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WAVES AND TSUNAMIS

Keywords

- Waves, tsunamis, coastal vulnerability and risk, erosion, flooding

Definition/overview

- Coasts are some of the most rapidly changing places on earth. Understanding the natural adjustments that occur between coastal landforms and the processes that influence them is essential for the better management of coastal resources, reducing catastrophic scenarios in these urban areas.
- Energetic sea actions (waves, tides and currents) play a major role in the natural dynamic of coastal zones. These dynamic processes can lead to local or more widespread coastal erosion, with land loss, that can be critical along some frontages, especially in a medium to long term (Figure 1).
- Human intervention can reduce the severity and/or extent of coastal erosion, for example by coastal protection measures, but can also increase erosion, e.g. down-drift of obstructions to long-shore drift along the shoreline. Increased urbanization at the coast increases risks of loss due to wave actions generated by storms (including cyclones and hurricanes) or by tsunami (Figure 2).
- Even where the coastline is protected against erosion, flooding by storm surges or by tsunami can be highly damaging to infrastructure or property, and cause substantial human and economic loss (Figure 3).
- Strategies for coastal zone management require better understanding of the hazard drivers (e.g. storms, surges, or tsunamis) or the responses (flooding, erosion, structural damage) and of community vulnerability.
- Prediction methods for these rare but damaging coastal processes are far from perfect, so physical and/or numerical modeling are still essential tools to understand storm and tsunami actions.

Figure 1. Coastal erosion (California, USA)

Figure 2. Coastal urban area (Espinho, Portugal)

Figure 3. Tsunami effects (Banda Aceh, Indonesia)

Main reason of the study/field of application

- The action of waves on natural coastlines is influenced by numerous parameters, such as wave energy, tides, bathymetry and topography, shoreline morphology and sediment budget, to name a few. Similarly, interactions between these drivers and the built environment require further study.
- Anthropogenic factors and climate change have been primary causes for the increasing degradation of coastal ecosystems. In order to address this degradation, it is important to understand the status and distribution of coastal populations, land cover, fragile ecosystems and the causes of their vulnerability.
- Major sea storms or tsunamis offer threats to many coastlines around the world, but many aspects of storm or tsunami behaviour require significant further investigation. Better knowledge on effects of climate change on storm occurrence, severity, size and track are all needed to improve predictions, and develop awareness plans.
- Generation and propagation of tsunami have been simulated by various numerical models, from source to nearshore. The critical gaps in knowledge are in the propagation of tsunami in the nearshore region, across the shoreline, and inland. These flow processes cannot yet be simplified sufficiently for numerical models as there are complex interactions with beaches, sediment, coastal defences, and then around buildings. Furthermore, due to the rarity of large tsunami events, very little empirical data (e.g. wave gauge data) are available for the validation of tsunami numerical models.
- For a given tsunami event, the loading on buildings and infrastructure is currently calculated by first running numerical simulations to obtain onshore inundation water heights and velocities. These values can also be obtained directly from pre-existing inundation maps, however the reliability of these varies as there are no guidelines for the derivation of such maps. The current state-of-the-art is to then take these values and calculate the structural loads, as if the tsunami were a large flood. FEMA 55 (FEMA, 2005) states that these structural loads consist of wave impact forces, hydrostatic pressure, hydrodynamic pressure, buoyancy, debris impact and scouring. However, a tsunami is significantly different from a flood and there are very large uncertainties in predicting its onshore height and velocity (FEMA, 2008).
- Tsunami effects can be simulated in physical models, but correct generation of tsunami waves are essential, including in some instances the characteristic draw-down of the preceding trough. The main limitation to date of tsunami physical modeling has been the simulation of the long characteristic wavelengths associated with these waves as conventional paddle generators simply do not have the stroke to reproduce the entire wavelength.

Technical information

- Natural transport and nourishment of sediments to the coast is impaired by sand extractions of rivers and beaches, fluvial regularization and barrier effect of dams. Damage to coastal dune systems or vegetation impedes accumulation of sand, representing one more contribution to the instability of those natural defences. Adding to these, the generalized sea level rise and the intensification or coastal areas urbanization represent negative factors.
- Flooding is defined as water covering land that usually is not covered by water. This definition includes coastal and estuarial areas. The *risk* of a flood is calculated as the product of the probability of flooding with its (damaging) consequences.

- Tsunamis are water waves caused by earthquakes, underwater landslides, volcanic eruptions or major debris slides. In deep water, tsunami waves have relatively small heights (typically 0.5-2m), but very long wavelengths (say 5-20km). As these waves enter the shallower waters of coastal areas, their length reduces sharply and their wave height increases dramatically. The resulting steep waves may cause violent wave impacts onto shoreline structures, and the very long wave lengths may lead to extensive inundation inland.

Structural aspects

- With changes to land use, and increases of sea levels and/or wave action, increasing numbers of coastal properties or assets are exposed to wave attack. Improved management of anthropogenic impacts may help reach goals such as the reduction of human lives losses, reduction of damage in structures and coastal buildings, preservation of natural environments, increase in evacuation capacities, location of new structures and buildings out of danger areas, and relocation of existing structures and buildings.
- Due to the complex variety of coasts worldwide, their geomorphologic nomenclature is a problematic scientific task. In addition, coastline data, number and location of buildings and infra-structures on urban coastal areas are difficult to collate due to the inherently different formats involved, the spatial and temporal scales of data acquisition and the use of different standards and definitions for coastal classifications. Therefore, most of classifications performed are regionally and themes focussed, providing uneven coverage of taxonomic units for the entire coastline of Europe.

Research activity and/or Guidelines

- A reliable assessment of the current status of the global coastal environment is long overdue. The major constraint has been a widespread lack of accurate and timely data at the global level. Recent advances in spatial data gathering and processing techniques, including satellite remote sensing and Geographic Information Systems have however, started to assist the scientific community in overcoming these constraints and may allow the development of a preliminary Coastal Vulnerability Index.
- The European Parliament presented a Directive (2007/60/CE) in 23 October 2007, related with the evaluation and management of flood risks. The document intends to reduce the risk of damaging consequences associated to floods in human being health and lives, environment, cultural patrimony, economic activities and infra-structures. Before 22 December 2011, the European countries should prepare the Preliminary Evaluation of Flood Risks. Also before 22 December 2013, those countries should present Maps of Flood Risks and before 22 December 2015, they should present Management Plans of Flood Risks (Directive, 2007).
- In the USA, the Federal Emergency Management Agency recently (June 2008) published guidelines for the design of structures for vertical evacuation from tsunami (FEMA, 2008). The document sets out some of the state-of-the-art in tsunami hazard calculation and structural load calculations, but also highlights gaps in knowledge.
- In the UK, a new tsunami generator is being built that will be capable of generating a complete tsunami within a physical model (Rossetto et al. 2008, and Allsop et al. 2008). The generator will sit at the end of one of the 45m long 2-dimensional wave flumes within the Froude Model Hall at HR Wallingford, see Figure 4. It works on similar

principles to HR Wallingford's pneumatic tide generators. The intention is to run tests at scales between 1:75 and 1:150 to both look at tsunami characteristics onshore and to measure tsunami loads on model buildings.

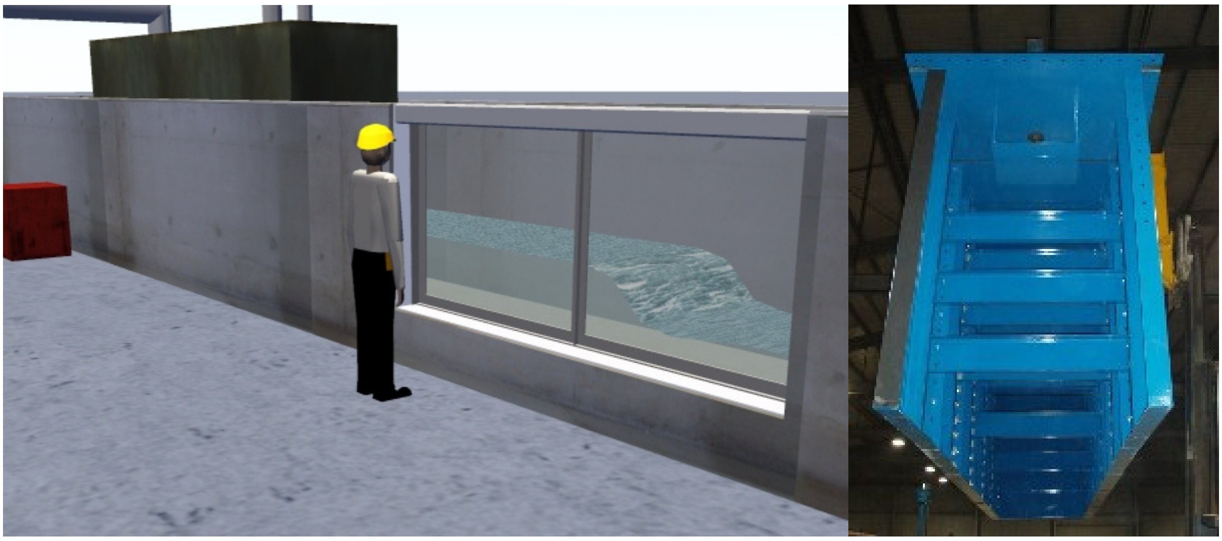
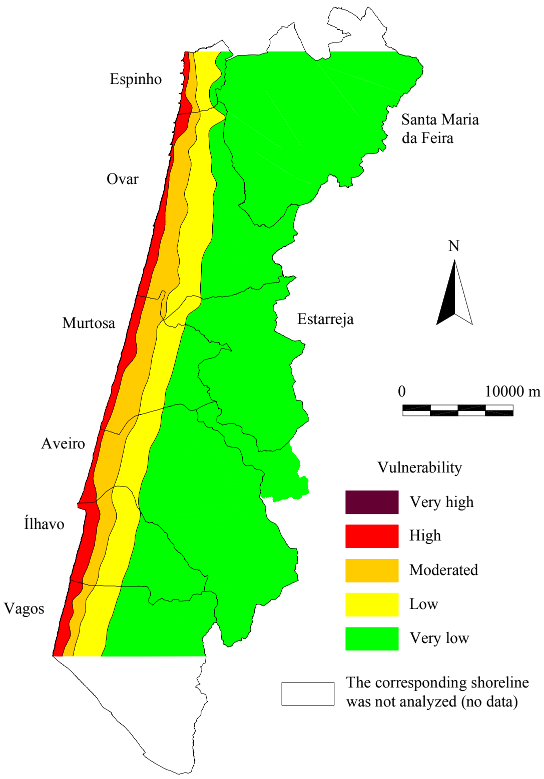


Figure 4. Schematic of the HRW Tsunami Generator, and (inset) the Tsunami Generator tank being lifted into the test facility

Example of application



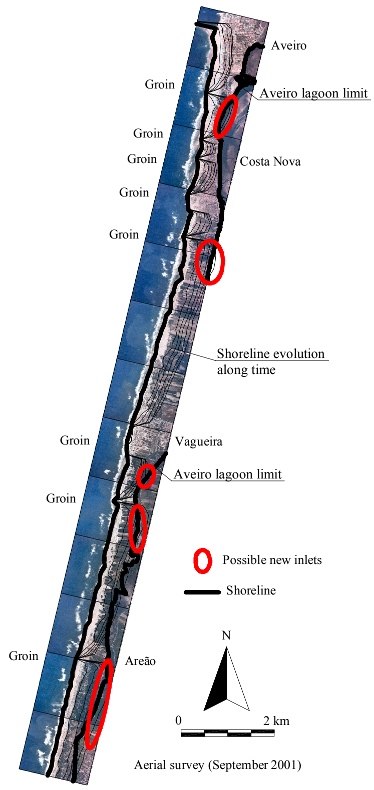


Figure 5. Costal vulnerability (Coelho et al., 2008) **Figure 6.** Shoreline evolution model (Coelho et al., 2004)
(Aveiro Municipalities, Portugal)

- A digital map based on different parameters related to the: distance to the shoreline, topographic data, geology, geomorphology, ground cover, wave height, tide levels, history rates of erosion/accretion and human intervention effects on the coast can represent global vulnerabilities (Figure 5). The isolated analysis of those parameters, which are assumed to be the main agents in the vulnerability evaluation, allows us to formulate different classes and an objective classification. The goal of this representation of coastal vulnerabilities is to produce an auxiliary tool for the management and planning of coastal zones, thereby supporting political priorities of an intervention.
- Numerical models prediction of shoreline evolution, specially designed for sandy beaches, where the main cause of shoreline evolution is the alongshore sediment transport, dependent on the wave climate, water levels, sediment sources and sinks, sediment characteristics and boundary conditions. Extensive areas can be analyzed up to one hundred years (Figure 6). The volumes transported are estimated through the application of formulae which depend on the shoreline to wave breaking angle and the wave breaking height, or the beach slope and the sediment grain size. The wave transformation by refraction, diffraction and shoaling is modelled in a simplified manner, or, wave conditions may be imported from more complex wave models.
- Structural loads on buildings from tsunami can be estimated for a given tsunami hazard and coastal characteristics. These can be used to assess existing infrastructure and guide strengthening prioritisation, building usage and land-use planning in coastal regions.

Further developments

- Reinforcement of research and monitoring is needed.
- With the advent of new techniques such as Geographical Information System (GIS) for data processing and classifying coastlines, it is needed to consider incorporation of all these data into a global open-ended and interrelated coastal classification system.

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