LIFE CYCLE COST ANALYSIS FOR PARKING STRUCTURES

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I. INTRODUCTION

The purpose of this study is to ascertain four specific coating systems for use on parking garage structures. These coating systems, which are outlined herein, are identified in terms of life cycle cost performance. Information garnered for this analysis is taken from field observations and reports of Tnemec Company Representatives, The Journal of Protective Coatings and Linings (SSPC), and The National Association of Corrosion Engineers (NACE).

Coating systems for parking garage structures and their life expectancies are contingent upon the surface preparation method used at the point of fabrication. Surface preparation is the key to any structure or freestyle cycling, deicing salts, changes in environment, and exposure are of paramount concern to the user. The life cycle cost analysis in this study is broken out into three environments.

1. <u>Metropolitan Environment</u>
   Where industrial fumes, deicing salts, chemical corrosion, and physical abuse are daily influences on the life of a coating system.

2. <u>Marine Environments</u>
   Where structures or locations of towns or cities are in close proximity to marine environments where salt, fog, and moisture are its predominant exposure.

3. <u>Rural Environments</u>
   Where a structure is located in the mid-west or outside a metropolitan location where less frequent use or less severe exposures are present.

Life cycle cost or purpose of this analysis is defined as a point by where recoating of the entire structure would be mandated. This procedure would require power washing steel surfaces, touching up rust areas, and applying another topcoat of the finish material. Touch-up of existing structures during this time frame is not part of this analysis. Touch-up is defined as locations where rust blooms or abrasions from daily use are maintained.

SYSTEM 1

COATING SYSTEM

ZINC RICH URETHANE PRIMER/ EPOXY INTERMEDIATE COAT URETHANE FINISH COAT

A. <u>Benefit of System</u>

A three-coat system will provide the longest protection to the structure than any of the three systems noted in this analysis. The zinc rich primer will provide galvanic protection to the substrate encapsulated with an epoxy polyamide with a full field coat of aliphatic urethane. Life expectancy can be in the 20+ years range for this coating system.

B. <u>Coating System</u>

1. <u>Surface Preparation</u>
   SSPC-SP6

2. <u>Prime Coat</u>
   Tnemec 90-97 Urethane Zinc Rich Primer applied at 3.0-3.5 mils dry.

   <u>Explanation</u>
   The use of a urethane zinc rich primer provides galvanic protection to the base metal. The zinc rich portion of the primer becomes an anode to the base metal, thus sacrificing itself prior to actual corrosion taking place of the base metal.

3. <u>Intermediate Coat</u>
   Tnemec 27 Typoxy applied at 4.0-6.0 mils dry.

   The epoxy polyamide intermediate coat provides encapsulation of the prime coat, which retains galvanic protection of the zinc rich primer. A thicker film of epoxy supplies insulation to the zinc rich primer below it. By protecting the zinc rich primer, we are in essence saving the zinc rich primer's sacrificial elements prior to the actual need.*

   *Zinc rich primers are sacrificial materials. They do not sacrifice until an abrasion breaks the film to start the galvanic process.

4. <u>Top Coat</u>
   Tnemec Series 73 Endurashield III - Aliphatic Polyurethane applied at 3.0 - 4.0 mils dry. This aliphatic urethane can be shop-applied or field-applied depending on sequence schedule of the project. Aliphatic urethanes provide an ultraviolet screen to the materials below them. Urethanes, by their generic nature, will retain their color and gloss retention for extended periods of time. Should accent colors be utilized, we would recommend a fourth coat of Series 76 Endura-Clear at 1.0-2.0 mils dry to attain that extra color and gloss retention needed on the long term life expectancy. Aliphatic urethanes will not chalk and fade when exposed to

ultraviolet light. Their use over epoxy polyamides and increased film thickness in the entire coating system provide protection longer than a two-coat zinc and epoxy system that will be mentioned later in this analysis.

C. <u>Life Expectancy/Life Cycle Cost</u>

A three-coat system of 90-97 Urethane Zinc Rich Primer, 27 Typoxy polyamide epoxy and Series 73 Endurashield Aliphatic Urethane is worth approximately $300.00 - $310.00 per fabricated ton.

1. <u>Metropolitan Environment</u>: 20-22 years
2. <u>Marine Environment</u>: 18-20 years
3. <u>Rural Environment</u>: 22-25 years

SYSTEM 2

COATING SYSTEM

URETHANE ZINC RICH PRIMER/ EPOXY TOP COAT A TWO-COAT SYSTEM

A. Benefit of System:
The coating system of the urethane zinc rich primer and epoxy topcoat would derive more than adequate performance for intended use given the three exposures of which this analysis is based upon. As mentioned previously, the urethane zinc rich primer encapsulated by an epoxy polyamide topcoat will achieve high degrees of salt, fog, and corrosion resistance. The weak link in this chain is that a two-coat system, with epoxy being its finish coat, is not an ultraviolet resistant system. Should structural steel be exposed to ultraviolet degradation, chalking of the epoxy film will become apparent. Depending upon the depth of color, i.e., purple versus a white or light gray, the chalking becomes more apparent rapidly.

B. Coating System:

1. Surface Preparation:
SSPC-SP6 Commercial Blast Clean

2. Prime Coat:
Tnemec 90-97 Urethane Zinc Rich Primer 3.0-3.5 mils dry.

3. Intermediate/Finish Coat:
Tnemec Series 161 Fascure applied at 4.0-6.0 mils dry. (As a compromise between System 1 and System 2, Series 73 Endurashield could be applied (in field) on all perimeter steel where ultraviolet exposures are critical to color and gloss retention.)

C. Life Expectancy/Life Cycle Cost:
The zinc rich urethane primer topcoated with polyamide epoxy has an estimated cost per ton of $240.00 - $250.00 per fabricated ton.

1.	Metropolitan Environment:	18-20 years
2.	Marine Environment:	15-18 years
3.	Rural Environment:	20-22 years

D. Summary:
A two-coat zinc and epoxy system, such as one noted herein, has provided corrosion protection for a number of structures in the Boston area that are now at the 18-year benchmark. The Fanueil Hall Marketplace Garage has to date less than 1% corrosion visually displayed. Outside of Pittsburgh, a Mullack steel garage has experienced 22 years. Comfort level is fairly high with this coating system as it has performed well over a long period of time in a number of harsh environments.

SYSTEM 3

COATING SYSTEM

URETHANE ZINC RICH PRIMER/ URETHANE TOP COAT

A. Benefit of System:

The use of the urethane zinc rich primer, topcoated with an aliphatic high build urethane, offers life protection similar to System 2 with a number of exceptions. The urethane topcoat applied directly to the urethane zinc will provide enhanced ultraviolet degradation resistance and will maintain color and gloss protection for an extended period of time over epoxy polyamides. Although these systems render additional protection as mentioned, they are also accompanied by added material costs.

B. Coating System:

1. Surface Preparation:
   SSPC-SP6 Commercial Blast Clean

2. Prime Coat:
   Tnemec 90-97 Urethane Zinc Rich Primer 3.0-3.5 mils dry.

3. Top Coat:
   Tnemec Series 73 Endurashield III Aliphatic Polyurethane Acrylic applied at 3.0-5.0 mils dry. Aliphatic urethanes are a sound choice in lieu of polyamide epoxy as long as their cost benefit can be weighed. Other benefits of epoxy polyamide versus urethane is their compatibility with other non-ferrous metals. Urethanes require a prime coat of zinc rich primer or epoxy polyamide under them should they be going over other non-ferrous or ferrous metals. Epoxy polyamides are typically more compatible when directly applied to these substrates. This being their only limitation, galvanized connections, should they be chosen, may require a touch-up prime coat of a compatible primer for urethane finishing.

C. Life Expectancy/Life Cycle Cost:

On a cost per fabricated ton, the urethane zinc rich primer and urethane topcoat are estimated at $250.00 - $260.00 per fabricated ton.

1. Metropolitan Environment: 18-20 years
2. Marine Environment: 15-18 years
3. Rural Environment: 18-20 years

D. Summary:

One could expect similar performance to that of the zinc rich urethane and epoxy topcoat system. With the exception of color and gloss retention, aliphatic urethanes provide more than satisfactory protection against corrosion in all the three given environments.

SYSTEM 4

COATING SYSTEM

ALKYD PRIMER/
ALKYD TOP COATS

A. Benefit of System:

The alkyd systems using rust inhibitive primers and alkyd topcoats have been used on parking garages for over 30 years. The inherent flaw to these systems is lack of good surface preparation, but also fair overall performance in terms of long term exposure for the three given environments cited. Rust inhibition of an alkyd primer is a far cry from the galvanic protection afforded by the use of a zinc rich primer. Alkyd systems have been used periodically in the garage construction primarily by developers or design build efforts where up-front cost was the primary concern. Life cycle analysis system does not bode well for exposures to severe marine environments, deicing salts (as they are not resistant to salt), or for severe industrial and chemical fume exposures.

B. Coating System:

1. Surface Preparation:
   Minimum SSPC-SP3 Power Tool Cleaning
   SSPC-SP6 Commercial Blast Cleaning (recommended)

2. Prime Coat:
   Tnemec 4-55 Versare Primer at 2.0-2.5 mils dry. Alkyd rust inhibitive primer*.
   *Rust inhibitive products do not provide galvanic scarificial protection as that of zinc rich primers.

3. Intermediate Coat:
   Tnemec Series 23 Enduratone (field applied) at 2.0-2.5 mils dry.

4. Finish Coat:
   Tnemec 23 Enduratone field applied at 2.0-2.5 mils DFT.

C. Life Expectancy/Life Cycle Cost:

The mentioned alkyd system has an approximate cost of $150.00 - $170.00 per fabricated ton. This would include shop priming utilizing SSPC-SPC6 Commercial Blast Cleaning with two field applied finish coats.

1.	Metropolitan Environment:	10-12 years
2.	Marine Environment:	8-10 years
3.	Rural Environment:	10-12 years

D. Summary:

We do not recommend alkyd systems for the majority of the parking garage structures now constructed. This approach is a false economy based upon increased maintenance due to overall performance of the system in comparison to zinc and epoxy coating systems. Where first cost is of paramount concern, this is a viable system with the understanding that maintenance will escalate after expiration of the life cycle and will be costly.

III. CONCLUSIONS

The enclosed analysis of all four coating systems is based upon field observations and documentation recorded by Tnemec Company and The Structural Steel Painting Council. The Structural Steel Painting Council's 11-year study of zinc rich primers was a part of this analysis where it measured coating performance in three specific environments. Attached you will find that study. Overall performance of Systems 1, 2, or 3 will meet a majority of the design criteria set forth by most users of structural steel framing design. Should any of the three be included for use on a given project, their life cycle estimates are real and factual with two stipulations:

1. Proper design of the parking garage structure. This would include drainage of water away from the steel frame, proper construction details as to minimize water salting from deteriorating the structural framing, and uniform thickness of coating.

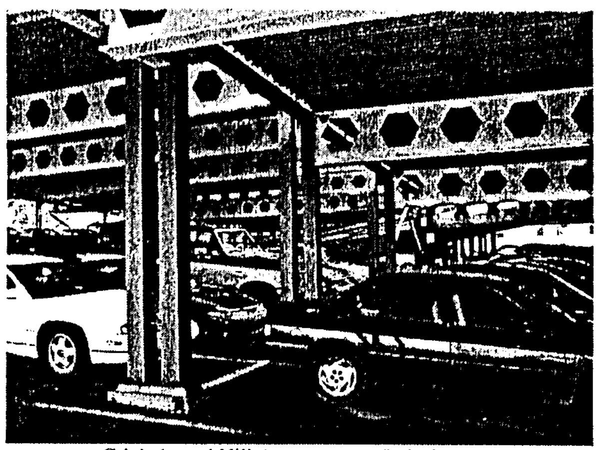
2. Designer and owner commitment to proper coating implementation and inspection. Millions of dollars are spent every year to protect both concrete and structural steel as a building element. Few dollars are spent to the actual coordination between structural drawings and related finishes. Inspection by qualified coatings personnel of the surfaces during fabrication, erection, and through to the end of construction is also greatly lacking. Without a commitment in these aspects of the process, expectations could be lowered solely based upon lack of good quality control throughout the process. Tnemec Company and its representatives have the commitment to make these two specific criteria a workable solution for both designer and user.

Enclosed you will find performance criteria data sheets outlining the specific systems for each coating mentioned herein. Performance criteria outlines utilizing each of the systems noted with specific performance data on salt, fog, abrasion, adhesion, and hardness. With this data and a clear understanding of what interpretation of said data is, a clear choice can be made for the right project given the right economic framework.

Life-Cycle Costs of Steel-framed Parking Structures

Life-cycle cost is the average annual maintenance and repair costs to be expected over the life of the parking structure. Structural engineers and others who have studied life-cycle costs conclude that steel framed structures are, at the least, no more expensive to maintain than concrete. (Chrest, A.; talk given at the American Concrete Institute Annual Convention, Philadelphia, PA, March, 2001. *"I've been in steel-framed structures built by Mulach Parking Systems more than 20 years ago. Mulach blasted the steel down to white metal and then used a high-quality three-coat epoxy paint system to protect the structural steel. All field connections were bolted – no field welding. The steel structures I saw looked better than some cast-in-place concrete frames of the same age."*)

Parking industry experts have indicated that over a 50 year life, the cost to maintain a precast concrete deck and frame system will be between $0.05 and $0.08 per square foot per year, while the cost to maintain a post-tensioned deck on a steel frame will be between $0.03 and $0.05 per square foot per year, a savings of 40%. High performance coatings (paints), galvanizing and metalizing systems are demonstrating superior long-term corrosion protection for exposed structural steel. If deterioration of the concrete deck itself occurs, a steel frame supporting that deck will minimize the cost and time required for rehabilitation of the slab and may even save the facility from demolition and total reconstruction.



Crickelwood Hill Apartments – Built in 1974
Pittsburgh, Pennsylvania
Mulach Parking Structures
Post-tensioned deck on steel frame

Innovative techniques have revolutionized the corrosion resisting capabilities of structural steel. Structural steel frames that are coated with a high performance multi-coat paint system using a zinc rich primer can be expected to perform well with little maintenance for 25 to 30 years. When properly applied over a prepared surface, a three coat paint system can provide over 30 years of corrosion protection. Recent studies have shown that after 15 years less than ½ of 1% of the surface area of the steel has required any form of maintenance attention. Some parking structure owners have chosen to protect their structures by using galvanized steel. This process which cleans steel in an acid bath followed by dipping in a hot zinc bath can provide effective protection from corrosion in excess of 40 years. Galvanized surfaces can be painted for aesthetic purposes and enhanced durability.

Investigation of the life-cycle cost of steel-framed parking structures in comparison to other framing materials indicates that significant life-cycle cost savings can be realized through the use of a steel framing system for an open deck parking structure. These results correlate to an independent study of a steel-framed parking structure that was performed by Hill International for the Port Authority of New York and New Jersey. That study is documented in the April 2000 issue of *Modern Steel Construction* (reprints available through AISC). In that study representatives of the Port Authority, Mr. Joseph Englot, P.E., Chief Structural Engineer and Mr. Robert Davidson, FAIA, Chief Architect, state:

> While the use of this hybrid structural system was driven by schedule and longer span length in the JFK Green Garage, the Port Authority decided to perform a value engineering (VE) analysis of the steel-framed system for the Newark Airport Lot E Garage in November 1998. The panel of 15 experts was assembled and led by Hill International. They were charged with making recommendations to improve the cost effectiveness relative to initial construction cost, life-cycle costs and schedule considerations. As a result of the VE effort, the structural system was validated to be the most cost-effective given the project siting, constraints and schedule.

Life-cycle costs are a function of the initial construction cost, routine maintenance and any future restoration costs of the structure. In evaluating the relative differences in life-cycle costs between a steel-framed and concrete (cast-in-place or pre-cast) structure it is necessary to evaluate the various components of the parking structure. For the sake of simplicity, it is assumed that an open deck parking structure consists of the following components:

- structural framing system – steel or concrete
- deck system – cast-in-place conventionally reinforced, cast-in-place post-tensioned or pre-cast using double-tees (other deck systems have been used, but these are the most common)
- secondary structural elements – stairs, facades, barriers, elevators
- infrastructure components – lighting, signage, collection, electrical

Evaluation of comparative costs of steel-framed parking structures versus concrete framed parking structures shows that the steel-framed structure typically ranges 10% to 20% less in cost than the concrete alternative. This initial cost difference is a function of a steel framed structure being lighter than a concrete framed structure resulting in reduced foundation costs, the steel-framing system itself being less expensive, the simplicity of attachment of facades to a steel-frame and an overall savings in cost due to a simpler, faster erection procedure.

As a conservative estimate it would be reasonable to assume a minimum $750 per space (based on a 300 square foot per space estimate) savings for a steel-framed system in original construction costs based on equivalent deck systems.

The maintenance and restoration costs for secondary structural elements and infrastructure components of the parking structure will be equivalent independent of the framing system.

The deck system maintenance costs have been assumed to be equivalent for the purpose of the life-cycle cost study.

If all other factors are assumed equal then the comparison becomes an evaluation of the maintenance of the framing system. For a steel-framed structure high performance coating systems and galvanizing techniques are designed to provide for at least 30 year performance. Typically, the high performance painting system consists of either a shop applied zinc-rich primer and a high build epoxy intermediate coat with a field applied topcoat or a two coat system utilizing the zinc-rich primer and an epoxy topcoat. Critical to the performance of the coating system is the proper surface preparation of the steel to a SSPC-SP6 or SSPC-SP10 standard. The cost of such a system (preparation and coating) or the cost of galvanizing has already been included in the comparison of overall construction costs of the structure indicated above.

According to representatives of the coatings industry, it is anticipated that less than one half of one percent of the surface area of the steel-frame will exhibit corrosion at the end of a 15 year period with no intervening maintenance. Similarly, in a typical urban environment a 4 mil galvanizing system is projected to provide 75 year life to a 5% level of surface corrosion with no regular maintenance.

However, it is recommended that a program of annual maintenance of the framing system be performed that includes the visual inspection of the framing members and the touch up of any corrosion noted on the frame. This annual maintenance program would also repair any areas of the frame that had been damaged by vandalism or vehicle contact. Typically less than 0.1% of the surface area of the steel requires maintenance on an annual basis due to damage, vandalism and normal corrosion action. At the end of the first year, any areas damaged during steel erection or deck construction need to be recoated increasing the anticipated area to 0.1% of the surface area of the steel. Maintenance would consist of cleaning the surface and reapplying a multi-coat paint system or metalizing the damaged areas of a galvanized structure.

A comparative cash flow analysis assuming a 60 year structure life was performed using a typical 500 space parking garage. Painting and restoration costs were projected to increase at a 3% inflation rate and a 5% discount factor was applied to the annual cash flow to determine a net present value. Concrete life-cycle costs were projected utilizing the LIFE-365 program developed by Bentz and Thomas. The use of epoxy coated reinforcing bar and a typical beam/column design was assumed.

Annual costs for painting were calculated at:

(Surface area of steel * .001) * touch-up-cost

where: the surface area of the steel is assumed to be approximately xxx square feet per space

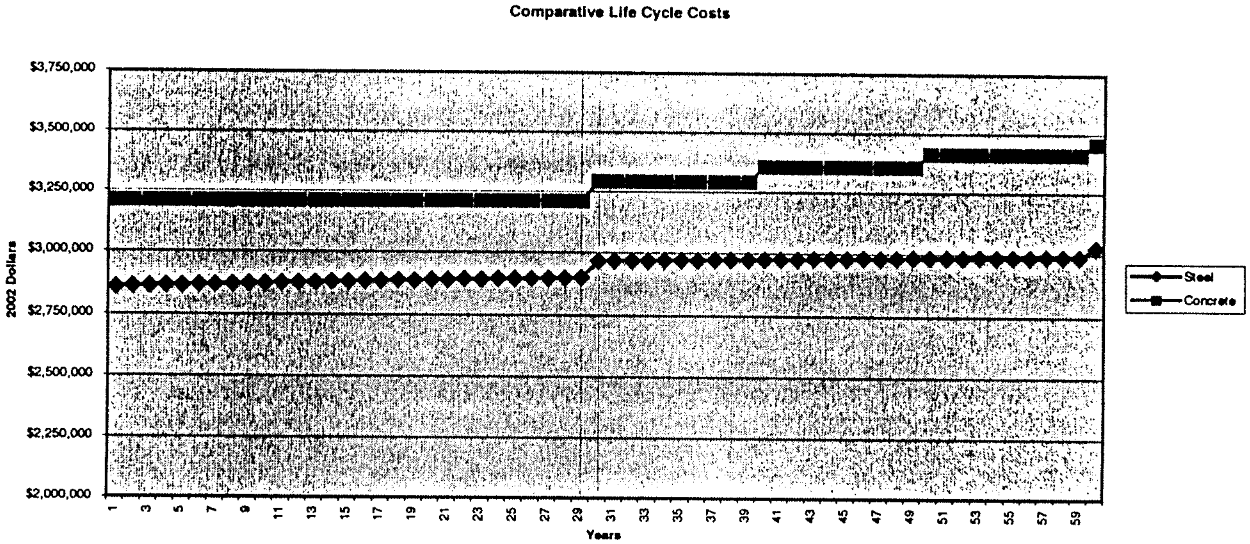
the touch-up-cost is the annualized cost per square foot of paint touch-up adjusted for inflation

Major maintenance costs for the painted system assume a full recoat of only the topcoat to refresh the aesthetic appeal of the garage. It would not be necessary to clean and reapply a three coat system if regular maintenance had been provided.

The results indicated a life-cycle cost differential in excess of $300,000 in favor of the steel alternative. Several factors were not taken into consideration that would further increase the differential in favor of a steel-framed system:

- no consideration was given to the cost of graffiti removal or impact damage for the concrete garage, but was considered in the annual maintenance of the steel structure
- it was assumed that the concrete structure was not painted although many concrete structures are now being painted and require annual touch up similar to steel-framed systems

- the reinforcing bars were assumed to be epoxy coated in the concrete columns and beams, but are often are not in practice. The use of non-coated rebars would have reduced the interval to initial maintenance significantly increasing the life-cycle cost of the concrete system



Significant cost savings are possible with the use of a steel framing system. These cost savings accrue both at the time of initial construction and throughout the life of the structure.