KGM to WSDOT Serial Letter # 0314

February 14, 2013

Dave Becher
WSDOT
3015 112th Ave NE, Suite #100
Bellevue, WA 98004

WSDOT Contract #008066 – SR 520 Evergreen Point Floating Bridge and Landings Project

RE: **Final Draft Gerwick Report**

Dear Mr. Becher,

Attached, please find the final draft of the Gerwick Report on the pontoon crack repair procedures. Please note that this report supersedes all previous versions.

If you would like further discussion in regard to this matter, please do not hesitate to contact us at 425-576-7100. Thank you.

Sincerely,

Kiewit/General/Manson, a Joint Venture

Erik Nelson,
Project Director

Enclosures: Gerwick Report – Final Draft

Cc: File

EN:AEH

KGM

SR-520

Recommendations for the Repair and Strengthening of the Cycle 1 Pontoons

DRAFT

February 2013

January 2013

Ben C. Gerwick, Inc.
a COWI company

KGM

SR-520

Recommendations for the Repair and Strengthening of the Cycle 1 Pontoons

DRAFT

Document no.	2012-069-0001
Version	DRAFT - v2
Date of issue	February 2013
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1 Executive Summary

Ben C. Gerwick, Inc. is retained by Kiewit-General-Mason Joint Venture (KGM), the design-build contractor of the SR-520 replacement project, to evaluate and recommend viable repair plans for the cracks on Cycle 1 pontoons (i.e., Pontoon W, V, U, and T). The main objectives of the work are:

1. Develop a repair program for the existing cracks. The repairs must be applicable to the floating pontoons under their current condition on the project site.
2. The repair program should ensure the structural strength, watertightness, durability, and performance of the floating bridge for a 75 years service life with low maintenance. No leakage to the pontoon is allowed.

This report documents the work in the following aspects:

1. Condition assessments of the existing Cycle 1 Pontoons;
2. Recommendations of the pontoon repair approach, repair measures, and a repair plan;
3. Prediction of the service performance of the repaired pontoons.

The work to date has reached the following conclusions and recommendations:

1. Overall, the Cycle 1 Pontoons are in a generally sound condition. The areas to be repaired are limited to a number of local zones. These pontoons can be repaired and strengthened to meet all of the performance requirements of the bridge for the 75 years service life.
2. The damages are mostly concrete cracks and spalls on the top decks, keel slabs and end walls. It is important to implement a structural strengthening system as well as repair of the existing damages.
3. No single repair measure can adequately address all of the critical issues in this repair project. The recommended strategy is to implement a combination of repair measures, including crack repair with epoxy injection, external post-tensioning, structural strengthening with externally bonded CFRP, and patch repairs of spalls.
4. In order to ensure the repair quality and quality control, it is recommended that all structural repairs on the submerged part of the pontoon be performed in a dry environment.

2 Condition Assessments in the Cycle 1 Pontoons

2.1 Introduction

The Cycle 1 Pontoons consists of Pontoons W, V, U. and T, which were fabricated in Grays Harbor, WA, in 2012. To our knowledge, condition surveys of the pontoons regarding concrete damages have been made at three separate times:

- A crack mapping survey was made on at least a major part of Pontoon V and W prior to the post-tensioning in Grays Harbor (Project Documents /17/).
- A condition survey was made on the pontoon damages after the post-tensioning in Grays Harbor.
- A condition survey is being conducted in the end bays of all Cycle 1 Pontoons and in center bays of Pontoon W where the transverse post-tensioning has been implemented. The extent of the survey includes mapping of damages on both interior and exterior faces of the keel slab and end walls. At this time, the survey data on Pontoon V and Pontoon W are available.

The pontoon condition assessment in this report is primarily based upon the condition survey data available to Ben C. Gerwick, Inc. (BCG) to date. The assessment will be updated as more survey data are available.

Overall, the Cycle 1 Pontoons are in a generally sound condition. Structural damages occurred in a few local areas, i.e., the end bays of all Cycle 1 Pontoons and the middle bays of Pontoon W where transverse post-tensioning was applied. In general, all of the Cycle 1 Pontoons exhibit similar damage patterns. It is anticipated that the repair plan as developed for Pontoons V and W may be applicable to Pontoons U and T.

The most significant damages are structural cracks and spalls near the post-tensioning anchorages, which reportedly occurred during or immediately after the post-tensioning of the pontoons in Grays Harbor. The post-tensioning strands were then released and the concrete spalls were removed and replaced the cast-in-place concrete with additional steel reinforcement. The pontoons were prestressed again. All cracks were monitored for at least five days until the cracking appeared to stabilize. Afterwards, structural cracks were repaired with epoxy injection or epoxy filling, and other non-structural cracks were coated with waterproof coating.

2.2 The Keel Slabs and Bottom Bolt Beams

The crack/spall mapping on the keel slabs and bolt beams of Pontoons V and W are illustrated in Figure 2-1. The cracks and large spalls on the keel slabs are of the most structural significance, since they have not been repaired and manifest the following distinct features:

1. The cracks typically run up to 4' to 5' in the vertical direction on the end wall and extend up to 10' into the keel slab. The vertical cracks on the wall are connected to the longitudinal cracks in

the keel slab. Figure 2-1 shows the crack mapping on the end wall (14T) and top/keel slabs of Pontoon V, and the potential problem areas.

2. Many of the cracks run vertically passing the bolt sleeves embedded in the bolt beams. When the bolt beams were subjected to tension from the post-tensioning of Pontoon V, it seems that the tension cracks tended to develop on the weak planes through which the bolt sleeves passed.

3. The stabilized crack width through the bolt sleeves generally ranged from 0.01" to 0.05".

4. There are a number of isolated concrete spalls on the keel slabs.

5. In the middle part of Pontoon W where the pontoon will be joined to Pontoon V, post-tensioning in the transverse direction of the pontoon was applied. Structural cracks mostly occurred near the post-tensioning anchorage on the keel slab. The cracks typically range from 0.006 inch to 0.01 inch in width and 2-3 feet in length (see Appendix A). The extent of the repair required in this area is lesser than those at the end bays, likely due to the presence of the longitudinal post-tensioning.

Our analysis concludes that the pontoons should be structurally repaired and strengthened prior to the pontoon assembly and put into service.

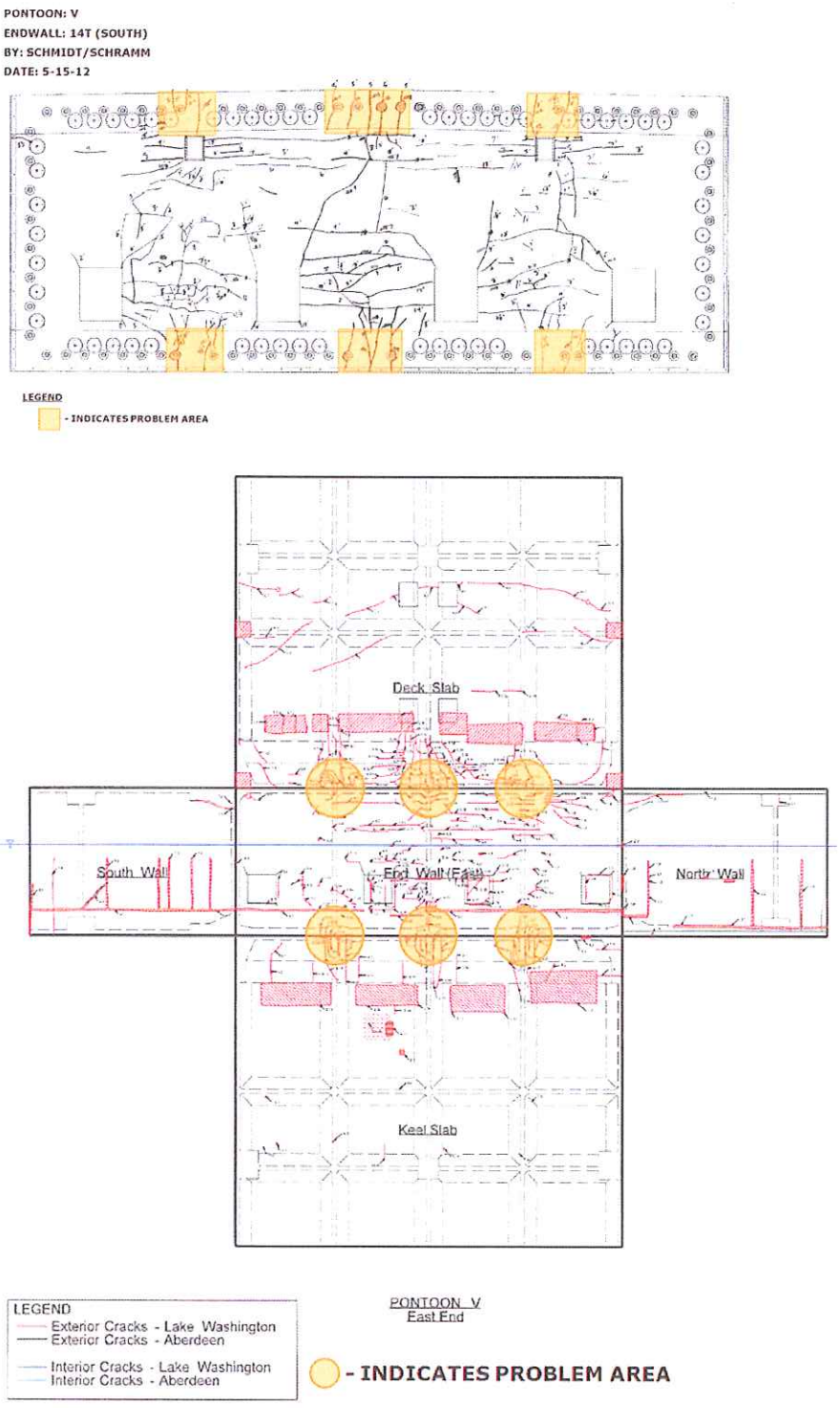

Figure 2-1. Crack mapping at the end wall, keel/top slabs, and potential problem areas

2.3 The Top Decks and Top Bolt Beams

The areas to be repaired on the top decks and top bolt beams are similar in nature to those on the keel slabs and bottom bolt beams. The discussions in Section 2.2 are generally applicable to the top decks and bolt beams.

All structural cracks on the top decks were repaired with epoxy filling by gravity feed. This repair method is acceptable. For structural repairs, it is important to achieve full depth penetration of epoxy. It is recommended that cores be taken to verify the epoxy penetration depths and be tested per ASTM C 496, "Splitting Tensile Test"[1].

There are numerous hairline cracks on the top deck in the middle part of the pontoons (Project Documents /1/). These cracks occurred prior to the post-tensioning in Grays Harbor and appear to be thermal and shrinkage cracks and non-structural in nature. A waterproofing coating was applied over these cracks. No noticeable leakage through the cracks has been reported to date.

2.4 End Walls

The end walls of the Cycle 1 Pontoons experienced substantial cracking at the precast yard in Gray Harbors. The cracks occurred during or immediately after the post-tensioning of the pontoons.

Finite element analysis indicates that the end walls were subjected to significant membrane tension and bending due to the post-tensioning. The analysis results are consistent with the field observations of the end walls. Figure 2-2 and Figure 2-3 superimposes a crack mapping of the interior surface onto that of the exterior surface of the end walls T14 and T1 of Pontoon V, respectively. The figures also highlight the through-thickness cracks on the end walls. It is apparent that the through cracks are limited in number and length.

After the post-tensioning in Grays Harbor, the cracks were allowed to stabilize for at least five days, and then repaired with epoxy injection. At the present time, there is neither new crack nor leaking crack on the end walls on Pontoons V and W. The end walls are currently protected by neoprene pads and, after the pontoon assembly, will be grouted on the exterior surface. The analysis indicates that the design loads on the end walls are not significant in comparison with the bolt beams. It is prudent to monitor the end walls without any further repair. Should any new crack develops or the existing cracks re-opens in the future, the crack can be repaired with epoxy injection and an externally bonded CFRP system be installed on the interior surface of the end wall.

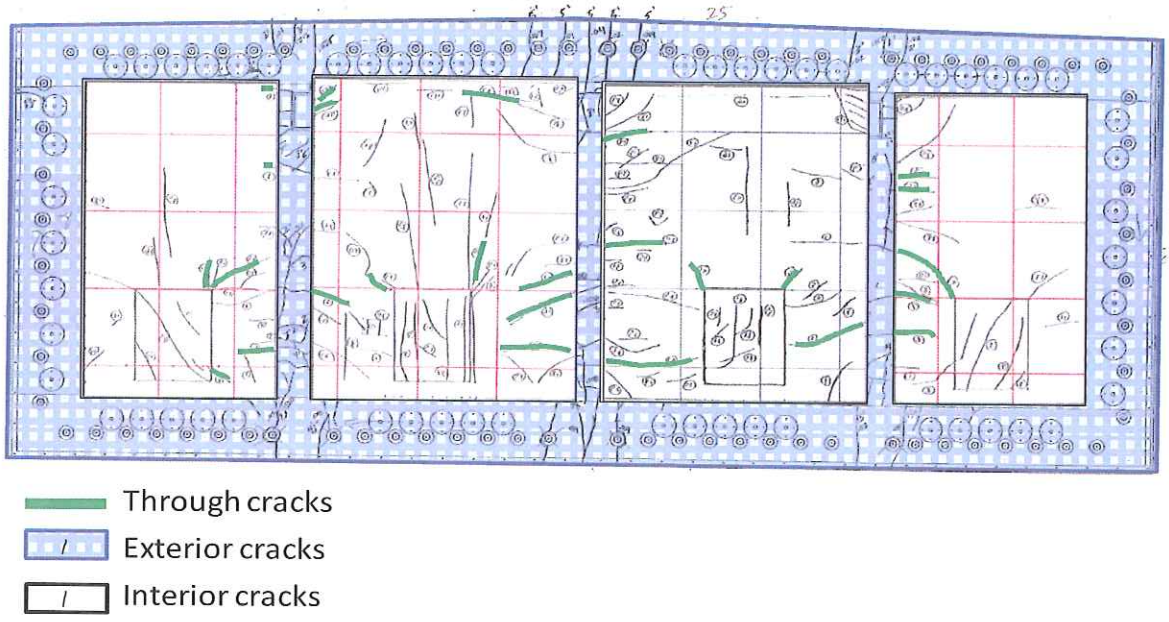

Figure 2-2 Crack mapping of the end wall T14 of Pontoon V

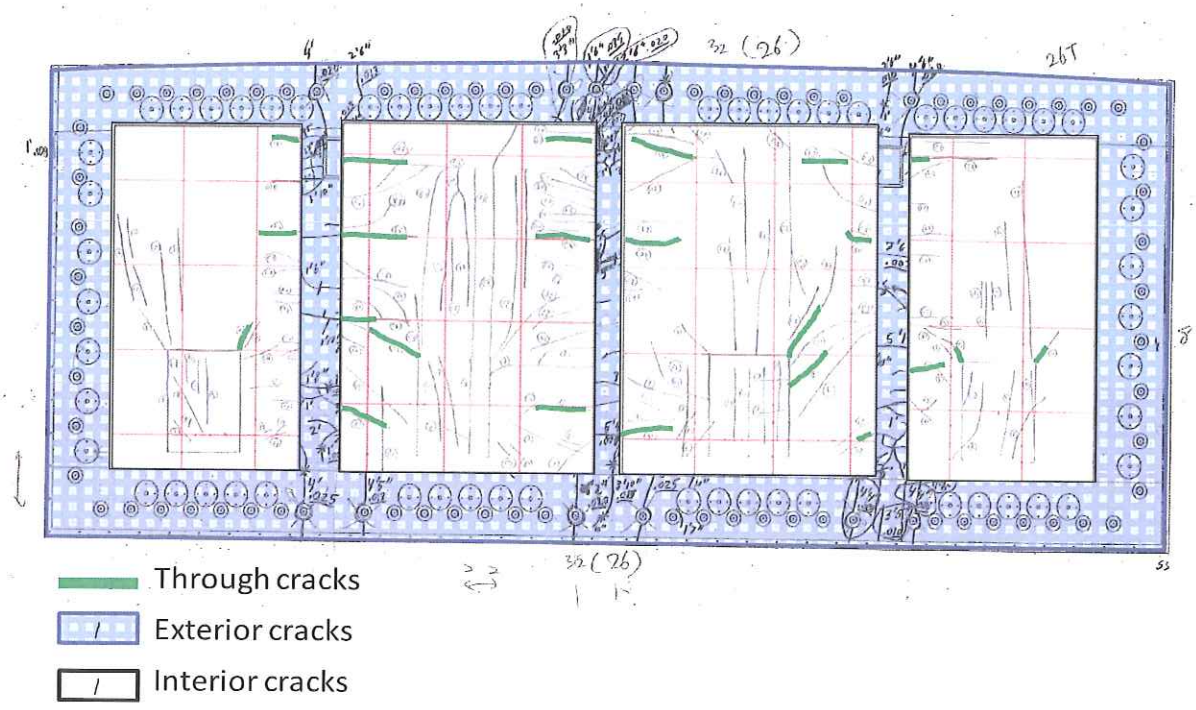

Figure 2-3 Crack mapping of the end wall T1 of Pontoon V

3 Repair Plan

3.1 The Repair Approach

As a mandate of the project, the objectives of the crack repair work are:

1. Restore the structural strength of the Cycle 1 Pontoons;
2. Prevent leakage into the pontoon through cracks under all circumstances;
3. Ensure structural integrity and serviceability for the 75 years design life of the pontoons.

To achieve the objectives, the following repair design criteria are proposed:

1. All structural cracks are to be repaired with epoxy injection to restore the concrete strength.
2. Some local areas of the pontoons are subjected to sustaining tensile stresses, which arose from the fabrication of the Cycle 1 Pontoons. To the maximum extent possible, the sustaining tensile stresses in the pontoons are to be eliminated by external post-tensioning in the direction perpendicular to the structural cracks.
3. A structural strengthening system is to be implemented in the distressed local areas in order to ensure adequate safety margin against all design loads on the bridge under all circumstances.
4. All leaking cracks and active cracks are to be sealed with resin injection and/or waterproof coating or membrane.
5. The repair/strengthening systems and materials are to be verified for long-term durability and performance for the 75 service life of the bridge.

We recommend that the following measures be considered for repair of the Cycle 1 Pontoons:

1. Epoxy injection of structural cracks
2. External post-tensioning of the pontoons in the direction perpendicular to major cracks, designed by others
3. Externally bonded carbon fiber-reinforced polymer (CFRP) system
4. Waterproofing coating or membrane for all non-structural cracks

3.2 Epoxy Injection

All structural cracks should be repaired with epoxy injections for the following reasons:

1. Restore the structural flexural strength and stiffness across the cracks.

2. Increase the concrete shear strength across the cracks.

3. Allow the external prestress to uniformly transfer across the cracks.

4. Increase durability of CFRP strengthening system: any water penetration through cracks into the interface between the FRP and concrete substrate reduces the long-term bond strength. Therefore, it is essential to repair and seal cracks prior to implementing FRP strengthening system.

5. Enhance watertightness of the pontoon by blocking water penetration through cracks.

In accordance with WSDOT's project criteria, any concrete crack wider than 0.006 inch is structural. All structural cracks are to be repaired with epoxy injection. It is recommended that any crack with a maximum width of 0.004 inch or wider be repaired with epoxy injection for leakage control.

The crack survey on the pontoons indicates that many structural cracks exhibit varying crack width along their entire length with decreasing cracks width towards the ends. Past experience concludes that crack repairs are not durable when epoxy fills less than 90% of the cracks, because partially filled cracks are likely to develop new cracks under additional loading or deformation (see Figure 3-1). Therefore, the engineering requirement is to inject epoxy to fill the entire cracks.

ACI 224.1R-07 [2] provides a general industry standard of the epoxy injection procedure, which should be followed in this project. Furthermore, additional requirements specific to this project are discussed below.

- Epoxy resin: The resin should be 100% solid and 100% reactive, with low viscosity and low shrinkage upon curing conforming to ASTM C-881 Type IV, Grade I, Class B (for use between 40 and 60 F) [3].

- Crack cleaning: In order to ensure the repair quality, it is critical to remove dirt and marine growth from the cracks, which would prevent epoxy penetration and bond to concrete. After installation of injection ports and surface seal, pressurized water and air are to be applied to flush the cracks.

- Distance of ports: Establishing entry and venting ports at proper intervals along the crack. Spacing between the ports governs the depth of injected epoxy into the crack. Based upon the length and width of the cracks, we recommend that the spacings do not exceed 6 inches for cracks less than 0.01 inch wide, and do not exceed 12 inches for cracks more than 0.01 inch wide.

- Injecting the epoxy under pressure: Positive displacement pumps should be used in which the two epoxy components are pumped independently and mixed together at injection nozzle just before entry into the crack. For overhead cracks, start injection from one end and move to the other end. Secure the feed line to the first port. If an adjacent port starts bleeding, cap the port

and continue the injection until refusal. Hairline cracks are sometimes not well suited to "pumping to refusal". In those cases, try injecting the epoxy at increased pressure. In order to eliminate the risk of further damaging the pontoon, the maximum injection pressure is to be limited at 250 psi during epoxy flowing into the crack. At final lock off, maintain the pressure at 100 psi for 5 min. The epoxy injection is acceptable if the lock-off pressure does not drop by 10 percent in 5 min.

- It is recommended that cracks strain gauges be installed to monitor any movement at the surface during epoxy injection. Also, the surface seal should be monitored closely during the process for debonding failure.

- After completion of epoxy injection, the ports are removed and surface seals are grinded to prepare for the bonding of CFRP sheets later.

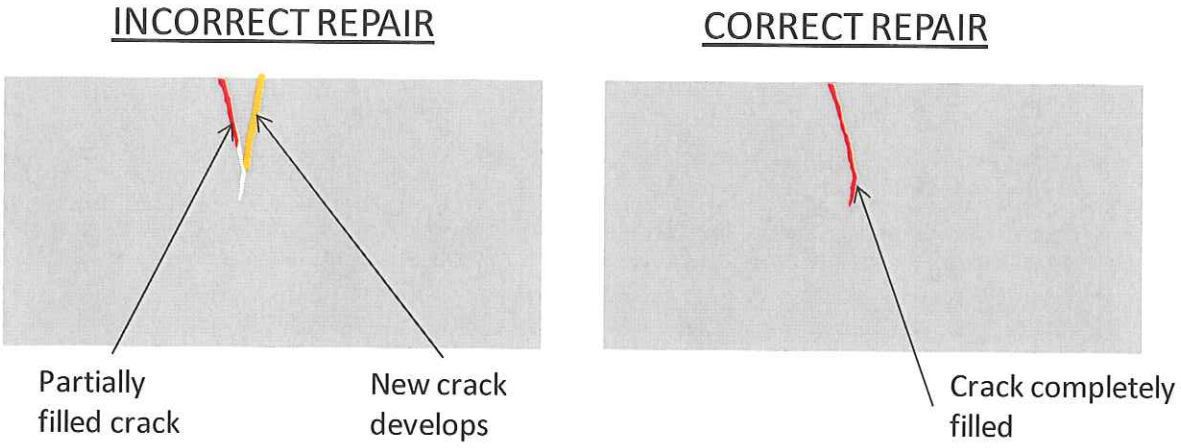

Figure 3-1 The effects of partially filled epoxy injection for structural performance

3.3 External Post-Tensioning

External post-tensioning has been successfully used in floating concrete structures such as the existing Evergreen Point Floating Bridge. In this project, external post-tensioning in the transverse direction of the pontoons is to be applied adjacent to the end walls and directly above the bolt beams of the end bays.

3.4 Externally Bonded Carbon FRP System

The externally bonded FRP system has been increasingly used for strengthening concrete structure. Carbon fiber-reinforced polymer (CFRP) and glass fiber-reinforced polymer (GFRP) are the most common FRP strengthening materials. CFRP is preferred in this project to its high strength and high resistance to fatigue and creep rupture, while glass fibers are extremely hydrophilic and vulnerable to water vapor penetration.

The CFRP strengthening system is recommended in this project for the following reasons:

- Increase structural strength of the bolt beams and end walls where the cracks have compromised the structural safety margin.
- Provide crack control by restraining the existing cracks and preventing new cracks
- Enhance waterproof of the pontoons, since CFRP materials are generally impermeable to water penetration.

An externally bonded CFRP system is developed to strengthen the bolt beams and keel slabs. The FRP design is based upon the assumptions that the transverse post-tensioning is implemented .

The FRP design criteria are in accordance with ACI 440.2R-08 [4] and AASHTO Guide Specifications [5]. The tensile strength of CFRP is reduced by an environmental reduction factor of 0.85 and an additional strength reduction factor of 0.85. To prevent both creep rupture and fatigue failure of CFRP, the maximum stress level in the FRP is computed using elastic finite element analysis for all sustained loads plus maximum cyclic loads moment. The design stresses should be less than 0.55 times the design ultimate tensile strength of CFRP.

To a large extent, the effectiveness of the CFRP strengthening system depends on the bond strength between FRP and concrete. At the interface, shear stresses act parallel to the interface and peeling stresses act normal to the interface. As the FRP thickness increases, the failure mode increasingly becomes debonding of the FRP as the interface stresses increase. Weak adhesive or improper adhesive application may result in a bond failure distinguished by delamination that emanates from the FRP ends and proceeds to shear-critical cracking and sudden failure. Hence, ACI 440.2R-08 [4] requires minimum bond strength of 200 psi as determined by the pull-off test per ICRI No. 03739 [11]. Furthermore, the ACI design guidelines limit the effective strain that CFRP can be designed for, which depends on the concrete strength, the properties of the FRP laminate, and the active bond length over which the majority of bond stress is maintained. In this project, the calculated effective strain of CFRP is within the allowable limit.

When an externally bond FRP system is installed in a dry condition, achieving the required bond strength is not a challenging problem. Nevertheless, proper concrete substrate preparation is crucial for the bond strength. Sand-blasting or other mechanical means is required in order to remove dirt and marine growth, and to achieve a rough surface for strong bond. Prepare the concrete surface profile to achieve CSP 3 or higher per ICRI Guideline No. 03732 [6]. The ambient temperature at the time of the system installation should be generally within the range of 50° and 90°F (10° and 32°C). In order to achieve satisfactory bond performance, particular attention should be given to the concrete surface moisture condition. The CFRP should be bonded onto a dry concrete surface dry in accordance with engineering requirements and in compliance with product manufacturer's installation guidelines. The system manufacturer's installation procedure should be followed.

Movements of active cracks may cause delamination or fiber crushing in externally bonded FRP systems. Water penetration through unrepaired cracks may deteriorate the bond between FRP and

concrete substrate. Therefore, it is important that all substrate cracks wider than 0.004 inch be filled using pressure injection of epoxy before an externally bonded FRP system is installed.

3.5 Spall Repair

The condition survey identified a limited number of concrete spalls on the keel slabs of the end bays in the pontoons. The spalls vary in size and depths. In general, large spalls are to be repaired with suitable concrete patch materials such as polymer modified concrete. Small spalls with a depth less than 3/4 inch have little effect on structural integrity, but their effect on durability of the pontoons is evaluated on a case-by-case basis. If necessary, small spalls are also to be repaired with patch repair.

Polymer modified concrete is recommended for this application due to its improved bond strength and resistance to water or chemical penetration and freezing-thawing damages. Since the depths of all spalls are less than 1.5 inch, the patch material would be polymer modified cement mortar without coarse aggregates.

The patch repair should follow the industry standard practice in ACI 546R [8]. The key requirements for the repair include

- The concrete substrate must be clean, dry and sound. Prepare the concrete surface profile to achieve CSP 5per ICRI Guideline No. 03732 [6]. Wet surfaces may be dried with artificial heat or dehumidifier.

- Completely remove all substances detrimental to bonding, such as dirt, chemical contaminants, and weak, loose, or unsound concrete.

- Patch perimeter should be sawcut to a depth of 0.5 inch or more, as patch repair materials cannot be feather-edged.

- Conduct bond tests with the patch repair to ensure proper surface preparation and adequate bond strength. Adhesion tests should exhibit failure in the concrete, not at the interface. The bond strength must be greater than 200 psi.

- The selection and application of the repair materials are to follow the guidelines in ACI E706 [9] and the material manufacturer's recommendations.

3.6 Recommended Repair Plan

This investigation concludes that no single repair measure can adequately address all of the critical issues in this repair project. The best strategy is to implement a combination of repair measures, including crack repair with epoxy injection, external post-tensioning, structural strengthening with externally bonded CFRP, and patch repairs of spalls.

Appendix A provides a recommended repair plan. Specific procedures are summarized below.

1. *The keel slabs and bottom bolt beams at the end bays*: Repair the cracks as shown on the repair plan using epoxy injection in a dry condition; install the transverse post-tensioning; repair concrete spalls with patch repair; installation of a CFRP strengthening system over selected areas as shown on the plan in a dry condition.

2. *The top slabs and top bolt beams at the end bays*: Install the transverse post-tensioning; and installation of a CFRP strengthening system over selected areas as shown on the plan.

3. *The end walls*: Monitor cracks on the end walls during the pontoon joining process. If any new crack develops or old repaired crack re-opens, repair the crack with epoxy injection and then install an externally bonded CFRP system over the cracks on the interior surface of the pontoon's end bay.

4. *The middle part of Pontoon W where transverse post-tensioning was applied*: Repair the cracks as shown on the repair plan using epoxy injection in a dry condition; repair concrete spalls with patch repair; installation of a CFRP strengthening system over selected areas as shown on the plan in a dry condition.

4 Technical References

[1] C09 Committee, "Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM International, 2011.

[2] ACI Committee 224.1R, *Causes, evaluation, and repair of cracks in concrete structures*. Farmington Hills, Mich.: American Concrete Institute, 2007.

[3] C09 Committee, "Specification for Epoxy-Resin-Base Bonding Systems for Concrete," ASTM International, 2010.

[4] ACI Committee 440.2R, *Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures*. Farmington Hills, Mich.: American Concrete Institute, 2008.

[5] AASHTO, "Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements." 2012.

[6] International Concrete Repair Institute, *Guideline for Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays*, 1997.

[7] A. Mirmiran, National Cooperative Highway Research Program, National Research Council (U.S.). Transportation Research Board, and American Association of State Highway and Transportation Officials, *Recommended construction specifications and process control manual for repair and retrofit of concrete structures using bonded FRP composites*. Washington, D.C.: Transportation Research Board, 2008.

[8] ACI Committee 546R, *Concrete repair guide*. Farmington Hills, Mich.: American Concrete Institute, 2004.

[9] ACI Committee E706, "Vertical and Overhead Spall repair by Hand Application." American Concrete Institute, 2005.

[10] ACI Committee 224R-01, *Control of Cracking in Concrete Structures*, American Concrete Institute, 2012.

[11] International Concrete Repair Institute, *Guideline to Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Mate*, 2004

5 Project Documents

/1/ Aberdeen Crack Mappings, 2012

/2/ Buckland & Taylor, 2012, "Response to KG Serial Letters and Buckland & Taylor LTD Independent Review"

/3/ Glosten Associates, 2010, "SR-520 Floating Bridge Replacement 21-Foot Truss Structure Wind and Wave Load Analysis"

/4/ Glosten Associates, 2010, "SR 520 Floating Bridge Replacement 21-Foot Truss Structure Ballasting Analysis".

/5/ KGM, 2012, "Cycle 2-6 Post-Tensioning Tendon Profiles"

/6/ KGM, 2012, "Pontoon 3A Repair Modifications"

/7/ KGM, 2012, "Type 1-1A and Type 3-3A Pontoon Drawings"

/8/ KGM, 2012, "Type 1-1A & 3A Repair"

/9/ KGM, 2012, "Tendon Profiles for Cycles 2-6"

/10/KPFF Consulting Engineers, 2012, "Floating Bridge Superstructure, Volume 5, East High Rise Design Properties"

/11/ KPFF Consulting Engineers, 2012, "Floating Bridge Superstructure, Volume 5, Low Rise Design Properties"

/12/ KPFF Consulting Engineers, 2012, "Floating Bridge Superstructure, Volume 5, West High Rise Design Properties"

/13/ KPFF Consulting Engineers, 2012, "Pontoon Column Connection Details"

/14/ KPFF Consulting Engineers, 2012, "Pontoon Column Foundation Plans"

/15/ KPFF Consulting Engineers, 2012, "Pontoon Re-Analysis Memo"

/16/ Overlay Crack Maps for Pontoons V and W (2012)

/17/ PSI Internal Crack Mappings for Pontoons V and W (2012)

/18/ State of Washington Department of Transportation (WSDOT) Structural Design Calculations:
Volume 6 - General/Common Pontoon Calculations
Volume 7 - Longitudinal Pontoon (Type I/IA) - Local Wall Design - Out of Plane - 1 of 2

Volume 8 - Longitudinal Pontoon (Type I/IA) - Local Wall Design - Out of Plane - 2 of 2
Volume 9 - Cross Pontoon (Type 3/3A) - Local Wall Design - Out of Plane - 1 of 3
Volume 10 - Cross Pontoon (Type 3/3A) - Local Wall Design - Out of Plane - 2 of 3
Volume 11 - Cross Pontoon (Type 3/3A) - Local Wall Design - Out of Plane - 3 of 3
Volume 17 - Local Allowable Elevated Structure Reactions and In Plane Wall Design
Volume 18 - Pontoon Global Capacities
Volume 19- Pontoon Joint Global Capacities
Volume 20 - Global Demand/Capacities Checks Including Allowable Bolt Tension - 1 of 3
Volume 21 - Global Demand/Capacities Checks Including Allowable Bolt Tension - 2 of 3
Volume 22 - Global Demand/Capacities Checks Including Allowable Bolt Tension - 3 of 3
Volume 24 - Bolt Beam & PT Tendon Anchorage Zones"

/19/ WSDOT Letter 0198 - Attachment 1 - LP3 Markup, 2012

/20/ WSDOT Letter 0198 - Attachment 2 - PT Tendon Profile Plan Sheets 1-14, 2012

/21/ WSDOT Letter 0198 - Attachment 3 - _Draft Plan Sheets EW1-EW4, 2012

/22/ WSDOT Letter 0198 - Rev M11 and PCP PT Plan Sheets, 2012

/23/ WSDOT, 2011, "Appendix M11- Conformed Combined Pontoon Minimum Technical Requirements"

/24/ WSDOT, 2011, "Appendix M22- Pontoon Minimum Technical Requirements"

/25/ WSDOT, 2011, "Appendix M23 - Outfitting and Assembly Min Tech Requirements"

/26/ WSDOT, "Appendix S02 - Design Criteria for Essential Bridges"

/27/ WSDOT, 2010, "Appendix S11- Criteria for bridges subjected to Light rail loading"

/28/ WSDOT, 2012, "Responses to KG Serial Letters and Buckland & Taylor LTD Independent Review"

6 Appendix A - Repair Plan

Table A-1 lists the repair measures and the FRP strengthening options, based on the condition survey. The features which require repair measure or FRP strengthening are illustrated in Figures A-1 to A-4. The numbering designation employed is similar to what is used in the condition survey notes, which are provided in a separate package.

Table A-1 Pontoon V East End Wall and Keel Slab Crack Mapping

	Location Designation	Feature	Length (in.)	Max Width (in.)	Depth (in.)	Repair Measure	FRP Strengthening
Pontoon V - East Side Keel Slab	1.1	Form Joint				N/A	
	1.2	Patch				N/A	
	1.3	Extra Piece				N/A	
	1.4	Form Joint				N/A	
	1.5	Rough Area				N/A	
	1.6	Crack	50	0.004		Epoxy Injection	N/A
	2.1	Crack	6	0.004		Epoxy Injection	Y
	2.2	Crack	27	0.004		Epoxy Injection	Y
	2.3	Crack	60	0.006		Epoxy Injection	Y
	2.4	Crack	25	0.006		Epoxy Injection	Y
	2.5	Crack	10	0.004		Epoxy Injection	Y
	2.6	Crack	47	0.006		Epoxy Injection	Y
	2.7	Epoxy Repair				N/A	
	2.8	Crack	27	0.004		Epoxy Injection	Y
	2.9	Crack	45	0.006		Epoxy Injection	Y
	2.10	Crack	4	0.004		Epoxy Injection	Y
	2.11	Crack	50	0.006		Epoxy Injection	Y
	2.12	Crack	7	0.004		Epoxy Injection	Y
	2.13	Crack	60	0.006		Epoxy Injection	Y
	2.14	Crack	63	0.006		Epoxy Injection	Y
	2.15	Rough Area				N/A	
	2.16	Extra Piece				N/A	
	3.1	Crack	17	0.004		Epoxy Injection	Y
	3.2	Crack	60	0.006		Epoxy Injection	Y
	3.3	Crack	12	0.004		Epoxy Injection	Y
	3.4	Crack	10	0.004		Epoxy Injection	Y
	3.5	Crack	32	0.016		Epoxy Injection	Y
	3.6	Crack	60	0.009		Epoxy Injection	Y
	3.7	Crack	25	0.006		Epoxy Injection	Y
	3.8	Crack	28	0.004		Epoxy Injection	Y
	3.9	Crack	47			Epoxy Injection	Y
	3.10	Epoxy Repair				N/A	
	3.11	Epoxy Repair				N/A	
	3.12	Crack	48	0.004		Epoxy Injection	Y
	3.13	Rough Area				N/A	
	3.14	Crack	61	0.006		Epoxy Injection	Y
	3.15	Crack	50	0.006		Epoxy Injection	Y
	3.16	Rough Area				N/A	
	3.17	Crack	50	<0.004		N/A	Y
	3.18	Crack	24	<0.004		N/A	Y
	4.1	Crack	12	<0.004		N/A	Y
	4.2	Crack	60	0.006		Epoxy Injection	Y
	4.3	Crack	36	0.004		Epoxy Injection	Y
	4.4	Crack	30	0.006		Epoxy Injection	Y
	4.5	Epoxy Repair				N/A	
	4.6	Crack	24	0.004		Epoxy Injection	Y
	4.7	Crack	30	0.006		Epoxy Injection	Y
	4.8	Crack	60	0.01		Epoxy Injection	Y
	4.9	Epoxy Repair				N/A	
	4.10	Crack	30	0.004		Epoxy Injection	Y
	4.11	Crack	36	0.004		Epoxy Injection	Y
	4.12	Crack	54	0.004		Epoxy Injection	Y
	4.13	Crack	50	0.006		Epoxy Injection	Y
	4.14	Rough Area				N/A	
	4.15	Crack	48	0.004		Epoxy Injection	N/A
	4.16	Rough Area				N/A	
	4.17	Large Spall (exposed rebar)	34	18	4	Patch (Polymer Modified Concrete)	Y
	4.18	Honeycombing	60	60		Patch (Polymer Modified Concrete)	Y
	5.1	Crack	26	<0.004		N/A	Y
	5.2	Crack	78	0.004		Epoxy Injection	Y
	8.1	Bugholes				N/A	
	8.2	Bugholes				N/A	
	9.1	Extra Piece				N/A	

	10.1	Small Spall	2.5	1.5	0.25	N/A	N/A
	12.1	Uneven Surface (Imperfection)	2	1		N/A	
	13.1	Uneven Surface (Imperfection)	1	1		N/A	
	14.1	Form Joint	36			N/A	
	15.1	Extra Piece				N/A	
	15.2	Small Spall	1	1	<0.25	N/A	
Pontoon V - West Side Keel Slab	1.1	Extra Piece				N/A	
	1.2	Rough Area			0.125	N/A	
	1.3	Crack	61	<0.004		N/A	Y
	1.4	Extra Piece			0.5	N/A	
	1.5	Crack	60	0.004		Epoxy Injection	Y
	1.6	Honeycombing	48	12	0.1875	N/A	
	1.7	Extra Piece	19			N/A	
	1.8	Rough Area				N/A	
	1.9	Extra Piece				N/A	
	2.1	Crack	60	0.01		Epoxy Injection	Y
	2.2	Crack	61	0.006		Epoxy Injection	Y
	2.3	Crack	1	0.02		Epoxy Injection	Y
	2.4	Crack	18	0.006		Epoxy Injection	Y
	2.5	Crack	60	0.016		Epoxy Injection	Y
	2.6	Extra Piece				N/A	
	2.7	Crack	60	0.006		Epoxy Injection	Y
	2.8	Crack	60	0.006		Epoxy Injection	Y
	2.9	Crack	24	0.006		Epoxy Injection	Y
	2.10	Extra Piece				N/A	
	2.11	Crack	61	0.009		Epoxy Injection	Y
	2.12	Crack	48	0.006		Epoxy Injection	Y
	2.13	Rough Area				N/A	
	2.14	Crack	18	0.004		Epoxy Injection	N/A
	2.15	Small Spall	9	6	0.5	Patch (Polymer Modified Concrete)	Y
	3.1	Crack	40	0.006		Epoxy Injection	Y
	3.2	Extra Piece				N/A	
	3.3	Crack	24	0.01		Epoxy Injection	Y
	3.4	Crack	42	0.006		Epoxy Injection	Y
	3.5	Crack	60	0.016		Epoxy Injection	Y
	3.6	Crack	48	0.009		Epoxy Injection	Y
	3.7	Crack	30	0.006		Epoxy Injection	Y
	3.8	Extra Piece				N/A	
	3.9	Crack	60	0.007		Epoxy Injection	Y
	3.10	Extra Piece				N/A	
	3.11	Crack	48	0.006		Epoxy Injection	Y
	3.12	Crack	18	0.006		Epoxy Injection	Y
	3.13	Crack	30	0.006		Epoxy Injection	Y
	3.14	Crack	48	0.004		Epoxy Injection	Y
	3.15	Crack	30	0.01		Epoxy Injection	Y
	3.16	Crack	24	0.007		Epoxy Injection	Y
	3.17	Crack	60	0.012		Epoxy Injection	Y
	3.18	Crack	36	0.004		Epoxy Injection	Y
	3.19	Epoxy Repair				N/A	
	3.20	Crack	72	0.004		Epoxy Injection	Y
	3.21	Crack	42	0.004		Epoxy Injection	Y
	3.22	Crack	18	0.004		Epoxy Injection	Y
	3.23	Rough Area				N/A	
	3.24	Crack	48	0.004		Epoxy Injection	Y
	3.25	Extra Piece				N/A	
	3.26	Extra Piece				N/A	
	4.1	Extra Piece				N/A	
	4.2	Extra Piece				N/A	
	4.3	Crack	68	0.009		Epoxy Injection	Y
	4.4	Crack	48	0.009		Epoxy Injection	Y
	4.5	Crack	60	0.006		Epoxy Injection	Y
	4.6	Crack	60	0.012		Epoxy Injection	Y
	4.7	Crack	30	0.004		Epoxy Injection	Y
	4.8	Crack	24	0.004		Epoxy Injection	Y
	4.9	Rough Area				N/A	
	4.10	Crack	60	0.006		Epoxy Injection	Y
	4.11	Crack	18	0.006		Epoxy Injection	Y
	4.12	Rough Area				N/A	
	4.13	Small Spall	9	6.5	0.5	Patch (Polymer Modified Concrete)	Y

	5.1	Crack	30	0.004		Epoxy Injection	Y
	5.2	Crack	60	0.004		Epoxy Injection	Y
	5.3	Form Joint				N/A	
	6.1	Extra Piece				N/A	
	6.2	Small Spall	15	8	0.25	N/A	
	6.3	Extra Piece				N/A	
	7.1	Indent	9	6.25	0.5	N/A	N/A
	7.2	Extra Piece				N/A	
	7.3	Extra Piece				N/A	
	8.1	Extra Piece				N/A	
	8.2	Extra Piece				N/A	
	8.3	Epoxy Repair	1	1		N/A	
	8.4	Indent	7		0.75	N/A	N/A
	8.5	Extra Piece				N/A	
	9.1	Indent	9	6.625	0.375	N/A	N/A
	9.2	Extra Piece				N/A	
	10.1	Epoxy Repair				N/A	
	11.5	Extra Piece				N/A	
	11.6	Extra Piece				N/A	
	11.7	Extra Piece				N/A	
	12.4	Extra Piece				N/A	
	13.6	Extra Piece				N/A	
	13.7	Extra Piece				N/A	
	14.3	Extra Piece				N/A	
	14.4	Extra Piece				N/A	
Pontoon W - South Keel Slab	1.1	Epoxy Repair				N/A	
	2.1	Crack	10	0.02		Epoxy Injection	Y
	2.2	Crack	32	0.008		Epoxy Injection	Y
	2.3	Crack	32	0.008		Epoxy Injection	Y
	2.4	Crack	60	0.016		Epoxy Injection	Y
	2.5	Crack	60	0.012		Epoxy Injection	Y
	2.6	Crack	60	0.03		Epoxy Injection	Y
	2.7	Crack	60	0.08		Epoxy Injection	Y
	2.8	Crack	60	0.02		Epoxy Injection	Y
	2.9	Crack	60	0.02		Epoxy Injection	Y
	2.10	Crack	14	0.03		Epoxy Injection	Y
	3.1	Large Spall	26		2	Patch (Polymer Modified Concrete)	Y
	4.1	Crack	60	0.025		Epoxy Injection	Y
	4.2	Crack	60	0.02		Epoxy Injection	Y
	4.3	Crack	60	0.02		Epoxy Injection	Y
	4.4	Crack	70	0.02		Epoxy Injection	Y
	4.5	Crack	70	0.02		Epoxy Injection	Y
	4.6	Epoxy Repair	48	0.012		N/A	
	4.7	Crack	44	0.02		Epoxy Injection	Y
	4.8	Crack	65	0.016		Epoxy Injection	Y
	4.9	Crack	44	0.009		Epoxy Injection	Y
	4.10	Crack	16	0.009		Epoxy Injection	Y
	4.11	Crack	12	0.012		Epoxy Injection	Y
	6.1	Epoxy Repair	5			N/A	
	6.2	Crack	24	0.012		Epoxy Injection	N/A
	6.3	Crack	25	0.016		Epoxy Injection	N/A
	8.1	Extra Piece				N/A	
	8.2	Extra Piece				N/A	
	13.1	Exposed Rebar	20			N/A	
Pontoon W - Middle Section Keel Slab	1.1	Extra Piece				N/A	
	2.1	Bugholes	7	4.5	0.25	N/A	
	2.2	Uneven Surface (Imperfection)			0.5	N/A	
	3.1	Uneven Surface (Imperfection)				N/A	
	3.2	Extra Piece				N/A	
	5.1	Uneven Surface (Imperfection)	9	2		N/A	
	5.2	Epoxy Repair	7			N/A	
	5.3	Crack	13.5	0.016		Epoxy Injection	Y
	5.4	Crack	16	0.012		Epoxy Injection	Y
	5.5	Crack	6	0.009		Epoxy Injection	Y
	6.1	Uneven Surface (Imperfection)	36			N/A	N/A
	6.2	Uneven Surface (Imperfection)	6		0.5	N/A	N/A
	6.3	Large Spall	39		0.75	Patch (Polymer Modified Concrete)	N/A
	6.4	Uneven Surface (Imperfection)				N/A	
	6.5	Small Spall	42	1.75	0.5	N/A	

	7.1	Honeycombing	4.5	2.5	0.25	N/A	
	7.2	Extra Piece				N/A	
	7.3	Extra Piece				N/A	
	7.4	Small Spall	5.5	1.75	0.75	N/A	N/A
	10.1	Crack	24	0.01		Epoxy Injection	Y
	10.2	Crack	10	0.016		Epoxy Injection	N/A
	11.1	Small Spall	3	2.5	0.25	N/A	
	11.2	Large Spall	25	15.5	0.75	Patch (Polymer Modified Concrete)	Y
	11.3	Large Spall	24	15	0.75	Patch (Polymer Modified Concrete)	Y
	11.4	Small Spall	3.5	2	0.5	Patch (Polymer Modified Concrete)	Y
	11.5	Crack	26	0.01		Epoxy Injection	Y
	11.6	Large Spall	16	3.5	0.5	Patch (Polymer Modified Concrete)	Y
	16.1	Large Spall	60	28.5	2	Patch (Polymer Modified Concrete)	Y
	16.2	Small Spall	24		1	Patch (Polymer Modified Concrete)	Y
	19.1	Extra Piece				N/A	
	20.1	Large Spall	45	14	1	Patch (Polymer Modified Concrete)	Y
Pontoon W - North Section Keel Slab	1.1	Small Spall	5	1	<0.25	N/A	
	1.2	Crack	54	0.016		Epoxy Injection	Y
	1.3	Crack	10	0.012		Epoxy Injection	Y
	2.1	Bugholes	2.5	2		N/A	
	3.1	Honeycombing	5.5	5	0.25	N/A	
	3.2	Small Spall	5		1	Patch (Polymer Modified Concrete)	Y
	4.1	Crack	31	0.016		Epoxy Injection	Y
	4.2	Crack	60	0.03		Epoxy Injection	Y
	4.3	Crack	30	0.012		Epoxy Injection	Y
	4.4	Crack	12	0.009	1	Epoxy Injection	Y
	4.5	Small Spall	2	2		N/A	
	5.1	Crack	6	0.01		Epoxy Injection	N/A
	6.1	Small Spall	4	3	0.25	N/A	
	7.1	Epoxy Repair	65			N/A	
	8.1	Uneven Surface (Imperfection)				N/A	
	9.1	Small Spall			0.375	N/A	
	10.1	Small Spall	3.5	1.5	0.25	N/A	
	10.2	Crack	16	0.006		Epoxy Injection	N/A
	14.1	Small Spall	0.75	0.75	0.375	N/A	

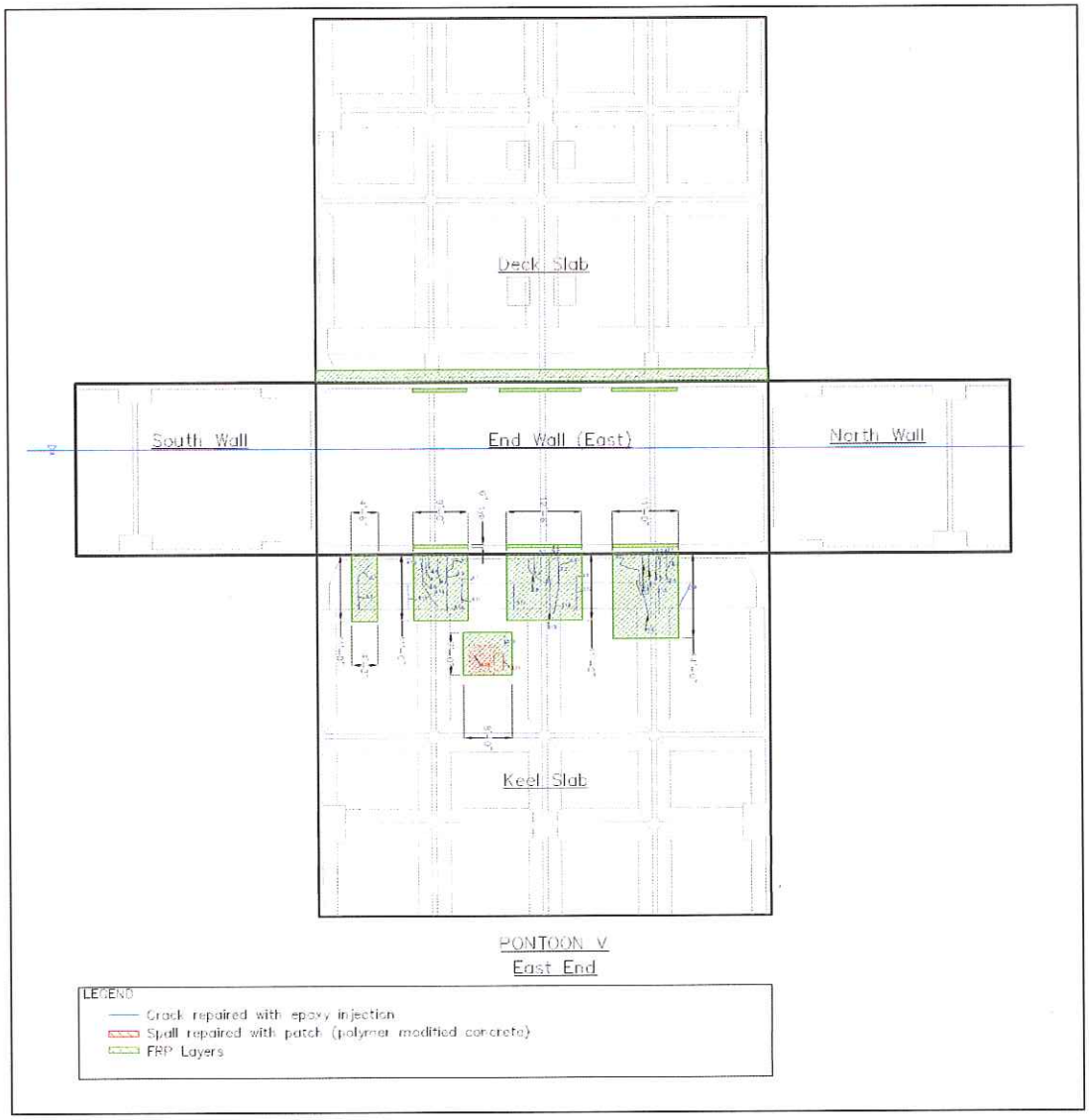

Figure A-1 Pontoon V East End Wall and Keel Slab Repair Plan

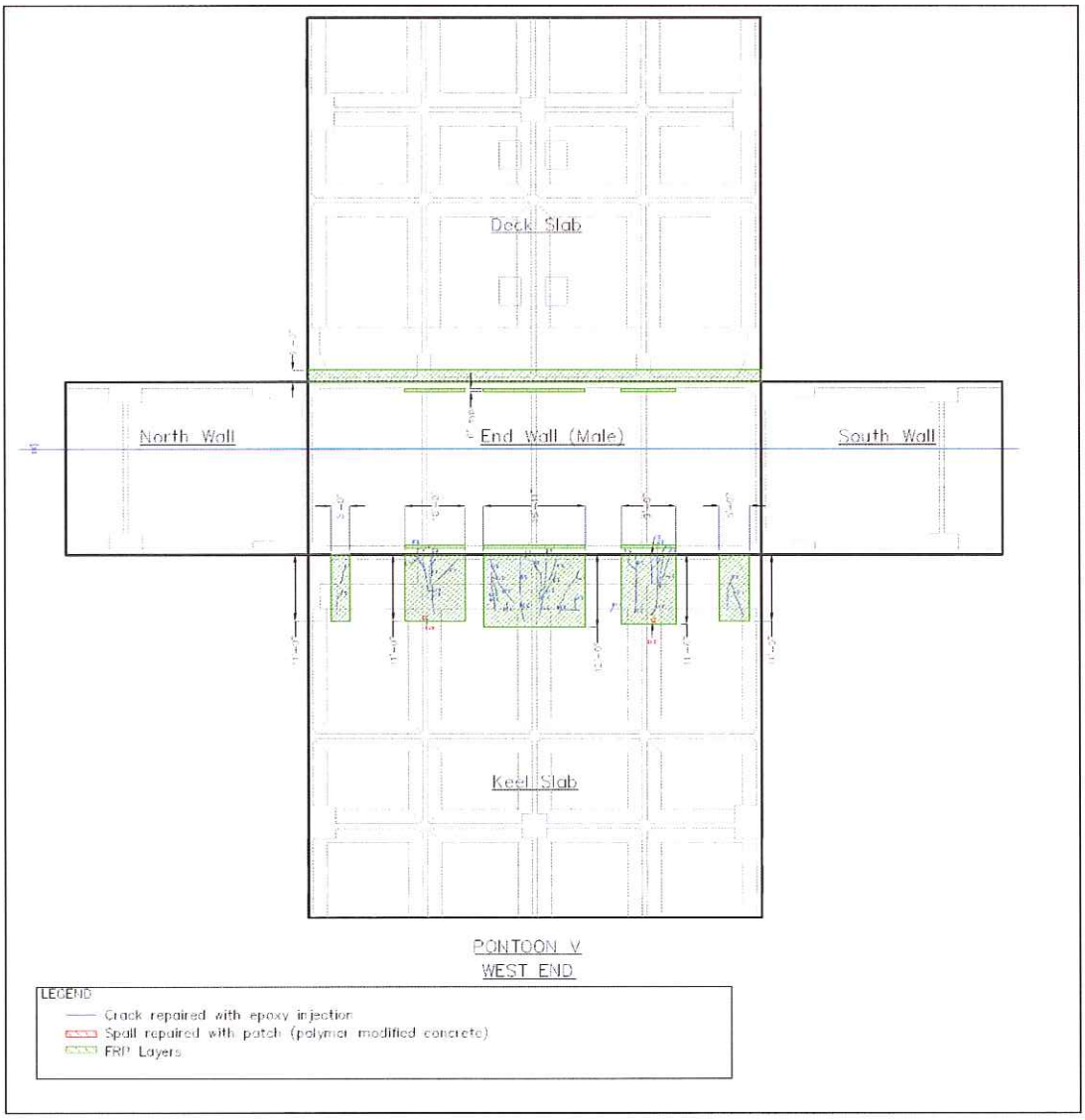

Figure A-2 Pontoon V West End Wall and Keel Slab Repair Plan

Figure A-3 Pontoon W North End Keel Slab Repair Plan

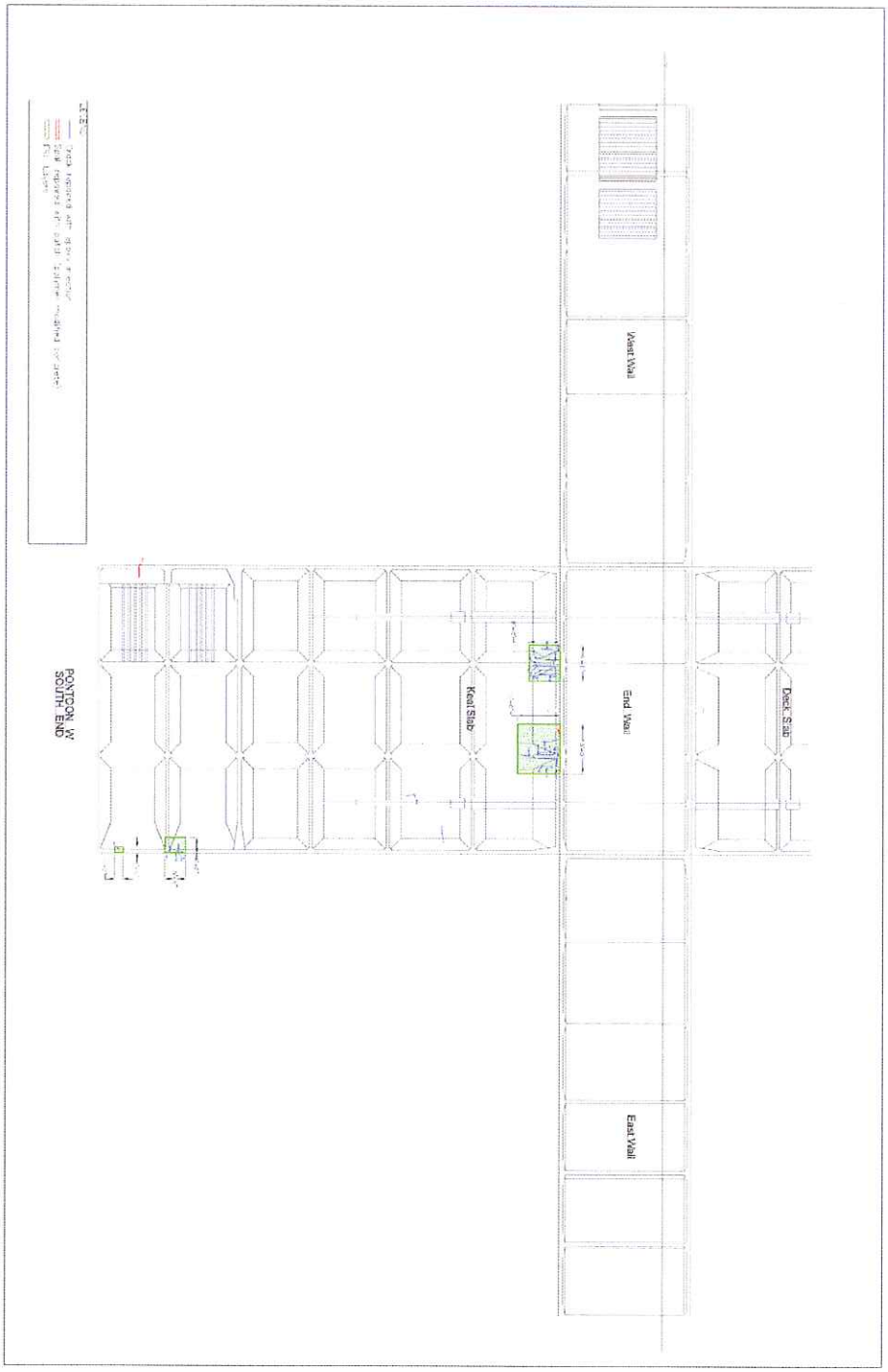

Figure A-4 Pontoon W South End Wall and Keel Slab Repair Plan