HERBERT C. BONNER BRIDGE
Structural Condition Assessment

Bridge #270011, Oregon Inlet, Dare County

Executive Summary

Bridge Description and Location

The Bonner Bridge spans the Oregon Inlet from Bodie Island on the north end to Pea Island on the south end, along the Cape Hatteras National Seashore in Dare County, North Carolina. The structure is 12,865 ± feet long. It is defined at its ends by End Bent No. 1 at Sta. 25+78.88 (on Bodie Island) and by End Bent No. 2 at Sta. 154+43.62 (on Pea Island). The original contract for construction of the Bonner Bridge was awarded by NCDOT to McLean Contracting Company, Baltimore, MD on February 15, 1962. Construction of the bridge was completed on April 7, 1964.

Consultant Team and Scope of Work

The team of Alpha & Omega Group, P.C. (A&O), H. W. Lochner, Inc. (Lochner), Wiss, Janney, Elstner, Associates, Inc. (WJE), and Ko and Associates, P.C. (Ko) was selected by the Bridge Maintenance Unit of the North Carolina Department of Transportation (NCDOT) in December, 2005 to perform an **In-depth Structural Condition Assessment** of the Herbert C. Bonner Bridge.

A&O was individually tasked with performing a **routine biennial bridge inspection of the Bonner Bridge according to National Bridge Inspection Standards (NBIS)**, from the level of the high water mark up (above water), inclusive of the pile caps. An underwater NBIS bridge inspection, from the high water mark down, was not included in the scope of work. Underwater NBIS inspections are routinely performed by NCDOT using in-house personnel. However, an underwater assessment was performed by Lochner for the purposes of the in-depth structural condition assessment.

The purpose of the **In-depth Structural Condition Assessment** was to supplement the NBIS Bridge Inspection, determine the current condition of the bridge, identify structural deficiencies, determine load carrying capacities of the structural components, develop repair recommendations, and provide an engineer's opinion of construction costs to keep the bridge open and functional at current design loads until the year 2016 (a 10-year service life.)

The overall project was divided into four main tasks:

Task 1: Perform the NBIS bridge inspection throughout the entire length of the bridge
Task 2: Perform the assessment of the high level spans (Spans 129-166)
Task 3: Perform the assessment of the approach spans (Spans 1-128B and Spans 167-204)

Task 4: Conduct a field load test with the assistance of NCDOT

The primary area of responsibility of each team member was as follows:

A&O: NBIS bridge inspection, overall project management and coordination of in-depth assessment, quantification of deficiencies, and assembly of repair recommendations and cost estimates.

Lochner: Structural analysis of the bents in the high level spans, steel superstructure analysis, underwater assessment of the substructure piles, and assistance with development of repair recommendations and cost estimates.

WJE: Concrete strength testing, corrosion potential testing, ultrasonic pulse velocity measurements, petrographic examinations, chloride analysis, carbonation testing, and assisting with repair recommendations and cost estimates for both the high level and approach spans.

Ko: NBIS load rating, structural analysis of the approach span bents, crutch bents, and assisting with the development of repair recommendations and cost estimates.

The scope of the In-depth Assessment did not include the Fishing Catwalks or the Fender System. Please refer to the NBIS Bridge Inspection Report for condition and repair recommendations for the Fishing Catwalks and the Fender System. In addition, scour analysis was not part of the scope and all assumptions regarding scour were based on NCDOT's existing critical scour elevations and the existing pile embedments.

NBIS Biennial Inspection

Purpose

The purpose of the biennial NBIS inspection was to satisfy the requirements of the Federal Highway Administration's (FHWA) National Bridge Inspection Standards and to provide the information necessary to perform a current in-depth structural assessment of the bridge (described below). Title 23 of the Code of Federal Regulations (23 CFR) requires each state to inspect, or cause to be inspected, all highway bridges located on public roads that are fully or partially located within the State's boundaries. 23 CFR also includes requirements and guidelines for the inspection procedures, frequency, and the qualifications of personnel performing the inspections.

Results

Each structural element of the bridge was rated numerically from 0 to 9 based on the observed conditions and the overall condition for each element and the bridge as a whole was rated as either "Good" (7-9), "Fair" (5&6), "Poor"(3&4) or "Critical" (0-2). The bridge elements that received a "Poor" rating included the concrete deck, fishing catwalks (its fencing and attached steel railing), AASHTO Girders, steel bearing assemblies, concrete caps, concrete columns, concrete pile caps, and the steel caps and piles. The overall condition of the bridge was rated as "**POOR**". As a result of the inspection, "Prompt Action" notifications were included in the NBIS Report provided to NCDOT.

The bridge, in its current state, is safe for use by the traveling public and does not require any weight limit posting. Its "poor" rating is an indication of the bridge's short remaining life span.

Assessment Inspection (Above Water and Underwater)

Purpose

The purpose of the Assessment Inspection was to visually observe the representative structural components of the bridge that would be included in the structural analyses or affect the input of the structural analyses. The Assessment Inspection efforts focused on the above water and underwater elements of the bridge that were generally representative of the structural elements to be analyzed. The NBIS inspection involved all elements of the bridge, many of which were not involved in the structural analyses.

Results

Structural Deficiencies Observed in the Superstructure

Conditions observed throughout the superstructure during the visual inspection included:

- delaminated concrete areas in both the original concrete and in the previously patched concrete areas
- spalled concrete areas with exposed reinforcing steel in underside of bridge deck and end diaphragms
- spalled areas at the end of AASHTO girders with exposed prestressing strands
- heavy corrosion of structural steel components and bearings

Superstructure Observations

Spalled Concrete Deck Underside

Spalled Deck and End Diaphragm

Spall at End of Girder

Spall with Exposed Strands on Girder (Prepared for Repair)

Corroded Gusset Plates on Steel Main Span

Corroded Lateral Bracing and Bearing

Structural Deficiencies Observed in the Bents (Above Water)

Conditions observed throughout the bents during the visual inspection included:

- delaminated concrete areas in both the original concrete and in the previously patched concrete areas
- varying degrees of cracking typically located in the columns and the pile caps, whereas the bent caps typically contained only moderate cracking
- surface rust staining, typically on the vertical faces of the pile caps and adjacent to existing cracks
- concrete spalls, frequently with exposed reinforcing steel

Substructure Observations


Spalled and Delaminated Bent Cap


Spalled and Delaminated Sub-cap


Spalled and Delaminated Crutch Bent Strut


Delaminated High Level Bent Strut


Delaminated Column with Rust Stains


Delaminated Column with Rust and Efflorescence Stains


Delaminated Pile Cap with Heavy Rust Stains


Spalled Sub-Girder with Heavy Rust Stains

Structural Deficiencies Observed in the Foundations (Underwater)

Conditions observed as typical throughout the foundations during the visual inspection included:

- widespread vertical cracking (hairline to 1/16") throughout the original 22" octagonal pre-stressed concrete piles
- patches of corrosion loss and light to moderate areas of corrosion on the steel H-pile crutch bents, without significant loss of cross-section
- two jacketed piles below the waterline in good condition
- spalled lower edges of six pile caps that exhibit exposed reinforcing steel
- cracks to 1/4" wide generally running parallel to the pile cap perimeter on the undersides of more than half the pile caps
- significant spalling of the concrete cover of nine of the concrete piles, three of which exhibit exposed reinforcing steel and steel prestressing strands
- deterioration of pile splicing at one of the piles
- horizontal cracking in four piles near the pile caps
- widespread horizontal cracks, typically to 3/16" wide, in crutch bent caps generally located between 1' and 1.5' above the lower edges (66" diameter concrete cylinder pile bents)
- delaminated concrete area near the waterline of one crutch bent pile (20" square prestressed concrete pile)

Materials Sampling (In-Situ) and Testing

Purpose

The purpose of materials sampling and testing was to determine the current general condition of the bridge's primary structural material–concrete. A sampling of the existing concrete within the various elements of the bridge was performed in order to test representative samples in the laboratory. The Bonner Bridge's primary structural concrete elements include the following:

- prestressed precast concrete piles
- cast-in-place conventionally reinforced pile caps, bents, and bent caps
- prestressed precast reinforced concrete girders
- cast-in-place conventionally reinforced concrete bridge deck

The concrete evaluation and testing work included close visual examination of selected structural elements, representative materials sampling and testing, and field testing and reporting.

Results

The results of the concrete materials testing are summarized in general terms as follows:

Prestressed concrete piles

- Concrete samples were not taken from the concrete piles due to the relatively fair condition of the piles.

<u>Cast-in-place pile caps, bents, and bent caps</u>

- The compressive strengths of the representative concrete samples from the caps and various bents frame components measured between 3,830 pounds per square inch (psi) to 8,430 psi. The original design called for a minimum concrete compressive strength of 3,000 psi.
- Very high chloride content was found at depths less that 1.5" in the concrete samples taken from the bents and pile caps. Chloride content significantly above the corrosion threshold for internal steel reinforcing was found at depths up to 4.5" in the pile caps and columns.

<u>Prestressed concrete girders</u>

- The compressive strengths of the representative concrete samples from the girders measured between 6,200 psi and 8,310 psi. The original design called for a minimum concrete compressive strength of 5,000 psi.
- Chloride content levels in the precast concrete girders were also found to be significantly above the corrosion threshold at depths of 0.5" to 1.0", but at depths of 1.5", corresponding to the depth of reinforcing steel, the chloride content levels were typically at or below the corrosion threshold.

<u>Cast-in-place concrete bridge deck</u>

- The compressive strengths of the representative concrete sample from the deck measured between 5,310 psi to 7,470 psi. The original design called for a minimum concrete compressive strength of 3,000 psi.
- The chloride content levels measured in the cast-in-place concrete bridge deck were found to be significantly high at depths of 0.5" to 1.0", but at depths of 1.5", corresponding to the depth of reinforcing steel, the chloride content levels were typically much lower.

Half Cell Potential (HCP) measurements on the pile caps typically yielded potential measurements more negative than -350mV which was indicative of areas of high potential for corrosion activity. These measurements were also consistent with the field observations where delamination and cracking in the pile caps was widespread. For the columns and bent cap components of the high level structures, the HCP measurements were typically between -200 and -350mV and represented areas where the probability of corrosion was uncertain. These measurements were also consistent with the observed field conditions of moderate cracking and localized areas of spalling.

In-Depth Structural Analyses

Purpose

The purpose of the In-depth Structural Analysis was to utilize the NBIS report findings, the findings of the Assessment Inspection, and the results of the materials testing to evaluate the bridge's current state and to ascertain what repairs and/or improvements may be recommended in order to keep the bridge open and functional, for current design loads, for an additional anticipated service life of 10 years, (until approximately 2016). The specific tasks performed for the in-depth structural condition assessment included:

- performing a structural analysis to determine load carrying capacities of the structural components of the bridge
- developing repair recommendations
- providing an engineer's opinion of probable construction costs for recommended repairs

Results

<u>Summary of Structural Analyses for the Approach Span Bents</u>

The analysis results for Bents 1 through 128B and Bents 167 through 186 indicate that they are adequate to carry the current design loads with the following exception: The calculated axial loads for the most heavily loaded piles were greater than the 50 ton pile capacity listed in the original plans. The analysis results for the model that represents Bents 187 through 200 indicate high shear stress in the bent cap area supporting the exterior girders. In the analysis, these bents were assumed to be supported entirely by their retrofitted crutch bents, and any potential support from the original 22" octagonal piles was ignored. However, for Bents 187 through 195 and Bents 199 and 200, there is an original 22" octagonal pile located near the area of high shear. Since there were no signs of shear cracking in the bent cap, it is reasonable to assume that these octagonal piles are still providing some support to the bent cap. However, if the mud line were to recede or shear cracks were observed during future inspections, shear strengthening would be needed.

At Bents 196 through 198 NCDOT documentation indicates that the tip elevation of the octagonal piles is near the current mud line. Although shear cracking in the bent cap was not evident in these three bents, it is unlikely that the original octagonal piles are providing significant support to the bent cap. Therefore, it is recommended that an additional concrete subcap be installed beside the existing exterior subcaps at the location of the exterior girder at Bents 196 through 198. Based on the current observed conditions, this repair is not needed immediately. However, it is recommended that it be done with the substructure repairs recommended in this report due to the ever-changing environmental conditions and the ever-changing mud line.

<u>Summary of Structural Analyses for the Bents in the High Level Spans</u>

The analysis results for the models that represent Bents 129 through 166 indicate that the bent caps, struts, columns, and pile caps are adequate to carry current design loads, with the following exception: The calculated axial loads for the most heavily loaded piles exceeded the 50 ton pile capacity listed in the original plans.

<u>Pile Capacities for Approach Spans and High Level Spans</u>

Over the past decade or longer, the piles and supporting earth have resisted current truck loadings when the subgrade was above the established critical scour elevations. It is not unusual for piles to support loads considerably in excess of their design loads without any distress, due to the large factors of safety typically used in design. **Therefore, there is currently no need to reduce loading on the bridge by posting.**

The pile loads determined in the analyses were up to 70 tons, with the current HS 20 live load applied. Determining the sufficiency of the piles to support the 70 ton load during a scour event, however, is beyond the scope of this assessment. Therefore it is recommended that NCDOT re-evaluate its previously determined critical scour elevations to determine if the piles possess the capacity to carry the anticipated loads through skin friction and end bearing capacities of the subsurface materials.

Load Test of Spans 186 and 189

The NBIS inspection by A&O revealed severe deterioration in girder G3 of Span 189, with 11 of the 36 strands in the bottom flange broken or deteriorated. With the assistance of NCDOT, WJE conducted an in-place load test on this girder using a loaded truck of known weight. For comparison, the test was also performed on Span 186 which had no severely damaged girders.

In routine rating of bridge girders, standard AASHTO equations are used to distribute the truck load to the individual girders. The results of the load test indicated that these standard equations are overly conservative for this bridge, and that a higher fraction of the truck load is distributed to the adjacent undamaged girders. The test also indicated that even for the most severely deteriorated girder the observed stresses were within allowable limits.

Repair Recommendations

Based on visual inspection and the results of the structural assessment analyses, repairs to various bridge elements are recommended. The purpose of these repairs is to reduce the rate of advancement of deterioration, to maintain the structural capacity of various deteriorated elements, and finally as preventative maintenance. In general, the recommended repairs include shotcrete patching, epoxy resin/chemical grout crack injection, epoxy mortar patching, penetrant sealer application, installation of pile jackets, painting of structural steel, replacing steel bracing components, and steel bearing replacement.

Alternative repair methods evaluated included fiber mesh wrapping, wire wrap and steel strengthening, chloride ion extraction, and comprehensive cathodic protection systems. Fiber mesh wrap, wire wrap methods, and steel strengthening require the concrete substrate to be in sound condition. Therefore, spalls and delaminations would need to be repaired prior to adding any wrap or other strengthening systems. Since strengthening is not required and the repairs are only required to provide ten years of service life, it is the opinion of the consultant team that these alternative repair methods are an unnecessary expense and they were not investigated further. Conventional repair methods will result in a ten-year service life; therefore, chloride extraction and comprehensive cathodic protection systems also would only be considered if the required service life was well beyond ten years.

Summary of Repair Strategy and Engineer's Opinion of Probable Construction Costs

The opinions of probable construction costs presented throughout this assessment were developed from the quantity of cracks, spalls, delaminations, and other deterioration and defects identified during the field investigation. The deterioration and defects are shown graphically in appendix B.1 through B1.10 and quantified in Appendix C. The cost estimates are based on the assumption that all of the repairs are made. Many of the delaminations are small in size and do not merit as high a degree of concern as large delaminated areas. The decision of which specific defects to repair should be made during the development of repair plans. However, if these repairs are delayed, repair costs will likely increase and defective areas left untreated will continue to degrade over time.

Each of the recommended repairs included in the assessment report was classified into one of four groups. **Group A repairs** are recommended to be completed within the next six to twelve months and include:

- jacketing the seven deficient piles identified in the Underwater Assessment
- replacement of the deck expansion joints (continued leaking of water through the joints is causing accelerated deterioration to diaphragms, ends of girders, bearings, caps and the top area of columns)

Group B repairs are to the substructure of the bridge: the substructure cap, column, or pile cap. The substructure components are non-redundant and key elements to the service life of this bridge; therefore, it is recommended that the substructure repairs be completed within the next two years. These repairs include:

- repairing 6,689 CF of spalled and delaminated areas and 1,561 LF of cracking of high level bent members
- repairing 3,669 CF of spalled and delaminated areas and 772 LF of cracking of approach bent members
- applying a penetrant sealer to the member surfaces
- constructing four supplemental caps to provide additional support of the superstructure at Spans 196, 197, and 198

Group C repairs are to the superstructure girders of the bridge. The superstructure components are key elements to the service life of this bridge and therefore it is recommended that the superstructure girder repairs be completed within the next two years. Group C repairs include:

- repairing 3,691 CF of spalled and delaminated areas and 497 LF of cracking on the AASHTO girders
- replacing 16 bearings for the steel spans
- replacement of end diaphragms and lateral bracing in the steel spans

Group D repairs are to the concrete deck and paint on the structural steel of the bridge. It is recommended that these repairs be completed within the next four years. Even though the concrete deck repairs are recommended to be completed within the next four years, if a hole develops in the deck, it could be hazardous to the traveling public; therefore, the deck should be monitored and maintenance repairs performed on an ongoing basis. Group D repairs include:

- repairing the reinforced concrete bridge deck of both the AASHTO girder spans and the steel girder spans
- complete repainting of the structural steel elements

The engineer's opinion of probable construction costs is as follows:

Group A – Pile Jacketing and Expansion Joints:	$ 1,089,000
Group B – High Level Bent Repairs:	$ 14,407,000
Group B – Supplemental Caps for Bents 196, 197, & 198:	$ 161,000
Group B – Approach Bent Repairs:	$ 6,590,000
Group C – Superstructure Repairs – AASHTO Girder Spans:	$ 9,025,000

Group C – Superstructure Repairs – Steel Spans:	$ 309,000
Group D – Superstructure Repairs – Deck and Painting Steel Girders:	$ 11,905,000

Total engineer's opinion of probable construction costs: $43,486,000

Conclusion

The Herbert C. Bonner Bridge is in advanced stages of deterioration and is nearing the end of its lifespan. The bridge is anticipated to be replaced within the next ten years. The findings of the NBIS inspection and in-depth assessment are summarized as follows:

1. The bridge, in its current state, is safe for use by the traveling public and does not require any weight limit posting. However, due to the advanced stages of deterioration, replacement of the Bonner Bridge within the next ten years remains a necessity.
2. Delamination, spalling, and cracking are widespread and the bridge had an overall NBIS rating of "POOR".
3. Testing indicates that the concrete is generally of good quality and strength. However, chloride ions above the corrosion threshold exist to a depth of 4.5" in the columns and pile caps; therefore, active corrosion is occurring and will continue to accelerate.
4. Structural capacities of the bridge components are adequate except for Bent Caps 196, 197, and 198. These caps are overstressed in shear, and it is recommended that additional concrete subcaps be placed to help in carrying the shear load to the crutch bents.
5. Pile loads in several locations were in excess of the 50 ton design capacity, nevertheless the piles have been performing satisfactorily over the past decade provided that the supporting soil substrate is above the critical scour elevation. Pile jackets are recommended for specific deficiencies in seven piles.
6. Re-evaluation of the critical scour elevations is recommended to determine if these elevations need to be revised for a computed 70 ton capacity.
7. Repairs of deteriorated concrete are necessary to minimize the advancement of deterioration, maintain the structural capacity of the bridge, and allow continued use over the next ten years. The repairs have been grouped into four groups – A, B, C, and D.
8. Group A repairs should be made within the next six to twelve months.
9. Group B and C repairs should be made within the next two years
10. Group D repairs should be made within the next four years.

It is anticipated that if these repairs are made properly by an experienced contractor, the Bonner Bridge will be capable of remaining in service and functioning under current design loads for the next ten years.