CAPITOL LAKE DAM CONDITION ASSESSMENT AND LIFE EXPECTANCY

Prepared for:

General Administration
STATE OF WASHINGTON

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Executive Summary

The Olympia Fifth Avenue Dam contains an 82 foot wide rectangular spillway that allows passage of water underneath the Fifth Avenue Bridge. Concrete abutments, wing walls, and pier walls support the dam in the area of the spillway, which accommodates a fishway channel and two flood control discharge channels, both operated by radial arm steel gates. Supporting a road deck above, the spillway is topped by a control house that holds the dam's machinery and controls.

The Fifth Avenue Dam was constructed between 1949 and 1951 to create the reservoir that is called Capitol Lake. The structure, also referred to as the Capitol Lake Dam, serves to control the water level in the lake within a narrow range and provides flood control for downtown Olympia and adjacent properties.

The Washington State Department of General Administration has retained Moffatt & Nichol (M&N) to assess the current condition of the dam and to provide a 50-year plan to maintain the structure in a fully serviceable condition. As part of the assessment, the structure was inspected in May and June, 2007. The inspection methodology consisted of field inspection, concrete core extraction (material sampling), laboratory testing and analysis followed by engineering evaluation. Fourteen concrete core samples were extracted from the dam's wing walls and pier walls for laboratory testing including Chloride Ion Sampling, Petrographic Analysis, and Transport Properties Testing. The assessment also incorporates an evaluation of the tide gate machinery and controls completed by Lund Engineering, Inc.

The inspection revealed minor to moderate cracking and spalling in the concrete wing walls and pier walls, with localized areas of advanced spalling and exposed steel near the bottom slab. The spillway components are sound, but the bottom slab exhibits moderate deterioration and localized areas of advanced spalling. The concrete deck soffits exhibit minor cracking, but no overstressing was observed. The underside of the pedestrian walkway exhibits minor and infrequent section loss on the steel I-beams, with no significant damage on the timber components. The concrete conduit bridge running parallel to the roadway is sagging approximately two inches.

M&N divers noted section loss of the steel faces of the radial gates, although the damage is not severe. The seals around the gates exhibit leaks on all sides. Based on the overall inspection findings, the majority of the dam is in fair condition or better. Individual components are assigned the following ratings:

Concrete Abutment/Wing Walls	FAIR
Submerged Concrete Pier Walls	FAIR
Spillway Components	
Ogee Crests	GOOD
Concrete Bottom Slab	FAIR
Riprap and Rock Armoring	GOOD
Concrete Girders	SATISFACTORY
Concrete Deck Soffits	SATISFACTORY
Radial Gates	
Steel Gate Surfaces	SATISFACTORY
Seals	POOR
Underside of Timber Walkway	
Timber	SATISFACTORY
Steel I-beams	SATISFACTORY

The Tide Gates Machinery and Controls Assessment identified a noisy bearing on the East Gate, but indicated an absence of significant deterioration of the machinery and control system equipment. While the machinery is in good condition for its age, it will most likely need replacement within the next 50 years.

The Chloride Ion Sampling tests indicate that the majority of the dam's concrete had chloride concentrations of less than 0.400% during the time of extraction. The testing revealed chloride ion concentrations in excess of 0.400% in only two of the ten cores: one from the westernmost wing wall and the other from the interior pier wall enclosing the fishway channel. Petrographic analysis of two cores revealed fracturing of the concrete caused by exterior forces and not from changes within the concrete itself, with no corrosion of the steel bars. Transport Properties Testing consisted of two core samples and revealed absorption percentages of 3.1% and 3.9%, porosity values of 7.6% and 9.9%, and Ionic Diffusion Coefficients of 1.1×10^{-11} m^2/s and 0.6×10^{-11} m^2/s.

The appearance of a structure does not always indicate the true condition of its concrete; therefore laboratory testing was used to identify deficiencies within the dam's concrete matrix that could act as failure mechanisms by chemically deteriorating the concrete. Common mechanisms for chemical concrete deterioration include corrosion caused by chloride intrusion, alkali-silica reaction (ASR), sulfate attack, and delayed ettringite formation (DEF).

All concrete properties obtained from the transport properties testing correspond to a good quality concrete. Overall, the laboratory results did not suggest the presence of ASR, sulfate attack, or DEF. However, chloride concentration was found to be above the acceptable threshold 0.400% in two of the cores. When a chloride percent of 0.400% or greater is measured at the level of the reinforcement in a concrete sample, it is reasonable to assume that corrosion of the inner reinforcing steel has been initiated.

Aside from chloride intrusion, laboratory testing did not indicate the structure has undergone significant chemical deterioration of the concrete matrix. We do not anticipate that the structure will undergo deterioration due to ASR, sulfate attack, or DEF. The structure has not yet undergone these types of deterioration, and given its age, the probability of the dam undergoing these types of deterioration in the next 50 years is low.

The laboratory results suggest that corrosion is the most probable mechanism that could compromise the serviceability of the Capitol Lake Dam. However, the Capitol Lake Dam should maintain its existing functionality over the next 50 years if an appropriate and aggressive program of inspection and repair is followed and natural disasters or other major events, such as earthquakes, do not occur.

In addition to addressing chloride intrusion, the inspection, repair and maintenance plan should include an initial set of concrete repairs, including epoxy-injecting cracks and patching spalls. Regular inspection frequencies must also be maintained. *Routine Inspections* are recommended to be carried out annually. *Special Inspections* are recommended to be carried out every 5 years. *Post-Event Inspections* should be conducted as necessary following significant, potentially damage-causing events. Routine inspections of the tide gates machinery and controls should also be carried out. Each type of inspection (except those applicable to the tide gates machinery and controls) is fully defined in the *ASCE Underwater Investigations Standard Practice Manual, 2001 Edition.*

We further recommend that if the decision is made to maintain the dam and Capitol Lake, or if a decision of whether to maintain or remove the dam is not imminent by the end of the year 2010, a detailed and aggressive inspection, repair and maintenance plan should be developed and implemented. Because the rate of deterioration of the dam structure is likely to accelerate rapidly, the inspection and repair plan should be developed and its implementation started within the 2009-2011 biennium. A complete service life modeling analysis would be a valuable part of this future repair planning. This analysis would identify appropriate anti-corrosion measures (likely to be a combination of corrosion inhibitors and passive cathodic protection), and would give the costs and likely performance associated with each alternative.

Based on our experience with concrete structures, the cost of implementing appropriate chloride-inhibiting measures and of concrete repair will be minimal in comparison to costs associated with dredging at Capitol Lake. Consequently, the costs associated with structure maintenance do not form a critical input to the decision as to the future of the dam and Capitol Lake.

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1. Introduction

1.1 Background and Location

Moffatt & Nichol (M&N) was retained by the Washington State Department of General Administration to assess the condition of the Olympia Fifth Avenue Dam and its life expectancy. The dam is located at the mouth of the Budd Inlet at the Deschutes Basin in Olympia, WA, as shown in Figure 1.

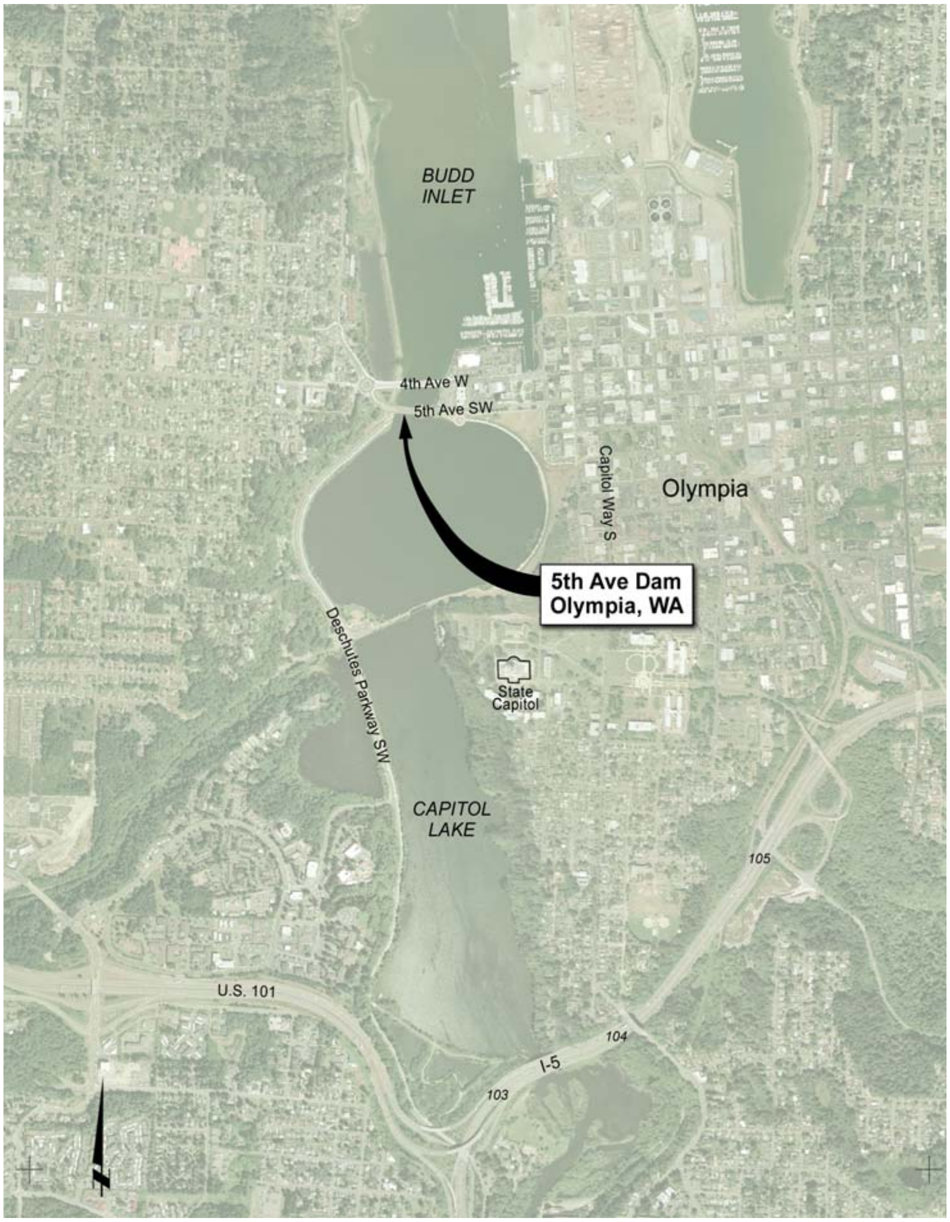

Figure 1. Capitol Lake Dam Vicinity Map

The Fifth Avenue Dam was constructed between 1949 and 1951 to create the reservoir that is called Capitol Lake. The dam serves to control the water level in the lake within a narrow range and provides flood control for downtown Olympia and adjacent properties. As part of the decision-making process for the Capitol Lake Adaptive Management Plan – specifically, the decision as to whether the dam should be maintained or removed – the Washington State Department of General Administration is considering the longevity of the dam, and the costs associated with maintaining the structure over the next 50 years.

1.2 Description of the Structure

The Fifth Avenue Dam contains an 82 foot wide rectangular spillway, with the base of the dam averaging 200 feet wide. Concrete abutments, wing walls, and pier walls support the dam in the area of the spillway, which accommodates a fishway channel and two flood control discharge channels, both operated by radial arm gates. The downstream channel bottom is defined by a concrete spillway divided at the south end by a pier wall. Refer to Figure 2 for schematics of the dam.

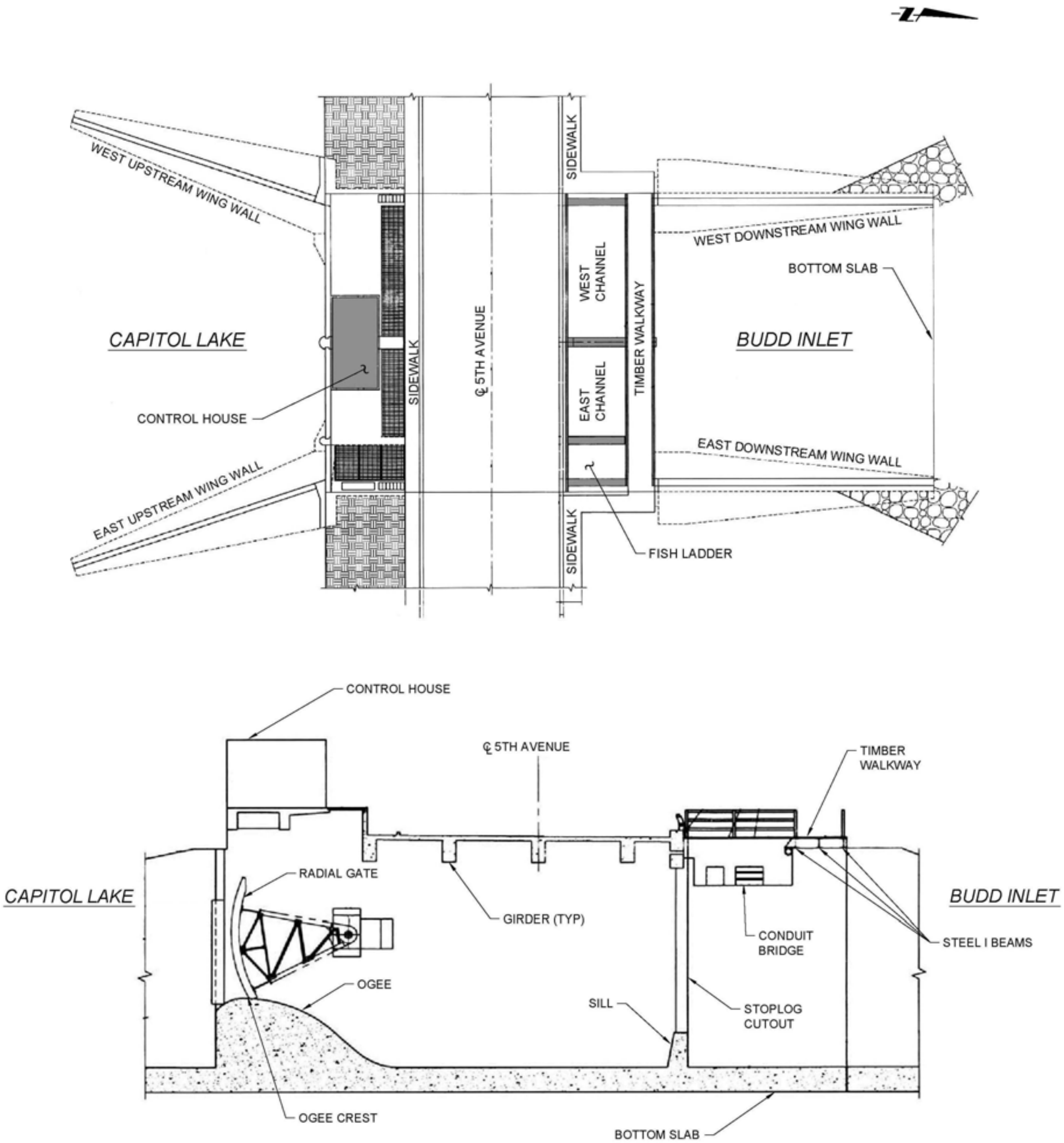

Figure 2. Capitol Lake Dam Plan & West Section

There is an ogee located just downstream of each gate, consisting of a crest that serves as a bearing pad for the lower radial gate seals. Looking downstream (North) from the gate, the ogees slope down gradually for approximately 20 feet, at which point the bottom slab becomes level for approximately 50 feet until reaching a sill, or wall that is approximately 6 feet high and 3 feet wide. Stoplog cutouts exist along the sides of the sill, which serves as a bearing surface for any future stoplogs that could alter the weir-effect of the sill.

Rock armoring lines the channel bottom of the Capitol Lake side of the dam, with rocks up to more than 5 feet wide. On the Budd Inlet side of the dam, rock armoring surrounds the bottom slab and wing walls.

The spillway supports a road deck above and is topped by a control house that holds electric motors, reduction gears, and controls necessary for gate operations. Each gate mechanism is operated by a large gearbox driven by an electric motor. Each gearbox drives cable drums that raise and lower the respective gate. An independent hydraulic backup system is incorporated for the west gate.

1.3 Objectives

This document takes into account the findings from the onsite inspection performed by Moffatt & Nichol to give an assessment of the current condition of the dam and its likelihood of continued, successful operation over the next 50 years. The dam must be fully operational in order to maintain adequate flood protection. A structural condition evaluation is a necessary part of the overall feasibility of the structure's continued operation.

The structure was inspected by Moffatt & Nichol in May and June, 2007, in accordance with the *ASCE Underwater Investigations Standard Practice Manual, 2001 Edition*. The inspection was recorded such that it fulfills the requirements of the National Bridge Inspection Standards (NBIS) of the Federal Highway Administration (FHWA), and the Washington State Bridge Inspection Manual (WSBIM) of the Washington State Department of Transportation (WSDOT). The corresponding WSDOT Underwater Inspection Form is attached as Appendix A. The WSDOT Form provides detailed explanations to the findings summarized in Section 3.

The dam's tide gates machinery and controls were also inspected. The inspection was conducted by Lund Engineering, Inc. and took place in mid-year, 2007. The *Capitol Lake Tide Gates Machinery and Controls Assessment Document* is attached as Appendix D.

The scope of work for this task includes the following:

1. Identify the extent of existing deterioration through a detailed inspection of all accessible components.
2. Assess the extent of chloride ion contamination in the key concrete elements of the dam facility in order to understand the future corrosion potential.
3. Determine the potential for chemical deterioration of the concrete matrix such as alkali-silica reaction (ASR), sulfate attack, or delayed ettringite formation (DEF).
4. Determine the condition of the concrete wing walls above and below water.
5. Identify repairs needed and suggest methods of repair to prolong the life of the dam.
6. Make recommendations pertaining to inspection frequencies and studies that may be necessary for continued, successful operation of the dam.

2. Inspection Methodology

2.1 Overview

Accessible parts of the following components were examined:

- Concrete Abutments/Wing Walls
- Submerged Concrete Pier Walls
- Spillway Components
- Radial Gates
- Riprap and Rock Armoring
- Concrete Girders
- Concrete Deck Soffits
- Underside of Timber Walkway

The inspection methodology consisted of field inspection, material sampling, laboratory testing and analysis followed by engineering evaluation. A general description of each type of observation/testing procedure follows.

2.2 Visual/Tactile Inspections

A visual/tactile inspection was performed on all reasonably accessible components of the dam, including both underwater and topside structural elements. Above-water inspection was conducted from shore where feasible, as well as from a boat operated by Pacific Geomatic Services (PGS).

2.3 Underwater Inspections

Underwater investigation of the structure was conducted using a three-member dive team. The dive team accessed the site from a boat, operated by PGS. Prior to the inspection, the Dive Supervisor accompanied maintenance staff for lockout/tag out of all switches and controls that could initiate full or partial operation of the radial arm gates.

Divers were unable to access areas in close proximity to the radial arm gates, particularly on the Capitol Lake (upstream) side of the dam due to suction pressure occurring at leaks in the seals. Other areas not accessible by divers include all fish ladder compartments except the three northernmost compartments. After inspecting the concrete components, divers swam the inlets on each side of the dam to detect scour damage or inconsistencies in the rock channel lining.

2.4 Coring

Fourteen concrete core samples were extracted from the dam's wing walls and pier walls. The core drilling machine was used from a boat to extract the samples (see Figure 3).

Figure 3. Over-Water Core Drilling

As seen from the Core Plan in Figure 4, twelve 2-inch (diameter) cores and two 4-inch cores were extracted from the structure. While drilling the cores, a vacuum was used to collect any falling debris and cementitious liquids. The voids left from the core extractions were filled with a non-shrink, two-part epoxy mortar.

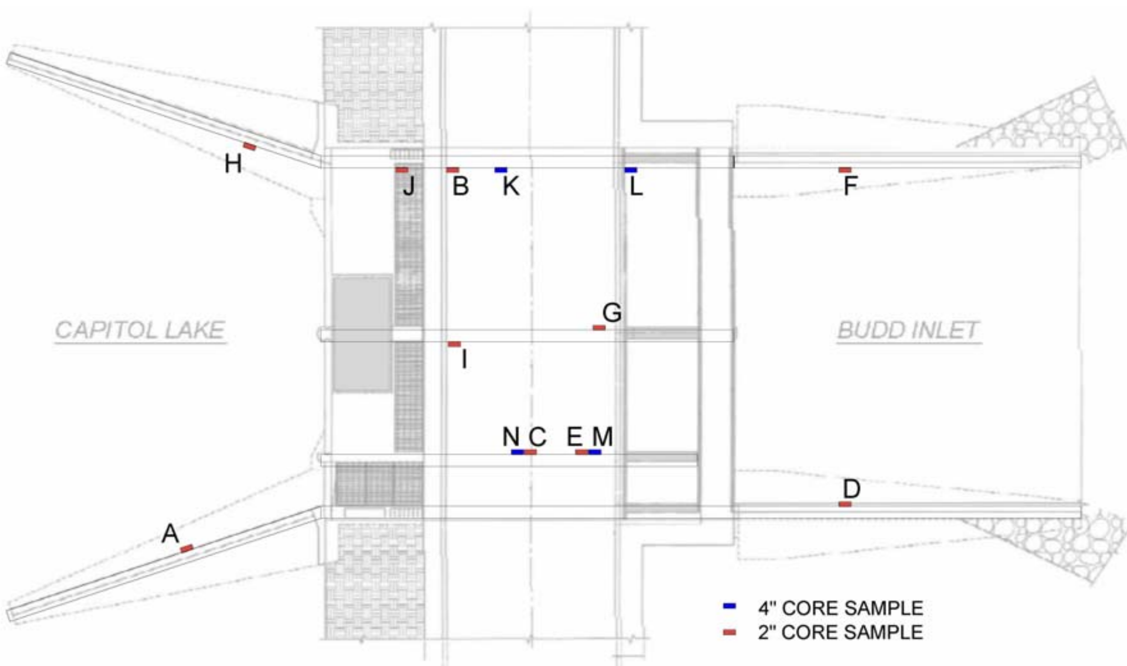

Figure 4. Core Plan

2.5 Laboratory Testing and Analysis

Laboratory testing was performed by Materials Service Life, LLC (MSL) and by Krazan & Associates. Twelve of the 14 cores were retained by Krazan & Associates for Chloride Ion Sampling and Petrographic Analysis. The two remaining cores were sent to MSL for Transport Properties Testing. Table 1 indicates which laboratory testing procedure was performed on each core, with cores A-N corresponding to those shown in Figure 4.

Table 1. Laboratory Testing Plan

CORE LABEL	TESTING PROCEDURE
A	Chloride Ion Sampling
B	Chloride Ion Sampling
C	Chloride Ion Sampling
D	Chloride Ion Sampling
E	Chloride Ion Sampling
F	Chloride Ion Sampling
G	Chloride Ion Sampling
H	Chloride Ion Sampling
I	Chloride Ion Sampling
J	Chloride Ion Sampling
K	Transport Properties
L	Petrographic Analysis
M	Petrographic Analysis
N	Transport Properties

Following are brief explanations for each laboratory testing procedure.

2.5.1 Chloride Ion Sampling

Acid soluble chloride profiles were determined per ASTM C1152 – *Standard Test Method for Acid Soluble Chloride in Mortar and Concrete*. The scope of this test includes procedures for the sampling and analysis of hydraulic-cement mortar or concrete for chloride that is acid soluble under conditions of the test.

2.5.2 Petrographic Analysis

Petrographic analysis was conducted to characterize potassium chloride contamination and determine the potential for chemical deterioration mechanisms. Core samples were analyzed in accordance with ASTM C 856 – *Standard Practice for Petrographic Examination of Hardened Concrete*. The test includes specimen preparation, visual examination, polarizing microscope examination and metallographic microscope examination. This standard is used to evaluate the present condition, to determine the future condition of, and to confirm to specifications of hardened concrete.

2.5.3 Transport Properties Testing

The values obtained from transport properties testing are used as input parameters in STADIUM®-IDC. The STADIUM® model is a helpful tool that can be used to predict the future conditions of concrete materials. The software uses finite-element code to predict the transport of ions in a porous medium and the chemical modifications occurring to the material as a result of these ionic movements. For this assessment, STADIUM®-IDC, a specialized version of the STADIUM® model, was used to analyze the migration test results and evaluate the ionic diffusion coefficients for Cores K and N.

The concrete transport properties testing included the following:

1. Ion migration per a modified version of ASTM C1202 – Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration;
2. Porosity testing per ASTM C642 – Standard Test Method for Density, Absorption, and Voids in Hardened Concrete;
3. Pore solution chemistry evaluation using special test method for pore solution extraction from hardened cementitious materials; and
4. Measurement of the rate of drying using standard test method for "Drying Tests for Concrete".

Standard C 1202 provides a system by which to relate the electrical conductance and resistance of concrete to penetration of chloride ions, and is often used to predict the time until the onset of corrosion in reinforced concrete. Standard C 642 provides a method of determining the density, absorptiveness, porosity, and relationship between mass and volume of hardened concrete.

3. Summary of Observed Conditions

3.1 Visual/Tactile and Underwater Observations

3.1.1 Overview

The observed deficiencies are summarized in Sections 3.1.2 through 3.1.9. Refer to the WSDOT Underwater Inspection Form in Appendix A for detailed descriptions of findings.

The general vicinities of the damage noted in the dam's concrete are displayed in Figures 5 and 6. The two figures are intended to convey a general understanding where the concrete damage is concentrated, and should not be used as repair plans. Figure 5 shows (in plan view) the damage observable below water. Similarly, Figure 6 indicates damage noted above water.

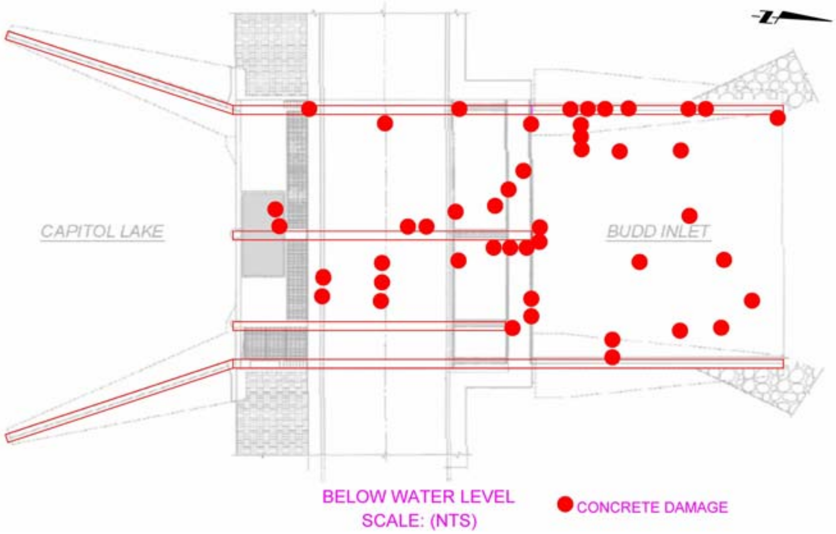

Figure 5. Concrete Damage Concentration Map (Underwater)

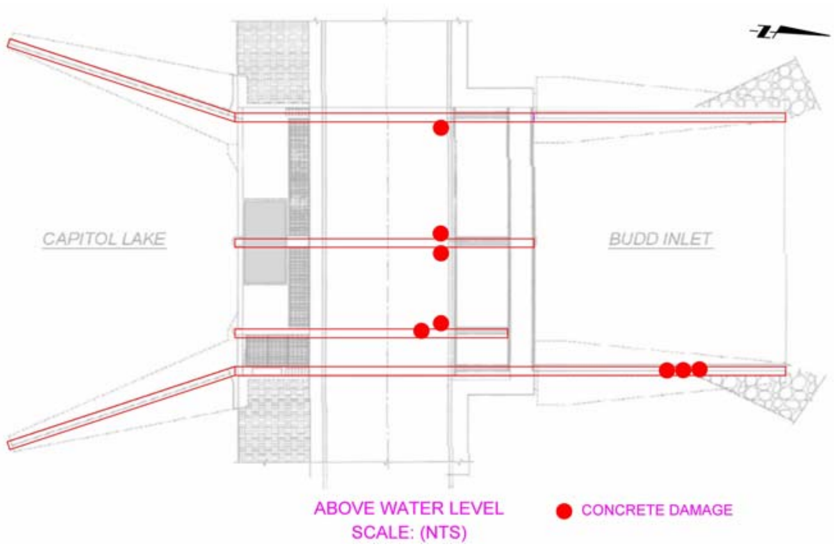

Figure 6. Concrete Damage Concentration Map (Above-Water)

3.1.2 Concrete Abutments/Wing Walls

Efflorescence and minor spalls and cracks were observed in various locations around the wing wall elements. The wing walls also exhibit occasional instances of significant localized delamination, spalling (see Figure 7), and cracking. Dywidag bars that were used during construction to support falsework were observed protruding out from the concrete of the entire inner face of the westerly abutment (see Figure 8). Most of the occurrences exhibit light spalling with what appears to be corrosion spreading to the surrounding concrete.

Figure 7. Spalled Downstream Wing Wall

3.1.3 Submerged Concrete Pier Walls

Similar to the concrete abutment and wing wall elements, minor spalls and delamination, efflorescence, and superficial cracks were observed above the waterline in various locations around the abutments and wing walls. Occasional patches of delamination, spalling, and exposed rebar with signs of corrosion were found below the waterline.

3.1.4 Spillway Components

The ogee crests and sills exhibit no significant damage or defects. The concrete bottom slab exhibited minor to severe cracking and spalling at varying locations throughout, some with exposed steel. Spalls in excess of 10 inches deep and several feet in diameter were noted along the bottom slab, many of which were in areas around the expansion joint located approximately 20 feet downstream of the stoplog cutouts. The majority of the concrete bottom slab's spalling and cracking is localized in the area bound between the two downstream wing walls.

Debris accumulated immediately downstream of the sills, due to a malfunction in the gate lifting mechanism which caused various mechanical and other components to fall into the spillway. The debris appears to have been stationary for a substantial amount of time, and is positioned such that flow is not restricted.

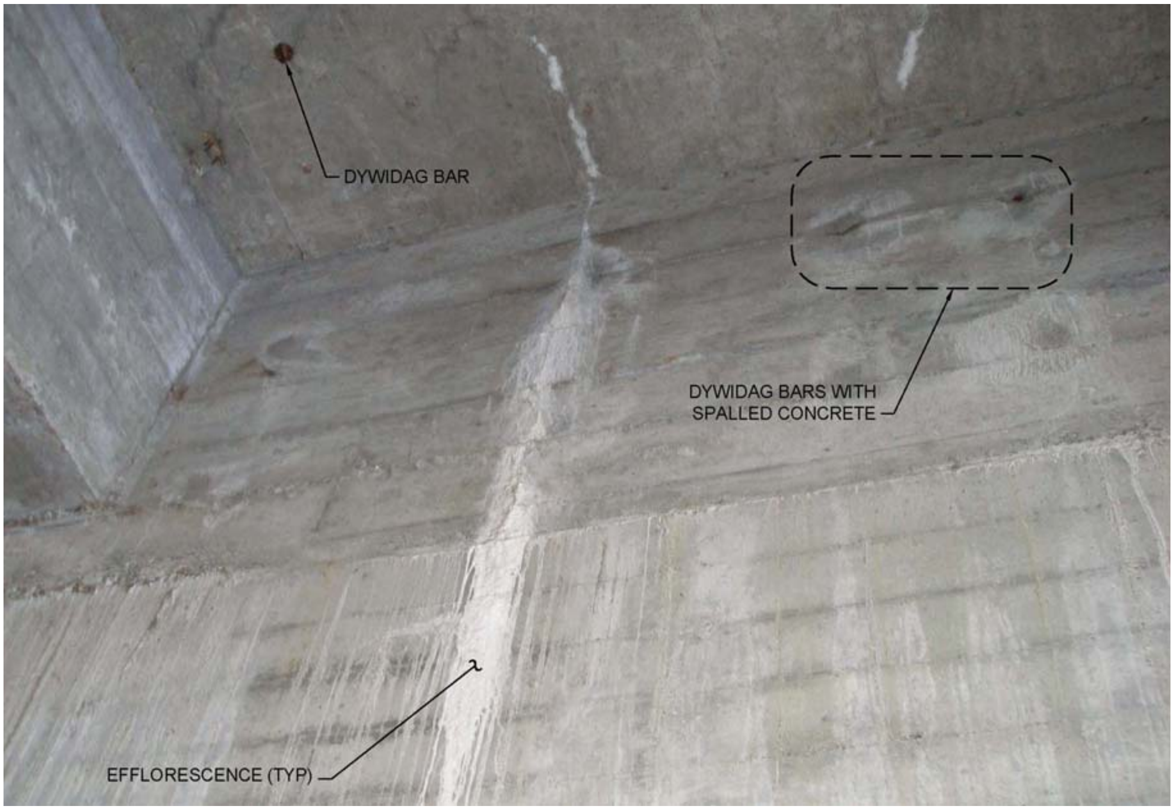

Figure 8. Defects and Efflorescence Observed on Walls and Deck Soffits

3.1.5 Riprap and Rock Armoring

Riprap lining around the channel exhibits minimal areas of voids where rocks appear to have moved over time. The rock armoring upstream of the dam shows consistency in rock size and shape.

3.1.6 Concrete Girders

Spotted efflorescence is visible on the soffits and in areas adjacent to abutments and pier walls, indicating seepage of water through the concrete. Minor tension and compression cracking is visible on the girders supporting the bridge structure.

3.1.7 Concrete Deck Soffits

Above-water inspection revealed the presence of dywidag bars scattered throughout the deck soffits, along with various buildups of efflorescence and superficial cracking, typically near corners between the girders and abutments supporting the roadway (see Figure 8).

3.1.8 Radial Gates

The steel faces of the gates are shown in Photographs 2 and 4 of Appendix A, and exhibit minor to medium deterioration, although section loss is not severe. Underwater inspection revealed leaks in the seals around all sides of both gates. During low tide, leaks in the seals were verified upon visual inspection (See Figure 9). Refer to Appendix D for findings associated with the tide gates machinery and controls.

Figure 9. Radial Gates As Seen From Budd Inlet Side During Low Tide

3.1.9 Underside of Timber Walkway

The underside of the timber walkway is composed of steel and timber members (see Figure 2). The timber exhibited no significant damage. The steel I-beams supporting the walkway have peeled and show moderate corrosion throughout, although section loss is minor and infrequent.

A two span structure extending the entire length of the bridge is located immediately to the south of the walkway. Intended as an overhead pathway for electrical conduit, the structure is composed of three stacked concrete members, each approximately 7 inches thick by 4 feet wide in cross section. Small steel bearing pads, approximately ¾ by 2 by 4 inches, are placed in the gaps above and below the middle member. The three concrete components are sagging approximately 2 inches at each midspan and exhibit typical tension and compression cracking. The steel bearing pads nearest the locations of maximum deflection can be moved freely or pulled out entirely by hand, indicating they are no longer load-bearing.

3.2 Laboratory Test Results

3.2.1 Chloride Ion Sampling

Chloride percentages obtained from laboratory testing are given in Table 2, with sample ID corresponding to Figure 4. The table summarizes the chloride ion sampling analysis provided in Appendix B.

Table 2. Analytical Results for Chloride In Concrete

Core Label	Chloride Percent
A	0.02%
B	0.13%
C	0.43%
D	0.38%
E	0.29%
F	0.32%
G	0.09%
H	0.03%
I	0.31%
J	0.42%

3.2.2 Petrographic Analysis

Table 3 summarizes the pertinent petrographic parameters obtained in the analysis and compares them to normal, non air-entrained concrete. The data in Table 3 is taken from the report attached as Appendix B. Cores L and M correspond to the locations shown in Figure 4. Refer to Appendix B for a full report of the petrographic analysis.

Table 3. Petrographic Parameters of Cores L and M

Core L ts No: Parameter	a	c	b	avg a+c+b	Normal Concrete non-air-entrained
% air (adjusted)	0.6 ± 0.6	1.6 ± 0.9	2.1 ± 0.9	1.5 ± 0.5	2.0
Reactive CA / Total CA	0	0.09	0.14	0.09	0
Reactive FA / Total FA	0.23	0.09	0.1	0.13	no limit
% pp/% p	0.31	0.05	0.02	0.09	<0.15
%p /% FA	0.75	0.80	0.80	0.79	0.91
% Fractures	0.2	0.1	0.1	0.1	0

Core M ts No: Parameter	a	c	b	avg a+c+b	Normal Concrete non-air-entrained
% air (adjusted)	2.3 ± 1.0	1.7 ± 0.9	1.2 ± 0.7	1.6 ± 0.5	2.0
Reactive CA / Total CA	0.58	0.05	0.05	0.18	0
Reactive FA / Total FA	0.14	0.12	0.17	0.14	no limit
% pp/% p	0.06	0.08	0.09	0.08	<0.15
%p /% FA	1.24	1.01	0.91	1.04	0.91
% Fractures	0.3	0.2	0.3	0.2	0

Legend: FA = fine aggregate ts = thin section
CA = coarse aggregate p = total paste

3.2.3 Transport Properties

Table 4 displays the results obtained from the transport properties testing, including absorption, Porosity, and Ionic Diffusion Coefficients. The data is compiled from Appendix C. Cores K and N respond to the locations shown in the Core Plan (Figure 4).

Table 4. Absorption, Porosity, and Ionic Diffusion Coefficients

Core Label	Absorption (%)	Porosity (%)	Ionic Diffusion Coefficient ($\times 10^{-11}$ m^2/s)
K	3.9	9.9	1.1
N	3.1	7.6	0.6

4. Engineering Evaluation

4.1 Physical Evaluation

As part of the overall condition assessment, the dam's structural components are rated based on Table 5 (*ASCE Underwater Investigations Standard Practice Manual*, *2001 Edition, Table 2-4*).

Table 5. Routine Condition Assessment Ratings

(Table 2-4 of the ASCE Underwater Investigations Standard Practice Manual)

Rating	Description
6 Good	No visible damage, or only minor damage is noted. Structural elements may show very minor deterioration, but no overstressing is observed. No repairs are required.
5 Satisfactory	Limited minor to moderate defects or deterioration are observed, but no overstressing is observed. No repairs are required.
4 Fair	All primary structural elements are sound, but minor to moderate defects or deterioration is observed. Localized areas of moderate to advanced deterioration may be present but do not significantly reduce the load-bearing capacity of the structure. Repairs are recommended, but the priority of the recommended repairs is low.
3 Poor	Advanced deterioration or overstressing is observed on widespread portions of the structure but does not significantly reduce the load-bearing capacity of the structure. Repairs may need to be carried out with moderate urgency.
2 Serious	Advanced deterioration, overstressing, or breakage may have significantly affected the load-bearing capacity of primary structural components. Local failures are possible and loading restrictions may be necessary. Repairs may need to be carried out on a high-priority basis with urgency.
1 Critical	Very advanced deterioration, overstressing, or breakage has resulted in localized failure(s) of primary structural components. More widespread failures are possible or likely to occur, and load restrictions should be implemented as necessary. Repairs may need to be carried out on a very high priority basis with strong urgency.

- Ratings are used to describe the existing in-place structure compared with the structure when new. The fact that the structure was designed for the loads that are lower than the current standards for design should have no influence on the ratings.

Based on Table 5and the damage noted in Section 3, the following condition ratings are assigned:

Concrete Abutment/Wing Walls	FAIR
Submerged Concrete Pier Walls	FAIR
Spillway Components	
Ogee Crests	GOOD
Concrete Bottom Slab	FAIR
Riprap and Rock Armoring	GOOD
Concrete Girders	SATISFACTORY
Concrete Deck Soffits	SATISFACTORY
Radial Gates	
Steel Gate Surfaces	SATISFACTORY
Seals	POOR
Underside of Timber Walkway	
Timber	SATISFACTORY
Steel I-beams	SATISFACTORY

The majority of the dam is in fair condition or better. The cracking observed on the abutments/wing walls is minor and can be reasonably expected of a loaded concrete member over 50 years old. The cracking observed on the girders is minor and can also be reasonably expected of a structure that age. Tension cracking is visible at midspan, and compression cracking at the supports, both of which are typical of concrete members that are not uniformly supported.

Nearly all concrete structures undergo some cracking due to shrinkage and flexure but typically the cracks are small and not a cause for concern. A structure may exhibit more extensive cracking due to overstressing or restraint of the structure against shrinkage and fluctuations in temperature. Overstress cracks show up on the tension side of beams and retaining walls (typically the bottom of beams between supports, the top of beams over supports, and the back of retaining walls near the bottom). Overstressing may also result from seismic loads.

Efflorescence is visible in patches along the sides of the abutment/wing wall elements and nearly all of the dams exposed soffits, including the underside of the deck and girders. Presence of the efflorescence is indicative of water seepage through the concrete, which is normal and warrants no concern.

The deep spalling exhibited on the wing walls and pier walls is primarily localized near the bottoms of the walls, although section losses generally appear incidental and should not significantly affect the serviceability of the structure. The spalls may become larger and more susceptible to damage over time if they are not repaired, especially those that exhibit exposed steel, which could initiate corrosion of the surrounding concrete and significantly escalate the damage. The bottom slab itself exhibits similar spalling, potentially compromising the behavior of the design flow through the concrete channel.

The damaged seals on the radial gates are in poor condition. This has the ability to affect flow through the dam, but does not yet significantly affect the dam’s performance. However, the leaks in the seals compromise the integrity of the surrounding (and still intact) seals by initiating small currents, or flows of water through the openings. The localized points of pressure caused by the ongoing currents make the surrounding seals more susceptible to failure by being torn or becoming separated altogether from the gates near the openings.

The three concrete components that span the length of the bridge, located south of the timber walkway, exhibit significant deflection in addition to typical tension and compression cracking. The deflection raises concern, and although the three concrete members do not affect the performance of the dam itself, their stability may be compromised.

The Fifth Avenue Dam was built between 1949 and 1951 and has therefore been in service for nearly 60 years. The dam has maintained its structural integrity since its initial construction, and given the dam's age combined with the fact that it has not been adversely affected by environmental factors, a structural failure is unlikely if existing loading conditions are sustained. Taking into consideration the Nisqually Earthquake of 2001, a major event that occurred near Olympia, the strength of the dam is further evidenced by its ability to remain in place with no major visible structural damage or noticeable settlement. The Nisqually Earthquake measured 6.8 on the Richter Scale, and was one of the largest on record in Washington State History. The epicenter of the seismic activity was approximately 10 miles northeast of Olympia.

4.2 Laboratory Testing

When constructed properly, marine concrete structures commonly remain in good condition for 20 or more years before showing signs of deterioration. The appearance of a structure does not always indicate the true condition of its concrete; therefore laboratory testing is often the only means of detecting the deficiencies. Laboratory testing of concrete is used to identify deficiencies within a concrete matrix that act as mechanisms for chemical deterioration of the concrete.

Chloride intrusion is a problem with any concrete exposed to salt water or salt spray. Unless sealers are applied, any concrete will eventually allow chloride ions to migrate into it. The migration can be slowed down by reducing the permeability of the concrete with various admixtures and pozzolans but eventually the chloride ions will migrate into the concrete and reach the rebar. Chloride ions from the seawater penetrate into the concrete, reaching the reinforcing steel. The chloride ions destroy the passive layer that protects rebar from corrosion and exists on rebar in contact with normal concrete. As rust forms on the rebar, the volume expands and the concrete cover spalls off. This result can be delayed with thicker cover and less permeable concrete, or with the addition of chemical corrosion inhibitors. Overall, the chloride ions reduce the pH to a threshold that allows corrosion to initiate. Some of the damage noted on the Fifth Avenue Dam may be due to this mechanism, such as the spall noted in Photograph 1 in Appendix A.

In addition to chloride intrusion, some of the common mechanisms for chemical concrete deterioration are alkali-silica reaction (ASR), sulfate attack, and delayed ettringite formation (DEF).

ASR is characterized by the formation of a "gel" around the aggregate that causes expansion and spalling. Expansion and spalling of concrete often results in major structural problems that ultimately lead to demolition. ASR is caused by hydroxyl ions in the alkaline cement pore solution in the concrete, when they react with certain forms of silica in the aggregate, such as chert, quartzite, or opal. This type of deterioration is rare in the Pacific Northwest because the region's most commonly used aggregates do not undergo this type of reaction. This assessment uses petrographic analysis to determine the presence ASR.

Sulfate attack can be external or internal. External sulfate attack in concrete occurs when sulfates from an outside source, such as seawater, penetrate into the matrix. Internal sulfate attack is due to a soluble source being incorporated into the concrete at the time of mixing. External sulfate attack is the more common of the two, although both will eventually lead to an overall loss of concrete strength.

DEF is seen as a form of internal sulfate attack, and is generally only a problem with concrete that has been cured at elevated temperatures. The elevated temperatures cause the normal formation of ettringite in concrete to be suppressed during hydration and curing. The alternate chemical formulation that results can subsequently react with water to result in ettringite crystal formation that causes expansion and resultant spalling of the hardened concrete.

4.2.1 Chloride Ion Sampling

In reinforced concrete, corrosion of the reinforcing steel typically occurs when concrete becomes significantly contaminated with chloride ions. If a chloride percent of 0.400% or greater is measured at the level of the reinforcement, it is reasonable to assume that corrosion of the inner reinforcing steel has been initiated. The 0.400% threshold is a general rule of thumb, indicating a significant level of chloride contamination in the concrete matrix. When the threshold is exceeded, a concrete structure typically exhibits corrosion spalls that are induced by corroded reinforcing steel. Chloride-induced spalling may not be evident for five or six years from the time the chloride ion concentration reaches the critical point in the concrete.

The chloride ion testing indicates the 0.400% threshold has been exceeded in core samples C and J, which yielded chloride percentages of 0.429% and 0.423, respectively. Cores C and J are both located on the Budd Inlet side of the dam, and as expected, chloride intrusion is more significant in structure areas that are exposed to salt water. Most of the other cores on the Budd Inlet site yielded chloride percentages in excess of 0.3%. Cores A and H, taken from the Capitol Lake side of the dam, yielded low chloride levels of 0.020% and 0.030%, respectively.

4.2.2 Petrographic Analysis

The petrographic analysis indicated that the concrete in the dam is fairly high-quality with relatively low permeability, which is comparable to a modern, good-quality mix. Some fracturing of the samples was present, but the fracturing appears to have been caused by exterior forces and not from the concrete matrix itself. This is evidenced by the parameters given in Table 1 of Appendix B. The steel bars, which are approximately 3.5 inches from the primary fracture or joint at the flat end of the cores, exhibited no corrosion.

The reactive coarse aggregate in the samples may normally cause ASR, but the high concentration of fine aggregates of the same material acts as a buffering agent to reduce the reactivity of the paste; therefore, ASR is not evident in the cores. Refer to Appendix B for a full report of the petrographic analyses performed.

4.2.3 Properties

Overall, all concrete properties obtained from the transport properties testing correspond to a good quality concrete. Chlorides were discovered in the pore solution, which suggests that the concrete is contaminated from an external source of chlorides.

The porosity values (see Table 2 of Appendix C) exhibited by Cores K and N are lower than those to be expected from good quality normal-weight concrete. Good quality normal-weight concrete typically exhibits values around 12%. Low porosity values would be expected to yield low diffusion coefficients. The absorption ranges from 3.1% to 3.9%, which correlates with the porosity values.

The ionic diffusion coefficients (see Table 4) evaluated correlate to the porosity results. The lower ionic diffusion coefficient corresponds with the lowest porosity. Based on the results, the Fifth Avenue Dam’s concrete is considered to have an ionic diffusion coefficient in the range of a good quality concrete prepared in laboratory and having a water/cement ratio of 0.45.

5. Conclusions and Recommendations

5.1 Dam Condition and Longevity

The Capitol Lake Dam should maintain its existing functionality over the next 50 years if an appropriate and aggressive program of inspection and repair is followed and natural disasters or other major events, such as earthquakes, do not occur. Signs of corrosion are evident, and since chloride levels exceeding 0.400% were detected in some of the core samples, installation of a corrosion inhibiting mechanism will be necessary as part of the maintenance program.

Aside from chloride intrusion, laboratory testing did not indicate the structure has undergone significant chemical deterioration of the concrete matrix. We do not anticipate that the structure will undergo deterioration due to ASR, sulfate attack, or DEF. The structure has not yet undergone these types of deterioration, and given their absence to date, the age of the structure adds confidence to the prediction that these types of deterioration are unlikely to occur over the next 50 years.

However, the Capitol Lake Dam's continued, successful operation for the next 50 years will require initial repairs of spalls and cracks, followed by determining and adhering to a schedule of inspections. Chloride intrusion must also be addressed. Specific repair recommendations are beyond the scope of the current task. However, general methods of repair are suggested for different types of damage. Based on the inspection and laboratory testing results, the repairs necessary to maintain the current condition of the Capitol Lake Dam are discussed below, followed by descriptions and timelines of recommended inspections and a discussion on the various anti-corrosion measures that can be put in place.

5.2 Initial Repairs

The ogee crests and the riprap/rock armoring are in good condition and no repairs are required. The concrete girders, deck soffits, and elements composing the underside of the timber walkway are all in satisfactory condition, exhibiting only limited minor to moderate deterioration. No repairs are required.

The concrete abutments/wing walls, pier walls, and bottom slab elements are all in fair condition and repairs are recommended, but with low priority. The damage consists of spalling and cracking. Suggested repair measures include cleaning the spalls and patching with a non-shrink epoxy mortar and epoxy-injecting the crack openings. Good preparation and installation technique are essential to a long-lived repair. For spall repairs, particular attention should be paid to the properties of the mortar when selecting a repair material. An example of a patching material is SikaRepair® 223 (see Appendix E). The properties of the selected mortar should be comparable to the properties of the concrete.

Following is a general repair procedure for a spall in concrete with 2.5 inches of cover (also refer to the general spall repair section in Figure 10).

1. Clean the area and remove all loose material.
2. Saw cut the edge of the area to minimum depth of ½" (although 1" is preferable). The concrete should be cut in a rectangular pattern around the damage.
3. Clean rust from any exposed reinforcing. If more than half of the rebar circumference is exposed, continue removing material until there is 1" clear behind the rebar. Clean all loose material from the surface of the spall and blast or grind to produce a surface roughness with approximately ¼" of depth variation.

4. Dampen the surface of the spall with water. The surface should be saturated but should not have standing water. Scrub in a thin mixture of the chosen repair mortar.
5. Apply repair mortar in lifts no thicker than manufacturer's recommendations to fill the void.
6. Cure the repair similar to typical concrete.

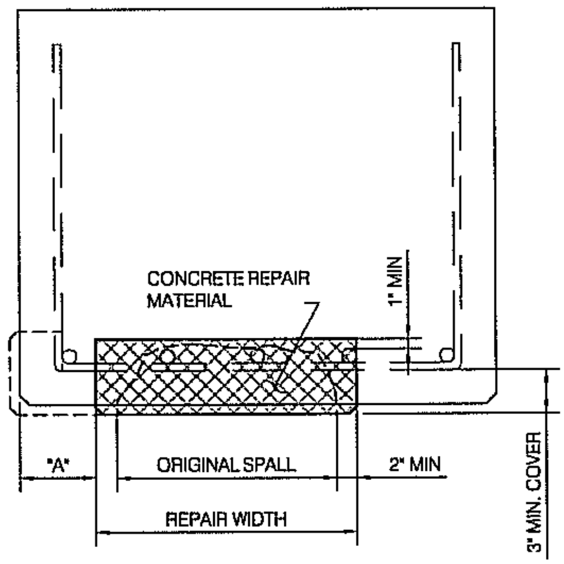

Figure 10. Patch Repair General Section

The two-span concrete structure supporting electrical conduit just south of the timber walkway does not impact the structural stability of the Fifth Avenue Dam, but repairs may be deemed necessary during future inspections. The three concrete elements of the combined structure should be monitored during routine inspections for further deflection and cracking. If the structure continues to sag or additional cracks propagate, the structure should be repaired. A repair method could consist of wrapping the combined structure with a composite carbon fiber wrap.

The seals around the radial gates are in poor condition and should be replaced in full. The radial gates exhibit localized areas of moderate section loss and no repairs are required. However, the gates should be monitored for further section loss during routine inspections. According to the Capitol Lake Tide Gates Machinery and Controls Assessment in Appendix D, the noisy shaft bearing on the west gate should be replaced immediately. Furthermore, it is imperative that a limit switch be added to the East Gate to detect the full up position.

5.3 Inspection Frequency

The results herein indicate a need for scheduled inspections of the dam in order to keep it fully serviceable for the next 50 years. The inspections are intended as a form of routine preventative maintenance and should identify the need for repairs as necessary. *Routine Inspections* are recommended to be carried out annually. *Special Inspections* are recommended to be carried out every 5 years. *Post-Event Inspections* should be conducted as necessary following significant, potentially damage-causing events. Lastly, refer to Appendix D for recommended inspections of the tide gates machinery and controls. Each type of inspection (except those applicable to the tide gates machinery and controls) is fully defined in the *ASCE Underwater Investigations Standard Practice Manual, 2001 Edition*, and is summarized below.

Routine Inspections: The primary purpose of a routine inspection is to assess the general overall condition of the structure, assign a condition assessment rating to the portions of the structure, and recommend what future course of action should be taken for the structure, if any. Routine inspections should be performed on a routine, cyclical basis and therefore represent a proactive, rather than reactive, approach to maintenance.

Routine Inspections of the Capitol Lake Dam are recommended to be carried out on an annual basis. During these inspections, previously reported damage should be observed and any discrepancies noted. Existing structural cracking should be monitored for growth. If overstress cracks are found in a structure it is important to determine the frequency at which cracking originates. The frequent opening of cracks in a corrosive environment can exacerbate chemical intrusion into the concrete eventually causing corrosion of the reinforcement and spalling. Any discoloration suggesting a possibility of corrosion should be noted. The steel gates should also be monitored for section loss, and the seals for leaks.

Special Inspections: Special Inspections are conducted for the purpose of collecting more detailed information than normally collected during a routine or repair design inspection. Such information may be necessary to understand the nature or extent of deterioration before determining the need for and type of repairs.

Special Inspections of the Capitol Lake Dam are recommended to be carried out every 5 years. These inspections should include investigation of both topside and underwater elements, similar to the inspection performed in May and June, 2007. We recommend inscribing markings into each wing wall and pier wall that can be located over the next 50 years. The intent is to designate points of future survey so the structure can be monitored for settlement. During Special Inspections, the wing walls and pier walls should be surveyed at the inscribed points to monitor any settlement. The bottom slab should additionally be surveyed and compared to previous elevation data to ensure the dam is not settling.

We further recommend that upon completion of each Special Inspection, the Engineer in responsible charge of the inspection shall determine the need for additional coring. If additional coring is deemed necessary, measurements of the concrete cover should also be conducted as appropriate. The additional coring is primarily intended to determine the progression of chloride ion penetration into the concrete, and when planning any future core samples, past core locations should be taken into consideration. If cores are taken in the future, any falling debris and cementitious liquids should be collected rather than discarded into the Budd Inlet or Capitol Lake. Immediately after each extraction, the structure should be patched with a non-shrink mortar.

Further studies that involve drilling core samples should also include profiling the depth of the chloride penetration at 0.5- inch increments to a minimum depth of 3.5 inches.

Post-Event Inspections: Post-Event Inspections should be conducted after a significant, potentially damage-causing event such as a flood, earthquake, storm, vessel impact, or tsunami. The primary purpose of a post-event inspection is to assess rapidly the structural stability of the structure and determine whether further attention to the structure is necessary as a result of the event. Post-Event Inspections are intended to be relatively rapid, visual or tactile inspections conducted to determine whether the event resulted in any significant damage requiring repairs or load restrictions.

An earthquake, such as the Nisqually Earthquake of 2001, is arguably the most significant type of recurring natural event to affect structures in Olympia. A Post-Event Inspection is recommended to be carried out within a reasonable amount of time following any earthquake or other event that potentially affects the stability or functionality of the Capitol Lake Dam. Adequate time should be allowed between the time the event occurs and the time the inspection takes place to ensure the structure can be safely accessed without concern of post-event occurrences, such as aftershocks in the case of an earthquake.

5.4 Anti-Corrosion Measures

The Capitol Lake Dam has reached an age where even a good concrete mix will start to see some corrosion of the rebar without intervention. Intervention will require implementing a chloride inhibiting system, or anti-corrosion mechanism. There are four basic types of anti-corrosion mechanisms: *cathodic protection*; *electrochemical chloride extraction*; *corrosion inhibitors*; and *concrete removal*. After implementing any of the four chloride inhibiting mechanisms, a sealant can be applied to the outside of the dam. Application of a sealant is may be favored due to the fact that the corrosive environment (salt water from the Budd Inlet) already surrounding the downstream side of the dam will not change as a result of installing an anti-corrosion mechanism. Therefore, an ideal solution might incorporate a sealant to preserve the structure's newly protected concrete from further chloride ions that are still able to penetrate the dam's outer surface.

There are two types of ***cathodic protection***: active systems and passive systems. Both systems prevent new corrosion activity from initiating while simultaneously reducing ongoing corrosion activity. Active cathodic protection requires installation of discrete zinc anodes into the concrete. The anodes receive an impressed current cathodic protection from an outside source. To become active, these systems incorporate wires that connect the anode to the outside source. An example of this type of system is called Ebonex®, by Vector™ (refer to Appendix E for a manufacturer brochure). Active cathodic protection, while very effective, tends to be more expensive to install and passive systems. Routine maintenance of active cathodic systems is critical, since malfunctions can be difficult to detect.

In a passive cathodic protection system, galvanic anodes are embedded into the concrete and connected by a wire to the reinforcing steel. The anodes serve as sacrificial units that draw chloride ions away from the reinforcing steel. An example of a passive cathodic protection system is a system called Galvashield® CC, by Vector™ (refer to Appendix E for manufacturer's brochure). Another type of passive system that does not involve embedding units into the concrete is a zinc coating applied to the outside of the structure to act as a sacrificial anode. Passive cathodic protection is one of the most common means of providing corrosion protection to marine structures. Anode installation is a relatively simple process and can be performed underwater. Once installed, the only maintenance usually needed is regular replacement of the anodes, with typical replacement intervals being up to 10 years.

Electrochemical chloride extraction removes chloride ions electrically from contaminated concrete. Chloride ions are extracted by applying a temporary electric field between the reinforcing steel in the concrete and an externally mounted anode mesh. While the ions are being transported out of the concrete, electrolysis at the reinforcement surface produces a high pH environment, returning the reinforcing steel to a passive condition over a period. An example of an electrochemical chloride extraction system is Norcure® Chloride Extraction, by Vector™ (refer to Appendix E for a manufacturer brochure).

Electrochemical chloride extraction is typically used on highway bridges and other structures that are not normally exposed to chlorides (i.e. exposure only comes from road salts); it is not normally applied to submerged structures or to structures that are in constant contact with chlorides. Consequently, this solution is not likely to be appropriate for the Fifth Avenue Dam.

Penetrating corrosion inhibitors are a means to halt the ongoing corrosion reaction. This type of system can be painted on the structure's surface, allowing it to migrate through the concrete and protect the passive layer of the reinforcing steel, thus preventing corrosion and spalling. There are several types of penetrating corrosion inhibitors, and different mechanisms have different design lives. As an example of a penetrating corrosion inhibitor, a manufacturer brochure for Sika FerroGard® 903 is included in Appendix E. Penetrating corrosion inhibitors must be applied in the dry: consequently it would be necessary to construct a cofferdam to apply this solution to normally the dam. Additionally, it would be desirable to apply an additional layer of waterproof sealant to the normally submerged areas of the dam.

Using ***concrete removal*** as an anti-corrosion mechanism involves significant effort. The contaminated concrete is physically removed and replaced from the structure. The extent of the concrete removal is determined by the depth that chloride contamination is known to exist.

The most suitable corrosion protection solution is determined by evaluating the existing corrosion behavior, cost and availability of each method, acceptable maintenance costs and frequencies, and desired extension of service life. It is likely, however, that the selected protection solution will involve one or both of passive cathodic protection and penetrating corrosion inhibitors. For a marine structure, these two methods are typically able to achieve the desired results with the lowest lifecycle cost. From a permitting standpoint, all of the methods are generally considered acceptable. The construction of a cofferdam for application of penetrating corrosion inhibitors is likely to be the most significant element from a permitting standpoint.

5.5 Closing Remarks

If the Capitol Lake Dam is to tolerate the corrosive environment of the Budd Inlet for another 50 years, an anti-corrosion measure must be put in place in the near term (i.e., in the next few years). The probability that a structure over 50 years old can withstand a saltwater environment without showing substantial levels of corrosion or even signs of failure is very low. Although the dam has withstood the environment in spite of the odds, expectations that it will remain stable for another 50 years without intervention are unrealistic; the rate of deterioration of the dam structure is likely to accelerate rapidly. The sooner an anti-corrosion measure is put in place, the more effective it will be. We recommend that if a decision of whether to maintain or remove the dam is not imminent by the end of the year 2010, a detailed and aggressive inspection and repair plan should be developed and implemented.

A complete service life modeling analysis would be a valuable part of this future repair planning. This analysis would identify appropriate anti-corrosion measures, and would give the costs and likely performance associated with each alternative.

Based on our experience with concrete structures, the cost of implementing an appropriate chloride-inhibiting measure and of concrete repair will be minimal in comparison to costs associated with dredging at Capitol Lake. Consequently, further repair planning – including inspection, sampling, and service life modeling – are not needed to support the decision as to whether to maintain the dam (and Capitol Lake) in its current configuration. However, if the decision as to the long-term future of the dam has not been made by the end of 2010, this repair planning and associated modeling work should be performed within the 2009-2011 biennium.