Project Proposal

Corrosion Protection
of the
Center Street Pedestrian Bridge
Principal River Walk Project

Center Street Pedestrian Bridge, Courtesy of Stanley Consultants, Inc., Des Moines, Iowa.

Prepared for the City of Des Moines, Iowa

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Project Summary

The Principal River Walk Loop features lighted, landscaped public spaces, world-class public art and unique pedestrian bridges and pathways that connect 300 miles of Central Iowa trails. The project was a gift to the City of Des Moines in honor of the 125th anniversary of the Principal Financial Group.

The Center Street Pedestrian Bridge links the east and west sides of the city at the northern edge of the Principal River Walk loop. It features two separate pathways - one for pedestrians and the other for bicyclists (see Figure 1.) The pedestrian bridge spans 400 feet over the Des Moines River and is 35 feet over a dam. It is constructed of approximately 1.4 million pounds of structural steel and has a total project cost of over $12 million.

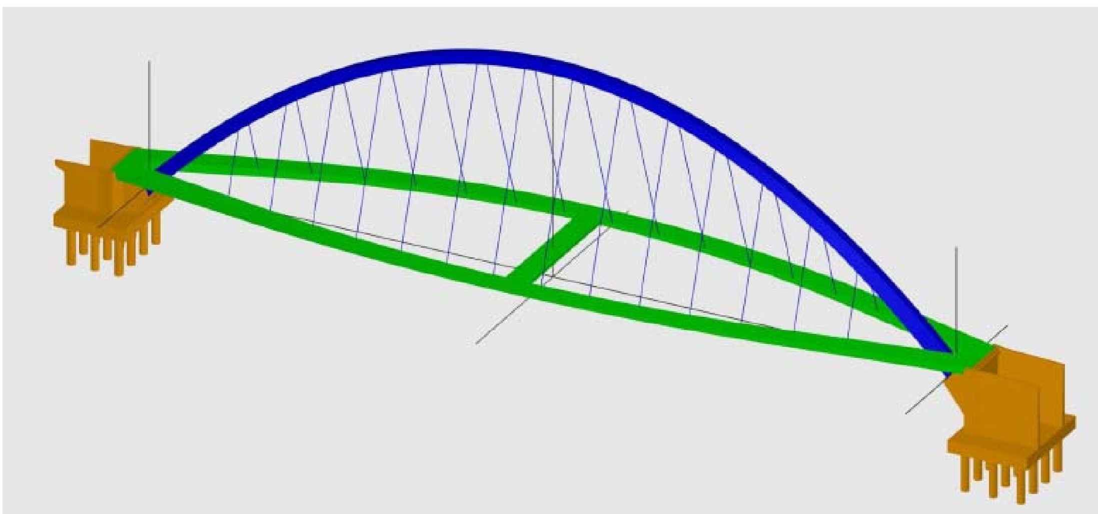

Figure 1: Steel structure of Center Street Pedestrian Bridge.
Courtesy of Stanley Consultants, Inc, Des Moines, Iowa

Objective

With a life requirement of 70 years, the performance of the corrosion protection system for this bridge is a critical factor in its design. In addition, maintenance requirements for the bridge need to be minimized to reduce life cycle cost. While the modern design of the bridge with its large flat surfaces already has a positive influence on the durability of its protective coating, its open design over a body of water will make future coating maintenance difficult. All these dynamics make the choice of protective coating a critical design factor.

This proposal will compare two corrosion protection options for the bridge: hot-dip galvanizing (HDG) vs. a three-coat system comprised of inorganic zinc primer, an epoxy intermediate and polyurethane topcoat. Three aspects of the protective coatings will be evaluated and compared: durability, sustainability, and life cycle cost.

Durability

Besides creating a barrier between the environment and the object it protects, hot-dip galvanizing (HDG) also cathodically protects the steel. In effect, this means that the galvanized coating sacrifices itself to protect the underlying base steel from corrosion. With a bond strength of around 3,600 psi, the coating is extremely abrasion-resistant, as the intermetallic layers are even harder than the base steel. Even when the coating is damaged, the sacrificial action of the zinc will protect the exposed steel up to a ¼ inch away.

HDG will protect steel from corrosion in a variety of environments, including air, water, and soil applications. In the case of the Center Street Pedestrian Bridge, the HDG steel application is generally considered to be in the atmosphere or open air.

Naturally exposing HDG steel to wet and dry cycles in atmospheric conditions is crucial to the development of a patina, or series of films on the zinc surface that contribute to HDG's long life. The extremes in temperature, humidity, and rainfall in central Iowa will all have an impact on the development of the HDG steel's patina. The amount of sulfur dioxide concentration in the air will also affect the corrosion of zinc in our situation. Automobiles, trucks and industrial plant exhaust found in our urban environment all contain some sulfides and phosphates that can cause a more rapid consumption of the zinc coating.

In addition to atmospheric conditions, the thickness of the zinc coating will also have an effect on determining the time to first maintenance in our environment. Per ASTM A123, we must have at least 3.9 mils of zinc coating in our application. Based on Figure 2, we can expect that our steel will be protected for approximately 72 years.

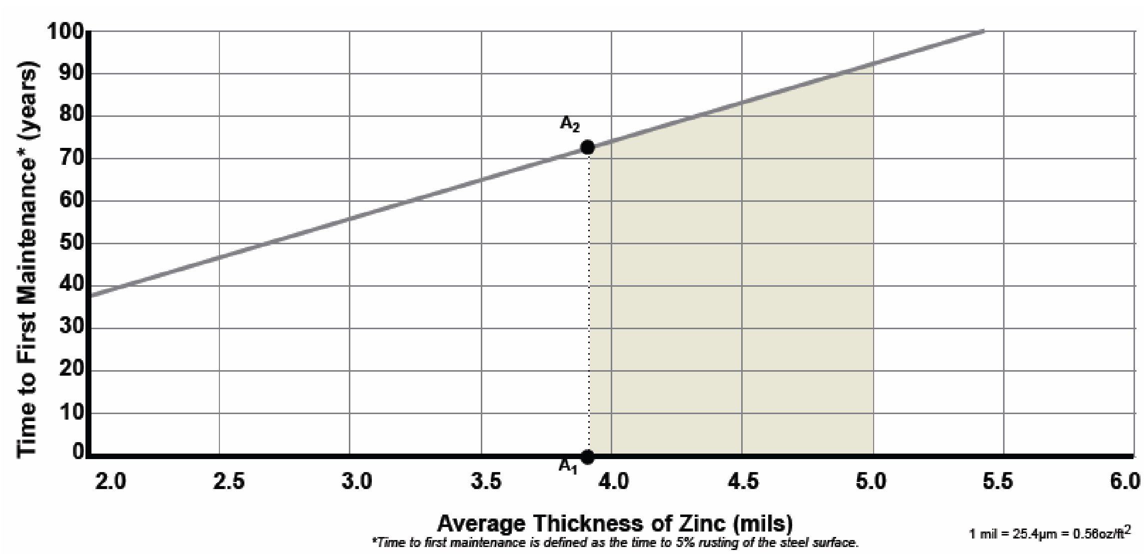

Figure 2: Time to First Maintenance Chart

Stronger environmental policies and industrial improvements leading to a cleaner environment in the future may further decrease the corrosion rates of zinc and lead to longer durability.

Time to first maintenance is defined as the life until 5% of the substrate surface is showing iron oxide, otherwise known as rust. With this amount of corrosion, it is unlikely that the underlying steel in our bridge will have weakened to the point where its integrity is compromised. Repairs to any exposed surfaces at this point could be performed inexpensively using a corrosion protection system such as zinc-rich paint, zinc metal spray, or zinc solder.

Comparison to Paint's Durability

Paint coatings generally require regular maintenance on a cycle of every 12 - 20 years. If the Center Street Pedestrian Bridge were to be protected with a three-coat system comprised of inorganic zinc primer (with SP-10 automated surface prep), an epoxy intermediate and polyurethane topcoat , we estimate that the first paint touch up would occur in year 20, followed by a maintenance repaint in year 26 and a full repaint in year 36. This cycle would occur another time during the 70-year lifespan of the bridge, resulting in a total of five occurances of paint maintenance.

By comparison, no finish maintenance would be necessary over the 70-year lifespan of the bridge if it received a hot-dipped galvanized coating.

Sustainability

Hot-dip galvanizing (HDG) is accomplished by immersing fabricated steel in a bath of molten zinc. Zinc has been used in construction as a protective coating for more than 150 years. It is considered a healthy metal and can be recycled infinitely without losing any of its physical or chemical properties. Zinc is an abundant element and can be found naturally in air, water and soil. Approximately 30% of the world's zinc supply comes from recycled sources, and 80% of zinc that can be recycled is reclaimed.

To understand the full environmental impact of galvanized steel, it is necessary to conduct a life-cycle assessment from production through use and end-of-life. This life cycle is represented in Figure 3.

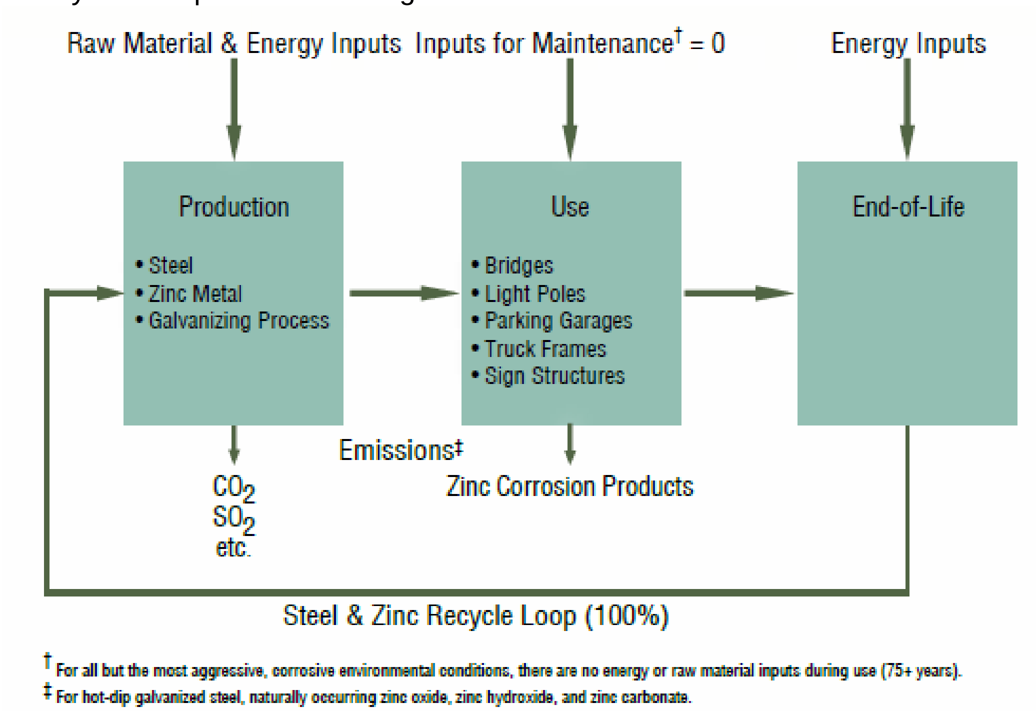

Figure 3: Life Cycle Assessment of Galvanized Steel

Production Phase Environmental Impacts

The primary component of HDG is steel. Steel can be sourced from either raw materials (coal, coke, limestone, and iron ore) or from recycled end-of-cycle scrap steel. Steel is the most recycled material in the world, with 70% of steel produced made from recycled material. Energy is consumed in the production of steel, as well as its casting and fabrication. Resulting emissions include carbon dioxide, sulfur dioxide, recyclable and slag material. All in all, very little solid waste is created throughout the process.

Zinc is the other primary component of hot-dip galvanizing. As with steel, the production of zinc originates from both mined zinc ore and recycled sources. As mentioned earlier, 30% of the zinc produced annually comes from recycled material. Energy is consumed during the mining, concentration and refining stages of the process. As with steel, the zinc production process creates emissions (CO_2 and SO_2) and some byproducts (copper, cadmium, and lead) which are separated from the zinc to be used for their own purposes.

We must also evaluate the energy demands and emissions generated by the hot-dip galvanizing process itself. The steel cleaning, surface preparation, and galvanizing process all require energy inputs. The process also results in emissions and byproducts, some of which are recycled and used in the production of cosmetics and tires.

The environmental impact of 1 kg of HDG steel during its production phase is shown in Figure 4.

Production Phase (Cradle-to-Gate)	Primary Energy Demand (PED)	Global Warming Potential (GWP) (CO_2 equiv.)	Acidification Potential (AP) (SO_2 equiv.)	Photo Chemical Ozone Creation Potential (POCP) (C_2H_2 equiv.)
1 kg of HDG Steel	25.9 MJ	1.80 kg	0.00615 kg	0.000824 kg

Figure 4: Environmental Impact During the Production Phase of Galvanized Steel

Use Phase Environmental Impacts

In the second phase of the life cycle of galvanized steel, we examine the additional material and energy inputs and emission outputs generated while our bridge is in use. As mentioned in the Durability section of this proposal, HDG steel requires no maintenance for 72 years or more. As a result, if we choose a HDG coating solution for our bridge, we accrue no additional environmental impact throughout our bridge's service life.

If we choose the epoxy zinc/epoxy/polyurethane coating solution, the environmental impact will continue to increase during the use phase. As mentioned earlier, at least 5 maintenance occurances will occur during the lifespan of our bridge with the three-coat system. Because paint must be maintained repeatedly throughout its use, an additional environmental impact will be generated during each maintenance cycle. In Figure 5, P1, P2, P3, and P4 represent the additional environmental costs associated with the maintenance of painted steel.

Use Phase	Primary Energy Demand (PED)	Global Warming Potential (GWP) (CO_2 equiv.)	Acidification Potential (AP) (SO_2 equiv.)	Photo Chemical Ozone Creation Potential (POCP) (C_2H_2 equiv.)
1 kg of HDG Steel	0 MJ	0 kg	0 kg	0 kg
Painted Steel	P_1 MJ	P_2 kg	P_3 kg	P_4 kg

Figure 5: Environmental Impact During the Use Phase of Galvanized Steel

End-of-Life Phase Environmental Impacts

At the end of life, both steel and zinc are 100% recyclable without the loss of any properties. During the demolition of a HDG steel bridge, the galvanized material can be captured and sent to a steel mill for recycling. The steel components enter an electric arc furnace where the zinc is captured as zinc-rich EAF dust for reuse in the zinc production process. The molten scrap steel can then be cast into new steel shapes. In the end, we actually receive an end-of-life energy credit for HDG steel for our recycled products (see Figure 6.)

End-of-Life	Primary Energy Demand (PED)
1 kg of HDG Steel	-8.61 MJ

Figure 6: Environmental Impact During the End-of-Life Phase of Galvanized Steel

For a demolished painted steel bridge, the steel component can also be captured and recycled. However, the paint coating becomes a permanent part of the waste stream, or is burned off as harmful emissions.

Total Environmental Impact

The total environmental impact of the steel portion of our bridge can be determined by combining the impacts derived from the production, use and end-of-life phases (see Figure 7.)

Complete LCA (Cradle-to-Grave)	Primary Energy Demand (PED)	Global Warming Potential (GWP) (CO_2 equiv.)	Acidification Potential (AP) (SO_2 equiv.)	Photo Chemical Ozone Creation Potential (POCP) (C_2H_2 equiv.)
1 kg of HDG Steel	17.3 MJ	1.80 kg	0.00615 kg	0.000824 kg

Figure 7 Total Environmental Impact of Galvanized Steel

Corrosion Protection System Cost Analysis

When comparing the total cost of our corrosion protection system options, we must look beyond just the initial cost of coating our bridge and consider the life cycle cost, which includes initial costs, touch-up costs, maintenance costs, coating costs, inflation, and opportunity costs.

Our bridge's corrosion protection cost comparison was based on the following parameters:

- 70-year service life
- Complex 50-100' high structure type
- Large structural member type
- Industrial (C3) service life environment
- Inorganic zinc primer: SP-10 automated surface prep, spray application in the shop
- Epoxy intermediate: two-pack product, spray application in the shop
- Polyurethane topcoat: two-pack product, spray application in the field
- 3% inflation, 5% interest

A complete cost analysis report can be found at the end of this proposal. A summary is displayed in Figure 8.

	HDG	Paint System
Initial Cost		
Per ft^2	$4.40	$3.95
Total	$308,000.00	$276,801.00
Life-Cycle Cost		
Per ft^2	$4.40	$35.72
Total	$308,000.00	$2,500,400.00
AEAC		
Per ft^2	$0.15	$1.23

For this project...
HDG Life-Cycle Cost Savings: 87%

Figure 8: Cost Comparison HDG vs. Epoxy Zinc/Epoxy/Polyurethane

Conclusion

Durability

Because an HDG finish can endure for 72 years or more before touch up is required, no finish maintenance would be necessary over the lifespan of our bridge if it received a hot-dipped galvanized coating. By comparison, a three-coat painted system rated for 20 years will require a total of five occurances of paint maintenance during the bridge's lifespan.

Sustainability

When considering their total environmental impact, the following comparisons can be made between a HDG and painted coating:

- In both coating scenarios, the primary component (steel) is highly recyclable and has a very low environmental impact.
- Because no maintenance is required, HDG has less environmental impact than paint during the use phase of our bridge.
- At end-of-life, HDG is 100% recyclable since the zinc of the galvanized coating is recycled. Paint coatings, on the other hand, either enter the permanent waste stream or create harmful emissions.

Cost

Although the initial cost of the HDG corrosion protection system is about 10% more than the initial cost of the three-coat paint system, when we consider the life cycle cost, the HDG solution offers an 87% savings on our bridge project.

Recommendation

Because of its superior durability, higher sustainability, and dramatically lower life cycle cost, it is our recommendation that the Center Street Pedestrian Bridge be protected from corrosion using a hot-dipped galvanized coating system.

Center Street Pedestrian Bridge, Courtesy of Stanley Consultants, Inc., Des Moines, Iowa.

Footnote

This is a fictitious proposal based on a real bridge project in the author's home town of Des Moines, Iowa. The Center Street Pedestrian Bridge officially opened on June 28, 2010.

Sources

Project Summary:

- http://www.dmgov.org/Departments/CityManager/PDF/PIO_CitySourceNovember09.pdf
- http://www.dmoed.org/udrb/centerstreetbridge/Center%20St.%20Bridge%20Info%204-18-06.pdf
- http://www.principal.com/riverwalk/
- http://www.ucs.iastate.edu/mnet/_repository/2009/transportation/pdf/David%20Bovee.pdf
- http://resource.npl.co.uk/docs/science_technology/materials/life_management_of_materials/publications/online_guides/pdf/protection_of_steel_bridges.pdf

Durability:

- http://www.galvanizeit.org/images/uploads/publicationPDFs/TFM_web.pdf
- http://galvanizeit.org/aga/about-hot-dip-galvanizing/how-long-does-hdg-last/
- http://galvanizeit.org/aga/about-hot-dip-galvanizing/how-long-does-hdg-last/in-the-atmosphere
- http://galvanizeit.org/aga/about-hot-dip-galvanizing/how-long-does-hdg-last/in-the-atmosphere/service-life-time-to-first-maintenance/
- http://www.galvanizeit.org/images/uploads/publicationPDFs/TFM_web.pdf

Sustainability:

- http://www.galvanizeit.org/images/uploads/publicationPDFs/HDGforSD_Web.pdf

Cost Analysis:

- http://www.galvanizingcost.com/coatings.php?s=11522
- http://www.galvanizeit.org/images/uploads/publicationPDFs/CLLL.pdf

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Center Street Pedestrian Bridge

Principal River Walk Project

Cost Comparison
HDG vs Epoxy Zinc / Epoxy / Polyurethane

	HDG	Paint System
Initial Cost		
Per ft^2	$4.40	$3.95
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For this project...
HDG Life-Cycle Cost Savings: 87 %

Project Specs

700 tons
PROJECT SIZE

70 Years
EXPECTED LIFE-SPAN

Complex - 50-100' high
STRUCTURE TYPE

Large Structural
MEMBER TYPE

Industrial (C3)
SERVICE LIFE ENVIRONMENT

Paint System

3-Coat System comprised of:
Epoxy Zinc/Epoxy/Polyurethane. SP-10 Automated surface prep. and 9mil minimum DFT.

Currency, Units & Assumptions

Calculations are based on U.S. units of measure and figured in USD.

Inflation and interest are figured at rates of 3% and 5%, respectively.

Report generated by
GalvanizingCost.com

Detailed Cost Comparison

HDG vs Epoxy Zinc/Epoxy/Polyurethane

Cost of Galvanizing

	TODAY'S COST	NET FUTURE VALUE	NET PRESENT VALUE
ORIGINAL GALVANIZING	$4.40	na	na
TOTAL PRICE/FT^2	**$4.40**	**$4.40**	**$4.40**

Cost of Paint System

	TODAY'S COST	NET FUTURE VALUE	NET PRESENT VALUE
ORIGINAL PAINTING	$3.95	na	na
TOUCH-UP - YEAR 20	$1.58	$4.20	$2.32
MAINT. REPAINT - YEAR 26	$2.77	$10.13	$4.62
FULL REPAINT - YEAR 36	$5.34	$31.84	$10.79
TOUCH-UP - YEAR 56	$1.58	$25.03	$4.70
MAINT. REPAINT - YEAR 63	$2.77	$60.44	$9.33
TOTAL PRICE/FT^2	**$17.99**	**$135.59**	**$35.72**

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700 tons
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EXPECTED LIFE-SPAN

Complex - 50-100' high
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