COPE LEVELS IN MODERN PORTS: A CASE STUDY FOR THE PORT OF NGQURA

TA AHMED[1] and K MUTOMBO[2]

[1]Transnet National Ports Authority, Neptune Road, Port of Ngqura
Cell: 072 392 0548; Email: Tauqeer.Ahmed@transnet.net
[2]Transnet National Ports Authority, 30 Wellington Road, Parktown, Johannesburg
Cell: 083 463 8092; Email: Kana.Mutombo@transnet.net

ABSTRACT

Nowadays, with the increasing climatic challenges, ports are beset with many uncertainties about their futures. They are confronted with new demands for infrastructure adaptation, new external constraints, and changed expectations. The inability to adequately meet these demands will lead to huge consequences for a port. This is mainly attributed to the fact that traditional practices of port planning have remained static in an ever-increasing dynamic world. Predicting the future using linear tools for complex non-linear systems is bound to fail. A new complex non-linear approach is needed.

The complex nature of climate risks presents major difficulties for port infrastructure adaptation. Despite the availability of climate data at large, there is presently no provision for a port wide approach for assessing and incorporating these data into port adaptation.

This paper proposes a methodology for determining cope levels in ports. In order to demonstrate the applicability of the methodology, the port of Ngqura is used as a case study. Central to this study is the building of widespread industry recognition of the need to factor climate change into decision making at early stages of port development.

1. INTRODUCTION

Since the end of apartheid, there have been remarkable progress in South Africa in terms of building an inclusive society, rolling back the shadow of history and broadening opportunities for all. Redressing the inequities caused by centuries of racial exclusion is a constitutional imperative (National Development Plan, 2030).

Unfortunately, despite this positive development, South Africa remains today one of the most unequal society in the world. The apartheid spatial divide continues to dominate the landscape (National Development Plan, 2030). In order to eliminate poverty and reduce inequality, the economy must grow faster and in ways that benefit all South Africans.

In this perspective, public infrastructure investment has increasingly been identified as a way to faster economic growth and create employment; in addition to providing basic services. In effect, it was found that, for historical reasons, South Africa has missed a generation of capital investment in roads, rail, ports, electricity, water, sanitation, public transport and housing. The country needs a higher level of capital spending in order to realise a sustained impact on growth and household services. Ports are becoming key enablers and catalysts for the competitiveness and development of any regional economy

(Mutombo & Olcer, 2016). It was under this background that the Port of Ngqura was built on the East Coast of South Africa.

Figure 1: Location of the Port of Ngqura in South Africa (Google Earth, 2016b)

The Port of Ngqura (PoN) is a deep-water and the newest port in South Africa, promulgated in the Port of Ngqura Establishment Act No.77 of 1998, and constructed from 2006 to 2009 (du Plessis, 2010). The port is one of two ports in the Nelson Mandela Bay Municipality and one of three in the province of the Eastern Cape, South Africa (see Figures 1 below, showing its relative regional location).

The port boasts four container berths and three general cargo berths, and handles imports, exports and transhipment, including abnormal project cargo. It is an industrial port able to accommodate post-panamax bulk cargo and container vessels (du Plessis, 2010). The entrance channel and main basin of the port has a level of -18.0 m Chart Datum (CD), general cargo berths at -18.0 m and -16.0 m CD and a container terminal at -16.0 m CD (du Plessis, 2010). The existing port area, Figure 2, is partially developed (approximately 20 percent) with large developments and expansions planned for the future (du Plessis, 2010). This study focused on the planned port expansion up the Coega River.

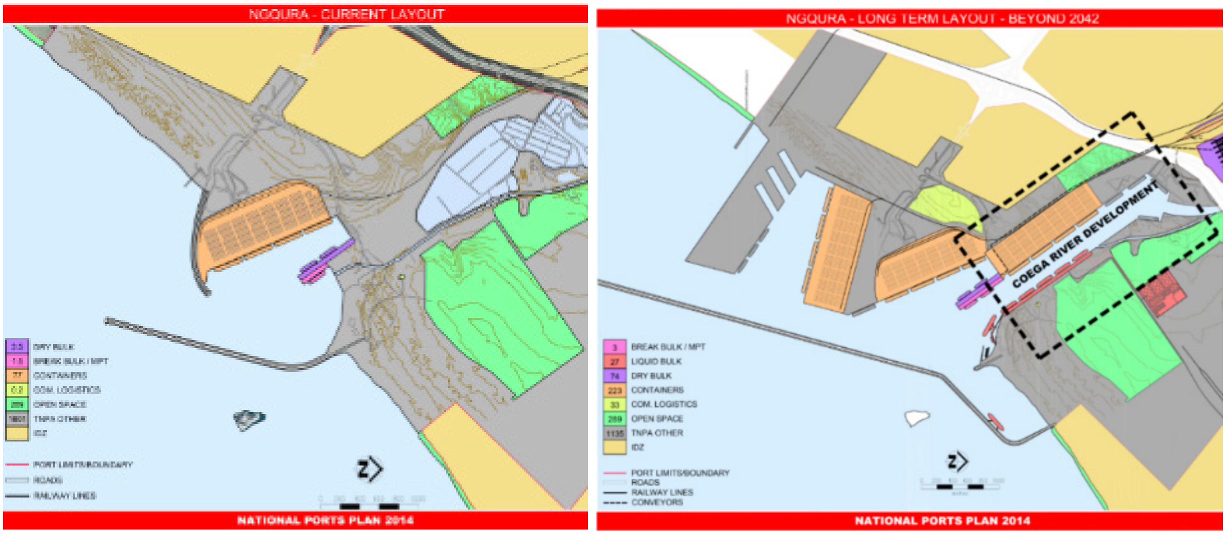

Figure 2: Current Port Development Framework Plan and Long Term Port Development Framework Plan as at 2014 (TNPA, 2014c). Study area in dashed line.

Various technical, environmental, nautical and economic factors need to be considered in the planning of port infrastructure (Ligteringen & Velsink, 2012, p. 53). The infrastructure needs to be designed for a dynamic marine environment dictated by tides, waves, currents, and coastal sediments (metocean), changes in shipping technology and vessel sizes, and global warming impacts.

For a river environment such as this study area, additional factors that may affect port development include the physical site limitation of in terms of the size of the navigational channel width, which in turn would dictate the vessel size that can be accommodated in the navigational channel. Sedimentation risks and impacts from river flooding also need to be taken into account for river developments.

Climate change is impacting ports and port developments as it affects sea level rise (Gharehgozli, Mileski, Adams, & von Zharen, 2016), increase in wave heights, changes in wave and wind patterns and changes in storm conditions, which all has an impact on port infrastructure design, which needs to be taken into account (Becker, Ng, McEvoy, & Mullet, 2018, p. 2).

For a port to be economically viable its infrastructure should be carefully planned and designed considering these dynamic aspects (including other site-specific aspects). (Ligteringen & Velsink, 2012)

2. PROBLEM STATEMENT

The problem statement identified for this study required an understanding of the dynamic metocean conditions and their impacts due to climate change, new generation vessel impacts, and how these factors contributed to the determination of the most suitable cope level for the future Port of Ngqura Coega River expansion.

The methodology used was a desktop study of the various factors assuming a 100-year design life of the structure and at a storm return period of 1,000 years.

It is critical to ascertain the future cope levels for the port, taking into account the long-term changing dynamic factors that affect the cope level. Planning is needed to ensure that the infrastructure, once built, functions well (Ligteringen & Velsink, 2012, p. 53).

3. QUAY WALL AND COPE LEVEL BASICS

3.1 Quay wall basics

Quay walls are earth-retaining structures built in the water (river, sea, lake), at which vessels can berth / moor (Thoresen, 2014, p. 551) for the transfer of cargo. Quay walls are typically constructed out of mass concrete, steel sheet piles or timber piles. The basic elements of a quay wall are the structural foundation, the scour protection of the wall, the wall structure itself, service tunnels, fenders, decking and bollards. The cope level is the top of the quay wall (as indicated in Figure 3).

Quay wall design, therefore, has a direct link to the cargo handling efficiency of a port, of which the cope level determination plays a key role.

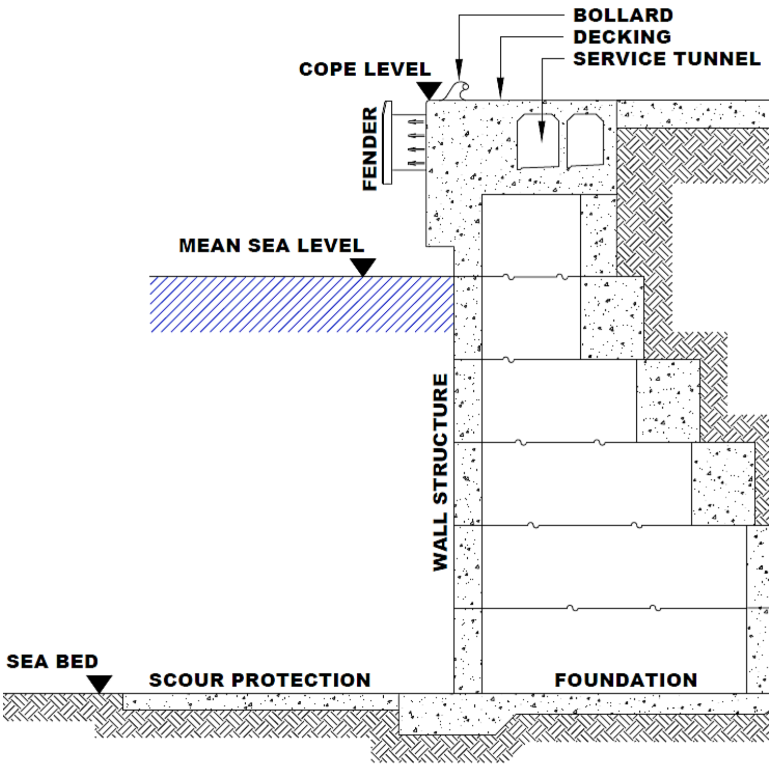

Figure 3: Basic elements of a quay wall (Ahmed, 2018)

3.2 Cope level basics

Factors that affect the determination of cope levels can be broadly categorised as water level criteria (design water level) and above-water operational freeboard criteria (Ahmed, 2018). The design water level is influenced by various factors as indicated in Figure 4. For this study, factors considered include astronomical tides, storm surge, long waves, port-generated waves and fluvial impacts.

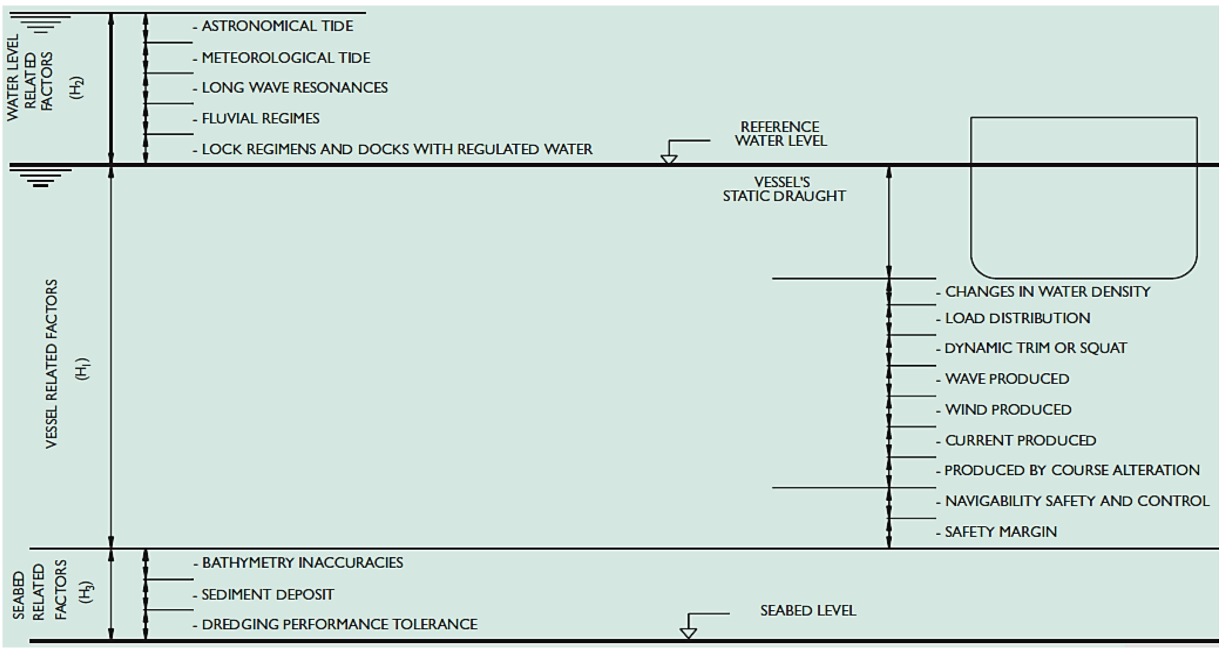

Figure 4: Total water depth factors (ROM 3.1-99, 2007, p. 171)

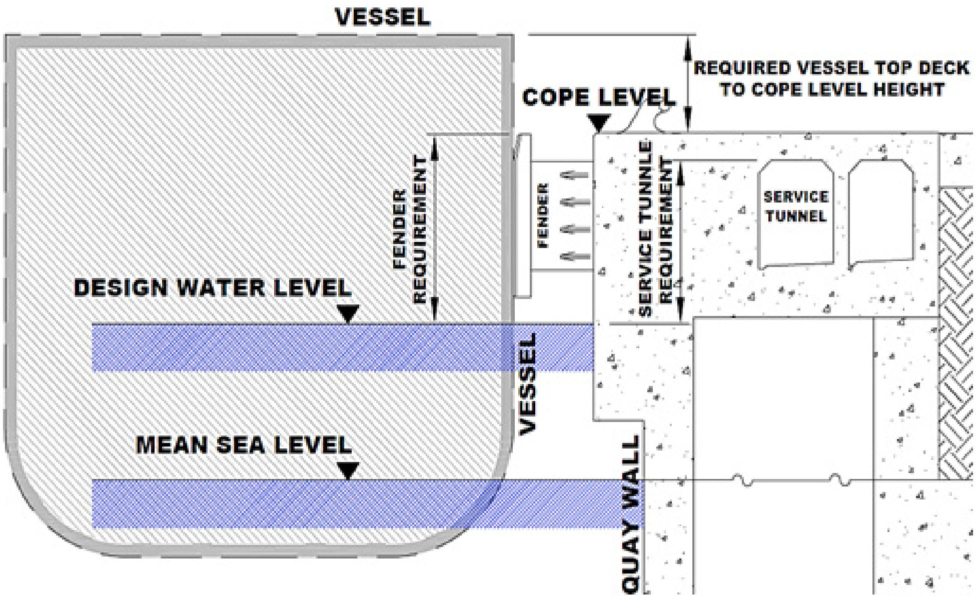

Figure 5: Above-waters factors (Ahmed, 2018)

In terms of the above water operational freeboard requirements, typical factors to consider include: ideal vessel operational height requirements, space for service tunnels (TNPA, 1994) and fenders (TNPA, 1994) (refer to Figure 5).

4. DETERMINATION OF COPE LEVELS

Comprehensive design guidelines for the designing and development of port infrastructure in the South African environment are provided in the Transnet National Ports Authority (TNPA) Port Engineering Hand Books (PEH) (1994; 2015). Further guidance can be sought in international guidelines such as, British Standards BS 6349-1:2010 and BS 6349-2-2010 (2000; 2010), PIANC Report on EnviCom Task Group 3 (2009) and Report No. 158 (2014), the Port Designers Handbook, (Thoresen, 2014), the Design of Marine Facilities (Gaythwaite, 2004), Ports and Terminal (Ligteringen & Velsink, 2012), Port Design Guidelines by the Government of Hong Kong (GHK, 2004), Recommendations for the Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins (ROM 3.1-99, 2007), Handbook on Quay Walls (CUR, 2005), EuroTop wave overtopping of sea defences (Pullen, Allsop, Bruce, Kortenhaus, Schuttrumpf, & van der Meer, 2007) and the United Nations Conference on Trade and Development (UNCTAD) guidelines.

4.1 Key Elements

The determination of Cope Levels involves the study of multiple facets from vessel parameters, metocean parameters and operational parameters (Ahmed, 2018), to name a few. Typical key elements that need to be considered in the determination of the cope level, which need to take into account the long term performance of a port in terms of port planning, can be identified as (as used in this study):

4.1.1 Vessel Parameters

- Vessel size (TNPA, 1994; Gaythwaite, 2004, p. 44; TNPA, 2015),
- Vessel type (Gaythwaite, 2004, p. 44; GHK, 2004, p. 18; Thoresen, 2014, p. 183; Alfredini, Arasaki, & Pezzoli, 2015).

4.1.2 Metocean Parameters

- Astronomical tidal range to be expected (TNPA, 1994; GHK, 2004, p. 18),
- The highest observed water level and tidal level in the port (Thoresen, 2014, p. 183; Alfredini, Arasaki, & Pezzoli, 2015) and its frequency (BS 6349-2, 2010),
- The wind-raised water level in the harbour basin (Thoresen, 2014, p. 183; Alfredini, Arasaki, & Pezzoli, 2015; TNPA, 2015),
- The wave action in the harbour basin (Thoresen, 2014, p. 183; Alfredini, Arasaki, & Pezzoli, 2015; Mutombo & Olcer, 2016, p. 27), including normal and extreme wave conditions (Gaythwaite, 2004, p. 44),
- Wave crest heights (Gaythwaite, 2004, p. 120),
- Short waves, long waves and surging in the harbour (Gaythwaite, 2004, p. 44)
- Extreme water levels (GHK, 2004, p. 18) obtained by adding the various tidal parameters, wave heights and water levels above the still water level (Ligteringen & Velsink, 2012).
- Sea level rise to be expected (TRB, 2008, p. 2; Mutombo K, 2014, p. 267) and its impact (BS 6349-2, 2010, p. 9; Mutombo & Olcer, 2016, p. 27),
- Normal and extreme wind conditions (Gaythwaite, 2004, p. 44; Mutombo K. , 2014, p. 267),
- Frequency and probability of storm conditions (Gaythwaite, 2004, p. 44; TRB, 2008, pp. 2, 90),
- Fluvial impacts of river floods (ROM 3.1-99, 2007; Mutombo K. , 2014, p. 267).

4.1.3 Operational Parameters

- Quay face height required to accommodate fenders (TNPA, 1994),
- The elevation of the terminal area and land behind the berth apron (GHK, 2004, p. 18; TRB, 2008, p. 90; Thoresen, 2014, p. 183),
- Spatial allowance to accommodate service tunnels in quay walls (TNPA, 1994),
- The risk impact of flooding from the sea and the effect and implications of such flooding (BS 6349-2, 2010, p. 9) from wave overtopping (PIANC, 2014),
- Drainage and stormwater requirements (TNPA, 1994; TNPA, 2015)

4.2 New generation vessel requirements

Quay walls are built to berth ships (CUR, 2005, p. 684; Meijer, 2006, p. 7; Thoresen, 2014, p. 551). The characteristics of vessels have an impact on the required cope level in terms of the ideal operational height required between the vessel operational deck and cargo terminal deck. This needs to be taken into account when determining cope levels (PIANC, 2014, p. 30; Thoresen, 2014, p. 183; Alfredini, Arasaki, & Pezzoli, 2015; TNPA, 2015, p. 52).

The art and science of port engineering have been greatly affected by technological advances that impact ship design (Gaythwaite, 2004, p. 5), and ports are typically designed for the largest ship that can be expected to berth at the port (Thoresen, 2014, p. 531). There has been a growing trend in the increase of container ship capacity over the years (Ligteringen & Velsink, 2012; Zwakhals, Taneja, & Ligteringen, 2012, p. 1552), and as of 2019, the largest container vessel produced is the OOCL Hong Kong at 21,413 Twenty Foot Equivalent Unit (TEU) (Marine Insight, 2019).

For this study, the maximum sized vessel that could be accommodated up the Port of Ngqura Coega River Channel was based on the channel width limitations of the proposed development as detailed in the CSIR Future Port Expansion Navigation Simulations Report (CSIR, 2013). This was determined to be an 18,000 TEU vessel.

Bigger vessels also signify bigger vessel weights, thus increasing the forces that act on the quay wall (Gaythwaite, 2004, p. 133). Fenders located on the quay wall need to be designed to counter these anticipated forces, with heavier vessels requiring a larger contact area to absorb the bigger forces (Taneja, Zwakhals, & Vellinga, 2013). Larger fenders may require additional space on the quay face (Kong, Setunge, Molyneaux, Zhang, & Law, 2013, p. 28).

4.3 Climate change impacts

Ports play a critical role in maintaining the economy of a country (Mutombo & Olcer, 2016, p. 26; Becker, Ng, McEvoy, & Mullet, 2018, p. 1). It is a key economic stimulus (Mutombo & Olcer, 2016, p. 26), therefore, there is a need to understand what the impact of climate change on port development is and understand how to plan for this (Mutombo & Olcer, 2016, pp. 26-27; Becker, Ng, McEvoy, & Mullet, 2018, p. 3).

Climate change affects infrastructure, operations and services in ports (Mutombo, 2017). The biggest impact would be from sea level rise (TRB, 2008), which may increase erosion of coastal structures, requiring more frequent inspection and repairs, and causing potential disruption (Nemry & Demirel, 2012). Climate change impacts will likely have varying degrees of operational and economic impacts, disruption to port and shipping operations, disruptions to international and national trade, disruption to supply chains, and impacts on broader economic activity at varying scales (Mutombo, 2017).

Focusing on the problem now should help avoid costly future investments and disruptions to operations (TRB, 2008, p. 2).

Climate change and the resulting sea level rise has been studied and debated in great detail over the past decades, with a vast knowledge base having been created (IPCC, 2014c, pp. 40-43). In the latest IPCC AR5 assessment report, it is indicated that, as a result of improved modelling and technological advancements, findings in terms of sea level rise indicate greater levels than those predicted in the Forth Assement Report (IPCC, 2013, p. 1140). For the purposes of this study, the results of the 95 percent confidence for scenario RCP8.5 from the AR5 assessment report was selected for the determination of the future cope level. This indicated a 0.82m rise in sea levels over a 100-year period (figure 6).

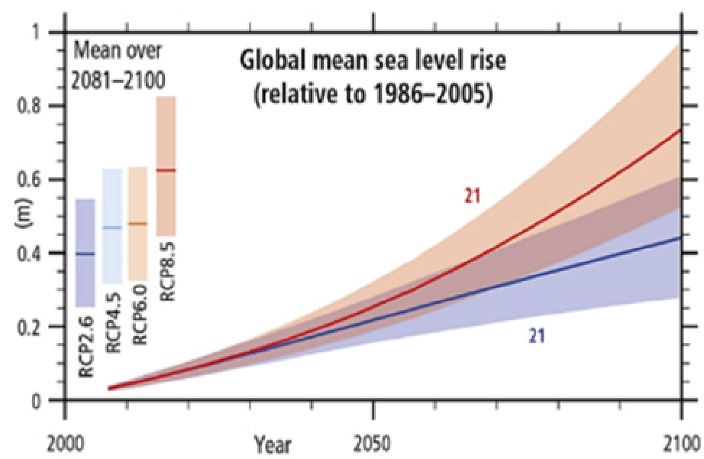

Figure 6: Projected sea level rise (IPCC, 2014c)

When comparing sea level rise for Southern Africa (based on approximately 30 years of South African tide gauge records) to global tide gauge records, the results show substantial agreement with global trends (Mather, 2007, p. 512; Mather, 2008). Therefore, data as published in the IPCC AR5 reports can be used in the South African environment to predict the sea level rise to be expected.

For the determination of cope levels, it is necessary to take into account the rising sea level (AS 4997, 2005, p. 16; CUR, 2005, p. 173; TRB, 2008, p. 90). Sea level rise directly affects the selection of cope levels (TRB, 2008, p. 90; ZAA, 2014, p. 2).

From a South African point of view, following change in parameters due to climate change impacts are recommended in Table 1 (PRDW, 2010b, p. 11).

Table 1: Adopted parameters for climate change to year 2100 (PRDW, 2010b, p. 11)

Year	Wind speed increase (%)	Storm surge increase (%)	Wave height increase (%)	Sea level rise (upper end of projection) (m)
2000	0	0	0	0.00
2050	5	10	8.5	+0.4
2100	10	21	17	+0.8

Figure 7: View of the Coega River flood towards the sea (TNPA, 2011b)

4.4 Port of Ngqura specific parameters

4.4.1 Coega River

In 2011, the Coega River flooded and washed away infrastructure in the port, causing damage of R2.6 million (Introna, 2011). The impact of this flood is shown on Figure 7. As stated in ROM 3.1-99 (2007), should navigation channels or harbour basins be affected by rivers that drain into them, the pertinent hydraulic regime must be taken into account. The impact of flooding of the Coega River for a design life of 100 years and at a storm return period of 1,000 years, while accounting for changes in regional precipitation due to global warming was studied and taken into account in the determination of the future cope level.

4.5 Flooding risk of port infrastructure from the sea

The risk of not factoring in the various variables mentioned above may cause flooding over the quay wall (Kong, Setunge, Molyneaux, Zhang, & Law, 2013, p. 28). Its implications may include damage to mechanical equipment by inundation (TNPA, 2015, p. 53) and may cause damage to quay wall equipment or pavements (PIANC, 2014). Design sea levels represent an important component in the safety analysis procedure in respect of coastal flooding and the reliability of the associated coastal structures (Wijnberg, 1993, p. 1).

5. PORT OF NGQURA DESIGN PARAMETERS USED IN THE STUDY

For the purposes of this study, a conservative worst-case scenario was selected in which, the proposed development was tested against a design life of 100 years and a 1 in 1,000 year return period event. The base year was taken as year 2020 and the design parameters were calculated up to the year 2120. All required data for this study was extrapolated and interpolated to the years 2020 and 2120 as and where required.

5.1 Cope level determination factors

There are two main broad variables for the determination of Cope Levels, namely: the design water level (X) which includes extreme still water level plus extreme waves), and the operational freeboard height (Y), including placement of fenders. These are graphically represented in Figure 8. Factors related in the determination of X and Y studied are included below.

It is important to note that the design of maritime structures should allow for the highest wave likely to occur on the structure over the selected design life (AS 4997, 2005, p. 24).

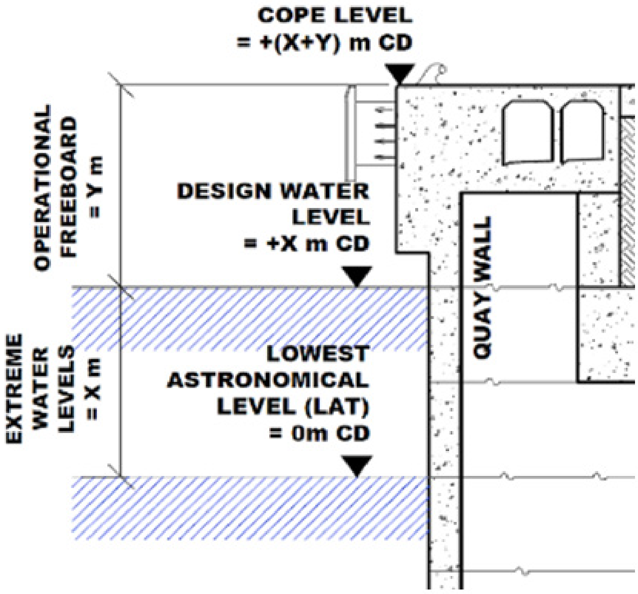

Figure 8: Cope level determination factors (Ahmed, 2018)

5.2 The design still water level and the design water level

In order to define the required cope level, there are two main water levels that need to be calculated. The Design Still Water Level (DSWL) and the Design Water Level (DWL) (Ahmed, 2018). The DSWL is considered as the still water level combining astronomical tide, storm surge, long wave and sea level rise (global warming) allowances. The DWL is considered as the wave effect on top of the DSWL, with the DWL being the top of the modelled wave crest. The cope level is then determined above and relative to the DWL. This is graphically presented in Figure 9.

In determining the elevation of cope level, allowance has to be made for adding a factor times the Hs above the DSWL to ensure that the cope level elevation exceeds the height of the wave crest during design conditions (Figure 10). In varying references, allowances for a factor from 0.5 to above 2 are provided for the ratio of freeboard height (cope level distance above DSWL) to wave height (Hs) (Green, 1989; EurOtop, 2016) in studies of wave action on vertical seawalls.

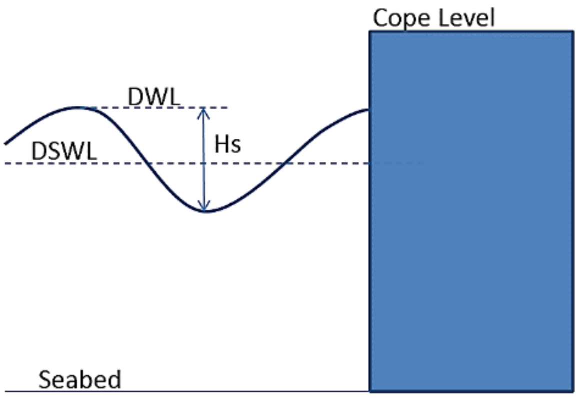

Figure 9: Graphical representation of DSWL and DWL (Ahmed, 2018)

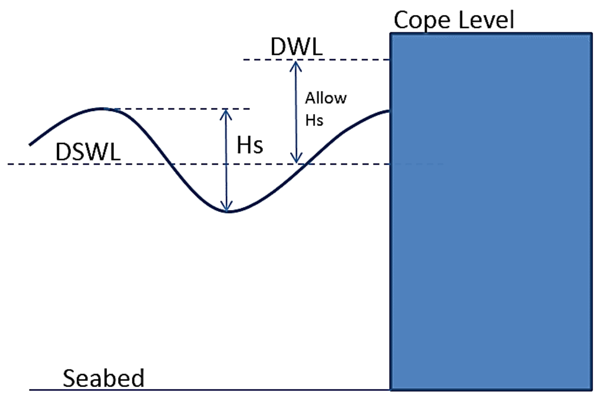

Figure 10: 1xHs allowance above the design still water level (Ahmed, 2018)

Since the waves are small relative to the total quay wall height they will be pulsating (non-breaking) rather than impulsive (breaking) at the quay wall, (terminology according to Allsop et al. (2005). Allowance need not be taken in a very conservative manner, especially due to the conservative approach taken to derive the combined wave height in the thesis (Ahmed, 2018) and this paper. In addition, in the new terminals, the waves will be mostly propagating with crests at 90 degrees to the line of the quay wall so they will be running along the seawall rather than impacting onto it.

Therefore, it is considered reasonable to adopt a 1 x Hs allowance above the design still water level for this case study. This is graphically presented in Figure 10. The determination of the cope level is therefore defined in the following basic expression as indicated in Equation 1:

Cope level ≥ DWL **_Equation (1)_**

Where: DWL = DSWL + (1 x Hs)

5.2.1 Extreme sea levels

The identification of the DWL required the identification of the expected extreme sea levels. This included identifying the maximum astronomical tide, sea level rise over 100 years, maximum surge levels, maximum short wave heights (off shore, port wind generated and vessel generated), maximum long wave heights, maximum shelf wave, maximum edge waves and maximum river flood levels to be expected. Over a design life of 100 years, most of these parameters are impacted by climate change (PRDW, 2016, p. 21). Climate change would cause a change in weather patterns, which in turn would impact storminess, and wind, wave and surge generation (TRB, 2008, p. 21). These impacts were factored into the determination of the extreme sea levels for the Port of Ngqura.

5.3 Datasets

Various datasets were available for PoN and it included recorded data from 1997 to 2015 taken at 5 separate stations around the port (PRDW, 2016, p. 19).

Data recorded included wind, wave and tidal data. The location of the station is indicated in Figure 11.

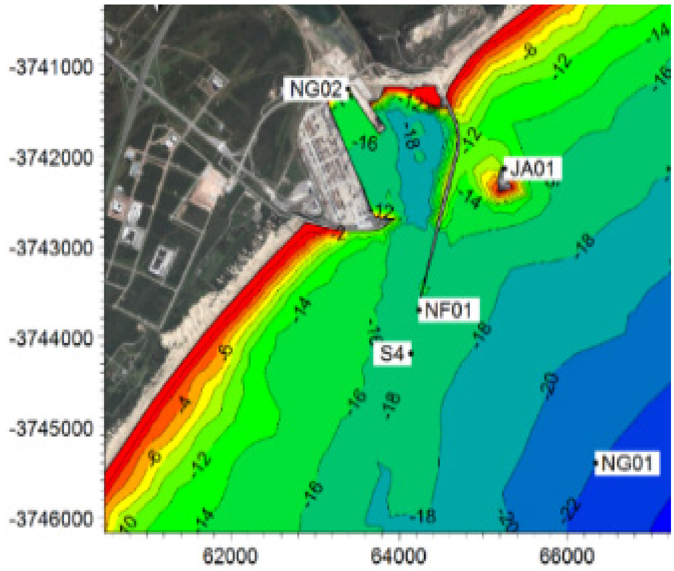

Figure 11: Location of the Station

5.4 Calculated cope levels

The proposed future cope levels calculated were, based on the estimated extreme water levels and a reduced minimum operational requirement (based on practical parameters). The calculated results are indicated in Table 2 and graphically presented in Figures 12.

Table 2: Year 2120 proposed future cope levels based on design still water levels and reduced operational requirements

	Return period	1:10	1:100	1:200	1:500	1:1,000
1	Design Still Water Level (DSWL)					
1.1	Highest Astronomical Tide (HAT) (m CD)	2.3	2.3	2.3	2.3	2.3
1.2	Sea level rise (m)	1.3	1.3	1.3	1.3	1.3
1.3	Surge (m)	0.9	1.1	1.1	1.2	1.2
1.4	Long waves (m)	0.5	0.7	0.7	0.8	0.8
1.5	Coega River impact (m)	0.0	0.0	0.0	0.0	0.0
1.6	DSWL (m CD)	5.1	5.4	5.5	5.6	5.7
2	Combined effect of short waves (Hs) (m)	1.1	1.3	1.3	1.3	1.3
3.	Design Water Level (DWL) (1+2) (m CD)	6.2	6.7	6.8	6.9	7.0
4	Minimum operational requirements					
4.1	Fender requirements (m)	0.0	0.0	0.0	0.0	0.0
4.2	Service tunnel requirement (m)	0.0	0.0	0.0	0.0	0.0
4.3	Free board allowance (m)	0.5	0.5	0.5	0.5	0.5
4.4	Total operational requirement (m)	0.5	0.5	0.5	0.5	0.5
5	Proposed cope level height (3+4) (m CD)	6.7	7.2	7.3	7.4	7.5

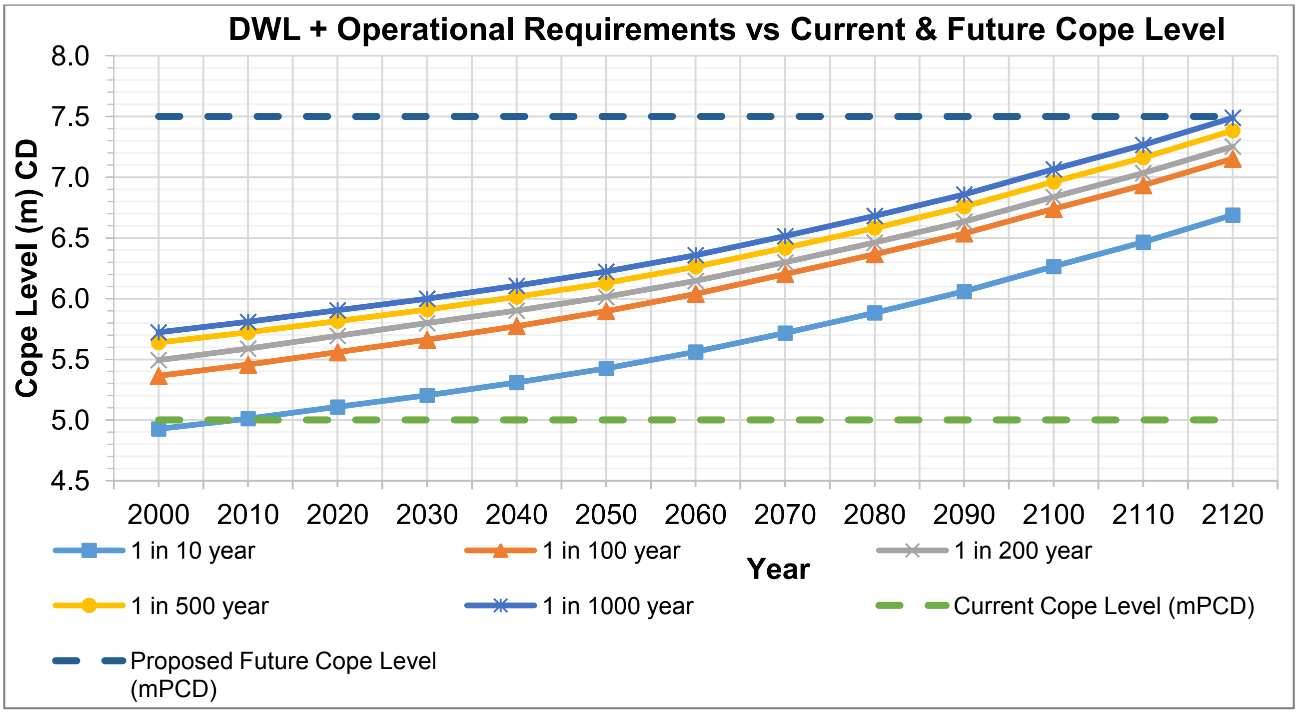

Figure 12: DWL + operational requirements vs current & future cope level

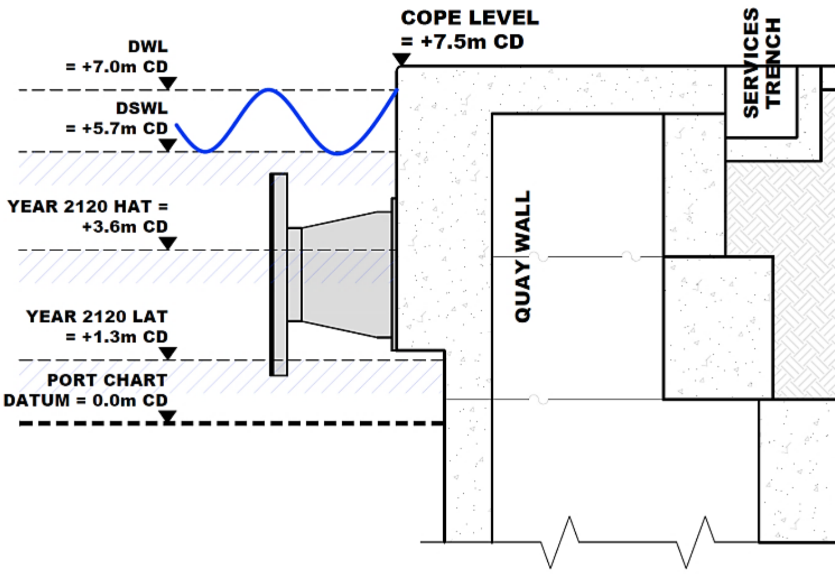

Figure 13: Year 2120 Cope Level Recommendation based on 1 in 1 000-year return period over 100 year design life

6. KEY FINDINGS

With the onset of climate change, it was found that climate change impacted various metocean factors influencing the determination of the cope level. This was due to changes in weather patterns, which impacted wind speeds, sea level rise, increase in surge, and increase in short wave and long wave heights.

The impact of the Coega River flooding has negligible impact on the DWL for the future Coega River berths due to the river size being small and navigational channel being both wide and deep. Therefore, any floodwaters entering the navigational channel are quickly dispersed.

New generation vessel requirements did not impact cope levels significantly. The main factors to consider with bigger vessels is water depth to sea bed at the quayside (to accommodate vessel draft) and the strength of the quay wall to counteract the forces of the berthing vessel. For terminal operations, bigger cranes may need to be deployed.

The determination of the above water freeboard by making allowance for fendering on the quay wall was found to be less important. This was due to the fact that fenders are designed to be submerged in water and therefore freeboard allowances could be reduced.

When considering the service tunnel requirements, and upon literature study (ZAA, 2014) and consultation with industry specialists, it was also established that service tunnel requirements did not have to be in the quay wall but could be located at a distance and with a shallower structure. Thus, service tunnel requirements were also found to be negligible.

7. CONCLUSION

The biggest contributor to the determination of the required cope level, when considering extreme events, came from climate change impacts. This pushed the still water level up by 2.8 m to 3.4 m for the various return periods in year 2120. The expected wave heights also increased due to climate change, which added an additional 1.1 m to 1.3 m for the various return periods in year 2120. This equated to an allowance for extreme events of 3.9 m to 4.7 m for the year 2120 above normal conditions.

Considering recommended operational freeboard criteria above the DSWL, such as service tunnels, the required cope level was greatly increased. Although in line with good practice, it was found to be impractical. Other practical alternative options could be found. Careful consideration should be given to the required practical freeboard for operations above the DSWL. Operational freeboard allowance from fendering was found to be negligible. It was concluded that the best and most practical scenario was to consider a freeboard allowance that prevented overtopping and flooding of the quayside.

Flooding impacts from the Coega River in relation to the cope level were minimal and considered negligible. The river itself is small and enters a wide and deep navigational channel that dissipates any flooding impacts.

Bigger and growing new generation container vessels did not pose any significant impact on cope level determination above the DSWL and DWL. The main impacts for ports are to ensure that cranes are suitable to handle cargo (larger cranes), ports have adequate navigational depth to cater for larger vessels, and the quay wall has sufficient strength to counter berthing forces.

The study concluded that, the recommended cope level for PoN should be 7.5 m Port Chart Datum to cater for extreme events and prevent flooding of the port.

This study focused on the extreme side of extreme events and what may be expected should an extreme event occur. Coastal and Port Authorities, based on its risk appetite, will need to establish their acceptable risk profile and parameters on what is considered probable and acceptable risks when determining the ideal cope levels in relation to current and future climatic and operational conditions, and the cost effectiveness of planned infrastructure.

It is recommended that Coastal and Port Authorities places focus on the impact of climate change on current and future planned infrastructures built into or adjacent to the sea, be they ports, recreational jetties, power stations, homes or any other form of structures.

Historically, climate change was not deemed an important consideration in the design of port structures, however, there is increasing awareness of the value of incorporating climate change factors into design and management of port infrastructures (Kong, Setunge, Molyneaux, Zhang, & Law, 2013). Recognising the vulnerabilities associated with climate change is a valuable step towards better planning of new port infrastructure and reducing potential damage to existing infrastructure (Kong, Setunge, Molyneaux, Zhang, & Law, 2013). The need to factor climate change considerations into the planning stage is becoming increasingly imperative, as, under normal circumstances, the adaptation of existing infrastructure would typically cost more than factoring in adaptation strategies at an early stage during infrastructure development (Mutombo K. , 2014, p. 267).

The eight commercial ports of South Africa under the authority of Transnet handle a major part of the South African economy via imports and exports of goods. Disruptions to this, due to flooding of port facilities or other operational impacts, may have detrimental knock-on impacts to the South African economy. It is therefore critical that climate change impacts and operational requirements are studied widely to determine the ideal practical cope level.

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