CONCRETE BRIDGE AESTHETICS, COATINGS AND COLORS

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ABSTRACT

This paper focuses on bridge aesthetics, coatings and colors for concrete structures; values becoming more popular as in-panel precast design and color specification demands increase over just structural protection needs.

Modern coating systems protect concrete and masonry against the elements by two different strategies: forming either a continuous, nonporous film or an open-pored water-repellent coating. Traditional paints, with organic polymer binders, follow the first strategy. The alternative is that found in coating systems known as silicone resin emulsion paints (SREP).

This paper, outlines performance limitations of conventional closed film coatings, then expounds dynamics of silicone resin emulsion paint (SREP) as a preferred coating system for concrete bridges, overpasses and related infrastructure.

Why SREP? Excellent durability and weather resistance lead; it endures for decades, having been tried and tested on over a million building facades. These paints "breathe," while providing an excellent shield against moisture – highly resistant to the effects of pollution, temperature and UV degradation – that does not bubble, crack or peel.

Moreover the mineral matte surface eliminates gloss and side sheen. Fade resistant oxide pigments deliver a wide spectrum of colors that, in tandem with a self cleaning surface resistant to mold and mildew, remain bright and clean.

And a fiscally accountable system; the expected life between recoats is 20-30 years – saving major maintenance needs and costs.

Keywords: Aesthetics; Architecture; Breathable, Bridge design; Bridge infrastructure,; Bridges; Color, Concrete, Design; Environmental engineering; Fade Resistant, Mildew, Mold, Parapets; Silicone Resin Emulsion Paint, SREP, Structural design, UV.

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INTRODUCTION

The commentary in this paper is based around concrete bridges given the large use of precast concrete in the same. The issues described for concrete bridges are similar to issues experienced with other above-grade precast concrete structures; retail complexes, parking garages, condominiums, warehouses, industrial complexes, office blocks to homes (though the relevancy of issues may vary to different types of structures).

The primary value for bridge aesthetics is design – from an architectural perspective as much as function. How the design values are perceived are – to a degree – in the eye of the beholder; however structural transportation infrastructure generally has such a bold presence that style, beauty and taste are visual components for all to experience. The Golden Gate Bridge in San Francisco is world-renowned for its beauty; the Milleau Viaduct in southern France for its sheer audacity in size and environmental presence.

Aside from the engineering and function of a bridge, architecture and design aesthetics encompass numerous values such as balance of form and harmony, contrast between form and mass, proportion, appearance of strength and stability through to decoration. The scope of the designer/architect balances the competitiveness of a bridge design not just in terms of financial cost, but also aesthetic principles and environmental concerns[1]. Even lighting plays a role in defining the design values and highlighting the structure as part of the environment at night.

Moving from the general aesthetics to concrete bridge infrastructure; for concrete structures traditionally left bare – such as bridges, ramps, flyovers – there is an ever growing trend to use coatings. Without a coating an attractive, dynamic design can see its aesthetics spoiled with the concrete becoming increasingly dirty and discolored over time.

Partly driven by changing environmental values in urban living (the "concrete jungle"), partly driven by improving aesthetics and partly driven by the need for structural protection there are major coating programs being applied on concrete bridge structures.

From the public sector, there is an urgency to protect infrastructure as the funds to repair, rehabilitate or replace the same are becoming scarcer. A design life for bridges of 100-years is becoming more the standard than, say 40-years, that may have applied ten years ago.

OVERVIEW

Given that bridge structures are highly visible and, in numerous cases, symbolic with a long service life; they are also expensive assets.

Add to the equation that structures are costly to maintain due to difficult access, the costs involved to remove failed materials, conduct repairs then apply replacement materials to meet upkeep, preservation and aesthetic needs. These values are compounded with the need to limit use – even shut down – operating aspects of the structure thus creating inconveniences for users and extending the time required, whilst adding cost, to the rehabilitation process.

As such, the interest to having a long life, durable coating system becomes of paramount interest – and a financial responsibility.
Cementitious and mineral building materials such as concrete are hygroscopic (absorb water) and need protection from moisture. The use of coatings on concrete bridges is for protective and/or decorative purposes.

Fig. 1 Example Painted Suspended Concrete Freeway

PROBLEM CHARACTERISTICS IN CONVENTIONAL COATINGS

As a continuous, nonporous film, conventional latex/acrylic emulsion coatings are used widely.

In the production of resins used in these coatings, such as Alkyds, Polyvinyl Acetates and Acrylics, long organic polymer chains are formed in a process called free radical polymerization. A catalyst is added to monomers in a reactor and a chain reaction is formed. The radical moves along the chain and grabs monomers.

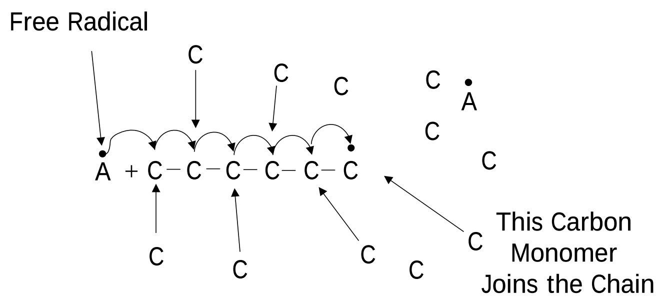


Fig. 2 Organic Polymer Chain (1)

When there is no monomer left to join on to the chains the chains are terminated when a radical group joins onto the end of an "active" chain.

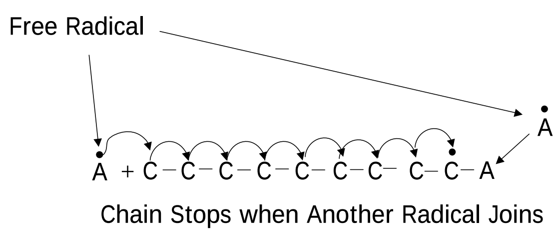


Fig. 3 Organic Polymer Chain (2)

When the paint is manufactured the resins are dispersed in either solvent or emulsified in water. When the solvent or water dries out the long polymer chains stick together and form a continuous film trapping the pigments and extender to make a final paint film.

Ultraviolet (UV) Light

Ultraviolet (UV) light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than soft X-rays. It is so named because the spectrum consists of electromagnetic waves with frequencies higher than those that humans identify as the color violet.

UV light is typically found as part of the radiation received by the Earth from the Sun.

Many polymers used in consumer products are degraded by UV light, and need addition of UV absorbers to inhibit attack, especially if the products are used externally and so exposed to sunlight. The problem appears as discoloration or fading, cracking and sometimes, total product disintegration if cracking has proceeded far enough. The rate of attack increases with exposure time and sunlight intensity.

It is known as UV degradation, and is one form of polymer degradation. Sensitive polymers include thermoplastics, such as polypropylene and polyethylene as well as specialty fibers like aramids. UV absorption leads to chain degradation and loss of strength at sensitive points in the chain structure. They include tertiary carbon atoms, which in polypropylene occur in every repeat unit[2].

When looking at conventional coatings exposed to UV;
1. Ultraviolet (UV) rays can vibrate and attack the chain.
2. Pigments absorb UV and release free radicals
3. The free radicals attack the chain
4. The chain is cut it into parts
5. The paint film degrades and becomes weaker

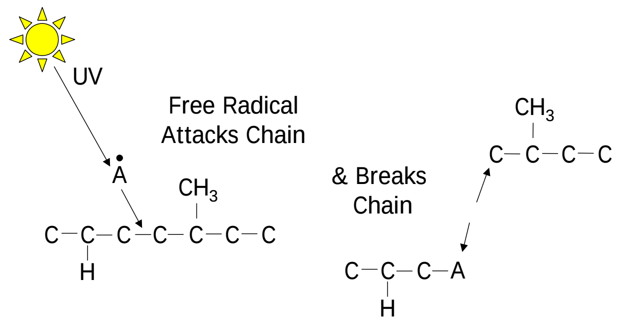


Fig. 4 Effect of UV on the Organic Polymer Chain

Chalking

Other than cracking/peeling or flaking the most obvious form of paint degradation is chalking and fading of paint. Chalking is where the surface looks white and powdery. The weakening and breaking of the film by UV attack, dislodges pigments, which appear as the powdery surface. Each year a certain amount of the paint film is lost to UV degradation.

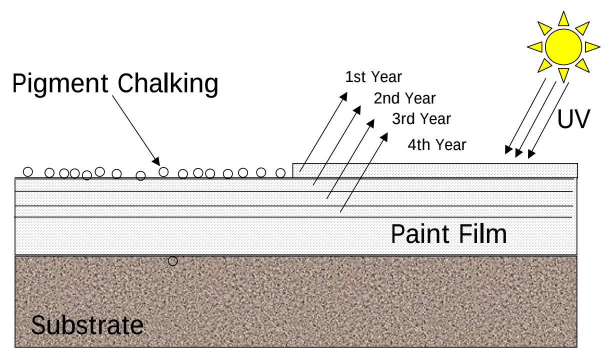


Fig. 5 Pigment Chalking

- UV attacks organic polymers
- Polymer chains weaken and break
- Film degrades and loosens pigments/extenders
- As result, Pigments migrate to surface
- Powder on surface makes the surface look white and chalky

Tinter Pigments

(Fading)

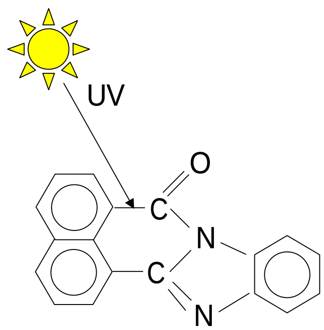
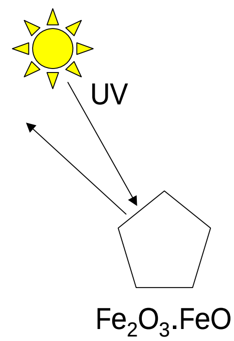
ORGANIC	INORGANIC
	
▪ Element with free radicals will alter the structure of pigments ▪ UV attack breaks the structure and fading will occur	▪ Pigment structure is more stable ▪ UV does not affect pigment ▪ No fading

Fig. 6 Comparison of UV on Organic and Inorganic Tinters

Mold And Mildew

Seen generally as black marks that discolor the wall and attack a polymer film, the environment for mold and mildew growth are warm, moist conditions and organic compounds – available from the coating as well as dirt pick up – serving as “food” for mold/mildew

Dirt Pickup

There are two factors that influence dirt pick-up; surface charge and roughness of the surface/angle of exposure.

For conventional emulsion paint the exterior surface always has a negative charge; generating an electrostatic force that attracts the positively charged airborne dirt particles and dust. Rough surfaces such as texture coats pick up dirt. In addition, conventional emulsion paint are generally thermoplastic; under the sun’s heat they become slightly sticky thus allowing dirt to become ingrained into the surface.

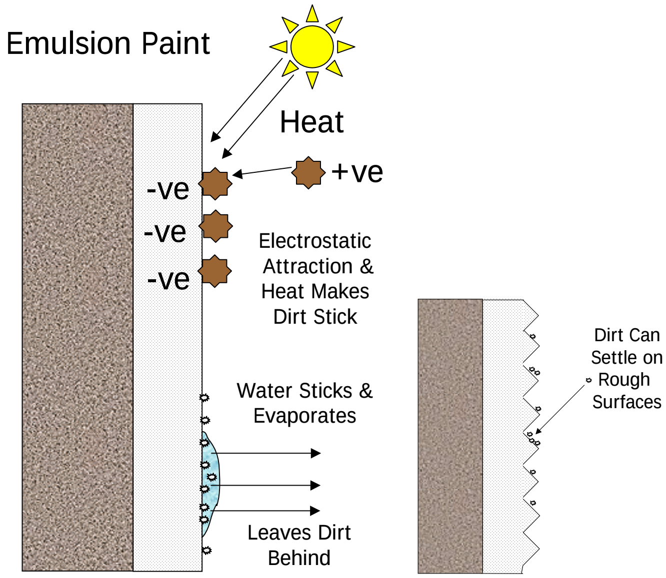


Fig. 7 Surface Charge and Textured Surface Detail

Any surface roughness will allow dirt to settle – such as a texture coating – plus exposed sloped or horizontal painted areas such as ledges and window sills.

Moisture

Moisture can get behind a paint film in many ways. Concrete substrates are hygroscopic attracting and retaining moisture; general humidity, cracks in the film, ground water, curing can all generate moisture behind a paint film.

Fig. 8 Example of Bubbling and Peeling Paint

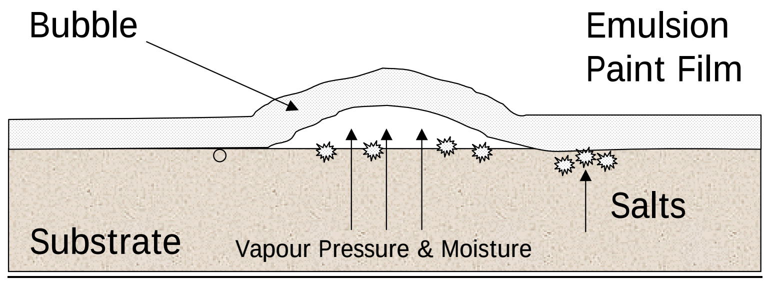


Fig. 9 Detail of Causes to Bubbles in Paint

Emulsion paints and solvent based paints form a closed film that does not breathe well; if moisture cannot breathe out, it pushes up against the surface. Alkalis and dissolved salts within the substrate attack the paint/substrate interface reducing the coatings' adhesion. Ongoing vapor pressure overcomes paint adhesion and bubbles are formed and these bubbles tend to crack. Cracks will let more moisture behind the coating and the resultant cycle leads to widespread cracking, peeling and flaking.

SILICONE RESIN EMULSION PAINT (SREP)

Silicone Resin Emulsion Paint (SREP) was invented by Wacker Chemie AG – a worldwide operating company in the chemical business – in 1963. The first applications in Germany from the 1960s are still going strong, with excellent fade resistance, clean appearance and strong water repellency. It is well understood in chemical engineering that silicone (and its derivatives) are inorganic/organic hybrids and completely UV resistant – whereas latex/acrylics and other organic compounds degrade with UV exposure. Over 1,000,000 projects have been completed around the world using SREP products.

The secret of success – the chemistry of silicone resin emulsion paints. Silicone resins have a chemical structure midway between that of purely inorganic and purely organic substances. Their molecular structure is based on that of quartz, a form of silicon dioxide (SiO2). The backbone consists of silicon and oxygen atoms. Unlike quartz, however, every fourth oxygen atom is replaced by a water-repellent organic R group. Silicone resins are more inorganic in character than all other silicones.

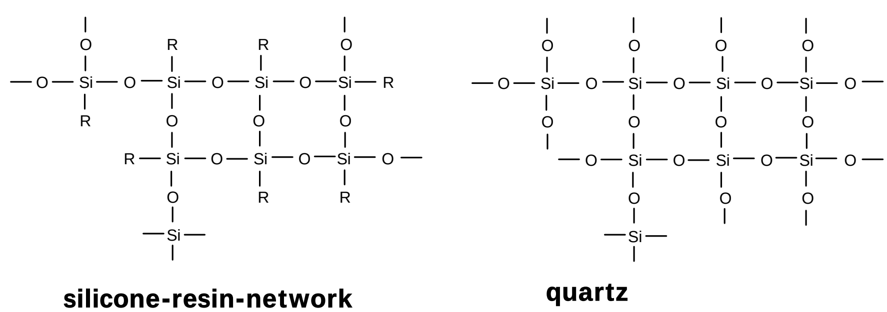


Fig. 10 Comparison of SREP Network and that of Quartz

Silicone Resins bear a strong resemblance to quartz and therefore are termed "quartz-like"; quartz being one of the most stable and durable compounds known to man.

In the production process, hydroxyl (-OH) groups are also incorporated into the silicone resin macromolecules. These groups are important for ensuring that the silicone resin bonds to the solid pigment and filler particles in the paint and also that the paint bonds firmly to the mineral construction material. In both these cases simple physical adhesion is supplemented by a chemical reaction. Pigment and filler particles, as well as mineral construction materials, all contain hydroxyl groups on their surface, which are bonded to metal or silicon atoms. Now, these hydroxyl groups can chemically react with the hydroxyl groups of the silicone resin with the elimination of water. As a result the silicone resin bonds firmly to pigments, fillers and construction material. At the same time, the hydroxyl groups still present in the macromolecules of the silicone resin react with water molecules. This produces crosslinks between the resin macromolecules at several points, forming a typical three-dimensional silicone resin network.

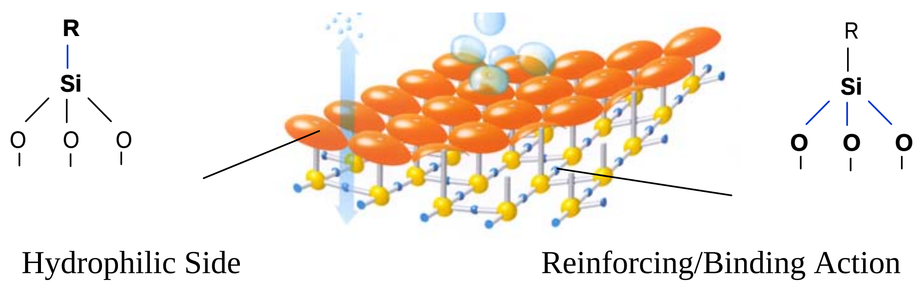


Fig. 11 Detail of Typical Three-dimensional Silicone Resin Network

The R group aligns together to provide a water-repellent surface. It does not allow liquid water to enter the film/substrate yet allows water vapor to escape. This structure is similar to the way Gore-Tex can breathe.

The silicone and oxygen parts of the silicone resin are a very strong binder and act as a reinforcing agent binding pigment, extender and also have an affinity to the substrate and so bind in strongly. The organic "R" group aligns itself on the outside and provides strong water repellency. This happens on the surface of the paint and within all the pores of the paint.

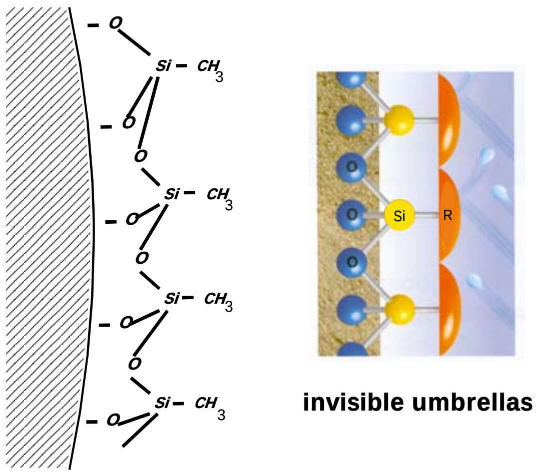


Fig. 12 Close Up Detail of Typical Three-dimensional Silicone Resin Network

Seen on a molecular scale, the surface of a filler particle is bonded to the inorganic portion of the silicone resin via silicon-oxygen bridges (three in the diagram). The inorganic portion of the silicone strengthens the filler by "lining" the capillaries, pores and cavities. Wacker chemists call this "pore reinforcement." These three silicon-oxygen bridges also bond to the particle surface in such a way that the organic groups R of the silicone resin project – like tiny umbrellas – out of the surface into the cavity. The organic groups make the surface water repellent. These two phenomena, hydrophobic pores and a reinforced pore structure, are the secret of silicone paints' success.

Silicone Resin Structure In A Paint Film

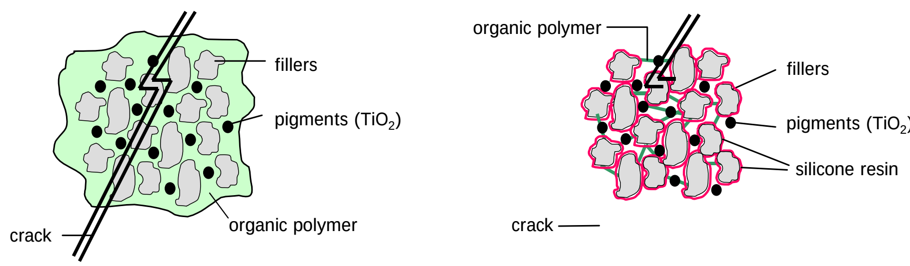


Fig. 13 Pictorial Diagrams of Conventional Emulsion Paint Against SREP

(Left) Organic Polymers bind in all the pigment and extender in a closed film. (Right) Silicone Resin acts as reinforcing along with some special organic polymer to form an open structure. Each of the pores is lined with R groups that repel water. The open structure allows the passage of water vapor out.

The silicone resin is resistant to acids – such as acid rain – and the ultraviolet and infrared components of sunlight. The upshot is excellent weathering resistance and outstanding durability.

Fade Resistant Inorganic Pigments

Inorganic oxide pigments not only provide excellent resistance to fading but also provide a natural and earthy color palette; colors whose neutral tones never go out of fashion. A large range of standard colors plus the ability to match to most charts - strong organic pigment colors excepted – allows versatility and creativity for owners and specifiers.

Fig. 14 Example of Color Finishes in SREP Applications

Self Cleaning Effect Of Silicone Resin Emulsion Paint

Dirt pick-up is minimized because the surface is repellent due to electrostatic repulsion. Dirt can however settle on rough surface or sloped/horizontal surface. As SREP is not thermodynamic it does not become sticky when heated; therefore any dirt that does settle on the surface does not bind to the paint.

When the surface comes in contact with water, the water beads and runs down the surface. As any dirt is generally loose and may be repelled the water tends to pick the particles and wash them away.

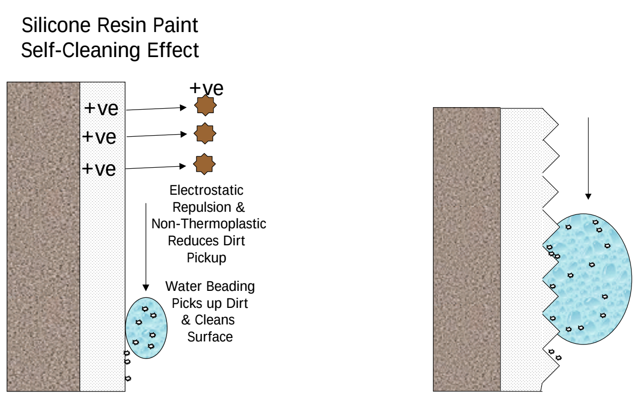


Fig. 15 Surface Charge Repellency and Water Beading Detail

Resistance To Microbial Attack

As mentioned earlier mold, mildew, algae and fungus prefer warm, moist conditions with food being organic matter in the film or by dirt pick-up. By keeping the surface dry, SREP minimizes the moisture content on the surface and so reduces the chance for microorganisms to grow. And as SREP is mostly inorganic it provides less food for microbes.
The lower dirt-pick-up and self-cleaning effect provide less food in the form of soiling while effective biocides are included in the formulation to also prevent microbial attack; both in the can and on the wall.

Low Thermal Conductivity

If a wall is painted in the same color with a SREP and a conventional emulsion paint, then receives the same exposure to the sun, the SREP seems much cooler to touch. The open structure of silicone resin paints acts as an insulating barrier – by keeping the substrate dry, moisture is not heated up; what moisture is heated up can easily escape as vapor. With conventional emulsion paints the moisture remains behind the paint film in the substrate.

Disadvantages Of Silicone Resin Paint:

While the actual abrasion resistance is good, when touching the paint surface by hand, the matte surface can be marked/polished – a property that improves with time. Whilst SREP is more expensive to produce it lasts significantly longer. Only available in matte or flat finish it cannot be produced in gloss/semi-gloss for certain applications

FINANCIAL ACCOUNTABILITY

We are witness to many painted concrete bridge and freeway structures whose coatings are in advanced stages of failure – paint peeling and falling away, colors faded, chalking well evident – and, in some cases, these structures were only painted in the past 2 to 5 years.

Typically, the cost of the paint itself is some 1% to 10% of the cost of painting a structure subject to amount of labor, scaffolding/lifts and preparation required. On average, the repaint cycle for conventional coatings 7-8 years – that is not always practical given the extraordinary costs involved in removal of failed materials and rehabilitation of the structure prior to painting.

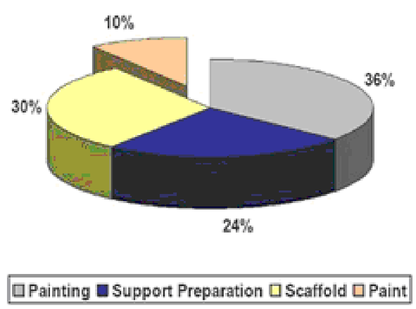


Fig. 16 Atypical Cost Sectors for Repainting Concrete Structures

A long life coating like Silicone Resin Emulsion Paint (SREP) extend significantly the time between recoating cycles (20-25 years) and therefore eliminate regular maintenance and the associated costs. And that for a small investment in superior coating material like SREP – say, for a 200,000sqft area – may only amount to an additional $10,000 or so over that for a conventional coating at the outset.

As an illustration, example of an elevated freeway built on grade.

	Regular Acrylic Paint @ 200sqft/gallon/coat	SREP @ 320sqft/gallon/coat
200,000 sqft (2-coats)	$50,000 (@ $25.00/gal)	$62,500 (@ $50.00/gal)
Labor, lifts, equip etc (est.)	$250,000	$250,000
Repaint @ Year 7	$400,000*	Not required
Repaint @ Year 14	$400,000*	Not required
Total coat @ Year 20	$1,100,000	$312,500**

* Includes a nominal allowance of $100,000 for removal of failed coatings, surface preparation.

** Does not include high performance primer and its application that could add further 5-years or so life to the SREP coating – allow $150,000.

Fig. 17 Cost Analysis between Painting with Regular Acrylic Paint Every 7-Years to Painting with SREP Once every 21-Years

CONCLUSIONS

Despite the water repellency of conventional coatings concrete bridge, freeway and related structures are virtually impossible to waterproof given moisture intrusion from horizontal areas. The incidence of ASR is prevalent in many structures in many states – a situation compounded by the failure in conventional coating systems. Conventional coating systems deficiencies also include color fading and chalking that means structures require regular maintenance/repainting to retain their look – an impractical scenario to consider given the general lack of maintenance funding and the demand on such funds for more urgent, structural maintenance needs.

Silicone Resin Emulsion Paints (SREP) represents a pragmatic solution based on proven performance for over 40-years. From a wide range of color fast inorganic pigments through to ease of application the result is a bright and clean water repellent coating that provides outstanding protection and long term aesthetic performance.

Of course, coatings for concrete bridges deal with very similar issues to that other above-grade concrete structures; retail complexes, parking garages, condominiums, warehouses, industrial complexes, office blocks. For precast operations there is the benefit of coating sections prior to shipping to site (or painting once at site prior to installation) as practical – with non-fading colors any touch ups can be made post application and save significant amounts to that where painting crews and equipment would be deployed on the finished structure.

Fig. 18 Example Precast Warehouse/Office Complex.

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