

## **Coating Failure by Design**

Leonard Phelps  
Wiss, Janney, Elstner Associates, Inc  
330 Pfingsten Road,  
Northbrook, Illinois 60062  
USA

Ralf Leistikow  
Wiss, Janney, Elstner Associates, Inc  
2500 Regency Parkway  
Raleigh, North Carolina 27518  
USA

### **ABSTRACT**

Although many industry resources for the design and selection of effective and durable coating systems are available to coating specifiers and manufacturer's technical representatives, too often the wrong surface preparation and/or coating system are specified and completed during construction and rehabilitation projects. This results in less effective coating systems and costly future remedial work. A case study of a project in a seacoast environment will be reviewed to illustrate an installation which resulted in significant remedial work on the existing structures. As a result of poor project specifications, limited or improper technical support, and deficient construction, the structural framing on this project deteriorated prematurely and required extensive remedial work. The project specification and construction deficiencies resulted in widespread coating failures and deterioration of the structural framing. In addition, the various field and laboratory techniques utilized to determine the cause(s) of the coating failures will be discussed. The scope of the completed project and remedial work will also be reviewed. Based on the findings related to the project, general recommendations, and practical steps to avoid such deficiencies that could be used by coating specifiers and manufacturer's technical representatives will be reviewed for the case study.

Key words: Failures, Specifications, Field Testing, Laboratory Testing, Investigation, Remediation, Overcoating, Corrosion

### **INTRODUCTION**

Although the form and function of a well-designed building are important, it is the long-term performance and durability of a building and its components that will be important to the owner(s) and occupants. Therefore, during the design of buildings, the selection of the appropriate materials and understanding the long-term performance of the specified materials exposed to various site-specific

environmental conditions is critical in avoiding the potential “failure by design”. The case study presented will focus on the *coating failure by design*, that could have been avoided by the original design and construction team and resulted in costly litigation and eventually the complete removal of a key architectural element on two high-rise condominium buildings located along the Florida coastline (Figure 1).

The buildings consisted of an eighteen-story tower (Tower 1) and a twelve-story tower (Tower 2). Construction of the buildings began in August 2004 and was completed in mid-2006. A decorative roof canopy constructed from structural steel framing and corrugated metal decking was located on the roof of both buildings. The original specified coating system for the roof canopies exhibited early deterioration in the form of peeling and flaking coating, corrosion of the ferrous metal of the structural steel framing, and corrosion of the galvanized and metal decking. The original coating system was installed in 2006 and was remediated in early 2011. Localized coating deterioration was observed by the design and construction team before the project was completed and the coating manufacturer’s technical representative was involved in the review of these conditions. These conditions were documented in the project punch list and appear to have been resolved by completing limited touch-up work on the coating system in areas that could be easily accessed. Staining of the building facade from the runoff containing some of the corrosion byproducts was noted on both towers in late 2011, and concerns about the long-term service life of the existing roof framing and coating system were raised by the condominium association. To determine the potential cause(s) of these coating failures, the available construction documents were reviewed, and a field and laboratory testing program was conducted. A key task in the investigation was to evaluate these documents, and assess subsequent decisions made by the design and construction team, to determine whether these contributed to a *coating failure by design*.



**Figure 1. - (a) Towers 1 and 2 with roof canopies (b) Towers with roof canopies removed<sup>(1)</sup>**

## REVIEW OF DOCUMENTS

The roof canopies consisted of both structural steel framing and corrugated metal decking. Project submittals were not available; therefore, the coating system for the structural steel was only understood on a generic basis. Shop painting details are summarized below:

1. Surface preparation for shop painting:
  - a. Unpainted steel (All structural steel that is not specified to receive a shop coat of primer paint)
    - (1) SSPC-SP 2,<sup>(2)</sup> “Hand Tool Cleaning” or SSPC-SP 3,<sup>(3)</sup> “Power Tool Cleaning”
  - b. Shop Painted Steel (All structural steel specified to be shop painted)
    - (1) SSPC-SP 2, “Hand Tool Cleaning” or SSPC-SP 3, “Power Tool Cleaning”

2. Structural Steel Primer Paint: SSPC-Paint 25.1, <sup>(4)</sup> Type II; zinc oxide, raw linseed oil and alkyd primer. Application rate per manufacturer requirements and DFT not less than 1.5 mils (38.1  $\mu\text{m}$ ). (Apply two coats to surfaces that are inaccessible after assembly or erection).

Field painting details are summarized as follows:

1. Surface preparation for field painting
  - a. Blast steel surfaces clean as recommended by paint system manufacturer and according to requirements of SSPC-SP 10.<sup>(5)</sup>
  - b. Treat bare and sandblasted or pickled clean metal with a metal treatment wash coat before priming.
  - c. Touch-up areas and shop-applied prime coats that have been damaged. Wire brush clean with solvents recommended by the coating manufacturer and touch up with the same primer as the shop coat.
2. Exterior Paint Schedule (Primer is not required on shop-primed items)
  - a. Primer Coat: Epoxy, 3.0 to 5.0 mils (76.2 to 127.0  $\mu\text{m}$ ).
  - b. Intermediate Coat: Aliphatic polyurethane enamel, 1.5 to 4.0 mils (76.2 to 127.0  $\mu\text{m}$ ).
  - c. Topcoat: Aliphatic polyurethane enamel, 1.5 to 4.0 mils (76.2 to 127.0  $\mu\text{m}$ ).

The structural steel section of the specification indicated surface preparation of both unpainted steel (i.e., all structural steel that was not specified to receive a shop coat of primer) and all structural steel specified to be shop painted as required by the paint manufacturer but not less than SSPC-SP2 (Hand Tool Cleaning) or SP3 (Power Tool Cleaning). The structural steel section of the specification indicated that all non-galvanized steel was to be shop primed, and that the shop painting of structural steel was to be coordinated with the architect's painting requirements in the specifications and the architectural drawings. However, architectural, and structural drawings did not reveal any specific paint requirements. Two coats of primer were to be applied to surfaces that would become inaccessible after assembly or erection.

The Type II primer detailed in SSPC-Paint 25.1, was based on oil modified alkyd resin and was germane at the time specifications were developed in 2004. According to SSPC-Paint 25.1, the primer was considered suitable for SSPC Environmental Zones<sup>(6)</sup> 1A (interior, normally dry) and 1B (exterior, normally dry).

## FIELD INVESTIGATION

The field work consisted of making observations of the structural steel's applied coatings on the towers' canopies, performing tests to assess the coating adhesion and thickness, evaluate surfaces and interfaces for contaminants, conduct holiday testing, and sample the coating and substrate. A summary of the field observations and testing of the coated structural steel framing follows:

### Observations and Examinations

Reportedly the canopies were recoated at least once since their original installation, and poor workmanship was evident throughout the work. Heavy roller marks, runs, and sags were common in the recoated areas. The runs and sags were sufficiently heavy that the coating had partially ponded onto the top of bottom flanges. Moreover, the coating finish was missing in some areas ("finish-coat holidays"). Runs, sags, pooling, and finish coat holidays are depicted in Figure 2(a). Many of the upward facing surfaces of the structural steel framing were covered by the corrugated metal decking and would limit or prevent access to these surfaces and a continuous application of the remedial coating. Similarly, at bolted connections, mating surfaces were also inaccessible.

Corrosion of the substrate and consequential coating peeling failures were apparent on the coated steel surfaces of the canopies of both towers. The peeling was judged to be the consequence of corrosion of the substrate, since the peeling was typically associated with corroded areas and the backside of peels typically had a layer of corroded material. Corrosion occurred predominately at the edges of steel

members, nuts, and bolt heads; edges corrosion of structural steel members is illustrated in Figure 2 (b). Extensive corrosion and lifting (peeling) of the coating system from the top of the bottom flanges was also observed (Figure 3 (a)). To a lesser extent, corrosion was also observed at localized areas of webs often leaching from cracks in the web coating. Blisters and under-film corrosion also were present at the underside of some steel components.

In addition to intermittent periods of rain, coastal fog coated the structural steel with a film of aerosolized seawater each night. Seawater was observed to cling to the underside of flanges of the structural steel well into the afternoon. Corroded surfaces of the top of bottom flanges were also found to be wet or damp during these periods.

Coating was removed from selected intact areas of webs to expose and evaluate the condition of the substrate. Partial removal of original reddish-brown primer at a selected, seemingly intact, non-rusted area, revealed smooth, non-scarified, black, mill scale surface as depicted in (Figure 3 (b)). Pull-off adhesion testing (detailed later) in this area, revealed small spots of under-film corrosion. The presence of mill scale alone suggests that substrate surfaces were prepared no better than SSPC SP2 or SP3 since these methods do not require the removal of firm, intact, mill scale and rust, and the lack of

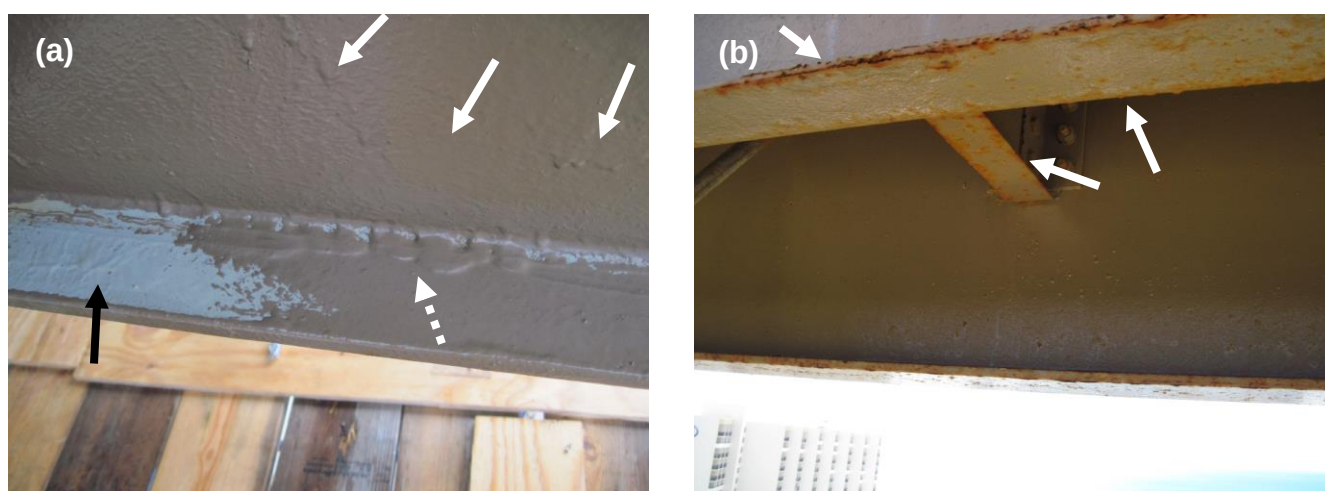


**Figure 2. - (a) Sagged remedial coating (solid white arrows) on web, and pooled coating on flange (white dashed arrow), and area of missing topcoat (solid black arrow), (b) Area where corrosion is predominantly at edges of steel (white solid arrows)**

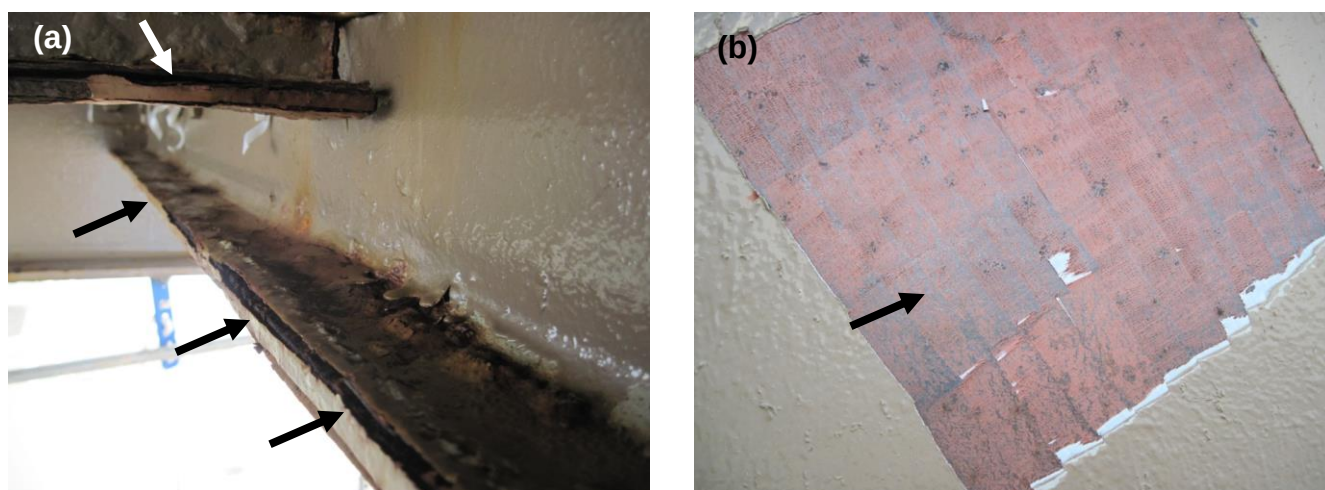


**Figure 3. - (a) Extensive corrosion of the top of bottom flanges and lifting (peeling) of coating system (b) Smooth mill scale surfaces were present beneath the reddish-brown primer (arrow)**

scarification of the substrate further suggests that substrate surfaces may not have been prepared by these methods at all.

### Coating Adhesion Testing

The strength of the bond of the coating to the substrate was determined by performing adhesion tests essentially by Method A of ASTM D3359<sup>(7)</sup> (tape adhesion) and by ASTM D4541<sup>(8)</sup> (pull-off adhesion).

Areas of seemingly intact coating were tested at eleven locations and the results of tape adhesion tests ranged from 2A to 5A. Fifty five percent (55%) of the adhesion tests performed were indicative of good adhesion (i.e., 4A or 5A), 36% were marginal (3A), and 9% represented poor adhesion (2A or less). The ASTM D3359 ratings were categorized by relative quality of good, marginal and poor adhesion based on the authors' collective experience in performance of this type of coating adhesion test. Those tests indicating marginal to poor adhesion occurred in areas where the test revealed under-film corrosion. However, some test areas showed higher adhesion ratings even though the substrate was corroded (Figure 4).

Adhesion of the coating system was also determined in accordance with ASTM D4541 using a Type VI adhesion tester. The average adhesion values of triplicate tests performed at five locations ranged from 880 to 1,720 psi (6.1 to 11.8 Mpa) and the average of all test performed was 1,290 psi (8.9 Mpa). Most of the tests yielded at the reddish-brown primer and the mill scale substrate. Test conducted in proximity to corroded areas indicated the lowest average adhesion of 883 and 997 psi (6.1 and 6.9 Mpa); other areas tested had pull-off strengths of 1,243 to 1,717 psi (8.6 to 11.8 Mpa).

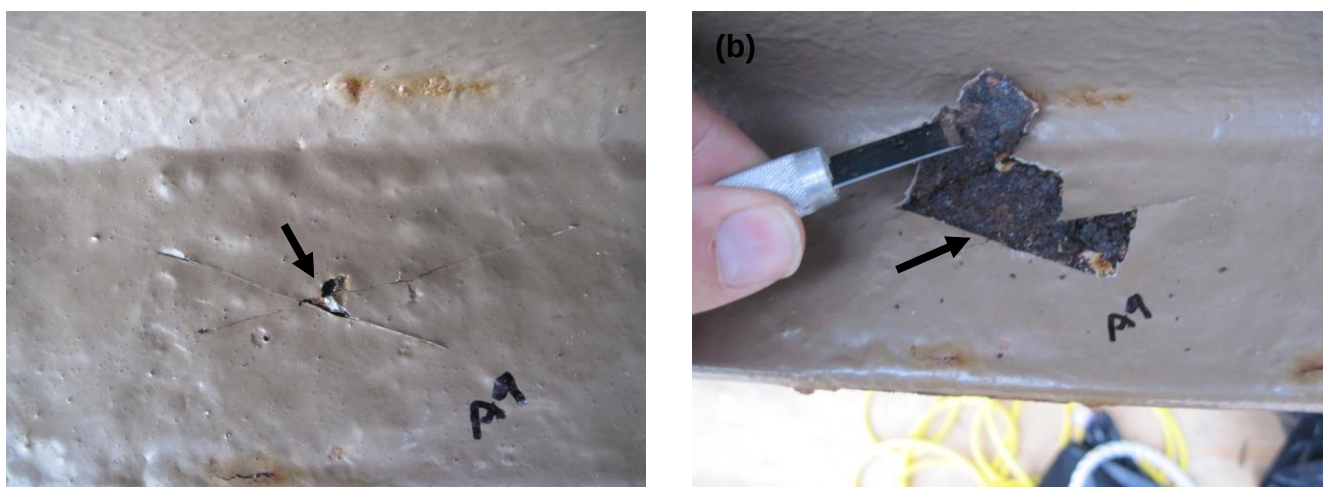


**Figure 4. (a) X-cut adhesion test with a marginal rating (b) The same adhesion test area showing corrosion and mill scale beneath the coating that was easily removed from the substrate.**

### Coating Thickness Testing

#### Coating Thickness Measurements by Paint Inspection Gage

Limited coating thickness tests were conducted on the coating system of the structural steel in accordance with ASTM D4138<sup>(9)</sup> using a paint inspection gage. With this method the individual coating layers of the coating system could be distinguished, and the thickness of the layers measured. The two test locations delineated in Table 1 exhibited a multi-layered coating system with corresponding average thicknesses of the exposed layers and of the total composite system.

#### Coating Thickness Measurements by Magnetic Gage

Total dry film thickness measurements were also completed using a magnetic thickness gage in general accordance with ASTM D7091.<sup>(10)</sup> The composite coating system thickness was variable depending upon the type of surface tested (flange, web, bottom, etc.) and whether the tested area consisted of the original three-coat coating system or the original coating system with a remedial