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Impact force of a floating woody debris on a masonry arch bridge

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ABSTRACT

This paper presents an experimental investigation of flood-induced hydrodynamic and floating woody debris impact on a scaled arch bridge based on a typical single-span masonry arch bridge geometry in the UK. A substantial proportion of masonry arch bridges spanning watercourses has been damaged or destroyed due to flood-induced loads in many parts of the world. Although the scour has been well understood, there are limited studies investigating the highly transient loads on the superstructures and associated responses due to a floating debris inside the flow. To represent a typical river flow situation, an experimental investigation used a 1:10 model in a flume such that the bridge abutments were fully submerged with the impact force from floating debris measured. Results indicate that the debris impact load exerted on the arch bridge was approximately 4.3 times higher than the hydrodynamic force with short impact duration, ~0.01s.

Keywords: *flood events, debris impact, masonry arch bridge, open channel flow, physical model*

1 INTRODUCTION

The majority of masonry arch bridges were built in the nineteenth century with simple design rules. This bridge form is still in daily use in many countries corresponding to approximately 45% of the bridge stock in Spain, 40% in the UK and 32% in Germany (Sarhosis et al., 2016). Although this bridge form has shown high load carrying capacity under vertical loads, many of them have been damaged or destroyed during recent flood events. While the effect of scour has been studied in detail, neither flood-induced hydrodynamic and debris impact loads on the superstructure of masonry arch bridges e.g. abutment, pier, arch barrel and spandrel wall, nor their response to these loads have yet to be investigated properly. An experimental study to complement numerical investigation has been performed at the University of Manchester (UK) to investigate this type of complex interface problem including fluid-solid and solid-solid interaction. This paper presents results from the experimental study to evaluate the drag forces exerted by hydrodynamic and floating debris impact on a scaled single-span arch bridge where the abutment was fully submerged.

2 PHYSICAL FLUME SETUP

Hydraulic experiments were carried out using an existing re-circulating flume at the University of Manchester (UK) with the dimensions of 4.88 m in length, 1.22 m in width and 0.61 m in height as shown in Figure 1(a). A representative masonry arch bridge was chosen according to geometrical properties of many masonry arch bridges (Majtan et al., 2021; Mathews & Hardman, 2017). Thus the prototype bridge was a single-span masonry arch bridge equivalent to an 8 m span, 0.25 rise to span ratio and 4 m stream-wise width in relation to a one-vehicular lane bridge. The model bridge with 1:10 scale was used for experiments corresponding to 0.8 m span and 0.4 m width considering the geometric similarity. Due to the presence of the debris and unknown location of the debris impact, the bridge was suspended using an aluminum beam and elbow joiner keeping an approximately 5 mm gap between the flume surface and bridge bottom. Another beam was mounted behind the bridge to carry the steel plates and load cells. To represent a tree log in the rivers, a cylindrical wooden debris, specifically English Oak, was used based on the span length of the bridge and the ratio between the length and diameter of the debris with 0.059 (Ebrahimi et al., 2016). The debris initial orientation was parallel to the bridge span and its initial distance from the bridge was 1.5 m. The free surface velocity was kept as 0.2 m/s at 1.75 m upstream of the bridge with 0.208 m flow depth corresponding to 0.043641 m^3/s. This represent the free surface velocity of 0.63 m/s in the prototype considering Froude scaling law, which is the main limitation of this experimental study compared to the velocity values observed during flooding cases (Mathews & Hardman, 2017).

3 RESULTS AND DISCUSSIONS

Figure 1(c) and Figure 1(d) show the drag force on a single-span arch bridge without and with the debris impact where the debris orientation was almost the same with its initial orientation (Figure 1(b)). To assess repeatability, three experiments were conducted for each case. Standard deviations of 1.42 N and 7.97 N based on the mean values of 12.33 N and 52.51 N were observed in the experiments for the cases without and with debris, respectively. The results reveal that the debris impact load on the bridge was 4.3 times higher than the case without the debris with short impact time, approximately 0.01 s. Despite this short impact duration, this significant increase in horizontal load may result in fissures and cracks in the masonry arch bridge. The bridge response to these loads is now under investigation to provide useful insight for assessing masonry arch bridges.

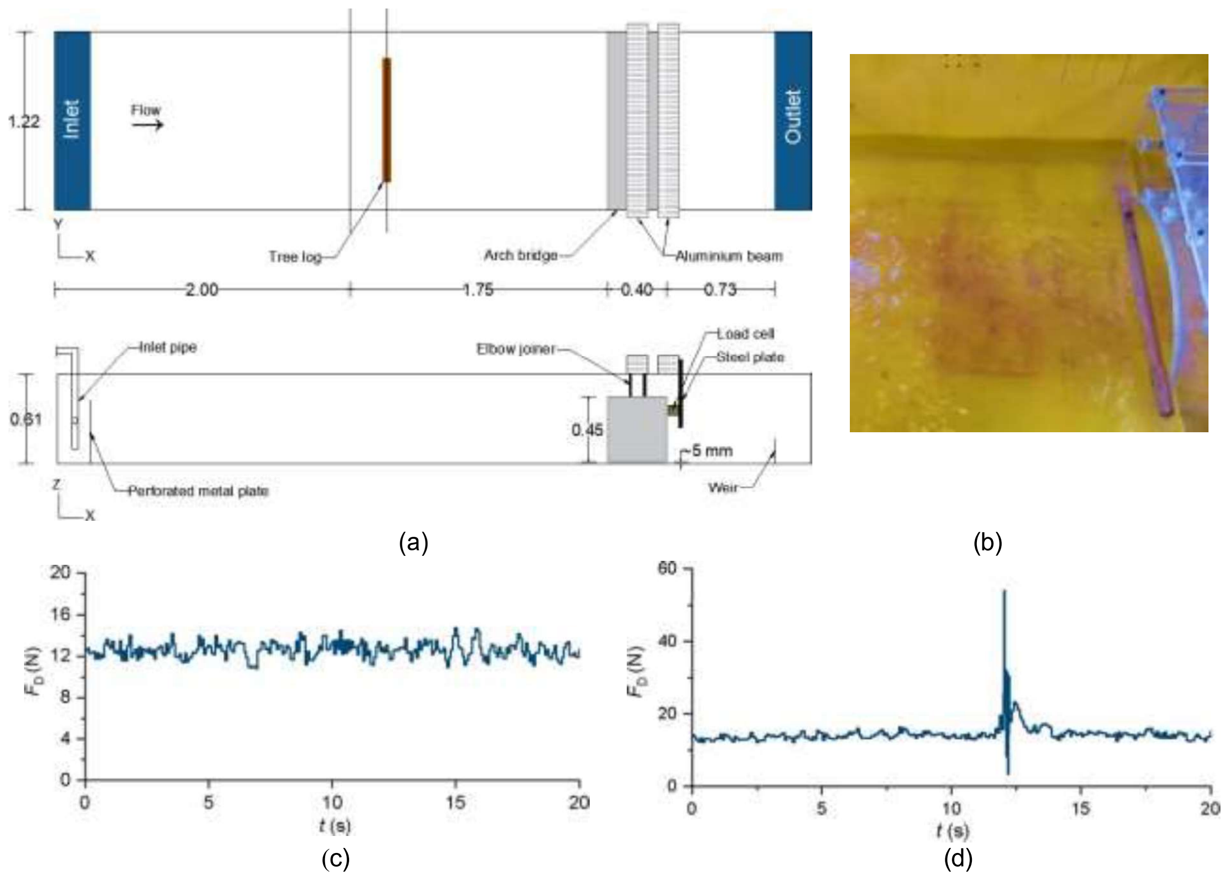

Figure 1: (a) Experimental setup (measures in m), (b) debris orientation around the bridge (c) drag force on the bridge in hydrodynamic case and (d) combination of hydrodynamic and debris impact case

4 CONCLUSIONS

Flood-induced hydrodynamic and debris impact loads were obtained experimentally. The results show that the debris impact results in significantly higher loading on the bridge within shorter duration compared to the hydrodynamic loads which may cause local failure e.g. fissures and cracks in the structure.

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