Assessing flooding impact to riverine bridges: an integrated analysis

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No.	Comment	Answer
Reviewer #1		
1.1	The paper deals with a topic of extreme interest, and correctly identifies gaps in the current literature. However, probably due to its ambition to define "a rigorous, multiphysics modelling approach for the hydrodynamic forces impacting inundated bridges, and the subsequent structural response, while understanding of the consequences of such impact on the surrounding network", it fails in its objectives and to the Reviewer's opinion appears more like a loose combination of various tools that are not well integrated together, with a not very rigorous application to a case study.	Authors appreciated that the Reviewer highlights the relevance of the topic, as well as the complexity of the work. Since the study is complex indeed, the modeling approach presented herein used several intentional simplifications for demonstration purposes, including reducing the CFD domain or neglecting soil-foundation effects, and assumed rigidity of the structural system among others. In scenarios where these issues (or others) may be of more concern for a particular bridge, the fidelity of the modeling approach could be improved. Additionally, the failure states presented here may not translate broadly to the general bridge inventory, but additional or alternative structural/functional failure states could be applied. We are aware of the assumptions and associated limitations are discussed (L426-443). Nevertheless, the proposed approach of impact analysis can give practitioners a holistic method for assessing susceptibility to flooding and relative consequences at systemic level. The case study presented here represents an archetype for this approach. Further, there has been a trend in recent years to develop interdisciplinary approaches to larger-scale engineering problems such as those presented herein. This approach provides a framework for engineers and researchers to study a problem by taking advantage of seemingly disparate physical models that address the whole problem, without addressing its various sub-problems in silos.
1.2	pag.7 line 211. The limitations of the proposed approach (no interaction between	Thank you for this comment. For many large-scale systems subject to natural hazards, full

	CFD and FE models) are not discussed. Can the bridge considered as case study be assumed as rigid for the purpose of evaluating the hydrodynamic forces, even in the case of such tall piers? Why are the piers not modeled in the computational fluid dynamic analyses?	coupling of the CFD and FE models is impractical. While we agree that the structure will interact with water, for a civil structure we need to require small enough displacements to maintain general serviceability. Thus, we feel confident that the rigid model is (a) acceptable given the assumption of small displacements, and (b) important to show the loads that will be present on the structure if it remains in place as designed, which is the ultimate objective of this type of study. We did not model the substructure for a related reason, since we are examining the loading on the bridge superstructure, and within the rigid assumption we would not expect the inclusion of any piers to have a notable effect on these values, since the critical loads for the superstructure would be at midspan between the piers where their influence on the fluid flow would be negligible. The fluid forces would be larger away from the piers as well since the flow would not be obstructed by the pier, resulting in larger flow velocities. Using the loads computed on a midspan section of the bridge as distributed demands long the length of the bridge spans will give conservative results.
1.3	pag.8 line 247. In correspondence of the M6 bridge over Carlisle, there is a large floodplain with ample opportunities for creating additional discharge. It seems very unreasonable that even under a rare-high intensity flood will be inundated. In fact, the floodwater maximum depth for a 500yrs return period is equal to 8.424m according to Figure 3. This suggests that the deck won't be inundated. Please consider a more realistic case study, for example one of the many masonry arch bridges that are more likely to be severely affected by floods.	The city of Carlisle was chosen because it is a flood-prone area. We are aware that the actual inundation depths may be associated with extreme return periods; these were selected to ensure that the bridge was actually inundated in the OpenFOAM CFD models. Regarding this aspect, it is important to emphasize that this work focuses on demonstrating a bridge risk assessment workflow using an arbitrarily-selected bridge for which we were able to obtain design data and create a structural model using OpenSees - compared for example to historical bridges in downtown Carlisle (e.g., masonry bridges that would require more advanced FEM modelling methods to assess failure). The M6 bridge was used as a proof of concept, and the choice was dictated by available data. Authors agree that other bridges could provide results for flooding events with a lesser return period, that would be more likely to occur on a regular basis. Nevertheless, the significance of the

		methodology does not change. We are aware that the inundation depths we simulated are unlikely to actually occur (although climate change impact is very uncertain), indeed the main focus of the work is the risk assessment workflow. Ultimately, the approach presented here should be independent of a specific bridge or location. We used a bridge for which we managed to collect the most available data. At the moment, we are looking to gather data and structural details of other bridges in the area, with the view of analysing "combined" consequences. This aspect was clarified in the text (451-452).
1.4	pag. 11 line 303. The values of the lateral forces, vertical forces, and roll moments determined from OpenFOAM are not reported. Similarly, many information in the rest of the paper are missing. This is not good practice in scientific paper writing, since a journal paper should report enough data to allow results to be checked and also reproduced by others.	We appreciate that more details could have been provided, as noted by the Reviewer. Figure 6 was added, as a "counterpart" of Fig. 7 (former Fig. 6), to show examples ofconverged outputs from the discussed simulations for initial flow velocity equal to 3 meters per second for all individual components and initial inundation levels. In addition to providing the requested results, a description of the OpenFOAM solvers and models that were used for all simulations as well as related physical parameters have been described in the text (L277-283). Girder profile geometry were also added as a part of Fig. 5, with some additional superstructure dimensions too (e.g. superstructure width). These modifications to the text along with the bridge geometry description, as well as the initial and boundary condition data provided in the OpenFOAM model description given in Section 3, give sufficient data to replicate the CFD analysis results.
	pag. 13 Line 351. If the piers and abutments are founded on rock, why is scour analysis carried out? Nevertheless, scour depths of 1-2m for foundations on piles are not a big problem.	We thank you for this note and we agree. The text has been modified so that scour is discussed as a general issue relevant for many bridges in Section 2 (L61-63), but excluded from Section 3 (L319-320).
	line 325-332. The coefficient of friction between rubber and concrete is more likely to be higher than 0.4, and the assumption of a value of 0.1 seems unjustified for the assessment. Similarly, assuming that the dowels do not provide any shear resistance is too conservative.	The authors agree in principle with the Reviewer and state on lines 352-355 that the assumed coefficient of friction and lack of dowel resistance is indeed conservative. The coefficient of friction value of 0.1 was selected to illustrate how the data may be used to evaluate bridge performance, not to suggest that this is the actual coefficient of

		friction. The text has been updated as follows to clarify how this is used in the evaluation: "To illustrate how the sequential fluid-structure modeling results may be applied, a highly conservative, reduced coefficient friction of 0.1 is considered. Using this threshold, the results indicate flow conditions for which the given frictional resistance is approached or exceeded: 13.5-m flow depth with velocity of at least 6 m/s, 15-m flow depth with velocity of at least 5 m/s, 18-m flow depth with velocity of at least 6 m/s."
	Why are bridge geometry and characteristics considered as exposure when they control the vulnerability and they even affect the hydraulic hazard?	The concepts of hazard, vulnerability and exposure can have slightly different interpretation. The following definition are considered for this study (from Grossi and Kunreuther, 2005). Hazard: possible, future occurrence of natural or human-induced physical events that may have adverse effects on vulnerable and exposed elements. Exposure: characteristics of the "asset at risk", *i.e.* an object at risk of damage or a business/service at risk of interruption (location, material, etc.). Vulnerability: the susceptibility to damage of elements, or other forms of loss, because of the hazard impact that can express via relationship e.g. damage curves. An application of vulnerability and criticality assessment is in Johnson and Whittington (2011). Exposed elements become vulnerable in the presence of the hazard(s) only. Therefore, the components of the bridge (and of the road network) themselves are considered exposed elements, i.e. exposure.
	Line 257. Does "Pier width" denote "Pier height"?	Pier width does not refer to the height of the pier columns. The intent was to describe the out-to-out width of each bridge deck for each direction of traffic. Since the original naming of this parameter was misleading, it will be changed to an alternate terminology such as superstructure (or bridge bent width). The width of the superstructure is 17.3 m (Table 2).
	Improve caption of Figure 6.	The caption has been improved as below to specify what each subfigure shows.

		“Maximum simulated demand on elastomeric bearings in M6 bridge, including (a)/(b) shear force, (c)/(d) total shear strain due to combined axial, moment, and shear demands, and (e)/(f) shear deformation; plots on left show demand versus flow velocity and plots on right show demand versus flow height.”

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No.	**Comment**	**Answer**
Reviewer #2		
2.1	This is an interesting, very well written and organized paper. I liked the combination of detailed modeling with existing qualitative and quantitative data. The work as presented seems to have a lot of potential for expansion into a larger network and as the basis for difficult decisions.	The authors thank the reviewer for this appreciation.
2.2	I have grown weary of seeing the Wardhana and Hadipriono, 2003, in papers. It is now nearly 20 years since it's publication and that was based on older data. Much has changed since then and I question whether it is in any way representative of the current situation. It would be worthwhile de-emphasizing its relationship to current situations.	Unfortunately, Wardhana and Hadipriono (2003) remains the study of reference for statistics of bridge failure (analysis of 500 failures in 1989-2000), although we agree their results could not be representative of our times. Nevertheless, scour is one of the major challenge and damage cause to bridges. The sentence has been modified as follow, with newer references (avoiding the direct reference to the "50%"): "Flood and scour represent one of the most frequent causes of bridge failures (Hunt, 2009; Wardhana and Hadipriono, 2003; Khan, 2015; Ahamed et al., 2020)" (L36).
2.3	There was a paper published 10 years ago that the authors might want to look at prior to publication, as it has some similar aspects, but a much simpler (maybe cruder?) approach. *Johnson, P.A., and Whittington, R.M., 2011. Vulnerability-based risk assessment for stream instability at bridges. Journal of Hydraulic Engineering, 137(10), 1248-1256.*	The work has been reviewed and considered in the literature review of the paper (L104-106).