Bridge scour: Why the engineering is sketchy and how it could be improved

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INTRODUCTION

Most river bridges fail because of scour. Though the principle is widely acknowledged, the engineering is typically applied in a sparse and inconsistent manner. This paper describes the current state of the art, and suggests better ways to engineer scour protection.

BRIDGE SCOUR IS AN ASSET MANAGEMENT ISSUE

Sour protection is usually designed by reference to a design flow or flood event, such as Q100, rather than the required robustness of the river crossing. This one-size-fits-all approach pays little attention to the risks and consequences to the transport network, and it risks under- or over-specifying scour protection. It is not uncommon to find that, because the requirements for scour protection have become so onerous due to the use of a design event that has an extremely remote possibility of occurrence, none is provided at all.

Design flows are the domain of the hydrologists and hydraulic engineers (such as the author), who are familiar with the behaviour of rivers and the risks of flooding. However, these engineers are less familiar with the function of the bridge in the context of a transport network and the risks of closure in terms of disruption to transport and communications. In response to the bridge engineer’s question of what scour protection is needed, the hydrologist might respond with the counter-question of how robust the transport system needs to be, knowing that the money spent on protecting one bridge might be poorly invested if the next bridge in the transport link is closed.

Bridge scour thus becomes one asset management issue in the context of a multitude of issues related to the transport network. It is, therefore, not a question that can be answered for one bridge in isolation from all the others in the network, and may be beyond the typical brief to a consultant to design a bridge. In answering the question of how robust the fixed infrastructure needs to be, and hence the level of scour protection, the following should be considered;

- The consequences of closure, which relate to the criticality of the transport link. Some links are less critical to transport networks than others, depending on whether alternative links can be used, or whether it is acceptable to wait for repairs. Examples of critical links include major arterial roads such as the Bruce Highway along the Queensland Coast, or Queensland Rail bridges on lines between the coal mines and coastal ports. Links may be critical for other reasons, such as the Peninsular Development Road because of the sociological impacts of its closure on remote communities such as Coen.
- Emergency response, or how quickly can repairs be carried out to get the system up and running again. In New Zealand, a pragmatic approach is adopted in which the bridge structures are designed to survive major flood events, even if the earth approach embankments are washed away. The strategy there relies on the ability to get earth moving equipment to the bridge to rebuild embankments as a temporary repair, which can only be possible if the bridge structure remains largely intact.

A better approach would be to use the risks and consequences to the transport network as the starting point, and then to move to identifying an appropriate design flow for the risk profile. For example, it could be acceptable to specify a lower level of scour protection (hence a higher risk of scour) for non-critical bridges in the knowledge that average annual times of closure could be longer, and maintenance costs higher. However, to do this, the asset manager (such as QR or DTMR) needs better visibility on how each bridge affects the network. The tools are currently emerging for the network analyses needed to quantify these risks and consequences, and they are likely to comprise the next wave of innovation in flood modelling. In the author's view, there is a need to develop broad scale, long-term hydrological modelling, augmented by, or reduced to Monte-Carlo techniques to build up a picture of how the transport network responds to storm events. The outcome, it is hoped, will identify priorities for bridge works, including scour protection, to develop a more robust transport system that has its strengths where they are needed, and not just where the accidents of history have placed them.

BRIDGE SCOUR IS A TECHNICAL ISSUE

The best current tool for predicting scour is HEC-RAS, which estimates the depths scour holes at abutments and piers by the Froelich or CSU equations. Though HEC-RAS has proven to be reliable within its intents and limitations, they must be acknowledged.

Firstly, HEC-RAS is typically used to estimate the depths of scour holes at abutments and piers in the river bed as if there were no scour protection. This outcome is useful to the structural engineer designing the piers because of the decreased length of embedment of the pier in the bed and hence the reduction in lateral support and increased bending moment. However, scour protection (e.g. rock blankets around the piers) might also be deployed to prevent the development of scour holes, thus leading to a redundancy in the design logic. This redundancy is typically rationalised in terms of conservatism, but it rarely features in optimising the design of the bridge and its scour protection as an integrated, structural whole.

Secondly, the HEC-RAS equations assume homogeneous, non-cohesive bed material, which is rarely the reality. In practice, the assumption of homogeneous material can be worked around by assuming the properties of the next lens of material lower in the bed on subsequent iterations, but it is still a crude approximation.

Thirdly, HEC-RAS uses a one-dimensional (1D) modelling technique at bridges. In practice, this provides a very sketchy picture of the required extent of scour protection. So, HEC-RAS can be used to determine the size of the rocks in the blankets, but it yields little information on the extents of these blankets in plan, and designers are forced to resort to established rules-of-thumb.

Two dimensional (2D) modelling techniques provide a better picture of where scour protection is needed by providing plans of bed shear stresses. These 2D models are useful in determining the required nature and extent of scour protection. The bed shear stresses can be used to specify appropriate levels of scour protection, from concrete to rock to reinforced grass to unreinforced grass.

Three-dimensional (3D or computational fluid dynamics - CFD) modelling techniques improve the picture even further, but are intensely data-hungry. Advances in surveying techniques, such as underwater point cloud survey, can now feed the need for data by providing highly detailed 3D surfaces as inputs to 3D flow modelling. It is hoped that CFD will yield bed shear stress maps around the bridge piers, abutments and beds, and that it will model important flow features such as vertical vortexes. It is acknowledged that these vertical vortexes play the principle role in the development of scour holes at piers and abutments but, until recently, there has been no way to model them digitally.

One major benefit of developing the CFD techniques will be the forensic analyses of actual scour events to estimate in-the-field soil parameters, especially the shear resistance of bed material. At present, much of what we know is derived from reference manuals and inferences (some of which have been drawn from laboratory testing). In the light of forensic investigations, some of the assumed parameters may prove to be inappropriate, such as the assumption in HEC-RAS of a homogeneous non-cohesive bed material.

Finally, it should be acknowledged that all the current hydraulic techniques assume a fixed bed, and the focus of most flood modelling is on overtopping, rather than scour. Future variations on the CFD approach could incorporate a mobile bed but, until then, the hydraulic models should be understood to provide a picture of what the bridge and river looks like at the start of a flood event, before scour.

BRIDGE SCOUR IS A PUBLIC RELATIONS ISSUE

Flood events tend to attract public censure, as illustrated in the court actions surrounding the 2011 floods in Brisbane. An unfortunate side-effect to the profession, is the tendency of local governments and agencies to retreat from a forensic examination of the engineering after a failure, thus stultifying attempts to build up a knowledge of the shear resistance of actual river bed material, for instance. In the author’s opinion, this has to be acknowledged, but it is one reason why the knowledge of bridge scour is not as advanced as it could be.

CONCLUSIONS

Current engineering practice is sketchy, for a variety of reasons. There is a spectrum of responses, from non-engagement with scour, to over-engineered solutions. The challenge is a difficult one; to match the improvements in technical methodologies with a broader, holistic view of bridges and their risks of scour, in the context of the operation of the transport network as an infrastructure asset. In short, we need both a deeper knowledge of the technicalities and a broader knowledge across disciplines and professions.

FURTHER INFORMATION

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