STORM-DRIVEN WAVE IMPACT LOADS AND SCOUR AT A BEACH SEAWALL

Sylvain Perrin, ARTELIA, sylvain.perrin@arteliagroup.com,
Thomas Saillour, ARTELIA, thomas.saillour@arteliagroup.com
Elodie Baillit, ARTELIA, elodie.baillit@arteliagroup.com

INTRODUCTION

The Grande-Motte port and seafront development project on the French Mediterranean coastline entailed evaluating wave impact loads (pressures and forces) on the new beach seawall and comparing the resulting scour potential at the base of the existing and new seawall. A physical model was built at ARTELIA's hydraulics laboratory in Grenoble (France) to provide insight into: wave and setup at the beach, the evolution of scour over time at the front of the wall, quasi-static and impulsive wave force intensity and distribution on the wall, and water and sand overtopping discharges over the wall. Light-weight sediment physical model and pressure and force measurements were performed with scale 1:18. The paper will discuss the pros and cons of a physical model versus numerical/ empirical models.

SITE CONDITIONS

The beach was constituted of fine sand and approximately 50 m wide above mean sea level. Seabed slopes were in the range of 0.5% offshore to 1.5% closer to the beach. Presently, during extreme events, the seawall is overtopped by sand and water and minor scouring is observed. No structural damages have been observed since its construction in the 1960s. The existing concrete seawall will be replaced by a smooth concrete structure with an elevated curved crown wall.

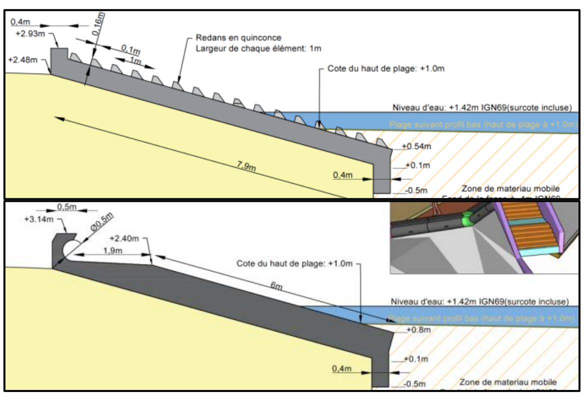

Figure 1 – Existing (top) and new (bottom) seawall geometry

MODEL CONCEPTION

Correctly modelling wave processes are a prerequisite for studying their interactions with a structure. At model scale, model Reynolds numbers were estimated in the range of 40 000 to 150 000, meaning that the influence of fluid viscosity was negligible compared to gravity and inertia on the scale of the wall protruding elements (Hughes, 1993). Froude scaling was consequently used to scale wave parameters and the wall geometric dimensions. Considering practicalities related to the test facilities and the model setup, a model scale of 1:18 was selected.

The size and density of the model sediments were selected to have similarities between model and prototype conditions with consideration of:

- The turbulent hydrodynamic regime at the scale of sediment grains
- The conditions of initiation of sediment motion
- The mode of sediment transport, mostly in suspension
- Sediment grain size distributions

Prototype sand was modelled with polyvinyl chloride light-weight particles which had a density of approximately 1 400kg/m^3 and a median diameter (d_{50}) of 0.3 mm.

MODEL INSTRUMENTATION

For the scour evaluation, quantitative assessments of the seabed evolution were made using a measuring rod and also a laser scan survey. Wave overtopping was visually characterized on the physical model and measured using a collective tray placed at the lee of the wall; overtopped suspended sediments were dried and weighted. For the wave load assessment, a load cell measured wave forces and moments, four piezo-resistive sensors were placed on the wall to measure quasi-static loads (GAVIN) and one piezoelectric sensor (PCB) was placed in the call curvature to measure impulsive loads. A load cell able to measure quasi-static and impulsive forces was selected for the testing. Hammer tests identified the model eigenfrequencies to be 48Hz/126Hz and 97Hz/234Hz inside and outside water respectively (0.09s/0.03s and 0.04s/0.02s periods at prototype scale), which were outside of the measured quasi-static regime. Post-processing involved removing signal component at frequencies larger than the low eigenfrequency (48 Hz) to limit spurious resonance effects in the impulsive regime.

The wall equipped with the pressure sensors and the load cell is shown hereafter:

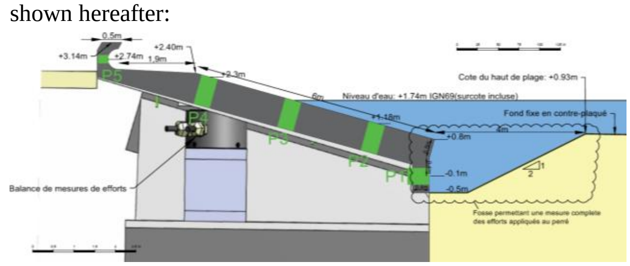

Figure 2 – View of the wall equipped with pressure sensors

MODEL UNCERTAINTY

The wall was built with a smooth concrete mixture and fabricated with plastic material for the new configuration. Model effects due to slope roughness differences were considered negligible in comparison with the effects of the protruding elements (existing wall) and the curved elevated crown element (new wall).

Froude scaling may lead to overestimation of pressure loads in the case of impact pressures induced by compression of the air entrapped between the wall and the wave. Model effects were estimated considering the practical methods based on Bagnold and Takahashi works considering vertical walls (Cuomo, 2010, Takahashi, 1985, Bagnold, 1939). Assuming full air entrapment, model effects were estimated to potentially induce an overestimation of up to above 60% on impulse pressure peaks. Froude values were however recommended for use in the design given uncertainty and as a measure of conservatism.

The slope angle in an unprotected scour hole at equilibrium increases with decreasing material density and with increasing sediment diameters (Migniot, 1977). Based on material properties, a slope angle of 31° at prototype versus 29° at model scale was estimated which may indicate a very slight underestimation of scour extents (10% or less).

WAVE PROCESSES

Prior the start of breaking (at -7 m MSL contour), storm-driven maximum spectral significant wave heights of 2.8 m and 3.2 m were estimated for the benchmark historical storm event dated of 1997 and the 50-year return period storm respectively, resulting in 1 m high waves, a 0.3 m setup at the beach top and the formation of infragravity waves. To capture the gradual shallow water limitation during storm build up, the storm was divided in three phases for physical model testing.

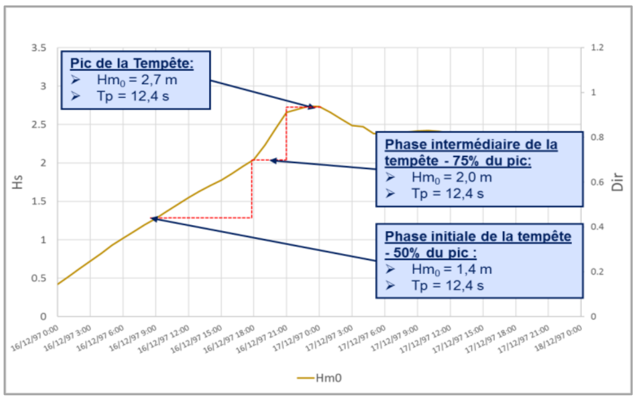

Figure 3 – Significant wave height schematization for 1997 storm

The following figure shows probe measured spectral significant wave heights and setups versus SWASH numerical model (http://swash.sourceforge.net/) estimations for the 1997 storm pic. The subsequent figure shows the measured and numerically estimated wave spectrums.

There was a good agreement between the two models on H_{m0} and long wave dynamics in SWASH but a divergence on wave setup. A provision for wave setup in the test total water level was included to limit such effect. A strong surfbeat was visually observed during physical model testing, and identified in wave spectrums at -4 m LAT seabed contour on both numerical and physical model signals (Figure 6).

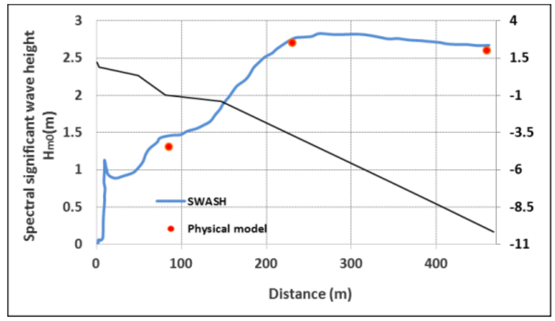

Figure 4 – Wave plots for physical model (red) versus SWASH (blue)

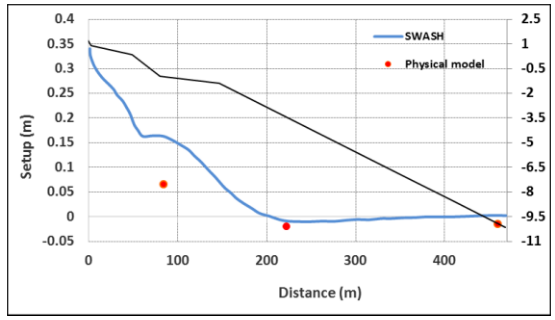

Figure 5 – Wave setup for physical model (red) versus SWASH (blue)

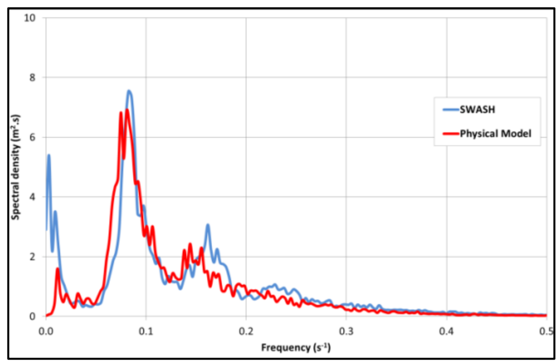

Figure 5 –Spectrums for physical model (red) and SWASH (blue)

WAVE OVERTOPPING

Wave overtopping was observed for both the existing and new wall but there was significantly less events for the new wall, water being sent back to the sea. The mean discharge was of Q_{H20} = 4.0 l/s/m and 1.4 l/s/m for the existing and new wall respectively with around 1% of suspended sediments.

Figure 6 – Curved wall effect on wave overtopping – New wall

The calibrated SWASH model provided further insight of wave overtopping for the existing configuration however the model was unable to represent the complex geometry of the new wall.

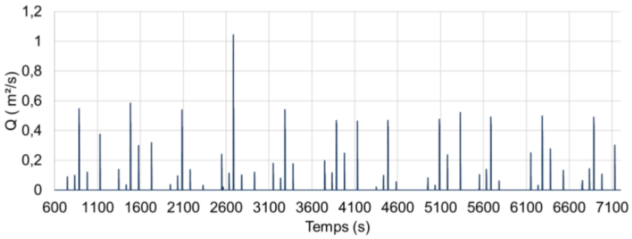

Figure 6 – SWASH overtopping events for the 1997 storm pic

SCOUR ANALYSIS

Scour processes was identified as type II in Powel and Lowe diagram (1994) for marginal scour as a result of the low water depth and low reflected energy. Scour at the base of the seawall is influenced by the structure geometry (roughness, slope, porosity), the water depth and wave characteristics at the base of the seawall. The estimated equilibrium scour depth at the front of the seawall was estimated at -0.7 m assuming a vertical structure and -0.4 m considering the 15° actual structure slope angle (HOFFMAN & VERHEIJ, 1997). SBEACH (https://csdms.colorado.edu/wiki/Model:SBEACH) model estimation were in the range of -0.7 m for the existing wall but the model was unable to account for structure geometry peculiarities. No comparison with the new wall was possible.

During physical model testing, a maximum scour depth of -0.9 m was measured for the new seawall versus -0.6 m for the existing seawall, which is imputable to increased wave reflection (coefficient was 25.7% - 30.4% vs 23.4% - 28.6%).

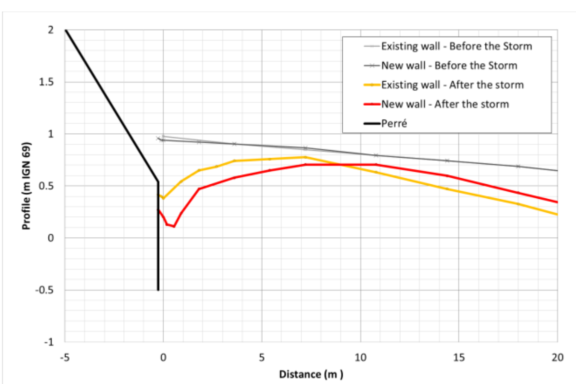

Figure 6 – Measured beach profile pre- and post- 1997 storm

WAVE IMPACTS

The wave regime on the seawall was categorized as broken wave impacts with less than 5% of impulsive impacts (PROVERBS). In the impulsive regime, estimated wave forces – resulting from the quasi-static component of impulsive forces – were in the range of 20 to 190 kN, considering beach elevation in the range of 0 to +1 m MSL to account for potential scouring. Contrarily, in the pure quasi-static mode, wave forces are estimated in the range of 10 to 40kN (Goda, 2000). IH2VOF monophasic model (https://ih2vof.ihcantabria.com/model) estimate of the total force was 114kN (F_X=70.8kN, F_Z=110.6kN) without account of the impulsive effects.

Testing demonstrated occurrence of numerous impulsive wave impacts on the reflector (22%), induced not by direct wave breaking but mostly by wave run-up slamming on the top curved part of the wall. The impulsive loads were separated from the quasi-static signal firstly by applying a low pass (LP) filter with a cutoff frequency of 0.4 Hz (prototype scale) and secondly Peaks Over Threshold method with an alpha-fraction of 50% of the 0.5 kPa threshold (e.g. two consecutive pressure pics are considered independent if the signal value goes below 50% of the 0.5kPa threshold between the two pics).

Wave forces of up to 264kN (F_X=57.9kN, F_Z = 125.6kN) and impulsive pressure spikes of up to 1127 kilopascals were measured inside the reflector. Comparison of the integrated pressure signal with the load cell signal showed a good agreement when considering a length of application for impulsive pressure of 5cms and 8cms without and with account of model effects respectively, which indicate that impulsive loads apply only on a small portion. The following figure shows a capture of the pressure signal measured on the curved wall top section.

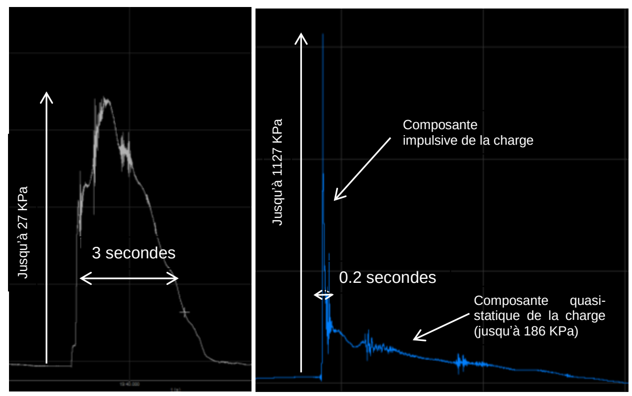

Figure 6 – Example of measured quasi-static (left) and impulse (right) pressure signals – curved wall section

CONCLUSION

This paper presents a methodology for the setup and operation of a physical model in order to assess the hydrodynamic and morphodynamic processes at a beach seawall during storms events. It discusses the pros and cons of such methodology versus others, notably regarding structures peculiarities and model effects.

REFERENCES

G. Cuomo. W. Allsop. S. Takahashi (2010): Scaling wave impact pressures on vertical walls. Coastal Engineering 57 604-609.
Oumeraci, Kortenhaus, Allsop, de Groot, Crouch, Vrijling, Voortman (2001): Probabilistic Design Tools for vertical breakwaters, Technical University of Braunschweig Hoffmans, Verheij (1997): Scour Manual, A.A. Balkeman
Goda (2000): Random seas and design of maritime, advanced Series on Ocean Engineering, World Scientific
Hughes, 1993, Physical Models and laboratory Techniques in Coastal Engineering, World Scientific.
Bagnold R.A. (1939). Interim report on wave pressure research. J. Inst. Civil Eng. 12, 202-226, ICE, London.
Migniot C., 1977, Action des courants, de la houle et du vent sur les sédiments, La Houille Blanche, 1, 9-47.