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Drilled anchor systems

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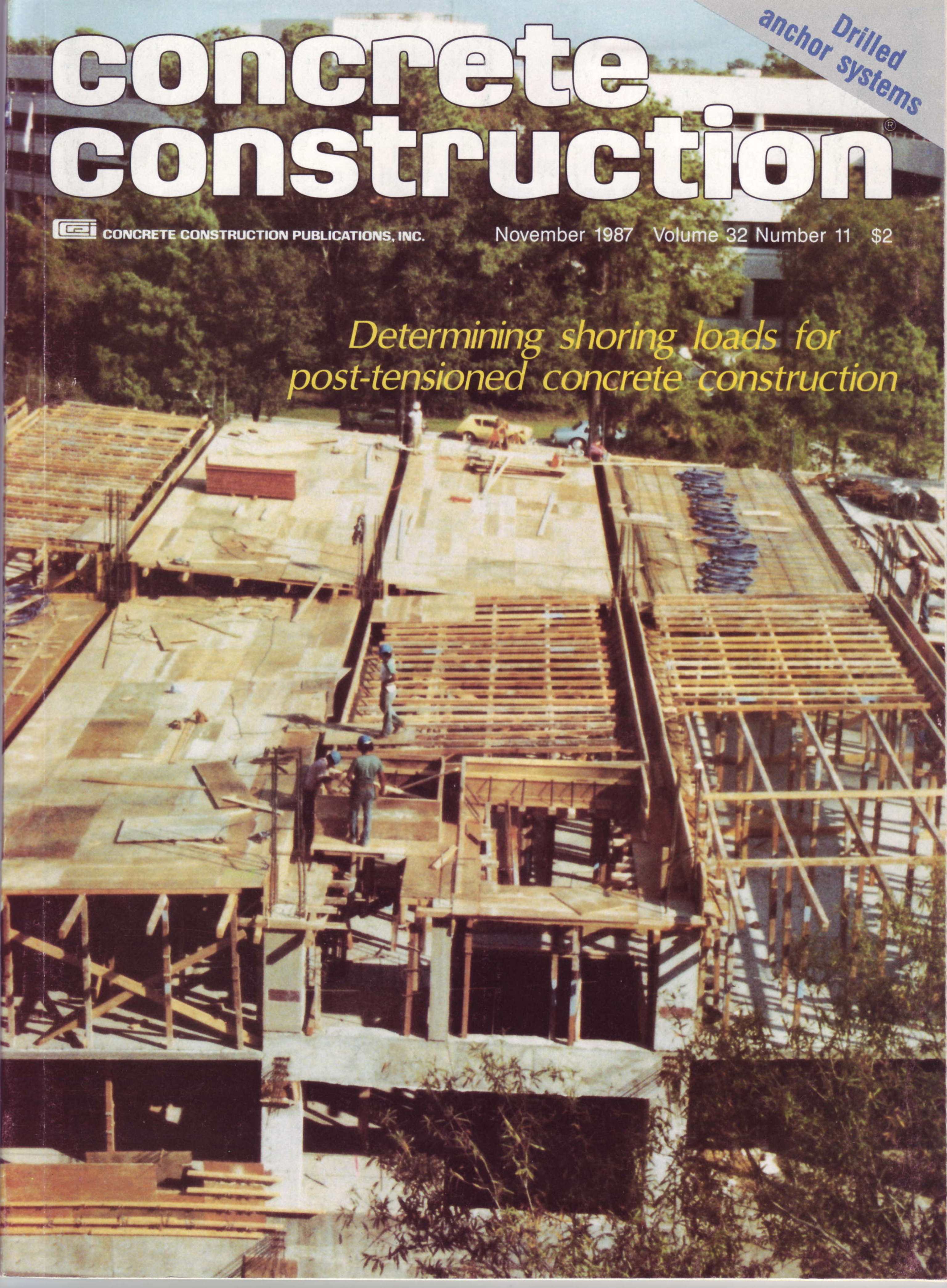

Determining shoring loads for post-tensioned concrete construction

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Placing concrete for a post-tensioned deck *may seem much the same as for other slab jobs to the workers on top. However, the shoring designer must recognize the possibility of greatly increased shoring loads in some areas when post-tensioning takes place.*

Since post-tensioned concrete is widely used in all types of buildings and civil works projects, the formwork designer and builder must understand how the post-tensioning will affect the selection and design of the shoring. Structural engineers today design unique structures using transfer girders, hanging floors, and stage-stressing in addition to the more common types of post-tensioned beams and slabs. Shoring that is designed to carry only the pouring load of the wet concrete can sometimes become severely overloaded during the post-tensioning process.

Preliminary formwork studies at the bidding stage help the designer choose a forming system. However, a system that initially looks satisfactory may no longer appear to be the best system after the shoring is checked for load transfer during the tensioning process.

Information needed to plan the shoring

An important first step in determining the loads for shore design is to obtain certain information from the plans and specifications and when necessary from the engineer of record. Questions that must be answered include:

1. Which members are post-tensioned?

2. What are the design service live loads and dead loads?

3. Did the engineer use any allowable live load reductions in the structural design? (Information needed for the reshoring design.)

4. Are any members stage-stressed?

5. What are the tensioning sequence and the amount of tensioning at each stage of stressing?

With this information, the designer can make a preliminary selection of the shoring and reshoring system. Then the shoring must be analyzed at least twice, considering:

- The pouring loads
- The post-tensioning transfer loads

Shoring for the pouring loads can be determined using basic structural engineering principles presented in Reference 1 or other standard references. After analyzing the pour loads and completing a preliminary shoring design, the designer should analyze the shoring for the post-tensioning load transfer. How to do this conservatively is shown here, assuming a worst-case sequence for post-tensioning. Forms are assumed to be in place as required for support of concrete, but are not shown in the simplified drawings.

How load transfer takes place

Two simple drawings show how load transfer takes place during post-

file: shoring

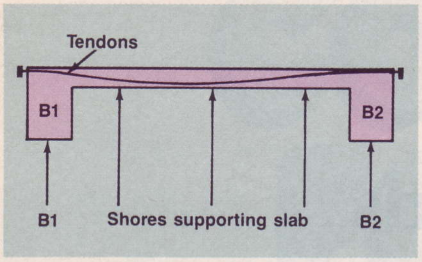


Figure 1. Shoring condition with concrete in place, before any post-tensioning occurs. *Shores B1 and B2 support the beams and are uniformly loaded; other shores support the slab.*

Figure 2. After the slab is post-tensioned and before the beams are tensioned. *Load in the slab shores has been relieved, and Shores B1 and B2 now support slab weight as well as beam load.*

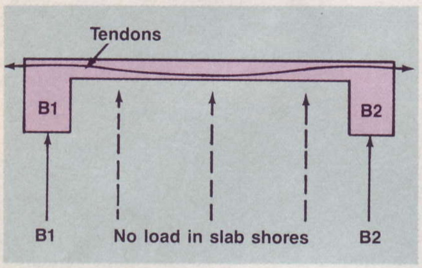
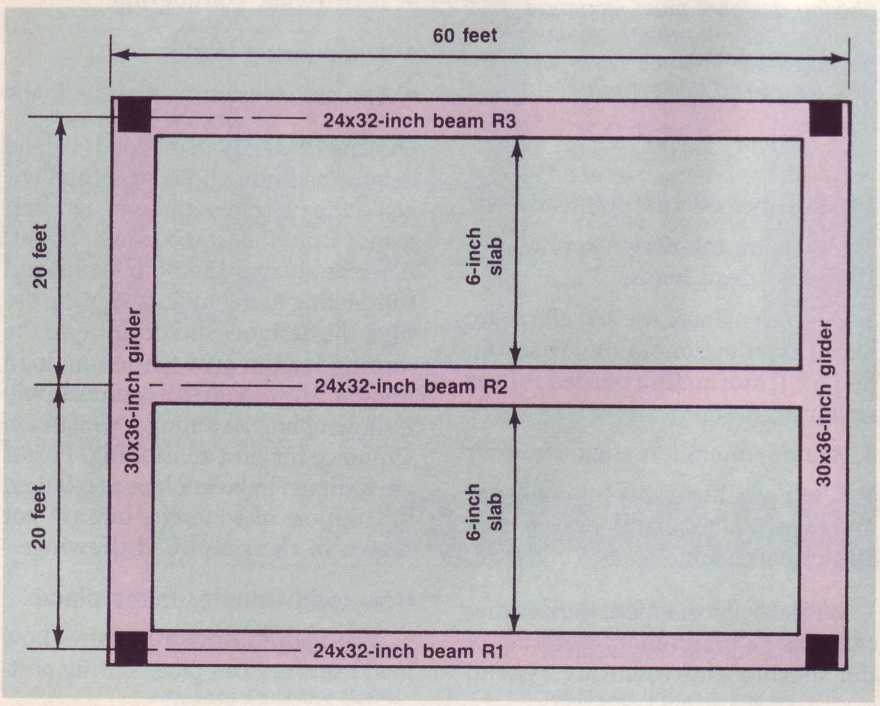


Figure 3. Floor plan (not to scale) of typical beam and slab structural bay *used in the text example to explain load transfer during post-tensioning.*



tensioning. In Figure 1 the concrete slab and beams have been poured and are supported by uniformly spaced shoring. Post-tensioning has not been started.

Figure 2 shows the same slab after slab tensioning and before the beams are tensioned. Post-tensioning causes some upward movement so that the weight of the slab is no longer supported on the shoring but has transferred its weight to the concrete beams. In a simple span like this, each beam takes half of the slab load. Since the beam has not yet been post-tensioned, it will not support the slab weight or its own weight. The *beam shoring* now must support the slab, beam, and any construction loads. Only after the beam is tensioned will it then support the weight of the beam-and-slab construction and some live load.

Beam and slab example

Figure 3 shows a common structural design. The structure has one-way post-tensioned slabs and post-tensioned beams and girders. We first answer the questions previously listed.

1. All slabs, beams, and girders are post-tensioned.

2. Design service live load is 50 pounds per square foot (psf).

OTHER POST-TENSIONING SEQUENCES

The author has taken a worst-case condition—one which is also quite common—in analyzing post-tensioning load transfer. This is necessary if the sequence of tensioning is not known in advance or if the formwork designer cannot be sure that the structural designer's planned sequence will be followed precisely.

However, if part of the tendons in the final load-carrying member are stressed first, the shoring or other falsework will not have to support all of the loads transferred by post-tensioning. Shown below is another possible sequence for the type of structure in the example. Structural engineers can reduce shoring costs by specifying a sequence such as this:

1. Temperature tendons (no load transfer)
2. Girder tendons, 40 percent
3. Beam tendons, 50 percent
4. Slab tendons, 100 percent
5. Girder tendons, remaining 60 percent
6. Beam tendons, remaining 50 percent

The specific percentages may vary from job to job. With a sequence like this properly executed in the field, post-tensioning reduces the loads on the shores below those imposed during concrete placing. To avoid cracking it is necessary to limit the uplift applied to the girder and beam until some of the slab tendons have been stressed.

Current designs normally provide load balancing for less than the dead load of the structure. That is, the uplift (not structural capacity) provided by the tendons is less than the dead load of the member. In parking structures usually about 70 percent of the dead load is balanced. In such a case, tensioning of the tendons would result in transfer of only 70 percent of the pouring loads, even if the author's sequence were followed. However, the shoring designer must confirm the applicability of this kind of design with the engineer of record before basing any shoring design or construction on it.

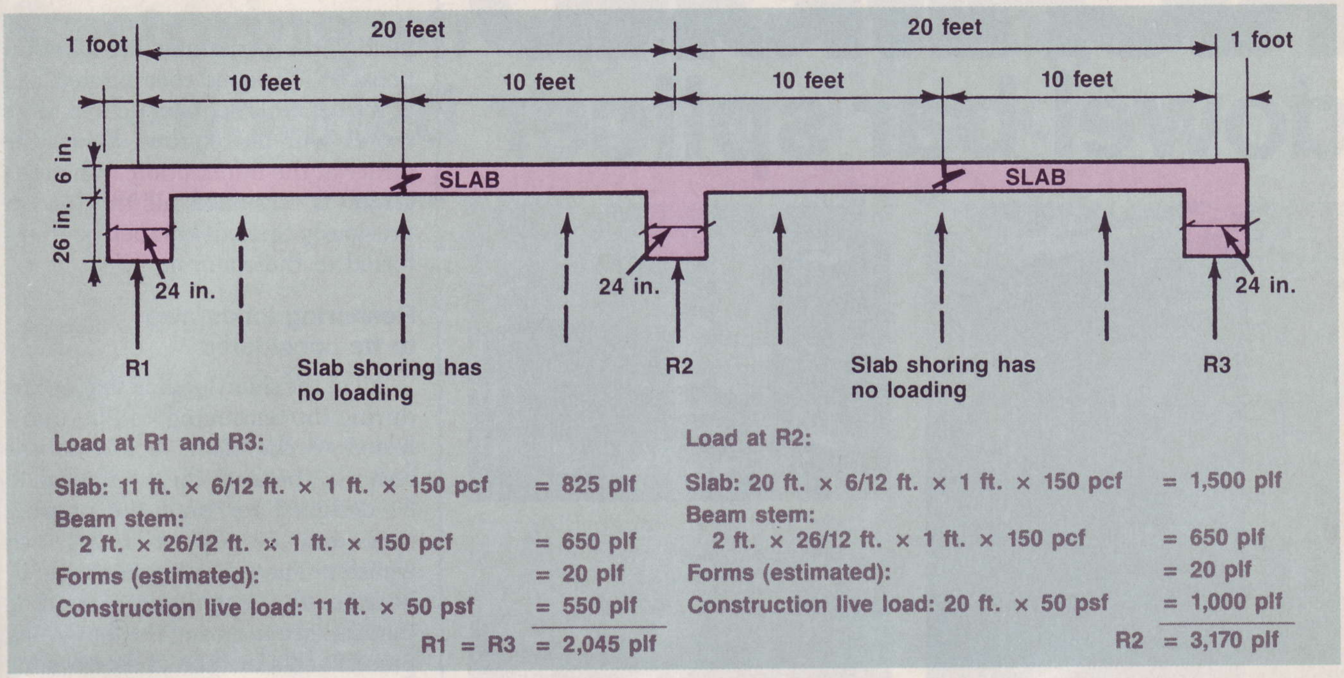


Figure 4. Calculation of load transfer during post-tensioning. *Slab has been tensioned, relieving load in shores beneath it, but increasing loads at R1, R2, and R3. NOTE: Construction live load as recommended in Reference 2. The formwork designer may determine that a lower value is appropriate for local conditions.*

3. Live load reductions have been used in the structural design of the beams and girders.

4. There are no stage-stressed members.

5. Tensioning takes place in this sequence:

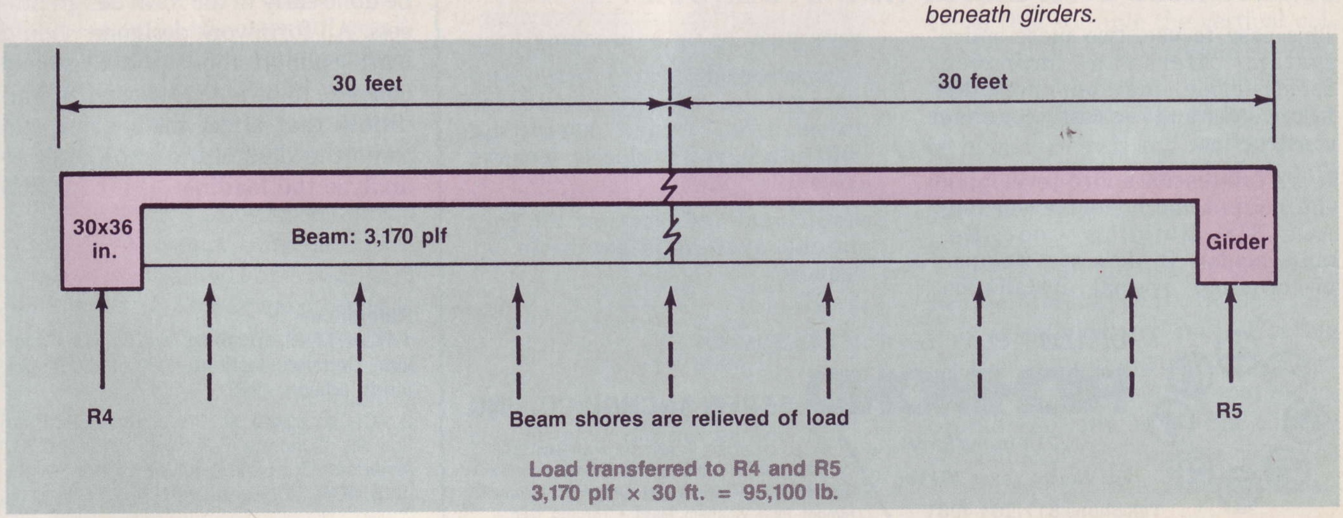
- Temperature tendons
- Slab tendons, 100 percent
- Beam tendons, 100 percent
- Girder tendons, 100 percent

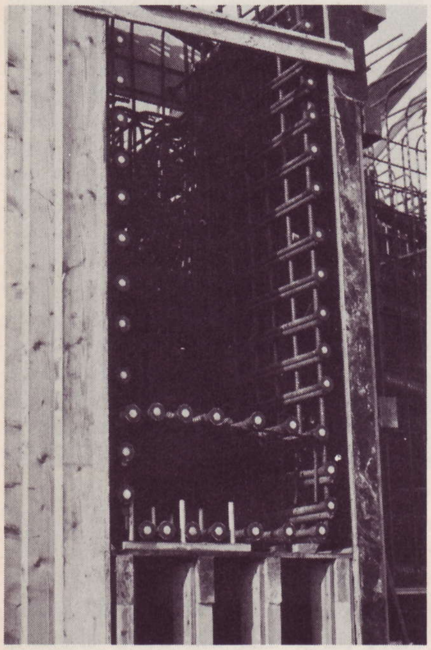
A preliminary decision is made to use a forming system with single post shores and single post reshores. The first calculations (not included in this example) cover the preliminary form design and the shore loading during the concrete pour.

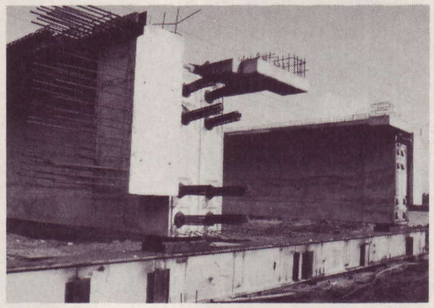
The next step is to check the preliminary design for load transfer during post-tensioning. Figure 4 shows the condition just after the slab tendons have been tensioned. The slab shores no longer support the slab, so they have little or no load. The full weight of the slab plus allowance for formwork and any construction loading is transferred to the beam shoring, which now carries 2,045 pounds per lineal foot (plf) at R1 and R3 and 3,170 plf at R2. The beam shoring must be able to support these loads with an appropriate factor of safety.

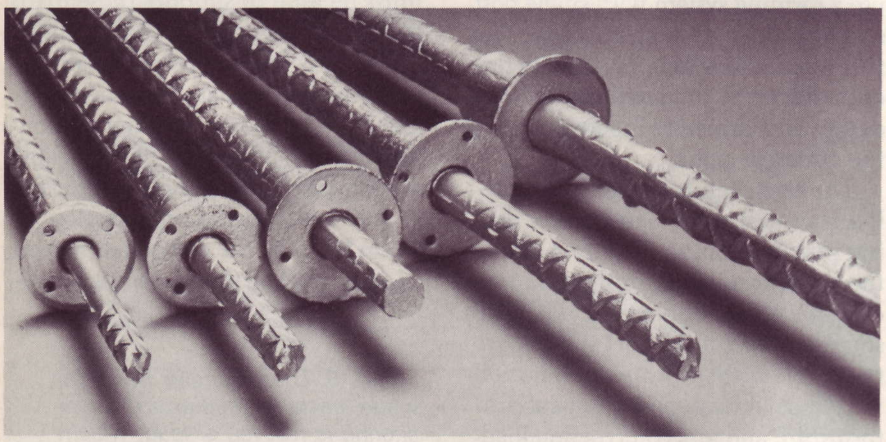
The next transfer occurs when the 24x32-inch beams are tensioned (Figure 5). The beam shoring is now relieved of load and all of the beam-shoring design load is now transferred to the beam-girder intersection at Beam R2 or to the column at Beams R1 and R3. The shoring already sup-

Figure 5. Load transfer to girder when beam is tensioned. *Beam shoring is relieved of load, which must now be carried by shoring beneath girders.*









porting the girder now has an additional 95,100-pound concentrated load at the beam-girder intersection. More shores will be required below the girder at the intersection. When the girder is tensioned all the load it previously carried will then be transferred to the column.

Reshoring loads also to be considered

All of the shore loading that occurs during the tensioning will be transferred to the floors below so the reshoring beneath them will need to be designed for both the pouring loads and the post-tensioning load transfer. The preceding example illustrates the magnitude of loading that can occur during the tensioning process and a method of determining the loads.

Other design considerations

The formwork designer should watch carefully for conditions that will require special attention. These include post-tensioned beams over thin-section slabs below, transfer girders that may not be tensioned until multiple levels of construction are complete, or transfer girders that are stage-stressed.

If stage-stressing occurs (where a member is post-tensioned in several increments alternating with other members), the formwork designer must receive information from the structural designer regarding the girder capacity at each stage of stressing.

The determination of load transfer is usually not too complex but it must be done early in the form design process. All formwork designers should learn enough about post-tensioned concrete to be able to recognize conditions that affect the shoring and reshoring design and know how to analyze the loading.

References

1. Hurd, M. K., *Formwork for Concrete,* American Concrete Institute, Detroit, Michigan, fourth edition, 1979.

2. ACI Committee 347, "Recommended Practice for Concrete Formwork, ACI 347-78," American Concrete Institute, Detroit, Michigan, 1978, 36 pages.