MODELLING THE EFFECTS OF TSUNAMI-INDUCED FORCES ON BUILDING FACADES

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ABSTRACT

Tsunami waves cause severe structural and non-structural damages in the shallow water and inundation areas. The intense development that coastal areas have experienced in the last decades, with a rapid growth in population and economy, has increased their exposure to tsunami waves.

Recent research on tsunami modelling has been mainly centred in the hydrodynamic issues (e.g., propagation). However, the major losses, human lives and economic, occur at the inland areas, and so further knowledge on what happens in these areas is needed. Main goal of this research is the assessment of inland buildings resilience to tsunami-induced flooding.

INTRODUCTION

The Indian Ocean (2004) and Tohoku (2011) tsunamis are recent examples of catastrophic earthquake-induced tsunamis with tragic consequences to the people, environment and economic activity. The Gulf of Cadiz is a tsunami prone area (linked with the western segment of the Eurasia-Nubia plate boundary) where the occurrence of major tsunamis has been described, at least, since 60 BC (Baptista and Miranda, 2009). The Algarve (the southernmost region of mainland Portugal and part of the Gulf of Cadiz Northern boundary) is a region susceptible to the seismic activity with origin at the Eurasia-Nubia plate boundary and at local tectonic faults. Major cities in the Algarve, situated near the coastline, suffered from a fast growth in urbanization due to the main economic activity in the region: tourism.

To asses buildings resilience, tsunami-induced forces on inland structures are simulated by coupling seismic-tectonic, hydrodynamic and structural models.

At the present stage and for the purpose of this work the maximum tsunami-wave height (10 m) and velocity (8 m/s) were obtained from Baptista et al. (2010) and Omira et al. (2011). Hydrostatic, hydrodynamic and impact forces were considered at the current stage of this study. Other tsunami-induced forces as buoyant, surge or braking-wave were not considered, despite their possible relevance, namely for extreme tsunami events. Structural analysis of the facade was performed with the Finite Element Method (FEM).

TSUNAMI LOADS

In this work the following loads and design assumptions were assumed accordingly to FEMA P646 (2008) and FEMA P-55 (2011):

- HYDROSTATIC LOAD, caused by the imbalance of pressure due to differential water depth on opposite sides of the facade.

$$F_h = \frac{1}{2}\rho_s g b h_{\max}^2$$

- HYDRODYNAMIC LOAD, caused by the flow of water moving at moderate to high velocity around the wall.

$$F_d = \frac{1}{2}\rho_s C_d B\left(hu^2\right)_{\max}$$

$$\left(hu^2\right)_{\max} = gR^2\left(0.125 - 0.235\frac{z}{R} + 0.11\left(\frac{z}{R}\right)^2\right)$$

- IMPACT LOAD, caused by debris carried by the water

$$F_i = C_m u_{\max}\sqrt{km}$$

$$u_{\max} = \sqrt{2gR\left(1 - \frac{z}{R}\right)}$$

BUILDING FACADE MODEL

A finite-element linear structural analysis was carried out using SAP2000 (Computers & Structures, INC.). A highly-detailed 3D model with 33066 solid elements was created to simulate the behaviour of a single brick wall with cement render (Figure 1). The facade with 2.82 m of height by 5.36 m of length has vertical concrete pillars and a concrete slab, respectively, at the lateral and upper extremities of the masonry wall (0.27 m width). Dead loads were not considered for the purpose of this analysis.

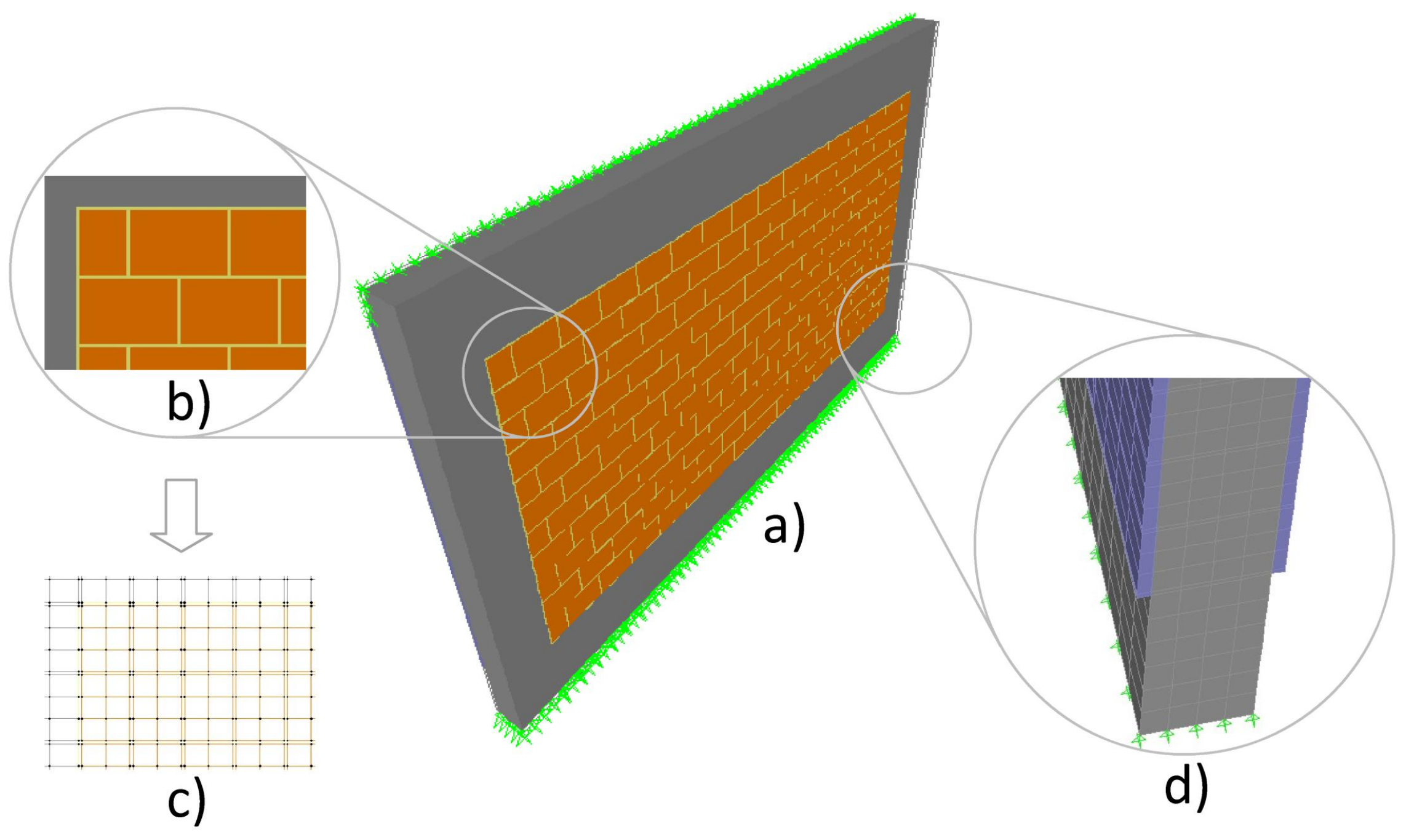

Figure 1. Finite-element wall model. a) Global view, b) detail of brick-concrete and brick-brick interfaces, c) detail of FEM mesh, d) detail of cement render (in blue).

RESULTS AND DISCUSSION

Figure 2 shows that, for this particular case, hydrostatic loads are more relevant than hydrodynamic loads.

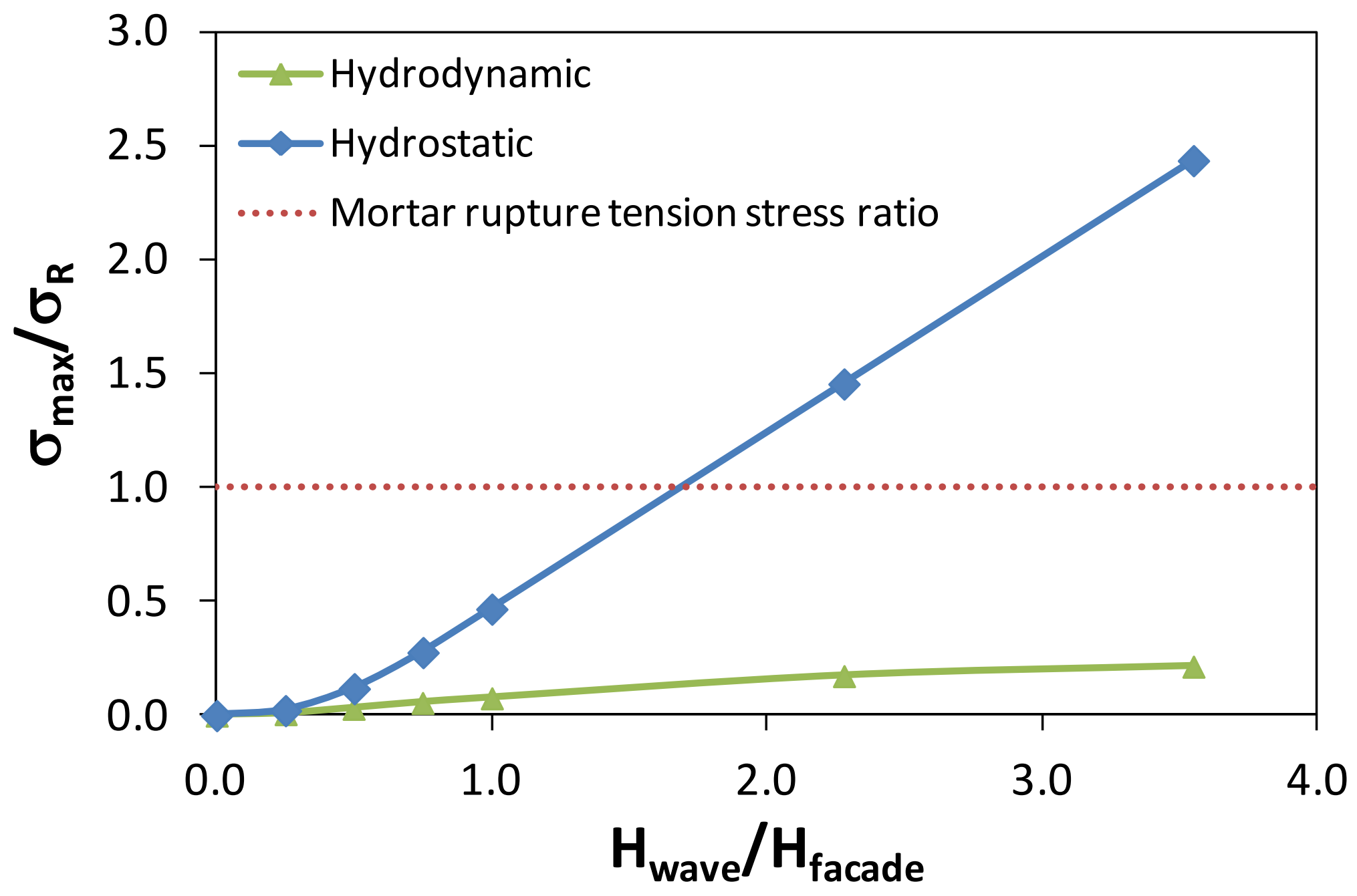

Figure 2. Principal tension stress to mortar rupture tension stress ratio (σ_{max}/σ_R) vs. wave height to facade height ratio (H_{wave}/H_{facade}).

Forces induced by the impact of debris carried by the water showed to be much higher than hydrostatic or hydrodynamic forces. Impact of a wood log (450 kg) approximately at the centre of the brick wall leads to σ_{max}/σ_R of 4.45 (Figure 3).

In a tsunami event damages to the facade would result from the combination of these forces.

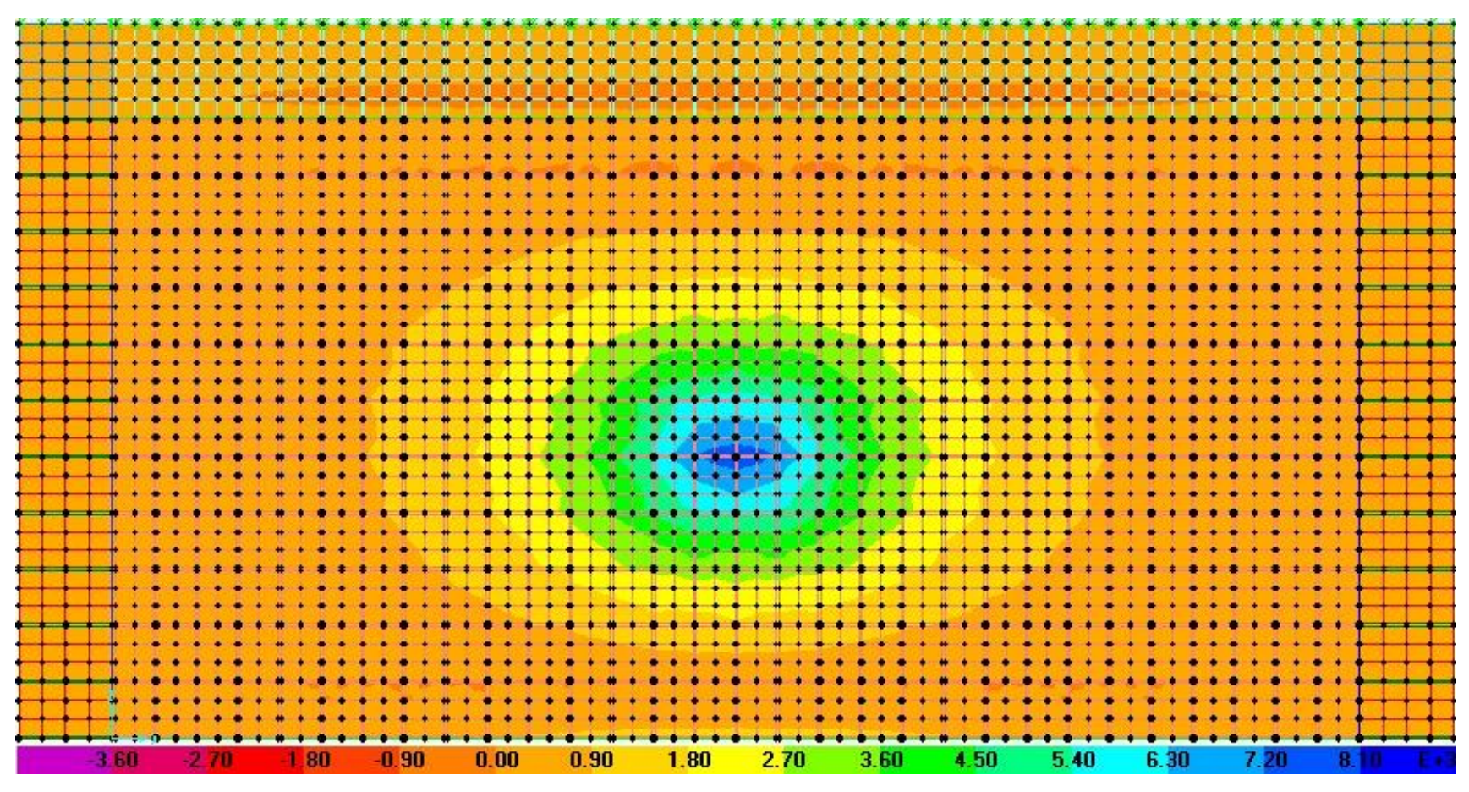

Figure 3. Example of principal tension stress field caused by the impact of a wood log.

CONCLUSION

Preliminary results from this simple numerical study shows that typical construction in the Algarve from the 60's to the 80's can suffer major damages from tsunami-induced forces. Computational nonlinear structural analysis and laboratory simulations are currently in progress to evaluate the response of different types of building facades (e.g., materials, construction methods). The authors hope that this research may give a useful tool to engineers and planners who deal with flood risk assessment in coastal areas and ultimately help to improve resiliency of building facades.

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