CONDITION APPRAISAL

MARITIME PARKING GARAGE

NORWALK, CONNECTICUT

Prepared for:

PARK NORWALK
11 NORTH WATER STREET
NORWALK, CT 06854

Submitted by:

DESMAN

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1. INTRODUCTION

A. AUTHORIZATION:

DESMAN was retained by **Park Norwalk (NP)** c/o the City of Norwalk (the City) to provide consulting engineering services to perform a condition appraisal update at the Maritime Parking Garage, Norwalk, Connecticut. This appraisal was performed in accordance with **DESMAN**'s proposal, dated March 27, 2025 and authorized to proceed by **PN** on April 24, 2025.

SCOPE OF SERVICES:

The scope of services is outlined in detail in **DESMAN**'s proposal. In summary, these services primarily consisted of the following work :

TASK 1: VISUAL RECONNAISSANCE/SURVEY:

- **DESMAN** will evaluate all available historical documents pertaining to this project inclusive of, but not limited to, original design drawings, condition assessment reports, and repair documents, paying particular attention to structural framing, expansion/construction joints and architectural/waterproofing detailing (i.e., drainage slopes, caulking details, etc.).
- **DESMAN** will then conduct a visual reconnaissance of the parking garage to identify and quantify the areas of deterioration, distress, corrosion, moisture infiltration, or unusual conditions. Issues to be reviewed include the following:
  - **DESMAN** will document the condition of concrete construction with respect to erection tolerances, bearing conditions at column corbels, corrosion of pre-cast concrete shear connector assemblies, cracking, spalling, surface scaling, and water leakage.
  - **DESMAN** will review the condition of concrete beam and column framing along with cast-in-place floor slab or topping concrete.
  - **DESMAN** will review the condition of joint detailing (tee joints, expansion joints, construction joints, control joints, cove joints), crack detailing, and other waterproofing components as may be appropriate.
  - **DESMAN** will review the condition of the facade, elevations, exterior perimeter walls, spandrel panels, exterior connections, etc. as may be exposed.
  - **DESMAN** will review the condition and configuration of deck drainage (i.e., the

locations of floor drains, locations of standing water/ponding conditions, condition of drainage piping, etc.), and overall apparent drainage performance.

- **DESMAN** will review the condition of the lighting and electrical components (i.e. locations of deteriorated conduit and boxes, locations of damaged light fixtures). **DESMAN** notes that it is not our intent to measure and comment on the actual lighting levels, but rather to provide general comments that may be determined by visual observation. If requested by **PN**, we can provide services to measure and comment further on the lighting levels of the garage as an additional service.

- **DESMAN** will review the general condition of the stairwells (i.e. treads, risers and landings, handrails/guardrails, etc.) and elevators. It is not our intent, however, to evaluate the elevators for recommended modernization or compliance with code requirements, except that which may be determined by visual observance. We recommend that a qualified elevator consultant review the elevator systems for recommended repairs and/or improvements. If requested by **PN**, we can arrange and procure the services of a specialized elevator consultant to review the elevators further for potential repairs and/or improvements as an additional service.

- **DESMAN** will identify and comment on areas of miscellaneous construction that may require specific and/or specialized maintenance.

- **DESMAN** will provide an evaluation of the results of the visual reconnaissance. To the greatest extent possible, general recommendations for the repair of the facility will be developed. These repairs will be presented in order of priority for further review, to be adjusted according to immediate needs and the availability of funds.

- **DESMAN** will provide the condition appraisal reports summarizing the various observations and recommendations. We will discuss the findings and recommendations with **PN** as appropriate and revisions will be made to the report if necessary prior to submission. We will then forward final reports to **PN** in PDF-format.

Task 2: Material & Field Testing:

DESMAN may perform a limited delamination survey over select cast-concrete surfaces of limited portions of the supported slabs, that are deemed necessary and appropriate, that are easily accessible using the chain-drag method; **DESMAN** notes that the intent is not to perform a comprehensive delamination survey over 100% of the surfaces but rather only as may be representative or appropriate to supplement our visual observations as determined by **DESMAN** at the time of our visual reconnaissance. This will help estimate the amount of delaminations or hollow areas in the concrete floor slab which require repair. These soundings will help to detect subsurface horizontal cracking within the slabs caused by corrosion of embedded ferrous materials, but which are not typically visibly detectable.

C. OBJECTIVE:

It is the intent of this condition survey and assessment to: (1) document the current condition and determine the influence of deterioration on safety; (2) determine the causes and extent of the deterioration, to the extent possible utilizing the proposed testing techniques and visual observations; (3) develop a recommended program of repair, and (4) estimate probable construction costs of the repair program. A visual observation and review of original design documents are utilized to gain an understanding of the structure and how it should be expected to perform as compared to what is identified in the field. Typically in the performance of a condition assessment an assumption is made that the structure was designed and constructed in compliance with industry standards and building code requirements in effect at the time the building was designed and constructed. If certain conditions are observed during an inspection/evaluation of a building it is sometimes necessary to do a more thorough engineering evaluation to determine an underlying cause of distress or failure; it is also sometimes necessary to perform supplemental destructive and/or non-destructive testing to determine an underlying cause of distress or failure. Due to the age of the structure and the fact that no significant structural distress was observed during the assessment, it has been determined that extensive structural evaluation or analysis is currently not deemed necessary. Similarly, no extensive destructive and non-destructive testing needed to be performed at this time.

As with any building assessment and the resultant repair program developed as a result of such an assessment, it is wise to include or anticipate within any estimated repair cost or budget a nominal construction contingency to account for concealed, unknown, or unanticipated conditions which may be encountered in performing the recommended repairs as outlined in this report.

D. QUALIFICATIONS:

DESMAN was retained to perform an appraisal of the Maritime Parking Garage, Norwalk, Connecticut. The conclusions, recommendations, and opinions of costs represented in this report are based on discussions with personnel familiar with this facility, our field observations and our experience with similar projects.

It is not the intent of this appraisal to perform an exhaustive study to locate every existing defect in the structure. Nor is it the intent to perform an extensive structural evaluation or analysis except as noted. Similarly, no extensive destructive or non-destructive testing needed to be performed at this time except as noted. A team of trained professionals conducted "walk-through" observations; however, there may be

defects at the facility that were not readily accessible or visible. Additionally, conditions may develop in the future that were not evident at the time of this survey.

Opinions of cost for repairs are approximations only and should not be interpreted as bids or offers to perform work. Actual costs can be affected by the extent of work done as one project, the quality of contractors, the quality of materials chosen and specific work conditions. These conditions are based on design criteria which are not known at the time of this report.

E. PARKING GARAGE REPAIR AND RESTORATION – AN OVERVIEW:

As stated by the American Concrete Institute (ACI) Committee 362.1R-97 in their report titled Guide for the Design of Durable Parking Structures, (reapproved in 2002), *"The durability of parking structures is related to many factors, including weather, the use of deicer salts, concrete materials, concrete cover over reinforcement, drainage, design and construction practices, and the response of the structural system to loads and volume change. The most common types of deterioration and undesirable performance of parking structures are due to corrosion of reinforcement, freezing and thawing, cracking, ponding of water and water penetration. Even walls and columns suffer distress from leakage, splash, and spray of salt-contaminated water."*

Concrete is a stone-like material obtained by permitting carefully proportioned mixture of cement, sand and stone or other aggregate and water to harden in forms of the shape and dimensions of the desire structure. The advantages of this building material include its high fire and weather resistance, local availability at low cost and high compressive strength. On the other hand, it is a relatively brittle material whose tensile strength is low compared to its compressive strength. This limitation is overcome by using reinforcing steel in combination with concrete in order to reinforce it where its low tensile strength would normally limit the carrying capacity of the prismatic member or element.

With the widespread use of deicing chemicals and road salt on our nation's highways and roadways, the condition of our bridge decks, parking garages and other reinforced concrete structures directly exposed to these materials began to change. The relationship between the deterioration and use of deicing chemicals and road salt was most evident by the extent of deterioration found in the "snow belt" states. With the development of this deterioration, programs were initiated to study the cause and effect of the problem in order that repair procedures and preventive maintenance could be instituted to assure the long term viability of these structures.

Research has confirmed that corrosion of the embedded reinforcing steel was the primary cause of the structural deterioration. It was further determined that the presence of chloride in the concrete (from both external and internal sources) greatly accelerated the development of the corrosion process. External sources of chlorides mainly occur from deicing chemical and road salt applications. Internal sources consisted of calcium chloride admixtures to the concrete used historically in winter months to speed up the temperature sensitive curing of the concrete mix. Repair programs began to consider that the only method to stop all subsequent corrosion deterioration was one where all concrete containing threshold values of the chlorides necessary to cause corrosion was removed and chlorides were further prevented from entering the new concrete. However, removal of all concrete containing significant chlorides is seldom a practical or cost effective solution.

The service environment of parking structures is more severe than most other buildings and is more nearly like that of highway bridges. In many cases, these structures are exposed to seasonal and daily ambient temperature variations. Deicing chemicals and road salts may be spread directly on the slab floors or they may be deposited from vehicles coming into the parking facility from surface streets where the chemicals are extensively used. Extreme temperature and volume changes can cause cracking of the floors, beams, columns, and walls which can lead to the ingress of water and chlorides leading eventually to deterioration. Use of deicing chemicals and road salt, and chloride contamination within the concrete can also increase freeze-thaw damage due to a fluctuation between freezing and thawing at the concrete's surface or near its surface causing localized spalling and loose of cement paste binding the concrete aggregate together. Deterioration of the concrete surface due to freeze thaw causes further moisture and chloride contaminated moisture intrusion into the concrete, down to the level of the embedded reinforcing steel where more extensive damage can occur due to corrosion.

To the greatest extent possible, visual observations, field-testing, laboratory tests and analysis performed on the data collected are used to gain as much information about the structure as possible. As stated by the ACI Committee 362 in an earlier report titled State of the Art Report on Parking Structures, issued in 1985, "*Repairing an existing deteriorated structure involves many unknowns, uncertainties, and risks. Especially with regard to repair of deicer caused corrosion damage, the process is considered an extension of the useful life of the deteriorated structure. It is not equivalent to building a new structure with current technology*." Therefore, in the development of repair programs within this report, contingency funds must be anticipated and included in any budget for repairs to account for concealed, unknown, or unanticipated conditions which may be encountered.

2. EXECUTIVE SUMMARY

CORROSION: Corrosion is the oxidation, or rusting of ferrous materials (i.e., embedded reinforcing steel), and the creation of iron oxide which has an increased volume compared to the base ferrous material. Besides the loss of steel strength and a loss of cross-sectional area of the steel, this chemical reaction and the resultant expansion in volume exerts great pressure on surrounding concrete causing concrete spalling and potentially a loss of structural load carrying capacity.

DELAMINATION: A delamination is a subsurface failure or cracking within concrete construction at the level of the embedded reinforcing steel; typically caused by the corrosion of the embedded concrete reinforcement, but can also be the result of cyclical freeze-thaw damage.

SPALL: Concrete spalling is the direct result of the corrosion or freeze-thaw process causing delaminated concrete to eventually break away, leaving a hole, and exposing embedded reinforcing steel to the effects of continued and progressive corrosion. Spalled concrete, often presents a potential tripping hazard to pedestrians, either due to the hole created or exposure of embedded steel reinforcing. Excessive spalling is clear

The Maritime Parking Garage is in fair structural condition; although no major structural deficiencies were identified during **DESMAN**'s site investigation at this time, conditions do exist, such as shallow cracking, spalled shear connections and joint sealant failure, that if left untreated or unaddressed may result in additional premature concrete deterioration.

Understanding that various concrete repair and waterproofing projects have been programmed over time, **DESMAN** recommends that a comprehensive program be implemented as funds become available.

Various enhancements are also recommended, spanning the disciplines of the plumbing systems, miscellaneous metals, as well as architectural improvements such as painting and railing enhancements.

A more complete outline and description of **DESMAN**'s visual observations is presented within Section 4 of this report. Section 5 of this report presents a breakdown of projected costs of recommended capital repairs and improvements. Projected repairs and capital improvement costs are prioritized into three (3) separate phases (Prioritized Repairs, Programmed Repairs, and Long-Term Repairs), with appropriate construction contingencies, and is summarized as follows:

PROJECTED REPAIRS AND CAPITAL IMPROVEMENT COSTS:

- Prioritized Repairs: **$575,150.00**
- Programmed Repairs: **$786,250.00**
- Long-Term Repairs: **$1,262,100.00**

TOTAL: $2,623,500.00.

The projected capital improvement costs presented here and more fully described later in this report are based upon current prices in the New England area for labor, equipment, and materials to implement similar work as currently recommended for implementation to the Maritime Parking Garage. The estimated construction costs includes a ±10% construction contingency allowance to account for uncertainties in the restoration market at the time of bidding, and to address possible unforeseen conditions which might arise during the complete design development of the repair documents and repair procedures.

Costs associated with providing engineering design services, bidding assistance, and contract administrative & sight observation services have not been provided as the exact scope of repairs and the scheduling of when and how they might be implemented has not yet been determined. Should **PN** wish to budget for design and construction management fees, **PN** should assume an additional 12% to 15% of total construction cost as a reasonable estimate for these services.

The design fees would vary depending on the magnitude and complexity of the repairs actually undertaken, and the suggested percentages for engineering services are meant only as a budgeting tool, and not as an actual proposed engineering fee for **DESMAN** to perform the engineering services. Should **PN** wish to proceed with any portion of the recommended repairs, **DESMAN** will gladly provide a proposal for the designated engineering services.

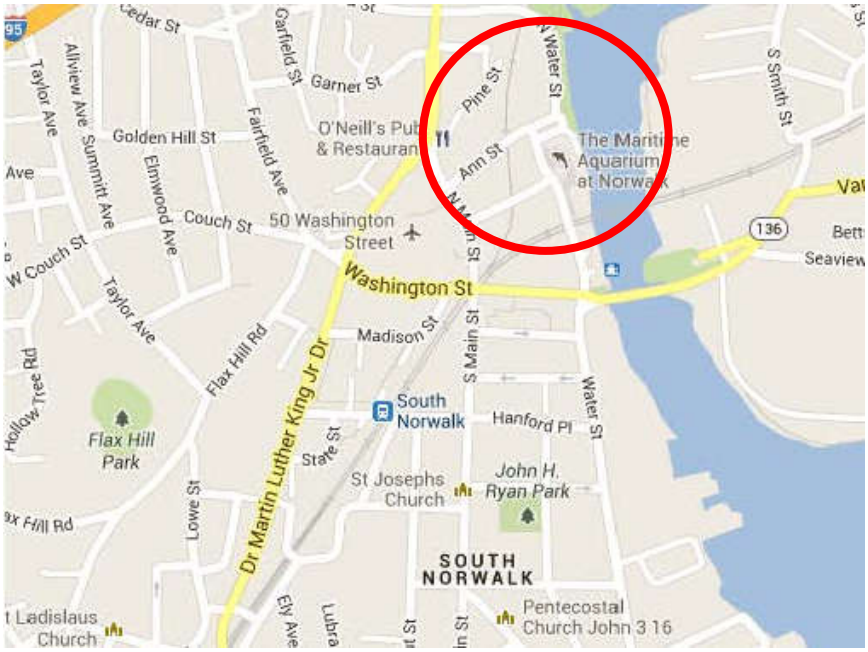
Due to certain economies of scale, the total cost of capital repairs could be reduced if the recommended repairs are implemented as part of a single phase repair program in lieu of the repairs being implemented in a phased or prioritized repair program. Additionally, it should be noted that a phased type of repair needs to account for a limited increase in repair quantities and associated repair costs to address an anticiapted increase in deterioration which might occur in the intervening period of time between phases of the work. A phased repair program also results in increased costs due to the need for multiple mobilizations by contractors onto the work site.

3. DESCRIPTION OF FACILITY

Photo No.1

Photo No. 2

The Maritime Parking Garage is located directly across from the Maritime Aquarium in South Norwalk, Connecticut. The structure consists of seven supported levels and a concrete slab-on-grade; the building was constructed in 2005. The north, south, east and west facades are adjacent to Ann Street, Marshall Street, North Water Street and North Main Street, respectively **(*reference Location Map below*)**. The parking garage has a capacity of 766 cars.



Location Map: courtesy of www.google.com

Photo No. 3

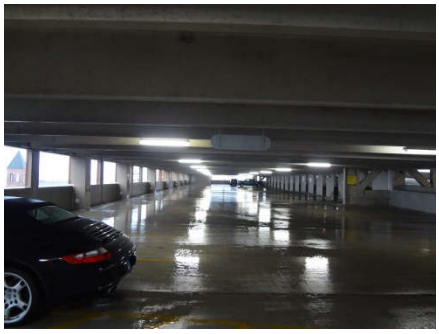


Photo No. 4

Photo No. 5

The garage is approximately rectangular in shape and measures approximately 298 FT x 127 FT. There are two triangular retail/office areas that abut the garage footprint, one at the eastern facade and the other at the southern facade.

There is an entrance/exit from Marshall Street at the southwest corner of the garage at grade level that consists of one entrance and one exit lane. Additionally there is another grade level entrance/exit from North Water Street at the northeast corner of the garage that consists of two entrance and two exit lanes.

The garage contains two parking bays that span from north to south. The eastern parking bay is flat while the western parking bay is ramped and provides traffic flow between parking floors. All traffic in the garage is two-way and the parking stalls are painted at 90°. The total parking and drive aisle area at the grade level is smaller than that of the supported levels due to some office/storage areas at the eastern end of the garage.

The structural system of the parking garage consists of pre-topped, precast concrete double tees supported by inverted tee beams, spandrels and 'lite' walls. The tees are approximately 11'-4" wide and there are three tees per each 34' column bay. The inverted tee beams and spandrels are supported by precast concrete columns. The lateral force resisting system consists of precast concrete shear walls and k-frames in the traverse direction and 'lite' shear walls in the longitudinal direction.

Photo No. 6

Photo No. 7

Photo No. 8

Photo No. 9

A 2 FT wide cast-in-place concrete pour strip runs along the perimeter of each supported level on a recessed section of the double tees. Further, there are pour strips on each side of the longitudinal shear wall at the middle of each parking deck and also above the inverted tee beams. The pour strips encase the welded connections between the precast tees and the precast frame.

The façade of the parking structure primarily consists of inclad brick spandrels. In addition to the inclad brick spandrels, the stair/elevator towers also contain punch windows and vertical strip windows. The stair/elevator tower at the southeastern corner of the garage contains a lighthouse-type structure at the top that rises above the roof level of the garage. The triangular retail/office areas that abut the garage are also clad in brick masonry, architectural metal panels and glass strip windows.

There are two single stair towers and a stair/elevator tower which serve the parking facility. The primary stair/elevator tower is located at the southeast corner of the garage. This tower contains two elevator cabs and a series of stairs ringed around an open atrium. The roof of this tower contains a glass and metal architectural structure that resembles the top of a lighthouse. There are two additional single stair towers. One is located at the north façade of the garage between gridlines C.4 and C.8. The other single stair tower is located at the southwest corner of the garage.

4. VISUAL OBSERVATIONS AND RECOMMENDATIONS

DESMAN performed a detailed visual observation of the facility's structural systems and waterproofing components, along with the general condition of the drainage system.

While **DESMAN** does offer comment on the general condition of miscellaneous electrical components and their relationship and potential impact to the garage's structural system and waterproofing components, **DESMAN** did not review the apparent lighting levels or the placement of the light fixtures. While **DESMAN** does offer comment on the general condition of the signage, **DESMAN** does not comment on the placement and/or functionality of the signage except where recommendations that **DESMAN** may consider typical areas of improvements are warranted. **DESMAN** also did not review the mechanical systems (i.e. fire standpipe, etc. as applicable) beyond general or visual conditions which may benefit from comment by **DESMAN**; **DESMAN** recommends that these systems be reviewed by a qualified engineer and/or maintenance company as appropriate.

Observations made were documented on copies of floor plans. An extensive number of photographs were also taken to help document the various conditions observed.

The following is a listing of observed conditions and issues of concern, along with recommendations to rectify them.

A summary of **DESMAN**'s visual observations is as follows:

Photo No. 10

Photo No. 11

Photo No. 12

Concrete Work:

- During erection and placement of the individual precast concrete double tee deck elements, each tee is tied to the adjoining tee with embedded shear connection assemblies spaced periodically along the length of the tee. **(*reference Photo Nos. 10, 11 & 12*)** Depending on the depth of the embedment, and the care utilized during the welding process to connect the adjoining tees, there can be instances where nominal spalling at various connections might occur. If the precast concrete at the shear connections retain sufficient moisture, the heat generated during welding can vaporize the moisture into steam causing tensile failure in the concrete and nominal surface spalling at the connections.

- The surface spalling at the shear connections can also be the result of insufficient embedment depth of the shear connection assembly and the surrounding concrete being stressed beyond its tensile capacity during erection, unintended restrained thermal movements in the entire structure in response to ambient temperatures. Failure can also potentially occur due to a temporary overstress condition as a vehicle or combination of vehicles move across the deck and up through the garage, or during snow removal operations.

Photo No. 13

- Interim repairs have been performed as **DESMAN** noted that select shear connector assemblies associated spalled/delaminated shallow-depth concrete surrounding the connections have been repaired. The majority of the concrete repairs are performing well. Miscellaneous locations have failed and new spalls have formed, though, throughout the garage, and require attention once more. These locations have failed for a variety of reasons inclusive of, but not limited to, snow removal operations and the nature of the original construction providing an embedment depth which is too shallow as discussed previously.

  While the interim repairs incorporated a cementitious polymer-modified concrete repair mortar, **DESMAN** now recommends the use of an epoxy/aggregate repair mortar to infill the shallow surface spalls. This material can be applied with minimal surface preparation and its material properties and enhanced bonding characteristics allow it to be feathered into the adjoining concrete surface. The recommended repair material is also more flexible than typical concrete/cementitious repair mortars. Similar periodic repairs at the shear connections throughout the garage can be expected throughout the useful life of this facility.

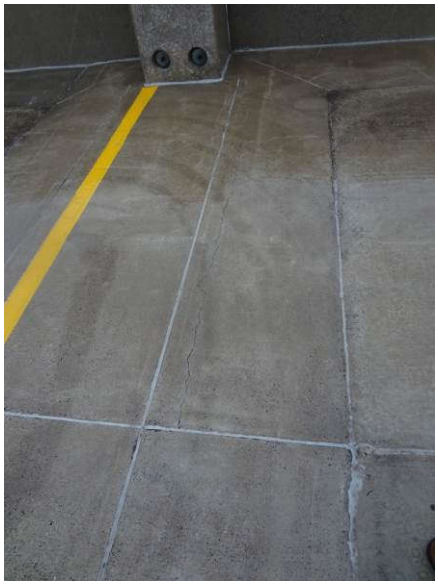


Photo No. 14

Photo No. 15

- The recommended epoxy/aggregate repair work required at the shear connections will need to be coordinated with waterproofing/sealant work needed as described later in this report.

- Cast-in-place concrete aprons and pour strips are located throughout the garage, specifically along the perimeter of the decks and along the inverted tee beams; the cast-in-place concrete appears to be performing well typically. **(*reference Photo No. 14*)**

- **DESMAN** noted minor surface scaling and shallow-depth delamination and/or spalling throughout the garage, particularly in those areas constantly exposed to moisture (i.e. adjacent to drains, adjacent to the ramps, exposed on the roof level, etc.) Scaling can be caused by cyclical freeze-thaw, and is typically exhibited by pitting on the concrete surface and an exposure of the aggregate within the concrete matrix. The reinforcing steel can become exposed, allowing further moisture penetration. **DESMAN** recommends that the scaling and shallow-depth deterioration be repaired using an appropriate epoxy/aggregate repair mortar, prioritizing the roof level. **(*reference Photo No. 15*)**

  Any recommended concrete repair work should be coordinated with waterproofing/sealant work needed, as described later in this report.

Photo No. 16

- Miscellaneous vertical and overhead concrete spalling was observed throughout the garage. Insufficient coverage of reinforcing steel and failed waterproofing above can allow moisture to access the steel, thus causing the spalling. Although cosmetic in nature, **DESMAN** recommends that these locations be repaired with a high-quality polymer modified repair mortar.

- **DESMAN** also notes limited cracking is observed throughout the garage. Cracking can occur for a variety of reasons, such as if the tees are pulled from their forms before minimum concrete strengths can be achieved. **DESMAN** is not concerned that the cracking has compromised the structural integrity of the members, however, **DESMAN** does recommend that epoxy injection be performed to address the cracking to maintain the waterproofing integrity.

- For aesthetic and architectural enhancement, **DESMAN** recommends that the remaining excess epoxy and injection ports be removed and an architectural coating be applied after completion of the epoxy injection. A coating can provide a more uniform appearance, minimizing the visibility of the repairs such as by a typical exterior concrete paint system. Depending on the selected product, this can provide additional waterproofing protection by bridging any minor cracking and minimizing further moisture intrusion. Application of a coating can also enhance ambient lighting levels and assist in

highlighting pedestrian entry/exit routes and areas of refuge throughout the garage. Since application of a coating is not required for structural or waterproofing integrity, assuming that epoxy injection repairs are performed, **DESMAN** has not included the projected cost for coating application in **DESMAN**'s recommended repair and capital improvement program; should **PN** be interested, **DESMAN** can provide the additional projected cost.

- Minor concrete spalling was observed in a limited number of areas of raised concrete curbs located around the parking facility. Minor cracking can be observed, typically where joints were not originally tooled during initial construction, and minor spalling was also noted, the majority being cosmetic and not the result of corrosion of embedded reinforcing steel, perhaps due to vehicular damage. **DESMAN** recommends that the cracking be routed and sealed, and all spalling be patched with a high-quality polymer-modified repair mortar.

Photo No. 17

- Minor cracking, scaling, and other deterioration mechanisms exist throughout the slab-on-grade (Level 1) **(*reference Photo No. 17*)**. Since the slab-on-grade is typically considered a lesser priority than a supported deck, **DESMAN** recommends that **PN** monitor the slab-on-grade to make certain no trip-and-fall hazards present themselves and the deterioration mechanisms don't expand or become exacerbated.

Photo No. 18

Photo No. 19

Photo No. 20

Waterproofing:

- As a general rule, the life expectancy of tee-to-tee joint sealant is between 8 to 12 years depending on exposure and level of usage. Roof level joints, though, are exposed to more aggressive circumstances due to environmental conditions and snow plow damage, and lower levels experience comparatively more traffic than the upper levels of the facility.

- Failed joints are observed throughout the garage. The failed sealant consists of a variety of failure mechanisms, such as debonding from the adjacent tee surfaces which can occur from poor surface preparation; insufficient grinding of the edges, leaving rough surfaces, creates an increased susceptibility to premature failure of the joint material. **(*reference Photo Nos. 18, 19, 20 & 21*)**

- Repairs to leaking tee-to-tee joints typically requires that old sealant material be entirely removed down to bare concrete, the edges detailed and the substrate properly primed prior to new polyurethane sealant material being installed. Limited "spot" repair of tee-to-tee joints can be problematic as new polyurethane sealant materials do not adhere well to preexisting or previously cured polyurethane sealant. Spot repairs can be accomplished but preexisting sealants need to be

Photo No. 21

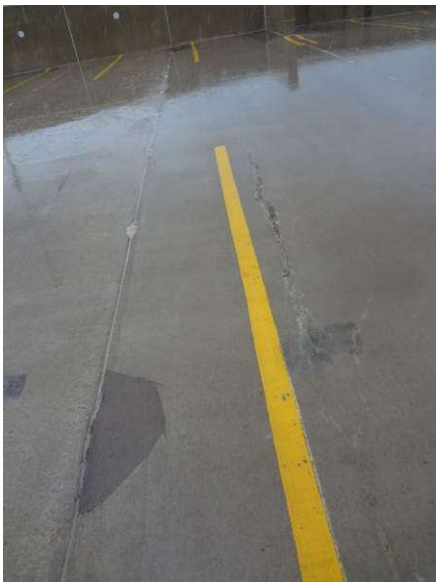


Photo No. 22

Photo No. 23

thoroughly cleaned and wiped down with solvents to soften the surface and enhance the bond between old and new sealant material. Unless there is only limited tee-to-tee joint failure along a 60 foot parking bay, **DESMAN** typically recommends that the entire length of tee joint be removed and repaired in its entirety.

- Considering the apparent age of the existing sealant material and the magnitude of shear connector repairs, **DESMAN** recommends full removal and replacement of the tee joint sealant be programmed. At the time of sealant replacement, all edges should be properly ground smooth to facilitate appropriate material bonding.

- Miscellaneous cracking was visually identified throughout the parking garage. The cracking observed within the precast concrete tees is similar to cracking observed in most precast concrete tee construction, and is usually related to restrained concrete shrinkage; cracking observed to be occurring on the top of the tees along the underlying tee stem where a joint was not originally tooled during construction. This cracking can also occur when the tees are pulled from their forms if minimum concrete strengths have not been achieved. None of the cracking identified is an immediate structural concern, but continued water infiltration into and through these cracks should be

Photo No. 24

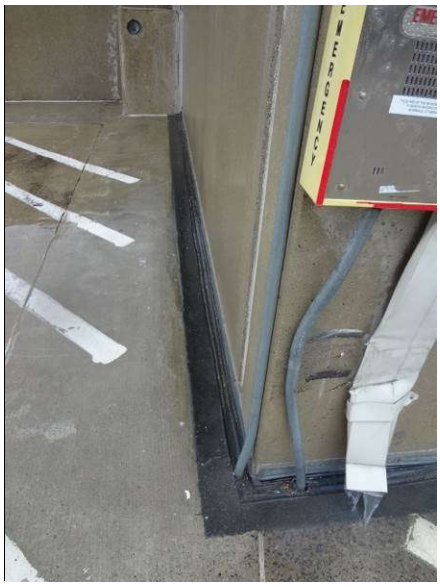


Photo No. 25

Photo No. 26

eliminated to prevent the egress of deicing chemicals and road salt.

- Considering the magnitude of cracking and the apparent full-depth penetration through a significant portion of the cracking in specific areas, **DESMAN** now recommends that an epoxy-based healer/sealer be considered, as well, to more permanently seal the cracks.

  DESMAN also observed shallow cracking throughout the vertical surfaces, specficially the roof level where these surfaces are exposed more to the weather and environmental conditions (as well as other miscellanoues former pockets and such, reamining from original costruction). **DESMAN** recommends that this cracking be moitored and that application of a waterproofing coating may become appropriate in the near future.

- Expansion joints are currently installed around the three stair towers **(*reference Photo Nos. 25 & 26*)**. Expansion joints are typically created within a structure to allow for thermal movements within the structure in response to ambient temperature variation and are also sometimes necessary to separate structural elements which are anticipated to move contrary to one another due to differential settlement or potential seismic activity (such as stair towers). These expansion joints need to be closed off to prevent water infiltration through the joint opening or to allow for a smooth transition between

adjoining structural elements; typically, a flexible material or gland is designed to handle the extent of movements experienced. These glands can be comprised of any number of materials and need to be tough enough to handle vehicular and/or pedestrian traffic as may be required and still allow for unimpeded pedestrian access.

Photo No. 27

Photo No. 28

- The existing joint glands are demonstrating their age due to wear and tear, as well as not providing a complete closure. **DESMAN** recommends that the existing glands be removed, and new glands installed that continue vertically at the parapet interfaces and across the stair tower surfaces (adjacent to the parapets), providing a complete closed interface .
- At the time of replacement, **DESMAN** recommends that penetrations through the glands be avoided; any penetration provides a means for the waterproofing integrity of the gland to be compromised. **DESMAN** therefore recommends that all electrical conduits be re-routed as required, as well as drainage piping be adjusted to avoid creating ponding on top of the glands; although the glands are designed to be watertight, constant exposure can aid in prematurely failing the gland.

- All expansion joint glands located throughout the facility would benefit from periodic cleaning to remove dirt and debris which tends to accumulate within the folds of the accordion shaped glands. Debris which collects within the expansion joints can

Photo No. 29

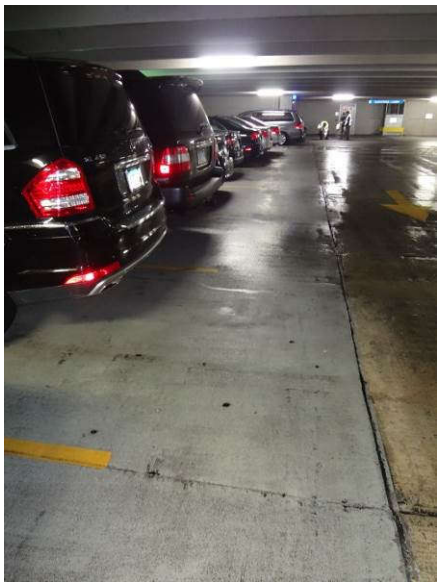


Photo No. 30

restrict proper joint movement and cause premature failure of the joint. It is recommended that this expansion joint cleaning be performed on a weekly basis, or as a minimum on a monthly basis.

At the time of joint replacement, **DESMAN** recommends that all vertical joints be reviewed and replaced with new non-sag polyurethane sealant, programmed accordingly. Additional openings may benefit from sealant installation, such as directly adjacent to stair doors, or perhaps with a more formal gland installation depending on opening width and movement requirements **(*reference Photo No. 29*)**

- A traffic bearing membrane has been installed over the pre-topped precast surfaces of Level 2 (recoated in 2011), which coincides with the office spaces below. Traffic bearing membranes are approximately 85%-90% effective as moisture and chloride screens inhibiting future chloride-ion migration into the deck. An elastomeric membrane will also traverse cracks that may form and joints that may be tooled.

- Generally speaking, the membrane installation is performing well, maintaining its bond to the concrete and its non-slip aggregate texture. However, certain areas are wearing more quickly than other locations, typically within the drive lane portions or in turning areas.

Photo No. 31

- Although a traffic bearing membrane is a superior chloride and moisture screening product, it is costly to install and to maintain, particularly if installed on precast concrete garages with their many joints; each joint acts as a location where a membrane can fail as each joint presents a discontinuous edge in the membrane where water can potentially enter, thus failing the membrane from below

Upon completion of a membrane installation, **DESMAN** suggests developing a yearly service contract with a qualified waterproofing contractor to assure that damaged portions of the membrane are successfully repaired each spring and autumn. It is important that all damage to waterproofing membranes be repaired, as continued and progressive de-bonding of the membrane will result if left unattended. **DESMAN** therefore cautions that installation of a membrane should be considered along with adequate funding for long-term maintenance.

A less expensive option to a membrane would be the application of a 100% solids, silane-based, penetrating sealer; a silane sealer has been applied on the remaining surfaces throughout the garage in 2011. A sealer is only approximately 60% to 65% effective in preventing moisture penetration, though, and does not bridge cracks and joints. The life-cycle of a sealer is shorter than a membrane, spanning between 7 to 10 years, but if concrete

repairs are properly addressed prior to application, the sealer is a viable alternative. Penetrating concrete sealers have proven to be an effective chloride screen, but their effectiveness diminishes over time.

Another option to a membrane and a more viable option to the penetrating sealer, would be the application of a topically-applied corrosion inhibitor throughout the parking garage. A corrosion inhibitor assists in raising the chloride threshold level necessary to support active corrosion of embedded reinforcing steel within the supported decks.

Not only do these materials inhibit corrosion, they also offer the additional benefit of performing as a penetrating concrete sealer, acting as a moisture and chloride screen. Because these materials are unable to bridge cracks in concrete, though, similar to sealers, the application of corrosion inhibitors needs to be done in conjunction with a program of crack and control/construction joint repair and quite possibly combined with the application of an elastomeric traffic bearing waterproofing membrane in certain areas.

Although no chloride ion testing was done as part of this facility's current assessment work, 10 years have passed and considering the extent of deteriorated and/or failed shear connections observed throughout the garage, **DESMAN** considers

Photo No. 32

Photo No. 33

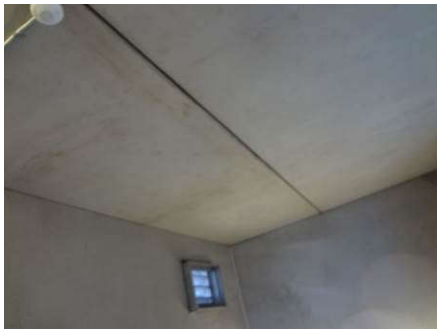


Photo No. 34

Photo No. 35

Photo No. 36

it beneficial to recommend that a corrosion inhibitor be applied to the precast concrete surfaces throughout the garage, re-coating the surfaces that currently have a membrane installed; reinforced fabric can be installed within the base coat of the membrane to provide additional durability to span the tee joints.

DESMAN recommends that all existing cove joint sealant be removed and new non-sag polyurethane cove joint sealant be installed at all vertical and horizontal interfaces throughout the garage, properly detailed to provide a sloped surface. At this time, **DESMAN** recommends that any conduit be re-routed to avoid penetrating the sealant material, and any drain piping re-routed to avoid depositing water directly onto the joint. **DESMAN** did observe miscellaneous locations that lacked a cove joint, typically related to the stair towers; although the stair interiors are not constantly exposed to exterior conditions, opened doors can provide a means for water to enter the stair tower, and when the stair floors are mopped and washed, the lack of cove joints can allow water to fall through.

DESMAN noted that the roof systems above the stair/elevator towers appear aged. Although the roof slabs, consisting of a concrete slab, appear to be dry, **DESMAN** observed various indications of moisture throughout the stair interiors, such as minor moisture stains. Considering the apparent age of the

roof systems, **DESMAN** recommends that the three roof systems be programmed for replacement; at a minimum, **DESMAN** recommends that all flashing and drainage components be reviewed and replaced as required.

Plumbing Repairs and Improvements:

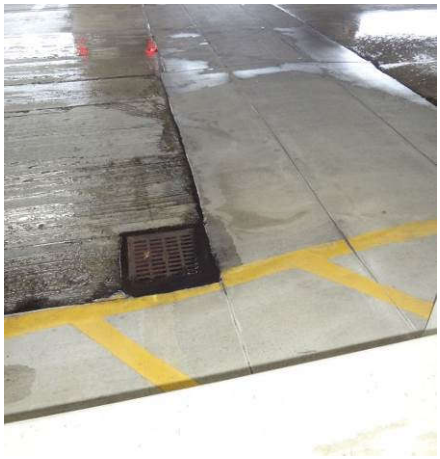


Photo No. 37

- Existing floor drainage continues to appear to perform satisfactorily with only minor pipe leakage identified. Minor areas of standing water, however, can be addressed with supplemental floor drains piped to the existing storm drainage system. Any drainage system within a parking facility should be flushed and tested annually to prevent debris collection and checked for system leaks.

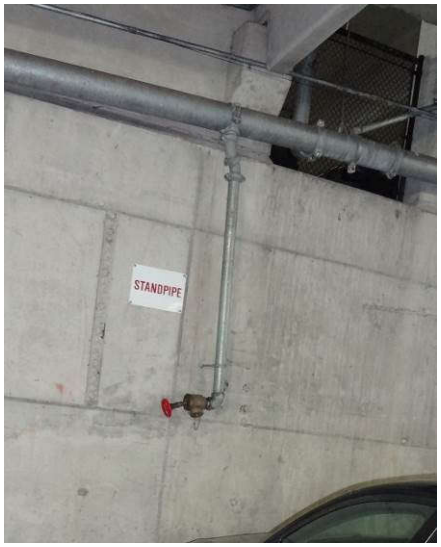


Photo No. 38

- In conjunction with the installation of supplemental drains, miscellaneous tee edges have become misaligned and resulted in a slight vertical offset. Not only does this offset provide a potential trip-and-fall hazard, but the offset also creates a dam for ponding and impedes water from reaching the intended drain. These tee edges should be ground down to allow the ponding to properly drain.

- Miscellaneous damaged drains and piping were observed throughout the garage, requiring repair and/or replacement. **DESMAN** recommends that all corroded grating and other components be replaced.

Photo No. 39

Photo No. 40

Photo No. 41

- **DESMAN** recommends that the fire protection system monitored, tested, and repaired as required, all in accordance with the appropriate operation and maintenance manuals and NFPA guideline

Miscellaneous Repairs and Improvements:

- Oil and debris, as well as bird guano, have collected throughout the garage in isolated areas. Although the garage generally appears to be in a clean condition, grease and oil drippings from vehicles are inevitable and birds will seek any nesting opportunity.

- The Maritime Garage possesses the benefit of having a washdown system installed, with risers accessing the roof level. With typical degreasers employed on a semi-annual basis, **DESMAN** recommends that a washing of the deck be performed to eliminate dirt and debris that hold moisture and chlorides which can be damaging to the concrete deck. Although limited netting has been installed in the past to minimize nesting, providing a comprehensive bird control system can be challenging and expensive. At the time of the garage cleaning, **DESMAN** also recommends that all ledges and other nesting locations be cleaned, removing any bird guano that may provide a health hazard.

DESMAN also recommends that regularly scheduled testing and inspection be performed on the washdown system, as well as cleaning and maintenance of the system components in accordance with O&M recommendations, to confirm proper operational capacity of the system; all insulation and heat trace should be repaired and/or replaced as required.

Photo No. 42

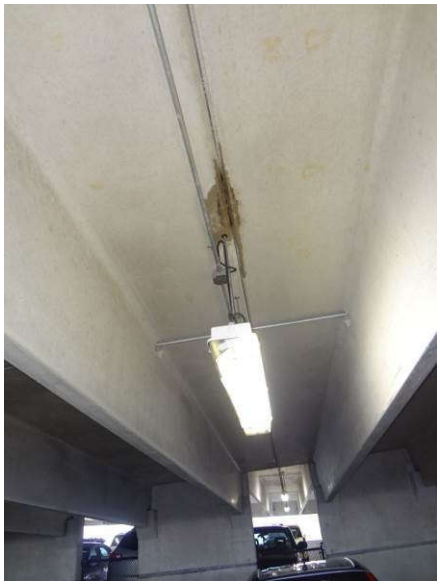


Photo No. 43

- Generally speaking, the electrical system is in good condition; miscellaneous repair is required to replace corroded boxes and segments of steel conduit. **DESMAN** recommends that funds be programmed for miscellaneous electrical repairs (i.e. deteriorated conduit, damaged fixtures, etc.) that may be necessary over time.

- **DESMAN** typically recommends that mounting various structures (light fixtures) below the tee joints or conduit through joints be avoided since should the joint sealant fail adjacent to or above, moisture will penetrate the joint, exposing the conduit or fixture, corroding the conduit or fixture**.** Since this parking garage consists of a double-tee configuration, there is the opportunity to relocate the applicable conduit and fixtures to between the tee stems to avoid the tee joint and/or adjust the conduit so as to avoid penetration of the joint sealant.

Photo No. 44

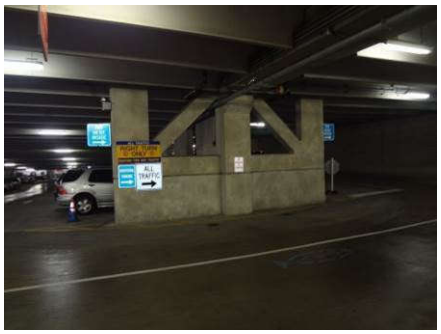


Photo No. 45

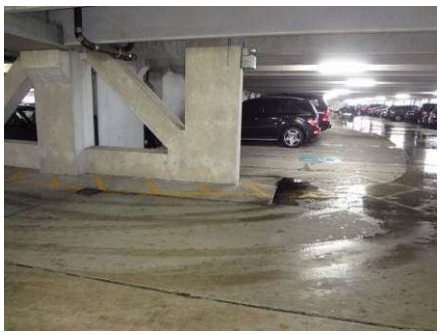


Photo No. 46

- Wayfinding signage throughout the garage appears to be in good condition, although a few isolated signs appeared to be damaged or are missing, and thus should be repaired and/or replaced as may be required.

- **DESMAN** does recommend that certain areas be reviewed for possible improvements, such as relocation of signs or lessening the amount of signage. In certain miscellaneous locations, parked vehicles can make visibility of the signs difficult, and in other locations, excessive signage can delay a patron due to additional time needed to read all the signs.
- Miscellaneous metal surfaces, throughout the garage, exhibit various stages of corrosion. **DESMAN** recommends that all miscellaneous metal surfaces be cleaned, primed, and re-painted (i.e. doors and frames, stair handrails/guardrails, fire standpipe, etc.), to both protect and enhance their appearance.

- Following completion of repairs, **DESMAN** recommends that all traffic markings (i.e. parking stalls, directional arrows, etc.) be re-painted. **DESMAN** recommends that all conflicting markings, if any, first be removed prior to re-painting, and all ADA requirements be updated as may be required.

Photo No. 47

Photo No. 48

- The various architectural treatments, throughout the garage, are in good condition and continue to perform well. Minor repairs, though, are recommended to maintain the building envelop. Damaged door frames should be repaired and/or replaced (to prevent water from entering the stairs), and all exterior vertical sealant should be replaced as well. Miscellaneous masonry repairs and re-pointing, throughout the façade, are also recommended to prevent moisture penetration and subsequent deterioration. At this time, **DESMAN** recommends that the roof level cornice be monitored as well; although the permieter appears to be in good condition, **DESMAN** did observe shallow cracking through, and thus **DESMAN** notes that a waterpoofing coating, of some form, may be appropriate in the near future.

- At the time of re-painting, **DESMAN** recommends that **PN** consider eliminating certain end-of-bay stalls, adjacent to the shear walls and hatch the areas for "no parking". When a vehicle is traveling up or down the garage, the vehicle is tempted to turn wide in order to avoid the shear wall, thus having to take care when turning into the bay in order to avoid another vehicle traveling up or down the same bay; at the same time, a vehicle parked in the end stall has to take caution when backing out and into the traffic with limited sight distance. Eliminating the end stalls would provide a greater sight distance for

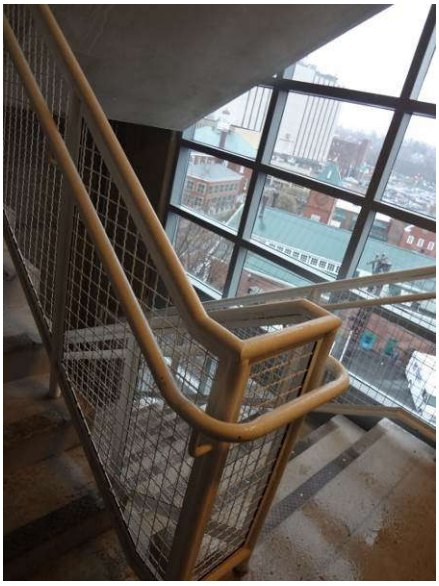


Photo No. 49

Photo No. 50

Photo No. 51

the vehicles making the turns and for the patrons parked in the end stalls.

- The various architectural treatments, throughout the garage, are in good condition and continue to perform well. Minor repairs, though, are recommended to maintain the building envelop. Damaged door frames should be repaired and/or replaced, and all exterior vertical sealant should be programmed for replacement as may be required, as well. Miscellaneous masonry repairs and re-pointing, throughout the façade, are also recommended to prevent moisture penetration and subsequent deterioration.

- The handrail/guardrail systems in the stairs appear to be performing well. **DESMAN** recommends that the systems be re-painted regularly to both protect and enhance their appearance.

- **DESMAN** observed however that the guardrail system does not extend to the lowest level's wall. The configuration of the guardrail results in a space below the last flight of steps, which, due to the lack of visibility may be difficult to maintain. **DESMAN** recommends that the guardrail be extended to prevent unauthorized access to this area, and that a locked gate be installed within the guardrail to allow access to the space as required.

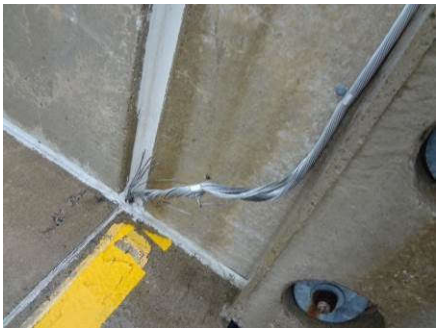


Photo No. 52

Photo No. 53

Photo No. 54

- **DESMAN** also observed that the railing on the ground level does not appear to be in compliance with current Code; as **DESMAN** understands, the applicable Code specifies that handrails are to be provided at 2'-10" from the surface of the floor with guardrails at 3'-6", as well as no openings be greater than that which would allow a 4" diameter sphere to pass through over a vertical drop greater than 12 inches. Although **DESMAN** assumes that the railing system was installed in compliance with the applicable Code at time of construction (and thus may be exempt from current requirements), **DESMAN** recommends that the railing systems be modified/replaced to comply with current Code requirements.

- The roof level is provided with a lightning protection system; miscellaneous components of this system are damaged and showing wear and tear. **DESMAN** recommends that the system be reviewed periodically to confirm that all air terminals and other components are secure, repairing/replacing the damaged components as may be required. At the time of repair/replacement, **DESMAN** recommends that various components should be relocated so as not to compromise the waterproofing integrity of certain cove joints or flashing.

- **DESMAN** observed stockpiles of ice-melt material; **DESMAN** notes that chloride-based ice-melt products can be detrimental to the long-term durability of the concrete matrix, and **DESMAN** therefore recommends that an alternative product be used. While **DESMAN** does not specifically endorse a specific product or manufacturer, **DESMAN** does suggest that in lieu of a calcium chloride product, an alternative product such as Cryotech NAAC®, as manufactured by Cryotech Deicing Technology, of Fort Madison, IA (tel: 800-346-7237, www.cryotech.com) be used. Products containing sodium fornate or urea will still induce corrosion in reinforced concrete decks, though at a lesser rate than generic road salt.

5. PROJECTED COST OF RECOMMENDED CAPITAL REPAIRS & IMPROVEMENTS

The phased repair and improvement program as developed by **DESMAN** addresses long-term durability issues at the **Maritime Parking Garage**, and is intended to maintain the garage at an acceptable level of service condition while extending the useful service life of the facility.

The repair program has been formatted into specific repair items showing projected costs of implementation. Although **DESMAN** has arranged the scope of proposed restoration work for specific reasons, such as structural priorities and patron comfort, certain additional adjustments could be made should there be limits to the amount of funding that is available for any given year.

In addition to the recommended repairs and improvements noted in Section 4, **DESMAN** also has provided projected costs for the following additional related work:

- Mobilization/Demobilization: This work is associated with, but not limited to, the cost of a contractor mobilizing men, equipment, and materials onto the site prior to beginning work and off the site when the work is completed, as well as the costs for the provision of any and all permits, labor, material and performance bonds and insurance necessary for the implementation of the work. It is worth noting that extending recommended repairs over a period of time in lieu of all of the work being performed at once will result in an increased number of contractor mobilizations,

- Miscellaneous Coordination Work (Traffic Control, Temporary Construction Signage, etc.: This work is associated with, but not limited to, the costs for the provision of any and all traffic control devises and signage necessary to direct vehicular traffic around repair areas, and to provide protective/dust proof partitions around work areas.

DESMAN notes that certain costs in the projections presented may require adjustment if any re-prioritization of work is made. These costs would include mobilization/demobilization as well as those costs associated with miscellaneous coordination work. Impact to costs associated with an economy of scale may also need to be reconsidered.

The construction costs shown are based upon current prices in the New England area for labor, equipment and materials. The projected construction costs also include a 10% contingency factor to account for unforeseen conditions and uncertainties in the restoration market at the time of bidding. Should **PN** wish to budget for design and construction management fees, **DESMAN** recommends that **PN** assume an additional 12% to 15% of total construction cost be considered as a reasonable estimate for the provision of these services.

Design fees would vary depending on the magnitude and complexity of the repairs to be undertaken, and the suggested percentages for engineering services are meant only as a budgeting tool, not as a proposed engineering fee for **DESMAN** to actually perform the work. **DESMAN** will gladly provide an engineering fee proposal, along with a detailed scope of services, should **PN** wish to proceed with all or any portion of the repairs suggested.

Recommended repairs and improvements are subdivided in three phases of action as follows, and are further developed and explained in the following table:

- Prioritized Repairs
- Programmed Repairs
- Long-Term Repairs

OPINION OF PROBABLE CONSTRUCTION COSTS:

	Work Description	Prioritized Repairs (Phase 1)	Programmed Repairs (Phase 2)	Long-Term Repairs (Phases 3 - 5)
A. Concrete Repair:				
1	"Spot" Repair of CIP Concrete Aprons & Washes	45,000.00	$ -	$ -
2	Shear Connector Repair	25,000.00	$ -	$ 12,500.00
3	Installation of Supplemental Connections	12,500.00	$ -	$ 12,500.00
4	Miscellaneous Concrete Curb Repair	1,750.00	$ -	$ 1,750.00
5	Miscellaneous Vertical & Overhead Concrete Repair	6,500.00	$ -	$ 6,500.00
6	Healer/Sealer/Installation of Epoxy Overlay (Roof Level)	315,000.00	$ -	$ -
7	Miscellaneous Healer/Sealer/Installation of Epoxy Overlay (Intermediate Levels)	-	$ 210,000.00	$ -
8	Epoxy Injection	-	$ 7,500.00	$ -
9	Miscellaneous SOG Repair	-	$ -	$ 7,500.00
10	Miscellaneous CMU Repair	-	$ -	$ 5,000.00
11	Miscellaneous Stair Repair	-	$ -	$ 15,000.00
B. Waterproofing:				
1	Miscellaneous Crack Repair	-	$ 17,500.00	$ -
2	Tee Joint Replacement (incl. grinding of tee edges)	-	$ 140,000.00	$ -
3	Cove Joint Installation, including Stair Towers	59,500.00	$ -	$ -
4	Application of Corrosion Inhibitor	-	$ 264,750.00	$ -
5	Recoat Traffic Bearing Membrane (Level 2)	-	$ -	$ 21,000.00
6	Replacement of Expansion Joints/Installation of Vertical Glands	-	$ -	$ 143,750.00
7	Vertical Joint Repair/Installation/Grout Replacement	-	$ -	$ 75,000.00
8	Coating of Spandrels (sealing of pockets, cracking, divets, etc.); Roof Level and Miscellaneous Locations	-	$ -	$ 150,000.00
C. Plumbing, Mechanical & Electrical Repairs and Improvements:				
1	Drain Pipe Flushing and Cleaning ***(before & after deck repairs)***	-	$ -	$ 10,000.00
2	Supplemental Drain installation/Replacement of Floor Drains	-	$ -	$ 112,500.00
3	Supplemental Drain Pipe Installation	-	$ -	$ 37,500.00
4	Miscellaneous Drainage System Repairs	-	$ -	$ 15,000.00
5	Miscellaneous Electrical Repairs	-	$ -	$ 25,000.00
6	LED Light Fixture Installation	-	$ -	$ 80,000.00
7	Lightening Protection Repairs	-	$ -	$ 20,000.00
D. Architectural Repairs and Enhancements:				
1	Painting of Metal Surfaces (i.e. railings, doors, standpipe)	-	$ -	$ 60,000.00
2	Door and Hardware Repair	-	$ -	$ 35,000.00
3	Re-Painting of Traffic Markings	10,000.00	$ 10,000.00	$ 10,000.00
4	Railing Improvements/Enhancements	-	$ -	$ 25,000.00
5	Miscellaneous Signage Repairs/Improvements (allowance)	-	$ -	$ 10,000.00
6	Roofing Repairs/Replacement	-	$ -	$ 60,000.00
7	Cleaning and Degreasing	-	$ -	$ 50,000.00
8	Fencing Repair, replacement of hardware	-	$ -	$ 5,000.00
E. Façade Repairs and Exterior Enhancements:				
	Precast Joint Installation	-	-	$ 37,500.00
F. Miscellaneous Coordination Work:				
		$23,800.00	$32,500.00	$ 52,200.00
G. Mobilization/Demobilization				
		$23,800.00	$32,500.00	$ 52,200.00
	Sub-TOTAL:	**$522,850.00**	**$714,750.00**	**$1,147,400.00**
	Construction Contingencies @ +/-10%:	$52,300.00	$71,500.00	$114,700.00
	Total Phased Construction Costs with Contingencies:	**$575,150.00**	**$786,250.00**	**$1,262,100.00**
	TOTAL Construction Cost with Contingencies:			**$2,623,500.00**

6. Deterioration Mechanisms

Reinforced concrete deterioration is typically caused by one or more factors of deterioration mechanisms including corrosion of reinforcement, water penetration, freeze-thaw cycling, volume change, or chemical attack. Any one or combination of these deterioration mechanisms can adversely affect the behavior/performance of a reinforced concrete structure. These adverse impacts include corrosion-induced distress, loss of reinforcing cross section, scaling, leaking, cracking, and delamination of concrete. The following is a brief discussion of each of the mechanisms noted above, and their effect on reinforced concrete structures.

Water Penetration:

The primary cause of the majority of reinforced concrete deterioration within parking structures is directly related to the penetration of water into the concrete. Reinforcing corrosion, concrete scaling, water leakage, leaching, and concrete delamination are all caused at least partially by water penetration.

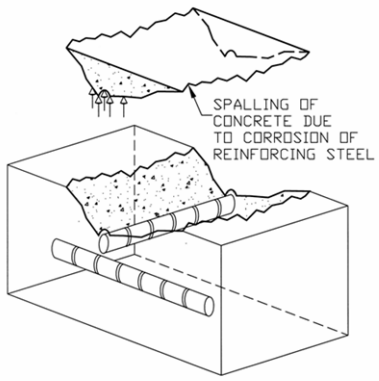


Fig. A

Concrete is a porous material, susceptible to water penetration which can result in increased potential for deterioration. Corrosion of reinforcing steel is an electrochemical process accelerated by the presence of water acting as an electrolyte. In addition, water penetrating into concrete ***(Reference Fig. A)*** can carry water-soluble chlorides (de-icing salts) to the reinforcing. The combination of chlorides and water further accelerates this corrosion process.

Scaling is also directly related to water penetration into concrete. Scaling is a surface deterioration resulting from pressures by freeze-thaw cycling of saturated concrete. These pressures within the pore structure cause progressive failure of the cement/sand paste. This progressive failure begins with degradation of the exposed surface, advances to the exposure of coarse aggregate, and in severe cases, causes paste failure surrounding the coarse aggregate, destroying the paste/aggregate bond.

Water penetration through a concrete section, cracked or not, can cause leaching of minerals from within the concrete matrix. Leaking of the parking deck exposes embedded reinforcing steel and underlying structural members to water and chloride ions (road salt) resulting in structural deterioration and potentially a loss of load carrying capacity of these building elements. Leaching is the result of frequent water penetration carrying water-soluble products from within the concrete to the surface below. Leached materials that tend to collect on overhead concrete surfaces are unsightly and potentially damaging to patron's vehicles using the parking facility.

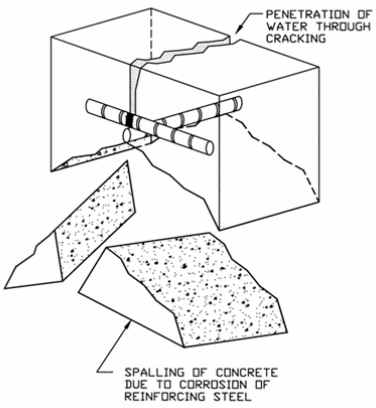


Fig. B

Water penetration can also cause delamination of concrete along subsurface fractures through pressures generated during freeze-thaw cycling.

CORROSION OF REINFORCEMENT:

Corrosion of reinforcing steel or other embedded ferrous items such as electrical conduit is a second major factor contributing to deterioration of reinforced concrete ***(Reference Fig B)***.

The corrosion process is an electrochemical process, which produces iron oxide (rust) and other by-products. These by-products occupy a minimum of 250% of the volume of the parent metal. This increase in volume produces tensile stresses within the surrounding concrete.

Because concrete has poor tensile strength properties, cracking occurs within the concrete matrix allowing additional moisture and chlorides to reach the reinforcing causing acceleration of the corrosion process. The deterioration caused by this corrosion includes the reduction of cross sectional area of the reinforcing, and the delamination of concrete surrounding the reinforcement.

FREEZE-THAW DAMAGE:

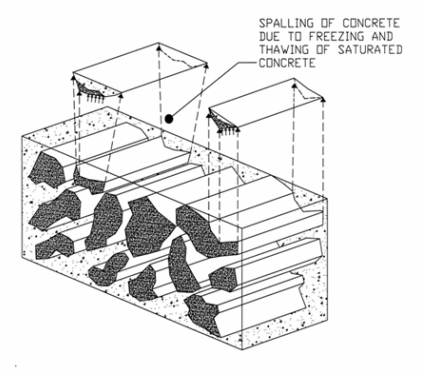


Fig. C

Concrete deterioration caused by freeze-thaw cycles is a third major deterioration mechanism. The mechanism occurs within saturated concrete subjected to freezing and thawing due to the pressures generated within the pores of the concrete paste resulting from the volume changes of water during the freeze/thawing process. These pressures are even greater in the presence of de-icing chemicals/chlorides as these chemicals reduce the freezing point and indirectly increase the pore pressures.

As previously mentioned, these pressures can cause progressive failure of the cement paste and result in scaling of the concrete, and delamination of concrete along subsurface fracture planes ***(Reference Fig. C)***.

VOLUME CHANGES:

Volume changes are a fourth major contributing factor of deterioration of reinforced concrete structures. These volume changes occur in both plastic and cured concrete. These volume changes can cause various types of cracking within the concrete member.

These cracks allow access for water and contaminants to the concrete and reinforcing, resulting accelerated deterioration to occur. The cracking most often associated with plastic concrete is shrinkage cracking produced by the reduction in volume of the concrete during curing. Improper detailing, proportioning, placement, or curing of the concrete can affect the extent of this cracking, but the primary cause is the volume change that occurs during curing.

Volume changes due to thermal movement, shrinkage, creep, and loading can also contribute to the deterioration of reinforced concrete. These volume changes will produce stress in restrained members, often resulting in cracking of the member ***(Reference Fig. D)***. These cracks also provide access to water and other deterioration mechanisms to attack the member.

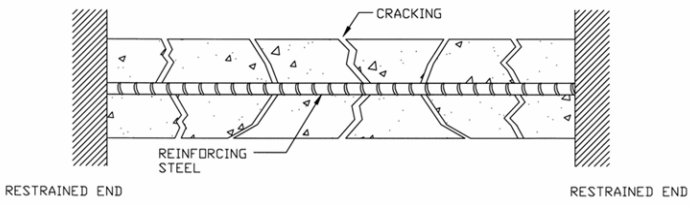


Fig. D

CHEMICAL ATTACK:

Chemical attack is a fifth major deterioration mechanism affecting the performance of reinforced concrete. The effect of de-icing chemical/chlorides upon reinforcing steel and scaling is one example of chemically influenced deterioration. Severe exposure to other chemicals, notably sulfates and acids, can also cause deterioration of cement paste, cement paste/aggregate bond, and reinforcing steel. Chemical properties occurring within certain types of aggregates can also cause an adverse reaction with the cement paste. The resulting volume changes can cause cracking of the concrete.