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Multistory Reinforced Concrete Building Construction: Shoring/Reshoring Operations – Economy and Safety

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Presentation Outline

Shoring/Reshoring Operations

- Shoring/Reshoring – What is it?
- Advantages of Reshoring
- Safe Shoring/Reshoring Schedules

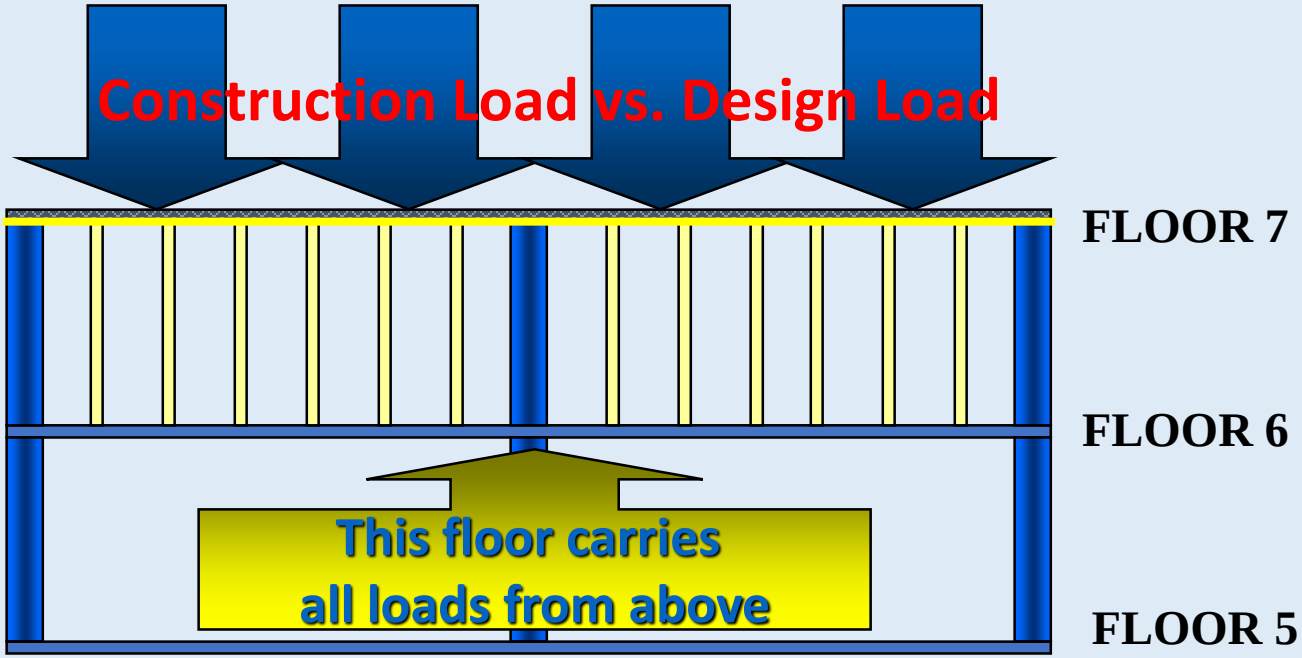
Typical Multistory R/C Building During Construction

Shores:
Vertical or inclined supports carrying the weight of the formwork, concrete slabs and other construction loads

Reshores:
Shores placed snugly under a Stripped concrete slab after the removal of forms and shores.

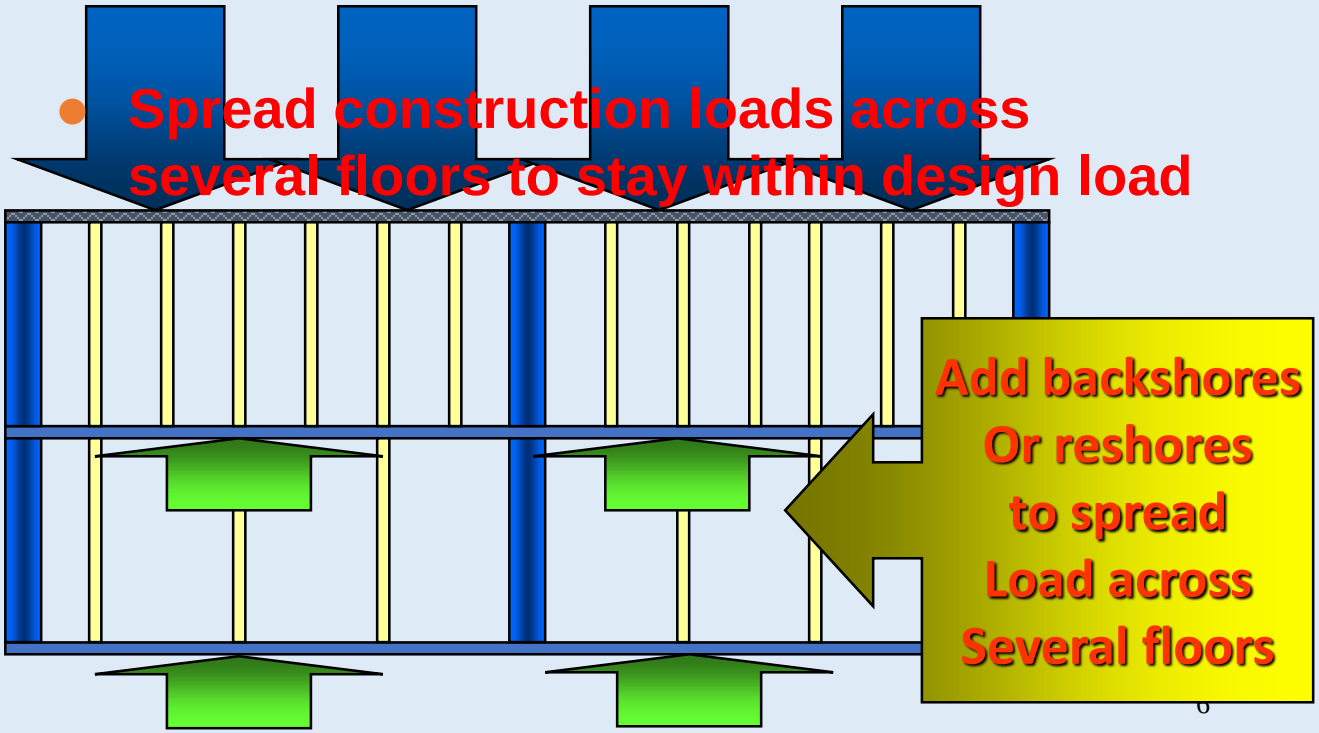
The slabs are allowed to deflect and support their own weight.

Reshoring in Multi-story Buildings



Reshoring in Multi-story Buildings

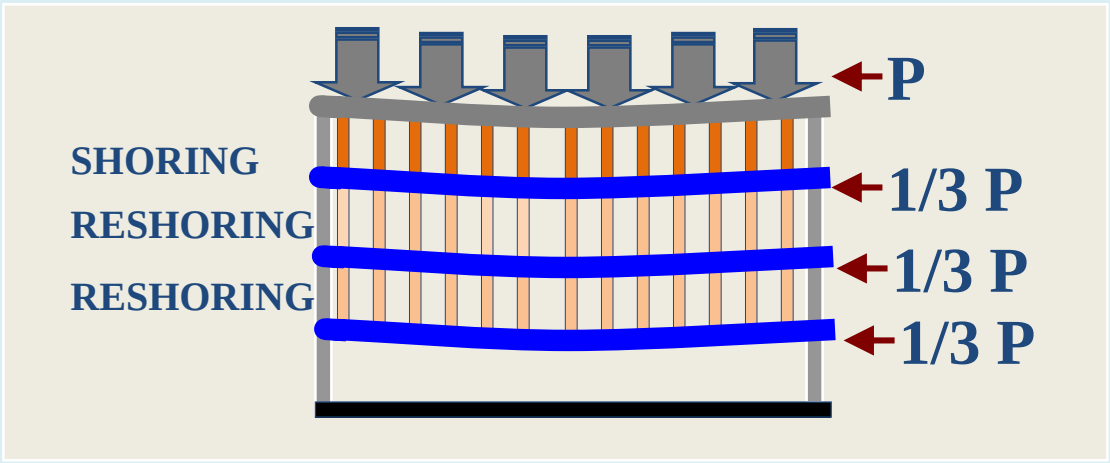
- Spread construction loads across several floors to stay within design load



Reshoring – Design Assumptions:

When floors are no longer shored to ground:

The floors deflect equally, and assuming they are identical design, all floors carry an equal amount of the new construction load.



Reshoring in Multi-Story Buildings Advantages

- Distribution of construction loads at Lower Levels.
- Economical & Safe Construction Schedules.
- Strip Early – Maximize Reuse of Material.
- Combination of Shore/Reshores Usually Requires Fewer Supported Floors; Thus More Free Areas for Other Trades.

Sources of Potential Problems with Shoring/Reshoring

Shoring/Reshoring Issues:

- Inadequate Shoring/Reshoring
- Premature Removal of Shores/Reshores
- Under-Designing of Shoring/Reshoring Components

May Result to:

- Complete or Partial Progressive Collapse
- Excessive Deflections and Cracking
- **Unsafe - possible human injuries and loss of life**
- **Uneconomic Consequences**

Sources of Potential Problems with Shoring/Reshoring

Over-Designing of Shoring/Reshoring

May Result to:

Safe construction ….

But Uneconomical Construction (Overdesign)

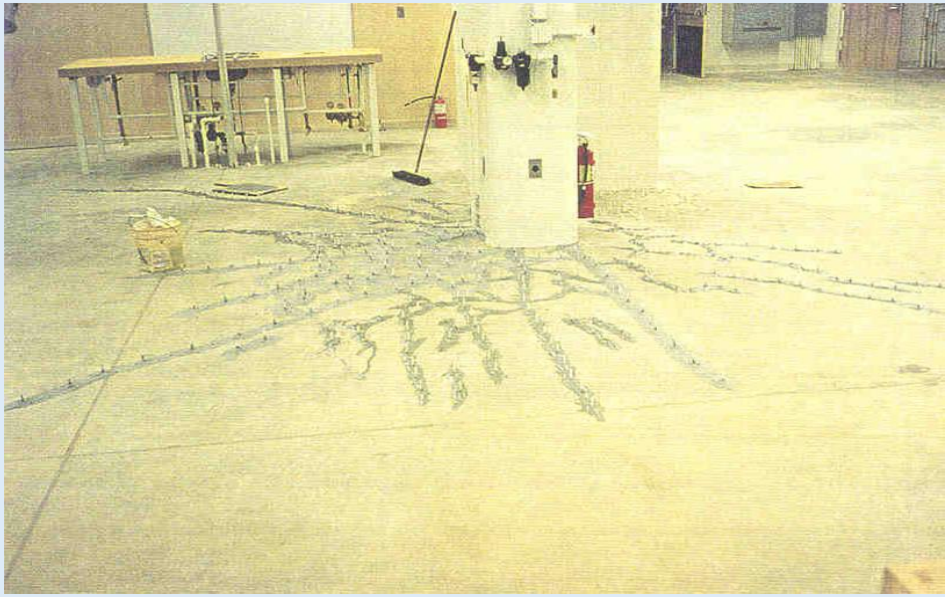
Multistory R/C Building Construction

Collapse of a five-story, cast-in-place concrete apartment house in Florida killed 11 and injured 23 workers.

The Problem

Multistory R/C Building Construction

The Problem



A three-story, cast-in-place concrete educational building, suffered excessive slab deflections and cracking due to premature removal of shores and reshores.

Multistory R/C Building Construction

A four-story, cast-in-place concrete parking garage, suffered excessive slab cracking soon after construction.

The Problem

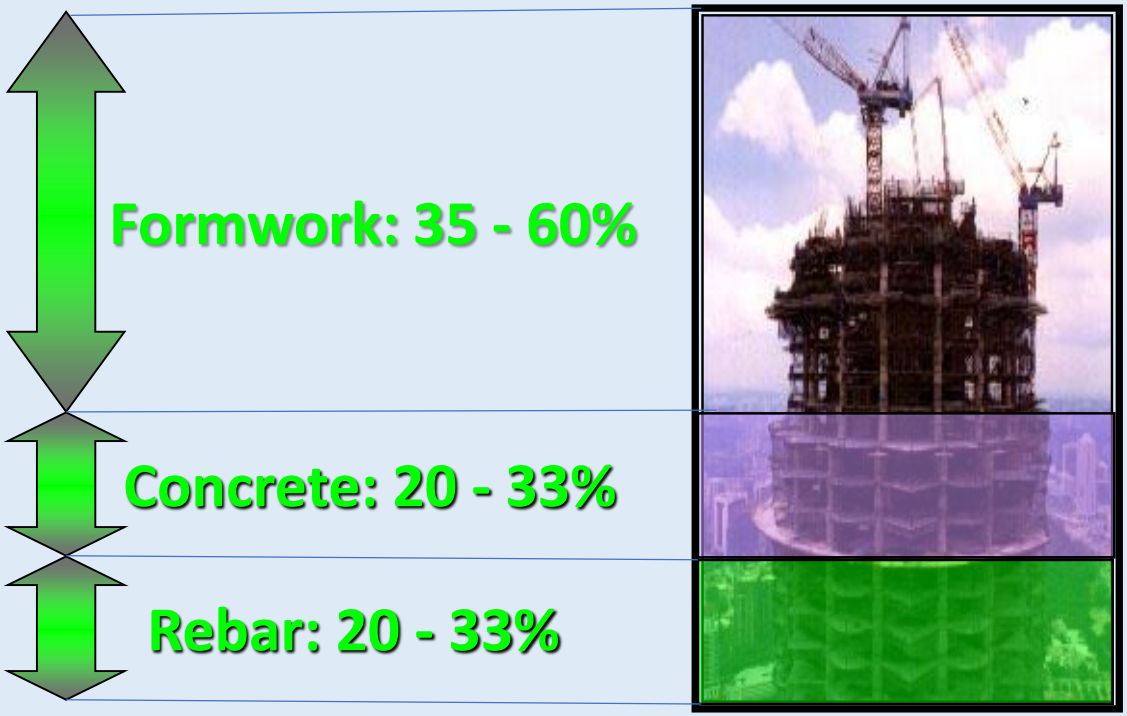
Where is the Economy in Reshoring Operations?

Why should we focus on

Formwork and Shoring/Reshoring

to economize construction?

Concrete Frame Costs



Where is the Economy in Reshoring Operations?

How can we achieve Economy in Reshoring Operations

Think Safety First

Economy will come along

How do we achieve economy in concrete formwork construction:

- Economy starts with the structural/architectural design
- Maximum reuse of the forms and the shoring materials.
- Adequate but not excessive formwork design.

How do we achieve Formwork economy through the building design:

Starting with the earliest schematic design, the designer can integrate constructability into a project by allowing three basic principles of formwork economy:

- **Design Repetition**
- **Dimensional Standards**
- **Dimensional Consistency**

How do we achieve economy in concrete formwork design and construction:

- **Maximum reuse of the forms and the shoring materials.**
  - **Standard sizes**
  - **Early form removal and reuse**

How do we achieve economy in concrete formwork design and construction:

- **Adequate but not excessive formwork design.**
  - **Know the service design loads of the building**
  - **Understand/identify construction loads**
  - **Understand the construction load distribution between the formwork and the partially completed structure**
  - **Knowledge of the behavior and the strength of early-age concrete slabs that support their own weight and construction loads.**

Where is the Economy in Reshoring Operations?

Maximize Use - Early Form Removal

- Speeds up construction
- Requires less form/shoring inventory
- Allows other trade early access
- Sooner completion date
- Reduces Cost

Need in-place Concrete Strength

How can we achieve “Early Form Removal?”

ACI 347-14 Guide to Formwork for Concrete:

5.8.5 *Removal of reshoring*—Shores should not be removed until the supported slab or member has attained sufficient strength to support itself and all applied loads. Shores should be removed or released before reshore removal. Premature reshore removal can be dangerous as it can result in overloading the slabs above.

How can we achieve “Early Form Removal?”

ACI 347-14 Guide to Formwork for Concrete:

5.7.2.1 The engineer/architect should specify the minimum strength of the concrete that should be reached before removal of forms or shores. The strength can be determined by tests on field-cured specimens or on in-place concrete.

Determination of the time of form removal should be based on the resulting effect on the concrete.

How can we achieve “Early Form Removal?”

ACI 301-16 Specifications for Structural Concrete: Default when to remove formwork and shoring

2.3.2.4 Unless otherwise specified, leave formwork and shoring in place to support construction loads and weight of concrete in beams, slabs, and other structural members until in-place strength of concrete determined in accordance with 2.3.4 is at least f_c'.

How can we achieve “Early Form Removal?”

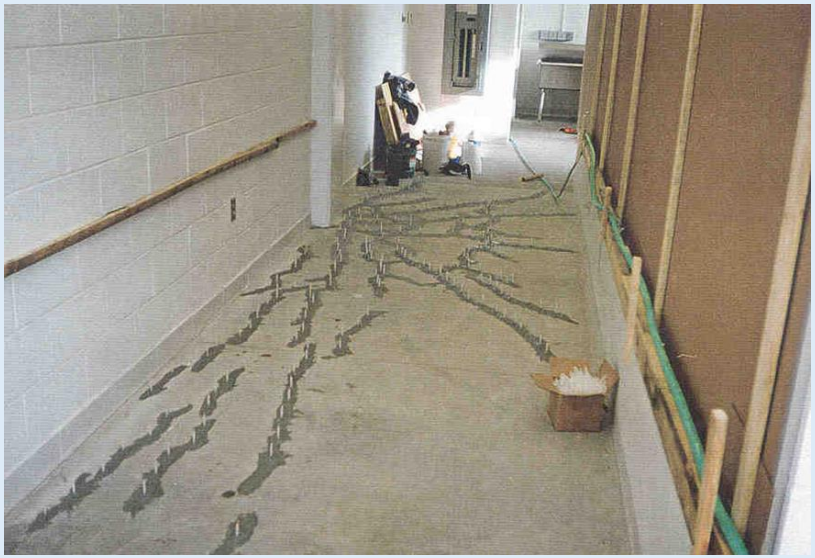
ACI 347-14 Guide to Formwork for Concrete:

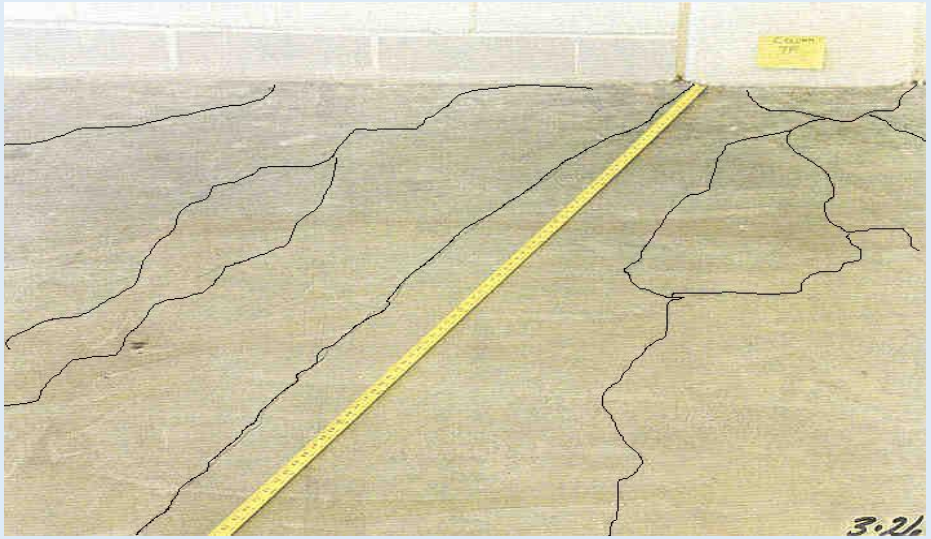
5.7.2.1 …… Determination of the time of form removal should be based on the resulting effect on the concrete.

- **Overloading**
- **Cracking**
- **Excessive Deflections**

How can we achieve “Early Form Removal?”

5.7.2.1 …… Determination of the time of form removal should be based on the resulting effect on the concrete.





How can we achieve “Early Form Removal?”

ACI 301-16 Specifications for Structural Concrete:

Field Cure Cylinders	(ASTM C31 & C 39)
Cast-in-place Cylinders	(ASTM C 873)
Penetration Resistance*	(ASTM C 803)
Pullout Strength*	(ASTM C 900)
Maturity-Factor*	(ASTM C 1074)
Break-off* (by ACI 301)	(ASTM C 1150)

* require correlation

How can we achieve “Economy?”

… So we need the concrete strength to remove the forms…
We need stronger slabs …

Contractors should Consider:

- Submitting a new mix design that increases the 1 to 3 day strength
- Trade off in cost between concrete mix and faster construction and faster form reuse
- May suggest to increase design live load

Where is the Safety and Economy in Reshoring Operations?

- Know the service design loads of the building

  Design loads are required to be listed on the design drawings.

  - Dead load
  - Additional superimposed dead loads
  - Live loads – Consider live load reduction

Why?

We need the partially completed structure to support some of the construction loads.

Use reduced load capacity based on the partially developed concrete strength.

Where is the Safety and Economy in Reshoring Operations?

- Understand/identify construction loads
    - Gravity Loads – Dead & Live Loads
    - Lateral Loads
    - Post-Tensioning Loads
    - Other Loads and Conditions
        - Impact During Placement
        - Unsymmetrical Concrete Placement
        - Starting and Stopping of Equipment
        - Storage of Construction Materials & Equipment

Where is the Safety and Economy in Reshoring Operations?

- Understand the construction load distribution between the formwork and the partially completed structure

Distribution of construction loads controlled by:

- Number of Shore/Reshore Levels
- Shore/Reshore Stiffness
- Slab Stiffness & Type
- Shore/Reshore Placement Configuration
- Time per Construction Cycle
- Post-Tensioning Sequence and Stressing Levels
- Whether backshores or reshores are used (Type of Shoring System)

Follow ACI 347.2R Reshoring Guide

Where is the Safety and Economy in Reshoring Operations?

- Knowledge of the behavior and the strength of early-age concrete slabs that support their own weight and construction loads.

Why?

We need the partially completed structure to support the construction loads.

Think about

Cracking, and

Deflections

Or worse – Punching Shear Failure

Where is the Safety and Economy in Reshoring Operations?

- Knowledge of the behavior and the strength of early-age concrete slabs that support their own weight and construction loads.

Early Age Concrete Properties

Compressive Strength – Measure of Early Age Member Strength

Tensile Strength – Measure of Cracking

Modulus of Elasticity – Measure of Deflections

Where is the Safety and Economy in Reshoring Operations?

... Be aware of slabs with less than the minimum span/thickness ratio and lightly reinforced ...

Cracking Due to Construction Loads

and Restrained Shrinkage

Decreases the Member Stiffness

Thus

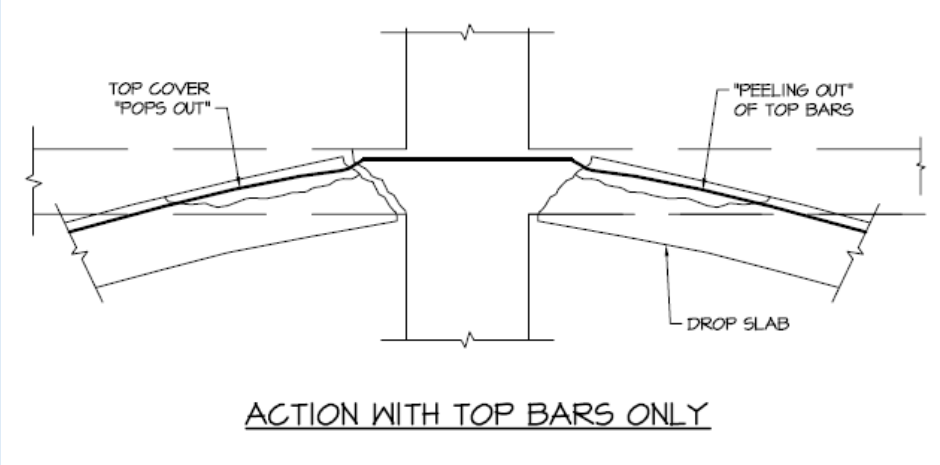
Increases Long Term Deflections
Creep/Shrinkage Under Sustained Loads

Where is the Safety and Economy in Reshoring Operations?

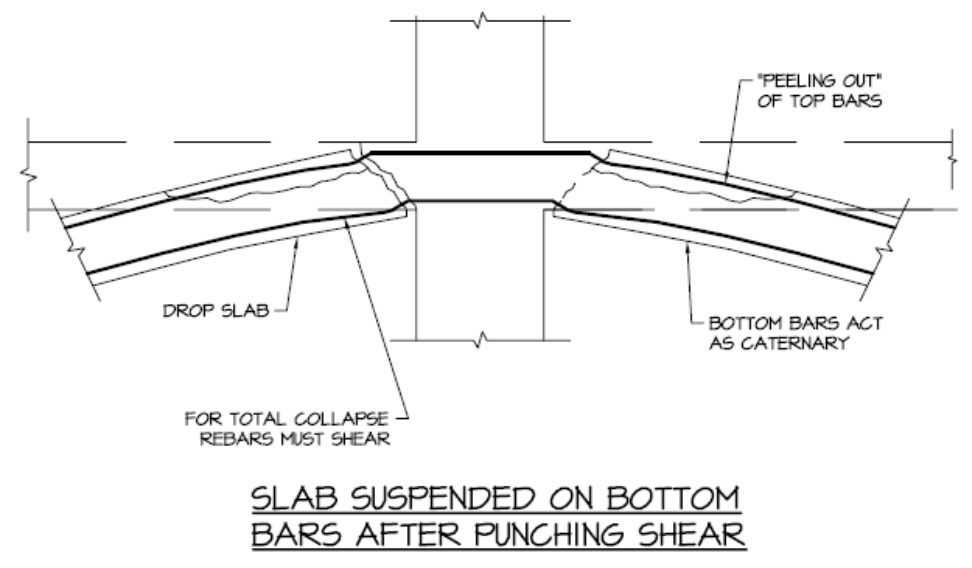
- Cracked Slabs During Construction
- Cannot Become Uncracked During Service Unless Are Repaired.

Where is the Safety and Economy in Reshoring Operations?

… think of Punching Shear



Where is the Safety and Economy in Reshoring Operations?



Bottom "integrity bars" resist punching shear failure

Control of Deflection in Concrete Slabs and Effects of Construction Loads

ACI 347.2R-17 Reshoring Guide Recommends:

- **Use the least-effective moment of inertia determined from either:**
  The construction loads with partial concrete strength, or
  the service loads with full concrete strength.

- **Shoring/reshoring analysis data by the contractor "should be furnished to the engineer/architect who should 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."**

Control of Deflection in Concrete Slabs and Effects of Construction Loads

Further Recommendations:

- Use lower modulus of rupture. This is to account for the lower early-age tensile strength of concrete.

  Use $f_r = 4 \sqrt{f'_c}$, instead of $f_r = 7.5 \sqrt{f'_c}$

- Use W_{sus} (Service Sustained) equal to **full design dead and live loads** to account for the high construction loads.

Ending Remarks

- Shoring/Reshoring Operations must be Planned in Advance.
- Design process cannot be independent of the construction process in order to achieve safe construction and serviceable structures. Require Close Coordination Between Engineer and Contractor.
- Construction engineers should consider the limitations of the design method in order to achieve safe construction schedules.
- Design engineers should consider the construction process to guarantee the serviceability of the building.
- Furnish Same to Engineer/Architect with Shoring/Reshoring Plans and Schedules.