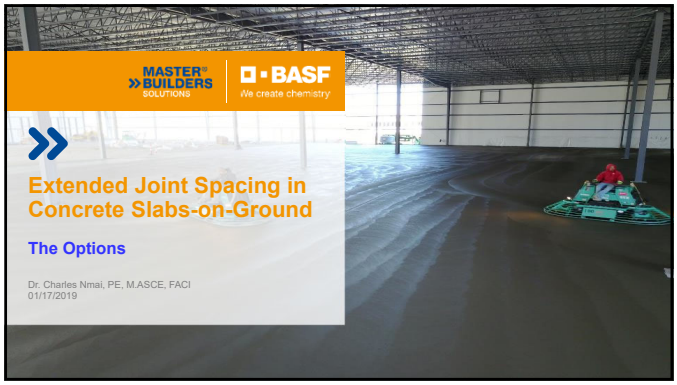
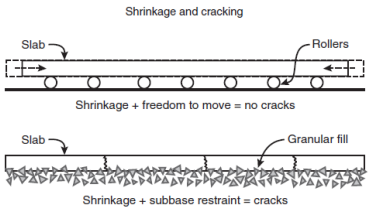
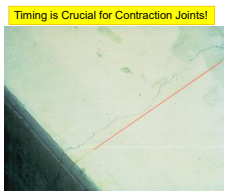


The Problem with Slabs-on-Ground



Joint Types

- Construction Joints
  - Formed joints
- Contraction Joints
  - Sawn / Tooled
  - Timing / Depth
- **Random Cracks**



Random Cracking in Concrete Slabs

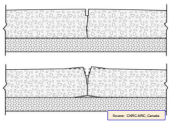


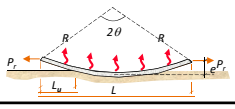
Random Cracking in Concrete Slabs

Safety Hazard!

Slab Cracking due to Curling

- Slabs dry from the top and are moist at the bottom.
- Differential shrinkage causes slab edges to lift (curl) and joints to open.
- The mass of unsupported concrete causes the slab center to sink into the soil.
- As joints open, shear transfer at joints is reduced.
- As joints open, loads applied along the joint can cause cracking in the unsupported length.
- Curling is more pronounced at corners.





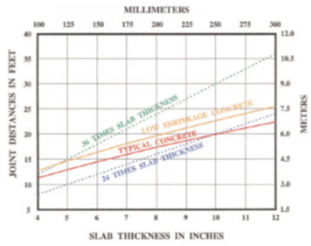

The Problem with Slabs-on-Ground

- PCA: "…the greatest portion of floor repair and maintenance is for **joint edge deterioration** and crack correction."
- Maintenance of joints constitutes approximately 80% of the problems with floors.

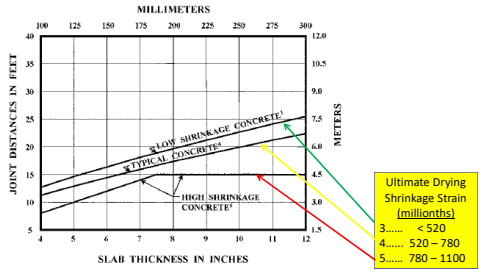
Spalled joints in 1-year old facility

Previous ACI 360R Recommended Joint Spacing

… for unreinforced slabs-on-ground

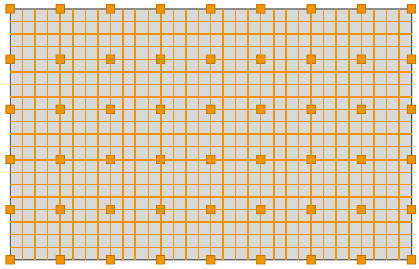


Current ACI 360R Recommended Joint Spacing

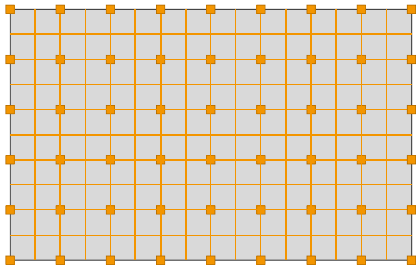


Ultimate Drying Shrinkage Strain (millionths)
3..... < 520
4..... 520 – 780
5..... 780 – 1100

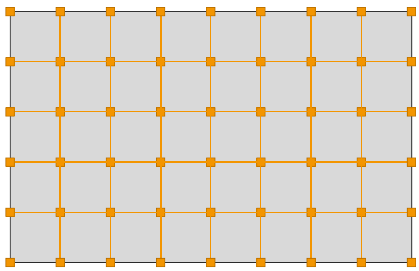
Joint Spacing (…Option 1)



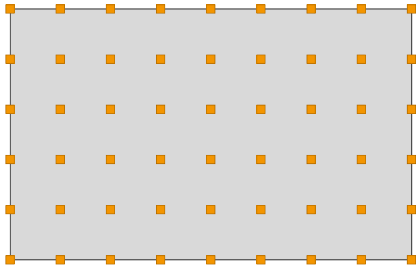
Joint Spacing (…Option 2)



Joint Spacing (…Option 3)



Joint Spacing (…Option 4)



Extending Joint Spacing in Concrete Slabs

- A number of techniques can be adopted to increase joint spacing in slabs-on-ground.
  - **Post-tensioning**
  - Expansive components
  - High steel reinforcing ratio ($\rho \geq 0.5\%$)
  - Low drying shrinkage & fiber reinforcement

Extending Joint Spacing in Concrete Slabs: Post-tensioning

- Foundation slabs post-tensioned since 1960s!
- Designed in accordance with Post-Tensioning Institute (PTI) method.
- Compression induced in slab by applying 33,000-lb load to post-tensioning tendons.
  - Cables placed in plastic ducts or sleeves and positioned in the forms before concrete placement.
  - Cables tensioned* after concrete has gained strength, but before loads are applied.
  - Minimum required net compressive stress – 50 psi.

* Stretched 8-in. over 100-ft length!

Extending Joint Spacing in Concrete Slabs: Post-tensioning

PTI Method:

- Slabs with exterior and interior footings (ribs)
- Footings:
  - Typically 18 – 24 in. deep / 12 in. wide / 12 ft spacing
  - Extend across foundation
  - Add strength and stiffness to resist applied loads
- Minimal reinforcement
  - #4 bars in footing
- Ribbed foundation can be converted to solid thicker slab
  - ex. 8 – 10 in. thick slab (or more) in lieu of 5-in. thick ribbed slab

Credits: Bryan Allred, Concrete Construction, Sep. 18, 2006

Extending Joint Spacing in Concrete Slabs: Post-tensioning

Advantages:

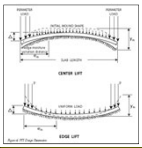
- Reduces / eliminates shrinkage cracking ➔ no / few joints.
- Cracks, if any, held tight
- Slabs can be thinner
- Strands can be placed around penetrations, etc.
  - Variable lengths – 15 to 200 ft

Credits: Bill Palmer, ConcreteNetwork.com Columnist

Extending Joint Spacing in Concrete Slabs: Post-tensioning

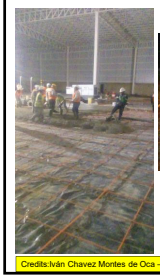
Common Applications:

- Slabs-on-ground (~50 percent residential homes!)
  - Over expansive soils (e.g. TX, CA, Southwestern U.S.A.)
  - Crack-free tennis courts
- Slabs typically 4 - 5 in. thick.
- 270 psi, seven-wire tendon spaced 48 in. o.c.e.w.
  - 50 psi requirement dictates no. of tendons needed
- 3,000 psi concrete; tendons stressed at concrete strength of 2,000 psi.
- Durability requirements may dictate concrete strength.



Credits: Bryan Allred, Structure Magazine, Jan. 2010

Extending Joint Spacing in Concrete Slabs:
Post-tensioned SOG Project: Comex Dist. Ctr. Guadalajara, Mexico



Credits:Iván Chavez Montes de Oca – Forzac Ready Mix, Guadalajara, Mexico

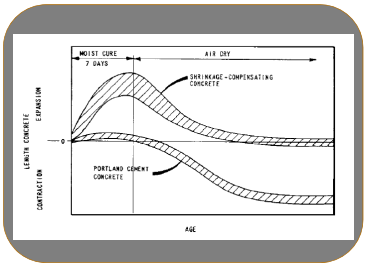
Extending Joint Spacing in Concrete Slabs

- A number of techniques can be adopted to increase joint spacing in slabs-on-ground.
  - Post-tensioning
  - **Expansive components**
  - High steel reinforcing ratio ($\rho \geq 0.5\%$)
  - Low drying shrinkage & fiber reinforcement

Extending Joint Spacing in Concrete Slabs: **Expansive Components**

- Materials that expand after concrete hardens
- Calcium oxide (CaO)
  - Type G component; calcium hydroxide platelets
  - 2 to 10 percent by mass of cementitious materials
  - Keep dry!!!
- Magnesium oxide (MgO) / Glycol ether
  - 2.5 to 5 percent by mass of cementitious materials
- Expansion has to be controlled and restrained!
  - Need minimum amount of reinforcement

Extending Joint Spacing in Concrete Slabs: Expansive Components



MgO / Glycol Ether System
Effect on Fresh & Hardened Properties

- Air content may drop 1-2 percent compared to control. Consistent after adjustment.
- May require slight increase in HRWR to achieve slump.
- Improves finishability.
- No effect on set times and strength.
- No cement-admixture interactions noted.
- No change in construction practices (not treated as shrinkage-compensating concrete). Special curing not required.
- Cracking reduced considerably.

Credits: PremierCPG

Field Trials – USBR Glen Elder Dam

Credits: USBR

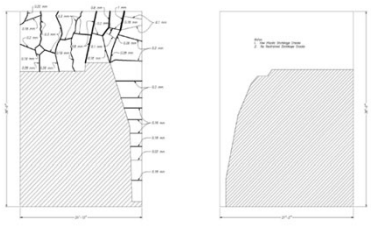
Partial Depth Hydrodemolition & Replacement

Credits: USBR

Partial Depth Hydrodemolition & Replacement

Credits: USBR

Partial Depth Hydrodemolition & Replacement



Credits: USBR

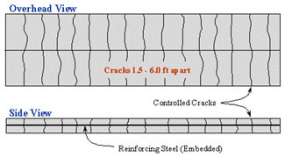
Extending Joint Spacing in Concrete Slabs

- A number of techniques can be adopted to increase joint spacing in slabs-on-ground.
  - Post-tensioning
  - Expansive components
  - **High steel reinforcing ratio ($\rho \geq 0.5\%$)**
  - Low drying shrinkage & fiber reinforcement

Extending Joint Spacing in Concrete Slabs: High Ratio of Steel

- Steel reinforcement ratio, ρ ~ 0.5 to 0.6 percent
  = 0.36 in.^{2}/ft (minimum) for 6-in. thick slab
  ➔ #5 @ 10-in. o/c or #6 @ 14-in. o/c
- Main purpose is to hold cracks tight!
  - Steel has to be placed in upper portion of slab.
- Similar in concept to continuously reinforced concrete pavement (CRCP)

Extending Joint Spacing in Concrete Slabs: High Ratio of Steel



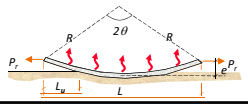
Credits: CRSI / ACPA

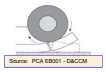
Extending Joint Spacing in Concrete Slabs

- A number of techniques can be adopted to increase joint spacing in slabs-on-ground.
  - Post-tensioning
  - Expansive components
  - High steel reinforcing ratio ($\rho \geq 0.5\%$)
  - **Low drying shrinkage & fiber reinforcement**

Why We Need Contraction Joints

Concrete Shrinks!





Extending Joint Spacing in Concrete Slabs: Low Shrinkage FRC

- Comprises the use of an **ultra-low shrinkage** fiber-reinforced concrete (ULS-FRC) mixture tailored to the desired joint spacing in combination with good concreting and construction practices.

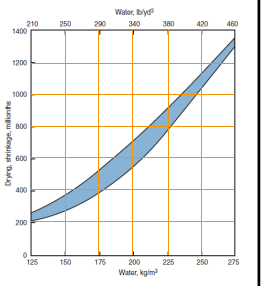
Address the fundamental problem!

Key Requirements of the EJS System

- Synthetic Macrofibers
- Shrinkage- or Crack-Reducing Admixture
  - **Crack widths much smaller with CRA**
- A proof-rolled subgrade
- Two layers of a slip sheet (as needed)
- Proper curing
- Protection for the concrete

ULS-FRC Mixture Considerations

- Limit Drying Shrinkage of Concrete
  - Limit total water (and paste) content
  - Optimize aggregate gradation, topsize & amount



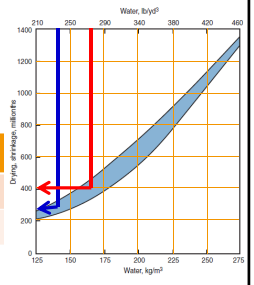
Start with the Basics!

Caution…

A low water-cementitious materials ratio (w/cm) does not imply a low total water content!

	Mix #1	Mix #2
Cement, lb/yd³ (kg/m³)	517 (307)	611 (362)
Water, lb/yd³ (kg/m³)	233 (138)	**275 (163)**

w/cm = 0.45

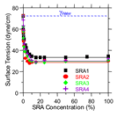


Shrinkage- / Crack-Reducing Admixtures (SRAs & CRA)

PURPOSE: To reduce the drying shrinkage of concrete.

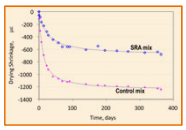
Some Facts…

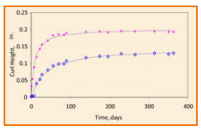
- First SRA developed in **1982!**
- Typically alcohol-based
- CRA ➔ smaller crack widths

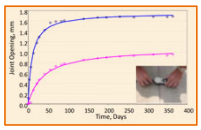


ULS-FRC Mixture Considerations

- Limit Drying Shrinkage of Concrete
  - Limit total water (and paste) content
  - Optimize aggregate gradation and topsize
  - Use Shrinkage- / Crack-Reducing Admixture (SRA or CRA) as needed







CRA & SRAs reduce drying shrinkage, curling & joint opening!

Burbank, CA Water Treatment Facility

- 4,000 yd^3 with SRA
- Constructed in 1998

Bridge Decks on I-80 near Truckee, CA (Constructed Fall of 2002)

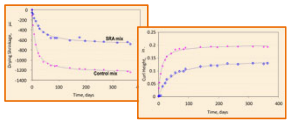
No SRA

With SRA

Note: Pictures taken about 9 months after construction (courtesy of Rick Maggenti, Caltrans).

ULS-FRC Mixture Considerations

- Limit Drying Shrinkage of Concrete
  - Limit total water (and paste) content
  - Optimize aggregate gradation and topsize
  - Use SRA (or CRA) as needed

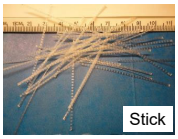


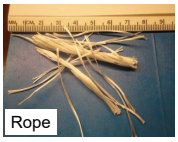
- Use Appropriate Dosage of Synthetic Macrofiber
  - Dosage will depend on desired increase in joint spacing
  - Fiber architecture (stick, hybrid, etc.) will depend on desired finish

Benefits of Fibers

- Provide uniform multi-directional, **post-crack** reinforcement in concrete.
  - Bridge cracks and reduce crack widths to provide tighter aggregate interlock and increased load-carrying capacity.
  - Improve shear strength of concrete
- **Increase the ductility, energy absorption (toughness) ➔ impact resistance.**
  - Improve fatigue endurance of concrete
- Increase the moment capacity of concrete sections to permit thickness reduction, if desired.
- Reduce labor and other costs required for installation of conventional steel reinforcement.
  - Economical relative to conventional steel reinforcement

Macrofiber Architecture: Synthetic





BEFORE MIXING

- Rope
- Tape
  - Serated
- Stick
  - Embossed

Macrofiber Architecture: Synthetic

BEFORE and AFTER MIXING

Fiber Basics: …Workability and Finishability

Conventional Macrofibers: Common Finishing Challenges

Fiber Basics: …Workability and Finishability

- Workability and finishability of concrete may be affected at high fiber dosages, depending on the specific fiber.
  - may require adjustments in mixture proportions.
  - may limit maximum dosage for use.

Fiber Basics: …Exceptional Finishability

Hybrid fiber @ 5 lb/yd³ ; 4,000 psi concrete mixture

Extending Joint Spacing in Concrete Slabs: ULS-FRC Option
What's Required for a Successful FRC Project?

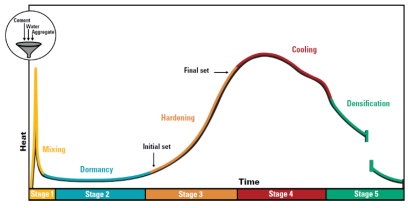
- Subgrade Preparation
  - Proof-rolled
  - Double slip-sheet
- Concrete Mixture
  - Controlling total water content
  - Adequate paste content for fiber dosage
- Macrofiber
  - Appropriate dosage for application
  - Excellent finishability / post-crack residual strength
- CRA / SRA
  - Dosage as needed to achieve target shrinkage level

Extending Joint Spacing in Concrete Slabs:
What's Required for a Successful FRC Project?

- Reinforcement
  - Temperature and shrinkage reinforcement not needed
  - Reinforcement required at re-entrant corners / penetrations, etc.
- Load Transfer Devices
  - At construction joints
- Curing
  - Moist cure preferred!
  - Protection from early-age (overnight) temperature differentials
    - Especially for thick slabs!

Early-Age Thermal Contraction

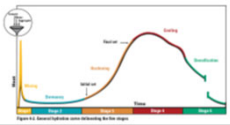
Volume change due to a decrease in temperature.



Source: FHWA HIF-07-004: Integrated Materials and Construction Practices for Concrete Pavement

Stage 4 of Cement Hydration: Cooling

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
	Mixing	Dormancy	Hardening	Cooling	Densification
	Lasts about 15 minutes	Lasts about 2–4 hours	Lasts about 2–4 hours		Continues for years
Characteristics of concrete mixture	High heat is generated immediately, followed by rapid cooling.	Mixture is plastic, workable, and not generating significant heat.	• Hydration generates significant heat. • Mixture sets, begins to harden, and gains strength. • Stress begins developing in the concrete.	Stress development will exceed strength development if stress is not relieved.	Slab continues to become stronger and less permeable.

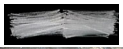


A Few Projects

Panels with 60 ft Joint Spacing!



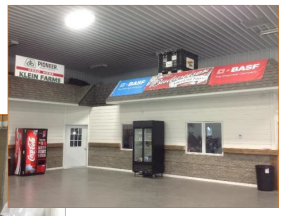





Project Photos

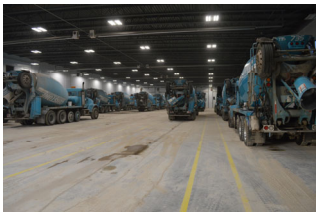
High toughness ➔ impact resistance & ductility!

EJS Application (Klein Farms, July 2013)

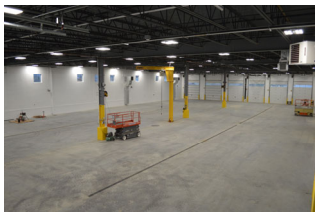


7.5-in. (190 mm) thick ~ 90 ft x 60 ft (27.5 m x 18.3 m)

EJS Application (Truck Garages – Dayton & South St. Paul; MN)

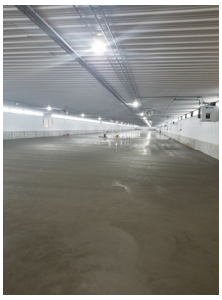


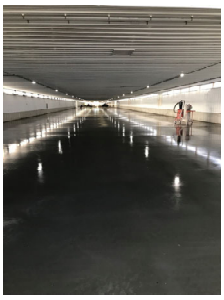
60-ft x 60-ft Panels



31-ft x 100-ft Panels

EJS Application (Poultry Barns – MN)





4.5-in. thick slabs

60-ft x 60-ft Panels

up to

60-ft x 130-ft Panels

EJS Application: Zap Water Reservoir, ND

- 1.6-million gallon (6-ML) water tank
- 98-ft (30-m) diameter slab

EJS Application: Zap Water Reservoir, ND

EJS Application: WAWSA Indian Hills Reservoir, ND

~112-ft (34 m) diameter slab

Jointless Slab Application
Global Water Expansion Project, Maricopa, AZ

Clarifiers (built in 2017)
- 68 ft (20.7 m) diameter
- 4,500 psi (31 MPa)
- 12 in. (300 mm) thick slab in middle; 18 in. (450 mm) thick exterior 3 ft (0.9 m) of slab
- 540 yd³ (415 m³)

In Summary…..

Extending Joint Spacing in Concrete Slabs

- A number of techniques can be adopted to increase joint spacing in slabs-on-ground.
  - Post-tensioning
  - Expansive components
  - High steel reinforcing ratio ($\rho \geq 0.5\%$)
  - Low drying shrinkage & fiber reinforcement

The End…

Thank You!