PROTOTYPE
FACULTY OF ENGINEERING AND APPLIED SCIENCE
Journal of Undergraduate Engineering Research and Scholarship

13: Coastal and Ocean Engineering ENGI.8751 Undergraduate Student Forum
Faculty of Engineering and Applied Science, Memorial University, St. John's, NL, Canada MARCH 2013

Paper Code. (13 - walsh)

The Challenge of Wave Scouring Design for the Confederation Bridge

Vanessa Walsh
Memorial University of Newfoundland
St. John's, Newfoundland, Canada
vmw674@mun.ca

ABSTRACT

The Confederation Bridge in Canada was designed in the 1990's with the desire of providing a more efficient access between Prince Edward Island and New Brunswick. Spanning over 8 miles of the ice-covered Atlantic Ocean made it one of the longest in the world. However bridges over water often present a special challenge to bridge engineers. Wave scour is the phenomenon associated with coastal structures, and is often difficult to design for due to the unpredictable magnitude of waves and high velocity wave surge flow.

Over the years, many bridges have been damaged due to excessive wave scouring. It generally occurs when water passes through obstructions that are part of the structure. In terms of bridges, these can include pile caps, columns, piles, slabs, or any other components of the bridge structure that would lead to scour. This phenomenon has substantial effects and in major cases can lead to a collapse of the structure. Due to the complex environmental conditions in the Atlantic Ocean, the design for wave scouring became a major challenge in this project.

This paper will highlight the project description, different techniques to prevent wave scouring, the challenges presented, and the unique design solution of scour protection and monitoring system used for the Confederation Bridge.

1 INTRODUCTION

A typical bridge is comprised of two main structural components; the superstructure and the substructure. The substructure component includes piers, columns, footing, and piles, which are essential for transferring the loads to the foundation bed. Piles connect the substructure of the bridge to the foundation. The presence of water flowing through the piles and around the columns can result in an erodible foundation bed, hence changing the flow pattern around the substructure. These changes in flow may result in the transport of sediment, further leading to scouring.

Wave scouring should be a major concern for any structure designed in a marine-based environment, as it is responsible for a large number of failures. When structures such as bridges are constructed in the Atlantic Ocean they are much more prone to this phenomenon due to the excessive wave action and unpredictability in ocean conditions.

2 WAVE SCOURING

2.1 DEFINITION

Scour is generally defined as the removal of granular material near marine structures, which occurs due to hydrodynamic forces. The depth and rate of scour is exponentially increased when waves and currents exist in the water body due to the addition of wave breaking, reflection, and diffraction.

2.2 SCOUR DEVELOPMENT

Generally, scouring develops first along the side edges of the object simply due to the water flowing in a steady direction. When the water flows through or around an object, this causes the water to change direction and accelerate. When water hits the structure, depending on the shape of the object, turbulent flow will be created causing vortex shedding on the leeward corners of the structure. Vortices are defined as circular patterns of rotating water masses and are a major component of turbulent flow. Along with vortex shedding, they make up part of the main parameters concerned with the overall scour depth. Vortex shedding occurs when the circular motion of water causes the granular material in the vicinity of the structure to be lifted and transported away, resulting in "scour holes".

Scouring may be localized around individual piles or grouped piles. How extreme the vertices affect the depth of the scour hole depends on the shape of the object the water is flowing around.

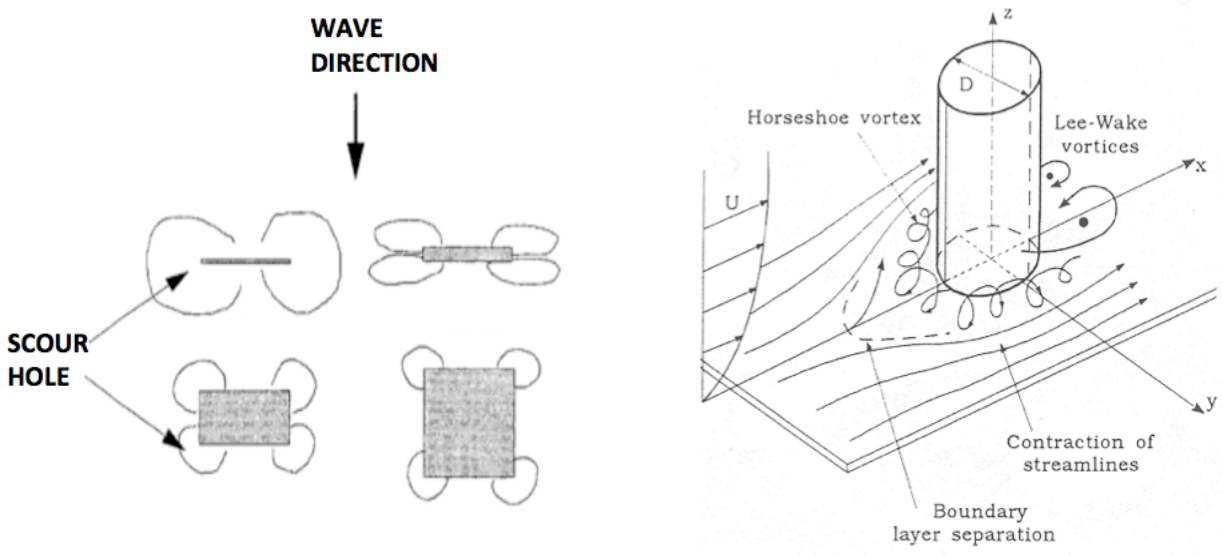
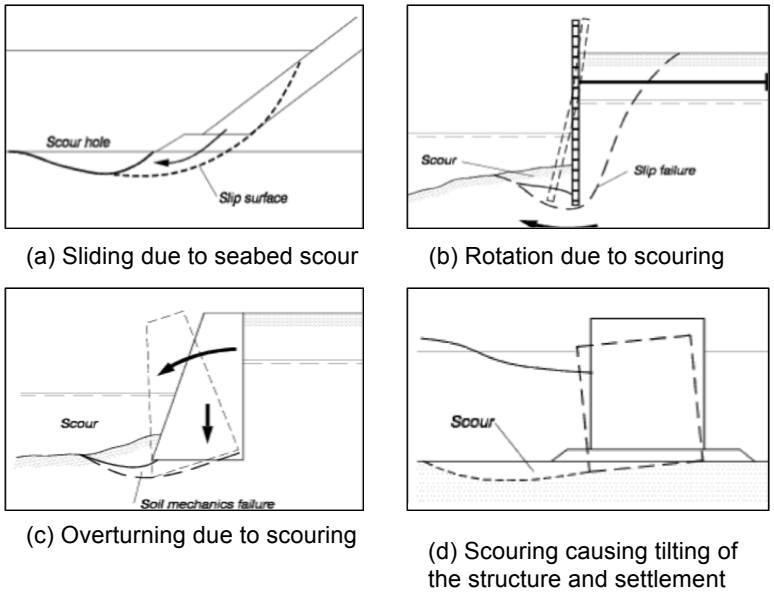


Figure 1: Water Flow Creating Vortices Around Marine Objects:
(http://www.faqs.org/patents/imgfull/20120134753_02com)

2.2 TYPICAL FAILURES

Continuous wave scouring occurring on an offshore bridge structure without protection can lead to failure of the bridge. There comes a point when the scour holes get so deep that the foundation becomes exposed, leading to piles or columns become unstable and lose their bearing. These factors may result in the load not transferring properly to the seabed. Scouring can cause coastal structures to fail in multiple ways. Some of the most common are presented below in figure 2, which include sliding, rotation of structure, overturning, tilting, and rotation.



(a) Sliding due to seabed scour

(b) Rotation due to scouring

(c) Overturning due to scouring

(d) Scouring causing tilting of the structure and settlement

Figure 2: Typical Failures due to Wave Scouring
Source: (http://www.oas.org/cdcm_train/courses/course4/chap_8.pdf)

2.3 PREVIOUS METHODS USED TO REDUCE SCOURING

Due to the high costs that it would incur to have complete protection from wave scouring, when designing for a marine structure the goal to reduce the scour holes such that the foundation bed is not exposed. Some techniques studied and used in the past for normal flow conditions include structure modifications and armouring the seabed against scour as listed below:

Structure Modifications:

(i) *Splitter Plates:* These plates are placed such that they simply divide the flow of water, resulting in a disruption of flow pattern, therefore reducing the effects of vortex shedding.
(ii) Threaded Piles: The threads on the pile cause the change in flow to disrupt the usual frequency pattern of vortex shedding. This technique is usually more efficient for steady state current.
(iii) *Slots:* Revert the water flow to reduce scour depth. Sizes of slots depend on the water conditions.

(iv) *Collars:* This technique is commonly used to reduce local scouring effects by redirecting the flow to protect the structure from direct impact of water. Collars are known to be more effective and efficient for water flowing around rectangle objects.

Protecting Seabed against Scour:

(i) Concrete Block Mattresses: Multiple layers of a geosynthetic material are internally connected which provides a thick layer of protection for the object. These are typically used for horizontal structures (i.e. horizontal pipes).
(ii) Riprap: Large rock which is used as an armor against scour or erosion.
(iii) Gravel Bags: Large gravel bags used to stabilize a structure and protect it from direct impact of water.

3 RELEVENT PROJECT CHARACTERISTICS

The Confederation Bridge is the longest bridge in the world over ice-covered water, spanning across the Atlantic Ocean between Prince Edward Island and New Brunswick, on the east side of Canada. It is compromised of post-tensioned concrete box girders at a length of 12.9 kilometers, a width of 11 meters, with 65 octagonal supporting piers in total. The substructure lies on a gravity foundation either on bedrock or in dredged pits over 14 m deep. Overall, the piers are placed in water up to 35 m deep. Each of the octagonal piers was integral with a conical pier base, which also acted as the ice shield. The design of scour protection was critical for the extreme environment in which it was constructed.

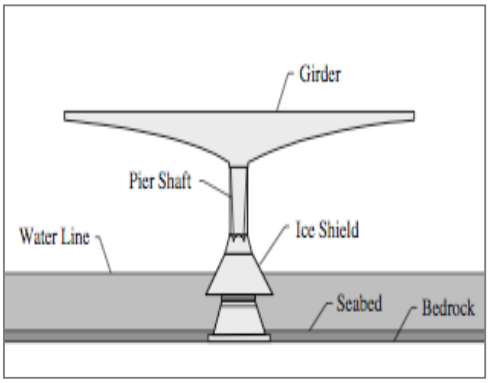


Figure 3: Main Span Pier Cross Section

Source:(http://www.westcoastcorrosion.com/Papers/11308%20CP%20of%20Ice%20Shields.pdf)

Total Length	12.9 km
Typical Elevation above water	40 m (60 m at Navigation Span)
Water Depth	up to 35 m
Width	11 m curb to curb
Number of East Approach Piers	7
Number of West Approach Piers	14
Number of Main Piers	44
Distance Between Main Piers	250 m
Amount of Concrete Used	478,000 m^3
Amount of Reinforcing Steel Used	58,500 tonnes
Length of Post Tension Cables Used	12,690 km
Heaviest Single Bridge Component	Main Bridge Girder - 7500 tonnes
Bridge Design Life	100 years

Figure 4: Confederation Bridge Information

Source:(http://www.westcoastcorrosion.com/Papers/11308%20CP%20of%20Ice%20Shields.pdf)

4 PROJECT CHALLENGES

Due to the depth of water in which the structure lays, bad weather, ice conditions, high lateral loading, complex geology, and the irregular strength in bedrock along the seabed, many engineering challenges were introduced during the design process. Compared to other bridges, the Confederation Bridge had to be designed for tremendous conditions, which includes high wave and current velocities (0.45 m/s, and 25 m/s respectively). The harsh conditions, along with the specific location of the bridge led to complex flow conditions, seabed conditions, and pier geometry.

Baird & Associates were hired to complete a coastal engineering investigation on the prevention of wave scouring, defining a number of challenges they would have to deal with. Baird & Associates defined the following project challenges they had to overcome:

(i) Complex seabed conditions results in difficultly of determining the potential of wave scouring
(ii) Due to unique pier geometry, complex hydrodynamic flow exists
(iii) The harsh environment in which the bridge is placed makes it challenging to determine new scour methodology

Importantly, it was concluded that the direct application of standard scour design techniques was not possible for this project, and a new scour methodology must be determined for the success of the Confederation Bridge. This was due to the wave and current conditions, weathered bedrock material, the conical pier bases, and the location of the dredged pier bases.

5 SOLUTION

5.1 EROSION PREDICTION

Baird & Associates completed their scour investigation and developed a new methodology to estimate scour in complex materials. The materials at the Confederation Bridge included weak fractured bedrock, which can be highly weathered when exposed to the complex hydrodynamic flow conditions present in the Atlantic Ocean. Complex materials make it difficult to predict erosion; therefore it was assumed that a new approach to quantify the potential for erosion would need to be identified. A new method was developed by Annandale to predict erosion in such materials, which could be applied to the Confederation Bridge. In order to apply this method appropriately, a number of items had to be evaluated, such as the stream power and the erodibility index. The Confederation Bridge being the first to use Annandale's new approach, calibration and verification had to be implemented, as it was a key component in the investigation. Both numerical and physical models were utilized to duplicate conditions at the Confederation Bridge when designing for the new scour protection design.

5.2 SCOUR PROTECTION REQUIREMENTS

The proper actions to ensure scour reduction during the investigation such that it would not lead to structure failure are summarized below:

(i) The maximum "EI" value was required at each pier borehole in order to represent the most erosion resistant material and its corresponding strength.

(ii) The design "EI" value is required at each pier based on Annandale's scour relationship
(iii) The local "EI" values would need to be compared at each pier, thus determining an appropriate factor of safety to be applied to the design.

Based on these assessments during the investigation, approximately 17 piers required special scour protection to avoid failure of the structure.

5.3 MONITORING SYSTEM

The Confederation Bridge was the first to utilize Annandale's new approach to erosion prediction for complex seabed materials. Therefore, due to the uncertainties with this approach, a scour monitoring program was developed and implemented by Baird & Associates to help improve and refine the protection on the bridge. This monitoring program serves as an important component of the overall scour protection design.

The system developed illustrates real-time waves as well as tide monitoring near the bridge piers to help quantify the scale of storms that which the bridge is exposed to. In conclusion, the system can help better predict the potential of scour and when inspections are required for the base of the piers.

6 CONCLUSION

The design of wave scouring depends on a number of factors such as the specific water conditions (existence of waves and/or currents, diffraction/reflection, wave breaking, etc), the type and shape of the structure, foundation bed material, and the hydrodynamic forces. Although there are various methods for reducing scour depth, complete protection is yet to be achieved. Depending on the complexity of the situation, further studies may be required to appropriately predict the scour depth as well as implement techniques to prevent or reduce the scour in an efficient and cost effective manner.

7 REFERENCES

[1] http://www.fhwa.dot.gov/engineering/hydraulics/pubs/07096/9_3.cfm

[2] C.D. Anglin, "Bridge Pier Scour Assessment for the Confederation Bridge",1997

[3] http://www.bairdsoftware.com/bridge.html

[4] http://www.fhwa.dot.gov/engineering/hydraulics/pubs/07096/9_2.cfm

[5] http://www.oas.org/cdcm_train/courses/course4/chap_8.pdf

[6] http://www.confederationbridge.com/about/confederation-bridge.html

[7] http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6063-1.pdf

[8] http://journals.tdl.org/icce/index.php/icce/article/viewFile/5868/5536

[9] http://www.ics2011.pl/artic/SP64_845-849_S.Umeda.pdf