Preserving Existing Concrete Structures With Protective Coatings

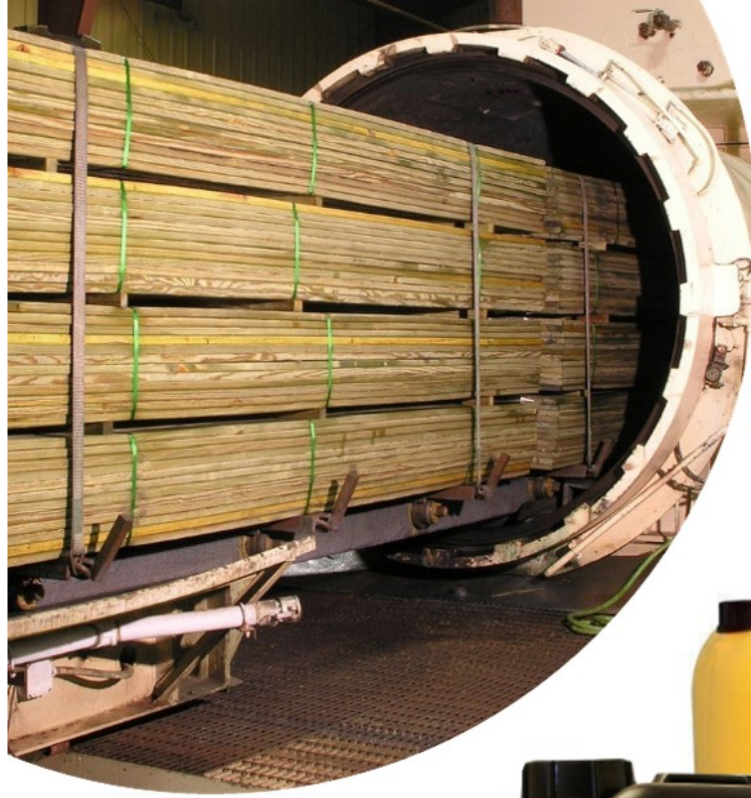
October 2019

Preserving Existing Concrete Structures....

- Huge variety of materials and building types.
- Their Achilles heel leads to the need to protect against degrading elements that are set to destroy them.
- Protection against the elements (human or natural) to preserve our investment of time and resources.
- Protection of heritage and artifacts that define who we are.

….With Protective Coatings

- In as much as there is a variety of building materials there are also coating systems and methods of preservation.
- Additives incorporated in the building material.
- Pre-treatment with preservatives and sealers
- Post construction application of surface coatings
- Additive sacrificial components
- Narrow focus of discussion to concrete.



Concrete

- Concrete is by far the most widely used man made building product.
- The concept has been used for more than 5000 years.
- In the 18th Century with the discovery of hydraulic lime concrete took on its modern form.
- Traditionally composition is very simple- cement: graded aggregates: water.
- Become a more complicated mix of chemical reactions to improve durability and longevity.
- Advantages include: compressive strength, stiffness, ease of fabrication, stable over time and low cost.
- Disadvantages: Low tensile strength, brittleness and subject to deterioration over time.

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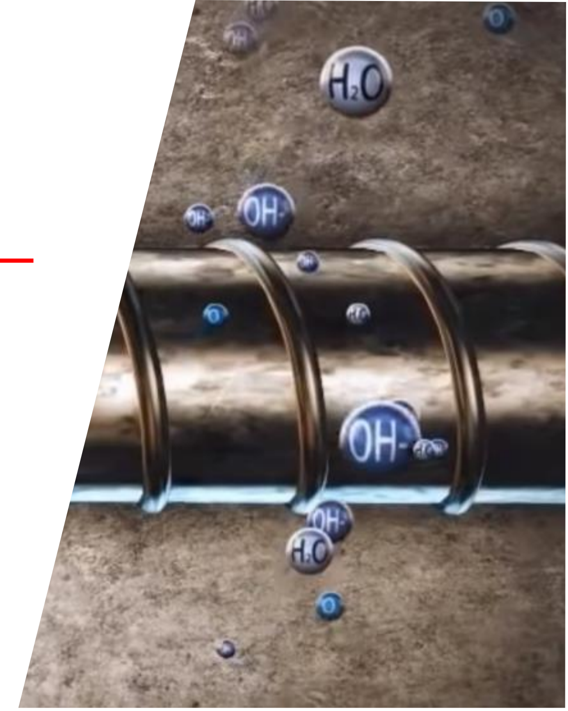
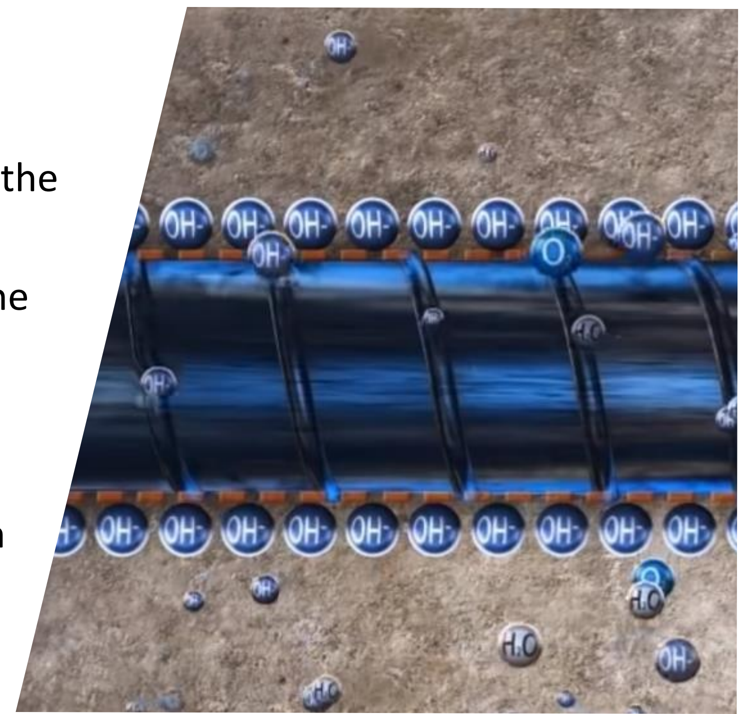
Concrete Chemistry

- Concrete hardens through the process of hydration.
- Cement and water form a paste that coats the aggregate, hardens and gains strength.
- During the curing process Calcium Silicate Hydrate and Calcium Hydroxide are formed.
- H2CaO4Si contributes to setting, hardening, strength development and volume stability.
- $Ca(OH)_2$ contributes to provide an alkaline environment, beneficial to the protection of reinforcing steel.
- The alkaline environment produces a passive layer around the steel to retard corrosion.
- There are a number of variables which have an effect on the quality of the concrete:

  cement – water ratio: aggregate ratios: curing condition: relative humidity….

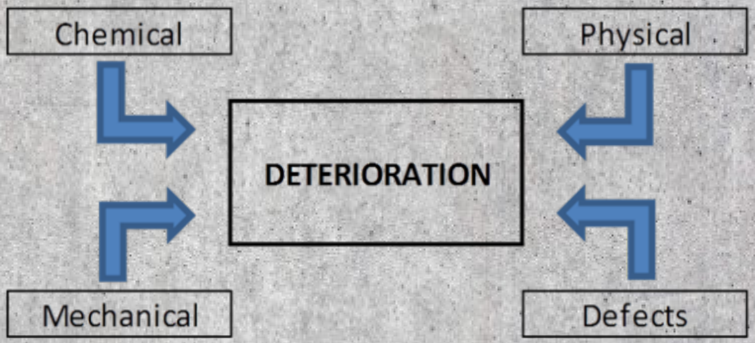
  …. but sooner or later defects that define the deterioration will appear.





Concrete Deterioration

- Concrete structures deteriorate with time and is much faster in extreme environments associated with high humidity, presence of chlorides and CO2 in the atmosphere.
- Ingress takes place through the pores of the concrete by a process of diffusion and initiates the corrosion of the reinforcing steel.
- Onset of corrosion is accelerated when the passivating layer is destroyed by reducing the alkalinity of the concrete.
- Resulting spalls reduce structural strength, aesthetic and integrity of the structure.



- Cumulative effects of external mechanical or physical forces as well as defects entrained during placement all contribute to accelerated deterioration.

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Carbonation

- Occurs when CO_2 present in the air penetrates the concrete and reacts with the calcium hydroxide to produce calcium carbonate $CaCO_3$
- The reaction reduces the pH of the concrete pore solution to 9.5 destabilizing the passive layer.
- Carbonation is generally a slow process depends greatly on relative humidity, temperature and overall concrete quality.
- Numerous predictive models, including accelerated carbonation tests simulating variable factors responsible for the acceleration of carbonation.
- Brown equation offer a more simplified means to calculate the carbonation depth using 28 day compressive strength (S).

Estimated 20 year carbonation depth	Initial 28 compressive strength (Mpa)
6mm (~1/4")	58Mpa (8400psi)
14mm (~1/2")	48Mpa (7000psi)
22mm (~7/8")	38Mpa (5500psi)
33mm (~1 5/16")	28Mpa (4000psi)

Browns Equation $d = k\,(\sqrt{t}.S)$

Sulphate Attack

- Naturally occurring sulphates of sodium, calcium and magnesium can be found in soil and ground water.
- As soluble sulphate ions they are carried into the concrete matrix by water.
- Reacts with hydrated compounds in the hardened cement.
- Resulting expansion can induce sufficient internal pressure to cause loss of cohesion and strength.
- Concrete exposed to higher frequency wet and dry cycling and porous concrete are more at risk.

Chloride Ingress

- Primary cause of premature corrosion of steel reinforcement.
- Chloride ions are present in deicing salt, seawater, airborne pollutants and even some concrete admixtures.
- Chlorides dissolved in water can permeate sound concrete and reach steel through defects.
- Carbonation also lowers the amount of chloride ions needed to promote corrosion.
- Depending on RH, temperature, chloride concentration, wet Dry cycles etc chloride penetration can reach 1” to 2½” in OPC in as little as 5 years.

Freeze Thaw

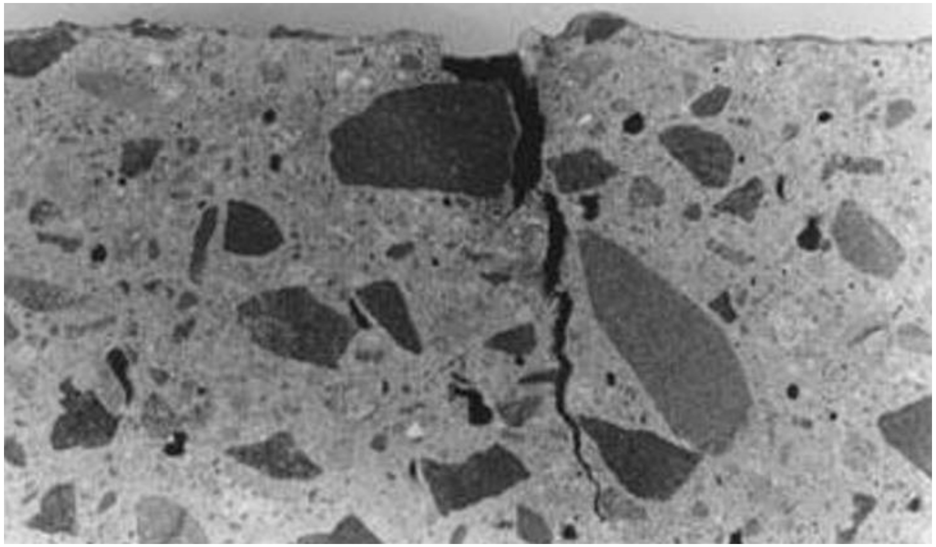
- As water freezes it expands about 9%.
- In moist concrete this produces a pressure in the pores and capillaries that can exceed the tensile strength of the concrete.
- The cavity will dilate and rupture, accumulative effect can eventually result in scaling, cracking and crumbling of the concrete.

Temperature

- Effect of high temperatures on concrete is also destructive.
- While concrete will withstand temperatures up to 650°C fire will provoke many types of damage to concrete including thermal spalling.
- As the reinforcing is heated up their volume increases, creating stress within the concrete resulting in spalls.
- Spalling also takes place as a result of rapidly heating the aggregate which expands and may detach areas of surrounding concrete.
- Prolonged exposure to excessive temperatures (500°C+) will cause reinforcing to melt and the tensile strength of the structure will be lost.

Plastic Shrinkage

- Without proper hydration during the curing process there can be a rapid loss of moisture at the surface of the concrete.
- As a result of the tensile stress between the concrete below the drying surface and the stiffening concrete on top cracks of varying dimension may occur.



Abrasion - Impact - Erosion

- Consider the effects of maintenance as well as normal wear and tear on a concrete surface.
- Progressively reduces effective cover of reinforcing as well as reducing overall mass of the design strength.
- Pressure washing, snow plows, vehicle impacts, traffic wear patterns, storm water run off and irrigation systems all contribute to overall cumulative damage to the structure.

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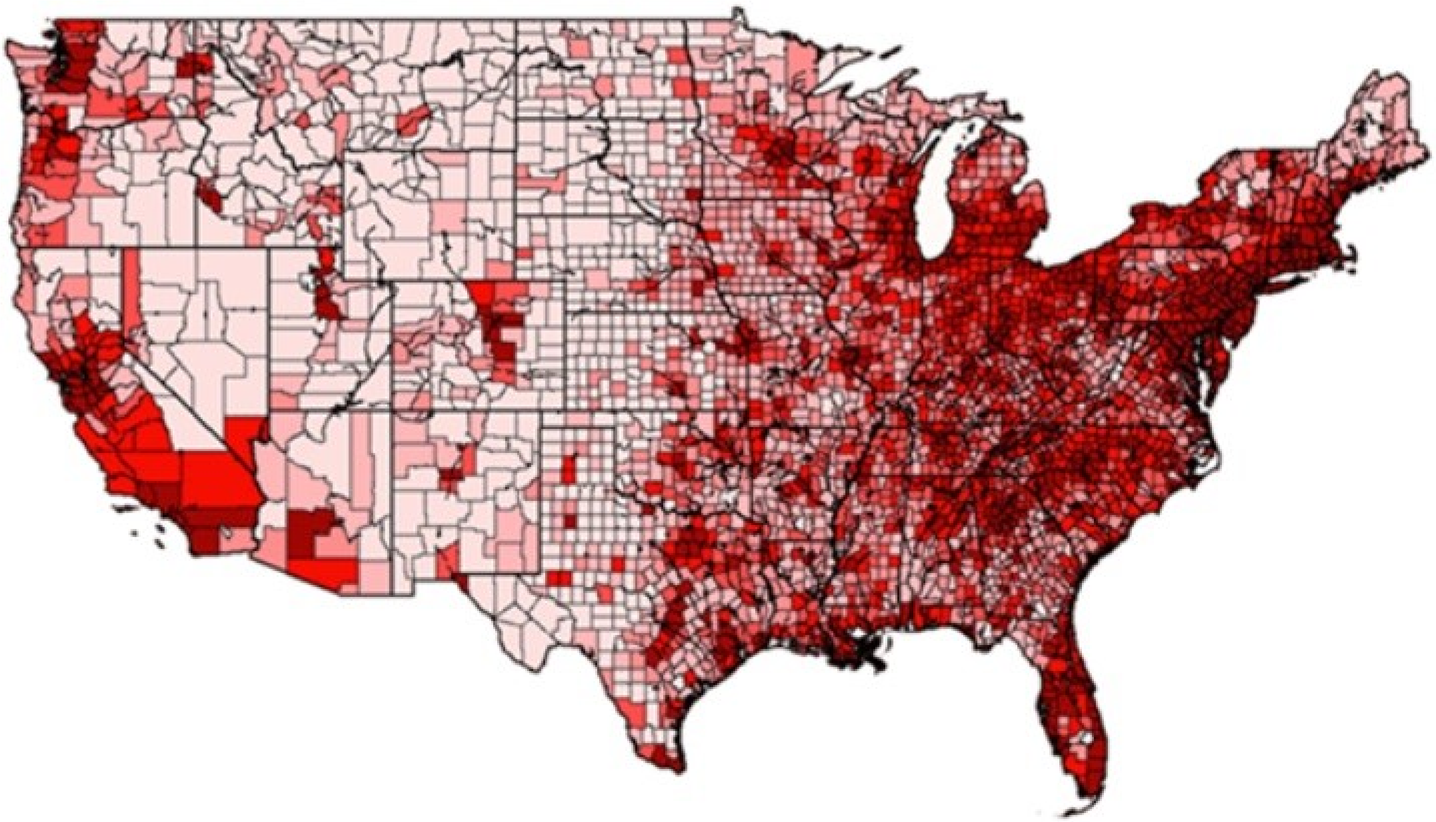
Installation

- Defects in the concrete can be entrained as a result of poor preparation or workmanship.
- Placement and position of rebar to maintain minimum cover.
- Formwork placement and support.
- QC during mixing, transportation and placement.
- Lack of compaction and over compaction.

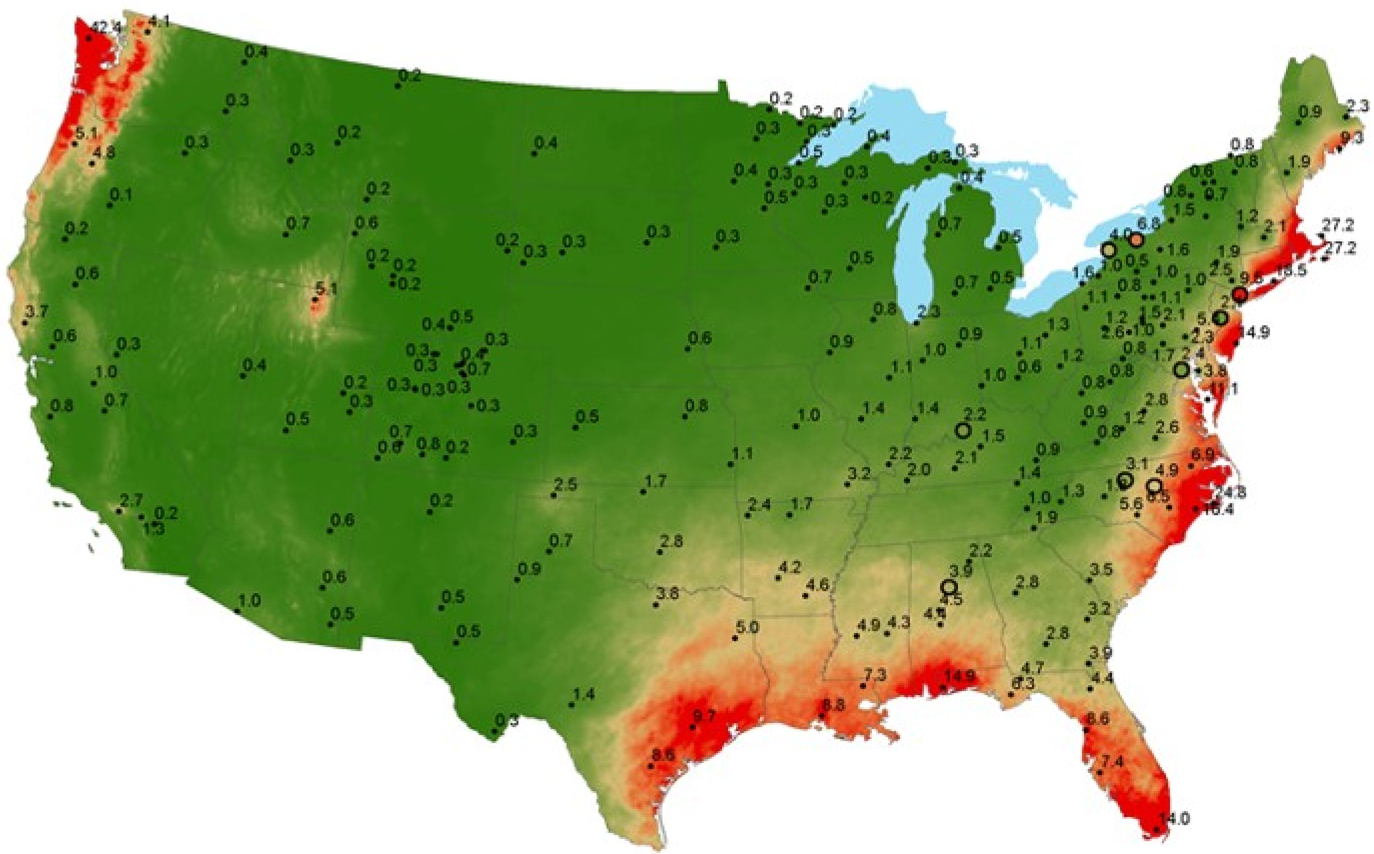
Environmental



- Created some of the problem for ourselves too.
- 39% of the US population lives in counties bordering the coastline, 64% live in coastal states.
- Somewhere between 1/3 and 2/3 of the US population resides in a severe coastal environment.

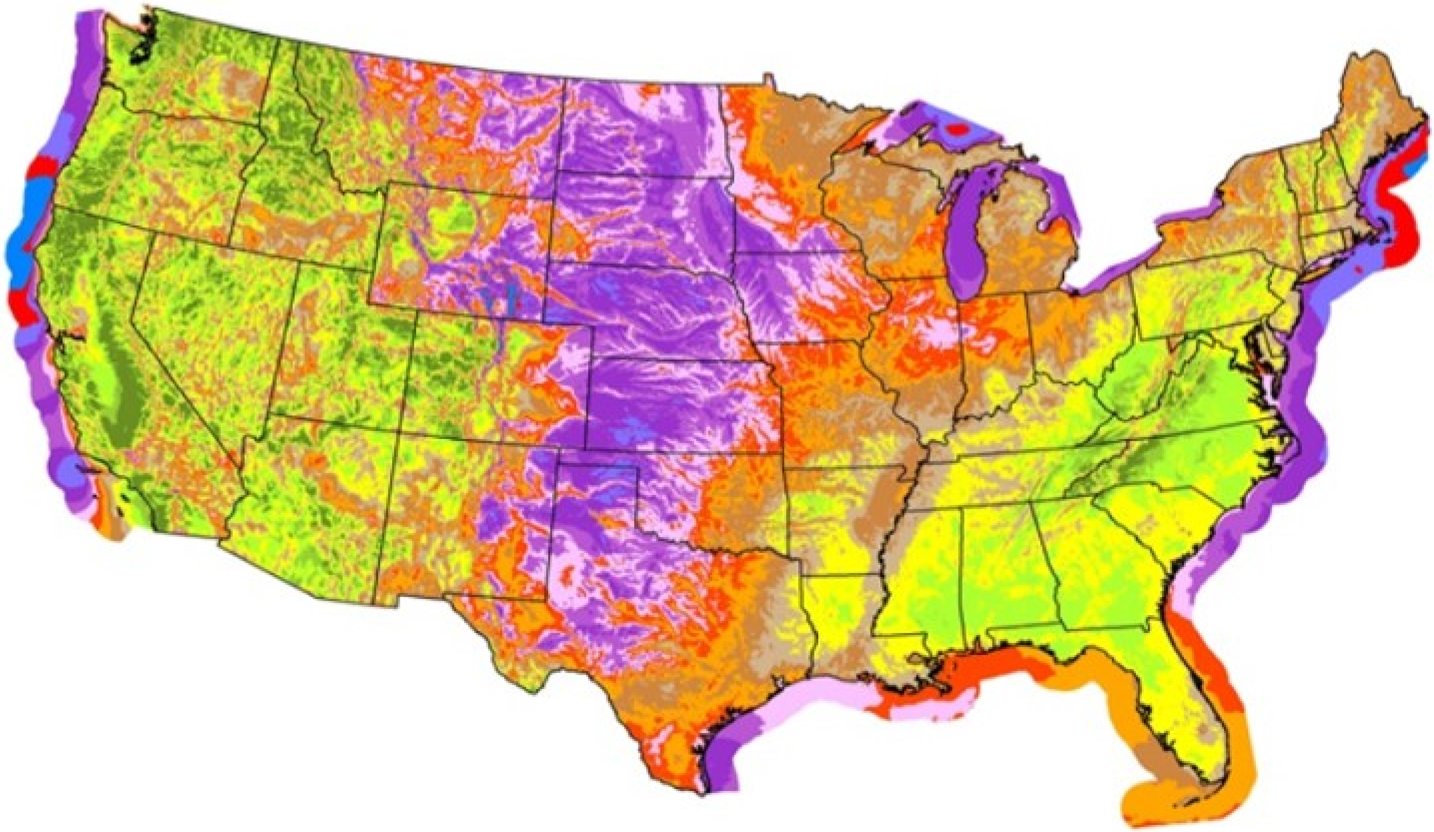
US Census Bureau
National Renewable Energy Laboratory
National Oceanic & Atmospheric Administration
National Atmospheric Deposition Program

Environmental



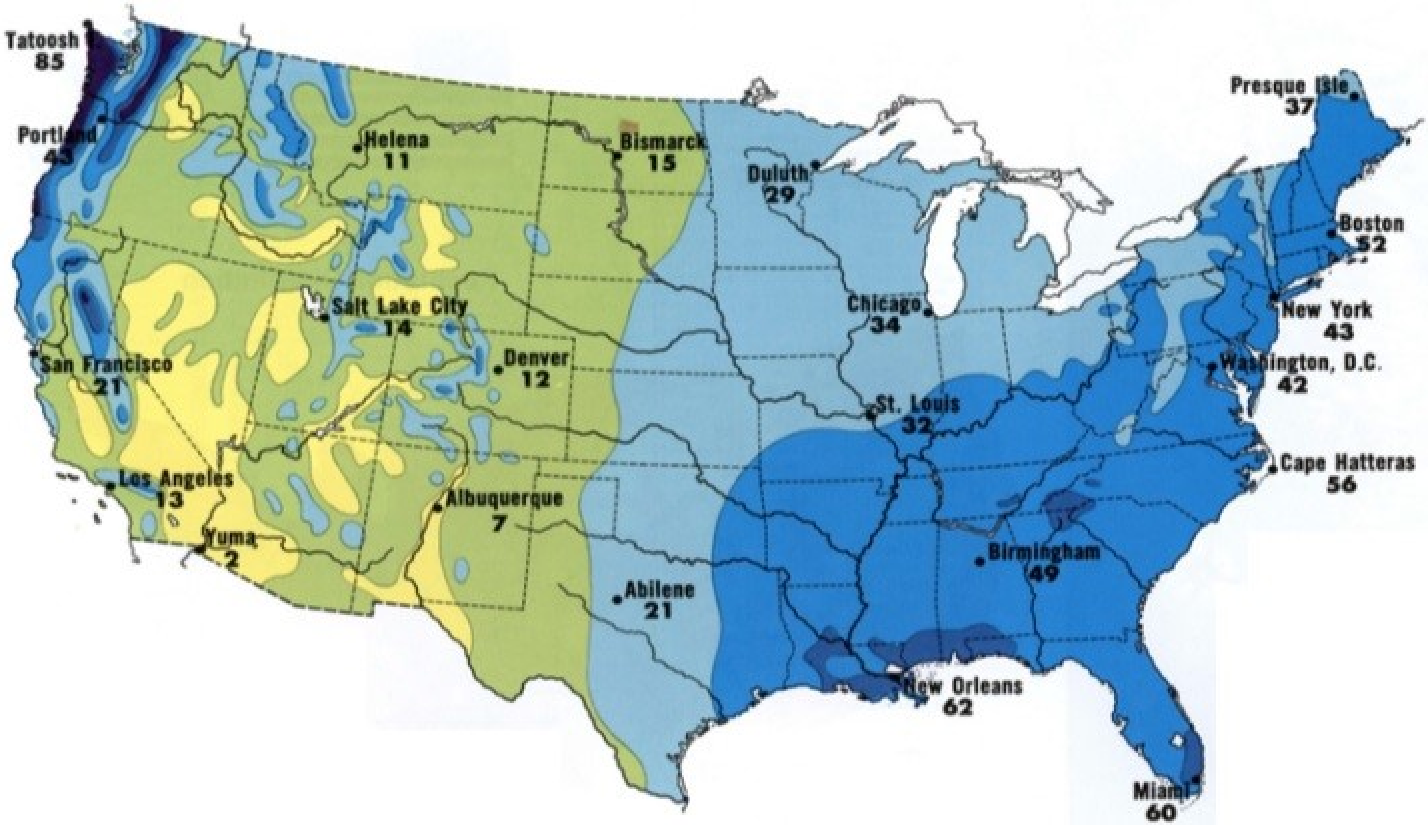
- Characterized by high chloride precipitation

Environmental



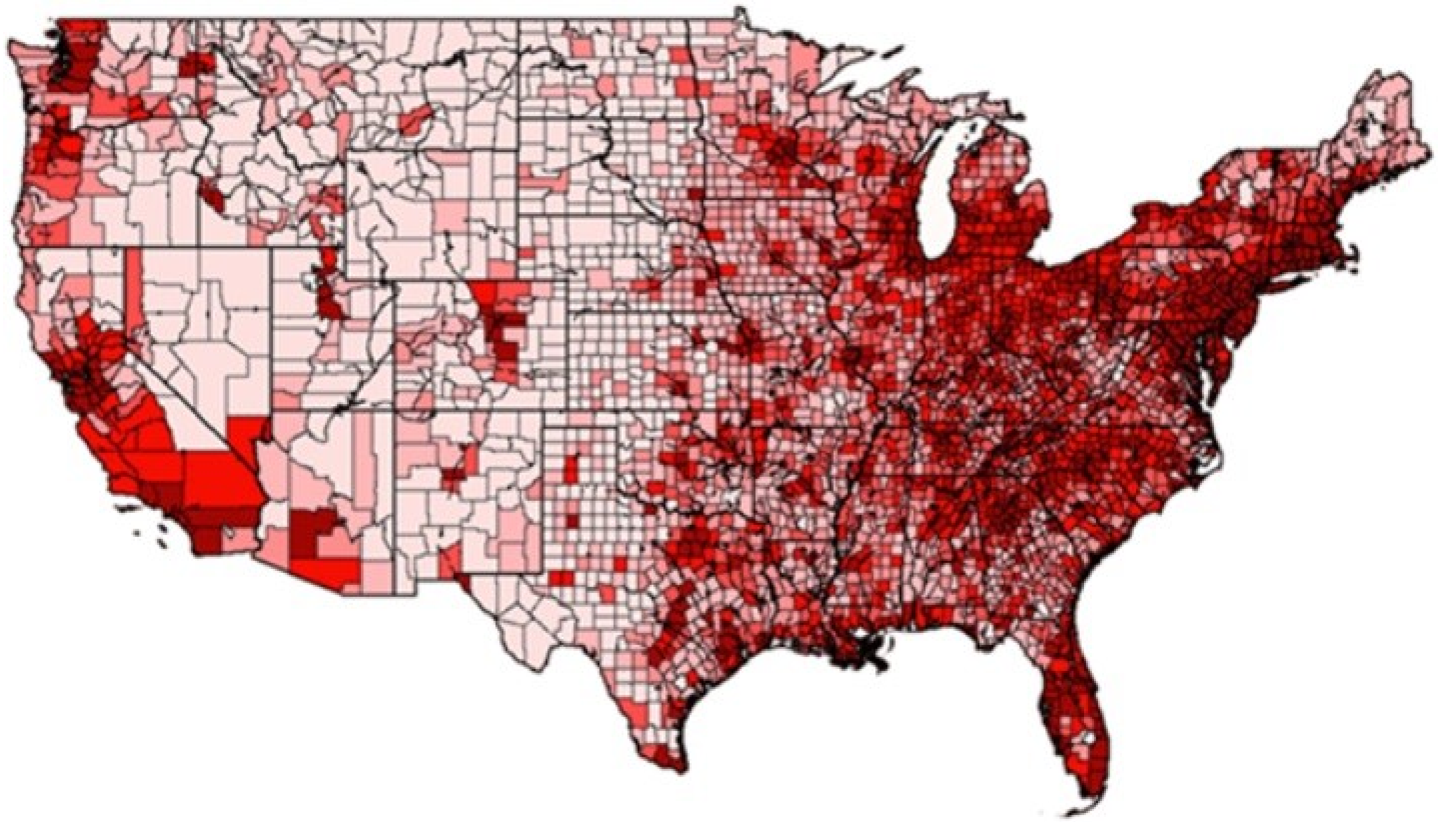
- High surface winds

Environmental



- High rainfall

Environmental

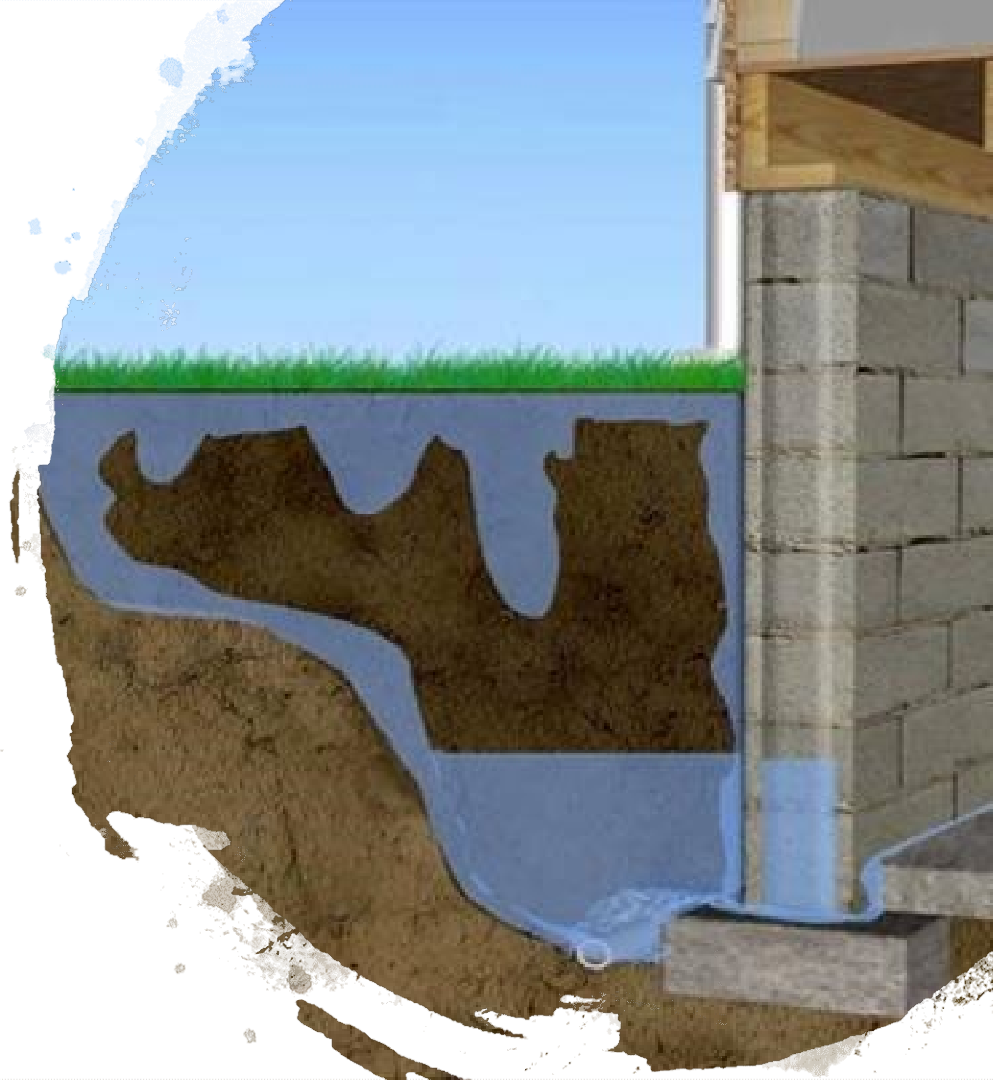


- Major population centers we also have the “heat island effect”, high concentrations of airborne pollutants and CO_2 emissions all contributing to the damaging environmental conditions.
- Protecting our buildings and infrastructure requires a robust protective systems designed and tested to withstand these conditions.

Above Grade
Concrete Waterproofing* Solutions
Points to Consider

Waterproofing & Damp Proofing

- Waterproofing is a treatment of a surface structure to resist the passage of water under hydrostatic pressures. Resisting moisture in a liquid state.
- Damp Proofing is a treatment of a surface structure to resist the passage of water in the absence of hydrostatic pressure. Prevents or reduces the flow of water through building components in a gaseous state.
- Does "waterproofing" apply to above grade elements – horizontal - vertical?



Hydrostatic pressure trivia:

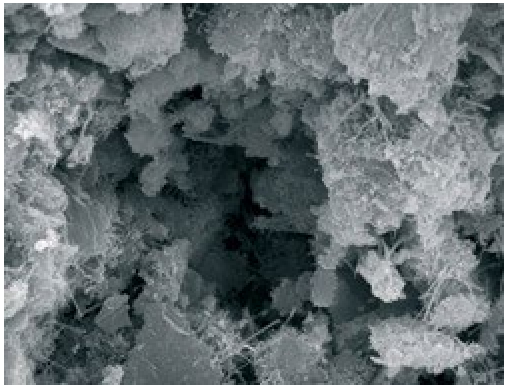
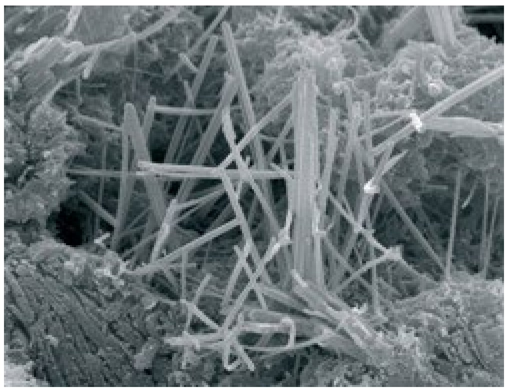
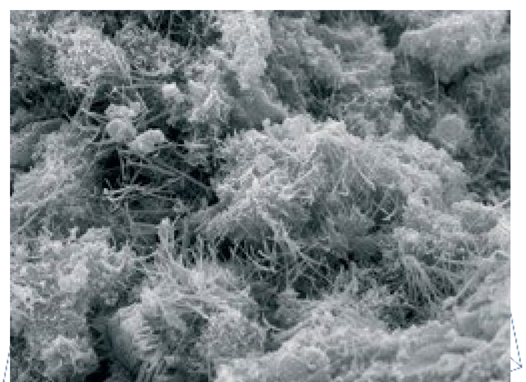
- 1 ft of fresh water is approx. 0.433 psi
- 1 psi of fresh water is a column 28 in high

A Need For Masonry Protection

- Regardless of condition or quality of the concrete it will remain both permeable and porous and subject to deterioration as result of the presence of moisture in the structure.

- Moisture being the root cause or key contributing factor in concrete deterioration.

- Chloride ingress, ASR, Freeze-thaw, Sulphate attack - all require the presence of moisture to act as a vehicle to transport soluble ions into the concrete matrix.

Admixtures & Surface Treatments

Crystalline Waterproofing

- Used as either a topical treatment on existing concrete or as an admixture prior to placement.
- Reacting with available water the crystalline structures develop within the open pores, capillaries and hairline cracks of the concrete to seal against further moisture ingress.
- Crystal structure becomes an integral part of the concrete and will continue to react with available water.
- Recommended for negative and positive side waterproofing.
- Limited to use on hairline cracks and not suitable for dynamic cracks.

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Admixtures & Surface Treatments

Mineral Silicates

- Can be incorporated as an admixture or as a topical densifier.
- When combined with inorganic pigment mineral silicates are also used as decorative coatings.
- The silicate reacts with the Calcium Hydroxide in the concrete to create Calcium Silicate Hydrate.
- Fills open pores in the concrete vacated by evaporating water during the curing process.
- Not a “waterproofing” system as it will not bridge or prevent cracking.
- Creates a permanent bond with the substrate and some positive attributes to reducing the incidence of efflorescence.
- Sodium – Potassium - Lithium

Admixtures & Surface Treatments

Water Repellents

- Silanes and siloxanes are two most common penetrating water repellents/sealers.
- Remain vapor permeable and non film forming, don't transform appearance of the concrete.
- Can be used horizontally and vertically.
- Weather over time and require re-application.
- Not a "waterproof" system.
- Silane chemically reacts with the Calcium Hydroxide in the concrete to form a hydrophobic layer within the pores and on the surface of the concrete.
- Only effective on concrete or masonry and penetrate deeper than Siloxane.
- Siloxanes react with atmospheric moisture and moisture in the substrate.
- Usable on non cementitious materials like clay, brick and stone.

Waterproof Masonry Coatings

- Includes high build acrylic and elastomeric waterproof coatings.
- Selection and application of the right coating system can mitigate adverse environmental effects.
- Compensate for defects in placement, overcome some of the inherent problems with concrete.
- Concrete can be a very challenging building material to work with.
- The challenge is to design a breathable, waterproofing and protective coating system to maximize service life potential of the concrete structure.
- As not all coatings are created equal therefore it is vital to understand the information presented and the interpretation to ensure optimum system design.

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Waterproof Masonry Coatings

- There is no substitute for a protective coating barrier between the substrate and the elements responsible for its deterioration.
- To protect against moisture infiltration, provide crack bridging and in doing so we can also protect against CO_2 diffusion and chloride ingress.

Waterproof Masonry Coatings

- And along with that protective barrier a coating will provide some aesthetic value even if it is just white ….. so much more appealing.
- Because of this the coatings will extend the deferred maintenance of the structure and ultimately increase the lifespan of the building.

Paint and Coatings

- Names are interchangeable but satisfy different performance criteria.
- Same 4 basic components: Binder, Pigment Solvent and Additives.
- Applied in a fluid form that coverts to solid on the substrate, both provide some level of surface protection and have aesthetic value.
- Similarity these building blocks are also the point of differentiation between paint and coatings.
- They are linked to both the performance of the product and the aesthetics it provides.

Pigmentation & Color

- Primary pigments provides color and hiding and provide the coating with the opacity necessary to hide underlying substrates.

- Titanium Dioxide (TiO2) is the predominant white pigment in a coating.

- Color pigments are classified as organic or inorganic depending on chemistry and incorporated into coatings in the powdered form as part of the manufacturing process or as a liquid dispersion colorant at point of sale.

- Organic colorants are generally brighter colors but exhibit poor exterior durability. Inorganic pigment colors are based on metal oxides and produce the more light stable earth tones.

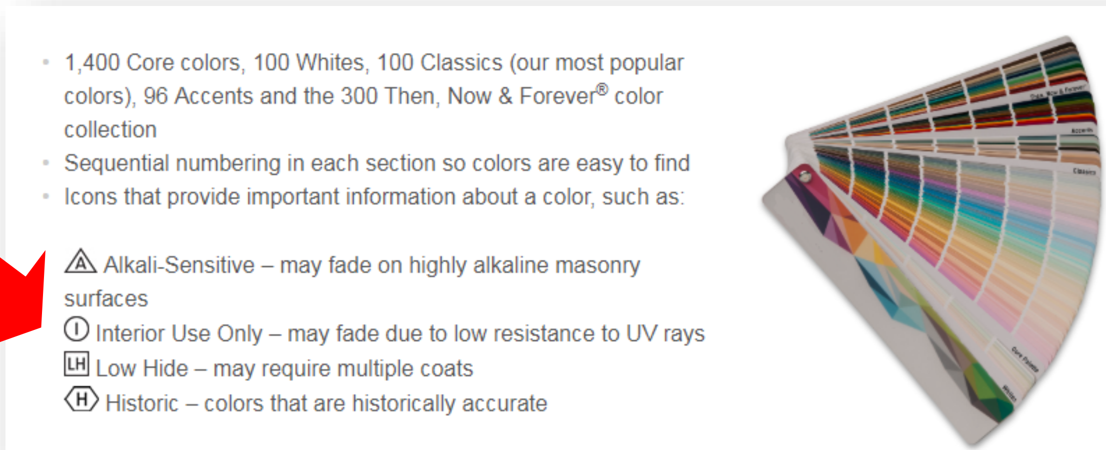
Pigmentation & Color

- Predominant use of organic colors in commerce today creates a special set of challenges for the paint and coatings manufacturers.

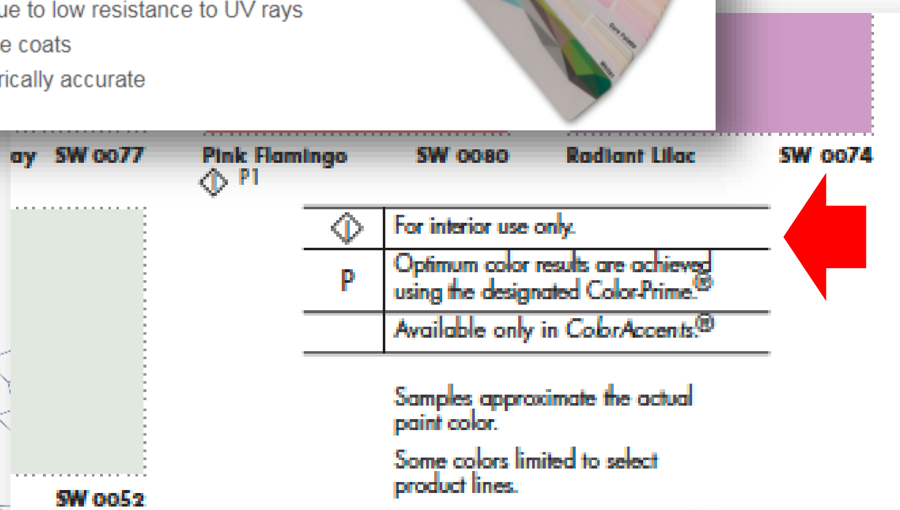
Pigmentation & Color

- Paint manufacturers will seldom support the use of these colors making specific exclusions because of the sensitivity of these pigment types.

- A commercial coatings manufacturer will take the extra steps to offer a more durable solution with higher cost inorganic pigment substitutes.


- 1,400 Core colors, 100 Whites, 100 Classics (our most popular colors), 96 Accents and the 300 Then, Now & Forever® color collection
- Sequential numbering in each section so colors are easy to find
- Icons that provide important information about a color, such as:

⚠ Alkali-Sensitive – may fade on highly alkaline masonry surfaces
Ⓘ Interior Use Only – may fade due to low resistance to UV rays
LH Low Hide – may require multiple coats
H Historic – colors that are historically accurate



I	For interior use only.
P	Optimum color results are achieved using the designated ColorPrime.®
	Available only in ColorAccents.®

Samples approximate the actual paint color.

Some colors limited to select product lines.

Performance Standards

- ASTM tests are the industry standard despite inherent problems in the test methods.
- Few tests were originally designed with coatings in mind and there is often more than one ASTM test for any particular performance measure.
- Manufacturers are at liberty to select their preference and standardized test procedures do not necessarily reflect real life coatings applications either.

ASTM INTERNATIONAL

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Performance Standards

Performance Comparison	**BRAND A**	**BRAND B**	**BRAND C**	**BRAND D**	**BRAND E**	**BRAND F**	**BRAND G**	**BRAND H**
Performance Tests								
ASTM E 96 Permiability	■					■	■	■
ASTM D 1653 Water Vapor Trans.	■	■	■	■	■			
ASTM D638 Tensile Strength psi	■							
ASTM D 638 Elongation	■							
ASTM 412 Tensile Strength						■		
ASTM 412 Elongation at break						■		
ASTM D2370 Tensile Strength			■	■				
ASTM D2370 Elongation			■	■				
FED. SPEC. TT-C-555B		■			■			■
D 6904-3 Wind Driven Rain	■		■	■		■		
ASTM G 23 Accelerated Weathering		■						
ASTM G 26 Accelerated Weathering							■	■
ASTM G 155 Accelerated Weathering				■				
ASTM D 4587 Accelerated Weathering					■			
ASTM D 6695 Accelerated Weathering	■							
EN 1062 - 6 CO2 Diffusion Coefficient (air ft equiv.)	■	■			■	■	■	■
ASTM F2476 CO2 Diffusion Coefficient (air ft equiv.)				■				
ASTM D 968 Sand Abrasion 3,000L	■	■			■			
ASTM D 418 Abrasion Resistance								■
ASTM C 666 Freeze/Thaw Durability								■
Freeze/Thaw 50 cycl. DOT method		■						
ASTM D 3273 Mold Resistance	■	■	■	■	■	■		
ASTM 3719 Dirt Pick Up 6 months		■			■			
ASTM D 4214 Chalking		■			■			
ASTM D 1792 Visual Color Change		■			■			
ASTM B 117 Salt Spray	■	■			■			■
ASTM D 4587 UV Exposure	■							
ASTM D 522 Flexibility Mandrel Bend	■	■	■	■	■	■		■
ASTM 2794 Impact Resistance 30 in-lbs		■			■			■
ASTM D 1308 Alkali Resistance			■	■				
ASTM E 1164 Light Reflectance				■			■	
EN 1062-7 Crack Bridging					■			
ASTM 2247 Moisture Resistance						■		
ASTM D 4541 Adhesion to Concrete						■		

- ASTM references hold have little value as a cross reference tool.

Performance Standards

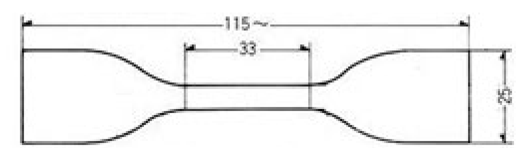
Elongation & Tensile Strength

- ASTM D2370 – 16
  Standard Test Method for Tensile Properties of Organic Coatings
- ASTM D638 – 14
  Standard Test Method for Tensile Properties of Plastics
- ASTM D412 – 16
  Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers

Technical Data

REPORT	TEST METHOD	TEST CRITERIA	TEST RESULTS 80211	TEST RESULTS 80212
Crack Bridging	ASTM C-1305	At -15ºF (-26ºC)	N/A	Pass No cracking
Tensile Strength psi (MPa)	ASTM D-412		290 (2.00)*	290 (2.00)
Elongation at Break (%)	ASTM D-412		450*	450
Flexibility, Mandrel Bend, % Elongation	ASTM D-522	At 70ºF (21ºC) At -14ºF (-26ºC)	>32 (no crack) >32 (no crack)	>32 (no crack) >3[illegible]
Moisture Resistance	ASTM D-2247	14 day exposure	No Deterioration	No[illegible]

Resistance to wind-driven rain – ASTM D69	
Fungal resistance – ASTM D3273	
Elongation (at break) at 73°F (23°C) and 50% relative humidity – ASTM D638	825%
Tensile strength – ASTM D638	65 psi (0,45 MPa)
Mandrel bend test – ASTM D522	Passed (no cracking)
Mandrel bend test – ASTM D522	Passed (no cracking)



- Test method and apparatus may be similar the results cannot be correlated
- Test requirements do not reflect actual applications: ASTM D 412 requires testing at 3.0mm (118 mils)

Performance Standards

Coatings Testing

- ASTM D4541
  Pull Off Strength of Coatings (metallic substrates)
- ASTM D7234
  Pull Off Adhesion Strength of Coatings on Concrete

Moisture Resistance	ASTM D-2247	14 day exposure	No Deterioration
Mold Resistance	ASTM D-3273	90 day exposure	No Mold Growth 85% Relative Humidity
Adhesion to Concrete psi (MPa)	ASTM D-4541		320 (2.20)
Water Vapor Permeability (ng/Pa·s·m²)	ASTM E-96 Wet-cup method	1 coat	25 (1434)
Carbon Dioxide Diffusion Resistance	EN-1062		1,400,000

- ASTM 7234 Pull Off Adhesion Strength of Coatings on Concrete, a test bias becomes a factor as a result of the various pull off testing apparatus that is used.

Performance Standards

Coatings Testing

- ASTM G23
  Carbon Arc Exposure With and Without Water Exposure (withdrawn 2000)
- ASTM G26
  Xenon Arc Exposure With and Without Water Exposure (withdrawn 2000)
- ASTM G155
  Xenon Arc Exposure for Exposure of Non Metallic Materials
- ASTM D4587
  Fluorescent UV Condensation Exposure of Paint and Coatings
- ASTM D6695
  Xenon Arc Exposures of Paint and Related Coatings

PROPERTY	RESULTS	TEST METHOD
Resistance to wind-driven rain	Meets requirement – no water penetration	TT-C-555B
Accelerated weathering, 5,000 hrs	Passes	ASTM G 23, Type D
[illegible]	Passes	ASTM D 1729

Flame Spread and Smoke Development (ASTM E-84-94)	Flame Spread: 0	Smoke Development: 5	Class Rating: A
Weathering (ASTM G-26)	2000 hours	Excellent, no chalking or cracking.	
Light Reflectance Value (ASTM E-1164)		91%	

- Accelerated weathering tests are the window on the future performance of a coating on exposure.

Industry Standards

- There are no unifying regulations in the coatings industry that maintains quality standards.
- American Coatings Association acts on behalf of the industry largely as an advocacy group.
- Federal regulations primarily concerned with health and safety and consumer protection.
- The 1998 EPA AIM rule restricted VOC emissions within the coatings industry.
- The South Coast Air Quality Management District established the first emission standards for the industry and that has really driven manufacturers to focus R&D efforts on VOC reduction.

Industry Standards

- Consumer groups establish minimum performance standards with approved product lists and approved vendors.
- Or in the case of USGBC placing further environmental limits on coatings products.

Industry Standards

- Giving rise to independent bodies to provide the authentication standards
- And independent testing and forensic laboratories for qualification.

Industry Standards

- As well as a dedicated media to promote what is best, new and exciting in the industry.
- But it also exists as an independent resource for many of the research articles that expose it's shortcomings

Industry Standards

- The Master Painters Institute (MPI) and Sealant Waterproofing & Restoration Institute (SWR Institute) develop product performance validation programs or establish standardized performance criteria.
- Membership is voluntary and requires a considerable financial commitment.
- MPI has been adopted by the Department of Defense and Department of Education and is also the minimum performance requirement in specifications using the Avitru (formerly ARCOM) (AIA) Masterspec system.
- SWRI validates manufacturers' own product claims presented on their tech data sheets through independent 3rd party testing.
- More likely to reflect a product's true capability versus a minimum standard.

Summary

- We know that a concrete structures are not permanent and there are a variety of factors affecting longevity.

- Regardless of condition or quality of the concrete it will remain both permeable and porous and subject to deterioration as result of the presence of moisture in the structure.

- Sooner or later defects are going to appear.

- There are a number of methods and to reduce the severity of the deterioration. Surface coatings offer a better solution to more of the problems encountered with concrete.

- With the selection and application of the right coating system, adverse environmental effects can be mitigated, and to some degree compensate for defects in placement to extend and optimize the service life of the structure.

- The performance qualities of these coating products is subjective as there are no industry standards.

- To avoid expensive mistakes owners and specifiers need to look for product credentials beyond the manufacturers' own product claims.