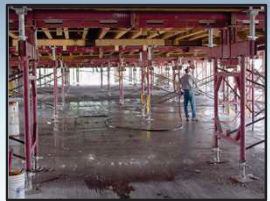


**minnesota Concrete Council**  
Dedicated to Cast-in-Place Concrete

**Shoring and re-shoring:**

- Introduction
- Whose problem is this? (*A Regulatory Forest*)
- How Shore and Reshore Systems Work
- Principles for Analysis with Example
- Rate-of-Strength-Gain
- In-Place Testing



*Ken Hover*

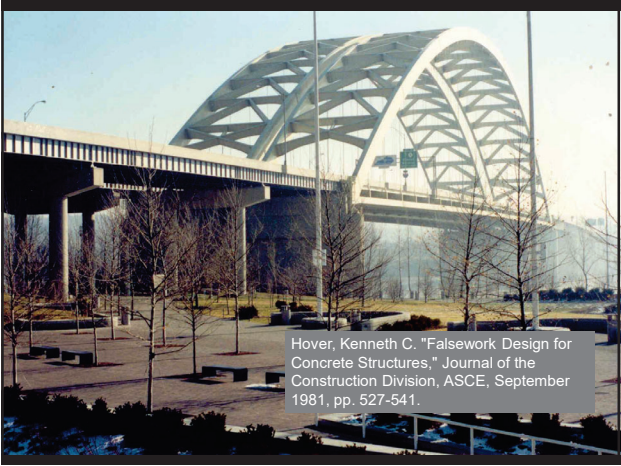
1



**A Challenge For:**  
Structural Design—Concrete Construction—Concrete Production




2



3



4



- Shoring and re-shoring:
  - ▶ **Introduction**
  - Whose problem is this? (*Regulatory Forest*)
  - How Shore and Reshore Systems Work
  - Principles for Analysis with Example
  - Rate-of-Strength-Gain
  - In-Place Testing

5



6



7

"The cost of formwork can be greater than half the total cost of the concrete structure"-ACI 347

**Cost**  $Cost_{Forms\&Shores} \geq Cost_{concrete} + Cost_{Steel}$

Owner pays more for temporary structure than the permanent structure

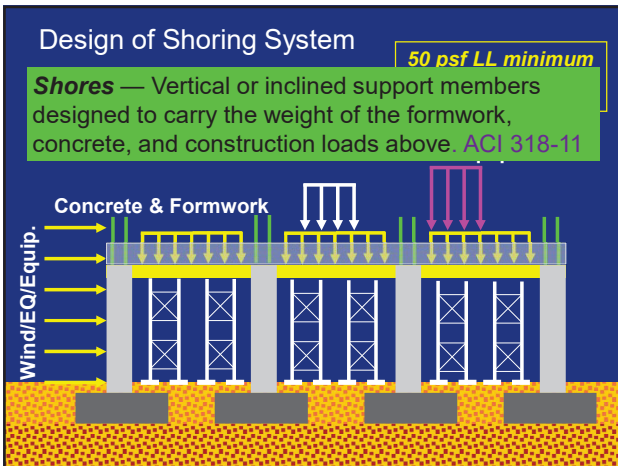
Design that Optimizes Forms & Shores can save more \$ than optimizing concrete & steel

**Environmental Impact**

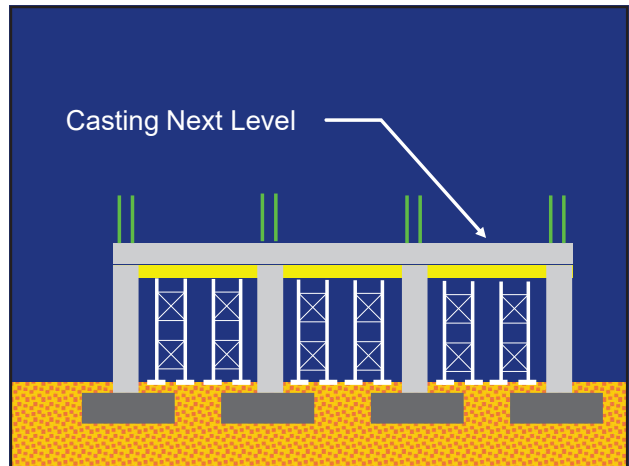
Construction loads may exceed service loads  
→ deflection/cracking/serviceability

Potential Failures of Shoring System and/or Permanent Structure → Life Safety Issue

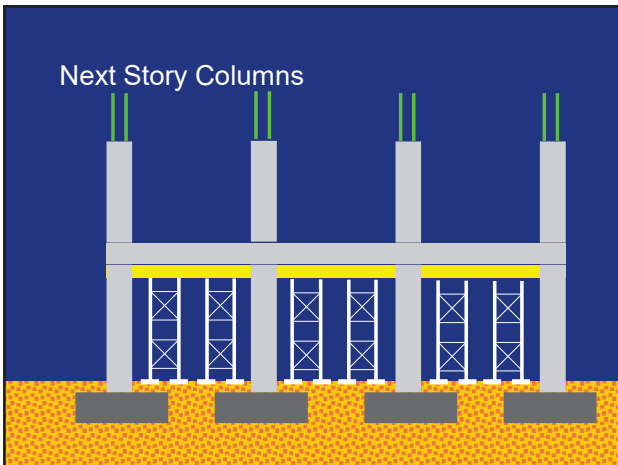
8



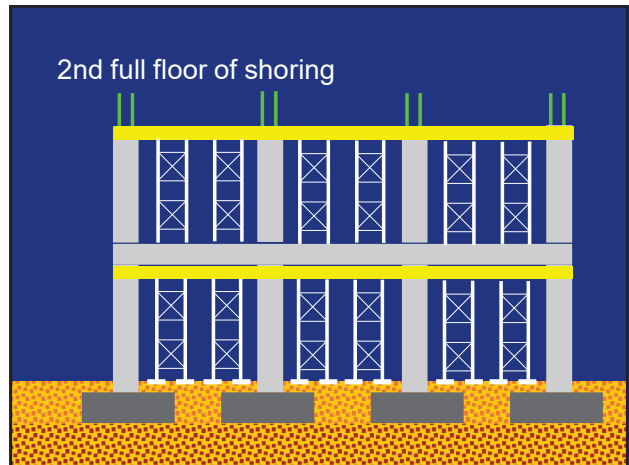
9



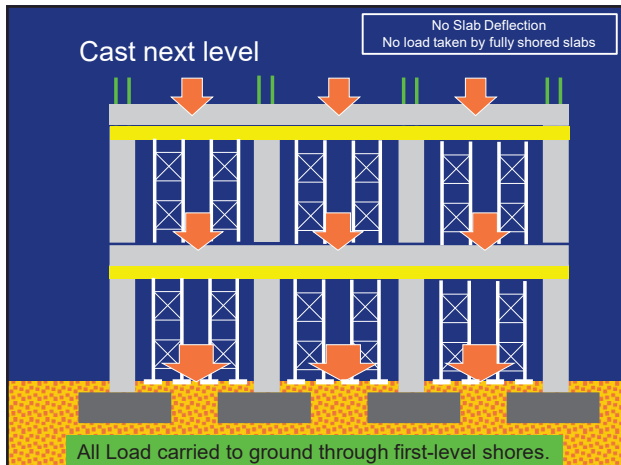
10



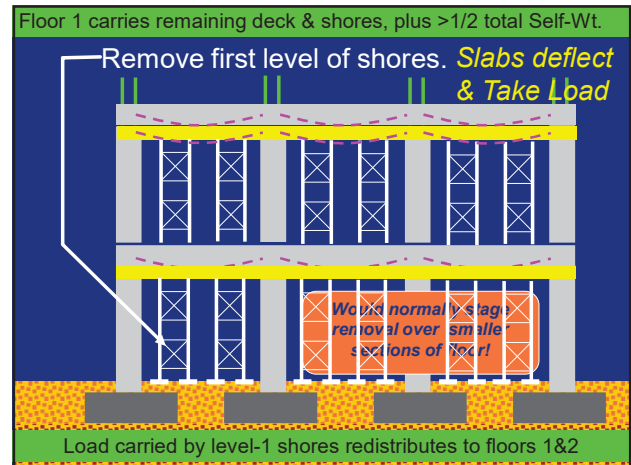
11



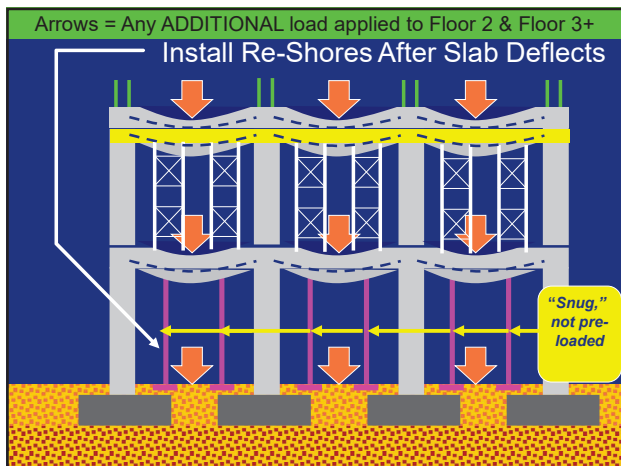
12



13



14



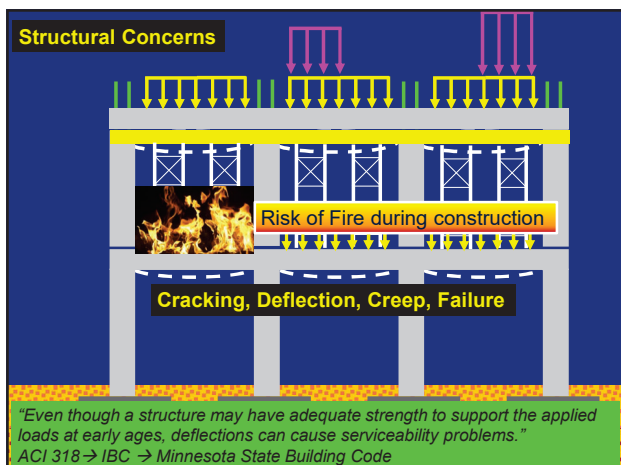
15

**Reshores** — Shores placed snugly under a concrete structural member after the original forms and shores have been removed from a larger area, thus requiring the new slab or structural member to deflect and support its own weight and existing construction loads applied prior to the installation of the reshores. ACI 318-11

**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, or support its own weight or existing construction loads. ACI 301-20

Backshores are not discussed further in this short presentation

16



17

### Issues at stake

1. Construction Operations
2. Structural Design & Performance of Shoring System
3. Response of Permanent Structure

18



### 1. Construction Operations


- Overall Project Schedule
  - Convert construction-loan to long-term
  - Time to Real-Estate Income
- Construction Schedule
  - Cycle-time per floor, All Trades
  - Form/Shore/Cast/Cure/Interior Access
- Construction Cost
  - Form/Shore Rental/Materials/Labor
- Construction Loads
  - Self-wt./workers/equipment/shores/stuff



19

### 2. Structural Design & Performance of Shoring/Reshoring System

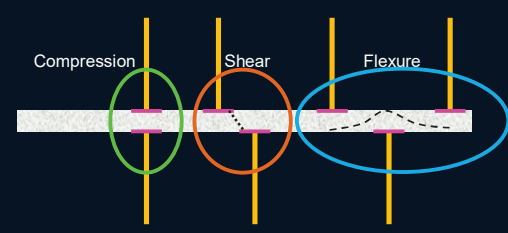
- Load Capacity of vertical and horizontal form & shore components.
- Inspection/Monitoring
- Load-Transfer Capacity
  - to ground
  - to and and through floors

Shown on Next Slide 

20

*(Related problem not addressed in detail today)*

### Critical alignment of shoring posts or legs




Concrete stresses generated by shore-leg alignment

21

### 2. Structural Design & Performance of Shoring/Reshoring System


- Load Capacity of vertical and horizontal form & shore components.
- Inspection/Monitoring
- Load-Transfer Capacity
  - to ground
  - to and and through floors
- Deflection / Deformation
- (ACI 301-20 Requires Licensed Engineer)



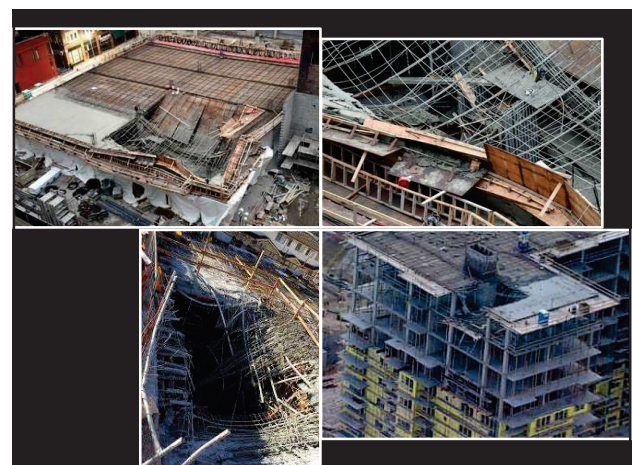
22

### 3. Response of Permanent Structure

- In-Place Conc. Strength vs. mix/time/temp.
- How to measure in-place strength?
- Structural analyses for serviceability:
  - Deflection [ $E_c(t, T)$ ] (flatness, levelness)
  - Cracking Resistance [ $f_r(t, T)$ ,  $M_{crack}(t, T)$ ]
    - More Deflection due to cracking
    - More Deflection due to creep (early loading)
- Structural analysis for load capacity
- Risk of structural failure & consequences

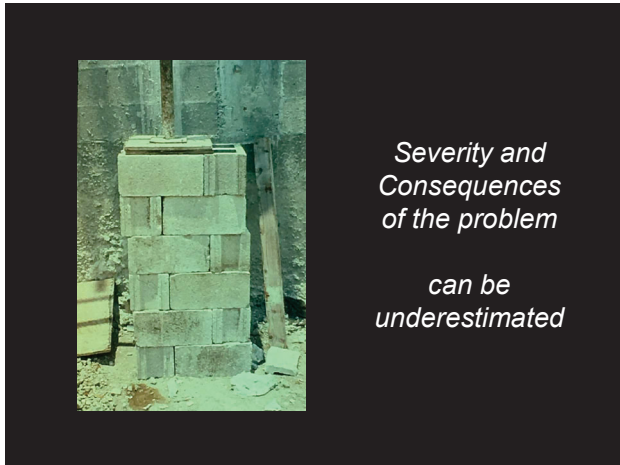


23



24



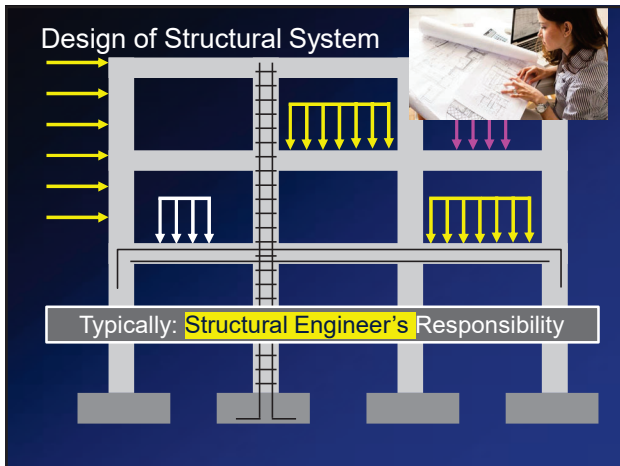


Severity and  
Consequences  
of the problem  
  
can be  
underestimated

25

- Shoring and re-shoring:
  - Introduction
  - ▶ – Whose problem is this? (Regulatory Forest)
  - How Shore and Reshore Systems Work
  - Principles for Analysis with Example
  - Rate-of-Strength-Gain
  - In-Place Testing

26



27

Typically: **Contractor's** Responsibility,  
but **Structural Engineer** remains involved

Shoring System

Performance influenced by **Concrete Producer's Mixture**  
as-designed, batched, delivered; Followed by water-  
control, placement, consolidation, curing & temperature.

28

Whose responsibility is this?

- Who are you asking?
  - Minnesota State Building Code = IBC / ACI 318 Building Code
  - County/Township/ Municipality Bldg. Depts.

"Fully integrated custom Minnesota code based on the 2018 International Building Code®."

29

INTERNATIONAL BUILDING CODE  
ADOPTION MAP

The IBC is in use or adopted in 50 states, the District of Columbia, the U.S. Virgin Islands, Guam and the Northern Mariana Islands.

IBC administered at the state and/or local level

30


Minn Building Code 2020  
**ADOPTS WITH AMENDMENTS:**  
International Building Code 2018 (IBC 2018)

IBC 2018  
ADOPTS WITH AMENDMENTS  
ACI 318-14  
Building Code Requirements for Structural Concrete

ACI 318-14  
An ACI Standard  
Building Code Requirements for Structural Concrete and Commentary  
Issued by ACI Committee 318

31

From ACI 318-14




**26.11.2 — Removal of formwork**

**26.11.2.1 (a)** Before starting construction, the contractor shall develop a procedure and schedule for removal of formwork and installation of reshores, and shall calculate the loads transferred to the structure during this process.

**(b)** Structural analysis and concrete strength requirements used in planning and implementing the formwork removal and reshore installation shall be furnished by the contractor to the licensed design professional and to the building official, when requested.

32

ACI 318-14 Commentary R26.11.2.1  
Removal of formwork



**Warnings:**

1. Construction loads:  
May be greater than specified live loads.  
(applied at earlier ages, at lower  $f_c, f_r, E_c$ )
2. Consider both construction loads and deflections.
3. Structure may support applied loads, but deflections can cause serviceability problems.

*None of us can say  
we weren't warned of the consequences*

33

**Whose responsibility is this?**

- Who are you asking?
  - ACI 301 Specification  
(Typically referenced by contract documents)
  - MasterSpec → ACI 301 Specification

*Governing Edition of ACI 301 depends on:*

- Date cited in concrete specifications, or
- Date of contract documents

34

301-1

**ACI 301-20 (To Contractor)**

- 1.1.3 This Specification is incorporated by Contract Documents and provides requirements for Contractor.

35

301-2

**ACI 301-20 (To Contractor)**

- 2.2.2.2 Design formwork, shores, reshores, and backshores to support loads ... comply with building code requirements, maintain specified tolerances.
- 2.1.2.2(b) Submit live & dead loads, design calculations, shop drawings, & procedures for formwork, shoring, reshoring, and backshoring... signed and sealed by a licensed design engineer\*
  - \*If required by local code or engineer of record

36

301-8

### ACI 301-20 & Engineer of Record

What does *Engr of Record* do with these submittals??

If *Engr.* doesn't ask for them, is *Engr.* in violation of *Engineer's own specification*?

If *Engr.* doesn't ask for them, or ignores them when submitted, is *Engr.* negligent?

If *Engr.* asks for them and reviews them, does *Engr.* share responsibility for Performance of Forms, Shores, and Reshores?

37

301-5

### ACI 301-20 (To Contractor)

- 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  $f_c$ .
- **Specifier's Option-Specify minimum in-place compressive strength** for removal of forms supporting the weight of concrete and construction loads **if different from  $f_c$ .**

38

301-6

### ACI 301-20 (To Contractor)

- 2.1.2.1(c) Testing for formwork removal—**Submit method and correlation data** for determining concrete strength for formwork removal if test methods of 2.3.4.2(b) through 2.3.4.2(d) are specified or proposed.

Correlation unique to specific concrete mixture, materials, consolidation curing, and jobsite conditions.

Cannot always rely on instrument manufacturer's generic calibrations.

39

### Whose responsibility is this?

- **Who are you asking?**
- **Occupational Safety and Health Administration (OSHA)**

40

UNITED STATES DEPARTMENT OF LABOR

Occupational Safety and Health Administration

1926.703(e)(1)  
Forms and shores (except those used for slabs on grade and slip forms) shall not be removed **until the employer determines that the concrete has gained sufficient strength to support its weight and superimposed loads.**

**Employer of the construction workers, or employer of anyone else who could be on, under, or near the shoring system.**

41

ANSI/ASSE A10.9-2013  
Safety Requirements for  
Concrete & Masonry  
Work

42



- Inspection prior to erection and immediately prior to, during, and after concrete placement, but not less than 24 hr. after placement.
- Inspection records, Damage
- 100 psf minimum total load
- Account for materials stored on deck
- Wind & lateral loads
- Mudills & soil stresses, frozen ground
- Factors of safety, wood stresses
- Baseplates, shoreheads, clamps, etc.
- Tolerance on plumbness (1/8 inch)
- Bracing in two mutually perpendicular directions
- Hoisting equipment

**Add  
Local  
Regs.**

*Plus Project Specifications & Referenced Documents.*



43

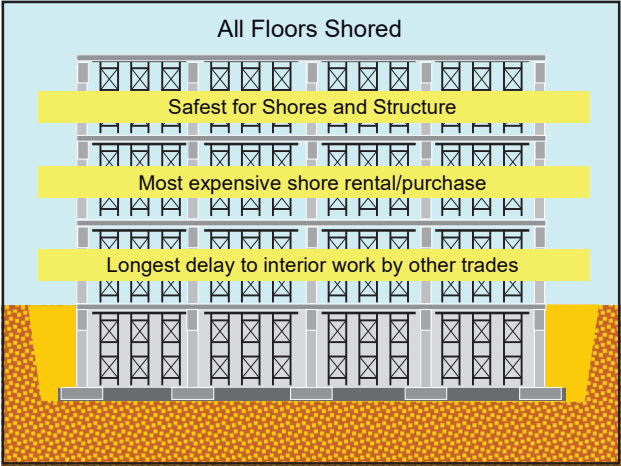


- Shoring and re-shoring:
  - Introduction
  - Whose problem is this? (Regulatory Forest)
  - ▶ **How Shore and Reshore Systems Work**
  - Principles for Typical Analysis with Example
  - Rate of Strength-Gain, Concrete Temperature
  - In-Place Testing

44

How Some Folks *imagine* Shore and Reshore Systems Work:  
*(The Full-Shore-Fallacy)*

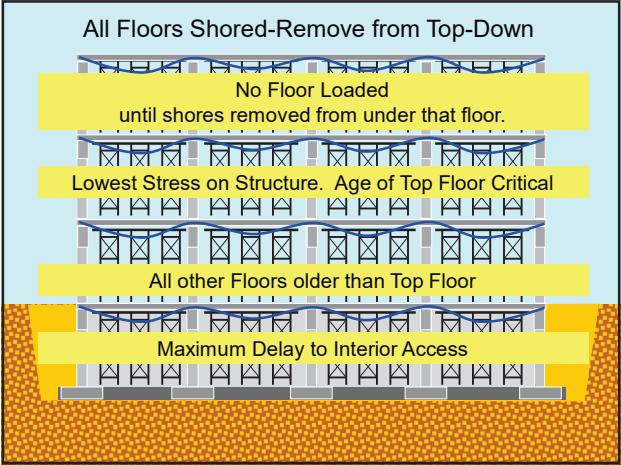
45



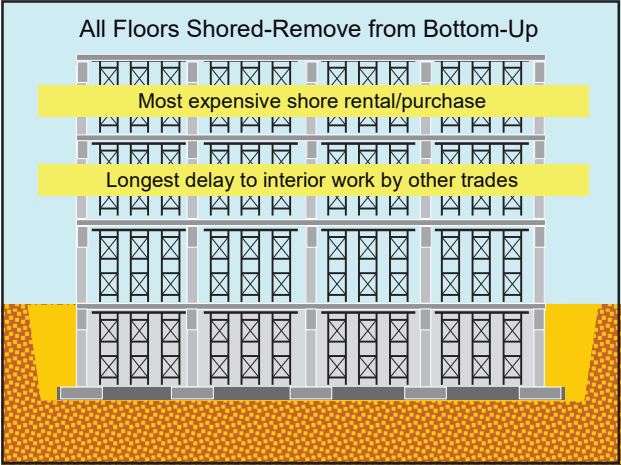
46



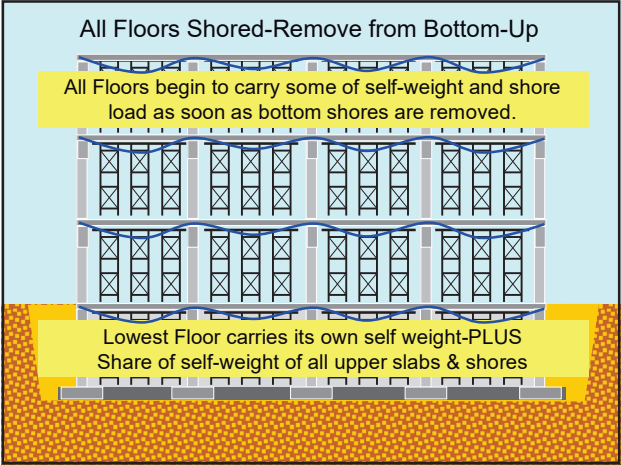
47



48



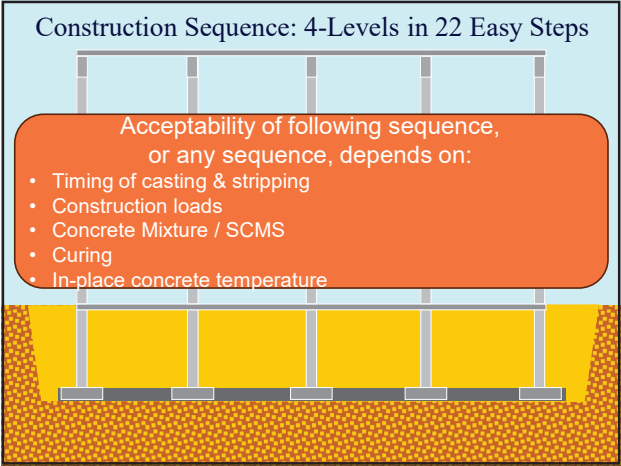
49



50

How Shore and Reshore Systems **Really** Work  
*(More practical sequence)*

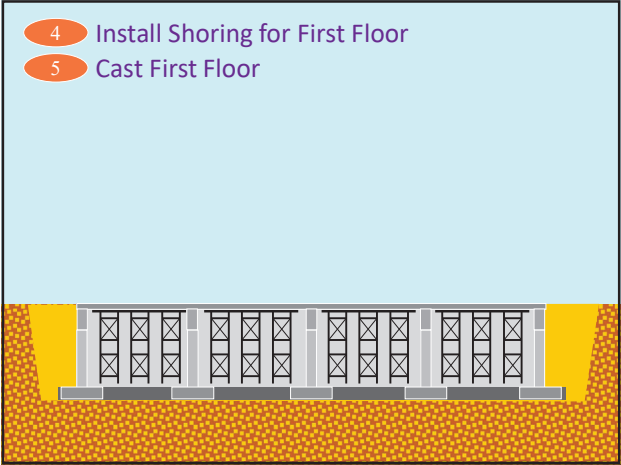
51



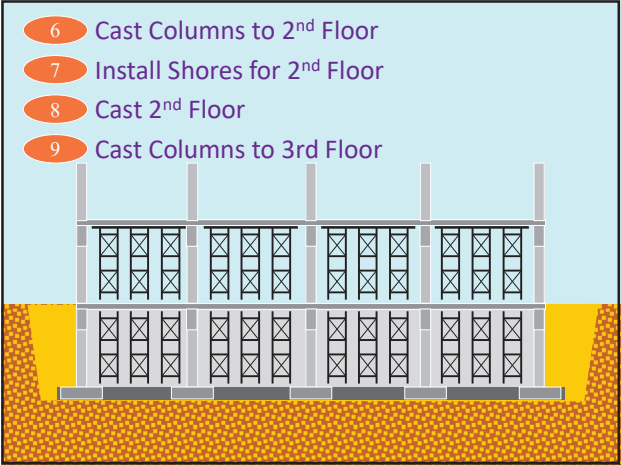
52



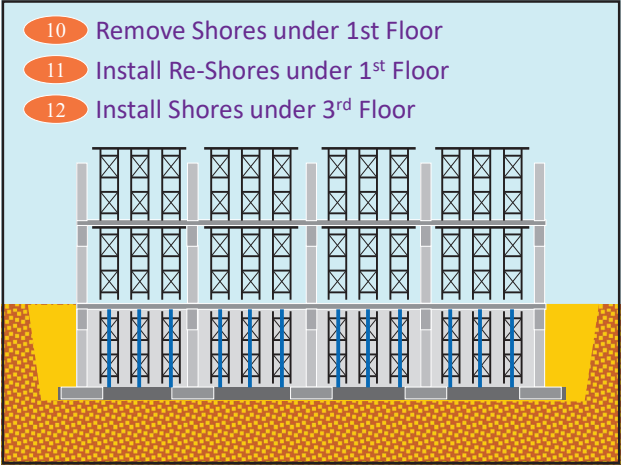
53



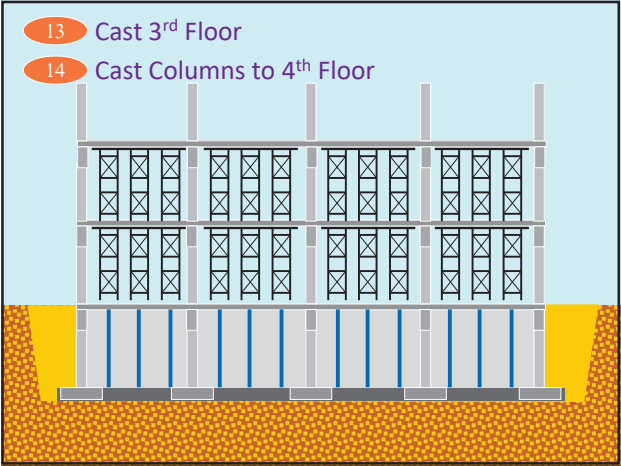
54



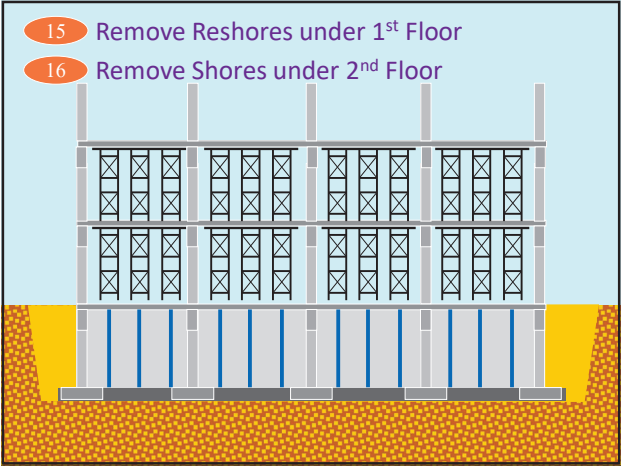
55



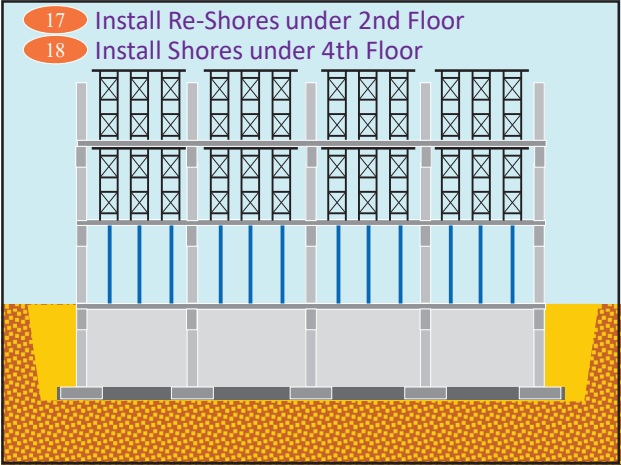
56



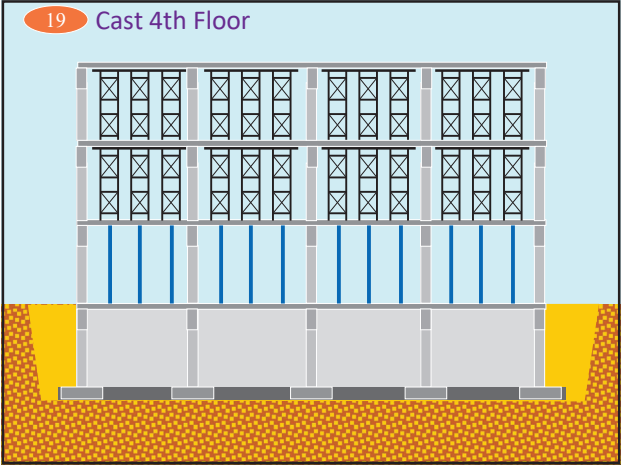
57



58

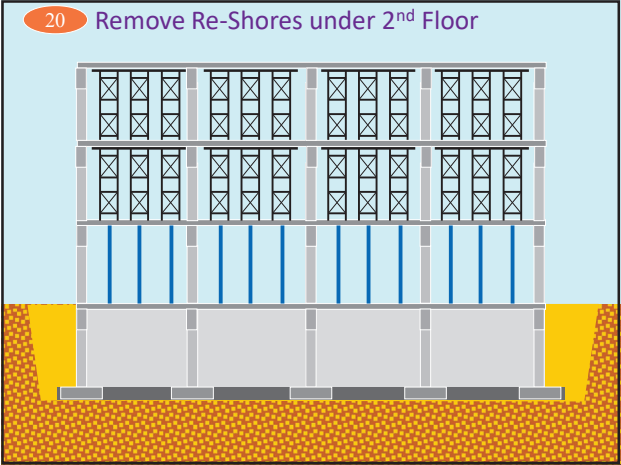


59

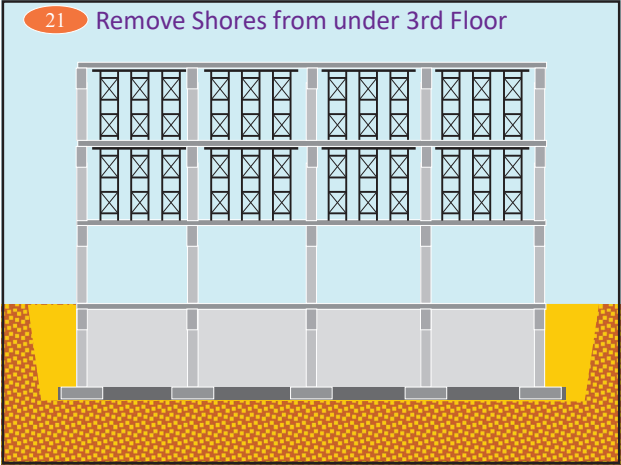


60

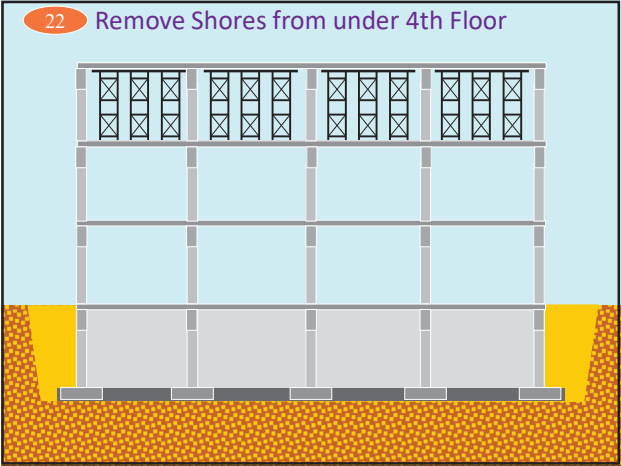




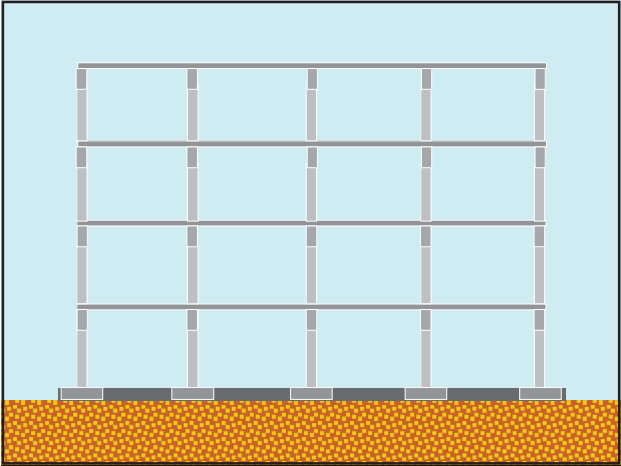
61



62



63



64

- Shoring and re-shoring:
  - Introduction
  - Whose problem is this? (Regulatory Forest)
  - How Shore and Reshore Systems Work
  - ▶ Principles for Typical Analysis with Example
  - Rate of Strength-Gain, Concrete Temperature
  - In-Place Testing

65

Structural Analysis of  
Permanent Structure at Early-Age,  
AND  
The Shore and Reshore System  
*“Grundy & Kabaila Simplified Method”*  
*Described in ACI documents & software*

66

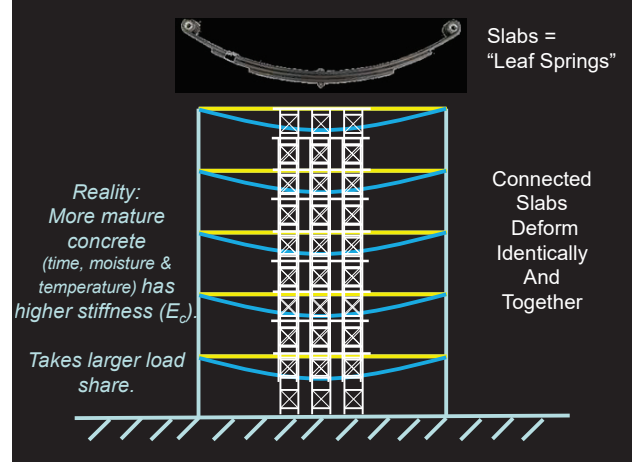
Guide to Formwork for Concrete  
ACI 347R-14

Guide for Shoring and Reshoring of Concrete Multistory Buildings  
ACI 347.2R-17

Formwork for Concrete  
3rd Edition

Awkwardly referenced by OSHA → ANSI 10.9  
Basis of the Appendix that satisfies OSHA → ANSI Regs.

67



68

**ACI 347 Simplified Shoring Analysis Method:**

- (a) Ground-level or other base support is rigid.
- (b) All previously cast slabs are identical and have equal stiffness [ Ignores  $E_c = f(\text{time} \& \text{temp})$  ].
- (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" initial load = zero.

69

*"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."*

*"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."*

Limitations: Shoring & Reshoring only, at least one support /13ft<sup>2</sup> Adam, et al., J.Perf.Constr. Facilities (ASCE), October, 2017.

71

ACI "AutoReshore"

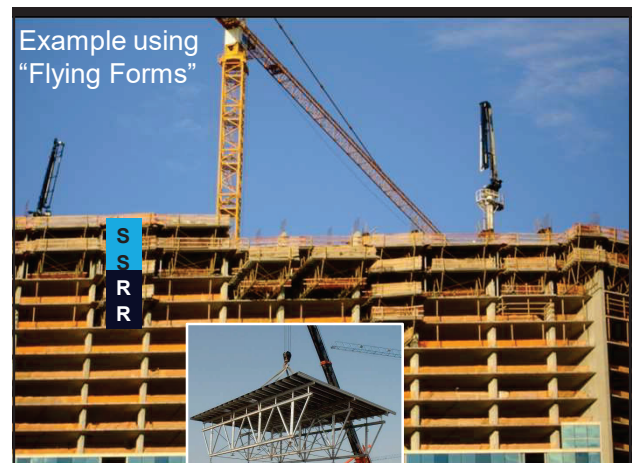
SHORING AND RESHORING ANALYSIS - ACI SP-4 METHOD - AutoReshore 2S-1R  
Version 1.1

Form sets	2	Reshore sets	1
Shore spacing		Reshore spacing	
N-S	5.000	N-S	5.000
E-W	5.000	E-W	5.000
Area	25.000	Area	25.000

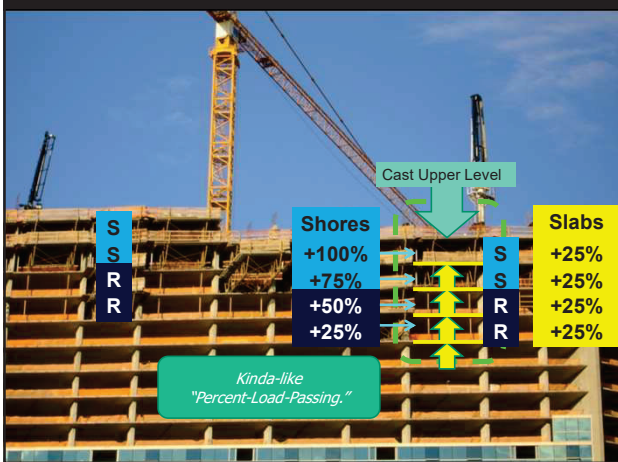
	Load Factor	Area	Load
Fresh slab weight	1.000	1.000	1.000
Cured slab weight	1.000	1.000	1.000
Formshore weight	0.000	20.000	0.000
Construction live load	1.000	0.500	0.500
Reshore weight	1.000	0.050	0.050

Step #	Slab #	Load carried by slab	Unit load carried by shore	Total individual shore load
		beginning	chg dur	end
		beginning	end of operation	end of operation
1-1	A	0.000	0.000	0.000
			1.600	
				40

72



74



75

Quantitative Example  
(with Score Sheet)

76

*May not be optimal scheme!*

4-Story Building  
2 Floors Shored  
1 Floor Reshored

Cast one floor (or section) each 7 days

"D" = unfactored self-wt of slab. = "1.0D"

Avg. 8" thickness;	self wt. = 100 psf
Deck form & Shores	self wt. = 10 psf
Construction LL (OSHA)	= 50 psf

77

**Analysis Assumptions:**

Form & shore self-wt.  
= 0.1 slab self-weight

Include form & shore self-weight with slab:

→ Slab self wt. = 1.1 D = "1.0D"

Avg. 8" thickness;	self wt. = 100 psf
Deck form & Shores	self wt. = 10 psf
Construction LL	= 50 psf

= "1.6D"

78

**Action**

- Cast Level-1 Columns
- Fully Shore Level-1
- Cast Beams & Slabs

Construction Live Load (50 psf)

Concrete & Rebar Self-Weight

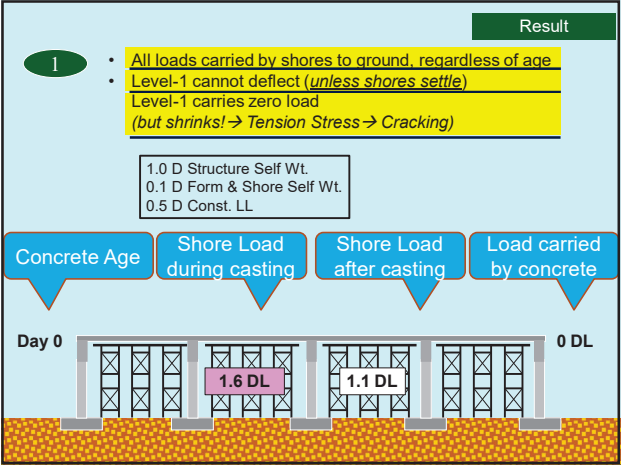
Is 50 psf LL reasonable?

79

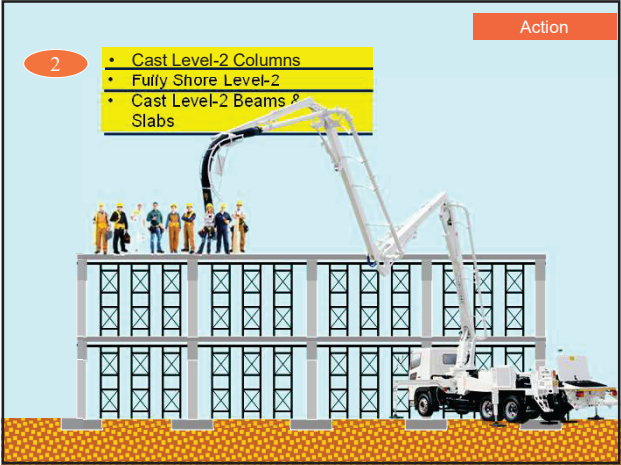


80





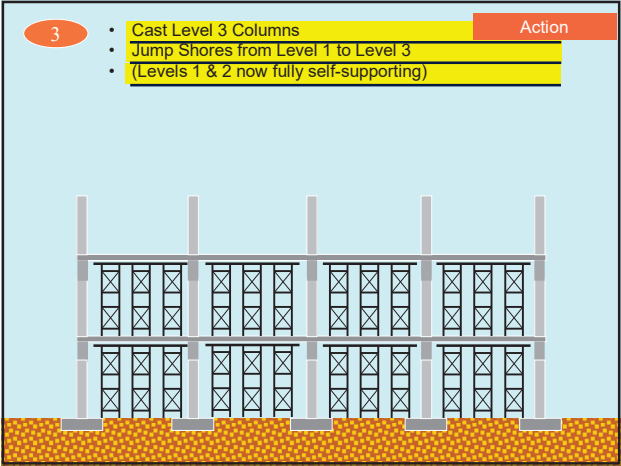
81



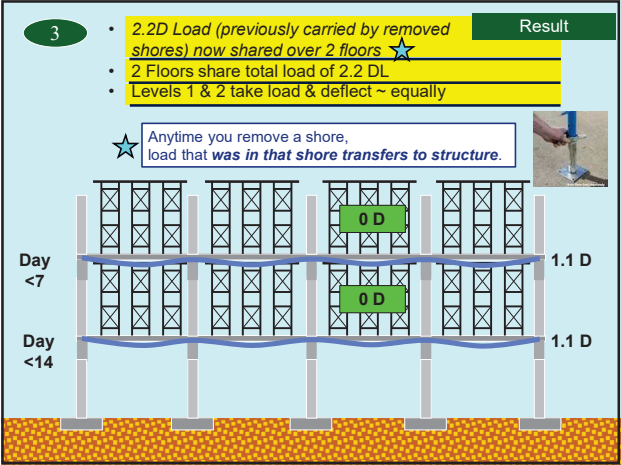
82



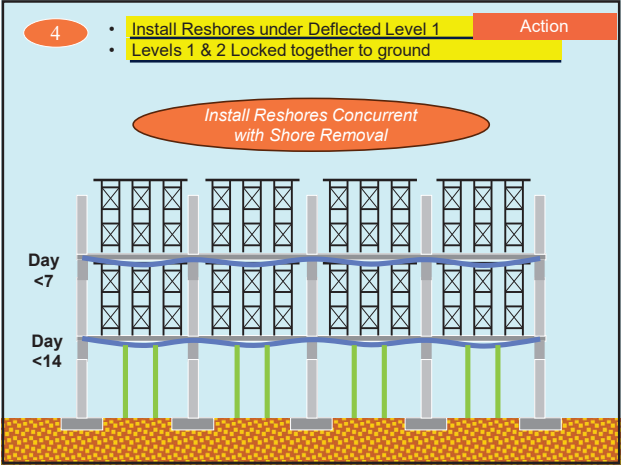
83



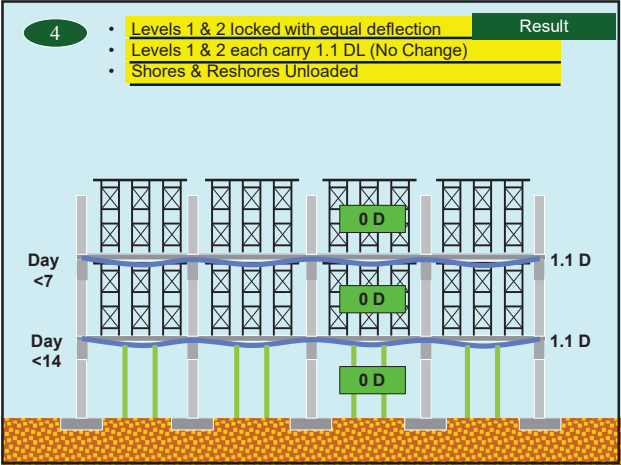
84



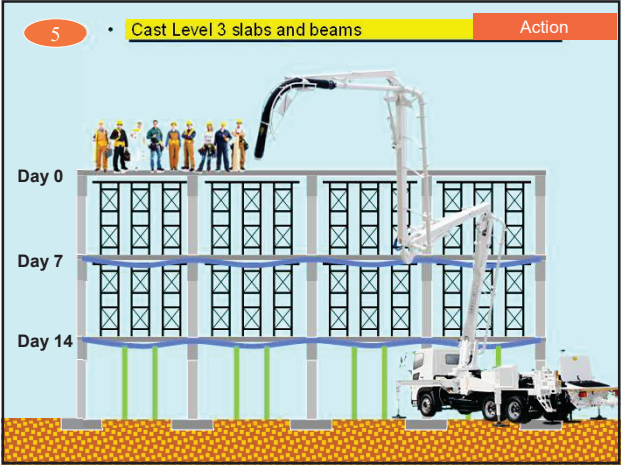
85



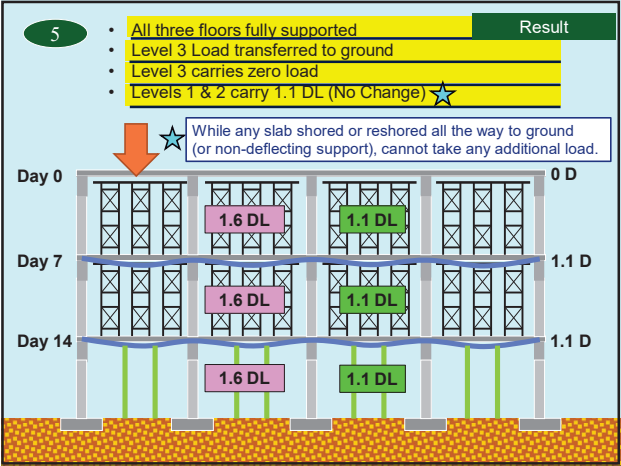
86



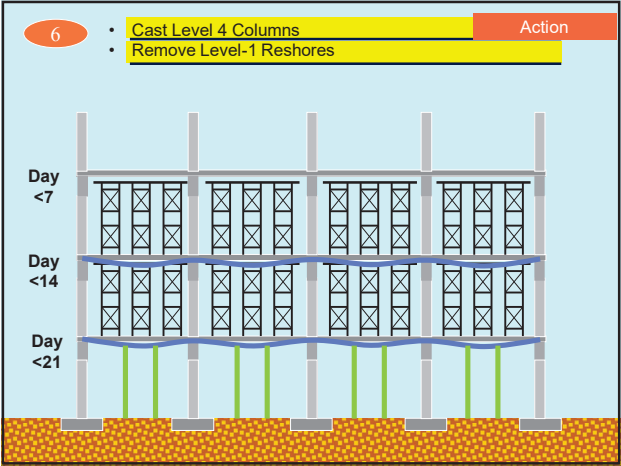
87



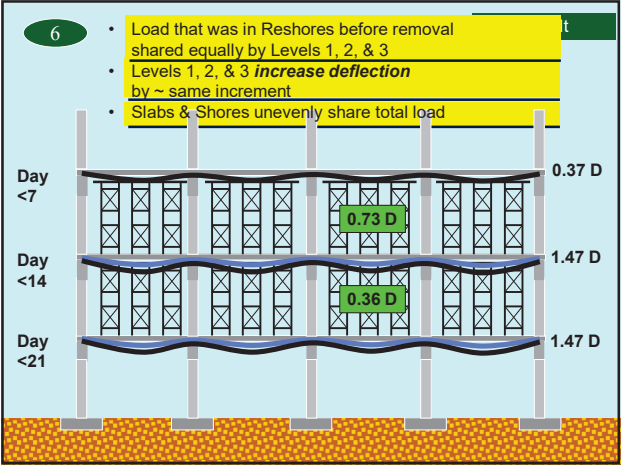
88



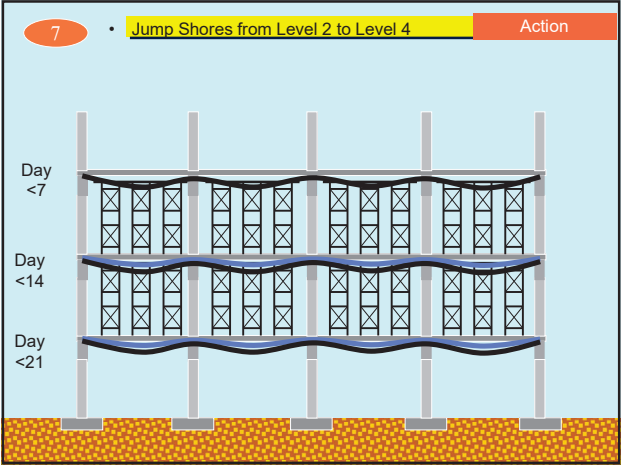
89



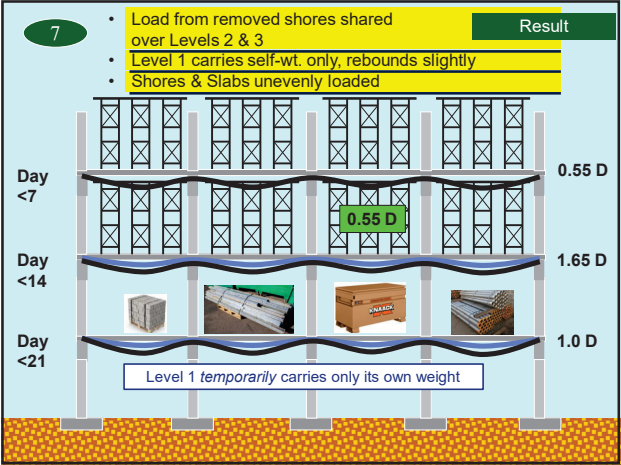
90



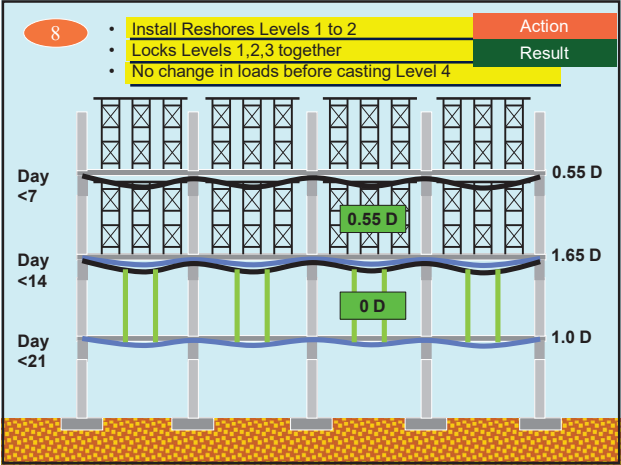
91



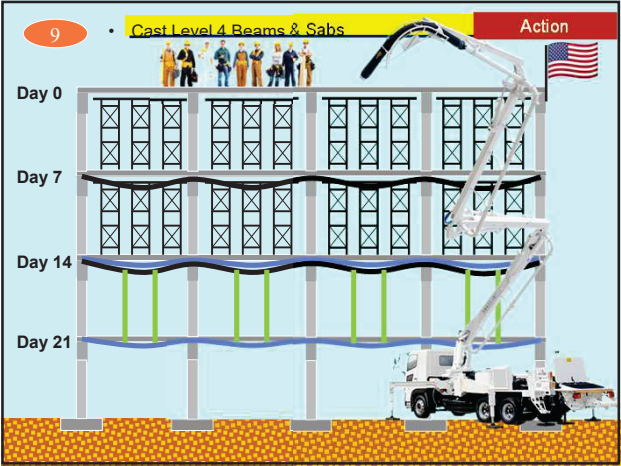
92



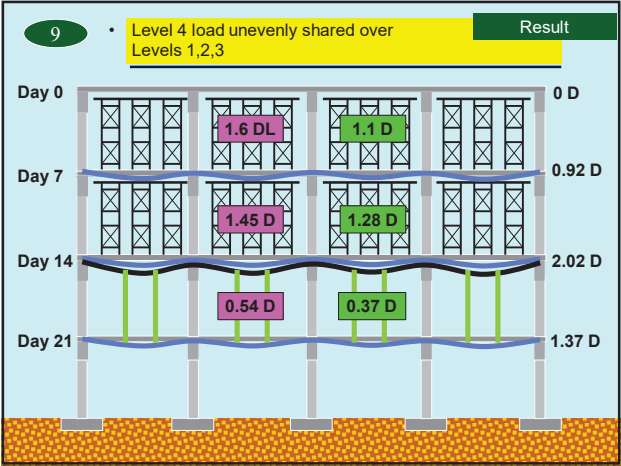
93



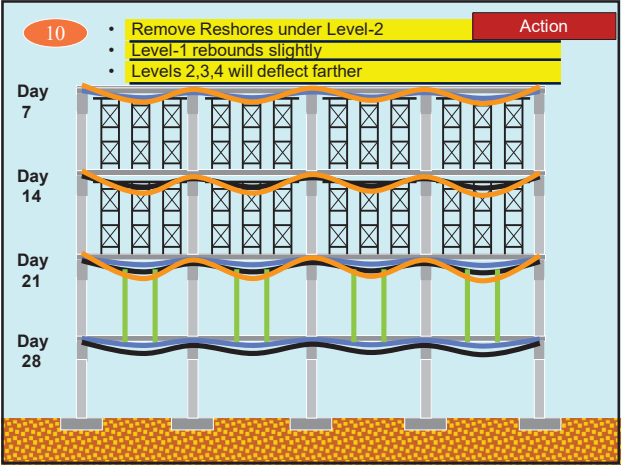
94



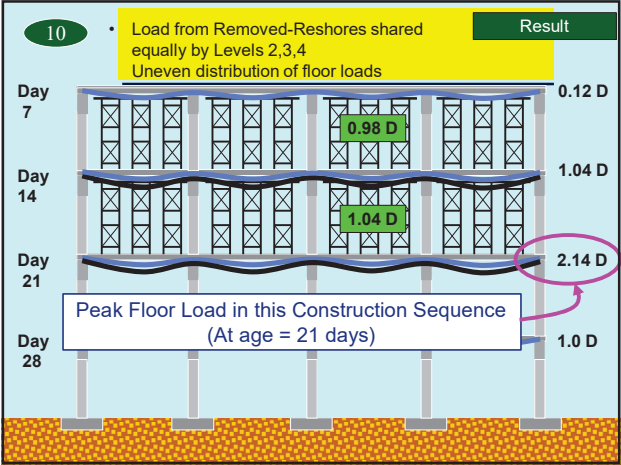
95



96

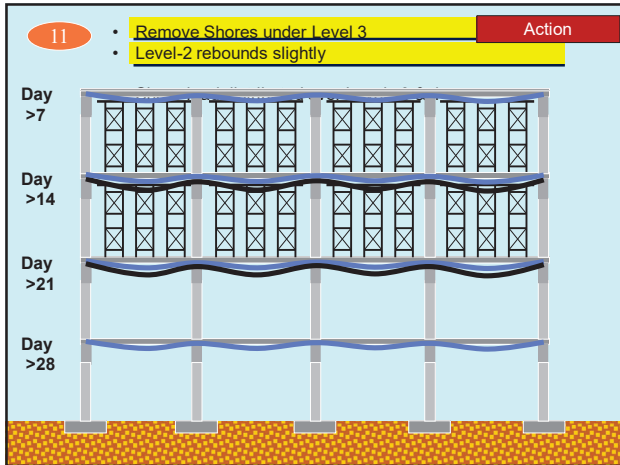


97

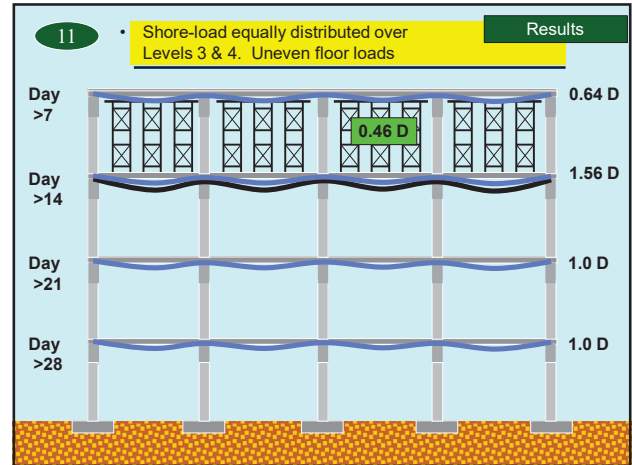


98

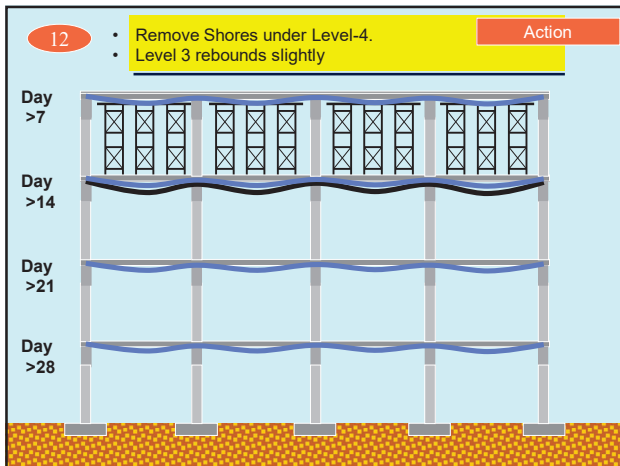




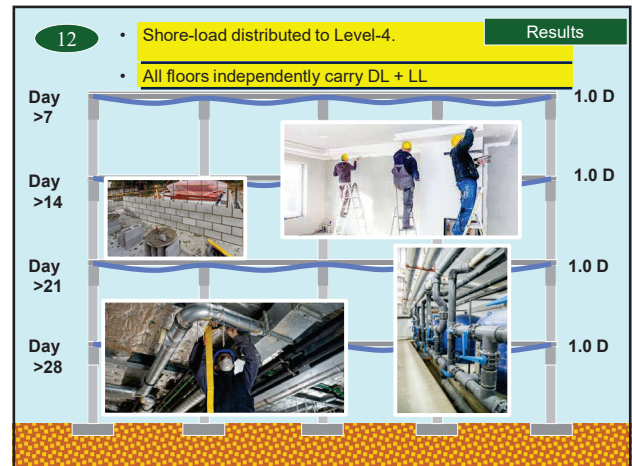
99



100



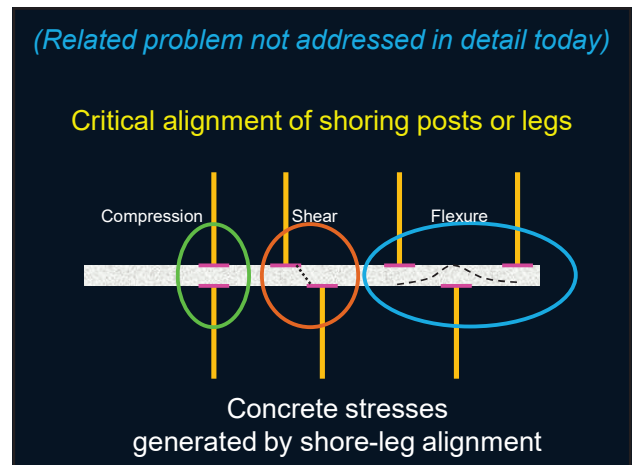
101



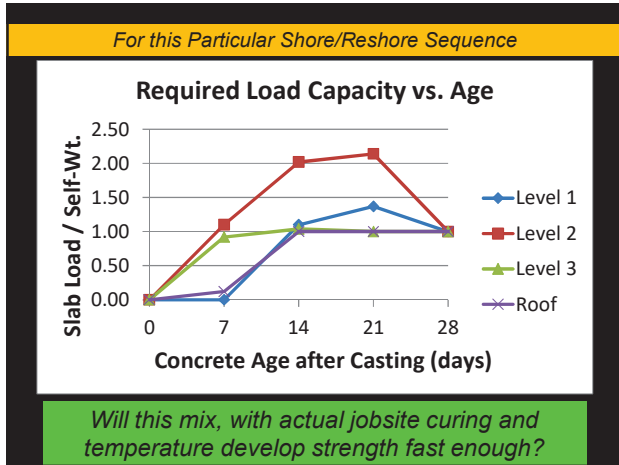
102

Loads on Shoring and Concrete Floor for 8-inch thick slab 4-Story Building 2 Levels Shored, 1 Level Reshored				
Step (from "Result") PPT Slides	Peak Shore Load	Peak Reshore Load	Peak Floor Load	Age of concrete at peak load
1	1.6D	0	0	
2	2.7D	0	0	
3	0	0	1.1D	≤ 7 Days
4	0	0	1.1D	≤ 7 Days
5	1.6D	1.6D	1.1D	≤ 7 Days
6	0.73D	0	1.47D	≤ 14 Days
7	0.55D	0	1.65D	≤ 14 Days
8	0.55D	0	1.65D	≤ 14 Days
9	1.6D	0.54D	2.02D	14 Days
10	1.04D	0	2.14D	21 Days
11	0.46D	0	1.56D	≥ 14 days
12	0	0	1.0D	> 7 days

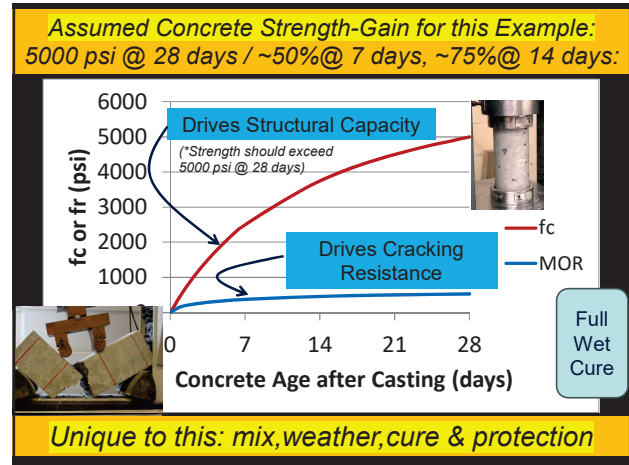
103



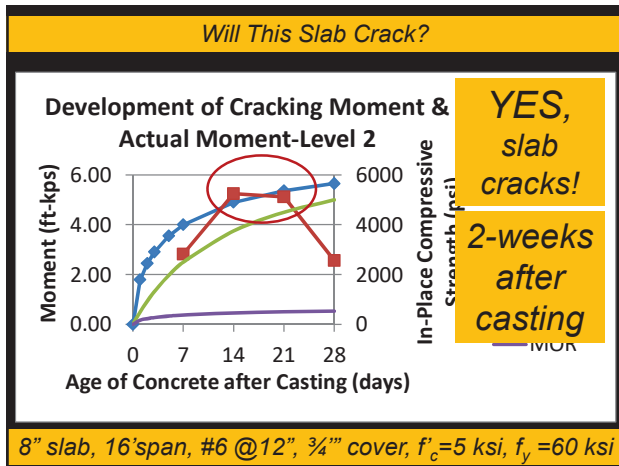
104



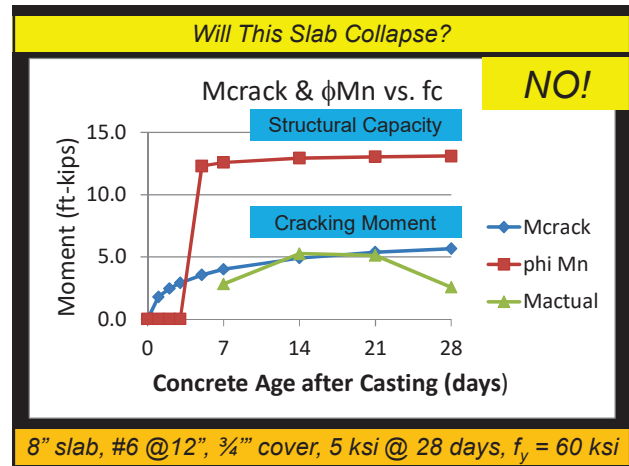
107



108



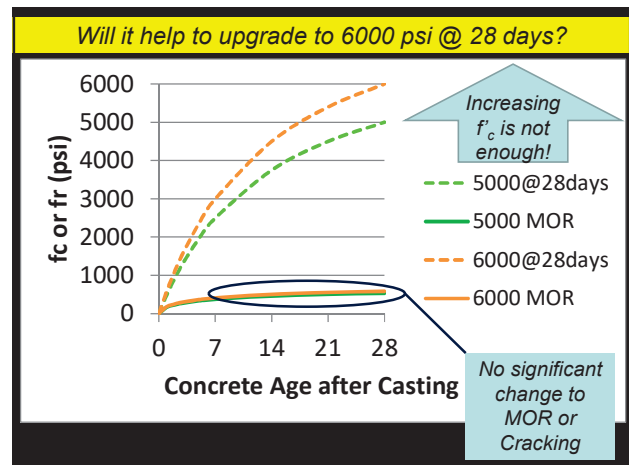
109



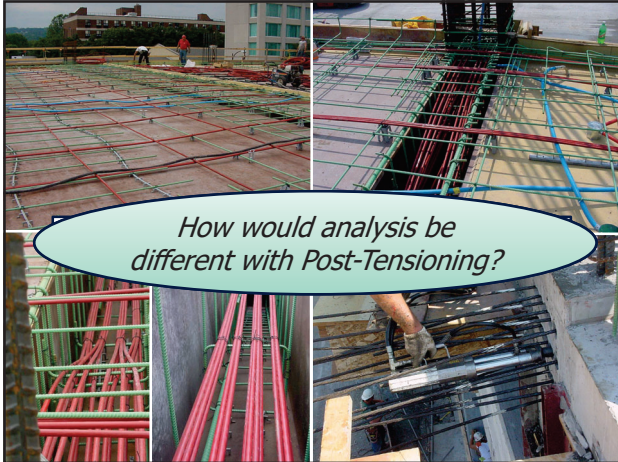
110

- So what if it only cracks?
- Reduced Stiffness ( $I_{cracked}$ )
  - Increased Deflection
  - Decreased Serviceability (leaks, corrosion)
  - Increased Creep
  - Engr/Arch/Owner Reaction
    - Crackiphobia

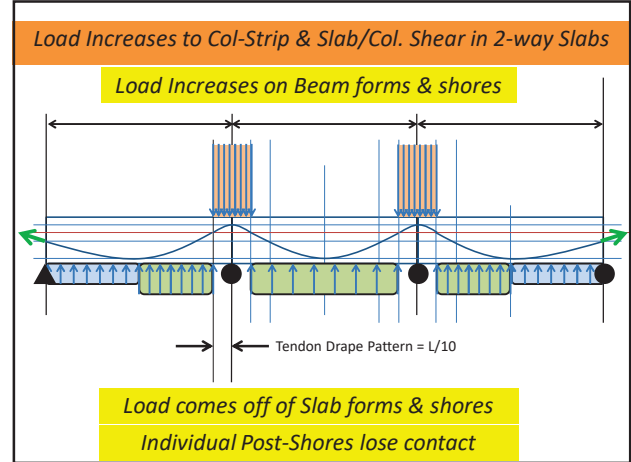
111



113



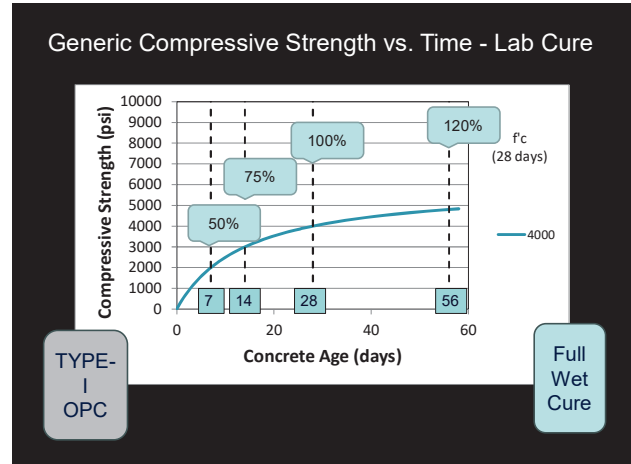
114



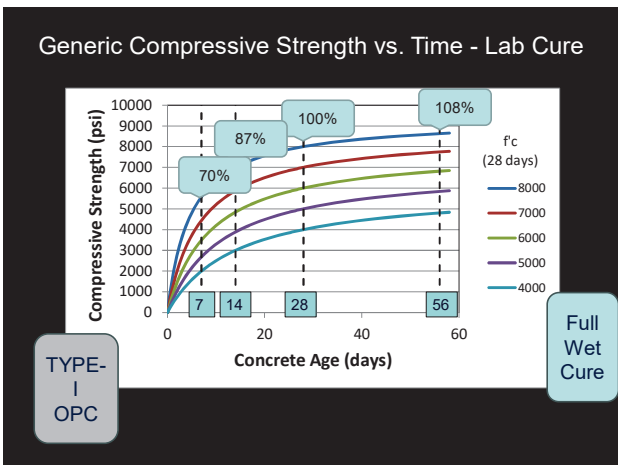
115

- Shoring and re-shoring:
  - Introduction
  - Whose problem is this? (Regulatory Forest)
  - How Shore and Reshore Systems Work
  - Principles for Typical Analysis with Example
  - ▶ Rate of Strength-Gain, Concrete Temperature
  - In-Place Testing

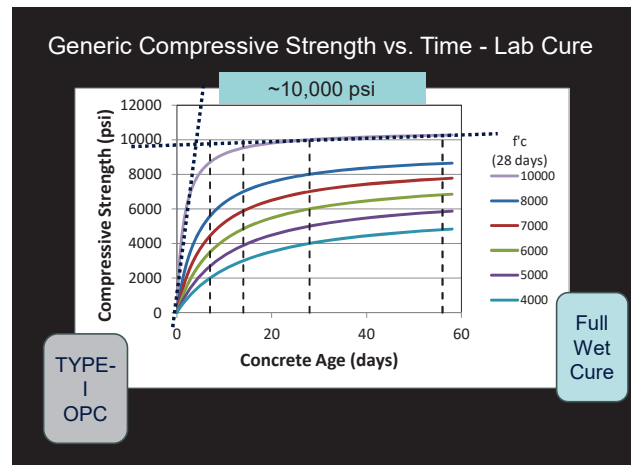
116



118

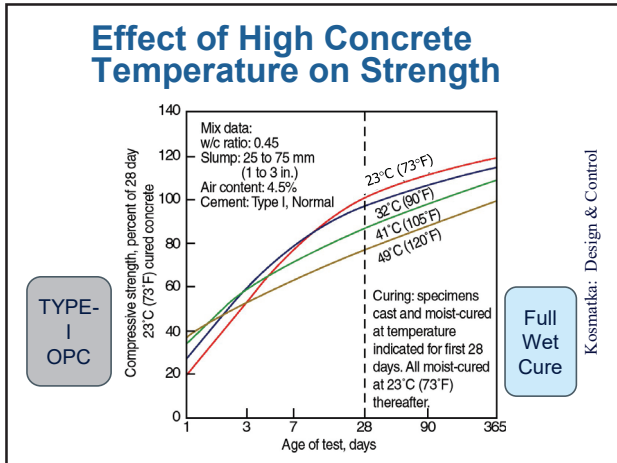


119

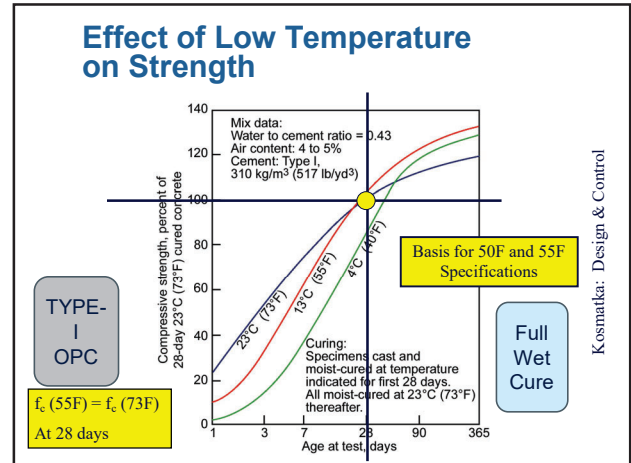


120

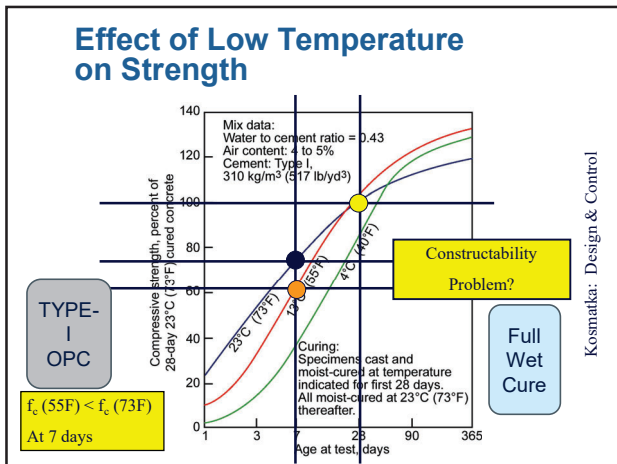




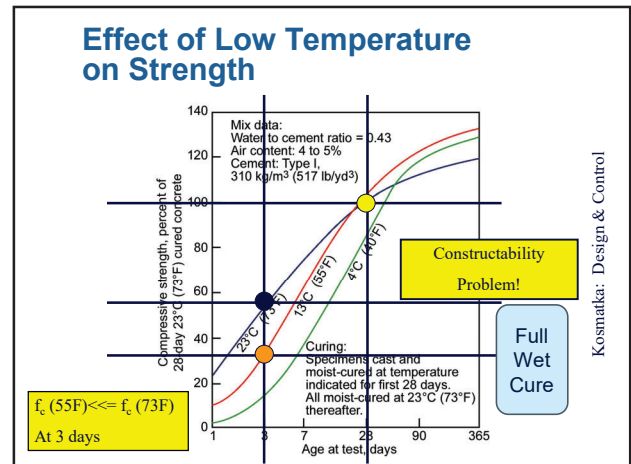
121



122



123



124

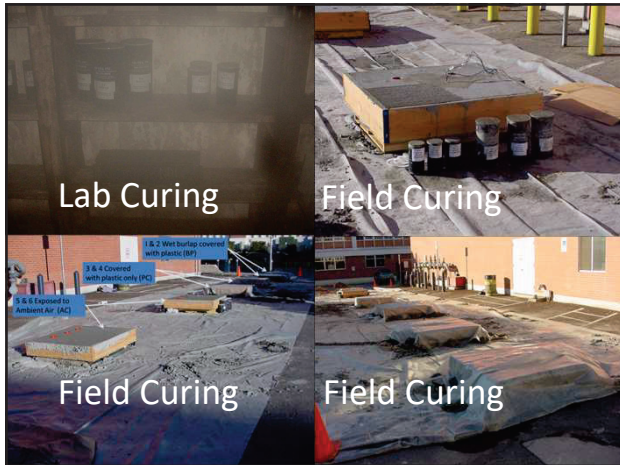
- Shoring and re-shoring:
  - Introduction
  - Whose problem is this? (Regulatory Forest)
  - How Shore and Reshore Systems Work
  - Principles for Typical Analysis with Example
  - Rate of Strength-Gain, Concrete Temperature
- ▶ In-Place Testing

125

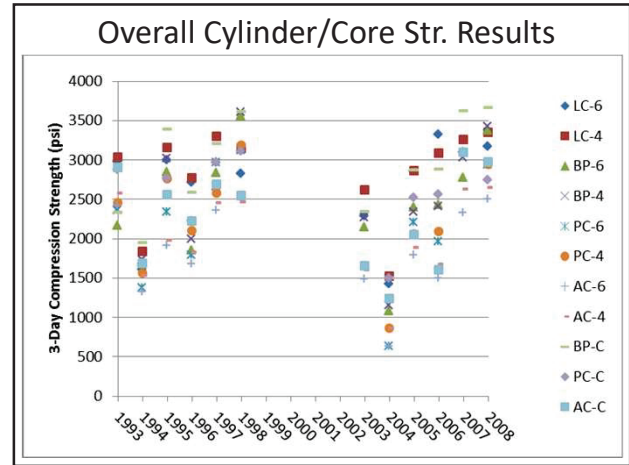
### In-Place Concrete Properties

#### In-Place Testing

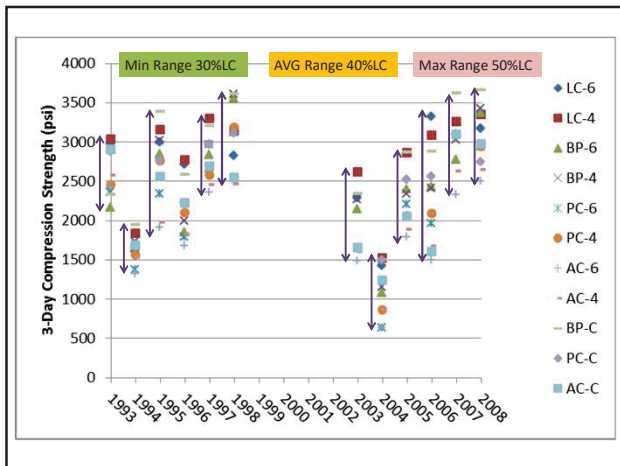
126



127



128



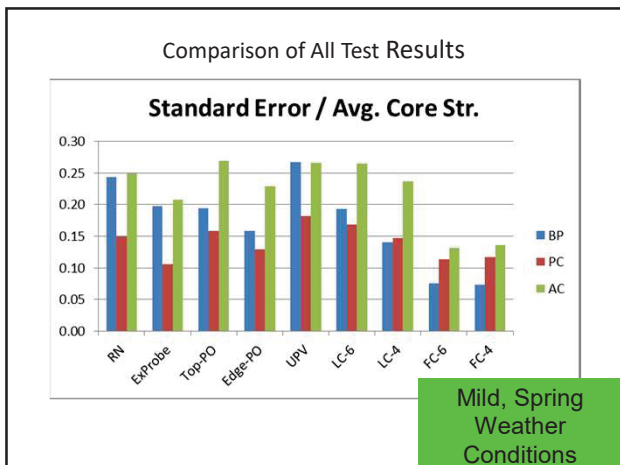
129

### Comparison of Non-Destructive Test Results with Core Strengths

As observed in the FHWA Highway Materials Engineering Course

Ken Hover  
Cornell University      Presentation 15-1927

130



131

### Maturity Testing

Every time you press **time and temperature (power)** on your microwave oven, you are using "Maturity."

Factors that can differ between [concrete in-place] and [concrete used in lab for $f_c$ -Maturity relationship]
Mixture ingredients and proportions
Batching/Mixing/Water-control/Placing/Consolidating
Type and duration of moisture-curing
Lo-to-Hi range of temperature

General Factors
Sensor location relative to zones of peak concrete stress?
Are you continuously comparing predictions with continued lab and in-place testing?
Are you determining unique <i>Datum Temperature</i> or <i>Activation Energy</i> for your specific cement & cementitious materials, and your temperature range?
or are you assuming generic values?

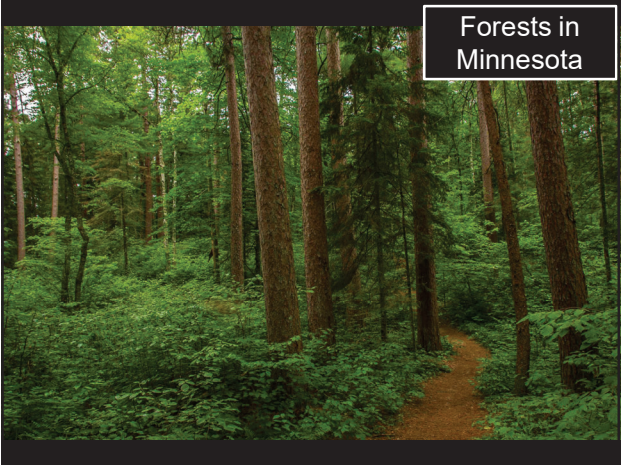
132



133



134



135



136