PORTS ADAPTATION MEASURES TO CLIMATE CHANGE AND THE INCREASE IN SHIP SIZES

F. Veloso-Gomes[1]

[1] Faculdade de Engenharia, Universidade do Porto, CIIMAR, Portugal; vgomes@fe.up.pt

Abstract: Ongoing Global Change, cumulatively resulting from natural climate variability, local anthropogenic actions, and Climate Change, induce changes in coastal environments. Ports located in estuarine and lagoon environments and on very dynamic coasts will be particularly affected. On the other hand, there is a clear trend towards an increase in the size of vessels with demands, impacts, and risks at port and environmental level that are not being fully assumed. Climate Change (at a global level) will most likely aggravate and make more unpredictable the problems of accessibility, safety, and operability in ports. The reduction of unit costs of goods should not be achieved only through the gigantism of ships, without assessing these requirements and impacts on ports and waterways. This paper is a synthesis of the results of an extensive research work conducted within the scope of doctoral theses and scientific research projects coordinated by the author, based on the analysis of national and international case studies, laboratory tests and numerical modelling. Examples of Ports Adaptation Measures to climate change and the increase in ship sizes are presented concisely. It is a challenge for ports to adopt strategies incorporating Adaptive Planning and Management to be considered in the Governance model.

Keywords: Climate change, ship sizes, ports adaptation measures, adaptative planning and management

1. Context on Climate Change

Ongoing Global Change, cumulatively resulting from natural climate variability (natural dynamics), local anthropogenic actions (economic activities and occupation of coastal territories) and Climate Change induce changes in the spectra of:

- Water temperatures.
- Wind intensity and directions.
- Waves (directions, heights, periods).
- Meteorological tides.
- Currents and interactions (tidal, wind and wave generated).
- Storms (duration, intensity, pathways, frequency), sedimentary flow and balances.
- Surface water levels.
- Groundwater levels and flows.
- Salinity (surface water, groundwater).
- Surface run-off from river basins.

Climate Change (at a global level) will most likely aggravate and make more unpredictable the problems of accessibility, safety, and operability in ports (hydrodynamic and sedimentary changes, morphology dynamics, overtopping with floods, waves and currents, water level dynamics, geotechnical and structural stability).

Ports located in estuarine and lagoon environments and on very dynamic coasts will be particularly affected.

In addition to the generalized rise in the average sea level, the scenario of changing the direction of wave regime on the Portuguese west coast began to be considered in the Regional Planning Plan for the Central Coast [5].

The simulation of Climate Change scenarios in the Aveiro coastal system, with the long-term LTC model (FEUP / UA), revealed in 2009 that within a 25-year horizon the consequences of a hypothetical change in the direction of maritime unrest will be more serious than the most pessimistic rise in average sea level [1].

In this study, the directional distribution of the waves recorded at the port of Leixões wave buoy (data from 1981 to 2003) was worked under Climate Change scenarios (Figure 1). Rotation of wave directions to the north and south were considered.

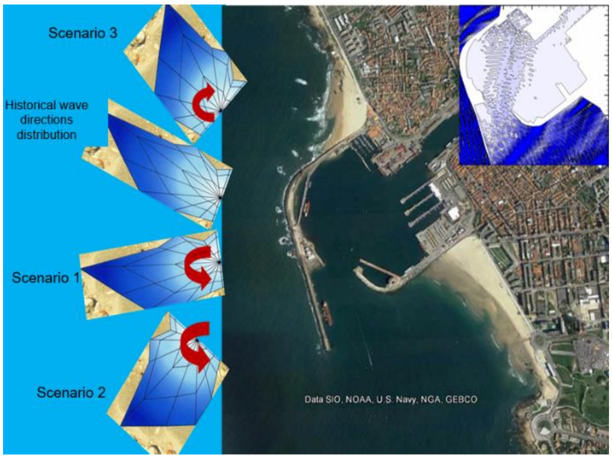

Figure 1. Example of waves directional distribution scenarios for Leixões harbour (Portugal).

In a scientific article [4], a vast amount of doctoral research work on coastal Climate Adaptation in port cities were summarized with a view to identifying deficits, barriers, and future challenges.

A research team [2] presents the development of hydrodynamic models, using Ensemble techniques, for projections of Climate Change in estuarine regions. Historically, many of the ports are in estuaries, not only benefiting from natural protection from sea disturbances, but also because estuaries favour river connections with vast inland territories.

Through a systematic review of scientific literature, a paper [3] identify the most relevant international works developed within the scope of incorporating Climate Change Adaptation Measures in the design of new ports and others maritime projects, also identifying the main knowledge gaps.

2. Context on the increase of ship size

On the other hand, there is a clear trend towards an increase in the size of vessels (length, beam, draught) and their carrying capacity (deadweight).

These increases in size will have demands, impacts, and risks at port and environmental level that are not being fully assumed.

The reduction of unit costs of goods cannot be achieved only through the gigantism of ships, without assessing these requirements and impacts.

The gigantic size of the most recent container ships, ships specialized in the transport of large equipment, cruise ships, bulk carriers (solid and liquid bulk) and motor vehicle carriers deserves reflection.

As shown in Figure 2, container ships have evolved since 1964 (feeder) from lengths of around 120 m and 1000 TEUs (Twenty-foot Equivalent Unit), to 400 m and 23,992 TEUs in 2022 (ULCV - Ultra Large Container Vessel and Mega Container Ships). They may reach 50,000 TEUs in the second half of the 21st century.

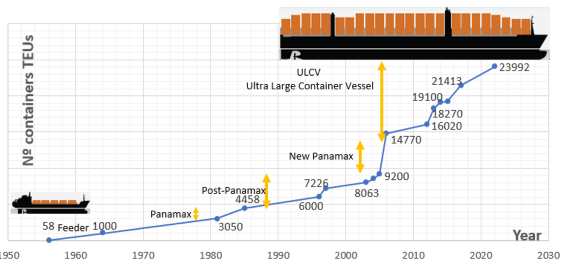

Figure 2. Evolution of container ship transport capacity, in TEUs, (sources: *McKinsey analysis 2017*, *container-xchange 2022*), This evolution should have drastic impacts on harbours and environment.

Only about two dozen ports in the world will currently be prepared to receive container ships with a capacity of more than 20,000 TEUs.

The supertankers (ULCC, capacity over 320,000 dwt) are exceeding 550,000 dwt, 420 m in length, 65 m in beam and 35 m in draft.

The gigantism of oil tankers predicted in the seventies of the century X induced the construction of a breakwater of unprecedented dimensions in the port of Sines, west coast of Portugal.

The accidents after wave storms that resulted in the almost complete destruction of the main breakwater (late seventies) cannot be dissociated from a design for the project that was extrapolated to situations of exposure to intense waves and depths when there was no previous experience for these situations, on an international scale.

If the cross section of the initial breakwater project with the cross section of the breakwater after reconstruction are compared (Figure 2) one can notice very big differences (type of armour blocks, toe berms, armour slopes, superstructure, crest level and width). Very important lessons were learned from the accident, but the costs were very high!

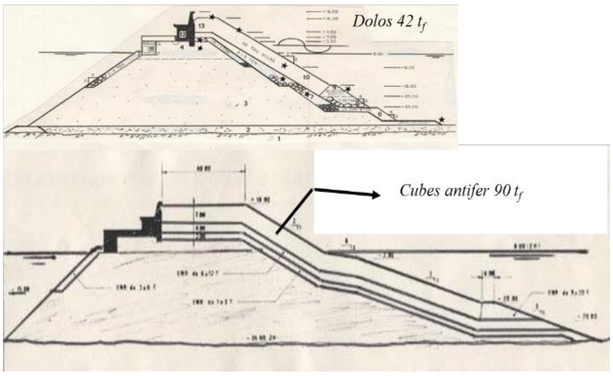

Figure 3. Comparation of cross section of the initial Sines breakwater project (oil tank terminal) in Portugal with the cross section of the breakwater after reconstruction. Breakwater design has changed at international level.

Cruise passenger ships are reaching 365 m in length (7600 passengers plus 2800 crew members, 250,000 GT) when between 1922 and 1999 the largest ships were about 290 m long and carried about 2000 to 2500 passengers and 1000 crew.

The increasing size of ships calling at Angola has made insufficient the capacity of ports in open bays (most of them) or ports sheltered by sandspits (Luanda, Lobito).

As a result of the demand for deep-water ports and terminals, in the 21st century the first breakwaters started to be built in Angola.

The construction of these breakwaters had misjudged impacts (severe erosion in Porto

Amboim beaches from 2010 onwards) or worrying technical problems, delays of many years in construction and increased costs (Tafe 0.57 km and Caio 3,5 km breakwaters built in Cabinda from 2018 onwards).

The construction and extensions of the Aveiro and Figueira da Foz main breakwaters in Portugal (at the mouth of a lagoon system and of an estuary) had relevant negative impacts in coastal erosion and accretion. These impacts have not been internalized in the costs of port operation, and their mitigation is the responsibility of the Ministry of the Environment.

The potential impacts of the (ongoing) extension of the Leixões breakwater in Portugal have aroused strong public controversy. This extension should be necessary in terms of the safety of navigation approach if the oil terminal were to remain in operation, but the oil refinery has been dismantled.

The planned increase in the extension of the existent breakwater of the port of Funchal in Madeira Island, to improve the capacity to accommodate more cruise ships, in addition to expected technical difficulties and costs, may generate undesirable negative impacts. Those impacts are associated not only with landscape issues, but above all with the level of tourist overload, Cruise activity is very localized in time and space, with potential logistical and road congestion and loss of quality in the reception of visitors, the tourist offer and the life quality of residents.

The accident that resulted in the blockage of the Suez Canal in March 2021 (container ship 400 m long and 60 m wide), with negative economic impacts on a global scale, activated the alarm about the navigation risks inherent in the manoeuvrability of large ships.

3. Objective and Method

Climate Change (at a global level) will most likely aggravate and make more unpredictable the problems of accessibility, safety, and operability in ports (hydrodynamic and sedimentary changes, morphology dynamics, overtopping with floods, waves and currents, stability).

But the problems of the increase in port movements and the increase in the size of ships also raise a growing concern in terms of diagnosis, impacts (environmental, economic, social) and adaptation measures.

The reduction of unit costs of goods should not be achieved only through the gigantism of ships, without assessing these requirements and impacts on ports and waterways.

What are the main port impacts and the potential Port Adaptation Measures that can be considered?

This paper is a synthesis of the results of an extensive research work conducted within the scope of doctoral theses and scientific research projects coordinated by the author, based on the analysis of national and international case studies, laboratory tests and numerical modelling.

Some of the most recent research work underway has the following main issues:

- "Incorporating Climate Change Adaptation Measures in the Design of New Ports and Other Maritime Projects";
- "Coastal Climate Adaptation in Port-cities: Adaptation Deficits, Barriers, and Challenges Ahead";
- "Hydrodynamic Model Ensembles for Climate Change Projections in Estuarine Regions".

4. Proposals

In this presentation, examples of Ports Adaptation Measures to climate change and the increase in ship sizes are presented concisely.

These Measures fall within the areas of strategic and adaptive planning, port engineering and management, logistics chains, security, integration into the surrounding natural and built environment, energy efficiency and transition, governance.

Table 1 presents a framework related with strategic and adaptive planning where the Adaptation Measures should be incorporated.

Table 1. Strategic and adaptative planning

<table>
<tr><td rowspan="10">Strategic and Adaptive Planning</td><td rowspan="10">Maritime

Coastal / estuarine / lagoon

Inland

Urban</td><td rowspan="10">Harbour</td><td>Medium and long-term</td></tr>
<tr><td>Adaptative to Climate Change</td></tr>
<tr><td>Adaptative to economic and social development</td></tr>
<tr><td>Scenarios</td></tr>
<tr><td>Strategic Environmental Assessment of scenarios and alternatives</td></tr>
<tr><td>Impact Assessment</td></tr>
<tr><td>Integrated cost/benefit and cost/effectiveness assessment</td></tr>
<tr><td>Retreat / reconversion/ relocation of existing infrastructures and buildings (if more favourable)</td></tr>
<tr><td>Adoption of buffer zones for development and port activities</td></tr>
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Table 2 exemplifies in a very condensed way Adaptation Measures at the level of port design and management.

Each of the Measures has technical specificities and can have positive and negative impacts. They may be excluded or adopted in a complementarity way and within parameters to be defined.
Cost/benefit and cost/effectiveness assessment are important tools in decision process.

Table 2. Examples of port engineering and management Measures

Consideration of more worrying project scenarios	Increased design actions (wave heights, directional spectrum, ….)
	consideration of persistent and cumulative actions, loads and effects
	consideration of "uncertainties" in projects
	Adaptive Planning
Port Structures	specialized Terminals
	increased project actions and loads
	increase of the dimensions and widths of the superstructures
	structural and foundation reinforcement
	reduction of slope angles
	new layouts, materials, construction methods
Breakwaters and other port structures, including berthing and mooring systems	construction of new breakwaters (if necessary) or structures
	modification of the design, extension, and layout configurations
Docks, navigation canals, and rotation basins	increased depths and widths, new layouts
Dredging	increase in first installation and maintenance dredging
	rational management of dredged sediments incorporating them into sedimentary transit, landfills, beaches. It should be a component of the port management costs
Embankments and "dry harbours" for parking and storage	construction, expansion, relocation
	alteration of layouts, elevations, pavements, and drainage systems
Dock and stowage equipment	modernization and specialization
	Increased capacity and cost-effectiveness

The logistics chains should be integrated, reinforced, and more efficient. Automation, computerization, artificial intelligence are important tools to be used. Land, river, and rail accessibility must be improved.

All port safety and security aspects and risk mitigation must be up to date and reinforced. They can include several Mitigation Measures linked with:

- Effective Programmes, Plans and Resources (human, financial, technical).
- Maintenance Programs.
- Pollution prevention and control.
- Accident and other risks prevention and control.
- Pre-alerts and civil protection.

Adaptation Measures for the integration of ports and new facilities into the surrounding natural and built environment means integration in the urban system, in the surrounding natural environments and in the landscape.

It includes conservation and restoration of habitats, public participation and a continuous dialogue with users and communities.

A priority for the entire port system and associated logistics chain is energy efficiency and transition. It is an "umbrella" for many Adaptation Measures.

A proper Management and Governance is the key. It needs:

- effectiveness (vision and mission, roles and responsibilities, objectives and horizons, policy coherence and coordination, capacity building, technical and scientific basis, sound projects, implementation),
- efficiency,
- trust and integrity,
- commitment,
- monitoring.

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5. Conclusions

It is a challenge for ports to adopt strategies incorporating Adaptive Planning and Management to be considered in the Governance model.

"Variability", "alterations", "changes" and therefore uncertainties are and will be increasingly present not only because of the "natural actions" inherent in coastal systems, but also due to increasing climatic and economic dynamics. They require more adapted and resilient operational and safe infrastructures.

Measures for the Adaptation of Ports to climate change should not be dissociated from the Measures for the Adaptation of Ports to the progressive increase in the size of ships and increase in port movements and traffic.

This Global Changes have impacts that must be previously assessed and internalized on port operation costs and on the surrounding territories.

Therefore, they will also have an impact on maritime transport and its costs, so formulations for optimizing the size of ships will need to address them.

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