Guide for Shoring/ Reshoring of Concrete Multistory Buildings

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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. Methods for developing safe construction practices, including sequencing and timing, as well as design examples, are provided. 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 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 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 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_o = perimeter of critical section for shear in slabs, in. (mm)
D = design dead load, lb/ft^2 (kPa)
D_c = construction dead load, lb/ft^2 (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/ft^2 (kPa)

L_c = construction live load, lb/ft^2 (kPa)
n = elevated slab number
R_{28} = nominal flexural strength at 28 days, lb/ft^2 (kPa)
R_c = early-age nominal flexural strength, lb/ft^2 (kPa)
U_{28} = design factored load, lb/ft^2 (kPa)
U_c = construction factored load, lb/ft^2 (kPa)
V_c = nominal shear strength provided by concrete, lb (N)
V_u = factored shear force, lb (N)
V_{uc} = factored construction shear force, lb (N)
β_c = ratio of the early-age concrete compressive strength to 28-day specified strength, $\beta_c \leq 1.0$
λ = modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normalweight concrete of the same compressive strength
ϕ = strength reduction factor

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," https://www.concrete.org/store/productdetail.aspx?ItemID=CT16. The definitions provided herein complement that source.

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 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