REPORT DOCUMENTATION SHEET

Technical Report No. **5453**	Date: January 2017

Title : **DESK AND WAVE FLUME STUDIES FOR THE CONFIRMATION OF BREAKWATER CROSS-SECTIONS FOR THE TUNA FISHERY HARBOUR AT THIRUVOTTRIYUR KUPPAM IN TIRUVALLUR DISTRICT, TAMIL NADU**

Officers Responsible for Conducting the Studies:

S/Shri A.V. Mahalingaiah, Scientist-D, B.R.Tayade, Scientist-C, N.V.Gokhale, Scientist-B, S.P.Jagtap, Assistant Research Officer, G.R.Pardeshi and Ganesh N.S. Research Assistants under the overall supervision of Shri M. D. Kudale, Additional Director.

Name and Address of Organization Conducting the Studies:

Coastal Hydraulic Structure Division
Coastal and Offshore Engineering Laboratory
Central Water and Power Research Station, Pune, India

Name and Address of Authority Sponsoring the Studies :

The Chief Engineer
Fisheries Department,
D.M.S. Compound,Teynampet,
Chennai, Tamil Naduï 600 006

Synopsis:

The Department of Fisheries, Government of Tamil Nadu has proposed to develop Tuna Fishery harbour at Thiruvottriyur Kuppam, Tamil Nadu. The layout plan of the breakwaters for the development of Tuna Fishery harbour was finalized based on mathematical model studies carried out by M/s Virgo Aqua Consulting engineers. The proposed layout consists of North breakwater of 852 m and South breakwater of 1088 m length. This report describes the desk and wave flume studies for the confirmation of breakwater cross-sections for the Tuna Fishery Harbour at Thiruvottriyur Kuppam in Tamil Nadu. The cross section consists of 2 t tetrapods from the root of breakwater to -2 m bed level for both the breakwaters. 4 t tetrapods in the armour placed at 1:2 slope from - 2 m bed level to -4 m bed level, 6 t tetrapods in the armour placed at 1:2 slope from - 4 m bed level to -6 m bed level, 8 t tetrapods in the armour placed at 1:2 slope from - 6 m bed level to -8 m bed level, 8 t tetrapods in the armour for North breakwater roundhead portion at -7.5 m bed level and 10 t tetrapods in the armour for South breakwater roundhead portion at ï 8.5 m bed level.

Keywords: Armour unit, Breakwater, Breaking Waves, Fishery Harbour, Hydraulic Stability, Tetrapods, Tides, Toe Berm, Wave Flume etc.

C O N T E N T S

SUMMARY

1.0 INTRODUCTION

2.0 SCOPE OF STUDIES

3.0 SITE CONDITIONS

4.0 DESIGN CONDITIONS

4.1 Tidal Levels

4.2 Design Wave Conditions

5.0 DESIGN OF BREAKWATER CROSS-SECTIONS

5.1 Cross-section of breakwaters from root to - 2m bed level (Section A-A)

5.2 Cross-section of breakwaters from - 2 m to - 4 m bed level (Section B-B)

5.3 Cross-section of breakwaters from - 4 m to - 6 m bed level (Section C-C)

5.4 Cross-section of breakwaters from - 6 m to ï 8 m bed level (Section D-D)

5.5 Cross-section of Roundhead portion of North breakwater at-7.5 m bed level (Section E-E)

5.6 Cross-section of Roundhead portion of South breakwater at-8.5 m bed level (Section F-F)

6.0 HYDRAULIC MODEL STUDIES

6.1 Model Scale

6.2 Compensation for Weight of Stones

6.3 HYDRAULIC MODEL TESTS

6.3.1 Wave flume test procedure

6.3.2 Test Conditions

7.0 DISCUSSIONS OF RESULTS

8.0 CONCLUDING REMARKS RECOMMENDATIONS

FIGURES & PHOTOGRAPHS

LIST OF FIGURES

Fig.1 Location map of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu

Fig.2 Layout plan of proposed breakwaters for the development of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu

Fig.3 Cross-section of breakwaters from the root to - 2m bed level (Section A-A)

Fig.4 Cross-section of breakwaters from -2 m to -4.0 m bed level (Section B-B)

Fig.5 Cross-section of breakwaters from -4 m to -6.0 m bed level (Section C-C)

Fig.6 Cross-section of breakwaters from -6 m to - 8m bed level (Section D-D)

FIG.7 Cross-section of Roundhead portion of North breakwater at -7.5 m bed level (Section E-E)

Fig.8 Cross-section of Roundhead portion of South breakwater at -8.5 m bed level (Section F-F)

Fig.9 Specification of 2 t Tetrapods

Fig.10 Specification of 4 t Tetrapods

Fig.11 Specification of 6 t Tetrapods

Fig.12 Specification of 8 t Tetrapods

Fig.13 Specification of 10 t Tetrapods

LIST OF PHOTOGRAPHS

Photo-1 Wave flume hangar at CWPRS, Pune

Photo-2 Wave flume facilities inside the hangar

Photo-3 Wave action on armour layer of breakwater consisting of 8 t Tetrapods at -8.0 m bed level with +1.5 m water level and 5.5 m wave height

Photo-4 Wave action on armour layer of breakwater consisting of 8 t Tetrapods at -8.0 m bed level with +1.5 m water level and 5.3m wave height

Photo-5 Wave action on armour layer of breakwater consisting of 8 t Tetrapods at -8.0 m bed level with 0.0m water level and 5.0 m wave height

Photo-6 Wave action on armour layer of breakwater consisting of 8 t tetrapods at -8.0 m bed level with 0.0 m water level and 4.5 m wave height

GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES, RIVER DEVELOPMENT & GANGA REJUVENATION
CENTRAL WATER AND POWER RESEARCH STATION
KHADAKWASLA, PUNE - 411 024

Technical Report No. 5453 **January, 2017**

DESK AND WAVE FLUME STUDIES FOR THE CONFIRMATION OF BREAKWATER CROSS-SECTIONS FOR THE TUNA FISHERY HARBOUR AT THIRUVOTTRIYUR KUPPAM IN TAMIL NADU

1.0 INTRODUCTION

The Department of Fisheries, Government of Tamil Nadu has proposed to develop Tuna fishery harbour at Thiruvottriyur Kuppam in the district of Tiruvallur, Tamil Nadu. Thiruvottriyur is located within the city limits of Chennai at 13.16°N latitude and 80.3° E longitude (Fig.1). Thiruvottriyur is one of the oldest habitations by the sea, has a diverse residential population due to industrial units, trading activity and nearby fishing hamlets. The area is easily accessible by Metropolitan Transport Corporation (MTC) by road and also served by Thiruvottriyur railway station of the Chennai Suburban Railway Network. The Layout and breakwater designs have been evolved by M/s Virgo Aqua Consulting Engineers. In order to understand wave conditions, wave tranquility studies were carried out. Two breakwaters are proposed to achieve the required tranquility in the harbor and an optimum layout with easterly opening was suggested by the consultants. The layout consists of 1088 m long South breakwater extending up to -8.5 m contour and North breakwater of 852 m length extending up to -7.5 m contour as shown in Fig.2. About 100 m spacing is proposed at the entrance of the harbour between the Southern breakwater head and Northern breakwater head for the entry of boat. Further, Department of Fisheries, Government of Tamil Nadu requested CWPRS for confirmation of breakwaters cross sections through wave flume studies for their hydraulic stability and suitability. Accordingly, the desk and wave flume studies are carried out to evolve the design of cross-sections of breakwaters at various bed levels. The details of desk and wave flume studies are presented in this technical report.

2.0 SCOPE OF STUDIES

The Chief Engineer, Department of Fisheries, Chennai has proposed to develop Tuna fishery harbour at Thiruvottriyur Kuppam in the District of Tiruvallur, Tamil Nadu. The scope of the studies is the confirmation of breakwaters cross sections for the Tuna fishery harbour, Tamil Nadu through desk and wave flume studies.

The present report describes the desk and wave flume studies for the confirmation of design of cross-sections of breakwaters at various bed levels for the proposed Tuna fishery harbour, Tamil Nadu.

3.0 SITE CONDITIONS

The proposed fishery harbour is situated at 13.16°N latitude and 80.3° E longitude in Thiruvottriyur, Tamil Nadu. It is an esplanade located on the shores of Bay of Bengal.

4.0 DESIGN CONDITIONS

4.1 Tidal Levels

According to data available for standard ports in Table-II of Indian Tide Table published by Survey of India, the tide levels for Chennai are as follows.

Mean High Water Level Springs	+1.15 m
Mean High Water Neaps	+0.84 m
Mean Low Water Level Springs	+0.14 m
Mean Low Water Level Neaps	+0.40 m
Indian Springs High Water Level	+1.52 m
Indian Springs Low Water Level (CD)	0.00 m

The tides are semi diurnal and average interval between high and low tides is about 6 hours. Since Tuna Fishery harbour at Thiruvottriyur Kuppam is located close to Chennai, the same tide levels as given above are adopted. For the design of breakwater cross-sections, High Water Level of + 1.50 m was considered for the wave flume studies.

4.2 Design Wave Conditions

The offshore wave climate off the project site at 13.16°N latitude and 80.3° E in the form of parametric quantities has been extracted from National Centre for Environmental Prediction (NCEP). The wave climate during the entire year indicates that the predominant wave directions in deep water are from NE, E and SE. The following design wave conditions were considered for evolving the design of breakwaters:

a) Zero order damage (i.e. Less than 1%) with the breaking waves of the order of 5.3 m at the High Water Level (HWL) of + 1.5 m.
b) First order damage (i.e. in between 1% to 5%) with the breaking waves of the order of 5.5 m at the High Water Level (HWL) of + 1.5 m.
c) The wave periods from 10 to 12 seconds.
d) The stability of the section was also assessed at low and intermediate water levels.

5.0 DESIGN OF BREAKWATER CROSS-SECTIONS

The proposed layout consists of Northern breakwater of 852 m and a Southern breakwater of 1088 m length. Desk studies have been conducted for evolving cross-sections at different bed levels based on empirical formulae, existing conditions at the site & previous in-house extensive wave flume studies conducted at CWPRS for hydraulic stability of breakwaters. The weight of armour units are basically evaluated based on Hudsonôs formula (as given below):

$$W = \frac{w_r . H_b^{\,3}}{K_D \times (Sr - 1)^3 . \cot\theta}$$

Where,

H_b = Breaking wave height
W = Weight of Armour
wr = Unit Weight of Armour
KD = Stability Coefficient for Breaking Wave Height
Sr = Specific Gravity of Armour relative to Water at the structure (wr/Ww)
Ww = Unit wt. of sea water
Cot d = Slope of armour

A conceptual design of breakwaters was evolved based on the desk studies. The design of cross-sections of breakwaters at different bed levels with tetrapods in the armour was finalized through wave flume studies. The cross sections at different bed levels are marked along the alignment of the breakwaters. The design cross-sections of breakwaters with tetrapods in armour at different bed levels were finalized through wave flume studies as shown in Figs. 3 to 8, considering the design wave condition at different bed levels. Design of these cross-sections at different bed levels are described below:

5.1 Cross-section of breakwaters from root to -2 m bed level (Section A-A) :

The section A-A is designed to provide from the root of the breakwaters up to -2 m bed level as shown in Fig.3. This section consists of 2 t tetrapods in the armour with 1:2 slope on sea side and 1.0 to 2.0 t stones in the leeside armour with 1:1.5 slope. The sea side toe consists of 0.5 to 1.0 t stones. The top level of the toe on the sea side is fixed at +1.0 m with 4 m wide toe-berm. A secondary layer consists of 100 to 300 Kg stones provided below the armour on seaside, leeside as well as crest. Core consists of 10 to 100 kg stones and a bedding layer of stones up to 10 kg weight is proposed. The top of the crest slab is at +4.0 m level with a crest width of 6 m. The top of parapet wall is fixed at + 5.0 m.

5.2 Cross-section of breakwaters from -2.0m bed level to -4.0m bed level (Section B-B) :

The section B-B is designed to provide from -2.0 m to - 4.0 m bed level and is shown in Fig.4. This section consists of 4 t tetrapods in the armour with 1:2 slope on sea side and 1.0 to 2.0 t stones in the leeside armour with 1:1.5 slope. The sea side toe consists of 2 to 3 t stones. The top level of the toe on the sea side is fixed at 0.0 m with 6 m wide toe-berm. A secondary layer consists of 300 to 500 kg stones is provided below the armour and crest whereas it consists of 100 to 200 Kg stones provided below leeside armour and sea side toe. Core consists of 10 to 100 kg stones and a bedding layer of stones up to 10 kg weight is proposed. The top of the crest slab is at +5.0 m level with a crest width of 6 m. The top of parapet wall is fixed at + 6.0 m.

5.3 Cross-section of breakwaters from -4.0m bed level to -6.0m bed level (Section C-C) :

The section C-C is designed to provide from -4.0 m to - 6.0 m bed level and is shown in Fig.5. This section consists of 6 t tetrapods in the armour with 1:2 slope on sea side and 1.0 to 2.0 t stones in the leeside armour with 1:1.5 slope. The sea side toe consists of 2 to 3 t stones. The top level of the toe on the sea side is fixed at -1.0 m with 8 m wide toe-berm. A secondary layer consists of 300 to 500 kg stones is provided below the armour, toe berm and crest whereas it consists of 100 to 300 Kg stones provided below leeside armour. Core consists of 10 to 100 kg stones and a bedding layer of stones up to 10 kg weight is proposed. The top of the crest slab is at +6.0 m level with a crest width of 6 m. The top of parapet wall is fixed at + 7.0 m.

5.4 Cross-section of breakwaters from -6.0m bed level to -8.0m bed level (Section D-D) :

The section D-D is designed to provide from -6.0 m to - 8.0 m bed level and is shown in Fig.6. This section consists of 8 t tetrapods in the armour with 1:2 slope on sea side and 1.0 to 2.0 t stones in the leeside armour with 1:1.5 slope. The sea side toe consists of 2 to 3 t stones. The top level of the toe on the sea side is fixed at -1.0 m with 8 m wide toe-berm. A secondary layer consists of 300 to 500 kg stones are provided below the armour, toe berm and crest whereas it consists of 100 to 300 Kg stones provided below leeside armour. Core consists of 10 to 100 kg stones and a bedding layer of stones up to 10 kg weight is proposed. The top of the crest slab is at +6.0 m level with a crest width of 6 m. The top of parapet wall is fixed at + 7.0 m.

5.5 Cross-section of roundhead portion of North breakwater at – 7.5 m bed level (Section E-E)

The section E-E is designed to provide for roundhead portion of North breakwater at -7.5.0 m bed level as shown in Fig.7. This section consists of 8 t tetrapods in the armour on 1:2 slope on both sides. The top level of the toe is fixed at -1.0 m with 10.0 m wide toe-berm consisting of 2 to 3 t stones on both sides. A secondary layer consists of 300 to 500 Kg stones provided on both the sides

below the armour, crest and the toe. Core consists of 10 to100 kg stones and a bedding layer of stones up to 10 kg weight is proposed. The top of the crest slab is at + 7.0 m level, with a clear carriage-way of 10.0 m. The top of the parapet wall is fixed at +8.0 m.

5.6 Cross-section of roundhead portion of South breakwater at – 8.5 m bed level (Section F-F)

The section F-F is designed to provide for roundhead portion of south breakwater at -8.5 m bed level as shown in Fig.8. This section consists of 10 t tetrapods in the armour on 1:2 slope on both sides. The top level of the toe is fixed at -1.0 m with 10.0 m wide toe-berm consisting of 2 to 3 t stones on both the sides. A secondary layer consists of 300 t to 500 kg stones provided on both the sides below the armour, crest and below the toe. Core consists of 10 to100 kg stones and a bedding layer of stones up to 10 kg weight is proposed. The top of the crest slab is at + 7.0 m level, with a clear carriage-way of 10.0 m. The top of the parapet wall is fixed at +8.0 m.

6.0 HYDRAULIC MODEL STUDIES

6.1 Model Scale

The model tests for the design of breakwaters were carried out in a wave flume by reproducing the section to a Geometrically Similar scale of 1:37. The bed level of the representative section was at -8.0 m. The model was based on Froude's criterion of similitude. The Froude's law considers that gravity forces are dominant and other forces such as viscous forces, capillary forces etc., are insignificant. As per Froude's criterion, the various scales obtained are as follows:

Model scale 1:37		
Length	- L	= 1:37
Area	- L^2	= 1:1,369
Volume	- L^3	= 1:50,653
Time	- $L^{1/2}$	= 1:6.08
Velocity	- $L^{1/2}$	= 1:6.08

6.2 Compensation for weight of stones

The density of stones in the prototype was considered as 2.6 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 weight of stones used in the model was compensated for these density differences by applying a weight factor, which was worked out as below:

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

$W_2 = 0.6678\, W_1$

W_1 = Weight of stones with density -- 2.6 t/cum

W_2 = Weight of stones with density -- 2.80 t/cum

Hence considering the weight factor of 0.6678, the weights of stones in the model were worked out.

6.3 HYDRAULIC MODEL TESTS

6.3.1 Wave flume test procedure

The trunk section of breakwater was tested under normal attack of waves in 2-D wave flume for its hydraulic stability. The section was constructed to a Geometrically Similar model scale in the flume. The number of tetrapods provided in double layer, on the seaside as armour and number of stones in the toe were counted initially, before starting the test. After conducting the tests for one-hour duration, the number of tetrapods displaced from its original position was 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. The damage is expressed as percentage of number of stones displaced from their position.

6.3.2 Test Conditions

The test conditions considered for the breakwater section are as follows :

1. Section was tested for wave height of 5.3 m at High Water Level (HWL) of +1.5 m and Low Water Level (LWL) of 0.0 m for zero order damage (0-1%).
2. Section was also tested for the breaking waves of the order of 5.5 m at High Water Level (HWL) of +1.5 m.
3. Trunk section was tested for normal attack of waves.

The trunk section at -8.0 m bed level is shown in Fig.6. The section was constructed with a Geometrically Similar model scale of 1:37 in the wave flume. The 8 t tetrapods are placed in the armour with 1:2 slope on sea side and 1 to 2 t stones in the armour with 1:1.5 slope on lee side. The top level of the toe is fixed at -1.0 m with 8 m wide toe-berm consisting of 2 to 3 t stones on sea side and of 1 to 5 t stones on lee side. A secondary layer consists of 300kg to 500kg stones provided below the tetrapods armour units. 100 to 300 Kg stones were provided below the leeside armour. Core consists of 20 to 100 kg stones and a bedding layer of stones up to 10 kg weight is proposed. The top of the crest slab is fixed at +6.0 m level and parapet top is at +7.0m, with a clear crest width of 6.0 m. The bed slope of 1:100 was reproduced in front of the structure.

Test was carried out with wave height of 5.3 m at High water level (HWL) of +1.5 m for one-hour duration (corresponding to 6.08 hours in prototype). It was also observed that the highest wave run-up was just above +6.30 m and rundown was up to -0.50 m. The waves were breaking on the armour causing no damage to armour and also to toe-berm consisting of 2 to 3 t stones on 1:2 slope.

The test was conducted with wave height of 5.5 m at High Water Level (+1.5 m). There was marginal splashing and no overtopping of the waves. It was also observed that the highest wave run-up was just above +6.5 m and rundown was up to -0.74 m. The waves were breaking on the armour causing no damage to toe-berm.

Another test was also conducted with wave height of 5.0 m at Low Water Level of 0.0 m. It was observed that marginal splashing and no over topping above the

+7.0 m crest level. It was also observed that the highest wave run-up was just above + 5.5 m and rundown was up to - 1.00 m. The waves were breaking on the armour causing no damage to the armour and toe-berm.

Typical photographs of wave flume tests are given in Annexure - 1.

7.0 DISCUSSIONS OF RESULTS

The design of cross-sections of breakwaters at various bed levels have been evolved based on desk and wave flume studies. It is presumed that, the seabed strata below the construction of breakwaters are adequate to sustain the load of the breakwater structures. The cross-sections of trunk portion and roundhead are shown in Figs. 3 to 8. The specifications of 2 t, 4 t 6 t 8 t and 10 t tetrapods are shown in Figs. 9 to 13.

8.0 CONCLUDING REMARKS AND RECOMMENDATIONS

Based on the desk and wave flume studies carried out for the design of cross-sections for the breakwaters, the following concluding remarks are drawn :

1. The design of cross-sections of breakwaters at various bed levels have been evolved at different bed levels and are shown in Figs. 3 to 8. These sections are stable under the design wave conditions and may be adopted for the construction at the site.

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. The tetrapods of 2 t, 4 t, 6 t, 8 t and 10 t weights in double layer in the armour of breakwaters should be placed with correct slopes as specified, as per the packing density of 117 blocks/ 100 sqm, 74 blocks/ 100 sqm, 56 blocks/ 100 sqm, 47 blocks/ 100 sqm and 40 blocks/ 100 sqm respectively.

4. There should not be any deviation from the design during the construction of the breakwaters in respect of the levels, slopes and the weights of stones.

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 breakwaters as and when damage occurs may be undertaken.

6. The grading of the stones to be used in the breakwaters construction should be as follows :

2-3 t stones	- 50% stones should be higher than 2.5 t
1-2 t stones	- 50% stones should be higher than 1.5 t
0.5-1 t stones	- 50% stones should be higher than 0.75 t
300-500 kg stones	- 50% stones should be higher than 400 kg
100-300 kg stones	- 50% stones should be higher than 200 kg

7. The construction phasing may be adhered, in order to have a safety and economy of the project. The construction of the breakwaters may not be possible during one season. As such, a temporary roundhead may be provided wherever the work is curtailed.

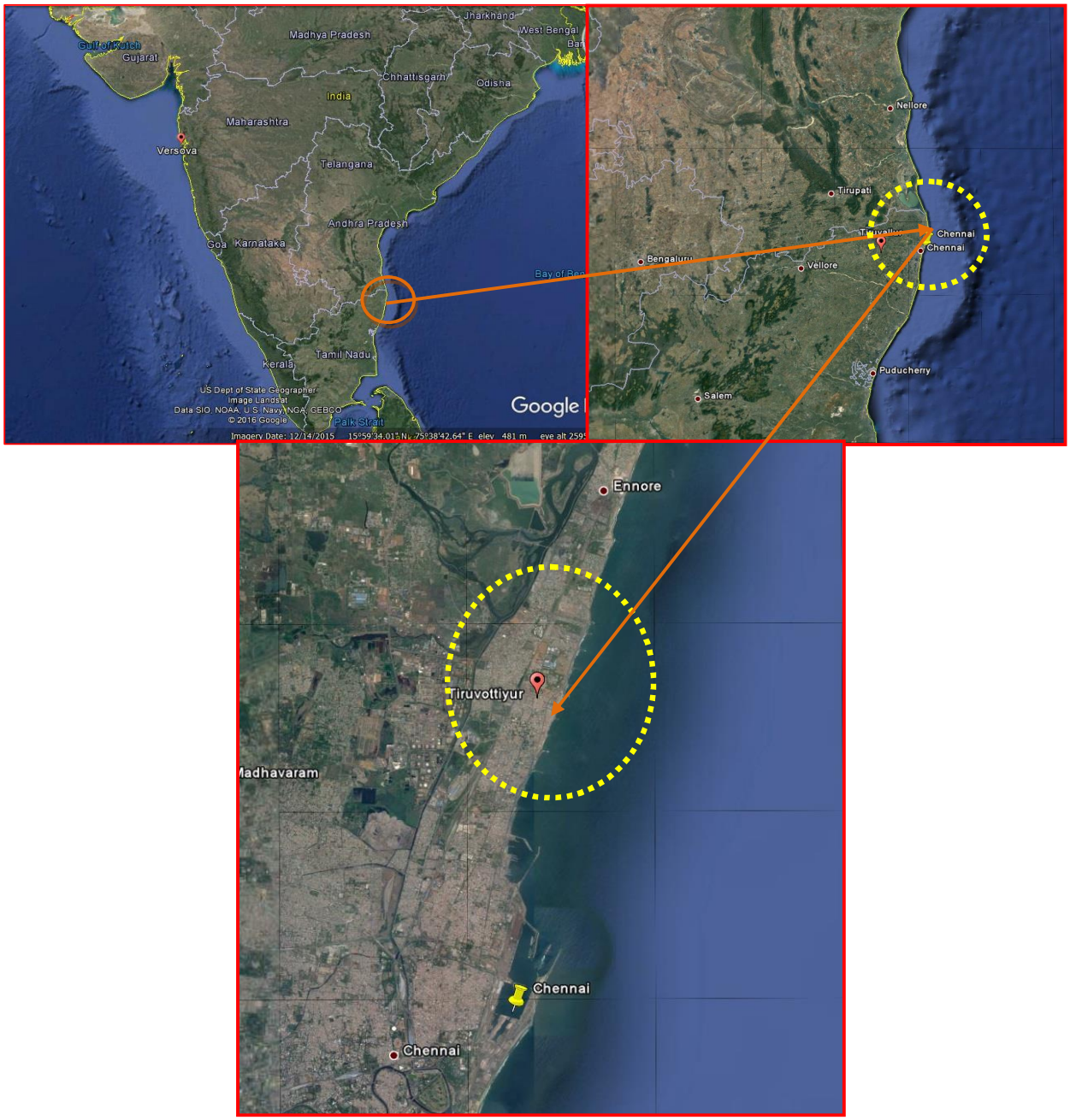


Fig. 1: Location map of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu

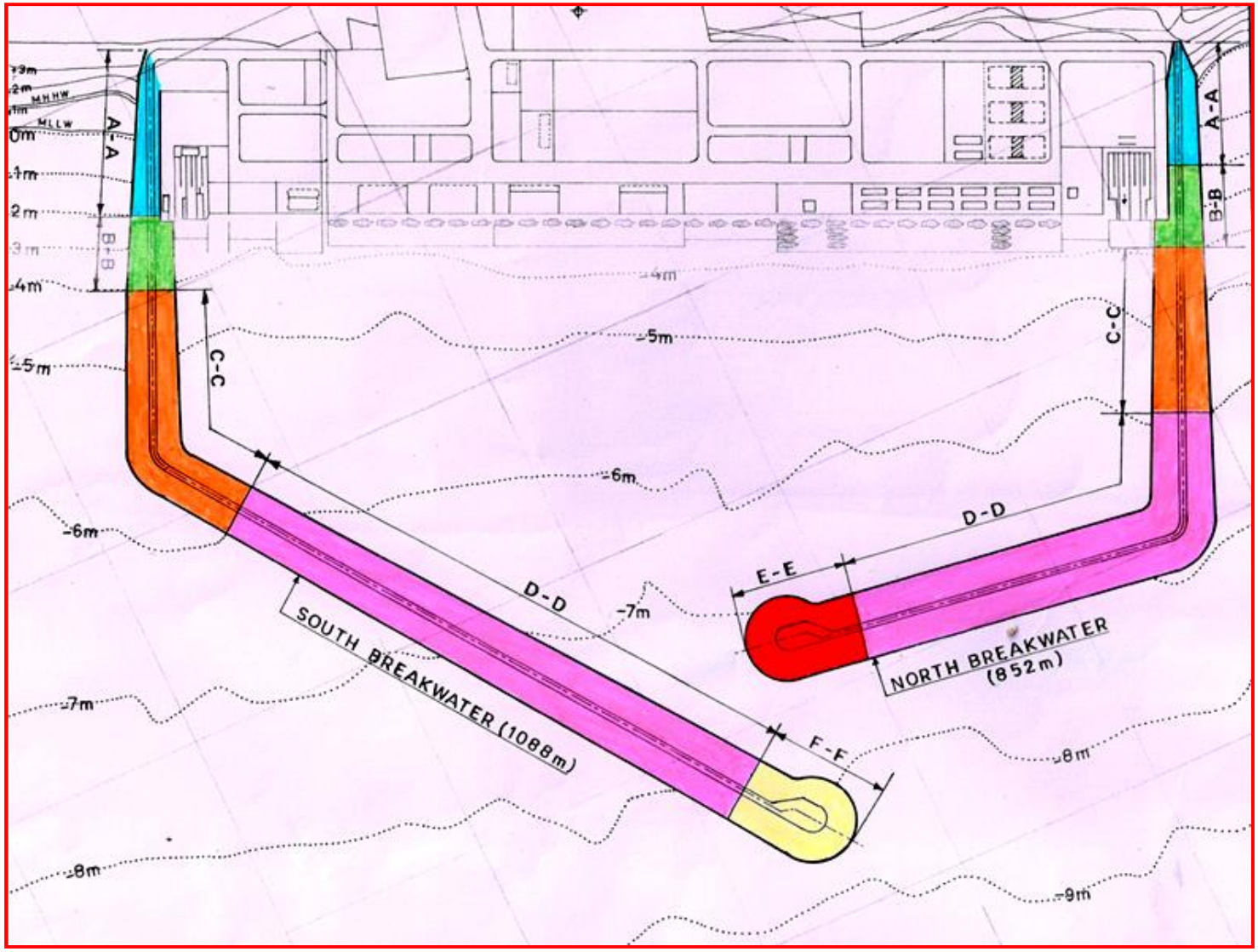


Fig. 2: Layout Plan of Breakwaters for the development of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu

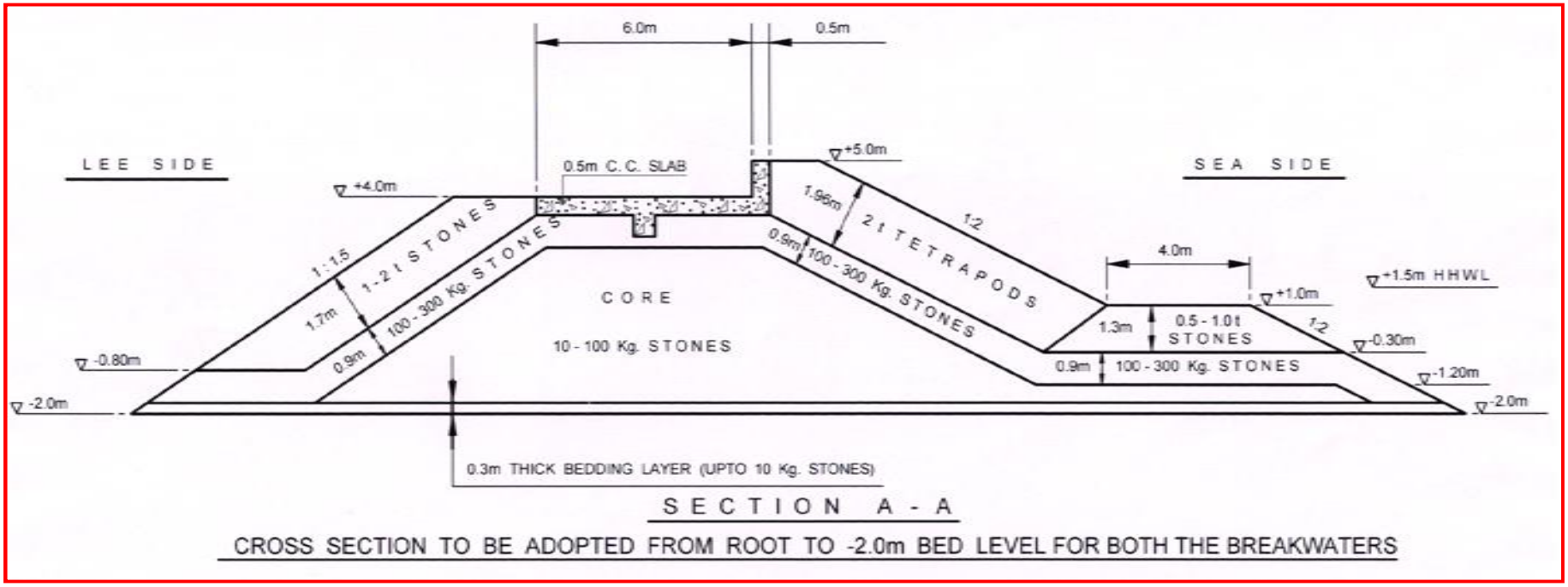


Fig. 3 Cross-section of breakwater for the development of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu

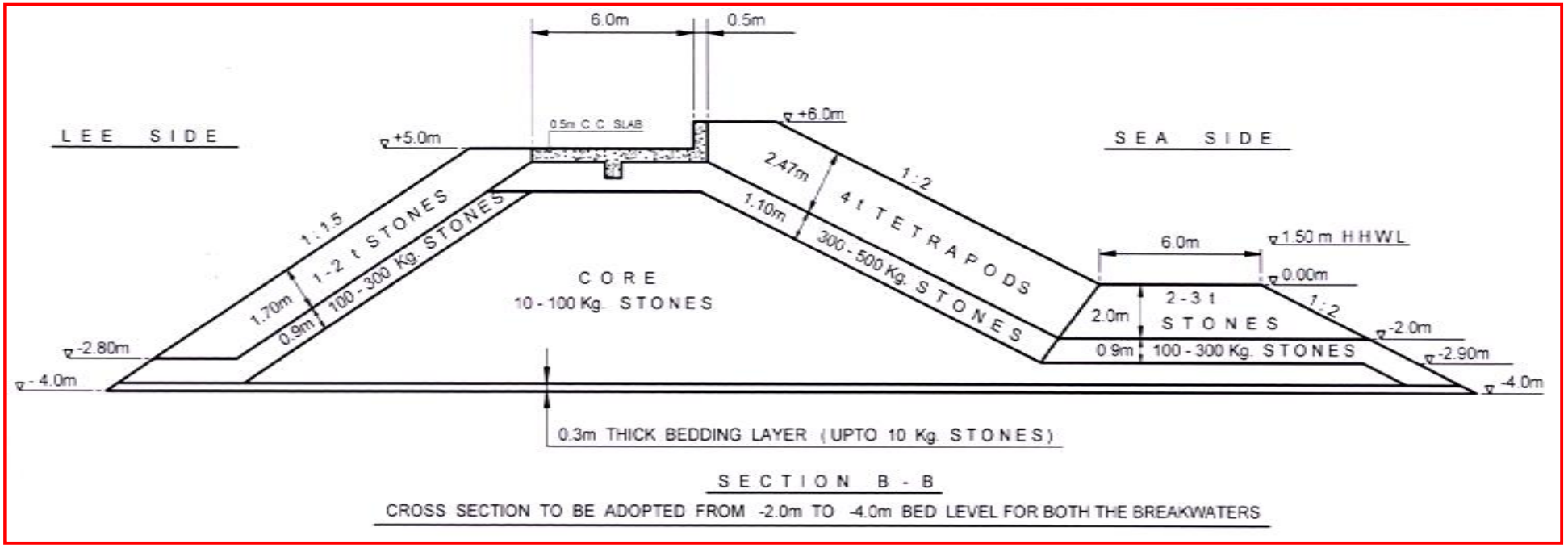


Fig.4 Cross-section of breakwater for the development of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu

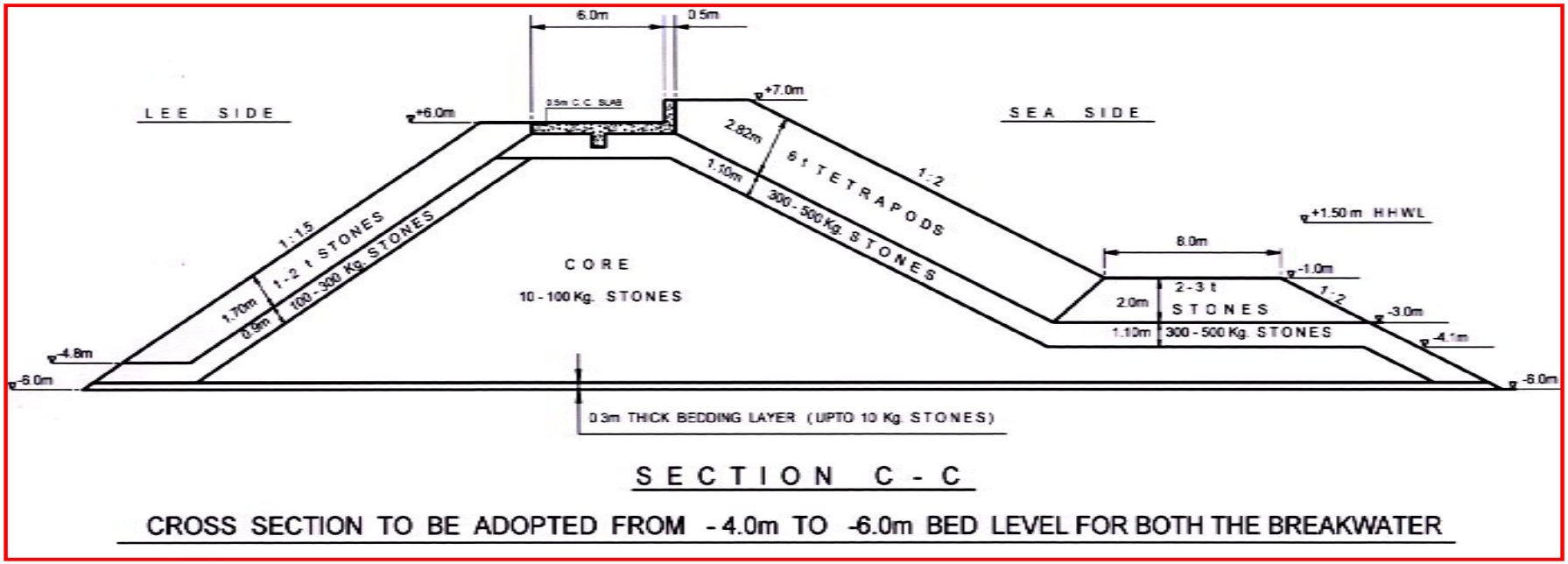


Fig.5: Cross-section of breakwater for the development of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu

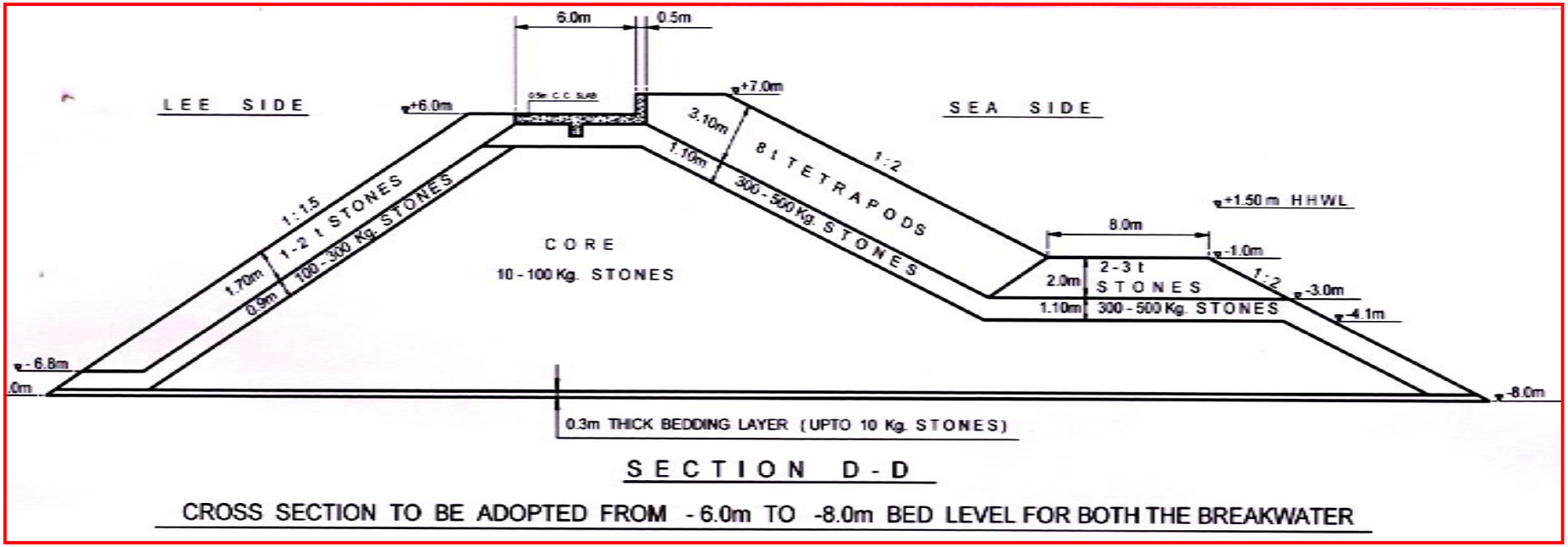


Fig.6: Cross-section of breakwater for the development of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu

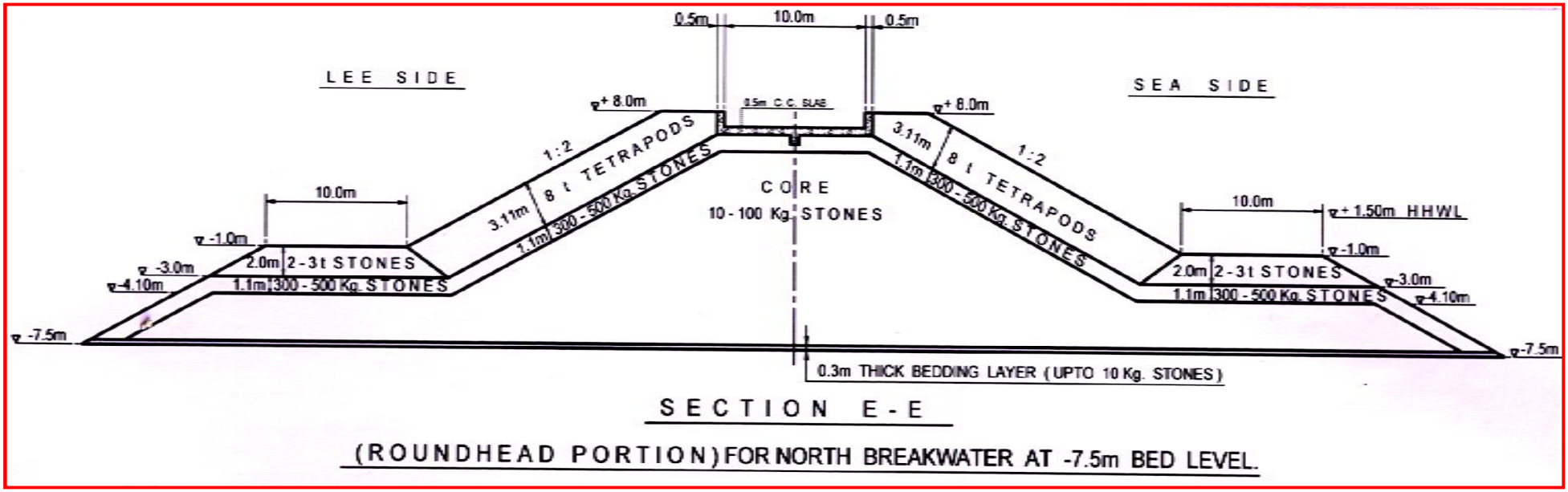


Fig.7 Cross-section of breakwater for the development of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu

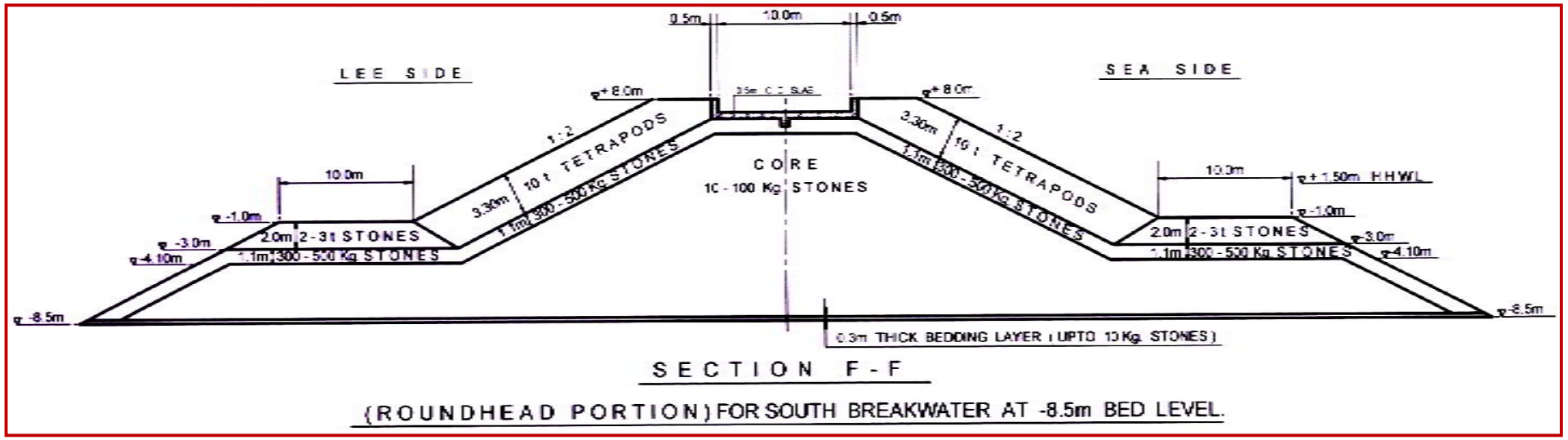
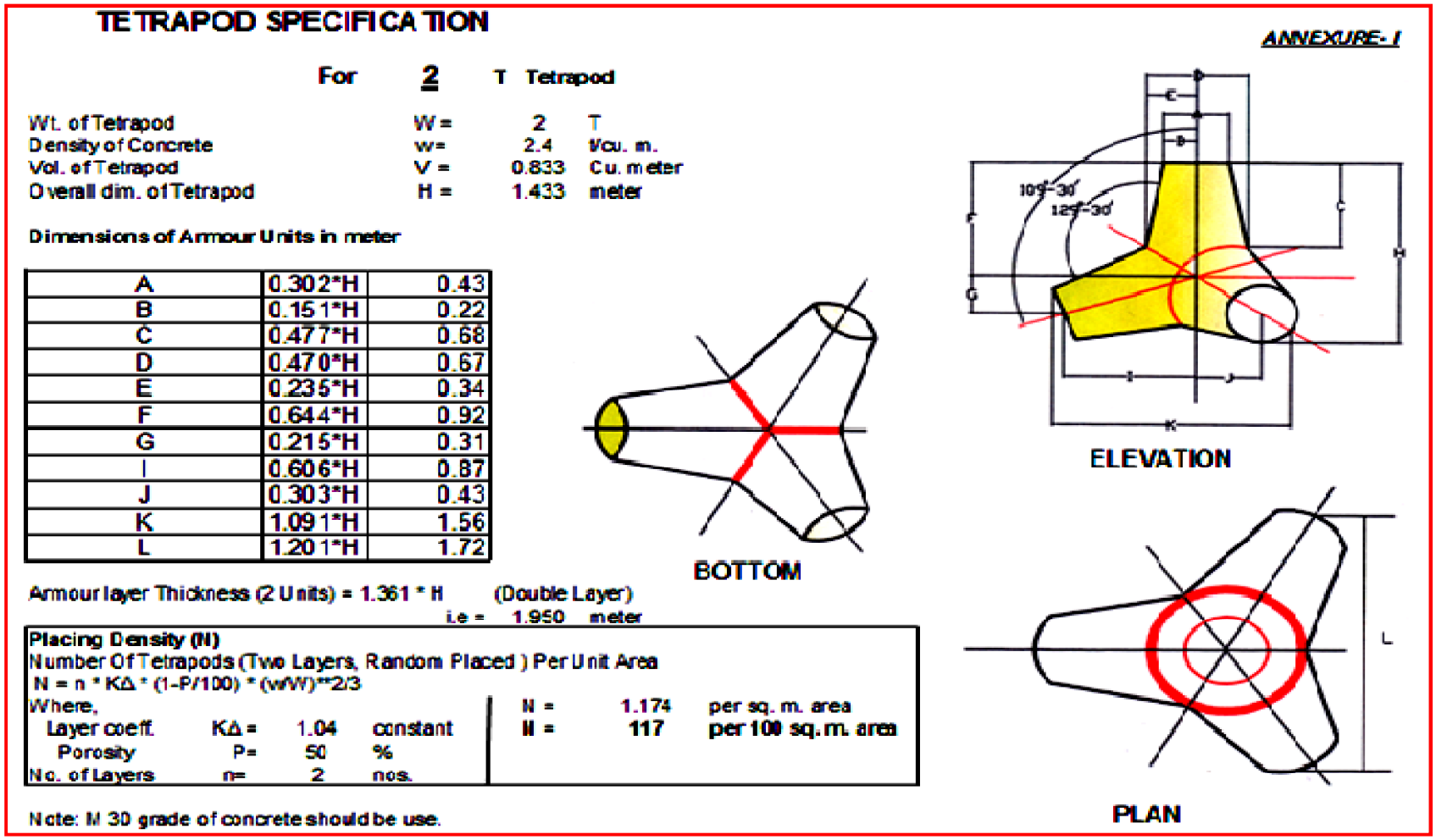


Fig.8 Cross-section of breakwater for the development of Tuna Fishery Harbour at Thiruvottriyur Kuppam, Tamil Nadu



TETRAPOD SPECIFICATION

ANNEXURE- I

For 2 T Tetrapod

Wt. of Tetrapod	W =	2	T
Density of Concrete	w=	2.4	t/cu. m.
Vol. of Tetrapod	V =	0.833	Cu. meter
Overall dim. of Tetrapod	H =	1.433	meter

Dimensions of Armour Units in meter

A	0.302*H	0.43
B	0.151*H	0.22
C	0.477*H	0.68
D	0.470*H	0.67
E	0.235*H	0.34
F	0.644*H	0.92
G	0.215*H	0.31
I	0.606*H	0.87
J	0.303*H	0.43
K	1.091*H	1.56
L	1.201*H	1.72

BOTTOM

ELEVATION

PLAN

Armour layer Thickness (2 Units) = 1.361 * H (Double Layer)
i.e = 1.950 meter

Placing Density (N)
Number Of Tetrapods (Two Layers, Random Placed) Per Unit Area
N = n * KΔ * (1-P/100) * (w/W)**2/3

Where,					
Layer coeff.	KΔ =	1.04	constant	N =	1.174 per sq. m. area
Porosity	P=	50	%	N =	117 per 100 sq.m. area
No. of Layers	n=	2	nos.		

Note: M 30 grade of concrete should be use.

Fig.9: Specification of 2 t Tetrapod

TETRAPOD SPECIFICATION

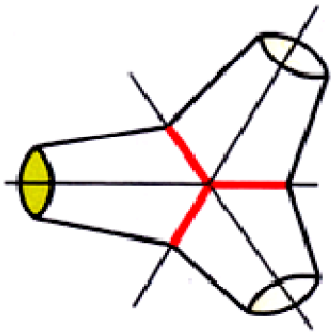
ANNEXURE- I

For 4 T Tetrapod

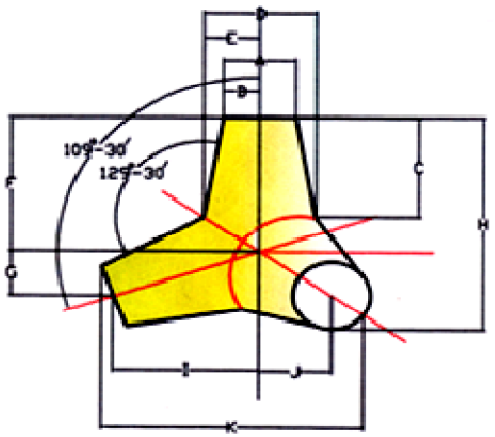
Wt. of Tetrapod	W =	4	T
Density of Concrete	w=	2.4	t/cu. m.
Vol. of Tetrapod	V =	1.667	Cu. meter
Overall dim. of Tetrapod	H =	1.801	meter

Dimensions of Armour Units in meter

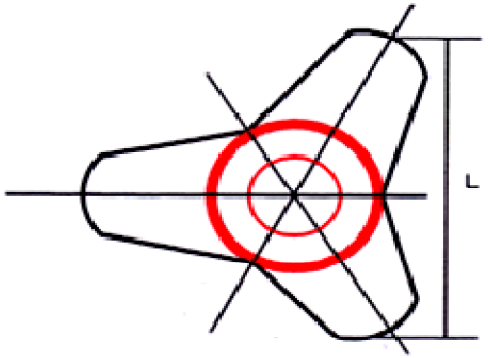
A	0.302*H	0.54
B	0.151*H	0.27
C	0.477*H	0.86
D	0.470*H	0.85
E	0.235*H	0.42
F	0.644*H	1.16
G	0.215*H	0.39
I	0.606*H	1.09
J	0.303*H	0.55
K	1.091*H	1.97
L	1.201*H	2.16



BOTTOM



ELEVATION



PLAN

Armour layer Thickness (2 Units) = 1.361 * H (Double Layer)
i.e = 2.452 meter

Placing Density (N)
Number Of Tetrapods (Two Layers, Random Placed) Per Unit Area
N = n * KΔ * (1-P/100) * (w/w)**2/3

Where,					
Layer coeff.	KΔ =	1.04	constant	N =	0.740 per sq. m. area
Porosity	P=	50	%	N =	74 per 100 sq. m. area
No. of Layers	n=	2	nos.		

Note: M 30 grade of concrete should be use.

Fig.10: Specification of 4 t Tetrapod

TETRAPOD SPECIFICATION

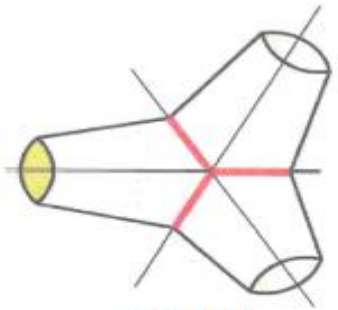
ANNEXURE- I

For **6** T Tetrapod

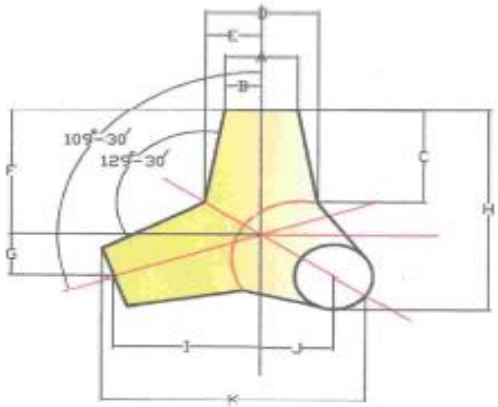
Wt. of Tetrapod	W =	6	T
Density of Concrete	w =	2.4	t/cu. m.
Vol. of Tetrapod	V =	2.500	Cu. meter
Overall dim. of Tetrapod	H =	2.059	meter

Dimensions of Armour Units in meter

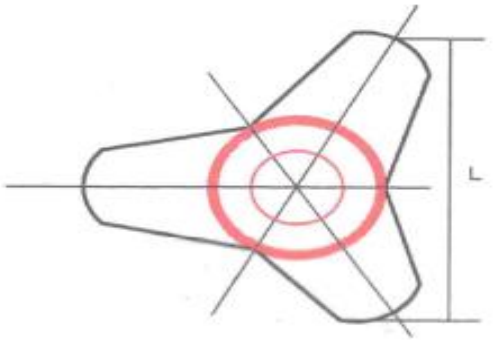
A	0.302*H	0.62
B	0.151*H	0.31
C	0.477*H	0.98
D	0.470*H	0.97
E	0.235*H	0.48
F	0.644*H	1.33
G	0.215*H	0.44
I	0.606*H	1.25
J	0.303*H	0.62
K	1.091*H	2.25
L	1.201*H	2.47



BOTTOM



ELEVATION



PLAN

Armour layer Thickness (2 Units) = 1.361 * H (Double Layer)
i.e = 2.803 meter

Placing Density (N)

Number Of Tetrapods (Two Layers, Random Placed) Per Unit Area

N = n * K? * (1-P/100) * (w/W)**2/3

Where,

Layer coeff.	K? =	1.04	constant	N =	0.565 per sq. m. area
Porosity	P=	50	%	**N =**	**56 per 100 sq. m. area**
No. of Layers	n=	2	nos.		

Fig.11: Specification of 6 t Tetrapod

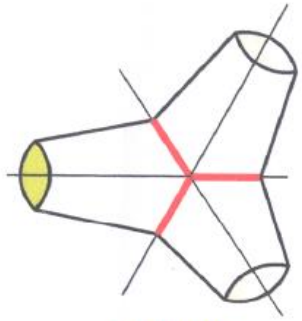
TETRAPOD SPECIFICATION

For 8 T Tetrapod

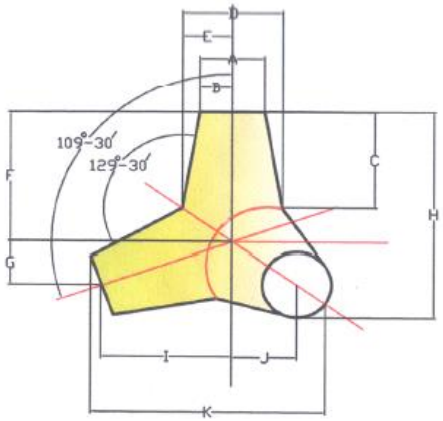
Wt. of Tetrapod	W =	8	T
Density of Concrete	w =	2.4	t/cu. m.
Vol. of Tetrapod	V =	3.333	Cu. meter
Overall dim. of Tetrapod	H =	2.264	meter

Dimensions of Armour Units in meter

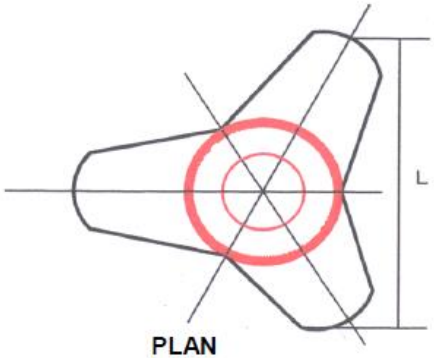
A	0.302*H	0.68
B	0.151*H	0.34
C	0.477*H	1.08
D	0.470*H	1.06
E	0.235*H	0.53
F	0.644*H	1.46
G	0.215*H	0.49
I	0.606*H	1.37
J	0.303*H	0.69
K	1.091*H	2.47
L	1.201*H	2.72



BOTTOM



ELEVATION



PLAN

Armour layer Thickness (2 Units) = 1.361 * H (Double Layer)
i.e = 3.082 meter

Placing Density (N)

Number Of Tetrapods (Two Layers, Random Placed) Per Unit Area

N = n * KΔ * (1-P/100) * (w/W)**2/3

Where,				N =	0.466	per sq. m. area
Layer coeff.	KΔ =	1.04	constant	**N =**	**47**	**per 100 sq. m. area**
Porosity	P=	50	%			
No. of Layers	n=	2	nos.			

Fig.12: Specification of 8 t Tetrapod

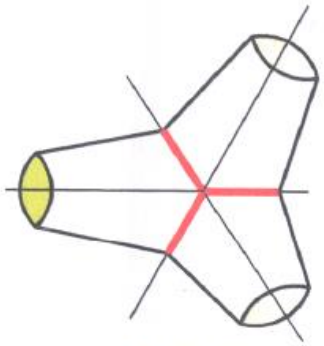
TETRAPOD SPECIFICATION

For 10 T Tetrapod

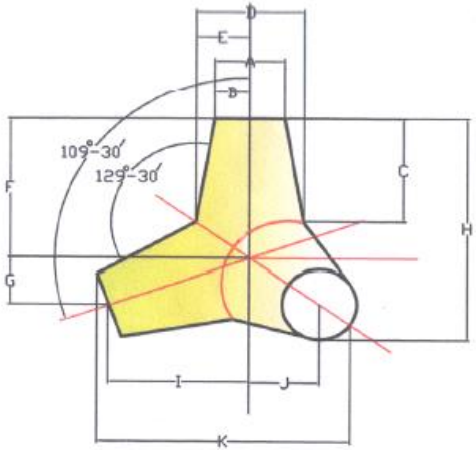
Wt. of Tetrapod	W =	10	T
Density of Concrete	w =	2.4	t/cu. m.
Vol. of Tetrapod	V =	4.167	Cu. meter
Overall dim. of Tetrapod	H =	2.437	meter

Dimensions of Armour Units in meter

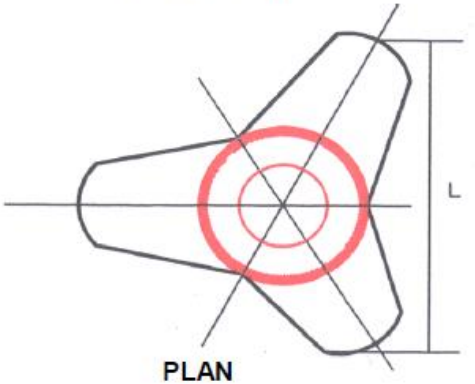
A	0.302*H	0.74
B	0.151*H	0.37
C	0.477*H	1.16
D	0.470*H	1.15
E	0.235*H	0.57
F	0.644*H	1.57
G	0.215*H	0.52
I	0.606*H	1.48
J	0.303*H	0.74
K	1.091*H	2.66
L	1.201*H	2.93



BOTTOM



ELEVATION



PLAN

Armour layer Thickness (2 Units) = 1.361 * H (Double Layer)

i.e = 3.317 meter

Placing Density (N)

Number Of Tetrapods (Two Layers, Random Placed) Per Unit Area

N = n * KΔ * (1-P/100) * (w/W)**2/3

Where,						
Layer coeff.	KΔ =	1.04	constant	N =	0.402	per sq. m. area
Porosity	P=	50	%	**N =**	**40**	**per 100 sq. m. area**
No. of Layers	n=	2	nos.			

Fig.13: Specification of 10 t Tetrapod

Annexure-I

Photo-1 : Wave flume hangar at CWPRS, Pune

Photo-2: Wave flume facilities inside the hangar

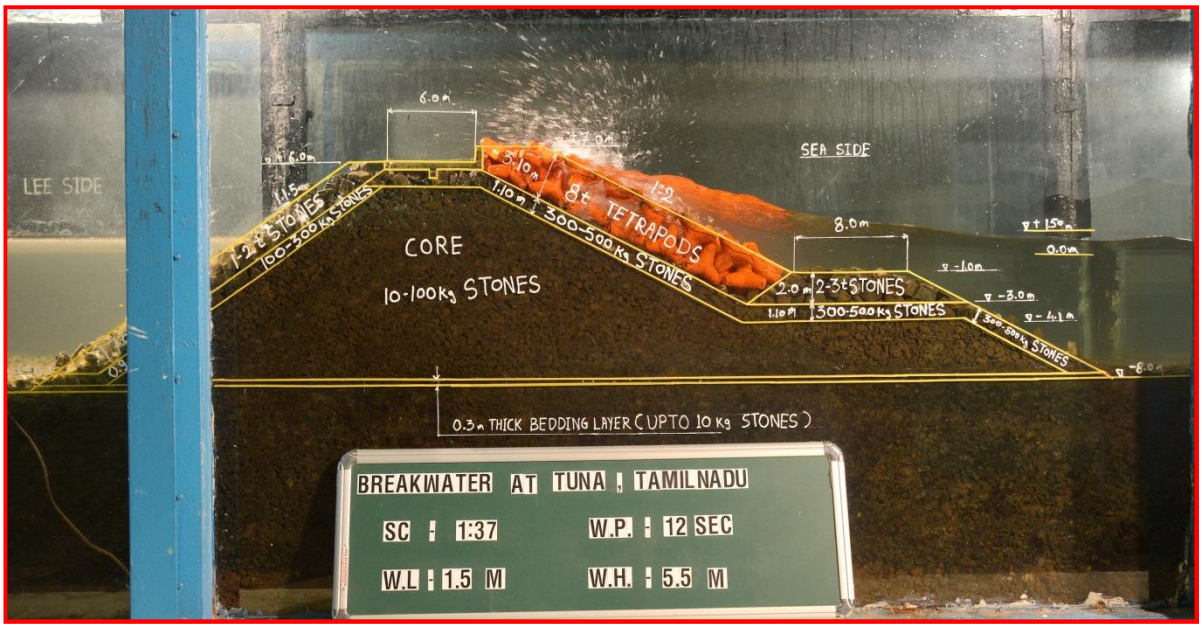


Photo-3 : Wave action on armour layer of breakwater consisting of 8 t tetrapods at -8.0 m bed level with +1.5 m water level and 5.5 m wave height

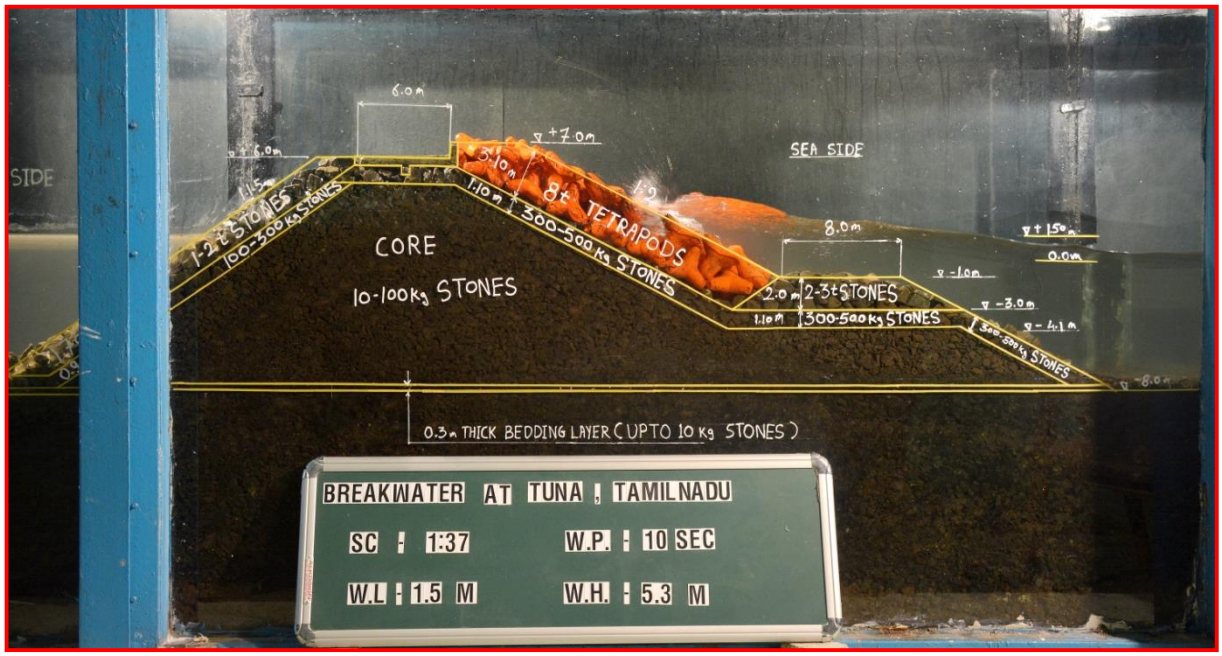


Photo-4 : Wave action on armour layer of breakwater consisting of 8 t tetrapods at -8.0 m bed level with +1.5 m water level and 5.3m wave height

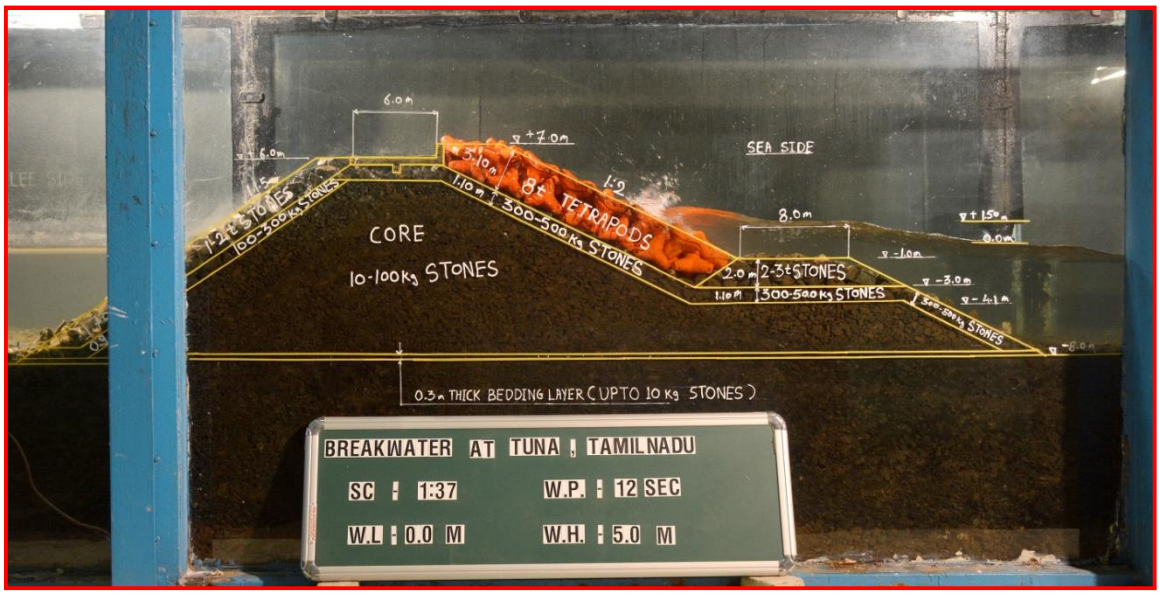


Photo-5 : Wave action on armour layer of breakwater consisting of 8 t Tetrapods at -8.0 m bed level with 0.0 m water level and 5.0 m wave height

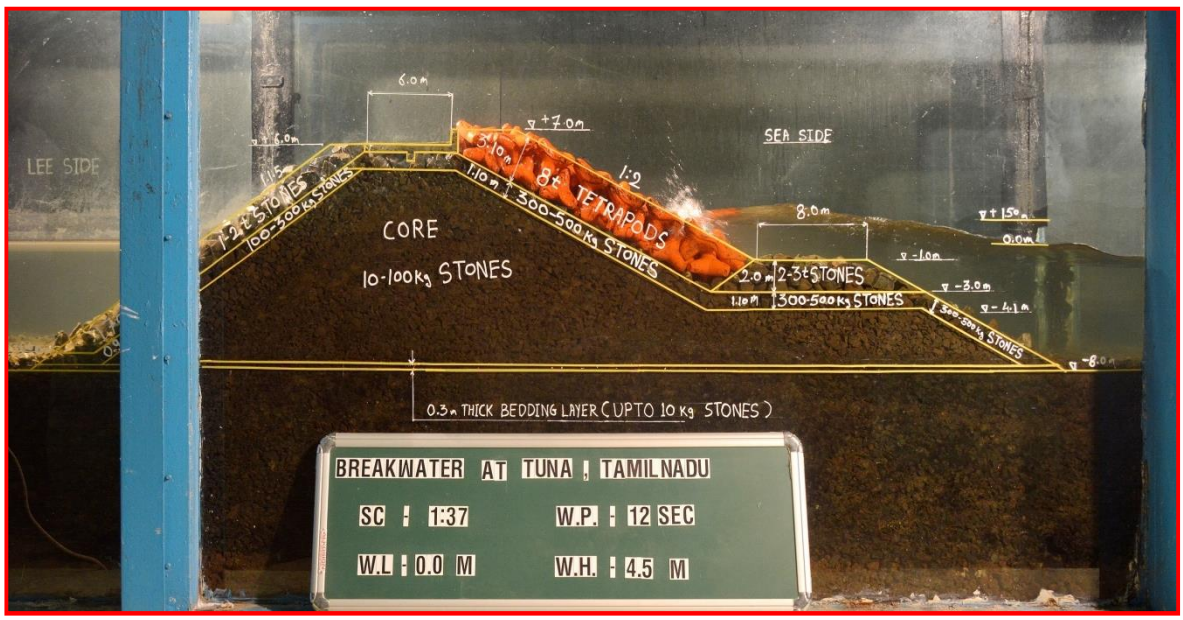


Photo-6: Wave action on armour layer of breakwater consisting of 8 t tetrapods at -8.0 m bed level with 0.0 m water level and 4.5 m wave height