NUMERICAL STUDY OF THE EFFECT OF SHIPPING CONTAINER STORAGE YARD LAYOUTS ON THEIR TRANSPORT IN EXTREME HYDRODYNAMIC EVENTS

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INTRODUCTION

Extreme hydrodynamic events, such as those driven by tsunamis, most notably in Tohoku, Japan 2011 (Mori et al., 2011) and in Indonesia 2004 and 2018 (Sassa et al., 2019), have shown the need to consider debris for an accurate hazard assessment. Three main processes are relevant in this context: (I) debris transport and dispersion (Naito et al. 2014), (II) debris impact on coastal structures and infrastructures (Stolle et al., 2018, De Iasio et al., 2023) and (III) debris damming (Mauti et al., 2020). For (II) and (III), multiple design guidelines for structures, such as the FEMA P646 (FEMA, 2012) and American Society for Civil Engineers design codes (ASCE, 2016), were developed. (I) is mainly addressed either by simple empirical laws or by laboratory experiments. Numerical simulations of debris transport are still challenging in realistic conditions (Koh et al. 2023). Simple empirical rules describe debris lateral dispersion defined by a spreading area ±22.5° from the initial position (Naito et al. 2014), and by a dispersion law depending on the number of debris transported (Nistor et al., 2017).

Harbours and nearby areas are exposed to container transport hazard (Naito et al. 2014., Koh et al. 2023). This makes understanding the role of tsunamis impact angle and storage yard layout on the movement of shipping containers particularly important. While dispersion at city scale can be simulated with depth integrated models (Koh et al. (2023), the analysis of the pick-up stage and near field transport requires modelling of the six degrees of freedom of the waterborne debris. Due to their nature, Lagrangian numerical models have been used to simulate these problems. More specifically Smoothed Particles Hydrodynamics (SPH) models coupled with the Multiphysics model CHRONO have recently demonstrated their capability in accurately simulating these type of phenomena (Ruffini et al., 2021, 2023). Using this numerical approach, this study aims to provide insight into the role of the initial debris layout in the hazard generated by their mobilisation, focusing on shipping containers in harbours.

METHODOLOGY

DualSPHysics v5.2 (Dominguez et al. 2022) was used in this study coupled with CHRONO. The MESH-IN (Ruffini et al., 2023) coupling technique was used to allow for a higher resolution simulation of the debris pick-up and transport. First, laboratory experiments from Stolle et al. (2020) were reproduced to calibrate and validate the numerical model for the first time using multiple containers in single and double stack configurations. Using the same reservoir depth, the wave flume was enlarged and any three-dimensional feature of the flow (Stolle et al., 2020) were removed to allow for a consistent two-dimensional flow field. This new domain was used to analyse typical storage yard container layouts by also varying the tsunami impact angles with the cluster. The container layout in a harbour primarily depends on the specific container handling system used (Notteboom et al., 2022) and they are classified as (i) linear layouts and (ii) block layouts. (i), shown in Figure1a, are usually used when containers are handled by trucks, straddle carriers or reach stackers, while (ii) (Figure1b) are used when gantries are used. Multiple examples of both types were analysed.

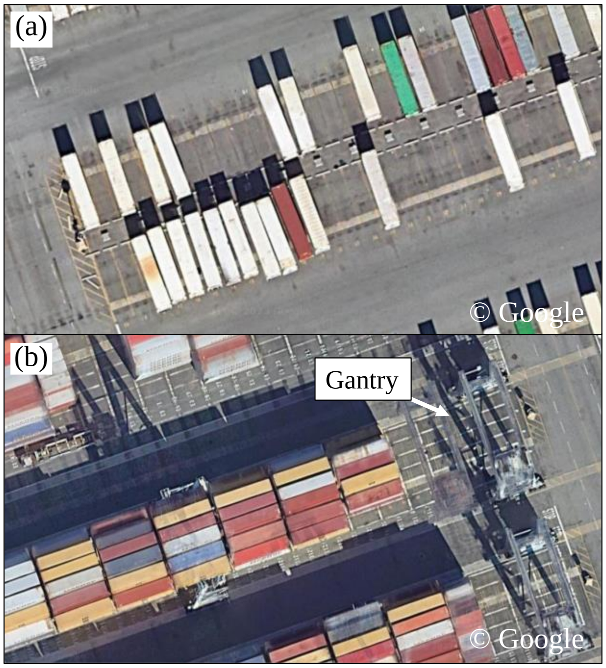

Figure 1 – Typical storage yard (a) linear and (b) block layouts from Los Angeles harbour (Copyright Google).

RESULTS

Numerical simulations are validated against the mean values of the trajectories from Stolle et al. (2020) (Figure 2) and the dispersion laws from Nistor et al. (2017) and Naito et al. (2014), for both single stack (Figure 2a) and double stack (Figure 2b). In both layouts, numerical results are always included in the experimental cloud of points. Numerical results are compared with the experimental results both in kinematics and trajectory in terms of nRMSE, showing values of 0.13 and 0.023 in a single stack layout and 0.14 and 0.044 in a double stack one for the *x*-velocity and *x*-trajectory, respectively.

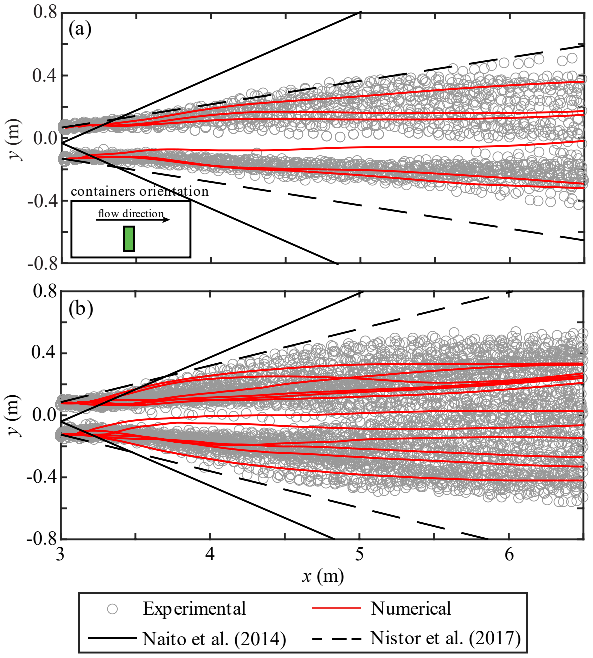

Figure 2 – Numerical trajectory validation for (a) single and (b) double stack configuration and comparison with Nistor et al. (2017) and Naito et al. (2014) dispersion laws.

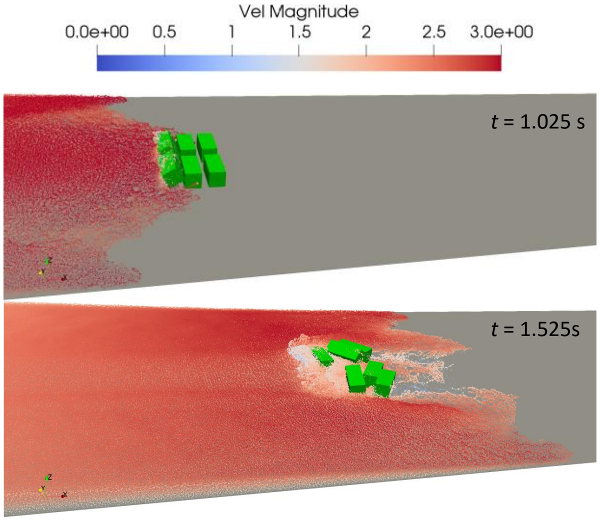

Figure 3 – Simulation snapshots for single stack validation simulation at pickup (top) and after stabilization (bottom).

In Figure 3, two different snapshots of a simulation with a single stack layout are shown. In the upper panel the initial pick-up of the container cluster is shown while the bottom panel is taken at a time when the containers cluster reaches a quasi-steady *x*-velocity. This is consistent with what was observed in the laboratory experiments of Stolle et al. (2020).

This contribution will discuss in detail the effect of different layouts on pick-up and transport as well as developing a better understanding of their role in the debris hazards.

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