FLORIDA HIGH-RISE BALCONY HANDRAIL ANCHORAGES:
SOLUTIONS FOR A DEFECTIVE DESIGN

———

A Project
Presented
to the Faculty of
California State University, Chico

———

In Partial Fulfillment
of the Requirement for the Degree
Master of Science
in
Interdisciplinary Studies
Concrete Construction Management

———

by

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Spring 2012
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A Project

by

Trevor Dean Prater

Spring 2012

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If the Office of Graduate Studies were to allow it, many more names would be included on the title page of this document. While I am responsible for the compilation of the following chapters and the analyses of information and personal experiences documented in them, this project would have accomplished much less if it were not for the support, mentorship and assistance of many people along the way.

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While the majority of my graduate studies has been concerned with concrete construction and management, many distinguishing features of my education would not be fulfilled without the support of Lori Brown. By tutoring me through sustainable construction accreditations and allowing me to hone my teaching skills in her classes, I
have personalized my degree with interests I have been passionate about long before I considered the professional path I am on now.

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Finally, and most importantly, I thank my parents and brothers for their continuous support throughout this endeavor. Going against my eager anticipation to quickly develop a career in order to pursue this degree has been a difficult decision, but their constant affirmation and pride has fueled my desire to accomplish this goal to the best of my abilities.

Eight years ago, when my parents moved me in to my freshman dormitory, I was assured that I would have their full support in whatever academic and career path I made for myself. “Aim high,” my dad said as he left, “you’ll never be able to say you didn’t try and you’ll always land ahead of those who didn’t.”

Whether I followed his advice the first few years is questionable; however this project and forthcoming degree acts as a testament to his advice and the change we can create when our sites are set above the obstacles we perceive to be in the way.
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ABSTRACT

FLORIDA HIGH-RISE BALCONY HANDRAIL ANCHORAGES:
SOLUTIONS FOR A DEFECTIVE DESIGN

by

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Master of Science in Interdisciplinary Studies

Concrete Construction Management

California State University, Chico

Spring 2012

This project conveys the processes and research efforts employed in order to eliminate the frequent cyclical repair of handrail anchorages affixed to coastal concrete balconies through a building code modification. This report also recognizes the benefits experienced through industry and professional partnerships, which helped expedite the code modification process by avoiding the bureaucratic and institutional barriers that have allowed the problem to continue.

Typical coastal balcony corrosion issues stem from design and construction practices that increase the exposure of dissimilar metals to an environment containing abnormally high levels of moisture and chloride. Eliminating or reducing the ability for the galvanic reaction that occurs in this environment will significantly reduce the likelihood of aggressive and rapid corrosion within the balcony.
To do this, care should be taken to use the materials and methods described in this report to prevent chlorides from penetrating into grout at the handrail posts and to prevent the effect chlorides have on embedded metals, should intrusion occur.

The code modification suggests two less-conductive handrail anchoring methods. Both methods forbid the use of the core-drilling method and cementitious grout. Instead, the builder is instructed to either:

1. Surface mount the handrail posts to the concrete slab
2. Pre-form handrail post-holes before concrete is placed using the “block-out” method and use an epoxy-based grout or equivalent material to anchor the handrails to the balcony slab.

Both of these alternative methods reduce the conductive environment that perpetuates this corrosive cycle.
CHAPTER I

INTRODUCTION

Project Purpose

This project has two primary purposes. First, the project constitutes an effort to research, understand, and remediate the impact of factors that promote the frequent and cyclical repair of concrete balconies along Florida’s coastline. Secondly, the project demonstrates an effective internship that provides significant industry benefit, including a uniquely focused effort toward creating an immediate change in the way balconies are designed and built.

The State of Florida includes more than 1,300 miles of coastline, much of it flanked by high-rise condominium buildings. The balcony is a ubiquitous feature of these condominiums, delivering the luxuries associated with coastal real estate to condominium tenants at a fraction of the cost of a private coastal home. As a result of insufficient building codes and a 5-year statute of limitations that limits condominium developers’ investment in durable design, these concrete balconies undergo structural repairs on a frequent, cyclical basis (Florida Statute 718.124, 2010). Furthermore, a lack of understanding of the problems that induce this degradation and ineffective management practices of the problem on behalf of condominium homeowners associations perpetuates the cycle of repairs.
This culminating graduate project documents the design flaws associated with this particular type of balcony degradation and suggests code changes to correct the problem. By partnering with the American Concrete Institute (ACI), findings from this internship will result in a published document that I will present to the Florida Building Commission in hopes of enacting permanent improvements to building code regulations for balcony structures in the coastal regions of Florida.

Project Scope

This project illustrates the results of an 11-week summer internship in Florida and subsequent investigation, research and synthesis during the 2011-2012 academic year. It was completed with oversight and thoughtful assistance from the CSU, Chico Concrete Industry Management (CIM) program, the international concrete repair and preservation contracting company Structural Preservation Systems (SPS) and Peter Emmons, the founder and chief executive officer of SPS.

The focus of the project—to suggest a means to remedy the ongoing problem of balcony deterioration on the Florida coast—was determined in concert with CIM Director Dr. Tanya Komas and Emmons. Prior to this project Komas and Emmons wished to create an advanced-level internship and student-managed project that would employ qualified students beyond the typical “work site” experience offered through most construction management internships. Realizing the prevalence of many reoccurring construction defects, Komas and Emmons sought to connect the knowledge and political power of the construction industry with the ambition and dedicated academic interest of a graduate student. Thus, the focus of their conceived project was to enact a change in a
reoccurring construction defect from the “top down.” Due to my position as a graduate student and my previous experience restoring corroded concrete structures on Alcatraz Island with Dr. Komas, I was able to pilot the internship imagined by Komas and Emmons and create my graduate culminating project through of this endeavor.

During the summer of 2011, I worked as a research intern for SPS, out of its Pompano Beach, Florida office. Reporting directly to Emmons, I traveled throughout Florida to interview a variety of stakeholders associated with the design, engineering, construction, and code enforcement of balconies in concrete high-rise buildings.

In addition to conducting interviews, I also researched building codes, industry-published standards, building plans, and similar construction issues associated with balcony construction in Florida and elsewhere. I was fortunate to use SPS resources to book initial interviews and work-site visits, as a large part of the company’s work is in the area of condominium balcony repairs.

The ultimate goal of my internship was to gather as much information as I could through research and direct field interviews with stakeholders and to set the stage for future interns by documenting the troubles and successes I experienced. At the end of the internship, I returned to Chico and used this accumulated information to research the technical and scientific aspects of balcony construction and corrosion throughout the succeeding academic school year.

While conducting interviews I employed the qualitative research method of participant observation as a tool to gather and evaluate the many opinions and perspectives I encountered. This method allowed me to best understand the social, cultural, and economic factors that have propagated the problem. As a student intern
already relatively familiar with construction practices and methods, the participant 
observation method allowed me to discuss and view the problems associated with my 
research topic on an equal level with those I interviewed (Mack, Woodsong, MacQueen, 
Guest, & Namey, 2005). Furthermore, as a result of the participant observation method of 
research, all of my experience witnessing the problem and interviewing subjects occurred 
in the field, where they existed, or at the offices of the stakeholders, where the problem 
was inadvertently created and perpetuated.

Upon completion of my summer internship, I was able to extrapolate common 
themes and trends that lead to balcony failures and develop a holistic and comprehensive 
interpretation of the issues that created these failures. The result of this process suggested 
the fault in balcony repairs stemmed mainly from the intrusion of chlorides present in 
airborne sea spray and the resulting corrosive reactions these chlorides induced upon 
metals embedded in concrete. Because of this, other corrosive agents such as carbonation 
of concrete, frequent freeze and thaw cycles or the corrosive effect stray currents create 
in reinforcement steel (to name only as few) are outside of the scope of this project.

Dr. Komas, Mr. Emmons, and myself continually met to discuss the best way 
to produce an action that would effectively stop the constant repair of balconies in 
Florida. Ultimately, we decided the most effective way to universally change the way 
balconies were designed and built by Florida architects, engineers and builders was to 
modify the Florida Building Code (FBC).

To submit a code modification, I worked with ACI Subcommittee 364 to draft 
a TechNote that details the recommended way to install handrails into coastal balconies. 
In developing this TechNote, I had the opportunity to present project findings at concrete
industry conventions in Chicago, Cincinnati and Dallas. The TechNote has been
approved by ACI Committee 364 and is now undergoing final editing and approval by
the ACI Technical Advisory Committee. When published, this TechNote will act as a
non-regulatory document that will nevertheless carry considerable weight within the
Florida Building Commission, as the FBC already adopts ACI standards for building
applications that involve structural concrete (FBC, 2009, Pt. 19.1). Furthermore, the FBC
is revised every three years. The next revision is scheduled for review in 2013 to take
effect in 2014. The code modification associated with this project will be reviewed in the
2013 review cycle, and, if found eligible and relevant by the Florida Building
Commission Structural Technical Advisory Committee, be adopted for all new
construction projects starting in 2014. As an associate member of ACI Subcommittee 364
and the administrator of a FBC code modification, I will continue to work with both of
these agencies in order to represent the work I have completed through this project. This
work generally involves an official representation of the respective TechNote and code
modification should concerns or a need for troubleshooting arise.

Project Significance

While firm financial data cannot be obtained or disclosed, nearly all of the
professionals I interviewed agreed that the cost of repair particular to this specific issue
would exceed between $250 million to $500 million dollars annually in Florida alone,
depending on the strength of the economy. One report by the Florida Community
Association Journal (Hill, 2008) listed Florida’s balcony restoration costs as high as $1
billion annually. However, the impact of this expense is obscured because costs are split
between the many individual unit owners. Furthermore, due to the high prevalence of retirees in these condominiums, individual owners rarely face this expense more than once in a lifetime. Nonetheless, the overall impact of balcony degradation is significant, both financially and in terms of professional values that are fundamentally established to construct structures of enduring quality.

However, throughout my research it has been apparent that the value of this proposed modification will be interpreted differently by the various groups of stakeholders it may impact. Specifically, I have experienced opposition from some contractors, engineers, and various supporting professions that benefit financially from the niche of repair and maintenance of degrading balconies. Indeed, with hundreds of millions of dollars being spent each year on an issue relatively unknown to many, balcony repair still remains a niche industry, with relatively few companies competing against each other.

Additional significance of this project comes from the demonstrated success of the internship Komas and Emmons created. As a result, the CIM department wishes to develop this internship in the future for advanced students who have proven themselves academically and through previous field experience. The CIM department believes that, by increasing the scale of this project’s demonstrated use of a student intern to solve real construction problems, future qualified student-interns will have a unique opportunity to gain trust and entry to an otherwise competitive construction industry to create large-scale changes. The research processes and methodologies that I used while interning in Florida are documented in this report and other notes, and will assist the CIM department as they expand this internship for future students.
Project Limitations

Although final publication is imminent, my project is being submitted before the TechNote is officially published by ACI. Also, the proposed code modification is not going to be reviewed until 2013, when the Florida Building Commission meets to begin forming the next building code.

While it did not directly contribute to this project, the CIM department’s Alcatraz Summer Field School (ASFS) provided me with requisite analytical and technical experience that significantly benefited my work throughout the execution of this endeavor. The ASFS is a summer internship operated through a partnership between the CIM department and the Golden Gate National Recreation Area. I was an intern for the ASFS from June to August of 2010. During this time I worked on Alcatraz Island as a concrete restoration technician; analyzing and repairing concrete structures that were decaying primarily because of the aggressive marine environment the island is located in. The interrelations between the knowledge I obtained as an ASFS intern and its benefits to this project are numerous. Consequently, the CIM department wishes to officially connect the two internships in the future for students wishing to pursue their education into higher levels of concrete repair and analysis.

Definition of Terms

Aggressive Environment

An environment that jeopardizes concrete durability. In the case of this project, an aggressive environment is classified as such because of the high airborne chloride content created by sea spray.
**Anchor, Anchorage, Anchor Bolt**

A metal bolt or stud, either cast in place, grouted in place, or drilled into finished concrete, used to hold various structural members or embedments in the concrete, and to resist shear, tension, and vibration loadings from various sources, such as wind and machine vibration. (ACI, 2010, p.8)

**Dense Concrete**

“Concrete containing a minimum of voids” (ACI, 2010, p. 17). This specific form of concrete is often utilized to resist permeation of water, chlorides, or other foreign agents that could compromise durability.

**Galvanic Corrosion, Galvanic Cell**

Effect of two dissimilar metals in the presence of an electrolyte to produce a weak voltaic cell causing rust, depletion or pitting of the more soluble metal (National Mechanical Insulation Committee, 2011).

**Grout, Cementitous**

“Mixture of cementitious material and water, proportioned to produce a pourable consistency without segregation of the constituents” (ACI, 2010, p. 34).

**Grout, Epoxy**

“A grout which is a mixture of ingredients consisting of an epoxy bonding system, aggregate or fillers, and possibly other materials”(ACI, 2010, p. 34).

**Spall**

“A fragment of concrete, usually in the shape of a flake, detached from a larger mass of concrete by a blow, the action of weather, pressure, or expansion within the larger mass” (ACI, 2010, p. 63).
TechNote

A narrowly focused, single-topic guide, usually practice oriented. A TechNote presents specific direction on a particular issue, and can cover topics such as design, construction, or repair methods, or can provide recommendations on a concrete technology. (ACI, 2010, Pt. 7.1.1.2)

TechNotes are published by many industry associations; however, the TechNotes referred to in this project are all published by the American Concrete Institute.
CHAPTER II

LITERATURE REVIEW

Overview

The following review outlines notable literature that supports my culminating project and the research process utilized to support this endeavor. The following synopsis of my research explains the catalysts that create corrosive reactions near the balcony edge and then introduces alternative design and installation methods that could work to drastically reduce and even eliminate the reoccurring repairs commonly experienced in balcony handrail attachments.

Corrosion-prone areas of concrete balconies are predominantly located along the handrail span of the slab. Exposed slab edges are most open to the ocean’s landward winds, carrying sea salts that increase the concentration and diffusion of chloride salts in these areas. While the reality of a high rate of chloride intrusion at the balconies exposed edges is inherent in its design, further affliction is caused by the design and placement method of balcony handrails at these locations. Due to environmental conditions and different physical properties between concrete and cementitious grout, the cementitious grout used to anchor handrails into the slab can shrink, crack, or wither to create a void or recessed pocket in the concrete (Figure 1). Chlorides gradually accumulate in this area and penetrate into the capillary pores of the grout to lower the pH of the surrounding
Figure 1. Voids created by cementitious grout weathering (left pocket) and shrinkage (right pocket).

Source: Frank and Jason Poma, Poma Construction. Reproduced with permission.

gROUT AND INCREASE THE RATE AT WHICH CHLORIDE INTRUSION AND DIFFUSION WILL OCCUR (ACI Committee 222, 2001, p. 6; Jo, 2008, p. 916).

To a contractor, the installation of handrails is a relatively quick procedure and therefore receives little coordination in relation to the larger work items associated with balcony construction and repair. As a result, this component of the balcony is relegated to a procedural level that receives insufficient qualitative attention and support. Thus, the first step in eliminating this cyclical repair process is to acknowledge handrail installations as an integral process and component of balcony construction and repair.
Aggressive Environment

An overwhelming amount of research has contributed to a wide array of coastal building codes and standards that address the corrosive effect coastal environments can exert on concrete and concrete reinforcing steel. Concrete balconies that are located in coastal environments are one such example of a structural component that falls victim to many corrosion-related issues. In Florida, the problem is especially acute because of the high concentration of condominium buildings developed along the state’s extensive coastline. A major component to condominium buildings, balconies are often stacked on each floor where they are exposed to the aggressive coastal atmosphere, especially when directly facing the ocean’s landward winds. Additionally, due to the region’s sub tropic climate and Florida’s shallow coastal waters, the saline concentration of Florida’s surrounding seawater is much higher than the global average (Lund & Curry, 2006, p. 2; LaQue, 1975, p. 95).

Balcony Corrosion

This specific form of concrete deterioration is influenced by a process of reactions initiated when chloride ions permeate into the concrete and reach reinforcing steel. While chlorides can come in contact with concrete surfaces through a variety of ways, in the case of coastal balconies, chlorides are introduced by means of salt spray released into the atmosphere by breaking ocean waves and landward-blowing winds (United States Federal Emergency Management & National Flood Insurance Program, 1996). As chlorides in the atmosphere come to rest on the horizontal surface of a concrete balcony they gradually accumulate into higher concentrations and diffuse into the concrete substrate through wither cracks or through the capillary pore structure of the
cement paste (ACI Committee 222, 2001, p. 6). With a year-round humid climate, there is a constant presence of moisture within Florida’s coastal balconies. When oxygen and chlorides are introduced to this aqueous environment, metals that are susceptible to corrosion will begin to corrode as a result of an electrochemical reaction.

Corrosion of aluminum balcony handrails initially occurs as a result of the formation of galvanic cells between two dissimilar metals embedded in the concrete. This electrochemical reaction is created by the presence of high levels of chloride in the concrete, water, and differing electrochemical properties between the reinforcement steel and the metal handrail post (Islam, 2005, pp. 2, 6). In the galvanic cell created by handrail anchorages (depicted in Figure 2) electrons flow from the anodic aluminum handrail post to cathodic reinforcement steel. The aluminum receives hydroxide ions from the reinforcement steel, which reacts to develop rust around the handrail post and causes concrete to crack or spall.

![Figure 2. Galvanic reaction between reinforcement steel and aluminum in concrete.](image)

In order for a galvanic reaction to occur between aluminum handrails and reinforcement steel, the reinforcement steel must make electrical contact with the aluminum (ACI Committee 201, 2001, p. 20). This connection frequently occurs as a result of the core-drilling method of boring handrail postholes into the concrete. This process will often expose the “edge bar” or other reinforcement steel to the handrail posthole, where grout and the aluminum post is anchored to the concrete slab (see Figure 3). The exposure of reinforcement steel to the posthole increases the likelihood of creating a contact with the aluminum handrail post, either directly or through an electrolytic connection created by an aqueous chloride bridge.

Figure 3. Edge bar exposed after core drilling.
The extent of this form of galvanic corrosion is directly proportionate to the amount of chloride in the concrete as well as the ratio of steel contact area to aluminum contact area. The magnitude of corrosion is inversely proportionate to the amount if distance separating the aluminum from the steel (Aberdeen Group, 1965, p. 2). Therefore, eliminating or reducing chloride penetration into handrail pockets, avoiding a direct connection between steel and aluminum and separating the two metals by as far a distance as possible is the most effective way to avoid galvanic corrosion of balcony handrail posts (Aberdeen Group, 1965, p. 2; Monfore & Ost, 1965, p. 113).

Corrosion can also avoid aluminum handrails entirely and occur in only reinforcement steel. This form of corrosion is known as “pitting” corrosion, and occurs when chlorides and water cause the pH of a localized area of concrete to drop past a certain threshold level. Once this happens, the reinforcement steel in this area loses a passive layer that protects it from corrosion and becomes anodic, creating a current with other areas of the reinforcement steel that are located in areas with higher alkaline concrete (ACI Committee 222, 2001, p. 5).

In either form of corrosion, the area of the anodic metal corrodes to create rust (see Figure 4). This rust occupies a larger volume than the original anodic metal and therefore exerts expansive forces on the surrounding concrete. The rust and expansive forces eventually create stains, cracks or spalls in the concrete (see Figure 5). This process of corrosion occurs exponentially, as an increase in cracks and spalls will also increase the rate of intrusion of chloride, oxygen and water as well as the surface area of exposed reinforcement steel (ACI Committee 222, 2001, p. 2). If left unnoticed or not acted on quickly structural failure and safety risks can become a major factor.
FBC regulations specific to concrete corrosion are adopted from ACI’s *Building Code Requirements for Structural Concrete* (ACI Committee 318, 2008; FBC, 2009, Pt. 19.1). Section 4.3.1 of ACI Committee 318 (2008) explicitly limits the amount of chloride allowed to be added to a concrete mix prior to placement, or the concrete’s *domestic* chloride content (ACI Committee 201, 2001, p. 17). ACI Committee 318 attempts to prevent *foreign* chloride intrusion by specifying density and coverage requirements for concrete exposed to moisture and an external source of chloride (ACI Committee 201, 2001, p. 17). ACI Committee 318 standards are sufficient for most
environments; however they do not adequately address the factors that lead to corrosion of Florida’s coastal concrete balconies.

The Florida Division of Hotels and Restaurants also oversees a mandatory safety inspection of balconies, stairways, and railways on all public lodging establishments (Florida Statute 509.2112, 2012). While somewhat effective in documenting visual defects of balcony features, this statute does not extend into the larger market of private residential buildings, including most high-rise condominiums. Furthermore, the qualifications required of the yearly inspector are considerably vague and call for no objectively-based indications of experience, instead calling for the inspector to be “. . . a person who, through education and experience, is competent to inspect multi-story buildings . . .” (Florida Statute 509.302, 2012).
Proposed Code Modifications

Location

The Florida Department of Transportation (FDOT) utilizes a comprehensive classification system to identify environments that require additional design considerations in order to prevent chloride-induced corrosion. The FDOT Structures Design Guidelines (2012) identifies slightly aggressive, moderately aggressive and extremely aggressive environments in order to determine the proper design and material requirements for their projects (see Figure 6). The extremely aggressive classification is reserved for any structures located within 2,500 feet of a body of water that contains a chloride level of at least 6000 ppm (FDOT, 2012, Pt. 1.3.2). FDOT construction projects that fall under the aggressive environment classification are subject to design requirements that further prevent the intrusion of chloride ions as compared to structures located in slight and moderately aggressive environments.

According to FDOT studies, structures that are within line-of-sight and within 2,500 feet of the Atlantic or the Gulf of Mexico are subject to increased chloride intrusion rates in the order of .016 lbs./cy/year at a 2-inch concrete surface depth (FDOT, 2012, Pt. 1.3.3). Other research has showed the exponential affect distance from the ocean plays in steel corrosion (see Figure 7). In one study, the corrosion rate decreased tenfold between a site located 800 feet from the ocean and a site 80 feet from the ocean (LaQue, 1975, p. 102). Another industry study found that chloride levels will decline rapidly within the first 300 to 3,000 feet landward of the shoreline, and vary depending on the presence of a variety of factors, like rising terrain, foliage, and buildings that may alter wind patterns (Cold Formed Steel Institute, 2007, p. 2; FDOT, 2012, Pt. 1.3.3).
The environmental classification system used by FDOT is a relatively simple test that communicates design and material specifications to all relevant stakeholders involved in the project’s construction. In order to standardize the areas this proposed code modification will apply to, the Extremely Aggressive Environment classification used by
Figure 7. Average Corrosion Rate of Steel in Florida at Various Distances from the Beach. (1980).


FDOT or a similar zoning standard that distinguishes the first approximately 2,500 feet landward the sea should be included in the Florida Building Code.

**Methods**

**Eliminate Core-Drilling**

Through my interviews and observations, I found “core-drilling” to be the most commonly used method to create post-holes within which handrails anchor to the concrete balcony. This process utilizes a large drill to core an approximately 4.0” deep by 4.0” diameter hole, or “pocket,” into the balcony. As a result of this practice
reinforcement steel is often exposed to the environment, as handrail installers cannot be sure they are drilling above a sections of steel or not. When steel is exposed to the open environment it will later be exposed to the cementitious grout that anchors the handrail post to the balcony. As previously explained, increasing contact area of reinforcement steel with the handrail post and cementitious grout will directly increase the corrosive ability of the galvanic cell created (Aberdeen Group, 1965, p. 2; Monfore & Ost, 1965, p. 113).

To decrease the susceptibility of concrete reinforcement steel to corrosion, more attention should be given to the amount of concrete cover located between reinforcement steel and any chloride-rich environment. Assuming size No. 5 or smaller reinforcement steel is used, as is typical with balcony construction, at least 1.5” of dense concrete must separate reinforcement steel from any concrete surface “directly exposed to moisture changes . . . including that due to condensation conditions or direct leakage from exposed top surface (ACI Committee 318, 2008, Pt. 7.7).” It is crucial that at least 1.5” concrete coverage be maintained not only on the surface of the slab, but from post hole pockets as well, as post holes frequently crack and shrink, directly exposing the subsurface area of the concrete slab to weather exposure and chloride salts. ACI 318 mandates at least 1.5” of cover but recommends 2.0” in “severe” environments that contain high levels of chloride and moisture. (ACI Committee 318, 2008, Pt. 4.3 & 7.7.6). Increasing the amount of concrete between steel and chloride-rich environments exponentially increases the time it takes for chlorides to reach reinforcement steel. For example, research has shown that the time it takes chlorides to reach the steel under 2” of cover is four times longer than the time it takes to reach steel under 1” of cover (National
Ready Mixed Concrete Association, 1995 p. 2). Additionally, due to construction tolerances and human error, simply designing and forming balcony decks to comply with the required 1.5” coverage is not sufficient enough to achieve this minimum coverage requirement. One study found that a design cover of 2.6” is needed to achieve a minimum coverage of 2.0” on top of 90 percent to 95 percent of reinforcement steel (ACI Committee 201, 2001, p. 19; Van Daveer & Sheret, 1975).

There are currently two handrail installation methods in use that avoid core drilling and, when properly designed and installed, also meet the necessary load requirements of the FBC’s Structural and High-Velocity Hurricane Zone codes. Each alternative method allows the construction worker to confidently install the handrail system at least 1.5” away from reinforcement steel. Additionally, these alternative methods provide extra protection by utilizing materials that are less conductive than aluminum, therefore decreasing the chance of creating a galvanic cell.

**Block Out Method with Epoxy-based Grout**

The “block-out” method of handrail installation is a less-used but viable alternative to core-drilling. The block-out method requires the construction team to block out the handrail postholes with Styrofoam, plastic or wood blocks before the concrete deck is cast. By blocking-out the postholes before the concrete is placed, the construction worker is able to insure there is at least 1.5” of concrete between the reinforcement steel and the posthole.

This modification suggests the use of epoxy-based grouts, but allows for the usage of a material with equivalent performance characteristics if any should come to market in the future. Epoxy-based grouts are less prone to shrinkage and less permeable
than cementitious grout (Emmons, 1993, pp. 134-135; Jo, 2008, p. 915). Many epoxy grouts also offer superior anchoring and bonding capabilities than their cementitious counterparts (Cleland, Yeoh, & Long, 1997, pp. 2-3; Kumar, 2008, p. 320). Even with increased exposure to outdoor environments and chlorides the impermeable nature of epoxy remains relatively constant (Jo, 2008, pp. 915-916). This prevents the accumulation of chlorides inside the post pocket, which will eliminate or greatly slow down the exponential rate at which corrosion occurs near handrail posts (Kumar, 2008, p. 31).

**Surface Mounted Handrail**

Surface mounting offers an alternative to both core drilling and grout anchoring. Surface mounting requires the builder to attach the handrail to the deck using galvanized or stainless steel anchor bolts without core drilling into the deck or using metals that may create a galvanic cell (see Figure 8).

*Figure 8. Surface mounted handrail post.*
While surface mounting does require the installer to attach the rail post to the slab with a dissimilar metal fastener, the fastener does not penetrate into the concrete deep enough to create a direct connection with reinforcement steel. Furthermore, the fasteners are made out of less reactive metals than aluminum, and designed to resist galvanic forms of corrosion. The risk of introducing chlorides into the concrete substrate is no greater in areas near the handrail post than other areas of the slab because surface mounting hardware is covered by a parapet and neoprene baseplate in order to deflect both water and electric current between the reinforcement steel and handrail metal (see Figure 9).

Figure 9. Surface mounted post detail.
Surface mounting is commonly used by the Florida Department of Transportation and other government agencies in order to address the risks of anchoring handrails in high-chloride environments (FDOT, 2012).
CHAPTER III

METHODOLOGY

Research Internship Phase

The methodology of this project is split into two phases. The first phase constitutes the in-person and on-site observations and studies I performed in Florida throughout the summer of 2011. The second phase represents the research portion of my work and the code modification submittal process. The majority of the second phase of my project was spent researching various codes, academic papers and industry publications that involved galvanic corrosion due to aggressive chloride environments. I also worked with ACI to develop a TechNote to supplement and endorse the code modification during the second portion.

The following outlines describe the first and second phase of this project. Details of each portion are addressed whenever I experienced difficulties, both unforeseen and expected.

In-Person Interviews

In-person interviews were the most delicate process of this research project. Because of the construction industries highly litigious environment, I found it difficult at first to secure interviews with many people I wished to speak with. To solve this problem I decided to take a different approach and, rather than “cold call” the people I wished to interview, I initially interviewed people in the office I worked out of, as these people
knew me better and understood the research I was doing. After interviewing each of the people in my office, I asked them if they could recommend me to any other associates in the industry that may be able to provide me with a similar or different opinion on the matter. I also asked them if I could mention our interview, so as to endorse or legitimize my desire to speak with the next interviewee. This allowed me to approach potential interviewees as a qualified and inquiring student rather than a complete stranger. Before each interview, I would also email the subjects a letter of endorsement signed by my graduate advisor, Dr. Tanya Komas, and Dr. Mike Ward, the Dean of the College of Engineering, Computer Science and Construction Management (see Appendix C). The letter explained the purpose of my research and helped support my academic approach to subjects who were unclear or skeptical of my research interests.

When interviewing subjects I would begin by telling them that my thesis project was to become the culminating project of my Master’s degree, and that I would not mention their name or identity in my work. For the rest of the interview, I was very careful to avoid directing the conversation. Rather, I simply started our conversation by asking them how they thought balcony corrosion occurred. Whenever they stopped talking I would ask questions relating to something they mentioned that I had not heard before or something particularly interesting to me. When this question was exhausted, I would ask them how they would solve the problem, and ask questions to reinforce the conversation in the same manner as before.

By allowing them to speak, and maintaining an interested and attentive tone and body language, I was able to comfortably converse with my subjects without creating a rigid or formal environment. This allowed me to gather many responses that
represented the genuine opinions of my subjects, rather than the scripted or safeguarded responses they may typically give in their work environments.

Site Visits

By visiting sites before, during, and after balcony repairs were performed, I was able to witness the practices and design methods that create balcony deterioration in their natural environment. The knowledge I obtained and the pictures I took in this setting are very valuable for this project’s documentation as well as the code modification submittal.

When visiting construction sites I would coordinate my arrival in advance with the project manager in charge of the construction project. By doing this I was able to clarify my plans to take pictures and observe work processes being done, so as not to cause any confusion when I arrived. I found this communication process to be very valuable, as I was able to quietly and quickly do my work, and the advanced notice gave the project manager time to prepare areas for me to view without creating safety concerns or interfering with the production schedule.

Implementation Phase

The second phase of my project was primarily completed throughout the 2011-2012 academic school year. Upon returning from the summer internship, I referred to the notes and observations I brought from Florida to further my research regarding building regulations, technologies, and practices relevant to balcony corrosion in marine environments. Nearly all of this phase took place in the CSU, Chico Library, and online
databases, which provided me a wide array of building codes, research papers and
technical publications.

I searched through multiple building codes employed by governmental
agencies to find previously implemented regulations similar to the code I was attempting
to create. I found the most applicable information in the Florida Department of
Transportation (FDOT) *Structures Design Guidelines*. This manual provides standards,
criteria and guidelines for developing and designing various structures managed by

Of particular relevance to my project was FDOT’s Environmental
Classification section, which requires specific concrete design standards for any
structures built within a predetermined “Aggressive Environment.” The aggressive
environment is determined by the structure’s proximity to the sea, or any other body of
water containing potentially destructive chloride concentrations. I have adopted this same
standard as my recommendation to the Florida Building Commission, in order to
determine the environment within which my proposed structural code modifications will
apply.

The majority of the evidence substantiating this project’s literature review,
TechNote and code modification was discovered in academic and professional
publications I located through web-based academic search engines. Using a relatively
small focus of galvanic corrosion of aluminum embedded in concrete, I was able to
expand my knowledge of this subject greatly by sorting through similar articles and
publications. I was also directed to more specific literature by studying the referenced
works listed in the papers I came across. By beginning with a few narrow focus points
particular to the reoccurring problems I came across during my internship, I gradually expanded my knowledge by searching for other publications using this process.

**ACI 364 TechNote**

Another aspect of this phase involved my collaboration with ACI Rehabilitation Committee 364 (ACI 364). With the generous support of Peter Emmons, I was able to become an associate member of the subcommittee in order to draft and present a TechNote covering proper handrail installation methods in coastal areas (see Appendix B). At the time of the defense of this project, the TechNote has been approved for publication, and will be released in the publication period following this project’s submittal.

I was encouraged to create a TechNote by members of ACI 364 after my project was introduced to them by Emmons, who is also a member of the committee. After attending a committee meeting in Cincinnati, Ohio and proposing the reasoning behind my intent to modify the Florida Building Code, the committee voted to allow me to create a draft of the document.

Per the *ACI Technical Committee Manual* (ACI Technical Activities Committee, 2012), a TechNote must undergo a four-step process to be published:

1. A new document is prepared or an existing document is revised.
2. Letter balloting of the draft document is made by the committee wishing to publish the document (ACI 364, in my case).
3. Document is submitted by the Chair of the committee to the Managing Director of Engineering of the Technical Advisory Committee (TAC) for the technical review process.
4. (a) The document is accepted and published by ACI, or (b) the document is sent back to the committee and revised in response to TAC comments. When published, the TechNote will be attached to the code modification proposal I have prepared for the Florida Building Code. Because the next review process for the FBC does not end until 2013, there is ample time for ACI’s publication process.

As a student, becoming a member of ACI 364 and publishing a TechNote for the committee is an incredibly honorable and significant feat. The members of ACI committees are all appointed and most (if not all) have been appointed as a result of their professional merits. Achieving the support of ACI 364 is a tremendous privilege that, in many ways, acts as a measure of success for this endeavor and the capability of future internships that are built upon this project’s demonstrated accomplishment.

**Florida Building Code Modification Proposal**

The Florida Building Commission oversees the code modification process as well as the development, interpretation and maintenance of the Florida Building Code (Florida Statute 553.76, 2011). The Florida Building Code is based off of the International Building Code (IBC), a standardized code developed every three years by the International Code Council for state and jurisdictional usage (ICC, 2011). Once the IBC is revised, the Florida Building Commission modifies the IBC with any code changes specific to the state of Florida, including approved code modifications from the public, and publishes their state-specific building code a year later (Florida Statute 553.73, 2011). The code modification I am proposing would be implemented in 2014 under the 2013 Florida Building Code, if it should be approved.
Under the direction of Florida Statute 553.73 (2011), the code modification proposal begins after the Florida Building Commission verifies that all submitted proposals are properly completed. Afterwards, the proposal will go through a 45-day public commenting period before they are reviewed by Technical Advisory Committee (TAC) at a meeting open to the public. If the TAC approves the proposal, it renders an action for recommendation to the Florida Building Commission. After this the proposal goes into another 45-day public commenting period is again evaluated by the assigned TAC before being sent to the Florida Building Commission for final approval.

For a general preview of the online code modification process, see Appendix A. While outdated, these five screenshots illustrate the process a proposer goes through in order to submit a code modification proposal. The online submittal process for the 2013 code is currently closed inaccessible until the FBC begins to accept new proposals at the beginning of 2013.
CHAPTER IV

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The information presented in this project is intended to lead the Florida Building Commission to recognize the clear necessity for this modification.

The scope of this project involved an investigative portion and a research portion; both of which contributed to the project’s ultimate end result: the submission of a viable code modification to the Florida Building Commission.

The investigative portion allowed for an in-field, subjective study of the issues and opinions that evolved around this particular issue. Through the process of interviewing stakeholders and witnessing construction practices, a holistic point of view was achieved that cannot be obtained merely through scientific or literary research. Upon the completion of the internship, scientific and peer-reviewed publications were sought and applied to the subjective data collected in the field to affirm both the need for change and the proposed changes.

The data gathered and analyzed for this project serves as a concise collection of evidence specific to one particular design flaw. Due to the anthropologic nature of the first portion of my studies and the fact-based nature of the second, it can be assumed that the research attributed to this work represents a collection of both subjective and
empirical findings. Together, these findings suggest a significant, endemic problem and also point to viable solution.

Conclusion

This project is expected to modify the way balconies are designed and built in the coastal regions of Florida. Through extensive empirical research and numerous field interviews, I was able to evaluate and document the social, economic and physical factors that have caused the costly degradation of balconies and propose changes to the Florida building code.

In 2014, when the code modification is expected to be implemented, the significance of this project may be measured by the impact it has on the longevity of future balconies in Florida. Arguably more important, however, is the door this project has opened for future young interns of the construction industry. By recording the processes and methodologies of this project, it is the hope of the CIM department that future industry partnerships can be created to deploy university students on similar missions. There are numerous flaws in the way America designs and builds structures, many of which escape detection due to a lack of information, demand, and resources to uncover and fix the problems. These problems may be known to some stakeholders affected by their occurrence; however, the negative impact they create is often shared across a large population to disguise their true cost to society. By utilizing this project as a template, future partnerships between industry and academia can expedite the problem-solving process: uncovering the components of the issue that allow the problem to occur
and using their subjective and objective knowledge of the problem to ascertain a viable solution.

The issues that create and perpetuate balcony degradation in Florida can be attributed to a variety of environmental, design and construction related factors. Because the environmental factors conducive to this problem cannot be changed, the only way to end balcony degradation is by altering the way balconies are designed and built in this environment. In order to do this, the Florida Building Code must identify the aggressive environments that instigate accelerated corrosion and design handrail anchorages differently in these areas.

By utilizing construction standards that are already practiced by FDOT, the FBC can mandate these specific design requirements within a 2,500-feet boundary of the ocean, where chloride levels are highest. The design of handrail anchorages installed in this area will differ from typical anchorages, as the assemblies’ conductive capabilities will be reduced or eliminated. This nonconductive design can be achieved by eliminating the core-drilling method and instead surface mounting or blocking-out the handrail posthole. By doing this, the builder can insure the distance and concrete coverage between the concrete reinforcement steel and aluminum handrail post is spaced far enough to avoid creating a galvanic current. Furthermore, by using an epoxy-based grout to anchor handrail posts into concrete pockets, the galvanic potential between the concrete reinforcement steel and the aluminum post can be greatly reduced or eliminated.
Recommendations

This project would not have been possible without the support of Peter Emmons and the employees at Structural Preservation Systems in Pompano Beach, Florida. Because of their commitment and interest in my work, I was able to quickly begin researching and interacting with stakeholders throughout Florida. I believe it would be very difficult for someone to undertake a similar project without the commitment and support of a mentor already established in the industry. The work one student can do in a relatively short amount of time is very much determined by the amount of access he or she is given to a company’s business contacts, financial documents, pictures and, most importantly, general knowledge of the issue. Additionally, SPS’s internship program provided a generous stipend, plus housing and transportation. This financial support allowed me to quickly adapt to the new locale and conduct the necessary research in a timely and expeditious manner.

Future interns of similar projects would benefit by rehearsing the interviews they plan to have with stakeholders. Practicing the casual-yet-professional skillsets needed to converse with a stranger, while also taking notes and ensuring the conversation continues in a constructive manner is essential to the first phase of this research process. Since stakeholders are typically willing to meet only once for an interview, one must make sure the conversation covers all areas relevant to the study. By asking “sub questions”, or questions particular to anything the subject brings up when responding to one of the standard questions, the interviewer is able to lead the conversation in a direction beneficial to his or her research. I found the best way to employ this method was to write down the sub questions as the subject talked, and then ask them one at a time
when it was a mutually understood time to ask another question. This allowed me to remain unobtrusive and polite by not interrupting and gave the subject the comfort of having control of his or her response.

While difficult to coordinate, site visits offered an incredible amount of information in a relatively short amount of time. It is extremely important to bring all required safety gear to the site; not only for personal safety, but also to maintain professional credibility by not imposing upon the host contractor or engineer for their own safety equipment. I found the simplest way to do this was by keeping a “safety kit” in the trunk of my vehicle with a hardhat, safety vest, safety-toe boots and safety glasses for indoor and outdoor use. I also kept a tape measure, camera, notebook, and pen in the box for notes and measurements.
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FLORIDA BUILDING CODE ONLINE
MODIFICATION PROCESS

ACI TECHNOTE

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Trevor Prater – Balcony Handrail TechNote DRAFT 01/05/12

ACI 364 TechNote – Installation of Handrails in Coastal Areas
(Document number)
Keywords: Handrail, balcony, corrosion, marine environment, galvanic,

Introduction
Concrete balconies and exterior walkways are subject to frequent and cyclical repairs when located in humid, high chloride environments. The majority of these repairs involve the replacement of spalling concrete and corroded concrete reinforcement steel located around and beneath embedded handrail posts.
Construction practices such as core-drilling handrail “pockets” and the use of cementitious grout to anchor handrails dramatically increase the likelihood and speed of corrosion in coastal areas.

Question
Can balcony corrosion issues endemic to coastal areas be addressed by modifying current design and construction practices?

Answer
Coastal-area balcony corrosion is accelerated by preventable flaws in design and construction. Eliminating the core-drilling method and the use of cementitious grout when installing handrails and instead replacing it with either of the following alternatives significantly reduce the likelihood of creating a corrosive galvanic reaction:
(a) Surface mount the handrail post to the concrete slab with stainless steel anchors.
(b) Pre-form or “block-out” the handrail pocket before casting the concrete slab and use an epoxy-based grout to anchor the handrail into the handrail pocket.

Discussion
A galvanic reaction will occur between reinforcement steel and dissimilar-metal handrail post when the two metals are embedded in a conductive material that allows for electrons to transfer from one metal to the other. In coastal environments chloride ions act as the primary conductive agent after they penetrate into the concrete surrounding the reinforcement steel and handrail post. Chloride levels are higher near the coast than inland and decline rapidly within 300 to 3,000 feet landward of the shoreline as salt-spray settles to earth. Additionally, while contributing to a galvanic reaction between the reinforcement and handrail assembly, chloride ions will simultaneously de-passivate a protective layer surrounding the reinforcement steel, making it susceptible to other forms of corrosion when water permeates into the concrete.

Concrete balconies and walkways typically contain an “edge bar” of reinforcement steel that runs approximately 2" in from the exposed edge of the slab. When core-drilling handrail pockets this edge bar is often cut by the drill bit, increasing the possibility of galvanic corrosion by exposing the steel to the same electrolytic environment that the handrail is embedded in (Figure 1 & 2). Due to dissimilar physical properties, the cementitious grout used to embed the handrail will cure and perform with different physical characteristics than the surrounding concrete, allowing any combination of cracks, shrinkage gaps, dissolution and permeation to occur. These characteristics also allow chlorides to permeate into the handrail pocket and create the conductive environment needed for a corrosive reaction to occur.
By eliminating the core-drilling process the likelihood of exposing reinforcement steel is greatly reduced. The practice of blocking-out the pocket with foam, plastic or wood blocks before placing the concrete is a common alternative to core-drilling and allows the builder to confidently place the reinforcement steel and handrail pockets far enough away from each other to avoid a reaction. Furthermore, using an epoxy-based grout instead of a cementitious grout will create a nonconductive barrier between the handrail and reinforcement steel, decreasing the likelihood of a galvanic reaction from occurring.

Surface mounting handrail posts to the concrete balcony is another viable alternative to core-drilling, as surface mounting does not require the creation of a pocket nor does it require the use of grout for anchorage. When surface mounting handrail posts, select fastening hardware designed to be used in concrete and in aggressive coastal environments, as they will be less likely to corrode at an accelerated rate.

**Conclusion**

The primary cause of balcony corrosion issues stems from current practices that increase the exposure of dissimilar metals to an environment containing abnormally high levels of chloride. Eliminating or reducing the ability for a galvanic reaction to occur between reinforcing steel and handrail assemblies significantly reduces the likelihood of aggressive and rapid corrosion within the balcony. To do this, care should be taken to use materials and methods that prevent chlorides from penetrating into the concrete at the handrail posts and to prevent the effect chlorides have on the embedded metals should intrusion occur.
Figure 1 - Reinforcement Steel Exposed by Core Drilling

Figure 2 - Corroded Handrail Post
(Image Source: Frank and Jason Poma, Poma Construction. Reproduced with permission.)
Figure 4 - Grout Shrinkage
(Image Source: Frank and Jason Poma, Poma Construction. Reproduced with permission.)

References


**I have come across an overwhelming amount of information that can be cited in this TN. If you think something I’ve said needs academic/scholarly backing, please tell me and I will cite it with something relevant.
June 12, 2011

Dear Industry Professional,

It is with great pleasure that we write this letter of introduction for Trevor Prater. Trevor is a graduate student at California State University, Chico who will be conducting a research project in the Florida area this summer. We are writing to introduce him, ask for your support of his research, and make ourselves available to answer questions should you have them.

The objective of his study is to gain a better understanding of the issues related to balcony design, construction, maintenance, and repair. The specific goal is to encourage better practices in these areas as well as set the stage for future students to conduct similar academic/industry studies of building systems and construction processes. The overall aim is improvement in optimum and healthy service life for structures.

Throughout the summer, Trevor will have the support of professional and academic leaders as he pursues this meaningful endeavor. We invite you to join us and work with Trevor as your schedule permits. Please feel free to contact either of us at any time. Thank you for your time and consideration.

Sincerely,

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