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Numerical Modelling of Shoreline Morphology – A Case Study by Royal HaskoningDHV

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ABSTRACT

Shoreline erosion takes place due to changes either on land or on sea. Shoreline erosion affects coastal communities through loss of land and flooding damaging properties, ecology, businesses and other coastal facilities. Shoreline erosion can be controlled either through constructing nature based soft defences or by constructing hard defences. This paper describes the use of a numerical model to assess the existing changes on a shoreline and then presents the potential changes in the shoreline due to the proposed development. The methodology described in this paper for numerical modelling of shoreline morphology adopted by Royal HaskoningDHV could also be applied to similar projects around the world.

Key words: Shoreline, Coastline, Sediment Transport, Morphology, Erosion, Accretion, Waves, Tides, Numerical Modelling, Litline, Royal HaskoningDHV

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1. INTRODUCTION

Definition of a shoreline

The shoreline (also known as a coastline) is the boundary line between sea and land. It is a narrow and linear extentalways in contact with sea. A positive change (deposition of sediments) in a shoreline is known as accretion and a negative change (removal of sediments) is called erosion.

Reasons of shoreline changes

Shoreline erosion takes place due to changes either on land or on sea. Changes on land include erosion, deposition (such as particles brought to the coast by rivers) or rising or falling of land itself due to geological forces. Changes on sea include sea level fluctuations, current circulation patterns, waves and tides leading to sediment movements.

The shoreline position changes continually throughout a year due to cross-shore and longshore sediment movements in the littoral zone because of the dynamic nature of water levels at the coastal boundary (such as waves, tides, storm surge, setup and run-up).

Decrease of sand supply from rivers to the coastal zone is a common cause of coastal erosion. Reduction of sand supply from rivers can result from different human interventions such as creation of reservoirs for power production and irrigation purposes by construction of river dams and mining of river sand. A further cause of erosion is changes in the wind driven supply of sand to the shoreline from snakylandscapes and dune systems.

Landfalling cyclones (typhoons or hurricanes) and tsunamis dramatically change shoreline through combination of storm surge and strong waves.

Impacts on coastal communities

Cities are built around seaports because seaports provide opportunities for trade, jobs and transportation. People live near the coast for recreational purposes such as surfing, sailing, fishing, swimming or walking. Approximately 40 percent of the world's population live on or near a coastline.

Shoreline erosion affects the coastal communities through loss of land and flooding damaging properties, ecology, businesses and other coastal facilities.

Mitigation measures

Shoreline erosion can be controlled either through constructing nature based soft defences (such as beach nourishment and beach management using vegetation, sandbags/geo-tubes, sand fences etc.) or by constructing hard defences (such as seawalls, revetments, groynes and breakwaters).

The present study

This paper describes the use of a numerical model to assess the existing changes on a shoreline and then presents the potential changes in the shoreline due to the proposed development. The confidential project, located in the Middle East, involved the construction of a large reclamation close to the shore along a length of coastline with major shore connected structure to the east and west. This effectively created an artificial bay within which there were a number of smaller shore connected structures.

Figure 1 shows the steps involved in a shoreline modelling study.

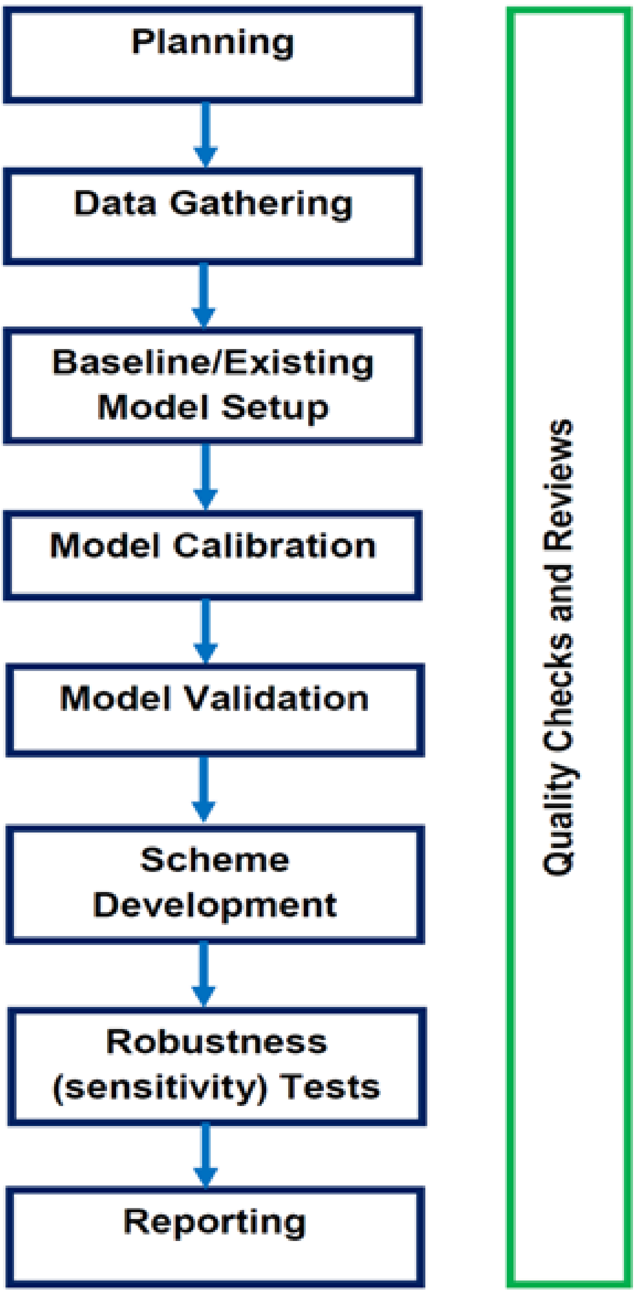
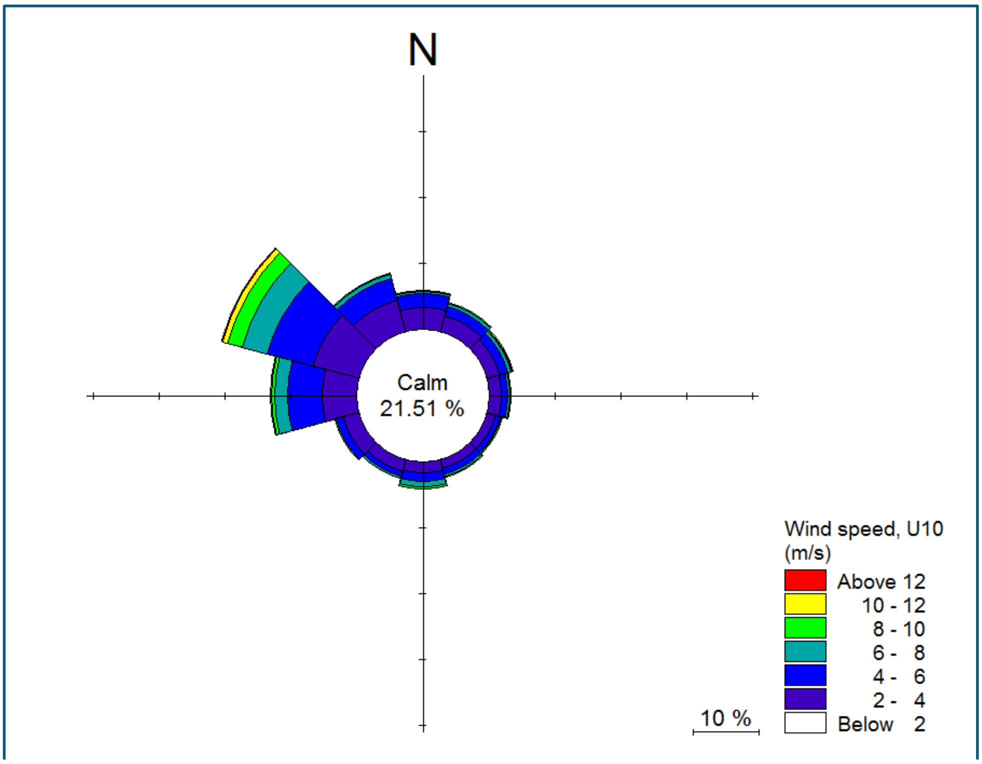


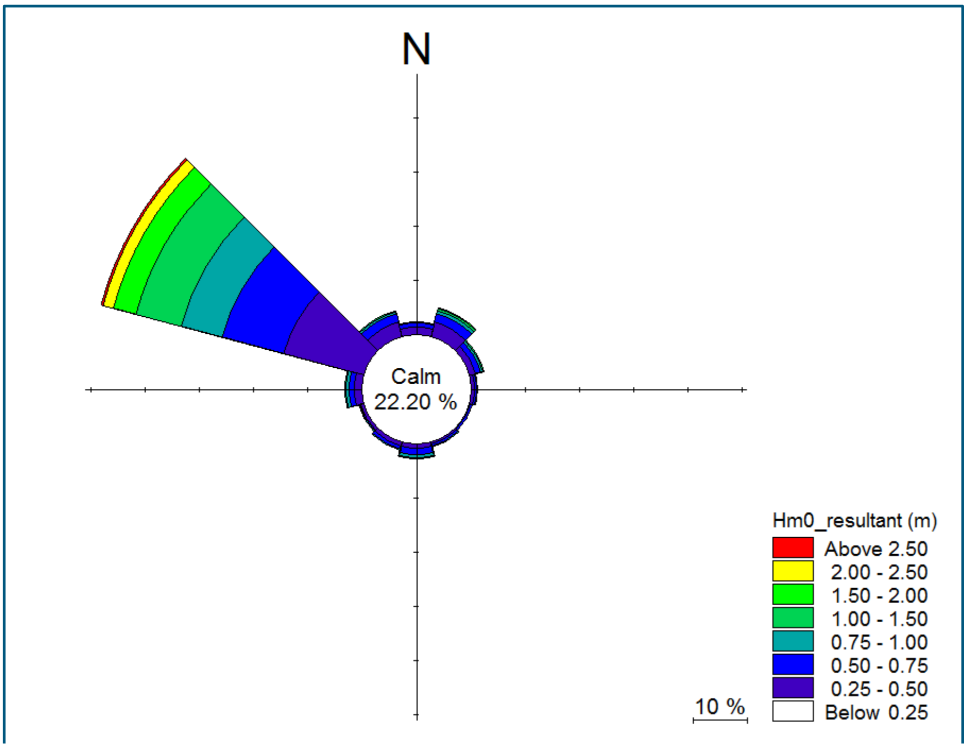
Fig. 1 Steps in shoreline modelling

2. WIND AND WAVE DATA AT OFFSHORE

Offshore wind and wave data was obtained from Infoplaza [1]. Time-series of wind (speed and direction) and wave conditions (significant wave height, period and direction) covering a period of about 26 years were obtained. Figures 2(a) and 2(b) show the offshore wind and wave roses respectively.



a) Wind rose at offshore



b) Wave rose at offshore

Fig. 2 Wind and wave roses at offshore

3. WAVE DATA AT INSHORE

The MIKE21 Spectral Wave (SW) model developed by DHI [2] was used to transform the offshore waves to inshore. Model bathymetry for the entire domain was obtained from the C-Map Database [3]. Model bathymetry at and around the study site was improved by using local survey bathymetric data.

The model was used to transform the offshore time-series waves to inshore for deriving wave climate in front of the study site. Figure 3 shows the inshore wave rose in front of the study site.

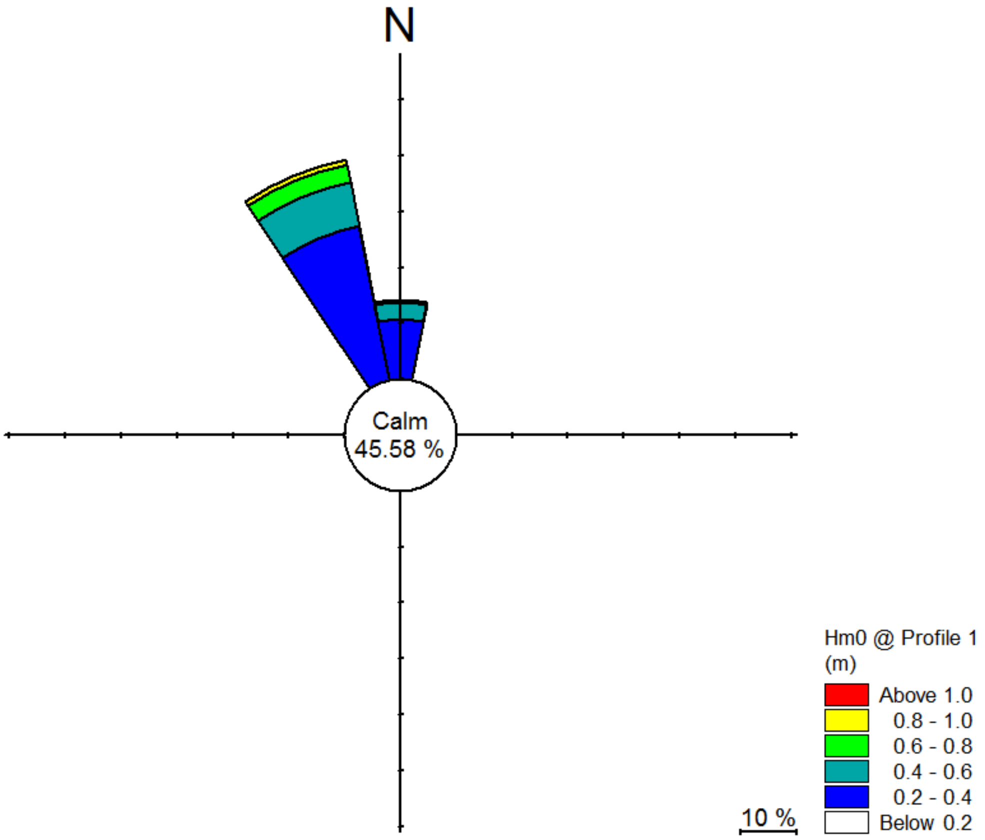


Fig. 3 Inshore wave rose in front of the study site

4. SHORELINE MODELLING

4.1 The shoreline model

The LITLINE model (also known as the Coastline Evolution module) under the LITPACK Suite developed by DHI [4] was used in the study. The model can be used for studying the evolution of coastlines influenced by various structures or sources and sinks. The model calculates the coastline evolution by solving a continuity equation for the sediment transport in the littoral zone. It simulates the coastal response to gradients in the longshore sediment transport capacity resulting from natural features and a wide range of coastal structures including groynes, jetties, revetments and offshore breakwaters.

4.2 Methodology

The first step in the modelling procedure is to assess the longshore sediment transport based on inshore wave climates and representative beach and offshore profiles which provides an indication of changes in the shoreline. Then a sediment transport table is generated which is used by the LITLINE model. The model calculates the breaking wave heights using the wave climates and then uses the sediment transport table to derive a transport rate. The LITLINE model then calculates the transport volumes and thereby determines the plan shape position of the coastline.The model was run for one year to look at immediate or short-term changes and 20 years to investigate long-term impact of the proposed development on the shoreline.

The proposed development was a square reclamation island. The four sides of the island were introduced into the model as detached breakwaters one by one to follow up the effects of each side separately.

4.3 Model set up

The horizontal X-axis of the model (known as the model baseline) was set behind and approximately parallel with the existing coastline near the study site. The baseline was extended in both directions so that an extra length of the coastline could be included in the model beyond the area of interest. This allows the model to "settle down" and avoids any edge effects within the area of interest. A 2m grid size was used throughout the model baseline to provide high resolution.

The LITLINE model requires an initial plan shape shoreline known as the "initial coastline". The distance of the initial coastline is defined from the baseline. The model boundaries at both ends were kept open to allow free sediment movement. The LITLINE model does not accept substantialchanges in coastline orientation and hence a "smoothed" coastline was maintained where necessary to avoid model instability. The resulting initial coastline profile and structures used in the LITLINE model have been described in the following section.

4.4 Input data

The LITLINE model requires the following input data to set-up and drive the model as well as to calibrate and validate it:

1) Cross-shore profile(s)
2) Coastline plan shape profile(s)
3) Existing structures
4) Inshore wave climate(s)
5) Water levels
6) Sediment properties
7) Calibration and validation data

Cross-shore profile

The LITLINE model requires information on the cross-shore profile of the beach. For the present study one cross-shore profile at the middle of the study site was used. Bed levels along the profile were obtained from the bathymetric survey data. A 1m grid size was used throughout the profile to provide high resolution for the modelling. The cross-shore profile is shown in Figure 4.

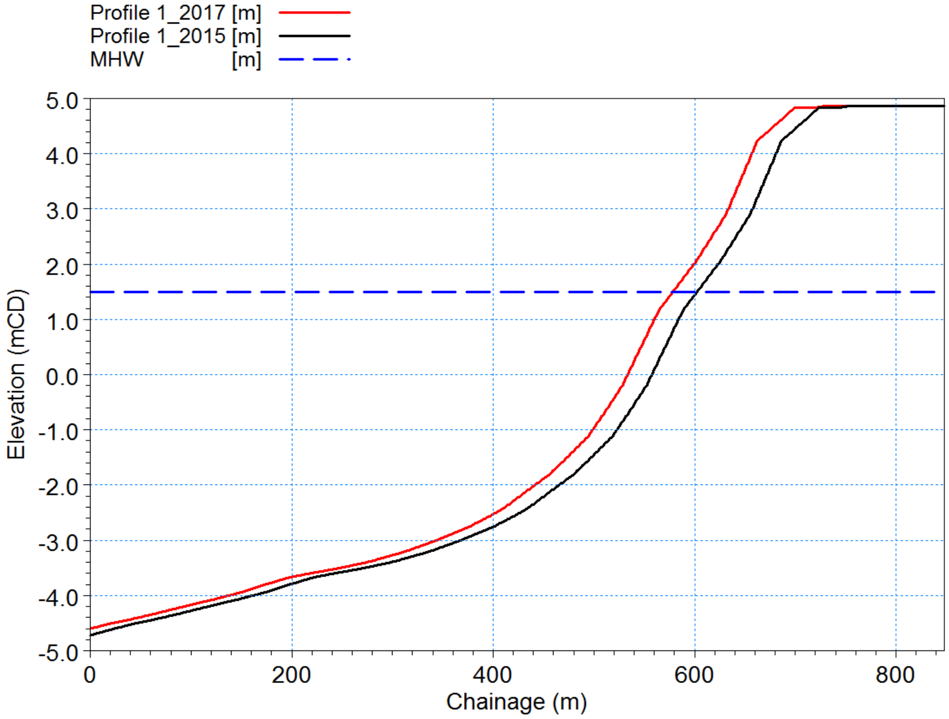


Fig. 4 Cross-shore profiles

Coastline plan shape profile

The LITLINE model requires an initial plan shape shoreline known as the "initial coastline". The distance of the initial coastline is defined from the model baseline. The Mean Higher Water (MHW) line obtained from the bathymetric survey was used as the initial coastline. A "smoothed" coastline was maintained where necessary to avoid model instability. The resulting initial coastline used in the LITLINE model is shown in Figure 5.

Existing structures

Figure 5 shows the schematisation of the existing structures (groynes) in the baseline model. All the existing groynes were included in the model. The other important (larger) cross-shore structures were also represented by equivalent artificial groynes in the model.

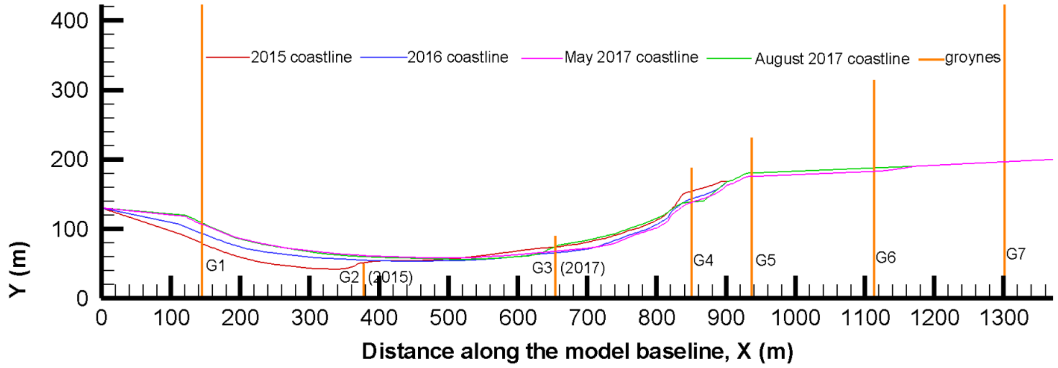


Fig. 5 Initial coastline and existing structures

Inshore wave climate

Wave conditions at the seaward end of cross-shore profile were obtained from the transformation of the offshore time-series wave data as explained earlier. Resultant waves were used in the study as these contain both wind-waves and swell waves. Figure 3 shows the inshore rose of the resultant wave climate used to drive the model.

Water levels

A water level of +1.7m above Chart Datum (mCD) was used in the modelling which includes the Mean High Water (MHW) of +1.5mCD plus an allowance of 0.2m for sea level rise.

Sediment properties

A median sediment size of d_{50} = 0.20mm was used in the modelling. The other sediment properties adopted for the modelling were:

- Porosity = 0.40
- Bed roughness = 0.0042m
- Geometrical spreading = 1.50
- Relative density = 2.65

Calibration and validation data

Measured coastline positions in 2016 and 2017 (described later) were available to calibrate and validate the model respectively.

4.5 Model calibration

Comparison with geomorphological assessment

Prior to the calibration runs, checks were made on the sediment table and longshore distribution of sediment to confirm that the model was performing satisfactorily. The general pattern of shoreline changes predicted by the model was examined to ensure that the model shows erosion and accretion at correct locations and magnitudes as expected. Model predicted erosion and accretion locations and magnitudes were compared with those suggested in a qualitative assessment and found to be in good agreement.

Comparison with Google Earth images

Model calibration results are shown in Figure 6. A reasonably good match was found between the observed and modelled coastlines of 2016. The figure clearly indicates that the model reasonably predicted the build-up of sediments against groyne G1 as can be seen on site.

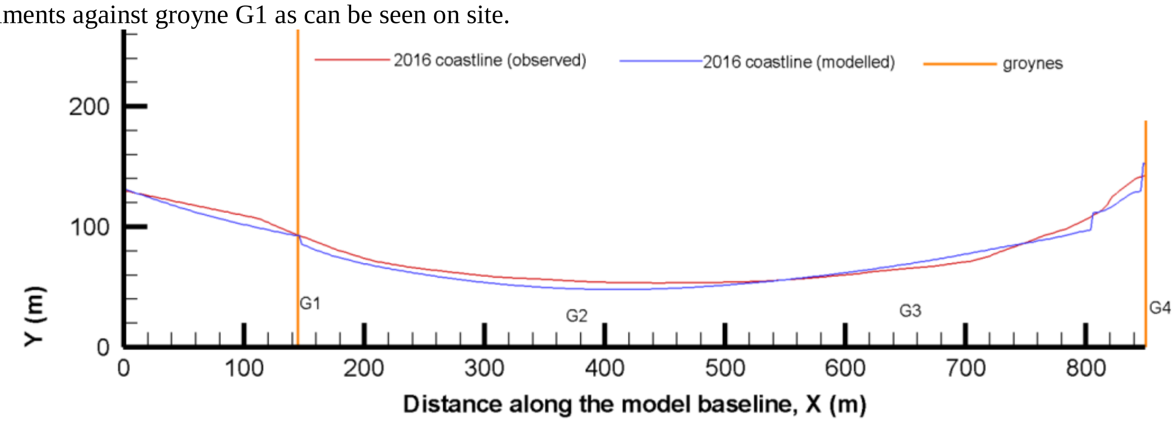


Fig. 6 Model calibration results

4.6 Model validation

Figure 7 shows the model validation results comparing the observed coastlines of August 2017 with the modelled coastline of August 2017. The figure suggests that the model reasonably reproduced the observed coastline at the study site.

There is likely to have been some nourishment of the beach between groynes G3 and G4 which was not included in the model and hence this length of the coastline remains underestimated. The influence of groyne G3, is however, represented in the model.

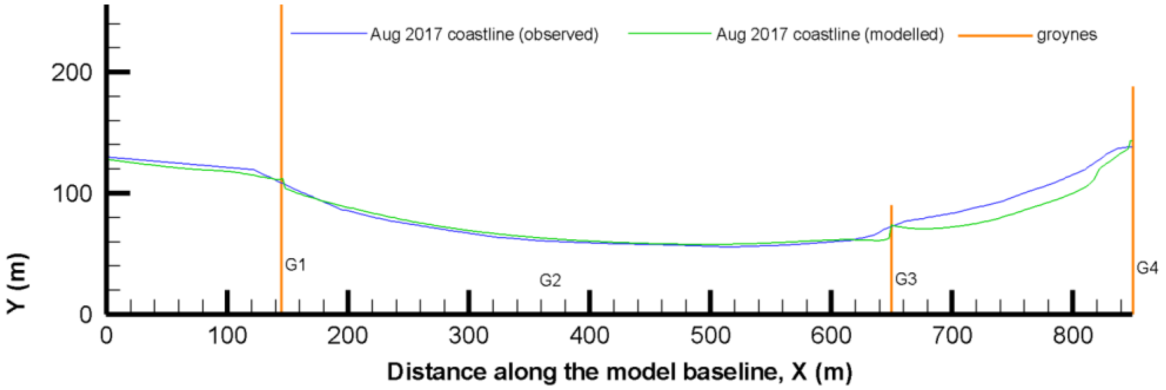


Fig. 7 Model validation results

4.7 Model results

General results

As stated earlier, the four sides of the proposed development were introduced into the model as detached breakwaters one by one to follow up the effects of each side separately. It was found that the effects of each side were well reproduced by the model. This confirms the reliability of the model to reproduce local physical processes and the impact of the structures on the shoreline.

There was an access road which was introduced into the model as groyne G8 to investigate its effects on the shoreline and to examine the reliability of the model to reproduce its effects. Figure 8 clearly shows the effects of the access road.The model predicted accretion at the north-east side of the access road and erosion at the lee side.

Figure 8 also shows the model results with the reclamation island and the access road. Almost no changes in the coastline were found between G8 and G3due to the shelter provided by the reclamation island. However, the wave conditions to the east and west are modified by the island resulting in a significant redistribution of sediment at the shoreline. In particular, the coastline south-west of G8 suffered significant erosion with accompanying accretion against the groyne G1. There was also significant accretion against Groyne G3 and erosion at Groyne G4.

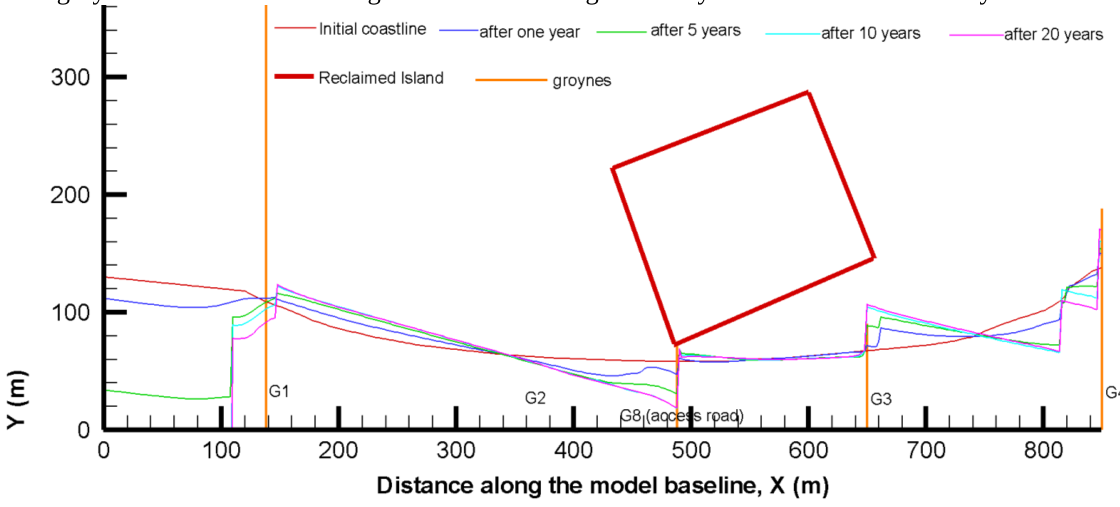


Fig. 8 Modelled short-term and long-term changes in the shoreline

Robustness of the scheme

Model results were presented initially for one year. A model run for up to 20 years was then carried out to investigate the long-term changes in the shoreline. Figure 8 shows model results after 1, 5, 10 and 20 years. It was found that the pattern of erosion and accretion after 1, 5, 10 and 20 years were almost similar although the magnitude was higher for longer run duration.

Impact of sediment size

Model results presented earlier were based on a median sediment size of d_{50} = 0.20mm. Generally, beach sediments are coarser than seabed sediments. Therefore, a sensitivity run was carried out using a coarser sediment of median size d_{50} = 0.30mm. Figure 9 shows the changes in the shoreline for d_{50} = 0.20mm and 0.30mm. No major differences in the shoreline changes were found for d_{50} = 0.20mm and 0.30mm.

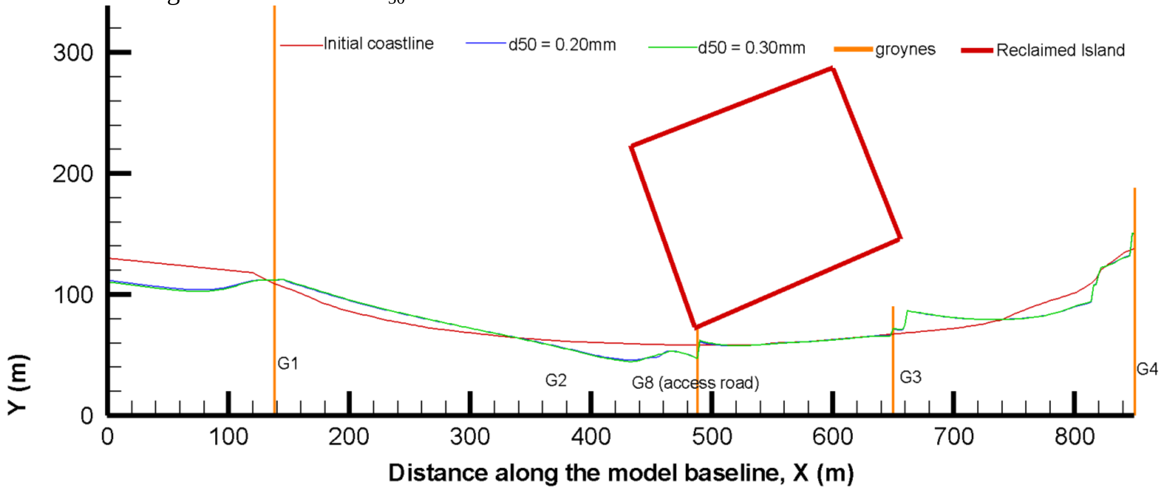


Fig. 9 Effects of larger sediment size (d_{50} = 0.30mm) on the modelled shoreline changes

5. SUMMARY AND FINDINGS

This paper describes the use of a numerical model to assess the existing changes on a shoreline and then presents the potential changes due to the proposed development.

Numerical modelling of potential changes on the shoreline due to the proposed island development was carried out in the study using the LITLINE model. The model was initially calibrated and validated using measured shoreline positions. Then production runs were carried out by introducing each side of the proposed island one by one as a detached breakwater.

The model showed the short-term and long-terms effects of each side of the island correctly as expected. Robustness of the model results were tested using a coarser sand.

The methodology described in this paper for numerical modelling of shoreline morphology adopted by Royal HaskoningDHV could also be applied to similar projects around the world.

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