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Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

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EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

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EXPERIENCES FROM BRIDGE SCOUR INSPECTIONS BY USING TWO ASSESSMENT METHODS ON 100 RAILWAY BRIDGES

Damir Bekić[1], Eamon McKeogh[2], Igor Kerin[1], Stephen Hand[2], Gillian Bruton[2]
1 University of Zagreb, Faculty of Civil Engineering, Croatia
2 University College Cork, Department of Civil & Environmental Engineering, Ireland

Abstract

This paper presents results of bridge scour risk assessment by using two qualitative methods. The first O'Connor Sutton Cronin method is based on a sum of parameters derived from flow charts taken from the Colorado method. The parameters describe general scour vulnerability, left and right abutments and the worst pier conditions, which are all evaluated by relative points. The output of the OCSC method is Vulnerability Ranking Score (VRS), based on which a Priority Rank for all bridges on a single railway line is given. The second Bekić–McKeogh method was developed for Irish Rail on the basis of various standards and policies for scour evaluation. The output from the Bekić–McKeogh method is a Priority Rating (PR), accompanied with the recommendations and a period for the next bridge inspection. Comparison of assessment results by using two methods are presented for 100 railway bridges over the rivers and streams in Ireland. The paper in particular shows different assessment results obtained for three bridges, where results of both methods are compared and analysed in detail.

Keywords: bridge scour, bridge inspection, scour risk assessment

1 Introduction

Bridge scour usually develops during flood flows. If a scour hole becomes relatively deep and close to the footings of a pier or abutment, it threatens the bridge stability. The further development of a scour hole could subsequently cause a partial or complete bridge collapse. Wardhana and Hadipriono [1, 15] analysed the causes of collapse on over 500 bridges in the USA from 1989–2000. Their study implies that scour is the most common cause of bridge collapse in the USA. Eighty three percent of all bridges collapse due to natural causes (earthquake, flooding, fire, ice, hurricane or other catastrophic factors), and bridge scour associated with flooding was the cause at 53% of bridges that collapsed due to natural causes.
This paper presents the results of bridge scour assessment for railway bridges in Ireland by using the two assessment methods. The first method is OCSC method which has been developed on the basis of Colorado method [2]. The second Bekić–McKeogh is a new method which is based on various US and UK standards and guidelines. Both methods are qualitative and use a combination of visual field appraisals and desk studies. The bridge scour risk was evaluated by two methods on 100 railway bridges by using the same input data and readily available information including previous desk studies, bridge construction records, historic mapping and flood records. As the standard procedure for scour risk assessment in Ireland was not available, two methods were developed to assist the national rail company, Irish Rail, in directing resources in an efficient way.

2 Description of methods

In the USA, three documents on bridge scour risk are available, HEC-18, HEC-20 and HEC-23 [11, 12, 13], as well as the Technical Advisory section [14]. These three HEC documents were developed for the Federal Highway Administration and serve as the base for the Departments of Transportation to develop their own programs for bridge scour analysis. The US Dept of Agriculture, Forest Service developed its own programme for the assessment of bridge scour risk [10].
In the UK, two standards for bridge scour analysis have been used. The first Railtrack method was educed in 1989 for British Rail and was published in 1993 as Handbook No 47 [5]. The second method was developed by the UK Highway Agency and was published in 2006 as Design Manual for Roads and Bridges – BA 74/06 [9].

2.1 OSCS method

The main steps in the O'Connor Sutton Cronin (OCSC) method [8] include office screening, bridge inspection, recommendations, bridge ranking and prioritization. With the exception of vulnerability ranking and subsequent prioritisation, the general OCSC approach is in accordance with the CIRIA [3] and HEC-18 [11] documents. The vulnerability ranking approach is in accordance with the procedure given in the USDA Forest Service [10].
Vulnerability of each bridge component (watercourse, abutment, pier, etc) is evaluated by a separate flow chart and is presented by points (see Figure 1). Vulnerability of each bridge component (number of points) is a sum of all parameter on a flow chart, and more points presents higher vulnerability. Each bridge component has different maximum number of points, as follows:
1. General vulnerability (maximum 23 pts)
2. Left abutment (maximum 14 pts)
3. Right abutment (maximum 14 pts)
4. The worst pier (maximum 15 pts)

The overall vulnerability of a bridge is then obtained as a sum of points for each bridge component. The overall vulnerability is termed Vulnerability Ranking Score (VRS), and the highest score is 66 points.
After obtaining VRS for all bridges, the scour risk for each bridge is presented through Priority Ranking, such as Low, Medium or High Priority (Error! Reference source not found.). The purpose of the assigned VRS is to provide an indicative comparison between bridges, so the absolute value of VRS has no physical meaning for a single bridge.

Table 1 OCSC Priority Ranking and Vulnerability Ranking Score (VRS)

Vulnerability Ranking Score (VRS)	Priority Ranking
≤30	Low Priority
31–39	Medium Priority
≥40	High Priority

2.2 Bekić–McKeogh method

The partial collapse of the Malahide Viaduct on the 21st August 2009 occurred due to weir scour and the undermining of one of the eleven bridge piers [6, 7]. Only three days prior to the collapse a bridge inspection was carried out. The Malahide Viaduct collapse showed that the existing bridge inspection method was inappropriate as it do not consider broader hydrological and hydraulic inputs.
The Bekić–McKeogh method was developed as a standard methodology for bridge scour inspections and subsequent actions for Irish Rail. The method uses a staged approach of scour risk assessment, based on various standards: CIRIA [3], BA 74/06 [9], USDA Forest Service [10], HEC18 [11] and other relevant documents, and involves three stages of risk assessment: Stage 1 Assessment, Stage 2 Analysis and Stage 3 Strategy.
The principal element of Stage 1 is an assessment by the Inspector as to whether the bridge could suffer from scour damage at all, and to identify those bridges where the risks are significant and remedial action needs to be taken. The main deliverables of Stage 1 are Priority Rating of the bridge scour potential and recommendations (see Table 2).

Table 2 Bekić–McKeogh method – Priority Rating and bridge scour risk

Bridge scour risk	Priority Rating (PR)
Insignificant risk	1
Low risk (maintenance, minor actions)	2
Move to Stage 2	3
Immediate action required (PoA)	4

Priority Rating 1 – Insignificant risk implies that scour risk is minimal and the next bridge inspection is recommended after 6 years. Priority Rating 2 – Low risk follows a special recommendation for the next bridge inspection which is within range from 1 to 5 years. Follow–up steps for the bridges which have been ranked with ratings 3 and 4, respective to table above are Move to Stage 2 or Immediate action required (Plan of Action).
For an estimate of scour vulnerability for each bridge element, the OCSC method uses flow charts from the Colorado method [2]. The overall bridge scour vulnerability (Total Vulnerability Score) is a simple sum of points of all bridge elements (according to USDA Forest Service [10]). The Bekić–McKeogh method uses a qualitative assessment of scour potential. The vulnerability to global and constriction scour are analysed separately, and global and constriction scour potentials are evaluated after an analysis of the extreme fluvial and, if relevant, tidal flows. Total bridge scour risk is assessed on the basis of potential of each type of scour and their estimated impact on bridge stability, and is presented as Priority Rating accompanied with the period for the next bridge inspection. Table 3 shows an overview and outputs of the OCSC and the Bekić–McKeogh methods.

3 Statistics of assessment results

From a total of 100 inspected bridge structures there were, 6 culverts, 17 simple bridges and 77 complex bridges. Foundation details were unknown for 79 bridges. Out of 6 culverts, foundations were known for 4 culverts. Also, out of 17 simple bridges, only 1 bridge had known foundations. Out of 77 complex bridges, 16 bridges had known foundations and 61 bridges had unknown foundations.

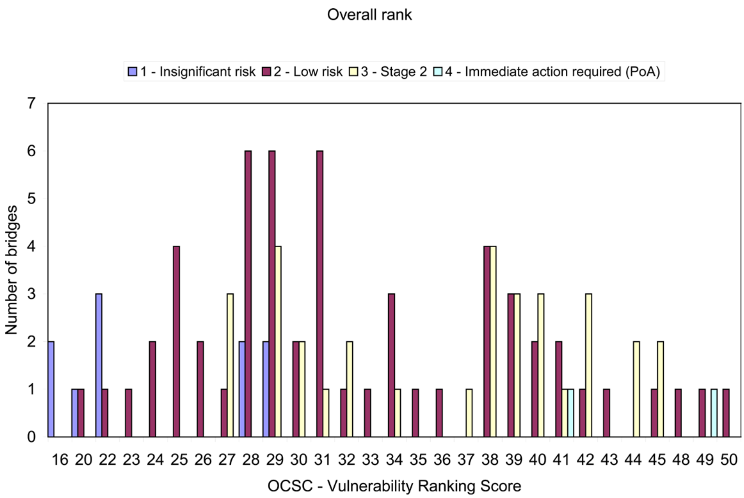

Figure 1 A comparison of scour risk assessment between Bekić–McKeogh and OCSC method

A comparison of assessment results of the two methods for all bridges is presented graphically (Figure 5). Horizontal axis shows the OCSC Vulnerability Ranking Score (VRS). Vertical axis shows number of bridges separately for each Priority rating (PR) from the Bekić–McKeogh method. For an illustration of comparison one reads that out of 4 bridges with Vulnerability Ranking Score of 22, 3 bridges were rated as Insignificant risk and 1 bridge as Low risk.
Similar assessment of bridge scour risk by two methods would show that bridges with VRS less than 30 (Low Priority) should be rated as Insignificant risk or Low risk only. Analogous would be for the bridges with VRS over 40 (High Priority) which should be rated only as Move to Stage 2 or Immediate action required if method would be similar. However, a comparison of results for 100 bridges implies that two methods gained different results in a significant number of cases. The assessment of scour risk deviates for 19 bridges, where 10 bridges rated as Low risk by Bekić–McKeogh have High Priority raking by OCSC. But the real issue of concern are 9 bridges rated as Move to Stage 2 by Bekić–McKeogh that have Low Priority raking by OCSC.

4 Examples of different scour risk assessments

It is useful and informative to analyse the factors which influence the final score (VRS and PR). Analysis was conducted based on the individual bridge examples. The VRS and PR values for 3 bridges were analysed. Besides the VRS and PR, for every bridge analysed the circumstances which led to the final score were explained. Finally a review of the OSCS and Bekić–McKeogh methods was made based on the type of factors that mostly influenced the final rating (VRS and PR) for each bridge.

4.1 UB65 Dublin/Belfast line (Delvin River)

The UB65 bridge (UB65 is the Irish Rail bridge identification number) is a Complex bridge with three open spans. Steel bridge piers are founded deeply in the bed of the river and they are probably founded on rock. The left bridge abutment is set away from the river channel on a higher level. The right abutment is set at the river channel. Extensive coastal erosion processes are evident around the bridge and the coastline has shifted landwards significantly. Further progressive erosion could undermine the right embankment toe from the sea and, combined with the potential inside erosion of the embankment slope, it gives the highest risk to the stability of the railway embankment.

Figure 2 Aerial view of UB65 bridge, looking upstream

The VRS of 29 implies Low Priority of scour risk by the OCSC method. The general vulnerability counted 9 points (of maximum 23), both abutments counted 16 points (8 points per each abutment) and the worst pier counted 4 points. The Bekić–McKeogh method rated the UB65 bridge as Move to Stage 2, as the bridge is located on tidal part of the river, and due to the evident coastal erosion which threatens the railway embankment and bridge stability.
This example shows that the assessment by the OCSC method cannot account the impact of coastal erosion to the scour risk, which in the case of UB65 bridge threatens the stability of railway embankment and the right abutment.

4.2 UB207 Dublin/Wexford line (Avoca River)

UB207 is a single span steel girder bridge on masonry abutments construction in circa 1865. The deck width is 6m and the bridge width is 29.7m. The bridge is classified as a 'complex bridge'. There is no information available regarding any modifications since its original construction and the foundations are unknown. There is evident erosion on the upstream river bank. Scour protection around the both abutments appears to have deteriorated. Further progress of bank erosion towards the bridge would threaten the stability of the left abutment and the bridge.
The VRS of 29 by the OCSC method implies Low Priority of scour risk. General vulnerability counted 12 points (of maximum 23), and both abutments counted 17 points. The Bekić–McKeogh method rated the bridge as Move to Stage 2 as the the bridge is located on an unstable river section. The river channel was rated unstable both upstream and downstream (Rank 4). The constriction scour potential was rated high (Rank 4).

Figure 3 Upstream river channel at UB207 bridge, looking downstream

The UB207 bridge example implies that the VRS by OCSC method is too low. The method gives too low score for the general and constriction scour potential, which is nearly the same score as for the generally stable channel. This case shows that the OCSC method for assessment of scour risk cannot properly account the risk of bank erosion to the bridge stability.

4.3 UB18 Mallow/Tralee line (River Glen)

The bridge UB18 is 3–span masonry arch bridge. It was constructed circa 1889 and is classified as a 'complex bridge'. The foundations are unknown. The width of the river channel at the bridge is approximately 17m. The bridge has two stone masonry piers, 6.15m long and 1.25m wide with sharp edged noses.
The bridge has a history of scour as shown by the presence of scour protection measures on the river bed and banks. Although general lateral movement of the river channel is not evident, there is high potential for vertical channel instability. A significant water level dropdown and at least 1.0m deep scour hole in the river bed are evident under Span 2. A scour hole in the river channel is a threat to the stability of Pier 1 and Pier 2. Heavy sedimentation downstream of Pier 2 and a dropdown of the river bed below the bridge confirms morphological activity.

Figure 4 Aerial view of UB18 bridge, looking upstream.

The VRS of 30 points implies Low Priority of scour risk by the OCSC method. The general scour vulnerability counted 13 points (out of 23 maximum), both abutments counted 7 points and the worst pier counted 10 points. The Bekić–McKeogh method rated the bridge as Move to Stage 2 as there are several local and global scour risk issues. The river channel was rated as unstable both upstream and downstream of the bridge (Rank 4). The UB18 bridge example also shows that the OCSC method underestimates the scour risk and does not account properly the bridge scour potential.

5 Conclusions

As a standard procedure for scour risk assessment in Ireland is not currently available, two methods were developed to assist Irish Rail in managing the bridge scour risk in an efficient way. The OCSC method has been developed on the basis of Colorado method [2], and the Bekić–McKeogh method is based on various US and UK standards and guidelines. The bridge scour risk was evaluated on 100 railway bridges over water in Ireland by using the same input data and readily available information including previous desk studies, bridge construction records, historic mapping and flood records. A comparison of results by two methods showed that assessments deviate for 19 bridges. The 10 bridges rated as Low risk by Bekić–McKeogh have High Priority raking by OCSC. The real issue are 9 bridges that have Low Priority raking by OCSC which are rated as Move to Stage 2 by Bekić–McKeogh. According to the obtained results and presented examples it can be concluded that the methods which use the Colorado flow charts and Vulnerability Ranking Score [2] are unreliable for evaluation of bridge scour risk on complex terrain and should be carefully utilized in rapid assessments of bridge scour.

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