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# SPH modelling of tsunami-induced bore and structure interaction using DualSPHysics

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## ABSTRACT

A series of 3-D smoothed particle hydrodynamics (SPH) models with a domain in the form of a water tank were undertaken to simulate tsunami-induced bore impact on a discrete onshore structure on a dry bed. The tsunami-like waves were represented by solitary waves with different characteristics generated by the numerical paddle wavemaker. Numerical probes were uniformly distributed on the structure's vertical surface with spacing twice that of the diameter of particle, providing detailed measures of the pressure distribution across the structure. This allows the impact forces acting on certain areas to be derived directly from the pressures output. The peak impact location on the structure's surface can be specifically determined and the associated peak forces are compared with existing design code predictions. The results show that the equations used to estimate the forces for design purposes can both over and under-predict the forces.

**Keywords:** *SPH; tsunami; bore; wave-structure interaction*

## 1. Introduction

At present, there is little, if any, detailed codified guidance specifically addressing the design of onshore structures situated in tsunami risk areas, Nistor et al. [1]. The work presented herein forms part of an investigation aiming to enhance current understanding of tsunami wave-structure interaction with a view to improving current design provisions, Pringgana [2]. The numerical modelling technique of smoothed particle hydrodynamics offers the potential for improved definition of wave characteristics and associated pressures on impacted structures. Previous studies have demonstrated the efficacy of the technique e.g. St-Germain et al. [3] where in addition to the laboratory experiments on tsunami wave impact on structures near shore, the associated numerical modelling study was conducted using smoothed particle hydrodynamics (SPH) on the basis of analogies between tsunami bores and dam break waves. SPH is a meshless Lagrangian technique which is ideal for simulating highly nonlinear free-surface phenomena such as breaking waves. Furthermore, the SPH technique has also been used to model other violent wave behaviour such as storm wave impact on vertical walls near shore, Altomare et al. [4]. A study by the authors on tsunami wave and structure interaction showed the applicability of SPH in quantifying tsunami wave characteristics within acceptable levels of accuracy, Cunningham et al. [5].

Robertson et al [6] stated that the main research on wave impact forces on structures can be categorized into the following three areas. Firstly, the work related with storm wave impact on offshore platforms, which at present is the most frequently studied. Secondly, combining experimental and numerical research in order to develop design formulae for associated loads on structures. Thirdly, research on the force and structural response resulting from tsunami bores impacting on land-based near shore structures, which is least studied. Consequently, there is a need to understand better tsunami bore impact on onshore coastal structures due to the relatively limited available research. In areas of vulnerability to tsunamis, designers of onshore structures need to have better guidance on quantifying tsunami induced loads that should be considered for building design and strengthening of existing structures.

Various equations have been proposed by researchers as a means of quantifying tsunami bore pressures on structures. The propagation of bores on a dry bed and its impact on vertical walls were

studied by Cross [7] who proposed the following equation to predict the bore impact force on the wall:

$$F = \frac{1}{2}\rho gh_b^2 + \rho h_b v_j^2 \quad (1)$$

in which  $\rho$  is the mass density of water,  $g$  is gravitational acceleration,  $h_b$  is the height of the bore, and  $v_j$  is the propagation speed. Fujima et al. [8] proposed two equations for a dry flat shoreline configuration based on the maximum water inundation level and the distance of the structure from the shoreline. The equation expresses the distance of structure from shoreline ( $D$ ) in terms of ( $h_{im}/D$ ), where  $h_{im}$  is the maximum inundation depth. For the numerical model presented here the condition where  $h_{im}/D > 0.05$  is satisfied, the structure is categorized as close to the shoreline, thus the equation that is applicable for an average estimation of force is:

$$F = 1.8\rho gh_{im}B \quad (2)$$

in which  $B$  is the breadth of structure. As an appropriate safety factor, Fujima [8] suggests the coefficient of 1.8 in Equation (2) be increased to 3.3. These equations have been based small-scale physical experiments for bores propagating over a dry bed.

## 2. Computational Domain

Numerical simulations using smoothed particle hydrodynamics (SPH) with the open source software DualSPHysics [9] were conducted to predict tsunami-like bores impacting on structures. A water tank simulating near-shore and onshore areas was set as the model domain, see Figure 1. The dimensions of the numerical water tank are 15 m high, 3 m wide and 5 m high. The numerical domain consists of an offshore region containing water particles, an inclined sea bed and onshore region where the coastal structure is placed. The particles representing water and solid parts in the domain have diameters ( $d_p$ ) equal to 1/20 of the still water level ( $h_o$ ) that was in this case set to be 1 m.

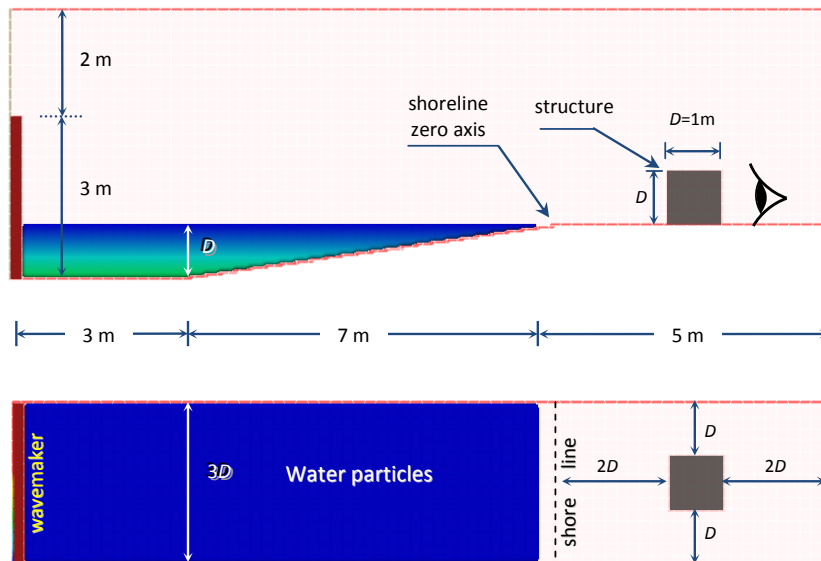


Figure 1 The side and top view of 3-D model (not to scale)

The paddle wavemaker was located at the left-hand side of the tank and partly submerged. The paddle generated solitary waves representing tsunami-like waves. The solitary wave travelled along the tank and produced a bore as it reached the shoreline before impacting the onshore structure at the opposite side of the tank. The solitary waves were designed to have different heights equal to  $H/h_o = 0.1, 0.3$  and  $0.5$ , hence, producing different bore characteristics. A separate simulation was performed for each different wave height. The paddle wavemaker motions were based on Goring's equation and related with wavemaker theory as explained by Dean and Dalrymple [10]. In accordance with this theory, for

example, a 1.63 m paddle stroke is needed for generating a solitary wave height equal to 50 cm or  $H/h_o = 0.5$ .

The tsunami bore can be defined as a steep, turbulent, rapidly moving tsunami wave front that can be very destructive [11]. The bore's characteristics for impact loading are velocity and height and both were measured by probes situated in front of the onshore structure. The pressures caused by bore impact were measured by probes mounted on the surface of the structure and from this pressure the acting force can then be derived. The pressure distribution on the structure's surface was also evaluated to determine the maximum impact occurrence location and time. The numerical probes were uniformly distributed on the structure's vertical surface, with spacing twice that of the diameter of particle, intended to be able to accurately measure pressure distribution. A numerical convergence study was conducted to identify the smallest resolution (particle size) such that simulations could be conducted in the shortest amount of time possible without compromising accuracy.

### 3. Results and Discussion

Figure 2 and Figure 3 show the 3-D simulation for the case with  $H/h_o = 0.5$ . Figure 2a depicts the side view snapshot of a propagating solitary wave which is then followed by a bore impact on the structure as shown by Figure 2b. Figure 3a shows the peak pressure impact that occurred at  $t = 4.150$  sec and the peak pressure which took place at the lowest level of probes as indicated by the circle in the figure.

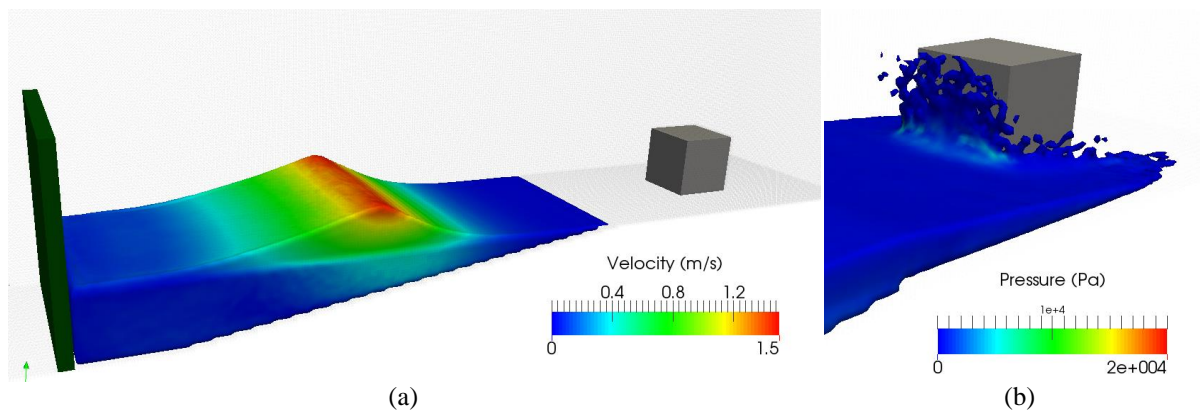


Figure 2 Side view of the 3-D simulation for case  $H/h_o = 0.5$ ; (a) solitary wave propagation at  $t = 2.875$  sec., (b) bore impacting structure at  $t = 4.325$  sec.

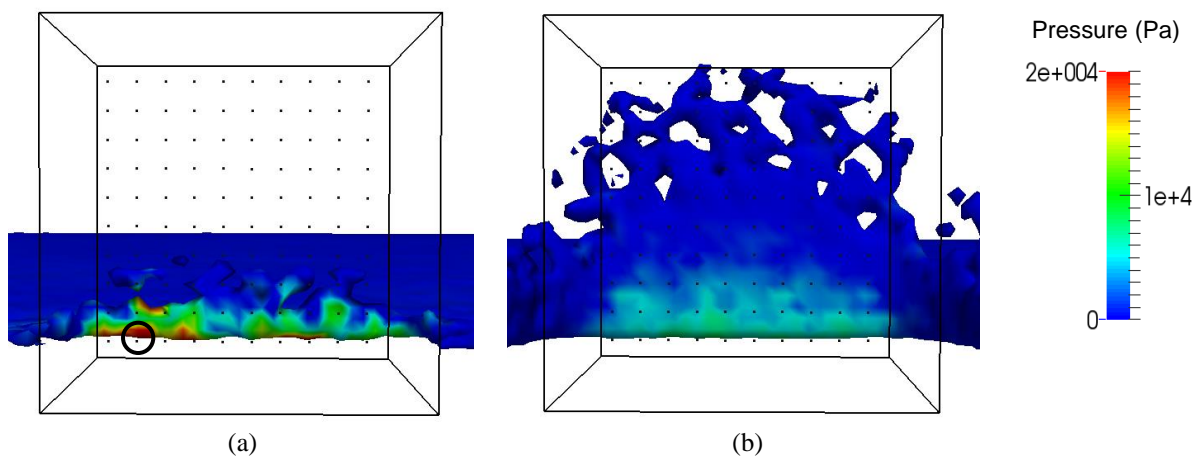


Figure 3 Pressure distribution on vertical surface for a model with  $H/h_o = 0.5$ ; (a) first impact at  $t = 4.150$  sec, (b) peak impact occurred at probe in a circle at  $t = 4.325$  sec.

In addition, Figure 3b shows the pressure distribution for the maximum bore runup on the surface of the structure that occurred at  $t = 4.325$  sec and corresponding with Figure 2b. Pressure distributions in

Figure 3 were seen from the rear of the structure (see illustration indicating direction of view in Figure 1) by assuming the cube structure is visually transparent.

The normalised peak pressures ( $P/\rho gh$ ) for the simulation with wave height equal to  $H/h_o = 0.1, 0.3$  and  $0.5$  were  $0.748, 18.165$  and  $83.287$ , respectively. The force ( $F$ ) acting at a certain point in the 3-D model can be determined by multiplying the pressure ( $P$ ) from SPH analysis output with the associated area ( $A$ ). Hence, the total force ( $F$ ) acting normal to a surface can be estimated by summing the total number of forces acting on the surface. The bore pressures for the case with  $H/h_o = 0.1$  were comparatively small, resulting in a correspondingly small impact force. Hence, the comparison of the predicted impact forces between the numerical and the empirical equation were made only for the case with  $H/h_o = 0.3$  and  $0.5$ . The maximum total forces (per  $m^2$  area) for the case with wave height equal to  $H/h_o = 0.3$  and  $0.5$  were  $1124.49$  N, and  $3915.46$  N, respectively. The associated impact forces determined by Equation (1) were  $2277.75$  N and  $4222.14$  N for the case with  $H/h_o = 0.3$  and  $0.5$ , respectively. In addition, the impact forces predicted by Equation (2) were  $1638.88$  N and  $3525.42$  N, for the case with  $H/h_o = 0.3$  and  $0.5$ , respectively, which indicate potential non-conservatism in the design equation, even with the onerous factors of safety. However, this must be viewed within the context that in general design equations adopt a quasi-static approach to the wave pressures, whereas in reality the peak pressure occur over a very short time period.

#### 4. Conclusion

A realistic simulation of a tsunami-like wave induced bore impacting onshore structures on a dry bed is performed using SPH. The numerical results are based on varying solitary wave heights but with the same resolution and domain dimensions. The numerical predictions of the bore impact can offer greater insight into the resulting pressures than those predicted by current design equations. This level of detail in the wave-structure interaction can lead to improved resilience of onshore structures in tsunami risk areas of the world.

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