

THE NEW OFFSHORE RAVENNA LNG TERMINAL (IT): COMPARISON BETWEEN EXPERIMENTAL AND NUMERICAL SIMULATIONS

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INTRODUCTION

The Italian company SNAM is planning a new offshore terminal for the import of Liquefied Natural Gas (LNG) that will be located in the northern Adriatic, SE of the Port of Ravenna (Fig. 1). The new terminal involves the permanent mooring of a Floating, Storage, and Regasification Unit (FSRU) at a jetty. The FSRU will be supplied with LNG by carrier ships using the ship-to-ship transfer technique (Fig. 2). The terminal will be protected by a vertically composite breakwater (Fig. 2) equipped with a recurved parapet wall and anti-reflective cells (see Fig. 3). The combination of anti-reflective cells and recurved walls represents the best solution to reduce wave overtopping.

In the present paper, the 2D numerical and experimental investigation carried out to support the design is presented. The aim of the tests has been to optimize the hydraulics and structural design of the structure.

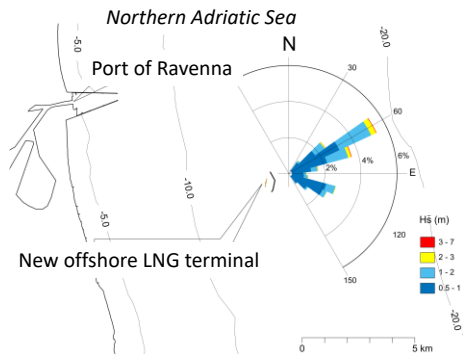


Figure 1 - Geographical location and wave climate exposure of the new offshore LNG terminal.

As demonstrated in the studies by Castellino et al. (2018, 2021) and Martinelli et al. (2018), one of the most effective parapet designs is the overhanging configuration. Consequently, multiple configurations have been examined, including both vertical and recurved parapets, each with varying freeboard heights. Despite the good performance of recurved parapets in decreasing the wave overtopping, an impulsive phenomenon named C-CI can arise from the interaction of non-breaking waves with overhanging parapets (Castellino et al., 2018). The main focus of this research study is to gain insight into the trade-off between wave overtopping and impulsive loads acting on the new Ravenna LNG terminal.

METHODS

For the presented research study, both numerical and experimental tests have been conducted.

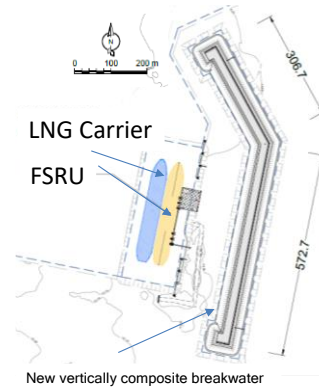


Figure 2 - Plan of the new offshore LNG terminal

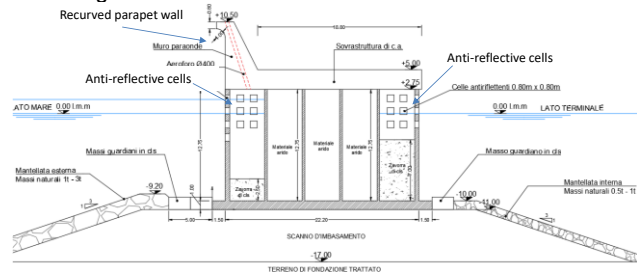


Figure 3 - Vertically composed breakwater cross-section

The contemporary use of these methodologies offers a multitude of advantages, above all the validation of the numerical results. The experimental tests have been carried out in HR Wallingford's Flume 2 (see Figure 4).

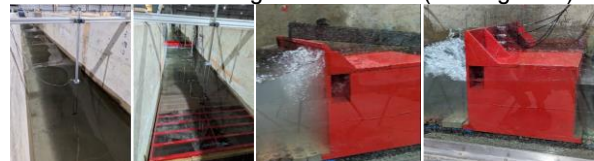


Figure 4 - Experimental facilities, HR Wallingford's Flume 2.

The flume is 40 m long, 1.2 m wide, and with operating water depths of up to 1.6 m. The generation of waves is performed by using a piston-type wavemaker and is controlled by HR Wallingford's Merlin software. This software enables the utilization of the active absorption technique, which is critical in the examination of highly reflective structures like the composite vertical breakwater. The different breakwater configurations have been tested under irregular waves, in a Froude scale of 1:35. The laboratory experiments have been accompanied by a series of numerical tests carried out

using OpenFOAM®. The solver adopted is interFOAM which resolves the Reynolds averaged Navier-Stokes equations for multiphase flow (air and water). Wave generation has been solved by using IHFOAM (Higuera et al., 2013a), built in OpenFOAM®. As for the experimental tests, it is possible to use the active absorption technique. The numerical experiments have been carried out in a wave flume 420 m long and 40 m high and therefore in a prototype scale. Unlike what has been performed for the laboratory tests, only regular waves have been generated because of the computational time cost. As shown by Castellino et al. (2021), a comparison between the effect induced by irregular and regular waves has been analyzed in terms of pressures.

A total of six configurations have been tested, three with a vertical parapet and three with a recurved parapet. The numerical results obtained on the plane parapet wall have been used to evaluate the pressures and forces with respect to the related recurved parapet configuration.

RESULTS

The new Ravenna LNG Terminal, has been tested under wave conditions characterized by a return period of 100 years ($H_s = 5.5$ m and $T_p = 9.6$ s). As above mentioned, in the laboratory campaign, irregular waves have been generated (about 1000 waves per test). In order to analyze the effective hydraulic efficiency of the recurved parapets with respect to the vertical one, the wave overtopping results are shown in Figure 3.

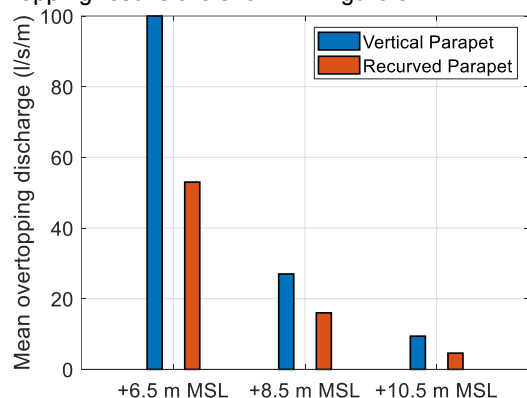


Figure 5 - Pressure distribution along the vertical section of the structure.

Analyzing Figure 5, it can be observed that, for a fixed freeboard, the recurved parapet is always subjected to half the mean overtopping discharge, confirming the high hydraulic efficiency of overhanging structures.

On the other hand, particular attention must be given to the force increase induced by the C-CI. For the experimental study, a total of 9 pressure probes have been used, designed to have a response rate of up to 10 kHz. In the numerical model, it is possible to set a higher number of numerical pressure probes. In this case, the pressure is calculated along the structure every 0.10 m. Due to the impulsive behavior of the C-CI, the acquisition rate is significant and linked, therefore, to the time step of the simulation. This has been set to be almost equal to 0.01 s or less. As a preliminary result, in Figure 6 the

comparison between the pressure distribution along a vertical section measured in the laboratory test and numerically calculated is presented. The red dots indicate the pressure distribution calculated in the laboratory test at the instant at which the maximum total force is realized on the vertical breakwater. Instead, the solid black line represents the pressure distribution numerically calculated.

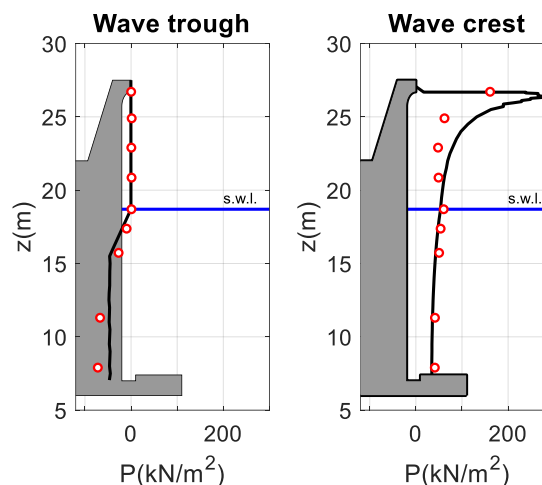


Figure 6 - Pressure distribution along the vertical section of the structure.

In the left panel of Figure 6, the pressure distribution during the trough phase has been shown. In this case, a slight underestimation of the numerical pressure can be observed. In the right panel, the pressure distribution is related to the crest phase. Unlike what can be observed for the trough phase, the numerical pressure assumes greater values on the emerged part of the structures. This trend can be justified by the fact that the Confine-Crest Impact mainly affects the upper part of the structures. By using the numerical model, and higher number of numerical probes can be used, this allows to catch the exact position in which the maximum pressure occurs. As a proof of this behavior, under the still water level a perfect accordance between the laboratory and numerical results can be observed. Further and detailed analysis about this research work will be shown during the conference.

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