Structural Safety 71 (2018) 1–12

Contents lists available at ScienceDirect

Structural Safety

journal homepage: www.elsevier.com/locate/strusafe

Effects of uncertain asset stock data on the assessment of climate change risks: A case study of bridge scour in the UK

Hristo Dikanski [a,b,*], Boulent Imam [b], Alex Hagen-Zanker [b]

[a] Network Rail, Furzton, The Quadrant:MK, Elder Gate, Milton Keynes MK9 1EN, UK
[b] Department of Civil and Environmental Engineering, University of Surrey, Guildford GU2 7XH, UK

ARTICLE INFO

Article history:
Received 25 July 2016
Received in revised form 22 October 2017
Accepted 24 October 2017

Keywords:
Uncertainty
Climate change
Bridge scour
Asset data
Risk assessment
Asset stock

ABSTRACT

Bridge owners worldwide manage large numbers of assets with limited budgets through risk assessments, using asset-specific data. However, when managing a large stock of aging assets, maintaining robust and up-to-date data records can be challenging. This issue comes to the fore when trying to understand asset vulnerability to current and future weather events in the context of a changing climate. By using a sample of data on railway bridges in the UK, this paper explores uncertainty associated with raw data used in bridge scour risk assessments for bridge stocks and its interaction with climate change uncertainty. Results indicate that our ability to foresee climate change impacts is not only limited by the aleatory uncertainty of climate change projections; avoidable uncertainty in basic asset data can outweigh aleatory uncertainty by an order of magnitude. Some parameters, such as floodplain width and the width of abutments, were found to be both subject to high uncertainty and also very influential for the estimation of scour risk, leading to reduction in the confidence in scour risk assessments. This finding contrasts with the unchallenged assumption in the field that dimensions of bridge elements are not associated with uncertainty. The nature of scour implies that a potential increase in the frequency and severity of extreme weather events will increase scour risk. This paper shows that in order to be able to understand and account for this increase, scour management processes must effectively address data uncertainty. Active measures to control data quality would be an effective step towards understanding and managing bridge resilience in the context of current and future climatic conditions.

1. Introduction

Many infrastructure operators worldwide manage large numbers of assets. The number of rail bridges in the European Union is approximately 217,000 [4], while the total number of bridges in the USA is over 600,000 [3]. Mirzaei et al. [28] compile information about 21 bridge management systems from 16 countries across the globe, used to manage 980,000 objects. Infrastructure operators often manage bridge stocks with limited budgets through prioritisation techniques based on risk assessments, using network- and asset-specific data. However, when managing a large asset base, maintaining reliable and up-to-date data records can be a challenging task. The challenge is exacerbated when the infrastructure is old and robust data records may have been lost or non-existent; for example, most of the 28,000 bridges on the British railway network were built in the 19th century [4]. Thus, asset managers often need to make decisions on the basis of incomplete and uncertain information, prompting the need for a robust risk management framework [34]. Numerous additional uncertainties from various sources affect the decision making process in bridge management. Notably, climate change is notoriously uncertain and its effects on infrastructure are still not well understood by engineers.

The foremost cause of bridge failure worldwide is scour, the removal of riverbed material at bridge foundations due to the flow of water [23]. It is also the bridge management risk most likely to be affected by climate change [45]. Global climate change affects local weather patterns, resulting in changes in river flow regimes. This can affect scour depths and the risk of bridge failure. Uncertainties from various sources, including climate change, propagate through all stages of the risk management process, ultimately affecting investment decisions. It is important to understand how uncertainty affects the management of scour risk, as a potential bridge failure may have severe impacts, both in terms of safety and operational performance of infrastructure networks. Several studies have demonstrated the benefits of considering the role of

* Corresponding author at: Department of Civil and Environmental Engineering, University of Surrey, Guildford GU2 7XH, UK.
E-mail address: h.dikanski@surrey.ac.uk (H. Dikanski).

https://doi.org/10.1016/j.strusafe.2017.10.008
0167-4730/

uncertainty in bridge management, including Kuhn and Madanat [22] and Omenzetter et al. [33].

Uncertainty is often divided into two main types: epistemic uncertainty, which can be reduced by gathering more information; and aleatory uncertainty, representing randomness in nature, which cannot be reduced [1,21]. This is a useful distinction for bridge managers, because the risks associated with these uncertainties can be managed in different ways. Parameter uncertainty is generally epistemic in nature, as it can be reduced by further data gathering. Model uncertainty may also be partly epistemic in nature, as it can be reduced by model refinement; however, it may also be partly aleatory, as it cannot always be eliminated due to natural variability.

This paper explores uncertainty associated with data used in bridge scour risk assessments at a bridge stock level. Studies to date have considered many of the inputs to scour prediction models, such as dimensions of bridge elements, as deterministic and have not explored uncertainties associated with them. However, in practice large bridge owners managing aging infrastructure may not be confident in the available data, which would reflect on the confidence in scour assessments. This uncertainty is explored in the context of a changing climate, which is expected to have an adverse effect on bridge scour risk. Several studies have previously quantified the effect of climate change on bridge scour risk [19,46,30,9,12]; these can be expanded to explore the propagation of climate change uncertainty through the scour risk assessment and its interaction with other sources of uncertainty.

First, the existing knowledge on the propagation of uncertainty in the link between climate change and scour risk is summarised, Section 2. Then an uncertainty analysis of the input parameters for a case study scour risk model is performed, based on 11 randomly selected bridges; here parameter is used to mean the measured inputs to the scour risk model. The effects of climate change uncertainty are quantified using probabilistic climate projections. The uncertainty analysis is combined with a sensitivity analysis of the case study scour risk model in order to identify the most influential uncertainties. This can support efforts to increase the confidence in scour assessments. The detailed analysis methods are summarised in Section 3.

2. Propagation of uncertainty in the link between climate and scour risk

Uncertainty arises in every analysis stage linking climate change to bridge scour and propagates through the assessment of scour risk.

2.1. Climate change and hydrological modelling

Modelling of future climate changes is inherently uncertain. Uncertainty stems from three major sources: natural climate variability, incomplete understanding of the climate system and unknown future greenhouse gas emissions. Different approaches can be employed to manage these uncertainties. For example, effects of unknown future emissions are often quantified by developing a range of emission scenarios. Uncertainty stemming from structural assumptions in different climate models can be assessed by using ensembles of independent models, thus creating probabilistic projections. Although a variety of tools are available for the assessment and management of climate uncertainty, it cannot be completely eliminated and remains a barrier to effective adaptation [11,40,31].

Uncertainty in hydrological and climate modelling has been extensively explored in the literature. Numerous studies explore the potential impacts of climate change on river flows at specific catchments, focusing on the role of uncertainties [13,32,35]. Several studies have also applied the analysis to multiple catchments, exploring different catchment responses with respect to river flow. One example is the study by Ledbetter [25], which is based on nine catchments in the UK and combines findings from probabilistic climate change projections with hydrological and flood frequency modelling. Results vary, depending on the selected catchment, but generally show that modelling uncertainties associated with climate change and flood frequency modelling play a major role in flood estimation. Uncertainty associated with greenhouse gas emissions can also be significant and its impact increases over time. Hydrological parameter uncertainty contributes only a small fraction to the total uncertainty.

The studies above help understand the role of uncertainty in the link between climate change and flood risk. Their findings can be useful for later studies, linking climate uncertainty to flow depth and velocity, which would be directly applicable to bridge scour risk.

2.2. Hydraulic modelling

Parameter uncertainty in scour prediction is closely linked to the uncertainty in hydraulic parameters; this has been the focus of abundant research. A summary of recent literature on the topic is provided by Lagasse et al. [24]. The study emphasises the major influence of Manning's 'n' coefficient on the flow distribution for a given flow and the resulting effect on different types of scour. The effects of modelling uncertainty can be quantified by comparing measured data to model results. However, measurements are also subject to uncertainty. Di Baldassarre and Montanari [8] show that this can be significant; their study shows the overall error affecting discharge observations to vary between 6.2% and 42.8% at the 95% confidence interval, with a mean value of 25.6%.

2.3. Scour modelling

Scour occurs as a combination of three distinct processes: long-term bed degradation, which occurs naturally in rivers; contraction scour, caused by the contraction of flow at the bridge opening; and local scour at a bridge pier or abutment [2]. Thus, it depends on the non-linear interaction between water flow and sediment transport. Such processes are known to create complex feedback loops and realistic scour modelling relies on high resolution geomorphological simulation models. However, such models are very resource-intensive and their widespread application for the management of large bridge stocks is not feasible. Instead, bridge managers often have to use simple empirical models to assess and manage scour risk, which introduces uncertainty to the bridge management process. Various scour models are available; Sheppard et al. [43] list 22 commonly used models. For example, HEC-18 model [2] is appealing to bridge managers, as it is relatively easy to apply. However, it does not incorporate some important aspects of scour mechanics; in particular, it excludes the consideration that local scour depth reaches a maximum at a critical flow velocity [26]. Also widely used, the Florida Department of Transport FDOT) local scour model is based on a more thorough consideration of the flow field around bridge piers [2]. Kirby et al. [20] describe another scour model, used in numerous countries across Europe, Asia and South America [6], which also recognises the existence of minimum and maximum local scour depths relative to the flow of water.

In practice only a small number of scour models explicitly quantify modelling uncertainty associated with scour predictions. For example, the model summarised by Kirby et al. [20] includes a range of safety factors linked to the probability of exceedance of predicted scour depth. Instead of formally estimating modelling