Stability study for the rehabilitation of the protective dike of the port El Jadida (Morocco)

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Abstract. In this study, we are interested in the stability study and reinforcement of protective structures represented by the breakwater of the port of El Jadida. This study is based on the numerical modeling of the interaction of the swell with an embankment dam. The swell simulation parameters were simulated using the SWAN model [1]. The results of this modeling show that the most constraining swells likely to reach the project site are the swells of 14s and 18s of 50 years and 100 years return period and that the residual swell heights are between 1.63 m and 1.96 m maximum. The redefinition of the project swell based on this numerical modeling makes it possible to resize the components of the protective dike by the Hudson formula [2].

Keywords: Morocco, El Jadida Port, Island, Stability, Dike, Swell, Numerical modeling, SWAN model.

1. Introduction
The EL JADIDA port is located on the Atlantic coast 100 km southwest of Casablanca and 170 km northeast of Safi. The harbor, which is primarily dedicated to fishing, is located on a portion of the coastline that extends south-east/north-west. (Fig.1) [3]. The location of the port is 33°15’N-8°29’O. Its vocation is fishing and it is sheltered from the prevailing swells by the main breakwater of 560 m, rooted at the corner of the Portuguese citadel.
The port of El Jadida began to be built in 1922-1924, with the two converging dikes marking a 40 m wide passage. The excavation to make a rectangular dock dug at -1,5 m ZH (fishing basin). The current configuration of the harbor has not changed since 1949, the date of the last works. In 1982, a project to reinforce the main dike was carried out. The elements of the main dike have been replaced by tetrapod’s and a large number of rehabilitation actions.
2. Expertise of the state of the protection dyke

The visit is based on the assessment of the state of degradation of the structures and their causes, the preparation of a visual diagnosis of the structures and the identification of the degradations and anomalies by type of structure.

At the beginning of the degradation, the effect of the swell is manifested by the tearing away of the carapace blocks leaving the guard wall and the inner layers unprotected. In the second class of degradation, the erosion of the base of the slope or the absence of a protective riser causes the collapse and descent of the tetrapods on the slope and the creation of a void between the guard wall and the protective structures. The deterioration of the feet of the structure puts the elements of the structure directly on the bottom which leads to a strong erosion and consequently the instability of the embankments.
In order to better understand the problem of dike degradation, it seems important to us to make a return of the experiments on the dike degradation. For this type of structure, there are four types of unstable dikes (Fig.3):

- Instability of the carapace that manifests as settling, falling blocks and breaking blocks. These instabilities result in a disorder of the inner slope, the crossing, the run-up, displacement and deterioration of the guard wall as well as the cavitation of the core and its settlement.

- Instability of the core and under layer are manifested by a disorder of the armour, a disorder of the inner slope as well as the disorder, settling and cavitation of the nucleus. These instabilities lead to the displacement and deterioration of the guard wall.

- Instability of the crown wall is manifested by a deterioration of the scour protection.

- Toe instability manifests a disorder of the carapace. The consequences are the instabilities of the entire dam.

Figure 3. Standard rubble mound breakwater failure modes [4]

3. Significant wave height

The redefinition of the project swell by transposing the swell from the open sea to the structures of the ports concerned must be based on a credible and exhaustive database and on a mathematical wave propagation model taking into account:

- The refraction, the effect of small depths on an irregular bathymetry.
- Dissipation by breaking and rubbing at the bottom.
- Wave generation under the influence of the wind.
- Diagrams of joint occurrences, Hs/Tp, Hs/Dirp, et Tp/Dirp.
- Diagrams of joint occurrences by sector Hs/Tp.
- Databases of reduced parameters of sea states and winds, over a period of more than 20 years, broken down according to independent energy peaks.

Tr: Return period, or recurrence interval (year).
Dir: Mean direction of waves, usually to grid north [(rad or °)].
Tp: Wave period (s).
Hs: Significant wave height, $H_s = H_{1/3}$ (Mean height of highest 1/3 fraction of waves).

4. SWAN Model

The Simulating WAves Nearshore (SWAN) model is a numerical wave model used to obtain realistic estimates of wave parameters in coastal areas, lakes, and estuaries from given wind, bottom, and current conditions. The model is based on the wave action balance equation (or energy balance in the absence of currents) with sources and sinks. SWAN is a third-generation wave model with first-, second-, and third-generation options.

**Equations of the physical problem:**

In SWAN the waves are described with the two-dimensional spectrum of the action density of the waves $N$ [Manuel SWAN] [5]:

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\[ N(x, y, \sigma, \theta) = \frac{E(x, y, \sigma, \theta)}{1} \] (1)

\( N(r, h) \): Wave action density \((= qgE(q, h)/r[J/s/m^2])\).

\( E(r, h) \): spectral variance.

where \( x \) and \( y \) are horizontal Cartesian coordinates.

\( \theta \): is the propagation direction of each wave component.

\( \sigma \): relative angular frequency (relative to current) [Hz].

In cartesian coordinates, this equation is written in the following form (Hasselman et al. 1973) [6]

\[
\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}(C_x N) + \frac{\partial}{\partial y}(C_y N) + \frac{\partial}{\partial \sigma}(C_\sigma N) + \frac{\partial}{\partial \theta}(C_\theta N) = \frac{S_{en}}{\sigma} \] (2)

\( \sigma \): relative angular frequency (relative to current) [Hz]

\( C_x, C_y, C_\theta, C_\sigma \): propagation speeds according to \( x, y, \theta \) and angular frequency

\( S_{en} \): term of energy sources [J/m^2]

\( C_x, C_y, C_\sigma \) and \( C_\theta \) are the propagation velocity in \( x \)-space, \( y \)-space, \( \sigma \)-space, and \( \theta \)-space respectively.

Details of these processes can be found in the SWAN technical documentation manual.

5. Model simulation

5.1. Bathymetric data

The bathymetry databases are:
- GEBCO: (General Bathymetric Chart of the Oceans): site www.gebco.net
- Etopo2 – Site : http://www.ngdc.noaa.gov/mgg/image/2minrelief.html
- Carte marine: Oceano Atlantico Norte RADA Y PUORTO DE MAZAGN (EL JADIDA)

![Figure 4. Nautical chart of EL JADIDA port [7]](image-url)
5.2. **swell of the site**

The various statistical studies on the nearshore of El Jadida and Safi lead to the conclusion that the orders of magnitude to be considered for the project swells are the following:

**northwest sector**

| Return period | Hs offshore | Hs to -30m | Tp – Dir(°N) |
|---------------|-------------|------------|--------------|
| 1             | 6.5 m       | 6.5 m      | 14/20s – 310°N |
| 10            | 8.75 m      | 9 m        | 15/18s - 310°N |
| 50            | 10.25 m     | 10.5 m     | 16/18s -310°N |
| 100           | 10.75 m     | 11 m       | 16/18s -310°N |

**southwest sector**

| Return period | Hs offshore | Hs to -30m | Tp – Dir(°N) |
|---------------|-------------|------------|--------------|
| 1             | 3.25 m      | 2.75 m     | 9s – 230°N   |
| 10            | 6 m         | 4.25 m     | 10s – 230°N  |
| 50            | 7 m         | 5 m        | 11s – 230°N  |
| 100           | 7.25 m      | 5.25m      | 11s – 230°N  |

5.3. **Current of de site**

General and tidal currents are generally low in the area. The average speeds are of the order of 0.15 to 0.20 m/s with moderate winds fairly regular without exceeding values of 0.5 m/s. It often happens that the currents are very low (0.10 m/s) or non-existent. Currents therefore do not constitute a constraint for a project in the site.

5.4. **Simulation results**

The Global right-of-way of numerical modelling is defined so that all geographical areas within which waves can be propagated to the coast are well taken into account. From the SHOM marine chart, the bathymetry was extracted and interpolated. It is considered to depths of more than 100m. The bathymetry is built in Lambert area 93-Morocco and water levels are referenced in NGM-Morocco.
The mesh consists of T3 triangular elements. It is regular with a step of 60 meters up to the coast. SWAN wave propagation model was used to simulate effects between 20 meters deep and the coastal zone of EL Jadida. These effects include local creation of waves by wind, refraction, shoals, friction dissipation on the bottom and breaking. In this project, SWAN was used in stationary mode.

**Fig.6.** Directional representation of Hs in the coastal domain Dirp=NNW

**Fig.7.** Directional representation of Hs in the coastal domain Dirp=West
5.5. SWAN Simulation Points

The NNW area incident swell characteristics off the El Jadida Port on the outskirts of the project area, offshore, the average inlet depth of the model (Z) and the height of the swell (Hs), calculated, were recorded in 9 points (Fig.9) and are reported in a summary table (table.3).
Table 3. Simulation points SWAN

| Simulation points | Depth(m) | Hs(m)   | Direction (deg) |
|-------------------|----------|---------|-----------------|
| JD2               | 3.3112   | 1.90158 | 328.338         |
| JD3               | 6.6430   | 1.96076 | 321.765         |
| JD4               | 7.3837   | 1.94945 | 325.108         |
| JD5               | 7.9875   | 1.92774 | 327.270         |
| JD6               | 8.5293   | 1.86711 | 327.349         |
| JD7               | 8.4827   | 1.84535 | 327.349         |
| JD8               | 8.6581   | 1.82231 | 327.349         |
| JD9               | 8.6922   | 1.82543 | 327.349         |

Figure 10. Hs for directions 300°N, 255°N, 240°N

6. Conclusion
The results of this modelling show that the most constraining swells likely to reach the project site are the swells of 14s and 18s of 50-year and 100-year return period and that the residual swell heights are between 1.63 m and 1.96 m maximum. The main dike is subject to repeated swell attacks, under its cuttings, some of the most exposed artificial blocks erode and the riprap forming the protective carapace moves, revealing breaches that can quickly enlarge under the action of the swell. These results are used to define a maintenance method that guarantees a significant time for repairs. The chosen solution consists of a reloading by riprap at dimensioning to be determined according to the empirical formulae (HUDSON), including a reprofiling of the slope to strengthen the foundation of the carapace blocks from the stop below sea level. A regulation of the external slope is essential to maintain continuity and adapt to the profile of the dike on the whole of the dike.
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[6] SHOM, Le service hydrographique et océanographique de la Marine.www.shom.fr

[7] ANP, Agence Nationale des Ports de Maroc.

[8] Niveauement Générale Marocain.