Chapter 102
Risk Management in Maritime Structures

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Abstract Maritime structures (breakwaters, groynes, ocean wave/wind energy converters, etc.) are exposed to wave attack, which generates common emergency situations with serious environmental and economic consequences. This paper presents a methodology developed at LNEC for forecasting and early warning of wave overtopping in ports/coastal areas to prevent emergency situations and support their management and the long-term planning of interventions in the study area. It is implemented in a risk management tool. The methodology uses numerical models to propagate waves from offshore to port/coastal areas to obtain the required input for overtopping assessment methods, such as empirical formulas and artificial neural networks. The calculated overtopping values are compared with pre-established admissible values in order to define the warning levels. These admissible values are derived from general international recommendations and information from local authorities. They depend on the characteristics of the overtopped structure and of the protected area, and on the activities developed there. The warning methodology is applied to Praia da Vitória Port (Azores-Portugal) as an illustrative example. Future developments include the use of complex numerical models (e.g. Navier-Stokes equations solvers; particle methods) to calculate wave overtopping and to extend the methodology to warn of risks associated with wave energy production failure.

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102.1 Introduction

Emergency situations caused by adverse sea conditions incident on maritime structures (breakwaters, groynes, ocean wave/wind energy converts and others) are frequent and endanger the safety of people and goods, lead to structural damage and wave energy production failure, with negative impacts for the society, the economy and the environment. Therefore, risk management in maritime structures is an important issue and the development of a methodology to warn of emergency situations in port/coastal areas is essential for a proper planning and management of these areas.

In particular, in Portugal, it is extremely relevant to study wave induced risks, and especially wave overtopping, due to its long coastline, the importance of the socio-economic activities in port/coastal areas and the severity of the sea conditions. In this context, the National Laboratory for Civil Engineering (LNEC), Portugal, has been developing the HIDRALERTA system [1–4], which is a set of integrated decision-support tools for port and coastal management, whose focus is to prevent and support the management of emergency situations and the long-term planning of interventions in the study area.

This system has coupled several wave propagation models, which transfer offshore wave conditions to inshore, and then calculates wave overtopping and flooding through artificial neuronal networks and empirical formulas. Moreover, it compares estimated values of wave overtopping with pre-established admissible values in order to define different warning levels. Although, the main goal of this paper is to present the warning module of the system, HIDRALERTA is also able to perform risk assessment, based on evaluation of historical wave data. Therefore, it is intended as a tool for both long term planning, and forecasting and warning. As a long-term planning tool, the system uses long-term (years) time series of sea-wave characteristics and/or predefined scenarios, and evaluates the sea-wave risks for the protected areas, allowing the construction of GIS based risk maps. These maps aim to support decision-making of the responsible entities regarding long-term management. As a forecast and early warning tool, the system uses numerical forecasts of sea-wave characteristics, that allow the identification, in advance, of the occurrence of emergency situations and enables the adoption of measures by those entities to avoid loss of lives and to minimize damage. It is also worth noticing that such a system does contribute to the fulfilment of the stipulated in directive 2007/60/EC of the European Parliament and of the Council of 23/10/2007, which recommends the development of risk maps by 2013 and flood risk management plans, including the establishment of systems of forecasting and early-warning, by 2015.

The warning system module is already running at LNEC on a daily basis for Praia da Vitória Port, in Terceira Island (Azores, Portugal) and it is being prepared to run for S. João da Caparica beach, in Costa da Caparica, Portugal.

This paper analyses the case of Praia da Vitória Port, as an illustrative application of the warning methodology. The system downloads sea-wave characteristics predicted offshore, up to 180 h, every day. These data correspond to results obtained through WAVEWATCH III [5], which is a regional model. To transfer to the port entrance and then into the port, SWAN [6] and DREAMS [7] are applied, which are a spectral wave model and a mild slope wave model, respectively. DREAMS model provides wave characteristics in front of each structure, which are then used as input to the neural network tool NN_OVERTOPPING2 [8], together with cross-section characteristics of the maritime structures. NN_OVERTOPPING2 gives an estimate of mean overtopping discharges per unit length of the structure crest [9]. In this case, different maritime structures were considered: the south breakwater, the north breakwater and the seawall that protects Praia da Vitória Bay. Thus, taking into account the limits of the mean overtopping discharge described in [10] and the recommendations from the local authorities, different thresholds were adopted specifically for each structure, bearing in mind the characteristics of the overtopped structure and of the protected area, and the activities developed there. The issue of warnings is activated whenever thresholds are exceeded.

After this introduction, the paper describes the steps of the methodology implemented in the HIDRALERTA system to warn of wave overtopping. An example of application of this methodology is next presented for Praia da Vitória Port. Finally, future developments for the system are discussed, including the use of complex numerical models to calculate overtopping and to extend the methodology to warn of risks associated with wave energy production failure.

102.2 Methodology

The methodology implemented in the HIDRALERTA system [1, 3] to assess wave overtopping risk and to warn of inadmissible overtopping events follows four steps (Fig. 102.1): I: Sea-wave characterization; II: Wave overtopping determination; III: Risk assessment; IV: Warning system. The next sections describe, in more detail, steps I, II and IV.

1. Sea-wave Characterization

In the HIDRALERTA system, the sea-wave regime within a port or at the coast is obtained from numerical models for sea-wave propagation. The use of one or more numerical models for the propagation depends on the study region characteristics and on the phenomena involved in the propagation. In the case of open coastal areas, the offshore wave characteristics are either obtained from buoy measurements or predicted by WAVEWATCH III [5], which is a numerical model for sea-wave prediction at regional level. The offshore wave characteristics are then propagated to the coast with the SWAN model [6], which is a spectral wave model. In case of sheltered areas, such as port areas, to perform the wave propagation into the port the DREAMS model [7], which is a mild slope wave model, is applied after SWAN.

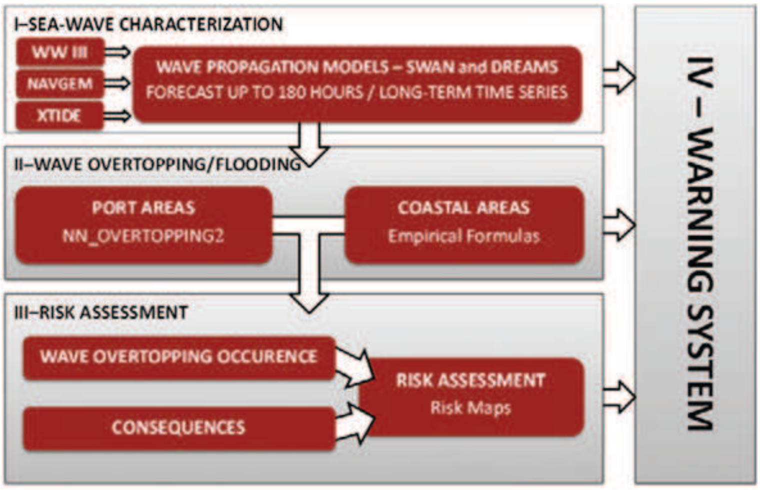


Fig. 102.1 HIDRALERTA scheme

Besides WAVEWATCH III input, numerical models used in HIDRALERTA also need to consider wind fields at a regional level and astronomical tide level, which are obtained from NAVGEM [11] and XTide [12], respectively. The offshore wave conditions from WAVEWATCH III and the wind field from NAVGEM are both provided through The Fleet Numerical Meteorology and Oceanography Center (FNMOC). FNMOC delivers forecast data for WAVEWATCH III up to 180 h and historic data since September 2003, with 1° resolution. It also delivers data for NAVGEM up to 180 h and historic data since January 2004, with 0.5° resolution.

So far, the storm surge has been considered in an approximate manner (considering a constant value), unless there are water level measurements available from tide gauges.

2. Wave Overtopping Determination

In the HIDRALERTA system, wave overtopping determination follows two different approaches, in case of port or coastal areas. For port areas, a tool based on neural network modeling is employed, NN_OVERTOPPING2 [8]. This tool was developed as part of the CLASH European project [10] to predict Froude-scaled mean wave overtopping discharges, q, and the associated confidence intervals for a wide range of coastal structure types (such as dikes, rubble-mound breakwaters and caisson structures). To run NN_OVERTOPPING2, the input needed includes the wave/water level conditions in front of each structure and its geometrical characterization. For coastal areas (whether simple beaches or beaches with coastal defence structures), empirical formulas are applied to evaluate wave run-up/overtopping.

3. Warning System

The warning system integrates all the information from the other modules and issues warning messages. It comprises two components: the data evaluation component, which integrates and processes the data from the other modules, and the user interface component. Whenever the pre-set wave overtopping thresholds are exceeded in a specific area, the system issues warning messages to the responsible authorities, by e-mail and/or by sms.

Thresholds are pre-defined for each structure based on the limits described in [10] and on the information provided by the local authorities to LNEC. Table 102.1 shows the recommendations presented in [10], which depend on the characteristics of the overtopped structure and of the protected area, and on the activities developed there.

Up to now, only the limits concerning the mean overtopping discharge have been used for the threshold definition. In the near future, LNEC aims to apply the limits provided on the maximum volume as well, since individual maximums are more adequate to characterize local overtopping hazard, due to the randomness of the overtopping spectrum [10].

102.3 Case Study: Praia Da Vitória (Azores)

1. Study Area

The port and bay of Praia da Vitória (Fig. 102.2) are located at the Terceira Island, the second largest of the Azores archipelago.

The so-called north breakwater was built to protect the port facilities that support the Lajes airbase. It is a rubble-mound breakwater, 560 m long, with a north-south alignment, rooted in the Ponta do Espírito Santo (Fig. 102.3a). The second rubble-mound breakwater (south breakwater) is rooted on the south side of the bay, near the Santa Catarina fort (Fig. 102.3b). The breakwater is approximately 1300 m long, with a straight alignment (north-south) that bends close to its shore connection. It protects the facilities (commercial sector and fishing port) of the Praia da Vitória Port.

The bay shoreline has a coastal road protected by a seawall which is 1 km long (Fig. 102.3c). In front of the port entrance and rooted to the seawall there is a field of five groynes. These groynes do not have the same length but they have approximately the same alignment (WSW-ENE).

In the port area, there are now several sea-wave measuring devices that can characterize the sea wave regime within the port. In fact, within the scope of the CLIMAAT project [13], a directional wave-buoy was deployed 4 km northeast from the port, in a region about 100 m deep, whose data were used to validate the methodology for wave propagation applied in this study.

2. Illustration of the Warning Methodology

Currently, the warning system is running permanently for Praia da Vitória. The first module (I: Sea wave characterization) runs every day to predict 180 h of wave propagation at the port entrance and into the port, together with wind field and tide level predictions. For each 3 h, the system creates the following layout for each model

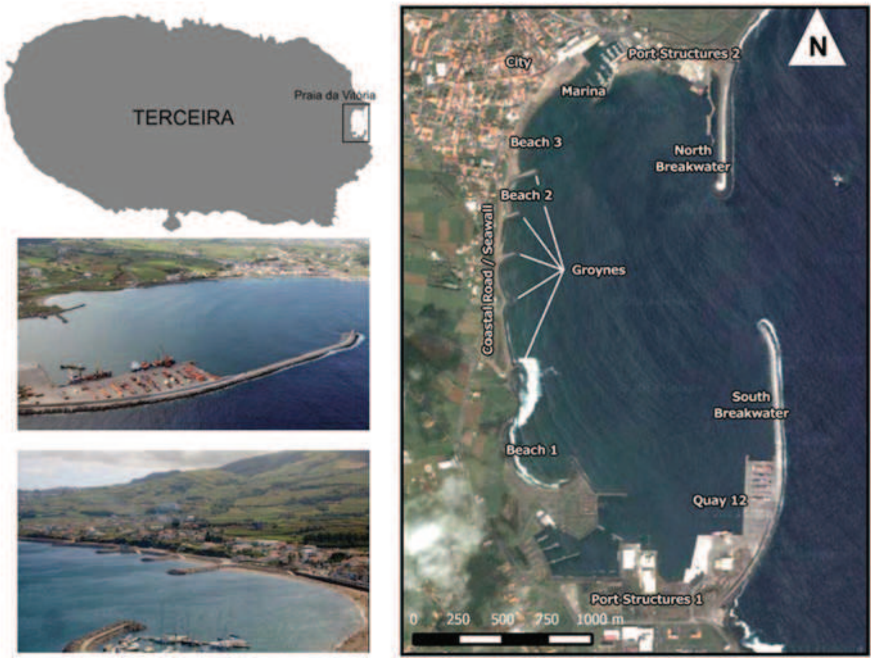


Fig. 102.2 Praia da vitória, Azores

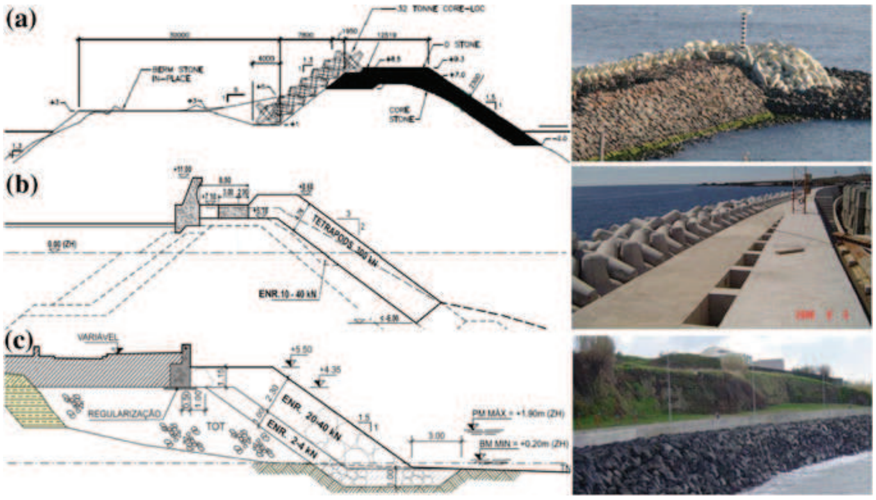


Fig. 102.3 Typical cross-sections of main structures of Praia da Vitória. **a** North breakwater, **b** South breakwater, and **c** Seawall at the bay

Table 102.1 Suggested limits for mean overtopping discharges and maximum volumes (adapted from [10])

Hazard type and reason	Mean dis-charge (l/s/m)	Maximum Volume (l/m)
Pedestrians		
Trained staff, well shod and protected, expecting to get wet, overtopping flows at lower levels only, no falling jet, low danger of fall from walkway	1–10	500 at low level
Aware pedestrian, clear view of the sea, not easily upset or frightened, able to tolerate getting wet, wider walkway	0.1	20–50 at high level/velocity
Unaware pedestrian, no clear view of the sea, easily upset or frightened, not dressed to get wet, narrow walkway or close proximity to edge	0.03	2–5 at high level/velocity
Vehicles		
Driving at low speed, overtopping by pulsating flows at low flow depths, no falling jets, vehicle not immersed	10–50	100–1000
Driving at moderate or high speed, impulsive overtopping giving falling or high velocity jets	0.01–0.05	5–50 at high level/velocity
Property		
Significant damage or sinking of larger yachts	50	5000–50000
Sinking small boats set 5–10 m from the wall Damage to larger yachts	10	1000–10000
Building structure elements	1	–
Damage to equipment set back 5–10 m	0.4	–
Maritime structure		
Embankment seawalls		
No damage if crest and rear slope are well protected	50–200	–
No damage to crest and rear face of grass covered embankment of clay	1–10	–
No damage to crest and rear face of embankment if not protected	0.1	–
Promenade or revetment seawalls		
Damage to paved or armoured promenade behind seawall	200	–
Damage to grassed or lightly protected promenade or reclamation cover	50	–

(Fig. 102.4) with Significant Height (Hs) and Wave Direction (θ). It is also possible to create a layout with Peak Period (Tp).

Once wave characteristics in the port are available, for every 6 h, the second module is applied (II: Wave overtopping/flooding). For each set of wave/water level

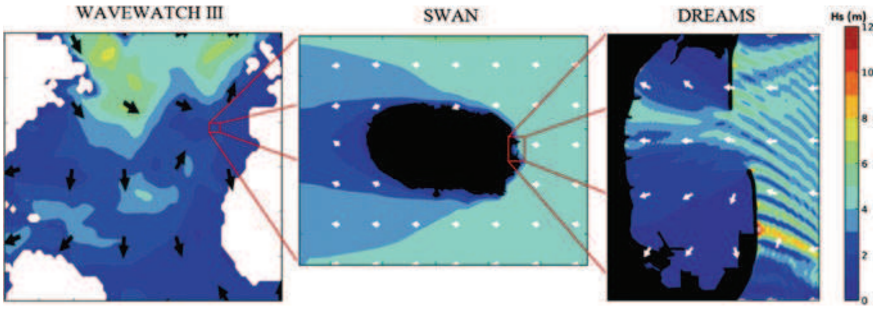
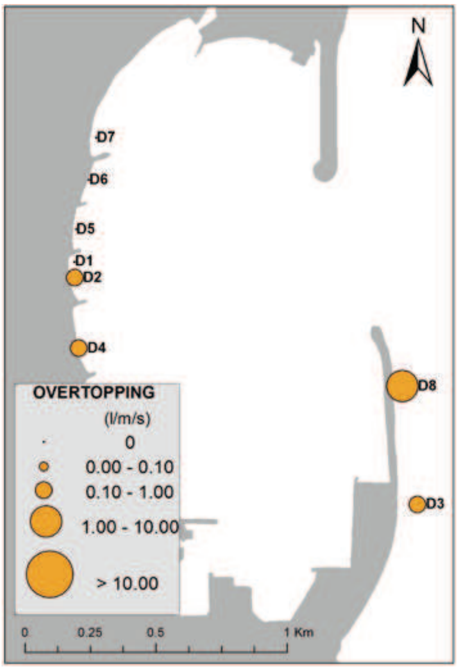


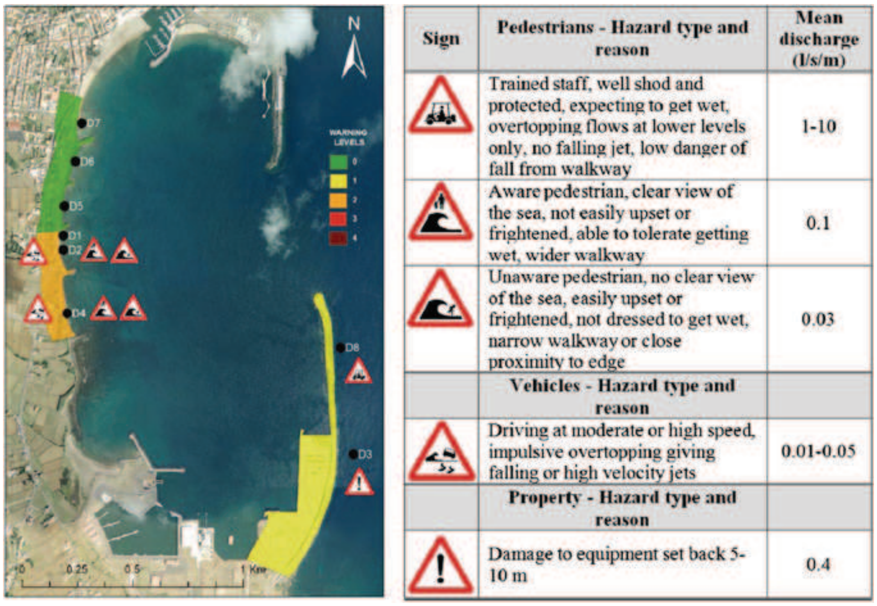
Fig. 102.4 Example of a layout created by the HIDRALERTA system for each wave propagation models

Fig. 102.5 Example of a layout created by the HIDRALERTA system for NN_OVERTOPPING2 results at 16/10/2010, 12 am



characteristics, NN_OVERTOPPING2 provides information on mean wave overtopping discharges, q, for each of the studied cross-sections of the structures. An example of the layout created by the HIDRALERTA system for NN_OVERTOPPING2 results is presented in Fig. 102.5.

Once the mean overtopping discharges are evaluated, the forth module (IV: Warning system) is applied for threshold definition for q for each of the studied cross-sections of the structures.



Sign	Pedestrians - Hazard type and reason	Mean discharge (l/s/m)
⚠	Trained staff, well shod and protected, expecting to get wet, overtopping flows at lower levels only, no falling jet, low danger of fall from walkway	1-10
⚠	Aware pedestrian, clear view of the sea, not easily upset or frightened, able to tolerate getting wet, wider walkway	0.1
⚠	Unaware pedestrian, no clear view of the sea, easily upset or frightened, not dressed to get wet, narrow walkway or close proximity to edge	0.03
	Vehicles - Hazard type and reason	
⚠	Driving at moderate or high speed, impulsive overtopping giving falling or high velocity jets	0.01-0.05
	Property - Hazard type and reason	
⚠	Damage to equipment set back 5-10 m	0.4

Fig. 102.6 Example of a warning layout created by the HIDRALERTA system when thresholds are exceeded

Thus, considering as an example the cross-section of the south breakwater protecting quay 12 (D3 in Fig. 102.5), taking into account the limits of the mean overtopping discharges described in [10] and the information from local authorities, the following thresholds were adopted:

1. Users of quay 12 are not easily disturbed or frightened by overtopping events and they move in a large area—0.1 l/s/m;
2. Containers on quay 12 are 5−10 m away from the structure—0.4 l/s/m;
3. All vehicles travel at low speed—10 l/s/m;
4. For the analyzed stretch of the south breakwater the limit for a promenade/revetment seawall has been used—200 l/s/m.

Since quay 12 is approximately 130 m wide, ships moored there are too far away from the overtopped structure to be disturbed by overtopping events.

In module 4, after threshold definition, the calculated mean discharges obtained from the second module are compared with the threshold values outlined for the different cross-sections of the structures. A warning message to the responsible authorities is sent by e-mail and/or by sms whenever these thresholds are exceeded (Fig. 102.6).

102.4 Future Developments

The HIDRALERTA system is currently based on the coupling of several wave propagation models, which transfer offshore wave conditions to inshore, and then calculates wave overtopping and flooding through artificial neural networks and empirical formulas. These two kinds of overtopping models have the great advantage of being very fast, but results are very dependent on good determination of all model parameters and the breakwater characteristics, since these models are developed for some classical breakwaters. Due to the strong increase of computation power that occurred during the last years, it is possible, nowadays, to use complex 3D numerical models based on RANS equations for modeling free surface flows interacting with complex port/coastal structures. These models include specific procedures for free surface flow and are based on a different numerical method: Eulerian formulation, including Volume of Fluid approach for free surface flow, such as OpenFoam [14] and FLUENT [15]; Lagrangian formulation based on a Smoothed Particle Hydrodynamics (SPH) approach, such as SPHysics [16] and SPHyCE [17]; ALE (Arbitrary Lagrangian Eulerian) formulation, such as FLUINCO [18]; and Particle Finite Element Method approach, such as PFEM [19].

These models allow considering all type of port/coastal structures, such as porous/impermeable breakwaters and Oscillating Water Column (OWC) Ocean Wave Energy Converters (OWEC). They output several important coupled parameters simultaneously, as: free surface level near and above the port/coastal structure; wave overtopping; velocity fields inside and outside the structure; pressures and forces on structures; energy production. As these values are instantaneous, it is possible to obtain, mean and maximum values of these parameters.

The OWC is considered to be one of the most technically known OWEC, due to the large research effort that has been subject to in recent years. This device is also one of the first to have reached the status of full-sized prototype deployed in the real sea. An OWC-OWEC consists of a partially submerged structure, open below the water free surface. Within this structure, an air pocket above the free surface is trapped. The oscillating movement of the free surface inside the pneumatic chamber, produced by the incident waves, forces the air to flow through the turbine, which is directly coupled to an electrical generator [20]. Figure 102.7 presents the Pico Island (Azores-Portugal) OWC-OWEC (left), a computational mesh of this OWC-OWEC (middle) and the resulting free surface flow RANS simulation (right). It is not a common practice to use a single numerical code to simulate all the fluid dynamics effects present in this type of device. This code should accurately simulate the 3D wave propagation and its transformation when subject to the OWC-OWEC influence, the water inflow and outflow in the device, the air flow in the pneumatic chamber and the damping caused by the pressure loss at the turbine. A correct simulation of these flows is essential to evaluate the design of the pneumatic chamber and to determine the operating conditions of the turbine [21–23].

In the near future, to perform risk management in OWC-OWECs, in particular to extend the HIDRALERTA warning system to this device, one should first identify the

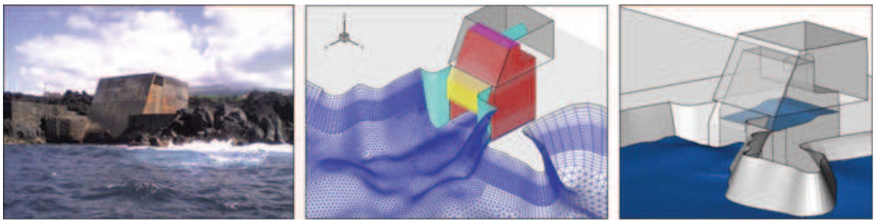


Fig. 102.7 Pico OWC device (Azores, Portugal): device, 3D mesh, numerical modeling

main failure modes of the OWC-OWEC, such as flooding of the installation, turbine failure, etc., and characterise their consequences in the electricity production. The aim is to produce a tool for business decision, as well as providing an effective technology development strategy.

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