Design of Jetty Decks for Extreme Vertical Wave Loads

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Abstract

One of the main aspects that can govern the design of an open piled jetty platform is the wave climate. Often a better way to deal with this is to ensure that the platform deck lies above the anticipated level of the wavetops.

Other considerations, however, sometimes dictate that the platform must be below this level. No clear (international) guidelines exist with respect to the vertical wave impact load on relatively large horizontal slabs such as jetty platforms.

Using published results of earlier investigations into the phenomenon of wave slamming and wave entrapment under decks a practical design approach has been developed. This approach has been used in the design of two jetty platforms. Both structures have been hit by hurricane induced waves since their completion and survived both the onslaught with only minor structural damage.

This paper will discuss the method with which the design waves were forecast and explain the chosen design formulae and design of the platform including the results of the lessons learned from the hurricane attacks.

Introduction

One of the governing features in designing port facilities is the environment. In its broadest sense it is not only something to be careful with, giving due consideration to materials used, constructions methods etc. but it is also one of the main features determining the basis for design. Wave directions, lengths and heights can largely determine the layout, geometry, structure and cost of a port.

When it comes to waves one of the best ways of dealing with them, when thinking of a deck on piles, is to avoid them, i.e. ensure the soffit of the deck lies above the wave tops under all circumstances. Unfortunately other conditions sometimes prohibit this possibility and the structure must be designed for the loads generated by these waves.

In the past 5 years the authors have been involved in the design of two jetty platforms, on the island of St. Vincent in the Caribbean, which were subsequently hit by hurricane waves and survived. In the first of the designs it as possible to avoid the loads induced by the waves simply by having a large area of its deck removed as discussed below. The second design did not allow this possibility and with the information learned from the first design's behaviour together with some study a new design was made. This paper will focus on the second design and its performance under extreme loading.

Prediction of extreme wave heights

In order to calculate the wave loads on a structure the design wave with a return period that fits with the type of construction has to be determined. Therefore the extreme wave climate has to be known.

Offshore wave climate - Extrapolation of data

In areas where no hurricanes or cyclones occur the design offshore wave height can be determined by extrapolation of known wave heights. Wave data can, for instance, be obtained from by ship observations, present wave buoys or satellite measurements. The design wave can then be determined by fitting a straight line in a log time scale, as the offshore waves height can be fitted in a Weibull distribution.

Given the fact that normally little wave data obtained during hurricane situations is available, resulting wave heights can not be predicted this way. Therefore, the wave height that is expected when a hurricane strikes a certain area has to be calculated by wave growth calculations.

Wave growth

The common method of predicting wave growth due to wind is based on wave developing formula, such as Brettschneiders formula [3]. The result depends on the average wind speed, the fetch in which the wind is active and the duration of the field.

Predicting waves caused by hurricanes or cyclones is more complicated, as the wind speed and wind direction varies in time and space.

According to [1] the parameters that effect the deep water wave heights caused by hurricanes are the central pressure of the hurricane, radius of maximum wind, radial distance to point of interest, the maximum sustained wind speed and the forward speed of the hurricane. For the determination of significant wave height the central pressure and the radius are the most important parameters.

The necessary hurricane data in the area of interest can be found in historical databases. For the projects under consideration a database of hurricanes in the Caribbean Sea was used which contains more than 100 years of statistical data. This database gathered by the Hurricane Research Services, Austin, Texas, contains wind speeds, propagation speed of the hurricane, local barometric pressure and track information. As no data on the radius of maximum winds is available this parameter has been estimated by meteorological observations of some recent hurricanes in that area. With the method described in [1] the deep water significant wave height has been established for each hurricane that had passed the area of interest.

Influence of hurricane direction

Normally hurricanes in the Caribbean follow a track from East to West. The sites of the projects lie on the Southwest side of the island, therefore only waves coming from Southerly to Westerly directions can reach the site. It has been observed that most known hurricanes pass the island from the North generating waves from that same general direction, and old charts therefore indicate this side of the island as sheltered. Considering the hurricanes from the database it was found that from the 64 hurricanes that passed in the vicinity of the island only 28 hurricanes generated waves that could reach the site directly.

Statistical analysis

For the area under consideration hurricane data is available over a period of more than 100 years, and it is possible to interpolate to estimate the wave height. This has been done by fitting a Weibull distribution on the obtained wave data. With this method the 1:100 years design wave height has been established.

Nearshore wave heights

With the offshore design wave height established, the nearshore wave height can be determined. For this purpose computer models are used that describe the propagation of random field in coastal areas. For the calculation of the nearshore wave height in this project a one-Dimensional (1D) model, called ENDEC, was used. This program is developed by Delft Hydraulics in the Netherlands. The ENDEC model computes the Energy Decay in random waves along a line, which obliquely approach the coast with parallel, straight bottom contours.

The most important assumption that has been applied in the program is that the random wave field is linear and may be fully described by its [invariant] wave peak period and its energy density.

Besides the use of a 1D model it can be useful to use a two-Dimensional (2D) wave propagation model as an 1D model has more spatial limitations. A 2D model that is used regularly in our wave propagation calculations is the SWAN model [Simulating Waves Nearshore]. This model is also developed at Delft University of Technology and computes random, short-crested wind-generated waves in coastal regions and inland waters.

Although the model calculates many quantities, it is sufficient for our design purposes to determine the nearshore significant wave height, wave period, mean wave direction and directional spreading.

Local wave heights at the site

Although high offshore waves occur during hurricanes, the offshore wave height near the site is relatively low because it is sheltered for waves of the normal westward moving hurricanes. Based on the 1D calculations a nearshore design wave height has been determined. The calculations produced results, which indicated that high local waves would occur. These local wave heights have subsequently been used in the design of the jetty.

Determination of design loads and details

The first design was that of a container jetty in Campden Park Bay at the island of St. Vincent in the Caribbean. Both because of the vessel size and the level of the hinterland the platform level is only 2.5 m above still water level, well below the level of any expected hurricane induced waves.

The challenge in this design was to achieve structural integrity of the structure whilst meeting the functional requirements on deck levels as given above. With the full agreement of the client a solution was chosen which would ensure that such a severe loading combination could not occur. The platform has been designed as a grid of concrete beams with removable concrete slabs. This choice was made because of the permanent availability of a container-handling unit, which will be able to remove the slabs when a hurricane warning is issued. The slab size and weight was therefore kept within the range of this equipment.

During hurricane Iris in 1995 some large swell waves ran into the bay, the exact height could not be determined but some had overtopped the platform by over 1.5 m according to eyewitness accounts and corroborated by the damage. Unfortunately the slabs had not been removed and as a result some damage occurred to them as well as the supporting beams by the fact the slabs were lifted by the waves and fell back when the uplift pressure was reduced, this caused the concrete to spall. No major structural damage occurred however.

The design of a cruise berth for ships upto 70,000 GRT (250 m length) was the second project on the island the convenient availability of heavy lifting equipment could not be relied upon. Here also the level of the passenger doors and of the hinterland determined that the deck level was at well below that of the maximum expected hurricane induced swell waves.

When design of the project started in 1996 a literature search was undertaken for guidelines on the design of horizontal platforms for vertical waveloads but only a limited number guidelines/articles was found.

One practical guideline was found in Ref. [2] which, for suspended deck structures, states that: "*the deck should be designed for a uniform uplift and down-drag pressure corresponding to one half of the maximum wave height with an additional uplift pressure corresponding to the average maximum wave height covering a 1 metre wide strip parallel to the wave front*", where the wave height is H_s.

A theoretical investigation was found in Ref. [5] where the phenomenon was investigated in the laboratory. Here a clear difference is made between the impact pressure and the slowly varying pressures, Fig 1. These 2 peaks are mentioned in other literature Ref. [2], [4] and are not dissimilar to the conditions imposed by waves impacting on vertical walls. For a recent example refer to Ref. [6].

Combining the data from the literature the following practical design formulae were used:

for the impact pressure, assumed over the first metre of the wave front:
$P_{ve} = c \cdot \rho \cdot g \cdot H_{max}$

for the slow varying pressure, assumed over the 'immersed part':
$P_{ve} = 1.0 \cdot \rho \cdot g \cdot (H_{cr} - d_c)$

where: P_{ve} = the vertical wave pressure [kN/m^2]
c = a constant, here assessed as 1.5
ρ = the specific density of the water
g = acceleration of gravity
H_{max} = the maximum wave height
H_{cr} = the wave crest above still water level
d_c = the height of the bottom of the deck above still water level

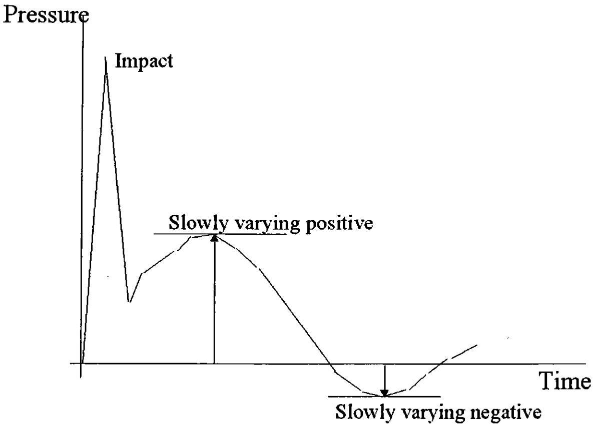

Figure 1 Impact pressure vs. slowly varying pressure

In the formula for the impact pressure the constant annotated 'c' is the most difficult to determine and in the referenced literature the value ranges widely. A value of 1.5 was chosen because the measured high impact values are of a very short duration and their influence on the large concrete mass under consideration was deemed small.

In the referenced literature attention is also drawn to 'trapped air' and other details that can increase the peak pressure. This also seems to correspond to the behaviour of waves impacting on vertical walls.

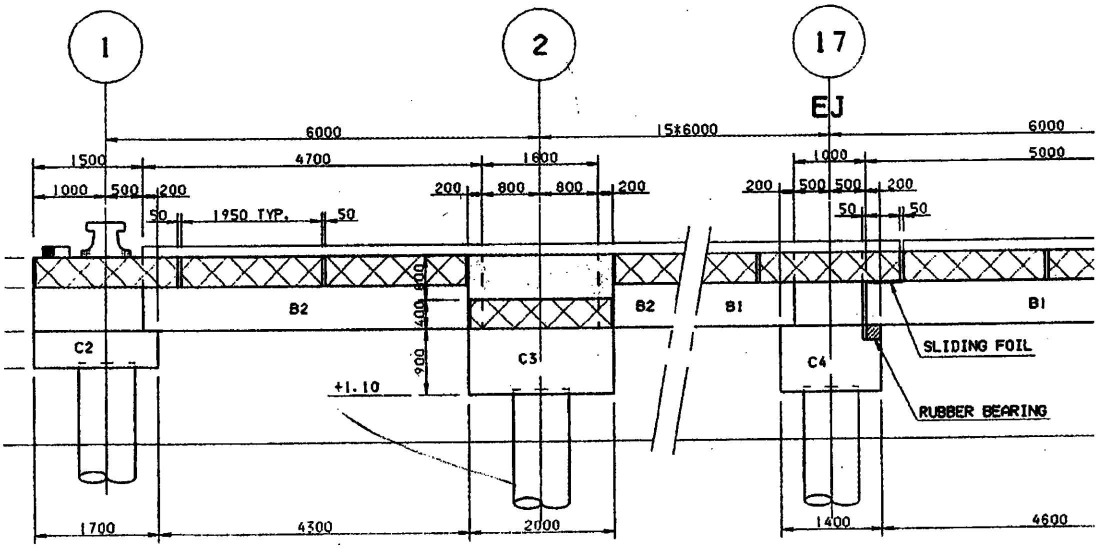

Figure 2 Typical deck section with gaps

For this reason the jetty was designed with beams in only one direction, parallel to the berthing line to avoid the entrapment of the waves in a beam grid. Apart from this the deck has gaps in the transverse direction (50 mm wide every 2 m), see Fig 2. For the comfort of the passengers these gaps are covered with timber, T-shaped strips that have no fixing and can 'blow-out' during wave attack.

Actual waves during hurricanes

Since the completion of the two projects described, there were two hurricanes that resulted in considerable wave heights at the site. These were hurricane Iris in 1995 and hurricane Lenny in 1999.

Iris

Hurricane Iris was a Cat. 1 hurricane, which caused damage at the end of August 1995. Wave heights of around 3 m were observed offshore at September 1. The study of the offshore hurricane wave indicated a 50-year design wave would have a significant wave height=Hs=5.5 m, and peak period=Tp=9.1 s. This suggests that design conditions were not reached, nonetheless there were eyewitness reports of waves overtopping the container berth by approximately 1.5 m, which is roughly consistent with the observed damage. The wave behaviour was also as expected, with waves turning into the bay as predicted.

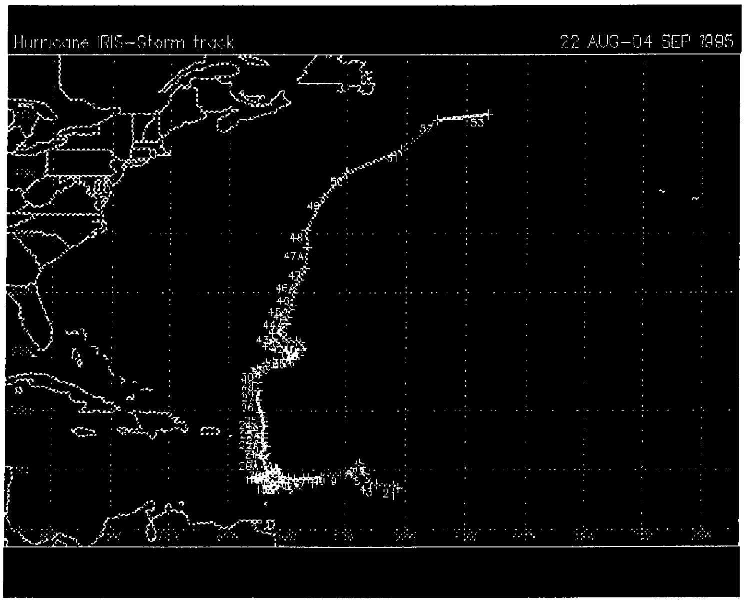

Figure 3 hurricane track of Iris

Lenny

The second hurricane that caused considerable wave heights was Lenny in November 1999. This was the first recorded hurricane to strike the islands of the lesser Antilles from the West.

The hurricane of Category 4 struck late in the season from an unusual direction generating waves entering the bay at an unusual angle. In the hurricane study made in the design phase of the cruise berth, a hurricane such as Lenny was not taken into account as the study was based on a statistical analysis of known data.

The observed offshore wave height around the site cannot be explained using the prediction method given in Ref. [1]. The low pressure of the hurricane, the distance between the centre of the hurricane and the site were too large and lie therefore outside the normal prediction method given in Ref. [1]. Even if the design graph were to be extrapolated, the expected significant wave height at the cruise berth would lie below 2 m.

A possible explanation may lie in the fact that the design graph is designed for 'normal' hurricanes. For hurricane Lenny, with its West to East path instead of East to West and its extremely low forward speed, the prediction graph could no longer be valid.

Wave observations however showed that considerable swell waves were produced. These, as in the case of Iris, did not produce the design value of offshore wave heights. Their extreme angle however caused local focusing of the waves resulting in the design wave height being reached locally at the platform.

The fact that design heights were reached could be deduced from computer simulations and also by studying the available video footage and photographs. What could be seen clearly from the video was that where the waves caused an increase of pressure at the underside of the deck, the timber blow-out strips covering the gaps were blown away and fountains of spray appeared through the gaps.

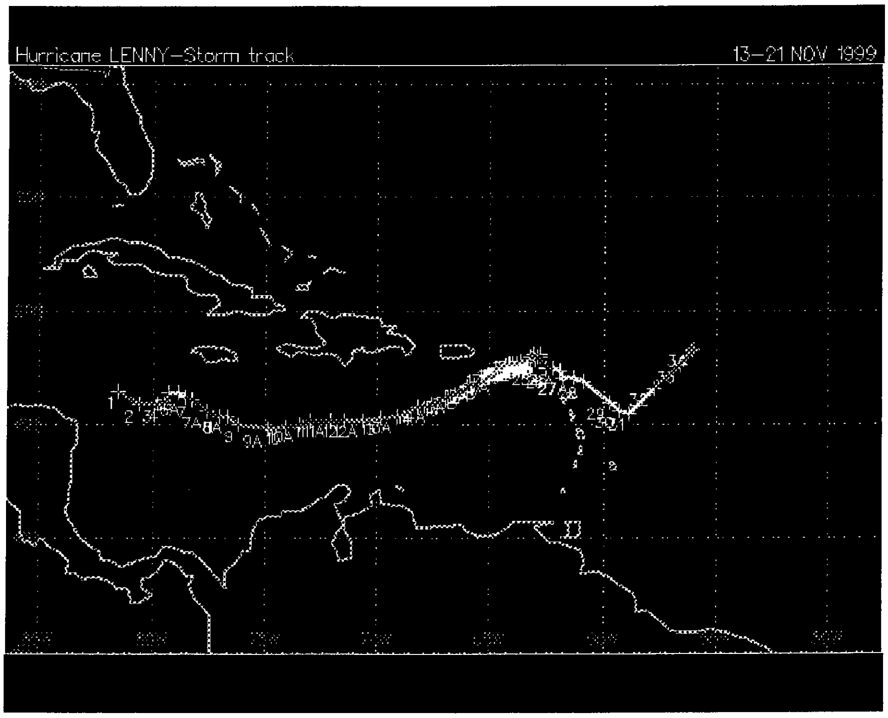

Figure 4 hurricane track of Lenny

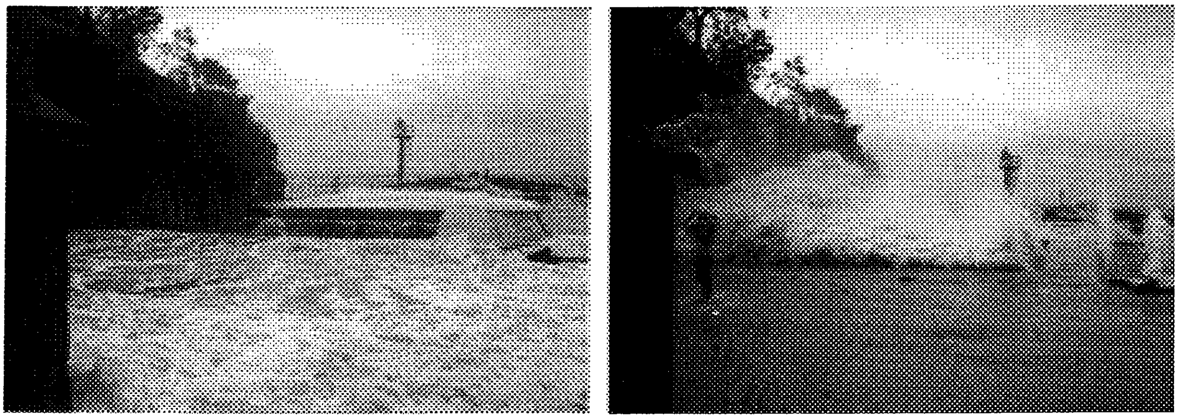

Figure 5 example of wave pressure build-up

Behaviour of the platform

The concrete slabs of the jetty were inspected after the storm and showed bending tension cracks on top of the deck in the centre of the spans. The fact that a moment was reached sufficient to cause bending cracks is an indication that the load levels which were imposed matched the design loads.

Though these observations alone are not conclusive the gaps in the deck seem to have been successful and acted as the intended 'pressure vents' reducing the load on the deck.

An interesting point is that a number of transition slabs, which were simply supported between the jetty deck and quay wall, disappeared in the waves. The slabs were designed with movement joints at both sides and secured against the vertical wave attacks. These vertical fixings were overstressed and broke. The fixings were designed for the same load level as the platform. There are several reasons why they may have failed:

- The gaps between the slabs were smaller giving less opportunity for pressure to release.
- Their relatively small size and mass made them more susceptible to the impact peak resulting in a higher value for 'c'. The recalculated value 'c' at failure of the supports is considered to be in the order of magnitude of 3 or higher.

Conclusions

For the design of jetties in relatively exposed locations a thorough wave climate study is essential to enable definition of the governing design parameters.

Although design standards for the design of large platforms subjected to horizontal wave attack are limited the available literature offers some guidance as evidenced by the performance of two structures which have so far been able to withstand full-scale exposure tests. The authors would however welcome further research resulting in the development of practical guidelines.

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