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Rehabilitation of Existing Seawall in Fujairah to Withstand Cyclone Conditions

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Abstract

This paper presents the results of studies performed to rehabilitate an existing seawall in Fujairah to withstand cyclone Gonu condition. The exiting section has not been designed for the cyclone Gonu condition. A desktop study was implemented to assess the functionality of the existing section by applying the methods recommended in the applicable standards and guidelines. This assessment showed that the existing seawall would be severely damaged and excessively overtopped during the cyclone wave condition. Some measures were implemented for the typical section of the seawall. The proposed improved sections were physical model tested and the results compared with the empirical methods.

Keywords: *Seawall, Cyclone Gonu, Overtopping, Rehabilitation.*

1. Introduction

The Fujairah F2 Plant is a power generation and seawater desalination plant located at Qidfa in the Emirate of Fujairah on the Gulf of Oman (Fig. 1). The layout of the shore protection is shown in Figures 2 and 3.

Fig. 1: Location Plan (from Google Earth 2012).

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Fig. 2: A satellite image showing the project site (from Google Earth 2012).

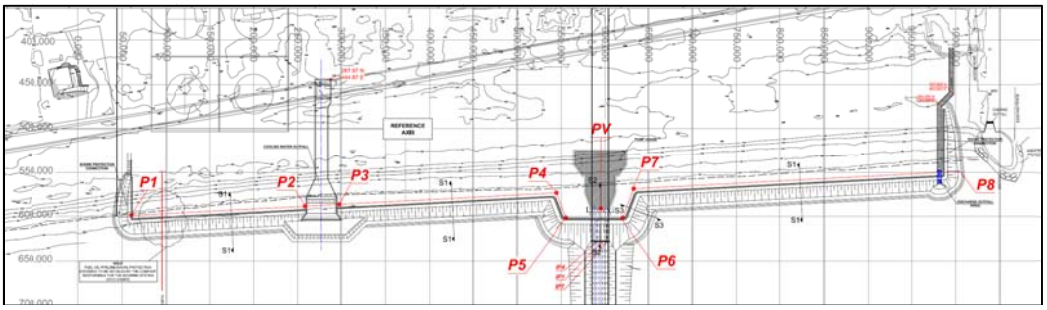

Fig. 3: Shore Protection Lay-out

1.1. Wave Climate

The significant wave heights at -15 m CD in front of the site are presented in Table 1. The Gonu wave characteristics of Fujairah coast are derived from two metocean parametric study and different offshore wave period was obtained (Table1). The nearshore wave transformation study was carried out for the different wave conditions. The design wave heights at the seawall are 2.5 and 3.2m for the 100 year return period and Gonu wave conditions, respectively.

Table 1. Wave conditions at -15mCD

Return period (year)	Water Level (mCD)	H_{mo} (m)	T_p (s)
1 year return period wave	3.00	1.9	8.2
5 year return period wave	3.00	2.4	10
100 year return period wave	3.30	3.1	10.5
First Gonu Condition	3.45	6.0	15
Second Gonu condition	3.45	6.0	18.6

1.2. Seabed Conditions

The seabed level at the toe of the section is -1.0 m CD. The local bathymetry is relatively gentle with a slope of 1.8%. Near the coastline, mean grain size ranges from 0.20 mm to about 0.25 mm.

A maximum erosion depth of about 1m is estimated in the vicinity of the existing seawall for the tested storm wave conditions.

1.3. Existing Structure

Fig. 4 shows a view of the existing seawall. A typical section through the existing seawall is shown in Fig. 5. The stability analysis showed that the existing seawall is stable for 100 year return period wave conditions but will not resist a storm like Cyclone Gonu. By using Van der Meer stability formulas for shallow water conditions (02004), the damage parameter under Gonou conditions has been assessed.

The result showed that the section would experience intermediate damage during Gonou condition with T_p=18.6. But the section would fail during Gonou condition with T_p=15 s. The duration of storms were assumed six hours for both Gonou conditions.

The overtopping has been calculated by applying TAW method which also recommended in Eurotop (2007). The TAW method has been combined with the formula of Besley (1999) to obtain wave overtopping behind the crest of the shore protection. The result showed that the seawall would be severely overtopped resulting in damage to the plant.

1.4. Design Criteria

The wave overtopping must be limited to prevent damage to infrastructure, equipment or danger to pedestrians and vehicles. In establishing allowable overtopping criteria, limit state design approach were considered.

The Serviceability Limit States (SLS) specify general functional requirements for the seawall which prohibits any danger to the safety of the pedestrians and vehicles. Depending on the use of the land behind the seawall, limited damage to the seawall and structures, buildings, equipment and property is accepted for extreme sea states (Ultimate Limit States (ULS)). Overtopping on the coastal structures is frequently assessed without applying safety factors. To ensure the necessary safety margins, the overtopping needs to be investigated for the overload conditions (Accidental Limit States (ALS)).

Fig. 4: Photograph shows the Existing Seawall

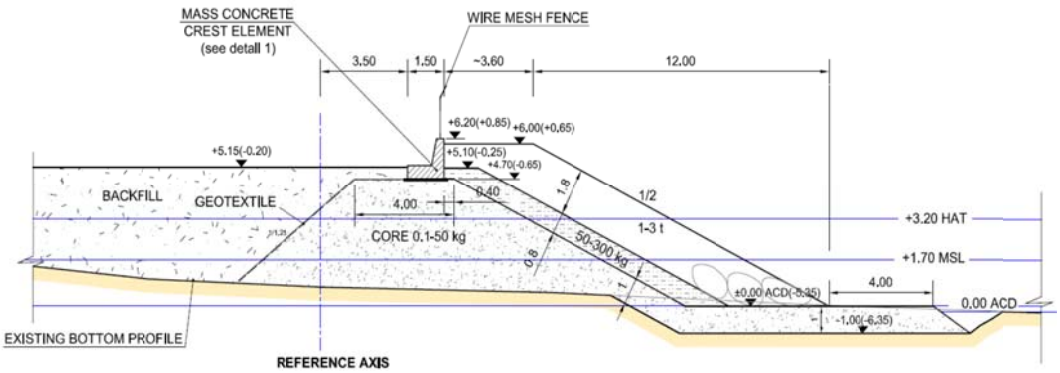

Fig. 5: Typical Section through Existing Seawall

Considering Limit state Design Approach), the following overtopping criteria were defined for the project:

- Overtopping rates associated with 1 years return period wave (SLS): q =0.03 l/s/m for no hazard to pedestrians 0(Eurotop, 2007).
- Overtopping rates associated with 100 years return period wave (ULS): q = 0.4 l/s/m for no damage to equipment set back 5 to 10m 0.
- Overtopping rates associated with Cyclone Gonu wave (ALS): q = 1 l/s/m

Another requirement for the seawall rehabilitation section was to provide a sea view from reclaimed level. This aesthetic requirement is against the functional requirement related to the overtopping.

2. Proposed Sections

To reduce the overtopping, the following measures may be taken:

- Increasing the crest level
- Reducing the seaward slope
- Building a berm in front of the seawall to dissipate the wave energy
- Increasing the crest width

To improve the stability of the section and reduce overtopping, it was proposed to use two layers of 1-3 tons stones for rehabilitation of armour layer and also a large toe are used in front of the structure (Fig. 6). To eliminate localized scour holes around the toe, an apron is proposed in front of the toe.

The combination of slopes and a wide berm near the water level increases the stability of the upper and lower slopes. The hydraulic stability of the structure was assessed using the design curves given in CIRIA/CUR C683 (2007) by applying the reduction factors to the stone diameter calculated according to the Van der Meer stability formulas for shallow water conditions (2004).

Fig. 7 shows a view of the physical model before tests. The first test results carried out on this section showed that the 1-3 ton rock armour layer would be dynamically stable, which meant that the berm in front of the structure was reshaped but reached to a stable profile. Nevertheless, the proposed section was heavily overtopped and failed due to the collapse of the crown wall on the top. The reclamation experienced unacceptable damage. Fig. 8 shows the section after 100 year return period wave test. The stability of the apron was found to be quite good until the cyclone Gonu condition (T_p=15s). It was reshaped but without destabilising the structure (Fig. 9). The crown wall was not stable under the first cyclone Gonu wave conditions. The large overtopping reached directly the crown wall and destabilized the structure (sliding of wave wall structure).

Fig.10 shows a snapshot of the section during first Gonu condition.

The performed tests enabled a better understanding of the stability and behavior of the seawall under cyclone Gonu wave conditions.

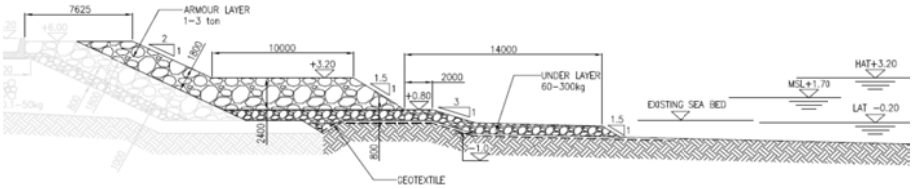

Fig. 6: A sketch showing the first proposed section

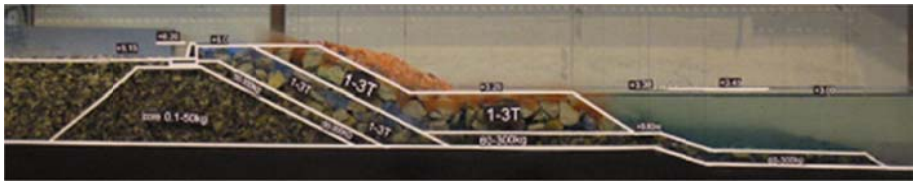

Fig. 7: Photo shows the first proposed section before test

Fig. 8: Photo shows the first proposed section after the test for 100 year return period wave condition

Fig. 9: Photo shows the first proposed section after the test for Gonu wave condition (T_p=15s)

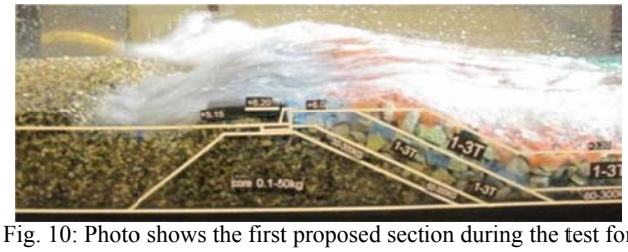

Fig. 10: Photo shows the first proposed section during the test for cyclone Gonu wave condition (T_p=15s)

In order to reduce the overtopping and also reshaping of the first section, two layers of 3-6 ton rock were proposed to be placed over the berm in front of the section as shown in Fig. 11. It was tested under cyclone Gonu wave condition with a wave period of 15 seconds.

The 3-6 ton rocks showed a good stability under cyclone Gonu wave conditions. At the end of the test series, less than 3% of rocks were displaced. Minor movements were observed in the apron under the cyclone Gonu wave conditions. Only drops (spray) were observed under the 5-year and 100-year wave conditions. For the cyclone Gonu wave condition, large overtopping rates were measured (11.8 l/s/m) which was significantly higher than the calculated value of 0.1 l/s/m. Due to the large overtopping (Fig.12), the backfill layer was severely eroded during the cyclone Gonu wave conditions. The tested section was not found to be stable since the crown wall was sliding under cyclone Gonu condition (Figs.13 and 14).

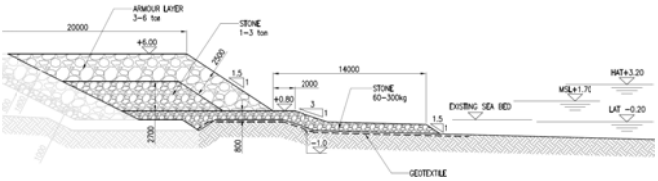

Fig. 11: A sketch showing the second proposed section

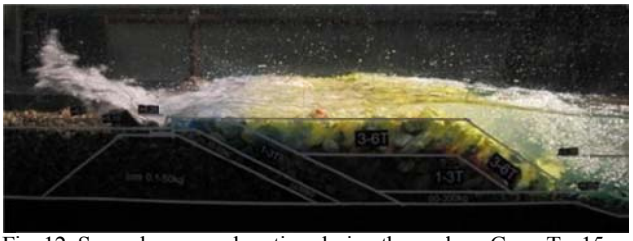

Fig. 12: Second proposed section during the cyclone Gonu T_p=15s

Fig. 13: Photo shows the crown wall stability after the test for cyclone Gonu wave condition (T_p=15s) on the second proposed section

Fig. 14: Photo shows the second proposed section after the cyclone Gonu wave condition (T_p=15s)

The third proposed section is shown in Fig. 15. A splash apron is located above the crest which served as a means of dissipating the remaining wave run-up, splash and spray that could extend above the armor layer. The existing crown wall was protected from both sides by 3-6 ton rocks set at +6.20 m CD. A new crown wall was implemented 20 m behind the existing one. The two crown walls are separated by 3-6 ton rocks.

Fig. 15: Photo shows the third proposed section before the tests

The crown wall was found to be stable under the cyclone Gonu wave conditions. The 3-6 t rocks showed a good stability under cyclone Gonu wave condition. At the end of the cyclone Gonu test (T_p=18.6), 3.5% of rocks were displaced. On the other hand, no rock was moved near the new crown wall. Six rocks were pushed over the existing crown wall position. Slight movements were observed under the cyclone Gonu wave conditions. These movements did not destabilize the structure (Fig. 16).

For the cyclone Gonu wave condition (T_p=15), only some drops were measured since two waves were just lapping at the new crown wall blocks without passing over the crown walls. For the second cyclone Gonu wave condition (T_p=18.6 s), the overtopping was about 0.14 l/s/m. Fig. 17 shows a snapshot of the third proposed section during the Cyclone Gonu test.

Fig. 16: Photo shows the third proposed section after the cyclone Gonu wave condition (T_p=18.6s)

Fig. 17: Photo shows the third proposed section during the cyclone Gonu wave condition (T_p=18.6s)

3. Conclusion

To rehabilitate an existing seawall to withstand long period waves generated during cyclone conditions and to protect the reclamation against damage by wave overtopping, limit the collapse of the crown wall while keeping the sea view from the site, some measures were implemented for the typical section of the seawall. Three proposed sections were model tested to verify the design.

The results of the stability tests on the first proposed section showed the section was not stable under cyclonic wave conditions. A very large overtopping discharge was observed under cyclonic wave conditions which induced the failure of the crown wall.

The second proposed section showed a good stability under cyclone wave condition but a very

large overtopping was observed which caused the failure of the crown wall. The tests on the third proposed section showed a good stability of the 3-6 ton armour and crest berm with no crest berm rocks passing over the new crown wall blocks under cyclone wave conditions. The new crown wall located 20 m behind the existing crown wall was stable. A quite small overtopping discharged under cyclonic wave breaking conditions behind the new crown wall (less than 0.2 l/m/s).

The results of the physical model tests were compared with the methods proposed for the assessment of the stability and functionality in the applicable design guidelines and standards.

The van der Meer formulae showed that the stability of the rock armour increased as breaker parameter increased for surging waves. But during the physical modeling tests, it was observed that the increase in breaker parameter from 6.4 to 7.9 decreased the damage to the structure. Also, it was observed that the combination of the TAW method with the formula of Besley (1999) significantly underestimated the overtopping for the long period wave conditions, such as cyclone generated waves.

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