Hot-Dip Galvanized

Parking Structures

A sustainable, economical solution
for a transportation necessity

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Hot-Dip Galvanized Steel Parking Structures

As countless cars whiz back and forth across busy streets and highways, the need for parking structures is obvious and undeniable. In an age of environmental consciousness, however, there is more to parking cars than the immediate gratification of need. Obligation to build a greener, more sustainable future is now standard – but where to begin? Before haphazardly erecting a structure that fits the needs of now, why not examine a smarter, more efficient way to meet our growing transportation needs?

Sustainable development (SD) is the social, economic, and environmental commitment to growth and development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Utilizing a hot-dip galvanized steel framing system in an open-deck parking structure not only creates a beautiful, functional structure that will stand the test of time, it also embraces the statutes of sustainable development by generating social benefits, economic savings, and environmental advantages that will benefit everyone for the life of the project.

DRIVE THRU
Sustainable Development

SUSTAINABLE DEVELOPMENT (SD):
The social, economic, and environmental commitment to growth and development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Hot-Dip Galvanized Steel

During the galvanizing process, steel is lowered into a molten zinc bath to form a strong, durable metallurgical bond.

Known for its ruggedness and durability, hot-dip galvanized (HDG) steel is the perfect pairing to a versatile, sustainable steel parking frame, and a durable, cost-effective solution for corrosion protection. Hot-dip galvanized steel is the process of coating steel pieces by submerging them into a molten zinc bath. The process is conducted in three steps.

First is steel surface preparation. The steel arrives at the galvanizing plant and is hung by wire or placed in a racking system to be moved through the plant. The pieces are moved through a series of cleaning tanks (degreasing, pickling, and fluxing) to remove dirt or markings that could interfere with the zinc-steel bonding process. Once the steel has traveled through these baths, it is then dipped into a tank of 830 F molten zinc so the zinc can flow freely throughout and around the piece. The iron in the steel metallurgically reacts with the molten zinc, creating a series of zinc-iron intermetallic layers and an outer layer of pure zinc. After being removed from the zinc bath and cooled, the coating is inspected for conformance to ASTM, ISO, or CSA specifications.

The metallurgical bond created during the galvanizing process provides a number of benefits. Not only does the galvanizing process create a barrier coating resistant to abrasion because it is harder than the substrate steel, it also protects the steel cathodically. Thanks to this cathodic protection property, the zinc will sacrificially corrode to protect exposed base steel. Additionally, the natural development of the zinc patina – an impervious, passive layer of zinc corrosion products – further extends the maintenance cycle - and corrosion protection of the steel. With a bond strength of around 3,600 psi, the HDG zinc coating is extremely well adhered. All of this makes HDG steel an excellent solution to protect a parking structure from corrosion.

Galvanized steel has a bond strength of approximately 3,600 psi, meaning the piece will stand strong against nicks and abrasion.

DRIVE THRU HDG Parking Garages

SOCIAL BENEFITS

Utilizing HDG steel creates an attractive, well designed, economical, and structurally sound product that will provide users with seamless service and functionality, as well as a source of pride for the community.

ECONOMIC SAVINGS

HDG steel framed garages benefit from a trifecta of savings – economical construction, affordable functionality, and lower life-cycle costs.

ENVIRONMENTAL ADVANTAGES

Galvanized steel structures utilize natural, abundant, and recyclable zinc and steel. A galvanized coating means no maintenance, and no maintenance means no wasted energy, materials, or harmful emissions from touch-ups.

Social Benefits

When approaching the materials and design of a parking garage, specifiers should examine how the new structure will affect the surrounding society, both immediately and into the future. A critical element of sustainable design, social benefits must be addressed in conjunction with the planning of a structure's function. The client and community require a structure that services many needs – the project must be attractive, well designed, economical, and structurally sound, as well as provide users with seamless service, functionality, and a source of pride for the community. Using hot-dip galvanized steel as the core frame of a new parking garage, designers can address these needs by providing the following benefits.

Appearance

Incorporating hot-dip galvanized steel into a structure can unlock a wide canvas of aesthetic possibilities affecting both beauty and functionality. A parking garage is often the first impression a visitor encounters when approaching a building – a gateway accompaniment to the flagship structure. Not limited by the weight and constraints of concrete exteriors, steel façade elements can take on a variety of appearances. Features such as streamlined steel cable supports; sleek, modern railings; elaborate decorative paneling, and more can all be incorporated to complement the structure of the facility.

Hot-dip galvanized steel will support these complementary features by protecting them from unsightly rust stains and streaks. As the aforementioned features will be constantly exposed to the damaging effects of sun, wind, water, and industrial pollution, a natural, attractive corrosion protection system must be implemented. The cool metallic sheen of galvanized steel is a desirable look itself, but the system is also proven to keep the unattractive effects of corrosion at bay for 70+ years. This keeps exposed elements, particularly façades, looking their best for generations to come.

Not only can a wide array of designs and façades be easily attached to the steel structure, the steel itself can be arched and bent into striking shapes. The Charlotte Douglas International Airport Parking Garage (right) features a unique convex exterior façade reminiscent of the curvature of an airplane wing. Also exemplifying the aesthetic nature of HDG steel, the exposed parking canopy, spiral staircase, façade supports, and other elements of the Arizona State University Garage (below) are fit for center stage – galvanized steel allowed for exceptional styling of these typically boring elements, creating a striking welcome to all who enter.

Charlotte Douglas International Airport Garage
Charlotte, NC

The Charlotte Douglas International Airport, with an average of 600 daily departures, is a rapidly growing airport in the southeastern United States. As the passenger traffic has increased over the past few years, so has the demand for more parking. In late 2004, the airport began reconstruction to expand the 3,000-space parking facility's capacity by 13 percent. In 2009, an additional garage at the site was specified to incorporate galvanized steel, due to the success of the 2004 structure. The designer wanted to break away from the normal square, concrete box structure of parking facilities, and envisioned a facility that would mirror the curvature of an airplane wing.

In order to accomplish this design, the architect and engineer decided to attach stainless steel cladding to a galvanized structural steel frame. Three hundred tons of hot-dip galvanized steel was used in the project including bow-string trusses, embed plates and anchors, stair towers, stairways, hand rails, and castellated beams. Galvanized steel was specified for its exceptional maintenance-free service life. By specifying a hot-dip galvanized coating instead of a paint system, the garage will not require costly maintenance. Furthermore, the galvanized coating will allow the structure to remain a corrosion-free, attractive piece of the airport landscape well into the future.

Arizona State University Parking Garages
Scottsdale, AZ

Hot-dip galvanized steel was used in this parking garage for its aesthetic appeal and also to protect the automobiles from UV rays and other elements in Arizona. The project contains many different HDG pieces including the parking canopy, columns and beams for the skin structure, crash barrier, and guard rails totaling 300,000 pounds of steel.

The project designer spent time with the galvanizer to learn more about hot-dip galvanizing in order to create details that worked well with the process, such as the steel framing from which to hang the stainless steel skin. The skin is used to help provide shade and protection from the elements for the parked vehicles. Using galvanized steel allowed the contractors to complete the project on time and under budget. In fact, the project was such a success, an expansion of the facility using galvanized steel is planned.

A wide array of designs and façades can easily be affixed to a core hot-dip galvanized steel structure.

In addition to a beautiful exterior, an aesthetically pleasing, breezy interior also lends itself to increased functionality. Concrete structures often call for weighty interior shear walls to support the burden of lateral loads. Such a system leaves the garage feeling heavy and blocked in, like a cumbersome hedge maze visitors quickly seek to exit or even avoid altogether. Contrarily, use of light long-span steel beams coupled with small, slender columns create more space, so vehicles can maneuver throughout the structure with ease. Lean and strong, a steel framed structure creates a well lit, open, and inviting garage.

Safety

To create a feeling of safety in the garage, wide-flange or long-span castellated beams and slim vertical supports engender a sense of openness, allowing light to penetrate and encouraging air flow and circulation. Lighting is critical to the success of any parking structure, affecting visibility, safety, and patron comfort. Eliminating the need for heavy shear walls means more natural light will flood the garage floors – the need for buzzing, glaring fluorescent lighting will be greatly reduced. Better lighting throughout the structure means an easier, safer drive for vehicles, preventing shadowy regions from inhibiting sight while driving. In this case, safer for cars means safer for pedestrians. With greater visibility, patrons walking to their cars will be obvious – no surprises around the corner. Fewer shaded areas also mean nowhere to hide for shady characters. Visitors can travel throughout the open, well-lit structure with confidence.

Beyond safety and aesthetics, the openness generated from utilizing galvanized structural steel beams serves to increase air circulation. Open-deck parking structures, whether concrete or steel do not require the use of mechanical ventilation systems, but rather rely on fresh gusts and breezes. The openness of a steel framed structure is a significantly better option as it allows natural air to circulate more freely compared to the dank, tinny air in a more closed-in concrete structure.

Hot-dip galvanized steel framing systems not only develop visibility and the appearance and feeling of safety in a garage, they also can provide seismic advantages. Steel framing structures are more seismic resistant than concrete frames due to the ductile, adaptable steel members. Able to bend within reason without breaking, the tensile strength of a steel structure can protect a garage from damage during seismic activity, protecting the builder's investment, and more importantly, the cars and people sheltered within.

Diagonal members, moment frames and connections can be utilized while taking up minimal usable space within the garage. Concrete, on the other hand, requires additional shear walls be installed, further limiting usable space and eliminating natural light. Concrete moment frames also require workers with a high degree of field expertise and may extend beyond the footprint of the structure, requiring additional site area.[1] Even after implementing these concrete 'solutions,' the rigidity of concrete can cause cracking and crumbling under duress. A steel frame protects the structure from seismic damage while accommodating the original design.

Speed of Construction

There are two primary structural systems that come together to form a parking garage: the framing system and the deck system. According to *Innovative Solutions in Steel: Open-Deck Parking Structures,* the occupancy date of a parking structure is often governed by the completion of these two systems.[1] The quickest route to a packed parking garage is the fast erection time and quick turnover provided by a hot-dip galvanized steel framing system.

The quick turnover and fast erection time of galvanized steel save time and money.

Several elements contribute to a steel framed structure scoring the fastest erection time compared to other systems. Steel beams are fabricated offsite and delivered to the site ready for construction. Because steel members have a high strength-to-weight ratio, these pieces prove more maneuverable onsite. Smaller parts mean the elements arrive onsite quickly without the difficulties or delays posed by locations with limited delivery/construction access. They slip onsite, ready to be swooped up and rapidly, efficiently placed by a crane.

The hot-dip galvanizing process works swiftly and seamlessly into the assembly progression. After the steel members are fabricated, they are sent to the galvanizing plant. As the galvanizing process is completed at an indoor facility, there are no hindrances due to inclement weather – the pieces are in and out of the galvanizing plant, then promptly delivered to the site. With the swift turnover of these elements, builders are measuring completion times in weeks, not months.

Speedy erection of the structure saves time and money – not only providing the savings benefits associated with fast turnaround time, but also putting the facility into use more quickly. Utilizing small, easy to maneuver members with a prearranged method of assembly makes framing easy and will have cars filling spaces quicker than any other framing system. As opening a new building often hinges on completion of the parking garage, time is of the essence to make the new structures available to the community.

More with Less

At every stage of construction, a hot-dip galvanized steel parking garage gives the consumer more – more design flexibility, more parking spaces, more options for future expansion, and more corrosion protection. In the initial design phase, clients must examine which type of structures grant the most options to get the job done efficiently and economically. Utilizing a steel framing system, specifiers can choose the most advantageous decking system from any of the three major categories: precast systems, cast-in-place floor slabs, or cast-in-place post-tensioned floor slabs. Other framing systems will limit the choice of decking.

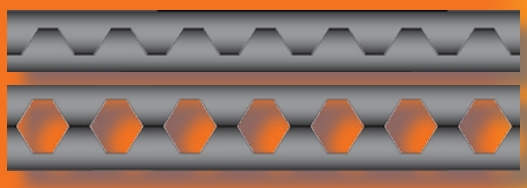
Once the framing system is determined to be steel and the decking system is chosen, a steel framed structure allows the designer more flexibility to adapt the structure to the site. By using techniques such as welding, bolting and splicing of existing columns, a steel framing system is easily adaptable to non-rectangular configurations that can be difficult to address with cast-in-place or precast concrete framing systems. With fewer, lighter pieces required and assembly techniques that can solve problems onsite, steel gives the designer more flexibility to negotiate problem areas and develop efficient solutions to challenging locations.

The interior layout of the structure can also take advantage of the lightweight flexibility of exposed hot-dip galvanized steel beams. With slender beams carrying the weight of the garage on fewer, narrower columns, the designer will be able to fit more parking spaces into the same ground footprint. Steel columns require 80% less floor space than equivalent concrete columns[1], increasing the usable floor area of the garage and decreasing the average cost-per-space of the design. Bulky concrete supports and shear walls take away from usable space, while steel capitalizes on it. In addition to utilizing traditional steel members, one of the most efficient ways to capitalize on materials and space is by working with castellated beams.

Castellated Beams

Originally created to improve efficiency during steel shortages, castellated beams increase the efficiency of one piece of steel.[2] As seen in ***Figure 1***, one steel beam is cut in either a toothed or circular pattern lengthwise, separated, offset, then rejoined into one cohesive piece. The resulting beam is not only lighter but also 50% stronger than the original beam, maximizing the potential of a single piece of steel. Generally, the weight savings when castellated beams are utilized in a complete structure is 20 – 50%.[2]

Figure 1: Fabrication of Castellated Beams



A single steel beam, top, is cut in a toothed pattern, separated, then offset and joined into a new beam 50% stronger than the original, bottom.

There are many implications for such a weight-bearing, lightweight structural element. With a limit on the size of the garage footprint, the increased strength of the castellated supports will allow for the possibility of more vertical stories and greater weight capacity per floor - meaning greater vehicle capacity for the garage on its limited footprint. Specifiers can take advantage of additional parking in the same amount of space or can design a smaller garage to achieve the desired number of parking spaces - reducing both the size and cost of the structure. The plethora of options opened up by use of steel castellated beam framing allows the designer to tailor the project closely to the needs of the client, without frivolous waste or excess.

Castellated beams also positively affect floor-to-floor height within the garage. The many mechanical, electrical, and fire protection systems required inside of the structure take up additional space when using impenetrable concrete framing, increasing floor-to-floor height as the systems have to be arranged in the space around and under the heavy core structure. Though the beams are slightly wider than typical wide-flange beams due to the creation process exhibited in *Figure 1* (pg. 7), with castellated beams, such systems can be woven through the holes and openings to make efficient use of space and decreasing the necessary floor-to-floor height.

Aside from opening up a range of structural and design advantages, incorporating hot-dip galvanized castellated beams can make a garage more aesthetically pleasing. Because of the superior corrosion protection of hot-dip galvanized steel, the open beams can be left fully exposed to the elements, and to the detrimental pollutants put off by legions of cars traveling daily through the structure. More natural light streams through the airy members, and the unique form of the beams adds distinctive character to any project.

The specifier will realize cost savings by integrating castellated beams into the core frame of a garage. Not only will the galvanized steel be protected from unsightly and damaging rust by the combined barrier and cathodic protection of the zinc coating, but the community will benefit from having an attractive, spacious parking garage that makes efficient use of material and design.

Eye to the Future

Not only does a smaller, stronger steel framing system support more design options in the conceptual and construction stages, it also sets the stage for future growth or adaptation. A lean, sturdy steel frame is the ideal setup for expansion. As the American Institute of Steel Construction (AISC) states in *Open Deck Parking Structures,* vertical expansion can be easily accomplished in a steel-framed structure through the splicing of existing columns and the placement of steel members with readily available cranes.[1] The most flexible option for vertical development, additional steel framing will couple easily with the original design to support the weight of new parking tiers.

Additionally, expansion of a steel frame will have less impact on the day-to-day functionality of the garage. Often times, only the top-most parking tier needs to be taken out of commission to facilitate the upward growth of the structure. Fewer cars will be inconvenienced, and, for the most part, business can continue as usual with the least interruption of service until the new tiers are unveiled.

Conversion is also a more feasible option with the quick, in-and-out tailoring of the original galvanized steel frame. With the structure in place, it will take little effort to develop tenant space on the lower or street level floors of the garage, or even take advantage of space above. The ability to penetrate, weld, bolt, and reinforce structural steel in the field makes even unanticipated changes and retrofit practical.[1] With procedures that will not take the entire garage out of commission for updating or expansion, a hot-dip galvanized steel frame will unlock new possibilities for the future.

Arysley Parking Garage
Charlotte, NC

Arysley, located in the uptown area of southwest Charlotte, North Carolina, is sandwiched in the middle of the second largest job center in the region. To address a lack of parking space, city officials gathered with architects and engineers to construct a parking structure in the commercial portion of the development. Requiring a quick turnaround time and a need for economical material, the steel fabricator suggested using galvanized steel for aesthetics, sustainability, and corrosion protection. Castellated beams provide great strength without wasting valuable parking space in the garage.

Unlike many galvanized parking decks covered with a precast concrete exterior, this parking deck has exposed galvanized steel as a design feature, making it an attractive addition to the mixed-use community. All beams, columns, angle braces, plates and connection details were coated, as well as post-tensioned cables used for safety railing between floors and outer perimeters of the structure. The steel structure was constructed in record time, only three weeks. Using space- and material-efficient castellated beams increased the value of this structure, and the benefits of hot-dip galvanizing will keep the parking deck looking attractive for many years to come.

Corrosion Protection

As steel protects the garage from the effects of nature, so hot-dip galvanizing protects the steel itself from deterioration due to damaging rust and corrosion. To preserve your frame long into the future, take advantage of the extended, maintenance-free lifespan attributed to hot-dip galvanized steel structures.

Galvanizing protects steel from the inside out, utilizing both tough barrier protection and intrinsic cathodic protection created during the coating process to defend against corrosion. The zinc coating created during the hot-dip galvanizing process is harder than the substrate steel, providing a tough-to-penetrate barrier that will defend the steel against the corroding effects of exposure, guarding the steel from corrosive moisture and vehicle pollutants.

The metallurgical reaction that occurs during the galvanizing process also protects the steel cathodically – meaning nicks and scratches (up to ¼ in. diameter) exposing the substrate

steel will be protected from corrosion by the sacrificial properties of the surrounding zinc. This makes galvanized steel particularly well-suited for the potentially rough garage environment, where vehicles may bump or scratch exposed beams. Corrosion protection is extremely important to the preservation of the frame structure, as rust can shorten the lifetime of the garage. By hot-dip galvanizing steel elements, the garage can have durable corrosion protection that will defend and uphold the structure for generations.

Corrosion is not only unattractive, but structurally damaging and dangerous, as well.

Social Benefits Summary

Providing social benefits is a key element of sustainable design. By attending to the appearance of a new parking garage, the designer creates a structure that is pleasing to the eye. Open, attractive, safe – to be sustainable, the structure must create more than just a space between two lines. Creating such a space can be facilitated by quick construction. With smaller elements and less complicated construction, a steel frame means the time to functionality is greatly reduced compared to competing products. Cars will be filling the garage in no time, especially considering slender steel elements take up less usable space within the structure. By creating more with less – more design options, more flexibility for the future with less material – a steel framed structure is a sustainable solution that both meets and exceeds the needs of society.

APPEARANCE
A wide array of visually appealing designs and facades can be wrought from strong, lightweight HDG steel framing systems, while the zinc coating protects from unsightly rust.

SAFETY
Slim, strong galvanized steel supports invite better lighting, allow greater visibility and improved air circulation, and are more adaptable than concrete counterparts.

SPEED OF CONSTRUCTION
Fabricated offsite and delivered ready for construction, the slender, easy to maneuver HDG steel members make framing quick and easy.

MORE WITH LESS
HDG steel frames provide more design flexibility, parking spaces, options for future expansion, and corrosion protection.

EYE TO THE FUTURE
Splicing of existing columns and easy placement of additional members grant galvanized steel frames a minimally invasive expansion.

CORROSION PROTECTION
Corrosion damage is both ugly and unsafe - the superior protection of the galvanized coating keeps the structure attractive and structurally sound.

Economic Savings

While everyone loves a striking, well-designed, functional piece of architecture, selection of a framing system is often determined by the bottom line. To be sustainable, designers should look to a product with a bottom line that not only suits the needs and abilities of the client, but also keeps an eye to future expenses and effects. This is an area where hot-dip galvanized steel stands a head above the rest. By specifying HDG steel, the client will benefit from a trifecta of savings – economical construction, affordable functionality, and lower life-cycle cost.

Construction Savings

From the very beginning of the project, using hot-dip galvanized steel members to construct a garage saves money. Simple, uncomplicated steel structural frame designs take less time to develop and are less costly. Pre-fabricated and galvanized offsite, the steel members move quickly through production. Because the fabrication and galvanizing processes are performed at indoor facilities, items move right down the line to completion with no hindrances due to inclement weather. The pieces are then loaded and delivered to the site ready for construction. When time equals money, a quick production phase puts money back in your pocket.

Because steel beams are considerably lighter than heavy, unwieldy precast concrete elements, transportation costs are significantly less as well. Less tonnage loaded onto trucks, train cars, or barges translates into a smaller transportation price tag. Once delivered, lightweight building materials will reduce onsite crane requirements – no special maneuvering equipment required. Additionally, less weight often means fewer and smaller diameter caissons are required. With all of these savings combined, steel-framed systems can typically be constructed with a cost savings of 10 – 20% over a concrete alternative.[1] ***Figure 2*** (pg. 10) is a comparison of initial costs for both concrete and hot-dip galvanized steel construction applications.

Savings in Use

One of the primary advantages of utilizing hot-dip galvanized steel elements for an exposed core frame structure is the durable corrosion protection provided by a coating that will withstand the effects of time, damage, and weather. Contrarily, framing competitors such as concrete can easily crack and spall, spelling costly maintenance throughout the life of a garage. Using paint for corrosion protection will rack up similar expenses, as paint coatings require regular, continuous touch-ups and maintenance.

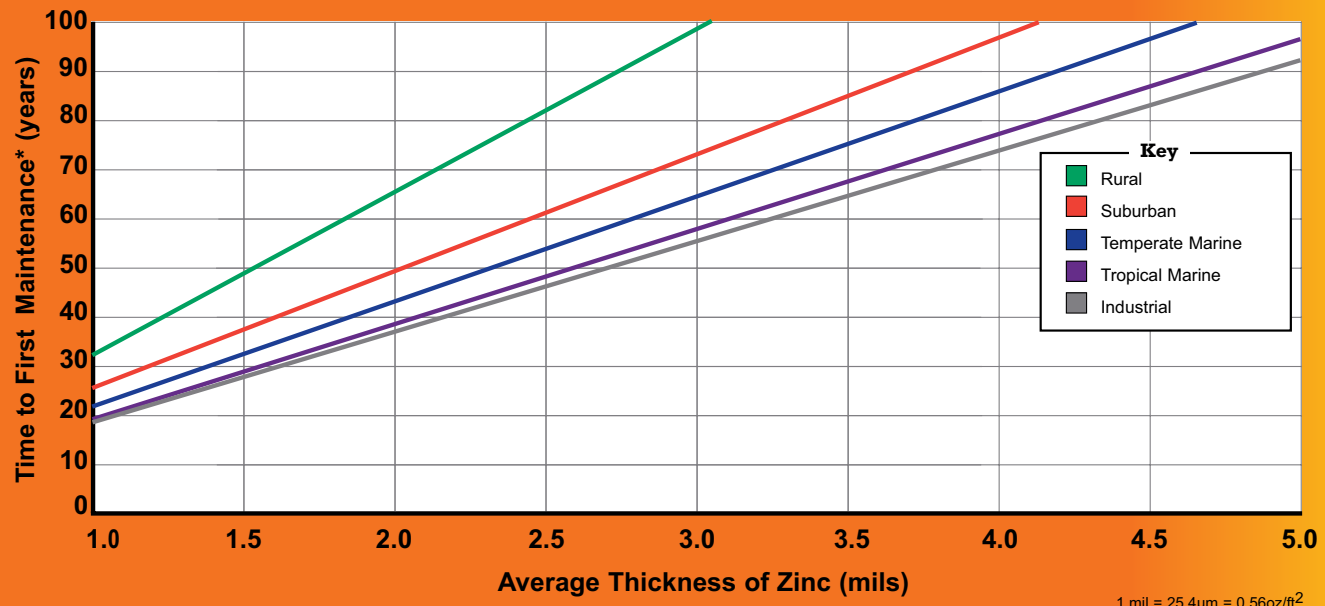
What makes HDG notable is the extended time-to-first maintenance. ***Figure 3*** shows the time to first maintenance of hot-dip galvanized coatings in five environments – rural, suburban, temperate marine, tropical marine, and industrial. ASTM A 123 requires at least 3.9 mils of zinc on steel greater than ¼ in. thick, castellated beams and other structural elements will have 70 -75 years of maintenance-free life in even the harshest environments. Therefore, a parking garage frame with a 4 mil HDG zinc coating located in an industrial environment will be protected from corrosion in even the worst environment for 70 years or more – essentially the working life of the structure.

Figure 2: Comparison of Initial Cost - Concrete vs. Hot-Dip Galvanized Steel

City	Concrete Cost[1] ($/sq. ft.)	Concrete Cost[2] ($/sq. ft.)	HDG Cost Range[3] ($/sq. ft.)
Atlanta	33.85	37.77	28.65 - 32.23
Baltimore	37.21	42.04	31.70 - 35.66
Boston	46.28	48.84	38.05 - 42.80
Chicago	43.43	47.19	36.25 - 40.78
Dallas	33.68	35.66	27.74 - 31.20
Denver	38.14	40.48	31.45 - 35.38
Detroit	42.11	45.33	34.98 - 39.35
Kansas City	41.30	43.73	34.01 - 38.26
Los Angeles	42.11	45.12	35.21 - 39.61
Miami	34.81	36.59	28.56 - 32.13
Minneapolis	45.03	47.40	36.97 - 41.59
New Orleans	34.73	36.50	28.49 - 32.05
New York	52.49	55.73	43.29 - 48.70
Philadelphia	45.83	48.33	37.66 - 42.37
Pittsburgh	39.05	42.33	32.55 - 36.62
St. Louis	41.68	43.22	33.96 - 38.21
San Francisco	48.84	51.42	40.10 - 45.12
National Average	**41.21**	**43.98**	**34.10 - 38.36**

[1] RSMeans, Reed Construction Data
[2] Parking Structure Cost Outlook for 2007 - "An Inconvenient Truth," Joey D. Rowland, P.E.
[3] Estimate derived from reducing the concrete averages 10-20%

Figure 3: Time to First Maintenance Chart



*Time to first maintenance is defined as the time to 5% rusting of the substrate steel surface.

1 mil = 25.4µm = 0.56oz/ft^2

Galvanized rebar will aid in the prevention of spalling, above, saving the costs of reconstruction.

This means when paint begins to crack and peel, the zinc coating of HDG steel will not only require no repair or maintenance, but also remain as strong as the day it emerged from the zinc bath. Paint requires continuous maintenance throughout the life of the project – the costs keep adding up with each required touch-up or complete overhaul of the paint coating, not to mention the gratuitous waste and environmental damage incurred. Meanwhile, galvanized steel stands corrosion, maintenance, and cost free for generations.

Also, because steel corrosion inspections can be performed with a quick visual check, deficiencies are easily detected and addressed. Other framing systems, such as concrete, often conceal corrosion issues until it is too late to act – as moisture and corrosive elements seep into the concrete attacking the steel reinforcement, which leads to spalling. Spalling can be an indicator of structural failure, and when a concrete deck on a concrete framed structure requires replacement, the entire structure may have to be demolished. At the very least, addressing concrete structural concerns take the structure out of operation, with 'solutions' often resulting in reduced parking capacity.[1]

With HDG steel structures, clients are also spared the indirect costs of loss of functionality for maintenance or repair shutdowns; because of the extensive time to first maintenance, there is no need to halt garage operation to allow time or space for routine paint touch-ups. Additionally, clients will be able to avoid total shutdowns for restructuring due to concrete issues. The maintenance-free nature of hot-dip galvanized steel will save indirect costs associated with time wasted searching for parking elsewhere, or worse – sales lost from visitors who will not even venture out due to the negative prospect of dealing with the inconvenience of an immobilized parking garage.

Life-Cycle Savings

Taking into account construction, transportation, direct, and indirect costs over the life of a parking garage leads to what is perhaps the most impacting structural cost analysis – life-cycle cost. From day one of the project, simple, easy to assemble HDG steel frame designs will cost less to build and save time (and therefore, money) in the construction phase. Because fewer beams and pieces are required to do the same amount of work, transportation fees are also reduced. A design material like precast concrete, conversely, will require heavy, cumbersome pieces to be transported at great expense, fitted together using costly special efforts and machinery, and will likely require continuous maintenance and upkeep until eventual failure due to spalling or deterioration.

Figure 4: Life-Cycle Maintenance Cost Report Using Life-Cycle Cost Calculator - Cincinnati Children's Hospital Garage

HDG vs. IOZ/Epoxy/Polyurethane		
	HDG	Paint System
Initial Cost		
Per ft²	$1.76	$2.87
Total	**$220,000.00**	**$358,500.00**
Life-Cycle Cost		
Per ft²	$1.76	$8.55
Total	**$220,000.00**	**$1,068,750.00**
AEAC		
Per ft²	$0.08	$0.40
HDG Life-Cycle Cost Savings: 79%		

PROJECT SPECIFICATIONS:
Cincinnati Children's Hospital Garage

Project Size:
500 Tons

Expected Life-Span:
50 Year Projected Life

Service Life Environment:
C3 (Industrial)

Structure Type:
Simple, 50 - 100' high

Member Type:
Typical Mix Size/Shape

Paint System:
3-Coat System Comprised of:
IOZ/Epoxy/Polyurethane
SP-10 Automated Surface Preparation
9 mil 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 2% and 4%, respectively.

During the use phase of the project, the galvanized frame will remain maintenance free – saving money on labor and materials, while ensuring indirect costs such as loss of business due to maintenance closures will be eliminated. Using a paint coating for corrosion protection, on the other hand, requires maintenance multiple times throughout the life of the structure, increasing lifetime expenses with each touch-up. Hot-dip galvanized steel not only saves you money initially, it also ensures your initial cost is the only expense you will have over the life of the parking garage. All these combined equal huge savings over the life of the project.

After examining how utilizing hot-dip galvanized steel saves money on both an initial and life-cycle basis, it is helpful to examine data from a real-world application. For an objective look comparing the life-cycle savings of HDG steel versus painted steel, visit the Life-Cycle Cost Calculator at **lcc.galvanizeit.org**.

The Life-Cycle Cost Calculator (LCCC) allows the user to input variables such as environment, coating system type, shop or field application, size of project, and estimated interest and inflation rates. Using calculations based on standard financial equations of net future value (NFV) and net present value (NPV), the LCCC delivers a detailed comparison of initial and total project costs and the average equivalent annual cost (AEAC), in a one-page printout. A Life-Cycle Cost comparison of galvanizing versus a 5-coat paint system for the Cincinnati Children's Hospital Parking Garage developed using the LCCC is summarized in ***Figure 4.***

Experts have also examined comparisons between steel and concrete frames. Structural engineers and others who have studied life-cycle costs conclude steel framed structures are usually less expensive over the life of the project.[3] Parking industry experts have indicated over a 50-year life, the cost to maintain a precast concrete deck and frame system is between 5 and 8 cents per square foot, while the cost to maintain a post-tensioned deck on a steel frame is between 3 and 5 cents per square foot -- a savings of 40 percent.[1]

Cincinnati Children's Hospital Garage
Cincinnati, OH

The University of Cincinnati and the Hospital District of Cincinnati have made a conscious decision to create architecturally interesting buildings, and the new Children's Hospital parking structure is no exception. Perched in the middle of the Hospital District and University, aesthetic appeal and durability were critical to this project.

Hot-dip galvanizing (HDG) was the ideal choice for the fabricator and architect, who realized the value of this system for corrosion protection in previous projects. Not only does HDG live up to the specifiers' corrosion protection and durability standards, the fact that HDG steel is 100% recyclable made it an even more environmentally friendly choice. This parking structure is certain to please patients and medical staff for generations to come thanks to the durable protection of HDG steel.

To compare the life-cycle savings of HDG steel versus painted steel for your next project, visit the Life-Cycle Cost Calculator at

lcc.galvanizeit.org

Economic Savings Summary

Affordable construction and transportation savings, in addition to savings created by quick turnaround, mean the initial price tag for construction is lower than competing systems. Because HDG steel requires no maintenance for 70+ years, costs during use are kept at a bare minimum – clients will even save on the electric bill! The real savings, however, are indicated by taking into account the life-cycle cost of the project. Structural engineers and others who have studied life-cycle costs conclude steel framed structures are usually less expensive over the life of the project.[3] As HDG steel can save both initially and continuously over the life of the structure, the sustainable choice for economic savings is clear.

DRIVE THRU Economic Savings

CONSTRUCTION
Uncomplicated steel frame designs take less time to develop and erect, and are lighter to transport, resulting in lower costs.

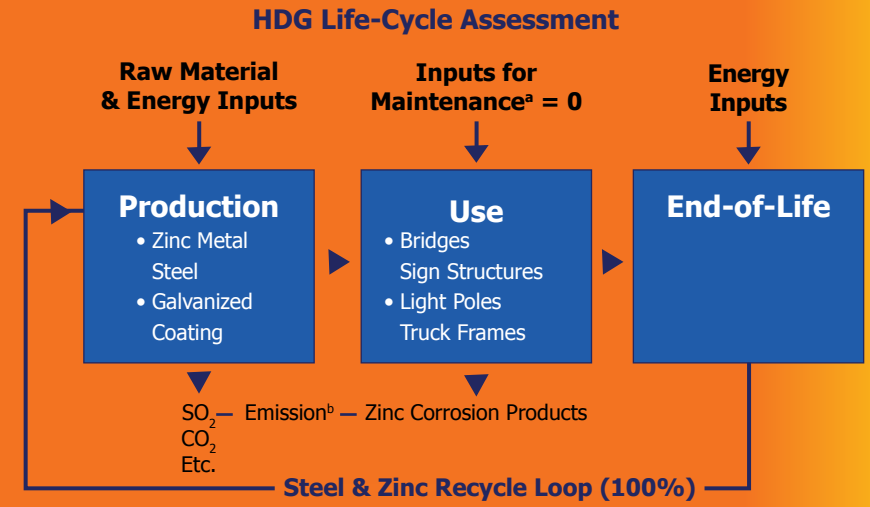
IN USE
The durable corrosion protection of HDG steel often means no maintenance-related costs or repairs of the steel frame for 70+ years.

LIFE-CYCLE
Accounting for direct, and indirect costs, construction, transportation, HDG steel framed parking structures save more over a lifetime.

Environmental Advantages

As delineated in the introduction, sustainable development (SD) is the social, economic, and environmental commitment to growth and development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Reflecting the third and, perhaps, most integral element of sustainable development, hot-dip galvanized steel structures minimize environmental impact by utilizing natural healthy, abundant, and recyclable steel and zinc. During use, no maintenance means no carbon footprint and no harmful repair or touch-up emissions for 70+ years. When the structure is at the end of its useful life, both zinc and steel are 100% recyclable, bringing the process full circle.

Figure 5: HDG Life-Cycle Assessment



[a] For all but the most aggressive, corrosive environmental conditions, there are no energy or raw materials inputs during this phase of the life-cycle
[b] For HDG steel, naturally occurring zinc oxide, zinc hydroxide, and zinc carbonate

To make a case for the sustainability of hot-dip galvanized steel, it is helpful to examine data produced when a life-cycle assessment (LCA) of a structure is conducted. Life-cycle assessment, often called a 'cradle-to-grave' study, is the study of the environmental impact of a process or product, and includes measurement of energy consumed and all emissions during raw material production and manufacturing of the final product through use and end-of-life (recycling/disposal). By examining data from worldwide sources regarding energy consumption and air/fluid/solid emissions measured during zinc production and during the actual galvanizing process, combined with analogous survey data collected from the steel industry, internationally renowned LCA experts Five Winds International and PE International compiled a LCA for hot-dip galvanized steel. ***Figure 5*** shows an overview of the environmental impact of hot-dip galvanized steel from production to end-of-life.

Production Phase

Long before galvanized steel is pieced together to form a parking structure frame, production begins on the steel and zinc metals. To begin, all structural steel contains an average of 93% recycled content[4], meaning a lower initial environmental impact. By specifying a hot-dip galvanized zinc coating for corrosion protection, you are choosing to utilize yet another abundant, recyclable, natural metal to further the cause of sustainability, as well as protect your parking structure. The production phase for HDG includes the life-cycle inventories of steel, zinc, and the galvanizing process. All emissions, energy, and material usage for hot-dip galvanized steel are isolated to the production phase. As delineated in greater detail in ***Figure 6***, the initial environmental cost is the final environmental cost, because there are no environmental outputs in the use phase.

Figure 6: Production Phase

Production Phase	Primary Energy Use[a]	Global Warming Potential (GWP) - CO_2 equiv.	Acidification Potential (AP) - SO_2 equiv.	Photo Chemical Ozone Creation Potential (POCP) - ethene equiv.
1 kg of HDG Steel	25.9 MJ	1.801 kg	0.00615 kg	0.000824 kg

[a] 10^6 Joules (unit of energy)

Figure 7: Use Phase

Use Phase	Primary Energy Use	Global Warming Potential (GWP) - CO_2 equiv.	Acidification Potential (AP) - SO_2 equiv.	Photo Chemical Ozone Creation Potential (POCP) - ethene 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

Use Phase

The use phase is where hot-dip galvanized steel passes competitors in the race toward sustainability. After the steel pieces have been fabricated, galvanized, sent to the site, and quickly assembled, there is nothing to do but wait. For 70+ years, galvanized steel will remain maintenance free – no raw material or energy expended, no carbon footprint extending beyond the production phase.

Conversely, a painted structure requires regular, routine maintenance – i.e., the entire painting process and all of its environmentally harming outputs must be repeated every 12-20 years. This means every decade or two, more paint chemicals and potentially VOC's will be expelled into the atmosphere and made a permanent part of the waste stream. There are also indirect costs associated with this continued maintenance, including exhaust from transport vehicles and particulate emissions caused by surface-preparation blasting, not to mention the disadvantage to the community caused by maintenance shut-downs and delayed usage. ***Figure 7*** provides the cost (or lack thereof) for HDG and identifies undetermined paint costs P_1, P_2, P_3, and P_4 during the use phase.

Also notable, though all structures use both steel and concrete, an equivalent utilization study conducted by the American Institute of Steel Construction (AISC) nets out the actual steel and concrete in a typical structure and then compares the remaining tonnage of structural steel in a steel framed system with the remaining concrete in a concrete framed system. The study shows the ratio of steel to concrete is typically between 1:6 and 1:18, ***Figure 8*** shows an average comparison.[5]

End-of-Life Phase

The true beauty and sustainability of incorporating hot-dip galvanized steel into a parking structure is there really is no 'end-of-life,' only a return to production – cradle-to-cradle, rather than cradle-to-grave. At the end of its useful life, the steel framing system of a parking structure can be recycled into new structural steel for new buildings and other applications and the zinc captured for reuse in new coatings.[1] In fact, steel is the most recycled material in the world. As indicated in ***Figure 9***, LCA credits HDG steel with 8.61 MJ for every kilogram recycled. Utilizing hot-dip galvanized steel for corrosion protection reinforces the environmentally friendly nature of steel framing, as the zinc used in the coating is also 100% recyclable. In contrast, after years of environmentally damaging maintenance, a painted coating becomes a permanent part of the waste stream when it is put to rest.

Figure 8: Equivalent Utilization[4]

1 Ton of Steel	8 Tons of Concrete
1.0 ton CO_2/ton	1.6 tons of CO^2/8 tons
70 gallons of water/ton	150 to 500 gallons of water/8 tons
1,860 pounds of recycled material/ton	160 to 800 pounds of recycled material/8 tons (fly ash)

Due to the LCA credit of 8.61 MJ/kg, resulting in a complete life-cycle primary energy use of 17.3 MJ, the complete life-cycle primary energy use for HDG steel is actually less than the primary energy used in the production phase. This, combined with the recyclability of the steel and zinc, means a hot-dip galvanized parking garage frame expends no extra energy or materials for the end-of-life phase and will be ready to continue on to a new phase of production.

Complete LCA

Common sense indicates incorporating a framing system using natural, abundant earth materials completely recycled at the end-of-life stage would be a more sustainable solution than applying a chemical cocktail requiring decades of maintenance to the same structure. Common sense aside, empirical, quantifiable LCA data proves a hot-dip galvanized steel frame is an environmentally friendly, sustainable solution for a parking structure (***Figure 10***).

Figure 9: End-of-Life Phase

End-of-Life Phase	Primary Energy Use[a]
1 kg of HDG Steel[a]	-8.61 MJ

[a] Steel is the primary component and is 100% recyclable, however, the zinc in the galvanized coating is also 100% recyclable. Paint on the other hand, becomes a permanent part of the waste stream

Figure 10: Complete Life-Cycle

Complete Life-Cycle	Primary Energy Use[a]	Global Warming Potential (GWP) - CO_2 equiv.	Acidification Potential (AP) - SO_2 equiv.	Photo Chemical Ozone Creation Potential (POCP) - ethene equiv.
1 kg of HDG Steel	17.3 MJ	1.801 kg	0.00615 kg	0.000824 kg

[a] Complete life-cycle energy use reflects production, use, and end-of-life credit

Though steel, the primary component of a steel framing system, is recyclable regardless of which corrosion protection system is chosen, the environmental impact of that coating is significant. With HDG steel, emissions, energy output, and material are isolated to the production phase. Because there are no emissions or energy requirement for hot-dip galvanized steel during the use phase, the initial environmental cost is the final environmental cost. Not only that, but both the steel and the zinc used are completely recyclable, making the parking garage less harmful to the environment from cradle-to-cradle, rather than cradle-to-grave. For more information on galvanizing sustainability, please refer to the AGA publication *Hot-Dip Galvanizing for Sustainable Design,* located at **www.galvanizeit.org/hdgforsd.**

Concurrent with the cradle-to-cradle concept, steel is the most recycled material in the world. When a material such as steel or zinc can be recycled over and over with new and varied uses, it is considered multicycled. Products such as paint or concrete are considered down-cycled, as the amount of reusable material deteriorates with each new cycle. In ***Figure 11***, AISC compares the multicycle and downcycled outputs of 1 ton of steel compared to that of 8 tons of concrete. Clearly, the steel is primarily recycled and put into another life of use, with miniscule amounts being appropriated to the landfills. The addition of a galvanized zinc coating to already multicycle steel means the complete life cycle of the steel structure will outlast concrete by generations.

Figure 11: End of Building Life[5]

1 Ton of Steel	8 Tons of Concrete
1,960 pounds multicycled	3,200 pounds down-cycled/8 tons
40 pounds landfilled/ton	12,800 pounds landfilled/8 tons

Environmental Advantages Summary

With the vast majority of structural steel and zinc in the galvanized coating entering the production phase as recycled material, there are minimal effects from mining and producing galvanized steel. Additionally, once the galvanized coating is produced, the only outputs that accrue throughout the life of a hot-dip galvanized steel structure are naturally occurring zinc byproducts. Because of galvanized steel's inherent durability and decades long time-to-first-maintenance, there is no need to expend wasted energy or make permanent additions to the waste stream due to continual maintenance. Finally, in addition to extending the design life of a garage by protecting the steel from deterioration due to corrosion, both the zinc and steel elements are fully recyclable indefinitely – meaning your initial environmental cost is the ONLY environmental cost throughout the life of the project.

DRIVE THRU Environmental Advantages

PRODUCTION, USE, AND END OF LIFE
The minimal effects of mining natural, abundant zinc and the naturally occurring byproducts of the galvanizing process are the only outputs that accrue throughout the life of a hot-dip galvanized steel structure. The initial environmental cost is the ONLY cost.

Conclusion

It has become increasingly important both nationwide and globally to examine how we can work to meet the needs of the present without compromising our responsibility to provide for future generations. By embracing the tenets of sustainable development – ensuring projects are socially, economically and environmentally sound – we are paying due tribute to these responsibilities.

Utilizing hot-dip galvanized steel framing systems to support new parking structures provides many social benefits. Attractive and versatile, HDG steel frames mean speedy construction, less intrusive design, ease of expansion, and superior corrosion protection. Economically, such a framework sets up a trifecta of savings over the life of the project with economical construction, affordable functionality, and life-cycle savings. Because society is moving away from an emphasis solely on social and financial needs, it is critical to examine hard data proving 'greenness' and environmental impact. As empirical life-cycle assessment data shows, hot-dip galvanized steel has a minimal impact on the environment, while returning to production again and again due to the recyclability of the natural elements utilized. All of these attributes work together to establish hot-dip galvanized steel as the most socially, economically, and environmentally sustainable solution for these transportation necessities.

Resources

[1] American Institute of Steel Construction (AISC). *Innovative Solutions in Steel: Open-Deck Parking Structures.* 2003.

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[4] American Institute of Steel Construction (AISC). *Steel Takes LEED® with Recycled Content.* November 2009.

[5] American Institute of Steel Construction (AISC). *Sustainability and Steel* PowerPoint presentation, 2009.

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