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Title : DESK AND WAVE FLUME STUDIES FOR THE DESIGN OF PROTECTION STRUCTURE / BREAKWATER WITH XBLOCPLUS ARMOUR UNITS TO THE PROPOSED MAIN DAM OF KALPASAR PROJECT, GUJARAT	
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Synopsis: <p>The Kalpasar Project envisages building a 26.70 km long dam across the Gulf of Khambhat with its extension on either side in shallow water tidal flats having length of about 19.83 km on Bhavnagar side and 13.60 km on Dahej side for establishing a huge fresh water coastal reservoir for irrigation, drinking and industrial purposes. In this regard, the detailed desk and wave flume studies for the design cross-sections of protection structure/breakwater to the proposed main dam considering the maximum Design Water Level (DWL) of +8.765 m w. r. to MSL and maximum Significant Wave height (H_s) of 8.1 m will be conducted with AccropodeTM II and XblocPlus patent blocks recommended by Kalpasar Department. In the present report, the details of desk & wave flume studies for the design cross-sections of protection structure/breakwater with XblocPlus as armour units have been described. The section is designed and evolved for different bed level of the protection structure/breakwater from +/- 5 m to - 25 m. In present studies section consists of 14 m³ (33.6 t) XblocPlus in the armour layer with 1:1.33 slope on sea side and 2 to 4 t stones in the armour with 1:1.5 slope on lee side. The top of the crest slab is fixed at el. + 17.5 m level with a parapet top at el. +19.0 m. A clear carriage way width of 10 m is provided on the crest slab.</p>	
Keywords: Armour unit, Breakwater, Breaking Waves, Accropode TM II, XblocPlus, Hydraulic Stability, Tides, Toe Berm, Wave Flume.	



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DESK AND WAVE FLUME STUDIES FOR THE DESIGN OF PROTECTION STRUCTURE/ BREAKWATER WITH XBLOCPLUS ARMOUR UNITS TO THE PROPOSED MAIN DAM OF KALPASAR PROJECT IN GUJARAT

1. INTRODUCTION

Kalpasar Project envisages construction of a proposed dam of about 26.70 km long across the Gulf of Khambhat in deep water with bed level of -25.0 m with respect to MSL and extension of dam on either side in shallow water tidal flats having length of about 19.83 km on Bhavnagar side and 13.60 km on Dahej side. The proposed total length of the dam is about 60.13 km (19.83 km + 26.70 km +13.60 km) for establishing a huge fresh water coastal reservoir for irrigation, drinking and industrial purposes. A typical index and location/layout plan of the proposed main dam to Kalpasar Project in Gujarat as shown in Figure 1. The project with 60.13 km long dam will have the capacity to store 10,000 million cubic meters (Mcum) fresh water, equating to 25% of Gujarat's average annual rainwater flow, from the rivers of Saurashtra region namely Narmada, Mahi, Dhadhar, Sabarmati, Limbdi-Bhagovo, and two other minor rivers. A road link will also be set up over the dam, greatly reducing the distance between Saurashtra and South Gujarat. The proposed project would create world's largest freshwater lake in marine environment and construction of the main "Kalpasar dam" across Gulf of Khambhat and another Bhadbhut barrage on Narmada River.

In this regard, Kalpasar department entrusted CWPRS to conduct various studies for the development of this Project. The interim report on the conceptual cross-sections of breakwater with XblocPlus armour units on the basis of desk studies carried out at CWPRS was sent on 14th October 2020. Further, the studies for design cross-sections of protection structure/breakwater on the seaside of the proposed main dam of Kalpasar project considering the effect of coastal parameters such as wave and tides were also carried out using the wave flume equipped with random wave generation facilities at CWPRS. The design of reservoir protection is required to be carried out considering cutoff wall, road width and inverse filter etc.

In the present Technical Report, the details of desk studies carried out to evolve the conceptual design cross-sections of protection structure/breakwater with XblocPlus as armour units at various bed levels considering the different design wave heights and the detailed wave flume studies have been described.

2.0 SCOPE OF STUDIES

The desk and wave flume studies for the design cross-sections of protection to the main dam, Kalpasar Project in Gujarat. The wave flume tests would be carried out with AccropodeTM II and XblocPlus patent blocks suggested by Kalpasar Department. The patent blocks of suitable weight according to the model scale required for the wave flume studies for the protection structure will be supplied by the project authorities. The Desk and Wave flume studies for the design cross-sections of protection bund/breakwater with **AccropodeTM II** armour units to the Kalpasar main dam, Kalpasar Project in Gujarat have been conducted and submitted vide **CWPRS Technical Report No. 5914 of April 2021**.

In this Technical Report the desk and wave flume studies conducted for the design cross-sections of protection bund/breakwater with **XblocPlus** armour units to the main dam of Kalpasar Project in Gujarat is described in details.

3.0 DESIGN CONDITIONS

During the video conference held on 21/10/2019 with Prof. Ioan Nistor and Project Officials from Kalpasar Department, Officers from NIOT and CWPRS Officers, it was decided to consider the maximum Design Water Level (DWL) of +8.765 m w. r. to MSL and maximum Significant Wave height (H_s) of 8.1 m for design of protection structure/breakwater to the proposed main dam of Kalpasar.

4.0 DESIGN OF PROTECTION STRUCTURE/BREAKWATER WITH XBLOCPLUS ARMOUR UNITS

The protection structure/breakwater to the main dam of Kalpasar project is proposed from either side of the bank, which extending up to - 25 m depth contour with respect to MSL. It is proposed to design rubblemound protection structure/breakwater with XblocPlus as primary armour. The desk studies have been conducted for evolving cross-sections of protection structure/breakwater with XblocPlus in the armour at different bed levels based on empirical formulae as per the existing conditions at the site. Initially, the stable unit weight of XblocPlus for protection structure/breakwater sections at various bed levels at suitable design wave conditions have been worked out using the equation by Hudson formula. The stability coefficient (K_D) depends on the slope of the seabed and K_D values to be used in the design are for non breaking waves and based on safe engineering practice, guidelines by Delta Marine Consultants, the License holder for the design of XblocPlus armour layers who recommended maximum values of Hudson's stability coefficient K_D of 12 for an armour slope steepness of 3V:4H (i.e. 1:1.33). The trunk sections were designed for K_D values, corresponding to non-breaking waves and a seabed slope of 1% for conservative sides. According to BS: 6349-Part-7, the relevant configurations of the toe-berms for the rubblemound breakwater have been designed. The under layer is extended to form the toe mound and the same size of rocks to be assumed for preliminary design. The toe designs have been checked for relevant low and high water levels and also in corresponding wave conditions. The breakwater sections include design of wave wall, which resist the impact pressures from wave up-rush. The wave wall design also includes vehicular and non-vehicular loads as per IRC Class 70 R loading.

4.1 Damage criteria

The damage criteria associated environmental loads for the seaside and rear side rocks shall be limited to $s = 2\%$ as per BS Code, and CIRIA rock manual, Similarly the armour layer of XblocPlus, designed for no damage criteria ($N_{od} = 0$).

4.2 Permissible wave overtopping

The allowable overtopping rate for safety and structural design shall be as per the specification in EurOtop manual 2008 & 2018 and no vehicle shall access the breakwater crest during the cyclone event. Therefore, the breakwaters shall be designed based on the wave overtopping criteria of 100 lit/s/m to estimate the crest level of the breakwater. The permissible overtopping for rubble mound breakwater with XblocPlus as primary units in the range of 50-200 lit/s/m will not damage the crest and rear slope of the breakwater if these are well protected.

The wave overtopping discharge will be estimated using the following method by EurOtop, (Equation 5.9) as presented below.

$$Q = C_r \times (\sqrt{g \times H_{mo}^3}) \times 0.2 \times \exp\left(-2.3 \times \left(\frac{R_c}{H_{mo} \times \gamma_f \times \gamma_\beta}\right)\right)$$

Where,

- Q = Discharge in $m^3/s/m$
- C_r = Crest width reduction factor (-): $3.06 \times \exp(-1.5 \times (C_w H_{mo}))$
- C_w = Crest width (m)
- H_{mo} = Spectral significant wave height (m)
- R_c = Vertical distance between water level and rock crest (m)
- γ_f = Roughness factor (-)
- γ_β = Reduction factor due to oblique wave attack (-)

The crest width in front of wave wall consists of 3 units of primary armour.

4.3 Road on breakwater crest

The road on the breakwater crest shall have a minimum width of 10 m wide. The crest element shall be founded on the breakwater quarry run. The roadway on top of the breakwater shall be designed as Reinforced Cement Concrete (RCC) element for loading condition as per IRC 70R.

4.4 Armour stability of XblocPlus concrete armour blocks

The equation to estimate the stable size of XblocPlus armour units for breakwater sections shall be estimated using the following equation by famous Hudson formula, and Stability number is given as ;

$$W = \frac{w_r \cdot H_s^3}{K_D \times (S_r - 1)^3 \cdot \cot \theta}$$

$$N_s = H_s / \Delta \times D_{n50} = (K_D \times \cot \theta)^{1/3}$$

Where,

- W = Weight of Armour
- H_s = Significant wave height (m)
- K_D = Stability coefficient,
- S_r = Specific Gravity of Armour relative to Water at the structure (w_r/w_w)
- w_r = Unit Weight of Armour ,
- w_w = Unit Weight of sea water
- $\cot \theta$ = Slope of armour
- N_s = Stability number
- $\Delta = (\rho_r / \rho_w) - 1$ = Relative buoyant density
- D_{n50} = Nominal diameter (m)

The stability coefficient depends on the slope of the seabed. K_D values to be used in the design are for non breaking waves and based on safe engineering practice, CWPRS wide experience in similar breakwater projects with monolayer armour units and guidelines from the developer of the concrete armour units. The equation to estimate the stable size of XblocPlus armour units for breakwater sections as suggested by Delta

Marine Consultancy (DMC), the Netherland with modified Hudson formula equation as follows;

$$V_{\text{XblocPlus}} = (H_s / (2.5 \times \Delta))^3$$

Where,

- V = Unit volume [m³]
- H_s = Design significant wave height [m]
- Δ = Relative concrete density $(\rho_c - \rho_w) / \rho_w$
- ρ_w = Mass density of seawater [kg/m³] – 1030 kg/m³
- ρ_c = Mass density of concrete 3 [kg/m³] - 2400 kg/m³

DMC does not recommended the use of concrete densities outside the range of 2350-2500 kg/m³. Armour slope steepness of 3V:4H and a K_d factor of 12 for XblocPlus.

4.5 Design of secondary layer

As per BS: 6349-part 7 and as per DMC design table, the weight of the secondary layer rock for concrete armour shall vary between W/7 to W/15 the weight of XblocPlus armour. However, 0.3 to 1.0 t, 1 to 3 t and 100 to 300 kg stones are proposed as secondary layer and apron extended from underneath toe mound to seabed for preliminary design.

4.6 Layer thickness

Rock armour and secondary layers shall have a minimum thickness equivalent to two rock layers for stability and to act as filter. The layer thickness shall be determined by the stone size as per DMC design table.

4.7 Design of Filter criteria for various layers

The British Standard BS 6349, Part 7, clause 4.4.3 provides guidance for sizing of under layers. The functionality of the filter is described as:

- To act as filter between core and armour layer,
- To provide a stable bed for the armour layer,
- To dissipate wave energy passing through the armour layer, and
- To protect the core material from moderate storms during construction.

The sizing of the under layer material for XblocPlus armour units shall be as defined in BS6349 - Part 7, clause 4.4.3 and as recommended by the XblocPlus armour units developer. The filter stability between the core and filter shall be checked by the Terzaghi filter criteria (see BS 6349).

$$\triangleright D_{15a} / D_{85u} < 4 \text{ to } 5$$

$$\triangleright D_{15a} / D_{15u} < 20\text{-}25$$

Where

- D_{xx} is the sieve rock diameter
- 'u' denotes under layer, and
- 'a' denotes armour

The Thomsen and Shuttler criteria shall be applied for filter criteria between filter and armour layer only:

$$\triangleright D_{50a} / D_{50u} < 7$$

The core material shall be quarry rock and well graded. It is important that the core material is not washed through the armour layers. From past experience in breakwater construction, the Terzaghi criteria shall be fulfilled between the size of armour and the filter or core material.

4.8 Design of toe-berm

According to BS:6349, Part-7, as per the toe configuration for rubble mound Breakwater in deep water, the secondary layer is extended to form the toe mound and the same size of rock may be assumed for preliminary design where the water depth exceeds twice the design H_s . The toe design is checked for relevant low and high water levels and corresponding wave conditions.

In shallow water, the toe of rubble mound breakwater is exposed to breaking wave action, which leads to high water particle velocity and reversal in the flow gradient. This can cause erosion of seabed material, as a result of which there will be a significant settlement in toe. Such settlement can be prevented by providing suitable toe protection. An important function of the toe mound is to provide the support to the

armour. The width of the toe-berm should be provided to accommodate at least four rocks, and accordingly toe-berm on seaside consist of one XblocPlus unit and 3 units of rocks, which satisfy the BS standard for minimum 4 units in the toe. The toe-berm stability shall be checked through wave flume studies at design low water level conditions. The stability of toe berm formed by two layers of rocks on variable berm width & slope structure is given by Van der Meer et al (1995). The equation to calculate the toe size is given below as:

$$\frac{H_s}{\Delta D_{n50}} = \left[2 + 6.2 \left(\frac{h_t}{h} \right)^{2.7} \right] n_{od}^{0.5}$$

Where,

- H_s = Significant wave height (m)
- $\Delta = (\rho_r / \rho_w) - 1$ = Relative buoyant density
- D_{n50} = Median nominal diameter of rock (m)
- h_t = Water depth on Toe (m)
- h = Water depth near sea bed (m)
- N_{od} = number of unit displaced

The damage level for toe is measured in terms of N_{od} and is defined as number of unit displaced with in a strip width of D_{n50} . The stability of toe for design shall be as per the following conditions.

$$N_{od} = \begin{cases} 0.5 & \text{No damage} \\ 2.0 & \text{Acceptable damage} \\ 4.0 & \text{Severe damage} \end{cases}$$

The unit weight of the stones in toe-berm calculated based on Van der Meer improved formulae (Eq. 5.187 and 5.188) of CIRIA rock manual. Although, 6 to 10 t stones are provided as toe berm for section A-A, higher size of rocks are proposed for sections B-B is 6 to 10 t, for section C-C is 4 to 6 t, for section D-D is 2 to 4 t stones and for E-E section is 0.3 to 1 t stones, which were tested successfully in wave flume the model test.

4.9 Design of Wave wall

The breakwater sections shall include a wave wall and the requirement of concrete and steel for the wave wall as per BS:6349-Part 7, The wave wall on these sections shall resist impact pressures from wave up-rush. Wave wall design includes vehicular and non-vehicular traffic loads as per IRC Class 70R loading. The structural design of crest slab and parapet wall are required to be carried out by Project Authorities. The impact pressure on the crest element and the uplift forces is determined based on equation presented below.

Wave pressure is given as,

$$\bullet \quad P_w = K W_w L((H_s/H_c)-0.5)$$

Where,

- H_s = Significant wave height (m)
- K = Constant(-)
- W_w = Seawater density(kg/cum)
- L = Wave length corresponds to significant wave period (m)
- H_c = Height of breakwater crest from design water level (m)

4.10 Design of Core

The core material shall consist of 10 to 500 kg well graded quarry run. Gradation of core will be estimated based on the filter criteria. The core rock with weight less than 10 kg shall be restricted to 1% and 5% of total volume respectively. The porosity of 37 % may be considered for the rock gradation.

4.11 Rear armour

Rear rock armour is designed based on the permissible wave overtopping and non-breaking incident waves propagating into the harbour, which are estimated from numerical modelling studies. The stability of rear armour under wave overtopping during the design storm event will be validated during 2D wave flume modelling tests.

The hydraulic calculations of conceptual design for protection structure/breakwater to the dam at Kalpasar project have been evolved based on the desk studies are as shown in Table 1.

Table 1: Design calculations of protection structure / breakwater to the dam at Kalpasar project

Sea bed level in m w. r. to		Depth of water In m	Design wave height in m	Armour volume in cum	Armour weight In ton	Weight of stones in Secondary	Toe-berm level in m	Weight of stones in Toe-berm
MSL	CD							
5.0	10.5	3.765	2.94	0.75	1.8	0.1 to 0.3 t	+7.40	0.3 to 1 t
2.0	7.5	6.765	5.28	3.0	7.2	0.3 to 1 t	+5.65	2 to 4 t
0.0	5.5	8.765	6.84	6.0	14.4	1 to 3 t	+4.10	4 to 6 t
-5.0	0.5	13.765	8.10	14.0	33.6	1 to 3 t	+0.10	6 to 10 t
-25.0	-19.5	33.765	8.10	14.0	33.6	1 to 3 t	-9.50	6 to 10 t

The design of breakwater cross-sections at different bed levels with XblocPlus concrete blocks in the armour was confirmed and finalized through 2D wave flume studies for its hydraulic stability as a whole. The design of cross-sections of breakwaters with XblocPlus in the armour considering the design wave condition at different bed levels are shown in Figures 2 to 6. The design of these cross-sections at different bed levels are described as follows:

i) Cross-section of protection structure/breakwater from bed level - 5 m to - 25 m

The section is designed to provide from -5 m to -25 m bed level of the protection structure/breakwater considering Design Wave Height (DWH) of 8.1 m (Hs) and Design Water Level (DWL) of 8.765 m as shown in Figure 2. This section consists of 14 m³ (33.6 t) XblocPlus concrete blocks in the armour with 1:1.33 slope on sea side and 2 to 4 t stones in the armour with 1:1.5 slope on lee side. A 7.56 m wide toe-berm consists of 6 to 10 t stones have been provided at the level -9.50 m on sea side. A secondary layer consists of 1 to 3 t stones has been provided below the armour units and crest slab and 0.5 to 1 t stones provided below the toe-berm. Core consists of 10 to 500 kg stones and a bedding layer of stones up to 10 kg weight are proposed. The top of the crest slab is fixed at el. + 17.5 m level with a parapet top at el. +19.0 m. A clear carriage way width of 10 m is provided on the crest slab.

ii) Cross-section of protection structure/breakwater from bed level 0.0 m to -5.0 m

The section is designed to provide from 0.0 m to -5.0 m bed level of the protection structure/breakwater considering Design Wave Height (DWH) of 8.1 m (H_s) and Design Water Level (DWL) of 8.765 m as shown in Figure 3. This section consists of 14 m³ (33.6 t) XblocPlus concrete blocks in the armour with 1:1.33 slope on sea side and 1 to 3 t stones in the armour with 1:1.5 slope on lee side. A 7.56 m wide toe-berm consists of 6 to 10 t stones have been provided at the level +0.1 m on sea side. A secondary layer consists of 1 to 3 t stones has been provided below the armour units, toe berm and crest slab. Core consists of 10 to 500 kg stones and a bedding layer of stones up to 10 kg weight are proposed. The top of the crest slab is fixed at el. + 17.5 m level with a parapet top at el. +19.0 m. A clear carriage way width of 10 m is provided on the crest slab.

iii) Cross-section of protection structure/breakwater from bed level +2.0 m to 0.0 m

The section is designed to provide from + 2.0 m to 0.0 m bed level of the protection structure/breakwater considering maximum breaking wave height (H_b) of 6.8 m and Design Water Level (DWL) of 8.765 m as shown in Figure 4. This section consists of 6 m³ (14.4 t) XblocPlus concrete blocks in the armour with 1:1.33 slope on sea side and 1 to 3 t stones in the armour with 1:1.5 slope on lee side. A 6.22 m wide toe-berm consists of 4 to 6 t stones have been provided at the level + 4.1 m on sea side. A secondary layer consists of 1 to 3 t stones has been provided below the armour units and crest slab and 0.5 to 1 t stones provided below the toe-berm. Core consists of 10 to 500 kg stones and a bedding layer of stones up to 10 kg weight are proposed. The top of the crest slab is fixed at el. + 15.5 m level with a parapet top at el. +16.5 m. A clear carriage way width of 10 m is provided on the crest slab.

iv) Cross-section of protection structure/breakwater from bed level +5.0 m to +2.0 m

The section is designed to provide from +5.0 m to +2.0 m bed level of the protection structure/breakwater considering maximum breaking wave height (H_b) of 5.3 m and Design Water Level (DWL) of 8.765 m as shown in Figure 5. This section consists of 3 m³ (7.2 t) XblocPlus concrete blocks in the armour with 1:1.33 slope on sea side and

0.3 to 1 t stones in the armour with 1:1.5 slope on lee side. A 5.2 m wide toe-berm consists of 2 to 4 t stones have been provided at the level + 5.65 m on sea side. A secondary layer consists of 0.3 to 1 t stones has been provided below the armour units, toe berm and crest slab. Core consists of 10 to 300 kg stones and a bedding layer of stones up to 10 kg weight are proposed. The top of the crest slab is fixed at el. +14.0 m level with a parapet top at el. +15.0 m. A clear carriage way width of 10 m is provided on the crest slab.

v) Cross-section of protection structure/breakwater from the root to +5.0 m bed level

The section is designed to provide from the root of the protection structure/breakwater up to +5.0 m bed level considering maximum breaking wave height (H_b) of 2.9 m and Design Water Level (DWL) of 8.765 m as shown in Figure 6. This section consists of 0.75 m^3 (1.8 t) XblocPlus concrete blocks in the armour with 1:1.33 slope on sea side and 100 to 300 kg stones in the armour with 1:1.5 slope on lee side. A 3.76 m wide toe-berm consists of 0.3 to 1 t stones have been provided at the level +7.4 m on sea side. A secondary layer consists of 100 to 300 kg stones have been provided below the armour units, toe berm and crest slab. Core consists of 10 to 100 kg stones and a bedding layer of stones up to 10 kg weight are proposed. The top of the crest slab is fixed at el. + 11.50 m level with a parapet top at el. +12.0 m. A clear carriage way width of 6 m is provided on the crest slab.

The technical specifications of XblocPlus armour units as shown in Figure 7.

5.0 HYDRAULIC MODEL STUDIES

5.1 Wave flume test procedures

The section of a protection structure/breakwater is tested under a normal attack of waves in a 2-D random wave flume for its hydraulic stability. The models of protection structure/breakwater cross-sections were constructed to a Geometrically Similar (GS) scale in a wave flume. The dimensions of the random wave flume (45 m length, 1.00 m width and 1.10 m depth) and the regular wave flume (50 m length, 1.20 m width and 1.80 m depth). Both regular as well as random waves of desired wave height & period and desired standard wave spectrum respectively could be generated. The number of XblocPlus armour units / stones provided in the armour and in the toe was counted

initially, before starting the test. After conducting the wave flume model tests for one-hour duration, the number of XblocPlus armour units / stones displaced from its original position were recorded and percentage of damage to the armour of breakwater was determined. During the test, extent of splashing/overtopping over the crest was also observed and recorded. The damage is expressed as percentage of number of XblocPlus armour units / stones displaced from their original position.

5.2 Model Scale

The model was based on Froude's criterion of similitude. The model tests for the design of protection structure/breakwater were conducted in 2-D random wave flume by reproducing the section to Geometrically Similar scales of 1:60, 1:44 and 1:35 for different cross-sections. The model scale depends on a number of factors varying from the prototype size, capacities of the testing facility in relation to the design wave and water level conditions as well as the available model armour units.

The final choice of the physical model is determined by the size of the available model armour unit. The various scales obtained are as follows:

$$\lambda = \frac{Dn_p \cdot \Delta_p}{Dn_m \cdot \Delta_m}$$

$$\Delta_p = \frac{\rho_{sp}}{\rho_{wp}} - 1$$

$$\Delta_m = \frac{\rho_{sm}}{\rho_{wm}} - 1$$

Where,

- λ = model length scale [-]
- Dn_p = XblocPlus nominal diameter in prototype [m]
- Dn_m = XblocPlus nominal diameter in model [m]
- Δ_p = relative density in prototype [-]
- Δ_m = relative density in model [-]
- ρ_{sp} = density of XblocPlus units in prototype [kg/m^3]
- ρ_{sm} = density of XblocPlus units in model [kg/m^3]
- ρ_{wp} = density of water in prototype [kg/m^3]
- ρ_{wm} = density of water in model [kg/m^3]

In the ideal situation the Δ_m of the model units is equal to the Δ_p of the prototype units. In this situation, the model scale will be geometrically most correct and there will be no influence on overtopping, wave run-up, wave run-down.

The section of protection structure/breakwater at -25 m bed level w. r. to MSL to a Geometrically Similar scale of 1:60 reproduced in the wave flume and other scale are as below;

Model scale 1:60		
• Length	- L	= 1:60
• Area	- L^2	= 1:3,600
• Volume	- L^3	= 1:2,16,000
• Time	- $L^{1/2}$	= 1:7.746
• Velocity	- $L^{1/2}$	= 1:7.746

The section of protection structure/breakwater at 0.0 m bed level w. r. to MSL to a Geometrically Similar scale of 1:44 reproduced in the wave flume and other scale are as below;

Model scale 1:44		
• Length	- L	= 1:44
• Area	- L^2	= 1:1,936
• Volume	- L^3	= 1:85,184
• Time	- $L^{1/2}$	= 1:6.633
• Velocity	- $L^{1/2}$	= 1:6.633

The section of protection structure/breakwater at +2.0 m bed level w. r. to MSL to a Geometrically Similar scale of 1:35 reproduced in the wave flume and other scale are as below;

Model scale 1:35		
• Length	- L	= 1:35
• Area	- L^2	= 1:1,225
• Volume	- L^3	= 1:42,875
• Time	- $L^{1/2}$	= 1:5.916
• Velocity	- $L^{1/2}$	= 1:5.916

5.3 Compensation for weight of stones

The density of stones in the prototype was considered as 2.60 t/cum and density of seawater is 1.025 t/cum. However, the density of stones in the model was 2.80 t/cum and fresh water with density 1.0 t/cum was used in the flume. As such, the weights of stones used in the model were compensated for these density differences by applying a weight factor, which was worked out as below:

$$\frac{W_1}{W_2} = \frac{2.6H^3 / \left(\frac{2.6}{1.025} - 1 \right)^3}{2.8H^3 / \left(\frac{2.8}{1.0} - 1 \right)^3}$$

Where,

$$W_2 = 0.6678 W_1$$

- W_1 = Weight of stones with density in prototype -- 2.6 t/cum
- W_2 = Weight of stones with density in model -- 2.80 t/cum

Hence considering the weight factor of 0.6678 for stones and 0.88 for Accropode™ II concreter armour units in the model were worked out.

The weight reduction factor of XblocPlus armour units is also can be calculated based on scale similitude by following Hudson formulae for buoyancy:

$$C = \frac{V_p}{V_m \times E^3} = \frac{H_{Sp}^3}{K_D \left[\frac{d_p}{d_{op}} - 1 \right]^3 \cot g \alpha \times E^3} \times \frac{K_D \left[\frac{d_m}{d_{om}} - 1 \right]^3 \cot g \alpha}{H_{Sm}^3} = \frac{\left[\frac{d_m}{d_{om}} - 1 \right]^3}{\left[\frac{d_p}{d_{op}} - 1 \right]^3}$$

Prototype volume is given as.... $V_p = V_m \times E^3 \times C$

Where “E” being the scale factor.

The XblocPlus model units in the range of 154 gram received at CWPRS Laboratory. The studies carried out considering the model units not exceeding 154 gram (represent

corresponding to 14 m³) for model scale of 1:60 and also for model scales of 1: 44 (represent 6 m³) and 1: 35 (represent 3 m³).

5.4 Random Sea Wave Flume

The random sea wave flume having dimensions 45 m (length) x 1 m (width) x 1.10 m (height) was utilised for the wave flume tests. The system is capable of generating maximum wave height of 0.4 m at a water depth of 0.6 m for wave periods ranging between 0.3 and 3.0 sec. The flume facility is equipped with a fully automated computerised random wave generating system comprising of hydro-servo system and wave board assembly. The command signals are sent by the computer to the servo-valve through which pressurised oil supplied by hydraulic power pack flows into the actuator. A *To* and *Fro* motion of the piston drives the wave board, which in turn generates waves in the flume as per desired input.

5.5 Wave Measurement and Calibration

The wave heights have been measured by capacitance type wave probes. A gauge was fixed at about 30 m water depth in Prototype and at corresponding depth in front of the breakwater section in the model and was analysed by computer. The desired wave conditions in front of the breakwater section in the model have been obtained by matching desired spectrum and achieved spectrum by iterative procedure. The typical wave spectrum (Pierson- Mosckowitz (P-M) spectrum) generated during wave flume studies as shown in Figure 8 & 9.

5.6 Placement of XblocPlus model units in the wave flume

A wooden template consists of horizontal / vertical distance between the two consecutive gravity centres of the block has been made for guiding the placement of the XblocPlus blocks for Geometrical Scale and are worked out using the formula as per M/s DMC manual as below;

- Horizontal distance between two consecutive gravity centres

$$D_x = 1.1 * L_2 \dots \text{cm}$$

- Up slope distance (Vertical) between two consecutive gravity centres distance

$$D_y = 0.63 * L_2 \dots \text{cm}$$

Where L_2 is an Unit width of Armour unit (m)

The placement methods of XblocPlus model units in the wave flume are as shown in Figure 5 & 10. The placement of XblocPlus armour model units for the breakwater section carried out at wave flume studies have been informed and confirmed with M/s DMC, the Netherland.

5.7 Wave flume test procedure

The section of the breakwater was constructed to a geometrically similar model scale of 1:60 in the 2-D flume. The number of XblocPlus armour units provided in single layer, on the seaside as armour and number of stones in the toe-berm were counted initially, before starting the test. After conducting the tests for one-hour duration, the numbers of XblocPlus armour units displaced from its original position were recorded and percentage damage to the armour of breakwater was determined. During the test, extent of splashing / overtopping over the crest was observed. The details of the wave flume tests for various cross-sections are described in the following paragraphs.

5.8 Wave flume studies

5.8.1 2-D wave flume test in the RSWG for protection with XblocPlus units Structure / breakwater at -25.0 m bed level w. r. to MSL

The number of XblocPlus armour units required in the 2-D wave flume model was derived by packing density calculations. The armour geometry and packing density of 9.1/100m² is considered for the calculations. The random sea wave flume having dimensions 45 m (length) x 1 m (width) x 1.10 m (height) was utilised for the wave flume tests. Total 257 nos. of XblocPlus blocks armour model units were placed in the armour of the protection structure/breakwater. There are total 19 rows of XblocPlus, which also satisfies the M/s DMC conditions of maximum allowable rows of 25 nos. A wooden template of horizontal and vertical distance between the two consecutive gravity centres of the block have been made for placement guidance of the XblocPlus blocks ($D_x=7.33$ cm and $D_y= 4.19$ cm) based on Geometrical Scale of 1:60.

The 2-D wave flume tests in the RSWG for protection structure/breakwater at -25.0 m bed levels as follows:

The section is designed to provide from - 5 m to - 25 m bed level of the protection structure/breakwater as shown in Figure 2. This section consists of 14 m³ (33.6 t) XblocPlus in the armour with 1:1.33 slope on sea side and 2 to 4 t stones in the armour with 1:1.5 slope on lee side. A 7.56 m wide toe-berm consists of 6 to 10 t stones provided at the level -9.5 m on sea side. A secondary layer consists of 1 to 3 t stones provided below the armour units & crest slab and provided 0.5 to 1 t stones below the toe-berm. Core consists of 10 to 500 kg stones and a bedding layer of stones up to 10 kg weight are proposed. The top of the crest slab is fixed at el. + 17.5 m level with a parapet wall top at el. +19.0 m. A clear carriage way width of 10 m is provided on the crest slab.

Initially, the test was conducted at the Design Water Level (DWL) of +8.765 m with respect to Mean Sea Level (MSL) under the attack of random waves with significant wave height (H_s) 8.1 m (Pierson-Mosckowitz (PM) spectrum). There was no overtopping and marginal splashing of waves. No damage was seen to any component of the protection structure/breakwater. The wave run-up & run-down of waves was observed at +18.2 m and +3.0 m respectively. No damage was seen to any part of the breakwater was observed during wave tests.

The test was also conducted at the Highest Astronomical Tide (HAT) of + 5.3 m with respect to MSL under the attack of random waves with significant wave height (H_s) 8.1 m (PM-Spectrum). There was no overtopping and splashing of waves. No damage was seen to any component of the protection structure/breakwater. The wave run-up & run-down of waves was at +13.5 m and 0.0 m respectively. No damage was observed to any part of the breakwater was observed during wave tests.

The test was also conducted at the Mean Sea Level (MSL) of + 0.0 m under the attack of random waves with significant wave height (H_s) 8.1 m (PM-Spectrum). There was no overtopping and splashing of waves. No damage was seen to any component of the protection structure/breakwater. The run-up & run-down of waves was at +7.8 m and -5.0 m respectively. No damage was observed to any part of the breakwater was observed during wave tests.

The test was also conducted at the Lowest Low Water Level (LLWS) with respect to MSL of - 4.8 m under the attack of random waves with significant wave height (H_s) 8.1 m (PM-Spectrum). There was no overtopping and splashing of waves. No damage was seen to any component of the protection structure/breakwater. The run-up & run-down of waves was at +2.5 m and -8.0 m respectively. No damage was observed to any part of the breakwater was observed during wave tests.

5.8.2 2-D wave flume test for protection with XblocPlus armour units protection Structure / breakwater at 0.0 m bed level w. r. to MSL

The number of XblocPlus armour units required in the 2D wave flume model was derived by packing density calculations. The armour geometry and packing density of 15.9/100m² is considered for the calculations. The regular sea wave flume having dimensions 50 m (length) x 1.20 m (width) x 1.80 m (height) was utilised for the wave flume tests. Total 186 nos. of XblocPlus armour units were placed in the armour of the protection structure/breakwater. A wooden template consists of horizontal / vertical distance between the two consecutive gravity centres of the block has been made for guiding the placement of the XblocPlus blocks for geometrical scale of 1:44 ($D_x=7.54$ cm and $D_y=4.32$ cm) and are worked out using the formula as per DMC manual.

The 2-D wave flume tests in the regular wave generation for protection structure/breakwater at 0.0 m bed levels as follows:

The section is designed to provide from + 2.0 m to 0.0 m bed level of the protection structure/breakwater as shown in Figure 4. This section consists of 6 m³ (14.4 t) XblocPlus in the armour with 1:1.33 slope on sea side and 1 to 3 t stones in the armour with 1:1.5 slope on lee side. A 6.22 m wide toe-berm consists of 4 to 6 t stones have been provided at the level + 4.1 m on sea side. A secondary layer consists of 1 to 3 t stones has been provided below the armour units and crest slab and 0.5 to 1 t provided below the toe-berm. Core consists of 10 to 500 kg stones and a bedding layer of stones up to 10 kg weight are proposed. The top of the crest slab is fixed at el. + 15.5 m level with a parapet top at el. +16.5 m. A clear carriage way width of 10 m is provided on the crest slab.

Initially, the test was conducted at the Design Water Level (DWL) of +8.765 m with respect to Mean Sea Level (MSL) under the attack of Maximum Breaking Wave height (H_b) of 6.83 m. There was no overtopping and marginal splashing of waves. No damage was seen to any component of the protection structure/breakwater. The run-up & run-down of waves was at +15.5 m and +6.5 m respectively. No damage was observed to any part of the breakwater was observed during wave flume tests.

The test was also conducted at the Highest Astronomical Tide (HAT) of + 5.3 m with respect to MSL under the attack of maximum breaking wave height (H_b) of 4.13 m. There was no overtopping and splashing of waves. No damage was seen to any component of the protection structure/breakwater. The run-up & run-down of waves was at +8.5 m and +4.0 m respectively. No damage was observed to any part of the breakwater was observed during wave flume tests.

5.8.3 2-D wave flume test for protection with XblocPlus armour units protection Structure / breakwater at +2.0 m bed levels w. r. to MSL

The number of XblocPlus armour units required in the 2D wave flume model was derived by packing density calculations. The armour geometry and packing density of 25.3/100m² is considered for the calculations. The regular sea wave flume having dimensions 40 m (length) x 0.70 m (width) x 1.80 m (height) was utilised for the wave flume tests. Total 99 nos. of XblocPlus armour units were placed in the armour of the protection structure/breakwater. A wooden template consists of horizontal / vertical distance between the two consecutive gravity centres of the block has been made for guiding the placement of the XblocPlus armour units ($D_x=7.51$ cm and $D_v= 4.30$ cm) for geometrical scale of 1:35. The 2-D wave flume tests in the regular wave generation for protection structure/breakwater at +2.0 m bed levels as follows:

The section is designed to provide from +5.0 m to +2.0 m bed level of the protection structure/breakwater as shown in Figure 3. This section consists of 3 m³ (7.2 t) XblocPlus in the armour with 1:1.33 slope on sea side and 0.3 to 1 t stones in the armour with 1:1.5 slope on lee side. A 5.2 m wide toe-berm consists of 2 to 4 t stones have been provided at the level +5.65 m on sea side. A secondary layer consists of 0.3 to 1 t stones has been provided below the armour units, toe-berm and crest slab. Core consists of 10 to 300 kg stones and a bedding layer of stones up to 10 kg weight

are proposed. The top of the crest slab is fixed at el. + 14.0 m level with a parapet top at el. +15.0 m. A clear carriage way width of 10 m is provided on the crest slab.

Initially, the test was conducted at the Design Water Level (DWL) of +8.765 m with respect to Mean Sea Level (MSL) under the attack of maximum breaking wave height (H_b) of 5.27 m. There was no overtopping and marginal splashing of waves. No damage was seen to any component of the protection structure/breakwater. The run-up & run-down of waves was at +14.0 m and +7.0 m respectively. No damage was seen to any part of the breakwater was observed during wave flume tests.

The test was also conducted at the Highest Astronomical Tide (HAT) of + 5.3 m with respect to MSL under the attack of maximum breaking wave height (H_b) of 2.57 m. There was no overtopping and splashing of waves. No damage was seen to any component of the protection structure/breakwater. The run-up & run-down of waves was at +7.0 m and +4.0 m respectively. No damage was observed to any part of the breakwater was observed during wave flume tests.

The typical photographs of the wave flume facilities, wave flume studies and placement of XblocPlus model units in the wave flumes are enclosed.

6.0 DISCUSSIONS OF RESULTS

The design cross-sections of protection structure/breakwater at various bed levels on the seaside have been evolved at different bed levels and are shown in Figures 2 to 6. The hydraulic stability of the cross-sections of protection structure/breakwater with XblocPlus armour model units have been confirmed through wave flume studies.

The design of reservoir protection is required to be carried out considering cutoff wall, and inverse filter etc. It is also confirm the requirement of top width (road width) of the protection structure/breakwater to the main dam. The structural design of crest slab and parapet wall is required to be carried out by Project Authorities. It is presumed that, the seabed strata below the construction of protection structure/breakwater are adequate to sustain the load of the structures. In order to ensure the foundation conditions, it is suggested to carry out the sub-soil investigations such as soil characteristics borehole data at different locations along the proposed protection structure/breakwater site.

7.0 CONCLUDING REMARKS AND RECOMMENDATIONS

Based on the desk and wave flume studies carried out for the design cross-sections of protection to the main dam of Kalpasar Project in Gujarat, the following concluding remarks are depicted:

1. The design cross-sections of the breakwater with XblocPlus armour units of 0.75 cum, 3 cum, 6 cum and 14 cum at various bed levels are as shown in Figures 2 to 6. These breakwater sections are hydraulically stable under the design wave conditions.
2. The density of concrete and stones to be used for the construction of the breakwaters should be about 2.4 t/cum and 2.6 t/cum respectively.
3. There should not be any deviation from the design during the construction for the breakwaters in respect of the levels, slopes and the weights of stones. The crest slab, the parapet wall and crest slab of the breakwater should be constructed monolithically.
4. The construction of the breakwater may not be possible during one season. As such, a temporary roundhead may be provided wherever the work is curtailed.
5. The rubble mound structures are flexible structures and it is essential to monitor and maintain them regularly. Therefore, periodic survey and maintenance of the breakwater as and when damage occurs may be undertaken immediately to restore.
6. The grading of the stones to be used in the construction for the restoration of the damaged south breakwater should be as follows:
 - 6-10 t stones – 50% stones should be higher than 8 t
 - 4-6 t stones - 50% stones should be higher than 5.0 t
 - 2-4 t stones - 50% stones should be higher than 3.0 t
 - 1-3 t stones - 50% stones should be higher than 2 t
 - 0.5 -1 t stones - 50% stones should be higher than 750 kg
 - 0.3 -1 t stones - 50% stones should be higher than 650 kg
 - 300-500 kg stones - 50% stones should be higher than 400 kg
 - 100-300 kg stones - 50% stones should be higher than 200 kg

8.0 REFERENCES

1. IS 4651: Part IV (2014): Code of practice for planning and design of ports & harbours
2. BS 6349: Part 1-1 (2013): Code of practice for planning and design for operations.
3. BS 6349: Part 7 (1991): Guide to the design and construction of breakwater.
4. CIRIA C683, 2nd Edition, London 2007: The Rock Manual - The use of rock in hydraulic engineering
5. EurOtop (2007): Wave Overtopping of Sea Defence and Related Structures: Assessment Manual, August 2007.
6. US Army Corps of Engineers, Coastal Engineering Research Centre: Coastal Engineering Manual EC 1110-2-1100, Sept. 2006.
7. Indian Road Congress (IRC) code and standards.

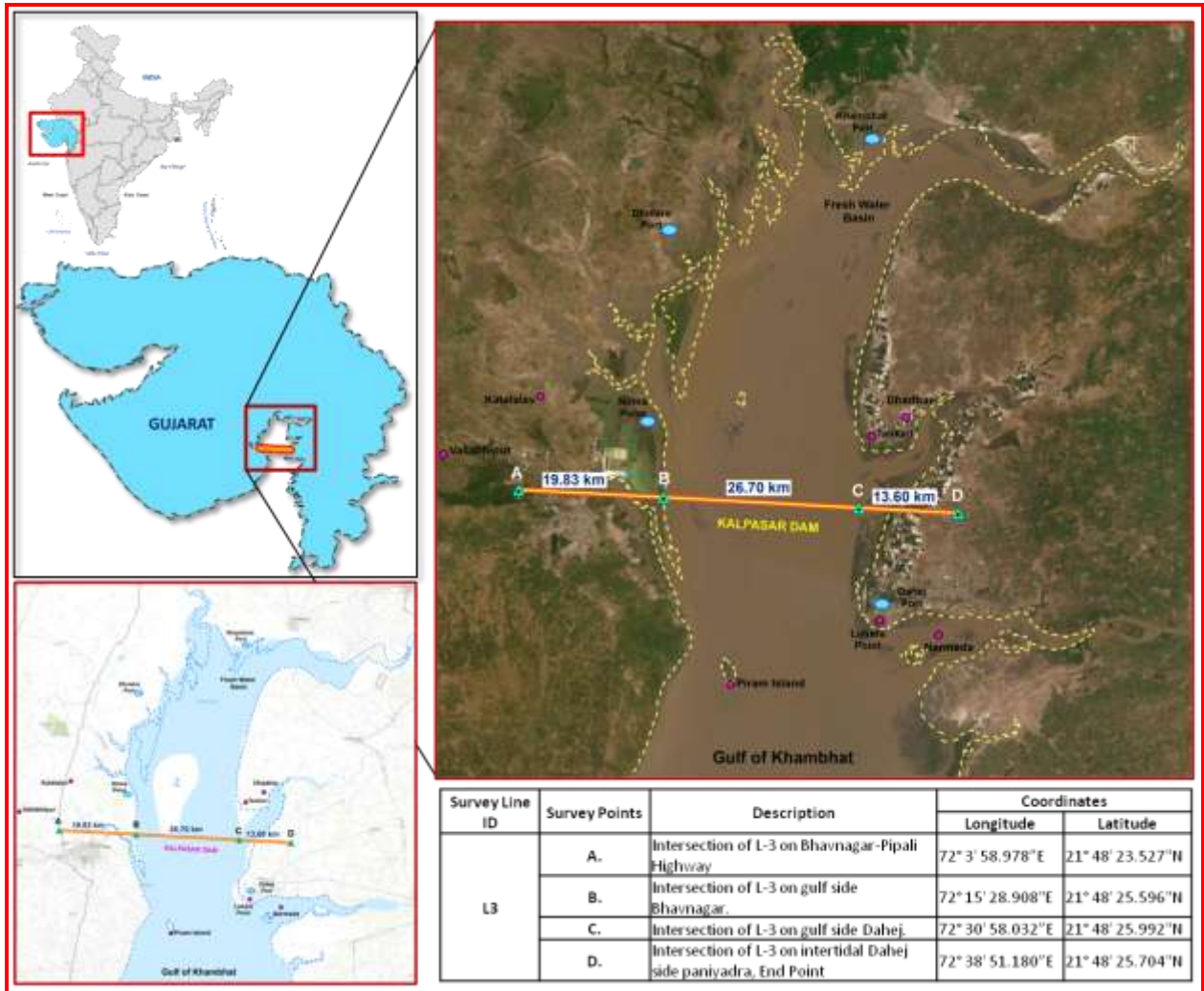
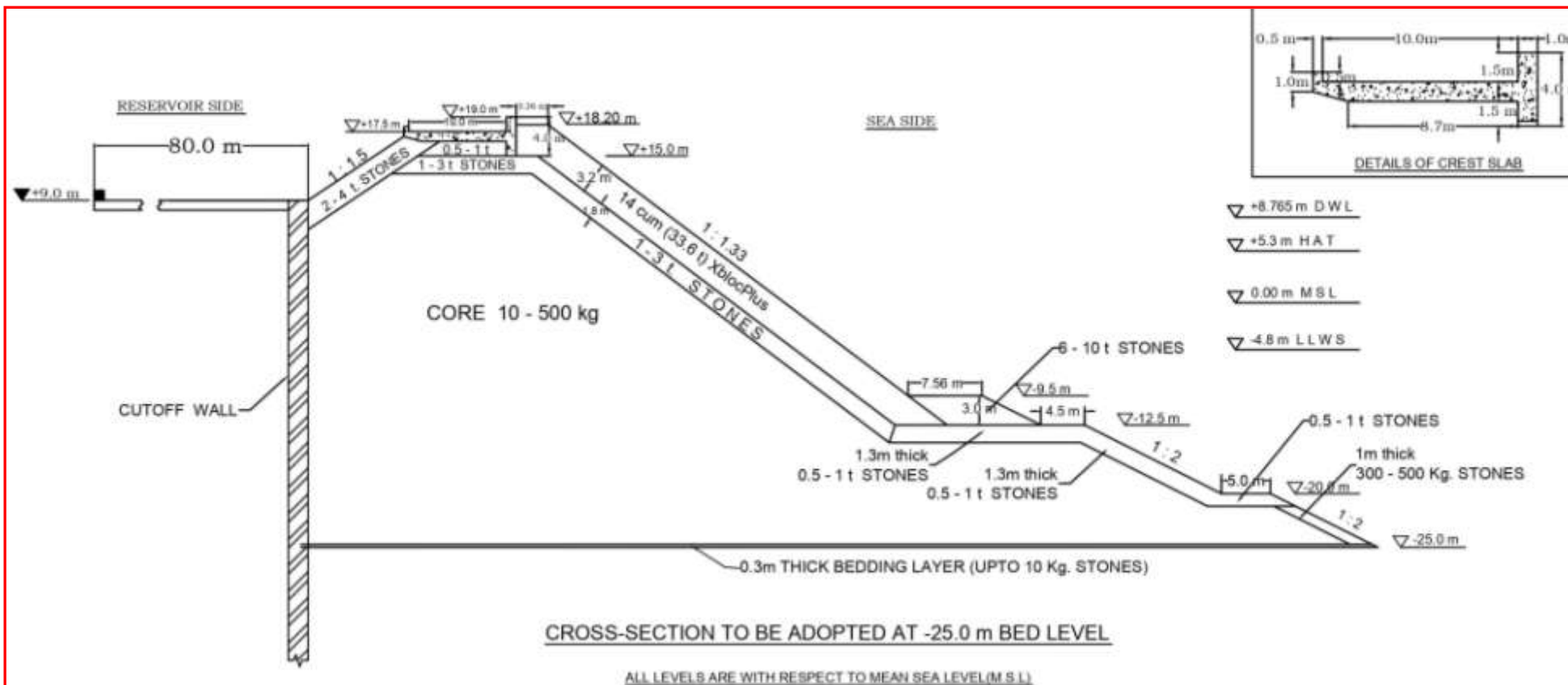
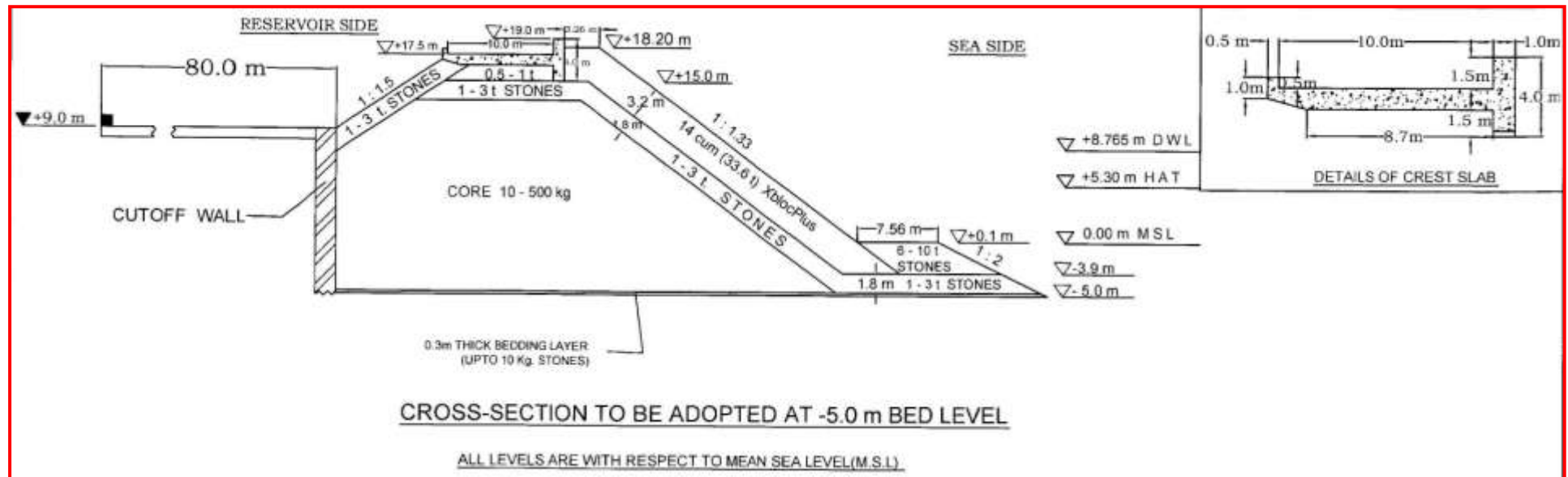


Figure 1: Index and location/layout plan of protection structure/breakwater for proposed main dam of Kalpasar Project in Gulf of Khambhat, Gujarat



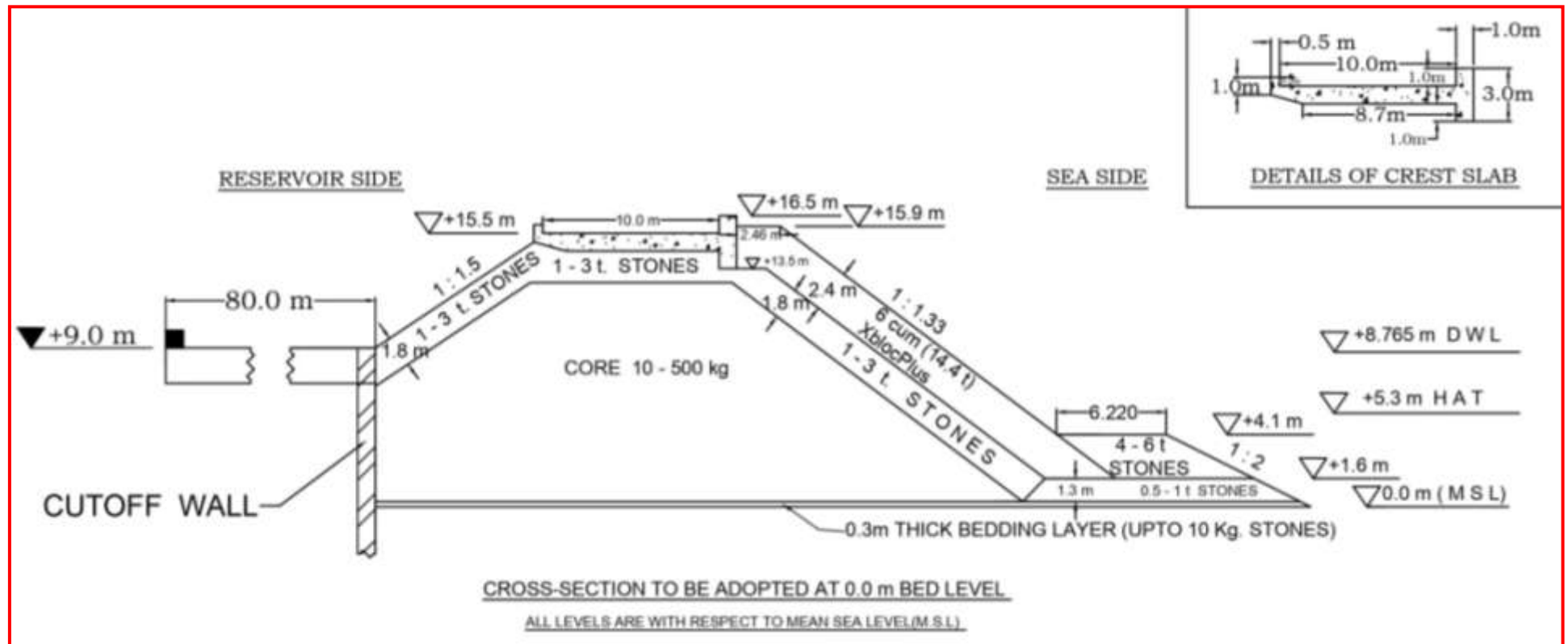
Section A-A

Figure 2: Cross-section of protection structure/breakwater for the proposed main dam of Kalpasar Project, Gujarat



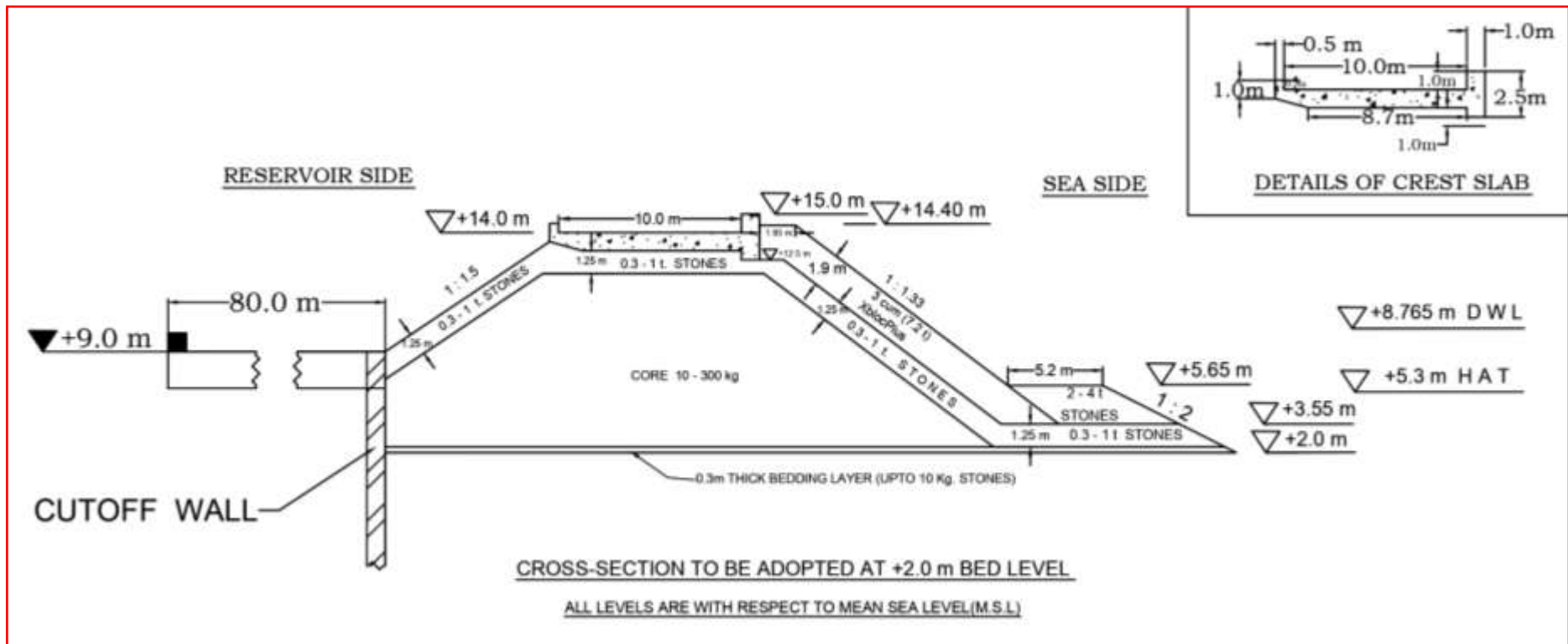
Section B-B

Figure 3: Cross-section of protection structure/breakwater for the proposed main dam of Kalpasar Project, Gujarat



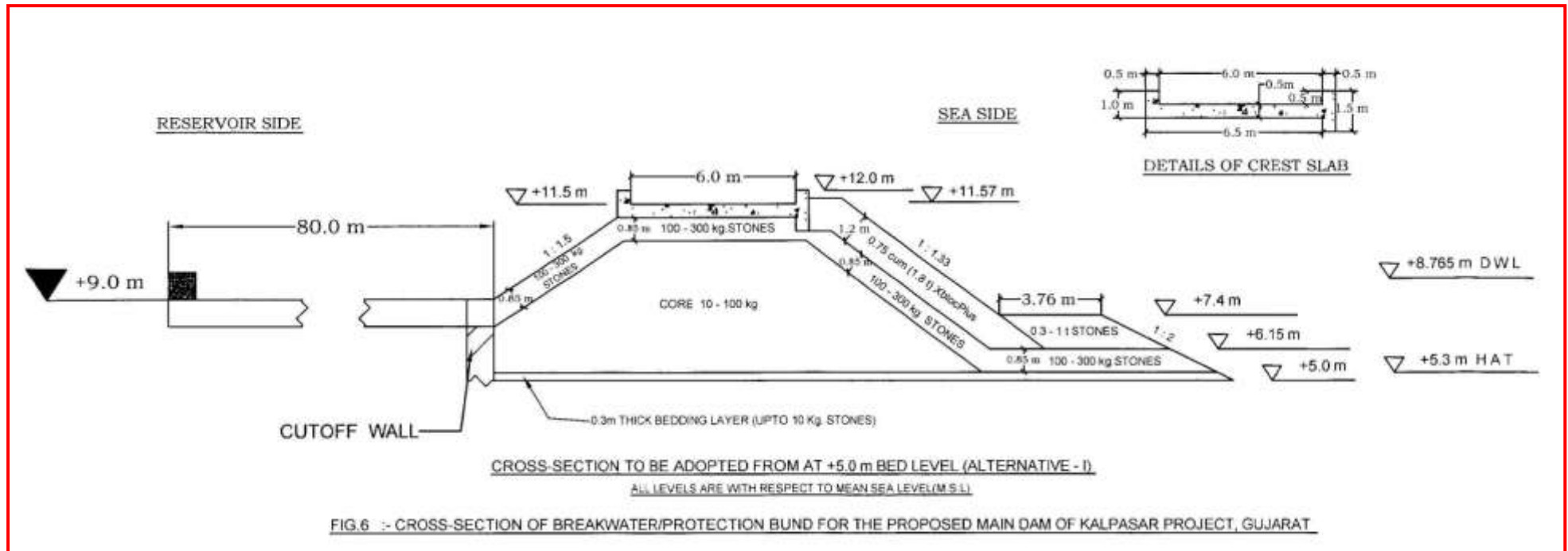
Section C-C

Figure 4: Cross-section of protection structure/breakwater for the proposed main dam of Kalpasar Project, Gujarat



Section D-D


Figure 5: Cross-section of protection structure/breakwater for the proposed main dam of Kalpasar Project, Gujarat



Section E-E

Figure 6: Cross-section of protection structure/breakwater for the proposed main dam of Kalpasar Project, Gujarat

Table 2: Dimensions of various parts of shore protection structure using XblocPlus based on design wave height



Unit volume	Design wave height	Unit height	Unit width	Unit length	Unit weight	Thickness of Armour layer	Packing density	Concrete volume	Placement Distance horizontal	Placement distance up-slope	Porosity of armour layer	Rock grading for underlayer	Thickness under layer
V [m ³]	H _d [m]	L1 [m]	L2 [m]	L3 [m]	W [t]	h [m]	N [1/100m ²]	[m ³ /m ²]	D _x [m]	D _y [m]	[%]	[t]	f [m]
0.75	3.02	0.75	1.51	1.91	1.8	1.2	63.7	0.48	1.66	0.95	60.3	0.06 - 0.3	0.8
1	3.33	0.83	1.66	2.10	2.4	1.3	52.6	0.53	1.82	1.04	60.3	0.06 - 0.3	0.8
1.5	3.81	0.95	1.90	2.41	3.6	1.5	40.1	0.60	2.09	1.19	60.3	0.06 - 0.3	0.8
2	4.19	1.04	2.09	2.65	4.8	1.7	33.1	0.66	2.30	1.32	60.3	0.3 - 1.0	1.3
2.5	4.51	1.12	2.25	2.85	6.0	1.8	28.5	0.71	2.47	1.42	60.3	0.3 - 1.0	1.3
3	4.80	1.19	2.39	3.03	7.2	1.9	25.3	0.76	2.63	1.51	60.3	0.3 - 1.0	1.3
4	5.28	1.31	2.63	3.34	9.6	2.1	20.9	0.83	2.89	1.66	60.3	0.3 - 1.0	1.3
5	5.69	1.42	2.83	3.59	12.0	2.3	18.0	0.90	3.12	1.78	60.3	0.3 - 1.0	1.3
6	6.04	1.50	3.01	3.82	14.4	2.4	15.9	0.96	3.31	1.90	60.3	1.0 - 3.0	1.8
7	6.36	1.58	3.17	4.02	16.8	2.5	14.4	1.01	3.49	2.00	60.3	1.0 - 3.0	1.8
8	6.65	1.66	3.31	4.20	19.2	2.7	13.2	1.05	3.64	2.09	60.3	1.0 - 3.0	1.8
9	6.92	1.72	3.45	4.37	21.6	2.8	12.2	1.09	3.79	2.17	60.3	1.0 - 3.0	1.8
10	7.16	1.78	3.57	4.53	24.0	2.9	11.3	1.13	3.93	2.25	60.3	1.0 - 3.0	1.8
12	7.61	1.89	3.79	4.81	28.8	3.0	10.0	1.20	4.17	2.39	60.3	1.0 - 3.0	1.8
14	8.01	1.99	3.99	5.06	33.6	3.2	9.1	1.27	4.39	2.51	60.3	1.0 - 3.0	1.8
16	8.38	2.09	4.17	5.29	38.4	3.3	8.3	1.33	4.59	2.63	60.3	1.0 - 3.0	1.8
18	8.71	2.17	4.34	5.50	43.2	3.5	7.7	1.38	4.77	2.73	60.3	3.0 - 6.0	2.4
20	9.03	2.25	4.50	5.70	48.0	3.6	7.1	1.43	4.95	2.83	60.3	3.0 - 6.0	2.4

Figure 7: Technical specification of XblocPlus armour units

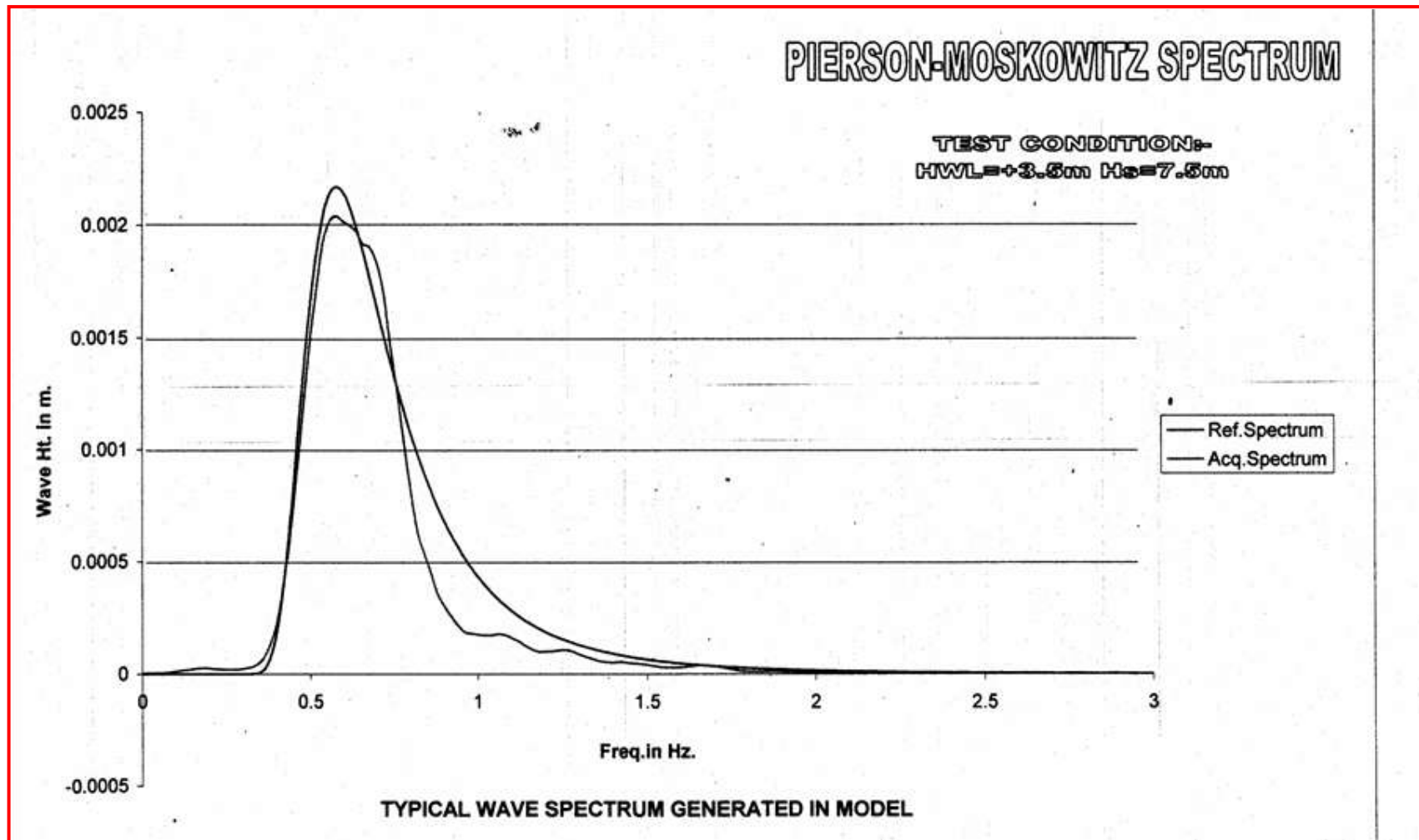


Figure 8: Typical Wave Spectrum

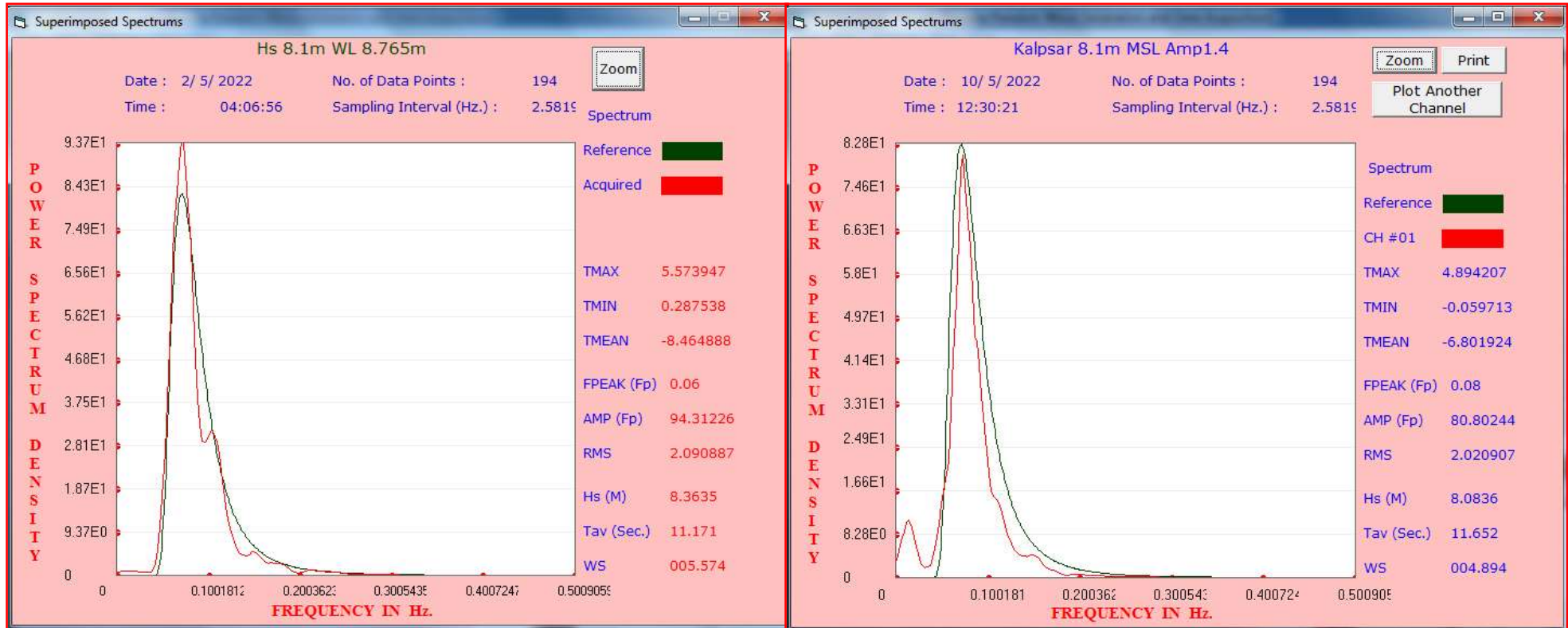


Figure 9 : Typical Wave Spectrum Generated in the Model



Photo 1 : Wave flume Laboratory facilities at CWPRS



Photo 2 : RSWG with Servo Actuator



Photo 3 : Wave basin (45 m x 11 m x 1.1 m)



Photo 4 : Control room with wave data acquisition System

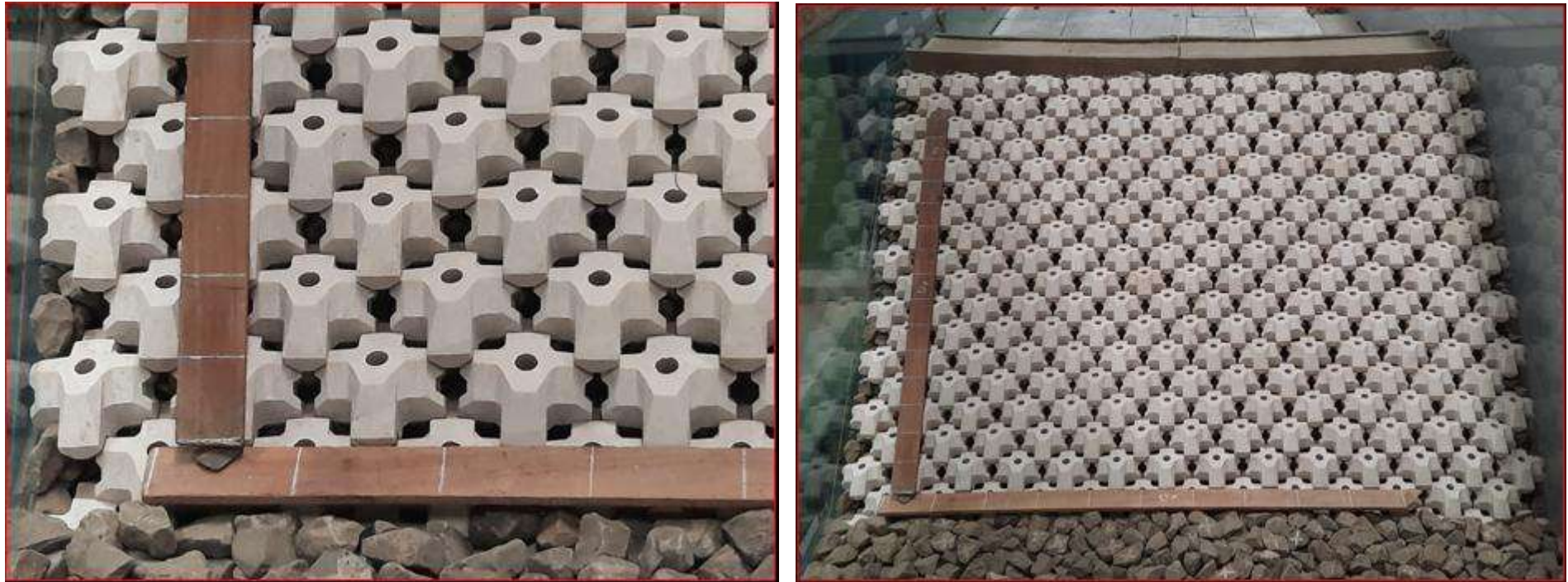


Photo 5 : Placement of XblocPlus model units in the wave flume at -25 m bed level

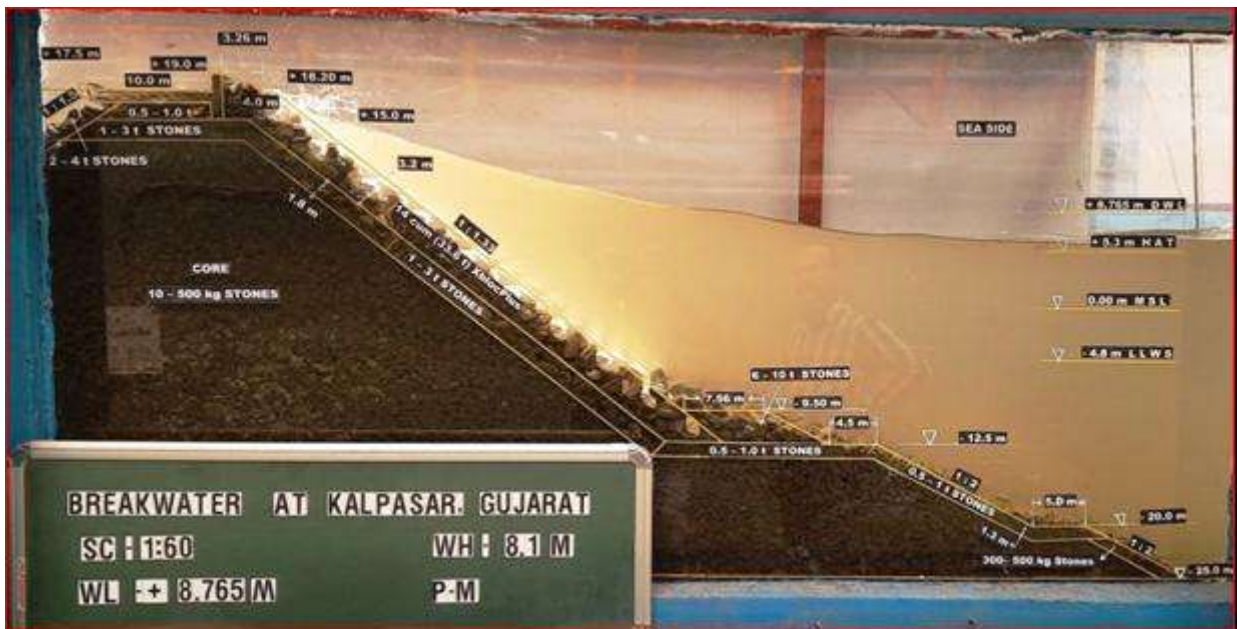


Photo 6 : Wave action on the armour of breakwater cross-section at -25.0 m bed level during significant wave height (H_s) of 8.1 m at Design Water Level (DWL) of +8.765 m



Photo 7 : Wave action on the armour of breakwater cross-section at -25.0 m bed Level during significant wave height (H_s) of 8.1 m at Highest Astronomical Tide (HAT) Level of +5.3 m



Photo 8 : Wave action on the armour of breakwater cross-section at -25.0 m bed level during significant wave height (H_s) of 8.1 m at Mean Sea Level (MSL) Level of 0.0 m



Photo 9 : Wave action on the armour of breakwater cross-section at -25.0 m bed level during significant wave height (H_s) of 8.1 m at Lowest Low Water Level (LLWL) of -4.8 m



Photo 10 : Placement of XblocPlus model units in the wave flume at 0.0 m bed level



Photo 11 : Wave action on the armour of breakwater cross-section at 0.0 m bed level during breaking wave height (H_s) of 6.84 m at Design Water Level (DWL) of +8.765 m

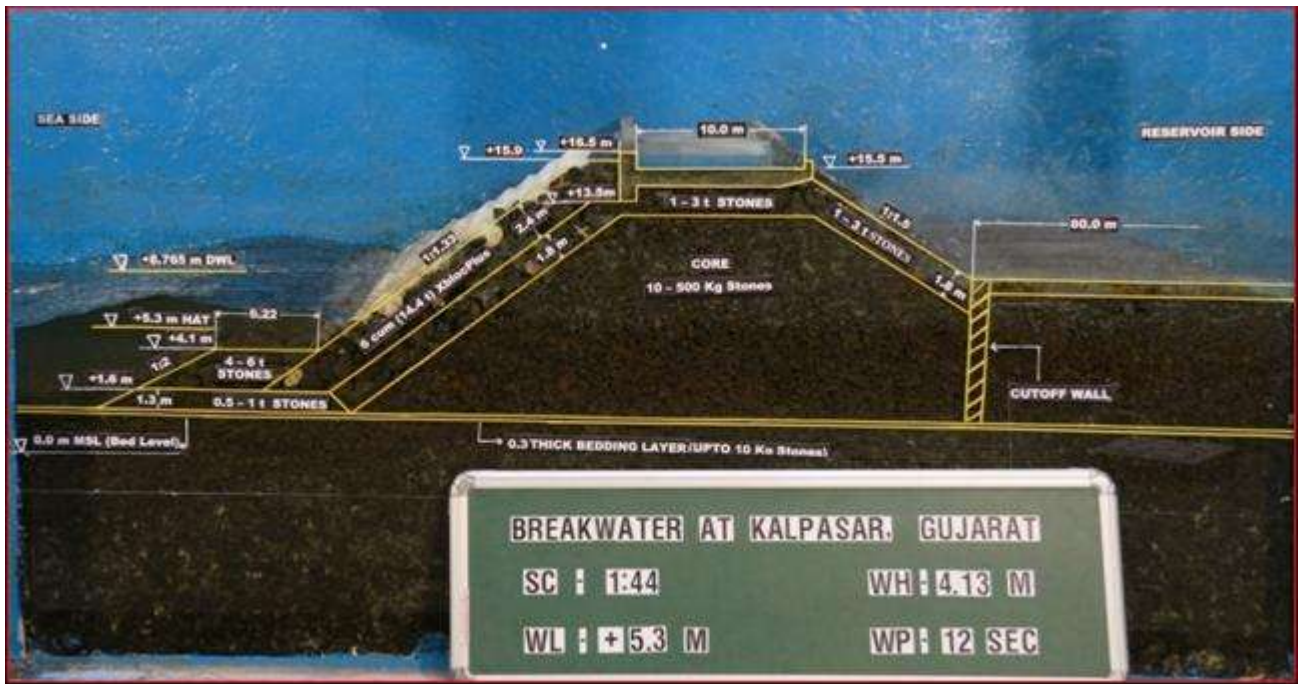


Photo 12 : Wave action on the armour of breakwater cross-section at 0.0 m bed Level during significant wave height (Hs) of 4.13 m at Highest Austronomical Tide (HAT) Level of +5.3 m



Photo 13 : Wave action on the armour of breakwater cross-section at +2.0 m bed level during breaking wave height (H_s) of 5.3 m at Design Water Level (DWL) of +8.765 m