BRIDGE SCOUR INVESTIGATION: DEVELOPING A SCREENING AND HYDRAULIC VULNERABILITY RATING SYSTEM FOR BRIDGES

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Abstract
Bridge Management is an important area of bridge engineering due to the large outlay of capital expenditure on bridge maintenance, repair and replacement, by stakeholders in their bridge stock and the requirement that the bridges are kept in a serviceable condition for the entirety of their design life. Iarnród Éireann (IE) is responsible for the maintenance of several hundred bridges that span across rivers and streams. Recently as part of Iarnród Éireann’s overall Bridge Management System a programme was initiated for assessing the vulnerability of IE bridges to scour and other related hydraulic forces. O’Connor Sutton Cronin Consulting Engineers were engaged to assist Iarnród Éireann in developing a screening and hydraulic vulnerability rating system so that any required maintenance could be prioritised.

This paper describes the screening and vulnerability rating system that was developed and how it relates to the two main industry standard documents on scour inspections (Hydraulic Engineering Circular No. 18 (HEC-18) and Bridge Advice Note 74/06 (BA 74/06). It will set out the desk study required and the on site inspections that are carried out by the bridge inspector in combination with an underwater dive team. Each step in the process will be set out in a series of logical step diagrams with a detailed explanation of each step.

Keywords: Bridge Management System, Bridge Scour, Iarnród Éireann, Vulnerability Ranking

1. Introduction

Iarnród Éireann is responsible for the maintenance of over 300 bridges that span across rivers and streams. As a bridge owner and operator who are following a bridge management regime they need to assess the risks of various deterioration mechanisms and their consequences in order to determine a suitable maintenance schedule within their overall budget.

One risk item that has come to prominence in recent times is the risk of structural damage to bridges as the consequence of river flooding and the resulting scouring that can occur due to these increasing flood events. Every structure over an existing watercourse that has support members within or adjacent to the waterways channel is likely to experience scour to some extent during a flood event. There are varying consequences that can occur due to scour, from safety considerations, requirements for additional maintenance works to the reconstruction of a bridge should a failure occur due to the undermining of a support member.

Therefore each and every rail bridge that is determined as being vulnerable to the effects of scour upon its structural foundations is required to be assessed for the potential scouring that can occur so that an appropriate action can be taken to ensure the ongoing stability and serviceability of the structure. If the assessment is
undertaken in an appropriately structured manner, there is no reason why this cannot be achieved at a relatively low cost.

It was based upon this premise that O’Connor Sutton Cronin Consulting Engineers were engaged by Iarnród Éireann to assist them in developing a screening and hydraulic vulnerability rating system so that any required maintenance could be prioritised in the most economical manner within Iarnród Éireann’s overall bridge management system.

2. Objectives

The overall aim of Iarnród Éireann’s bridge management programme as it related to the risk of scour to its bridge inventory was to develop a system that would permit Iarnród Éireann to reduce the vulnerability of the network of rail bridges to failures caused by scour or related failure. No bridge structure over water has a zero probability of failure due to scour, as even the best protected structures can be undermined. However, it is reasonable to put in place a system where there is a balance between the level of protection provided by the bridge owner to meet safety requirements and the maintenance costs of the structure.

The specific objectives that were set in relation to developing the screening and hydraulic vulnerability system were as follows:

- Review and assess the existing industry standard scour inspection processes and in particular if these processes could be integrated into Iarnród Éireann’s bridge management programme;
- Develop a bridge screening process that could be used so that the overall inventory of bridges could be assessed to determine which are required to be progressed to the next stage of the process which determines the susceptibility of a bridge to scour;
- Develop a scour susceptibility scheme that determines whether a bridge is vulnerable to scour or other hydraulic forces;
- Develop a classification stage to evaluate the vulnerability of the structure to scour damage. The purpose of this was to provide a quantitative score for a structure so that it could be compared in a relative manner to other structures on the same rail line. In addition each structure could be placed in a hydraulic vulnerability class i.e. High, Medium or Low.

3. The Scour Problem

Scour is defined as the erosion or removal of streambed or bank material from bridge foundations due to flowing water (Kattell and Eriksson, 1998). Although it may be greatly affected by the presence of structures encroaching on the channel, scour is a natural phenomenon caused by the flowing of water over an erodible boundary.

In a river, scour is normally most pronounced when the stream or river bed and river banks consist of granular alluvial materials. However, it also occurs with cohesive materials, such as clay, and even deeply weathered rock can be vulnerable in some circumstances. Under constant flow conditions, scour will reach a maximum depth in sand and gravel bed materials in hours; cohesive materials in days; glacial till, sandstones, and shale in months; limestone in years and dense granite in centuries.
(Richardson and Davis 2001). Under flow conditions typical of actual bridge crossings, several floods may be needed to attain maximum scour.

It is useful to classify the various types of scour that can occur at a bridge crossing. The total scour that can occur is comprised of three components, the following definitions are taken from Richardson and Davis, 2001:

1. Natural scour (aggradation and degradation) are long-streambed elevation changes due to natural or man induced causes which can affect the reach of the river on which the bridge is located. Aggradation involves the deposition of material eroded from the channel or watershed upstream of the bridge; whereas, degradation involves the lowering or scouring of the streambed due to a deficit in sediment supply from upstream;

2. General scour (contraction scour) is a lowering of the streambed across the stream or waterway bed at the bridge. This lowering may be uniform across the bed or non-uniform, that is, the depth of the scour may be deeper in some parts of the cross section. General scour may result from contraction of the flow, which results in the removal of material from the bed across all or most of the channel width, or from other general scour conditions such as flow around a bend where the scour may be concentrated near the outside of a bend. General scour may be cyclic and/or related to the passing of a flood;

3. Local scour involves the removal of material from around piers, abutments, spurs, and embankments. It is caused by an acceleration of flow and resulting in wake and horseshoe vortices induced by obstructions to the flow.

These three scour components are added together to obtain the total scour at a bridge pier or abutment (see Figure 1). In addition, lateral migration of the stream must be assessed when evaluating total scour at piers and abutments.

4. Existing Assessment Methods
The main industry standards in the US and UK were reviewed to assist in developing a framework for carrying out an assessment and rating system. The two principle manual/standards reviewed was the Hydraulic Engineering Circular No. 18 (HEC-18) – Evaluating Scour at Bridges, (Richardson and Davis, 2001) and BA 74/06 Assessment of Scour at Highway Bridges (DMRB 2006).

4.1 Hydraulic Engineering Circular No. 18 (HEC-18)

HEC-18 is the technical standard for knowledge and practice in the design, evaluation and inspection of bridges for scour in the US. This standard was developed by the Federal Highway Administration to provide each Department of Transport within the various states with a process within which they could each develop a programme for conducting scour evaluations.

The process developed by HEC-18 was the following 5 stage scour screening and evaluating process:

- Stage 1 – All bridges over waterways were to be screened into five categories (1) low risk, (2) scour susceptible, (3) scour critical, (4) unknown foundations, or (5) tidal;
- Stage 2 – Scour susceptible bridges and bridges with unknown foundations were prioritised by conducting a preliminary office and field examination of the list of bridges compiled in Stage 1;
- Stage 3 – Field and office scour evaluations were conducted on the bridges prioritised in Stage 2 using an Interdisciplinary Team of hydraulic, geotechnical and structural engineers;
- Stage 4 – Bridges identified as scour critical from the office and field review or during a bridge inspection in Stage 3 should have a plan of action developed for correcting the scour problem;
- Stage 5 – After completing the scour evaluations for the list of potential problems compiled in Stage 1, the remaining waterway bridges included in the states bridge inventory should be evaluated. In order to provide a logical sequence for accomplishing the remaining bridge scour evaluations, another bridge list should be established, giving priority status based upon the functional class of the highway the bridge is upon and the bridges that serve as vital links on the transport network.

The two stages that were of most importance to O’Connor Sutton Cronin in developing a screening and evaluation process for Iarnród Éireann were Stage 1 and 2 of HEC-18. Stage 1 described a mechanism for the screening of a large bridge inventory and prioritising the order in which the field evaluation should occur.

Stage 2 of the HEC-18 process set down the requirements for the office review that provides a better basis for inspecting the bridge and the stream, while also detailing a framework for the site inspection and each element that should be carried out. The site inspection was broken down into the following elements (Richardson and Davis, 2001):

- Safety considerations;
- Recording and coding guide;
- General site/river conditions;
- Assessing the substructure condition;
- Assessing the scour potential at bridges;
- Underwater inspections;
4.2 Assessment of Scour at Highway Bridges BA 74/06

The Advice Note BA 74/06 (DMRB, 2006) was intended by the Highways Agency in the UK as a means of assessing the potential for scour to damage a bridge. While it was developed by the Highways Agency primarily for use on road bridges, it was recognised that it could also be adopted for other bridge types.

The Advice Note set out a two stage process for the carrying out an assessment and analysis of bridges for scour. While also including further advice and recommendations for putting in place a plan of action for a bridge once its Priority Rating had been determined.

Stage 1 of BA 76/04 is the assessment stage. This stage is broken down into 3 elements:

- Collection of data regarding the bridge, its foundations, the river and any historical information available;
- Inspect the bridge site. This is the principle element of Stage 1. With requires the inspection of the river banks, main river channel, floodplain, and bridge waterway both upstream and downstream. There is a requirement for an underwater inspection as part of this inspection;
- Assess for scour potential. This is where it must be determined if there are any features that make the risk of scour endangering the bridge very low. If there are then the analysis need precede no further, otherwise the assessment should proceed to Stage 2.

Stage 2 is the analysis stage of the process and involves a calculation of the potential scour depths and then an assessment of the priority rating. There are 5 steps in the calculation as follows:

- Collect additional information relating to the details of the river channel. This may be mapping of the catchment or information from gauging stations;
- An estimation is made of the magnitude of the 200 year flood;
- Estimation on the depth and velocity of the flow at the bridge site;
- Estimation of the depth of the scour adjacent to the bridge footings;
- Based upon all of the above, assess the priority rating for the bridge.

5. Screening and Hydraulic Vulnerability System Developed

Following a review and a comparison of both BA 74/06 (DMRB, 2006) and HEC-18 (Richardson and Davis, 2001) it was noted that the ranking and priority procedures given in BA 74/06 relied on a significant amount of data collection with hydrology studies and hydraulic analysis to estimate flood flows, water depths and water velocities. This information is then used to estimate total scour depths with subsequent comparison with known foundation depths.

This requires considerable time and resources to provide a quantitative priority ranking of this type. In addition, where a significant number of the bridges have an unknown foundation depth it would not be possible to carry out this type of assessment without obtaining detailed Site Investigations.
While in comparison HEC-18’s scour susceptibility assessment and hydraulic vulnerability calculation to provide a priority ranking system can be carried out through a combination of the following:

- A field appraisal of scour, through the completion a field appraisal questionnaire which reviews the main features of a river channel and its interaction with a bridge structure;
- A structural inspection to determine the current condition of a bridge, structural features that may render it susceptible to scour and the signs of any distress that may indicate that it is currently being affected by scour;
- An underwater inspection to determine the presence of existing scour and the condition of scour protection measures.

Therefore to meet the objective set by Iarnród Éireann to develop a structured assessment method at a low cost to prioritise their bridge management in directing resources in an efficient way, a system was developed that would incorporate elements of the Stage I assessment from BA 74/06 while adopting and developing a hydraulic rating score that could be used to prioritise what bridges were required to be brought to Stage II analysis in accordance with BA 74/06.

The approach developed was a combination of the scour susceptibility system outlined in HEC-18 which details a screening and vulnerability rating system using desk studies and the visual field appraisals described above. While the qualitative system for establishing a bridge rating was based upon the vulnerability rating charts developed by the US Forest Service as part of their scour evaluation program, (Kattell and Eriksson, 1998). These charts use the findings recorded in the field appraisal to carry out the numerical rating for each bridge.

The Forest Service, U.S. Department of Agriculture, manages a bridge stock of approximately 7,650 bridges on National Forest lands that bridge watercourses. Scour is almost the single most common cause for bridge damage and failure on National Forest lands (Kattell and Eriksson, 1998). To arrest this problem, the Forest service developed a process to review and evaluate all bridges over water to determine the scour potential of each bridge.

The logical step diagram shown overleaf (see Figure 2) sets out the various stages in the scour evaluation programme developed based upon the systems set out in HEC-18 and the Forest Service scour evaluation program. The screening and hydraulic vulnerability system is broken up into 3 distinct processes, i.e. screening, classification and vulnerability rating.

**Stage 1 – Screening**

The screening stage is the preliminary stage carried out by the bridge stakeholder to evaluate a large population of bridges using the information contained in the stakeholders bridge inventory and inspection system. The purpose is to determine which structures require a scour inspection. While structures not over water require no further action, the order of the remaining structures is prioritised for inspection based upon information available for the following:

- Pier, abutment or footing in channel or floodplain;
- Pier, abutment or footing on scourable material;
- Stream velocity (if known);
- Foundation type;
- Previous inspection reports.
Stage 2 & 3 – Classifying

The purpose of the classification stage is to evaluate the vulnerability of a structure to scour damage on the basis of geologic, hydraulic and river conditions (NYSDOT, 2003). The product of this is to determine whether a structure can be designated as scour susceptible and to try to ascertain as to whether the structure is (1) low risk, (2) scour susceptible, (3) scour critical or (4) unknown foundations. This stage is carried out in 3 parts:

1. Collection of available data, i.e. bridge drawings, historic maps, previous underwater reports, river flood data, bridge inspection cards;
2. Field evaluation is carried out by the engineer to assess the general site conditions, assess the scour potential at bridges and assess the substructure condition;
3. Carry out an underwater inspection.

Through assessing the data gathered and comparing it to historical data, foundation information and riverbed characteristics, it is then possible to designate if the bridge is scour susceptible.

Stage 4 – Vulnerability Rating
The purpose of this vulnerability rating stage is to provide a uniform measure of the vulnerability of a structure to scour through a numerical analysis of the findings of the field appraisal, underwater inspection and desk top study carried out as part of the bridge classification stage.

This is carried out through the use of vulnerability ranking flow charts (see Figure 3), (Kattell and Eriksson, 1998). The specific parameters used in the vulnerability charts are based upon the variables that affect the level of scour at a structure where a calculation to be carried out. There are 4 charts used in this process:

1. General Conditions Flow Chart – This addresses parameters that have a general impact on the potential scour depth at a bridge based upon the river channel and its interaction with a bridge structure. The variables that are assessed for this flow chart are (i) River slope/velocity, (ii) Channel bottom stability, (iii) Channel bed material, (iv) Channel configuration, (v) Debris/ice problem, (vi) Near a river confluence, (vii) Affected by backwater, (viii) Historic scour depth, (ix) Historic maximum flood depth, (x) Adequate opening, and (xi) Overflow relief available. Each of these parameters relate to a variable that would be required to determine the level of general, contraction and local scour at a bridge;

2. Abutment Vulnerability Flow Chart – This chart is intended to evaluate the relative vulnerability of a bridge to scour considering factors that affect abutment scour. A separate evaluation is carried out for both abutments. As with the general conditions chart, the parameters evaluated in the abutment vulnerability charts reflect the variables that would affect the level of scour at a bridge site; (i) Presence of scour countermeasures, (ii) Abutment foundation type, (iii) Abutment location on river bend, (iv) Angle of inclination and (v) Embankment encroachment;

3. Pier Vulnerability Flow Chart – This chart is intended to evaluate the relative vulnerability of a bridge to scour considering factors that affect pier scour. A separate evaluation is carried out for each pier as the level of scour could vary at each pier. The parameters that are assessed reflect the variables that affect the level of scour at a structure; (i) Presence of scour countermeasure, (ii) Pier foundation type, (iii) Skew angle, (iv) Pier/pile bottom below streambed and (v) Pier width.

The product of this step is a vulnerability rating score which serves two purposes: first, it quantifies the potential vulnerability of a structure to scour damage relative to other bridges on the same rail line, and second, the score is used to place the hydraulic vulnerability rating into a High, Medium or Low hydraulic vulnerability class. Both of which permits the stakeholder prioritise any further maintenance work as part of their overall long term management plan.
6. Conclusion

It is not considered economically feasible for a bridge owner to protect all bridges to resist all conceivable floods; the purpose of a Bridge Management System should be to reduce risk to as low as reasonably possible. Bridge owners should be able ask themselves ‘Have we done all that is reasonable to ensure safety?’

The system adopted by Iarnród Éireann provides a numerical assessment that can be used to carry out a vulnerability analysis on a large stock of bridges. This numerical analysis is based upon accepted calculations (Richardson and Davis, 2001) for determining the level of general, contraction and local scour that can occur at a structures substructure unit where it interacts with a watercourse, thereby using the parameters that influence the level of scour at a structure to determine the vulnerability of the same. Unlike a Stage I assessment in accordance with BA 74/06 which does not account for different types of bridge structure, the vulnerability ranking charts take into account the influence that the different bridge substructure elements have and their relationship to a river environment, be they multi-span or single span structures.

With the scour screening system and vulnerability assessment method developed it is felt that this will permit Iarnród Éireann to best allocate resources in the most efficient manner to ensure the serviceability of the rail network over its design life. It
allows for the review of the inventory of river bridges in a cost effective manner, determines the scour susceptibility of the bridges and provides Iarnród Éireann with a mechanism to prioritise the bridges that need to be brought to a Stage II analysis by determining a hydraulic vulnerability rating.

References