

**ACI 360 Concrete Slab on Ground
Design and Details**

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A member of the Concrete Solutions

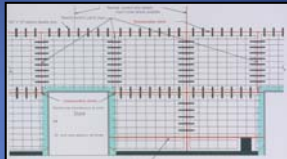
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January 13, 2021

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Slab Design



and Detailing



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The slab every owner expects to see ...



“Lab-Crete”



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American Concrete Institute
(ACI 360) Definition

Slab Design - The decision-making process of planning, sizing, detailing, and developing specifications preceding construction of slabs on ground.



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Designer Responsibility: Develop Clear Project Specs...



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Contractor Responsibility: Follow Project Specifications...




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Load-Carrying Capacity

- Determining Factors
 - ✓ Slab Thickness
 - ✓ Concrete Strength
 - ✓ Subgrade Modulus (k)


Always remember that increasing slab thickness is the most effective way to increase floor load-carrying capacity.

Assuming Load-Transfer is Achieved at Joints



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Concrete Slab Thickness



PCA Design Method


Typical Loading Conditions:

- Axle Loads – Lift Trucks
- Post Loads – Rack Storage
- Distributed Loads – Pallets, Boxes, Rolls




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Axle Load Design



In general, 80 to 85% of total loaded vehicle weight on front axle.
Critical Design Axle Load



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Information Needed for Axle-Load Design

- From materials, site, and designer
 - Concrete compressive strength
 - Subgrade modulus
 - Safety Factor (SF)
 - Joint conditions – Joint Factor (JF)
- From lift truck specifications
 - Lift truck capacity
 - Vehicle weight (total axle load)
 - Wheel configuration and spacing
 - Tire pressure
 - Wheel contact area

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Design for Maximum Capacity

Why?

“I will only transport one pallet at a time.
I promise...”

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Design for Maximum Capacity



“Just One Pallet!”

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Maximum Allowable Bending
~~Concrete Working Stress~~

$$WS = \frac{MR}{SF \times JF}$$

where,
WS = Working stress
MR = Modulus of rupture (flexural strength)
SF = Safety factor
JF = Joint factor

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Concrete Working Stress

Concrete Flexural Fatigue Equations

$\log N = 11.737 - 12.077SR$	for $SR \geq 0.55$Eq. 1
$N = \left(\frac{4.2577}{SR - 0.4325} \right)^{3.368}$	for $0.45 < SR < 0.55$Eq. 2
$N = unlimited$	for $SR \leq 0.45$Eq. 3

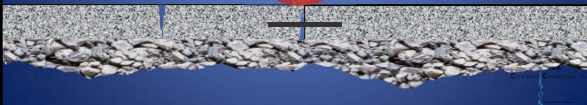
Where:
SR = Stress ratio (flexural stress divided by the flexural strength)
N = Projected number of allowable 16-kip single axle bus load applications to flexural fatigue failure.

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Joint Factor

- Original PCA Charts developed for interior loading by pneumatic tired wheels
- Stresses due to edge loading are higher - up to 60% higher
- Edge loading occurs at joints that do not have complete load transfer
 - Smooth dowel bars or dowel plates
 - Aggregate interlock decreases when joint opens



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Joint Factor

Concrete Shrinkage

Table 5-2. Joint Factors Based on Ultimate Concrete Shrinkage*

Ultimate concrete shrinkage, %	Joint factor
<0.052%	1.0
0.052 to 0.057	1.1
0.057 to 0.062	1.2
0.062 to 0.067	1.3
0.067 to 0.072	1.4
0.072 to 0.078	1.5
>0.078	1.6

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Engineering Judgement

- Joint Factor (JF)
- Safety Factor (SF)
- Applied Load Considerations
 - Effective Contact Area
 - Back-to-Back Post Legs
 - Aisle Width v. Load Width

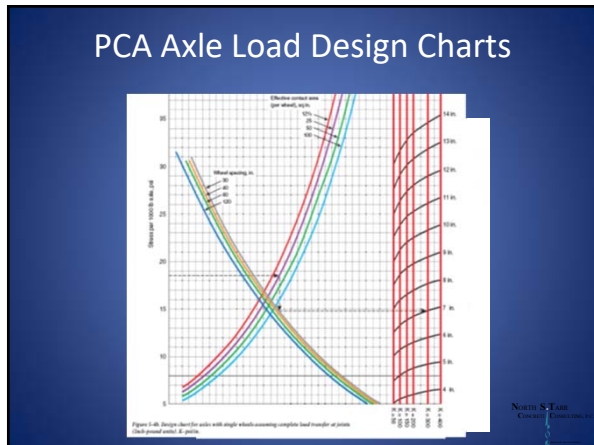
**Complete Set of Design Assumptions
Must Be Considered!**

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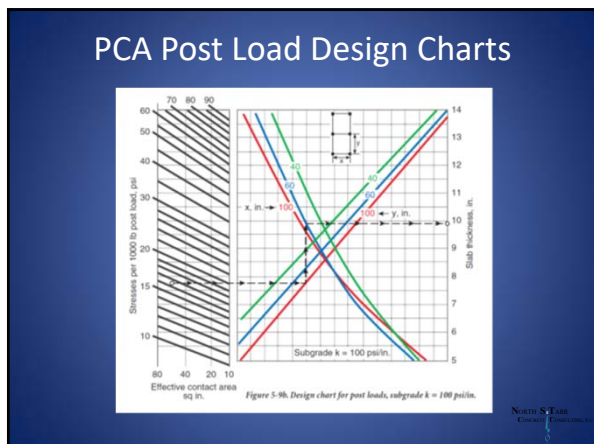
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Responsibility of the Contractor

Perform Construction Per Specifications And Per Industry Standards

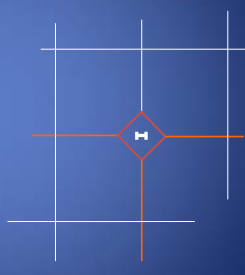


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Jointing

- Joint Types
 - Construction
 - Isolation
 - Contraction/Control



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Construction Joints

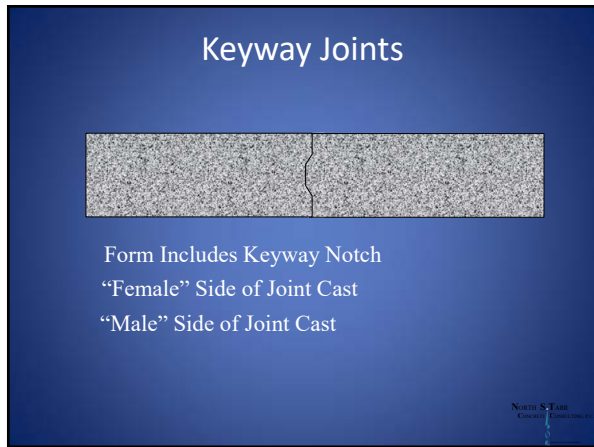
- Designate Pour Limits
 - Single Days Placement
- Butt-Type (Formed)
 - Keyways Not Recommended
- Must be Doweled
 - Load Transfer
 - Prevent Differential Movement

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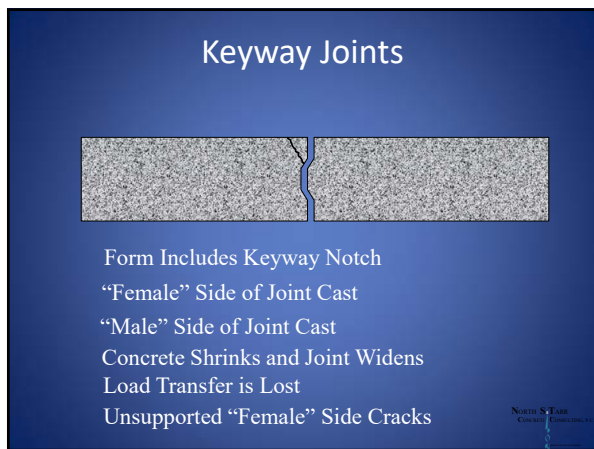
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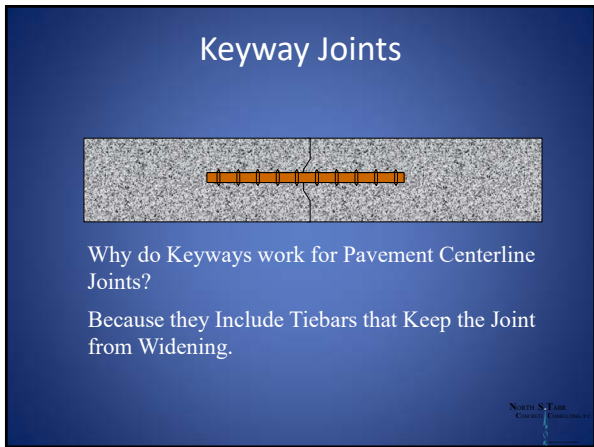
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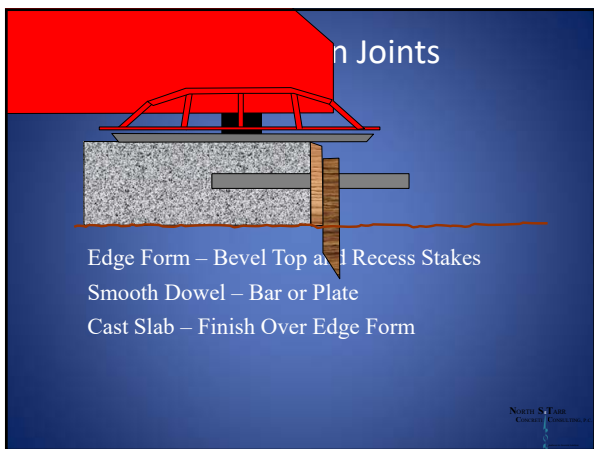
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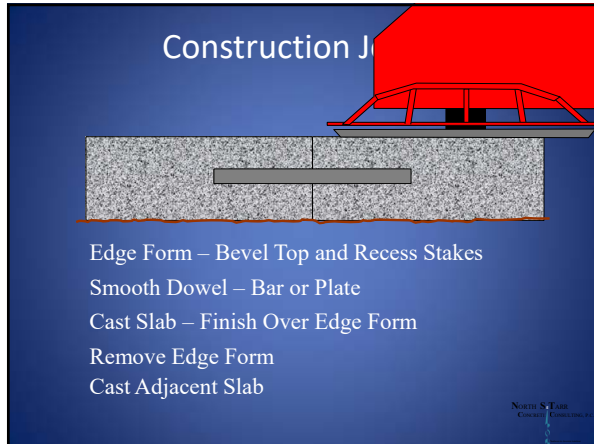
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Contraction Joints

- Control Random Cracking Due To Restraint to Concrete Shrinkage
- Installed at Proper:
 - Spacing
 - Depth
 - Timing


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Contraction Joints

Joint - A crack placed where we want it to be.

Crack - A joint placed where the concrete wants it to be.



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Joints are Generally Preferred



Spacing Depth Timing Ban Joints!


Say No To Crack

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Contraction Joint Spacing

- American Concrete Institute (ACI)
 - 36 Times Slab Thickness
 - 6-in.-thick slab = 18 ft joint spacing
- Portland Cement Association (PCA)
 - Joint Spacing (ft) = 2 to 2.5 Thickness (in.)
 - 6-in.-thick slab = 12 to 15 ft joint spacing

Maximum 30 Times Slab Thickness
15 ft (4.5 m) Maximum - Pavements



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Contraction Joint Spacing

ACI
360R

NOTES:

- Joint spacing recommendations based on reducing the curling stresses to minimize shrink-pond cracking (Wolke-Hilford 2003). See discussion on Section 5.2 for joint spacing for aggregate interface.
- Joint spacing criteria of 36 and 24 times the slab thickness has been utilized in the past.
- Concrete with an ultimate dry shrinkage strain of less than 720 microstrains placed on a dry base material.
- Concrete with an ultimate dry shrinkage strain of 720 to 780 microstrains placed on a dry base material.
- Concrete with an ultimate dry shrinkage strain of 780 to 1100 microstrains placed on a dry base material.

Fig. 6.6—Recommended joint spacing for unreinforced slabs.

Random
Crack
Control
Only!

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Contraction Joint Depth

- Create a Weakened Plane to determine Crack Location
 - How Deep? Deep Enough to Cause Crack
 - ¼ Slab Thickness
 - 6-in.-thick slab = 1½-in.-deep joint
- Grooving/Tooling or Sawcutting
 - Beware of Crack Promoting Insert (Vertical?)

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Contraction Joint Timing

- Before Tensile Stress Exceeds Developed Tensile Strength (Crack)
 - Restraint to Volumetric Decrease
Friction, Penetrations
- Just After Peak Heat of Hydration (Cooling)
 - Drying Shrinkage & Temperature Contraction
 - Generally 8 to 12 Hours After Placement

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Joint Reinforcement

- Load Transfer
Transfer load from one panel to the next
 - Aggregate Interlock
 - Mechanical Devices
 - Dowel Bars
 - Plate Dowels
 - Transferred Steel Reinforcement

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Aggregate Interlock



Minimal Opening Required
< 0.035 in.

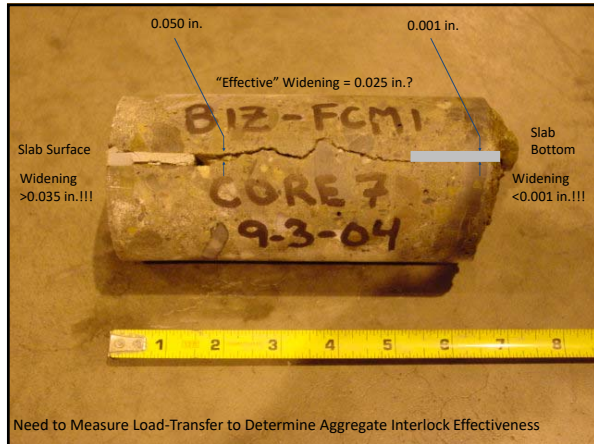
Minimize Concrete Shrinkage and Joint Spacing

Be Aware of How Cracks Form in Slabs – “v” Shape

Sawcut Joint Activation

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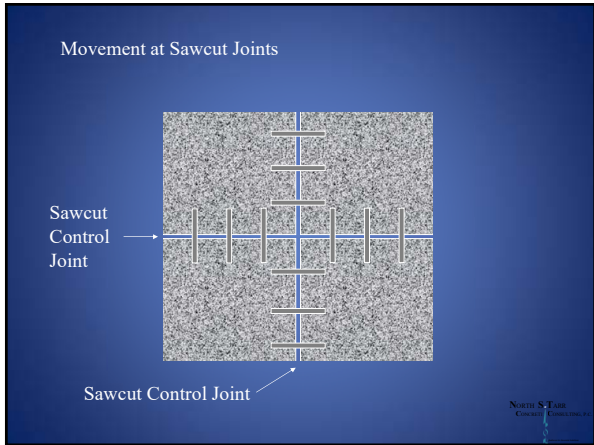
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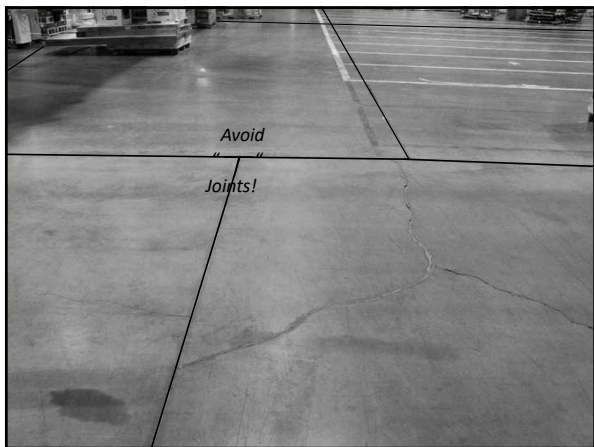
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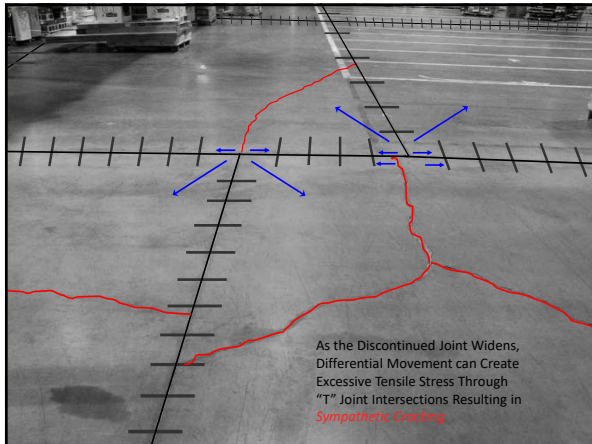
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Reinforcement Transferred Through Joints

- Welded Wire Fabric (WWF)
 - Mesh - Rolls or Sheets
- Reinforcing Bars
 - Mats
- Post-Tensioning
- Shrinkage-Compensating

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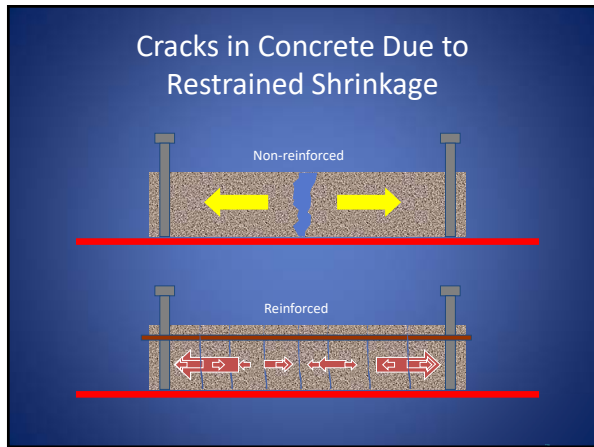
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Transfer Steel Through Joints

- ACI 360
 - <0.1% Steel per Area of Concrete Cross-Section
 - Enhanced Aggregate-Interlock
 - Cracking occurs beneath sawcuts only
 - Joint Spacing per ACI 360R Figure 6.6
 - >0.5% Steel per Area of Concrete Cross-Section
 - Conventionally Reinforced Slab
 - Visible tight cracks expected at 3-5 ft spacing
 - No sawcut joints necessary – no “control”
 - 0.1-0.5% Steel per Area of Concrete Cross-Section
 - “Legalcrete”
 - Visible random cracks that require filling



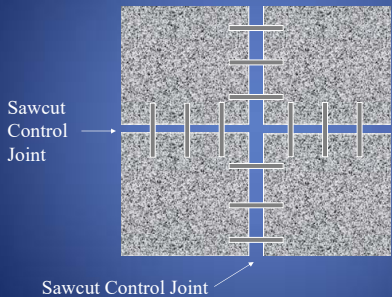
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Transfer Steel Through Joints



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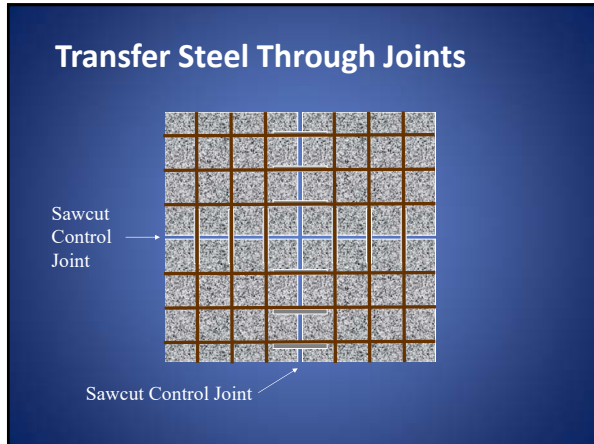
Movement at Sawcut Joints



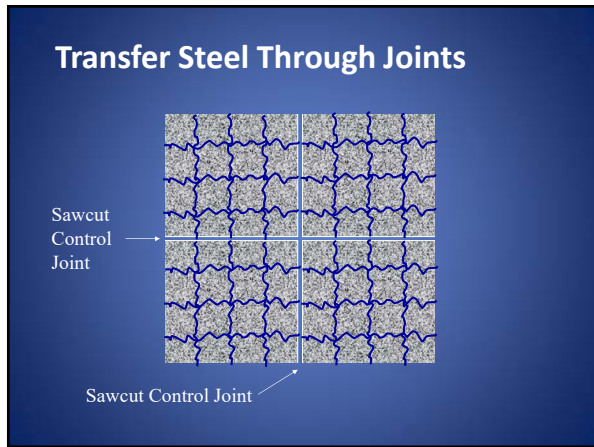
Sawcut Control Joint

Sawcut Control Joint

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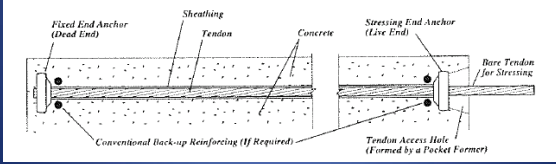
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Post-Tensioned Slabs

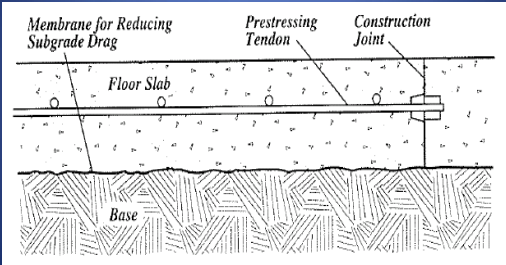
Tensioned tendons put slab into permanent compression.
Therefore, no tensile stress and associated cracking.



The diagram shows a cross-section of a post-tensioned slab. On the left, a 'Fixed End Anchor (Dead End)' is shown where a tendon is embedded in a concrete block. The tendon is surrounded by 'Sheathing'. The main part of the slab is 'Concrete' containing 'Tendon's. On the right, a 'Stressing End Anchor (Live End)' is shown, with a 'Bare Tendon for Stressing' extending from it. A 'Tendon Access Hole (Formed by a Pocket Former)' is also indicated. 'Conventional Back-up Reinforcing (If Required)' is shown at the bottom of the slab. A small logo for 'North S-Tarr Concrete Construction, Inc.' is in the bottom right corner.

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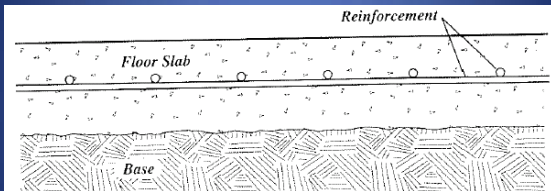
Post-Tensioned Slabs



The diagram shows a cross-section of a post-tensioned slab on a 'Base'. A 'Membrane for Reducing Subgrade Drag' is located between the slab and the base. A 'Prestressing Tendon' is shown within the slab. A 'Construction Joint' is also indicated. A small logo for 'North S-Tarr Concrete Construction, Inc.' is in the bottom right corner.

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Shrinkage-Compensating Slabs



The diagram shows a cross-section of a shrinkage-compensating slab on a 'Base'. 'Reinforcement' is shown within the 'Floor Slab'. A small logo for 'North S-Tarr Concrete Construction, Inc.' is in the bottom right corner.

Expansive cement or an expansive admixture causes concrete to expand (type K cement).
Steel reinforcement is tensioned and restrains expansion.
Concrete is put into compression – no cracking.

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Extended-Joint Slab Systems



- Design Extends Joint Spacing Beyond that Recommended by ACI 360.
 - Presumably Assumes No/Minimal Out-of-Joint Random Cracking or Achieves Serviceable Cracking.
 - Owner Should be Informed of Expectation
 - Must Accomplish One or More of the Following:
 - Reduce Concrete Shrinkage Potential to Negligible
 - Reduce Restraint
 - Keep Random Cracks Tight and Closely-Spaced
 - Design for Joint Widening (1/4 the Joints Results in 4 Times the Widening Per Joint)
 - Slab Systems That Require Sawcut Contraction Joints Shrink and Curl.



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Fiber Reinforcement

- Microsynthetic (0.1% or Less)
 - Monofilament
 - Fibrillated
- Macrosynthetic
 - 0.25 to 1%
- Steel (0.25 to 0.5%)
 - Smooth
 - Deformed



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Concrete Mix Design and Placement Conditions

- ~~High Compressive Strength~~
- ~~Low Water/Cement Ratio~~
- ~~Low Slump~~

Not for Slabs!

- Low Shrinkage Potential
 - ASTM C 157 and ACI 209R
- Good Workability/Finishability
- Required Strength and Durability

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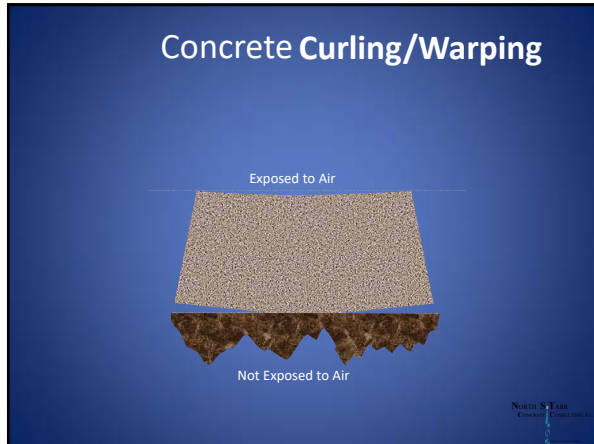
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Concrete Shrinkage/Contraction

- Temperature Contraction
 - 3.2 to 7.5 millionths/°F
 - 1/2 to 1 in. over 100 ft for 100°F change
- Moisture Loss – Volumetric Shrinkage
 - 0.020% to 0.200%
 - 1/4 to 2-1/2 in. in 100 ft

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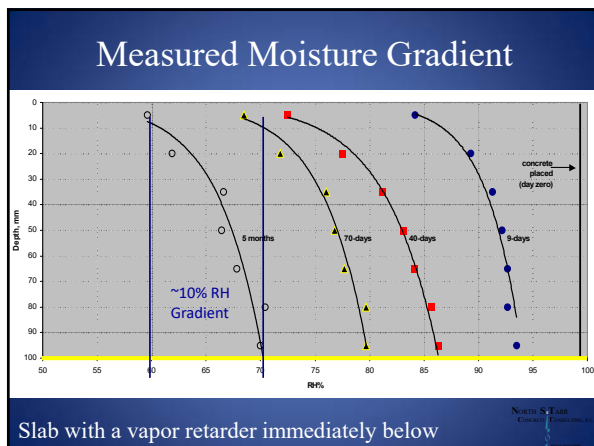
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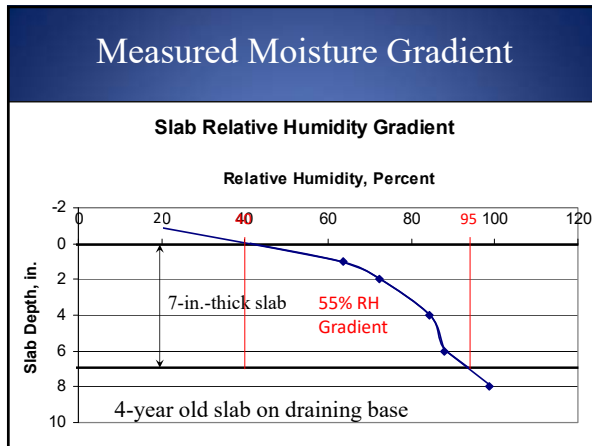
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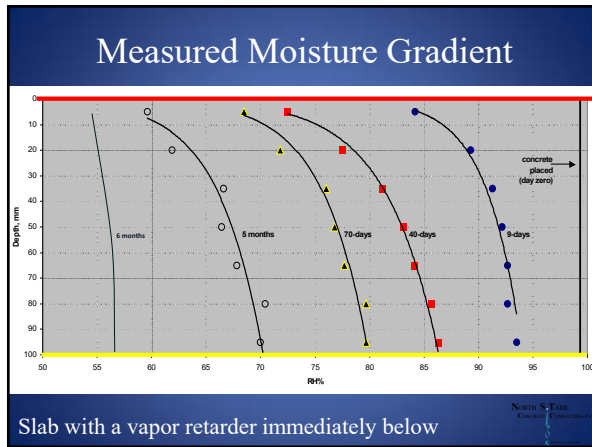
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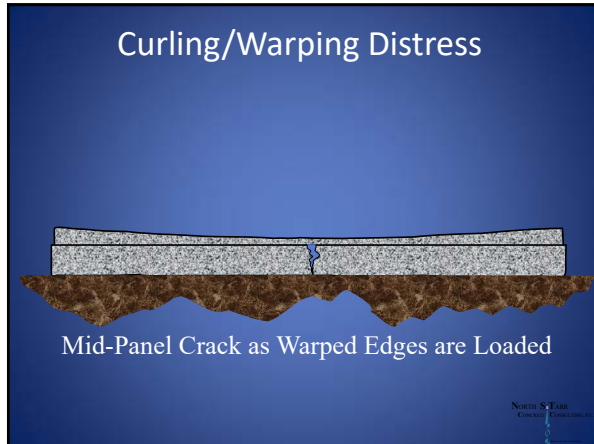
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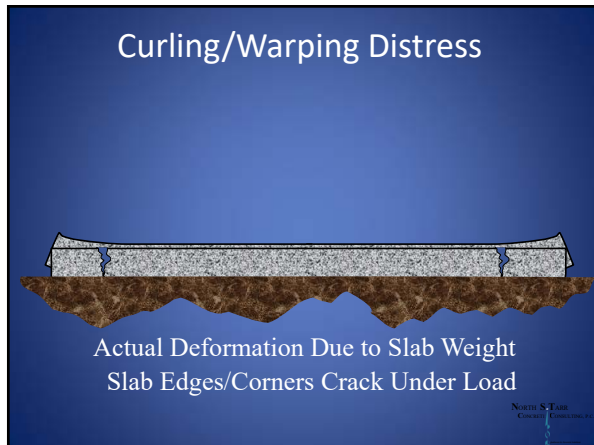
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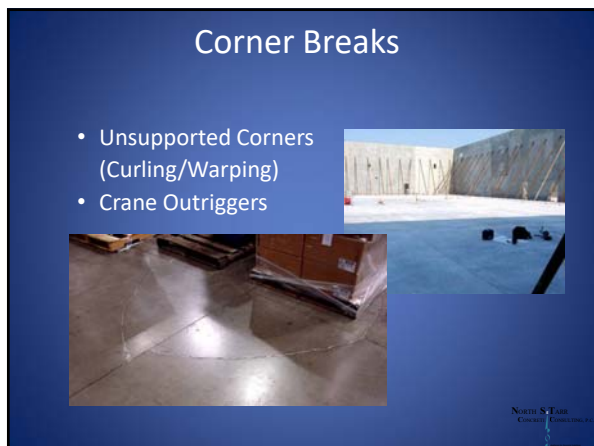
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Problems with Slab Warping

- Decreased Load-Carrying Capacity Resulting in Long-Term Slab Cracking
 - Mid-Panel Cracks
 - Corner Breaks
- Slab Rocking – Joint Stability

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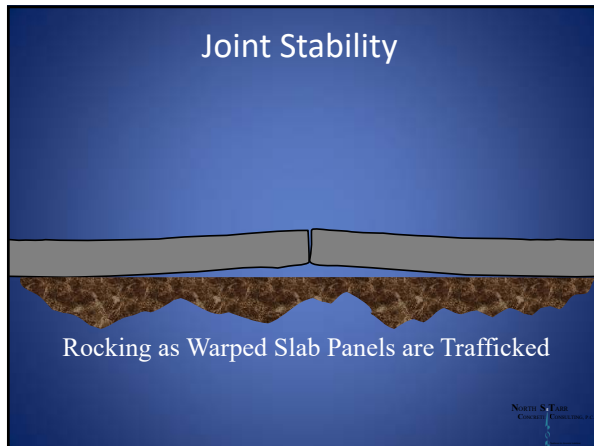
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Joint Stability

Rocking as Warped Slab Panels are Trafficked

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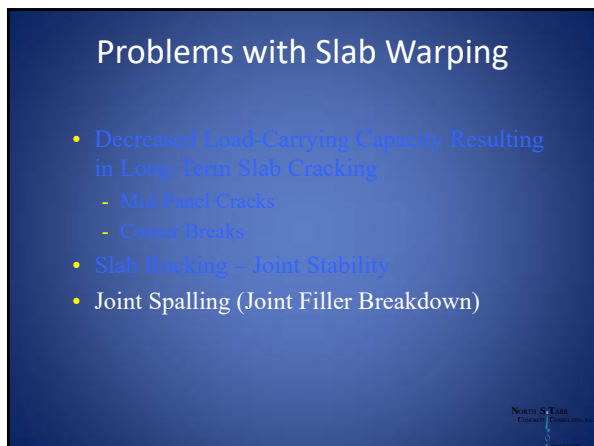
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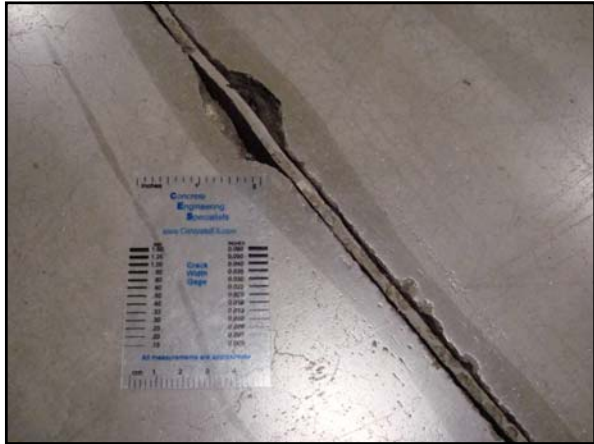
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Joint Spalling

- Stable Joint
- Joint Filler Material
- Wheel Type/Traffic

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Exterior Pavement Joints

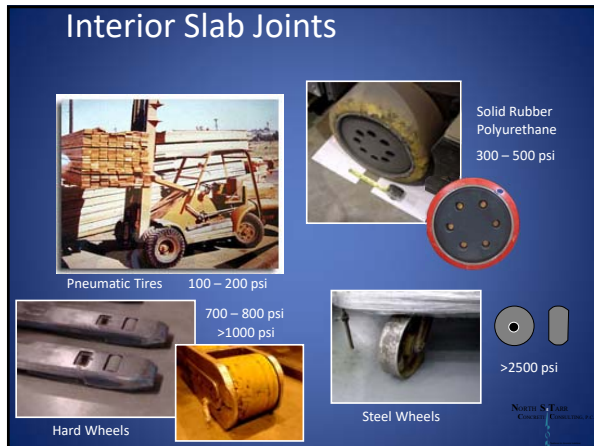
120 psi

Install Flexible Joint Sealant

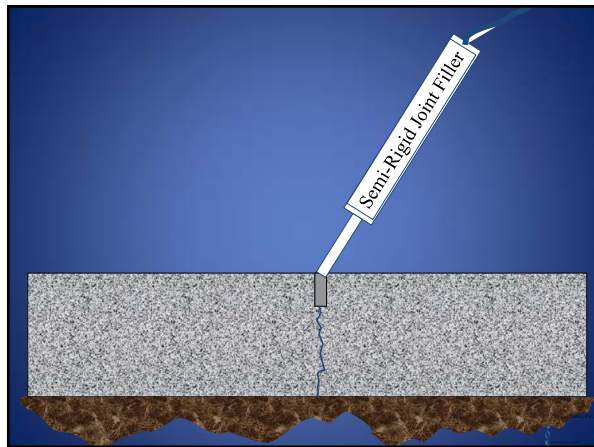
Install Foam Backer Rod

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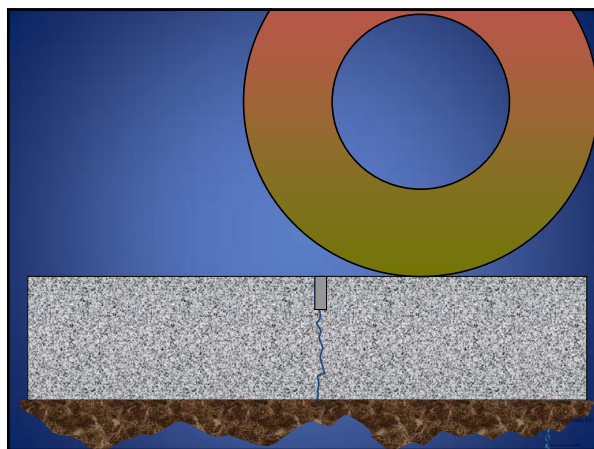
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“Minimizing” Shrinkage and Slab Warping

- Use Quality Aggregate
- Minimize Paste Quantity
 - Increase Aggregate Size
 - Optimize Aggregate Gradation
 - Minimize Cement Content
- Maximize Paste Quality
 - Reasonable Water/Cement Ratio
 - Just Enough Water for Workable Slump

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ACI 309.1R-16
 Guide to Concrete Floor and Slab Construction
 Reported by Committee 309

8.2—Concrete
 Because minimizing shrinkage is of prime importance, special attention should be given to selecting the best possible concrete mixture proportions. When necessary to determine if a proposed concrete mixture has other than normal shrinkage (ACI 209R), the proposed concrete mixture should be compared with the specified or a reference concrete mixture using ASTM C157/C157M testing, modifying curing, and drying of specimens similar to Caltrans Test 530 (Caltrans 1995). It is essential that the concrete used in these tests be made with the same materials, including admixtures, that will be used in the actual construction.

8.4—Recommended concrete mixture

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MATERIAL DISTRIBUTION BY SIEVE
 Combined Aggregate Retained

Haystack Curve
~~8-18 Gradation?~~

In general, 5–22 percent retained provides workable mix

Blend aggregates to minimize alternating high and low retainage on successive sieves.

Fig. 8.9.4a—Material sieve analysis showing change in aggregate distribution with blending of 3/8 in. (9.5 mm) aggregate.

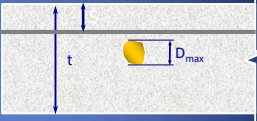
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Maximum Coarse Aggregate Size



Slab Thickness, t : $D_{max} \leq T/3$
 $D_{max} \leq 1/4 S$


For pumped concrete:
 $D_{max} \leq 1/3$ diameter of hose or
 $\leq 1\frac{1}{2}$ in.
whichever is smaller



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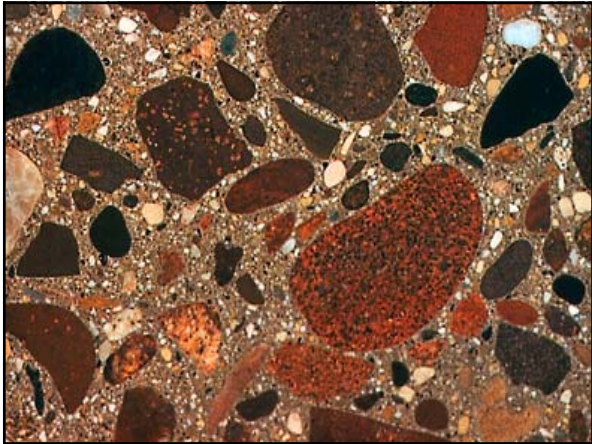
Sieve Analysis ASTM C 136



Well-Graded
Vs.
Gap-Graded

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Minimizing Paste Quantity

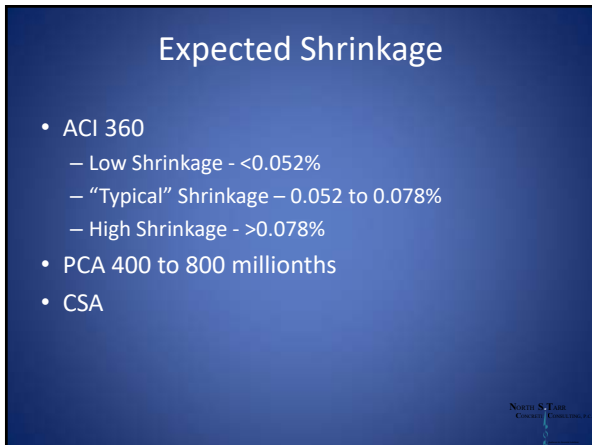
Balance Between:
Low Shrinkage
and
Workability/Finishability

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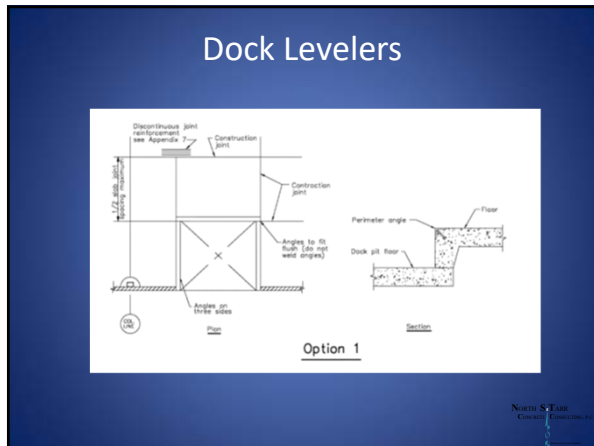
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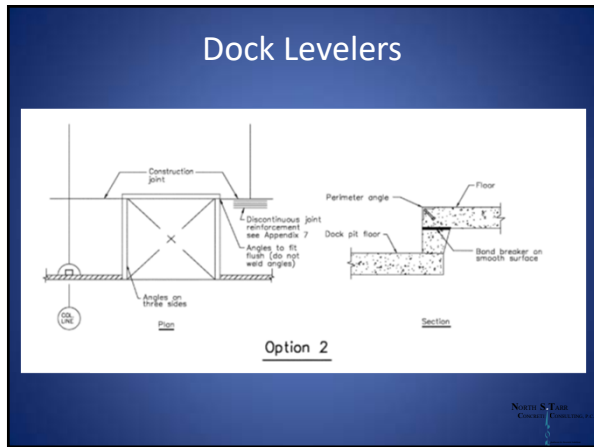
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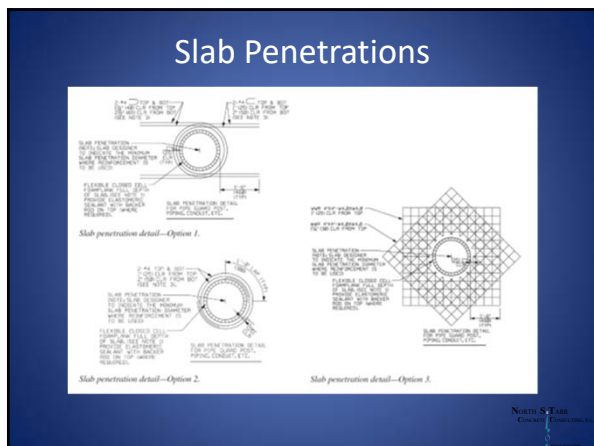
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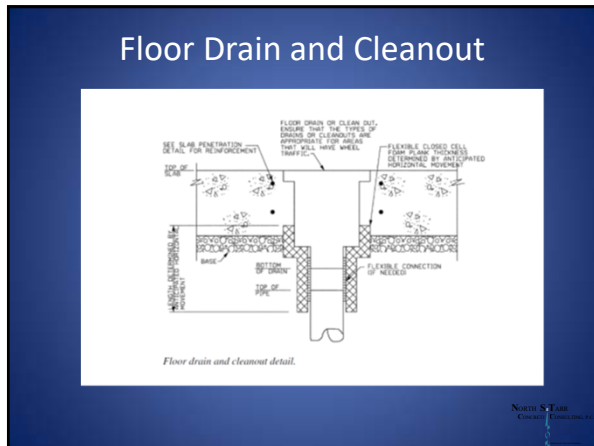
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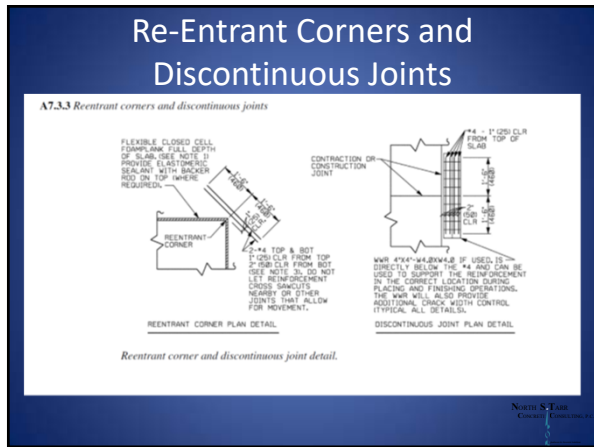
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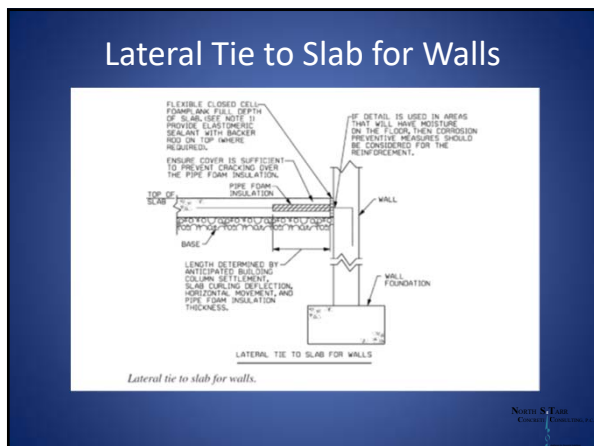
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Slab on Ground Design and Details Conclusions

- Design and build for serviceability in accordance with owners expectations
- Anticipate the drying shrinkage potential for local materials when determining joint reinforcement

Aggregate Interlock

Dowels or Light Reinforcement

Heavy Reinforcement

Post-Tensioned or Shrinkage-Compensated

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Slab on Ground Design and Details Conclusions

- Design and build for serviceability in accordance with owners expectations
- Anticipate the drying shrinkage potential for local materials when determining joint reinforcement
- Predict the impact of each design and construction feature and advise the owner

Aggregate Interlock

Dowels or Light Reinforcement

Heavy Reinforcement

Post-Tensioned or Shrinkage-Compensated

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**Slab on Ground Design and Details
Conclusions**

- Design and build for serviceability in accordance with owners expectations
- Anticipate the drying shrinkage potential for local materials when determining joint reinforcement
- Predict the impact of each design and construction feature and advise the owner
- Always “design” an industrial floor slab. Don’t simply “specify” slabs

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Slab on Ground Design and Details Conclusions

- Design and build for serviceability in accordance with owners expectations
- Anticipate the drying shrinkage potential for local materials when determining joint reinforcement
- Predict the impact of each design and construction feature and advise the owner
- Always “design” an industrial floor slab. Don’t simply “specify” slabs
- And remember...

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Remain Calm!



"STAND BACK - MAKE ONE MORE UNREASONABLE DEADLINE AND I'LL EXPLODE THE DIMENSIONS!"

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Thank You!
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