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Scour and the Test of Time: Herbert C. Bonner Bridge Crossing Oregon Inlet, North Carolina

By Dave Henderson

On Tuesday December 3, 2013, a public news release announced North Carolina Department of Transportation's (NCDOT) closure of NC 12 Herbert C. Bonner Bridge crossing of Oregon Inlet. Inlet dynamics and movement of the 65–feet deep channel coupled with bridge scour jeopardized stability of an interior bent between the navigation span and the southern terminus. A second element of danger loomed over the only highway connection to the NC Outer Banks. A major low pressure system centered over the Midwest would race east, stall off shore, and set up a major Nor'easter in just four days. Rapid response by NCDOT, with collaboration and cooperation of other agencies and private contractors, stabilized the scour condition allowing the bridge to be reopened on Sunday, December 15, 2013. Restoring traffic to the Outer Banks was crucial in advance of the holiday influx of tourists headed south to the 60 miles of barrier islands, seven historic villages, and gateway to Ocracoke Island.

Location and Importance

North Carolina's most celebrated coastal highway, NC 12, and Bonner Bridge play a primary role in tourism industry and economic strength of the region. The route is the critical link in public safety, emergency services, and hurricane evacuation and recovery.

Figure 1—Map of Bonner Bridge over Oregon Inlet

NC 12 begins near the Virginia line at Corolla Lighthouse, passes the site of the Wright Brother's first flight at Kitty Hawk, Roanoke Island home of the first English child born in the America's and the Lost Colony. Via Bonner Bridge, NC 12 crosses Oregon Inlet (Figures 1 and 2), created by a tropical storm in 1846, near Manteo and Nags Head. NC 12 then threads through 70 miles of Cape Hatteras National Seashore passing Hatteras Lighthouse and the Graveyard of the Atlantic.

Figure 2—Aerial photo of Bonner Bridge

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Inside this issue:

Register Now!

2014 NHEC

August 19-22, 2014

Sheraton Hotel
Iowa City, IA

http://www.uiowa.edu/~confinst/nhec2014/index.html

Upcoming Hydraulic Events

May 2014

S	M	T	W	Th	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

June 2014

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July 2014

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27	28	29	30	31		

MAY 2014:

- NHI Course 135010—Oakland, CA - May 6 - 8, 2014
- NHI Course 135056—Atlanta, GA - May 6 - 8, 2014
- NHI Course 135041—Mesquite, TX - May 13 -16, 2014
- NHI Course 135027—Salt Lake City, UT - May 20 - 22, 2014
- NHI Course 135071—Columbus, OH - May 20 - 23, 2014

JUNE 2014:

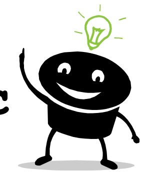
- NHI Course 135056—Columbus, OH - June 3 - 5, 2014
- NHI Course 135090—Baton Rouge, LA - June 3 - 5, 2014
- NHI Course 135027—Columbus, OH - June 10 - 12, 2014
- NHI Course 135048—Concord, NH - June 24 - June 26, 2014

JULY 2014:

- NHI Course 135056—Worcester, MA - July 15 - 17, 2014
- NHI Course 135027—Newington, CT - July 29 - 31, 2014

For more information, please visit the NHI website: https://www.nhi.fhwa.dot.gov/

At the Concept Corner with Eric



Does a 100-Year Flood Produce 100-Year Scour? - Not Necessarily!

You may have heard a bridge owner make a statement along this track: “This bridge has been here for 60 years, it has experienced numerous floods, including a 100-yr flood, and its foundations are perfectly fine.” Perhaps you have made similar remarks yourself. Ideas such as this commonly come up when owner agencies are considering their scour-critical bridge inventories and developing and implementing scour plans of action (POAs). It seems counterintuitive, inefficient, and perhaps even wasteful to spend additional resources to develop and implement a POA for a bridge that ostensibly has no existing or imminent foundation issues, as evidenced by observed scour that is substantially less than the design value. And there’s the rub—the calculated design scour depth does not necessarily co-occur with the scour design flood. In other words, a 100-yr flood, the flood with a 1 percent annual exceedance probability, does not necessarily produce the 100-yr scour depth. The same holds true for floods with other recurrence intervals.

Consider the 100-Year Storm vs. the 100-Year Flood

To better understand this concept, first consider the 100-yr storm. There are multiple reasons why a 100-yr rainfall may fail to generate a corresponding 100-yr flood, including: insufficient storm duration, only partial storm coverage of a watershed (i.e., a portion of the watershed remains dry or receives less rainfall), dry antecedent soil conditions, and watershed regulation practices (such as detention and irrigation), to name a few. More information on this topic can be found on the USGS Water Science School website (http://ga.water.usgs.gov/edu/) by selecting “Surface water” and then browsing under the “Events and Hazards” heading.

Factors that Inhibit Scour Development

In a similar vein, several factors may inhibit the initial full development of scour at a bridge during a flood, as predicted by scour estimation equations and methods. In flume studies of bridge scour conducted in sand, scour develops very quickly, but it may take several hours to a couple of days to develop the ultimate or deepest scour depth. *Hydraulic Engineering Circular No. 18 (HEC-18), Evaluating Scour at Bridges, Fifth Edition* (http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=17&id=151) also indicates results from flume studies can be generalized to full-size bridges in streams and rivers. So although a single flood having the magnitude of the design scour flood may be sufficient to generate the design scour depth in sandy soils, such scour won’t necessarily occur to full depth if the storm

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In the Lab with Kornel

The Feather River Bridge Study

CFD Modeling of Hydraulic Force Distribution using Sonar Bathymetric Surveys:

Due to high flows occurring in March 2011, the Feather River Bridge — Br. No. 18-0009 (Figure 3) - experienced massive scour in the main channel at Pier 22. The severity of the scour prompted an emergency structural retrofit of Pier 22, that was completed in December 2011. CalTrans engaged the J. Sterling Jones Hydraulic Research Lab (HRL) through the Transportation Pooled Fund 5(211) "Bridge Pier Scour Research" to study the scour at the bridge.

Figure 3— Feather River Bridge: Br. No. 18-0009 in Sutter County, CA

Bathymetric Study Data Base for CFD Model

The research study utilizes sonar bathymetric data taken in 2007 and after the 2011 flood to construct full scale Computational Fluid Dynamics (CFD) models. Bathymetric data from the 2007 survey are used as a baseline stream bed condition (Figure 4) while the data obtained after March 2011 flood is used as a post-event scour condition. The CFD analysis, run on the Argonne National Lab high performance computing clusters, will identify the hydraulic erosion/scouring force distribution and reveal the change of hydraulic forces during the development of the scour hole (Figure 5).

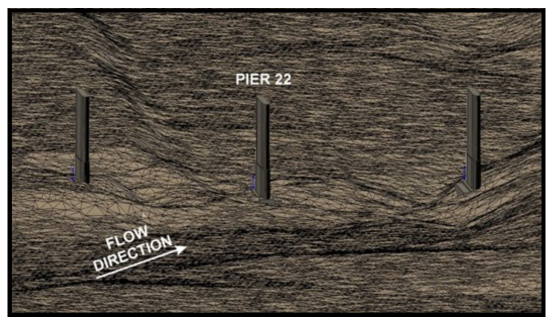

Figure 4—Full scale model using the 2007 sonar bathymetric field data

In addition, the CFD model will utilize sonar bathymetric data recorded after the new retrofitted pier construction to evaluate potential new scouring areas.

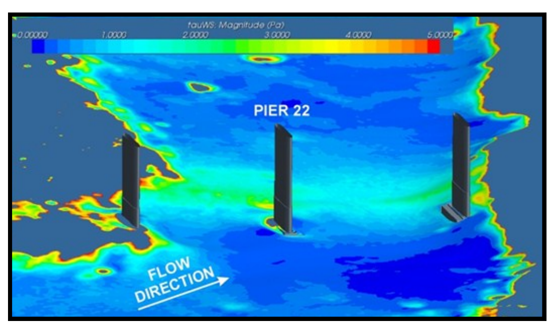

Figure 5—CFD-bed shear stress distribution in the main channel using the constructed 2007 model

Research should be completed by Fall 2014. For more information about this project or initiating your own project through the TPF 5(211), please contact Kornel Kerenyi at kornel.kerenyi@dot.gov.

In the Lab with Kornel

Fish Passage in Large Culverts with Low Flows

In recent years, resource agencies have compelled state DOTs to provide fish passage by using very wide culverts that span the stream. To increase our understanding of the low flow hydraulics in large culverts and to develop a design procedure for characterizing the variation in velocity within non-embedded and embedded culverts, the HRL conducted research using CFD modeling. This research was sponsored by Alaska, Georgia, Maryland, Michigan, Vermont, and Wisconsin DOTs through the Transportation Pooled Fund TPF-5(164): http://www.pooledfund.org/Details/Study/388.

Model Validation

To ensure the numerical CFD analysis results were representative of real culverts, the HRL conducted a series of physical model runs to collect data to validate the CFD model. The physical models used symmetrical half-section circular culverts.

CFD Model

The initial CFD modeling featured two-phase numerical computations that successfully reproduced the physical modeling results. To further simplify, single phase modeling and truncated single phase modeling were evaluated with good results. For the embedded culvert runs, a successful strategy for representing natural bed material within the culvert was developed.

The CFD modeling analyzed the full culvert cross-sections. One series of runs maintained Froude number based scaling and one series tested larger sizes without the scaling constraint. Using the 42 CFD runs for a 3-foot diameter culvert, the 5 parameters necessary for the velocity model were estimated. Then, based on geometric and hydraulic parameters available to a designer, relations were developed to estimate those parameters. The approach was successfully validated on CFD runs for 6-foot and 8-foot diameter culvert models.

Final Results

The CFD runs and velocity distribution model formed the basis of a design methodology for determining the velocity distribution within a culvert cross-section. The methodology allows one to estimate the velocity throughout a cross-section. The data may be depth-averaged to provide a distribution of velocity and depth across the culvert cross-section that may be used to evaluate fish passage. Although developed for circular culverts, the parameters used are such that the methodology could be applicable to rectangular and other shapes.

The FHWA research report for this study will be published in summer 2014. Two design examples and an application guide are provided to illustrate the method and the required computations. A graphical user interface within FHWA's Culvert Hydraulic Analysis and Design Program (HY-8) will integrate the new fish passage design methodology.

Computing with Scott

FHWA Adopts the USBR SRH-2D Hydraulic Model

The FHWA Hydraulics Team is pleased to announce the adoption of the US Bureau of Reclamation (USBR) SRH-2D hydraulic model and the development of several new modeling features. The SRH-2D model has been used by the USBR and others for several years, but it has not had the capability to simulate many transportation related hydraulic features. In recognizing the limitations of the current FHWA FST2DH model and seeing the much improved modeling capabilities of SRH-2D, FHWA has teamed with the USBR to incorporate several new features into the SRH-2D model (Figure 6).

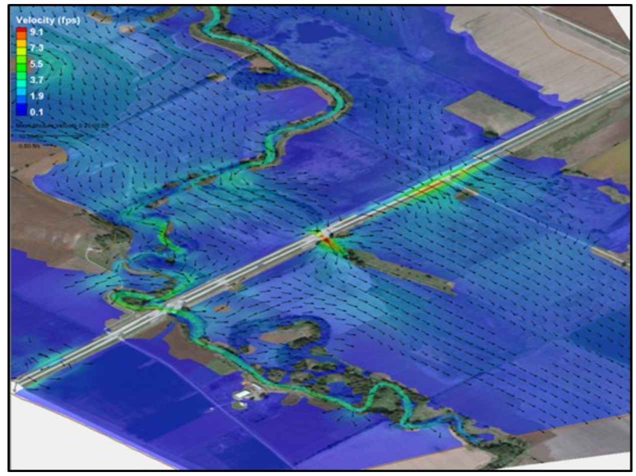

Figure 6—Example of SRH-2D model results showing velocity, velocity vectors, and flood limits for a multiple opening highway crossing with overtopping

What is SRH-2D?

SRH-2D is comparable to many existing two-dimensional (2D) models with regard to modeling capabilities, but it 'stands-out' in two key areas. First, it uses a hybrid irregular-mesh that accommodates arbitrarily shaped cells (Figure 7). A combination of quadrilateral and triangular elements may be used with varying densities to obtain the desired detail and solution accuracy in specific areas of interest. In other words, the entire model mesh does not need to have a high density throughout the entire model to get a high resolution of results at a bridge or other structure. This flexibility allows for greater detail in specified areas without compromising computing time. Second, SRH-2D uses a numerical solution scheme that is impressively robust and stable. The element wetting and drying issues that plagued many FST2DH (FESWMS) models are no longer a problem. Together, the improved SRH-2D model and custom SMS interface will provide a powerful tool for transportation hydraulics. As several states have already experienced, user's will find it much simpler to prepare and run a model, and review results.

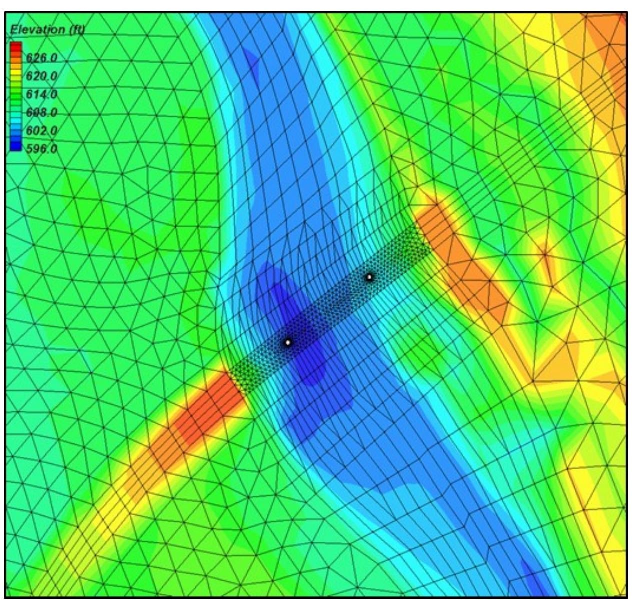

Figure 7—Example of a SRH-2D model irregular mesh for a bridge with cylindrical piers

SRH-2D Capabilities

The current and new (under-development) features and capabilities of SRH-2D:

Current

- Steady and unsteady flow
- Sub- and supercritical flow
- Unstructured mesh
- Graphical user interface with SMS (beta)
- Multiple inflows and outlfows
- Multiple boundary conditions
- Robust wetting and drying algorithm
- Sediment transport modeling (in model but not SMS interface)
- Output solutions for water surface elevation, flow depth, depth averaged velocity, Froude number, and bed shear stress.

Under Development (by the end of 2014)

- Culvert hydraulics
- Weir hydraulics
- Gate hydraulics
- Drop inlets and other outlets (orifice, weir, conduits)
- Bridge pressure flow
- Depth dependent roughness
- Sediment transport model interface

Integration with SMS

In addition, FHWA is also sponsoring the development of a custom graphical user interface in the Surface Water-modeling System (SMS) software. The current version of SRH-2D and a beta version of the SMS interface are currently available and the new SRH-2D features are expected to be incorporated by the end of 2014.

Training Opportunity

For those interested in learning more about the SRH-2D model, a short course is being offered at the National Hydraulic Engineering Conference in Iowa City, Iowa on Tuesday, August 19, 2014. More information can be found on the conference webpage: http://www.uiowa.edu/~confinst/nhec2014/index.html

Additional Information

Information on the model and interface can be found at the following web links: http://www.usbr.gov/pmts/sediment/model/srh2d/ and http://www.aquaveo.com/software/sms-srh.

The SRH-2D program is public domain software and FHWA provides licenses for the SMS interface to all FHWA and DOT employees. Please refer to the following link for more licensing details and information:

http://www.fhwa.dot.gov/engineering/hydraulics/software/sms_wms_instructions.pdf.

For more information on the use of SRH-2D and future developments, please contact one of the FHWA Resource Center Hydraulic Engineers.

Scour and the Test of Time, cont.

At the southern end of NC 12, a ferry transports visitors to Ocracoke Island, one of Blackbeard's safe haven ports. Ocracoke is also the location of the only Sovereign British territory in the US. Four WW II British sailors, their ship torpedoed by German submarine, rest here. The US Coast Guard at Station Hatteras raises and lowers the British Jack daily.

Recent Scour

The 2.5 mile long Bonner Bridge was constructed in 1963 replacing ferry service to Hatteras Island. The coastal geology of the site required the bridge to be founded on friction piles in deep sand. The north terminus is anchored on National Park Service property and the south end touches down on US Fish & Wildlife's Pea Island Refuge. Design life for the bridge was 30 years. NCDOT's 1992 replacement project was challenged by environmental advocates and continues to be held up by legal appeals in federal court.

Structural decay and scour have long plagued the bridge. Bonner Bridge has been identified as scour critical with a comprehensive and aggressive monitoring plan. Hydrographic surveys and underwater inspection performed monthly and post storm event have been conducted for more than two decades. In 2012 NCDOT initiated monthly side scan sonar monitoring (Figure 8). The October 2013 survey identified a change in conditions south of the navigation span. Monitoring was stepped up to weekly inspection. The November 29th inspection revealed bed elevation approached scour critical condition at Bent #166. Daily monitoring was implemented. On Tuesday December 3, the sonar survey and underwater dive team inspection revealed that the ten pile cluster at Bent 166 had 9 piles with embedment below scour critical elevation. Three of the piles had less than 4' embedment. NCDOT immediately implemented bridge closure in accordance to the monitoring plan of action (POA).

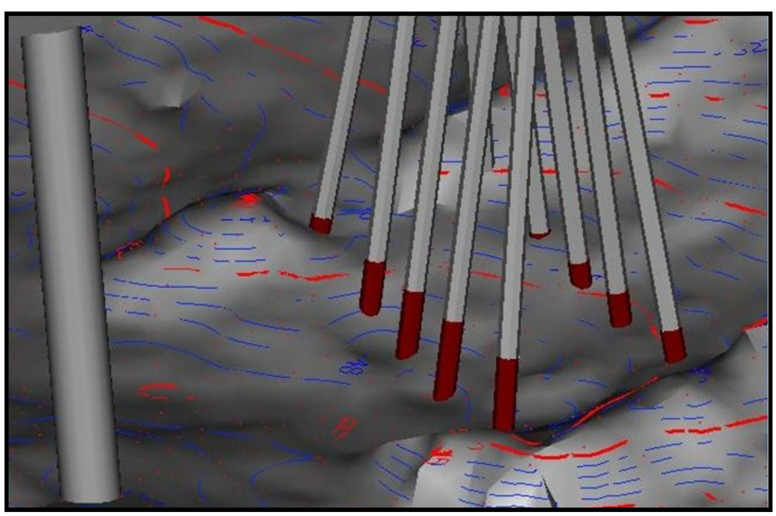

Figure 8 - Bonner Bridge Bent 166 Sonar Survey
(red indicates scour critical elevation)

Emergency Operation

On December 3rd, NCDOT Ferry Division moved four vessels into Pamlico Sound to begin operations between the emergency docks at Stumpy Point on the mainland and the village of Rodanthe on Hatteras Island (Figure 9). The 180' River Class boats carry a maximum of 38 vehicles and operates during daylight hours only. Priority boarding was implemented for the 18 mile and 90 minute trip one way. Overland travel to Stumpy Point added an additional 45 minutes to the detour operation.

Figure 9— Graphic showing ferry operations between mainland and Hatteras Island

Countermeasure Strategy

The weather forecast added an additional factor of urgency to the situation. High winds, heavy seas and extreme tidal exchange from a three day nor'easter is always a concern for Oregon Inlet and the coastal highway which parallels the shoreline along most of the Outer Banks. Although the bridge was closed to traffic, the immediate concern was potential loss of two spans during storm tides created by the nor'easter.

NCDOT formulated a three phase strategy for structural countermeasure response. The strategy addressed immediate action to stabilize the scour, intermediate countermeasure installation, and long term integrity of Bent 166. Long term stability involved construction of a crutch bent with installation of longer piles to provide required embedment. The crutch bent required lead time for pile fabrication, precast pile/bent cap, and geotechnical investigation which may require test pile installation. The intermediate action would stack three tiers of A-jacks® to form a perimeter around Bent 166. Geotextile sandbags, 3'cube and 4' cube, would be placed inside the battered pile cluster to avoid damage to the existing concrete piles. The configuration would trap sand available in the high sediment transport of diurnal tidal exchange. NCDOT contacted suppliers and manufactures for availability and delivery. Geotextiles would require 5–7 days to be delivered. The A-jacks® components would require 12-14 days for delivery to the site. The immediate need was large volume of sand and a delivery system within 72 hours.

(Continued on page 10)

Action and Response Effort Timeline

December 4th:

Carolina Bridge Company of Orangeburg, SC was awarded emergency contact. The contractor begins mobilization to drive test piles and install A-jacks® and sandbags.

December 5th:

NC Governor issues emergency declaration which will facilitate negotiations with other agencies and contractors. USACE has a contract maintenance dredging project of the navigation channel through the inlet bar. Great Lakes Dredge & Dock is finishing Corps work and agrees to contract with NCDOT before moving to their next contract obligation in four days.

December 6th:

Great Lakes Dredge & Dock begins relocating 2000' of 36" diameter discharge line from the beach disposal site to the vicinity of Bent 166. The dredge *ALASKA* can pump 30,000 cubic yards per day. The slurry transports 30% solids. The *ALASKA* will be working around the clock, weather permitting.

December 7th:

Dredging operation begins. Carolina Bridge successfully negotiated with National Park Service and their vender at Oregon Inlet Fishing Center for a staging area for A-jacks® assembly and sand bag filling operation.

December 8th:

Sonar survey (Figure 10) indicates dredge material has accrued filling the scour hole above scour critical elevation. Estimated volume indicates 65%-68% of dredged sand was retained. This is considered by the author to be very successful placement considering 45'-60' free fall through tidal waters and passage of the nor'easter tropical storm.

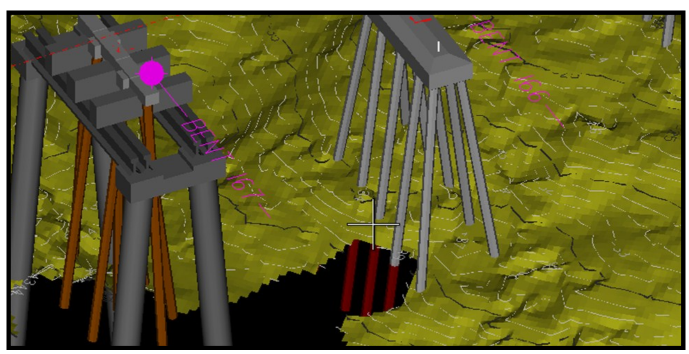

Figure 10 —Side Scan Sonar Survey Post Dredge Placement (cut away shows scour critical depth on piles)

December 9th:

NCDOT Bridge Maintenance delivers 24" diameter test piles to site in record time. Bridge Maintenance forces fabricated the test piles at nearby Manns Harbor Ferry Rework Facility to take advantage of environmental controlled work area.

December 10th:

Geotextile bags (Figure 11) begin arriving and filled. Contractor's crane and pile hammer are moved to work off the bridge deck at Bent 164.

Figure 11—Geotextile Sand Bag Stockpile (4'x4'x4' cubes)

December 12th:

Divers confirm consolidation of dredge placed sand at Bent 166. First shipment of A-jack® elements (Figure 12) arrive at staging area.

Figure 12—Pallets of 4' A-jacks® (3 jacks per pallet)

The contractor, Carolina Bridge, battles weather conditions but gets test piles punched into place.

December 13th:

Carolina Bridge performed restrike hammer test (Figure 13). Strain gage and pile driver analyzer results confirmed pile capacity. Crane, hammer, wooden mattes, and support equipment are removed from the bridge deck. Underwater inspection confirms sand consolidation at a minimum of 13' embedment above scour critical elevation.

Figure 13—Bonner Bridge Test Pile #2

December 15th:

NCDOT opens Bonner Bridge to traffic! Access to the Outer Banks and historic villages is open for Holiday Season destination travel.

(Continued on page 12)

Action and Response Effort Timeline, cont.

December 15th—February 10th:

The contractor, Carolina Bridge, continues A-jacks® and sandbag installation (Figure 14). Weather conditions were favorable immediately after passage of the nor'easter. However, diver safety protocol limited placement of A-jack® logs (Figures 15, 16, 17, and 18) and sandbags to periods of slack tide twice a day. Water temperature, visibility, and tidal flow velocity allow for a dive window of only 75 to 90 minutes at slack tide. Carolina Bridge dive support was provided by Crofton Diving of Portsmouth, Va.

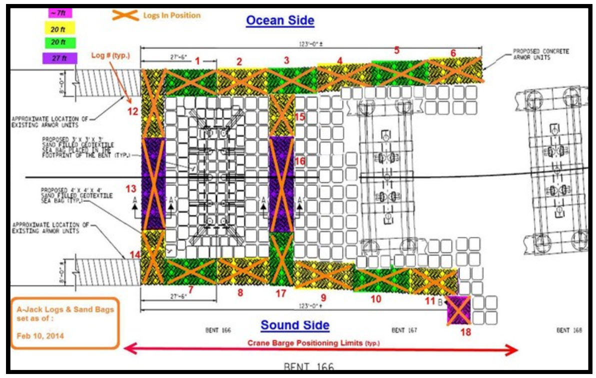

Figure 14 —Countermeasure (shaded A-jacks® surround bent 166 & extend to flank bent 167)

Figure 15—A-jacks® Assembly Area and Stockpile

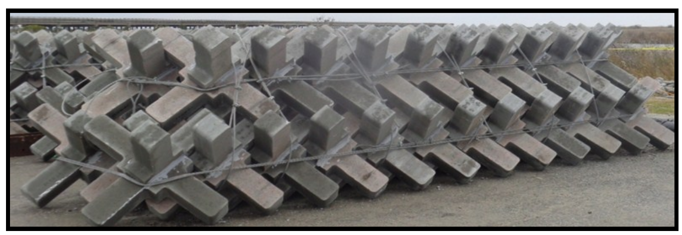

Figure 16 - Stainless Steel Cable & Hardware Binding

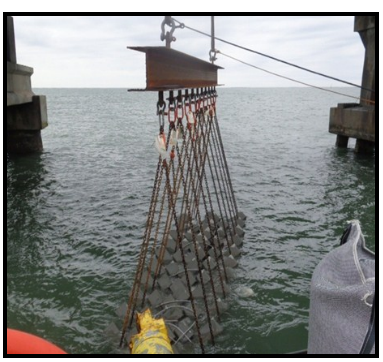

Figure 17—Contractor Jig For A-jack® Log Placement

Figure 18—Geotextile Filter Applied to A-jack® Logs

Weather conditions would soon change. Although contractor work continued over the Holiday, high winds and heavy seas impacted work in the inlet. Unusually cold temperatures interrupted epoxy application in the A-jacks® assembly process.

Upon establishing A-jacks® perimeter, the area around and between the battered 10 pile group of Bent 166 was protected with geotextile sandbags (Figures 19 and 20).

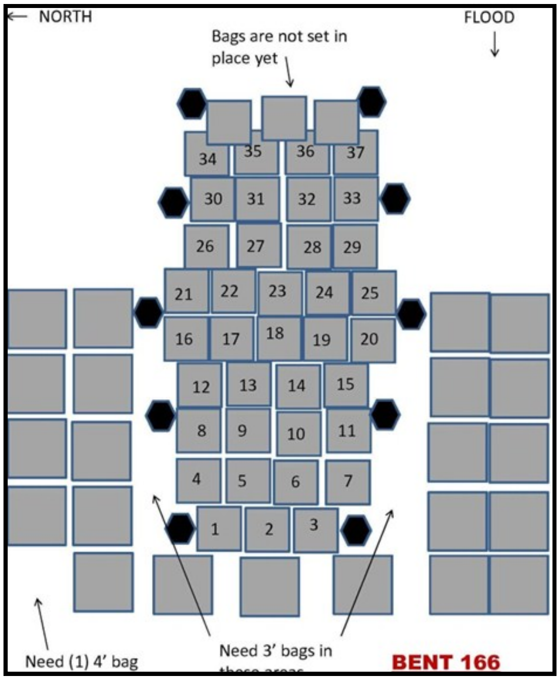

Figure 19—Placement of Geotextile Sand Bags around Bent 166

Figure 20—Contractor lifting the Sand Bags to place at Bent

February 10th:

The last A-jack® log was installed and emergency contract for Bonner Bridge was completed. The emergency contract had a 90 day completion clause.

The **project was completed ahead of schedule** even though weather conditions were not the most accommodating.

The final numbers for work performed are;

78 – 3’x3’x3’ geotextile bags
158 – 4’x4’x4’ geotextile bags
980 – A-jack® elements.
Cost = $1.79 million (excluding dredge activity estimated at +/- $1 million)

(Continued on page 14)

Contributions to Success

Emergency Declaration minimized many potential obstacles in immediate contract negotiation and established dialogue with a host of state agencies including Marine Fisheries, Division of Water Quality, and Coastal Area Management Commission. Collaboration with USACE, US Fish & Wildlife Pea Island Refuge, and National Park Service Hatteras National Seashore was effective and responsive.

Table Top Exercise Leads to Clear NCDOT Internal Communication

One of the key components to timely response action was NCDOT internal coordination and chains of command communications. During the spring and summer of 2013 the North Carolina FHWA Division promoted and facilitated a Table Top Exercise for implementation of an emergency plan of action for Bonner Bridge closure. Bonner Bridge has experienced four decades of emergency crisis from tropical storms to vessel impacts. NCDOT's Executive Leadership, Operational Management, Ferry Division, and various Design Units have always responded to the call for recovery efforts and restoring access to the otherwise isolated Outer Banks communities with the highest level of professionalism. However, areas of responsibility and authority often become clouded by public and political pressures which can be brought to bear in crisis situations. As result of the recent Table Top Exercise predicated on valuable experiences, open dialogue, and outside observations there was a clear and concise determination of authority, decision making, and cross lines of communication which created a positive climate for managing internal roles and external influences of social, media, and political pressures. The Table Top Exercise can be a time and resource commitment which can bring great benefit to any DOT organization.

Figure 21 — Bonner Bridge Witnesses Another Sun Rise

At the Concept Corner, cont.

duration is short. And it is important to note that, when observing scour in the field, one should always be aware of the potential for scour hole infilling, which occurs as flood waters recede and sediments settle to the channel bottom. If it is not accounted for, infilling of scour holes can provide an underestimate of how much scour actually occurred during a flood. Infilling can be detected by probing for scour around abutments and piers with a rod, and imaging techniques such as ground-penetrating radar have been used successfully to detect infilling.

In addition to flow duration, soil properties play a critical role in scour formation. As often observed by bridge owners, designers, and inspectors, scour in cohesive soils (silts and clays) and erodible rock occurs differently than scour in sand. Scouring in silts, clays, and erodible rock occurs gradually over time and the course of numerous floods during the design life of a bridge, and not just with a single flood event. If one wanted to consider the future performance of an existing structure in cohesive soil or erodible rock, the following information should be reviewed: a time comparison of channel cross-sections at the bridge over a number of years, anecdotal evidence of scour and foundation exposure from bridge inspection and maintenance records, the long-term flow history of the site, and the geotechnical properties of the foundation soils, including erodibility rates. This information, when used with the technical guidance and procedures recommended in HEC-18 may provide some excellent insights into the site-specific scour that has occurred and may be expected to occur over the remaining life of a structure. These insights may then inform POA implementation.

Estimating Future Scour

A site's flood history and field observations and measurements of scour are integral to evaluating bridges for safety. This information needs to be used in conjunction with soil properties and robust technical methods, such as those in HEC-18, by an interdisciplinary evaluation team in order to draw appropriate and meaningful conclusions about a bridge's existing and future performance, including vulnerability to future scour. For more information on this topic, please consider contacting a FHWA hydraulic engineer.

KEY CONCEPTS

Factors that Inhibit Scour Development
- » Too Short Flood Duration
- » Cohesive Soils or Rock

Ingredients to Estimating Future Scour
- » Site History
- » Field Observations
- » Soil Properties
- » Technical Methods (HEC 18)
- » Interdisciplinary Team

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NCDOT:
Pablo Hernandez
(Construction Unit)
Charlie Brown
(State Location and Surveys Engineer)

FHWA Hydraulic Contacts

The FHWA Hydraulic Staff are available to assist you with FHWA Hydraulic related issues. A list of Hydraulic Staff may be found at:
http://www.fhwa.dot.gov/engineering/hydraulics/staff.cfm

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