SILICA FUME ASSOCIATION

2007 Western Bridge Engineer’s Seminar.

HPC Tools (software) To Reduce Bridge Deck Cracking

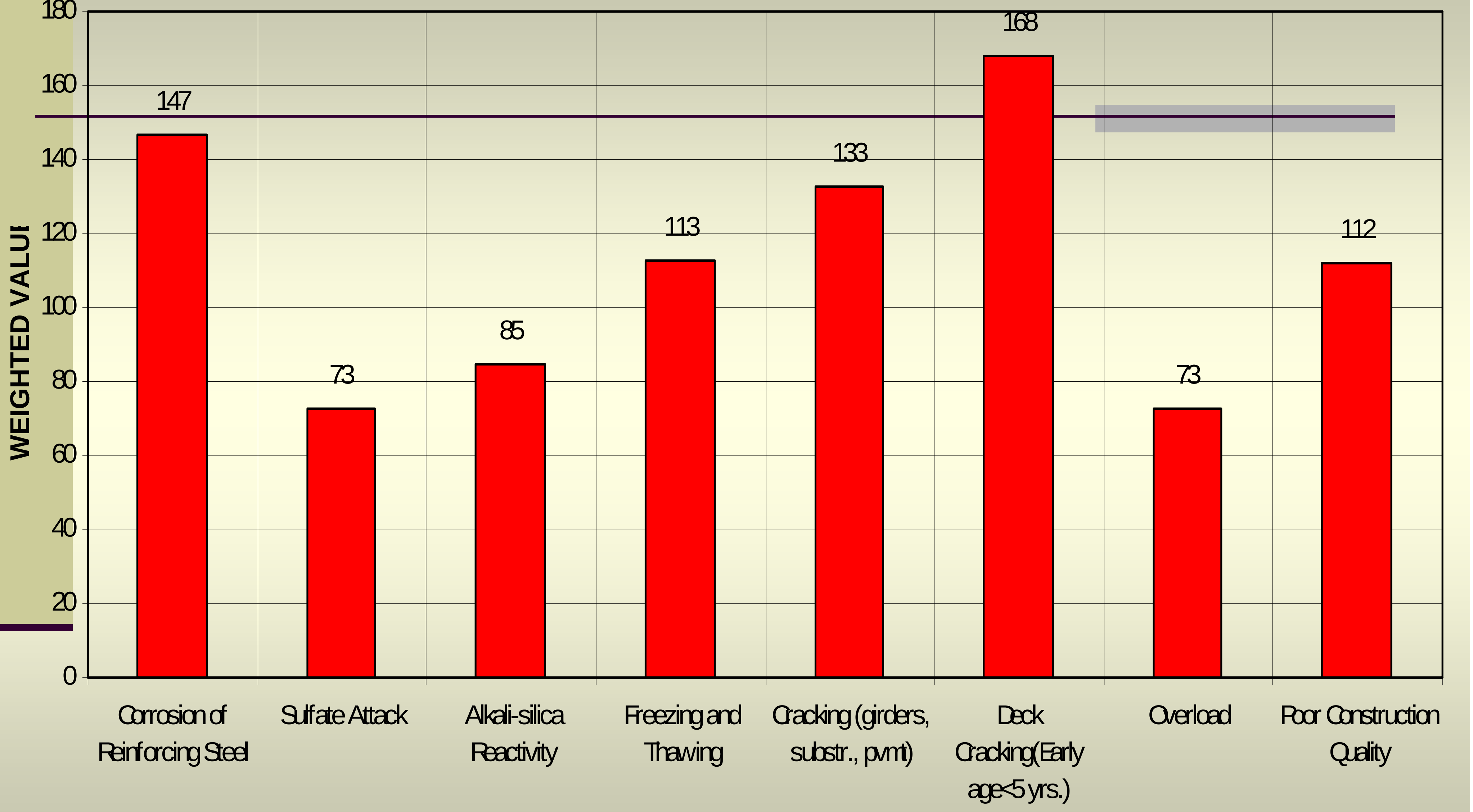
Tony Kojundic

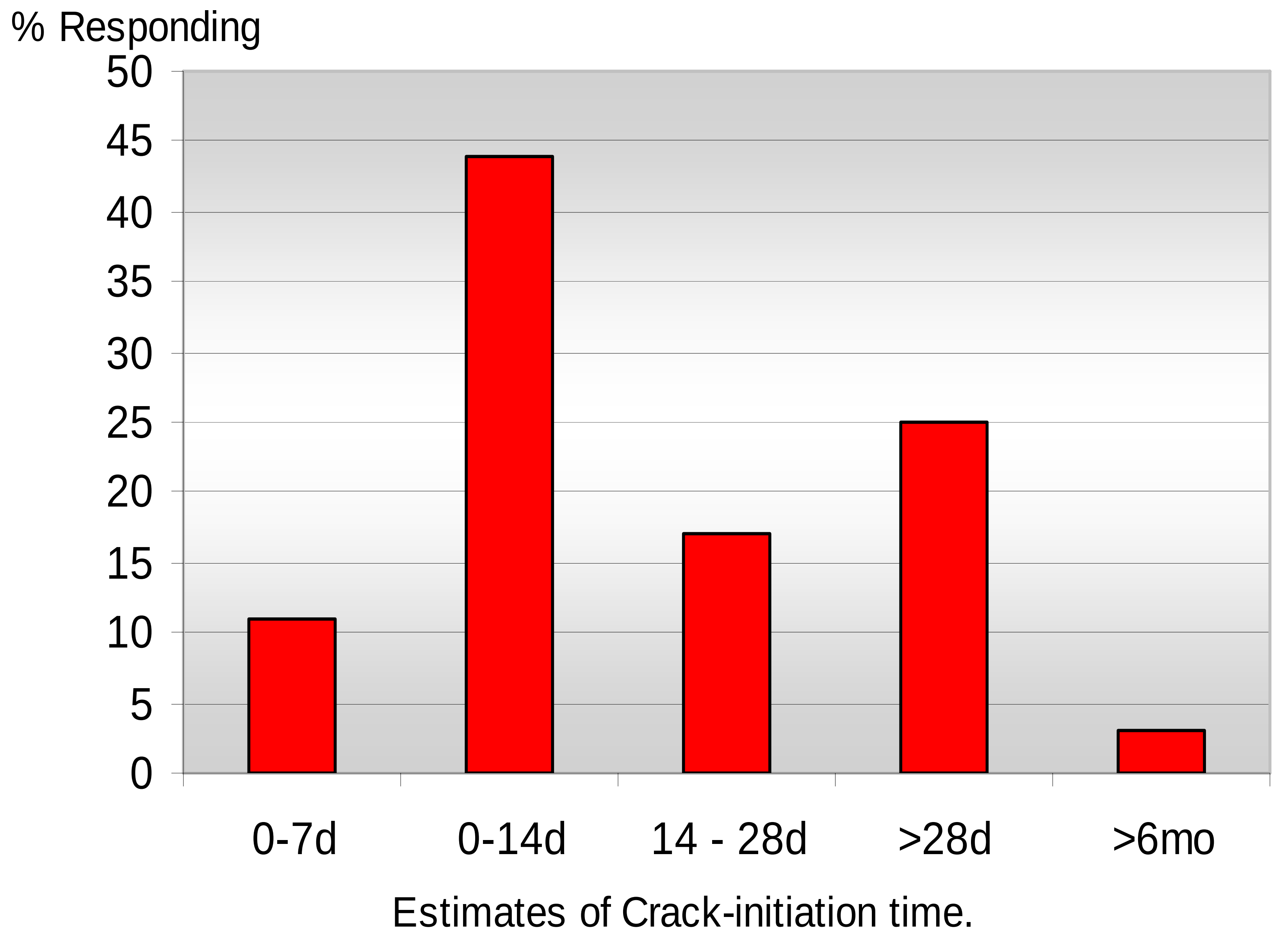
September 24, 2007

U.S. Department
of Transportation

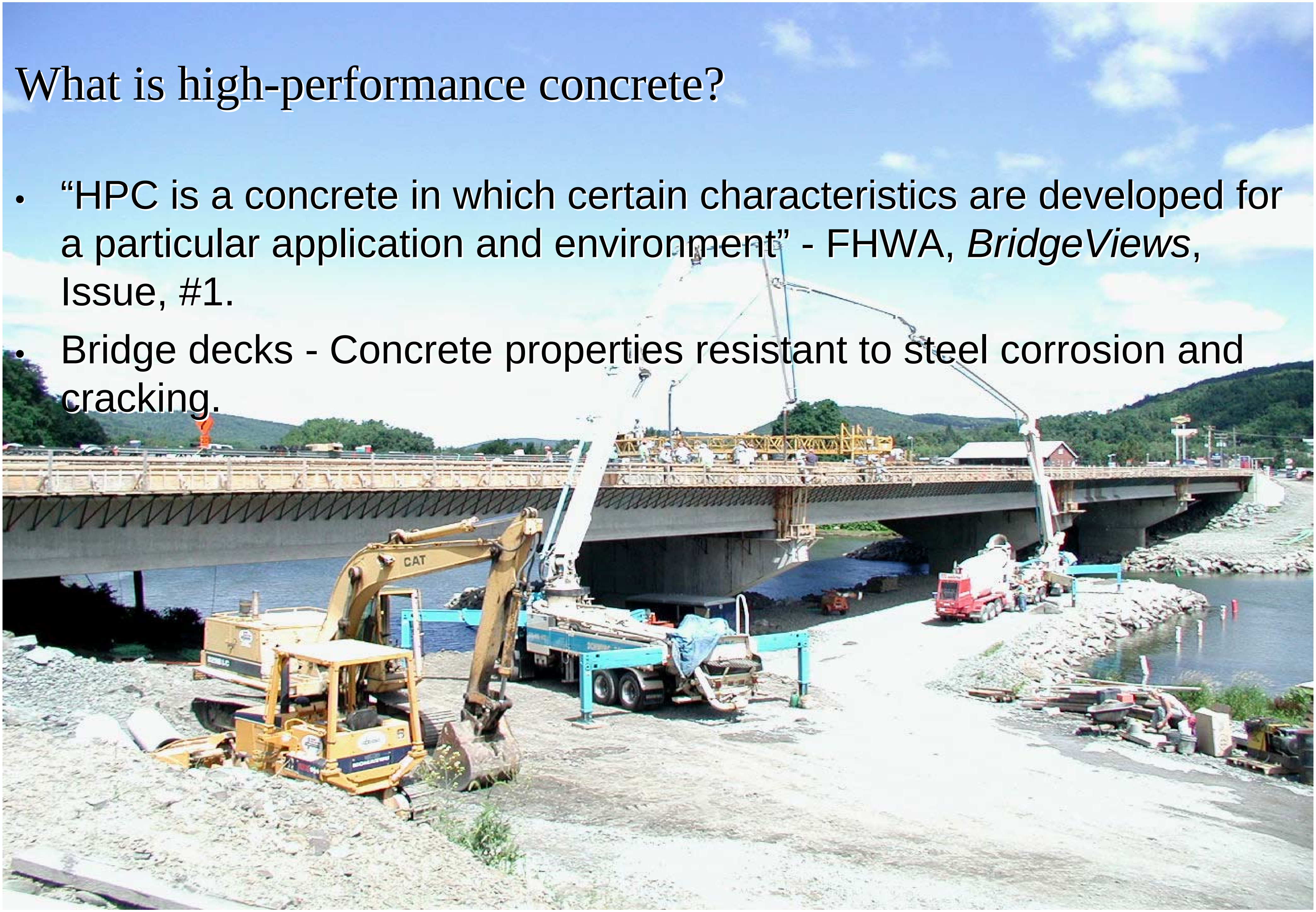
**Federal Highway
Administration**

Weighted Value Summary for Types of Distress Experienced




% Responding
50
45
40
35
30
25
20
15
10
5
0
0-7d
0-14d
14 - 28d
>28d
>6mo
Estimates of Crack-initiation time.

What is high-performance concrete?



- “HPC is a concrete in which certain characteristics are developed for a particular application and environment” - FHWA, *BridgeViews*, Issue, #1.
- Bridge decks - Concrete properties resistant to steel corrosion and cracking.

Service Life Estimate

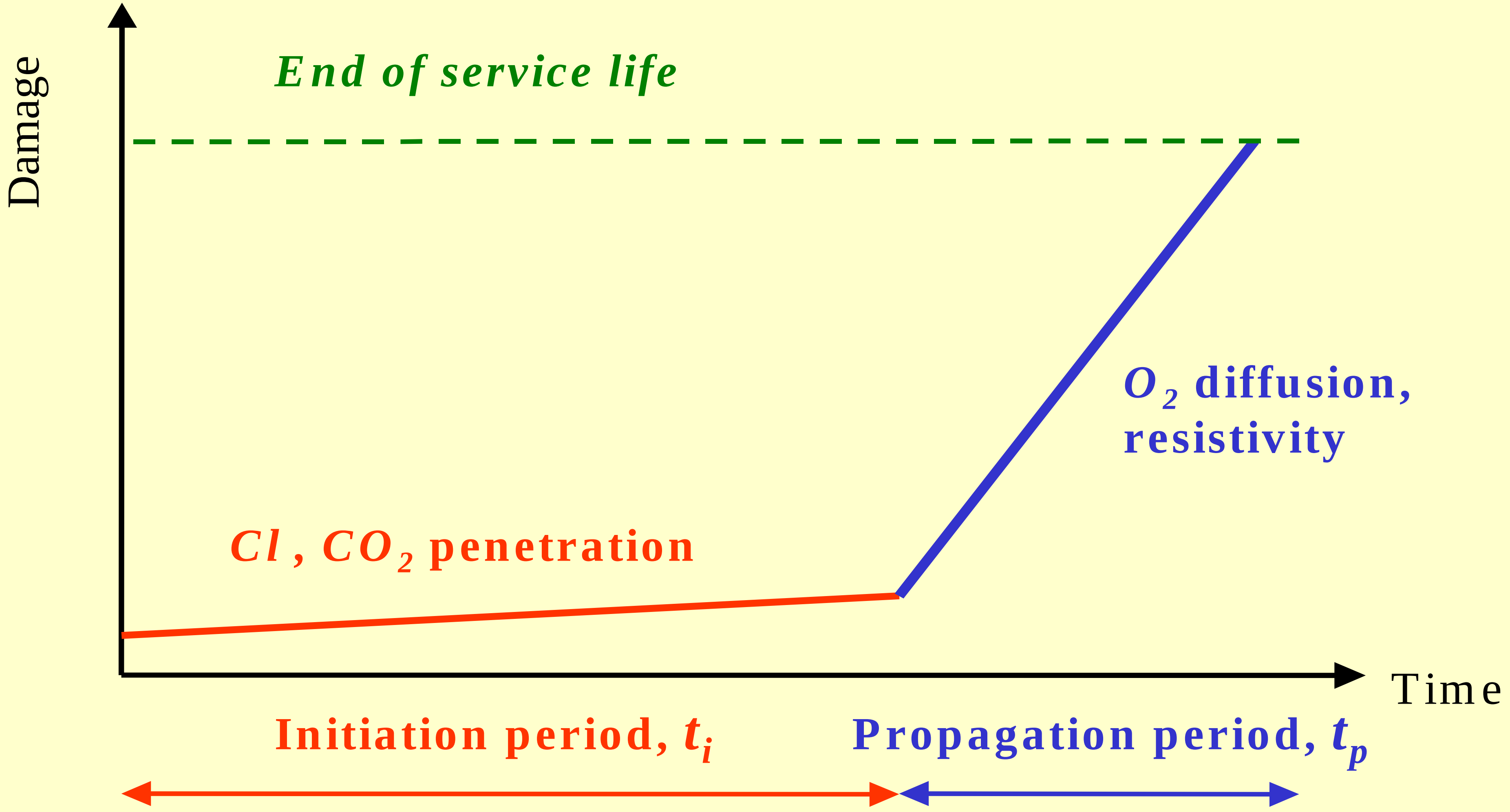
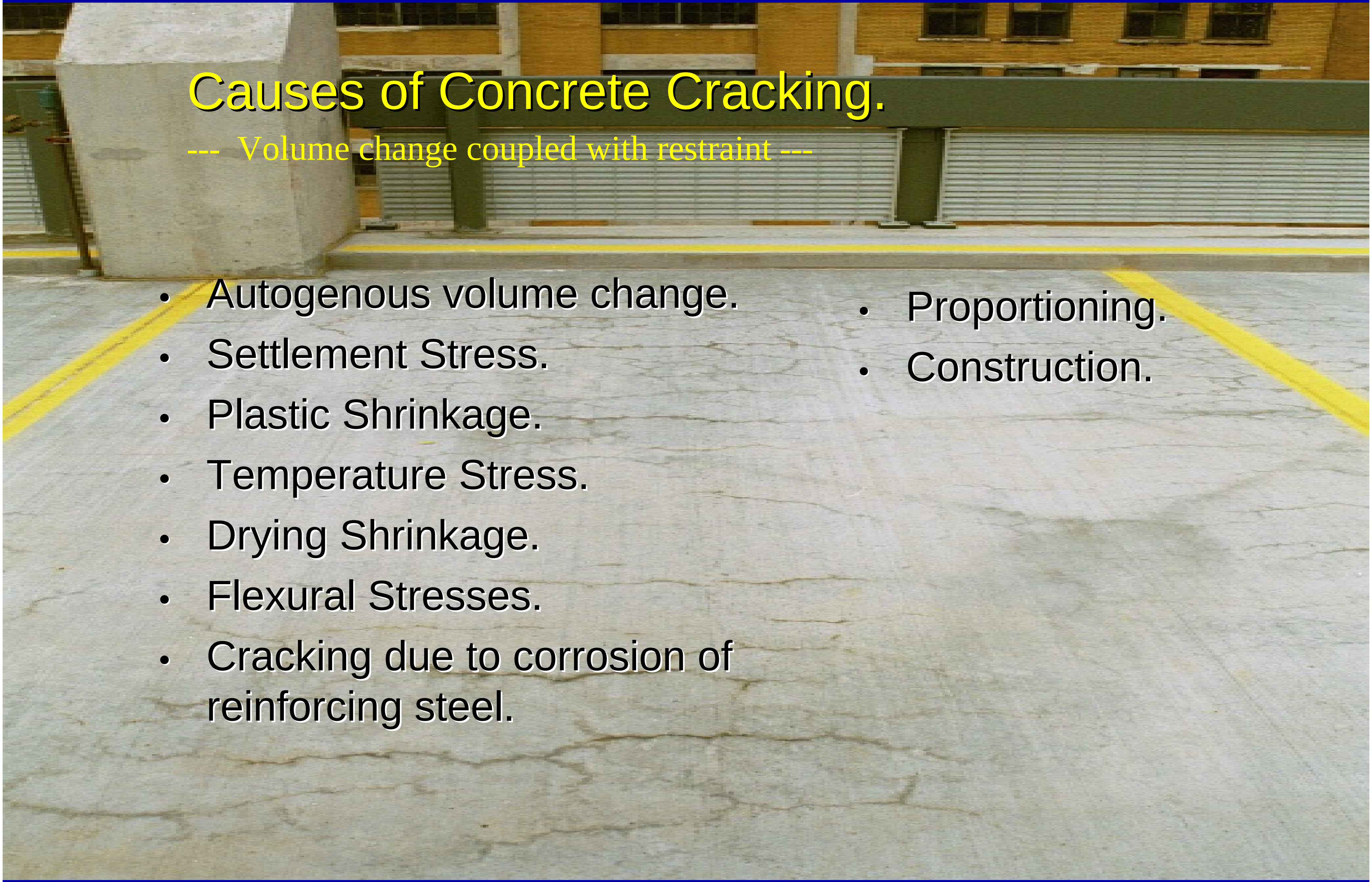


Figure 4.1 Two-Stage Service Life Model Proposed by Tuutti (1982)



Causes of Concrete Cracking.

--- Volume change coupled with restraint ---

- Autogenous volume change.
- Settlement Stress.
- Plastic Shrinkage.
- Temperature Stress.
- Drying Shrinkage.
- Flexural Stresses.
- Cracking due to corrosion of reinforcing steel.
- Proportioning.
- Construction.

University of Kansas

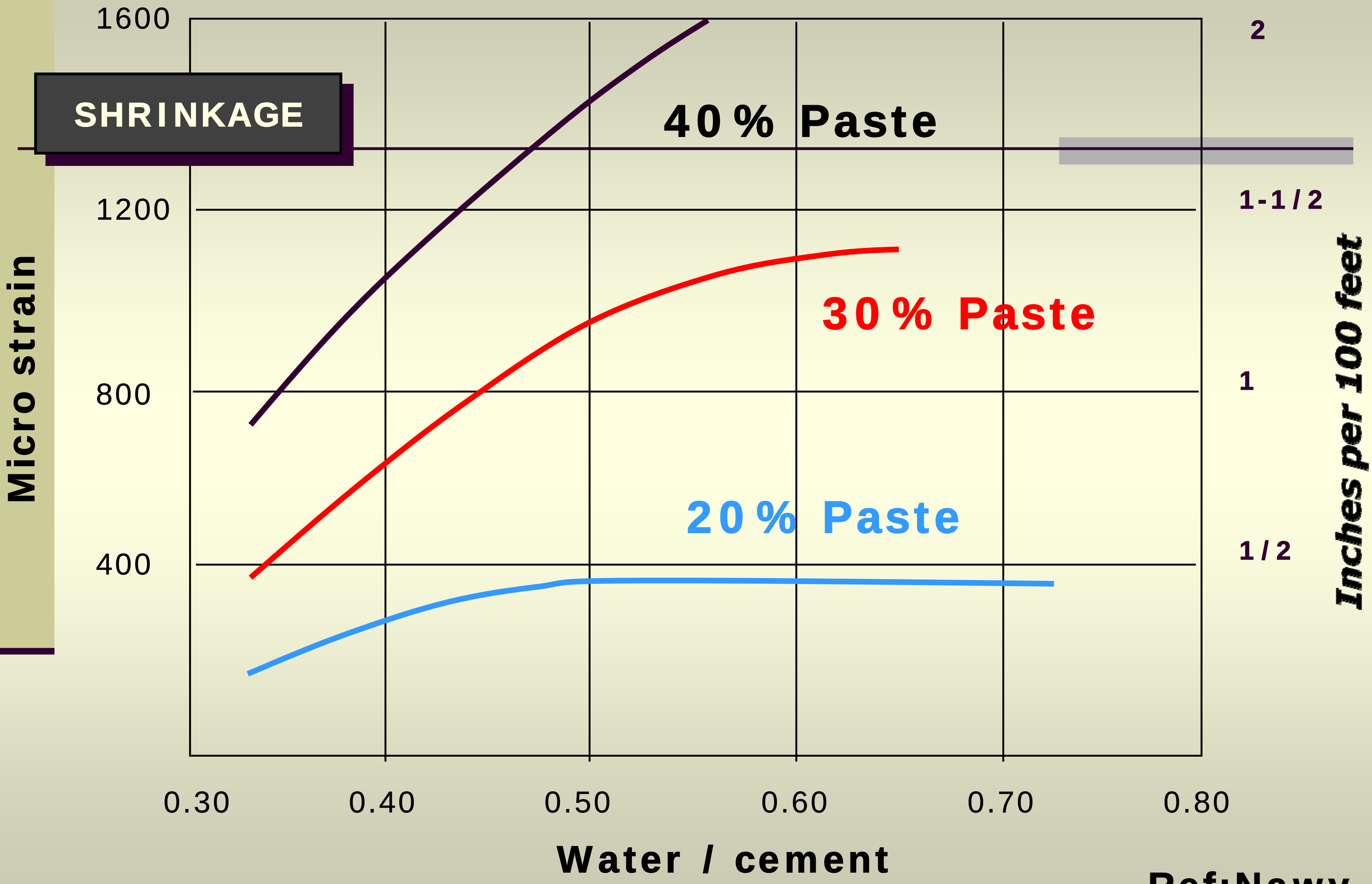
Construction of Crack-Free Bridge Decks

- FHWA / 15-State, Pooled-fund Study
  Lead State: Kansas.

University of Kansas

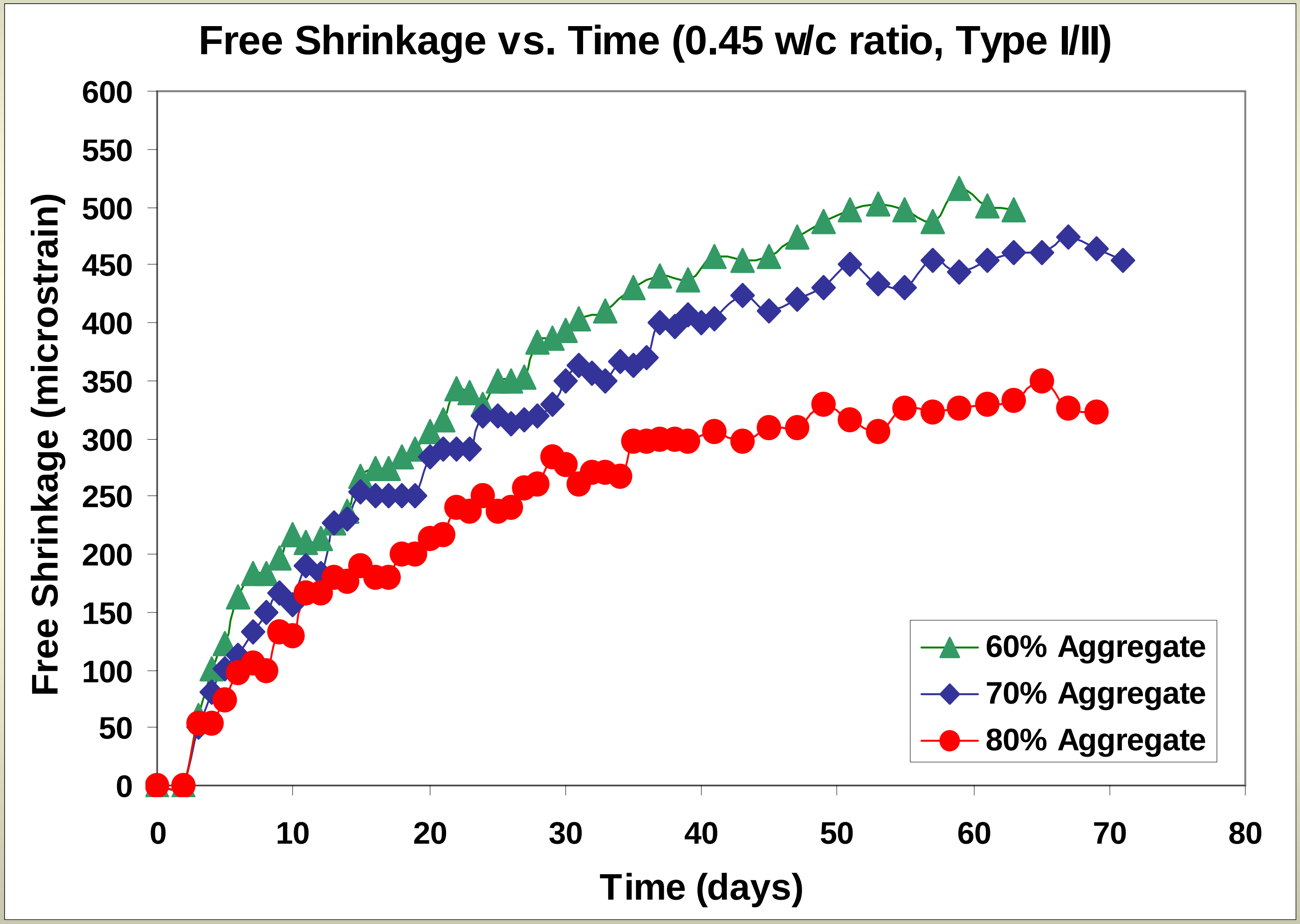
David Darwin
JoAnn Browning

SHRINKAGE



Ref:Nawy

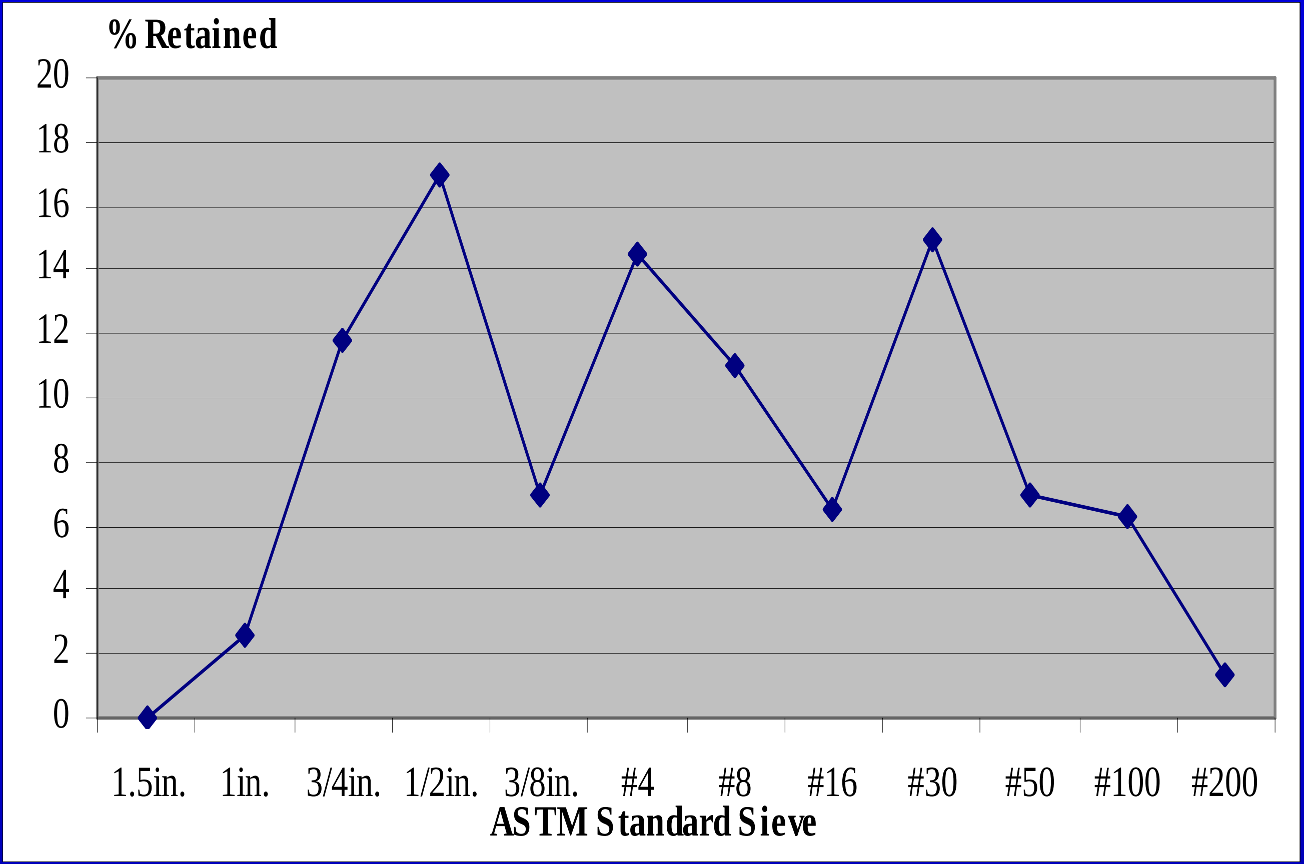
Proportioning - Aggregates



- Largest aggregate allowable.
- Absorption?

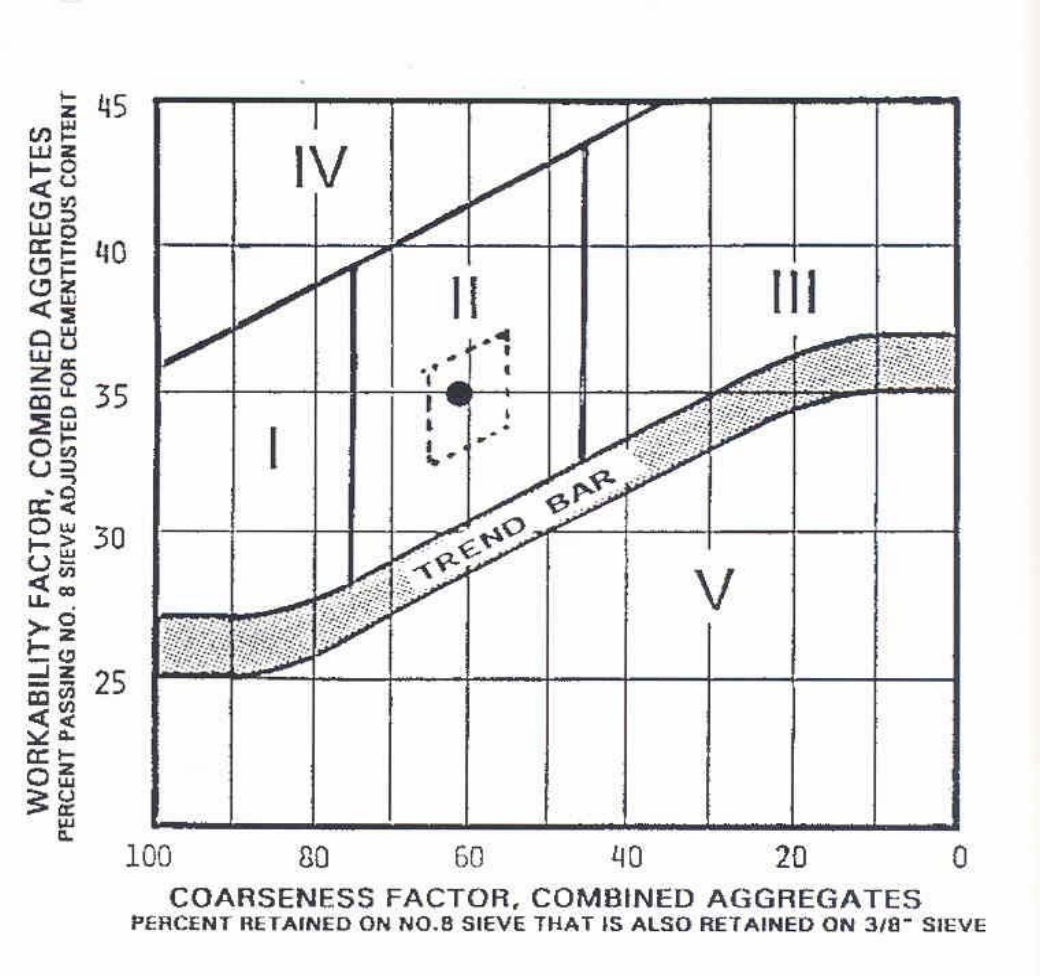
Ref: Darwin

Proportioning Aggregates – Optimized Particle Packing



- **Coarseness Factor** = % Cum. Retained (3/8in) / Cum. Retained (#8) x100.
  - 40/ 65= 0.61x100=61
- **Workability Factor** = % Cum. Passing #8 sieve. - 35%

Proportioning Aggregates



- Zone I - Mixture Segregates during placement.
- Zone II - Desirable.
- Zone III - Extension of II for CA <1/2 in. max.
- Zone IV - Too much fines & mortar, can be expected to crack, produce low strength, segregate during vibration.
- Zone V - Too rocky.

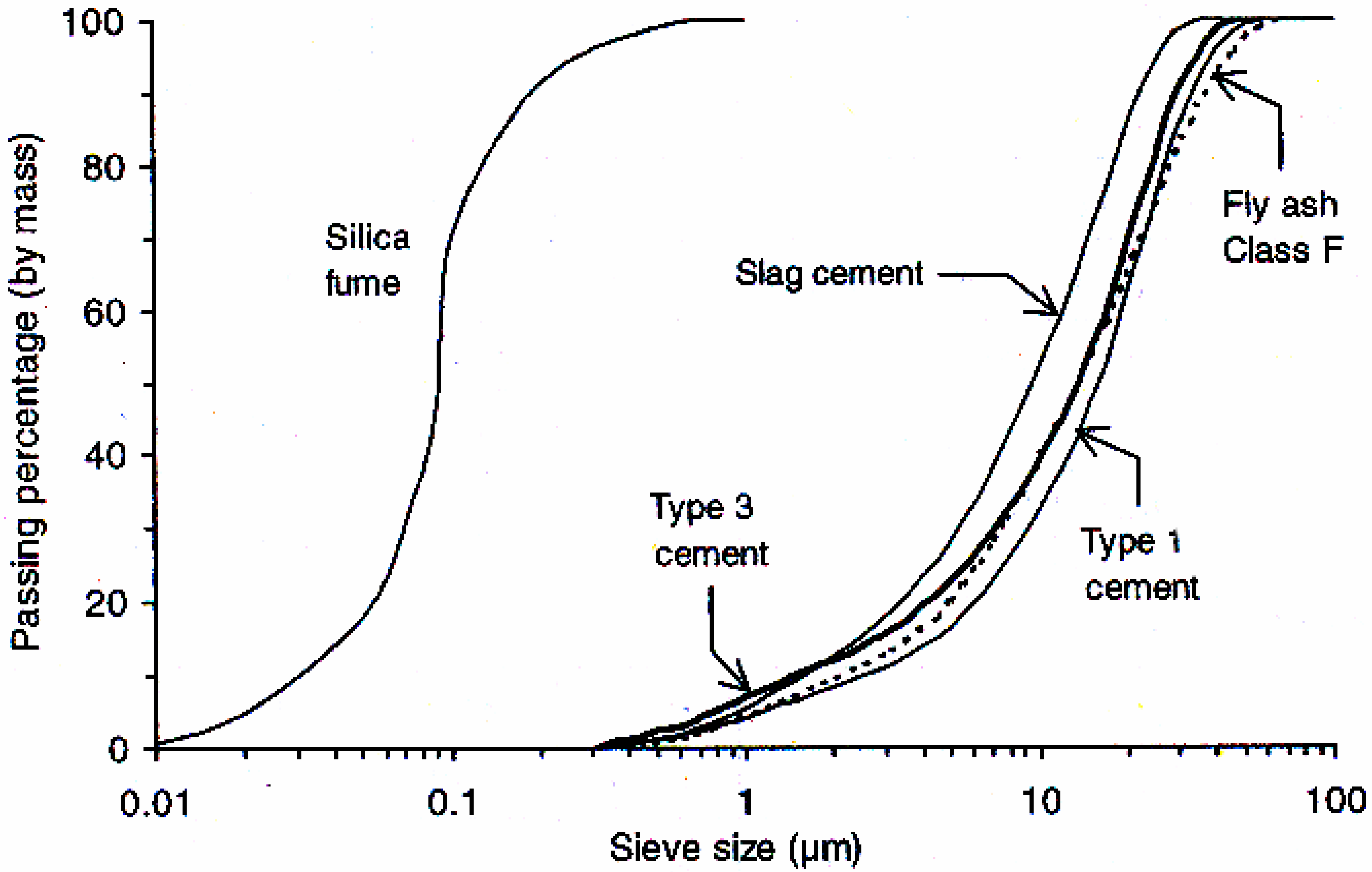
- Add 2.5% to WF for every 94pcy cement above 564pcy.

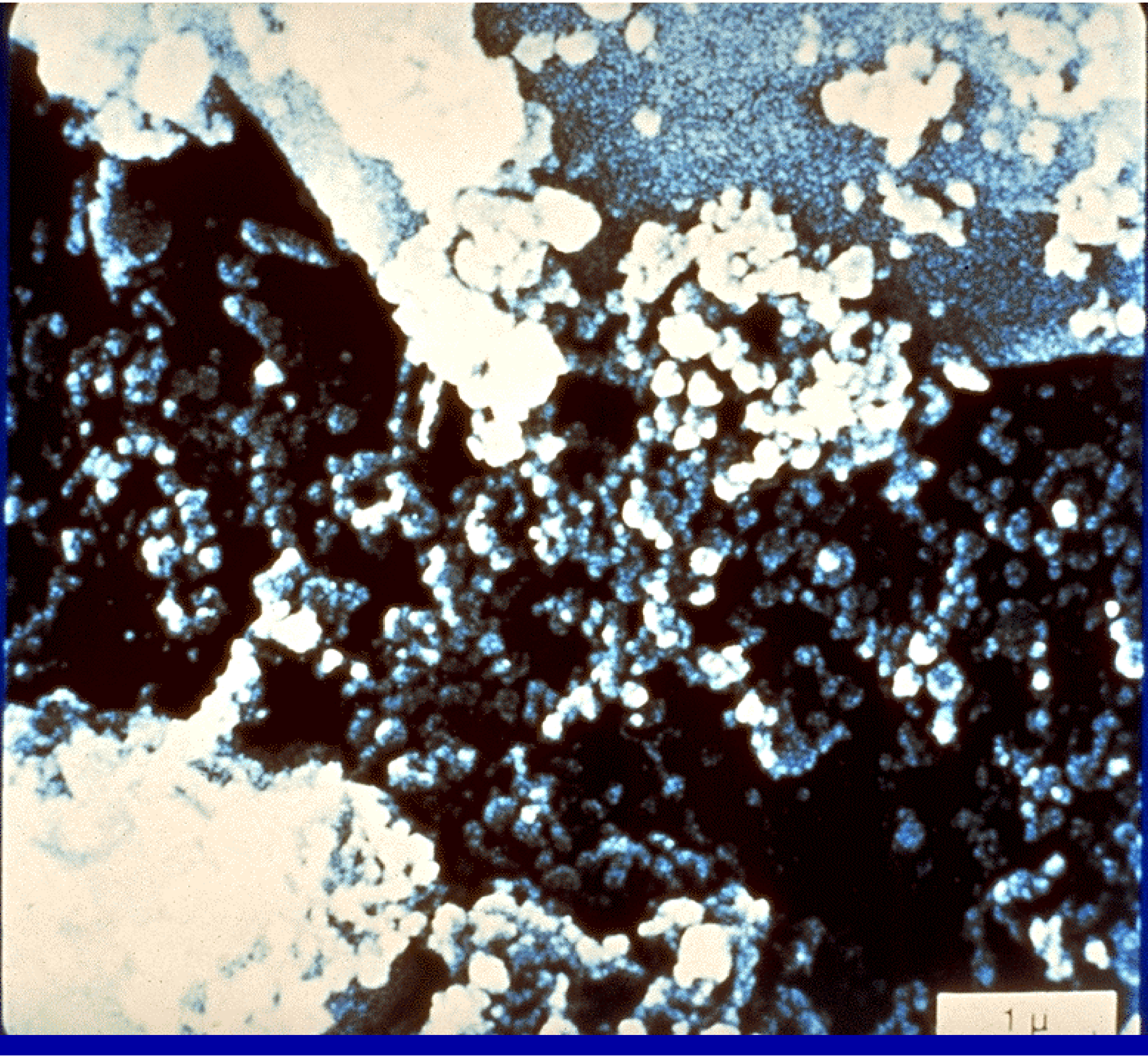
KU MIX

CONCRETE MIX DESIGN AND COMBINED AGGREGATE OPTIMIZATION

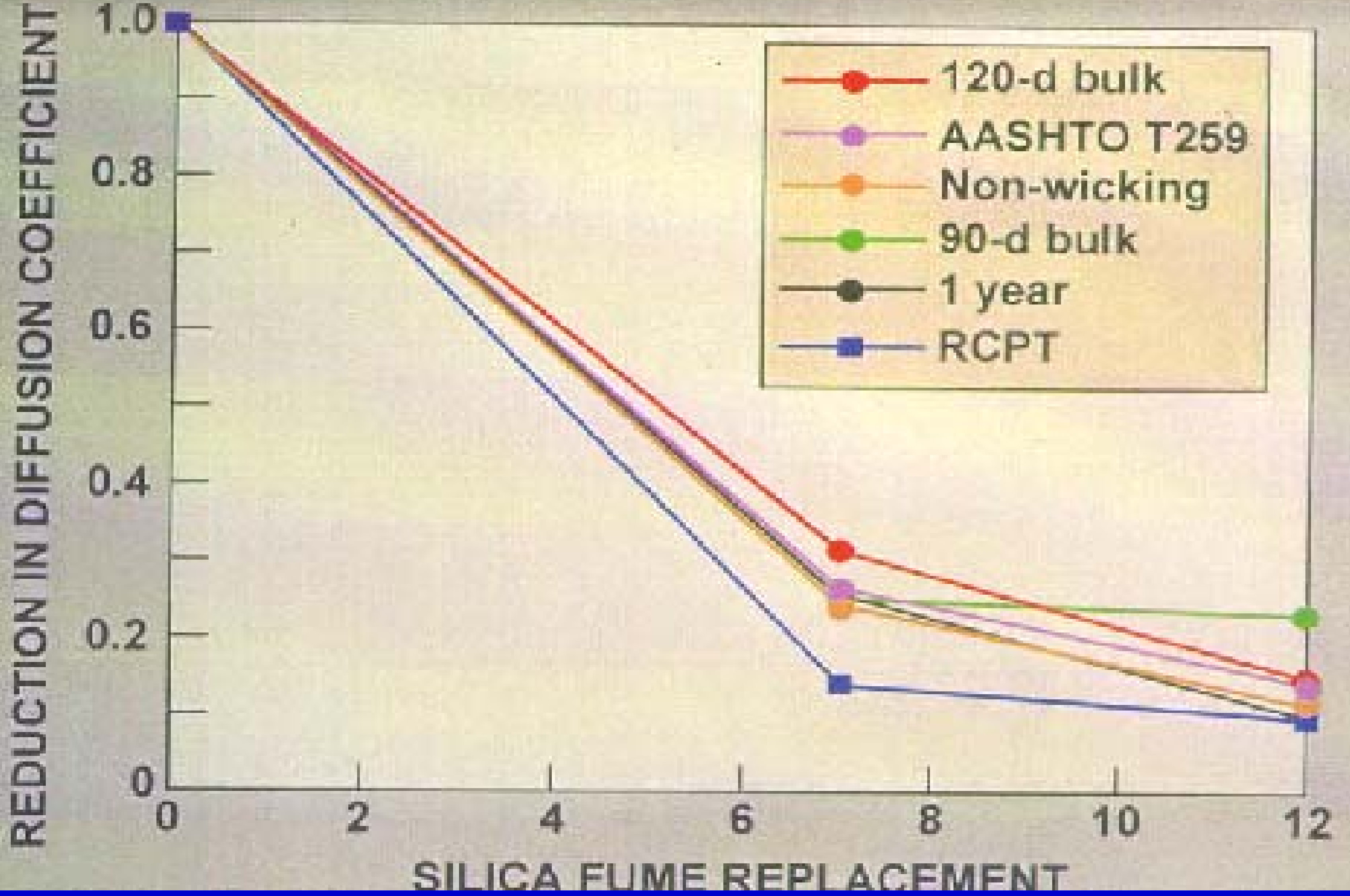
KU MIX Version 1.0 Beta 1
Please Email Questions or Comments to kumix@ku.edu


GGBF slag
grade 120
Si Silica Fume
(microsilica)
Portland Cement
Type I
Fly Ash
class C

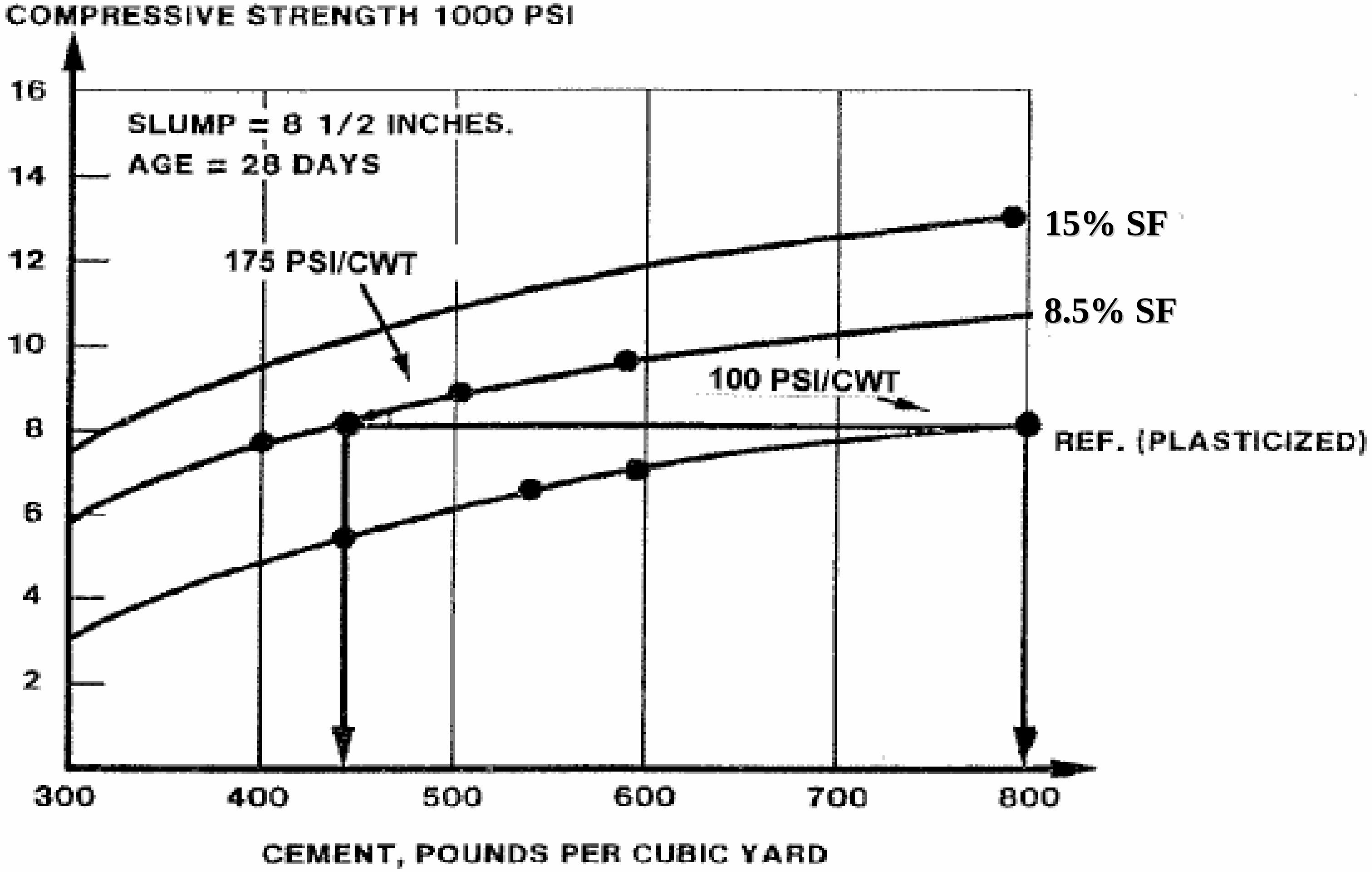

100
80
60
40
20
0
Passing percentage (by mass)
0.01
0.1
1
10
100
Sieve size (μm)
Silica fume
Slag cement
Fly ash Class F
Type 3 cement
Type 1 cement


1 μ

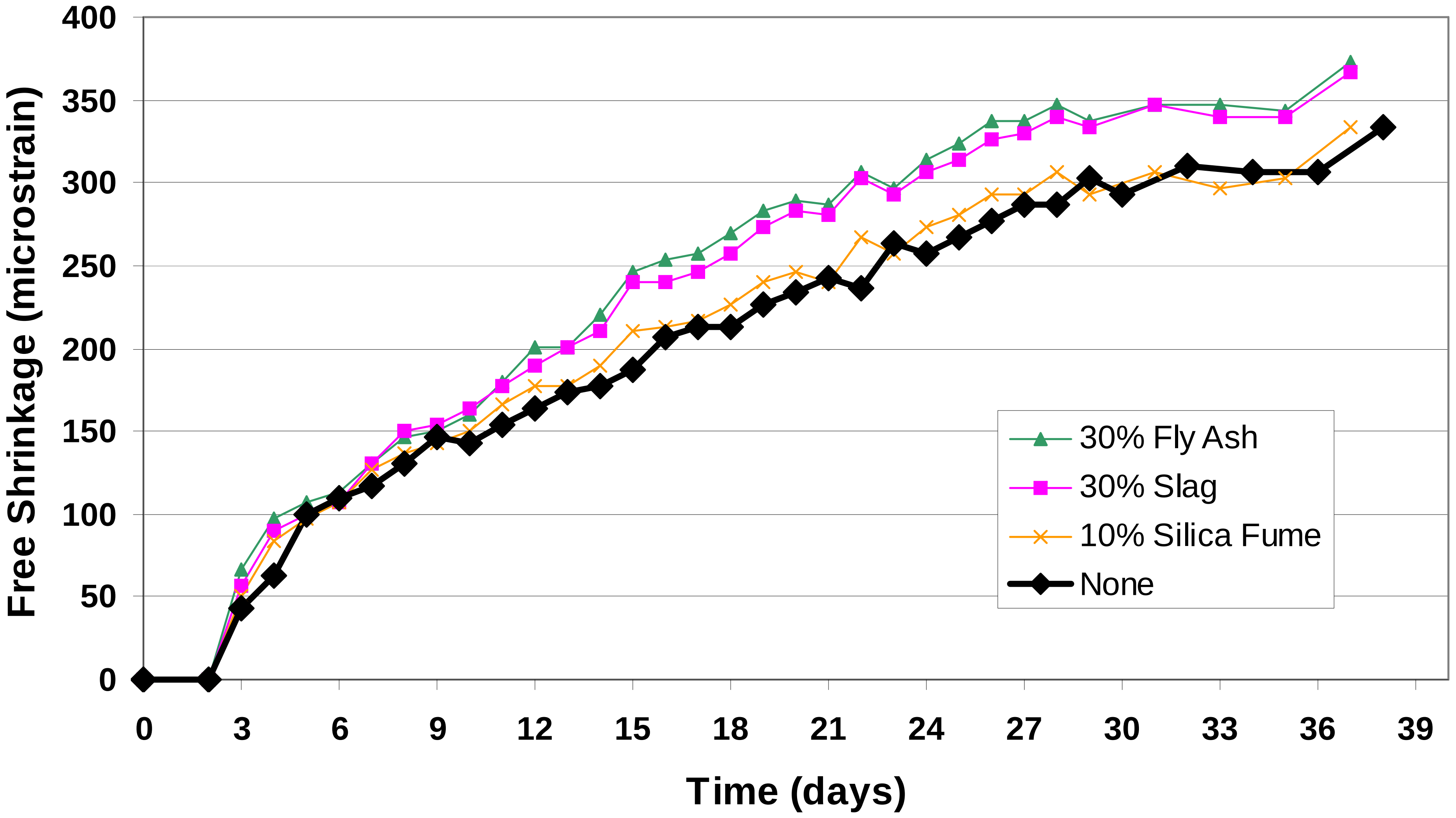
Relative Reduction in Penetration Coefficients with Silica Fume (w/cm = 0.35)



ALL MIXES AT 15% FA BY CEMENT WT



Average Free Shrinkage Mineral Admixtures



Proportioning Paste.

- Reduce water per volume (cy) of concrete.

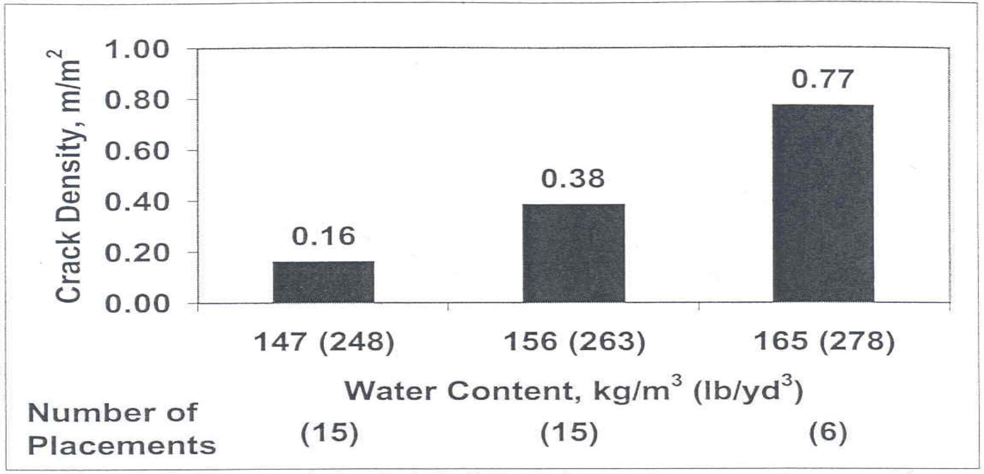


Figure 3.46: Mean crack density for individual placements versus water content for monolithic bridges

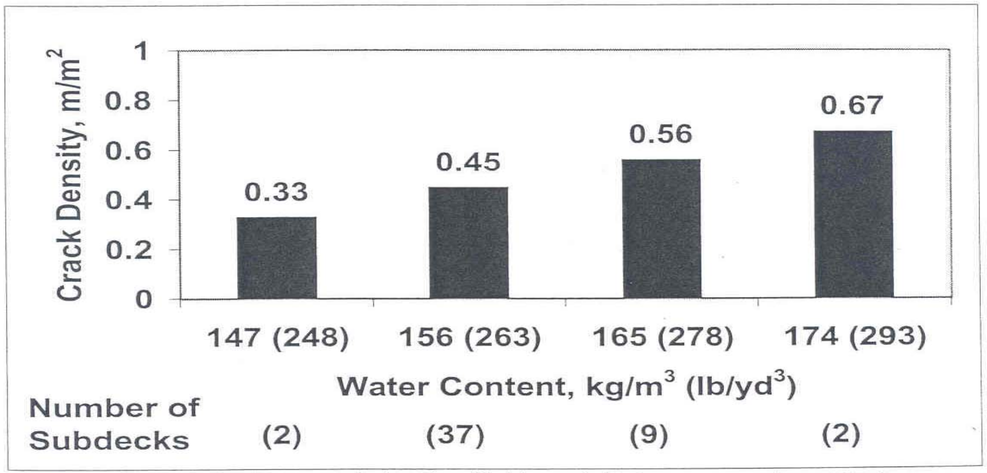


Figure 3.47: Mean crack density of bridge subdecks versus water content

Proportioning Paste

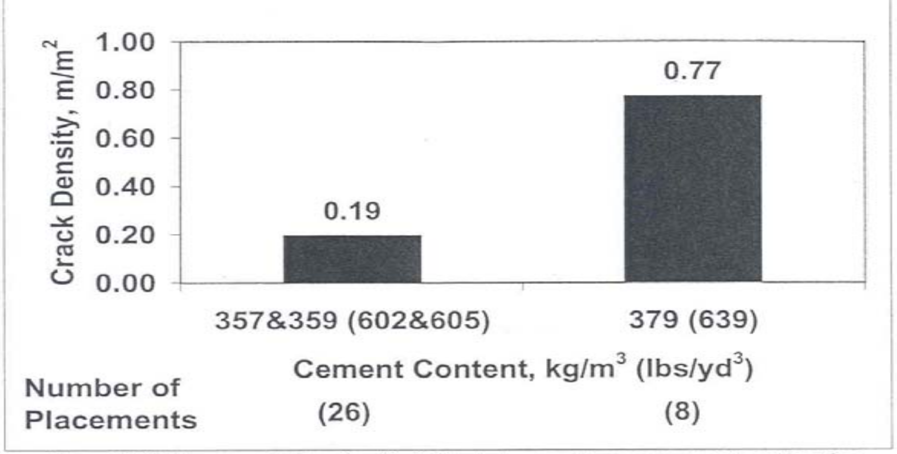


Figure 3.48: Mean crack density of individual placements versus cement content for monolithic bridge decks

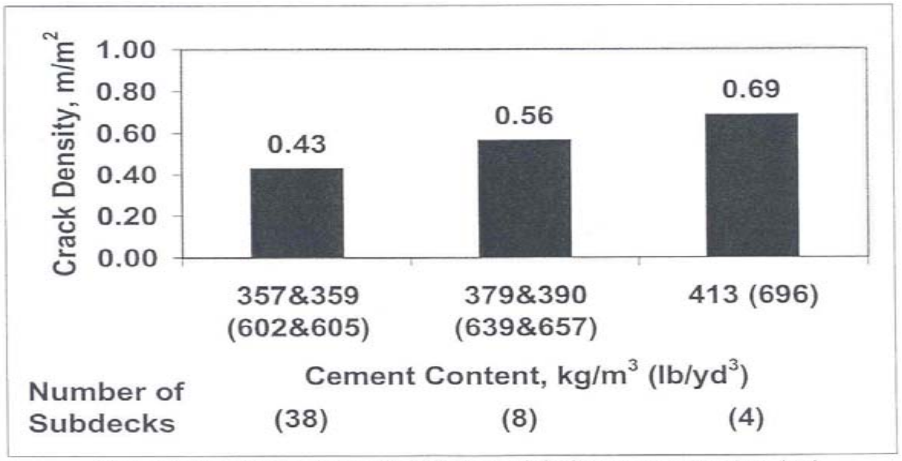
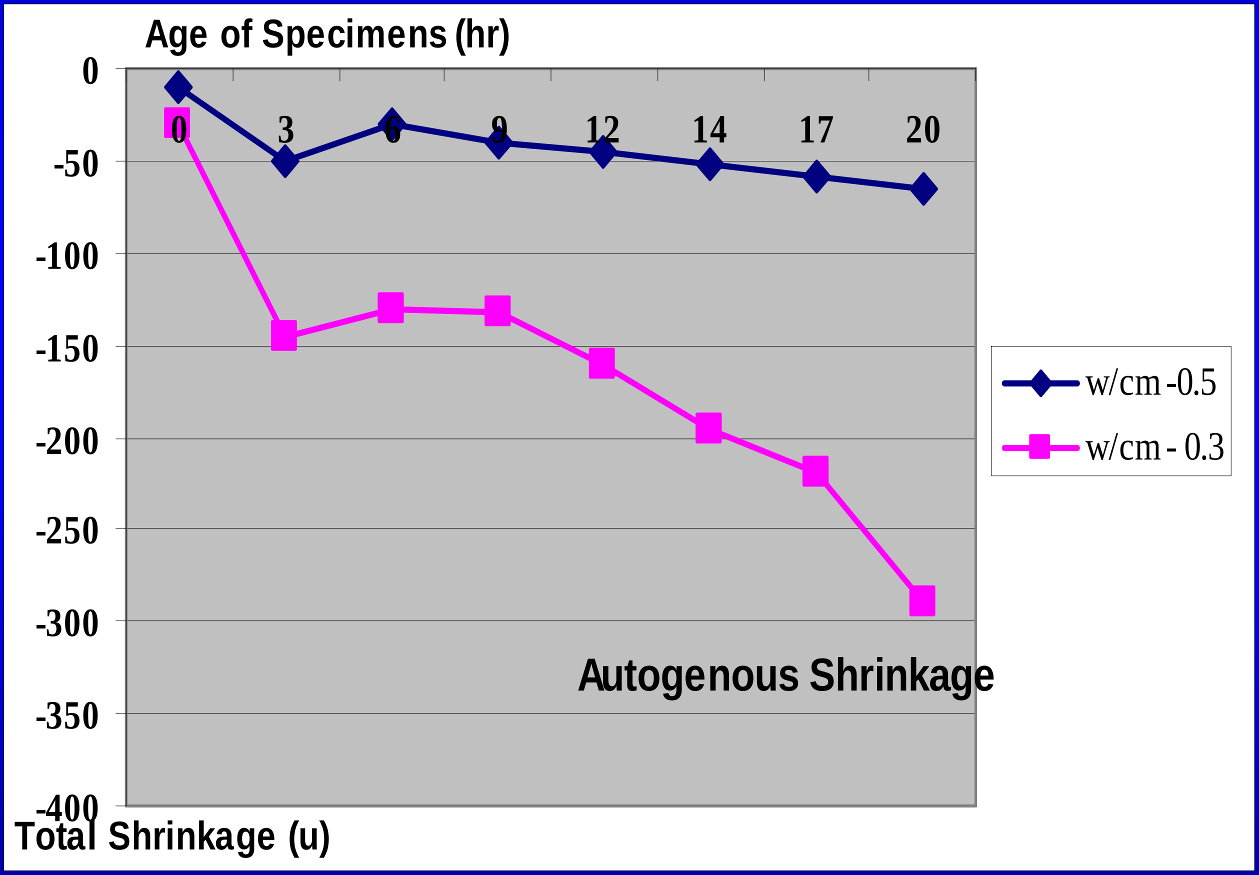


Figure 3.49: Mean crack density of bridge subdecks versus cement content

Lower Strength.

- **Slow strength development critical.**
- **Increased creep.**
- **Lower modulus of e.**
- **Lower heat of hydration.**

Proportioning Paste



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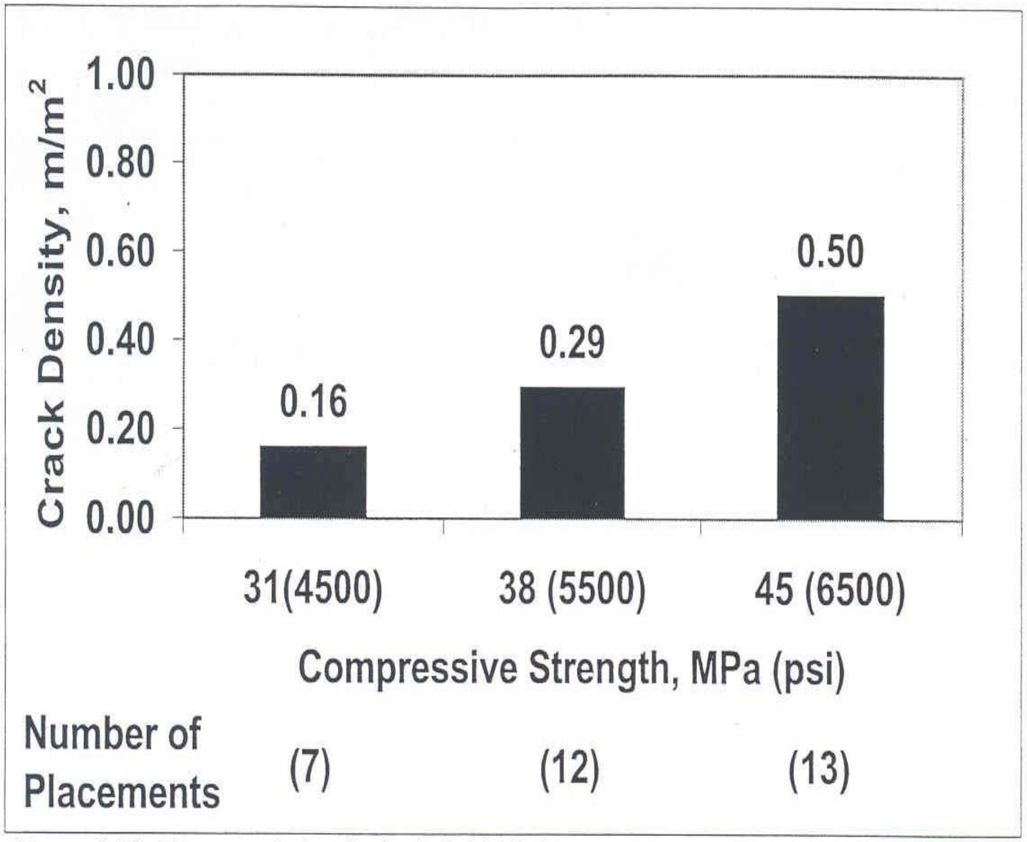

Figure 3.72: Mean crack density for individual placements versus compressive strength for monolithic bridge decks

Lower Strength.

- **Slow strength development critical.**
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- **Lower modulus of e.**
- **Lower heat of hydration.**

Proportioning Paste.

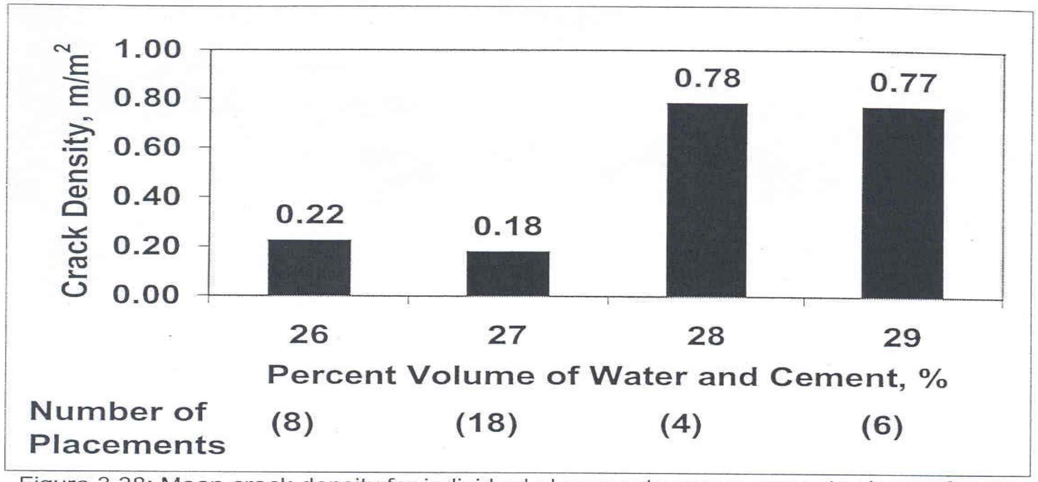

Figure 3.38: Mean crack density for individual placements versus percent volume of water and cement for monolithic bridges

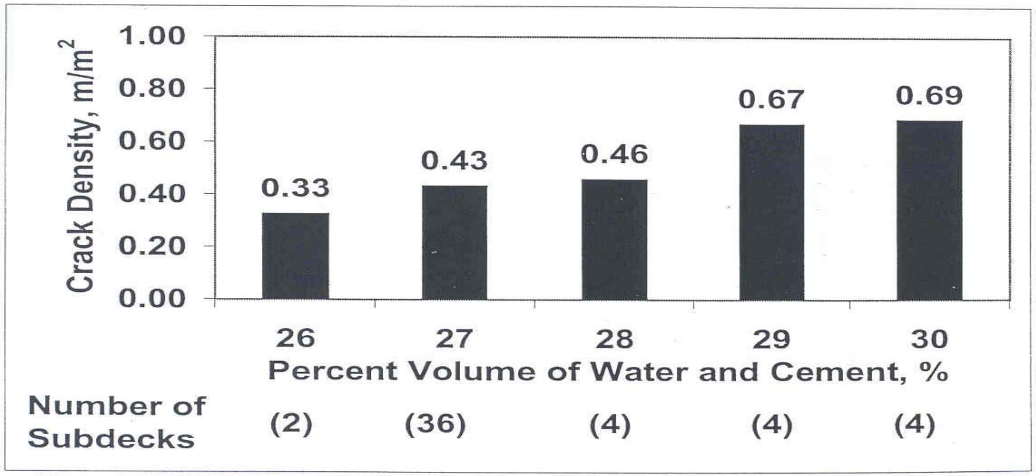

Figure 3.39: Mean crack density of bridge subdecks versus average percent volume of water and cement

- <27% paste, (7.29 cft/cy).
- Lower slumps.
- >6% entrained air.

Proportioning Paste.

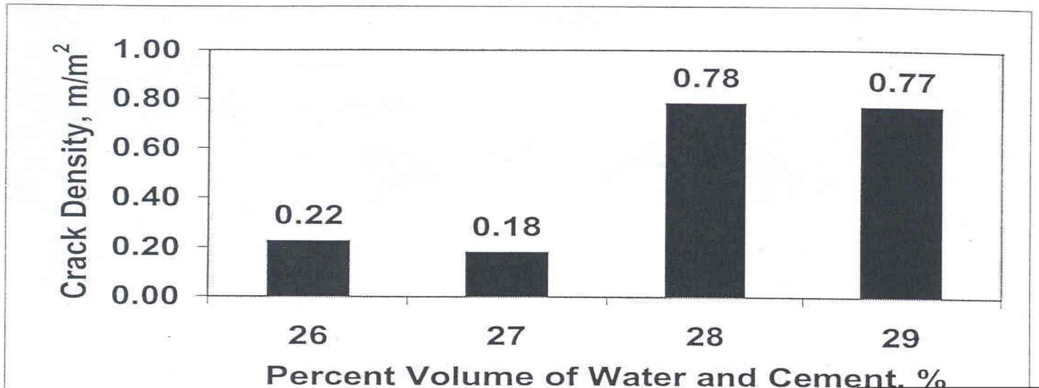

Figure 3.38: Mean crack density for individual placements versus percent v
and cement for monolithic bridges

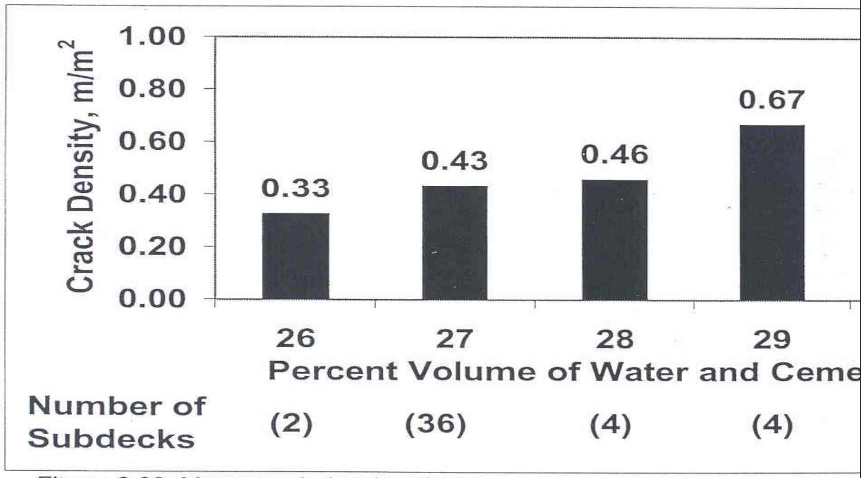

Figure 3.39: Mean crack density of bridge subdecks versus average perce
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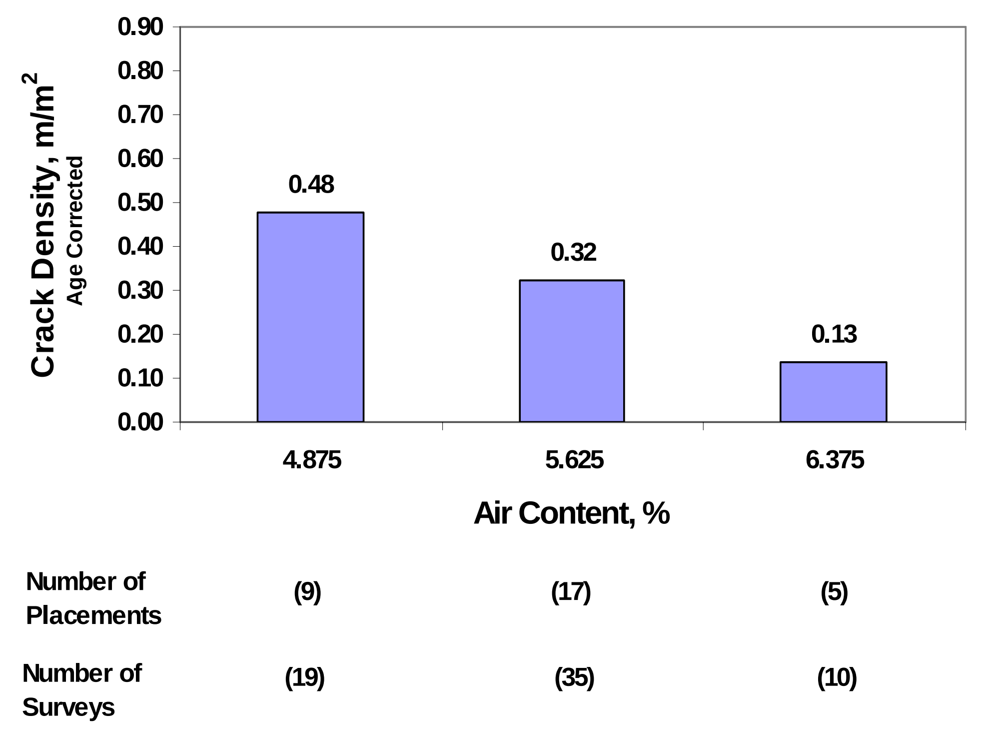
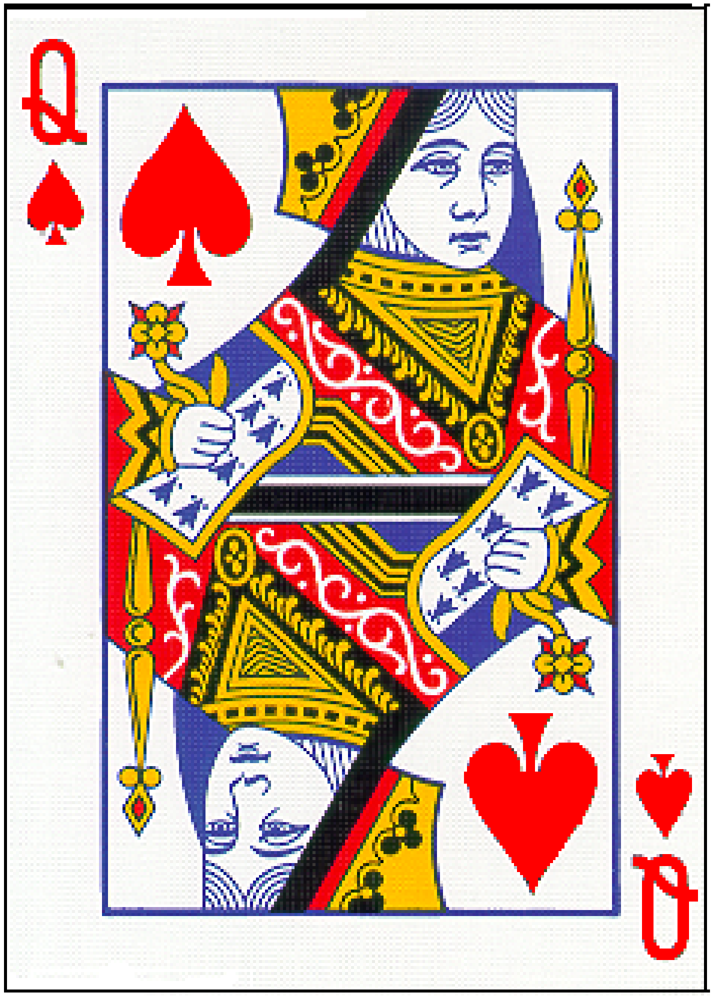


Bridge Deck HPC Philosophy



- **Implies using the <u>least amount of cement</u> possible!**
- **Judicious use of pozzolans.**
  - **Particle packing - reduced permeability.**
  - **ASR control.**
  - **Less water - less shrinkage.**
  - **Reduced heat of hydration.**
  - **Lower strength - reduced cracking.**

HPC – An Evolution in Proportioning.

	HPC	vol.	DOT AAA mix.	
Cement, pcy	470	2.39	665	3.39
Fly ash, pcy	100	0.64	117	0.75
Silica fume, pcy	40	0.29	---	
Water, gal	29.8	3.97	36.8	4.91
Total volume (<27%)		7.29		9.05
w/cm		0.407	0.392	
Crushed gravel, pcy	1770		1680	
Natural sand, pcy	1190		993	
Aggregate volume		17.96		16.20
Rapid Cl permeability	1200		2850	
3d, psi	2760		3200	
28d	5390		5160	
56d	6210		5790	

CO, (I-255) Bridge Deck Proportions / Results

Proportions	pcy
Cement	485
Fly Ash F	97
Silica Fume	20
Coarse Agg.	1700
Fine Agg.	1350
Water	247
HRWR	5-12oz/cwt
Air	5.5-8.5%
Paste content	26.5%

Results (no cracks)

Strength: 3d - 3000psi
7d - 3900psi
28d- 4700psi
Permeability:
28d - 2500 coulombs
56d - 1400

Shrinkage (ring test)
1st crack 17days.

I-15 Bridge Deck Proportions and Results

Proportions	pcy
Cement	460
Fly Ash F	90
Silica Fume	40
Coarse Agg.	1854
Fine Agg.	1300
Water	240
HRWR	AR
AEA	AR
Air	6%
Paste content	26%

Results (no cracks)

Strength: 7d - 4600
28d - 6760

Permeability:
60d - 628 coulombs

Shrinkage:
28d - 380 microstrains

Tensile:
56d - 590 psi

PA, (I-99) Bridge Deck Proportions and Results

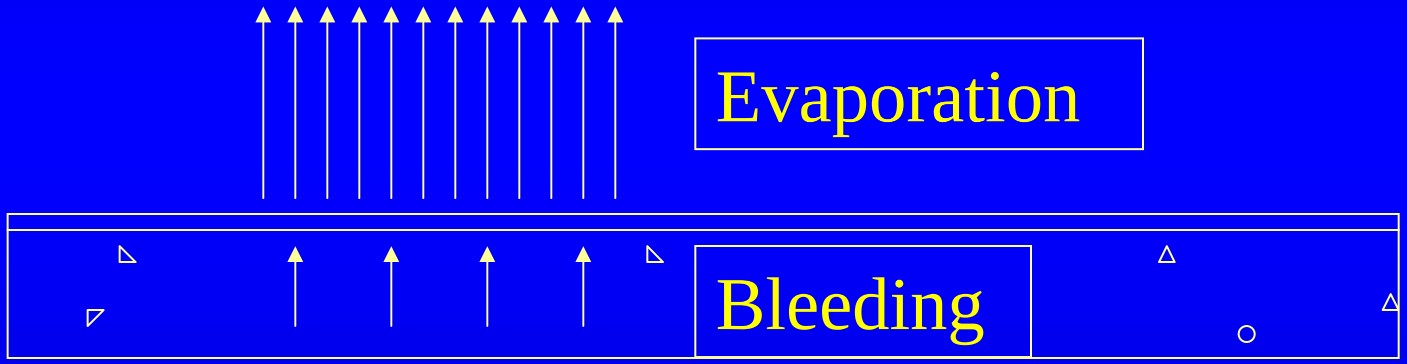
Proportions	pcy
Cement	383
Fly Ash F	176
Silica Fume	29
Coarse Agg.	1758
Fine Agg.	1278
Water	254.9
MBVR	11oz.
MB1466	35oz
Air	6%
Paste content	27%

Results (no cracks)

Strength: 7d - 4620psi
14d - 6310psi
56d - 8010psi
Permeability:
28d - 1100 coulombs
56d - 670
Shrinkage:
28d - 310 microstrains
56d - 340 microstrains
Tensile:
56d - 590 psi

Construction

Problem: Concrete Surface Drying



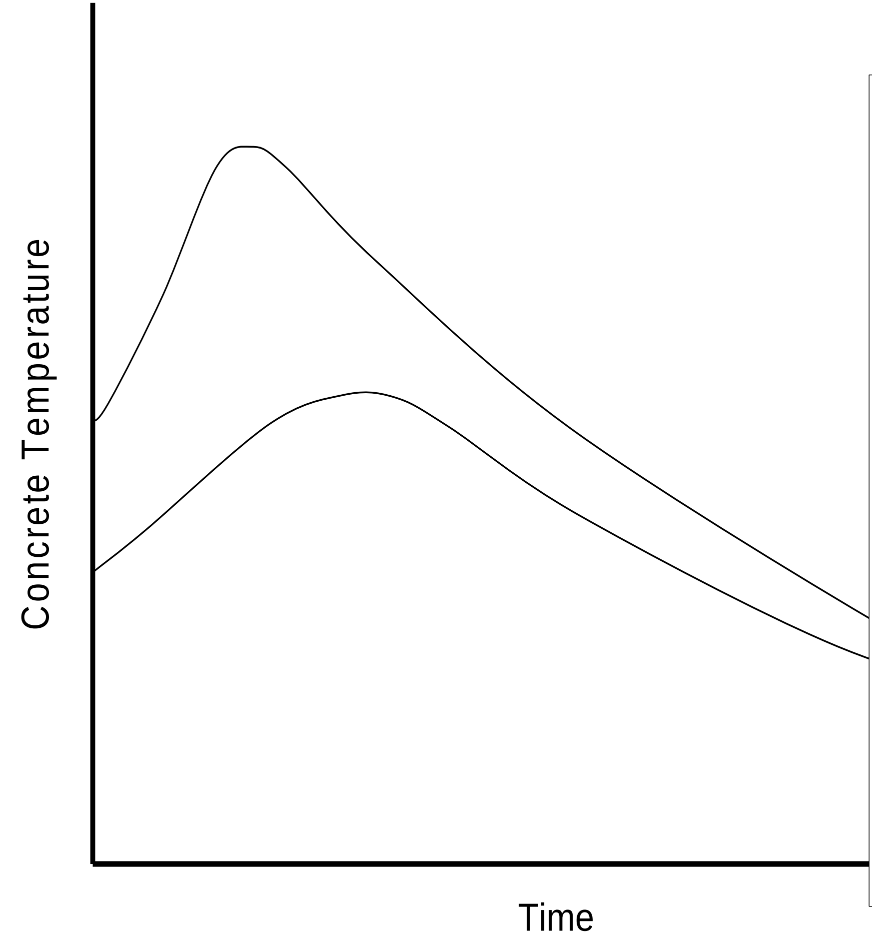
Evaporation

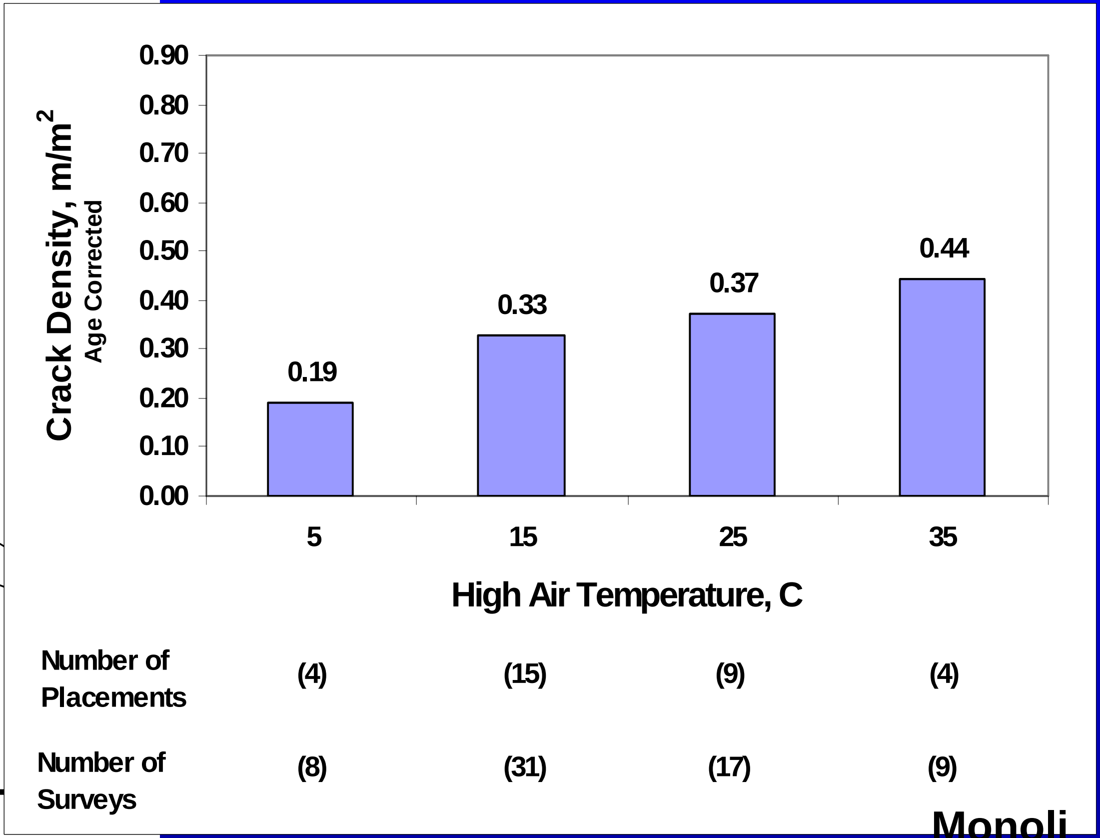
Bleeding

If Evaporation > Bleeding ⇒ Plastic Shrinkage Cracking

Construction

- Lower concrete temperature than air.
- Limit difference between concrete and formwork prior to placement.
- Temperature differentials > 20C (36F) may cause thermal cracking.





Monolithic

Construction

- Lower concrete temperature than air.
- Limit difference between concrete and formwork prior to placement.
- Temperature differentials > 20C (36F) may cause thermal cracking.

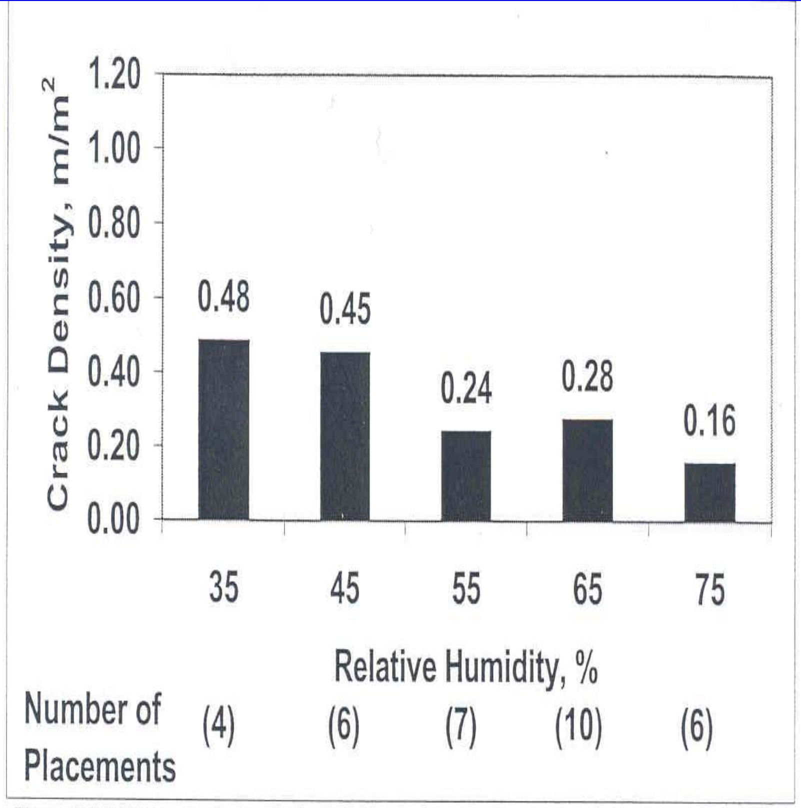
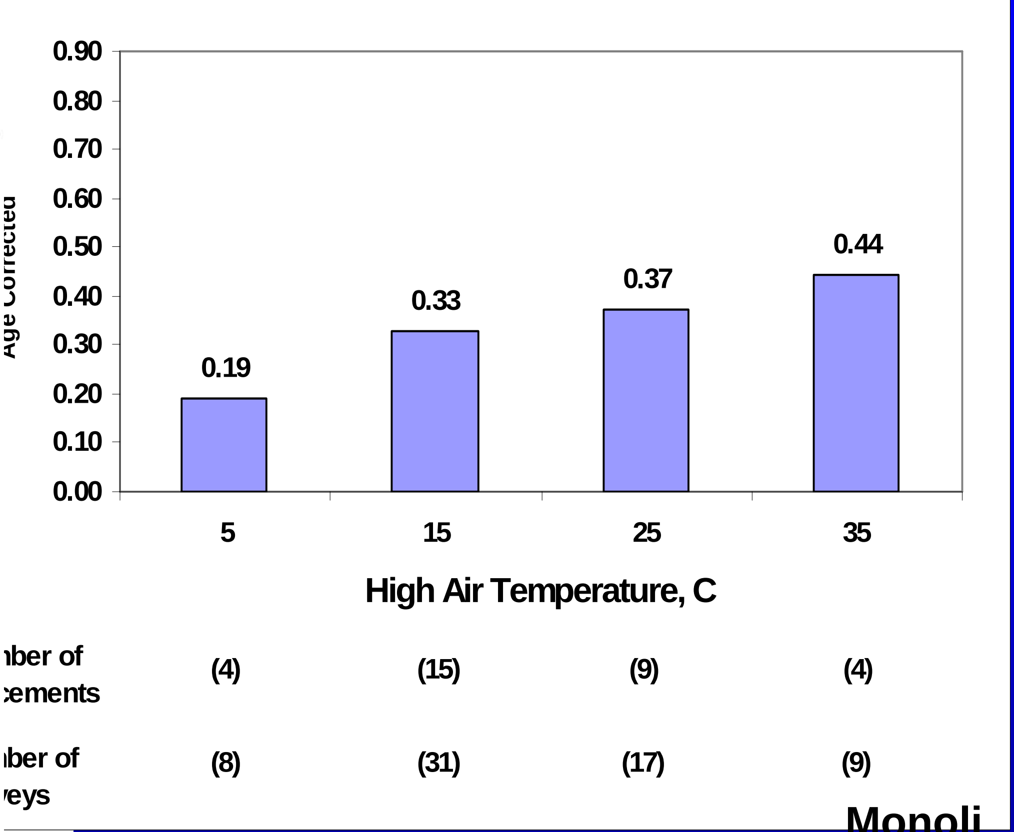
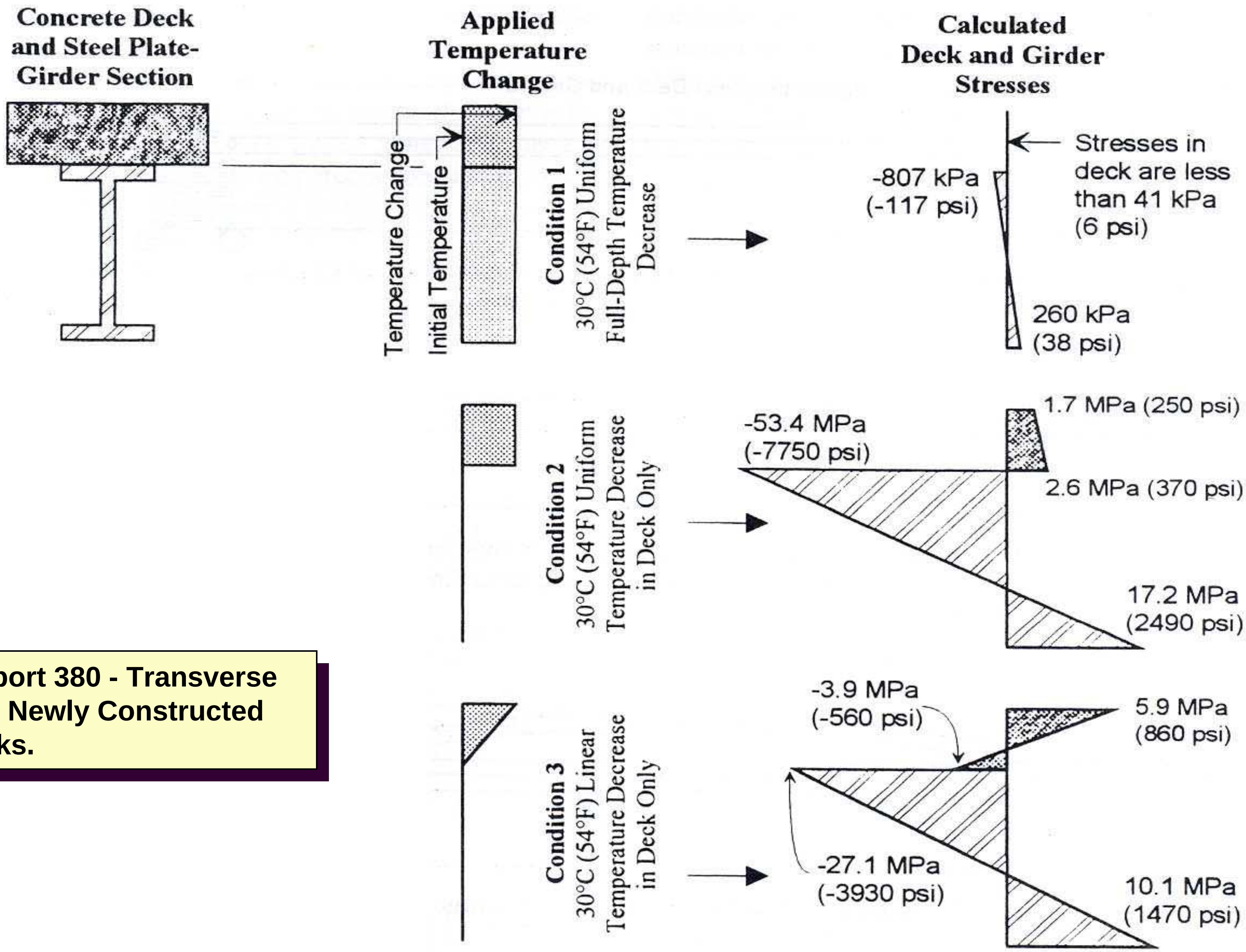


Figure 3.90: Mean crack density for individual placements versus relative humidity for silica fume overlay bridge decks

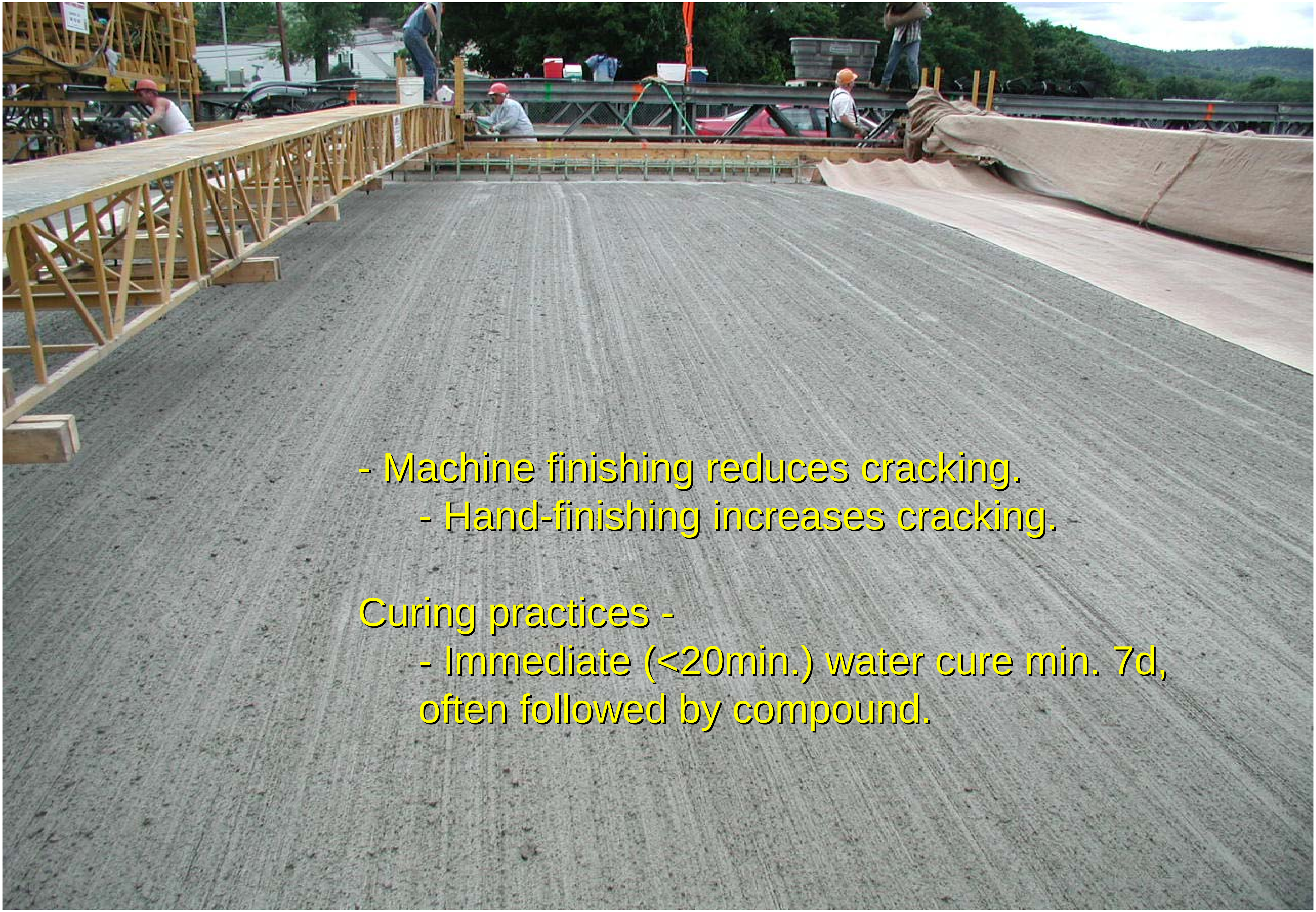


Monolithic



NCHRP Report 380 - Transverse Cracking in Newly Constructed Bridge Decks.


HIPERPAV II
Minimum System Requirements:
Desirable System
Instruction for Use:
US Department of Transportation
Federal Highway Administration
HIPERPAV



- Machine finishing reduces cracking.
  - Hand-finishing increases cracking.

Curing practices -

  - Immediate (<20min.) water cure min. 7d, often followed by compound.

Expedite placing, finishing, texturing and use immediate curing

The end of service-life.

Thank you.