35th PIANC World Congress, 29 April – 23 May 2024, Cape Town, South Africa
Paper Title: Design Approach for the Access Channel of Port Victoria, Seychelles
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Design Approach for the Access Channel of Port Victoria, Seychelles

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Abstract: Existing spatial and infrastructural limitations of Port Victoria and its potential effect on Seychelles' economy have made the expansion of the port essential for future development. To accommodate post-Panamax container vessels and fuel tankers with static drafts of up to 14 m, the port basin and access channel must be expanded and deepened.

The design approach for the new access channel comprised: an assessment of the existing vertical and horizontal channel dimensions; a conceptual design, based on empirical channel design guidelines; and a detailed probabilistic assessment using ship motion and navigation simulation models.

Fast-time navigation simulations were conducted and supplemented with real-time simulations. The navigation simulation data were statistically analysed to confirm the alignment and horizontal dimensions of the access channel. The vertical dimensions of the channel were determined by a vertical response analysis of the design vessel to ensure sufficient under-keel clearance while transiting the channel.

The use of modelling and simulation proved to be valuable in refining the dimensions necessary for the safe navigation and manoeuvring of the proposed design vessels. These dimensions informed the dredging requirements for the project.

Keywords: Channel Design, Navigation, Simulation, Under Keel Clearance

Introduction

Seychelles is an archipelagic island country in the Indian Ocean near the equator.

Key to the country's economic prosperity is Port Victoria, Seychelles' primary international sea-freight terminal located on Mahé, the main island. The port is base to an industrial-scale fishery generating a major part of the country's revenue-earning exports of produce. It also handles most of the country's imports, including fuel, cement and general cargo (mostly containerised). Cruise ships also call at the port. The existing spatial and infrastructural limitations of Port Victoria and its potential effect on Seychelles' economy have made the expansion of the port essential for future development.

One of the key spatial limitations is the port vessel navigation areas that are currently too shallow for safe access of Panamax-sized and larger container vessels frequenting the region. To accommodate larger Post-Panamax vessels with static drafts of up to 14 m, the port basin and access channel need to be expanded and deepened. As such, numerical ship navigation simulation and moored ship motion studies were undertaken to establish changes required to the existing port navigation areas to enable safe navigation of the design vessels.

The approach followed comprised revisiting the access channel alignment as well as the horizontal and vertical dimensions of the basin and access channel. The conceptual design was supported with a more detailed analysis that included a numerical ship navigation simulation study using the Fast-time and 2D real-time modules of the Simflex Navigator 4 system.

The vertical dimensions of the channel were confirmed by undertaking a vertical response analysis of the design vessel to ensure sufficient under-keel clearance while transiting the channel. The 3D Panel numerical model, WAVESCAT, was used to simulate the vertical response of the sailing vessels due to wave action.

These dimensions informed the required dredging for the project.

Port Layout

The port layout, existing entrance channel layout, navigational aids and bathymetry were obtained from the British Admiralty Chart. An extract of the chart, showing the port area, is presented in Figure 1.

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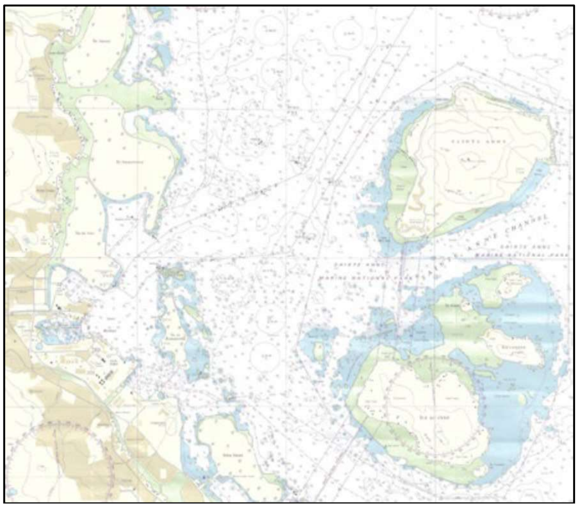

Figure 1: Bathymetric Chart for Port Victoria and surroundings (BA chart 227)

Tidal Levels

The tidal range at Port Victoria, relative to MSL (CD +1.07m), is shown in Table 1. A tidal level of MSL (CD +1.07m) was used for all environmental and navigation numerical models.

Table 1: Tide levels relative to MSL

Description	Level (m to MSL)
HAT	+1.10
MHWS	+0.58
MLWS	-0.62
LAT	-1.04

Wind

The wind climate at the Port was based on the data collected at Seychelles International Airport, covering about 10 years. Since the Airport is approximately 9 km away from the Port, it is reasonable to assume the wind climate in the Port area will be similar. The wind rose of wind speed versus direction is given in Figure 2.

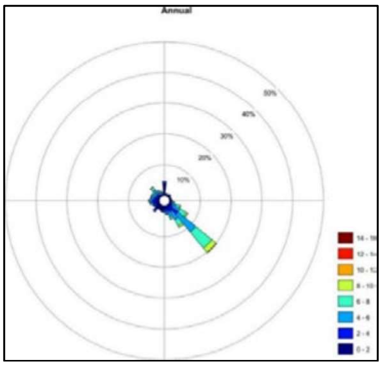

Figure 2: Wind rose based on measurements at Seychelles International Airport

For the navigation simulations, a wind speed of 10 m/s was used, which is exceeded for about 1% of the time on an annual basis. This represents a storm condition for this climate. This wind speed is equivalent to a "fresh breeze" according to the Beaufort Scale.

The dominant wind directions, South-east (SE) and North-west (NW) were applied in the navigation simulations. These correspond to the January monsoon conditions.

Waves

Offshore wind and wave conditions covering 28 years were transformed to key locations along the entrance channel and into the Port basin using the wave refraction model, SWAN. Long-term wave time series were derived for these key locations. The output locations and associated wave roses are presented in Figure 3. The SWAN model was validated with wave measurements from the Seychelles Ocean State Forecast & Advisory System, in the vicinity of an island east of Mahé Island.

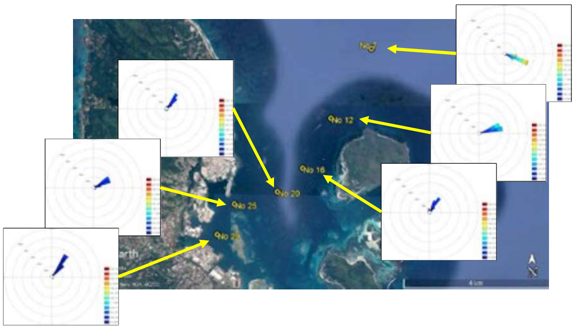

Figure 3: Key output locations and associated wave roses

Input wave conditions for the simulation models were derived, based on the occurrence distributions of the significant wave height (Hmo), peak period (Tp) and direction. As with the wind, wave heights representing the approximate 1% exceedance value were obtained, representing a general storm condition. The conditions are listed in Table 2.

Table 2: Wave conditions representing general storm conditions at key locations along the entrance channel

Loc.	Condition 1			Condition 2		
	Hmo [m]	Tp [s]	Dir [deg]	Hmo [m]	Tp [s]	Dir [deg]
7	2.3	10	112	2.0	12	112
12	1.3	10	67	1.2	12	67
16	0.8	10	22	0.8	12	22
20	0.8	10	22	0.8	12	22
25	0.8	10	45	0.8	12	45
29	0.5	10	22	0.5	12	22

These waves are associated mostly with wave periods of 10s and 12s, while the directional distributions are quite narrow as indicated by the wave roses.

Currents

The current field at the Port of Victoria was modelled with Delft3D-FLOW. Two periods of a month each were modelled taking into account the variation in wind conditions (*e.g.* the January-February monsoon), the tidal variations and wave conditions. Thus, two different current regimes could be derived. Hydrodynamic simulations were performed for January 2015 and September 2015, representing the more severe conditions as based on the available wind and wave data. An example of the depth-averaged currents for January 2015 is given in Figure 4. Note that no measurements were available for validation of the model at the time.

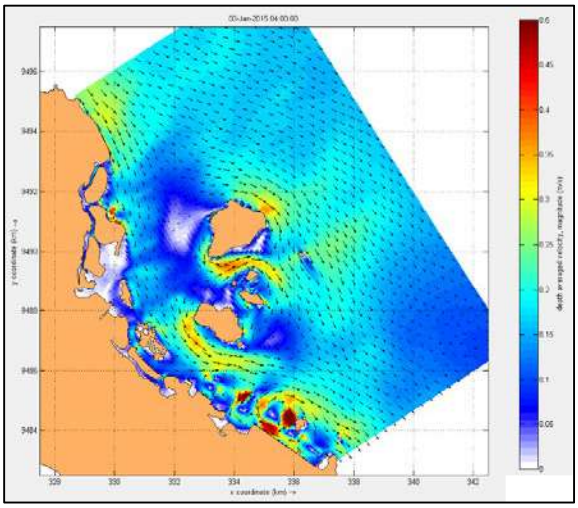

Figure 4: Example depth average current field from the January 2015 simulation

Maximum current conditions were extracted at key locations along the entrance channel, with speeds up to about 0.35 m/s. A more conservative approach was followed for the current conditions since the laden deep-draught vessels will be the most affected by this environmental factor.

Design Vessels

The design vessels for this study were specified as a Post-Panamax Container vessel with a maximum draught of 14.0 m and a Tanker with a length over all (LoA) of approximately 250m. The average carrying capacity of such a container vessel is approximately 6 000 TEUs and the Tanker vessel falls into the Cape Size class of vessels which typically has laden draughts of 15m or more. The maximum draught for the channel design was 14 m. Thus, the Tanker draught for this port is also restricted to 14 m.

The principal dimensions adopted for the design vessels are shown in Table 3 and were based on the available numerical ship navigation model vessels that most closely matched the design vessel specifications.

The draught of the tanker vessel exceeded 14m. To compensate for the difference the water level in the navigation simulations was increased by one meter to keep the depth-to-draught ratio consistent. The draught of an existing 110kDWT tanker was adjusted to a 14m half-laden state for the ship response simulations.

Table 3: Principal dimensions of the design vessels

Vessel class	**Container vessel (ship 3064)**	****Tanker vessel (ship 3236)**	**Tanker vessel (B100HL 01)**
TEU/DWT	Up to 6 000	84 000	110 000
LOA [m]	318	228.6	233
LPP [m]	303	218.7	221
Beam [m]	43	32.2	42
Draught [m]	14	15.0	*14

Horizontal Channel Dimensions and Layout

The entrance channel was divided into five sections for the analyses. The edges of the sections are represented by the letters A to F in Figure 5. Conceptual design methods were first used to approximate the horizontal dimensions of the entrance channel. More detailed analyses were subsequently used to refine the horizontal dimensions and layout of the entrance channel. The PIANC *Design Guidelines for Harbour Approach Channels* [2] were used for the conceptual entrance channel design.

The parameters that apply to Port Victoria and which were considered to determine the conceptual width of the entrance channel are shown in Table 4.

Table 4: Parameters and factors influencing channel width estimates at Port of Victoria

Parameter	**Influencing Factors**
Manoeuvring lane	Vessel type and size Controllability
Vessel clearance	Vessel size Operational experience
Bank suction	Bank slope Channel depth to draught ratio
Channel bottom	Bottom type Channel depth to draught ratio
Environmental effects	Currents, Winds, Waves
Channel with bends	Ship type, size and bend radius
Navigational aids/pilot	Leading lights, Visibility, Pilot experience, ECDIS availability

The PIANC 2014 *Guidelines* [2] were applied to the various channel sections to determine the required channel width. The contributions of various factors are tabulated in Table 5 and the conceptual layout is shown in Figure 5.

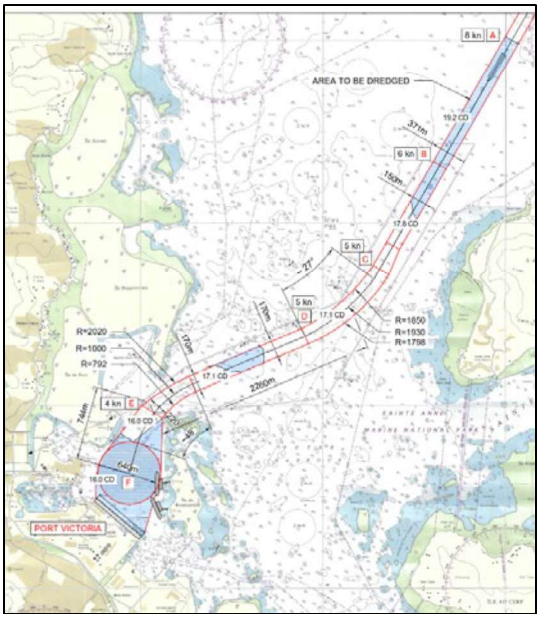

Figure 5: Conceptual channel layout. The edges of the 5 channel sections are given by the letters A to F

Table 5: Channel width beam factors for the different channel sections

Beam Factor	AB	BC	CD	DE	EF
Basic Manoeuvring Lane	1.8	1.8	1.8	1.8	-
Sailing Speed	0	0	0	0	-
Cross Winds	0.6	0.6	0.6	0.6	-
Cross Current	0.3	0.3	0.3	0.8	-
Longitudinal Current	0	0	0	0	-
Open Swell	0.5	0	0	0	-
Bottom Surface	0.2	0.2	0.2	0.2	-
Channel Depth	0.1	0.2	0.2	0.4	-
Aids to Navigation	0	0	0	0	-
Bank Clearance Starboard	0	0.5	0.3	0.3	-
Bank Clearance Port	0	0	0	0	-
Passing Distance	0	0	0	0	-
Bend	0	0	0.72	0	-
Beam Factor Total	3.5	3.5	4.1	4.1	-
Width (m)	147	147	172	172	220

Section EF (Figure 5) connects the entrance channel to the turning basin. In this section, the vessel will be under tug control and most of the beam factors are therefore not applicable to this section. A smooth transition between the full available width of the entrance to the inner harbour and the proposed turning circle with a diameter of 640 m (2 x LOA) was proposed.

The conceptual channel layout was analysed in more detail with a ship manoeuvring simulator. The manoeuvring simulations aimed to confirm:

- the proposed width of the various sections, subject to extreme operating environmental conditions
- the channel bend radii
- the tug connection time (section DE) and stopping distance (Section EF)
- turning circle diameter

A set of fast-time simulations were conducted with the Simflex Navigator. A fast-time simulation analysis is applicable for most cases where a ship is sailing under its own rudder and engine power. Using fast-time simulations, many simulation runs can be carried out. The resulting vessel tracks can be statistically analysed.

A numerical navigator navigates a predefined path (in this case the centre line of the channel). In essence, the numerical navigator performs the same task as a ship's conventional autopilot system. However, human error is incorporated through the introduction of random events which include a delay in rudder command, oversteering, insufficient speed, an increase in speed etc. These error events are generated randomly so that no two simulation runs are identical. A total of 10 fast-time scenarios were assessed with Simflex Navigator. Each of the scenarios comprised 25 fast-time simulation runs.

An example of a track density plot of the fast-time simulations of the container vessel is shown in Figure 6.

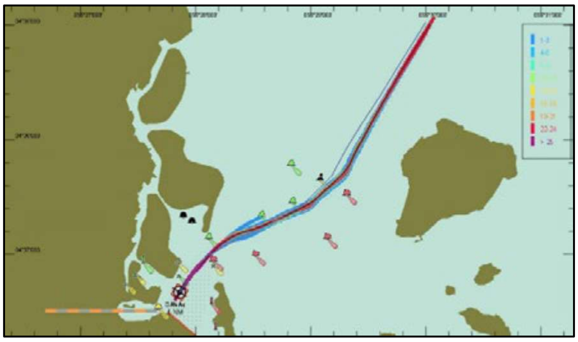

Figure 6: Track density plot of the container vessel simulations

The dark red colour indicates a large number of overlapping tracks. The light blue indicates the path of a small percentage of the tracks, *i.e.* minimum overlapping. In this case, one track indicates the vessel left the channel just after the inner bend, *i.e.* just 1 of the 25 simulations in this scenario. The colour contours thus indicate the variation in manoeuvring of the vessel under this set of environmental conditions.

Some real-time simulations were also performed with the Container vessel. These included entering and sailing manoeuvres. Two scenarios were assessed, comprising simulations under calm conditions (no winds, waves or currents) and a scenario with a SE wind, storm wave conditions and general WNW flowing currents (*i.e.* the September 2015 condition).

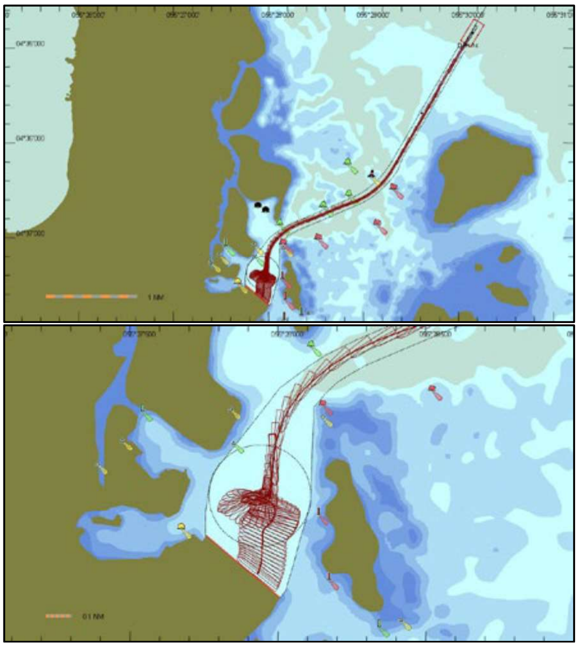

Figure 7: Track outline plot of the arriving container vessel for the real-time simulation under the September 2015 wind, wave and current conditions

Vertical Channel Dimensions

The PIANC *Guidelines* [2] for approach channels recommend the following factors to be considered for determining the depth of a navigation channel. The factors are schematically illustrated in Figure 8

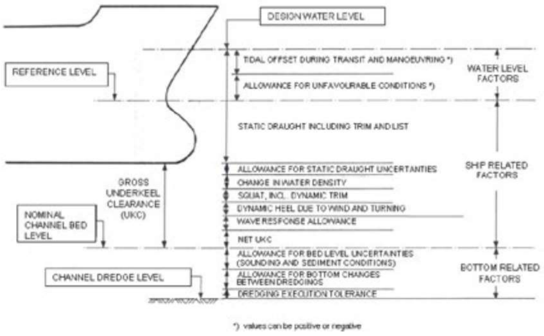

Figure 8: Channel depth factors (PIANC, 2014 [2])

A quick estimate of the required channel depth at the concept design stage can be obtained from the PIANC *Design Guidelines for Harbour Approach Channels* [2]. The PIANC guidelines provide a table with a range of values for the related factors (see Table 6). This simplified approach gives indicative values that should lead to a conservative design depth.

Table 6: Channel depth components and air draught estimates for concept design (PIANC 2014 [2])

Description	Vessel Speed	Wave Conditions	Channel Bottom	Inner Channel	Outer Channel
		Ship Related Factors F_s			
Depth *h*	≤ 10 kts	None		1.10 *T*	
	10-15 kts			1.12 *T*	
	>15 kts			1.15 *T*	
	All	Low swell (H_s<1m)			1.15 *T* to 1.2 *T*
		Moderate swell (1m<H_s<2m)			1.2 *T* to 1.3 *T*
		Heavy swell (H_s>2m)			1.3 *T* to 1.4 *T*
		Add for Channel Bottom Type			
	All	All	Mud	None	None
			Sand/clay	0.4 m	0.5 m
			Rock/coral	0.6 m	1.0 m
		Air Draught Clearance (ADC)			
ADC	All	All		0.05 H_{st}	0.05H_{st}+0.4T

Notes:
1. For Ship Related Factors: Assumes *T* > 10 m. If *T* <10 m, use value for *T*=10 m.
2. Swell means waves with peak periods greater than 10 s.
3. For Outer Channel swell values, use lower value for smaller swell wave periods and higher value for larger swell periods.
4. Value of H_s is dependent on required operation, design ship type, level of accessibility, wave period, and relative wave direction.
5. H_{st} is the distance from the sea surface to the top of the ship.
6. Salt-water density assumed for *T*. Additional adjustments required for fresh water.

The entrance channel to the Port of Victoria is subject to low to moderate swells. The channel bottom type appears to be sandy with rock/coral outcrops and the design vessel draught (T) is 14.0 m. The expected sailing speed in the channel is estimated to be between 4 and 8 knots. Based on these assumptions, conceptual design estimates for the channel depth can be derived from Table 6 and are shown in Table 7. A rock/coral bottom type was applied.

Table 7: Conceptual channel depths

Channel Section	Vessel Speed [kts]	Wave Conditions	Draught Factor	Channel Depth [m CD]
AB	8	Moderate Swell (12 s)	1.30*T + 1.0	-19.2
BC	6	Moderate Swell (10 s)	1.20*T + 1.0	-17.8
CD	6	Low Swell	1.15*T + 1.0	-17.1
DE	5	Low Swell	1.15*T + 1.0	-17.1
EF	4	N/A	1.10*T + 0.6	-16.0

The conservative estimates for channel depths can be refined with a more detailed analysis. A ship response study was undertaken with the 3D panel model WAVESCAT to determine the vertical response of the sailing vessels subject to waves in the different channel sections. In this analysis, the vertical motion of six critical points on the keel of the vessel was modelled. The panel model mesh and critical keel points for the container and tanker vessels are shown in Figure 9.

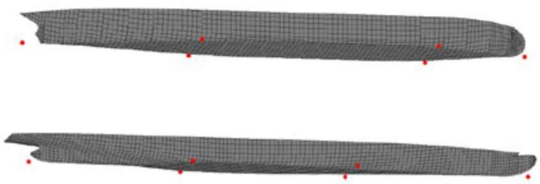

Figure 9: Critical keel points for the tanker (top) and container vessel (bottom)

The amount of squat of each of the keel points was calculated by the 3D Panel model, WAVESCAT, for the design vessels sailing in a channel with varying depth and sailing speeds. As an example, the modelled squat is shown in Figure 10 for the tanker. The squat of the container vessel was found to be significantly less than the tanker due to the smaller block coefficient and streamlined hull shape.

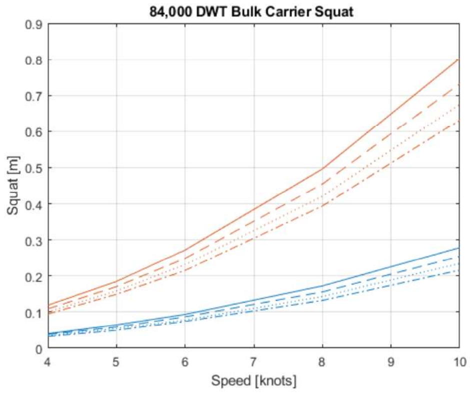

Figure 10: Modelled bow (red) and stern (blue) squat for the 84 000 DWT Tanker in 19 m (dashed-dot), 18 m (dot), 17 m (dashed) and 16 m (solid) metres water depth

The effect of the dynamic heel will be negligible for a fully-laden tanker and was therefore determined only for the 6 000 TEU container vessel. The dynamic heel consists if wind related and turn related heel components.

The heel angle for a maximum wind speed of 10 m/s beam on the 6 000 TEU container vessel can be calculated as:

$$\varphi_W = \frac{M_W}{\gamma_W \nabla \overline{GM}} = 0.20° \qquad (1)$$

Here M_W is the wind heel moment, γ_w the specific weight of seawater, ∇ the ship's volume displacement, $\overline{GM}$ the ship's metacentric height. The ship's bilge keel heel due to wind is then:

$$z_W = 0.9\frac{B}{2}\sin\varphi_W = 0.07\ m \qquad (2)$$

where B is the beam of the vessel and a bilge keel factor of 0.9 is assumed.

The channel has a fairly mild bend with a radius of approximately 1 850 m. A sailing speed of 6 knots is assumed in the turn. The heel angle due to turning may be determined by:

$$\varphi_R = \frac{l_R U_C^2}{g \mathrm{R}_C \overline{GM}} = 0.18° \qquad (3)$$

where l_R is the heel moment arm due to the ship turning, U_C the ship's speed during turning and R_C the turn radius.

The ship's bilge keel heel due to turning is given by:

$$z_R = 0.9\frac{B}{2}\sin\varphi_R = 0.06\ m \qquad (4)$$

The motion response of the sailing design vessel in waves was calculated with the 3D Panel model WAVESCAT. The heave, roll and pitch motions were used to determine the Response Amplitude Operators (RAOs) of the vertical motions of each of the critical keel points at various sailing speeds and channel depths.

The keel point RAOs were used to determine the significant vertical movement of the keel points for extreme operational wave conditions in the channel. The wave conditions in the channel were obtained from the wave modelling results.

The criteria for an entrance channel depth depend on the risk acceptable to the port, where the risk is defined as the probability of a grounding incident multiplied by the financial and environmental impact and consequence. The design criteria employed in this study is:

The probability that a vessel touches the channel bottom during a single channel transit must always be less than 1% for all weather conditions.

The static under keel clearance, excluding wave response allowance, can be defined as:

$$UKC_s = h_{cd} - T - z_{squat}^{max} - z_{WR} - F_B \qquad (5)$$

Where h_{cd} is the channel depth, T the draught of the vessel, z_{squat}^{max} the maximum squat of all 6 keel points, z_{WR} is the bilge sinkage due to heel and F_B is the bottom-related factor.

The static under-keel clearances for the channel sections are shown in Table 8 and Table 9 for the 84 000 DWT Tanker and the 6 000 TEU Container vessel respectively. Note, F_B factor of 1 was applied for all sections, except for EF, where 0.6 was applied.

Table 8: Static under-keel clearance and manoeuvrability margin for the 84 000 DWT Tanker

#	h_{ch} [m]	T [m]	z_{squat}^{max} [m]	z_{squat}^{mean} [m]	z_{WR} [m]	UKC_s [M]	MM [m]
AB	19.2	14.0	0.39	0.26	-	3.81	3.94
BC	17.8	14.0	0.23	0.16	-	2.57	2.64
CD	17.1	14.0	0.25	0.17	-	1.85	1.93
DE	17.1	14.0	0.17	0.12	-	1.93	1.98
EF	16.0	14.0	0.12	0.08	-	1.28	1.32

Table 9: Static under-keel clearance and manoeuvrability margin for the 6 000 TEU Container Vessel

#	h_{ch} [m]	T [m]	z_{squat}^{max} [m]	z_{squat}^{mean} [m]	z_{WR} [m]	UKC_s [M]	MM [m]
AB	19.2	14.0	0.19	0.17	0.07	3.94	3.96
BC	17.8	14.0	0.11	0.10	0.07	2.62	2.63
CD	17.1	14.0	0.12	0.10	0.13	1.85	1.87
DE	17.1	14.0	0.08	0.07	0.07	1.95	1.96
EF	16.0	14.0	0.06	0.05	0.07	1.81	1.82

It is recommended that there is at least 0.6 m or 5% of the draught (whichever is greatest) available under the lowest *average* position of the bottom of the ship. This is called the manoeuvring margin (MM) and in this case, it is recommended to be at least 0.7 m. The calculated manoeuvring margin is also listed in Table 8 and Table 9 and may be calculated by:

$$MM = h_{cd} - T - z_{squat}^{mean} - z_{WR} - F_{B}. \qquad (6)$$

The calculated manoeuvring margin (MM) in all channel sections is more than the recommended minimum value of 0.7 m.

Six wave conditions were selected from the modelled wave climate, each corresponding to a 2% wave height exceedance for a discrete set of swell wave periods. These wave conditions were used to determine the probability of the bottom touch of the design vessels inside the channel. Representative wave parameters were determined for the various channel sections, with wave heights ranging from about 0.1 m to 2 m.

The channel was divided into five sections for the purpose of the assessment. The channel sections are shown in Figure 5 and their properties are listed in Table 10.

Table 10: Properties of the entrance channel sections

Property	**AB**	**BC**	**CD**	**DE**	**EF**
Length [m]	1400	1200	1000	1600	800
Orientation [°TN]	210	210	225	247	210
Sailing Speed [knots]	8	6	6	5	4
Sailing time [min]	6.5	7.8	6.5	10.4	6.5

The probability of a single maximum vertical motion, a_z, exceeding the static under-keel clearance, UKC_s, was calculated for the respective channel sections using short-term statistics (see *e.g.* Holthuijsen, 2010 [1]) based on the Raleigh distribution:

$$\Pr\{a_z > UKC_s\} = 1 - \left[1 - \left(e^{\frac{-\mathrm{UKC}_s^2}{2m_0}}\right)\right]^N \qquad (7)$$

Here m_0 is the zeroth order moment of the vertical response amplitude spectrum of a keel point and *N* the number of response cycles in the channel section.

The probability of bottom touch of a single transit, *G*, was calculated according to the probabilistic detailed design guidelines (see PIANC 2014 [2]) for various channel depths:

$$G = 1 - \prod_{i=\{AB,\ldots,EF\}}(1 - \Pr\{a_z > UKC_s\}_i) \qquad (8)$$

The subscript "i" refers to the channel sections.

This was done for both arriving and departing design vessels. The channel depths in the calculations were iteratively reduced until an optimised channel depth was reached.

The vertical motion of the 84 000 DWT tanker was significantly higher than the 6 000 TEU container vessel for all the scenarios. The probabilities of bottom touch of an arriving and sailing (departing) 84 000 DWT Tanker, for the 6 extreme wave conditions, are listed in Table 11 for the optimised channel depths. A channel transit by this vessel incurs a probability of bottom touch of less than 1% for all extreme wave conditions, which is in line with the PIANC recommendations.

The recommended depth at the berths and in the turning basin, −15.5 m CD, was calculated as the sum of the design draught (T = 14.0 m), minimum manoeuvrability margin (MM = 0.7 m), expected maximum squat in the basin (Squat = 0.2 m) and allowance for bottom-related factors (Fb = 0.6 m).

Table 11: Probability of bottom touch for the 84 000 DWT tanker for the various extreme wave conditions

Section	**AB**	**BC**	**CD**	**DE**	**EF**	**Tot.**
Depth [m]	**18**	**16.5**	**16.5**	**16.5**	**16**	**[%]**
Wave Cond.	**84 000 DWT Arriving Vessel**					
1	0	0	0	0	0	**0**
2	0.233	0.124	0	0	0	**0.328**
3	0	0	0	0	0	**0**
4	0	0	0	0	0	**0**
5	0	0.012	0	0	0	**0.012**
6	0	0	0	0	0	**0**
Wave Cond.	**84 000 DWT Sailing Vessel**					
1	0	0	0	0	0	**0**
2	0	0	0	0	0	**0**
3	0	0	0	0	0	**0**
4	0	0	0	0	0	**0**
5	0	1.021	0	0	0	**1.021**
6	0	0.638	0	0	0	**0.638**

The conceptual and recommended optimised channel depths, per channel section, are summarised in Table 12.

Table 12: Conceptual and optimised entrance channel depth per channel section

Channel Section	**Conceptual Design [m CD]**	**Recommended [m CD]**
AB	−19.2	−18.0
BC	−17.8	−16.5
CD	−17.1	−16.5
DE	−17.1	−16.5
EF	−16.0	−16.0
Turning basin and berths	−16.0	−15.5

Discussion and Conclusion

The existing entrance channel to the Port of Victoria in Seychelles was assessed and redesigned to accommodate Post-Panamax container vessels and Cape Size bulk carriers with a length over all of 250 m and a draught of up to 14 m.

The design approach included initial conceptual calculations to determine first order conservative estimates of the horizontal and vertical channel dimensions.

A further detailed analysis was undertaken to confirm and refine the horizontal dimensions using ship navigation simulations. These simulations consisted of an extensive set of fast-time simulations with a numerical navigator (AI pilot) as well as limited real-time desktop simulations.

The vertical channel dimensions were refined with a probabilistic bottom touch analysis by modelling the response of the sailing vessel in waves with a 3D panel model.

The horizontal dimensions were considered to be safe and the channel depths at various channel sections could be reduced and lead to a saving on capital dredging costs. The redesigned channel should, however, be confirmed with a full-bridge ship simulation exercise.

References

[1] Holthuijsen, L. H. (2010). *Waves in oceanic and coastal waters*. Cambridge university press.

[2] PIANC (2014). Harbour Approach Channels Design Guidelines. Report of Marcom Working Group, 49.