Expectations vs Reality:

What we want and what we get

Presented by:

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American Engineering Testing

A little Background

Disclaimer

Acknowledgements

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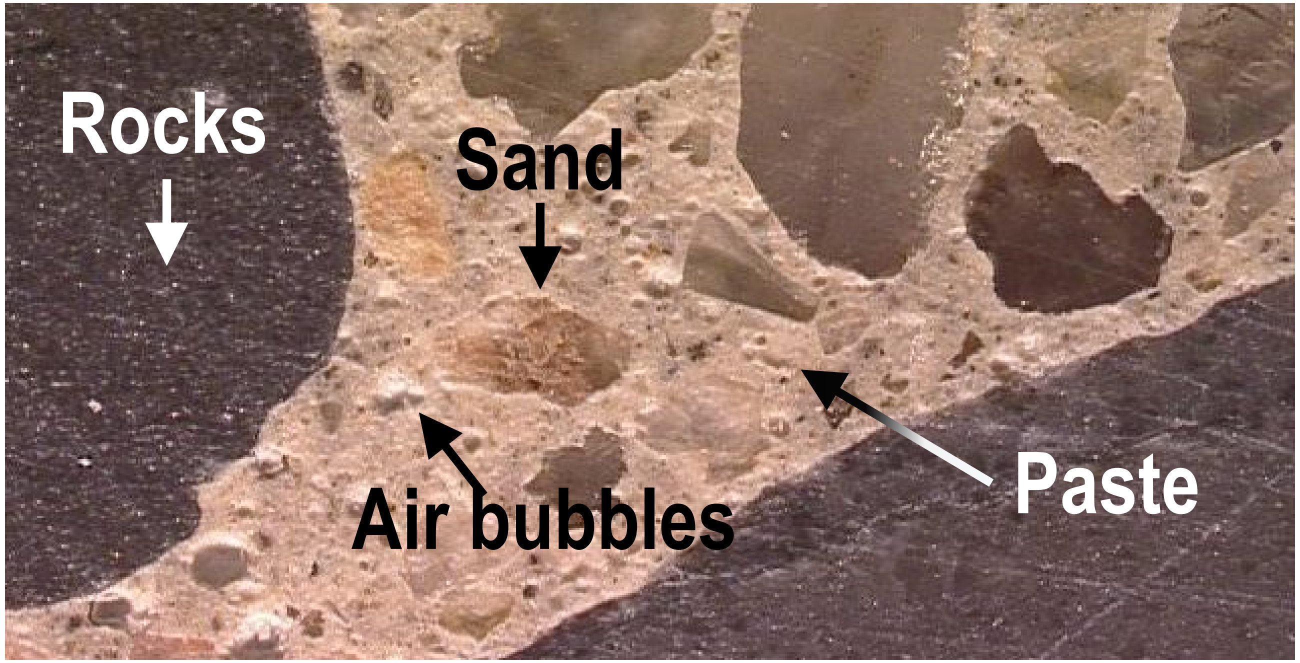
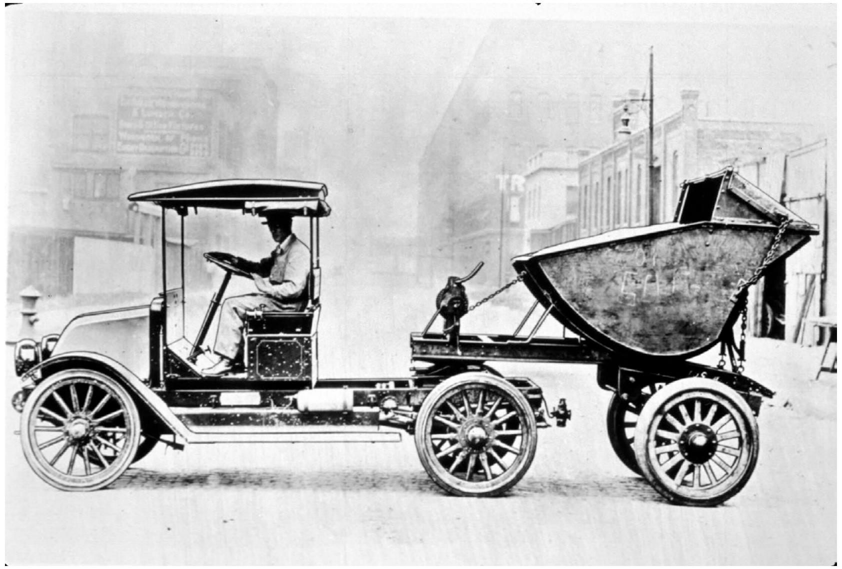
Once Upon a Time ....

Concrete was:

- Coarse Aggregate
- Fine Aggregate
- Portland Cement
- Water





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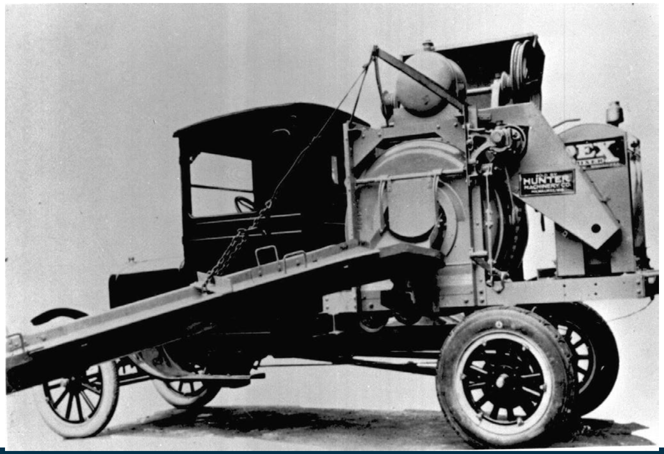

Source : PCA

Once Upon a Time ….

Concrete was “just CONCRETE”

- Coarse Aggregate
- Fine Aggregate
- Portland Cement
- Water

Requirements were mostly Strength and Economical

- **Slump**
  - Constructability
  - Water content
- **Compressive Strength**

It was Mostly About the Physics

However……. Concrete is NOT what it Used to be

Adding Other Materials:

- Air Entraining Admixture
- Supplementary Cementitious Materials (SCM)
- Cocktail of Admixtures
- Several SCMs at a time
- Fillers
- Blend of Aggregates
- Fibers
- Recycled Concrete Aggregate
- Other Cements - Type IL

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We still measure slump and think it telling us something

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Potential for adverse chemical interactions

Now it is Mostly About Chemistry

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Now it is Mostly About Chemistry

Concrete is NOT just "Concrete"
Now it can be:

- Lightweight Concrete
- Cellular Concrete
- Heavy Weight Concrete
- High Strength Concrete
- Pervious Concrete
- Shrinkage Compensating Concrete
- Shotcrete
- Self Consolidating Concrete
- Fiber Reinforced Concrete
- Roller Compacted Concrete

Even Concrete Definition has "Changed"

ACI 116R-15 Defined Concrete:

a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate, usually a combination of fine and coarse aggregates;
in portland-cement concrete, the binder is a mixture of portland cement and water, with or without admixtures.

ACI CT-21 Defines Concrete:

mixture of hydraulic cement, aggregates, and water, with or without admixtures, fibers, or other cementitious materials.

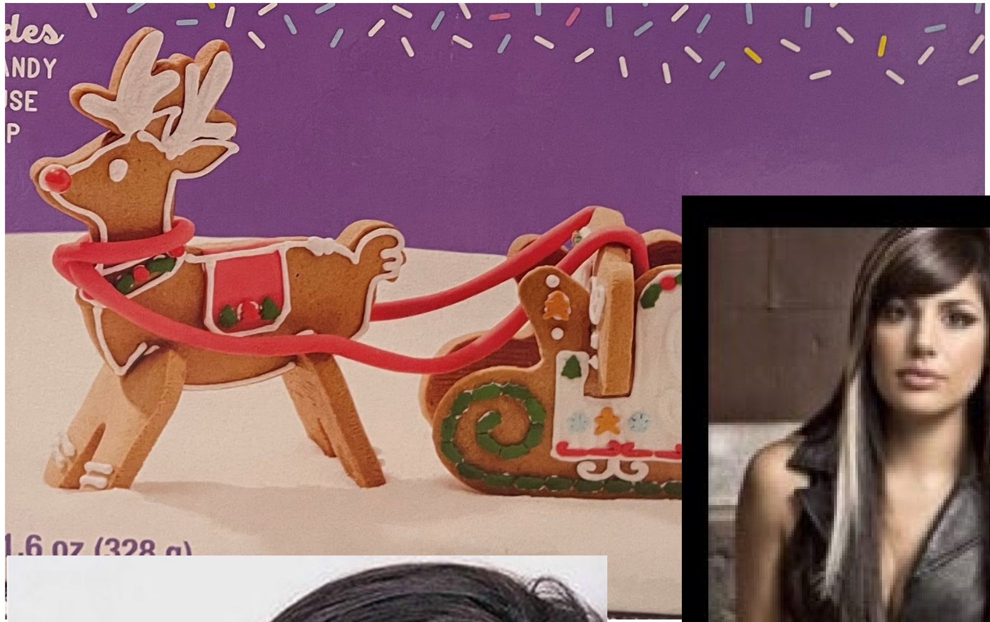
- Ultra High-Performance Concrete
- Concrete with Nano Materials
- 3D Printing Concrete

Do you remember when cement had to react with water for concrete to harden??

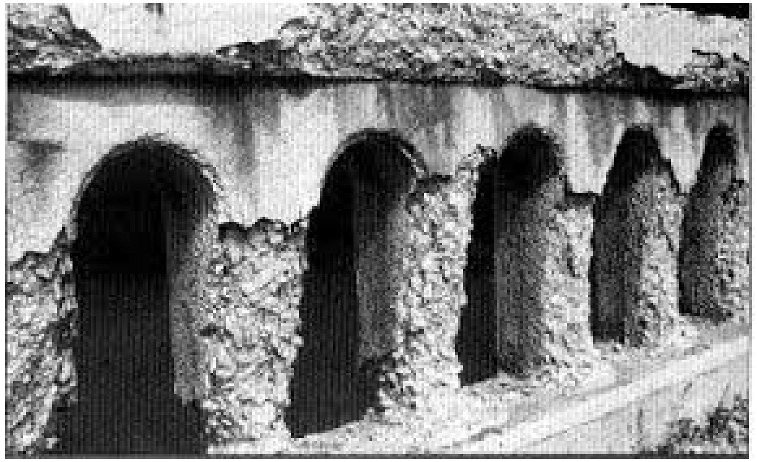
- Lunar Concrete
- Non-Hydraulic Cement Concrete

So What?

Expectation vs Reality



Reality



What causes this Mismatch between Expected Performance and In-Service Performance?

This Puzzle is Getting More and More Complicated

Quality Control:
Needs to include testing that guarantee that the mix designed in the lab is similar to the mix delivered, in terms of the desired performance

Specification:
- Quantification of expectations
- Roadmap to achieve expectations
- Measurable properties that correlate with field performance
- Set of criteria

Mix Design is NOT Mix Proportioning:
- Properties need to match intended performance for intended use
- Mix needs to be robust

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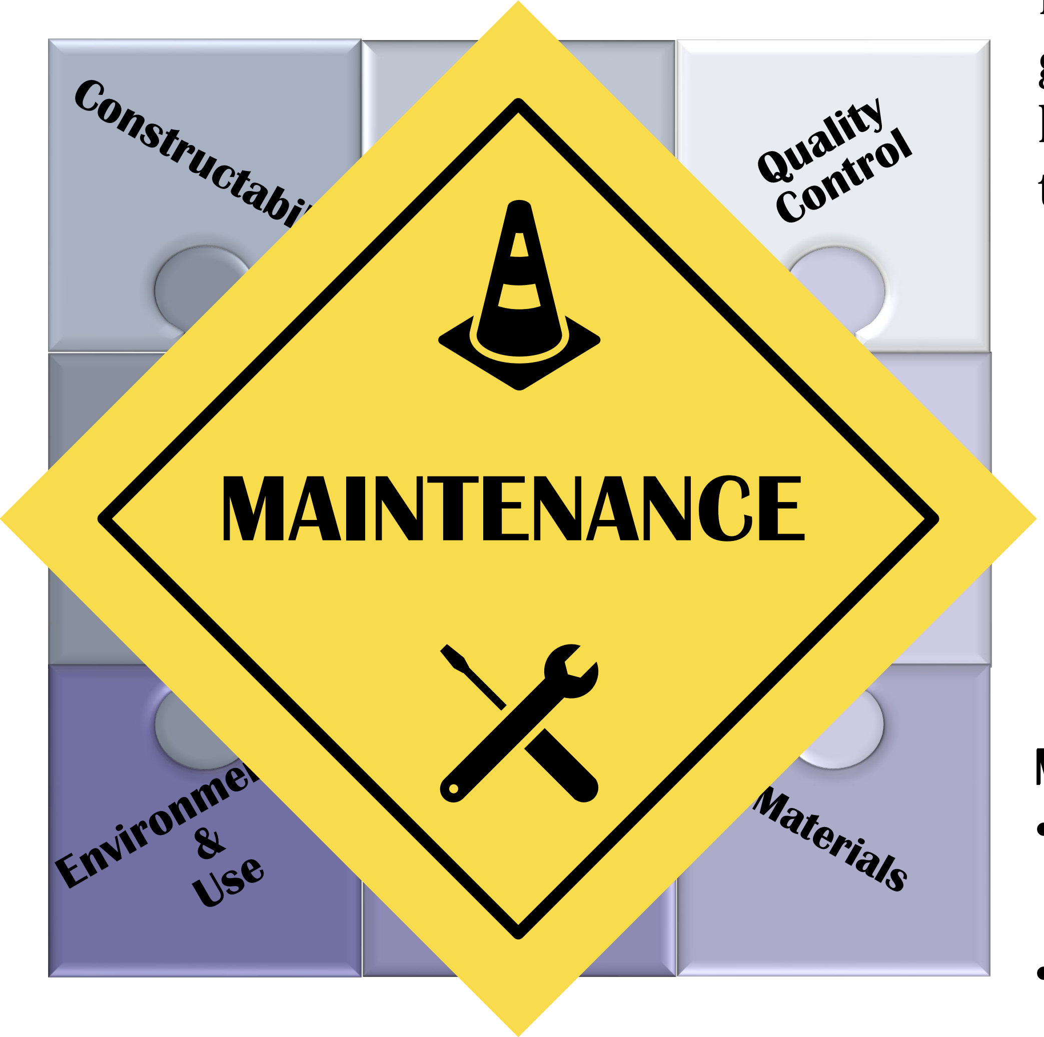

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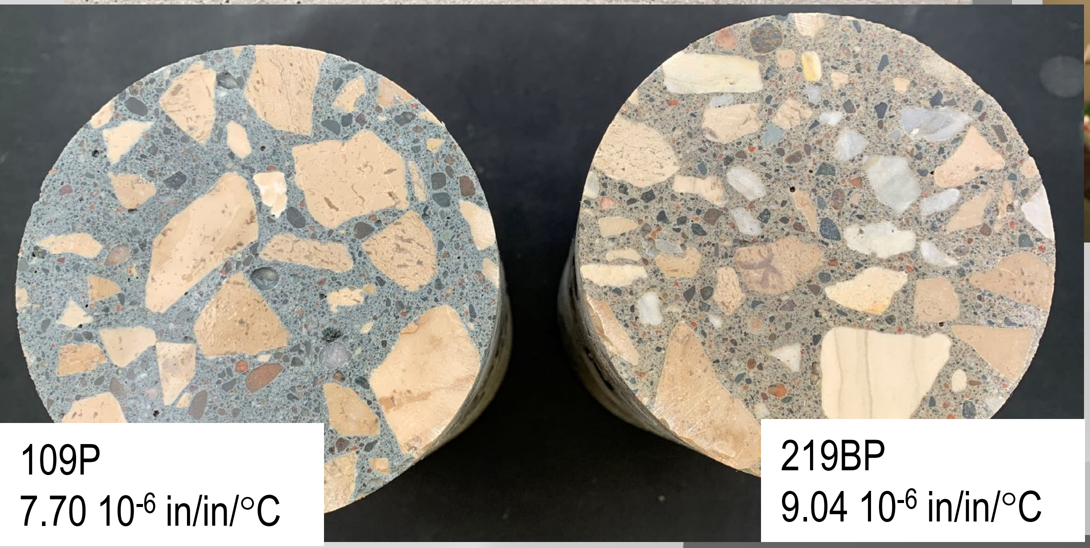
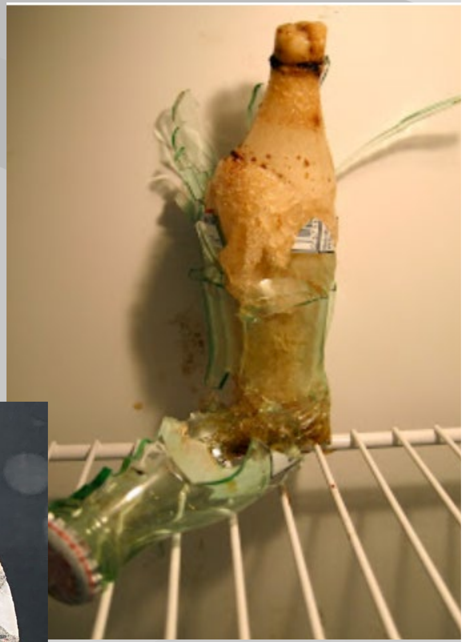
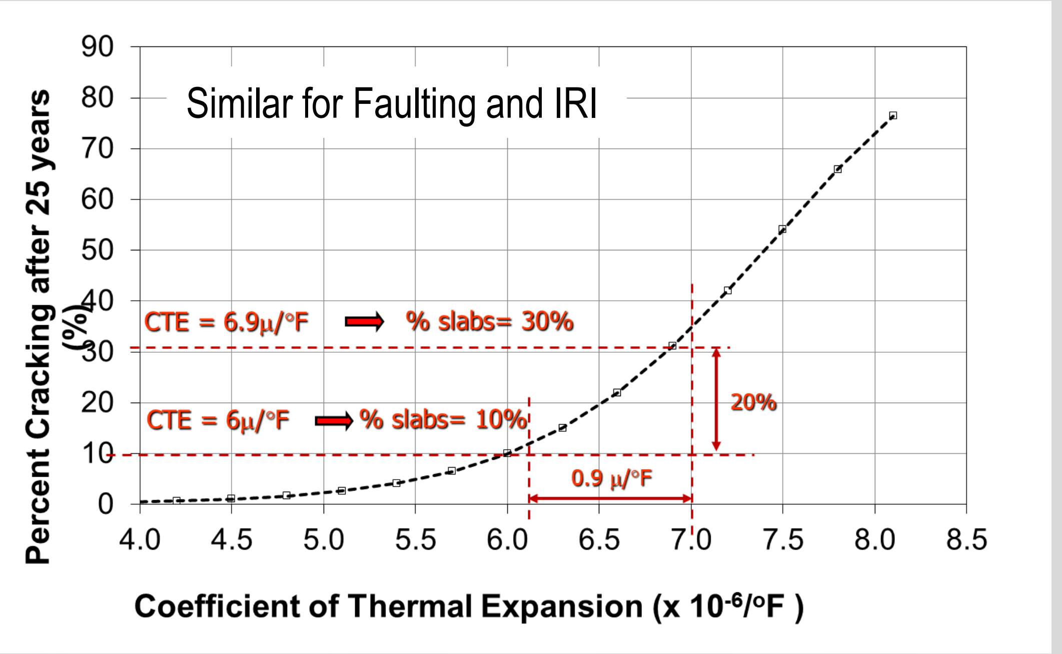
Design:

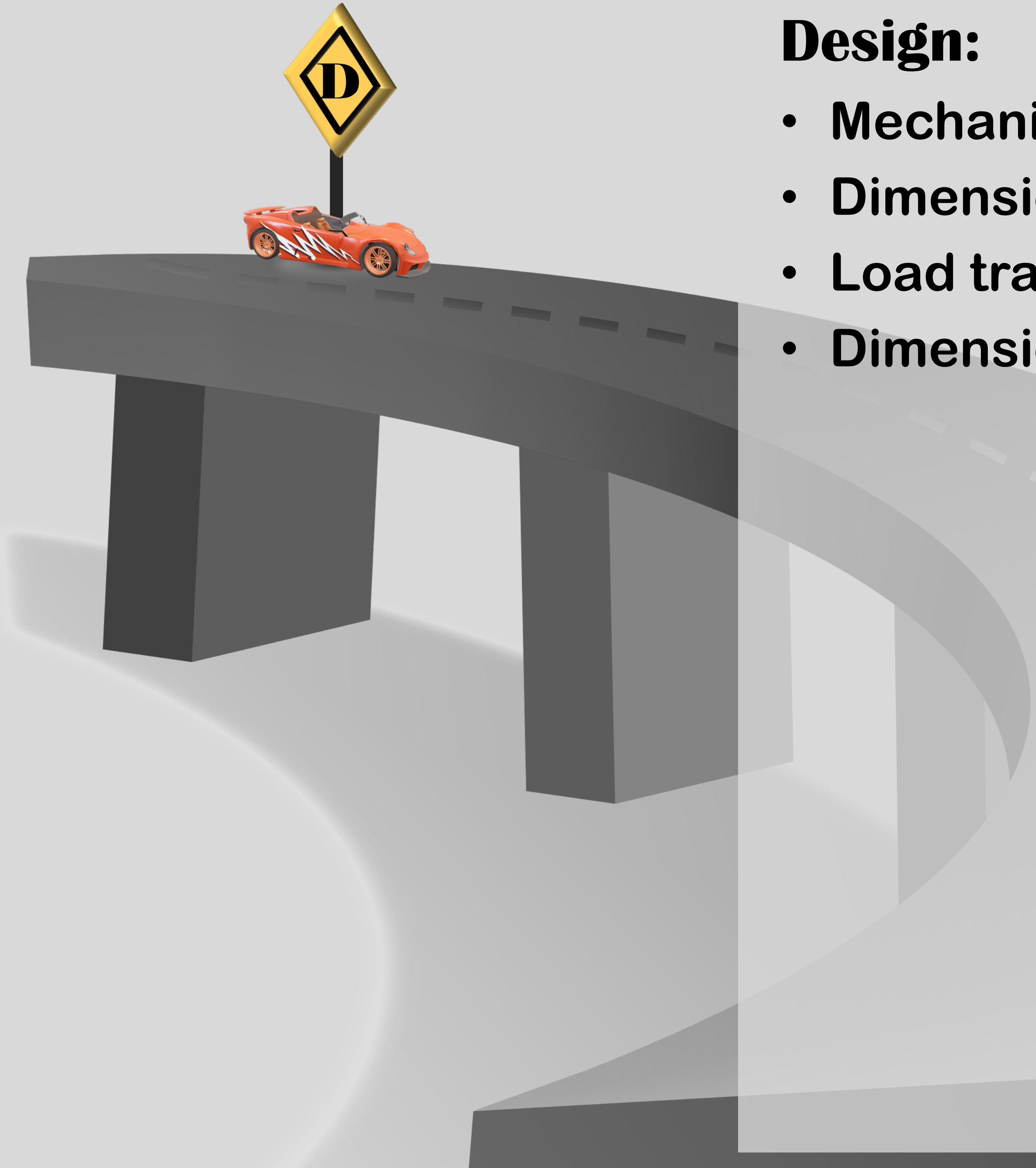
- Mechanical properties → Strength, Creep
- Dimensional stability → Emod, CTE, Shrinkage
- Load transfer
- Dimensions







Source: Tanesi, J, *et al.* Effect of CTE test variability on concrete pavement performance as predicted using the mechanistic-empirical pavement design guide. In: TRR No. 2020, 2007.



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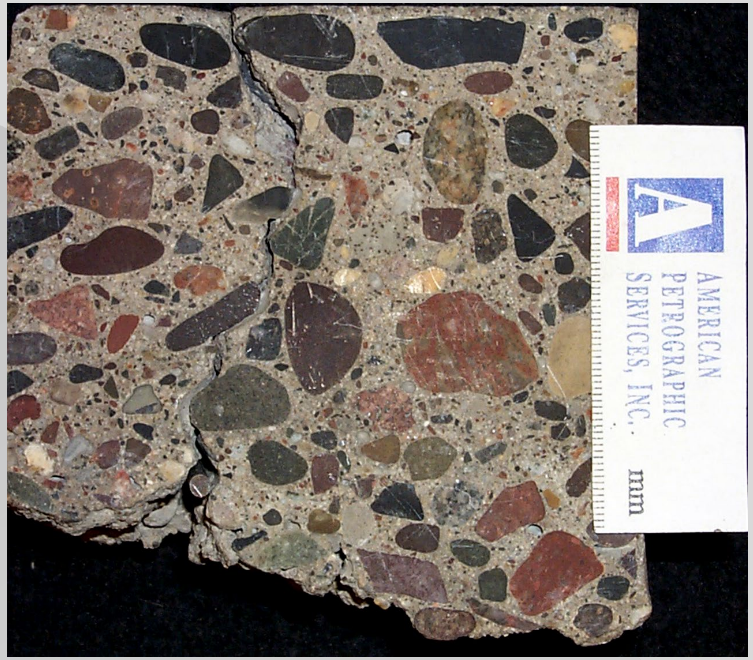
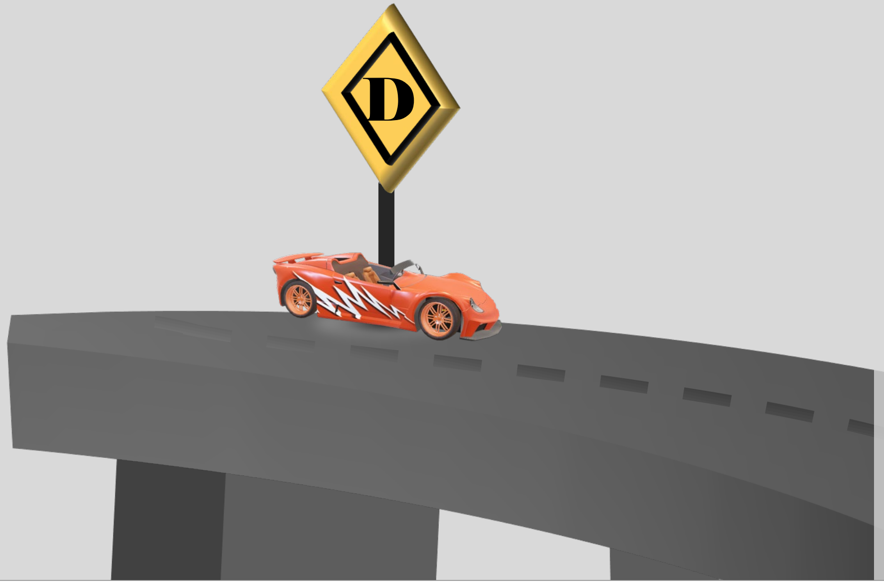
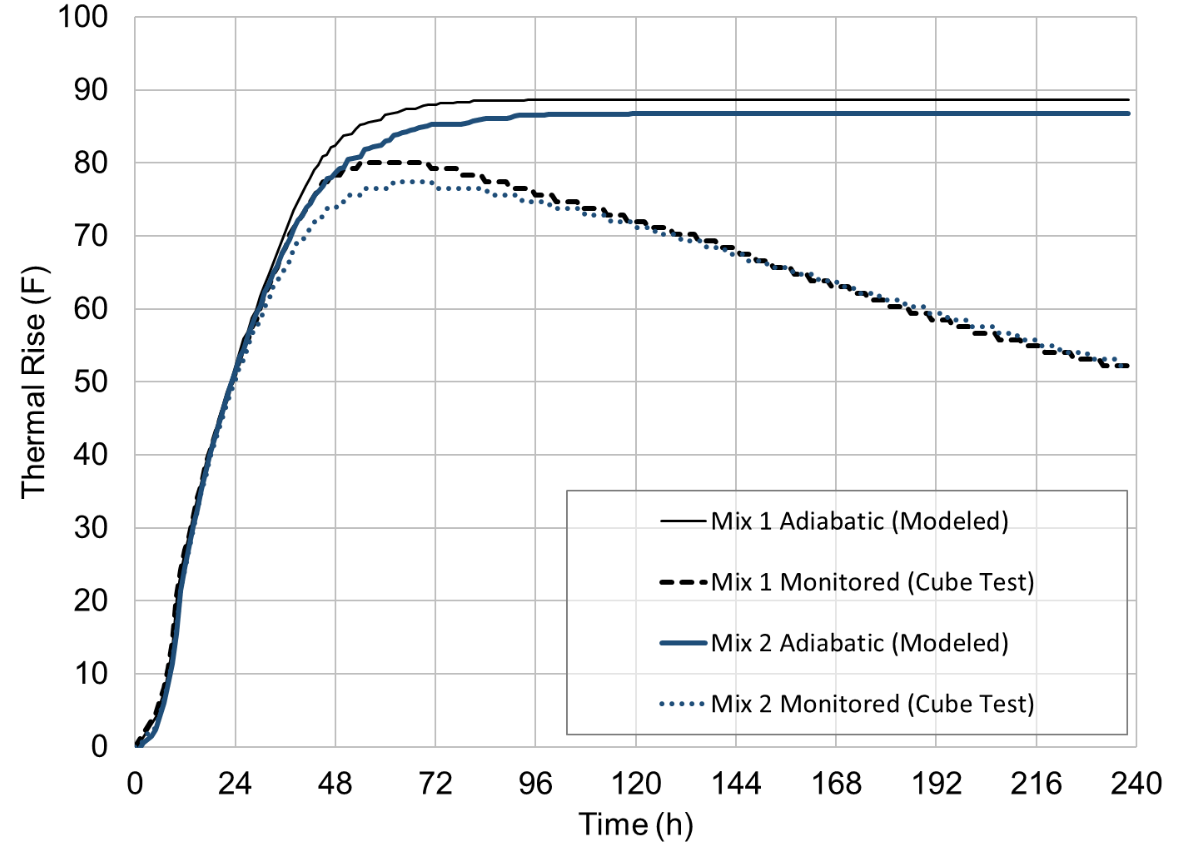




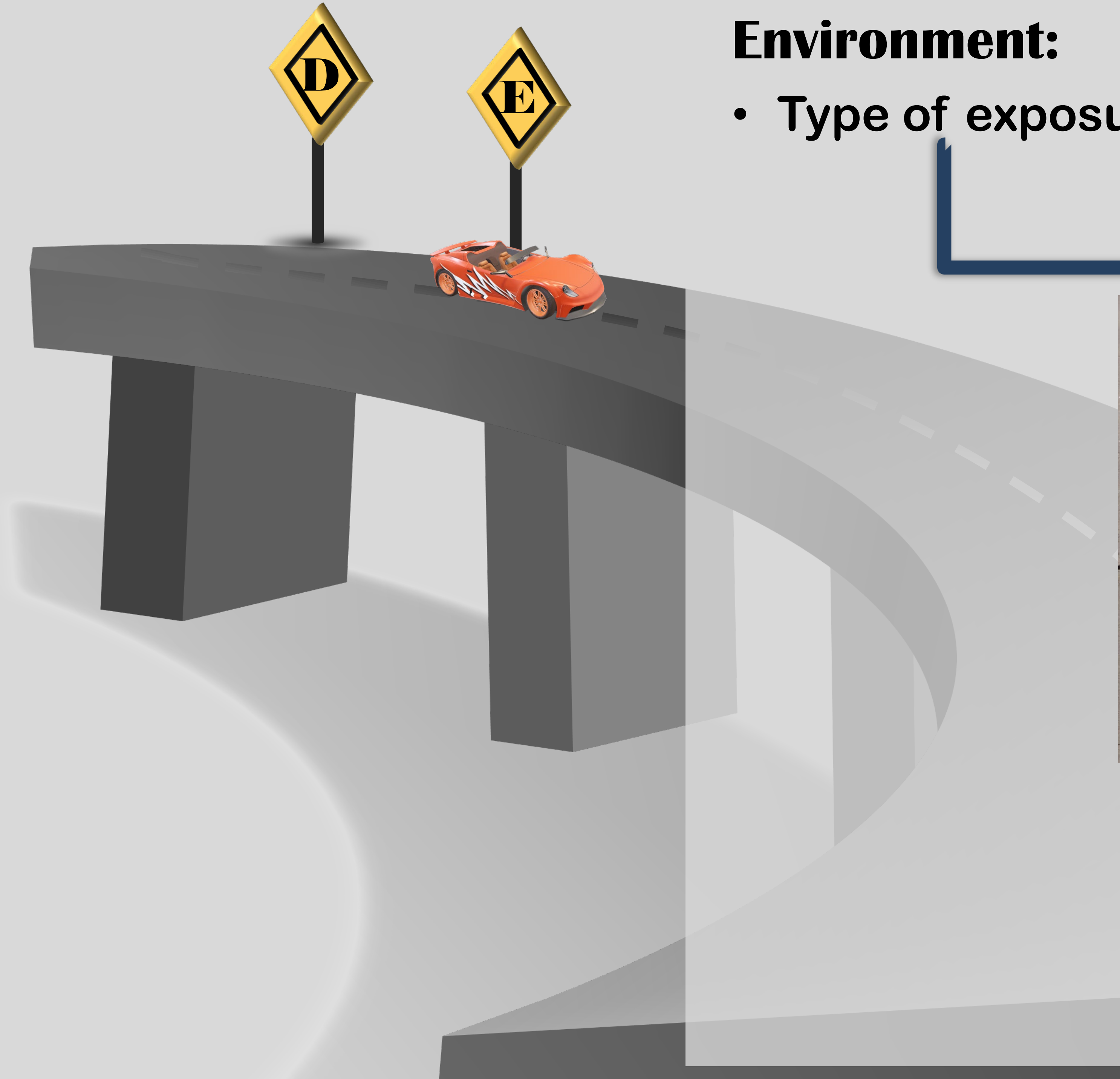
Design:

- Mechanical properties
- Dimensional stability
- Load transfer
- Dimensions → Heat



	Mix 2	Final Mix
Type IS(38) Cement (lb/yd^3)	553	460
Class C Fly Ash (lb/yd^3)	75	81
Coarse Aggregate (lb/yd^3)	1,598	1,708
Fine Aggregate (lb/yd^3)	1,341	1,410
(lb/yd^3)	234	215
w/cm	0.37	0.40

* Water reducer and air entraining admixtures were used.

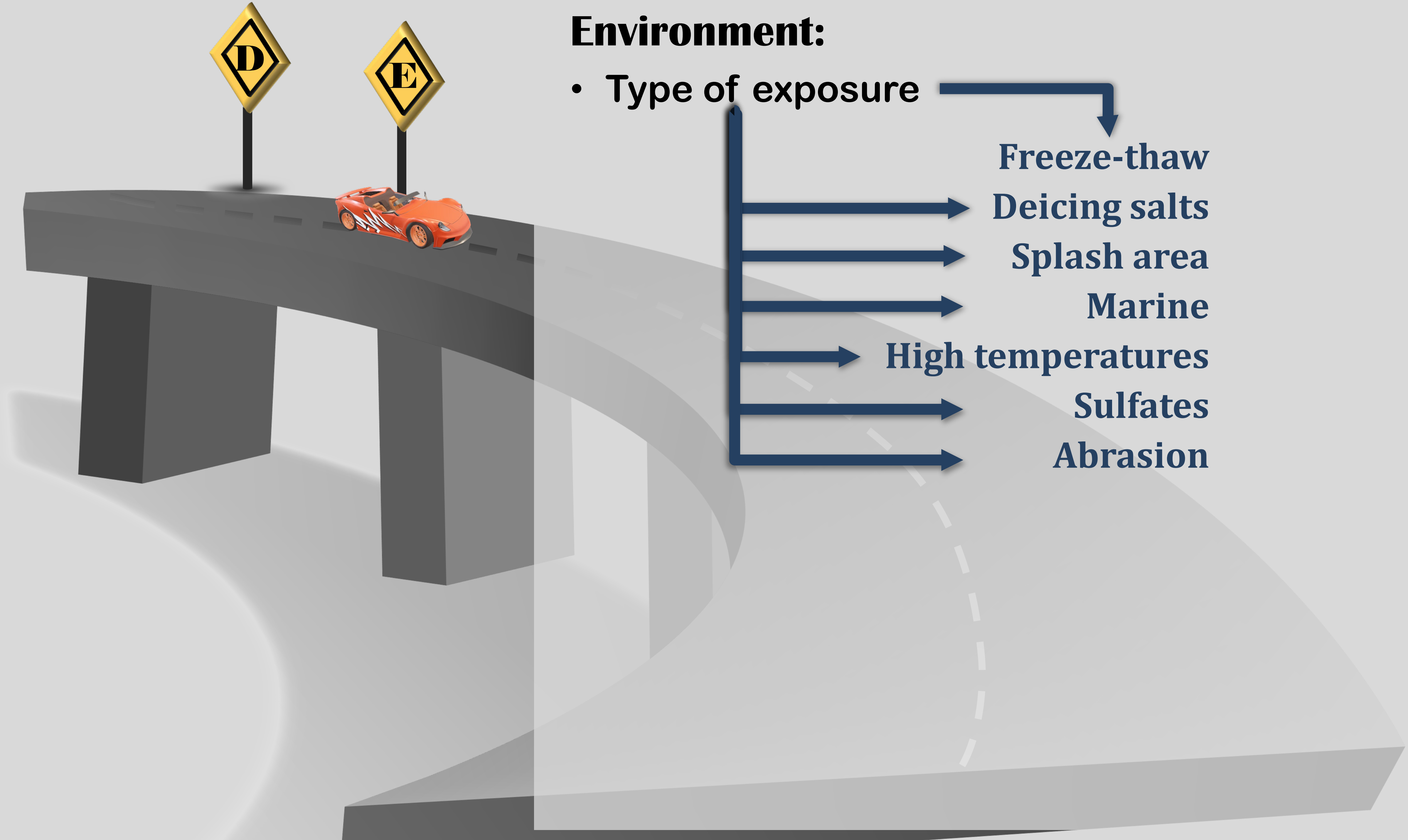


Environment:

- Type of exposure

Freeze-thaw

Deicing salts



Environment:

- Type of exposure
  - Freeze-thaw
  - Deicing salts
  - Splash area
  - Marine
  - High temperatures
  - Sulfates
  - Abrasion

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  - Freeze-thaw
  - Deicing salts
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- Conditions during construction
  - Shrinkage
  - Hot weather concreting
  - Cold weather concreting
  - Unexpected interaction between cementitious materials and admixtures

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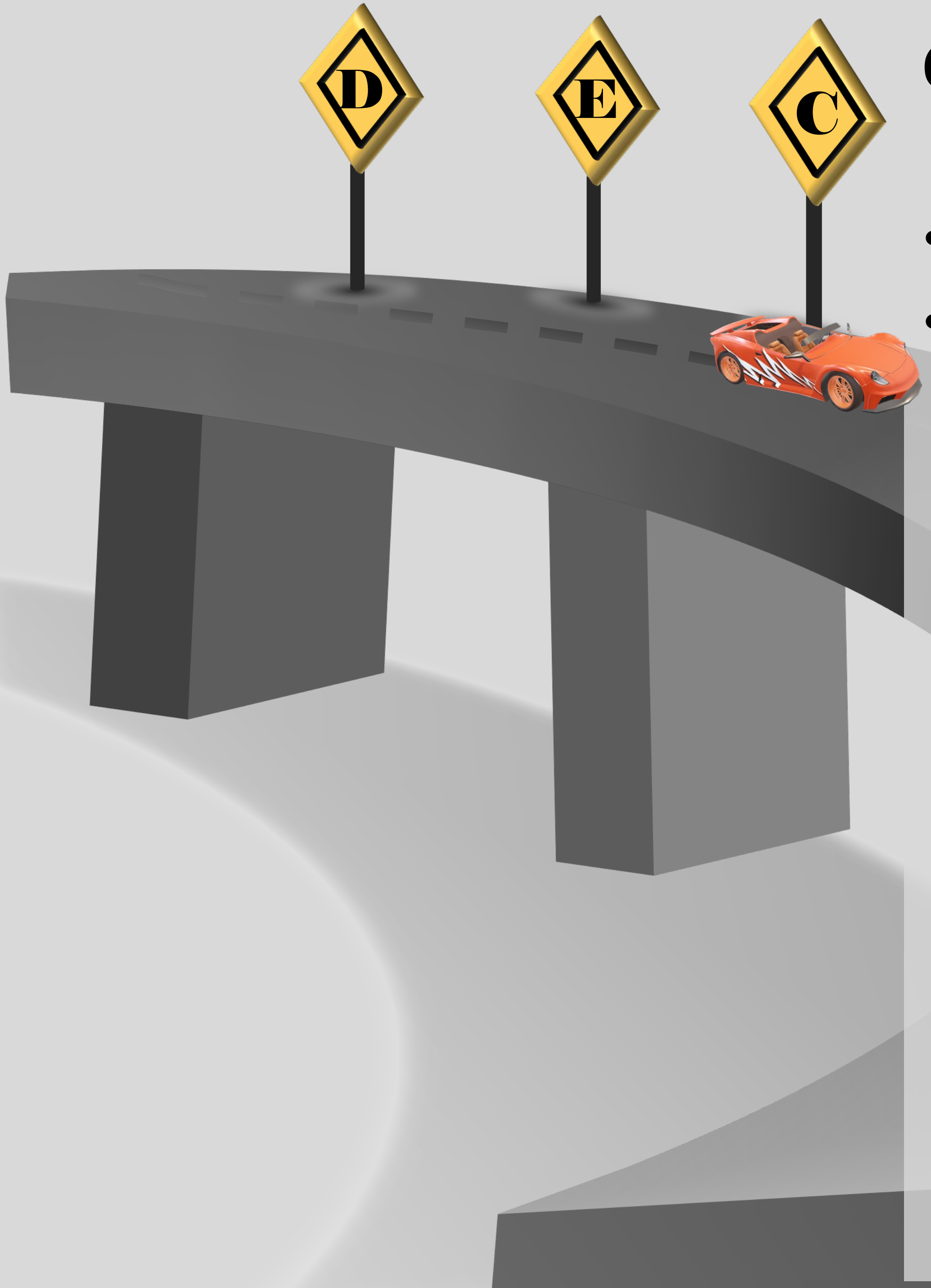
Use:

- Pavement or parking lot
- Indoor industrial floor
- Bridge deck
- Bridge superstructure
- Building structure

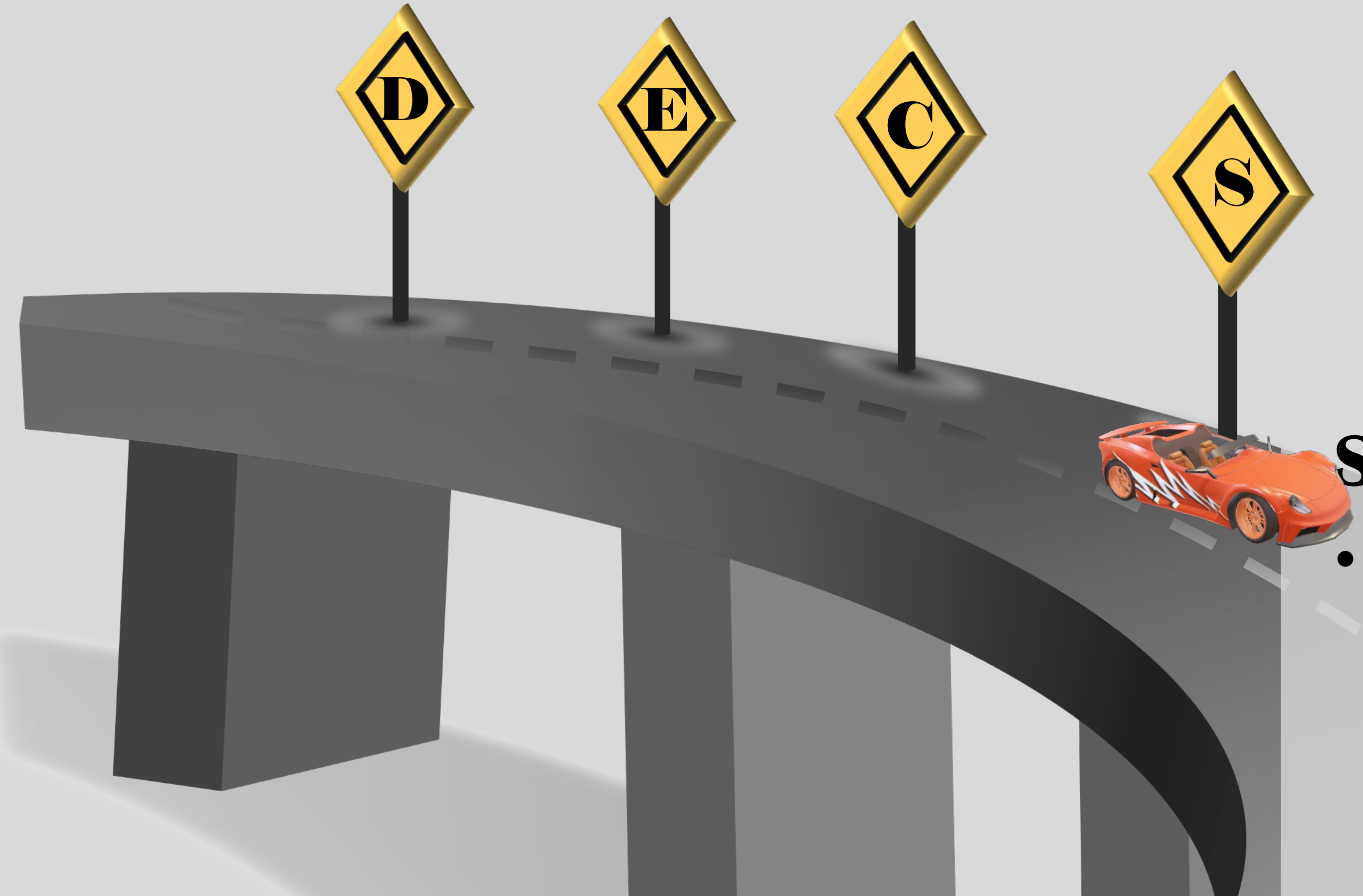


Constructability:

- Workability
- Segregation
  - What type of construction
  - How is being placed
  - Paste content
  - Aggregate combined grading
  - Admixtures
- Finishiability
  - Paste content
  - Aggregate combined grading
  - Admixtures
  - Particle size distribution of cementitious
  - Bleeding

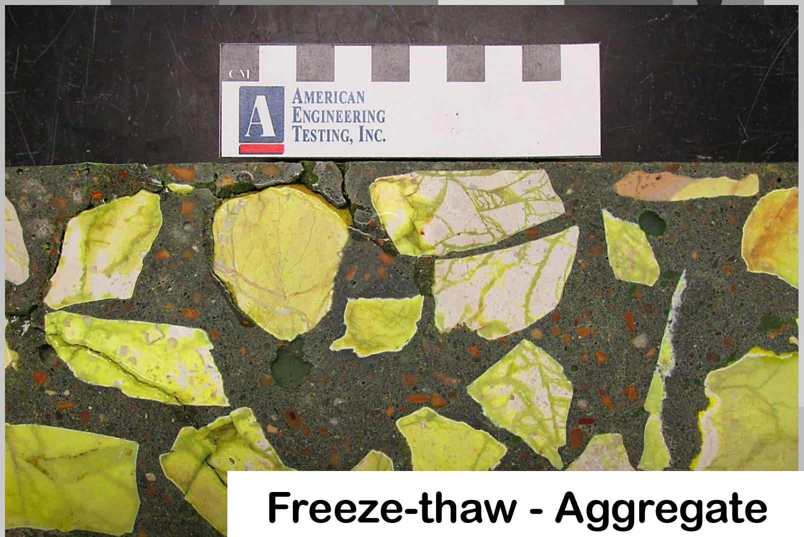
Constructability:

- Workability
- Segregation
- Finishiability
- Setting and Strength development rate
  - Cementitious Materials
  - Admixtures

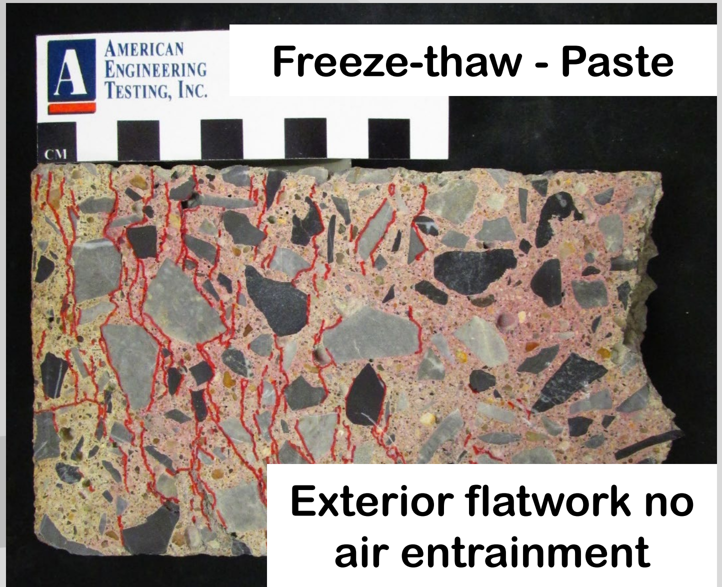


Specification:

- Appropriate for Exposure
  - Relation with durability
  - Involves mostly ingress of:
    Water
    - Freeze-Thaw



Freeze-thaw - Aggregate



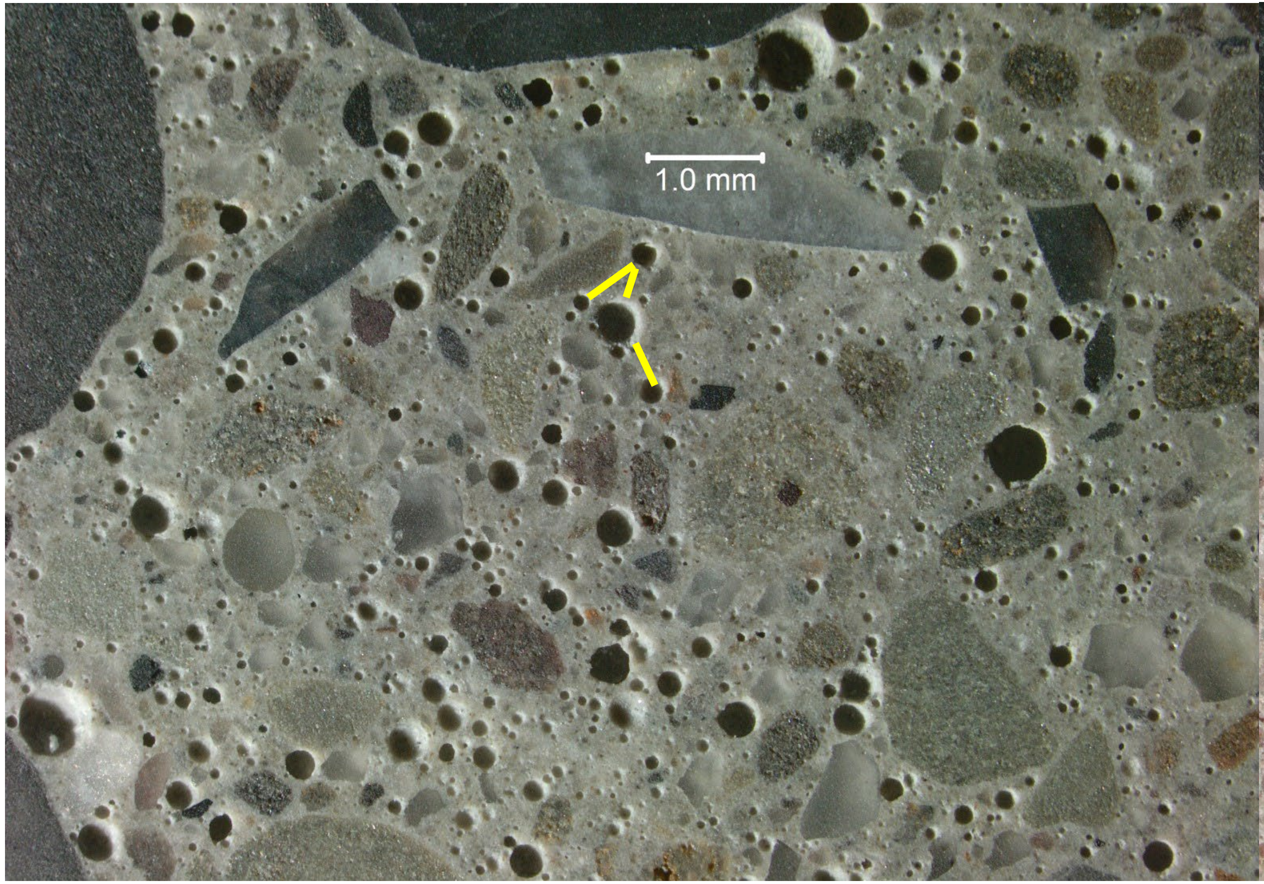
Freeze-thaw - Paste

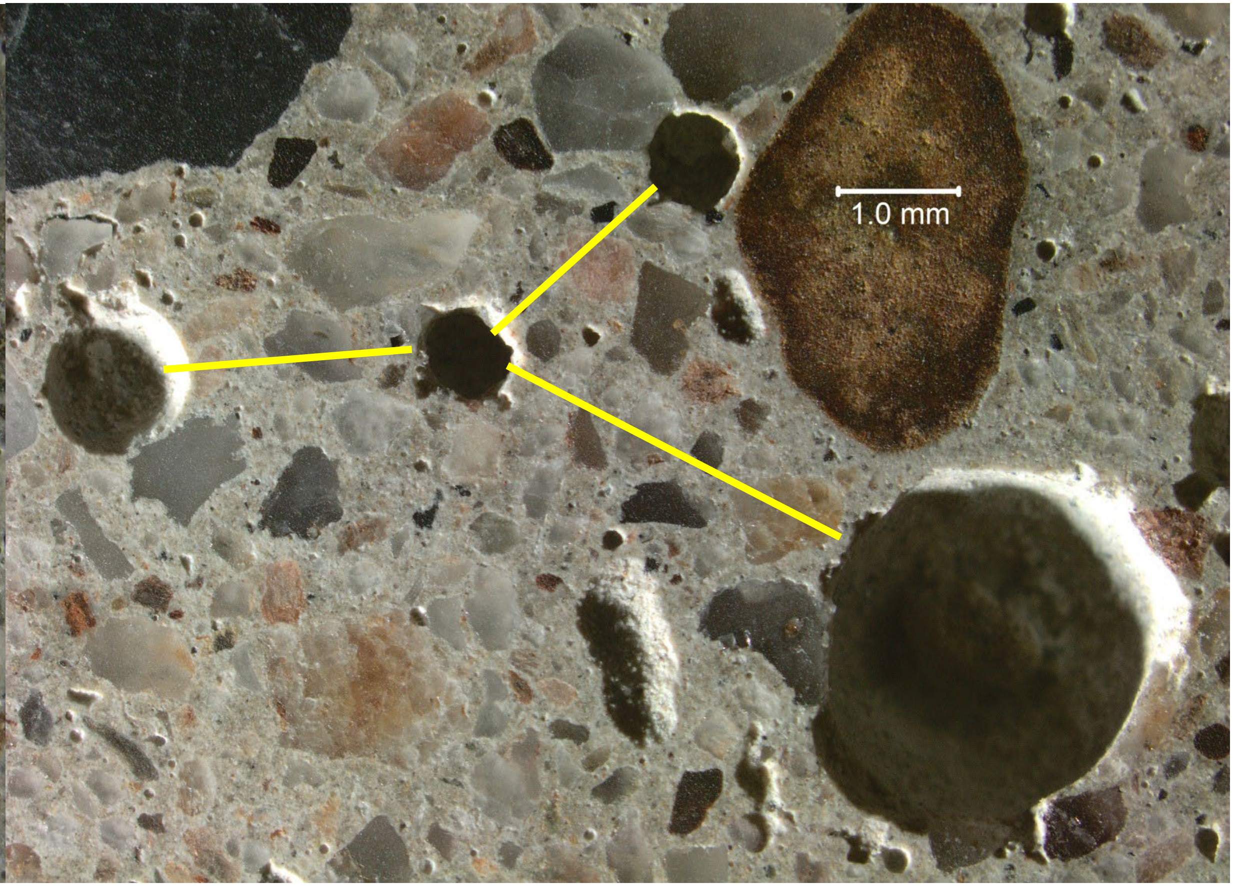
Exterior flatwork no air entrainment

Freeze-Thaw

Depends on the:

- **Air void system**





Specification:

- Appropriate for Exposure
  - **Relation with durability**
  - **Involves mostly ingress of:**

Water
- Freeze-Thaw
- ASR

Ions
- Chlorides:
  - Sea water
  - Deicing salts
- Acid
- Sulfates
- Carbonation

Freeze-Thaw

Depends on the:

- Air void system
- The microstructure of the paste (transport properties)
- Aggregate susceptibility

ACI 201.2R

Select Exposure Class

- Strength
- Max w/cm
- Air
- Cementitious

F0: not exposed to F/T

F1: Moderate: Exposed but low probability of saturation

F2: Severe: F/T but no deicing exposure

F3: Very severe: F/T and deicing

AASHTO R101

Requirements

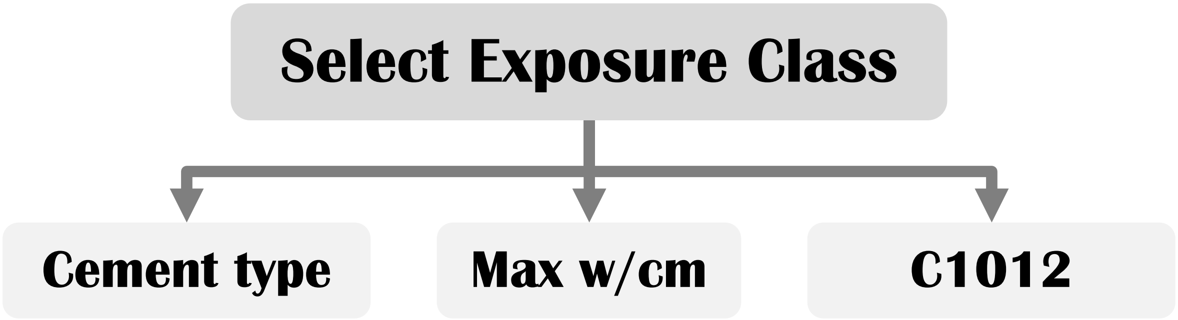
- Max w/cm
- Air Content
- SAM
- Time for critical saturation
- Calcium Oxychloride

Sulfate Attack

Depends on the:

- The microstructure of the paste (transport properties)
- Chemistry of the paste
- Curing temperature

ACI 201.2R



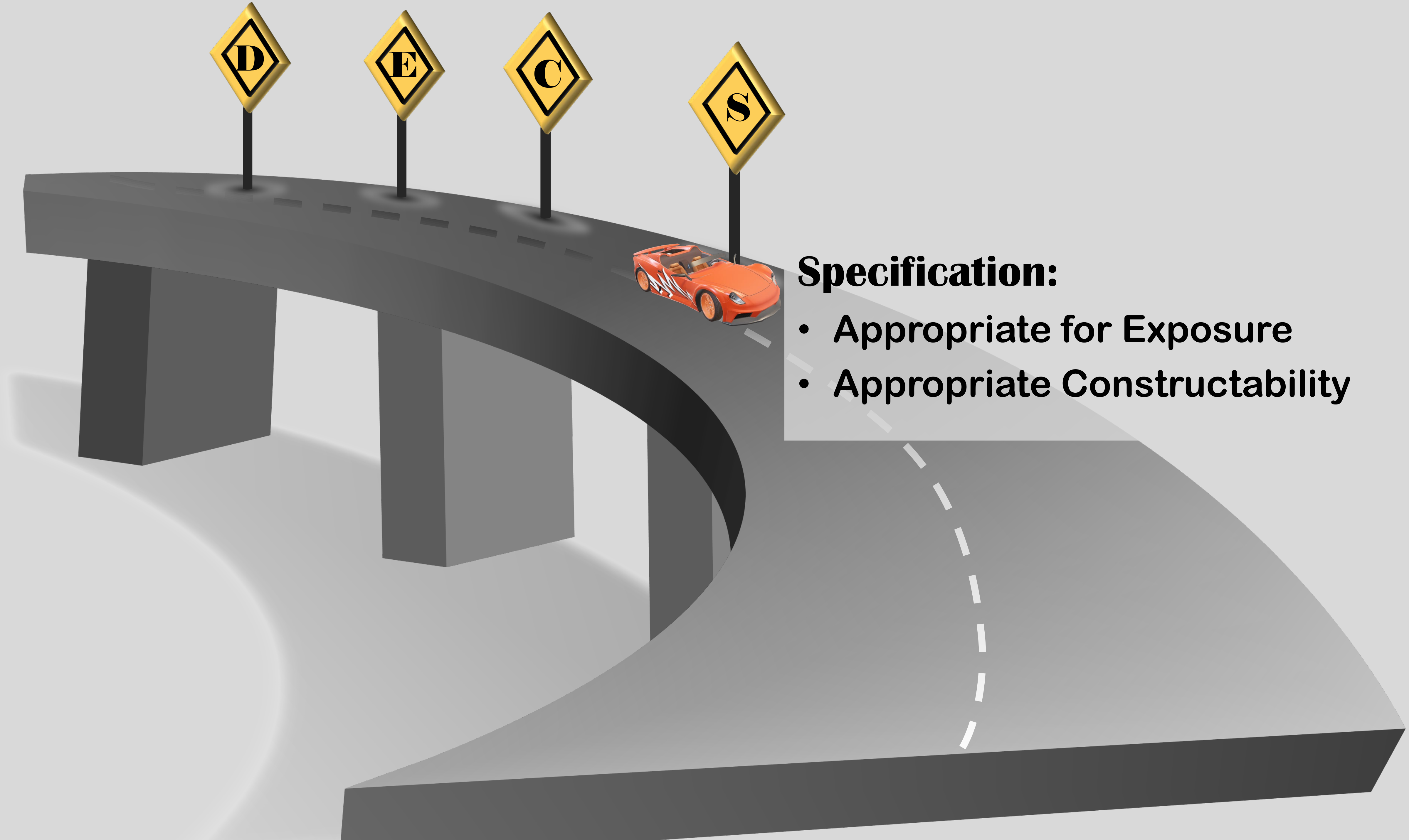
Based on SO_4^{2-} in soil or water

S0: negligible

S1: Moderate

S2: Severe (seawater)

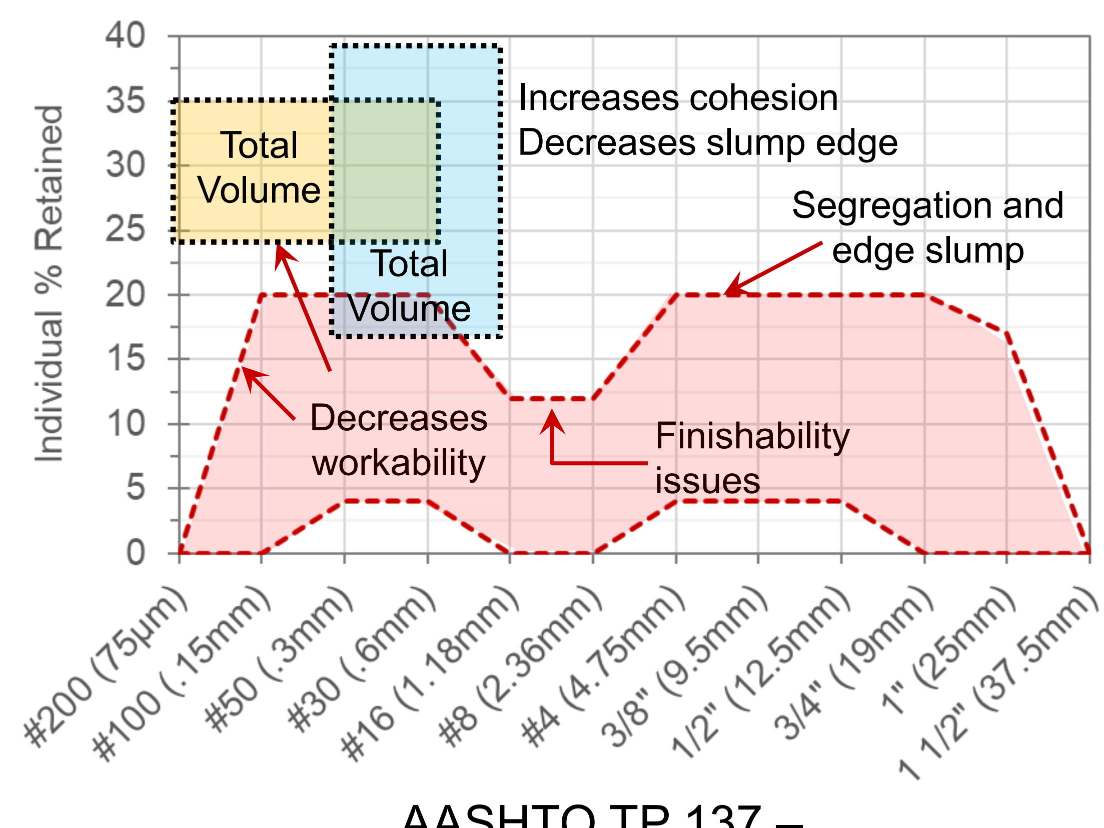
S3: Very severe



Specification:

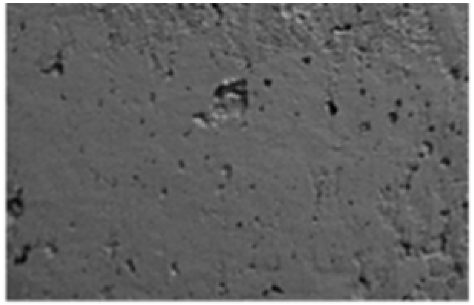
- Appropriate for Exposure
- Appropriate Constructability

Workability: Slump is not Always Applicable

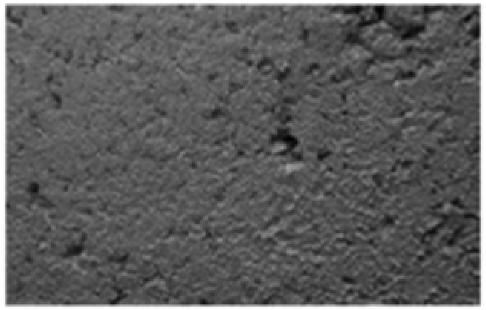


AASHTO TP 137 – Box Test Procedure

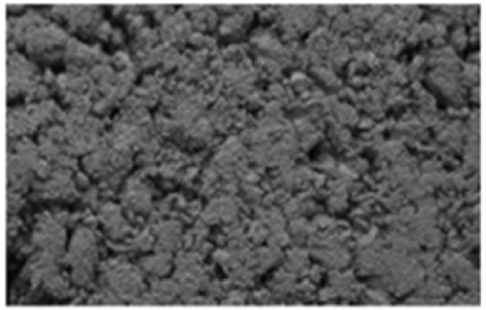
Box Test Rating



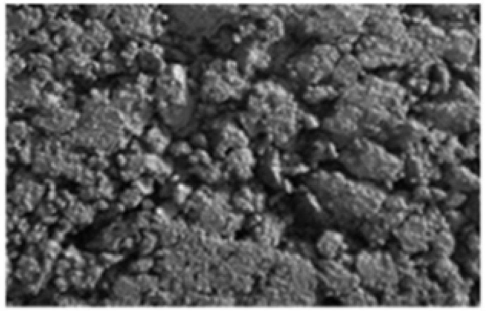
1
Less than 10% overall surface voids



2
10-30% overall surface voids



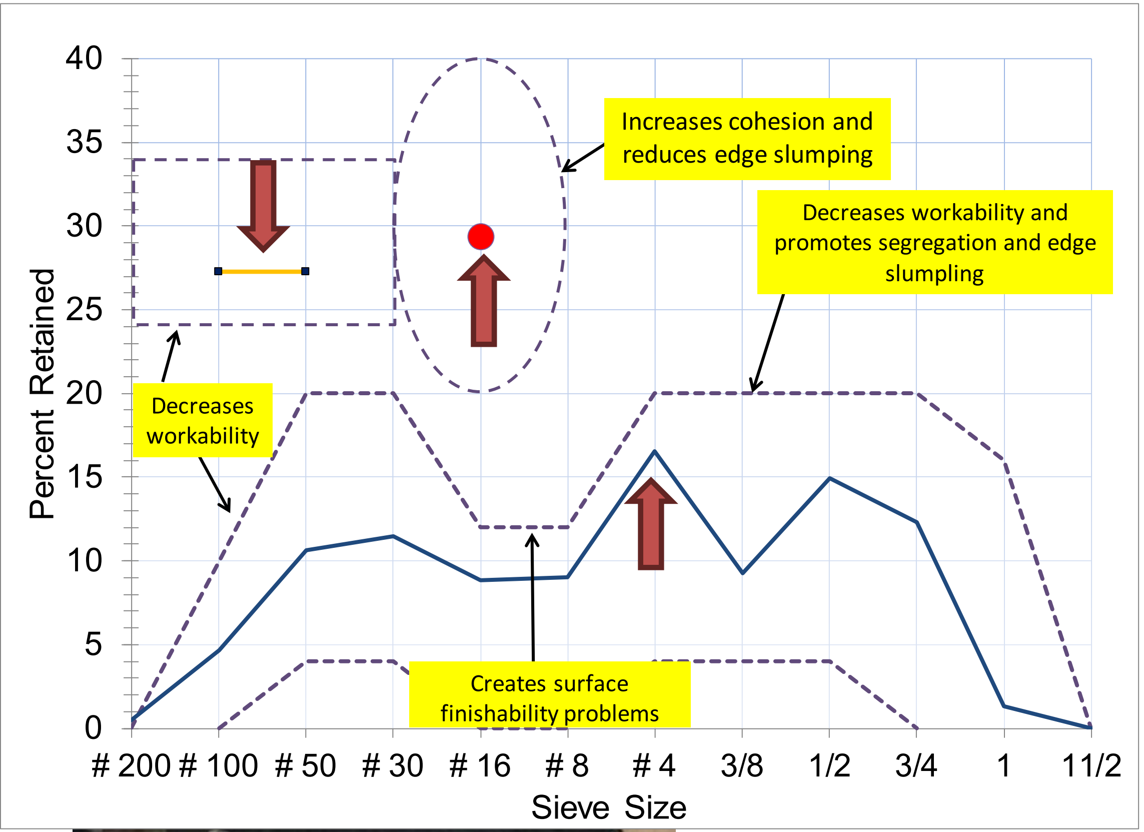
3
30-40% overall surface voids

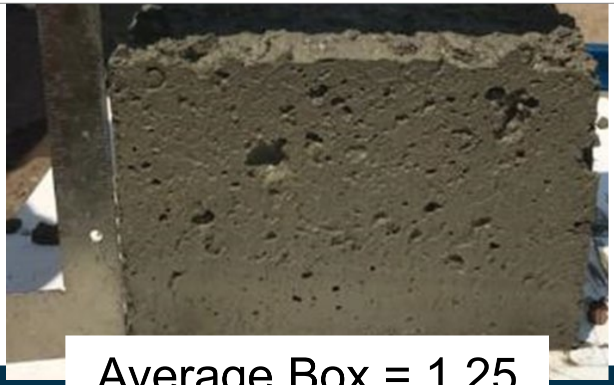


4
Over 50% overall surface voids

Source: CDOT

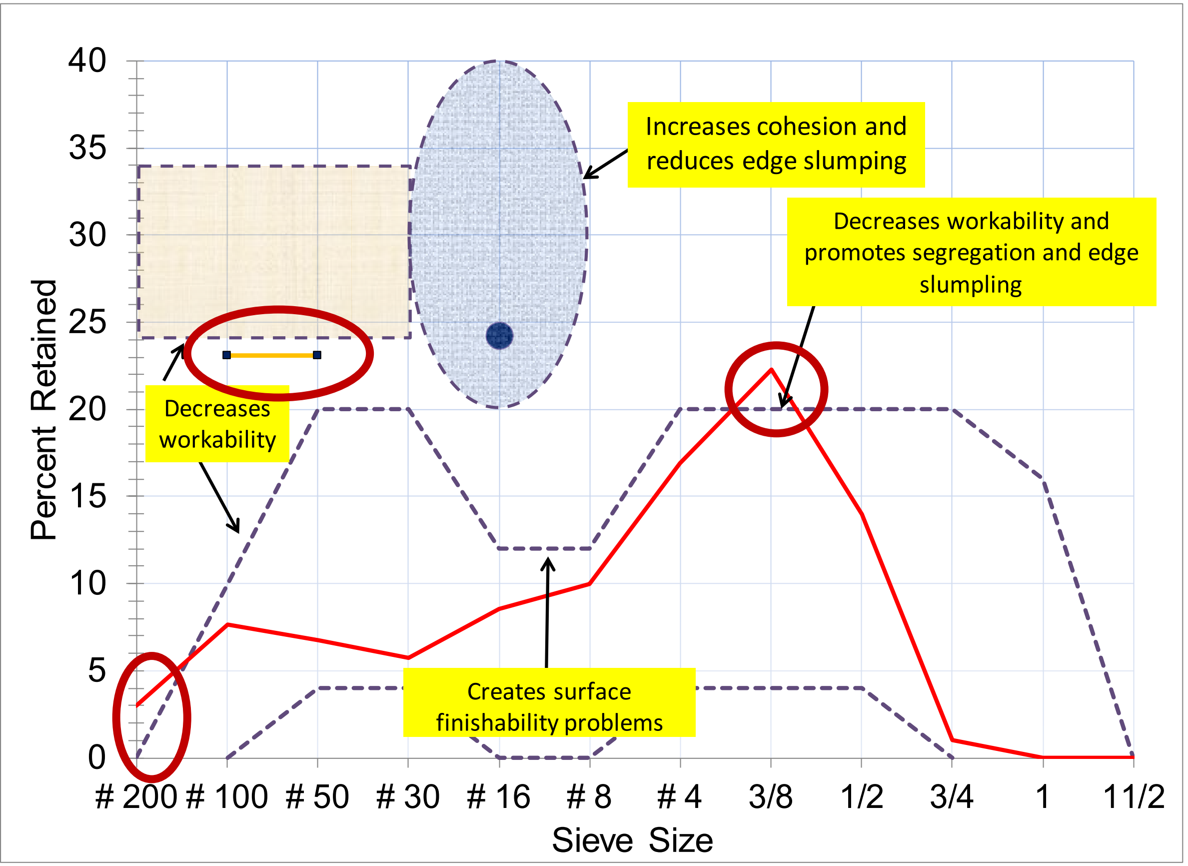
Workability: Slump is not Always Applicable





Average Box = 1.25

Workability



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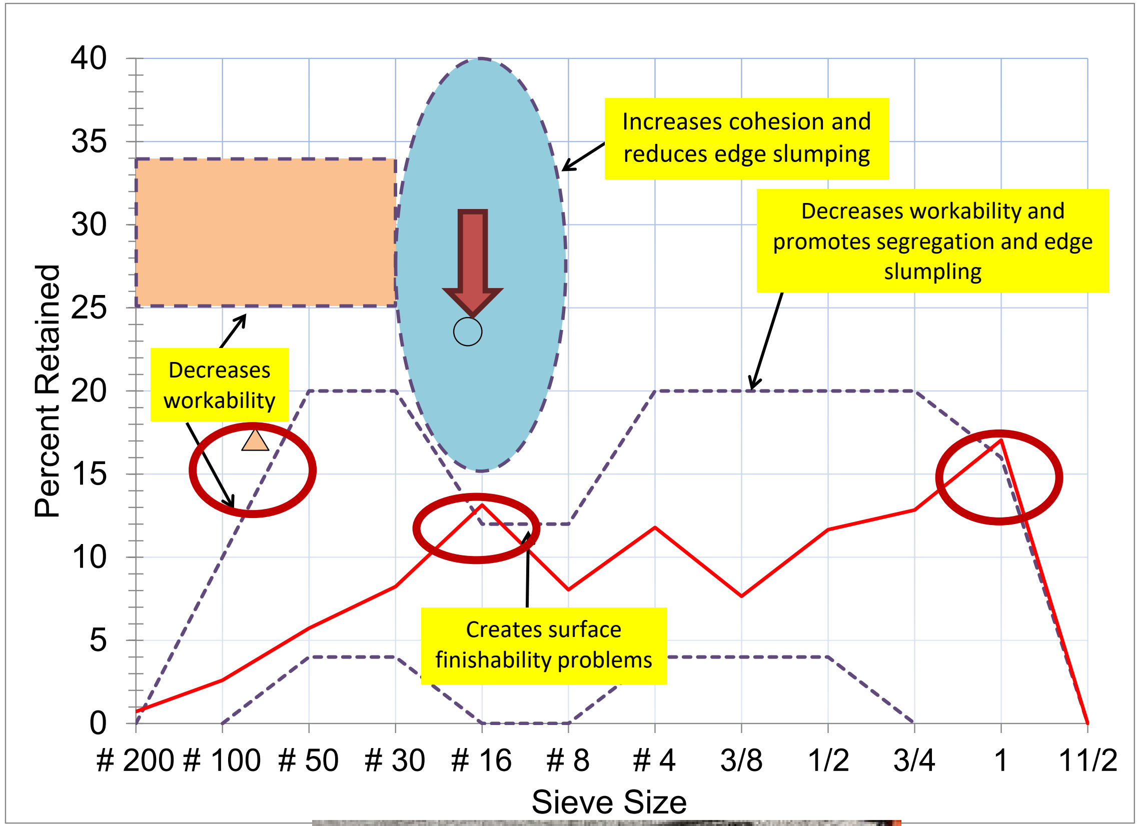
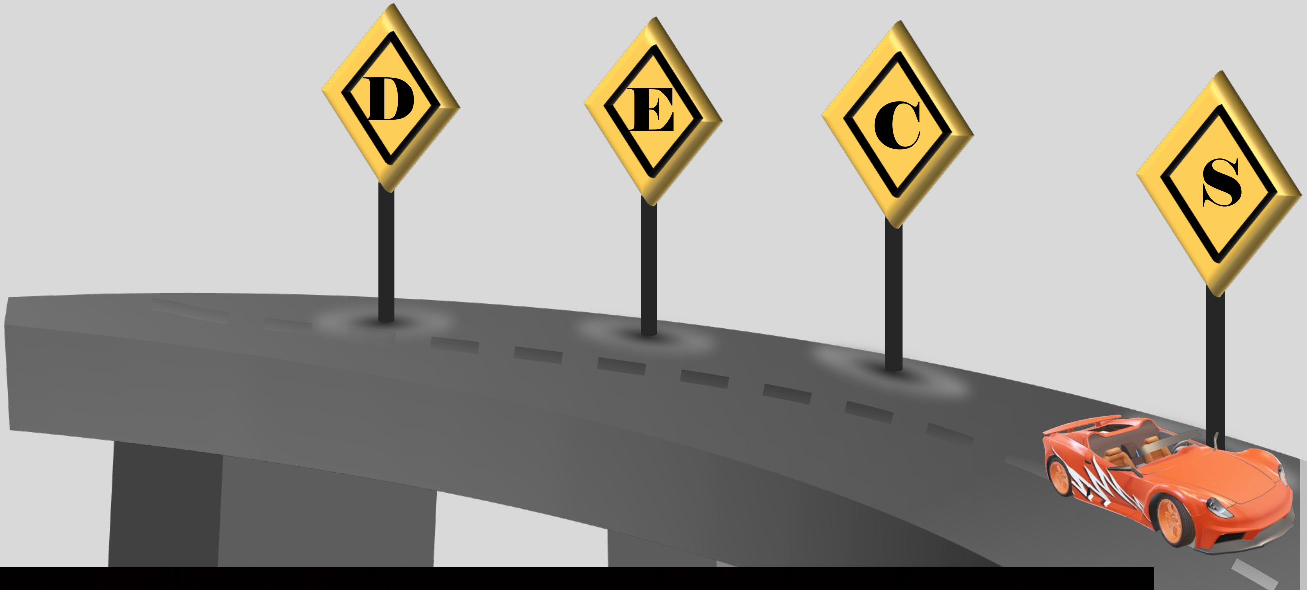
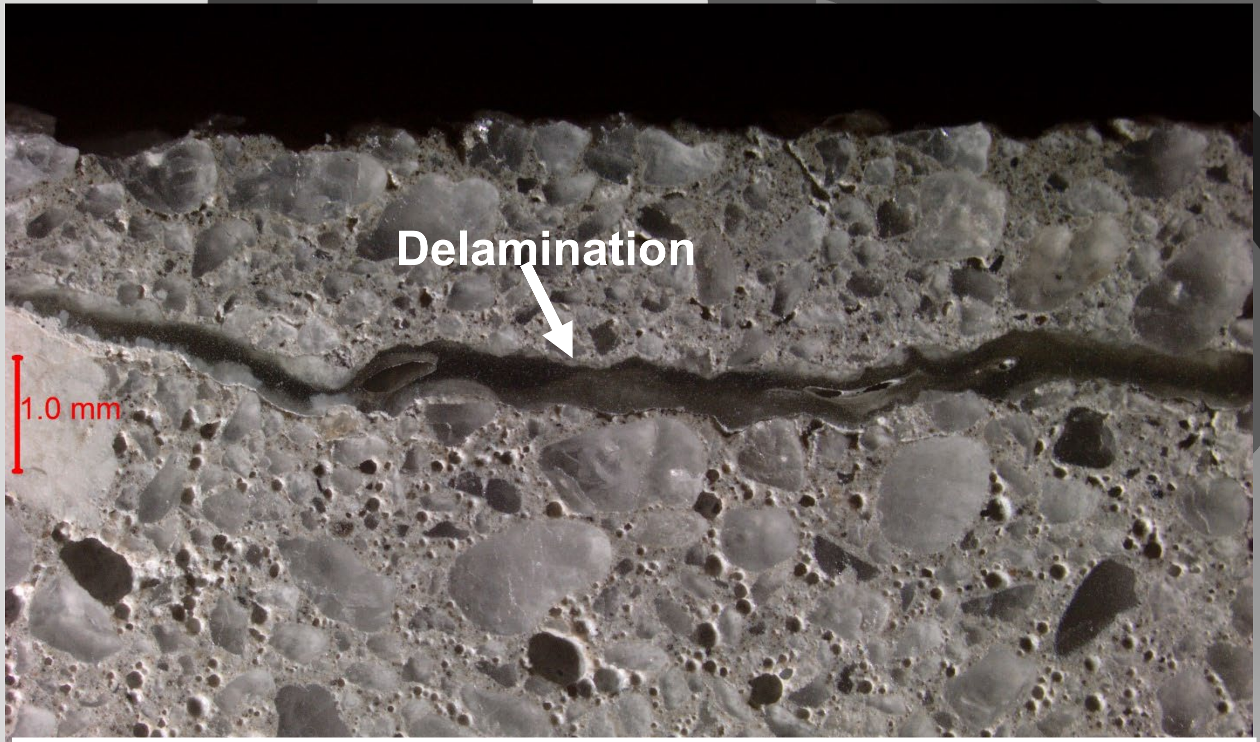




Specification:

- Appropriate for Exposure
- Appropriate Constructability
- Account for Application



Hard troweled interior slab air entrainment ≤ 3%

Air delayed bleed water rise

⇩

Early finishing

⇩

Bleed water entrapped beneath surface

Specification

Select Properties to be measured that are really representative of:

- Structural performance
- Constructability
- Durability
- Materials Related Distress
- Serviceability

Do we know what issues to look for?

How about new materials?

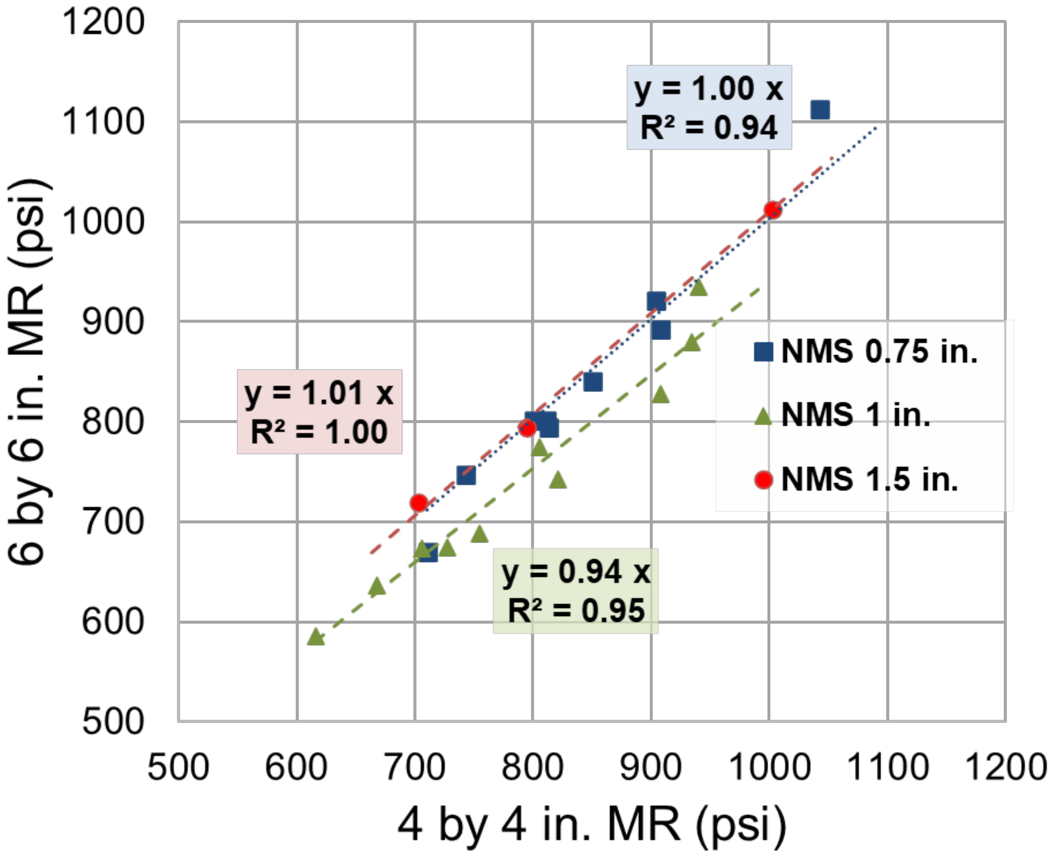
Specification

Select Property

Select Test for each Property

Tests used in the lab represent ideal conditions… Not field conditions

- Temperature is controlled
- Curing is controlled
- Do not represent size of structure



Don't Ask, Don't Tell

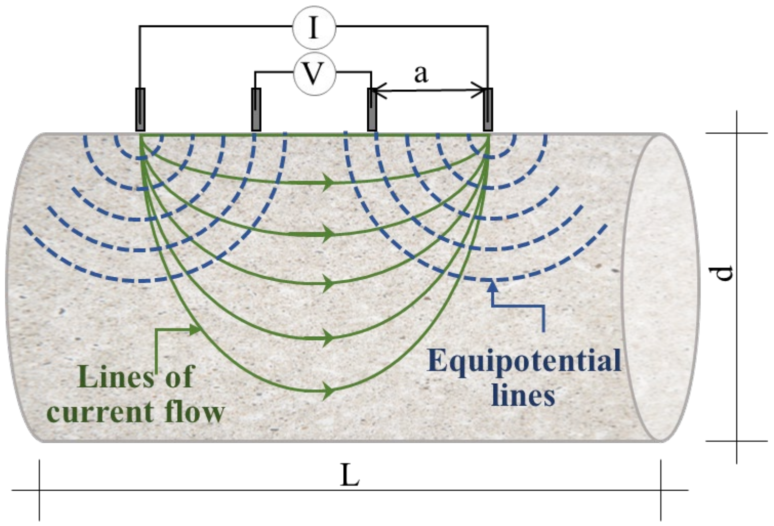
Specification

Select Property

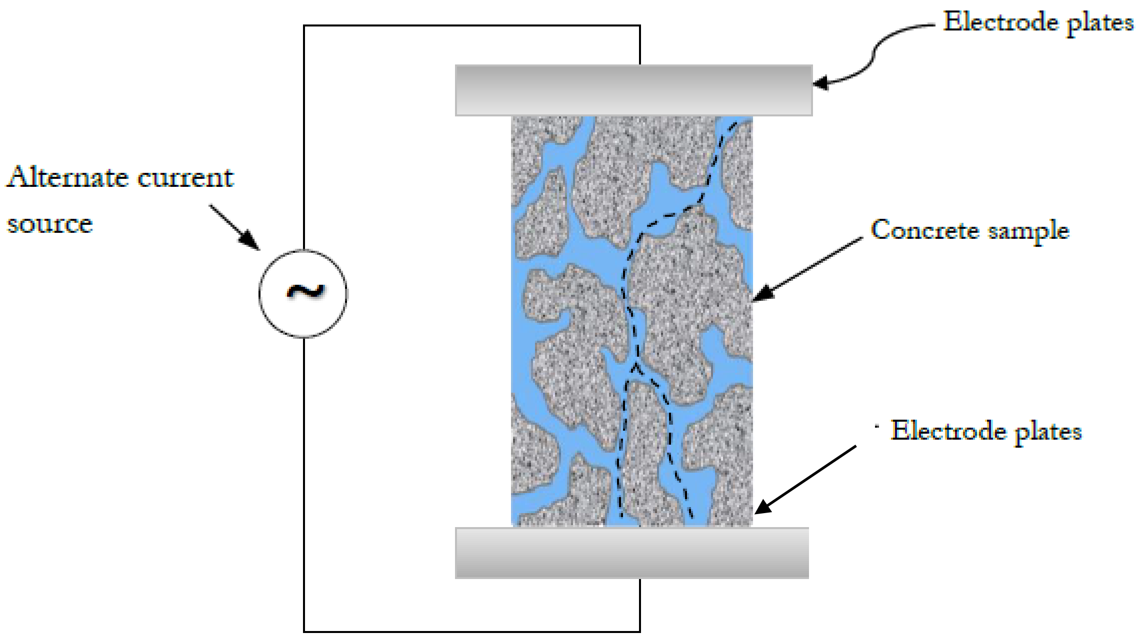
Select Test for each Property

- What are the tests measuring?

RESISTIVITY



AASHTO T 358

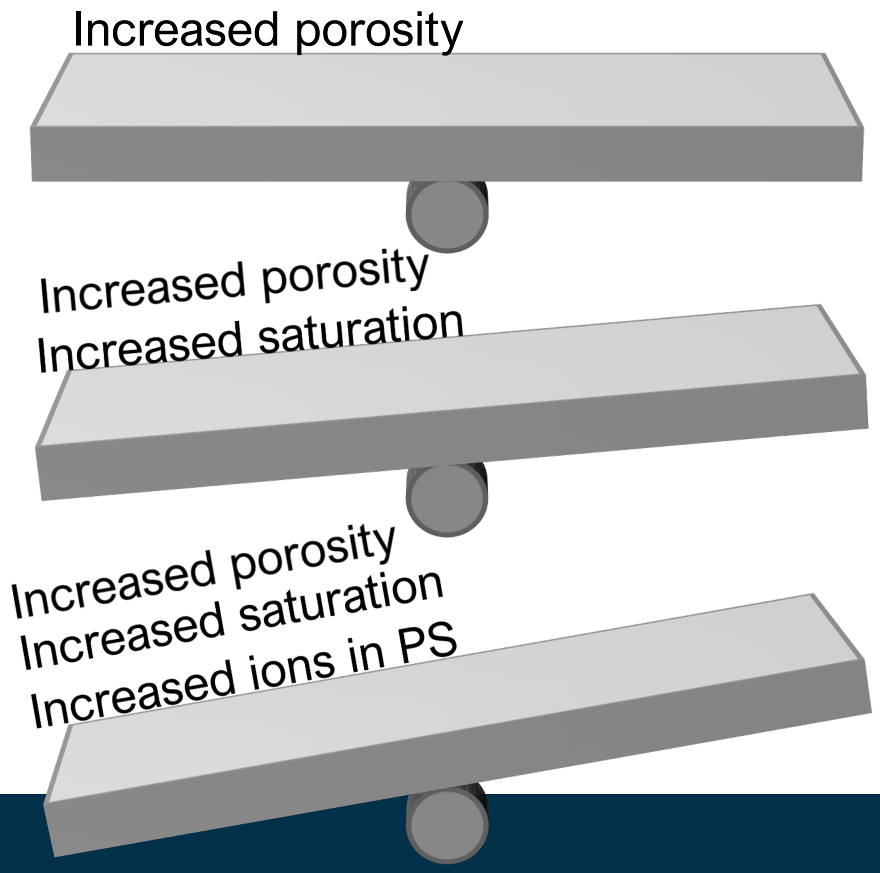


ASTM C1876

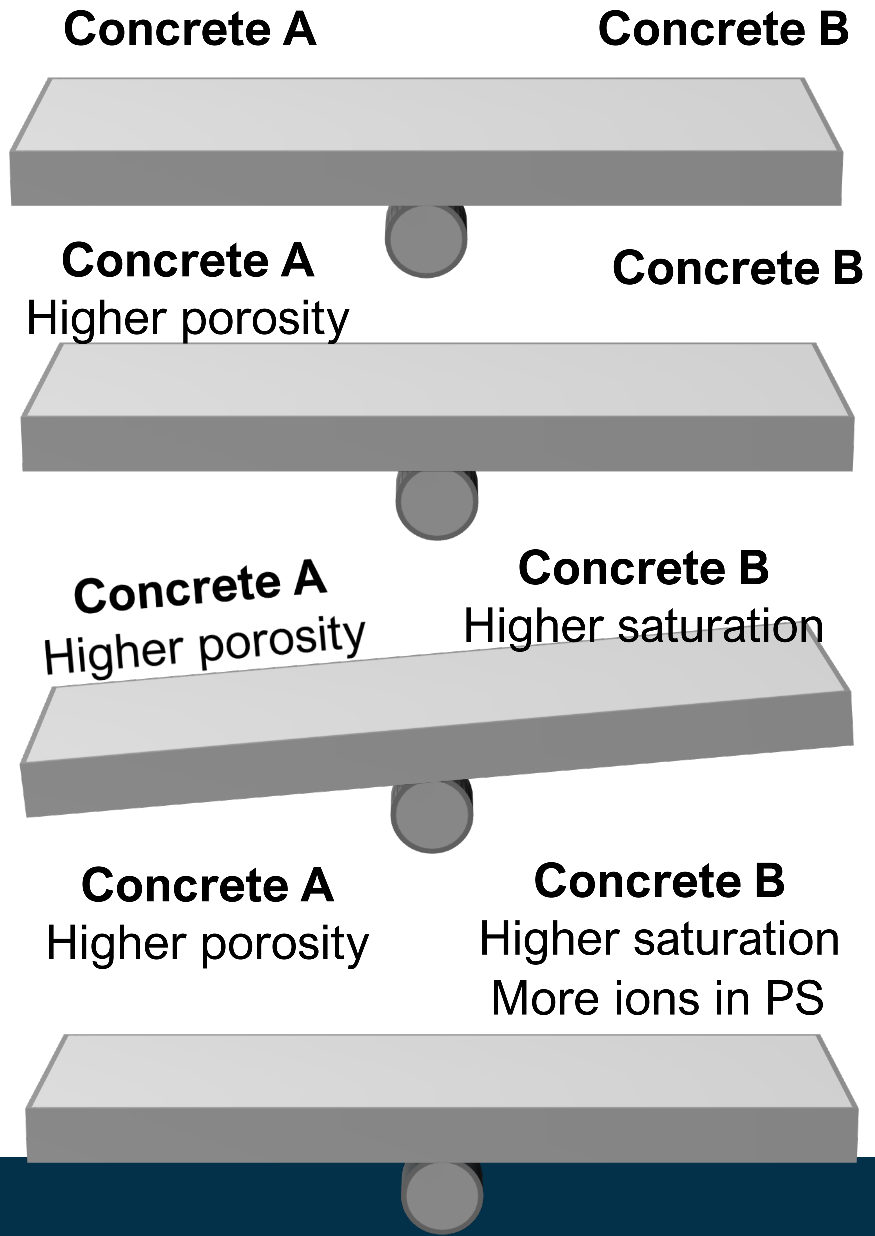
Specification

Resistivity is a function of:

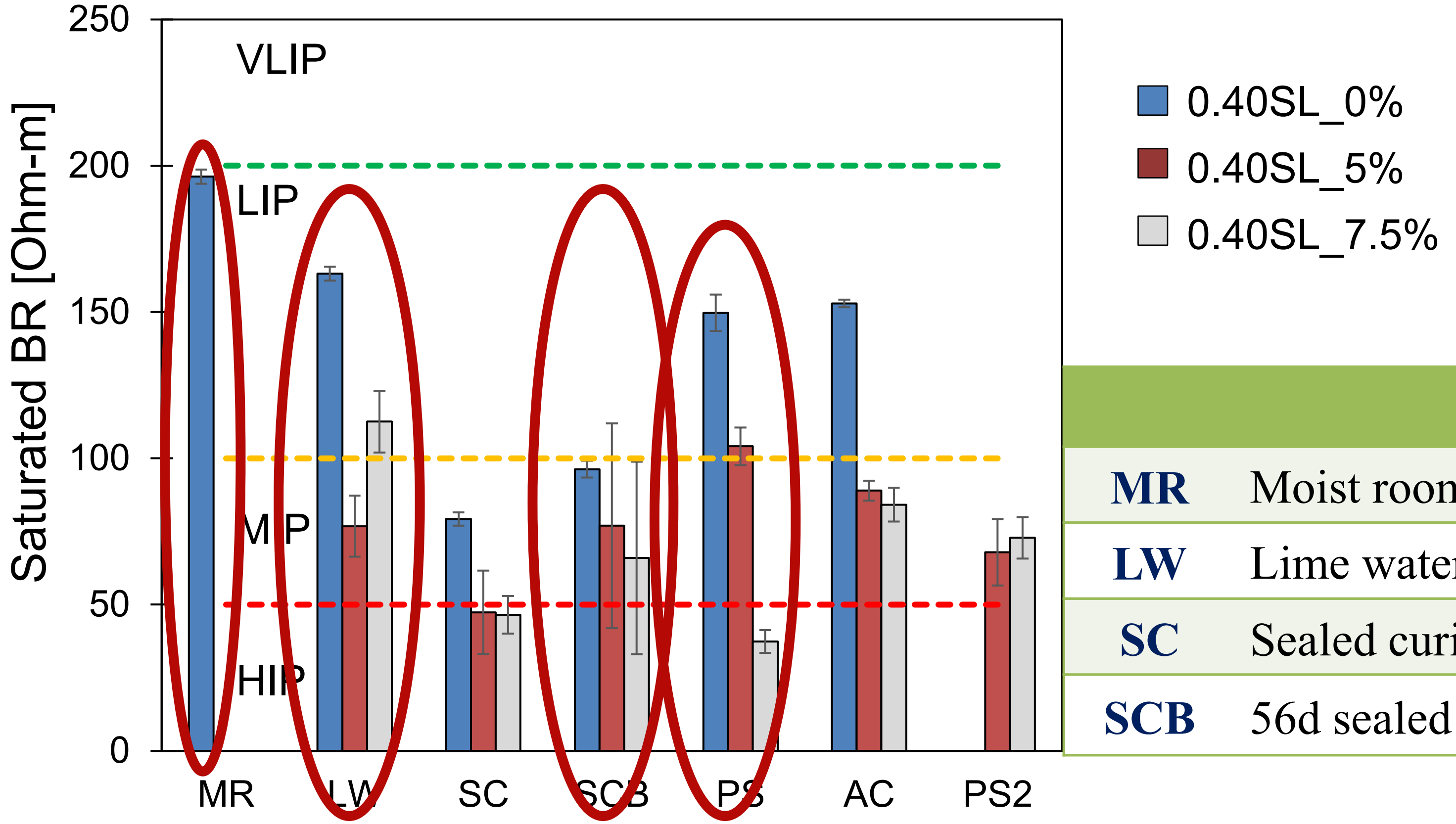
- Pore volume
- Pore size
- Pore connectivity
- Saturation of pores
- Ions in the pore solution



Resistivity



Specification



50% slag cement, w/cm = 0.40

Curing Condition			
MR	Moist room curing	**PS**	Pores solution
LW	Lime water curing	**AC**	27d accelerated curing
SC	Sealed curing	**PS2**	Pores solution 2
SCB	56d sealed curing + 1 week bucket curing		

Source: Montanari, L; Tanesi, J; Kim, H; Ardani, A; Obla, K; Hong, R; Lobo, C. Effect of Concrete Curing Conditions and Air Content on the Formation Factor and the Transport Properties Classifications Based on AASHTO PP84. 99th TRB annual meeting, January 2020

Specification

Select Property

↓

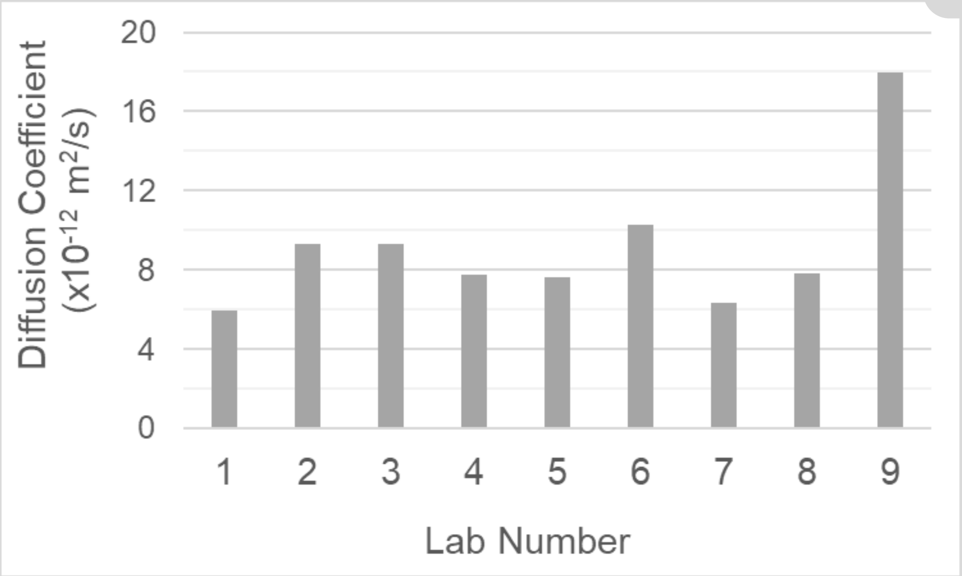
Select Test for each Property

↓

Select Criterion each Property

- What are the tests measuring?
- How reliable they are?
- What is their variability?

Criterion needs to correlate with field performance



ASTM C1556 InterLab Testing

Coefficient of variation single operator = 32%

Between labs d2s = 119%

Specification

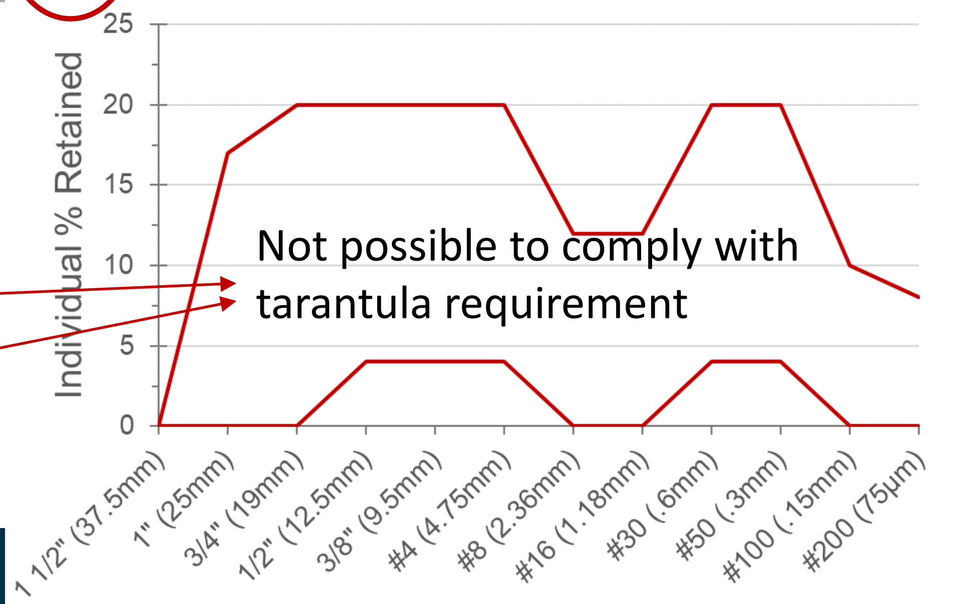
- Properties to be measured that are really representative
- Tests and criterion for each property
- Be consistent

Example of Specification with requirements that are not compatible

Concrete Class	Min. 28-day Compressive Strength (psi)	Cementitious Content (lb/yd^3)	w/cm	Maximum Size of Coarse Aggregate (ASTM C33)	Entrained Air (%)	Slump (in.)
A	3,000	Min. 423	Max. 0.62	#8	5 ± 1.5	3 to 6
B	4,500 at 56 days	535 to 550	0.40-0.42	#4	6 ± 1.5	2 to 4

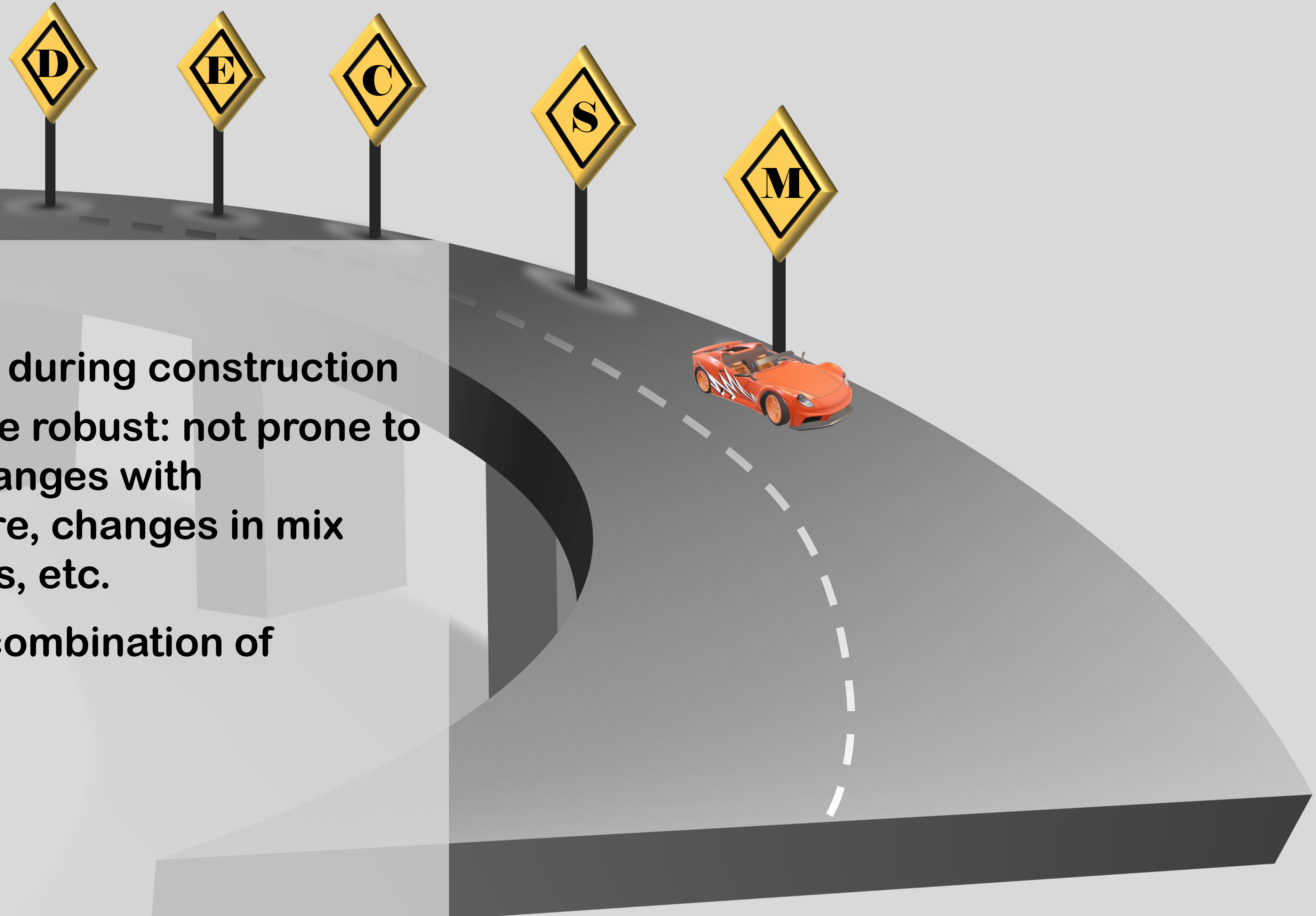
Amounts Finer Than Each Sieve (%)

Sieve	2 in.	1 ½ in.	1 in.	¾ in.	½ in.	3/8 in.	No.4	No.8	No.16
#4	100	90 to 100	20 to 55	0 to 15					
#8					100	85 to 100	10 to 30	0 to 10	0 to 5



Specification

- Properties to be measured that are really representative
- Tests and criterion for each property
- Be consistent
- Consider materials
- Understand the influence of one requirement to other properties
    - Example: minimum cementitious content may lead to high shrinkage
- Consider quality control



Mix Design:

- Conditions during construction
- Needs to be robust: not prone to sudden changes with temperature, changes in mix proportions, etc.
- Consider combination of materials

Combination of Materials

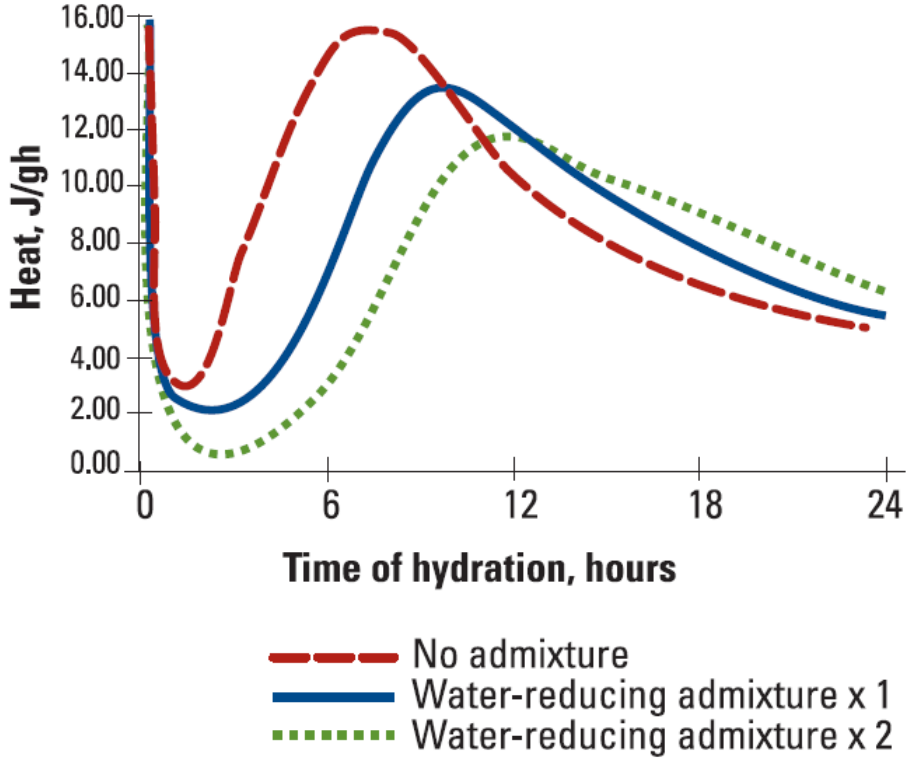
- Incompatibilities:
  - Admixture – Admixture
  - Binder – Admixture
    - C_3A content and reactivity
    - SO_4 balance
    - Cement fineness
    - SCM chemistry and content
    - Admixture chemistry
    - Temperature
    - Time of admixture addition
    - Cement alkalis
    - SCM chemistry

- Setting issues
- Strength gain issues
- Flash set
- False set

- High alkali cement: Slump loss, Air stability issues, Higher doses of polycarboxylate
- Low alkali cement: Air void clustering
- SCM: higher doses of AEA

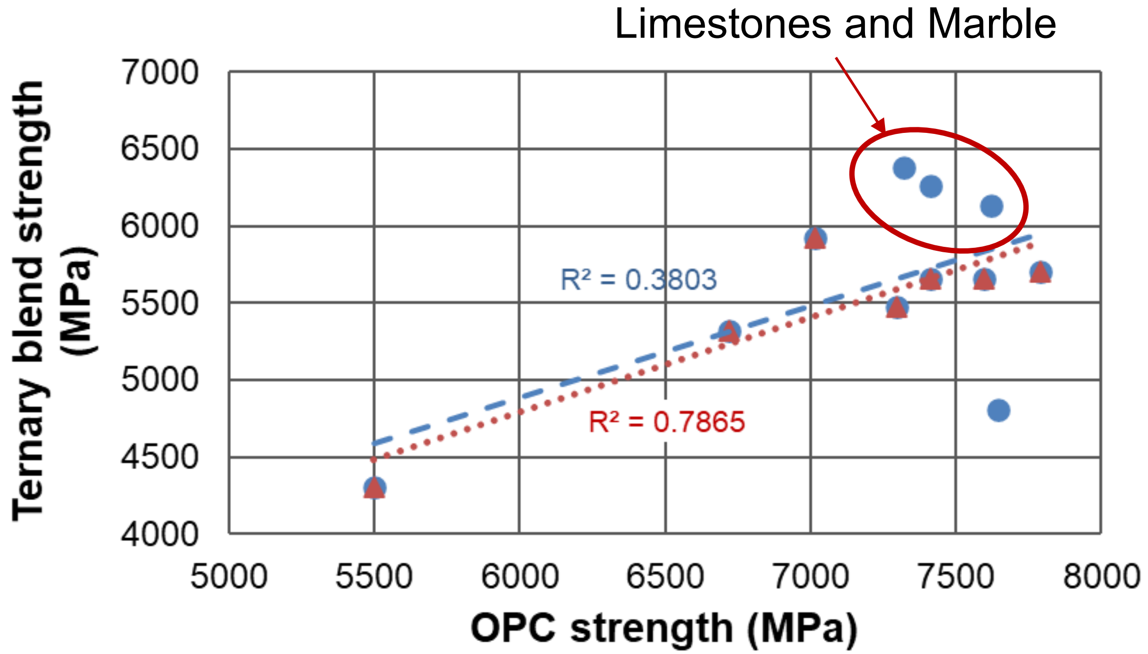
Combination of Materials

- Incompatibilities:
  - Admixture – Admixture
  - Binder – Admixture
    - C_3A content and reactivity
    - SO_4 balance
    - Cement fineness
    - SCM chemistry and content
    - Admixture chemistry
    - Temperature
    - Time of admixture addition
    - Cement alkalis
    - SCM chemistry
- Paste-aggregate interaction

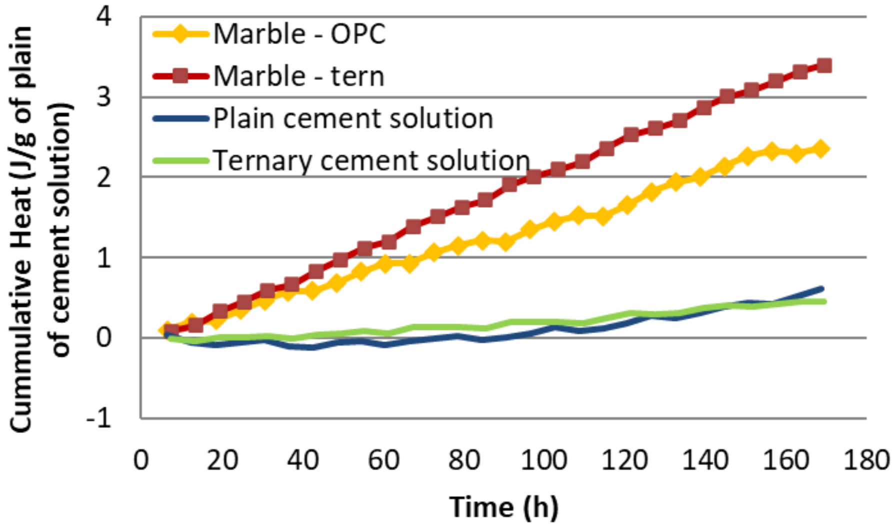


Combination of Materials

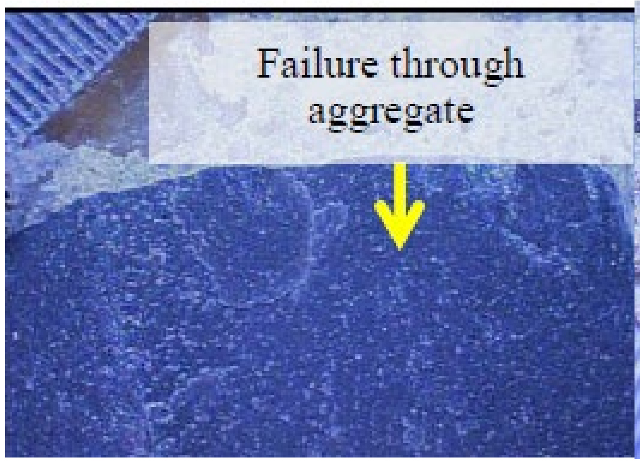
- 10 different coarse aggregates
- Same gradating
- 2 binders – OPC and Ternary



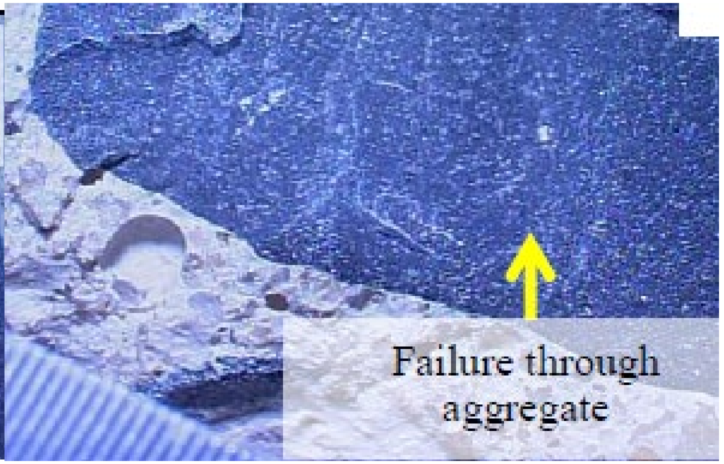
28-day Compressive strength



Limestones and marbles showed more reaction with ternary paste than OPC, improving ITZ and bound between paste and aggregate.



OPC at 91-day



Ternary blend at 91-day

Source: Tanesi, J., *et al.* “Influence of Aggregate Characteristics on Concrete Performance”, NIST Technical Note 1963, 2017. http://doi.org/10.6028/NIST.TN.1963.

Combination of Materials

- 10 different coarse aggregates
- Same gradating
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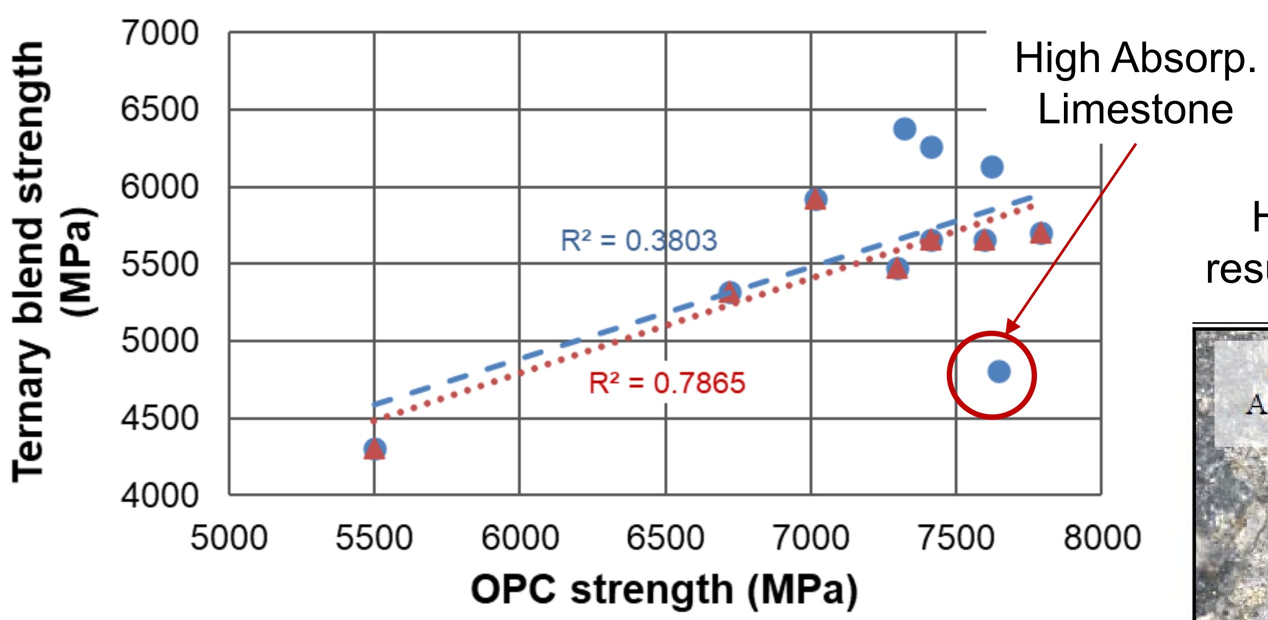
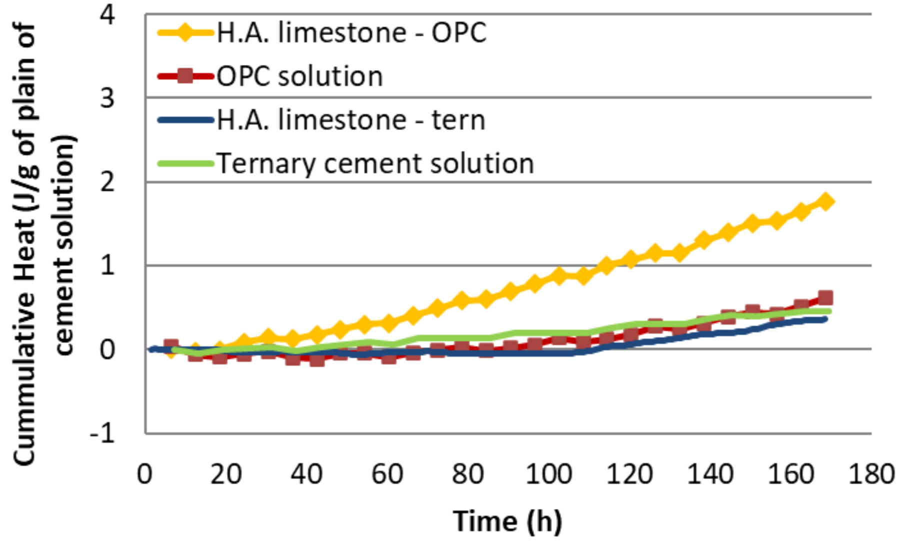
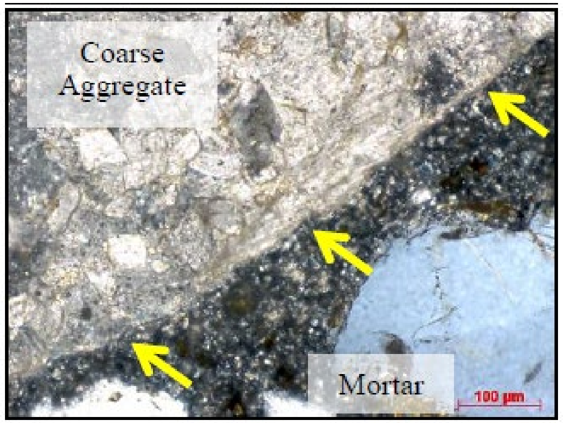


28-day Compressive strength

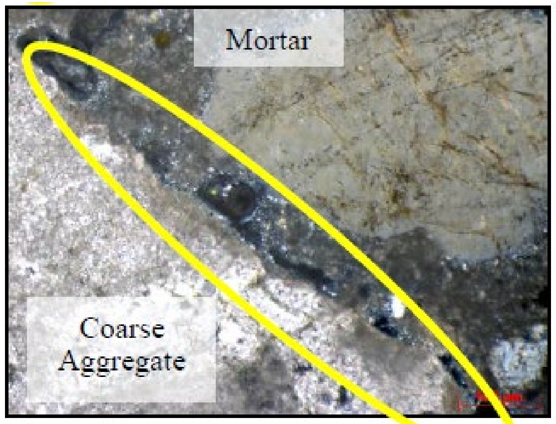
Source: Tanesi, J., *et al.* "Influence of Aggregate Characteristics on Concrete Performance", NIST Technical Note 1963, 2017. http://doi.org/10.6028/NIST.TN.1963.



High absorption limestone showed no reaction with ternary paste resulting in poor ITZ and lack of bound between paste and aggregate.

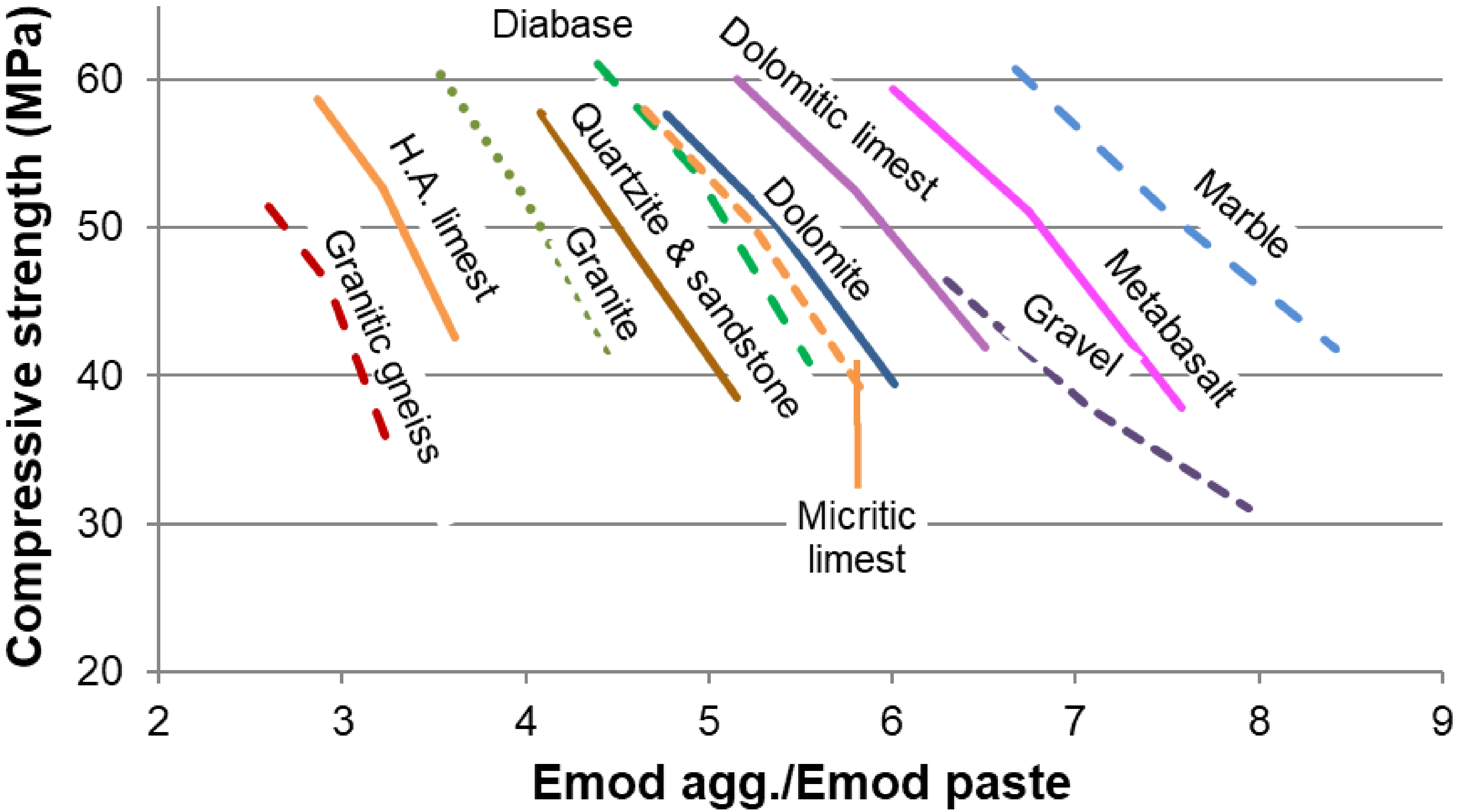


OPC at 91-day



Ternary blend at 91-day – lack of bound

Combination of Materials



Source: Tanesi, J., *et al.* "Influence of Aggregate Characteristics on Concrete Performance", NIST Technical Note 1963, 2017. http://doi.org/10.6028/NIST.TN.1963.

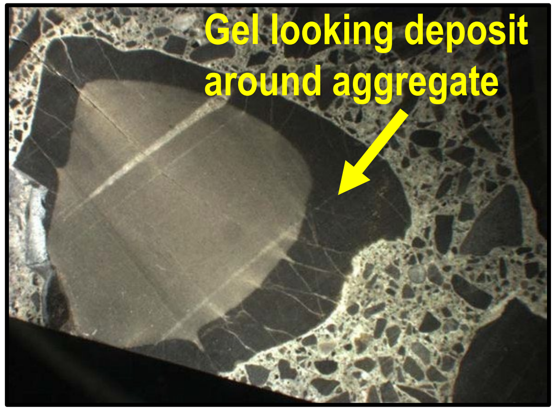
Materials:

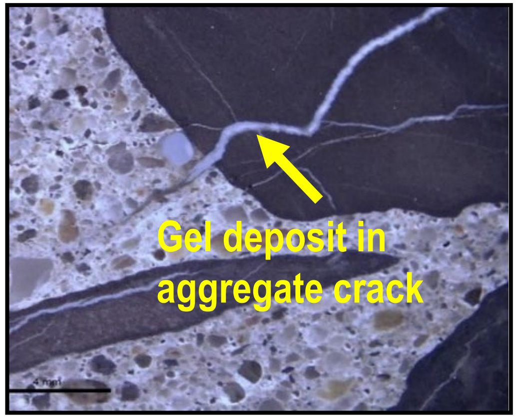
- Consider variability
- Consider supply
- Not prone to MRD

How reliable and representative of field exposure are the tests?

Important Facts about ASR

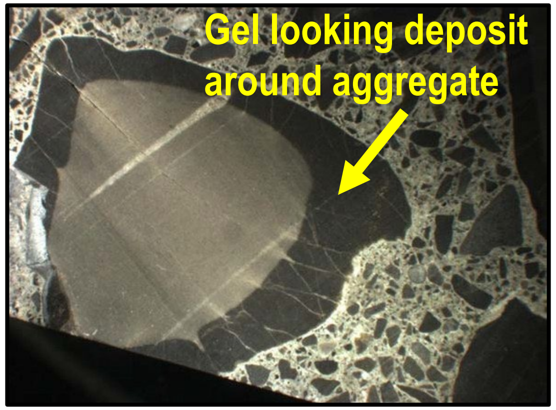
- Slow reaction occurs years or decades after construction
- Reported in 46 countries (as of 2009), in UK alone, 40% of 225 bridges affected
- Reported in about 40 USA States (as of 2003)
- Safety concern
  - Nuclear facilities
  - Dams
- Economic impact is very significant
  - Mactaquac Generation Station – Aggregate showed as non-reactive
    US$ 6-7 million/year to reduce impact
  - Channel Island Air National Guard Base apron replacement **US$ 16 million**
  - Denver International Airport – repairs cost **US$ 10 to 30 million per runway**
  - Willow Run Airport reconstruction:
    US$ 45 million
  - Munna Point Bridge, Queensland
    Repair and maintenance of piles over $ 5 million

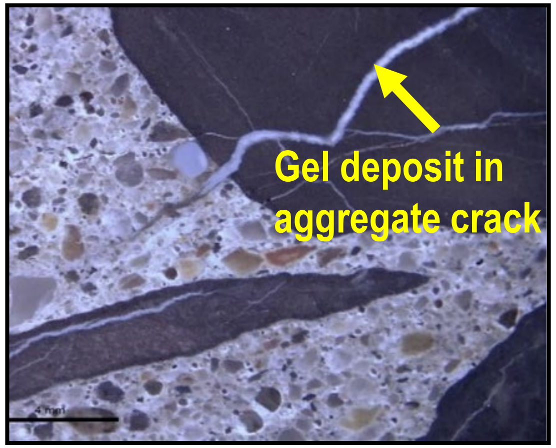




Important Facts about ASR

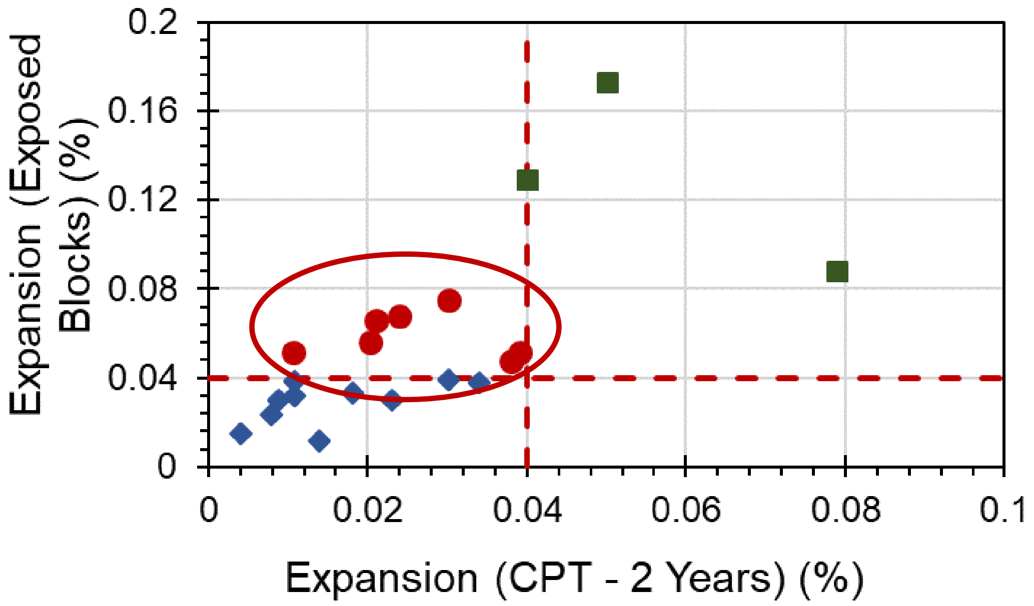
- Slow reaction occurs years or decades after construction
- Reported in 46 countries (as of 2009), in UK alone, 40% of 225 bridges affected
- Reported in about 40 USA States (as of 2003)
- Safety concern
  - Nuclear facilities
  - Dams
- Economic impact is very significant
- Not all reactive aggregates react the same way or at the same rate
- Efficiency of mitigation measures are controversial
- Prevention is possible by:
  - Chemical treatment, such as lithium impregnation
  - Keeping moisture out, such as sealants and crack filling
  - Saw cutting to accommodate movement
  - Restraint to prevent expansion



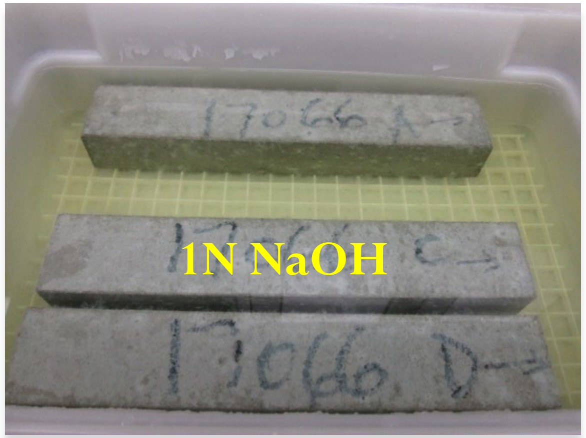


Prevention is the KEY BUT depends on RELIABLE TESTS

Test Methods for Identification and Prevention

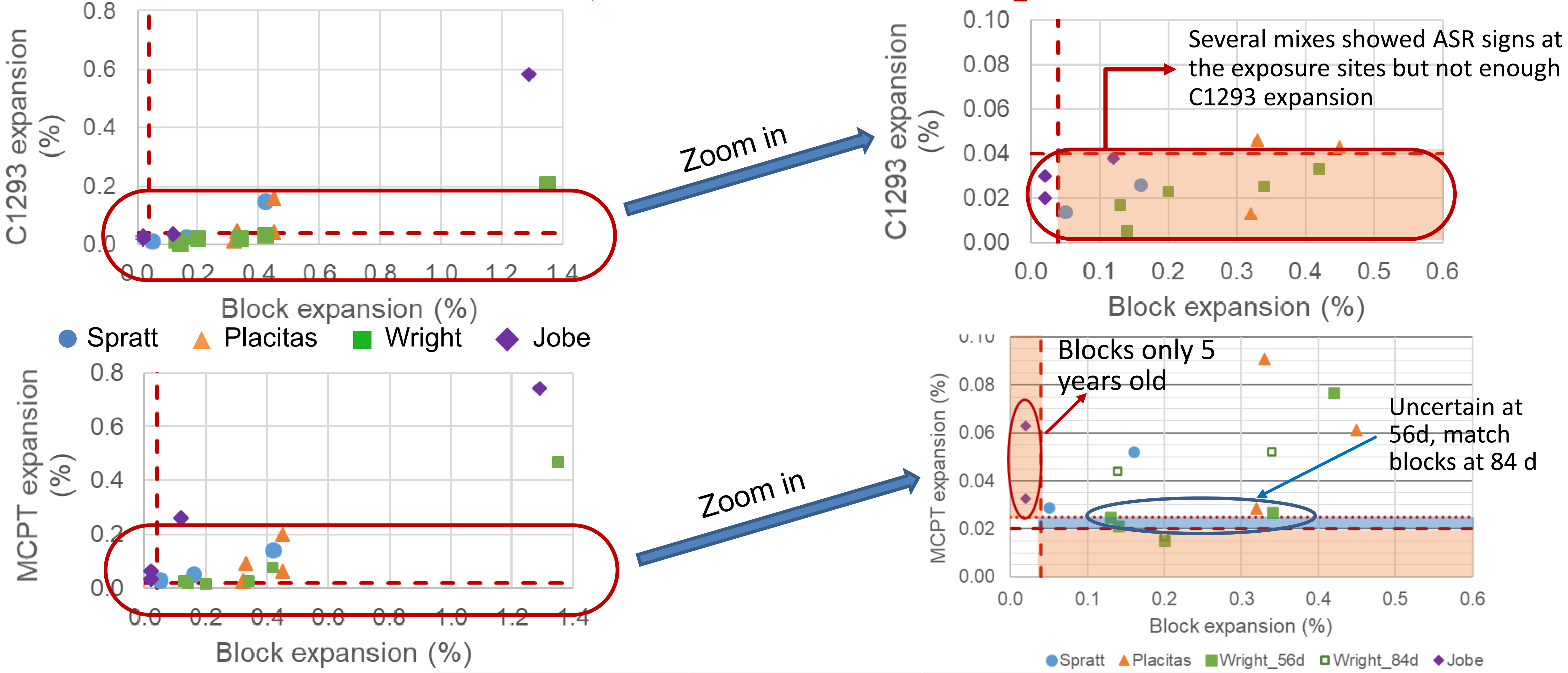


CANMET exposure site



	ASTM C1293	AASHTO T380 (MCPT)
Material	Concrete	
Specimens	3 by 3 by 11 1/4 in.	2 by 2 by 11 ¼ in.
Mix Proportions	w/cm = 0.42 to 0.45	w/cm = 0.45
	Cement with alkali 0.9 ± 0.1 percent	
	Cement alkali boosted to 1.25 percent	
	Cementitious 708 lb/yd³	
	Aggregate vol/Concrete vol	
	0.70	0.65
Temperature	38 °C (100 °F)	60 °C (140 °F)
Immersion solution	None	1N NaOH
Duration	**1 or 2 years**	**56 to 84 days**

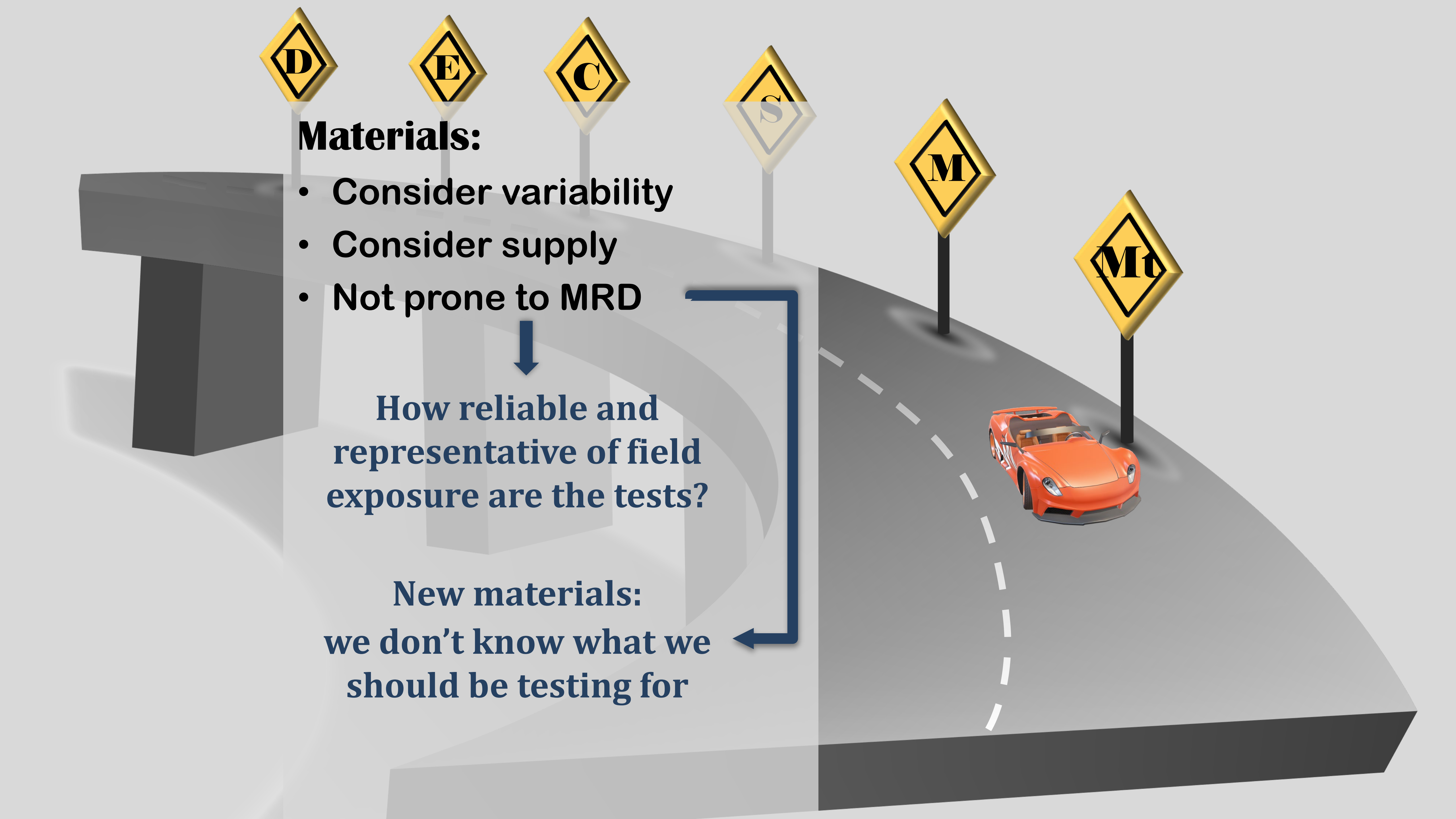
Benchmarking with Outdoor Exposed Blocks



	Block/Lab	C1293	MCPT at 56d
Matched blocks	**Fail/Fail**	46.7%	80.0%

→ **86.7% at 84d**

Source: Tanesi, J, *et al.*, "Alkali-Silica Reaction: Divergence Between Performance in the Field and Laboratory Test Results." TRR vol. 2674, issue 5, 2020. https://doi.org/10.1177/0361198120913288



Materials:

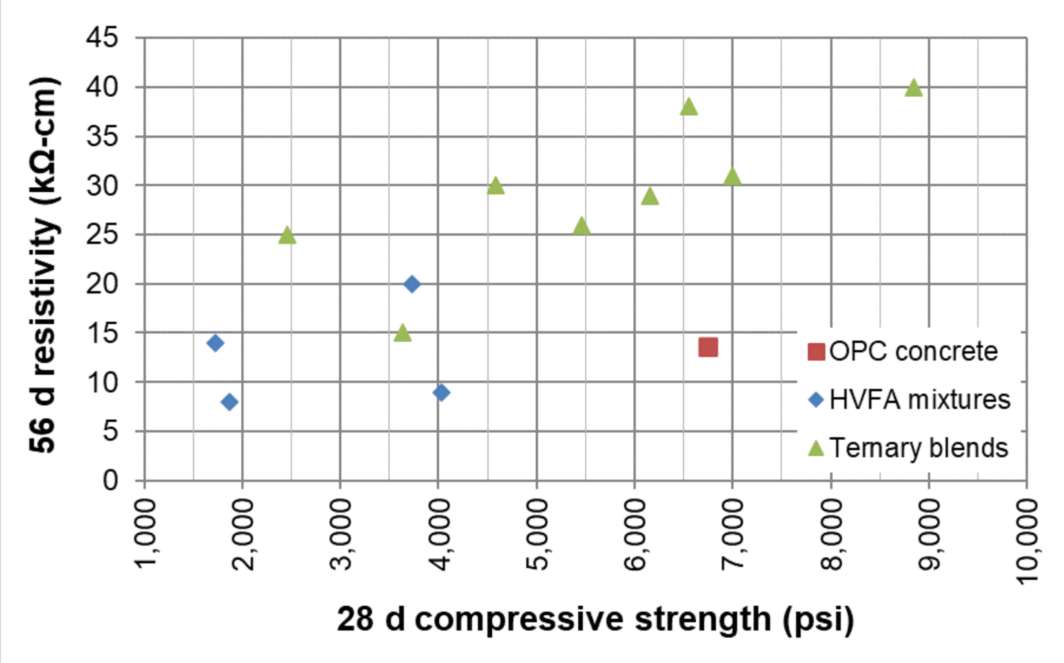
- Consider variability
- Consider supply
- Not prone to MRD

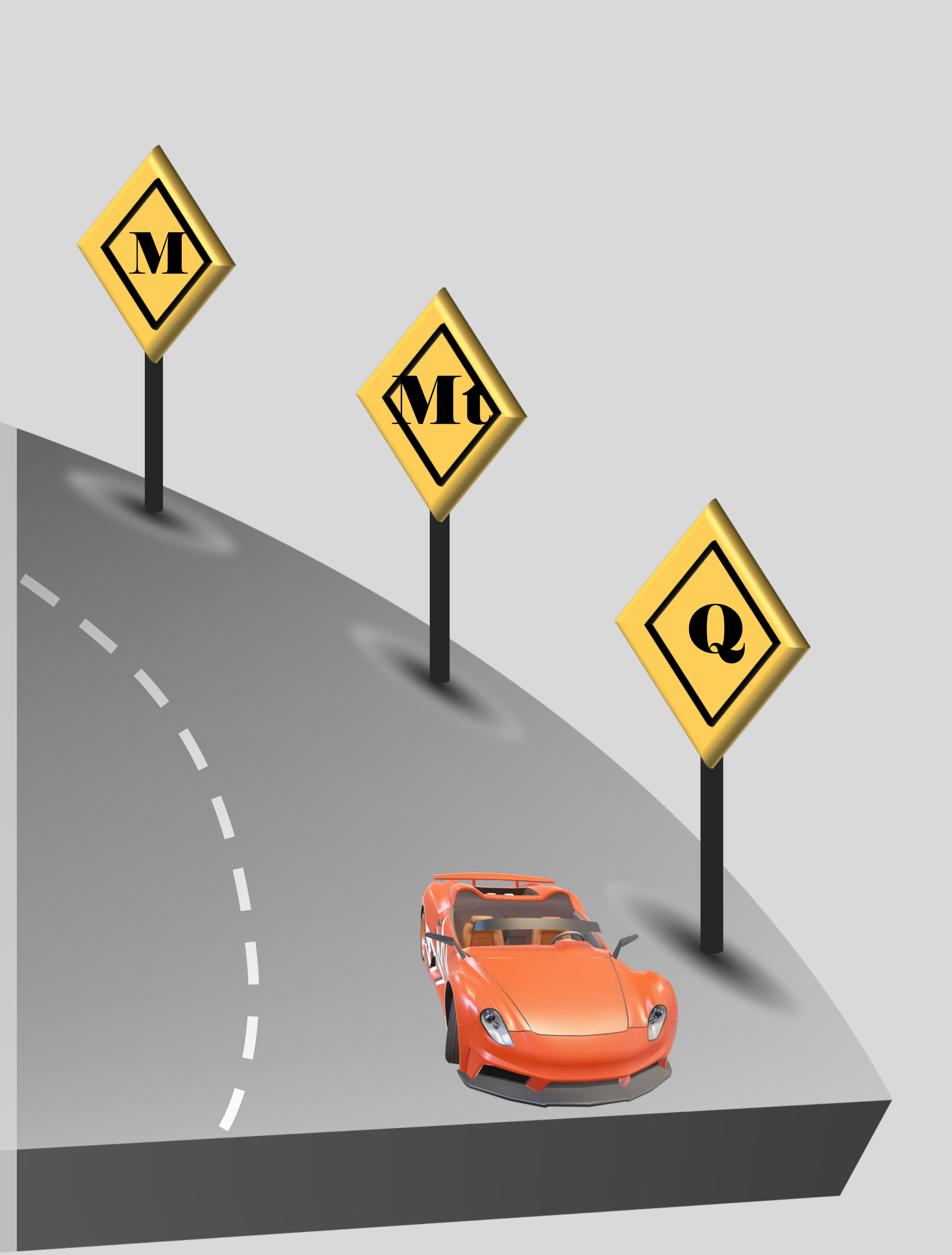
How reliable and representative of field exposure are the tests?

New materials: we don’t know what we should be testing for

Quality Control:

- Performance will only be appropriate if what is placed is similar to what was designed
  - ➢ In terms of the properties that reflect what is needed in performance





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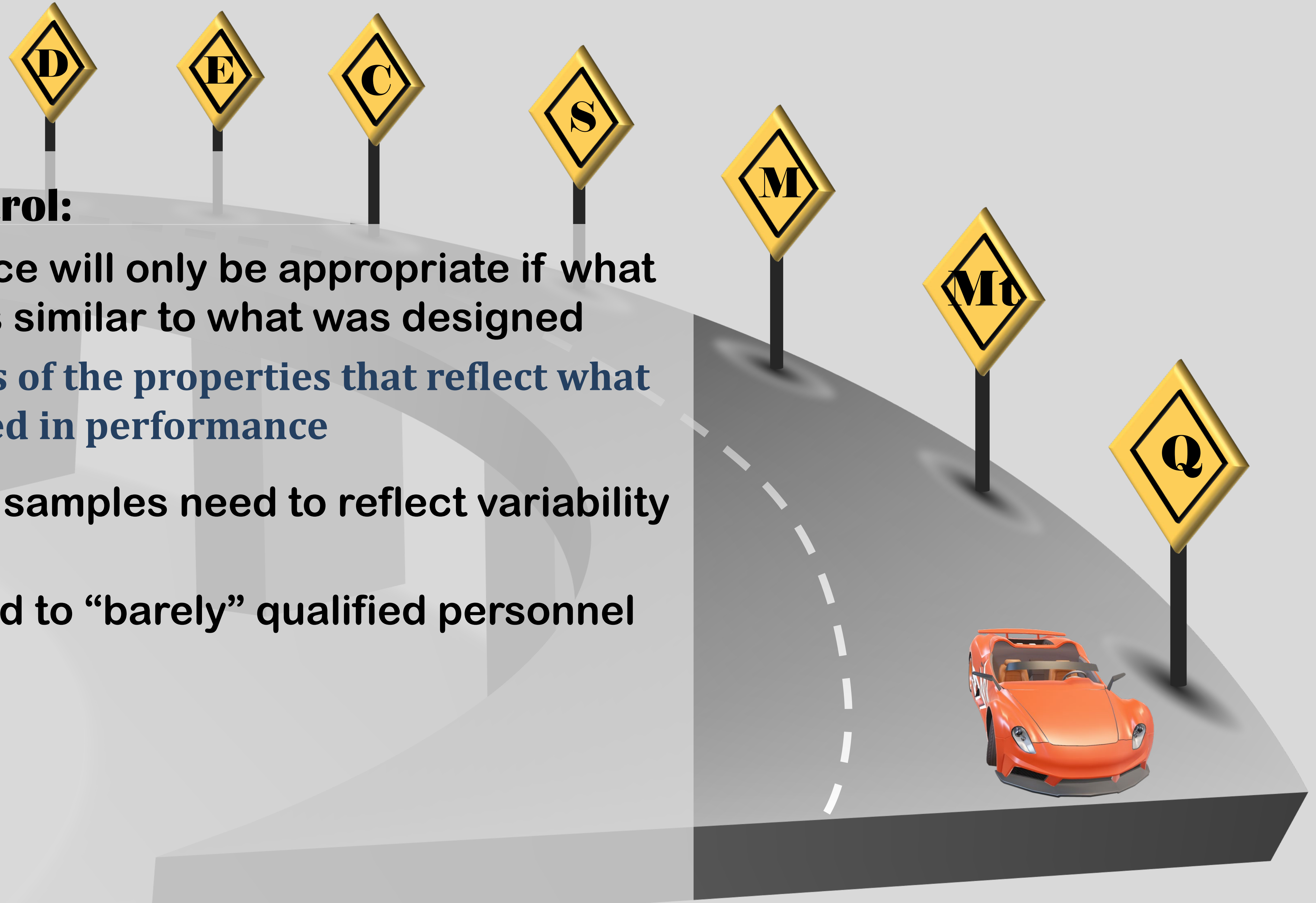

Quality Control:

- Performance will only be appropriate if what is placed is similar to what was designed
  - In terms of the properties that reflect what is needed in performance
- Number of samples need to reflect variability of the test
- We are used to “barely” qualified personnel

- The guy adds water to the truck
- Aggregate moisture is not controlled

Final Thoughts

- Concrete is getting more and more complicated
- However, we still treat it as the “vanilla” concrete of the past
- Concrete will only perform satisfactorily if we have appropriate specifications, testing methodologies and criteria that relate to field performance
- Several new materials are under development and will be implemented sooner than we expected
- These materials may behave very different than conventional ones
- We need to develop better testing methodologies and determine appropriate criteria
- Concrete production needs to be verified in terms of affects performance
- Not even the best concrete mix design will perform well if it is not properly placed and cured
- We can't continue treating concrete materials as “Rocket Science” and not have trained personnel in the field.