

Shoring and Reshoring for Multistory Concrete Buildings

Formwork economy and safety must go together

BY PERICLES C. STIVAROS

Are three levels of reshoring needed? Or will two suffice? Is it safe to strip? These simple questions require a complex answer. The recently published document by ACI Committee 347, “Guide for Shoring/Reshoring of Concrete Multistory Buildings (ACI 347.2R-05),”¹ can help construction professionals and engineers answer these questions by providing methods for developing safe and economical construction schedules. This article outlines the new guide and highlights some of the many factors that must be considered.

Economy in concrete formwork construction requires maximum reuse of forms and shoring materials, as well as adequate, but not excessive, formwork design. This is particularly true for multistory buildings, where standardized dimensions and repetition result in the least number of forms needed to ensure a smooth workflow. To maximize reuse, workers must strip the forms as soon as possible, and reinstall them for the floor that follows. The relocated forms must then be supported by the structure below.

Shores carry forces from the formwork, concrete, and construction loads above, and reshores—installed after the original forms and shores have been removed—distribute loads over several floor levels. One level of shores and two levels of reshores may permit placement of one story per week in the most economical manner, but

how do we evaluate the safety of a construction schedule that incorporates two levels of reshores? An engineering analysis is needed, and this analysis must consider both the construction load distribution and the early-age load carrying capacity of the supporting structure when the shoring/reshoring schedule is developed. If the provided support is insufficient, the best that can be expected is a series of deflected slabs and beams with radial cracks around columns (Fig. 1); the worst outcome is a local collapse that triggers a progressive collapse through the whole height of the building.

CONSTRUCTION LOAD DISTRIBUTION

The question of how construction loads are distributed between the formwork system and the newly cast supported concrete members has been the subject of debate in the construction industry. The most significant work on construction load distribution was published in 1963 by Grundy and Kabaila.² This landmark paper presented a simple method of calculating the construction loads carried by slabs and shores during the construction of multistory flat plate and flat slab concrete buildings. The method is known as the simplified method. The fundamental assumptions of the method include:

- Elastic deformation of the concrete slabs (creep and shrinkage are neglected);



Fig. 1: Typical radial concrete cracking around columns due to premature removal of shores and reshores

- Infinitely stiff shores relative to the supported slabs;
- Uniformly distributed shore reactions;
- Shores and reshores supported on a rigid foundation at the beginning of construction; and
- Load distribution between the supporting slabs in proportion to their relative flexural stiffnesses.

Obviously, the assumptions of the simplified method are not precisely true. Several analytical studies by other researchers, however, have verified the method's validity by comparing the predicted values with field measurements. Most of the available field observations were found to be in fair agreement with the predicted values. The most controversial assumption is the infinite stiffness of the shoring/reshoring system, as compared with the flexural stiffness of the supported slabs. ACI 347-04³ warns that caution should be taken when a compressible system is used. With a more compressible shoring/reshoring system, the structural system tends to shift as much as 15% of the slab loads to the uppermost interconnected floors as compared with rigid shores/reshores.^{4,6} The floors immediately below the level to be cast may have limited strength and are more sensitive to possible overload. The estimated construction loads at the upper floor may be increased to compensate for the error in calculating the construction loads when using the simplified method. Alternatively, the relative stiffness between the shoring/reshoring system and the supported slabs should be considered while calculating the construction load distribution.

STRENGTH REQUIREMENTS

Although detailed calculations can be used to show a greater rate of strength gain, the flexural, tensile, shear, and bond strengths of early-age slabs can be conservatively assumed to be proportional to the concrete compressive strength at that age. Cracking and deflections are dependent on the early-age concrete tensile strength and modulus of

elasticity, respectively. The load capacity of an early-age slab is also determined by the total service load for which the slab has been designed. The reserve strength of the slabs to carry service loads is called upon during construction to carry the imposed temporary construction loads.

The same strength reduction factors, load factors, and load combinations used for the original design of the structure should also be applied during the strength evaluation of the partially completed structure. It's also recommended that the loads and load factors discussed in SEI/ASCE 37⁷ be considered for construction loads not covered in ACI 318-05.⁸

When the applied construction load on a slab exceeds the early-age strength of the slab, there are two basic alternatives: either reduce the load on the slab at the critical concrete age, or change the concrete mixture. The first alternative can be achieved by modifying the type of shoring system or the number of shored/reshored floor levels to reduce the applied construction load to an acceptable level. The second alternative can be achieved by using high-early-strength concrete, controlling curing temperatures, increasing the construction cycle to permit the concrete to gain strength, or a combination of these measures. Under no circumstances, however, should the factored construction load exceed the factored design load.

Traditionally, field-cured cylinders have been used to determine early-age concrete compressive strength. The testing of concrete cylinders, however, can become cumbersome (mainly due to the large number of cylinders required). Other, nondestructive methods for estimating in-place concrete strength, such as rebound-hammer tests, penetration resistance, pulse-velocity measurements, pullout tests, or maturity methods, may be more desirable. These methods require careful calibration based on cylinder tests of the same concrete mixture to be used on the project.

At an early age, concrete is susceptible to tensile cracking. A concrete failure due to deficiency in tensile strength, and consequently low shear resistance, is the most serious type of slab failure, because most shear failures are preceded by little, if any, advance warning. Furthermore, tensile cracks caused by excessive construction loading of early-age concrete can contribute to unanticipated nonrecoverable deflections.

For flat-slab and flat-plate structures, one of the critical strength parameters during construction is usually punching shear strength at columns. Also, punching shear forces due to loads from shores and reshores can be critical in cases of very thin slabs, especially when they are not aligned from one level to another, or at the bottom level of reshores. In such cases, an analysis should be made to ensure that the maximum punching shear force is within code limits. In most cases, however, the shore/reshore axial strength will govern over the

punching shear strength of the slab. Beam shear may also control in a one-way slab when shore loads are placed near a concrete beam.

SERVICEABILITY REQUIREMENTS

Excessive construction loads at an early age, in combination with normal shrinkage and many other factors, can cause higher creep deflection and more extensive cracking than anticipated and adversely affect the long-term serviceability of the structure. Excessive construction loads are usually the result of an inadequate number of shored/reshored levels, early stripping, or both.

Early-age nonrecoverable deflections and cracking are primarily due to the initial low concrete strength. Early loading of concrete members having a low modulus of elasticity and stiffness will cause larger nonrecoverable long-term deflections. A low modulus of elasticity produces relatively large immediate deflections, and a low modulus of rupture promotes cracking, which in turn reduces the slab stiffness and also increases slab deflections. The extent of initial concrete cracking depends on the magnitude of early-age shrinkage, the magnitude of construction loads, and the age of the concrete when the loads are applied, which in turn affects the shoring and reshoring schedule. Furthermore, long-term creep deflections are increased because creep effects depend on the magnitude of the stress resulting from the applied loads relative to the concrete strength. Most of the early-age creep deflections are not recoverable. Deflection due to a combination of higher creep and premature cracking caused by excessive construction loads can be several times the normal elastic, creep, and shrinkage deflection.

The ACI 318-05 requirements for minimum slab thickness do not consider the effects of early-age construction loads on long-term deflections; therefore, slab thickness can't be used as a safeguard against excessive deflections and cracking when large construction loads are improperly applied to an early-age concrete slab. After the concrete members are cracked during construction, they will remain cracked throughout the life of the structure, unless repairs are made. Therefore, coordination between the design engineer and the formwork engineer is recommended for checking slab deflections during construction.

TWO-WAY SLAB CONSTRUCTION EXAMPLE

Two construction examples are presented in the ACI 347.2R guide: one for a two-way flat plate building, and one for a post-tensioned multistory building. The reader is referred to the guide for details of the flat plate construction example that are not included in the following discussion.

The flat plate construction example is designed based on ACI 318-05 and covers various scenarios with respect

to the shoring system, construction rate, concrete strength development, and slab design loads. The scenarios considered in the example include:

- A shoring system with one level of shores and two or three levels of reshores;
- Construction cycles of 7, 10, or 15 days per floor;
- 40, 60, or 80 °F (4.4, 15.5, or 26.7 °C) concrete curing temperatures; and
- Service live loads of 50 and 100 lb/ft² (2.4 and 4.8 kPa).

Construction load distribution

The construction load distribution between the concrete slabs and the shoring/reshoring system is evaluated using the simplified method. It is assumed that the compressibility of the shoring/reshoring system does not significantly impact construction load redistribution. The resulting load distributions for construction of the fourth and fifth slab levels using the shoring system with one shore level in combination with three reshore levels are shown in Table 1. Load distributions for the steps leading up to the construction of these floors are provided in the guide.

Table 1 shows that the maximum slab load first occurs on the fourth slab level during placement of the fifth slab level (refer to Step 3). The fifth slab level is the first level to be placed after the reshores have been removed from the first floor, thus removing the direct path of the construction loads to the ground. The maximum slab load is repeated for all floors above the fifth level each time the shoring system is installed at the active level and the new slab is placed. The maximum slab construction load is $1.38D$ (where D is the slab selfweight), or 155 lb/ft² (7.42 kPa), for the system with three reshore levels. The maximum slab construction load would increase to $1.5D$, or 169 lb/ft² (8.09 kPa), if only two reshore levels were used.

The maximum shoring/reshoring construction load occurs during the placement of the top floor level and includes the slab selfweight of 112.5 lb/ft² (5.39 kPa), the form weight of 6.5 lb/ft² (0.31 kPa), and the construction live load of 50 lb/ft² (2.4 kPa) during the concrete placement. The maximum shore and reshore construction load is $1.5D$, or 169 lb/ft² (8.09 kPa), for both the three- and two-reshore systems.

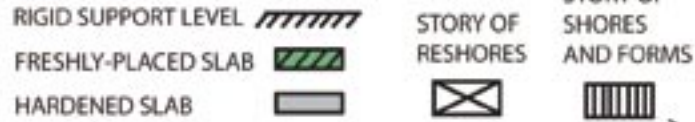
The upper shoring level and all reshore levels carry the same maximum construction load as long as the shoring/reshoring system is supported on the ground (refer to Step 1). After the removal of the lowest level of reshores from the ground, the maximum applied construction load on the reshores decreases at the lower reshored levels. Therefore, the lower reshored levels will require fewer reshore posts than the upper floors.

The floor slabs of this example have equal thickness and approximately equal flexural stiffness. Thus, the construction load is distributed equally between the

TABLE 1:

LOAD DISTRIBUTION TO SLABS AND SHORES/RESHORES FOR CONSTRUCTION EXAMPLE USING ONE LEVEL OF SHORING AND THREE LEVELS OF RESHORING

D = weight of slab (112.5 psf or 5.39 kPa)
 Construction live load = 0.44 D
 Shore and form weight = 0.06 D
 Reshore weight is neglected



Step 1

Form, shore, and place Level 4 concrete. All added load, including construction live load, is carried to the ground through the reshores. Slabs can't deflect and there is no change in slab loading.

Story	Load on slab in multiples of D			
	At beginning	Change during operation	Total at end of operation	Shore/reshore load at end of operation
4	0	0	0	1.5D
3	1D	0	1D	1.5D
2	1D	0	1D	1.5D
1	1D	0	1D	1.5D

Step 2

Slab 4 hardens and construction live load is gone. Remove the Level 4 forms and shores, allowing Slab 4 to carry its own weight. This leaves no net load in the reshores beneath Slab 1, and they are removed and installed snugly beneath Level 4. They carry no load at this stage.

4	0	+1D	1D	0
3	1D	0	1D	0
2	1D	0	1D	0
1	1D	0	1D	0

Step 3

Form, shore, and place Level 5 concrete. The total new applied load, including construction load, is distributed equally to the four interconnected slabs.

5	0	0	0	1.5D
4	1D	+0.38D	1.38D	1.12D
3	1D	+0.38D	1.38D	0.74D
2	1D	+0.37D	1.37D	0.37D
1	1D	+0.37D	1.37D	0

Step 4

Level 5 concrete hardens and the construction live load of 0.44 D is removed in equal parts from the slabs to which it was distributed.

5	0	0	0	1.06D
4	1.38D	-0.11D	1.27D	0.79D
3	1.38D	-0.11D	1.27D	0.52D
2	1.37D	-0.11D	1.26D	0.26D
1	1.37D	-0.11D	1.26D	

Step 5

Remove forms and shores beneath Level 5, allowing it to carry its own weight. The load in those shores, including their own weight, is removed from the slabs to which it had been distributed. The reshores from Level 2 are brought up and placed snugly under Level 5, without carrying any load. THE SYSTEM IS NOW IN THE SAME CONDITION AS IN STEP 2, AND THE CYCLE WILL REPEAT WHEN LEVEL 6 CONCRETE IS PLACED.

5	0	+1D	1D	0
4	1.27D	-0.27D	1D	0
3	1.27D	-0.27D	1D	0
2	1.26D	-0.27D	1D	0
1	1.26D	-0.26D	1D	

interconnected floor slabs. In cases where the floor slab thickness and slab weight varies, the slab stiffness should be considered when calculating the slab, shore, and reshore construction loads.

Available early-age slab load capacity

The concrete slabs for this example have been designed for a slab dead load of 112.5 lb/ft² (5.39 kPa), and a superimposed dead load of 20 lb/ft² (0.96 kPa). Live loads of 50 and 100 lb/ft² (2.4 and 4.8 kPa) are considered in the following discussion. If live load reduction was taken by the engineer, the factored design loads of the structure would need to be reduced accordingly. Because the building design is based on ACI 318-05, load factors of 1.2 for dead load and 1.6 for live load are used. The resulting factored design loads for the slab are 239 and 319 lb/ft² (11.44 and 15.27 kPa) for the 50 and 100 lb/ft² (2.4 and 4.8 kPa) live load scenarios, respectively. The specified concrete strength is 4000 psi (27.6 MPa).

Based on the previous discussion, both the flexural and shear strengths of the young concrete slabs can be conservatively assumed to be proportional to the compressive strength development. Figure 2 shows the ratio of early-age concrete compressive strength to the 28-day design compressive strength based on the maturity method for the concrete mixture assumed for this example. The ratios of 7-day strength to 28-day strength are 0.49, 0.75, and 0.89 for the 40, 60, and 80 °F (4.4, 15.5, and 26.7 °C) curing environments, respectively. The concrete strengths given in Fig. 2 are valid only for the concrete mixture used in this example and the assumed curing conditions. The early-age slab strength is obtained by multiplying these ratios by the factored design loads calculated above.

Slab evaluation

For the system with three levels of reshores, the maximum slab load during construction occurs on Level 4 during placement of the fifth level slab. The total construction service load on Level 4 is 1.38D or 155 lb/ft² (7.44 kPa), consisting of a construction dead load, $D_c = 142.5$ lb/ft² (6.82 kPa), and a construction live load, $L_c = 12.5$ lb/ft² (0.60 kPa), (1/4 of the 50 lb/ft² [2.4 kPa]) construction live load shared by each level). Using the same load factors as for the design loads, the factored construction load is 191 lb/ft² (9.15 kPa).

Similarly, for the system with two levels of reshores, the maximum slab load during construction occurs on Level 3 during placement of the fourth level slab. The total load is 1.5D or 169 lb/ft² (8.09 kPa), consisting of $D_c = 152$ lb/ft² (7.27 kPa) and $L_c = 17$ lb/ft² (0.82 kPa), (1/3 share at each level). The factored construction load is 210 lb/ft² (10.05 kPa).

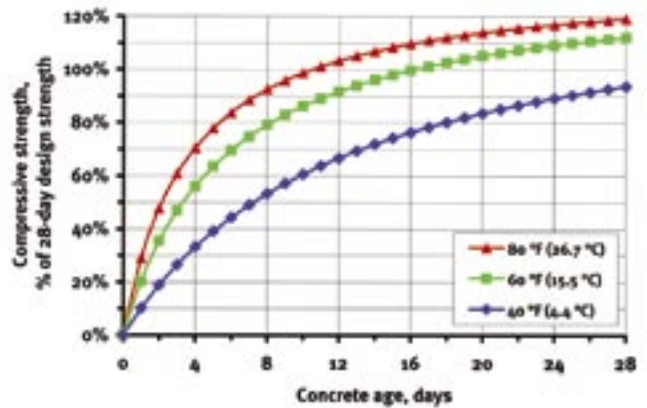


Fig. 2: Concrete compressive strength development for various curing temperatures

The construction loads and maximum allowable slab loads are summarized in Table 2. For a 7-day cycle with a 50 lb/ft² (2.4 kPa) live load, two levels of reshoring will be adequate only if the slab is cured at 80 °F (26.7 °C). For the 40 °F (4.4 °C) curing environment, the table shows that only the slab designed for a 100 lb/ft² (4.8 kPa) live load with a 15 day cycle is adequate when only two floors of reshores are used. This condition can be avoided by changing the mixture proportions, increasing the ambient curing temperatures, or by increasing the number of reshore levels.

Slab deflections

Though the slabs may have enough flexural strength to carry the high construction loads, they may lack the concrete tensile strength and stiffness required to prevent extensive cracking and excessive deflections. Deflection calculations for service load conditions should be based on the least effective moment of inertia determined from either the construction loads with partial concrete strength or the service loads with full concrete strength.

According to ACI 318-05, the contractor is required to produce structural calculation and concrete strength data used in planning shoring and reshoring operations. Such data and information should be furnished to the engineer who should evaluate the effects of construction loads on immediate and long-term deflections. A team effort between the contractor and the engineer is required to avoid deflection problems associated with construction procedures.

SAFETY AND ECONOMY

The ACI 347.2R Shoring/Reshoring Guide provides practical guidance for developing safe and economic construction schedules involving shoring/reshoring operations. It can be used by contractors and engineers to plan shoring/reshoring schedules and make critical decisions regarding formwork removal. Such decisions affect both the safety and the economy of construction.

TABLE 2:
CONSTRUCTION LOAD DISTRIBUTION AND SLAB CAPACITY SUMMARY

Construction Cycle, days	Design live load, lb/ft ² (kPa)	Ultimate slab load capacity at selected temperatures, lb/ft ² (kPa)			Maximum factored slab construction load, lb/ft ² (kPa)	
		40 °F (4.4 °C)	60 °F (15.5 °C)	80 °F (26.7 °C)	Two reshore levels	Three reshore levels
7-day cycle	50 (2.4)	117 (5.60)	179 (8.57)	213 (10.20)	210 (10.5)	191 (9.15)
	100 (4.8)	156 (7.47)	239 (11.44)	284 (13.60)	210 (10.5)	191 (9.15)
10-day cycle	50 (2.4)	146 (6.99)	206 (9.86)	237 (11.35)	210 (10.5)	191 (9.15)
	100 (4.8)	195 (9.34)	274 (13.12)	316 (15.13)	210 (10.5)	191 (9.15)
15-day cycle	50 (2.4)	177 (8.47)	234 (11.20)	239 (11.44)	210 (10.5)	191 (9.15)
	100 (4.8)	236 (11.30)	312 (14.94)	319 (15.27)	210 (10.5)	191 (9.15)

It's possible to economize in construction time and formwork material, while still maintaining site safety and the performance of the structure.

The avenue to reach higher levels of safety and economy is through education, training, and knowledge dissemination. Recognizing this, ACI Committee 347 has developed the Shoring/Reshoring Guide to bring together the collective knowledge of contractors, manufacturers, designers, and academia.

Acknowledgments

This article is based on the ACI 347.2R "Guide for Shoring/Reshoring of Concrete Multistory Buildings" developed by ACI Committee 347, Formwork for Concrete. We are very grateful to the committee members who shared their expertise during the preparation of the Reshoring Guide, particularly D. W. Johnston, who chaired the committee during much of that time.

References

1. ACI Committee 347, "Guide for Shoring/Reshoring of Concrete Multistory Buildings (ACI 347.2R-05)," American Concrete Institute, Farmington Hills, MI, 2005, 18 pp.
2. Grundy, P., and Kabaila, A., "Construction Loads on Slabs with Shored Formwork in Multistory Buildings," ACI JOURNAL, *Proceedings V*, 60, No. 12, Dec. 1963, pp. 1729-1738.
3. ACI Committee 347, "Guide to Formwork for Concrete (ACI 347-04)," American Concrete Institute, Farmington Hills, MI, 2004, 32 pp.
4. Gross, J.L., "Implementation of Compressible Shoring Analysis for Multistory Concrete Construction," NBSIR 84-2964, National

Institute of Standards and Technology, Washington, D.C., 1984, 53 pp.

5. Gross, J.L., and Lew, H.S., "Analysis of Shoring Loads and Slab Capacity for Multistory Concrete Construction," *Proceedings of the Second International Conference on Forming Economical Concrete*, SP-90, American Concrete Institute, Farmington Hills, MI, 1986, pp. 109-130.

6. Stivaros, P.C., and Halvorsen, G.T., "Shoring/Reshoring Operations for Multistory Buildings," *ACI Structural Journal*, V. 87, No. 5, Sept.-Oct. 1990, pp. 589-596.

7. SEI/ASCE 37-02, "Design Loads on Structures During Construction," American Society of Civil Engineers, Reston, VA, 2002, 36 pp.

8. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (318R-05)," American Concrete Institute, Farmington Hills, MI, 2005, 430 pp.

Selected for reader interest by the editors.



ACI member **Pericles C. Stivaros** is a principal with Feld, Kaminitzky & Cohen, P.C., Consulting Engineers, Roslyn Heights, NY. He is the Chair of ACI Committee 347, Formwork for Concrete, and is the principal author of the Reshoring Guide. He is a member of ACI Committee 362, Parking Structures, and the ACI TAC Tolerances Coordinating Committee.