

Two-day construction cycle for high-rise structures based on use of preshores

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Procedure permits rapid form cycling with safe support for slabs

Forming and stripping practices, particularly for flat slab and flat plate construction, have developed to a high degree of efficiency during the past 25 years. Contractors, with the aid of structural engineers, have been able to reduce the slab cycle time to a bare minimum consistent with safety.

A procedure for using *preshores* during the stripping of primary forms and shores has been developed over the past two decades by our firm in consultation with various leading contractors and with the approval of government agencies supervising housing construction in New York City. This procedure allows fast cycling of reduced sets of primary forms while maintaining full support of the newly placed floors during a stripping operation that may commence as early as 24 hours after placement of concrete.

Stripping and reshoring example

To understand how the 2-day construction cycle works, consider the case of a typical flat plate building where slabs are being built on field-erected forms made of 4x8-foot plywood sheets on wood joists. Joist spacing and size are determined by the slab loads, and the joists rest on stringers spaced 4 feet on centers. Single post shores are set 4 feet apart under the stringers, producing a 4x4-foot shoring grid (Figure 1).

Our firm has designed a number of high-rise buildings like this, with slabs 7 to 10 inches thick, for residential and commercial occupancy. Thus dead loads are around 90 to 125 pounds per square foot (psf) and live loads are in the 40- to 100-psf range. Currently we are using concretes with 28-day compressive strengths from 4000 to 4500 psi. Examining a few days of an average work week shows how rapidly this construction can move.

MONDAY: Concrete for a typical slab (N) is placed, starting at the west side of the floor. Extra test cylinders are taken both morning and afternoon to be field cured overnight in the pour location and tested at 24 hours. As soon as the workers can walk on the freshly placed slab without leaving footprints, they begin erecting forms for the next level, again working from the west side of the building.

TUESDAY MORNING, Step 1: Forms are removed from columns and beam sides. *Preshores* are installed un-

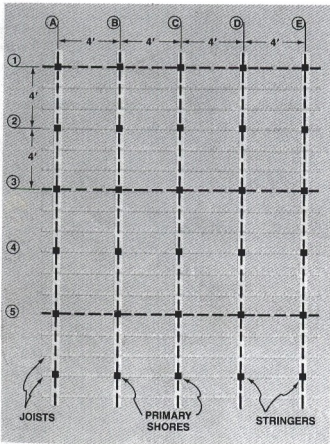


Figure 1. Plan view of original formwork with primary shores in place on 4x4-foot grid. Dashed lines show 4x8-foot plywood sheets used for deck forming.

der alternate sheets of plywood at locations marked in Figure 2. Note that the preshores are placed at both ends of the same sheet of plywood, bypassing the joists and stringers that support the plywood sheets (Figure 3). These preshores are wedged in securely but not tight enough to cause any lifting of the Monday slab above.

The strength test results from Monday's early morning cylinders are phoned in. If the strength reaches 1700 psi or more, Step 2 may proceed—but NEVER earlier than noon. We have found this strength satisfactory for our buildings, but others should verify the strength level necessary for safe work in their own structures. This is a decision for the structural designer.

TUESDAY AFTERNOON, Step 2: A thinning-out operation starts at the west end where concrete was first placed. The contractor removes half of the stringers and about 75 percent of the original or primary shores (Figure 2). The preshores remain in place.

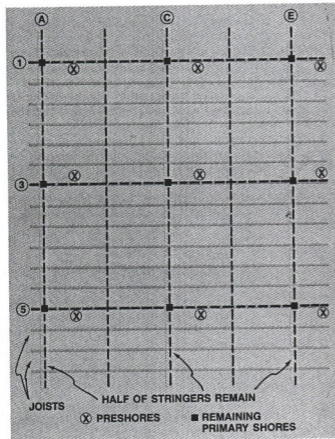


Figure 2. Preshores placed under alternate sheets of plywood (Step 1) are about 8 feet apart. Thinning out (Step 2) has removed half of the stringers and three-fourths of the primary shores. Most of the joists are still in place.

EARLY WEDNESDAY MORNING, Step 3: By now formwork is in place for the next slab (N+1). Before placing any concrete on the next level, however, the contractor removes all remaining primary shores and forms, a small area at a time, except the plywood sheets pinned by the preshores. Simultaneously, reshores are placed and wedged against the bare concrete soffit at 8-foot intervals at locations shown in Figure 4. Not shown in Figure

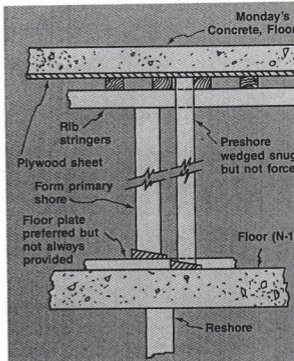


Figure 3. Schematic cross section through shoring system during thinning out of primary shores. The preshores have been wedged snug to the under side plywood, but not forced enough to cause lifting of the above.

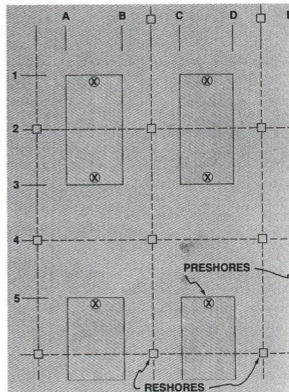


Figure 4. The rest of the formwork has been removed (Step 3) except for plywood pinned by preshores. Reshores are placed on an 8-foot grid. Not shown in this schematic are the reshores which are placed within 3 feet of the faces on all four sides. After a complete bay has been reshored, its preshores and the remaining plywood are removed.

4, but important to the process, reshores are also placed within 3 feet of column faces on all four sides. **PRESHORES ARE LEFT UNTOUCHED** at this point.

When a complete bay has been stripped of any remaining primary shores and is completely reshored, and as this process advances into other bays, the reshores and their pinned sheets of plywood are also removed.

Some safeguards required

Wednesday's stripping and reshoring work below Slab N must be well advanced (at least two full bays ahead) before any concrete placement on Slab N+1. This is necessary to avoid any disturbance in the primary forms supporting Level N+1 immediately after they receive the load from freshly placed concrete. It also keeps the crew working below away from the active area on Slab N+1. If the concrete placing operation catches up with the stripping work below, stripping is halted at once and does not proceed until the next day.

This construction process uses 2¼ sets of forms and primary shores. The quarter set allows an earlier forming start on a couple of west bays Monday afternoon before a full set of forms is stripped out below. No crane drops are permitted during this early setup of primary forms; workers are cautioned to hand carry all materials.

Construction loads safely distributed

We have used this stripping operation with reshores successfully for over 20 years, with an excellent safety record. The method has one major advantage over other forming and stripping procedures. The one-day-old concrete slab is already reshored in a manner similar to the levels directly below it, and its supports will remain largely undisturbed during the time it is required to support construction loads transferred from levels above. This period is not less than 21 days, usually 28 days. The distribution of construction loads among the reshored supporting levels is fairly uniform and individual slab loads can remain relatively low.

Number of stories reshored affects load buildup

Figure 5 shows part of the high-rise building with reshores left undisturbed under Monday's Slab N for about 28 days. Many floors—ten in this case—are interconnected by the reshores and contribute almost equally to the support of the floor being placed. There is no shoring support to rigid sills, so permanent set is induced in all floors supported on yielding levels due to the deformation in the supports while the concrete is still plastic enough not to receive induced stresses.

The part of the construction load that must be supported by each slab depends on the number of levels interconnected by the reshores. Even when reshores below the lowest supporting level are removed at the earliest permitted time—21 days—at least eight levels will participate in support of the new slab and its construction live loads.

If we assume rigidity of the reshores, division of the load among the interconnected slabs will be in proportion to the stiffness of each of the supporting slabs. For a simplified analysis we distribute loads in proportion to the modulus of elasticity of the concrete in the slabs at the time the construction load is applied. This modulus

of elasticity will be different for each slab because they are all "young" and of different ages. We used these equations from Reference 1 to find the moduli for different slabs.

$$(f'_c)_t = \frac{t}{4 + 0.85t} (f'_c)_{28}$$

and

$$(E_c)_t = 33w^{1.5} \sqrt{(f'_c)_t}$$

where t is the age of the concrete in days and w is its weight in pounds per cubic foot. E_c and f'_c are the modulus of elasticity and the specified compressive strength of the concrete respectively, both in psi.

(more)

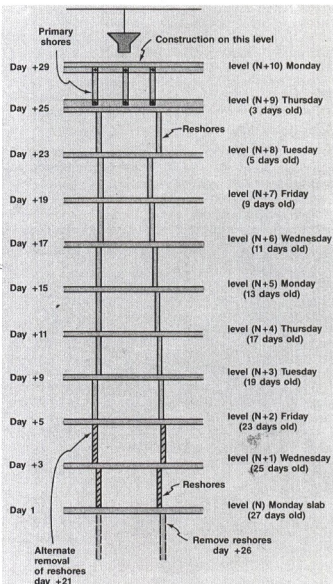


Figure 5. Schematic view of high-rise construction with reshores undisturbed under Slab N for about 28 days. This provides ten levels of interconnected slabs to share new loads of construction at Level N+10. With alternate removal of reshoring at about 21 days, eight slab levels would share construction loads.

Our calculations show that when concrete levels remain reshored for 28 days and therefore ten levels participate in supporting the construction at Level N+10, the lowest participating Slab N will support about 11 percent and the top level (N+9) about 7 percent of the load at the working level. When reshores are removed after 21 days, the lowest level (N+2) will support about 14 percent and Slab N+9 about 10 percent of the construction at Level N+10.

Slab loads calculated

To see the actual loads being supported, assume an 8-inch slab weighing 100 psf. The two sets of primary shores and forms in the system weigh a total of about 20 psf. Reshores weigh about 2 or 3 psf on each level, and we may allow for another 10 psf for miscellaneous construction materials on a typical lower slab. We also must provide for construction live load of 50 psf, according to American Concrete Institute recommendations (Reference 2).

To find the maximum load on any of the supporting levels, two extreme conditions must be reviewed. The first, *Condition A*, assumes that the process of shoring, reshoring, and the subsequent construction activity will release shores sufficiently that most of the supporting levels will, soon after construction, support their own weight. The second, *Condition B*, assumes that stripping is done in such a way to prevent load redistribution and that all floors are "locked in" to support the loads in proportion to their relative stiffnesses.

Using the loads described above, with reshores removed at 28 days, we find for Condition A that the slab at Level N is carrying its own weight and the reshores and miscellaneous loads directly applied to it, plus an 11 percent share of the new loads at construction level:

$$\begin{aligned} \text{Condition A: Self} \\ \text{loads plus shared} \\ \text{construction loads} &= 100 + 3 + 10 \\ &\quad + 0.11[100 + 50 + 20] \\ &= 132 \text{ psf} \end{aligned}$$

For the assumptions of Condition B, Level N will support 11 percent of the total loads that occur on the above Level N:

$$\begin{aligned} \text{Condition B: 11} \\ \text{percent of total load} \\ \text{on N and above} &= 0.11[10(100 + 3 + 10)] \\ &\quad + 0.11[100 + 50 + 20] \\ &= 143 \text{ psf} \end{aligned}$$

Removal of reshores after only 21 days is sometimes permitted by the engineer when the flat slab is designed as part of the lateral load system and therefore is provided with extra reinforcement and greater depth than would be required for gravity loads only. When reshores are to be removed after only 21 days (that is removal under Level N+2, Figure 5), the share of the construction load in-

creases to 14 percent instead of 11, and the load on Slab N+2 is still no more than

$$\begin{aligned} \text{Condition A: } 100 + 3 + 10 \\ + 0.14[100 + 50 + 20] = 137 \text{ psf} \end{aligned}$$

$$\begin{aligned} \text{Condition B: } 0.14[8(100 + 3 + 10)] \\ + 0.14[100 + 50 + 20] = 150 \text{ psf} \end{aligned}$$

In actual structures it is likely that a condition between the extremes, A and B, will prevail and the maximum load might be an average of the two. Following this reasoning, we would expect Level N to support about 138 psf with shore removal at 28 days. With shore removal at 21 days, Level N+2 would support about 144 psf. In both cases, construction loads are less than 50 percent of the slab's dead load and do not exceed design loads.

This is a far cry from construction loads of up to 110 percent of slab dead load observed with another common system using three sets of primary forms without the shoring procedure. More sets of primary forms do not necessarily improve construction safety, and in some procedures for multistory work that safety margin becomes perilously small.

Disadvantages of shoring reduced by proper supervision

The shoring procedure has some disadvantages that can be minimized with good supervision. A careless thinning out operation can topple reshores and cause damage to the day-old slab. Manipulation and removal of primary forms even in a correct manner cannot totally prevent some self load being carried by the day-old slab. Some cracks will therefore develop.

A more troublesome item is that the two-day-old slab has already gained enough stiffness to span fair distances. It does therefore participate in supporting the new construction directly above it and must deform to remove the slack in reshores below it and to account also for additional compressibility of reshores under the applied loads. Placement of reshores does not match location of primary shores, and this increases load transfer requirements for the two-day slab.

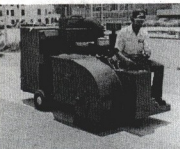
Hairline cracks, usually at midspans of large exterior bays, may develop even alongside the line of reshores as the construction load is applied above. The structural engineer can anticipate this type of cracking and can add more reinforcement to help improve the effective stiffness of the slab.

Speed, accuracy and safety considerations

The reduced construction cycle takes its toll on construction tolerances. Maximum accuracy is not possible when speed of construction is the prime consideration. This problem exists with any forming system using a two- or three-day cycle. The owner and contractor must be aware of this and consider its effect on future installation or application of nonstructural elements.

Contractors have commonly been seen to circumvent some of the guidelines of the step-by-step procedure presented above. They do this to distribute the work load

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of the construction crew more equally throughout the cycle. However, this small cost saving in building the floor will usually be spent later to solve added problems in the application of finishes.

Construction safety is also being tampered with when Step 2 or Step 3 is performed prematurely. Under good weather conditions, however, our office has allowed starting Step 3 for a couple of bays directly under the next day's placement, LATE in the afternoon after Step 2 is completed for the whole floor. This helps to keep the stripping operation further ahead of placement operations the following day.

It is clear that better control by both the contractor and the engineer is required. The resulting efficient construction methods and better safety record are certainly worth the extra effort.

References

1. ACI Committee 209, "Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures," *Designing for Creep and Shrinkage in Concrete Structures*, SP-76, American Concrete Institute, Detroit, 1982, pp. 193-300.
2. ACI Committee 347, "Recommended Practice for Concrete Formwork (ACI 347-78)," American Concrete Institute, Detroit.

Acknowledgment

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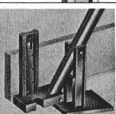
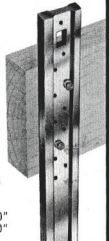
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