JOURNAL OF COASTAL AND HYDRAULIC STRUCTURES

Review and rebuttal of the paper

Vulnerability of power distribution utility poles to tsunami bore impacts

M.T. Stephens, Z. Xu, C. Whittaker, and L. Wotherspoon

Editor handling the paper: Alessandro Antonini

Authors’ Response to Reviews of

Vulnerability of power distribution utility poles to tsunami bore impacts

M.T. Stephens, Z. Xu, C. Whittaker, and L. Wotherspoon

Journal of Coastal and Hydraulic Structures,

The authors would like to thank the editor and reviewers for their time, constructive comments and suggestions that have helped improve the quality of this manuscript. The manuscript has undergone a revision according to the editor and reviewers’ comments. Please see our responses below. For the reviewers’ convenience, we have highlighted significant changes in the revised manuscript in this document. Line numbers in the author’s responses have been updated to reflect the updated manuscript with track changes.

RC: ***Reviewers’ Comment***, AR: Authors’ Response, ☐ Manuscript Text

1. Reviewer A

1.1. Comment 1

RC: ***Throughout the manuscript the authors intermittently use model and prototype values of the variables/parameters, which can be a source of confusion. I would recommend the authors to specify which values refer to the prototype and/or to the model (e.g. paragraph 198-208).***

AR: We agree that in the original manuscript it was sometimes difficult to differentiate experimental *models* and numerical *models* and what has been done at prototype vs. reduced scale. To clarify this, all text that references scaled-*models* has been updated to scaled-*specimens*. In addition, the *full scale* table in Figure 2 has been re-labeled *prototype scale*.

Line 85:

> The generated bore propagated down the working section of the flume before impacting the scale~~-model~~ utility pole specimen 13.2 m from the gate of the reservoir.

Line 95:

> The wooden poles at prototype had a length above the ground level 9 m and a diameter of 0.3 m, and the scale specimens had a length of 375 mm and diameter of 12 mm. All of the scale ~~models~~specimens were fabricated...

Line 105:

> An initial series of experiments without the scale ~~models~~ specimens in place were used to characterise the bore properties generated from a range of gate and reservoir conditions.

Line 121:

> During testing, each ~~model~~ scale specimen was connected to a three-axis load cell (JR3) beneath the flume level with a base plate, ensuring that the utility pole base was located at the same elevation as floor of the flume noting that this boundary condition is not consistent with what would typically used in service where the poles are embedded in soil. The load cell provided three-axis measurements of the forces and moments exerted on the ~~model~~scale specimen utility poles during testing.

Line 146:

> The initial experiments without the ~~scale models~~ scale specimens in place showed that velocities measured at 40 mm, 80 mm and 120 mm above the flume bed were approximately equal.

Line 153:

> The flow pattern around the ~~scale models~~scale specimens in the quasi-steady stage (approximately seven seconds after the bore tip reached the specimens) is shown in Figure 4.

In addition, to ensure it was clear all numerical modelling was conducted at the prototype scale, Line 214 was modified.

> To evaluate the response of full scale prestressed concrete utility poles subjected to tsunami bore impacts, the opensource structural analysis software OpenSeesPy (Zhu et al., 2018) was used to develop nonlinear numerical models at the prototype scale accounting for the effects of soil deformability and soil-structure interaction.

1.2. Comment 2

RC: ***The authors use the expressions "down line" and "across line" to define the scenarios that are tested. These wordings are not self-explaining (it took some time to understand what they meant!) and it would be recommendable to define them with a small definition sketch to be included in the manuscript (e.g. in Figure 6).***

AR: We agree it was difficult to keep track of *down line* and *across line* when looking at the plots. We have updated Figure 2, Figures 6-14, and Figures 17-20 to include sketches that indicate direction of loading.

1.3. Comment 3

RC: ***Line 25 - Tsunami evacuation occurs before the tsunami arrives, i.e. when the electricity network is still functioning, so it is not clear how their vulnerability would affect their role during this phase.***

AR: We agree - the vulnerability of the network to tsunami attack is not relevant for tsunami evacuation which occurs before the tsunami arrives. Line 25 has been updated to reflect this.

> Although the electricity network is of vital importance to ~~any tsunami evacuation and post-disaster~~ post-tsunami response, the network and its components are also vulnerable to damage from tsunamis (Williams et al., 2019, 2020).

1.4. Comment 4

RC: ***Line 63-64 – The authors neglect some relevant literature in the experimental investigation of free-standing structures, including the contributions of Arnason et al. 2009, Foster et al. 2017 and Wuthrich et al. 2020,***

among others.

AR: The suggested references have been added to Line 64.

> Tsunami loads on free-standing structures have been extensively investigated using scaled flume experiments (Nouri et al., 2010; Al-Faesly et al., 2012; Shafiei et al., 2016, 2018, Arnason et al., 2009, Foster et al., 2017, Wüthrich et al., 2020).

1.5. Comment 5

RC: ***Line 68 – The authors rightfully mention scale effects in terms of water density, but the reviewer would argue that the use of salt-water would also affect the processes linked to surface tension, including debris accumulation (although not tested in the present study) and air-entrainment, clearly visible in Figure 4.***

AR: We agree that the use of salt water would influence the results of the experiments. We have highlighted this limitation of the research on Line 86.

> It should be noted that fresh water was used in the physical experiments~~; this~~, which created an additional density-related scaling term when applying the experimental results to the numerical model in Section 4.4 to reflect the density of salt water. It is important to note that salt-water may influence processes linked to surface tension, including debris accumulation and air-entrainment, which were not assessed in this research..

1.6. Comment 6

RC: ***Line 69 – The word Section is repeated twice.***

AR: The second Section has been deleted.

1.7. Comment 7

RC: ***Line 102 – The authors mention the repeatability of the free-surface elevation, but a similar analysis should be provided for the velocity measurements.***

AR: A similar analysis was conducted for velocity, however we failed to mention it in the original submission. Line 118 was been modified to reflect this.

> The measured free surface elevations and bore velocities were highly repeatable, with relative errors of recorded depth from each of the repetitions within 4% and relative errors of recorded velocity within 10%.

1.8. Comment 8

RC: ***Table 1 – The authors do not mention what where the conditions of the flume prior to the bore arrival: were the tests conducted on dry or wet bed? It was shown in many previous studies that a dry/wet bed condition can highly affect the hydrodynamic properties of dam-break waves.***

AR: All tests were conducted on an initially dry bed. A note has been added to Figure 1, and Line 86 has been modified to include this information.

> The generated bore propagated down the working section of the flume before impacting the scale-model utility pole specimen 13.2 m from the gate of the reservoir. Each test was conducted on a dry flume bed.

1.9. Comment 9

RC: ***Line 125 – The decreasing behaviour of velocities behind the front was shown in a number of previous studies, including the work of Arnason et al. (2009) for dam-break waves, Leng and Chanson (2016) for positive surges and Wuthrich et al. (2018) for tsunamis. The latter study also showed a relatively constant velocity profile across the flow depth, which supports the statement that the authors make in line 129.***

AR: We have added a sentence on Line 140 to reflect this.

> The bore had a larger velocity at its front and a steady decreasing trend. The decreasing behaviour of velocities behind the front was shown in a number of previous studies, including the work of Arnason et al. (2009) for dam-break waves, Leng and Chanson (2016) for positive surges and Wuthrich et al. (2018) for tsunamis. The latter study also showed a relatively constant velocity profile across the flow depth.

1.10. Comment 10

RC: ***Figure 3 – The reviewer would recommend the authors to switch figure (c) and (d) such that the maximum bore depth can be easily compared to the momentum flux.***

AR: Figures 3c and 3d have been switched.

1.11. Comment 11

RC: ***In Figure 10a it is unclear which is the experimental data and which is the numerical.***

AR: Figure 10a only plots the normalised moment arms generated from experimental data to justify using a uniformly distributed loading assumption for the tsunami loading in the numerical model. To clarify this, text has been added to the figure caption. Further, Line 247 and the figure caption on Figure 10 have been updated.

Line 267:

> Figure 10a illustrates the normalised moment arm for the I-section pole configurations for loading Case f in Table 1 as calculated using data recorded from the experiments. For all pole configurations and geometries, there was a surge in the normalised moment arm due to water splash up at initial impact, however in the quasi-steady flow stage the normalised moment arm stabilised to 0.5 - 0.6 of the water depth which is consistent with a UDL as is indicated in the figure. Similar normalised moment arm values were observed for all bore heights.

Figure 10 caption:

> Figure 10| (a) Time history of normalised moment arms for I-sections as calculated using experimental data and (b)...

1.12. Comment 12

RC: ***Line 162 – kg/m3, 3 should be a superscript.***

AR: The superscript has been added.

1.13. Comment 13

RC: ***Line 189 – In Figure 8c the authors provide a relationship between the Froude number and the drag coefficient. It is unclear how this Froude numbers was calculated, since in Figure 3c it is shown to have a highly decreasing behaviour.***

AR: The Froude number used in the quasi-steady stage is 4 sec-averaged Froude number in the quasi-steady stage, which occurred at around 10s-14s as shown in Figure 3c. This time period was selected because the Froude number is relatively steady over this range. This information has been added to the caption for Figure 8.

> Figure 8| (a) Time history of Cd for five pole configurations with h = 220 mm, (b) Cd with Re in the quasi steady stage and (c) Cd with Fr in the quasi-steady stage. The Froude number Fr used in the quasi steady stage is the 4 sec-averaged value in the quasi-steady stage, which occurred at approximately 10 - 14 sec as shown in Figure 3c.

1.14. Comment 14

RC: ***Figure 10 – The authors use a very thick line to represent experimental data. While this could be explained by a certain variability of the up-scaled data, it would be more interesting to include this variability with a more scientific approach including a mean value + an error.***

AR: We agree that the variability between the experimental loading history and the history applied in the numerical model using the uniformly distributed load (UDL) assumption should be quantified to a greater degree. To address this, Figure 10b was updated to include additional load histories for different bore heights, and a new table (Table 4) was added to quantify the ratio between the maximum scaled experimental base moment (M_{exp}) and the maximum moment base moment achieved in the numerical model using the UDL assumption (M_{num}). In addition, text was added on Line 271.

> Next, the overturning moments recorded from a fixed-base model were compared to the scaled overturning moments from the experiments. For demonstration, Figure 10b shows the scaled experimental and numerical overturning moments for ~~an 11 m pole loaded down line~~a 9.5 m pole loaded across line for loading cases (a), (c) and (f) from Table 1. ~~From this figure it is clear the overturning moments are effectively captured using this loading approach.~~ From Figure 10, it is clear the the numerical overturning moment histories approximately trace the experimental histories with some variation. To quantify differences in the maximum magnitudes of the experimental and numerical overturning moments, the ratios of the maximum moments (M_{exp}/M_{num}) were calculated and are summarised in Table 4 for all scaled experimental load cases, pole geometries and loading configurations. From Table 4, it is clear the numerical loading approach captured the maximum moment demands within approximately 20% in all cases.

1.15. Comment 15

RC: ***Line 322 – Lr/Le should be in subscripts.***

AR: The subscripts have been updated.

2. Reviewer B

2.1. Comment 1

RC: ***...there could have been more extensive discussion on whether tsunami bore generated by dam-break methods can adequately describe a tsunami event time history for the purposes of force generation.***

AR: We have added a discussion regarding the use of a dam break scenario to estimate tsunami forces beginning on Line 68.

> Tsunami loads on free-standing structures have been extensively investigated using scaled flume experiments (Nouri et al., 2010; Al-Faesly et al., 2012; Shafiei et al., 2016, 2018). The experiments in this work were conducted at a 1:24 geometric scale in a flume where the tsunami bore was approximated as a dam-break flow generated by the sudden release of water from an upstream reservoir, where sudden was defined relative to the criteria discussed in previous research (Lauber and Hager, 1998; von Hafen et al., 2019). The dam break approach was used here because it is impractical to model tsunamis from source through propagation to runup and impact for the purpose of force generation. Previous research has used solitary waves, which has a strong theoretical underpinning as well as a "mass displacement" element that made them more useful than regular (linear) waves (Madsen et al., 2008). However, the period of these solitary waves is far too short for them to be used for tsunami load research. A dam break is currently the most widely used method for creating a bore that is representative of a tsunami as it runs up onshore (Chanson, 2006; Esteban et al., 2020; Nouri et al., 2010; Palermo et al., 2009; Wüthrich et al., 2019, 2018). Dam-break simulated tsunamis do not capture situations where a tsunami is trough-led or has any kind of complicated phasing. In addition, the simplified approach used here does not capture processes such as the receding wave of the tsunami or the increase in density through the bore's sediment load or entrained debris. However, the initial stage and steady stage of the tsunami is effectively simulated, and the rise, peak, and steady stage forces on the utility poles are captured. ~~It should be noted that fresh water was used in the physical experiments; this created an additional density-related scaling term when applying the experimental results to the numerical model in Section Section 4.4.~~
>
> Figure 1 shows side views of the flume, which is 19.2 m long and 1.2 m wide. The reservoir length is relatively short in the along-flume direction; the effects of this are discussed in prior work (Barranco and Liu, 2021). For each bore case in the experiments, the reservoir was filled to a given level, and the automatic gate was opened a set height and remained open for ten seconds before closing. The generated bore propagated down the working section of the flume before 74 impacting the scale-model utility pole specimen 13.2 m from the gate of the reservoir. It should be noted that fresh water was used in the physical experiments; this created an additional density-related scaling term when applying the experimental results to the numerical model in Section Section 4.4.

2.2. Comment 2

RC: ***...there is some variability in scaled experimental base shears vs bore heights versus best fit regressions especially around the 4m bore height. I would have preferred to see more discussion on the effects of this variance and its potential impact to real world performance of the systems.***

AR: We agree there is some un-conservatism in the applied loads resulting from error in the regression for bore heights ranging from 3.75-4.5m that should be noted. We have added a sentence to Line 283 to highlight this.

> As only six tsunami loading cases were available from the experiments for each pole type and orientation, additional loading cases were generated using bore height to base shear scale factors that were developed using a best-fit regression that related the prototype-scale bore height to the maximum recorded base shear as illustrated in Figure 11. It is worth noting that the best-fit regressions for all loading cases predict slightly un-conservative base shear values for tsunami bore heights in the range of approximately 3.75 m to 4.5 m (with the largest discrepancy occurring in the 11 m pole loaded down line). This can result in potentially un-conservative damage estimates for tsunami inundation depths in this range.