Case Study: Corrosion of the Alewife MBTA Parking Garage

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Abstract

Pitting corrosion is a type of deterioration mechanism that plagues transportation facilities such as parking garages, roadways, and bridges. In this case study that analyzes the Alewife MBTA Parking Garage, it was discovered that corrosion throughout the project site created countless unsafe structural and drainage deficiencies. Though this site is just one example of failing domestic infrastructure, it is worthy of further investigation to determine how these component oversights are indicative of overall structural failure. In this final paper, a case study is proposed that explains corrosion causes, details corrosion mechanisms, explores corrosion detection methods and discusses corrosion prevention methods by using two engineering condition assessment reports from Thornton Tomasetti and Kleinfelder/SEA Consultants.

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I. Introduction

Located in Cambridge, Massachusetts, the Alewife MBTA Parking Garage, as shown in ***Figure 1***, was built in 1985 [1]. This 638 ft by 324 ft parking garage structure was designed to support commuters from the Greater Boston area and serve as a transportation hub to those commuting by car, bus, or metro [2,3]. The site is located along wetland habitat, and often contributes contaminated stormwater runoff and sewer overflow to the nearby Alewife Reservation and Alewife Brook [4]. With five levels of parking, the Alewife MBTA Parking Garage, as shown in ***Figure 2***, has over 2,700 parking spaces for vehicles, circular drum ramps, mixed commercial space on the first floor, bus boarding and passenger waiting areas, bicycle storage cages, and an active metro station below ground [2, 3, 5]. Despite this garage's frequent use by the general public, this structure is quite unsafe. In 2011, an engineering report from Kleinfelder/SEA Consultants noted "structural deterioration" in the garage [3]. In 2017, an

Figure 1: *Image of Alewife MBTA Parking Garage Station Complex from a Street View [1]*

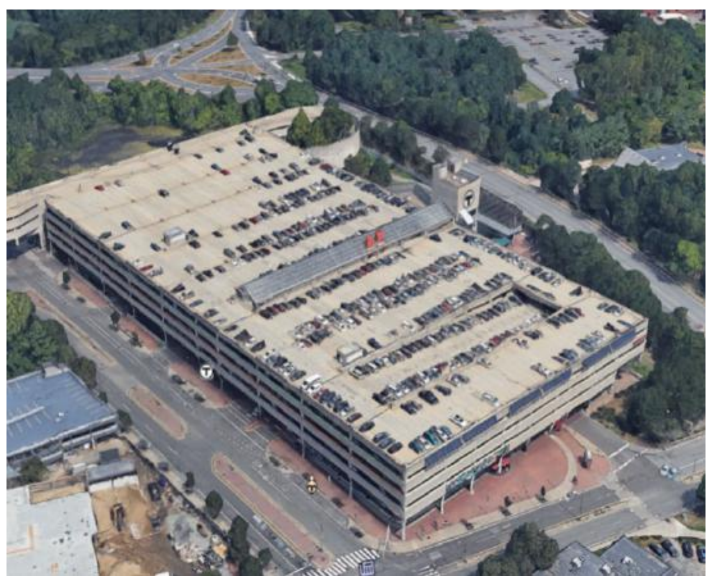

Figure 2: *Image of Alewife MBTA Parking Garage Station Complex from a Bird's Eye View [5]*

engineering report from Thornton Tomasetti noted “imminent failure” in the structure [2]. Though both of these concerns were taken into account, it was only the significant media exposure regarding the garage’s failing status that caused vital repairs to begin. In 2018, a piece of delaminated concrete fell upon a car and nearly 500 parking spaces and an entire floor of the garage were closed off [6]. Despite no injuries being reported from the incident, the crumbling concrete proved to be an indication of the project’s deteriorating state and dire need for repair [7]. Upon news break of this horrifying event, the garage was given the much-needed attention and funding for repairs that it deserved. In 2020, decreased ridership throughout all metro lines accelerated the project’s repair timeline, but supply chain disruptions ultimately led to a three-month delay for site improvements [8].

Most of the corrosion in the Alewife MBTA Parking Garage is visible in the deteriorated concrete beams and decks along with the exposed steel reinforcing bars, which are also known as rebar [9]. Though this project was granted a $14 million project, as shown in progress in ***Figure 3***, in 2021 and has had over $20 million in rehabilitation projects in the past 10 years, the Alewife MBTA Parking Garage is a perfect example of the types of corrosion projects that are so prevalent and costly throughout the United States [7]. In

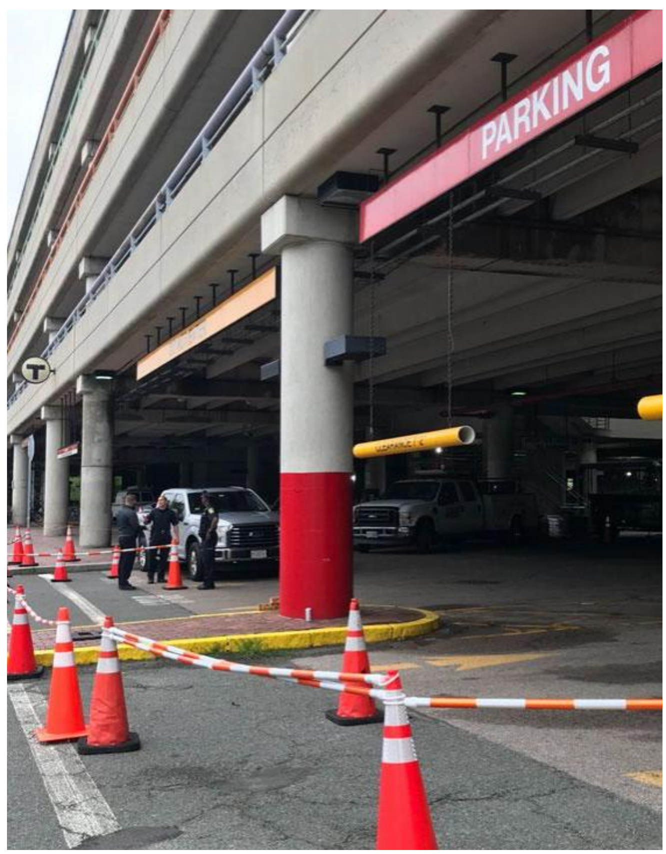

Figure 3: *Image of Ongoing Construction and Rehabilitation Project Repairs at Alewife MBTA Parking Garage Station Complex [7]*

fact, over 3% of the gross domestic product goes towards corrosion in the form of rehabilitation, maintenance, and improvement projects [10]. It is estimated that corrosion preventative practices could save over $875 billion annually on a global basis if properly used [10]. This horrifying statistic regarding the prevalence of corrosion throughout the globe, and specifically throughout the United States, is perhaps best shown by the United States' poor report card grade for the 2020 evaluation of domestic infrastructure. Designed by the American Society of Civil Engineers, the Infrastructure Report Card evaluates a plethora of public works, including categories such as bridges, roads, dams, ports, rails, and transit, and assesses their current condition and overall performance. In 2020, The United States was given a score of a C- [11]. Though this grade is an improvement from that of previous years, this report score indicates the current failing condition of countless public works. For example, the ASCE Infrastructure Report brings to light the current condition of roadways throughout the US and indicates that nearly 43% of public roadways are in "poor or mediocre condition" [11]. The Alewife MBTA Parking Garage is just one example of a substandard public transportation service with potentially hazardous implications. The unsafe conditions throughout the site, including structural and drainage system deficiencies, pose immediate life safety concerns to pedestrians and commuters alike [2, 3]. The case study included in this final paper will serve as a method for explaining corrosion causes, detailing corrosion mechanisms, understanding detection methods and discussing prevention strategies. The findings included in this engineering report are largely derived from the aforementioned 2011 and 2017 engineering condition assessment reports conducted by Thornton Tomasetti and Kleinfelder/SEA Consultants [2, 3]. These engineering condition assessment reports, which were provided by two employees of the WCVB-TV news television station, proved to be essential in conducting research for this case study project [9].

II. Analysis and Discussion

Figure 4: *Image of Flange Joint Deterioration at Alewife MBTA Parking Garage Station Complex [3]*

The main sources of deterioration in this case study project can primarily be attributed to three different sources: water infiltration, cold climate and bird nesting. For the Alewife MBTA Parking Garage, broken and clogged drainage pipes often cause concrete spalling and cracking [2, 3]. The sealant and spalling failures permit water to seep through and cause deterioration to metal decking. This concrete and decking erosion is exacerbated by broken and clogged drainage, where pooling and ponding can accelerate structural deterioration. It is worth noting that the lower levels of the parking garage experience the highest levels of corrosion, as beam and joint cracks, as shown in ***Figure 4***, allow water to leak and infiltrate to lower levels of the garage especially in comparison with corrosion levels in upper roof levels [2, 3]. Though this water can come directly from natural sources like rain or ice, this water can also come from indirect sources such as car tires, vehicles and other contaminated runoff. In addition to corroding the concrete decking and metal rebar of the Alewife MBTA Parking Garage, the water infiltration can have harsh environmental effects on the nearby Little River and Alewife Brook from contaminated runoff [4].

The garage is located in the Northeast where environmental temperatures frequently range from about 90 to 10 °F [12]. Throughout the Boston and Cambridge areas, deicing salts, as shown in ***Figure 5***, are often using during the winter to combat ice and snow conditions [13]. Typically, deicing salts and chemicals are carried into parking garages through the tires of different vehicles. These salts, which tend to have high chloride ion content, speed up corrosion in reinforcing steel and concrete decking via failed sealants and broken joints. Another component of the cold winter climate includes freeze-thaw degradation, as constant successive cycles of varying temperatures can create expansion and contraction in concrete.

Figure 5: *Image of Deicing Salts on Concrete Typically Used in Northeastern US Locations [13]*

An additional source of degradation experienced by the Alewife MBTA Parking Garage relates to pigeons and the creation of nests in precast birders along the perimeter of the structure, as shown in ***Figure 6*** [2, 9, 14]. These birds, which often create their nests in

Figure 6: *Image of Pigeons Nesting in HVAC Systems Along Perimeter of Alewife MBTA Parking Garage Station Complex [9]*

HVAC systems and throughout the shelves of girder ledges, accelerate structural deterioration of the garage [3]. In fact, bird droppings tend to be highly acidic in nature, so accumulated droppings throughout the parking garage accelerate deterioration of concrete and reinforcing steel over time.

The main corrosion mechanism located in the Alewife MBTA Parking Garage falls within the pitting category. This corrosion mechanism tends to be a very highly localized type of attack due to the failure of the passive film layer, which results in very high-speed penetration in smaller areas [15]. This type of corrosion mechanism can be one of the hardest to control, as it is incredibly uncertain in terms of the location and rate at which it will occur. As a result, there can be an entire parking garage floor with varying levels of corrosion [2]. Surface discontinuities, such as scratches, wears, and debris, can commence pitting corrosion by serving as an initiation location. Within this specific case study, high chloride ion content, which is usually carried in from deicing salts washing off of vehicles, attacks the passive film of concrete flooring and metal rebar, as shown in ***Image 7*** [16]. The anodic reaction occurs within the steel rebar, and has a chemical equation as follows:

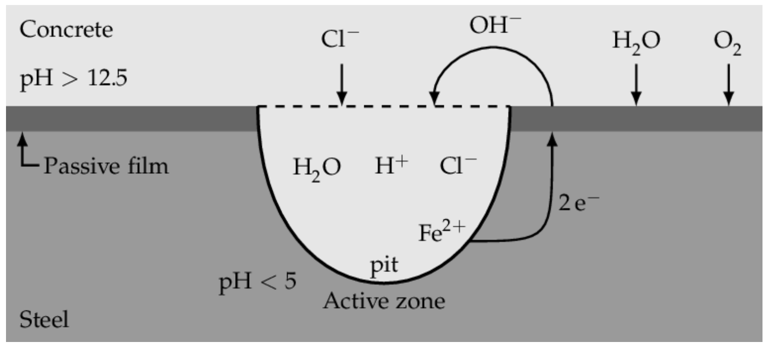

Figure 7: *Image of Pitting, the Predominant Corrosion Mechanism, at Alewife MBTA Parking Garage Station Complex [16]*

$$Fe \rightarrow Fe^{2+} + 2e^-$$

The cathodic reaction within this system occurs along the surface, and has a chemical equation as follows:

$$\frac{1}{2}O_2 + H_2 + 2e^- \rightarrow 2\,(OH)^-$$

The dissolved chloride salts in water act as the electrolyte solution, and the resulting corrosion-accelerating reaction has a chemical equation as follows:

$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2HCl$$

As a result of these reactions, pits form and grow. A loss of material occurs, which first penetrates the protective passive film and eventually leads to defects within the concrete decking and steel rebar [15]. Typically, different corrosion detection methods will be used to examine and evaluate altering levels of deterioration while several different corrosion prevention techniques will be employed to ensure no further degradation and structural failure occurs within the project.

After understanding the primary mechanism responsible for deterioration within the Alewife MBTA Parking Garage, it is also crucial to evaluate the kinetics of the corrosion mechanism. In evaluating the different oxidation rates of most metals, including linear, parabolic, and logarithmic relationships, it becomes apparent that this project is predominantly experiencing a logarithmic oxidation rate, as shown in ***Figure 8*** [15, 17]. Upon experiencing initial levels of corrosion and accepted levels of deterioration, the Alewife MBTA Parking Garage was experiencing linear oxidation. However, the conditions

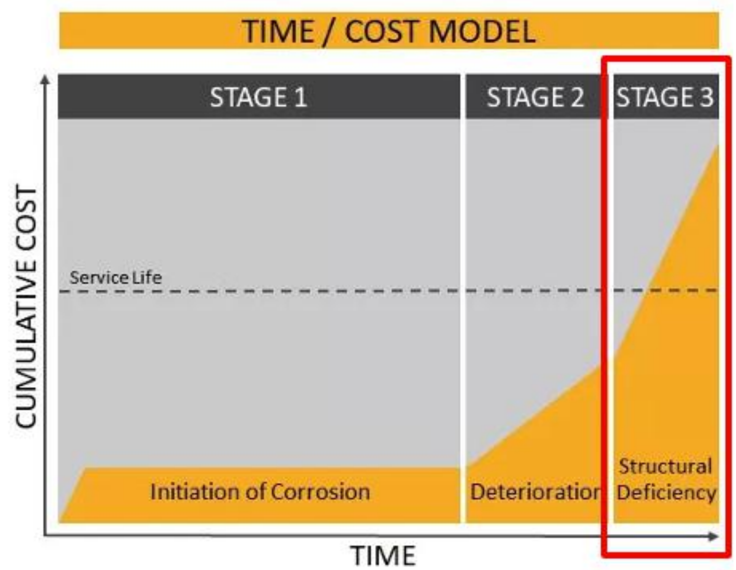

Figure 8: *Image of Corrosion Time vs. Cost Model to Describe the Kinetics of the Corrosion Mechanism at Alewife MBTA Parking Garage Station Complex [17]*

state in the aforementioned 2011 and 2017 engineering condition assessment reports indicated a different type of oxidation [2, 3]. The levels of corrosion included within these reports are indicative of a logarithmic oxidation rate, which is typically applied for thin, protective films at low temperatures [15]. In this model, the logarithmic oxidation rate has an equation as follows:

$$x = k \ln(at + 1)$$

In this equation, x represents the oxide film thickness, t represents time, and k *and* a represent constants. Given the current condition of the Alewife MBTA Parking Garage, this logarithmic oxidation rate formula can be used to calculate the oxidation that will explain the structural deficiency within the project [15].

Some of the methods involved for corrosion detection include non-destructive testing and destructive testing. Non-destructive testing incorporates industry techniques where no damage is done to the original component or material of interest [18]. Some of these specific methods include visual observations, photographic documentation, physical measurements, and hammer sounding. The most popular technique used for this specific project includes photographic documentation, as shown by the images included within this case study taken by the consulting engineering firms [2, 3]. Destructive testing incorporates industry techniques

Figure 9: *Image of Precast Beams Before and After Repairs at Alewife MBTA Parking Garage Station Complex [19]*

where damage is done to the original component of interest for the intent of understanding service life and product integrity [18]. Though this method does disrupt the component of interest, it does in fact provide a more accurate determination for the component's status. Some of these specific methods include partial depth concrete removal, such as concrete coring and drilling, chloride ion tests, petrographic analysis, and other laboratory techniques.

Though a variety of prevention methods are possible for this project, three in particular were suggested by the engineering firms tasked with assessing the current condition of and providing solutions to improving the Alewife MBTA Parking Garage [2, 3]. The first suggestion includes the method of sanding, cutting and cleaning out exposed reinforcing bar rust, as shown in ***Figure 9*** [19]. This technique enhances the service life and current state of the precast beams, as it removes corroding and rusted components. The second suggestion includes the method of applying an epoxy bonding agent coating or rust inhibitor paint. It is worth noting that this technique was the most popular suggestion for this project, as corrosion-prevention coatings tends to be a cheaper and more time-effective alternative for replacing specific structural components. Additionally, this method is superior when understanding that corrosion can happen in localized and uneven rates. The third suggestion includes the method of cleaning and fully replacing joint covers, as shown in ***Figure 10*** [20]. This technique protects joints, which are some of the most susceptible locations in concrete decks and prevents further deterioration from occurring. It is worth noting that throughout the project, many of the joint covers were found to be either fully corroded or

Figure 10: *Image of Expansion Joint Covers at Alewife MBTA Parking Garage Station Complex [20]*

completely missing. Thus, this technique was the second most popular suggestion for preventing corrosion throughout the project.

III. Conclusions

Parking stations, especially those like the Alewife MBTA Parking Garage, are particularly susceptible to corrosion because of their frequent use and exposure to harsh conditions. The parking garage examined in this case study is in critical condition. Fortunately, this site is currently undergoing a $22 million project aimed at improving overall safety, commuter accessibility, and structural longevity [19]. This project, which is projected to finish in Fall 2023, aims to tackle beam and deck concrete repairs, storm and sanitary sewer system repairs, busway shelter roof replacements, and deck joint re-caulking [19]. These project features are in addition to the concrete structure improvements, which began in September 2018. In particular, the main corrosion mechanism observed in this project is pitting, which causes localized deterioration that can be both unpredictable and swift [15]. The concrete and metal deterioration throughout the Alewife MBTA Parking Garage is primarily due to water infiltration, cold climate conditions, and acidic bird droppings from nesting [2, 3]. Because of the prevalence of corrosion-related projects throughout the United States, continuous experimentation and research is needed to evaluate and understand the transportation features that comprise domestic infrastructure.

IV. References

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