General Characteristics of Long Waves around the South African Coast

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Abstract

Long-period waves are almost invisible waves due to the long wave-lengths of several hundreds of metres and heights of only decimetres. The effect of these long waves can, however, be devastating in the form of harbour basin oscillations and their effect on moored ships. Measurements indicate that the South African coast and ports are exposed to relatively high levels of long wave energy. This exposure can lead to significant mooring problems in some of the ports. Data on long waves have been collected in a number of ports where moored ships experienced excessive motions. This information formed the basis of an assessment of the long wave conditions around the South African coast. Since the long waves could be correlated with offshore swell conditions, it was also possible to derive a predictive algorithm to forecast the long waves a number of days in advance.

Keywords: South Africa, long waves, ports, forecast

1. Introduction

Long-period waves are almost invisible due to the long wave-lengths of several hundreds of metres with heights of only decimetres. However, the effect of long-period waves can be problematic for moored ships.

Long-period waves are also called low-frequency waves, surfbeat, or infra-gravity waves. The waves have typical periods in the range of 25 s to several minutes. The relation of these waves to the dominant swell conditions is depicted in Figure 1 which shows the schematised distribution of the wave energy as a function of frequency.

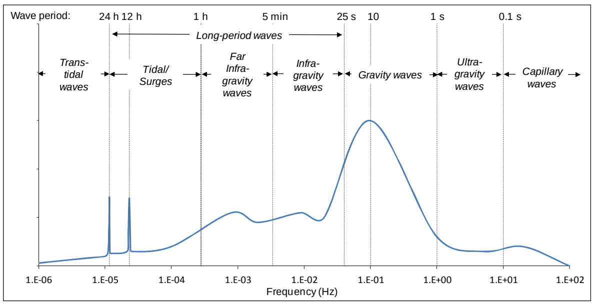


Figure 1: Schematised wave energy distribution (after [7])

The focus in this paper is on the long-period wave component with periods between 25 seconds and 5 minutes. These long waves can have a significant effect on the dynamic conditions of moored ships in ports and thus could affect port operations. Conditions inside a port or harbour can become unsafe for large vessels due to the presence of the long waves. Mooring lines are placed under excessive loading and in extreme cases vessels may have to leave the port.

The South African (SA) coast hosts a wide range of activities, which include maritime transport around the coast, fishing, and imports/exports through seven major ports. A map showing the major ports is presented in Figure 2. Considering that over 90% of SA exports pass through these ports [4], the impact of long waves is a concern to the maritime industry and port authorities.

This paper provides a brief overview of an assessment of the long wave conditions around the South African coast.

Figure 2: Map of southern Africa showing locations of major ports of South Africa

2. South African Experience

The first port in South Africa where significant problems occurred was the Port of Cape Town, especially during the war period of 1941 to 1944. Wilson [15] and Joosting [6] investigated these problems and concluded that the main cause was long-period waves. These waves were amplified in the main basin, Duncan Dock, as standing waves (also called seiches). Modifications were later made to the layout of Duncan Dock and an additional basin, Schoeman Dock, was constructed. With the aid of physical and numerical model testing [1], the problems in the Port of Cape Town have been significantly reduced.

A second harbour where significant ship motions were encountered was the Port of Saldanha (West coast). This port was completed in 1976 and was built primarily for the export of iron ore and the import of oil, receiving bulk carriers and tankers of up to 300 000 DWT, moored at an open and fairly exposed jetty. During the 1980s the mooring problems were investigated by the CSIR [11]. It was concluded that long waves were also the cause of the mooring problems in this port [12]. The focusing of reflected long wave energy from the beaches of the Bay towards the jetty area appeared to be a major mechanism. A solution was sought in optimizing of the mooring-line layout, which has resulted in the reduction of the long wave problem.

The third harbour with long wave occurrence is the Port of Ngqura in Algoa Bay on the South coast, which has been in operation since October 2009. Design studies conducted prior to construction using numerical modelling techniques, identified the presence of long waves. Since the model results showed that long wave amplification could be expected in the port, the original design was subsequently modified. It was, however, found that the long wave action did not disappear completely. State-of-the-art numerical models (e.g. Surfbeat) are presently being used to further investigate long waves in the Ngqura area.

The SA coast is by no means the only area of long wave activity with adverse mooring conditions. Similar problems have been experienced in other ports and terminals around the world, e.g. Long Beach Harbour in California [10], Salalah in Oman [2], Tomakomai in Japan [14] and Port Geraldton in Australia [5].

3. Long Wave Generation

A number of mechanisms appear to contribute to the generation of long waves. These include the breaking of wave groups on a beach [11] and atmospheric low-pressure systems [3].

Two types of long waves are distinguished, that is, bound long waves and free long waves. Bound long waves are associated with the groupiness of swell. The gradient of the momentum flux, caused by the grouped appearance of the short waves, force water away from the groups [8]. This creates a set-down underneath the larger wave groups and consequently a set-up underneath the smaller waves groups. This set-down wave is also referred to as a bound long wave since it stays bound to the wave groups and travel with them towards the shore at the speed of the group velocity (see Figure 3). The bound long wave enhances considerably in the shoaling process near the coast due to an increase in the gradient of the momentum flux as a result of the shoaling process of the short wave groups.

Free long waves are generated directly by ocean weather systems, but they can also originate at the surf zone, where the swell breaks and the bound long waves are set free and reflect from the breaker zone. The free long waves propagate at their own speed, independent of other waves.

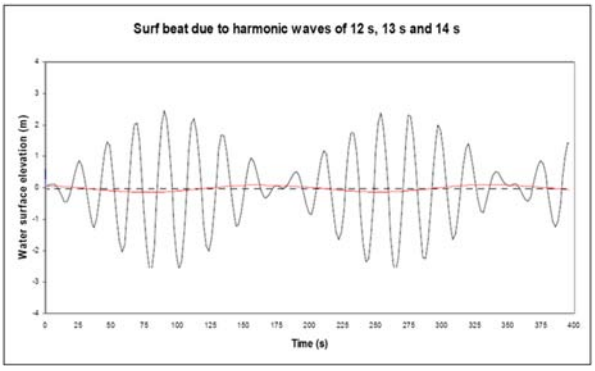


Figure 3: Generation of bound long waves (in red) under wave groups

When moored ships are exposed to bound or free long waves, and the natural period of oscillation of the moored ship is close to the period of the long waves, large vessel motions can occur. This has been experienced specifically as a result of the present trend to build harbours, ports and marine terminals near the open ocean (near deep water). A good understanding of these long waves and their effect on moored ships is important to avoid or alleviate long wave problems on moored ships.

4. South African Wave Climate

The general weather climate of Southern Africa is influenced by different types of synoptic patterns [9]. Short waves, comprising local seas and swell, are generated mainly by passing frontal systems (low pressure systems) from the Southern Atlantic, Cut-off low pressure systems along the SA South to East coast and occasionally by tropical cyclones moving down the Mozambican channel.

The wave climate around the SA coast shows clear seasonality and varies in intensity and directionality around the coast. Adverse conditions can be expected off the South and South-west coasts, especially during the winter season (May to September). Waves of up to 8 m (Hmo) can be expected at least once during winter. These storms approach mostly from a south-westerly to westerly direction, being driven by frontal systems originating over the Southern Atlantic Ocean. This type of wave generating mechanism, comprising of a large sustaining fetch, allows for the development of large wave groups. In turn, the wave groups induce the associated long wave energy.

An overview of the annual variation in wave height and period around the South African coast is given in Figure 4, as based on over 10 years of model data from the National Centre for Environmental Prediction (NCEP). The most severe wave conditions occur on the South-west and the South coasts but decreases in magnitude along the West and East coasts. The distribution of the wave period remains fairly constant, due to the swell propagating northwards. The NCEP data and historical measurements indicate 12 s is the most frequently occurring wave period. Longer period swell of 14 s is also not uncommon. Wave directions are predominantly south-west but swing more toward a South-south-westerly direction on the East coast.

Given the prevailing swell conditions, it is clear that the long waves will also be present around the SA coast.

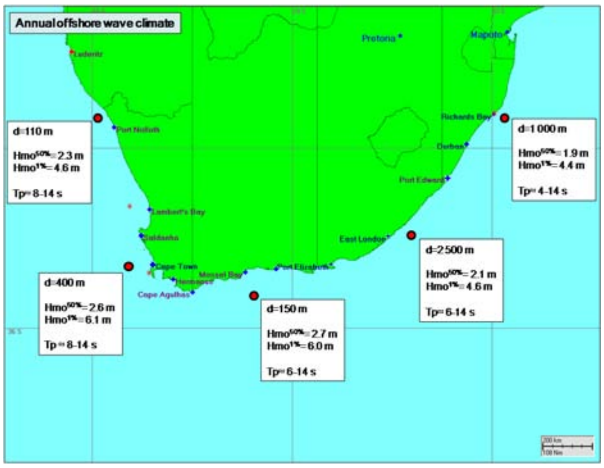


Figure 4: Overview of offshore wave conditions around SA coast

5. Long Wave Information

The CSIR has been involved in collecting wave data around the SA coast for over two decades, as part of the Wavenet programme. The data represent mainly swell and local sea conditions, i.e. short waves. The data coverage on long waves is, however, far more recent. Data have been collected in Saldanha Bay (West coast) and in Algoa Bay, close to the Port of Ngqura (South coast) for a number of years. On the East coast, off the Port of Durban, only five months of long wave data were available.

Studies conducted in the Table Bay (Port of Cape Town) and in Richards Bay provided some insight into the long wave conditions at these ports. Table 1 presents a summary of the available long wave information.

As indicated in Table 1, short wave and corresponding long wave data were collected outside the Port of Ngqura, Algoa Bay. Figure 5 presents a Google Map image of the S4 current meter measurement locations as well as the location of a long wave recorder inside the port.

The data collected with the S4 allowed a direct comparison between the short and long waves. This correlation is shown in Figure 6.

Table 1: Summary on long waves

Location: Saldanha Bay (Port of Saldanha)
A reliable data set was obtained for the period May 2001 to November 2005. This data set is presently being used to calibrate the numerical long wave model for ship motion studies. $Hmo^{50\%} = 0.07$ m; $Hmo1^{\%} = 0.20$ m Tp range: 25 to 340 s (25 to 130 s)*
Location: Table Bay (Port of Cape Town)
Based on limited information on long waves from reports, the data collected in the main basin (Duncan Dock) showed a range of heights between 8 cm and 15 cm. Long waves were defined for the range of 50 s to 200 s. More data are required inside and outside the port, since long waves are present in Table Bay [1].
Location: Algoa Bay (Port of Ngqura)
Extensive studies have recently been conducted by the CSIR on the long wave climate at this port. Wave data have also been collected for about 12 years outside the port in Algoa Bay for Transnet. $Hmo^{50\%} = 0.07$ m; $Hmo1^{\%} = 0.25$ m Tp range: 25 to 300 s (25 to 125 s)*
Location: Port of Durban
A measurement exercise of five months has recently been undertaken inside the harbour as part of a harbour development project. Outside the port, the following information was obtained: $Hmo^{50\%} = 0.09$ m; $Hmo1^{\%} = 0.19$ m Tp range: 25 to 300 s (25 to 100 s)* These measurements were taken during May to October, the period when the waves are generally larger. The statistics can therefore not be directly compared to those of Saldanha Bay and Algoa Bay. The long waves inside the Port of Durban appears to be quite small (<0.1m). The geometry of the port and a large sand bank or mud-flat inside the harbour are probably reasons for the dampening of the long waves.
Location: Port of Richards Bay
Although the electronic data are not available, statistics were obtained from reports on long wave records collected inside the port over a period of one year (1993). The port is located inside a natural estuary, which probably provides some dampening of long wave energy. $Hmo^{50\%} = 0.02$ m; $Hmo1^{\%} = 0.08$ m Tp range: 150 to 350 s (250 to 350 s)* The long waves are generally small. The prevailing wave periods are generally outside the vessel response range.

** Dominant peak period range*

Figure 5: Location of S4 current meter and long wave recorder – Algoa Bay (Port of Ngqura). *Source: Google Earth*

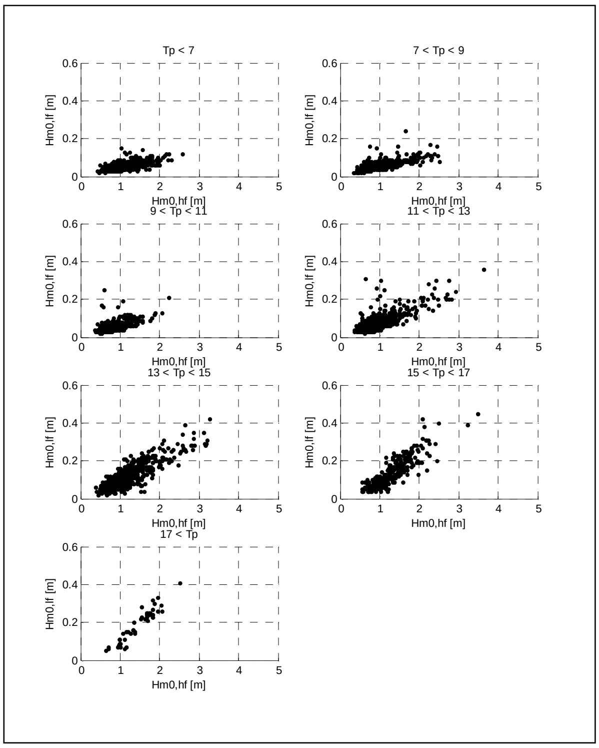


Figure 6: Correlation between long- and short waves as a function of wave period (outside Port of Ngqura)

The relationship between the short waves (Hmo,hf) and the long wave height (Hmo,lf) is presented as function of wave period – seven period bins were used (Figure 6). As shown, the relationship between the short- and long waves is well defined. A reasonable relationship was also found in Table Bay [1].

Also of interest is the relationship found in Saldanha Bay [12]. Figure 7 presents the correlation between the short waves measured by a Waverider buoy, located in the entrance channel, and the long waves measured with a pressure sensor at the tip of the harbour jetty. The locations of the wave recording instruments in Saldanha Bay are shown in Figure 8.

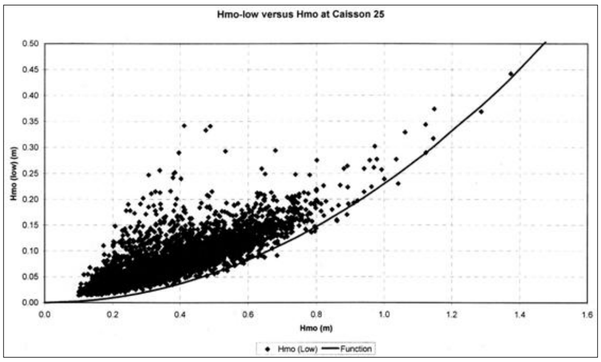


Figure 7: Correlation between long waves and short waves in Saldanha Bay - tip of jetty (Source: [12])

Although some scatter was found, a lower envelope appeared to be present. The scatter can perhaps be explained by some long waves enter the bay as free waves, and even the contribution of wave period (as shown to be the case in the Algoa Bay results). Furthermore, the data samples would also contain the reflected waves from the shore in the bay, resulting in a complex long wave pattern in the bay. It was suggested that the envelope function represents the bound long wave component, while free long waves are responsible for the scatter.

Figure 8: Location of Waverider buoy and pressure sensor in Saldanha Bay (Source: Google Earth)

6. Prediction of Long Waves

A set of non-linear correlations were computed between a historical wave forecast dataset and the corresponding S4 long wave data set, collected outside the Port of Ngqura in Algoa Bay (Figure 5). The location of the NCEP grid-point relative to Algoa Bay is shown in the Google Earth map presented in Figure 9.

The non-linear correlations were obtained by grouping the data into several sets, each with a different offshore period and direction range. An example of the scatter plots with the non-linear data fits between the offshore swell wave height and the S4 long wave height are shown in Figure 10 for a particular offshore directional sector. Similar fits are done for all offshore directional sectors. An interpolation scheme was then used to estimate a long wave height from a specified offshore wave condition, using the derived non-linear relationships of all period and direction ranges.

Figure 9: Location of NCEP grid-point relative to Algoa Bay (Source: Google Earth)

These derived relationships were then used to set up an algorithm that allowed the estimation of the long wave from the offshore wave conditions. A time-series plot showing a comparison between the predicted long waves and the measure long waves at the S4 location is shown in Figure 11. In general, a reasonable comparison was found.

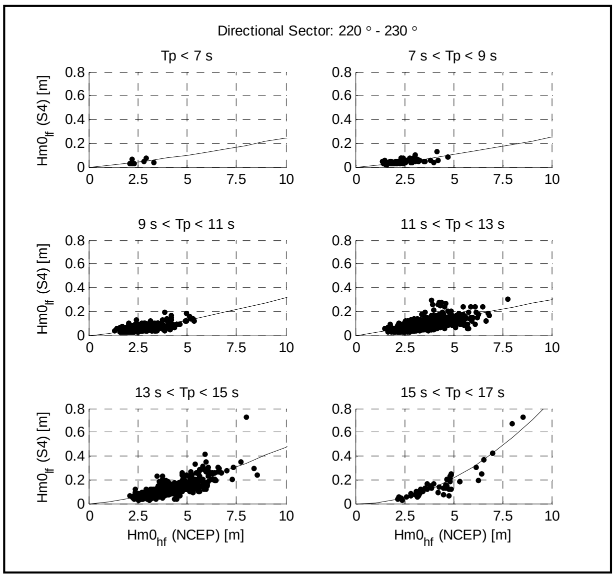


Figure 10: Non-linear correlation fits between NCEP offshore wave heights and S4 long wave heights for offshore wave directions between 220° and 230°

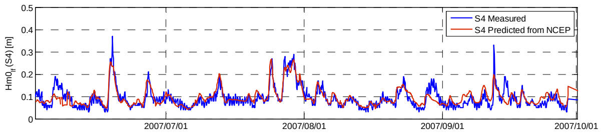


Figure 11: Comparison of measures and estimated computed long waves at S4

Since the offshore wave conditions were available in the form of the NCEP wave forecast data, it was possible to convert the offshore wave forecast into a 5-day long wave forecast. This algorithm was implemented as part of an early warning system on the Integrated Port Operation Support System (IPOSS), which provides real-time marine environmental data for the Port of Ngqura.

It is worth noting that more development is required to refine the procedure for deriving the algorithm. Aspects that still need attention include:

(i) The transformation of the offshore wave condition to nearshore wave conditions, e.g. SWAN modeling. Thus, take the wave fetch between the NCEP grid-point and the nearshore area of interest into account.
(ii) Taking the tidal water level into account.
(iii) Deriving the non-linear relationship between the forecast nearshore short waves and long waves.

Although the present long wave forecast is based on a fairly simplistic set of relationships, the estimated long wave forecast provides reasonable results when compared to measurements in the port. The magnitude of the long wave height is not highly accurate, but the forecast provides a reasonably good warning of significant events approaching the port up to 5-days in advance.

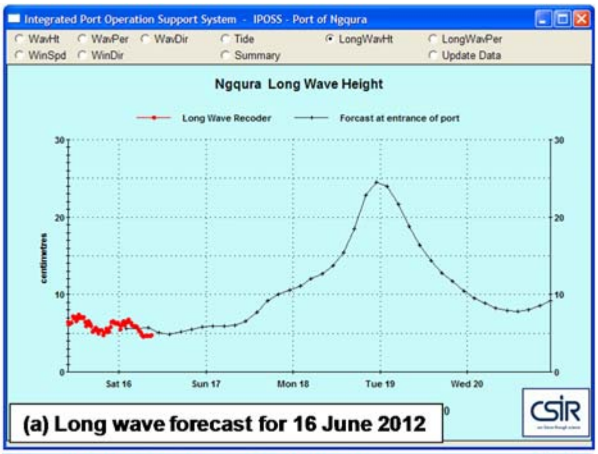
An example of the forecast display system, as provided to the port on the IPOSS, is presented in Figure 12. Figure 12a presents the forecast made on 16 June 2012 indicating a significant event arriving two days later (18th). Also shown (in red) is the long wave height as measured by a long wave recorder inside the port (see Figure 5). As predicted, the storm event arrived during the evening of the 18th. The forecast made on 19 June 2012 with the measured long waves are presented in Figure 12b.

7. Conclusions

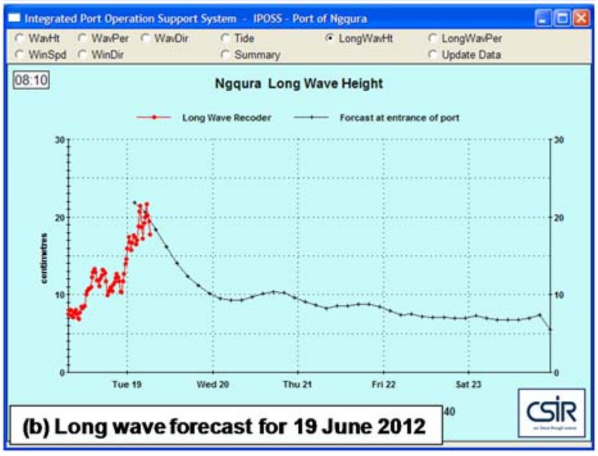
The South African coast and ports are exposed to relatively high levels of long-period wave energy, as indicated by the available information around the coast. These high levels of long wave energy have led to significant mooring problems in some of the harbours. The drivers of these waves have been identified as being predominantly swell wave groups.

Based on long wave and simultaneous short wave (sea and swell) data collected on the South coast in Algoa Bay, a clear correlation was found. The long wave height can be estimated based on the short wave height and peak period.

As a result, it was possible to derive a set of relationships to estimate the long wave conditions based on the NCEP offshore wave forecast, thereby providing useful information on potential events approaching the Port of Ngqura, located in Algoa Bay.



(a) Long wave forecast for 16 June 2012



(b) Long wave forecast for 19 June 2012

Figure 12: Examples of long wave forecasts – Port of Ngqura (Algoa Bay)

8. Acknowledgments

The authors wish to thank Transnet for the support of the study and permission to use the wave information in this paper.

9. References

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