

FLOATING BREAKWATERS COMBINED WITH SHEET PILES. AN APPLICATION FOR THE DEFENSE OF SAN MARCO SQUARE (VENICE, IT)

Luca Martinelli, University of Padova, luca.martinelli@unipd.it
Matteo Volpato, University of Padova, matteo.volpato@unipd.it
Piero Ruol, University of Padova, piero.ruol@unipd.it
Chiara Favaretto, University of Padova, chiara.favaretto.1@unipd.it

INTRODUCTION

The Lagoon of Venice is the largest of the Mediterranean area with a unique and fragile ecosystem. It is the result of its long-term management, that dates back to the fourteenth century, when the Venetians decided to divert the major tributaries (Adige, Bacchiglione, Brenta, Sile, Piave rivers) out of the lagoon, so that they discharge their fresh water and sediments directly into the sea, reducing the siltation of the lagoon (Gatto & L. Carbognin 1981). These monumental hydraulic works, decisive for the splendor of Venice, gave rise to several other variations: subsidence was not compensated for by the alluvial deposit, deepening of the lagoon increased the erosion processes, diversion of freshwater caused an increment of the salinization, etc. As a result, a unique lagoon environment developed, that however cannot survive without constant management. Today, at the three inlets that connect the lagoon with the Adriatic Sea, impressive hydraulic works, storm surge barriers named Mo.S.E. (from the Italian acronym for "Experimental Electromechanical Module", www.mosevenezia.eu) are present. They are crucial to prevent coastal flooding caused by high water levels during extreme storm events. The system started to be operative in October 2020 (Mel et al. 2021) and since then the barriers were activated more than 50 times.

MOTIVATION

The Mo.S.E. defends the lagoon islands with the ultimate goal of keeping the water level below a safeguard value that in front of Venice is +1.10 m (Umgiesser, 2020) above the local chart datum (ZMPS). This value is selected based on several environmental considerations, and it is certainly not specifically aimed at preventing the flooding of San Marco Square. Additional and specific mitigation measures are under design to prevent the flooding of the Square, which (with water level of +1.1 m ZPSS) is now caused by back-flow through the drainage system, filtration, overflow, and wave overtopping (Ceccato et al., 2021). The design includes the upgrading and renovation of the ancient drainage system with the installation of valves that will be closed during extreme events, the upgrade of portions of the Square pavement and of some boundaries, and the installation of a barrier to reduce the waves incident the San Marco quay.

The present study focuses on this latter part of the project. In fact, the San Marco quay will be the sole portion of the square subject to wave overtopping, and the overtopping discharge is acceptable only if the significant wave height at the quay is smaller than 0.2 m (Ruol et al., 2020). In order to reduce the residual wave, a feasible mitigation measure, that meets the strict architectural constraints, is a narrow floating concrete structure in front of the quay.

AIMS

The aim of this contribution is to experimentally investigate, in the wave flume of Padova University, an effective floating breakwater (FB) that, placed in front of the quay, limits the wave to the 0.2 m threshold, and thus ultimately defend Piazza San Marco from flooding reducing the overtopping discharge to values compatible with the drainage system. As explained in the following, in order to achieve the desired performance with the existing architectural constraints, the narrow FB is integrated with sheet piles always submerged.

COMPLEMENTARY PERFORMANCE

The cultural heritage protection policies suggest to use structures with crest freeboard not exceeding 0.5 m and width not exceeding 3 m. Liang et al. (2022) examined different mooring configurations and conclude that in most cases the fixed (that we consider "pile restrained") floating breakwater is the most efficient. This solution was considered feasible for Venice, provided that piles have limited diameter. Note that the constraint on the anchoring pile diameter also indirectly limits the overall mass and draft (forces on piles are however not discussed in this note). Simple design formulas (Ruol et al., 2013) immediately showed that a box and Pi-type FBs complying with the constraints, can provide a barely sufficient attenuation even with the maximum draft (compatible with depth and tidal range).

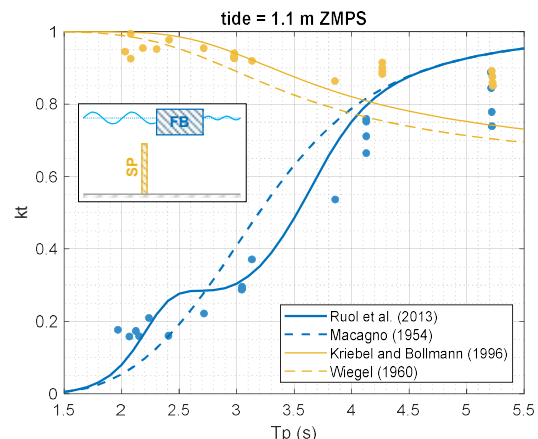


Figure 1 - The attenuation capacity for Floating breakwater and sheet piles is complementary.

In order to guarantee a safety margin, different methods to increase the FB efficiency were investigated. Possible couplings of the FB with dissipative mechanisms, such as oscillating water columns (Howe et al., 2020) or semi-

enclosed moonpools (Tay, 2022), dissipative vertical plates (He et al., 2023), just to quote a few of the many investigated solutions, appeared not feasible. In agreement with the designers, it was decided to use a structure combining a floating breakwaters (FB) with “always submerged” sheet piles (SP).

Obviously, the sheet pile crest must remain very low, in order to be not visible even in low tide. Particular care is required to avoid interference with the FB and with navigation. The SP should only give the small efficiency increment that allows to reach the design attenuation capacity.

This combination of FB and SP has apparently never been investigated, probably because FBs are mainly placed in deep waters, where sheet pile solution is not economical. Figure 1 shows that the two types of structures are complementary with respect to different ranges of the period of the incident waves and therefore may provide an interesting combo.

EXPERIMENTAL INVESTIGATION

The experimental investigation is carried out to evaluate the performance of a structure formed by the combination of a floating breakwater (FB) and a steel sheet pile (SP). The tests are performed in the wave flume of the Maritime Laboratory of the Department of Civil, Environmental and Architectural Engineering (ICEA), Padova University. The flume is 36.0 m long, 1.0 m wide, the 1.3 m high, and it is equipped with a dual piston-flap type wavemaker, capable of generating regular and irregular waves, with active wave absorption. The tests are carried out in geometrical scale 1:8, using Froude similarity. The bottom of the flume is horizontal, non-erodible and reproduces the bathymetry in front of the quay, with bed level at -4 m ZMPS at prototype scale.

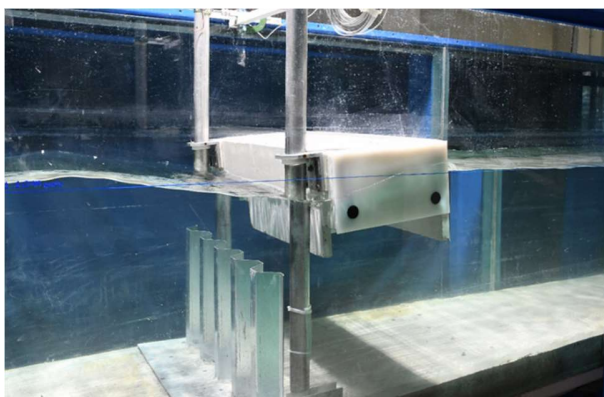


Figure 2 -Floating breakwater and sheet pile.

Four configurations are analyzed: 1) the SP is placed in front of the FB (see Figure 2); 2) the SP is placed in the rear area; 3) FB only; 4) SP only.

The reason to test the FB and SP separately is to evaluate separately their contribution on wave reduction.

The FB in prototype is 3800 kg/m (76'000 kg for a 20 m long FB), 3.0 m wide and 2.4 m high and has a freeboard of 0.5 m. It is moored with piles placed on the offshore

side. The SP prototype head is located at -0.8 m ZMPS. The extensive test program consists of 336 tests, i.e. 21 wave attacks repeated for 4 water levels and 4 configurations.

All wave attacks are irregular, with JONSWAP spectrum. Five tests are carried out (in an exploratory investigation) for design purposes, and are characterized by H_s ranging from 0.2 to 0.75 m and T_p from 2 s to 5 s in prototype, and include the SLS and ULS.

The remaining 16 tests were studied for research purposes only, and are characterized by $H_s = 0.2$ m, 0.3 m, 0.4 m, 0.5 m and $T_p = 2$ s, 3 s, 4 s, 5 s.

The 4 water levels are: -0.8 m ZMPS (minimum water level in the lagoon), 0 m ZMPS, 1.1 m ZMPS (Mo.S.E. safeguard value) and 1.3 m ZMPS (for possible application in another similar context with higher tide).

Waves are measured by two arrays of four wave gauges, one placed in front of the structure and one behind. Waves are analyzed separating the incident and reflected components at both arrays. Standard zero down-crossing time domain and spectral analyses are carried out.

MAIN RESULTS

Physical model tests showed that the combined structure performs much better than the FB and SP tested separately, especially in low tide, but also in high tide conditions.

The combo has the potential, in shallow water depths, to provide a significant wave attenuation for a wide range of wave periods.

ACKNOWLEDGEMENTS

The support of Ministero delle Infrastrutture e dei Trasporti - Provveditorato Interregionale alle OO. PP. del Veneto - Trentino Alto Adige - Friuli Venezia Giulia through the Consorzio Venezia Nuova technical team is gratefully acknowledged.

REFERENCES

- He, F., Li, J., Pan, J., & Yuan, Z. (2023). An experimental study of a rectangular floating breakwater with vertical plates as wave-dissipating components. *Applied Ocean Res.*, 133, 103497.
- Howe, D., Nader, J. R., & Macfarlane, G. (2020). Experimental investigation of multiple Oscillating Water Column Wave Energy Converters integrated in a floating breakwater: Energy extraction performance. *Applied Ocean Research*, 97, 102086.
- Liang, J. M., Liu, Y., Chen, Y. K., & Li, A. J. (2022). Experimental study on hydrodynamic characteristics of the box-type floating breakwater with different mooring configurations. *Ocean Engineering*, 254, 111296.
- Mel, R. A., Viero, D. P., Carniello, L., Defina, A., & D'Alpaos, L. (2021). The first operations of Mo. SE system to prevent the flooding of Venice: Insights on the hydrodynamics of a regulated lagoon. *Estuarine, Coastal and Shelf Sc.*, 261, 107547.
- Ruol, P., Favaretto, C., Volpato, M., & Martinelli, L. (2020). Flooding of Piazza San Marco (Venice): Physical model tests to evaluate the overtopping discharge. *Water*, 12(2), 427.
- Ruol, P., Martinelli, L., & Pezzutto, P. (2013). Formula to predict transmission for n-type floating breakwaters. *J. Waterw. Port Coast. Ocean Eng.*, 139, 1-8.
- Tay, Z. Y. (2022). Effect of resonance and wave reflection in semi-enclosed moonpool on performance enhancement of point absorber arrays. *Ocean Engineering*, 243, 110182.