IOP Conference Series: Earth and Environmental Science

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IOP Conf. Series: Earth and Environmental Science **643** (2021) 012104 doi:10.1088/1755-1315/643/1/012104

Experimental Study on the Physical Model of Breakwater at a LNG Wharf in Pakistan

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Abstract: In this paper, a two-dimensional physical model was established in a laboratory sink, the stability of a breakwater structure at a LNG terminal in Pakistan was studied, and the wave propagation simulation of two designed cross-sections was studied. And make conclusions to evaluate the layout scheme and provide a reference for other similar structures.

1. Introduction

Pakistan requires an adequate supply of energy to be made available to industrial and commercial consumers in order to meet the economic growth target. Bahria Foundation is considering through the installation of an offshore LNG receiving terminal to set up an LNG importing infrastructure thereby to improve the current domestic energy supply situation within the country.

The project is located on the island of Chana, Pakistan, as shown in figure 1. This project will include: marine facilities (LNG terminal comprising topside, jetty and breakwater); subsea pipeline (riser and arrangements at landfall point); one onshore custody transfer station (metering skid, pig receiver and gas chromatography) connecting with subsea pipeline.

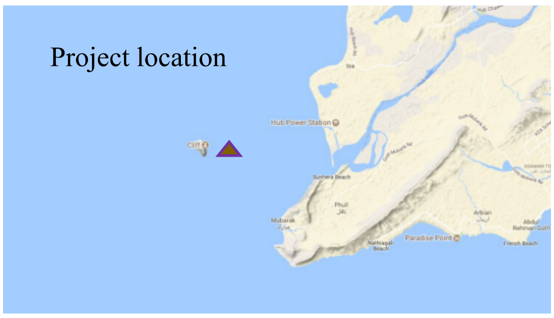


Figure 1 Project location

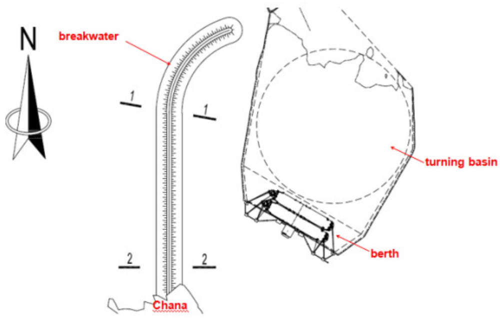


Figure 2 Project layout

2. Design Overview of Breakwater

The length of the breakwater is 1089 meters. Elevation at bottom of circumflex waters -15 m. Waterway bottom elevation -17.2 m, width 220 m. As shown in Figure 2.

Design High Water Level (DHWL):3.87m; Design of low water level (DLWL):-0.28m;

Construction High Water Level (OHWL):2.84m; Construction low water level (OLWL):0.26m.

3. Physical Modelling Facilities and Equipment

3.1 Physical Model Test Purpose

The objective of this document is to present 2D physical modelling results on the stability of toe berm, apron berm and CORE-LOC units, as well as wave transmission for design cross-section of 1-1 and 2-2 of the breakwater.

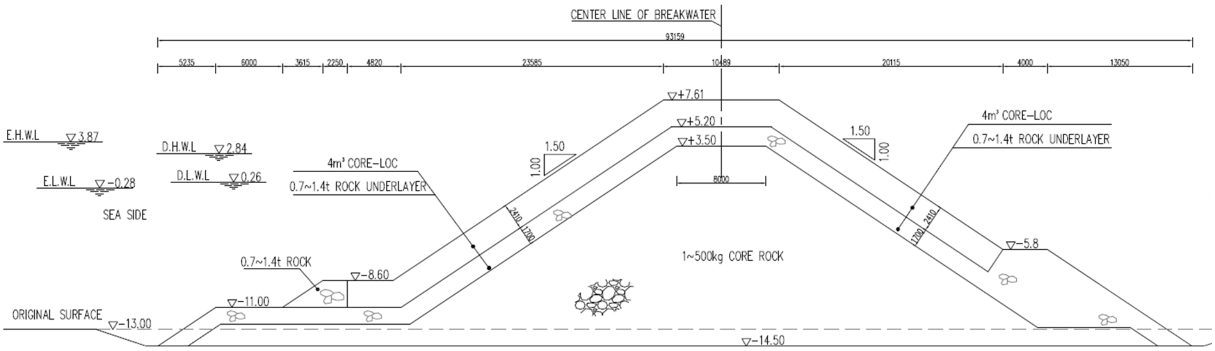


Figure 3 Section 1-1 of breakwater

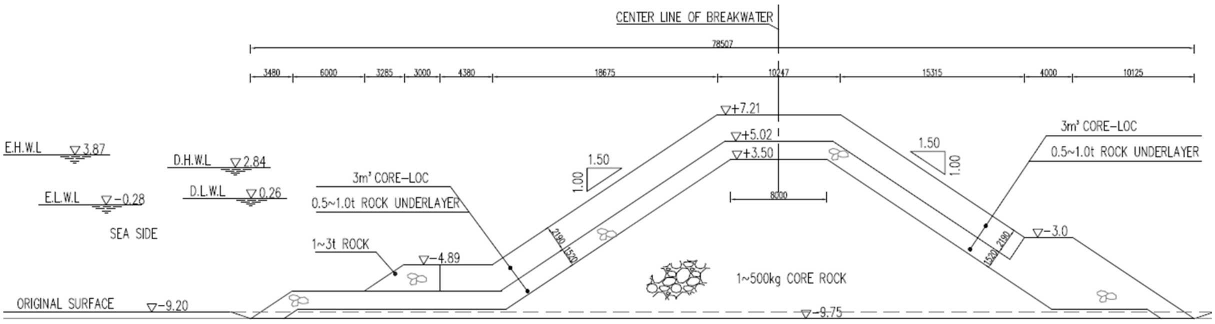


Figure 4 Section 2-2 of breakwater

3.2 Wave Grooves and Generators

The physical modelling was conducted at Tianjin Institute of Water Transport Engineering wave flume, which is 1.0 m wide x 75 m long x 1.5 m deep.Figure 5 shows the image of the sink.2D flume is equipped with an active absorption wave generator (AFM105 type designed by Tianjin University of Science and Technology), which can generate irregular and regular waves. The random waves generated by the wave generator meet the JONSWAP and Pierson-Moskowitz.

Figure 5 Wave flume for the model test

Figure 6 Waveform meter for waveform calibration

3.3 Wave Probe

The waves in the model were measured with capacitance probes and coupled to an amplifier(Figure 6). As the water level varies around the probes, so does the voltage reading. By calibration, the voltage readings are coupled to the corresponding water level. The data is simultaneously captured in a binary voltage measurement format. By analysing the probe output, the voltage data is converted to a time-series of the variation in the wave surface elevation, from which the wave parameters are calculated. In order to record wave conditions in the model, totally twelve single probes were used in the 2D flume. Three of the probes measured wave heights at the model location during calibration before model construction, and the other nine probes were used to measure wave transmission during test with model in place. The wave data was spectrally analysed by professional software, and the relevant wave parameters such as significant wave height (H_{mo}) and peak period (T_p) were derived. The probes that were used here are accurate to 0.5mm.

3.4 Camera Equipment

High definition 1080P digital cameras were used to take photographs of the CORE-LOC and rock armouring before and after each test condition. The camera was positioned above the structure (Figure 7). By comparison between the pictures from before and after each test, the breakwater stability can be determined through measuring the number of displaced armour units at the end of each test segment.

Figure 7 Camera system used in the test

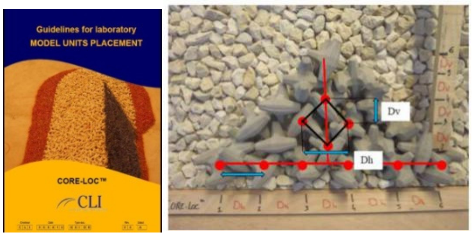


Figure 8 CORE-LOC Model unit placement

4. Model Setting and Test Conditions

4.1 Model Settings

As per prototype and model material density and Rock Manual Equation 5.247[1] (As shown in formula 1), a 1:31 geometry scale was employed, which results in a time scale of 1:5.567 (Froude law) and the mass scale factor for studying the stability of armouring rocks (i.e. toe & underlayer/apron) as shown in Table 1.

$$n_M = \frac{M_P}{M_m} = n_L{}^3 \frac{\rho_{a,p}}{\rho_{a,m}} \left(\frac{\Delta_m}{\Delta_p} \right)^3 \qquad (1)$$

Table 1. Mass scale for CORE-LOC units and armour rocks

Section	CORE-LOC/ Rock	Mass Scale n_M	Prototype Mass M_p (t)	Model Mass M_m (g)	Prototype Density$\rho_{a,p}$(t/m)	Model Density $\rho_{a,p}$(t/m)	Prototype Relative Submerged Density $\triangle_p$(t/m^3)	Model Relative Submerged Density $\triangle_m$(t/m)	Overall Length Scale Factor n_L
1-1	4m^3 CORE-LOC	31541.2	9.4	298.0	2.35	2.31	1.29	1.31	31.0
	700~1400kg Rock	32624.9	(e.g.) 1.4	42.9	2.65	2.63	1.59	1.63	31.0
2-2	3m^3 CORE-LOC	30381.6	7.1	232.0	2.35	2.29	1.29	1.29	31.0
	1000~3000kg Rock	32624.9	(e.g.) 2.0	61.3	2.65	2.63	1.59	1.63	31.0
	500~1000kg Rock	32624.9	(e.g.) 1.0	30.7	2.65	2.63	1.59	1.63	31.0

The CORE-LOC armour blocks were placed as CORE-LOC Guidelines for laboratory model units placement[2]. The placement resulted in an actual usage of 490 blocks for section 1-1 and 462 blocks for section 2-2, i.e. a placing density of 24.87 units/100m^2 for 4m^3 CORE-LOC and 29.28 units/100m^2 for 3m^3 CORE-LOC, which meets the design requirement .

The breakwater model was constructed near the central section of the flume length with a 1:20 foreshore, and to the harbour side nine wave probes were set up for wave transmission measurement.View of completed breakwater models can be seen in Figure9.

Figure 9 View of completed models (left: section 1-1; right: section 2-2)

4.2 Test Conditions

The test wave conditions for section 1-1 and 2-2 were JONSWAP waves. These test wave conditions are based on the project’s Numerical Wave Model Study. waveform calibration was performed before building the model in the flume. the test calibration results are shown in Table 2(take section 1-1 as an example). The difference rate between measured values and target H_{mo} for all tests was strictly controlled during calibration, and the difference rate between measured values and target T_p. During wave calibration, the measured and target spectra are basically consistent. The test can be carried out after calibration.

Table 2. Wave calibration results for section 1-1

Test No.	Return Period (a)	Target H_{m0} (m)	Target T_p (s)	Water level (m)	Measured H_{m0} (m)	Difference Rate for H_{m0}	Measured T_p (s)	Difference Rate for T_p
1	1	3.8	11.4	OHWL(2.84)	3.79	-0.49%	12.11	6.18%
2	10	4.6	12.6	OHWL(2.84)	4.60	0.20%	12.86	2.06%
3	10	4.6	12.6	OLWL(0.26)	4.57	-0.43%	12.85	1.99%
4	50	5.3	13.4	DHWL(3.87)	5.31	0.18%	14.05	4.84%
5	50	5.3	13.4	DLWL(-0.28)	5.35	0.84%	13.27	-0.97%
6	100	5.5	13.6	DHWL(3.87)	5.41	-1.32%	13.85	1.85%
7	100	5.5	13.6	DLWL(-0.28)	5.41	-1.36%	14.53	6.80%
8	120% of 100	6.6	15.9	DHWL(3.87)	6.58	-0.33%	16.39	3.04%
9	120% of 100	6.6	15.9	OLWL(0.26)	6.56	-0.58%	15.93	0.21%

5. Test Results

5.1 Stability Criteria

For design conditions (100 year waves and overload test (120% of 100year)), the stability criteria of the CORE-LOC armour blocks are as follows:a, Limited rocking and settlement of the artificial units;b.

No extraction of the armour units.

Rock toe and apron stability criteria are as follows:a, Toe berm: Nod=1, Reparable damage, maintain its function for armour; b, Apron berm: Nod=2, Reparable damage, no exposure of core material.Nod is the damage parameter. for the definition of Nod, see equation 5.101 in the geotechnical manual[1] (also shown in formula 2).

$$N_{od} = \frac{\text{number of units displaced}}{\text{width of tested section}/D_{n50}} \tag{2}$$

5.2 Stability Results

The stability of the CORE-LOC unit was checked by visual monitoring throughout the test period, and it was found to be stable because there was no swing, obvious settlement or upward shift of the CORE-LOC unit during the test. Check the stability of foot block stone and tank block stone by comparing the photos before and after test. During the whole test, it was observed that the surface block stone was obviously stable. The photos before / after the test of some models were shown in Table 3,,and the damage parameters were shown in Table 4 and Table 5. It shows that the Nod of foot block stone and pit block stone is less than 1, which meets the stability standard.

Table 3. Photographs before and after sea side model test

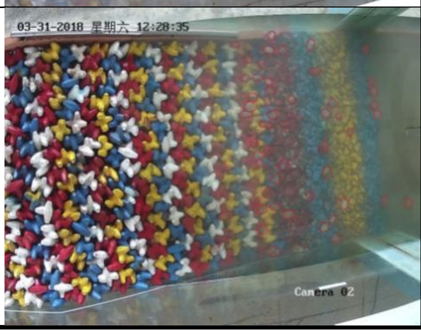
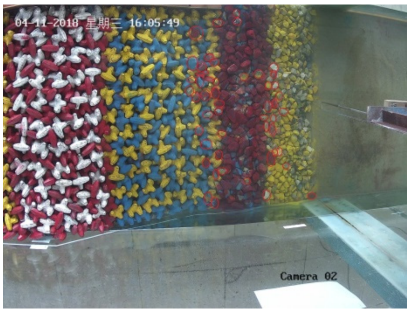
Test Number	Side slope，Photos of Foot and Pit (displaced rocks marked with red circles)(section 1-1)	Test Number	Side slope，Photos of Foot and Pit (displaced rocks marked with red circles)(section 2-2)
Projection		Projection	
Test 9		Test 9	

Table 4. Damage parameters of section 1-1 after each test (cumulative damage)

Test Number	CORE-LOC of instability	CORE-LOC Nod	Number of displaced foot block stones	Foot block (sea side)N_{od}	Number of displaced tarantulas	Protector Stone(sea side)N_{od}
1	0	0	0	0.00	1	0.02
2	0	0	4	0.09	1	0.02
3	0	0	8	0.18	2	0.05
4	0	0	9	0.20	2	0.05
5	0	0	16	0.36	3	0.07
6	0	0	26	0.59	4	0.09
7	0	0	34	0.77	4	0.09
8	0	0	35	0.80	4	0.09
9	0	0	43	0.98	8	0.18

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Table 5. Damage parameters of section 2-2 after each test (cumulative damage)

Test Number	CORE-LOC of instability	CORE-LOC Nod	Number of displaced foot block stones	Foot block (sea side)N_{od}	Number of displaced tarantulas	Protector Stone(sea side)N_{od}
1	0	0	2	0.06	0	0.00
2	0	0	7	0.20	2	0.04
3	0	0	7	0.20	3	0.06
4	0	0	9	0.26	5	0.10
5	0	0	16	0.46	6	0.13
6	0	0	16	0.46	7	0.15
7	0	0	24	0.69	10	0.21
8	0	0	24	0.69	14	0.29
9	0	0	34	0.97	16	0.33

5.3 Wave Transmission Results

The wave propagation is measured with nine wave probes (see figure 10 for the probe position)(take section 1-1 as an example).#1-8 is located near the breakwater and #9 is located near the berthing area of the ship. H_{mo} measured for each probe are listed in Table 6 and Table 7. The results show that the transmission wave height of the port side of the breakwater is generally limited. Specifically, the wave height of the berth area of the ship under the RP10yr wave height is H_{mo} much less than 1.5 m.

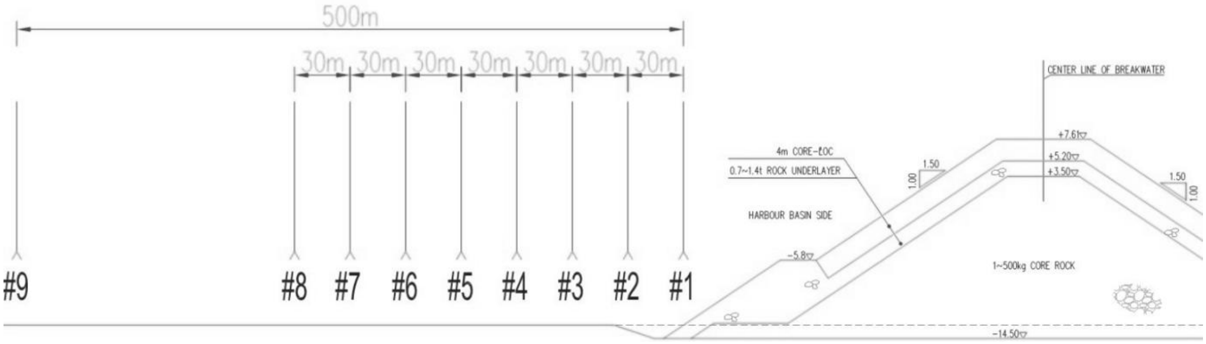

Figure 10 Wave gauge position on the port side of the breakwater(not proportional)

Table 6. Wave transmission Hmo (m) results with section 1-1

Testing Number \ Probe number	#1	#2	#3	#4	#5	#6	#7	#8	#9
1	0.30	0.28	0.30	0.23	0.27	0.35	0.30	0.25	0.21
2	0.25	0.26	0.27	0.22	0.26	0.37	0.30	0.23	0.18
3	0.14	0.14	0.12	0.13	0.18	0.34	0.26	0.18	0.20
4	0.90	0.87	0.79	0.75	0.76	0.70	0.73	0.76	0.71
5	0.49	0.34	0.32	0.30	0.24	0.39	0.30	0.21	0.20
6	1.09	0.97	0.87	0.79	0.80	0.79	0.79	0.79	0.74
7	0.51	0.48	0.29	0.28	0.25	0.41	0.34	0.26	0.21

Table 7. Wave transmission Hmo (m) results with section 2-2

Testing Number \ Probe number	#1	#2	#3	#4	#5	#6	#7	#8	#9
1	0.23	0.21	0.17	0.20	0.16	0.35	0.24	0.22	0.19
2	0.66	0.53	0.50	0.50	0.39	0.46	0.43	0.41	0.40
3	0.16	0.13	0.13	0.11	0.19	0.44	0.16	0.16	0.15
4	0.81	0.69	0.64	0.61	0.62	0.63	0.59	0.57	0.59
5	0.48	0.24	0.22	0.22	0.18	0.36	0.17	0.20	0.18
6	1.21	1.00	0.89	0.84	0.84	0.75	0.78	0.74	0.70
7	0.47	0.26	0.24	0.24	0.20	0.37	0.22	0.21	0.21

6. Conclusion

The physical wave model of breakwater (2D) carried out by Tianjin Institute of Water Transport Engineering, Ministry of Communications and Transport of China includes two cross sections of the breakwater of a LNG project in Pakistan, with a model scale of 1:31.

The structure was tested for nine wave conditions. Nine conditions include various water levels and various return cycles and overloaded waves to assess slope, foot and tank stability and wave propagation.

According to the tests carried out, it is found that the structure is stable for all test conditions.Wave propagation adjacent to breakwaters and waves is also measured and presented in the ship berth area. The results show that the transmission wave height on the port side of the breakwater is generally limited. Specifically, the wave height of the ship berth in the RP10yr wave state is H_{mo} much less than 1.5m.

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