# The Contractor’s Execution – Should Means and Methods ~~Reduce~~ Cracking???
Eliminate

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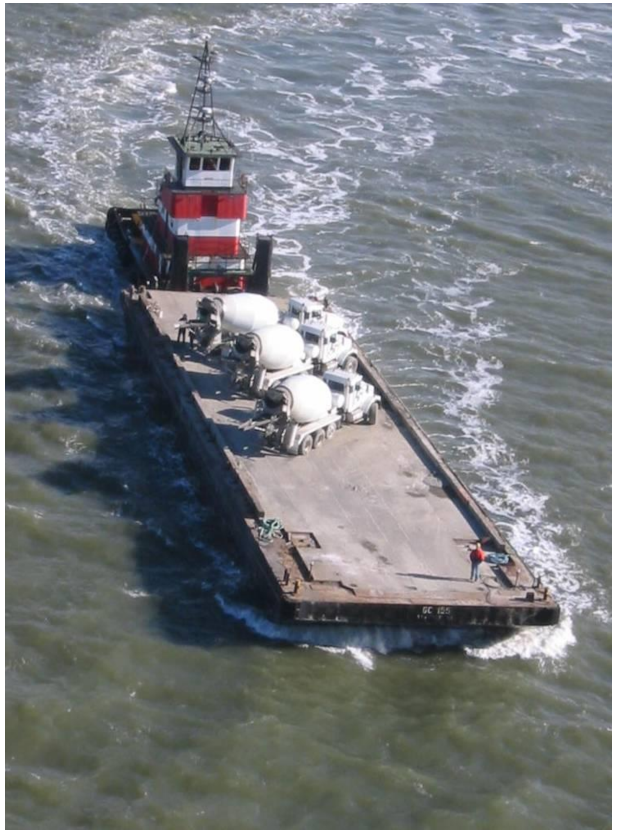
# My Perspective


# PERSPECTIVE ON UNIQUE CONCRETE CHALLENGES



# PERSPECTIVE ON SPECIFICATIONS' CHALLENGES

*Clear Goals, Undefined Requirements*

"*The contractor shall submit the combination of materials that will produce concrete to meet the requirements of the structure with respect to workability, dimensional stability and freedom from cracking, low temperature rise, adequate strength, durability and low permeability to the...*"

*Hidden Goals, Defined Requirements*

**Minimum Volume of Coarse Aggregate**: The minimum requirements detailed herein apply to all methods of placement, including pump mixes. All mixes shall contain a minimum of 39% coarse aggregate by volume...

1) ...,
2) ...,
3) Bridge decks; bridge deck concrete mixes shall contain a minimum of 41% coarse aggregate and total minimum aggregate volume of 67%,

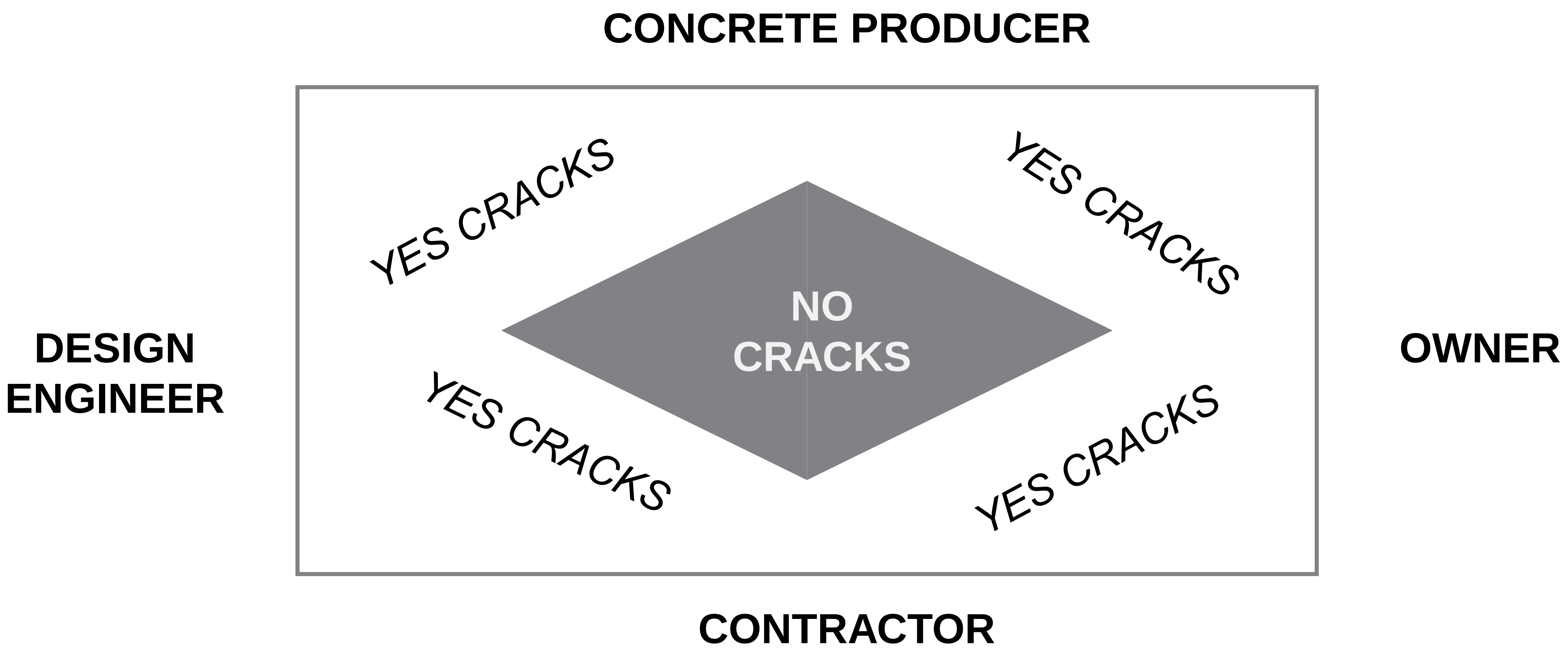
# PERSPECTIVE ON S.M.A.R.T REQUIREMENTS

| S | M | A | R | T |
|---|---|---|---|---|
| Specific | Measurable | Achievable | Relevant | Time-Bound |

- Clear expectations
- Defined requirements
- Consistent with design goals
- Aligned with construction
- Qualify performance
- Ensure quality is met
- Be Safe

*Can Specifications be S.M.A.R.T?*

# PERSPECTIVE ON CRACKING



# CONCRETE PROPERTIES

**STRENGTH**

- w/cm ratio
- Materials
- Quality

**DURABILITY**

- Freeze/Thaw
- Sulfate Resistance
- Permeability
- Service Life

**WORKABILITY**

- Slump Retention
- Placing
- Consolidation
- Finishing

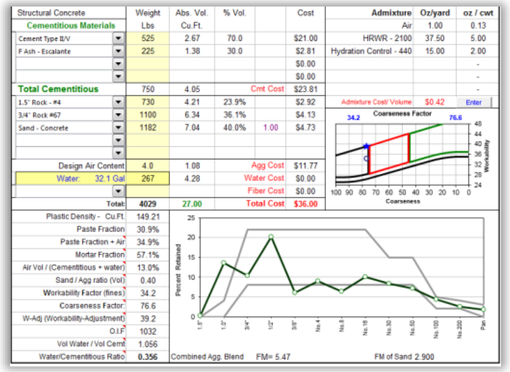
**ECONOMICS**

- Mix Costs
- Consistency
- Rework

**Meet design criteria and construction demands!**

# CONCRETE MIX DEVELOPMENT

| BOOK-CRETE | | LAB-CRETE | | CON-CRETE |
|---|---|---|---|---|
| (30 TO 60 days) | → | (90 TO 120 days) | → | (15 TO 30 days) |

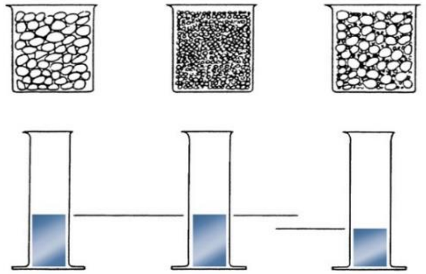


| Structural Concrete | Weight | Abs. Vol. | % Vol. | | Cost |
|---|---|---|---|---|---|
| Cementitious Materials | Lbs | Cu.Ft. | | | |
| Cement Type II/V | 525 | 2.67 | 70.0 | | $21.00 |
| F Ash - Escalante | 225 | 1.38 | 30.0 | | $2.81 |
| | | | | | $0.00 |
| | | | | | $0.00 |
| Total Cementitious | 750 | 4.05 | | Cmt Cost | $23.81 |
| 1.5" Rock - #4 | 730 | 4.21 | 23.9% | | $2.92 |
| 3/4" Rock #67 | 1100 | 6.34 | 36.1% | | $4.13 |
| Sand - Concrete | 1182 | 7.04 | 40.0% | 1.00 | $4.73 |
| | | | | | |
| | | | | | |
| Design Air Content | 4.0 | 1.08 | | Agg Cost | $11.77 |
| Water: 32.1 Gal | 267 | 4.28 | | Water Cost | $0.00 |
| | | | | Fiber Cost | $0.00 |
| Total: | 4029 | 27.00 | | Total Cost | $36.00 |

| Admixture | Oz/yard | oz / cwt |
|---|---|---|
| Air | 1.00 | 0.13 |
| HRWR - 2100 | 37.50 | 5.00 |
| Hydration Control - 440 | 15.00 | 2.00 |
| | | - |
| | | - |
| | | - |
| Admixture Cost/ Volume | $0.42 | Enter |

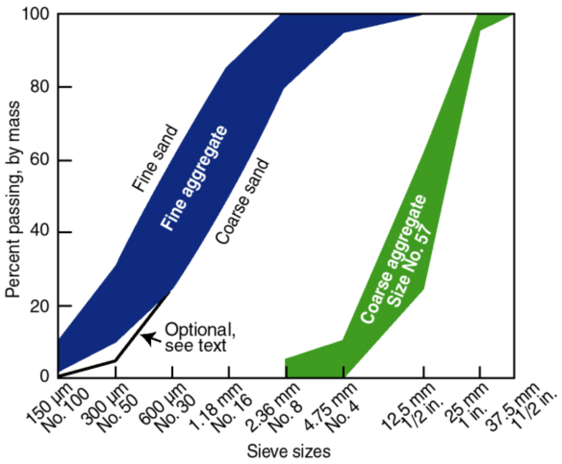
| | |
|---|---|
| Plastic Density - Cu.Ft. | 149.21 |
| Paste Fraction | 30.9% |
| Paste Fraction + Air | 34.9% |
| Mortar Fraction | 57.1% |
| Air Vol / (Cementitious + water) | 13.0% |
| Sand / Agg ratio (Vol) | 0.40 |
| Workability Factor (fines) | 34.2 |
| Coarseness Factor | 76.6 |
| W-Adj (Workability-Adjustment) | 39.2 |
| O.I.F | 1032 |
| Vol Water / Vol Cemt | 1.056 |
| Water/Cementitious Ratio | 0.356 |

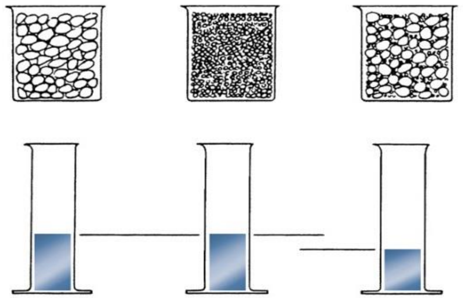




# CONCRETE MIX OPTIMIZATION

- Improve aggregate grading



- Admixtures enhance performance



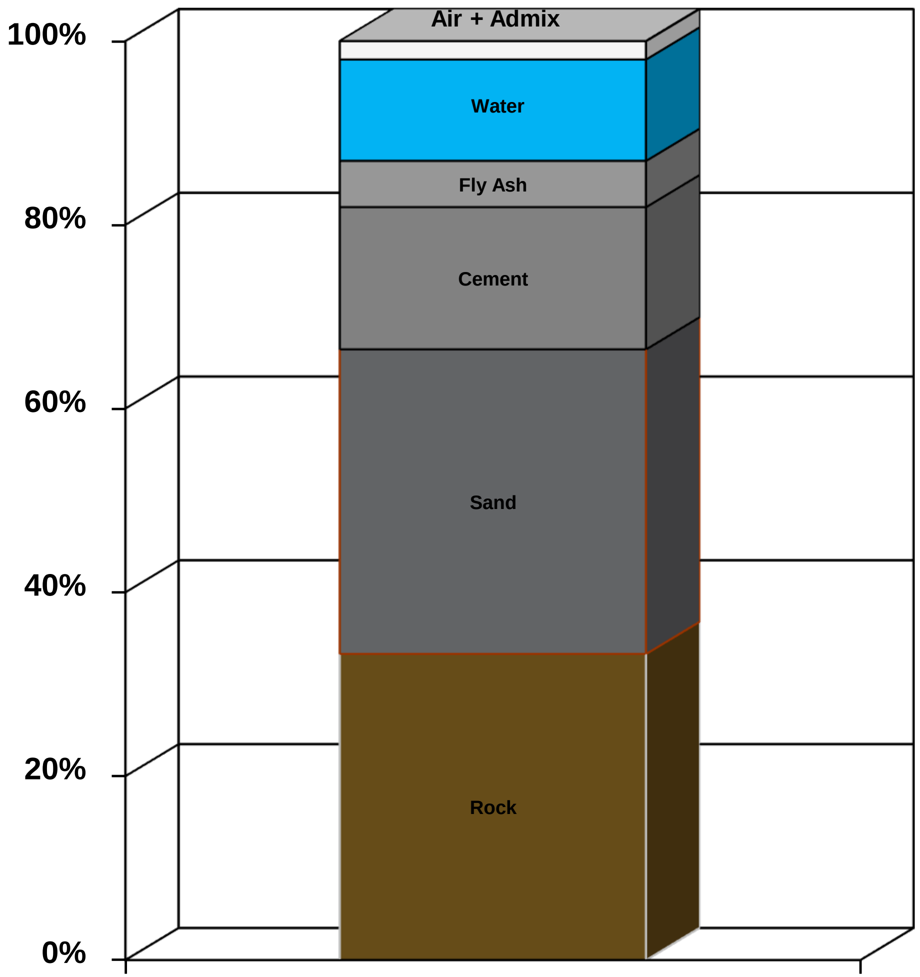
# SELECT THE RIGHT CONCRETE MIX

| Low-Price Concrete Mix | | High-Value Concrete Mix |
|---|---|---|
| • Meets the Specs<br>• Lowest unit price per cy<br>• Does not facilitate the construction process<br>• Higher total costs<br>• Low value option | ≠ | • Meets the Specs<br>• Reasonable unit price per cy<br>• Facilitates the construction process<br>• Lower total costs<br>• Best value option |

# CONCRETE MIX – LEVELS OF LUBRICATION

## ***CONCRETE LEVELS OF LUBRICATION***

- **Water:** 1st level of concrete lubrication. Water lubricates the paste. Chemical admixtures enhance lubrication and affect water demand performance.
- **Paste:** 2nd level of concrete lubrication. Paste lubricates the mortar. Quality of paste lubrication relies on adequate quantity of water, w/cm ratio and amount/type of cementitious.
- **Mortar:** 3rd level of concrete lubrication. Quality of mortar lubrication relies on adequate quantity of paste and the amount/type of sand.



# ACI GUIDANCE ON LUBRICATION

**Mortar fractions for various construction methods**

| Construction classification | Placing and construction method | Approximate mortar fractions (% volume of concrete) |
|---|---|---|
| 1 | Steep sided bottom-dropped bucket, conveyor, or paving machine | 48 to 50 |
| 2 | Bottom-drop bucket or chute in open vertical construction | 50 to 52 |
| 3 | Chute, buggy, or conveyor in an 8 in. (200 mm) or deeper slab | 51 to 53 |
| 4 | 1-1/2 in. (37.5 mm) maximum size aggregate mixture receiving high tolerance finish<br><br>5 in. (125 mm) or larger pump for use in vertical construction, thick flat slabs and larger walls, beams, and similar elements | 52 to 54 |
| 5 | 3/4 to 1 in. (19 to 25 mm) maximum size aggregate mixture receiving high tolerance finish<br><br>5 in. (125 mm) pump for pan joist slabs, thin or small castings, and high reinforcing steel density | 53 to 55 |
| 6 | 4 in. (100 mm) pump | 55 to 57 |
| 7 | Long cast-in-place piling shells | 56 to 58 |
| 8 | Pump smaller than 4 in. (100 mm) | 58 to 60 |
| 9 | Less than 4 in.-thick (100 mm) topping | 60 to 62 |
| 10 | Flowing fill | 63 to 66 |

*Ref. ACI 302.1R- Guide to Floor and Slab Construction*

**Table 4.1—Suggested powder content ranges***

| | Slump flow of < 22 in. (<550 mm) | Slump flow of 22 to 26 in. (550 to 600 mm) | Slump flow of >26 in. (>650 mm) |
|---|---|---|---|
| Powder content, $lb/yd^3$ ($kg/m^3$) | 600 to 650 (355 to 385) | 650 to 750 (385 to 445) | 750+ (458+) |

*or as needed for strength.

**Table 4.2—Summary of SCC proportioning trial mixture parameters**

| | |
|---|---|
| Absolute volume of coarse aggregate* | 28 to 32% (>1/2 in. [12 mm] nominal maximum size) |
| Paste fraction (calculated on volume) | 34 to 40% (total mixture volume) |
| Mortar fraction (calculated on volume) | 68 to 72% (total mixture volume) |
| Typical *w/cm* | 0.32 to 0.45 |
| Typical cement (powder content) | 650 to 800 $lb/yd^3$ (386 to 475 $kg/m^3$) (lower with a VMA) |

*Up to 50% (3/8 in. [10 mm] nominal maximum size).

*Ref. ACI 237 – Report on Self-Consolidating Concrete*

# POTENTIAL FACTORS AFFECTING CRACKING

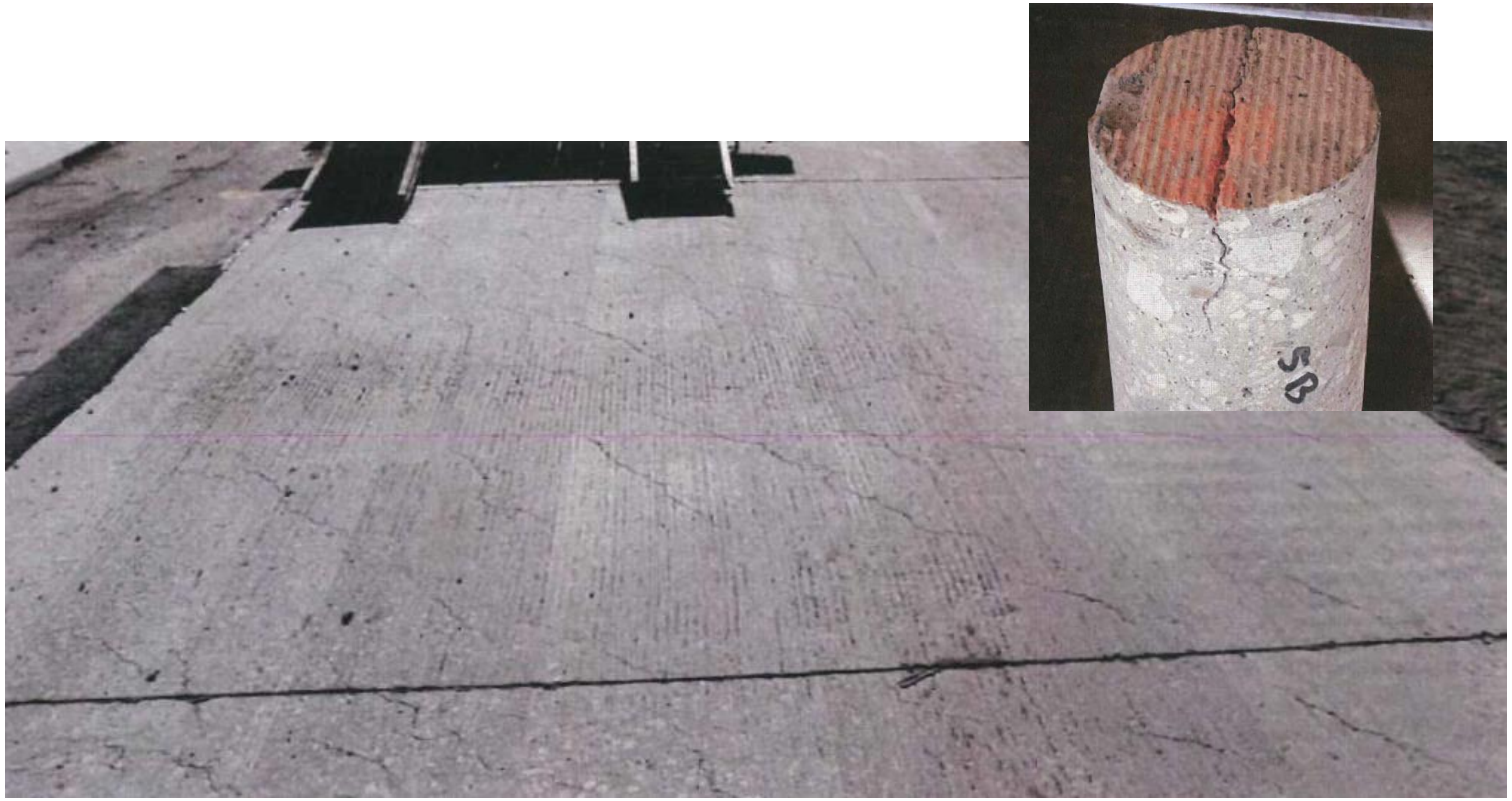
**Table 6.40** Investigated factors that may affect bridge deck cracking

| **Factor** | **Higher paste content** | **Higher slump** | **Higher compressive strength** | **Maximum daily air temperature** | **Higher daily air temperature range** |
|---|---|---|---|---|---|
| Concrete behavior that influences cracking | Drying Shrinkage, thermal contraction (heat of hydration) | Settlement cracking | Creep | Plastic shrinkage, thermal contraction | Thermal contraction |

Darwin et al (various year)

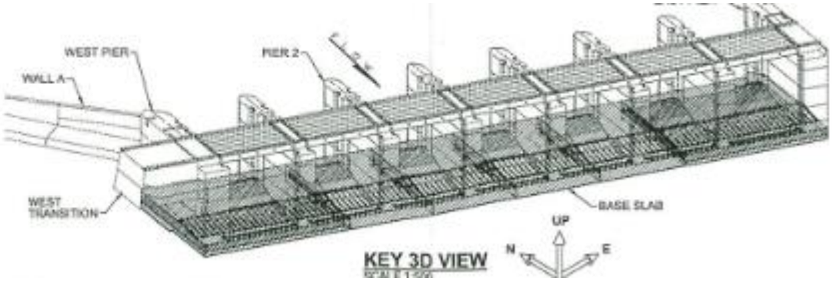
# HOT WEATHER CONCRETING

**Tearing (?)**




**Plastic Shrinkage Cracking**

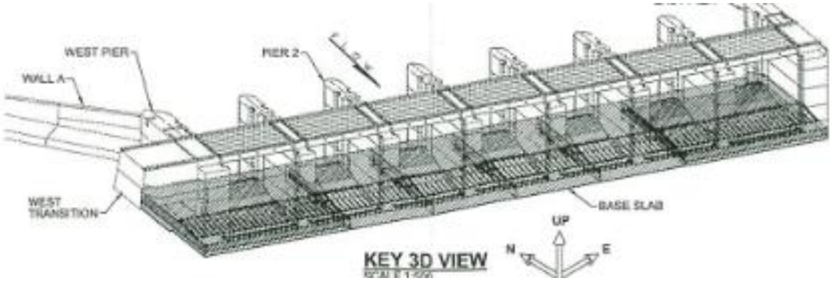
# MASS CONCRETE

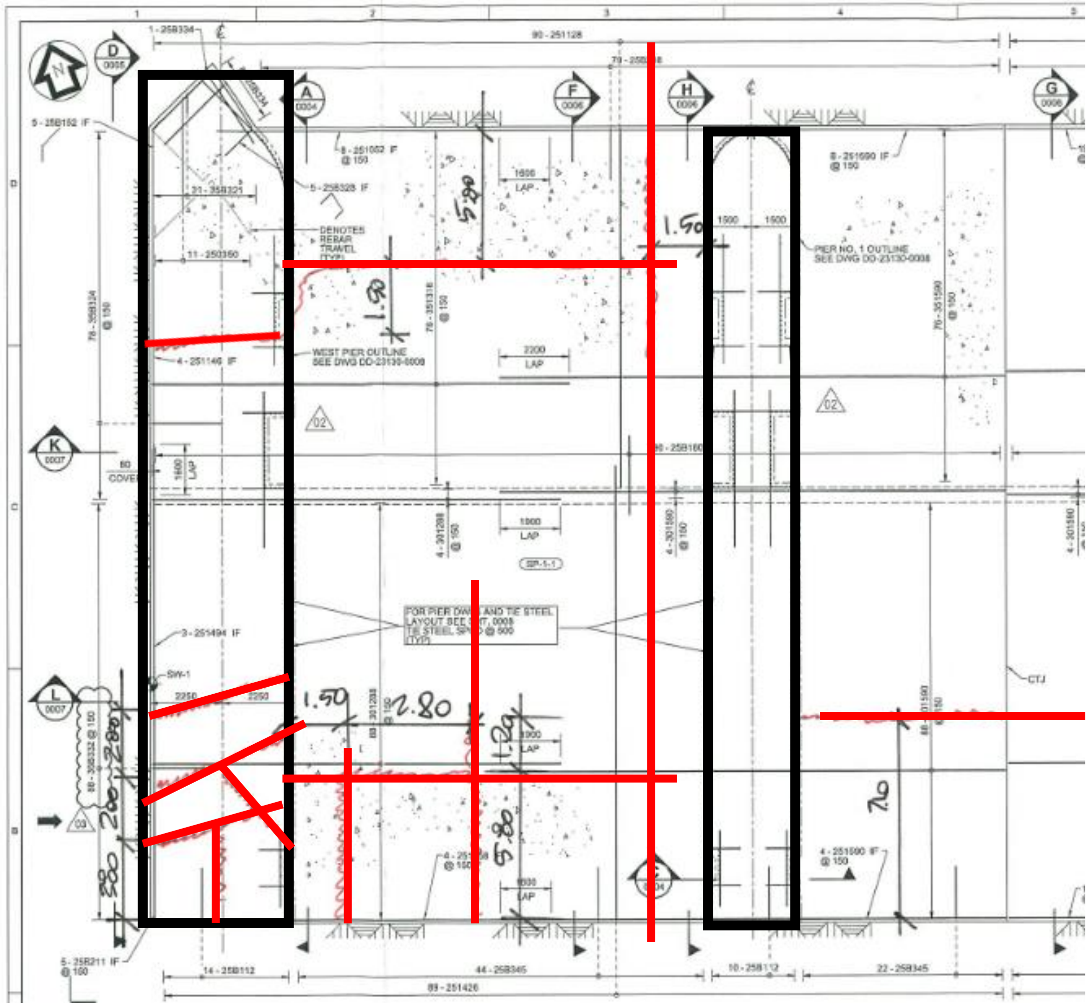



There are many situations within normal concreting practice when early-age thermal cracking may be difficult to avoid. Also, even in structures that have no special requirements, cracking can be a source of dispute. It is important that clients appreciate that early-age cracking can be consistent with good construction practice, providing it has been dealt with properly in the design and construction process. In many cases it may be either unnecessary or uneconomical to avoid cracking entirely. Indeed, the avoidance of cracking is contrary to the concept of reinforced concrete design, which assumes that concrete has no tensile capability and uses the reinforcement to carry the tensile stresses and to control crack widths. If the concrete does not crack then the reinforcement is not being used effectively. When specific performance requires cracking to be avoided, special measures are available, but these may have significant cost implications that the client should be aware of.

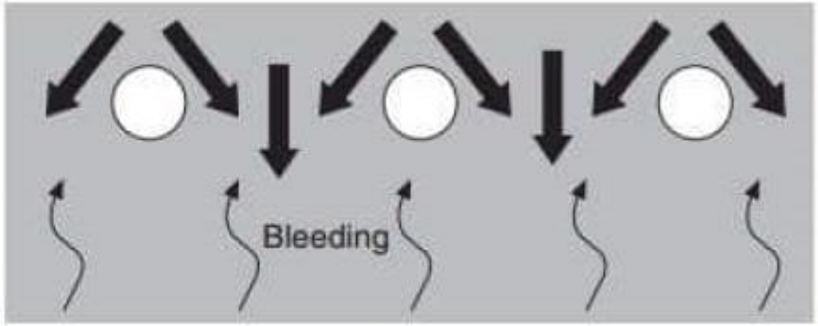
**CIRIA C766**

# MASS CONCRETE

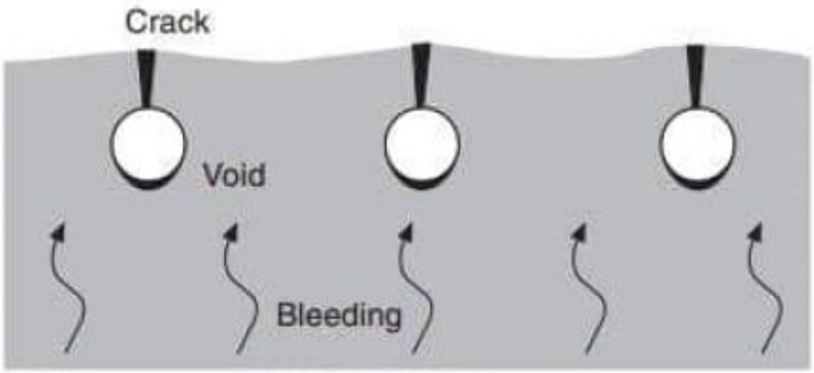


# PLASTIC SETTLEMENT CRACKING



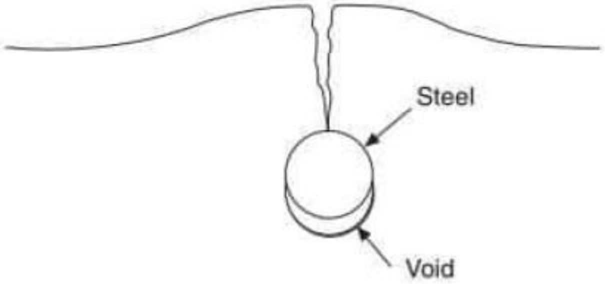

(a) Initiation




(b) After a few hours

(a) Elevation

(b) Plan




# PLASTIC SETTLEMENT CRACKING

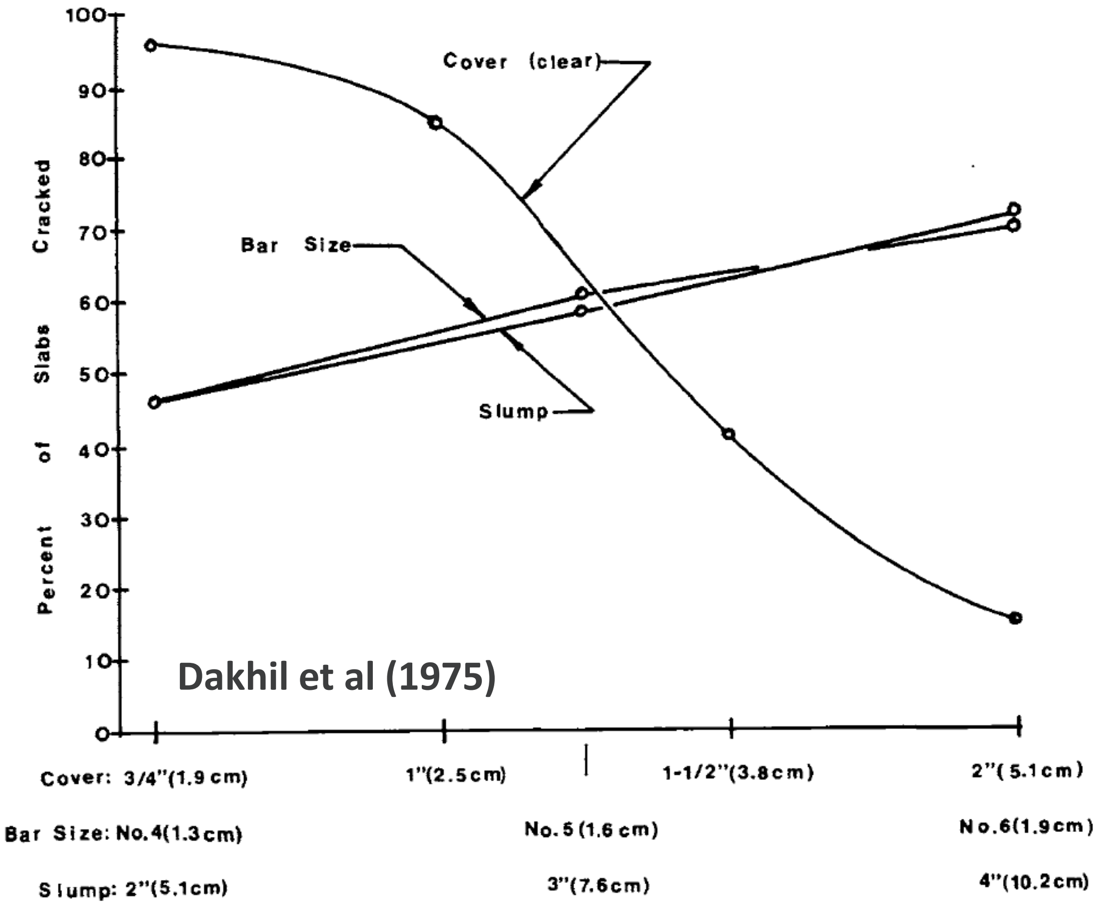



Fig. 2—Cracking as a function of bar size, slump, and cover

**8.4—Settlement**

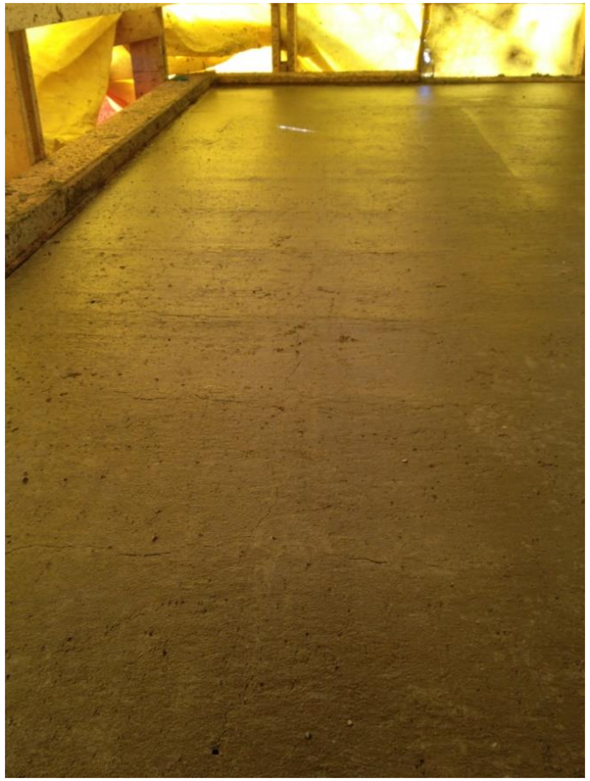
Settlement or subsidence cracks develop while concrete is in the plastic stage after the initial consolidation. Settlement cracks are the natural result of heavy solids settling in a liquid medium. Settlement cracks occur along rigidly supported elements, such as horizontal reinforcement, form ties, or embedments. Sometimes concrete will adhere to the forms. A crack will appear at these locations if the forms are hot at the top or are partially absorbent. Cracks often appear in horizontal construction joints and in bridge deck slabs over reinforcing or form ties with only a few inches of cover (about 75 to 125 mm [3 to 5 in.]). Settlement cracks in bridge decks can be reduced by increasing the concrete cover along with mixture proportioning that minimizes bleeding and settlement. Properly executed late revibration can be used to close settlement cracks and improve the quality and appearance of the concrete in the upper portion of such placements, even though settlement has taken place and slump has been lost (ACI 309R). Use of a low-slump concrete is also recommended to help prevent settlement cracks in bridge decks and slabs.

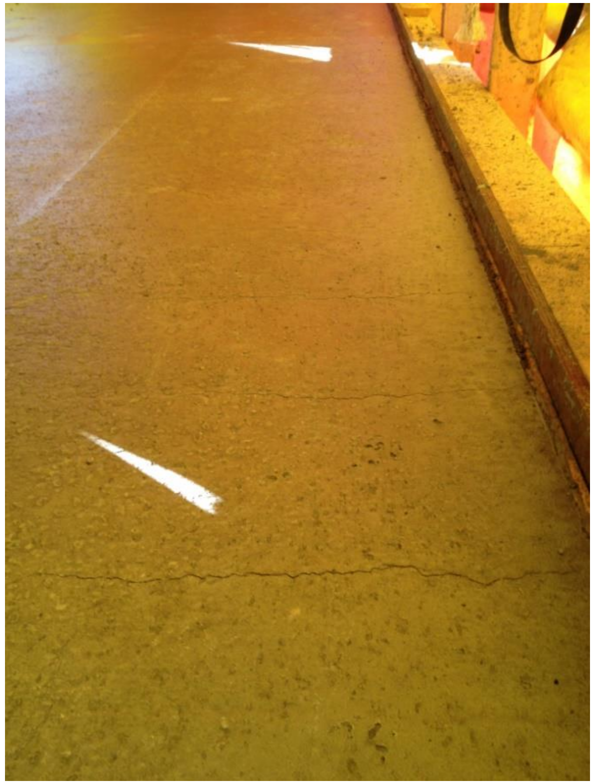
**ACI 224R**

# PLASTIC SETTLEMENT CRACKING

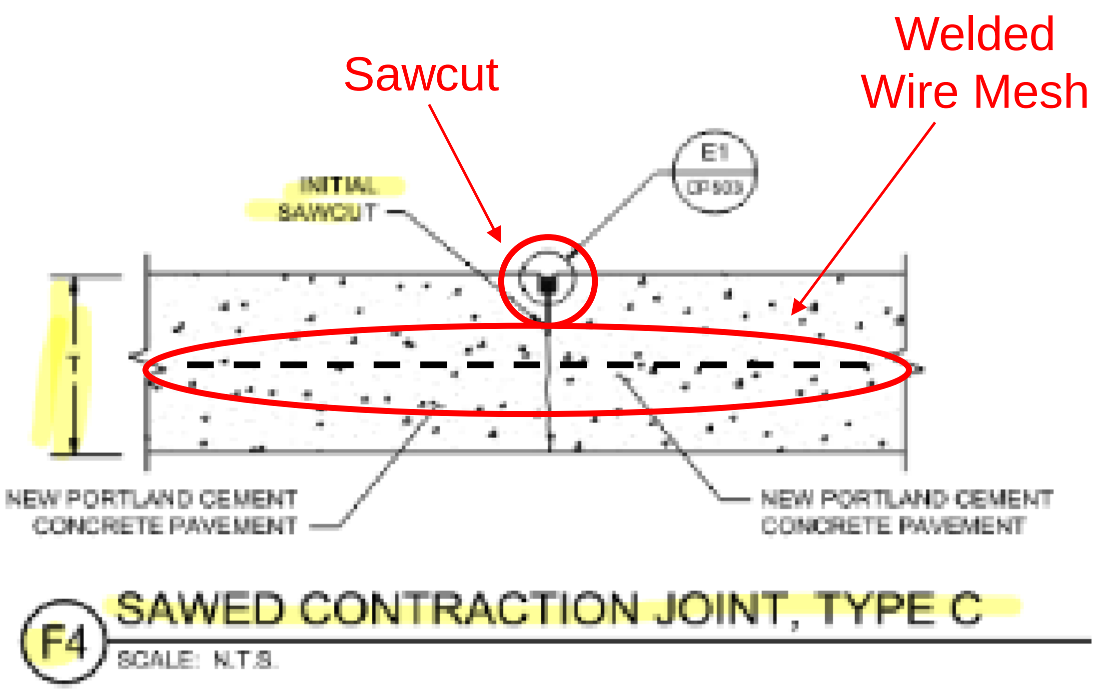
# THIN SLAB – HPC – SCC (COLD WEATHER)

# THICK SLAB – MASS – 4” SLUMP (COLD WEATHER)

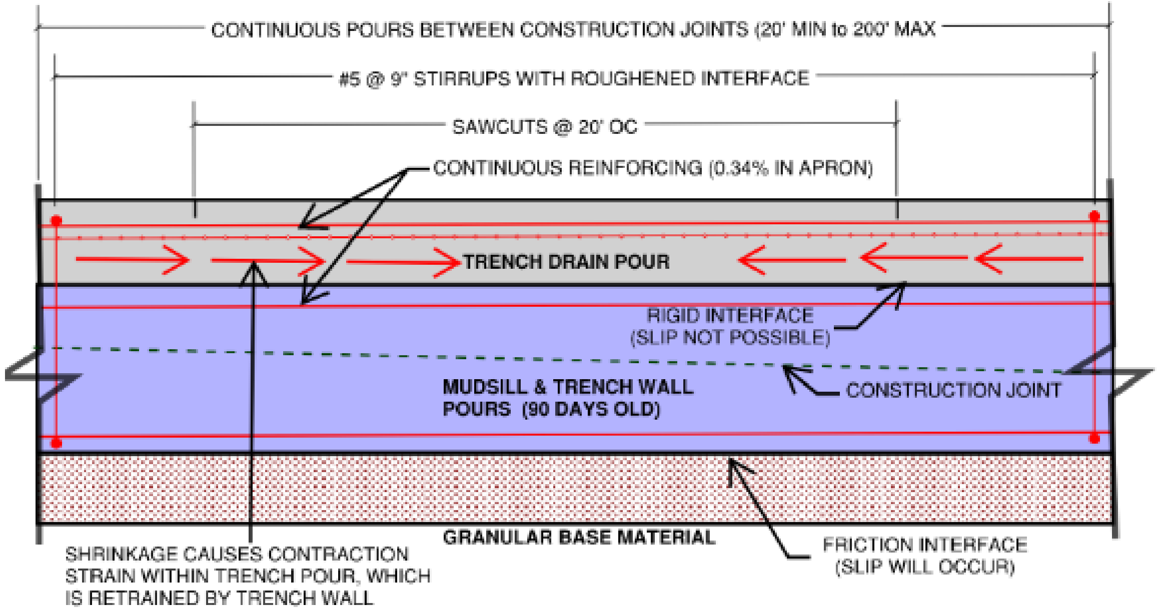




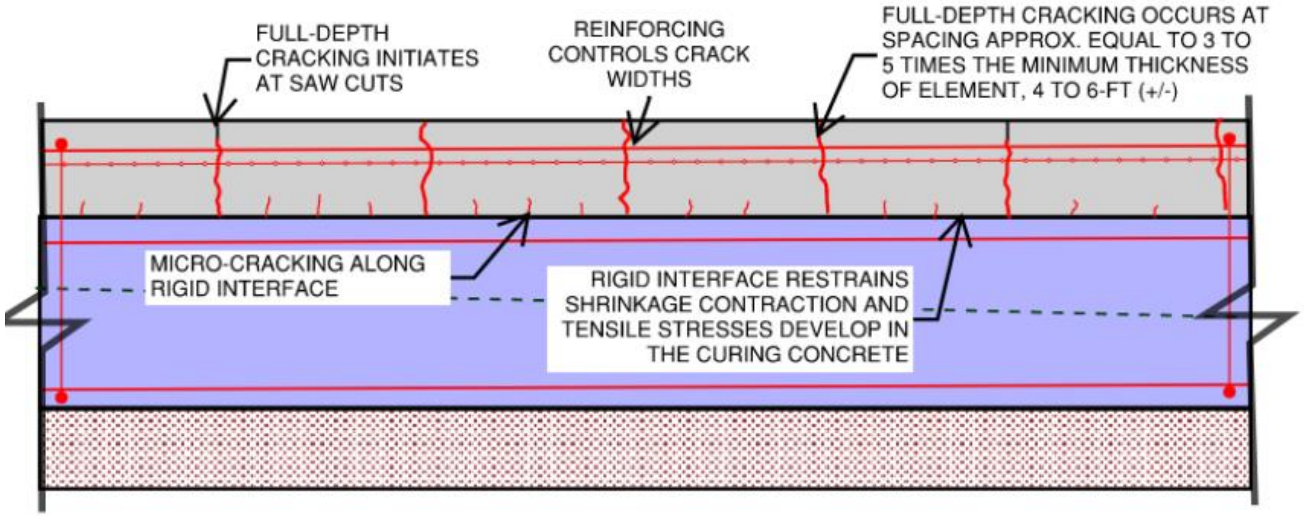
# RESTRAINT SHRINKAGE CRACKS




# RESTRAINT SHRINKAGE CRACKS

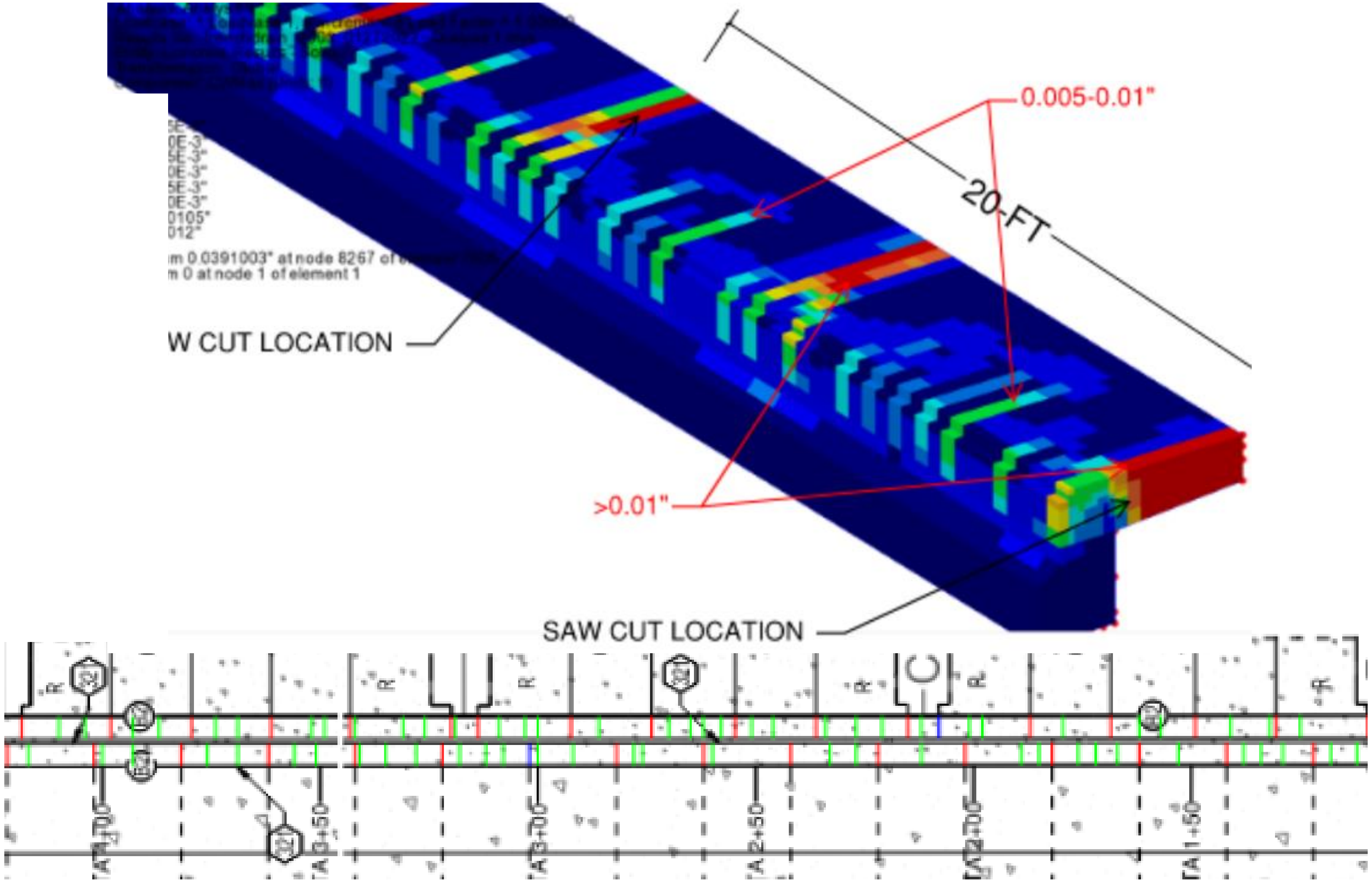



Restraints

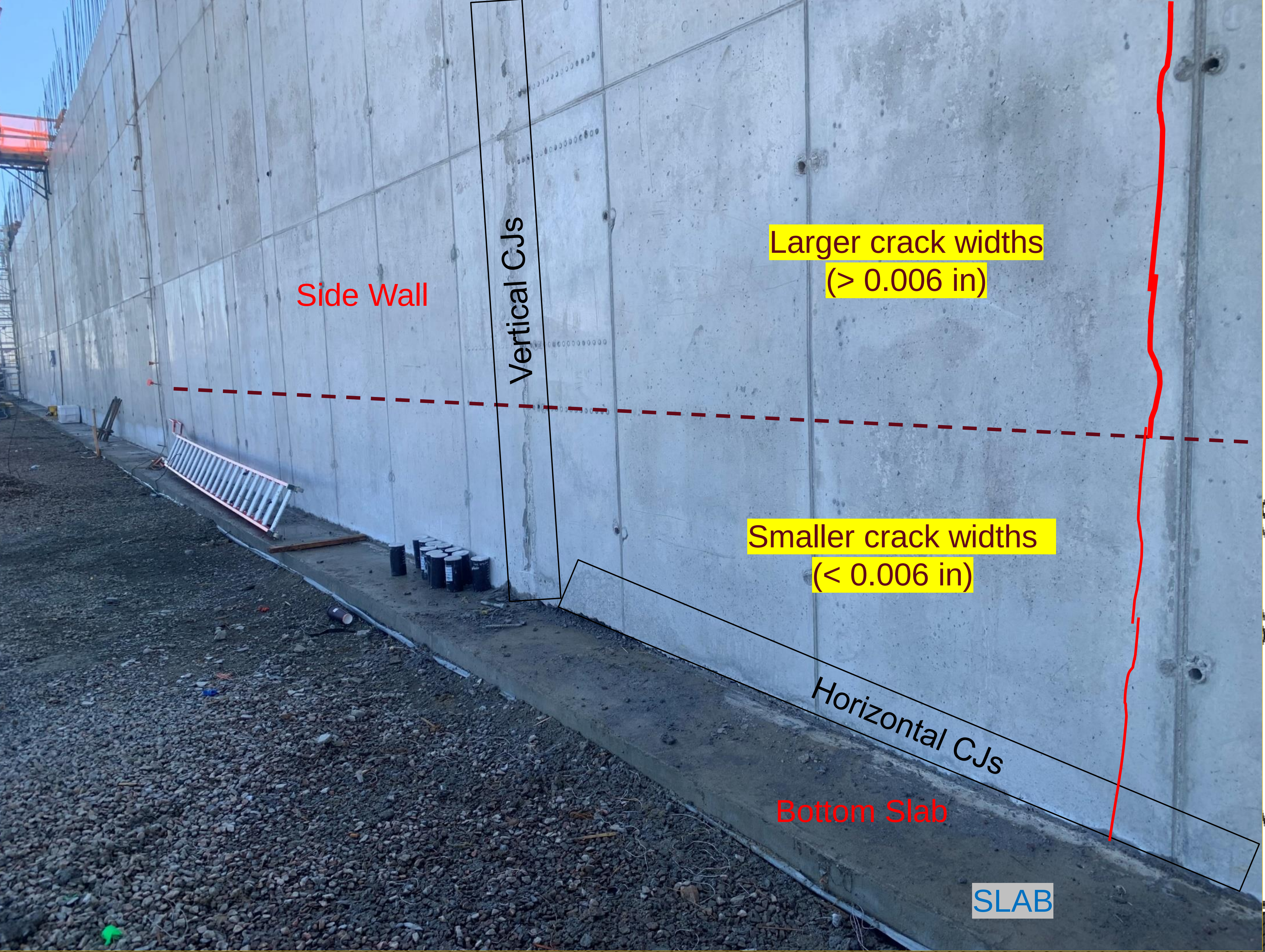


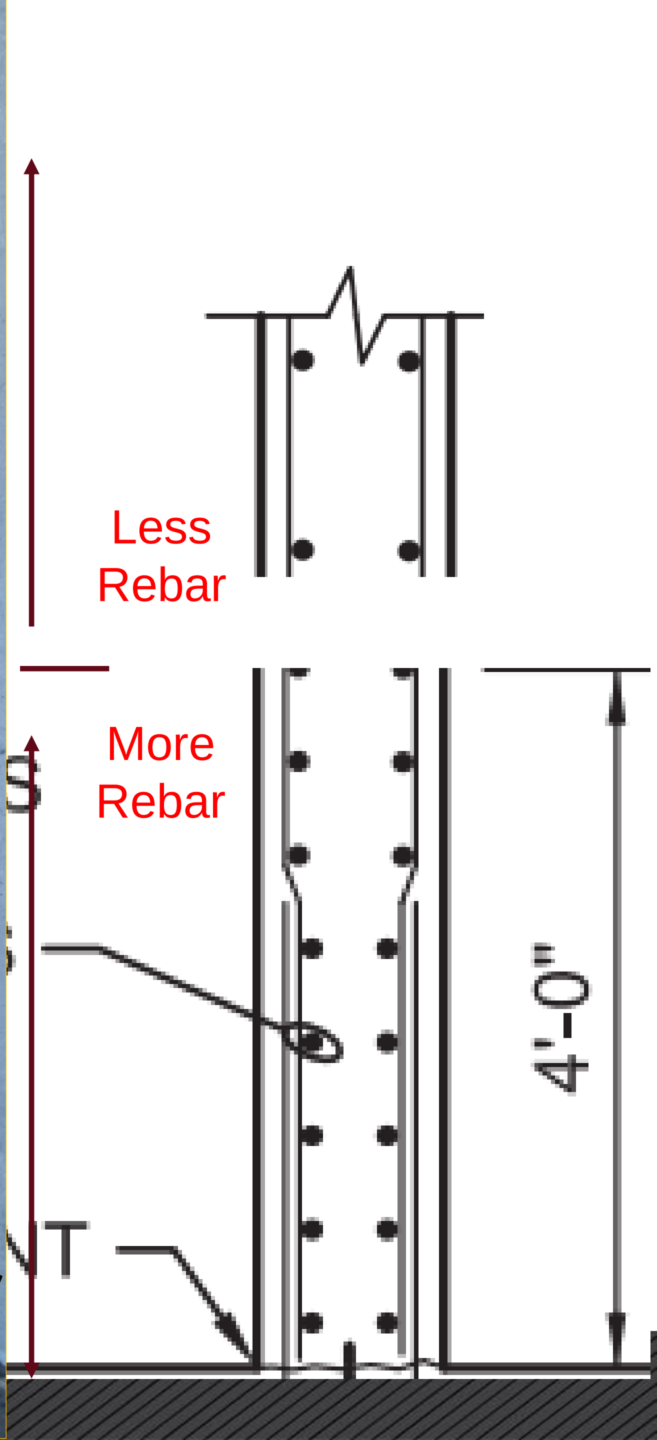

Cracks

# RESTRAINT SHRINKAGE CRACKS



# EXPERIENCE WITH RESTRAINED CRACKING DURING CONSTRUCTION


Side Wall
Vertical CJs
Larger crack widths
(> 0.006 in)
Smaller crack widths
(< 0.006 in)
Horizontal CJs
Bottom Slab
SLAB


Less
Rebar
More
Rebar
4'-0"

**Side Wall**

Less rigidity, lightly reinforced
(SMALLER CRACKS)

Transition of rigidity, lightly reinforced
(LARGER CRACKS)

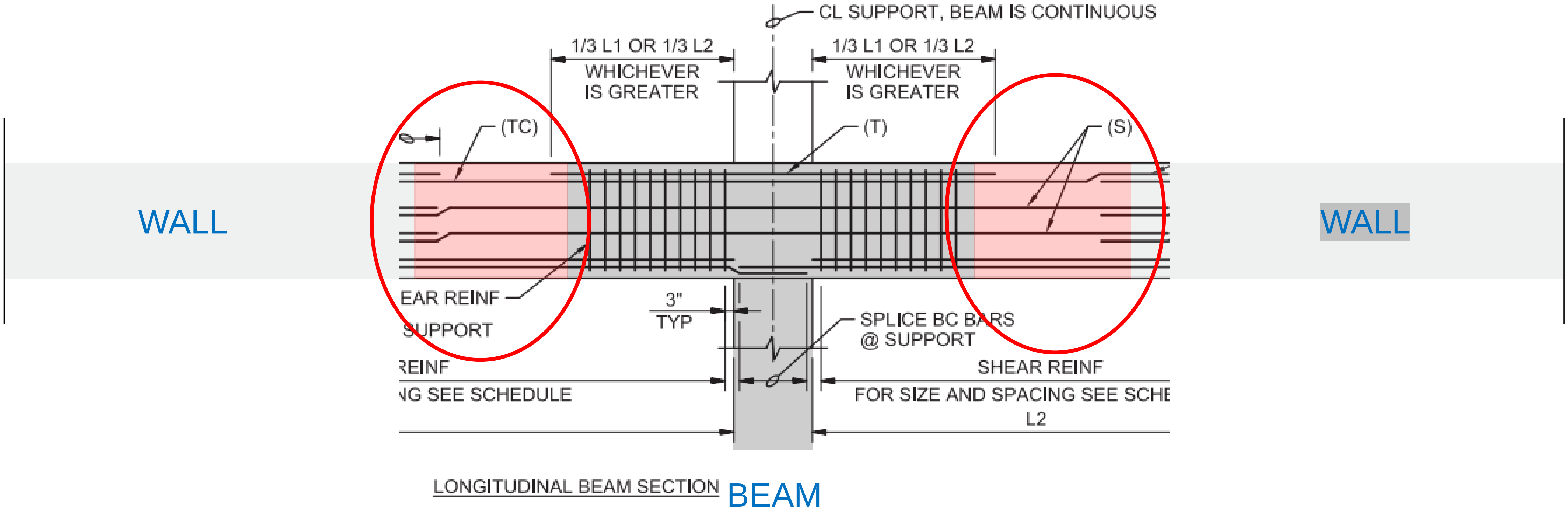
**Rigid Transition**

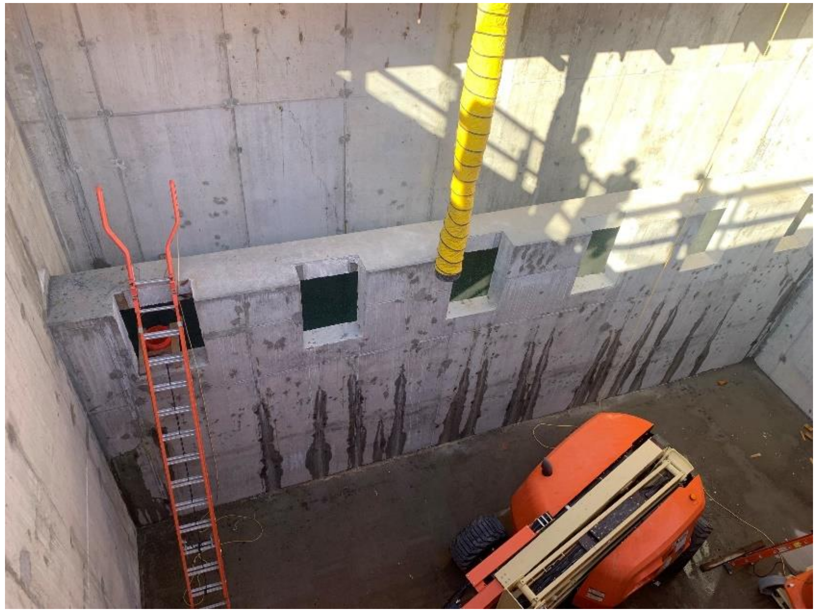
High rigidity, heavily reinforced
(NO CRACKS)

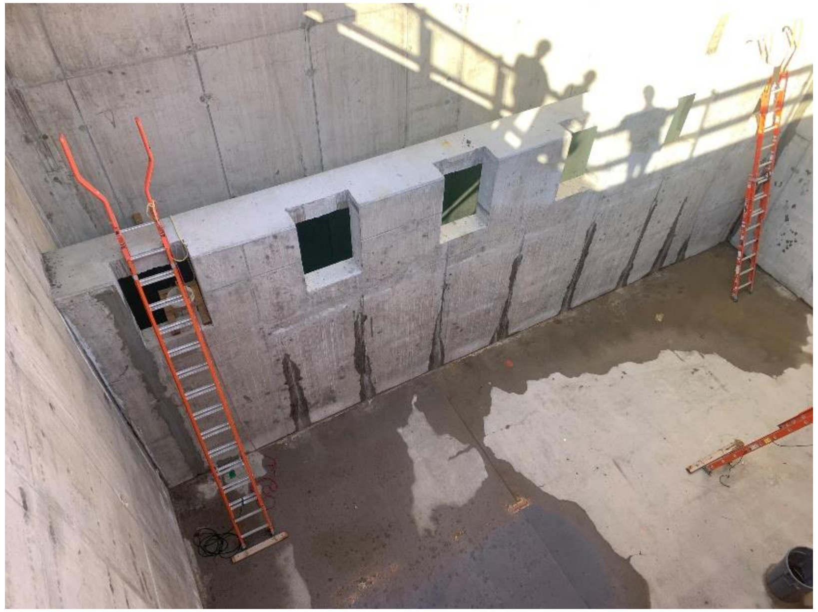
Transition of rigidity, lightly reinforced
(LARGER CRACKS)

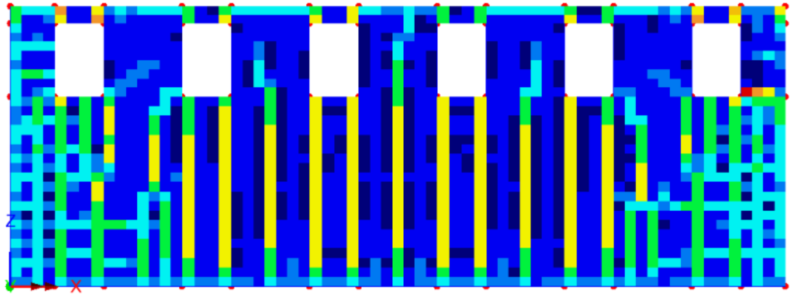
**Side Wall**

Less rigidity, lightly reinforced
(SMALLER CRACKS)

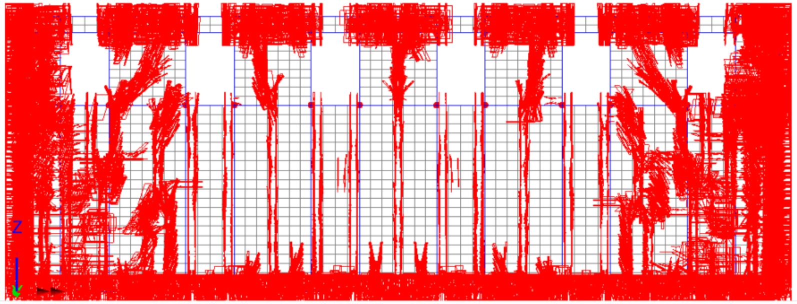






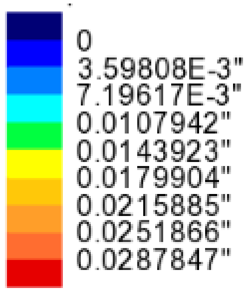


Crack Planes



| Effects on Crack Widths | | Design | Potential Changes | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | - | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Rebar | % | 0.00306 | 0.00611 | - | - | 0.00611 | - | 0.00611 | 0.00611 |
| Shrinkage | % | 0.040 | - | 0.035 | - | 0.035 | 0.035 | - | 0.035 |
| Temp Δ | °F | 44 | - | - | 38 | - | 38 | 38 | 38 |
| Crack width | in | 0.0171 | 0.0138 | 0.0162 | 0.0168 | 0.0131 | 0.0159 | 0.0135 | 0.0128 |
| % Change | % | - | -19% | -5% | -2% | -24% | -7% | -21% | -25% |

Crack Models
(as per design)



# CRACKS RESPONSIBILITY

*Thank you!*

*Oscar Antommattei, MS, PE, FACI*
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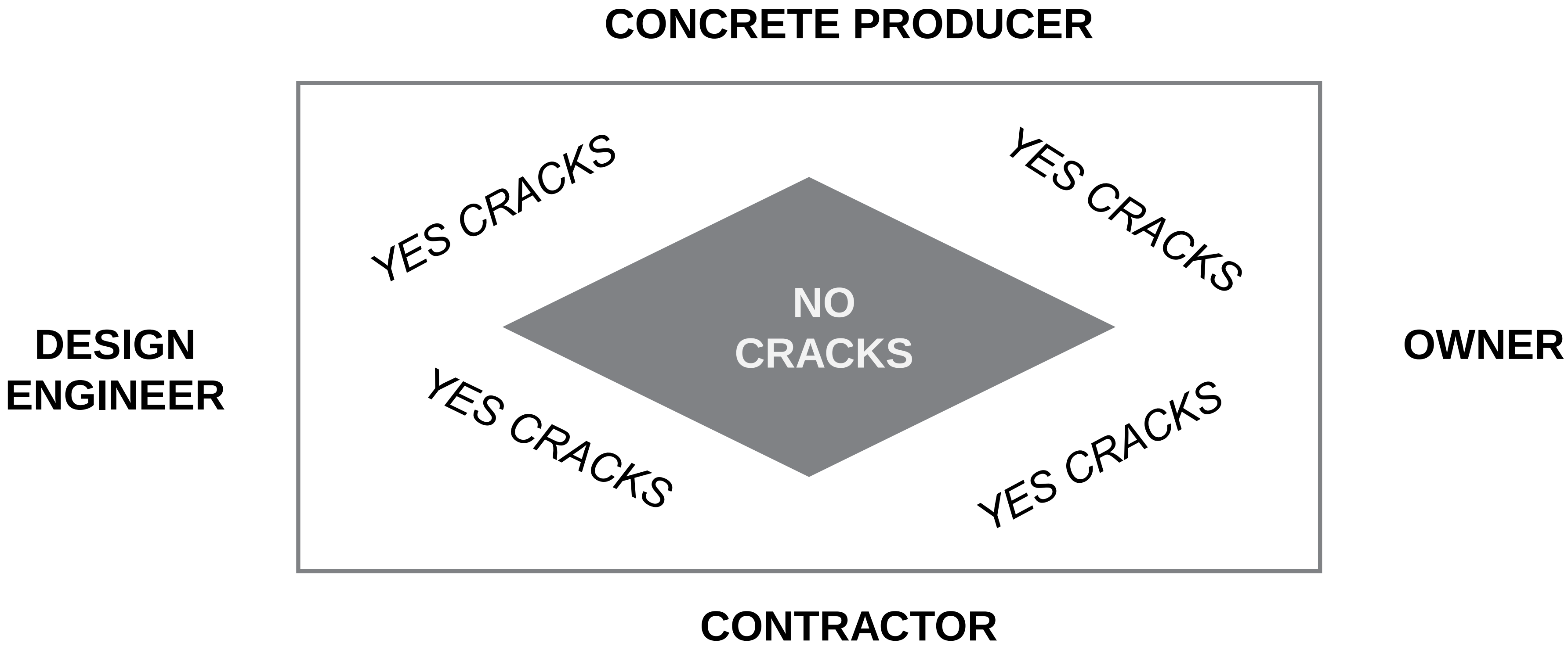
*concrete@kiewit.com*




*Cracks can be controlled, mitigated and reduced; however, crack free structures require a very special attention to specifications, costs, schedule, design, materials and constructions methods.*

# QUESTIONS

For more information, contact me at concrete@kiewit.com

**THANKS!!!**