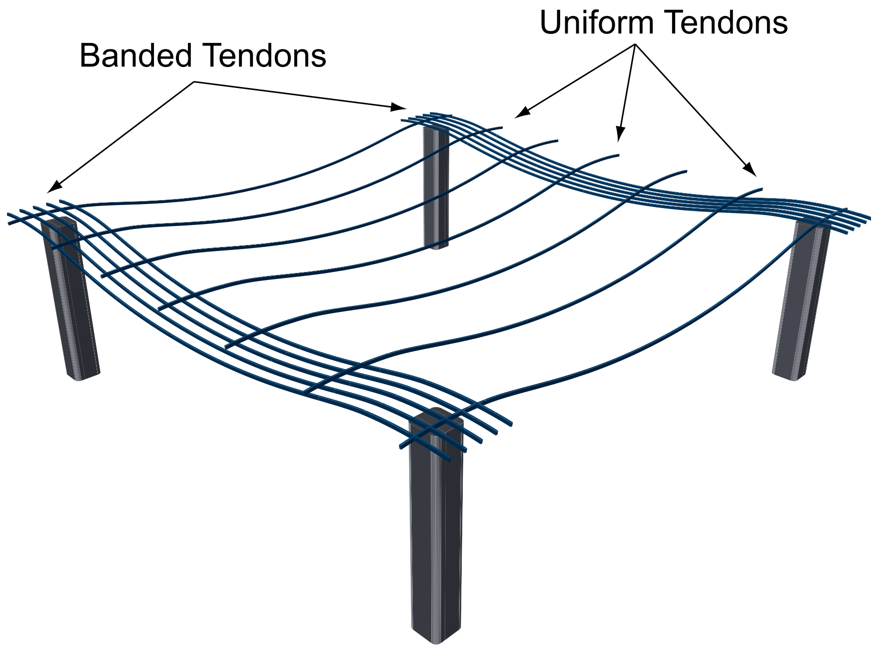
Determining pre-stressing amounts

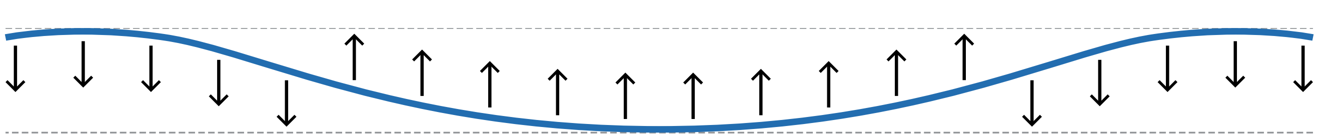
To estimate the amount of pre-stressing steel needed for a floor design, assume that the draped tendons provide sufficient distribution of forces to balance a certain percentage of the floor self-weight. This percentage depends on the ratio of total load to permanent load and is typically between 70 and 130 percent. For typical office floors with live loads of 50 to 100 pounds per square foot (psf) or residential floors with live loads of 40 to 100 psf, the pre-stressing steel would normally balance 70 to 90 percent of the self weight. For floors with higher live loads, 100 percent of the self weight, plus any additional live loads, should be balanced.

The other effect responsible for the improved deflection and cracking behavior of post-tensioned floors is the in-plane compression stress field in the concrete stemming from the anchorages of the pre-stressing tendons. Provided that there are no significant restraints, these compression stresses neutralize a part of the flexural tensile stresses caused by the portion of the loading not balanced by forces from the tendon drape. Typically, the post-tensioning in floors provides an average in-plane compression stress of 125 to 500 pounds per square inch (psi).

Span-to-depth ratios

For light loading, which typically ranges from 40 to 70 psf where punching shear is not critical, a post-tensioned flat plate can be designed with a span-to-depth ratio of approximately 1-to-45 of the larger span dimension (for interior panels), compared with approximately 1-to-30 for a flat plate in reinforced concrete. If drop panels are provided over the columns, the span-to-depth ratio can be increased to approximately 1-to-50 for the interior panels of post-tensioned slabs and 1-to-35 for the interior panels of reinforced concrete slabs.





(left) For regular, unrestrained floor plates with normal to light loading, simple rules of thumb can provide an excellent starting point for post-tensioned, flat plate concrete floor designs. (right) Figure 1: Typical tendon configuration forms a net that exerts the load-balancing forces on the concrete. (below) Figure 2: In the span, the forces caused by the uniform and banded tendons act on the concrete to oppose gravity.

For greater super-imposed loading, the span-to-depth ratio decreases, particularly if the super-imposed load is predominantly variable in location and time. In these instances, the amount of post-tensioning cannot simply be increased to balance the super-imposed load. Instead, a greater floor thickness is required to meet deflection and stress requirements.

Figure 3 shows where the span-to-depth ratios of a number of post-tensioned flat plates and flat slabs with drop panels are plotted against the total load, normalized by the slab self weight. In spite of the resulting large scatter, the diagram clearly shows a trend that the span-depth ratio decreases markedly with increasing super-imposed load.

The large scatter can be explained by the following four main factors:

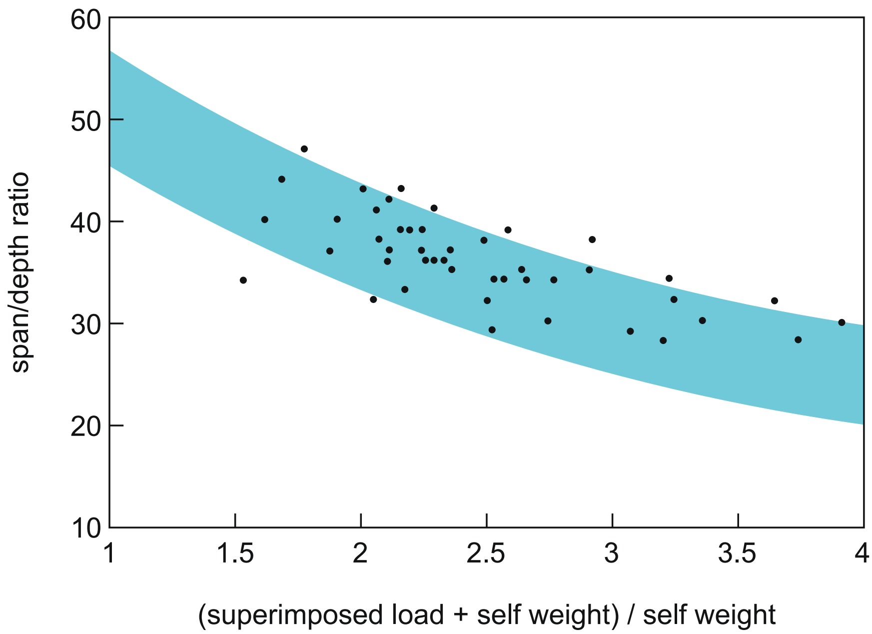


Figure 3: Span-depth ratio decreases with increasing super-imposed load. (Source: Data from internal VSL records and from references)

- many different requirements for deflection and cracking;
- ever-present trade-off between slab thickness and the quantity of both the mild reinforcement and the pre-stressed steel;
- treatment of punching shear by increasing the slab thickness or providing shear reinforcement; and
- dependence of the total load-to-self weight ratio on the span length, which also affects the span-to-depth ratio.

With the exception of a few extreme cases in the graph, the data fall within an optimal curved band with that variation of approximately 10 feet/inch.

To use these graphs for a preliminary estimate of the slab thickness, an engineer has to assume a reasonable thickness, calculate the total load-to-self weight ratio, and then check whether the resulting span falls within the band in the corresponding graph. For short spans (such as 20 feet) the span-to-depth ratio may be closer to the upper edge of the band. In the case of a very long span (such

as 36 feet), the span-to-depth ratio is closer to the lower edge. This reflects the dependence of the span-to-depth ratio on the absolute span length. Note that the graph is only meant to give some guidance in selecting a first estimate of the slab thickness. Other steps in the design — such as calculating the punching shear capacity or the expected deflection — may dictate selection of a different thickness.

For total load-to-self weight ratios greater than approximately 2.5-to-1 and spans in excess of 30 feet, flat plates and flat slabs with drop panels will normally be uneconomical. Other floor systems with greater structural efficiency — that is, stiffness and flexural strength for a given average weight per unit floor area — should then be considered. One-way slab and beams, one-way slab with shallow beams, wide beams with skip joists, or waffle slabs with drops are all lighter than an equivalent flat slab.

Determining guidelines for the span-to-depth ratio is much more difficult for these systems. This is due to additional variables such as the spacing of band beams, the beam width, the slab thickness between the beams, et cetera. This circumstance usually necessitates study of a number of options before deciding on the dimensions. Typically, wide shallow beam widths that are 1/4th to 1/5th of the beam center line spacing and beam depths of 2.0 to 2.5 times the slab thickness result in economical designs for floors with light to moderate loading.

As a crude guideline for post-tensioned, one-way slab and beam systems designed to support superimposed loads of 60 to 80 psf, the slab thickness may be assumed to be 1/35th to 1/45th of the clear span between beams unless governed by minimum thickness requirements. The span-to-depth ratio of the beams will most often be between 1-to-20 and 1-to-30. With 60 to 80 psf floor loading, a value of 1-28 is a reasonable estimate for 8-foot-wide post-tensioned beams spaced at about 28 feet. When sizing post-tensioned floors, edge and corner panels should be distinguished from interior panels because of their different boundary conditions. This requires about 20 percent more pre-stressing and reinforcing steel than the quantities derived for interior panels. Where this is not practical, increase the thickness or decrease the span length by about 20 percent. For simple spans, select a 20-percent greater thickness. ▼

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