# Bridge and Operational Maintenance Training for Professionals and Asset Managers at the College Level

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**Abstract -** United States transportation network is the most extensive in the world. Bridges are a critical element of that network, and they are essential to the country's economic development, emergency response and national defense. As this millennium dawns, the United States is in the midst of a "bridge crisis", i.e. maintenance needs for older bridges have far outpaced available resources. This situation indicates the need not only for improved repair and rehabilitation techniques but also for a comprehensive approach to bridge management. In order to implement effective bridge maintenance and management programs and strategies, trained asset managers and bridge professionals are needed now than ever. The new field of expertise related to aging infrastructure is on the rise, as the nation realizes that existing assets are failing, and maintenance has recently suffered in large part due to limited federal and state funding. But having professionals who understand these systems in depth and can prioritize needs based on limited funding opportunities can make all the difference. Today many of the bridges in the United States are in various stages of disrepair with a disturbing number being classified as structural deficient requiring the bridge to be closed or limited to specific times of operation or load capacities across the bridge. This paper attempts to discuss some of the state-of-the art maintenance techniques and suggested training needs, to allow for safe use, increased performance capabilities and an improved condition of aging bridges in the United States.

*Keywords:* Bridge Operations, Operational Maintenance, Asset Managers, Training

## INTRODUCTION

There are more than half a million bridges in the United States, which are used every day, including to cross obstacles like streams, valleys, and railroad tracks. An overwhelming majority of these bridges are more than 50 years old, meaning the design life of the bridges is imminently approaching the end. And the nation is unable to operate with the current state of a crumbling infrastructure that requires system performance and proper maintenance strategies [1]. U.S. has a very efficient bridge inspection system, where most only get inspected once every one or two years. American Society of Civil Engineers (ASCE) Infrastructure report card indicates that one of every four nation's bridges has known structural problems or exceeds its intended life-span.

To fix nation's bridges and roads infrastructure with an overall grade of C, ASCE score card suggests that the country requires about $930 billion over five years [12]. The National Highway System (NHS) consists of 161,000 miles (or about 4 percent) of U.S. highways and includes the Interstate system, about half of the primary system, and important links to airports, military installations, ports, and international borders. The NHS carries about 60 percent of all traffic and about 80 percent of all truck traffic. Significantly, although the NHS represents only 4 percent of total highway miles in the country, it contains over 20 percent of all bridges. According to the American Association of State Highway Transportation Officials (AASHTO), the current NHS bridge investment backlog is estimated to be at least $32.1 billion (in 2004 dollars) [3]. Travel on the NHS has increased by approximately 50% from 1990 to 2004 while capacity grew 6%, according to TRIP (The Road Information Project). TRIP predicts interstate travel will increase an additional 60% by 2026 [4]. According to the 2007 U.S. bridge inventory, approximately 24.1% of U.S. bridges are either structurally deficient or functionally obsolete. With the collapse of the Interstate 35W Bridge in Minneapolis at the forefront of many people's minds, it was a sad reminder that aging bridges are at risk. These bridges are not necessarily unsafe, but a deficient bridge needs significant attention, and

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an obsolete one doesn't meet current design standards. Structurally deficient bridges are considered more serious, since they have structural problems that require limiting weight or require more frequent inspections. Some must be closed. Functionally obsolete bridges, on the other hand, may be in perfectly fine condition, but do not meet the needs of heavier traffic because they are too narrow or for other reasons [5].

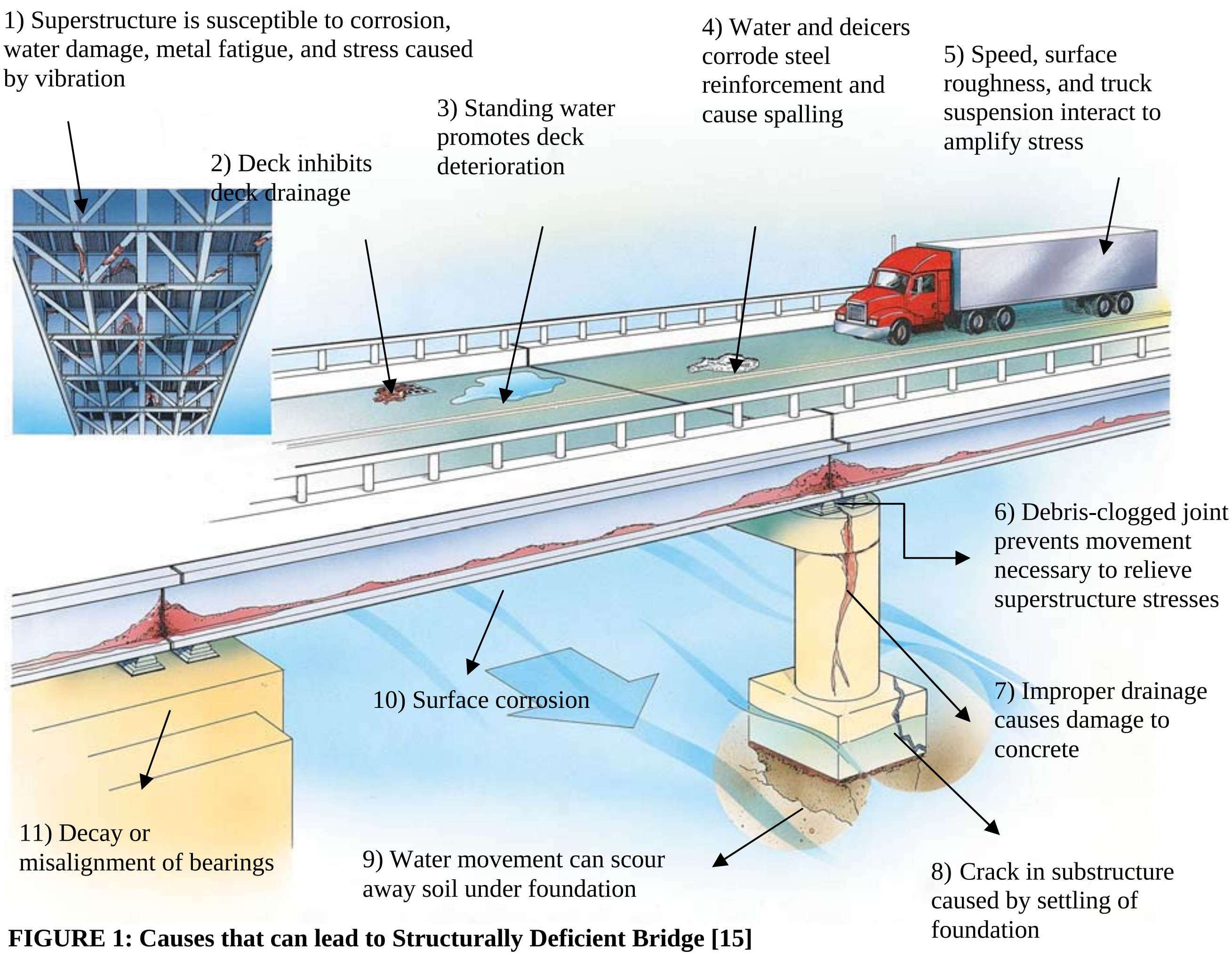


**FIGURE 1: Causes that can lead to Structurally Deficient Bridge [15]**

Inadequate load capacity is the most significant factor contributing to structural deficiency. Over 21,000 bridges are classified as structurally deficient solely because of a low load rating. The second most frequent factor leading to structural deficiency is a poor substructure condition rating, which accounts for approximately 14,000 bridges, and the third most frequent factor is a bad deck, accounting for over 8,000 bridges. The two most frequently found reasons for NHS bridges to be classified as structurally deficient are a bad deck and a bad substructure [11].

The demand for rehabilitation of existing bridges is on the rise, as the failing infrastructure nears its expected useful design life. This presents for an incredible opportunity to train the next generation of bridge and structural professionals and asset managers earlier in their professional life to prepare them for the upcoming challenges in the foreseeable future. Trainings like certification in bridge safety inspection are great tools for the working professionals, but providing interested graduates with the option to study specialized courses related to bridge and operational maintenance as part of College curriculum would better train them for tomorrow. Recent survey by MIT suggests that the nation’s youth is very unlikely to pursue Science, Technology, Engineering and Math fields, as they felt that they weren’t well prepared in school to seek out a career or further their education in these fields. Research through USA colleges and universities’ curriculum indicates that there are specialized trainings offered to working professionals but as such no bridge or infrastructure management related courses are offered anywhere in the schools throughout the country.

## KEY TOPICS AND STRATEGIES FOR MITIGATION

As most bridge failures in the United States result from unpredictable extreme events, such as earthquakes and floods, we must improve our understanding of the vulnerability of bridges to such events. With this understanding, we will improve strategies to reduce the risk of failure.

Throughout the country, departments of transportation (DOTs) and various public entities have implemented bridge asset and/or maintenance programs intended to alleviate maintenance deficiencies. These programs are driven partially by the National Bridge Investment Analysis System (NBIAS) by mandated bridge integrity inspections. However, the bottom line is typically the funding that can be allocated towards the endeavor. A substantial portion of the various agencies funding is tied up in road maintenance and construction, and is unavailable for bridge maintenance. As a result, bridges do not necessarily receive the funding required to maintain them, often resulting in the aforementioned large number being classified as structurally deficient or functionally obsolete. Some of these strategies are fundamental and would seem obvious while others are complex and involve much research [11].

Cost analysis is the most important component for bridge maintenance program to prioritizing, budgeting and programming. The cost of applying a maintenance action can include both direct costs and indirect costs. Direct costs are those directly imputed to the bridge owner as those associated with the direct application of maintenance actions, including materials and workmanship. Indirect maintenance costs are those associated to losses imposed on the user of the structure and include costs associated with increase in travel time, vehicle operation, and accidents, among others [11]. Direct costs are composed of two parts: cost at time of application and yearly cost after application.

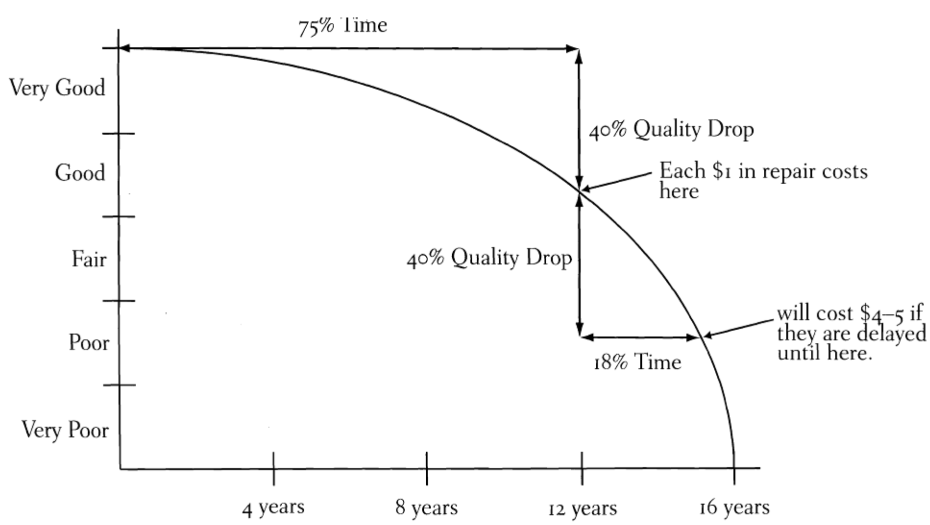


**FIGURE 2: Cost of delaying maintenance - Based upon a Generic Deterioration Curve (Condition vs. Age)**
(Adapted from Road Surface Management for Local Governments FHWA, DOT 1-85-37)

Figure 2 shows the variation of cost if the maintenance of the bridge is delayed. The cost increases by a substantial amount if the maintenance is not carried out at right time. Therefore, preventative bridge maintenance measures should be taken as soon as possible in order to avoid the escalation of cost, when more expensive repairs become necessary. And the trained professionals can help in identifying the right time based on life cycle design and cost analyses.

# BRIDGE DECK MAINTENANCE

The maintenance of bridge decks must be well-timed and performed to a high standard to prevent further deterioration. Repair of holes or deterioration must be done immediately and not delayed for approval at the time of the annual bridge inspection [13].

Concrete deck repairs range from crack sealing to full depth repairs. Emergency partial depth repairs may temporarily be made with bituminous materials. Full depth failure should be repaired immediately. Concrete repairs of full or partial depth failures may be made with high early strength cement or approved quick setting cement concrete, such as duracrete. In an extreme emergency, where traffic or weather conditions make it impossible to do this, the short term use of steel plates is acceptable. They must be anchored firmly to the deck and appropriate signing erected [13].

Failures less than 1 in. deep are called *spalls*. Spalls are repaired using partial depth methods or they may be filled with approved polymers or latex modified asphalt emulsion mixes. Failures over 1 in. deep but that do not go through the deck are classed as *partial depth*. Partial and full depth repairs are made with concrete, or approved accelerated mortars. The area around the failure should be sounded to determine the limits of the failure. The area should be marked and sawed with a concrete saw. Care must be taken not to cut the reinforcing steel. On a deck with an asphaltic overlay, it should be removed wider than the deck area to be patched. The patch can then be finished smooth and flush with the deck and the overlay properly compacted [13].

The total deck repairs made to bridges with concrete superstructures (main supporting element for span) such as voided slabs, concrete box girders, concrete girders, etc., are limited to 100 sq. ft. per span per day. This also applies to culverts. This limit does not apply to bridges with steel superstructures. If extensive repairs are required, a special repair and rehabilitation plan should be drafted by the bridge maintenance professional [13].

### Concrete Members

Concrete members are subject to spalling due to corrosion of the underlying reinforcement, scaling caused by freezing and thawing; and cracking caused by shrinkage, flexure, or differential settlement. Advanced materials such as polymers and high-performance hydraulic cement concretes show promise for making repairs. Various kinds of non-corroding reinforcement that are under evaluation may eliminate spalling and thus reduce the need for repair. As spalling is caused by corrosion of the reinforcement, which is brought on by chloride contamination, a permanent repair must halt the corrosion process. Cathodic protection - effective, but seldom used to date, is one alternative. Research on chloride ion removal from the concrete also looks promising. Improved instrumentation for detecting corrosion and controlling the cathodic protection process will expand the popularity of these techniques. Protective coatings and overlays applied in a timely manner can slow salt penetration and delay the initiation of deck corrosion. The emphasis in these applications (both now and in the future) is on rapid repairs, often performed at night to minimize user costs. Polymer concretes are effective in such applications, and very early strength latex modified hydraulic cement concretes, which can be opened to traffic in only three hours, were recently tested. Overlays and patching also can use high-performance concrete or shotcrete that contains microsilicas to decrease permeability [14].

### Steel Members

Damage to steel members typically results from corrosion, fatigue, and impact. If the damage from any of these causes is extensive, either a portion or the entire member may have to be replaced. Often, however, such a drastic remedy can be avoided by research findings in the following areas. The application of paint management systems should greatly extend the service lives of coatings. Prompt detection of fatigue cracks through health monitoring of bridge members, a promising area of research and training, will facilitate the identification and repair of cracks at an early stage. The application of heat straightening, a technique that continues to benefit from ongoing research, may eliminate the need to replace an impacted member [14].

# BRIDGE DECK DRAINAGE SYSTEM

The bridge deck and its highway approaches shall be designed to provide safe and efficient conveyance of surface runoff from the traveled way in a manner that minimizes damage to the bridge and the adjacent terrain, and maximizes the safety of passing vehicles. In an effort to appreciably decrease potholes that cause premature pavement failure, a study and field performance was conducted by Lee et al.  In the 1980's waterproofing layers were introduced into bridge pavement systems which reduced structural failures due to moisture damage. However, the problem of water retainage still existed due to the previously penetrated water into the pavement which either had no or poor/inefficient drainage systems. The moisture retained in the members over time compromised the structural integrity of the pavement which consequently resulted in the high probability of pothole occurrence [6].

The existing draining method used by the bridges studied utilized a drain channel installed at the edge of the pavement (Figure 3(a)). This is a potential problem as water that had previously penetrated the system is located in an area that is subject to a higher volume of heavy traffic. This will prevent proper draining through the drain channel and therefore will remain causing subsequent cracks followed by potholes over time. What Lee et al. proposed is a technique that was developed in Denmark in the mid-1970, that is, the use of a porous asphalt mixture which forms a drainage layer (Figure 3(b)) [6]. The porous asphalt mix is sandwiched between the wearing course and the waterproof layer. This allows all the water that infiltrates the deck pavement system to be properly drained quickly and thereby removing any potential for moisture damage caused by standing water.

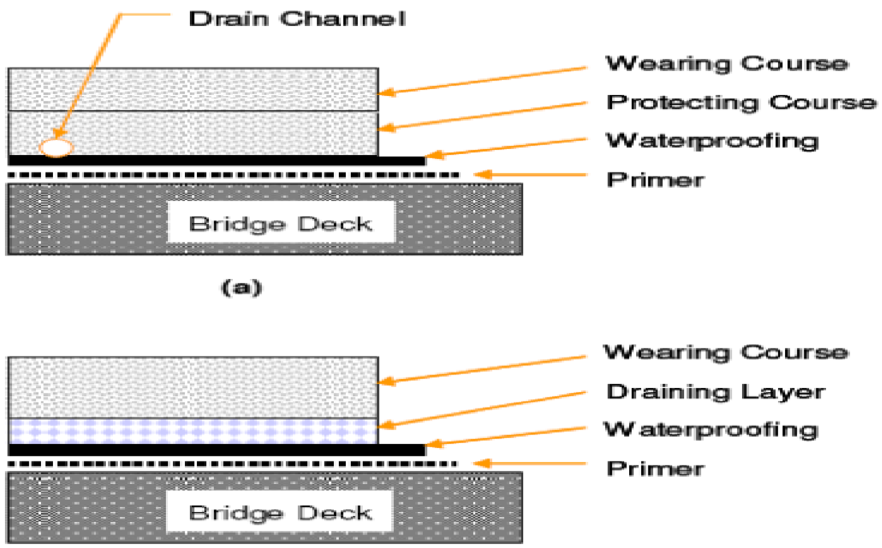


**FIGURE 3: Drainage systems in Bridge deck pavements:**
**(a) Traditional system; (b) Proposed new system.**

Due to the availability of local materials, modifications to the porous asphalt mixture may be necessary. Then there could be instances when due to abrasive surface of concrete, it is recommended that it may not be appropriate to use waterproofing sheets. Application of methyl methacrylate (MMA) type systems as waterproofing membrane has been quite successful. Use of MMA has several advantages over conventional concrete, such as rapid setting, ease of use, usability in hot and cold temperatures, and water and salt resistance. Optimum level of compaction of the draining layer is always useful [6].

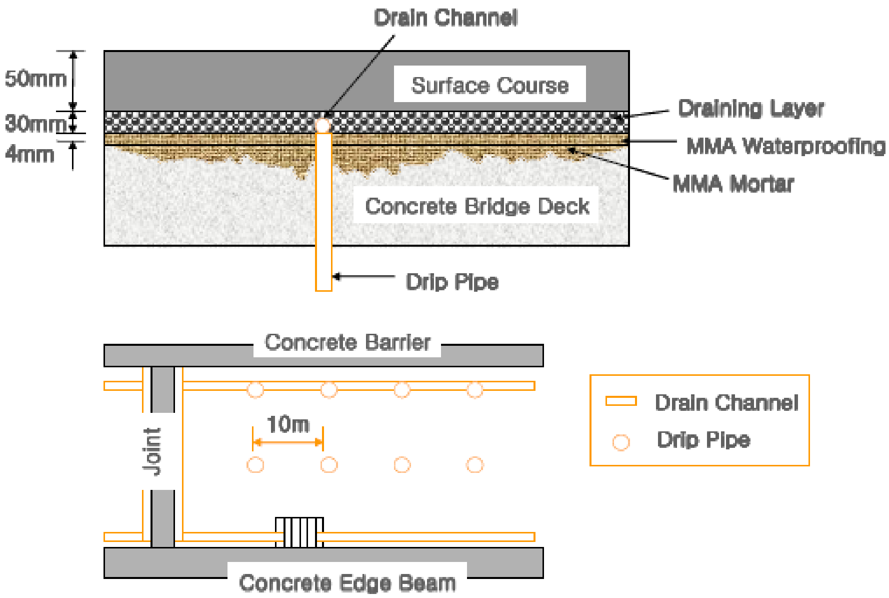


**FIGURE 4: Section and plan view of bridge deck pavement with drainage system**

## CFRP STRIPS AND NEW REINFORCED CONCRETE DECK SLAB

Carbon Fiber Reinforced Polymer (CFRP) strip method is an expensive yet has reported to be a credible technique to increase load capacity [7]. The tensioned CFRP strip application to the bridge girders proves effective to reduce the stress in the reinforcing bars, and to reduce crack widths. The method consists of a tension plate, base plates and intermediate anchoring devices. The tension plate is a CFRP strip that has anchoring devices at both ends. Base plates are steel frame which are attached to the concrete surface for anchoring the tension plate and for holding the specially modified hydraulic jack. And intermediate anchoring devices are simple stainless steel plates and anchor bolt. This method has proved itself cost-effective in a number of field applications strengthening concrete, masonry, steel, cast iron, and timber structures. Its use in industry can be either for retrofitting to strengthen an existing structure or as an alternative reinforcing (or prestressing material) instead of steel from the outset of a project.

## PENETRATING SEALERS

Penetrating sealers can be an effective and initially inexpensive method of dealing with corrosion problems which in turn will increase the service life of reinforced concrete bridges. Many steel-reinforced concrete bridges are exposed to corrosion from chloride ions particularly in coastal areas and northern areas where chloride salts are used to keep roads free from snow and ice. These chloride ions from the salts cause a negative impact on the structural stability of reinforced concrete bridges. Concrete sealers slow the rate of water intrusion in concrete, thereby providing improved protection against corrosion for the internal rebar. The deep penetration reduces the permeability of the concrete which protects against water, gasoline, and diesel, ultraviolet (UV) light and mild chemical exposure. The use of penetrating sealers offer increased protection for the portions of the deck with increased permeability due to shrinkage cracking or increased water-to-cement-ratio (w/c). It is expected that application of penetrating sealers will provide a concrete surface with additional uniform durability characteristics [8].

## OVERCOATING

During the last few years, overcoating has become the common term used to describe bridge maintenance painting operations which only partially remove existing paint and apply new coatings over a mixed substrate of existing paint, bare steel, and rusted surfaces.

One method of providing an accurate and objective rust defect assessment on a steel bridge surface is through digital image recognition. Two methods are the Neuro-Fuzzy Recognition Approach (NFRA) method and the Simplified K-Means Algorithm (SKMA) method. The NFRA method uses artificial intelligence techniques to separate rust pixels from background pixels. The SKMA method segments object pixels and background pixels in a digitized image using a statistical method. Even if both methods pass through different processing procedures, one common thing is that they first convert original color images to grayscale images and further process the grayscale images [9].

Overcoating is the preferred and more cost effective method of extending the service life of a bridge. Overcoating is analogous to conventional maintenance and touch-up painting. However, overcoating differs from customary maintenance painting [9].

For example:

- Overcoating is considered an alternative to full removal and replacement of a failed existing paint system whereas maintenance painting was either accomplished as part of routine lifecycle maintenance (for larger bridges) or in conjunction with other maintenance activities (e.g., steel component replacement, etc.). Due to increasing cost constraints, overcoating is now being viewed by some bridge owners as a primary bridge rehabilitation option as a reasonable substitute for abrasive blasting and application of a full paint system.

- Maintenance painting has generally involved the application of coatings similar to those already applied (e.g., lead-containing alkyd over existing lead-containing alkyd). Overcoating, as currently practiced, may involve the application of materials vastly different from those previously applied.

Overcoating operations vary widely depending on the condition of the existing steel and paint system and the specified surface preparation and new coating system, but generally these operations have the following components [9]:

1. **Washing** - bridge areas must be washed to remove dirt, bird droppings, grease and soot. Washing is generally accomplished using a pressure washer or steam cleaner. The goal is to remove surface contaminants and not the existing coating system although some loose paint and rust will be removed by most washing operations.

2. **Mechanical surface preparation** - mechanical removal of loose paint and rust generally follows washing. This operation may vary from light hand tool cleaning with scrapers or wire brushes, to removal of all visible rust and loose paint with vacuum shrouded power tools or vacuum blasting machines. The goal of this step is to remove rust and non-adherent paint while leaving as much of the intact existing coating system as possible.

3. **Overcoat system application** - there are many different paint systems sold on the market today. They vary from high-build, single coat systems to multiple coat systems with inhibitive pigments in the primer coats. In general, multi-coat systems are intended for spot primer application over the bare steel areas with full overcoating of the structure with one or two additional coats [9].

**Key Variables for Overcoating Success**

Several variables have a significant effect on overcoating risk for bridges. These factors are:

- **Condition of Existing Coating** - The most common used coating during original construction of highway system bridges were single component oil-alkyds containing lead or lead/chromate pigmentation. These coatings were generally applied in multiple thin coats totaling 6 to 12 mils. After many years of exposure to the environment, these alkyds become brittle and inflexible, and heavily chalked in areas exposed to sunlight. This aging and deterioration of the coating film has, in most cases, severely reduced both the cohesive and adhesive strength of the coating system. In overcoating maintenance, the existing coating which remains there after cleaning and minor surface preparation of the structure will serve as the chemical and mechanical basis for adhesion of any new applied coatings. If the existing coating has lost the majority of its cohesive and adhesive properties, an applied overcoating will be at the mercy of the disbonding of the original poor coating. In large part, the degree of risk associated with overcoating is directly related to the remaining adhesion and cohesion of the original coating. Measurement of adhesion of the existing coating by methods ASTM D4541 or ASTM D3359 (or by cutting to existing coating to the substrate and attempting to lift with a knife blade), is an important step in determining the acceptability of an existing system for Overcoating [10].

- **Millscale** - Prior to 20 to 25 years ago, most highway bridges were fabricated from steel members covered with intact millscale. Most painting was accomplished directly over the millscale. Millscale is a relatively poor surface for coating adhesion and performance. Intact millscale can be protective to steel in the short term, but once breached, the millscale will tend to electrochemically accelerate the corrosion of adjacent bare steel. The presence of millscale can add to the risk associated with overcoating by limiting the adhesion of the overcoating paint and accelerating deterioration of the existing coating and the new overcoat at the site of any holidays or breaches in the paint film [10].

- **Surface contamination and corrosion** - Paint performance can almost always be directly related to the quality of surface preparation. This is particularly true for paints applied over previously rusted or contaminated surfaces. In overcoating, the washing and mechanical surface preparation steps remove some, but not all of the rust and non-visible contamination from the surface. While some coatings are formulated to adhere to and perform better than others over contaminated or rusted surfaces, no coating will perform better over a contaminated surface than the same coating over a clean surface. Maintenance paints applied over previously pitted surfaces or over adherent or "packed" rust will likely fail first in those areas [10].

Resulting considerations for overcoating:

- The extent and distribution of corrosion or coating deterioration must be conducted.
- Techniques such as digital imaging are available to determine if the use of overcoating is a viable solution.
- The financial benefits of overcoating are significant. This procedure can be from 45 to 80% less expensive than complete paint removal.
- Anytime new coating material is applied over old coatings, some risk of a disbonding-type adhesion failure is inherent. Risk management is therefore necessary.

**Coatings**

Experience with the handling of lead-based paint, which constitutes a hazardous material when removed, has forced a management approach to coatings. Coatings management encompasses three considerations [14]:

1 Selection of coating systems,
2 Technologies for the removal of existing coatings, and
3 Replacement strategies.

**Coating Systems**

The paint systems emerging as "the longest lasting" incorporate zinc-rich organic and inorganic primers with urethane-based midcoats and top coats using moisture-cured media. This kind of system is becoming more popular because of its tolerance to application under both low-temperature and high-humidity conditions. Recent research indicated that these systems yield favorable results. However, the coating system with the best indicated life expectancy is not paint. Metallization with 100 percent zinc or 85 percent zinc/15 percent aluminum produces a coating that protects bridge steel longer than any paint system currently available. Lifecycle cost analysis gives a very positive argument for using this technology, especially on new construction. Although its use on older steel is increasing, it is not as successful at present [14].

**Removal Technologies**

Older paints that contain lead-based components must be removed cleanly and with the greatest respect for the environment and for worker health. New technologies often reduce the volume of hazardous waste and ease containment requirements. Abrasives blasting with traditional and new materials completely remove the paint and provide a mechanical anchor profile for the new paint system. Depending on the combination of materials used, the lead-based paint debris may be stabilized so that it can be disposed of as a nonhazardous material. Several paint removal technologies under development may provide viable, cost effective options to owners and Contractors for handling the lead-based paint [14].

These technologies include

- Electrochemical, debonding paint via low-voltage direct current;
- Plasma jet, ablating paint without distressing substrate; and
- Bioingestion, using paint-eating bacteria.

**Education and Management Strategies**

Effective management systems provide owners with practical and economically sound choices for coatings maintenance. Up-to-date information about the kind of paint, its application, and whether an overcoat is feasible is important to the owner in making replacement and renewal decisions [14].

## CONCLUSIONS

The approach to bridge maintenance is increasingly influenced by emerging management systems. Other trends that probably will influence future developments and practices in this field include increased attention to life-cycle cost analyses and the incorporation of user costs into maintenance decisions. Certainly, bridge maintenance engineers and professional with the right training should be able to use an array of increasingly sophisticated instruments, procedures, and systems to evaluate, repair, and rehabilitate structures. Research into materials also will continue, with an emphasis on products such as noncorroding reinforcements, more impermeable concrete, and superior coatings that will drastically reduce maintenance requirements when used in new construction. There are thousands of techniques available that can provide improvements to the myriad maintenance problems that obstruct the performance of bridges in the United States. While this paper discussed some of these techniques, there is a considerable amount of research that is currently being conducted worldwide to find solutions to maintaining ailing bridges. The driving factor which prevents the necessary maintenance from being carried out is lack of proper training and available resources, and funding limitations.

Although this paper did not address the cost of implementing the cutting edge technologies discussed, it is believed that cost should be considered when training and teaching the students, to see whether the technology being considered is feasible and cost effective.

This paper covers several bridge rehabilitation methods currently used in the industry for bridge maintenance. Compiling existing information to determine current state of the art techniques in the bridge maintenance industry should help us track our progress to date, help identify training needs and provides us with opportunities to look ahead to the challenges that this industry will face in the upcoming decades.

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