CROWN-WALL WITH EXTENDED BASE SLAB

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This paper presents the design philosophy and the construction stages of a n6n-standard crown-wall geometry. This geometry has a standard L-shape but built with an extended base slab at the front. The advantages of this crown-wall are that it can be made out of pre-cast elements which are easy to produce and place. This reduces the construction time and the downtime due to adverse weather conditions. Besides this its friction and overturning moment have been increased compared to the standard L-shape which reduces the required weight of the element.

INTRODUCTION

General

In 2004 and 2005 Delta Marine Consultants (DMC) carried out the concept design and detailed design of a 700m long and 20m high rubble mound breakwater which had to be located near the city of Limbe in Cameroon. DMC carried out this project for the contractor Interbeton. The Client of Interbeton was Chantier Naval Industriel du Cameroon (CNIC). The breakwater had the aim to protect the ship repair harbour from long swell waves. A service road was required on top of the breakwater which was planned as a concrete crown-wall. Besides this the crown-wall also had the aim to reduce the overtopping rate to an acceptable level. The project site is outlined in Figure 1 and 2.

Figure 1. Project site Shipyard Limbe, Cameroon.

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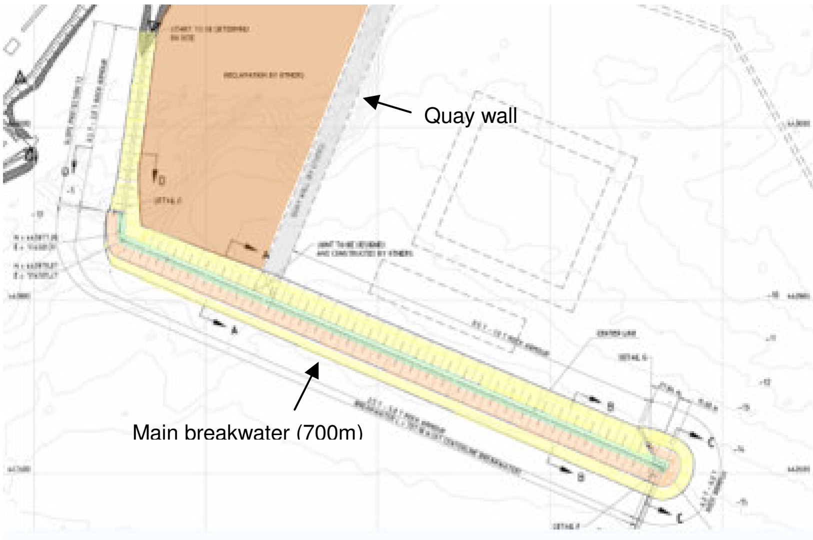


Figure 2. Overview Shipyard Limbe, Cameroon.

Selected Geometry

CNIC presented a crown-wall with shear-key on their tender drawings. The aim of this shear-key was to increase the friction between the crown-wall and the core of the breakwater. This type of crown-wall is normally constructed in-situ. The layout of this geometry is presented in Figure 3.

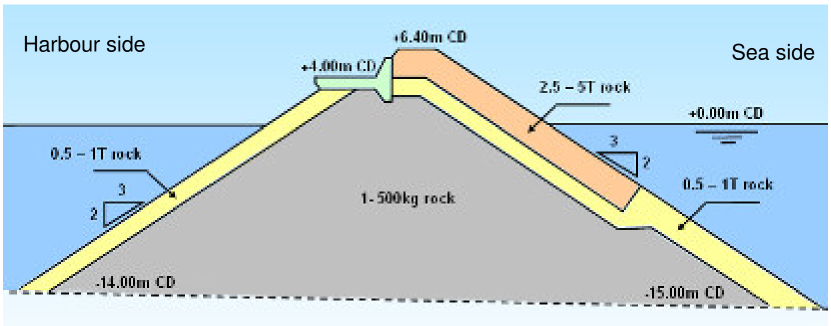


Figure 3. Cross-sections of breakwater and crown-wall presented by CNIC.

DMC and Interbeton considered various geometries for the crown-wall to increase the ease of construction. The option finally selected was to omit the shear-key and extend the base slab of the crown-wall at the seaside (see Figure 4 and 5) so that the crown-wall could be constructed with pre-cast elements. In this way the crown-wall could be placed in parallel to the progressing breakwater construction. Besides this the construction time was in dependent on hardening of any concrete. So that downtime was low compared to the in-situ method. In addition to this the elements were easy to place based on the simple geometry and there was a concrete saving compared to other pre-cast methods. The elements were poured in one go when lying on their side. The width of each crown-wall element was 2m. The weight of each element was approximately 40 tons.

A comparison of this design with a standard L-shaped crown-wall without shear-key showed that the sliding resistance through friction was increased as a result of a longer contact area between crown-wall and base. Retarder was applied at the under side of the slab to increase the friction factor between base and slab. The elements were placed in a fresh concrete layer which was positioned on a gravel bed. Besides this the sliding resistance was also increased as a result of the 2.5 – 5 T armour stones placed on top of the extended base slab section.

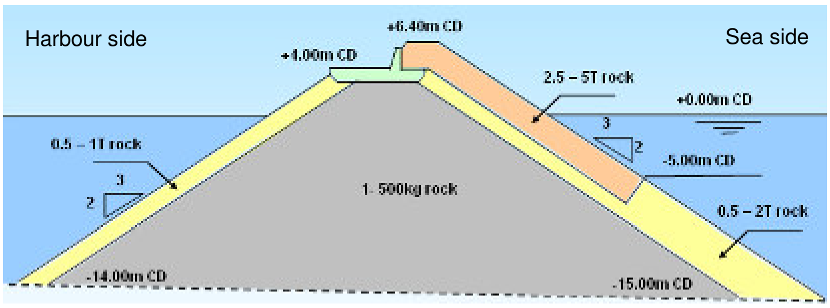


Figure 4. Cross-sections of breakwater and crown-wall.

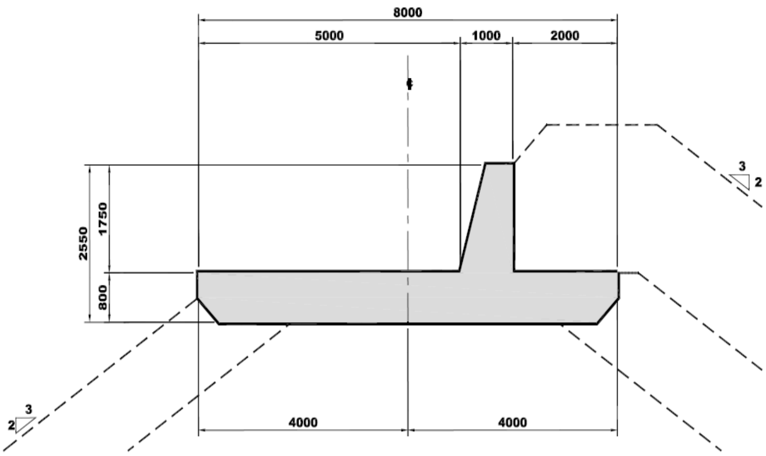


Figure 5. Cross-sections of breakwater and crown-wall.

DETAILED DESIGN

Design Checks and Loadings

During detailed design the following design checks were carried out in order to ensure the stability of the crown-wall:

- Stability of the crown-wall structure against sliding;
- Stability of the crown-wall structure against overturning (tilting);
- Check on how the bearing pressure on the crown-wall affects the global stability of the breakwater.

The forces on the crown-wall which have been taken into account are:

- Self weight structure;
- Live loads;
- Loading due to rock armour;
- Wave loading;
- Seismic loads;
- Construction loads.

The sliding check has been carried out based upon:

$$F_{driving} * SF \leq \mu * F_{resulting\ vert} \quad (1)$$

Where:

$F_{driving}$	[kN]	driving force (depends on load combination considered)
SF	[-]	minimum safety factor to be achieved
$F_{resulting\ vert}$	[kN]	resulting vertical force down
μ	[-]	friction coefficient

The overturning check has been carried out based upon:

$$M_{driving} * SF \leq M_{resistance} \tag{2}$$

Where:

$M_{driving}$	[kNm]	driving moment (depends on load combination considered)
SF	[-]	minimum safety factor to be achieved
$M_{resistance}$	[kNm]	resulting moment

The safety factors applied for the stability checks are presented in Table 1.

Table 1. Safety factors for stability checks crown-wall.

Description	Normal conditions	Extreme conditions (OBE* for seismic loading)	SSE** for seismic loading
Sliding	1.5	1.2	1.0
Overturning	1.5	1.5	1.0
Bearing pressure	2.0	1.5	1.0

*: OBE: Operational Base Earthquake
**: SSE: Safe Shut down Earthquake

"Ground" pressures resulting from the armour stones placed against the crown-wall will be taken into account, based on an internal friction angle of ϕ = 40 degrees. For stability checks, the horizontal pressure was based on the active ground pressure coefficient (the resulting K_{active} = 0.217):

$$K_{active} = \left(\tan\left(45^0 - \frac{1}{2}\phi\right)\right)^2 \tag{3}$$

Dead loads comprise the structure self weight plus super-imposed loads of a permanent structure. The following specific loads were considered:

In-situ concrete	[kg/m^3]	2400
Precast concrete	[kg/m^3]	2500
Seawater	[kg/m^3]	1025
Rock armour layer	[kg/m^3]	2800
Rock filter layer	[kg/m^3]	2700
Rock core	[kg/m^3]	2400

The following live loads were considered:

Uniform Distributed Load [UDL]	[kNm^2]	10
Concentrated load	[kN]	100

During operation the crown-wall was considered to be a service road only. No continuous road traffic was taken into account. The construction loads which are taken into account are a weight of the trucks of 45tons on three axles. For the stability checks, the construction load was treated as a life load with the applicable safety factors as per Table 1.

Wave Forces

Various methods were considered to determine the wave loading on the crown-wall as there are:

- Method developed by WL Delft Hydraulics (now called Deltares);
- Method presented in CUR/CIRIA 169 (which is now the Rock Manual);
- Method presented in BS 6349;
- Method developed by Pedersen and Burcharth in 1992;
- Method developed by Burcharth in 1994.

A comparison of these theories showed that for the considered case the last two theories were best applicable. The two equations are presented by Pedersen & Burcharth 1992 in (1) and Abott and Price 1994 in (2). Both equations are presented below. The equation which resulted in the largest wave forces was used.

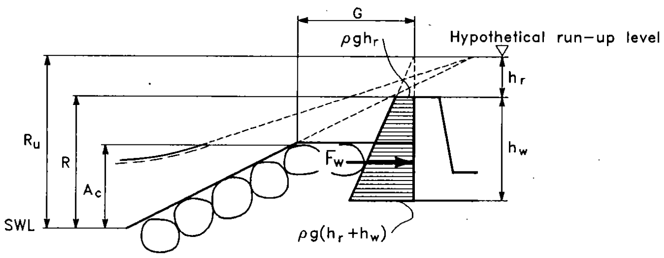


Figure 6. Estimation of wave forces on crown-wall (2).

$$F_w = \left(0.22 + 0.12\left(\frac{R - A_c}{G}\right)\right)F'_w \tag{4}$$

$$F_w = \left(0.304 + 0.054\left(1 + \frac{R - A_c}{G}\right)^{\frac{Hs}{Ac}}\right)F'_w \tag{5}$$

Where:

$F'_w = \rho_w g(h_r + 0.5h_w)h_w$

$\xi_m = \dfrac{\tan\alpha}{\sqrt{s_m}}$

$R_u = b(\xi_m)^c Hs$

h_r	[m]	Hypothetical run-up level in relation to crest level crown-wall
h_w	[m]	Height of the crown-wall element
H_s	[m]	Significant wave height
R	[m]	Crest level of crown-wall element in relation to still water level
A_c	[m]	Crest level of rock berm in relation to still water level
G	[m]	Width of the rock berm at crest level
b	[-]	1.34
c	[-]	0.55
s_m	[-]	wave steepness based on mean wave period
ξ_m	[-]	breaker parameter

The considered horizontal and vertical wave pressures on the crown-wall are presented in Figure 7. The left hand figure presents the complete pressure distribution. The right hand figure presents the simplified pressure distribution as used in the calculations. It was assumed that the horizontal pressures on the crown-wall were constant over the full height of the element.

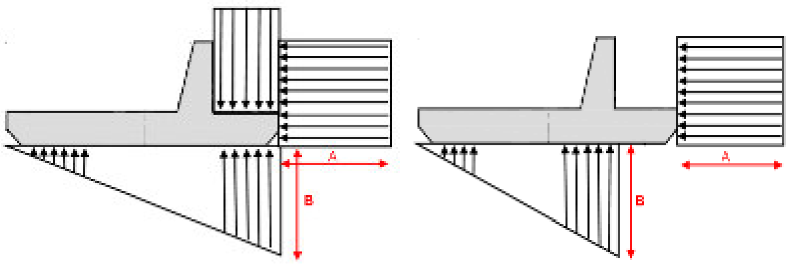


Figure 7. Wave pressures on the crown-wall element.

The wave loads have been based on the wave parameters for different return periods Tr as presented in Table 2. SLS stands for the Serviceability Limit State condition and ULS is the Ultimate Limit State condition.

Table 2. Wave parameters for loads on crown-wall.

Case	Tr (years)	Hs (m)	Tp (sec)	WL (m to CD)
SLS	5	2.4	18	+2.4
ULS	50	2.8	18	+2.4

The following design loads were determined:

SLS: Serviceability Limit State wave loading:

Fw (horizontal)	kN/m	60
Fv (vertical)	kN/m	70

ULS: Ultimate Limit State wave loading:

Fw (horizontal)	kN/m	70
Fv (vertical)	kN/m	80

Seismic Loads

Table 3 presents the seismic coefficients which were applied during detailed design of the crown-wall:

Table 3. Horizontal and vertical seismic coefficients.

Event	PGA	kH	kV
Operational Base Earthquake (OBE)	0.10 x g	0.050	0.025
Safe Shutdown Earthquake (SSE)	0.30 x g	0.150	0.075

Load Combinations

For calculation of overturning stability, sliding stability and geotechnical stability, the following basic load combinations were taken into account:

Table 4. Load factors and load combinations for concrete design crown-wall.

Load	Combination				
	I	II	III	IV	V
dead load	x	x	x	x	x
life load		x		x	x
wave			x	x	
ground pressure			x	x	
seismic					x

Stability against Sliding and Overturning

The required friction factor was calculated with the aid of the required safety factor against sliding. The minimum friction factor which had to be guaranteed was approximately 0.63 considering the safety factors against sliding as presented in Table 1. This friction was realised by applying retarder at the underside of the slab and placing the crown-wall in a 10cm thick fresh concrete layer which was poured on a gravel bed.

For the overturning stability the following safety factors were achieved (the required safety factors are presented in Table 1):

- Normal conditions 3.3 (required 1.50);
- Extreme conditions + seismic condition (OBE) 2.9 (required 1.50);
- Seismic condition (SSE) 9.9 (required 1.00)

2D Physical Model Testing

Optimisation of the crown-wall design was carried out during 2D physical model testing at Deltares laboratories. Each element was scaled to weight and size. The breakwater was exposed to the 1/50 year design storm (H_s = 2.8m in combination with HHWL = +2.4m CD) plus the 120% overload case (H_s = 3.4m). The elements were optimised in both unit weight and slab thickness. For the optimised situation with a concrete density of 2400 kg/m^3 and a slab thickness of 800mm no movement of the elements was found.

In October 2006 a near design storm was observed at the project site and no damage to the breakwater or the crown-wall was detected.

Figure 8. Crown-wall during 2D physical model testing (view from rear side).

CONSTRUCTION WORKS

The prototype elements were constructed at the pre-cast yard in 2006 and placed in 2006 & 2007. The elements were poured in one go when lying on their side. Reinforcement was required in the slab section only. After the formwork was removed the elements were lifted with a 60T gantry crane on to a turning frame which turned the elements from the horizontal into the vertical position. The elements were transported to site by road. Before placing the elements a bed had to be prepared. This bed consists of a fine gravel layer overlain by 10cm thick fresh concrete. The retarder at the underside of the crown-wall element sticks to the fresh concrete layer and thus to the gravel bed integrated to the core material. After the elements were put into position the 2.5 – 5T rock armour was placed on top of the extended base slab section. At last a 20cm thick concrete layer is added on top of the slab sections in order to make driving over the crown-wall much smoother.

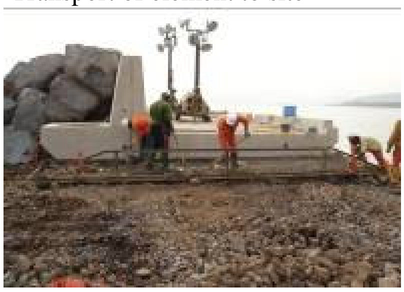
Elements at pre-cast yard with retarder at underside of slab

Elements lifted with 60T gantry crane on to turning frame

Element on turning frame

Transport of element to site

Concrete on gravel bed



Preparation of fresh concrete bed

Positioning of crown-wall

Crown-wall in position

Figure 9. Overview of Construction Works.

CONCLUSION

As a general conclusion it could be said that the crown-wall developed for this project is easy to construct and place. It gives a fast construction method as construction of the elements can be done at the same time as when the breakwater is being constructed and there is no time delay due to hardening of any concrete. Besides this the geometry gives concrete savings up to 15% compared to other pre-cast methods and there is less weather downtime compared to other in-situ methods.

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KEYWORDS – ICCE 2008

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Crown-wall
Breakwater
Wave forces
Pre-cast concrete
Friction