**Proceedings of the 9th International Conference on Physical Modelling in Coastal Engineering (Coastlab24)**

Delft, Netherlands, May 13-16, 2024

©2024 published by TU Delft OPEN Publishing on behalf of the authors

This work is licensed under a CC BY 4.0

Extended Abstract, DOI: 10.59490/coastlab.2024.732

# TSUNAMI DEBRIS DAMMING DRAG FORCES AND ASSOCIATED COEFFICIENTS ON ELEVATED COASTAL STRUCTURE COLUMNS

KELLEN DOYLE*[1], MYUNG-JIN KOH[2], RAVINDU JAYASEKARA[3], DANIEL COX[1], PEDRO LOMONACO[1], HYOUNGSU PARK[2], SABARETHINAM KAMESHWAR[3]

*1 Oregon State University, USA, *corresponding author: doyleke@oregonstate.edu*

*2 University of Hawaii at Manoa, USA*

*3 Louisiana State University, USA*

**KEYWORDS:** experimental, damming loads, closure ratio, elevated structure, ASCE 7-22

## 1 INTRODUCTION

Tsunami overland flow induces hydrodynamic loads on coastal structures and may transport various objects located within the inundation zone, which could become debris and exacerbate hydrodynamic loading. In the process of adopting “the first national, consensus-based standard for tsunami resilience” (Chock, 2016) in the form of ASCE 7-16 Chapter 6: Tsunami Loads and Effects, emphasis was placed on evaluating debris transport and impact forces. This is evidenced by the robust body of literature regarding physical model experiments of these processes and thorough design procedures for both load considerations in current structural engineering standards (ASCE, 2022). Debris damming forces, resultant of debris being transported and accumulating against structures, are less thoroughly studied, having only recently begun to transition from steady flow experiments to transient flow conditions representative of coastal inundation events. A recent pair of experiments bridges this gap, comparing debris damming via steady-state, subcritical flow conditions to that caused by a dam-break style hydraulic bore (Stolle *et al.*, 2018). That paper aimed to study debris dam formation, stability, and loading as well as runup of the flow onto idealized structural columns. Another study varied debris quantity, orientation, and arrangement to determine the effect had on damming and impact loads (Shekhar *et al.*, 2020), however neither compared findings to current standards.

The experimental work presented herein represents initial findings of a multi-year experimental campaign to better understand the mechanisms that lead to debris damming and increased structural loading. This work builds upon previous studies by using larger scale debris elements, more numerous debris fields, and more trials to better model such a stochastic process as debris damming. Three different incident wave conditions also led to varied hydrodynamics at the column specimen. In later phases, this campaign will also investigate the debris damming consequences of heterogeneous debris, which more accurately represent highly variable debris fields observed in post-event site surveys (Nistor *et al.*, 2017).

This paper aims to compare experimental debris dam loading parameters to those in the current ASCE 7-22 standard (ASCE, 2022). Namely, evaluating conservatism of ASCE 7-22 design values for: overall drag force on buildings, minimum closure ratios used in load determination, and empirical rectilinear structure drag coefficients during both debris accumulation and quasi-steady debris damming phases.

## 2 METHODS

The experiment described here was performed in the Large Wave Flume at the O.H. Hinsdale Wave Research Laboratory of Oregon State University (USA). Incident waves were generated via error function paddle displacement of a piston-type wavemaker and propagated as a hydraulic bore over a flat wet-bed testing area. The testing area included a debris source platform and column array specimen, representing columns of an idealized elevated coastal structure. The debris elements in this experiment were modelled at 1:20 geometric scale and included 6.1m and 12.2m standard ISO shipping containers.

The column specimen included interchangeable configurations to vary column density as well as force and moment instrumentation for both the entire column array and the seaward center column individually. Plan view video recordings were captured for each trial across the full experimental extents as well as isometric video of the column specimen (Figure 1). Videos were synchronized with overall force and overturning moment data and hydrodynamic data including inundation flow velocity, free-surface elevation, and Froude number. The submerged projected areas of experimental debris dams were quantified via a validated photogrammetric method during both debris accumulation and quasi-steady damming phases. This photogrammetric method involved calculating the submerged projected area of each debris element based on angle relative to the incident flow, correcting for partial submersion and debris overlapping, then summing over all elements in the experimental debris dam.

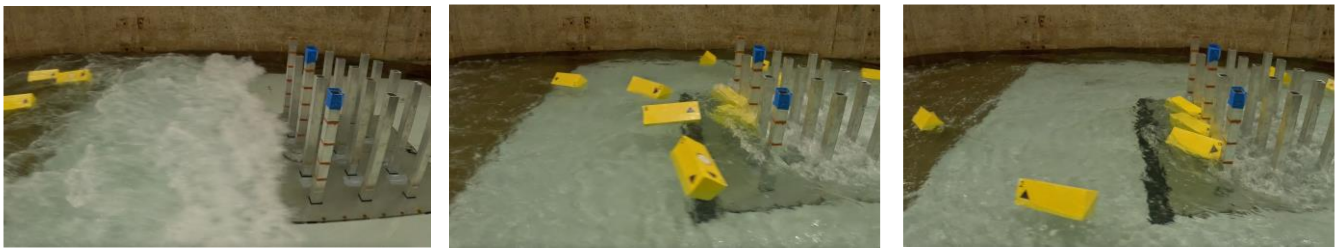

**Figure 1. Experimental trial showing phases of debris damming: bore arrival (left), dam accumulation (center), and quasi-steady debris dam (right). Shown are the 3x5 column specimen configuration and 6.1m shipping containers debris.**

## 3 RESULTS

Following debris dam analysis, a comparison to ASCE 7-22 design values (ASCE, 2022) includes:

1. The equation to compute simplified equivalent uniform lateral static pressure (Eq. 6.10-1) is conservative across all tested experimental conditions, is reasonable for design under near-transitional Froude regimes (Fr > 0.8), but potentially overconservative under more subcritical Froude regime inundation (Fr < 0.7).
2. The equation to compute detailed hydrodynamic lateral forces (Eq. 6.10-2) is often unconservative, particularly under higher Froude regime (Fr > 0.6) inundation flows and large debris elements.
3. Prescribed minimum closure ratios (Section 6.8.7) appear conservative for closed structures, but are often unconservative for the open structure condition modelled in this experiment, especially in the presence of large debris elements. Open versus closed structure conditions are ASCE 7-22 definitions affecting minimum assumed closure ratio due to debris accumulation against a structure.
4. Prescribed drag coefficients (Table 6.10-1) are less than computed hydrodynamic bulk resistance coefficients for all three column configurations modelled in this experiment.
5. Bulk resistance coefficient may represent an improved dimensionless measure of flow resistance than drag coefficients currently used in ASCE 7-22 load predictions (Arnason *et al.*, 2009).

## 4 CONCLUSIONS

Synthesis of the above results yields the following conclusions about current tsunami-resilient design standards (ASCE, 2022):

1. Two alternative methods (Equations 6.10-1 and 6.10-2) for predicting lateral force-resisting system hydrodynamic loads yield varying levels of conservatism relative to experimental debris damming forces.
2. Conservatism of minimum closure ratios (Section 6.8.7) varies depending on open or closed structure classification.
3. Drag coefficients prescribed based on building width to inundation depth ratio (Table 6.10-1) are unconservative relative to experimental bulk resistance coefficients, which potentially represent an improved dimensionless measure of flow resistance for an array of surface-piercing flow obstructions.

## ACKNOWLEDGEMENT

This material is based upon work supported by the National Science Foundation (NSF) and Natural Hazards Engineering Research Infrastructure (NHERI) under Grants #2203131, #2203116 and #2037914.

## REFERENCES

Arnason, H., *et al*, 2009. Tsunami bore impingement onto a vertical column. *Journal of Distaster Research,* 4, 6, 391-403.

ASCE, 2022. *ASCE 7-22: Minimum design loads and associated criteria for buildings and other structures,* American Society of Civil Engineers, Reston, Virginia, USA. 9780784415788.

Chock, G. Y., 2016. Design for tsunami loads and effects in the ASCE 7-16 standard, *Journal of Structural Engineering*, 142, 11.

Doyle, K., *et al,* 2024. Tsunami Debris Damming Drag Forces and Associated Coefficients on Elevated Coastal Structure Columns: Comparison to ASCE 7-22 Minimum Design Loads. *To be submitted to ASCE Journal of Structural Engineering.*

Nistor, I., *et al.,* 2017. Tsunami-driven debris motion and loads: A critical review, *Frontiers in Built Environment*, 3.

Shekhar, K., *et al.*, 2020. Conceptual evaluation of tsunami debris field damming and impact forces, *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 146, 6.

Stolle, J., *et al.,* 2018. Experimental investigation of debris damming loads under transient supercritical flow conditions, *Coastal Engineering*, 139, 16–31.