Guide for Shoring/Reshoring of Concrete Multistory Buildings

Reported by ACI Committee 347
Guide for Shoring/Reshoring of Concrete Multistory Buildings

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at http://concrete.org/Publications/DocumentErrata.aspx. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org
Guide for Shoring/Reshoring of Concrete Multistory Buildings

Reported by ACI Committee 347

Kenneth L. Berndt, Chair

Matthew J. Poise!, Secretary

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

CONTENTS

CHAPTER 1—INTRODUCTION, p. 2
1.2—Scope, p. 2

CHAPTER 2—NOTATION AND DEFINITIONS, p. 2
2.1—Notation, p. 2
2.2—Definitions, p. 3

CHAPTER 3—SHORING/RESHORING CONSTRUCTION NEEDS, p. 3
3.1—Use of reshoring, p. 3

3.2—Types of forming systems, p. 3

CHAPTER 4—CONSTRUCTION LOADS ON FORMWORK, p. 4
4.1—Construction loads, p. 4
4.2—Load combinations, p. 4
4.3—Typical construction phases, p. 5
4.4—Construction load distribution, p. 6
4.5—Application of the simplified method, p. 6
4.6—Factors affecting the construction load distribution, p. 8
4.7—Post-tensioning load redistribution, p. 9

CHAPTER 5—STRENGTH OF CONCRETE SLABS AND FORMWORK, p. 10
5.1—Early-age concrete material strength development; p. 10
5.2—Construction load factors, p. 11
5.3—Early-age strength of concrete slabs, p. 11
5.4—Serviceability of concrete slabs, p. 12
5.5—Strength of formwork, p. 12

CHAPTER 6—CONSTRUCTION EXAMPLES, p. 12
6.1—Two-way slab construction, p. 12
6.2—Post-tensioned construction example, p. 18

CHAPTER 7—REFERENCES, p. 20

Authored documents, p. 21

ACI 347.2R-17 supersedes ACI 347.2R-05 and was adopted and published January 2017.

Copyright © 2017, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

American Concrete Institute
Provided by IHS under license with ACI
No reproduction or referencing permitted without license from IHS
CHAPTER 1 — INTRODUCTION

In multistory cast-in-place concrete building construction, freshly cast floors are placed on formwork that is temporarily supported by a system of shores and reshores until the concrete has the ability to be self-supporting. Construction loads imposed by the shoring system can be greater than the permanent structure service load on a single floor. Construction loads can also be applied in a manner that differs from the design intent of the completed structure. Furthermore, the concrete of the supporting slabs has to attain sufficient strength, considering that the capacities of the floors below vary depending on concrete age, ambient conditions following placement, and the rate of strength development properties of the slabs. As a result, it is critical to determine the early-age load capacity of the floor slabs, including punching shear strength, to avoid the possibility of partial or total failure of the structural system. To reduce the construction load on the floor immediately below and distribute it to several lower floors or to the ground, it is necessary to add reshores. Therefore, an engineering analysis that considers both the construction load distribution and the early-age load-carrying capacity of the concrete slabs should be performed before shoring/reshoring operations begin.

Formwork failures and failures caused by improper shoring or premature removal of supports and inadequate lateral bracing have periodically occurred throughout the history of concrete construction. Premature removal of shores and reshores prior to concrete slabs achieving the necessary strength can contribute to construction failures or defects such as permanent deflections (sagging) or cracking in the completed structure in excess of those anticipated by the design. Also, if overloaded prematurely, time-dependent deflections under load (creep) will be larger than predicted by the design and may be more noticeable and objectionable.

The schedule and process for removal of forms, shores, and reshores should be based on an analysis of the structural effects. Except for the simplified method described in ACI 347R and ACI SP-4, there is no method universally accepted as the proper analysis of the distribution of construction loads to the floor slabs and the shoring system.

To ensure structural performance and safety during construction, a thorough understanding of construction loads applied to the slabs at early ages is necessary. Equally important is knowledge of the behavior and the strength of early-age concrete members that support their own weight and construction loads.

For guidance in formwork operations, the formwork engineer/contractor can refer to several codes, standards, or guides, including ACI 347R, ACI 318, ACI 301, ACI SP-4, ANSI/ASSE A10.9, OSHA 29 CFR 1926, and ASCE/SEI 37. These documents provide basic guidelines for general formwork operations.

Other documents that can provide formwork design requirements or guidelines include state and local building codes, and guidelines prepared by contractors, formwork manufacturers, and other construction agencies governing construction practices.

1.2 — Scope

Although the aforementioned documents provide basic guidelines for general formwork operations, there are no codes or standards that provide detailed design and construction requirements specifically for shoring/reshoring operations for multistory reinforced and post-tensioned concrete construction. Investigations for usable procedures to establish safe and cost-effective shoring/reshoring operations have been ongoing for several decades. These investigations focus on two major areas: 1) determining the distribution of loads carried by the concrete structure during construction; and 2) estimating the ability of the concrete members to resist construction loads.

This guide outlines the importance of appropriate shoring/reshoring design for multistory structures and provides basic requirements for safe construction. ACI SP-4 serves as an expanded commentary to ACI 347R and provides detailed information related to formwork practices, including a discussion of shoring/reshoring procedures and analysis examples. Contract documents or the authority having jurisdiction may require the contractors to supply to the building official, upon request, the structural analysis and concrete strength requirements used in planning and implementing shoring/reshoring operations. Such data and information should be furnished to the engineer/architect who should evaluate the effects of construction loads on the immediate and long-term deflections. The contractors and formwork designers should acquire an understanding of the construction loads and the structural behavior of the buildings during construction. This understanding enables them to develop a rational shoring/reshoring system design that is economical without compromising safety, quality, and serviceability.

The objective of this guide is to present practical guidelines for the design of shoring/reshoring operations. This guide provides tools to design and evaluate construction schedules for shoring/reshoring of multistory reinforced and post-tensioned concrete structures.

CHAPTER 2 — NOTATION AND DEFINITIONS

2.1 — Notation

\( b_s = \) perimeter of critical section for shear in slabs, in. (mm)
\( D = \) design dead load, lb/ft² (kPa)
\( D_c = \) construction dead load, lb/ft² (kPa)
\( d = \) distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in. (mm)
\( E_w = \) reference design value for modulus of elasticity of wood, psi (MPa)
\( F_c = \) reference design value for compression parallel to grain of wood, psi (MPa)
\( f_c = \) compressive strength of concrete, psi (MPa)
\( f'_c = \) specified compressive strength of concrete, psi (MPa)
\( K = \) resulting coefficient of the governing punching shear equations from ACI 318 that is a function of column and slab geometry
\( L = \) design live load, lb/ft² (kPa)
\[ L_{nc} \] = construction live load, \( \text{lb/ft}^2 \) (kPa)
\[ n_e \] = elevated slab number
\[ R_{28} \] = nominal flexural strength at 28 days, \( \text{lb/ft}^2 \) (kPa)
\[ R_{ec} \] = early-age nominal flexural strength, \( \text{lb/ft}^2 \) (kPa)
\[ U_{28} \] = design factored load, \( \text{lb/ft}^2 \) (kPa)
\[ U_c \] = construction factored load, \( \text{lb/ft}^2 \) (kPa)
\[ V_e \] = nominal shear strength provided by concrete, \( \text{lb} \) (N)
\[ V_s \] = factored shear force, \( \text{lb} \) (N)
\[ V_{sc} \] = factored construction shear force, \( \text{lb} \) (N)
\[ \beta_c \] = ratio of the early-age concrete compressive strength to 28-day specified strength, \( \beta \leq 1.0 \)
\[ \lambda \] = modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normalweight concrete of the same compressive strength
\[ \phi \] = strength reduction factor

2.2—Definitions

backshores—shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area without allowing the entire slab or member to deflect or support its own mass or existing construction loads.

drop-head shore—shore with a head where part of the head can be lowered to allow removal of horizontal forming components without removing the shore or changing its vertical support for the floor system.

engineer/architect—engineer, architect, engineering firm, architectural firm, or other agency issuing project plans and specifications for the permanent structure, administering the work under contract documents, or both.

formwork engineer/contractor—engineer of the formwork system or contractor in charge of designated aspects of formwork design and formwork operations.

preshores—added shores placed snugly under selected panels of a deck forming system before any primary (original) shores are removed.

reshores—shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a full bay, requiring the new slab or structural member to deflect and support its own weight and construction loads applied before installation of the reshores.

shore—vertical or inclined support member or braced frame designed to carry the weight of the formwork, concrete, and construction loads.

CHAPTER 3—SHORING/RESHORING CONSTRUCTION NEEDS

3.1—Use of reshoring
In multistory cast-in-place construction, rapid reuse of form material and shores is desired to allow other trades to follow concreting operations as closely as possible. The shores that support the newly placed concrete, formwork, and construction live load transmit those loads to the recently completed floor below, which usually exceeds that floor slab’s load capacity if it is the only source of support. For this reason, shoring or reshoring is provided over a number of floors to distribute the construction load to several floor levels below.

Stripping formwork is usually more economical if all the form material is removed at the same time before placing reshores. In this case, the structural system is required to support its own weight, thus reducing the load in the reshores. A combination of shores and reshores usually requires fewer levels of interconnected slabs, thus freeing more areas for other trades. If prefabricated drop-head shores are used, the shores can become the reshores if a large area of shoring is unloaded, permitting the structural members to deflect and support their own weight. The drop-head shore has a head that can be lowered to remove forming components without removing the shore or changing its support for the floor system. Later, the shore may be retracted and resnugged to act as a reshore. If the load is not relieved, then they become backshores.

Backshoring and preshoring are other methods of supporting new construction that are less widely used and involve leaving the original shores in place or replacing them in a small area at a time so as not to allow the slab to deflect and carry its own weight. These methods require careful supervision by the formwork engineer/contractor and review by the engineer/architect to ensure excessive slab and shore loads do not develop.

3.2—Types of forming systems
An important consideration in multistory cast-in-place concrete building construction is the type of forming system being used. Selecting the forming system for constructing a cast-in-place concrete structure is a critical decision that affects both the construction schedule and cost. Systems vary from traditional wood post-and-beam formwork/shoring to prefabricated systems that involve sophisticated engineering, materials, and equipment.

There are several prefabricated forming/shoring systems that are used to support concrete slabs during construction, including the four discussed in this guide: 1) shoring-based; 2) flying truss; 3) column-mounted; and 4) tunnel-forming systems. The following description of these systems is adapted from Jensen (1986).

3.2.1 Shoring-based systems—Deck (slab) forms are supported on shores placed on the slab below. The shores may be single posts of wood or metal or assembled from frames. Job-built deck forms usually consist of wood or aluminum stringers and joists (runners) with the deck surface made of plywood, supported on single-post or frame-type shores. These forms are sometimes made up in larger panels tied or ganged together as tables with attached frame-type shores for movement by crane. Deck forms may also be assembled on the job from proprietary panels framed in wood, steel, or aluminum, sometimes with their own proprietary shoring systems. Some of these systems allow removal of the slab.
forms while the shores remain in place until sufficient concrete strength is developed to allow the shore removal and reshoring process.

3.2.2 Flying truss systems—Flying truss systems are made up of steel or aluminum trusses, topped with aluminum or wood joists and decked with plywood. Adjustable legs or shores support the truss on a previously cast slab. The truss-mounted forms are moved as a unit by crane from one casting position to the next.

3.2.3 Column-mounted systems—Column-mounted systems are long-span form panels supported by brackets or jacks anchored to concrete columns and shear walls. The deck panel is generally moved by crane. Similar systems available for bearing wall buildings support slab forms on brackets anchored to the walls. These systems make it possible to eliminate most vertical shoring and reshoring.

3.2.4 Tunnel-forming systems—Tunnel-forming systems are factory-made, inverted, U-shaped steel form systems that permit casting both slab and supporting walls at the same time. When concrete has gained sufficient strength, the tunnels are collapsed or telescoped and moved to the next placement location. For longer slab spans, the tunnel form may be made in two inverted L-shapes, which are termed “half-tunnels”.

CHAPTER 4—CONSTRUCTION LOADS ON FORMWORK

4.1—Construction loads

Construction loads are those loads imposed on a partially completed or temporary structure during the construction process. Construction loads on formwork include gravity loads such as vertical dead and live loads of both formwork and structure, lateral loads due to wind and seismic, and vertical and horizontal forces induced by inclined support members of the formwork. Concrete placing and equipment operations may create vertical dead and live, lateral, and impact loads. The formwork system is required to support all construction loads that may be applied until these loads can be carried by the concrete structure itself.

4.1.1 Gravity loads—Gravity loads are categorized as either dead or live loads. The dead load includes weight of reinforcement, freshly placed concrete, and formwork. The live load includes the weight of workers, equipment, tools, and runways as well as impact loading of concrete placement or equipment operations. Although impact loads are dynamic, for simplicity, they are treated as statically applied loads.

ACI 347R recommends both vertical supports and horizontal framing components of formwork be designed for a minimum live load of 50 lb/ft² (2.4 kPa) of horizontal projection to provide for weight of workers, runways, screens, and other equipment. When motorized carts are used, the minimum live load should be 75 lb/ft² (3.6 kPa). The minimum design value for combined dead and live loads should be 100 lb/ft² (4.8 kPa) or 125 lb/ft² (6.0 kPa) when motorized carts are used.

The construction live load is usually applied to the uppermost slab during concrete placement of that slab, and is assumed to be removed when the concrete placement is complete. If other loads, such as equipment or stored materials, are known to be present on lower floors during construction, they should be considered. When justified by an analysis of construction operations, the construction live load used for design of shores and evaluation of floor system capacity may be reduced, as provided by Chapter 4 of ASCE/SEI 37-14.

4.1.2 Lateral loads—Lateral loads on the formwork system arise from wind, seismic events, inclined formwork supports, impact of concrete placement, sequence of concrete placement, thermal effects, and mechanical equipment used. ACI 347R recommends a minimum horizontal load as either 100 lb/linear ft (1.46 kN/m) of floor edge or 2 percent of the total superimposed dead load, whichever is greater. ASCE/SEI 37 provides methods for determining appropriate design wind speeds and seismic lateral loads for short time intervals of construction exposure. Wind loadings can be estimated based on either closed or latticed configurations of shoring and formwork.

4.1.3 Other loads and conditions—Formwork may be subjected to loads due to unsymmetrical placement of concrete, impact of concrete during placement, starting and stopping of equipment, uplift, concentrated loads of reinforcement, form handling loads, and storage of construction materials and equipment. Where possible, such loads should be avoided. Usually these loads occur over a relatively small area and can cause local failures of the formwork and perhaps the structure if not controlled. Some loads, such as temporary mounding of concrete, cannot be anticipated and should be avoided. Additionally, large point loads from shores bearing on a slab could create excessive flexural and shear stresses.

4.1.4 Post-tensioning load distribution—Shores, reshores, and backshores should be analyzed for load redistribution that occurs when slabs and beams are post-tensioned. This analysis should also include members of floors below; the redistributed shoring loads under the floor being post-tensioned could be transferred to supporting members and shores of the floors below.

While the engineer/architect is ultimately responsible for the structure, close coordination between the engineer/architect and the formwork engineer/contractor is recommended to estimate the magnitude and location of construction loads when members are post-tensioned. An understanding should be reached between the engineer/architect and contractor with respect to the post-tensioning sequence and magnitude of stressing that could result in additional loads induced in the shores, reshores, or backshores. Based on this information, an analysis of the construction load redistribution can be performed.

4.2—Load combinations

A combination of construction loads, based on the proposed construction method and sequence, should be considered to establish the critical loading conditions on the formwork and temporary construction loads on the structure. For example, concrete placement and shore/reshore removal
are the most critical construction phases for concrete slabs and the formwork. The construction phase after the form and shore installation and before concreting presents the most critical condition for the effects of wind load. During this stage, it is necessary that the formwork be designed to resist its own weight and any other gravity loads, as well as lateral wind loads, uplift wind loads, or both.

4.3—Typical construction phases

In a typical construction cycle for a multistory cast-in-place concrete building where both shores and reshores are used, there are four construction phases:

1) **Phase 1**—Installation of the shores and formwork followed by casting of the floor slab
2) **Phase 2**—Removal of the shores and formwork from a full bay, allowing the slab to deflect and carry its own weight and any applied construction loads
3) **Phase 3**—Removal of reshores at the lowest interconnected level
4) **Phase 4**—Placement of reshores in the story from which the shores and forms were removed; reshores are placed snugly without initially carrying any load

This stripping procedure allows the slab to deflect and transfer its self-weight to supporting elements of the building structure. Shores should be installed snugly under the newly stripped slab so that they are relatively load-free at installation.

The following example of one level of shores and two levels of reshores in a simple three-bay, multistory structure illustrates the four phases.

1. Figure 4.3(a) shows Phase 1, when the \((n+4)\) floor is being cast. The weight of the fresh concrete and the formwork along with the 50 or 75 lb/ft² (2.4 or 3.6 kPa) construction live load is distributed among the interconnected slabs \((n+1)\), \((n+2)\), and \((n+3)\) through the shoring/reshoring system.

2) Figure 4.3(b) shows Phase 2, when the top slab has the capacity to support its own weight and any construction loads at that stage. Shores are removed from the \((n+3)\) floor and any remaining load in these shores is redistributed to the slab above.

3) Figure 4.3(c) shows Phase 3 removal of the reshores from the \((n+1)\) floor. Any construction or live load existing on levels \((n+2)\) or \((n+3)\) in the reshores is removed from the lowest slab \((n+1)\) and redistributed to those slabs.

4) Figure 4.3(d) shows Phase 4, installation of the reshores on the \((n+3)\) floor. During Phases 3 and 4, there is no load transfer to the floor above because the reshores are assumed to be relatively load-free at installation.

Although this example uses two levels of reshoring, each structure and job-specific circumstances should be individually evaluated. Depending on the specifics of the structural capacity and the planned construction sequence, more or possibly less levels of reshoring may be required.

![Fig. 4.3—Typical construction phases for multistory reinforced concrete buildings.](image-url)
4.4—Construction load distribution

The question of how construction loads are distributed between the formwork system and newly cast supported concrete members is a subject of debate in the construction industry. Several designers and researchers have published proposed methods to determine the forces in concrete structures during construction.

Grundy and Kabaila (1963) published a paper presenting a simple method for calculating construction loads carried by slabs and shores during the construction of multistory flat plate and flat slab concrete buildings. The model consisted of a single-bay structure where the slabs were interconnected with the shoring system. The concept of reshoring was not included in the originally introduced method. The expanded analysis method, including reshoring operations, is covered in ACI SP-4.

The analysis method, now known as the simplified method, is based on a single-bay structure model with the following assumptions:

(a) Ground-level or other grade base support is rigid
(b) All previously cast slabs are identical and have equal stiffness
(c) Shores and reshores are spaced closely enough to treat their reactions as a distributed load
(d) Shores and reshores are infinitely stiff relative to the slabs
(e) Reshores are installed snug-tight without initially carrying any load

These assumptions result in two important behaviors during the analysis. First, because shores have infinite stiffness, slabs interconnected by shores and reshores deflect equally when a new load is added and rebound equally when a load is removed. Second, because the slabs have equal stiffness, when they deflect equally due to an increment of imposed load, the slabs share the load increment equally. Effects of creep and shrinkage are neglected.

In practice, special situations are encountered that require additional analytical consideration. As an example, the first few floors sometimes have a different structural design to accommodate higher service loads. If some lower floors are stiffer than subsequent floors, the stiffer floors will carry more load from operations above. Variations in each slab’s self-weight will also require consideration.

Even though the assumptions of the simplified method do not model the structure exactly, analytical studies and field measurements verify the validity of this method. Field measurements consisted of measured loads on shores and reshores during the construction process. Most of the available field observations were found to be in fair agreement with the predicted values. The assumptions and limitations of the method were investigated and the model refined in various ways to reflect those studies: in construction methods and schedules, analysis of short- and long-term deflections, consideration of variable slab stiffness, consideration of compressible shores, and structural reliability. Further information from these studies can be found in Agarwal and Gardner (1974), Gardner and Muskat (1989), Gardner (1985), Liu et al. (1985, 1988), Gross (1984), Gross and Lew (1986), Stiver and Halvorsen (1990, 1992), Arafat (1996), McGurl and Johnston (2012), Monette and Gardner (2015), and Zhang et al. (2015).

4.5—Application of the simplified method

Table 4.5 demonstrates the application of the simplified method. The example uses one level of shores and two levels of reshores. The construction live loads and weight of forms and shores are included in the load analysis. The slabs are assumed to have equal thickness and stiffness and, therefore, the construction loads are distributed equally among the slabs. The shores and reshores are assumed to be infinitely stiff relative to the supported slabs. Table 4.5 shows a sample load case with formwork system loads and construction loads as a proportion of slab self-weight. Actual construction live loads and formwork loads vary from project to project.

Following the four phases of construction, each floor level is subjected to construction loads that vary in magnitude as construction advances.

In Step 1, the first elevated floor slab is placed, and the full load is transferred to the ground by the shores. In Step 2, the shores are removed and the slab is now carrying its own weight. The shores are placed snugly under the slab, carrying no load. In Step 3, the second elevated floor slab is shored and placed. The first floor slab cannot deflect and all added load goes through the shores to the ground. In Step 4, the shores are removed, and the second elevated floor slab carries its own weight. Reshores are placed under the second floor, but do not carry load initially. In Step 5, the third elevated floor slab is shored and placed. All added load goes through the shores and reshores to the ground.

In Step 6, the shores are removed, and the third elevated floor slab carries its own weight. The shores are removed from beneath Level 1 and are placed under the third floor without carrying any load. During this step, the support conditions have changed because there is no longer a continuous support to the ground. When the fourth floor slab is shored and placed during Step 7, the added load is equally shared among the supporting slabs below.

The removal and relocation of shores and reshores, and the placement of a new slab at the top active floor, continues in a similar manner for the remaining steps. After Step 6, the cycles repeat throughout the full height of the building.

The load in shores at the end of each step is calculated on the basis of a summation of vertical forces. The total weight of slabs and construction loads above the shelf level being considered, less the loads carried by slabs above, gives the load transmitted by the shores.

Similar construction load calculations can be developed for shoring systems using more than one level of shores. Examples of calculating the construction loads when more than one level of shores is used are discussed in ACI SP-4.

The simplified method assumes distribution of the construction loads between the supported floors based on uniform stiffness. Some project-specific circumstances, such as varying structural stiffness, alters the load distribution.

Some prefabricated commercial forming and shoring systems allow removal of the slab forms while the shores remain in place for a longer duration. Depending on the sequence of operations, the sequence of steps in the analysis would need to be modified.
Table 4.5—Simplified analysis of loads on shores and slabs using one level of shoring, two levels of reshoring

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation and remarks</th>
<th>Load on slab in multiples of D</th>
<th>Structure status</th>
<th>Shore/reshore load at end of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>At beginning</td>
<td>Change during operation</td>
<td>Total at end of operation</td>
</tr>
<tr>
<td>1</td>
<td>Place Level 1 concrete. Full load is transmitted to ground by shores.</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Construction live load is gone. Remove Level 1 shores, allowing Slab 1 to carry its own weight.</td>
<td>1</td>
<td>0</td>
<td>+1D</td>
</tr>
<tr>
<td></td>
<td>Then place reshores beneath it, snug but not loaded.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Form, shore, and place Level 2 concrete. Slab 1 cannot deflect and all added load goes through reshores to ground.</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1D</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Slab 2 achieves required strength and construction live load is gone. Remove the Level 2 forms and shores, allowing Slab 2 to carry its own weight. Then place reshores beneath it, snug but not loaded.</td>
<td>2</td>
<td>0</td>
<td>+1D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1D</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Form, shore, and place Level 3 concrete, including the 0.5D construction live load and shore load. All added load goes through shores to the ground because slabs cannot deflect further.</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1D</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1D</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Construction live load is assumed removed as Slab 3 achieves required strength. Remove shores beneath Level 3, allowing it to carry its own weight. This leaves no net load in reshores beneath Level 1, and they are removed and installed snugly beneath Level 3. They carry no heat.</td>
<td>3</td>
<td>0</td>
<td>+1D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1D</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1D</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Form, shore, and place Level 4 concrete with the assumed 0.5D construction live load and shore load. The total new applied load, 1.5D, is distributed equally to the three interconnected slabs.</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>1D</td>
<td>+0.5D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1D</td>
<td>+0.5D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1D</td>
<td>+0.5D</td>
</tr>
<tr>
<td>8</td>
<td>Level 4 concrete achieves required strength and the construction live load of 0.4D is removed in equal parts from the slabs to which it was distributed.</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>1.5D</td>
<td>-0.13D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1.5D</td>
<td>-0.13D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1.5D</td>
<td>-0.14D</td>
</tr>
</tbody>
</table>
Table 4.5(cont.)—Simplified analysis of loads on shores and slabs using one level of shoring, two levels of reshoring

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Remove shores beneath Level 4, causing that slab to carry its own weight. The load in those shores, including their weight, is removed from the slabs to which it had been distributed.</td>
<td>1.37D</td>
<td>-0.37D</td>
<td>1D</td>
<td>1D</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Move reshores beneath Level 2 up, placing them snugly beneath Level 4, where they carry no load. There is no change in system loads. System conditions are now the same as at the end of Step 6, and when the Level 5 slab is placed, the cycle repeats.</td>
<td>1D</td>
<td>0</td>
<td>1D</td>
<td>1D</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes:
The results indicated in the table should not be used for actual projects because the actual construction live loads and formwork loads may differ from those assumed in the table.

D is weight of slab.
Assumed construction live load = 0.4D.
Assumed shore and form weight = 0.1D.
Reshore weight is neglected.

4.6—Factors affecting the construction load distribution

Major factors affecting the construction load distribution and performance of concrete buildings during construction are slab continuity, slab type and stiffness, type and stiffness of shoring/reshoring system, and the rate of construction. Several studies (Gross 1984; Stivaros and Halvorsen 1990) investigated the effects of these factors on the construction load distribution.

4.6.1 Shore/reshore stiffness—The shoring/reshoring system stiffness can be a factor affecting the construction load distribution. The simplified method assumes infinite stiffness of the shoring/reshoring system, as compared with the flexural stiffness of the supported slabs (Grundy and Kabaila 1963). Shores selected for use as reshores should be evaluated for take-up, slippage, and compressibility when analyzing the construction load distribution. With a more compressible shoring/reshoring system, the structural system tends to shift as much as 15 percent of the slab loads to the uppermost interconnected floors as compared with rigid shores/reshores (Gross 1984; Gross and Lew 1986; Stivaros and Halvorsen 1990; Monette and Gardner 2015). Floors immediately below the level being cast could have limited strength and are more sensitive to possible overload. The estimated construction loads at the upper floor can be increased to compensate for error in calculating the construction loads when using the simplified method. Otherwise, the relative stiffness between the shoring/reshoring system and the supported slabs should be considered while calculating the construction load distribution among the interconnected slabs.

4.6.2 Floor stiffness and type—Increased slab stiffness resulting from concrete strength gain during construction has little effect on the construction load distribution among the slabs. Because modulus of elasticity rises rapidly as concrete cures (refer to Chapter 5), the difference in stiffness of the top slab and bottom slab is small. To the extent that higher strength contributes to slightly higher stiffness, it would result in slightly more load carried by the lower interconnected floors and, thus, partly compensate for the opposite effects due to finite reshore stiffness. Although the difference of concrete strength in the interconnected slabs does not significantly affect the construction load distribution among the slabs, it does make a significant difference in the early-age slab’s resistance to cracking and deflection.
Any increase in slab stiffness due to the presence of beams, drop panels, or increase of slab thickness results in higher construction loads resisted by these slabs, because the stiffer members in a structural system attract a higher percentage of distributed loads.

4.6.3 Shore system configuration—The shore or reshore placement configuration affects the construction load distribution. Where shoring supports are located close to columns or structural walls, the floor slabs will share less construction load with the floors below because a significant amount of the load will be transferred directly to the columns or walls. Conversely, shoring supports located far apart from each other, such as truss-table systems, create large point loads that will cause more severe loading conditions in the structure than the uniformly distributed loads designed by the engineer/architect. This configuration may necessitate an increase in the number of floors of reshores to safely transfer the construction load into the floors below. Punching shear becomes a concern with large point loads. Placement of reshores directly below the shores may be required.

4.6.4 Number of shored levels—An increase in the number of shored levels will increase the maximum construction load on the top reshored slab and the slabs below. However, additional levels of shoring will allow the slabs to develop greater strength before the maximum construction load is applied.

4.6.5 Number of reshored levels—The use of reshoring effectively decreases the maximum applied construction load to any one previously cast floor by distributing the construction loads among two or more previously cast floors. The number of reshored levels should be selected to reduce the applied construction loads to values that the early-age slabs can withstand. The maximum construction load supported by a cast slab decreases at a decreasing rate as the number of the reshored levels increases (Stivaros and Halvorsen 1990). Therefore, the number of reshored levels is effective only up to a certain number, beyond which any additional reshore levels will not carry any significant amount of construction load.

As the number of reshored levels increases, the simplified method could underestimate the maximum construction loads shared by the upper-level slabs, depending on the compressibility of the reshores used. The larger the stiffness of the reshoring system, the greater the accuracy of the simplified method. Other factors, such as how snug or plumb the reshores are installed and how much vibration has occurred on the floor to loosen them, can reduce the ability of reshores to redistribute loads.

4.6.6 Rate of construction—The rate of construction determines number of days between when the concrete slabs are placed and when they are subjected to maximum construction loads. Because concrete strength gain is time-dependent, the rate of construction has an effect on the building’s performance during construction, and will have an effect on the reshoring required to maintain construction load distribution within the predicted, early-age capacity of the structure.

4.7—Post-tensioning load redistribution

Load redistribution occurs during the application of post-tensioning to various concrete structural members such as slabs, beams, and girders. Depending on the level of tensioning, the shoring that supports these members can be partially or totally relieved of load. The loads from these members are transferred to adjacent supporting structural members, thus increasing the loads on shores supporting those adjacent structural members. The increased shore loads are imposed on members, shores, and reshores below. If not carefully evaluated, the load redistribution due to post-tensioning can overload shores or reshores, as well as concrete members.

Therefore, it is necessary to analyze the construction load distribution on shores and reshores of post-tensioned structures in both of two stages:

1) During concrete placement
2) During post-tensioning

Determining construction loads during concrete placement is similar to the methodology described in the previous sections of this chapter.

The construction load redistribution depends on the sequence and magnitude of tensioning at each stage of stressing. When a slab is post-tensioned, a portion of the shore load is transferred to the supporting beams. If the beam is shored, the beam shoring has to have the ability to carry this redistributed load. When the beams are post-tensioned, a portion of the shore load is transferred to the supporting columns or girders. The load transfer associated with post-tensioning of the beams can cause significant increases in the shoring loads at the beam/girder intersections for the period of time in which the girders have not yet been stressed. The maximum construction loading condition for stressing occurs when slabs are fully stressed first, followed by beams, then girders. In this case, a careful analysis of the load transfer to the beam and girder shores/reshores is needed. Should the tensioning sequence be reversed or the magnitude of the deformation of the beams be reduced, the construction load redistribution during tensioning will be different and, most likely, will result in lower shore loads. The implications of the choice of sequence are further discussed in 6.2.2.

The design of shoring/reshoring for post-tensioned construction requires the engineer to understand many variables such as site conditions, shoring system type, and numerous combinations of stressing sequences and the magnitude of stressing. Therefore, only general guidelines are presented in this guide. Given the variability of design and construction methods, the construction of each project should be planned carefully in advance by the formwork engineer/contractor in close coordination with the engineer/architect. Information should be exchanged regarding design details and construction methods. A clear understanding should be established for each party’s responsibility in determining post-tensioning procedures and shoring/reshoring operations. Information required for the development of safe post-tensioning operations include:

(a) Members to be post-tensioned
(b) Design service live loads and dead loads, including any allowable live load reductions used in the structural design
(c) Post-tensioning sequence and the magnitude of stressing at each stage of stressing.
CHAPTER 5—STRENGTH OF CONCRETE SLABS AND FORMWORK

The strength of an early-age slab is influenced primarily by the rate of concrete strength gain and loads for which the slab has been designed. Instead of more detailed calculations, the flexural, tensile, shear, and bond strengths of the early-age slab can be conservatively assumed to be proportional to the concrete compressive strength at that age, as discussed in ACI SP-4 (refer to Fig. 5a and 5b). A more refined analysis can be used to take advantage of the member strength gain, which may be greater than the rate of concrete strength development, as discussed in ACI SP-4. Also, the proportion of slab design load capacity resulting from post-tensioning exceeds the proportion of concrete compressive strength gain. Cracking is dependent on early-age concrete tensile strength, and deflections are dependent on both concrete tensile strength and modulus of elasticity.

The early-age strength of a slab needs to be checked against anticipated construction loads. When the applied construction load on a slab is more than the slab’s early-age load capacity, even though these construction loads may be less than the slab’s design, distress may occur and the proposed construction scheme should be modified. In such a case, there are two alternatives: to either 1) reduce the load on the slab at the critical concrete age; or 2) change the concrete mixture for accelerated strength gain. The first alternative is achieved by modifying the type of shoring system or the number of shored or reshored floor levels in such a way that the applied construction load is reduced to an acceptable level. The second alternative is achieved by using high-early-strength concrete, controlling curing temperatures to achieve the required early concrete strength, increasing the duration of the construction cycle to permit the concrete to gain sufficient strength before the application of construction loads, or all of these. In no circumstances, however, should the factored construction load exceed the factored service loads.

5.1—Early-age concrete material strength development

Determining concrete strength is the decisive factor for the earliest possible removal of formwork. In general, the decision regarding safe formwork removal depends on the rate of concrete strength gain, the accuracy of strength determination of in-place concrete, and the level of load and deformation that the structure can withstand.

5.1.1 Compressive strength—The traditional method to determine early-age concrete compressive strength is testing field-cured cylinders. If the field cylinder is cured similar to the structure, then the compressive strength test results will represent a conservative strength estimate for the structure. A drawback of this method is that the curing history and strength development of the cylinders and the structure will not be the same simply because of the difference in shape and size of the actual structural members. Depending on the curing conditions of both the actual structure and the concrete cylinders, the compressive strength of the field-cured cylinders can be greater than or less than the compressive strength of concrete in the structure. Also,
testing concrete cylinders can be cumbersome mainly due to the large number of required cylinders.

Employing reliable nondestructive test methods in combination with concrete cylinders to estimate the concrete compressive strength for formwork removal operations is desirable. Several nondestructive methods are available for estimating the in-place strength of concrete. Such methods include penetration resistance, pullout test, and maturity methods. Note that these methods only indirectly measure strength. They include estimating strength by: 1) the resistance to penetration probe or pullout device; or 2) keeping a log of concrete temperatures and other data and comparing them to the strength gain over time of laboratory-cured specimens. Accuracy of the strength estimate requires carefully developed calibration data based on tests of cylinders made from the same concrete mixture used.

5.1.2 Tensile strength—Concrete at early age 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 or no advance warning. Furthermore, the increased tensile cracks caused by loading of early-age concrete can contribute to unanticipated, nonrecoverable deflections. The concrete tensile strength is critical for flat plate and flat slab floors because these slabs are susceptible to cracking and deflections, as well as potentially catastrophic punching shear failure.

The importance of concrete tensile strength cannot be overlooked, but there is no agreement as to how early-age concrete tensile strength relates to cylinder compressive strength. Split cylinder tests (ASTM C496/C496M) or tensile beam flexural tests (ASTM C78/C78M) can be used to determine concrete tensile strength in relation to compression strength of a specific concrete mixture being used.

5.1.3 Modulus of elasticity—Another important property of concrete is the modulus of elasticity, which is inversely related to deflection. ACI 318 relates the modulus of elasticity to concrete unit weight and the square root of compressive strength. This empirical relationship is often used, with caution, for calculating the deflection of early-age concrete members on the basis that it adequately reflects behavior of concrete modulus of elasticity after approximately 24 hours. However, when slabs are loaded at very early age or when course aggregates adversely influence modulus of elasticity estimates, testing of specific concrete mixtures at early age is advised (Oluokun et al. 1991; Khan et al. 1995; Pinto and Hover 1999; Mesbah et al. 2002).

5.2—Construction load factors

ACI 318 specifies load factors for specific combinations of factored service loads used in design of the permanent structure. It does not, however, specify load factors for construction stage loads. ACI 347R does not specify construction load factors. ASCE/SEI 37 specifies a minimum load factor of 1.4 for dead load when combined with only construction and material loads, a 1.2 for dead load for all other combinations, and a load factor of 1.6 for construction live loads. ASCE/SEI 37 also permits allowable stress design as well as load and resistance factor design (LRFD). Care should be taken to apply load factors consistently while performing strength or LRFD design checks.

Use the same load factors and load combinations required by ACI 318, that is, 1.2 and 1.6 for construction dead and live load, respectively. The ACI 318-specified strength reduction factors should also be applied during the strength evaluation of the partially completed structure.

The load and strength reduction factors of previous ACI 318 editions should be used if the structural design of the building is based on earlier ACI 318 codes. Consider the load factors discussed by ASCE/SEI 37 for construction loads not included in ACI 318.

5.3—Early-age strength of concrete slabs

5.3.1 Flexural strength—The flexural strength gain of early-age slabs, $R_c$, as compared to the 28-day flexural strength, $R_{28}$, can conservatively be taken as proportional to the concrete compressive strength gain between those ages. Although the available concrete compressive strength has little effect on the flexural strength of a lightly reinforced member (refer to Fig. 5b), other properties such as shear and bond strength are directly affected by concrete compressive strength.

It is reasonable to assume that the structure is designed to satisfy the governing code provisions for flexure. Therefore, the available flexural strength of early-age concrete members is expressed as

$$\phi R_c = \beta \phi R_{28}$$

5.3.2 Shear strength—For flat-slab and flat-plate structures, one of the critical strength parameters during construction is usually punching shear strength at columns. The available punching shear strength depends on the size of the shear perimeter and the concrete tensile strength. If factored construction loads do not exceed the strength of the permanent structure (reduced to take into account the early strength of concrete), then the punching shear strength at the columns is considered adequate. Consider punching shear forces due to loads from shores/reshores on top of the slabs,
especially when the shores/reshores are not aligned from one level to another, or at the bottom level of reshores. Although in most cases the shore/reshore axial strength governs over punching shear strength of the slab, punching shear forces imparted by shores/reshores can be critical in some cases, depending on the slab thickness, shore/reshore base area, and applied construction load. In such cases, an analysis should be made to ensure that maximum punching shear stress is within code limits. Additionally, shear may control in a one-way slab when shore loads are placed near a beam face; therefore, consider the shear capacity of the slab.

ACI 318 relates the concrete punching shear stress of two-way slabs to the square root of the concrete compressive strength. The shear force capacity is then calculated by

\[ V_c = K \sqrt{f_y b_d} d \]  

where \( K \) is the result coefficient of the governing punching shear equations from ACI 318-14 Sections 22.5 and 22.6 that is a function of column and slab geometry.

Therefore, during construction,

\[ V_{sc} = \phi K \sqrt{f_y b_d} d \]

where \( V_{sc} \) is the factored construction shear force.

The shear strength of beams, one way slabs and joists should be calculated in accordance to ACI 318.

5.4—Serviceability of concrete slabs

Construction loads imposed on the supporting slabs at early ages are typically comparable in magnitude to the permanent structure service loads. Loads applied onto early-age slabs can cause increased long-term creep deflection. These factors, in combination with normal shrinkage and many other factors, can adversely affect the long-term serviceability of concrete structures. As previously discussed, excessive construction loads are usually the result of an inadequate number of shored/reshored levels, early stripping, or both.

The early-age concrete slab nonrecoverable deformations 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 deformations compared to concrete members loaded after attaining the specified strength and stiffness (Sbarounis 1984; Fu and Gardner 1986; Ofosu-Asamoah and Gardner 1997). Low concrete tensile strength affects concrete cracking, which in turn reduces slab stiffness and increases slab deflection. The extent of initial concrete cracking depends on the magnitude of the amount of early-age shrinkage and construction loads, and the age of the concrete when the loads are applied, which in turn affect the shoring/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 concrete strength. Most early-age creep deflections are not fully recoverable. Deflection due to a combination of higher creep and premature cracking caused by construction loads increases the normal elastic, creep, and shrinkage deflection (Huang et al. 2016).

The ACI 318 requirements for minimum slab thickness do not consider the effects of early-age construction loads on long-term deflections, and the Code required minimum span-depth ratios cannot be used as a safeguard against cracking and deflection when construction loads are 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/architect and the formwork engineer/contractor is recommended for checking slab deflections during construction. Calculations of immediate and long-term deflections should be based on principles in ACI 435R. This guide recommends using the effective moment of inertia when construction loads are applied, a cracking moment using \( 4 \sqrt{f_{cy}} \) to represent the effect due to shrinkage and long-term deflection multipliers. The calculated deflections using ACI 435R principles will result in larger deflections than those calculated based on applying service loads at 28 days, a cracking moment using \( 7.5 \sqrt{f_{cy}} \) and the long-term multipliers in ACI 318. If field measurements of deflections are desired for comparison to calculated deflections, these measurements should be taken at the top of the slab and also soffit if needed. Selected locations for sampling (for example, midspans, cantilever tips, or others critical locations) should be consistent throughout the structure and always accessible for verification. Measurements should be taken according to the following sequence:

(a) Immediately following the slab placement and finishing, before any supporting formwork is removed and, if applicable, before any post-tensioning strands are tensioned
(b) Immediately following the initial release of the shoring, as the slab deflects under its own load, taking note of formwork and other construction loads above the unshored slab, in advance of the next slab placement
(c) Following the removal of reshores

5.5—Strength of formwork

Forms, shores, and reshores comprising the formwork system should be adequate to carry the applied construction loads. The construction loads are determined by the construction load analysis discussed in 4.5. The shoring system load capacity can be checked following either load and resistance factor design (LRFD) or allowable stress design methods. ACI SP-4 presents a detailed procedure for formwork design including lateral bracing.

Inspection before concrete placement is recommended and is required in some jurisdictions, and shoring/reshoring drawings should be available at the site at all times.

CHAPTER 6—CONSTRUCTION EXAMPLES

6.1—Two-way slab construction

The following construction example assumes various scenarios with respect to the construction rate, concrete strength development, slab service loads, and shoring system.
6.1.1 Construction example data—A multistory, cast-in-place, reinforced concrete building is constructed using a system of shores and reshores. The building is designed based on ACI 318. A typical floor plan and elevation are shown in Fig. 6.1.1.

6.1.1.1 Member sizes
(a) Slab thickness: 9.0 in. (229 mm)
(b) Interior column size: 20 in. (508 mm) square
(c) Exterior column size: 12 x 20 in. (305 x 508 mm)
(d) Spandrel beam size: 12 x 20 in. (305 x 508 mm)

6.1.1.2 Concrete structure service loads
(a) Slab self-weight: 112.5 lb/ft² (5.39 kPa)
(b) Superimposed dead load: 20 lb/ft² (0.96 kPa)
(c) Live load cases:
   1) LL = 50 lb/ft² (2.4 kPa) (No live load reduction taken)
   2) LL = 100 lb/ft² (4.8 kPa) (No live load reduction taken)

6.1.1.3 Concrete mixtures
(a) Concrete unit weight: 150 lb/ft³ (24kN/m³)
(b) Slabs and beams:
   Design concrete strength f’c = 4000 psi (27.6 MPa)
   Cylinder strengths: f’c (7 days) = 3300 psi (22.7 MPa); f’c (28 days) = 4650 psi (32.1 MPa)
(c) Columns: design concrete strength f’c = 5000 psi (34.5 MPa)
   During concrete mixture design, the measured cylinder strengths are of laboratory-cured cylinders. The measured strengths are also used to develop the concrete maturity relationships for assessing early-age concrete strength development. The early-age concrete strength can also be established by testing field-cured cylinders.

6.1.1.4 Shoring system
(a) One level of shores with two reshoring cases:
   1) Three levels of reshores
   2) Two levels of reshores
(b) Shore/reshore material: Douglas Fir-Larch, construction grade
(c) Shore/reshore size: 4 x 4 in. (100 x 100 mm), S4S, posts
(d) Modulus of elasticity of wood (reference design value):
   \[ E_w = 1500 \text{ ksi} \times 10^3 \text{ MPa} \]
(e) Compressive strength of wood parallel to grain (reference design value):
   \[ F_c = 1650 \text{ psi} \times 10^{12} \text{ MPa} \]

6.1.1.5 Construction loads
(a) Slab self-weight: 112.5 lb/ft² (5.39 kPa)
(b) Live load during placement: 50 lb/ft² (2.4 kPa)
(c) Form and shore load: 6.5 lb/ft² (0.31 kPa)

6.1.1.6 Concrete curing condition scenarios
(a) Hot weather: assume average concrete temperature during curing of 80°F (26.7°C)
(b) Mild weather: assume average concrete temperature during curing of 60°F (15.5°C)
(c) Cold weather: assume average concrete temperature during curing of 40°F (4.4°C)

6.1.1.7 Construction rate scenarios
(a) One floor per week
(b) One floor every 10 days

Although the one-floor-per-week rate does not provide enough time to recover the forming material from the floor below to install it above the floor, it can be assumed that a second set of forms is available at the site to achieve this rate of construction. An alternate would be to adjust the concrete mixture proportion, concrete curing temperature, or both, to achieve faster concrete strength development and, therefore, quicker stripping time.

6.1.2 Construction load distribution—the construction load distribution between concrete slabs and the shoring/reshoring system is evaluated by using the simplified method. Although this example uses a wood shoring/reshoring system, it is assumed that compressibility of the shoring/reshoring system has little impact on construction load redistribution. The results of the shoring system using one shore level in combination with three reshore levels are shown in Table 6.1.2. A similar construction load distribution table can be developed for a second case of two reshore levels. Note that Table 4.5 can also serve as a basis for the construction load distribution for this...
Table 6.1.2—Construction example: simplified analysis of load on shores and slabs using one level of shoring, three levels of reshoring

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation and remarks</th>
<th>Structure status</th>
<th>Load on slab in multiples of ( D )</th>
<th>Shore/reshore load at end of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>At beginning</td>
<td>Change during operation</td>
</tr>
<tr>
<td>1</td>
<td>Place Level 1 concrete. Full load is transmitted to ground by shores.</td>
<td><img src="image1" alt="Diagram" /></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Construction live load is gone. Remove Level 1 shores snug but not loaded. Level 1 slab carries its own weight.</td>
<td><img src="image2" alt="Diagram" /></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Form, shore, and place Level 2 concrete. Slab 1 cannot deflect, so all load goes through reshores to the ground.</td>
<td><img src="image3" alt="Diagram" /></td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Slab 2 hardens and construction live load is gone. Remove Level 2 forms and shores, allowing Slab 2 to carry its own weight. Then reshore Slab 2 snugly, but without picking up load in reshores.</td>
<td><img src="image4" alt="Diagram" /></td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Form, shore, and place Level 3 concrete. Slabs 1 and 2 cannot deflect and therefore do not pick up any added load. All added load of Level 3 is carried to ground by shores and reshores.</td>
<td><img src="image5" alt="Diagram" /></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Slab 3 hardens and construction live load is gone. Remove shores beneath Level 3, allowing slab to deflect and carry its own weight. Then place reshores beneath Level 3 slab, snug but not loaded.</td>
<td><img src="image6" alt="Diagram" /></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Form, shore, and place Level 4 concrete. All added load, including construction live load, is carried to the ground through the reshores. Slabs cannot deflect and there is no change in slab loading.</td>
<td><img src="image7" alt="Diagram" /></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>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.</td>
<td><img src="image8" alt="Diagram" /></td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 6.1.2 (cont.)—Construction example: simplified analysis of load on shores and slabs using one level of shoring, three levels of reshoring

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

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

11 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, and the reshores under 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 8 and the cycle will repeat when Level 6 concrete is placed.

Notes:
The results indicated in the table should not be used for actual projects because the construction live loads and formwork loads may differ from those assumed in the table.

D is weight of slab (112.5 lb/ft² [5.39 kPa]).
Construction live load = 0.44D.
Shore and form weight = 0.06D.
Reshore weight is neglected.

The results indicate the following:
- The maximum slab load first occurs on the fourth floor slab during placement of the fifth floor slab (Step 9). The fifth floor is the first floor level to be placed after the reshores were removed from the first floor, thus removing the direct path of the construction load to the ground. The maximum slab load is repeated for all the floors above the fifth level every time the shoring system is installed at the active level and the new slab is placed. The maximum slab construction load is 1.38D, or 155 lb/ft² (7.42 kPa), for the three reshore system, and 1.5D, or 169 lb/ft² (8.09 kPa), for the two reshore system.
- The maximum shoring and reshoring construction load occurs during placement of the top floor level. This load includes the slab self-weight 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/reshore construction load is 1.5D, or 169 lb/ft² (8.09 kPa), for both the three- and two-reshore system.

Both the upper shoring level and all the reshore levels carry the same maximum construction load as long as the shoring/reshoring system is supported on the ground. After removal of the lowest level of reshores from the ground, the maximum applied construction load on the reshores becomes less at the lower reshored levels because each slab is carrying a portion of the load to the columns. Therefore, the lower reshored levels will require fewer reshore posts than the upper floors.

According to the simplified method, construction loads are distributed among the supporting slabs in proportion to their relative stiffnesses. Floor slabs of this example have equal thickness and approximately equal flexural stiffness. Thus, the construction load is distributed equally among the interconnected floor slabs. In cases where the floor slab stiffnesses and slab weight varies, consider slab stiffness when calculating the slab and shore/reshore construction loads.

6.1.3 Concrete strength development—The engineer/architect should specify the minimum compressive strength of concrete to be attained before removal of forms or shores. The strength can be determined by test methods described in 5.1.1 and approved by the architect/engineer.

For this example, the concrete maturity method is employed to determine the concrete strength development. The strength-maturity relationship of concrete mixtures is based on the principle that the strength of concrete depends on the temperature history of concrete during the curing period. A detailed description of the maturity method and application is given in ASTM C1074, ACI 228.1R, and Carino (2004).

Figure 6.1.3 shows concrete compressive strength development based on application of the maturity method for the concrete mixture assumed for this example. Figure 6.1.3 indicates a significant strength difference for the 40, 60, and 80°C (4.4, 15.5, and 26.7°C) curing temperatures. The concrete strengths shown in Fig. 6.1.3 are valid only for the assumed specific concrete mixture used in this example and the assumed curing conditions. These concrete strengths should not be used beyond this example. The maturity method can be applied to predict the concrete strength development for other concrete mixtures and curing conditions.

While it is useful to demonstrate the differences in strength gain for a given mixture proportion at 40, 60, and 80°C (4.4, 15.5, and 26.7°C) constant concrete temperature, in practice, the actual concrete temperature will vary during curing due to cementitious material hydration and ambient environment. Different mixture proportions would likely be used to account for the different expected ambient temperature environments. The strength gain curve for each specific concrete mixture proportion should be obtained from the concrete supplier for the project.

6.1.4 Adequacy of concrete slabs

6.1.4.1 Available early-age slab load capacity—The concrete slabs for this example were designed for the slab dead load of 112.5 lb/ft² (5.39 kPa), superimposed dead load of 15 lb/ft² (0.75 kPa) and the superimposed construction load of 15 lb/ft² (0.75 kPa) during the construction placement. The maximum applied construction load on the reshores becomes less at the lower reshored levels because each slab is carrying a portion of the load to the columns. Therefore, the lower reshored levels will require fewer reshore posts than the upper floors.

According to the simplified method, construction loads are distributed among the supporting slabs in proportion to their relative stiffnesses. Floor slabs of this example have equal thickness and approximately equal flexural stiffness. Thus, the construction load is distributed equally among the interconnected floor slabs. In cases where the floor slab stiffnesses and slab weight varies, consider slab stiffness when calculating the slab and shore/reshore construction loads.

6.1.3 Concrete strength development—The engineer/architect should specify the minimum compressive strength of concrete to be attained before removal of forms or shores. The strength can be determined by test methods described in 5.1.1 and approved by the architect/engineer.

For this example, the concrete maturity method is employed to determine the concrete strength development. The strength-maturity relationship of concrete mixtures is based on the principle that the strength of concrete depends on the temperature history of concrete during the curing period. A detailed description of the maturity method and application is given in ASTM C1074, ACI 228.1R, and Carino (2004).

Figure 6.1.3 shows concrete compressive strength development based on application of the maturity method for the concrete mixture assumed for this example. Figure 6.1.3 indicates a significant strength difference for the 40, 60, and 80°C (4.4, 15.5, and 26.7°C) curing temperatures. The concrete strengths shown in Fig. 6.1.3 are valid only for the assumed specific concrete mixture used in this example and the assumed curing conditions. These concrete strengths should not be used beyond this example. The maturity method can be applied to predict the concrete strength development for other concrete mixtures and curing conditions.

While it is useful to demonstrate the differences in strength gain for a given mixture proportion at 40, 60, and 80°C (4.4, 15.5, and 26.7°C) constant concrete temperature, in practice, the actual concrete temperature will vary during curing due to cementitious material hydration and ambient environment. Different mixture proportions would likely be used to account for the different expected ambient temperature environments. The strength gain curve for each specific concrete mixture proportion should be obtained from the concrete supplier for the project.

6.1.4.2 Applied construction load—For the system with two levels of reshores (Table 4.5), the maximum slab load during construction occurs on Level 3 during the placement of the fourth level slab (Step 7). The construction live load of 50 lb/ft² (2.4 kPa) is distributed equally to three levels at 17 lb/ft² (0.82 kPa). The total load is 1.5D or 152 lb/ft² (8.09 kPa), with dead load Dc = 152 lb/ft² (7.27 kPa) and live load Lc = 17 lb/ft² (0.82 kPa), and the factored construction load is

**Applied construction load**

The construction live load of 50 lb/ft² (2.4 kPa) is distributed equally to three levels at 17 lb/ft² (0.82 kPa). The total load is 1.5D or 152 lb/ft² (8.09 kPa), with dead load Dc = 152 lb/ft² (7.27 kPa) and live load Lc = 17 lb/ft² (0.82 kPa), and the factored construction load is

\[
U_e = 1.2D_c + 1.6L_c = 1.2 \times 152 \text{ lb/ft}^2 + 1.6 \times 17 \text{ lb/ft}^2 = 210 \text{ lb/ft}^2 (10.05 \text{ kPa})
\]
Similarly, for the system with three levels of reshores (Table 6.1.2), the maximum slab load during construction occurs on Level 4 during the placement of the fifth level slab (Step 9). The construction live load of 50 lb/ft² (2.4 kPa) is distributed equally to four levels at 12 lb/ft² (0.60 kPa). The total load on Level 4 is 1.38D or 155 lb/ft² (7.44 kPa), with dead load $D_c = 142.5$ lb/ft² (6.82 kPa) and live load $L_c = 12.5$ lb/ft² (0.60 kPa), and the factored construction load is

$$U_e = 1.2D_e + 1.6L_e = 1.2 \times 142.5 \text{ lb/ft}^2 + 1.6 \times 12.5 \text{ lb/ft}^2 = 191 \text{ lb/ft}^2 (9.15 \text{ kPa})$$

The construction loads and maximum slab load capacities are summarized in Table 6.1.4.2.

### 6.1.4.3 Strength adequacy

Table 6.1.4.2 shows that for a 7-day cycle and with 50 lb/ft² (2.4 kPa) live load, two levels of reshoring will be adequate only for the 80°F (26.7°C) curing temperature. The table also shows that, except for the 100 lb/ft² (4.8 kPa) live load on the 15-day cycle, all 40°F (4.4°C) cured slabs will be overloaded when only two floors of reshores are used. This overload condition can be avoided by changing the mixture proportion, increasing the ambient curing temperatures, or by increasing the number of reshore levels.

### 6.1.4.4 Slab deflections

Although the slabs may have enough flexural strength to carry the high construction loads, they may lack the concrete tensile strength and stiffness to limit cracking and deflection to be suitable for the building’s intended use.

Deflection calculations for service load conditions should be based on the smallest effective moment of inertia determined from either the construction loads with partial concrete strength or the service loads with full concrete strength. A detailed deflection calculation method taking the construction loads into consideration is provided in ACI 435R.

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

### 6.1.5 Adequacy of shoring/reshoring system

The wood shores/reshores used in this example are construction Grade S4S, Douglas Fir-Larch sawn lumber with reference design value of compressive stress parallel to grain $F'_c = 1650$ psi (11.37 MPa) and $F'_m = 550,000$ ksi (3790 MPa). The unbraced shore/reshore length for a typical floor is taken as 9 ft 3 in. (282 m). The shores are assumed to be pin-ended. The adjusted allowable axial compression design value $(F'_c)$ is calculated to be 420 psi (2.89 MPa). The allowable stress is calculated according to the specification requirements of AWC NDS for visually-graded sawn lumber. Based on the adjusted compression design value, the maximum allowable axial compression load on a single post is 5150 lb (22.91 kN).

As calculated previously, the maximum uniformly distributed construction load to the shores or reshores is 169 lb/ft² (8.09 kPa). Based on the maximum allowable axial load of each shore or reshore, the maximum tributary area of each post is calculated to be approximately 30 ft² (2.80 m²). A practical shore or reshore spacing can be chosen, provided the maximum tributary area of each post is kept within the calculated limit.

Special consideration should be given to the first-floor shores and reshores because the first floor is taller than a typical floor and, therefore, the allowable axial load of the shores and reshores is lower. The unbraced shore/reshore length of the first floor is 13 ft 3 in. (4.04 m). The adjusted compression design value and axial load are 212 psi (1.46 MPa) and 2600 lb (11.56 kN), respectively. The maximum tributary area of the shores and reshores at the first floor is approximately 15 ft² (1.40 m²), which requires a close spacing of wood posts, for example, 3 x 5 ft (0.9 x 1.5 m). Properly installed horizontal lacing, bracing, or both, is required to decrease the unbraced length, thereby increasing the shore/reshore load capacity and the post spacing.

Similar calculations should be performed for the lower floor reshores that, according to Table 6.1.2, receive reduced construction loads as the construction advances and the reshores are removed from the ground floor.

ACI SP-4 provides extensive details for formwork design. Where manufactured shores/reshores are used, consult the manufacturer’s data for safe working loads and other safety requirements of the shores/reshores and hardware.

### Table 6.1.4.2—Comparison of slab maximum capacity to factored construction load distribution

<table>
<thead>
<tr>
<th>Construction cycle, days</th>
<th>Design</th>
<th>Available slab load capacity at selected temperatures, lb/ft² (kPa)</th>
<th>Maximum slab factored construction load, lb/ft² (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Live load, lb/ft² (kPa)</td>
<td>Two reshore levels, lb/ft² (kPa)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40°F (4.4°C)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>50 (2.4)</td>
<td>213 (10.20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100 (4.8)</td>
<td>284 (13.60)</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>50 (2.4)</td>
<td>237 (11.35)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100 (4.8)</td>
<td>316 (15.13)</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>50 (2.4)</td>
<td>239 (11.44)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100 (4.8)</td>
<td>319 (15.27)</td>
</tr>
</tbody>
</table>

### Note:

1. Table 6.1.4.2 shows that the maximum tributary area of each post is kept within the calculated limit.

2. Special consideration should be given to the first-floor shores and reshores because the first floor is taller than a typical floor and, therefore, the allowable axial load of the shores and reshores is lower. The unbraced shore/reshore length of the first floor is 13 ft 3 in. (4.04 m). The adjusted compression design value and axial load are 212 psi (1.46 MPa) and 2600 lb (11.56 kN), respectively. The maximum tributary area of the shores and reshores at the first floor is approximately 15 ft² (1.40 m²), which requires a close spacing of wood posts, for example, 3 x 5 ft (0.9 x 1.5 m). Properly installed horizontal lacing, bracing, or both, is required to decrease the unbraced length, thereby increasing the shore/reshore load capacity and the post spacing.

3. Similar calculations should be performed for the lower floor reshores that, according to Table 6.1.2, receive reduced construction loads as the construction advances and the reshores are removed from the ground floor.

4. ACI SP-4 provides extensive details for formwork design. Where manufactured shores/reshores are used, consult the manufacturer’s data for safe working loads and other safety requirements of the shores/reshores and hardware.
6.2—Post-tensioned construction example

This construction example illustrates the effects of post-tensioning on the shoring/reshoring loads. After stressing of tendons, construction loads are partially or totally relieved from the shores that support the tensioned concrete members. The relieved shore loads are transferred to shores that support other members that have yet to be tensioned. Thus, the selection and design of the shoring-reshoring system should be based not only on the placement load, but also the post-tensioning stressing sequence and resulting transfer loads.

This example does not account for any load redistribution that will occur due to structural deflections, shoring/reshoring system axial shortening, or both. Further, the example assumes that the structural members do not have the capacity to carry added post-tensioning transfer loads before stressing of such members is complete. Often in the case of large transfer girders, post-tensioning is provided to support upper levels of the structure that are not present at the time the girder floor is post-tensioned. Finally, the example assumes 100 percent of the structure's dead load is balanced by the post-tensioning and it is further assumed that the shores are fully relieved of the slab dead load. A safe method is to use the full dead load; however, the shoring designer may elect to determine the actual load transfer, or use information furnished by the engineer/architect.

ACI SP-4 provides general guidelines on formwork for post-tensioned structures. Bordner (1987) presents a detailed method on how construction loads are distributed during the post-tensioning process. The following example is based on the concepts and examples given in SP-4 and Bordner (1987).

6.2.1 Post-tensioned example data—A post-tensioned multistory reinforced concrete building is to be constructed using a system of shores and reshores. A partial floor plan of a typical story level is given in Fig. 6.2.1. The post-tensioned members include the slabs, beams, and girders.

6.2.1.1 Member sizes
(a) Slab thickness: 6 in. (152 mm)
(b) Beams: 24 x 32 in. (610 x 813 mm)
(c) Girders: 30 x 36 in. (762 x 914 mm)
(d) Columns: 24 x 24 in. (610 x 610 mm)
(e) Story heights: 10 ft (3.0 m)

6.2.1.2 Service loads
(a) Slab self-weight: 75 lb/ft² (3.59 kPa)
(b) Beam stem: 650 lb/ft (9.48 kN/m)
(c) Girder stem: 937.5 lb/ft (13.68 kN/m)
(d) Superimposed dead load: 20 lb/ft² (0.96 kPa)
(e) Live load: 50 lb/ft² (0.24 kPa)

Live load reductions were considered in the design of beams and girders.

6.2.1.3 Concrete mixtures—The same as the two-way slab construction example presented in 6.1.1.3.

6.2.1.4 Shoring system
(a) One level of shores with two levels of reshores
(b) Shore/reshore material and sizes are the same as the two-way slab construction example

6.2.1.5 Construction loads
(a) Slab, beam, and girder self-weight
(b) Live load during concrete placement: 50 lb/ft² (2.4 kPa)
(c) Live load during post-tensioning: 20 lb/ft² (0.98 kPa)
(d) Form and shore self-weight:

For slabs: 5 lb/ft² (0.24 kPa)
For beams and girders (estimated): 20 lb/ft (0.29 kN/m)

6.2.1.6 Average concrete temperature during curing—
60°F (15.5°C) average daily concrete curing temperatures.

6.2.1.7 Construction rate—One floor level every 10 days.

6.2.1.8 Post-tensioning sequence—The slabs, beams, and girders are post-tensioned at the end of each 10-day cycle in the following sequence:
1. Temperature tendons (no load transfer)
2. Slab tendons, 100 percent
3. Beam tendons, 100 percent
4. Girder tendons, 100 percent

This sequence represents the worst condition for calculating shoring loads, which should be assumed, unless the tensioning sequence is known.

6.2.2 Construction load distribution—The construction load distribution is calculated corresponding to two construction stages. The first stage is during concrete placement of the top active level, and the second stage during post-tensioning. The method of calculation of construction loads during concrete placement is the same as the previous example; refer to 6.1.2.

6.2.2.1 Concrete placement stage—The construction load distribution between concrete slabs and the shoring/reshoring system is evaluated by using the simplified method. A construction load table similar to Table 4.5 for one level of shoring with two levels of reshoring would be developed. The maximum slab load occurs on the third-floor slab during placement of the fourth-floor slab. The maximum slab load is repeated for all floors above the fourth level every time the shoring system is installed at the active level and the new slab is placed.

During concrete placement, it is assumed that the three slab levels interconnected by reshoring equally share the weight of the newly placed slab. Thus, the maximum slab
construction load includes the slab self-weight and one-third of the dead and live loads from the new slab. 

Slab dead load  
- self-weight + 0.333(new slab weight + formwork load)  
- 75 lb/ft² + 0.333(75 + 5 lb/ft²)  
- 80 lb/ft² (11.67 kN/m)

Slab live load = 0.333(50 lb/ft²) = 16.7 lb/ft² (0.80 kPa)

Total maximum slab load = 118.4 lb/ft² (5.67 kPa)

The maximum shoring load occurs during the concrete slab placement step. The shoring construction load includes the dead load of concrete and form weight, and the live load of 50 lb/ft² (2.40 kPa). The shoring construction load is:

**Slab shores**

- Dead load:
  - Concrete = 75 lb/ft² (3.59 kPa)
  - Forms (estimated) = 5 lb/ft² (0.24 kPa)
  - Subtotal = 80 lb/ft² (3.83 kPa)
- Live load = 50 lb/ft² (2.40 kPa)
- Total = 130 lb/ft² (6.23 kPa)

**Beam shores**—dead load:
- Concrete = 2 ft × 32/12 × 1 ft × 150 lb/ft³ = 800 lb/ft³ (11.67 kN/m)
- Forms (estimated) = 20 lb/ft (0.29 kN/m)
- Subtotal = 820 lb/ft (11.96 kN/m)
- Live load = 2 ft × 50 lb/ft² = 100 lb/ft (1.46 kN/m)
- Total = 920 lb/ft (13.42 kN/m)

**Girder shores**—dead load:
- Concrete = 2.5 ft × 3 × 150 lb/ft³ = 1125 lb/ft² (16.4 kN/m)
- Forms (estimated) = 20 lb/ft (0.29 kN/m)
- Subtotal = 1145 lb/ft² (17.6 kN/m)
- Live load = 2.5 ft × 50 lb/ft² = 125 lb/ft² (1.82 kN/m)
- Total = 1270 lb/ft² (18.52 kN/m)

**6.2.2.2 Post-tensioning stage**—The post-tensioning of slabs, beams, and girders causes some upward movement of these members so that they carry their own weight and any other construction live load. Thus, once the members are stressed, the shores supporting the members are relieved from some or all loads. The relieved shore loads are transferred by the post-tensioned members directly to other supporting members that in turn transfer these loads to the shores supporting them. For example, post-tensioning of the slab relieves the construction load from the slab shores and transfers it to the beams. Shoring of beams carries the additional load from the slabs. When the beams are post-tensioned, the beam shores are relieved from the load and the load transferred to the girders and columns. Figure 6.2.2.2 illustrates the construction load transfer due to post-tensioning.

Following the prescribed post-tensioning sequence, shore loads are estimated as follows.

**6.2.2.3 Post-tensioning of slabs**

**Slab shores**—Carry only 5 lb/ft² (0.24 kPa) form load. All other shore load is transferred to the beams.

**Beam shores (center beam)**—
- Dead load: 820 lb/ft² + 75 lb/ft² × 17 ft = 2095 lb/ft³ (30.57 kN/m)
- Live load: 20 lb/ft³ × 19 ft = 380 lb/ft³ (5.55 kN/m)
- Total: 2475 lb/ft³ (36.12 kN/m)

**6.2.2.4 Post-tensioning of beams**

**Slab shores**—No load change from the previous step.

**Beam shores**—Carry only 20 lb/ft³ (0.29 kN/m) form load. All other shore load is transferred to the girders and columns.

**Girder shores**—Uniform load:

---

**GUIDE FOR SHORING/RESHORING OF CONCRETE MULTISTORY BUILDINGS (ACI 347.2R-17)**

---

Fig. 6.2.2.2—Post-tensioning sequence and construction load redistribution.
Dead load: 1125 lb/ft + 20 lb/ft² = 1145 lb/ft (16.70 kN/m)
Live load: 2.5 ft × 20 lb/ft² = 50 lb/ft² (0.73 kN/m)
Total uniform: 1195 lb/ft (17.43 kN/m)
Concentrated load at center span (reaction from beams):
Dead load: (2095 lb/ft - 20 lb/ft²) × 27.5 ft = 57,062 lb (253.82 kN)
Live load: 380 lb/ft × 27.5 ft = 10,450 lb (46.48 kN)
Total concentrated: 67,512 lb (300.31 kN)

6.2.2.5 Post-tensioning of girders—The post-tensioning of girders will relieve the load from the girder shores, and all construction loads are transferred to columns. Based on the foregoing shore load analysis of both the concrete placement stage and post-tensioning stage, the maximum shore loads are summarized as:

- **Slab shores**—130 lb/ft² (6.23 kPa), during concrete placement
- **Beam shores**—2475 lb/ft (36.12 kN/m), during slab tensioning
- **Girder shores**—1195 lb/ft (17.43 kN/m) uniform; 70,125 lb (311.93 kN) concentrated, during beam tensioning

This example shows that maximum shore loads can occur during the tensioning process. These loads are much larger than the shore loads during concrete placement. The shore load redistribution is affected by the sequence and level of post-tensioning. For example, should the sequence of post-tensioning be reversed, such as girders, beams, and slabs, then the shore loads during tensioning could be lower than those shown in the aforementioned calculation. Such sequence, however, is limited to the amount of stage load balancing. Usually, the amount of load balancing is less than the dead load of the structural members. Excessive post-tensioning may cause excessive upward deflections as well as development of damaging reverse stresses, because the expected service loads are not necessarily present during post-tensioning.

**6.2.3 Adequacy of concrete members**—The maximum allowable slab load at the age of 10 days with curing temperature of 60°F (15.5°C) is estimated as

\[ U_{c8} = 1.2 \times (75 \text{ lb/ft}^2 + 20 \text{ lb/ft}^2) + 1.6 \times 50 \text{ lb/ft}^2 = 194 \text{ lb/ft}^2 (9.29 \text{ kPa}) \]

The factored construction load on the slab is

\[ U_c = 1.2D_c + 1.6u_c = 1.2 \times 101.7 \text{ lb/ft}^2 + 1.6 \times 16.7 \text{ lb/ft}^2 = 149 \text{ lb/ft}^2 (7.12 \text{ kPa}) \]

The ratio of early-age concrete compressive strength to the 28-day specified compressive strength is 0.86 (Fig. 6.1.3). Therefore, the maximum allowable slab load is 167 lb/ft² (8.00 kPa), which is larger than the construction factored load of 149 lb/ft² (7.12 kPa).

Similar design checks should be performed for beams and girders. The beams and girders of the floor below should be checked for the construction load that is transferred onto them during post-tensioning of the floor above. In addition to strength adequacy, the concrete slabs, beams, and girders should be checked for deflections.

**6.2.4 Adequacy of shoring/reshoring system**—The shore/reshores used in this example are the same as those for the previous example; refer to 6.1.1(d). The allowable compressive stress on a 4 x 4 in. (100 x 100 mm), S4S, 9.5 ft (2.90 m) long wood shore is estimated to be 400 psi (2.75 MPa). Therefore, the allowable axial load on a wood shore is 4900 lb (21.80 kN).

The shores and reshores should be sized and spaced so construction loads do not exceed the maximum allowable load for each individual shore/reshore member. The following shore design considers only the shores below the top active level. Similar analysis and design should be performed for the reshoring that supports the floors below.

**6.2.4.1 Slab shores**—The maximum slab shore load and maximum allowable axial shore load were previously calculated (6.2.2.5 and 6.2.4) to be 1195 lb/ft² (6.23 kPa) and 4900 lb (21.80 kN), respectively. The maximum tributary area of each shore is calculated to be approximately 36 ft² (3.34 m²). Based on the maximum shore tributary area, a practical shore spacing can be chosen.

**6.2.4.2 Beam shores**—The maximum beam shore load is estimated to be 2475 lb/ft (36.12 kN/m). Allowable axial shore load for beams may be higher because the unbraced length is smaller. Based on the maximum allowable axial shore load, a practical shore spacing is determined to be 22 in. (559 mm) on center. If only the concrete placement loads are considered and the post-tensioning transfer loads ignored, the shore spacing would be as much as 5 ft (1.52 m). With such shore spacing, the shores would be highly overstressed after post-tensioning, leading to possible failure of both the shoring system and the supported concrete beams and slabs.

**6.2.4.3 Girder shores**—The maximum girder shore load is estimated to be 1195 lb/ft (17.43 kN/m) and 67,512 lb (300.31 kN) concentrated load at midspan from the supported beams. Based on the maximum allowable axial shore load, the practical shore spacing is determined to be 48 in. (1219 mm) on center along the girder length. Additional shores are required at the girder midspan to carry the expected concentrated load. Considering the magnitude of the concentrated load, it is not practical to use the 4 x 4 in. (100 x 100 mm), S4S, wood shores. Larger size timber or steel shores should be considered.

**CHAPTER 7—REFERENCES**

ACI committee documents and documents published by other organizations are listed first by document number, full title, and year of publication followed by authored documents listed alphabetically.

*American Concrete Institute*

ACI 228.1R-03—In-Place Methods to Estimate Concrete Strength
ACI 301-16—Specifications for Structural Concrete
ACI 318-14—Building Code Requirements for Structural Concrete and Commentary
ACI 347R-14—Guide to Formwork for Concrete
GUIDE FOR SHORING/RESHORING OF CONCRETE MULTISTORY BUILDINGS (ACI 3472R-17) 21

ACI 435R-95(00)—Control of Deflection in Concrete Structures
ACI SP-4(14)—Formwork for Concrete

American National Standards Institute (ANSI)/American Society for Safety Engineers
ANSI/ASSE A10.9-2013—Safety Requirements for Concrete and Masonry Work

American Society of Civil Engineers
ASCE/SEI 37-14—Design Loads on Structures During Construction

American Wood Council

ASTM International
ASTM C78/C78M-16—Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C496/C496M-11—Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
ASTM C1074-11—Standard Practice for Estimating Concrete Strength by the Maturity Method

Occupational Safety and Health Administration
OSHA 29 CFR 1926—Safety and Health Regulations for Construction

Authored documents


As ACI begins its second century of advancing concrete knowledge, its original chartered purpose remains “to provide a comradeship in finding the best ways to do concrete work of all kinds and in spreading knowledge.” In keeping with this purpose, ACI supports the following activities:

- Technical committees that produce consensus reports, guides, specifications, and codes.
- Spring and fall conventions to facilitate the work of its committees.
- Educational seminars that disseminate reliable information on concrete.
- Certification programs for personnel employed within the concrete industry.
- Student programs such as scholarships, internships, and competitions.
- Sponsoring and co-sponsoring international conferences and symposia.
- Formal coordination with several international concrete related societies.

Benefits of membership include a subscription to Concrete International and to an ACI Journal. ACI members receive discounts of up to 40% on all ACI products and services, including documents, seminars and convention registration fees.

As a member of ACI, you join thousands of practitioners and professionals worldwide who share a commitment to maintain the highest industry standards for concrete technology, construction, and practices. In addition, ACI chapters provide opportunities for interaction of professionals and practitioners at a local level to discuss and share concrete knowledge and fellowship.

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org
The American Concrete Institute (ACI) is a leading authority and resource worldwide for the development and distribution of consensus-based standards and technical resources, educational programs, and certifications for individuals and organizations involved in concrete design, construction, and materials, who share a commitment to pursuing the best use of concrete.

Individuals interested in the activities of ACI are encouraged to explore the ACI website for membership opportunities, committee activities, and a wide variety of concrete resources. As a volunteer member-driven organization, ACI invites partnerships and welcomes all concrete professionals who wish to be part of a respected, connected, social group that provides an opportunity for professional growth, networking and enjoyment.