MOORED SHIP MOTION FORECAST TOOL FOR THE PORT OF NGQURA

Chris Troch, CSIR, ctroch@csir.co.za
Luther Terblanche, Stellenbosch University, luther.terblanche@gmail.com
Marius Rossouw, WSP Group Africa, marius.rossouw@wsp.com

BACKGROUND

The Port of Ngqura is situated in Algoa Bay, about 20 km Northeast of Port Elizabeth, South Africa (see Figure 1). Operations commenced in 2009, and it is the newest of the South African ports. Originally planned as a bulk port, the port has been adapted for container handling. Ngqura's current primary role is the transhipment of cargoes for the East and West African ports, as well as for inter-continental transshipments.

Figure 1 - Port of Ngqura, South Africa (Google image)

Significant future growth is planned for the Port of Ngqura, but the Port does, however, suffer problems with moored container vessels. Under certain environmental conditions, these moored vessels experienced large motions, which lead to reduced operability or downtime and sometimes mooring line failures. One of the main contributing factors to the mooring problems is infra-gravity or long-waves (i.e. wave periods between approximately 25 s and 300 s), which induce basin and moored vessel resonance.

A long-wave forecast system has been developed to assist the Port. Although this forecast system is accurate in predicting long-wave heights inside the Port, it does not give the port operators a full picture of the effects on moored vessels due to the complex nature of the interaction between these waves and the moored vessels. The long-wave forecasts alone are therefore difficult to interpret if the port operators do not have a background in vessel dynamics. A new tool, in the form of a moored vessel motion prediction system, was therefore developed.

GENERAL APPROACH

The SWAN and Delft3D-Surfbeat numerical models were used to simulate the long-wave penetration into the port for a complete wave climate. The models were calibrated and verified using measured offshore wave data and water level recordings inside the Port. The dynamic mooring analysis software, *QUAYSIM,* was used to determine the motions of moored ships and the loads in the mooring lines for each modelled wave event. The model solves the equations of motion of the ship in the time domain to account for nonlinear effects. Quadrilateral panel meshes were generated based on the line drawings of several typical vessels that moor at the berths under consideration. The panel meshes were used by the 3D panel model, *WAVESCAT,* to compute the hydrodynamic properties of the vessels, such as added mass and damping coefficients, as well as the wave force transfer functions. The long-wave forces on the moored ships were obtained directly from the time-series of surface elevations and flow velocities calculated with the Delft3D Surfbeat model at the position of the moored ship with the strip theory model *LF-STRIP*. These forces were then used as input to the *QUAYSIM* model. The vessels are moored using a typical arrangement and mooring line type for the specific vessel under consideration.

A relationship was derived between forecast offshore swell wave data and vessel motions and associated mooring line forces at the berth locations for each moored vessel resulting from long-waves. Operability percentages were calculated based on international guidelines for motion criteria of un/loading containers. Downtime predictions were based on safety criteria of maximum mooring line forces.

WAVE MODELLING

To predict the infra-gravity wave field near a berth accurately for a given wave condition in deep water, it is required that all relevant wave propagation and inter-frequency energy transfer processes are taken into consideration in the modelling process. The nonlinear long-wave modelling tool Delft3D-Surfbeat (Reniers et al., 2001, 2004), takes these processes into account and was used in this study.

A nested SWAN model, consisting of three grids, was set up to compute the swell wave propagation inside Algoa Bay. The extent of each of the grids is shown in Figure 2. Each nested grid has a finer resolution and the ability to resolve the swell waves in more detail.

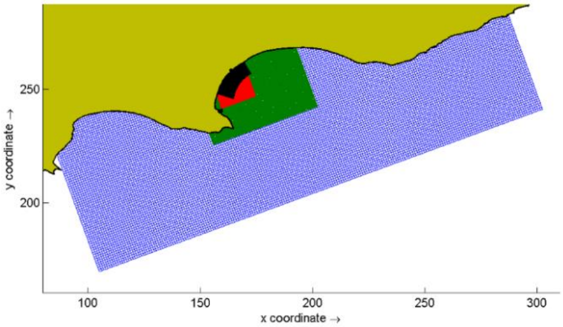


Figure 2 - The extent of each grid used for the models where the coarse, medium and fine SWAN grids are indicated by blue, green and red, respectively and the Surfbeat grid is indicated in black

The berths inside the Port of Ngqura are protected by breakwaters. These breakwaters and the approach channel affects the waves and associated moored ship motions inside the port. They provide protection from short-waves, swell waves and to some extent long-waves induced by wave groups. However, harbour basin oscillations can still be generated which may have detrimental effects on the behaviour of ships moored inside the port. Therefore, special focus is placed on the propagation of long-waves into the port and their effects on the moored ships.

MOORED SHIP MOTIONS

The time domain computer program, *QUAYSIM*, capable of analysing the dynamic behaviour of a moored ship subject to wind, waves and current, was used in this study. The program predicts the mooring loads and ship motions when the vessel is exposed to operational environmental conditions.

In most detailed mooring analysis studies, a time-domain simulation model is used to determine the motions of the moored ship and the loads in the mooring lines. These models solve the equations of motion of the ship in the time domain, so that nonlinearities, such as the characteristics of fenders and mooring lines, drift forces and current forces, can be accommodated. A pre-calculated hydrodynamic file was used, which includes the hydrodynamic coefficients and first and second-order wave force transfer functions. The hydrodynamic data were generated using a panel model that represents the 3D shape of the ship hull, the quay and the sea-bed and is based on 3D diffraction theory. Having this data, quick computations can be performed to determine the response for a range of wave, current and wind conditions or different configurations of the mooring layout.

WAVE FORCES ACTING ON THE VESSEL

Although the description of bound long-waves is included in the moored ship model *QUAYSIM*, this only applies to scenarios where these waves are still bound to the wave groups and the moored vessel is in open water. However, when these bound long-waves are released (due to diffraction or wave breaking for example), Delft3D Surfbeat is used to describe their propagation into the port and at the berths. Due to the presence of the breakwater and the reflections from the shoreline and the inside of the harbour basin, *QUAYSIM* needs to be coupled directly to the Surfeat flow field at the berth to properly assess the long wave forces acting on the vessel.

The long-wave forces on a moored ship are determined with the model *LF-STRIP* (Van der Molen, 2003; Van Der Molen et al., 2006), developed at the Delft University of Technology. The model calculates the forces directly from the long-wave elevations and fluid motions as obtained with Surfbeat. *LF-STRIP* is based on strip theory, where the submerged ship hull is divided into several cross-sectional strips (usually 20) and the force per cross-section is calculated with the assumption that the section is part of a long cylinder. Integration of the cross-sectional forces yields the total force on the ship.

In the diffraction part of the wave force (where the ship modifies the incident waves), the model uses the relative motion principle, which relates the diffraction force to the fluid motions and the hydrodynamic coefficients. These coefficients are obtained from the ships' hydrodynamic file, as obtained with the panel model *WAVESCAT* (van der Molen et al., 2016, 2010). This hydrodynamic computation includes the effect of a (partially) reflecting quay wall near the ship. Hence, despite the use of a 2D strip theory method, the diffraction analysis uses coefficients obtained with 3D diffraction theory.

MOORED VESSEL SETUP

The container quay at the Port of Nqqura is equipped with Unit Element fenders. The reaction force as a function of deflection was used as input to the model. Polypropylene mooring lines with various Minimum Breaking Loads were used in the model, depending on the vessel size.

The vessels used in the numerical dynamic mooring analyses represented a 9 000 TEU and a 4 500 TEU container vessel since these are the most common vessels calling at the port. Computations were carried out in the laden and ballast condition. A typical mooring arrangement, that is commonly used at the port, was used for each vessel size.

Panel meshes were generated for the vessels, based on the line drawings of a typical container vessel. The panel mesh is used by the 3D panel model, Wavescat to compute the hydrodynamic properties of the vessels as well as the wave force transfer functions.

SHIP MOTION TOOL

Based on the long-wave modelling framework developed for the Port of Ngqura (Troch et al., 2020) a ship motion tool was developed. Each offshore swell wave condition (measured or forecasted) was associated with a moored ship motion and mooring line force for each of the vessel sizes at 4 different berth locations along the container quay. In this case, a framework of 50 wave conditions was modelled. For the wave events not modelled, an interpolation scheme was applied to the framework to obtain corresponding values for each possible wave condition.

Based on the results, a set of algorithms were developed for a web-based support system tool. The tool displays the long-wave heights measured inside the port in real-time, together with the modelled long-wave heights using swell wave buoy measurements outside the port entrance and offshore swell wave forecast data. An output example for the long-wave heights is presented in Figure 3.

Since each ship motion model run is associated with a Surfbeat run, vessel motions can only be related to the long-waves using the swell wave input from the buoy and offshore model data. A comparison between these two modelled long-wave heights to the measured long-wave height indicates how well the models are performing.

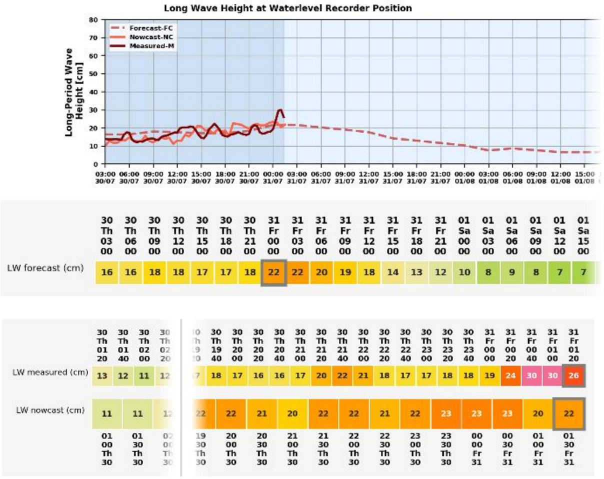
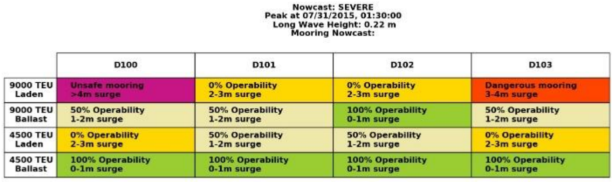


Figure 3 – An example of the long-wave heights displayed on the web-based support system tool

A 7-day long-wave height forecast is also displayed using the offshore swell wave forecast. The support system tool automatically detects the peak of any significant long-wave events during this time, as shown in Figure 4.

Figure 4 – An example output of a detected long-wave event

The support system tool also generates a table containing predicted information on moored vessels for the present long-wave conditions for each container berth and vessel size modelled as shown in Figure 5. These predictions are based on the output from the linked moored ship motion results e.g., vessel surge and mooring line forces. Operability percentages are then determined using the PIANC guidelines on the motion criteria of (un)loading container vessels. A similar table is generated for each detected forecast long-wave event at the peak of the event, as shown in Figure 6.



Nowcast: SEVERE
Peak at 07/31/2015, 01:30:00
Long Wave Height: 0.22 m
Mooring Nowcast:

	D100	D101	D102	D103
9000 TEU Laden	Unsafe mooring >4m surge	0% Operability 2-3m surge	0% Operability 2-3m surge	Dangerous mooring 3-4m surge
9000 TEU Ballast	50% Operability 1-2m surge	50% Operability 1-2m surge	100% Operability 0-1m surge	50% Operability 1-2m surge
4500 TEU Laden	0% Operability 2-3m surge	50% Operability 1-2m surge	50% Operability 1-2m surge	0% Operability 2-3m surge
4500 TEU Ballast	100% Operability 0-1m surge	100% Operability 0-1m surge	100% Operability 0-1m surge	100% Operability 0-1m surge

Figure 5 – The output table predictions for the current conditions

Event 1: MILD
Peak at 08/05/2015, 00:00:00
Long Wave Height: 0.14 m
Mooring forecast at PEAK of event:

	D100	D101	D102	D103
9000 TEU Laden	0% Operability 2-3m surge	50% Operability 1-2m surge	50% Operability 1-2m surge	50% Operability 1-2m surge
9000 TEU Ballast	100% Operability 0-1m surge	100% Operability 0-1m surge	100% Operability 0-1m surge	100% Operability 0-1m surge
4500 TEU Laden	50% Operability 1-2m surge	100% Operability 0-1m surge	100% Operability 0-1m surge	100% Operability 0-1m surge
4500 TEU Ballast	100% Operability 0-1m surge	100% Operability 0-1m surge	100% Operability 0-1m surge	100% Operability 0-1m surge

Figure 6 – The output table predictions for the detected Event 1 conditions

CONCLUSIONS

The results show how long-waves in the Port of Ngqura have different effects on the vessels for different berthing locations due to the prevailing long-wave patterns inside the basin. The vessel size and loaded state also have notable effects on the moored ship's motions.

This ship motion forecast support system tool can assist the port operators to make important operational decisions, such as which ships can be safely/effectively moored, where they should be moored and during which time window. The tool can improve terminal operability and safety by assisting port operators to determine when it is unproductive or unsafe to moor ships at specific berths. Prototype measurements and feedback from the Port should however be considered to verify the model results.

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