Guide for Shoring/Reshoring of Concrete Multistory Buildings

Reported by ACI Committee 347

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This guide presents information and design criteria for shoring/reshoring operations during the construction of reinforced and post-tensioned multistory buildings. It provides methods for developing safe construction schedules and provides design examples. It is written for the use of formwork engineer/contractors and engineer/architects.

Keywords: construction loads; falsework; form removal, formwork; post-tensioning; reshoring; shoring.

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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 on the slabs below, may be significantly larger than the design loads of those floors. Furthermore, the concrete of slabs below may not have attained sufficient strength before the construction loads are applied. As a result, it is critical to determine the early-age load strength of the floor slabs, including punching shear strength, to avoid the possibility of partial or total failure of the structural system due to construction overload. To reduce and distribute the large construction load on the floor immediately below, to several lower floors, it is important to add reshores on lower levels. 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 reshoring or premature removal of supports and inadequate lateral bracing, have periodically occurred throughout the history of concrete construction. Premature removal of shores and reshores can contribute to construction failures or defects such as permanent excessive deflections (sagging) or cracking in the completed structure. Also, if over-loaded prematurely, time-dependent deflections under load (creep) will be larger, and sagging is more likely to be both noticeable and objectionable.

Decisions regarding the removal of forms and relocation of the shores are too often made without the benefit of a proper analysis of the structural effects, or in many cases, without any analysis at all. Still, there is no commonly accepted method considered as the proper analysis in the construction industry.

To ensure satisfactory performance and structural 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.

The formwork engineer/contractor is usually guided in formwork operations by the following codes, standards, or guides:

- ACI 347, "Guide to Formwork for Concrete"
- ACI 318, "Building Code Requirements for Structural Concrete"
- ACI 301, "Specifications for Structural Concrete"
- ANSI A10.9, "American National Standard for Construction and Demolition Operations—Concrete and Masonry Work—Safety Requirements"
- OSHA 29 CFR, "Construction Safety and Health Regulations for Construction"
- SEI/ASCE 37, "Design Loads on Structures During Construction"

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

The above referenced documents provide basic guidelines for general formwork operations. At the present time, however, 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. Investigation for usable procedures to establish safe and cost-effective shoring/reshoring operations has been ongoing for several decades. The effort has focused on two major areas: determining the distribution of loads carried by the concrete structure during construction, and estimating the strength of the concrete members to resist the construction loads.

This report outlines the importance of proper formwork design for multistory structures and provides basic requirements for safe construction. ACI SP-4, *Formwork for Concrete*, serves as an expanded commentary to ACI 347, "Guide to Formwork for Concrete," and provides detailed information relative to formwork practices, including a discussion of and procedures for shoring/reshoring analysis. ACI 318, "Building Code Requirements for Structural Concrete," requires contractors to furnish the building official, upon request, with the structural calculations and concrete strength data 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 to immediate and long-term deflections. This code requirement obliges contractors and formwork designers to 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 as economical as possible without compromising safety, quality, and serviceability.

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

CHAPTER 2—SHORING/RESHORING CONSTRUCTION NEEDS

2.1—Definitions

The following terms will be used in this guide. All these terms may also be found in ACI 347.

backshores—shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area at a time, without allowing the slab or member to deflect; thus, the slab or other member does not yet support its own weight or existing construction loads from above.

centering—specialized temporary support used in the construction of arches, shells, and space structures where the entire temporary support is lowered (struck or decentered) as a unit to avoid introduction of injurious stresses in any part of the structure.

engineer/architect—the engineer, architect, engineering firm, architectural firm, or other agency issuing project plans

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and specifications for the permanent structure, administering the work under contract documents.

formwork—total system of support for freshly placed concrete, including the mold or sheathing that contacts the concrete as well as all supporting members, hardware, and necessary bracing.

formwork engineer/contractor—engineer of the formwork system, contractor, or competent person 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. Preshores and the panels they support remain in place until the remainder of the complete bay has been stripped and backshored, a small area at a time.

reshores—shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a large area, requiring the new slab or structural member to deflect and support its own weight and existing construction loads applied before the installation of the reshores. If prefabricated drop-head shores for slab formwork systems 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. If they are not, then they become backshores.

shores—vertical or inclined support members designed to carry the weight of the formwork, concrete, and construction loads above.

2.2—Advantages 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 transmit that weight to the floor slab below, which can exceed that floor slab's design load capacity. 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 structure 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.

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 individually 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.

2.3—Types of forming systems

An important consideration in multistory cast-in-place concrete building construction is the type of forming system to be used. The selection of 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 modern prefabricated systems involving sophisticated engineering, materials, and equipment.

There are several prefabricated forming/shoring systems that are used to support concrete slabs during construction, including shoring-based systems, flying truss systems, column-mounted systems, and tunnel-forming systems. The following description of these systems is adapted from Jensen (1986).

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 shoring. These forms are sometimes made up in larger panels tied or ganged together as tables with attached frame-type shoring 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.

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.

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.

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 the concrete has gained sufficient strength, the tunnels are collapsed or telescoped and moved to the next pour. For longer slab spans, the tunnel form may be made in two inverted L-shapes (termed half-tunnels).

CHAPTER 3—CONSTRUCTION LOADS ON FORMWORK

3.1—Construction loads

Construction loads are those loads imposed on a partially completed or temporary structure during the construction process. Construction loads on formwork include vertical dead and live loads of both the formwork and the structure, horizontal loads due to wind, vertical and lateral impact of the equipment, and vertical and horizontal forces induced by inclined support members of the formwork. 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.

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3.1.1 *Gravity loads*—Gravity loads are categorized as either dead or live loads. The dead load includes the weight of reinforcement, freshly placed concrete, and formwork. The live load includes the weight of workers, equipment, tools, runways, and any impact produced by concrete placement or equipment operations. Though impact loads are dynamic, for simplicity they are treated as statically applied loads.

ACI Committee 347 recommends that both vertical supports and horizontal framing components of formwork be designed for a minimum live load of 50 lb/ft^2 (2.4 kPa) of horizontal projection to provide for weight of workers, runways, screeds, and other equipment. When motorized carts are used, the minimum live load should be 75 lb/ft^2 (3.6 kPa). The minimum design value for combined dead and live loads should be 100 lb/ft^2 (4.8 kPa), or 125 lb/ft^2 (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 it is assumed to be removed when the concrete placement is completed. 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 the construction operations, the construction live load used for design of reshores only may be reduced as provided by SEI/ASCE 37, Chapter 4, "Construction Loads."

3.1.2 *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 347 recommends a minimum horizontal load as either 100 lb/linear ft of floor edge (1.46 kN/m) or 2% of the total superimposed dead load, whichever is greater. SEI/ASCE 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.

3.1.3 *Other loads and conditions*—The 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 piling up of concrete, cannot be anticipated and must be avoided. Additionally, large point loads from shoring bearing on a thin slab may create excessive flexural and shear stress.

3.1.4 *Post-Tensioning load distribution*—Shores, reshores, and backshores need to be analyzed for the load redistribution that occurs when slabs and beams are post-tensioned. This analysis should also include members of floors below the post-tensioning activity because the relieved shoring loads above the post-tensioned members are transferred to the other supporting members.

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 engineers as to who is responsible for the determination of the post-tensioning sequence and the subsequent analysis of the construction load redistribution.

3.2—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, the formwork must be designed to resist its own weight, any other gravity loads, as well as horizontal and/or uplift wind loads.

3.3—Typical phases of construction

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:

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

If only shores are used, then the third and fourth phases are eliminated. According to ACI Committee 347, the reshores should be installed snugly under the slab, just stripped so that they are relatively load-free upon installation. This stripping procedure allows the slab to deflect under its own weight and the reshores are installed without preload.

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

Figure 3.1(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 lb/ft^2 (2.4 kPa) or 75 lb/ft^2 (3.6 kPa) construction live load is distributed among the interconnected slabs (n+1), (n+2), and (n+3) through the shoring/reshoring system.

Figure 3.1(b) shows Phase 2 when the slab has hardened and the construction live load is gone. Shores are removed from the (n+3) floor and any remaining load in these shores is redistributed to the slabs above.

Figure 3.1(c) shows the removal of the reshores from the (n+1) floor, Phase 3. Any load in the reshores is removed

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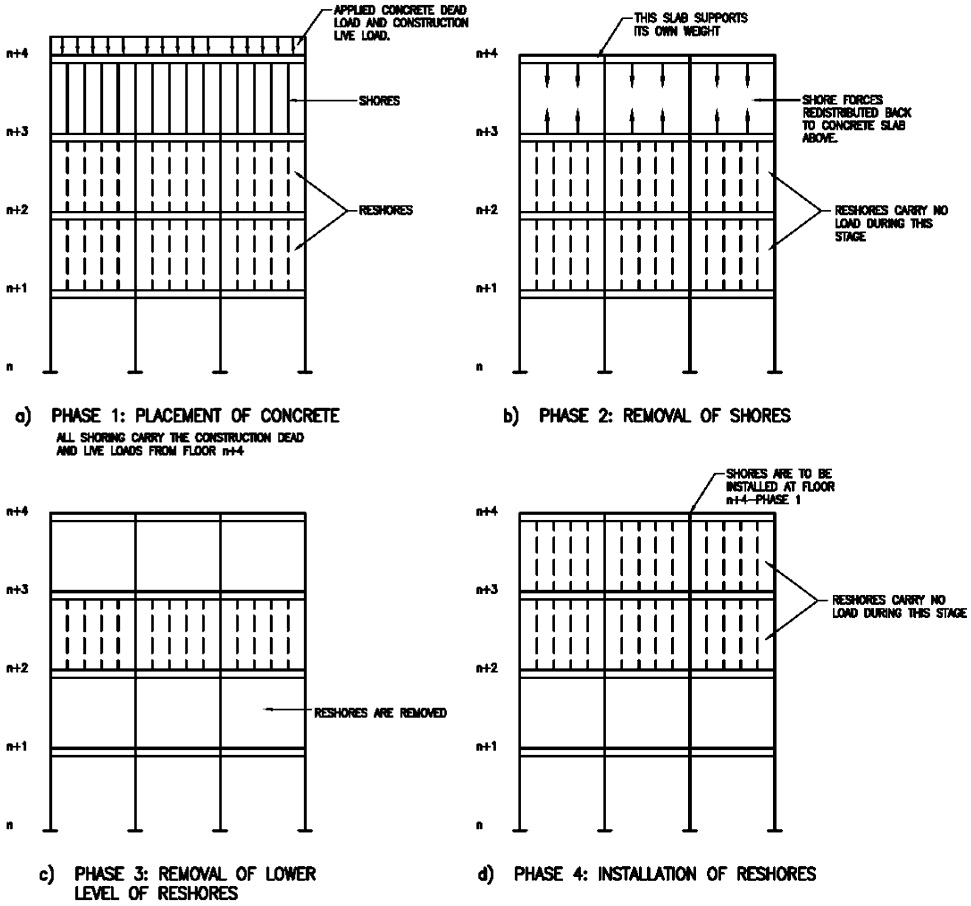


Fig. 3.1—Typical construction phases for multistory reinforced concrete buildings.

from the lowest slab (n+1) to which this load was supported and distributed to the slabs above.

Figure 3.1(d) shows the installation of the reshores on the (n+3) floor, Phase 4. During Phases 3 and 4, there is no structural disturbance to the floor above because the reshores are assumed to be relatively load-free upon installation.

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

3.4—Construction load distribution

The question of how construction loads are distributed between the formwork system and the newly cast supported concrete members has been 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.

The most significant work was published in 1963 by Grundy and Kabaila. This landmark paper presents a simple method of calculating construction loads carried by slabs and shores during the construction of multistory flat plate and flat slab concrete buildings. The method is known as the simplified method. The model consists of a single bay structure with the following assumptions:

- The deformations of concrete slabs are considered as elastic (shrinkage and creep of concrete are neglected);
- The shores are infinitely stiff relative to the supported slabs;
- The reactions of the shores are assumed as uniformly distributed;
- The lowest level of shores and reshores are supported on a rigid foundation at the beginning of the construction; and
- The loads applied to the slab/form system are distributed between the supporting slabs in proportion to their relative flexural stiffnesses. The original simplified method did not include the reshoring levels (Grundy and Kabaila 1963).

Obviously, the assumptions of the simplified method are not precisely true. Analytical studies by other researchers based on the simplified method verified its validity by comparing the predicted values with field measurements. Field measurements have 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 have been investigated and the simplified method has been refined in various ways: in construction methods and schedules, introduction of reshores, analysis of short-and long-term deflections, and in structural reliability. Further information on the simplified

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Table 3.1—Simplified analysis of loads on shores and slabs using one level of shoring, two levels of reshoring

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

RIGID SUPPORT AT STARTING LEVEL
FRESHLY PLACED SLAB
HARDENED SLAB
STORY OF RESHORES
STORY OF SHORES AND FORMWORK

STEP	OPERATION AND REMARKS	STRUCTURE STATUS	Load on slab in multiples of D: At beginning	Change during operation	Total at end of operation	Shore/reshore load at end of operation
1	Place Level 1 concrete. Full load is transmitted to ground by shores	1	0	0	0	1.5 D
2	Construction live load is gone. Remove Level 1 shores, allowing Slab 1 to carry its own weight. Then place reshores beneath it, snug but not loaded.	1	0	+1 D	1 D	0
3	Form, shore, and place Level 2 concrete. Slab 1 cannot deflect and all added load goes through reshores to ground.	2 1	0 1 D	0 0	0 1 D	1.5 D 1.5 D
4	Slab 2 hardens 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.	2 1	0 1 D	+1 D 0	1 D 1 D	0 0
5	Form, shore, and place Level 3 concrete, including the 0.5 D construction live load and shore load. All added load goes through shores to the ground since slabs can't deflect further.	3 2 1	0 1 D 1 D	0 0 0	0 1 D 1 D	1.5 D 1.5 D 1.5 D
6	Construction live load is assumed removed as Slab 3 hardens. 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 load.	3 2 1	0 1 D 1 D	+1 D 0 0	1 D 1 D 1 D	0 0 0
7	Form, shore, and place Level 4 concrete with the assumed 0.5 D construction live load and shore load. The total new applied load, 1.5 D, is distributed equally to the three interconnected slabs.	4 3 2 1	0 1 D 1 D 1 D	0 +0.5 D +0.5 D +0.5 D	0 1.5 D 1.5 D 1.5 D	1.5 D 1 D 0.5 D 0
8	Level 4 concrete hardens and the construction live load of 0.4 D is removed in equal parts from the slabs to which it was distributed.	4 3 2 1	0 1.5 D 1.5 D 1.5 D	0 -0.13 D -0.13 D -0.14 D	0 1.37 D 1.37 D 1.36 D	1.1 D 0.73 D 0.36 D
9	Remove shores beneath Level 4, causing that slab 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	4 3 2 1	0 1.37 D 1.37 D 1.36 D	+1 D -0.37 D -0.37 D -0.36 D	1 D 1 D 1 D 1 D	0 0 0
10	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.	4 3 2 1	1 D 1 D 1 D	0 0 0	1 D 1 D 1 D	0 0 0

method can be found in Agarwal and Gardner (1974); Gardner and Muskati (1989); Gardner (1985); Liu, Chen, and Bowman (1985); Liu, Lee, and Chen (1988); Gross (1984); Gross and Lew (1986); Stivaros and Halvorsen (1990, 1992); and Arafat 1996.

3.5—Application of the simplified method

Table 3.1 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.

Following the four phases of construction, each floor level is subjected to construction loads that vary in magnitude as the 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 reshores 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 reshores to the ground. In Step 4, the shores are removed, and the second elevated floor slab carries its own weight. The reshores are placed under the second floor, but do not carry load. 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 reshores 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 between 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 shore 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 utilizing more than one level of shores. Examples of calculating the construction loads when more than one level of shores is used are discussed by M. K. Hurd in ACI SP-4.

While the simplified method assumes distribution of the construction loads between the supported floors in proportion to their relative stiffness, some project-specific circumstances may necessitate altering the distribution slightly.

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 appropriately modified.

3.6—Factors affecting the construction load distribution

Some of the major factors affecting the construction load distribution and the 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.

3.6.1 *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

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