A MONTE-CARLO MODEL FOR CAISSON OVERTURNING BY TSUNAMIS

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INTRODUCTION

Robust planning, engineering, and design in regions exposed to coastal inundation and wave extremes are critically important for ensuring economic and community resilience. To address this need, the profession is moving toward multi-faceted, risk-based approaches based on probabilistic hazard exposure that account for uncertainty. Herein, a Monte-Carlo model for sliding and overturning of caissons under extreme hydrodynamic loading is presented. The model may be used to support risk-based analyses during caisson design as well as in the characterization of inundation extremes from contemporary hazard reconnaissance and from the geological and archaeological records. Herein, model applications are presented (1) to characterize the 2nd century AD Mediterranean tsunami that damaged the ancient harbor of Caesarea, Israel and (2) to develop a scaling law for overturning.

METHODS

Within a Monte-Carlo framework, overturning and sliding are calculated from the one-dimensional equations of motion governing caisson sliding and overturning (e.g., Burcharth et al. 2008, Sekiguchi & Ohmaki 1992), where the model builds on that of Weiss & Diplas (2015) for boulder dislodgement. For overturning, the governing equation is $(I_A + I_m)\frac{d^2\theta}{dt^2} = -Wl_w + Bl_B + Dl_D + Ll_L$, where I_A and I_m are respectively the mass moments of inertia of the caisson and the added mass, θ is rotation angle, W is caisson weight, B is buoyant force, D is drag force, L is lift force, and l are the moment arms. The classical quadratic form is used to estimate drag and lift forces, and the added mass moment of inertia is estimated as the product of the moment of inertia of the displaced volume and an added mass coefficient. To account for uncertainty associated with specifying the drag and lift coefficients and the added mass coefficient, these parameters are varied within the Monte-Carlo framework. Hydrodynamic forcing is represented by flow speed and flow depth, where steady conditions are assumed during the period of overturning by tsunamis (order of 10 s or less).

CHARACTERIZATION OF 2ND CENTURY AD TSUNAMI

Geological and archaeological evidence demonstrate a sizable tsunami inundated ancient Roman Caesarea Maritima (present-day Israel) in the early 2nd century AD, around the same time one of the colossal caisson-constructed towers flanking the harbor entrance capsized (e.g., Goodman-Tchernov & Austin 2015). The tower is estimated to have been in a depth of 11 m when it capsized. The model reveals that even a small tsunami (height of 1 m) could have overturned the tower, and that it is very likely a moderate to large tsunami would have overturned the tower (Fig. 1).

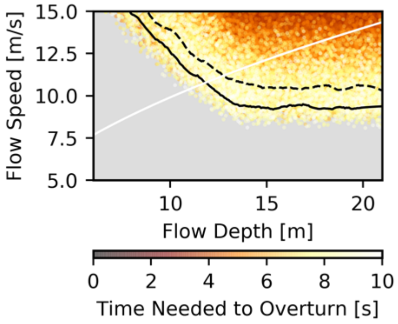

Figure 1 - Overturning of 12-m wide by 13-m high caisson predicted by 6-parameter Monte Carlo simulation (2 million cases); gray indicates non-overturning cases. Black lines show median overturning times of 5 (dashed) and 10 (solid) seconds. Froude number of 1 shown in white.

OVERTURNING SCALING

For partially and fully submerged rectangularly shaped caissons, an 8-parameter Monte Carlo simulation (8 million cases) reveals that overturning scales with:

$$\left[\left(\frac{[c-(c-h)H[c-h]]^2}{bc}\right)^{\alpha} \left(\frac{u^2}{g\sqrt{b^2+c^2}}\right) \;,\; s \right] \tag{1}$$

where b and c are respectively caisson width and height, h is flow depth, u is flow speed, s is caisson specific gravity, $H[]$ is the Heaviside step function, and α is a fit coefficient on the order of 1. Uncertainty in the threshold condition for overturning is larger when the caisson is partial submerged, with respect to full submergence.

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