Design and Analysis of Potable/Medium Size Cofferdam

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Abstract

This paper presents the detailed description of the multipurpose and cost-effective cofferdam. It contains the forces acting on cofferdam, factors governing its design criteria, various construction techniques, design and analysis of a sheet pile cofferdam. A cofferdam is a temporary structure designed to keep soil and water out of the excavation in which some permanent structure (like bridge piers) is built. When construction takes place below the water level, a cofferdam provides a dry work environment to workers working inside it. Sheet piling is done around the work site, and seal concrete is placed into the bottom to prevent seepage of water from underneath of the sheet piling, and then the water is pumped out. This paper also contains the techniques to install sand filtration bed inside the cofferdam to purify river water.

Keywords: Bracings, comparative analysis, steel sheet pile cofferdams and filtration bed, sequential construction method, tremie concrete seal.

I. INTRODUCTION

Cofferdams are temporary enclosures which are designed to keep out soil and water to permit dewatering and construction of permanent structure/facility in the dry environment. It involves the interaction of soil, structure, and water. The loads imposed include the hydrostatic forces (due to water), as well as dynamic forces due to current waves. During its construction, maintaining close tolerances is quite difficult since they are usually constructed offshore and sometimes under very severe weather conditions. Under these conditions, significant deformations of cofferdam elements may happen during its construction, and therefore, it would become necessary (sometimes) to deviate from the design dimensions and considerations in order to complete the project according to the plan/schedule [1].

The loads put on the cofferdam by construction equipment and operations must also be considered, both during the construction or the installation of the cofferdam. During its construction, safety is a serious concern, since workers are exposed to the hazard of collapse and flooding. Safety requires that every cofferdam and every part of it should be of suitable design and construction, of suitable material, and of sufficient strength for the purpose for which the cofferdam structure is used. Proper construction and its verification that the structure is being constructed as planned, monitoring the behavior of the cofferdam and its surroundings, provision of adequate light, ventilation, and attention to the safe practices on the part of all workers, shall be properly maintained. Steel cofferdam can be constructed by single-wall steel sheet pile cofferdam and double-wall steel case cofferdam. Generally, single-wall steel sheet pile cofferdam is used unless the water depth is less than 10m, and double-wall steel case cofferdam applied to the river with depth larger than 10m. There are many construction cases of single wall steel cofferdams which required that the steel sheet piles to be inserted into river bed before building inner bracing, thus, resulting in large displacement, low integral stability, and high risk for traditional steel sheet

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pile cofferdam.

II. TYPES OF COFFERDAM

1) Braced Cofferdam: Formed from a single wall of sheet piling, driven into the ground to form a "box" like shape around the excavation site. The box is then braced on the inside,and the interior area is dewatered. It is mainly used for bridge piers in shallow water (30 - 32 ft depth).

2) Earth-Type Cofferdam: Simplest type of cofferdam. It mainly consists of an earth bank or vertical sheet piling enclosing the site (excavation). It is used for low-level waters with low velocity, and these are easily scoured by water rising over the top.

3) Timber Crib Cofferdam: These are constructed on the land and are floated into place/river. The lower portion of the cell is matched with the contour of the river bed. It uses rock ballast sand soil/earthen material to decrease seepage and sink into place. It is also known as **Gravity Dam**. It usually consists of 12'x12' cells and is primarily used in rapid currents or on rocky river beds.

4) Double-Walled Sheet Pile Cofferdam: These are double wall cofferdams made up of two parallel rows of sheet piles driven into the ground, andthey are connected together by a system of rods (ties) at different levels. The empty space between the walls is generally filled with granular material like gravel, sand or broken rock.

III. ADVANTAGES

To perform work over water is always more difficult and costly than performing the same work on land. When work is performed below water, the difficulties and cost difference may increase significantly as the depth of the work is increased. The key to working in the marine environment efficiently is to minimize the work over water and perform most of the work on land. Some of its advantages are listed below [2]:

- It allows the excavation and construction of structures in the otherwise poor environment and provides a safe environment for the workers to work inside it.
- We can install sand filtration beds in several cofferdams in which river water can be used as raw water which purifies it.
- Contractors typically have design responsibility, and steel sheet piles are easily installed and removed. Also,

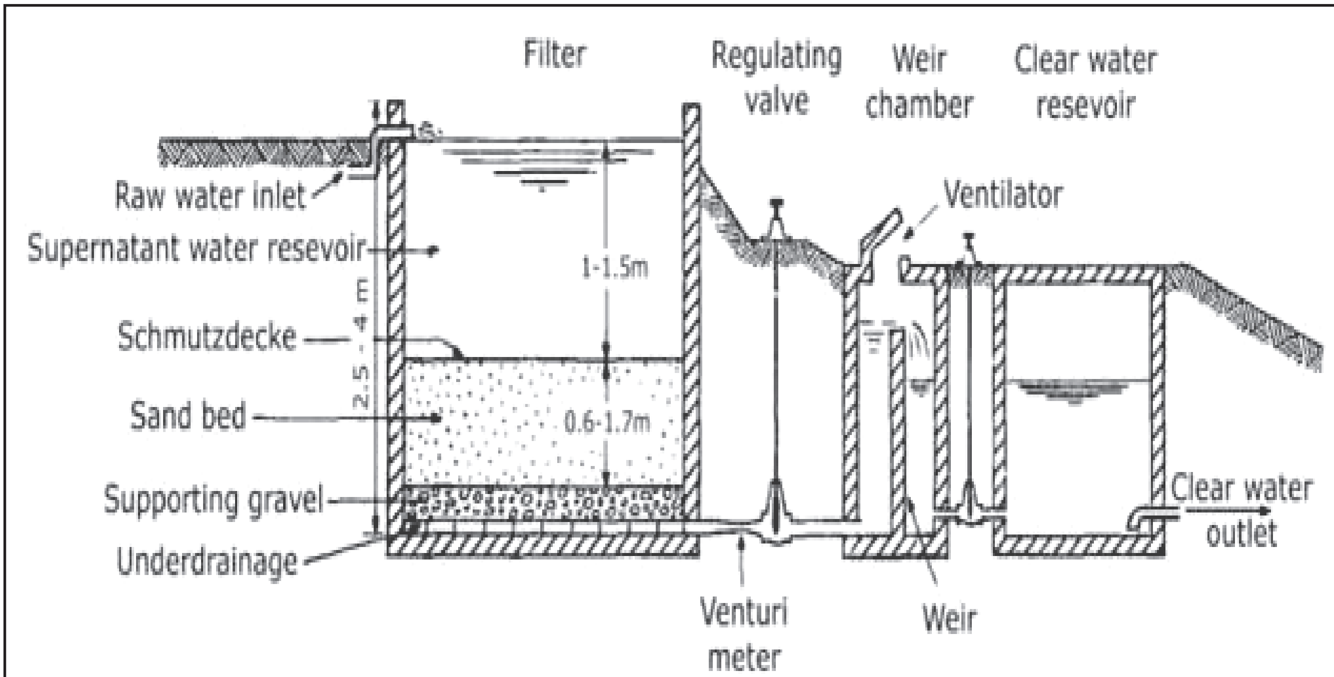

Fig. 1. Sand Filtration Bed

materials can typically be reused on other projects.

IV. COFFERDAM FOR WATER PURIFICATION

A. Sand Filtration Bed (SFD) Procedure

Slow sand filters use sand with effective sizes of 0.15 - 0.35 mm to remove a large percentage of coliforms and Giardia cysts. Their operational efficiency is the most effective at a flow rate of 0.1 – 0.3 m/h (or $m^3/h/m^2$), which is equal to 100 – 300 l/h per m^2 of the filter area.

These filters use physical processes such as sedimentation and adsorption to remove fine particles as well as biological processes to remove bacteria and organic matter;due to its slow rate, the water can sit on sand for many hours before passing through it, various oxidation reactions break down the organic matter during this time. Algae which grow on the sand surface consume this oxidized organic matter and releases the oxygen back into the water.

Various techniques like post-filtration chlorination and UV-purification can also be used, but for a filter that is functioning well,such treatments are not always

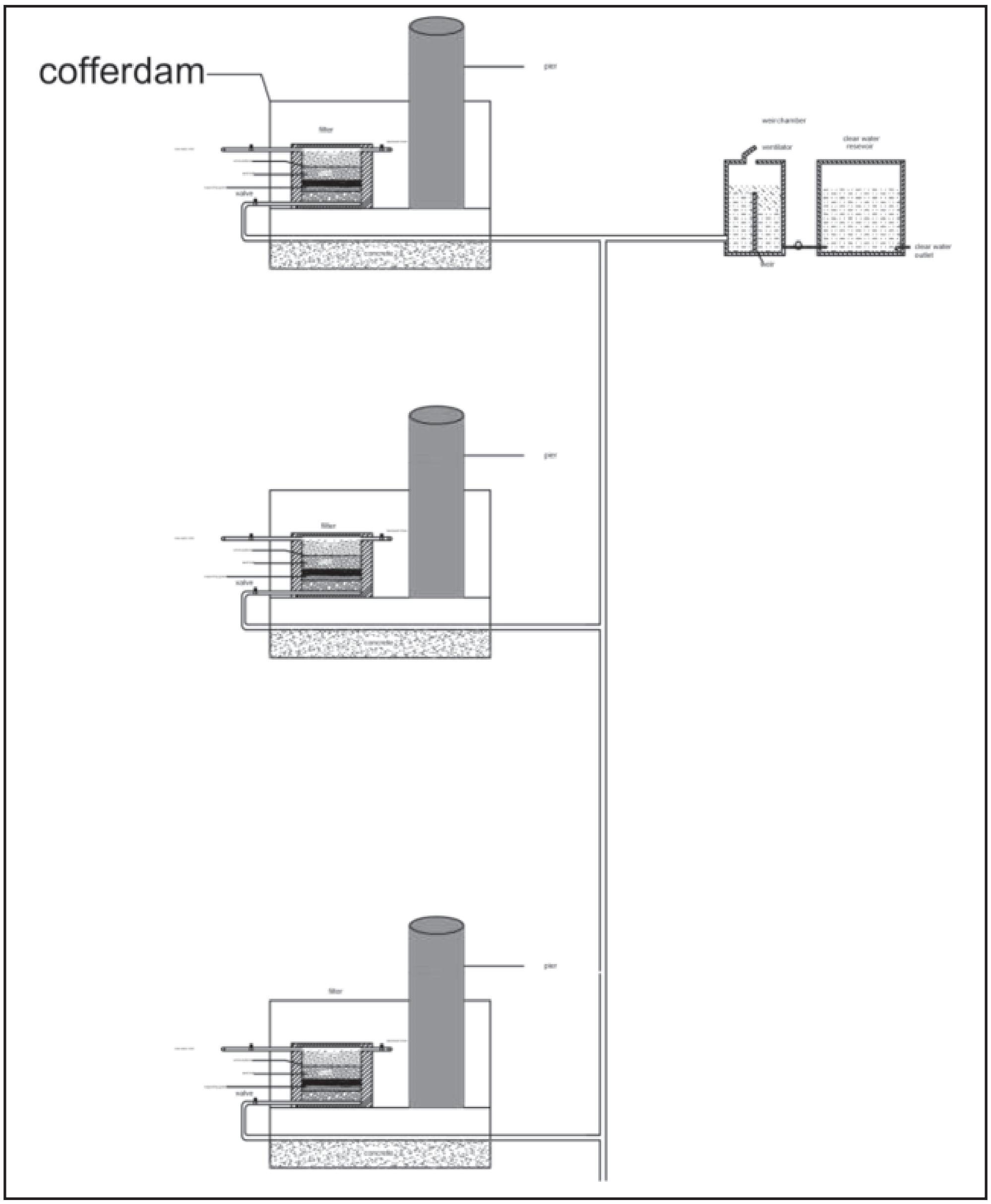

Fig. 2. Model (SFD)

required.

The flow of raw water through these slow sand filters should be continuous. However small-scale filters, for use in households, have been designed to work intermittently (few hours a day).

B. Model (SFD)

Sizing of Filter

The amount of water required for a community/village is calculated in the normal way, taking account of population growth. In our sand filtration process, the flow rate is about 0.1 – 0.3 m^1/h (100 – 300 l) per m^2 of filter surface. If possible, this test should be conducted for an entire year.

In our paper, we took an example of a village with a population of about 1000 with a 2.5% per annum growth rate of the population(assumption).The total population in ten years would be about 1280 people. The slow sand filter is designed for this number of people. Assuming the requirement of 40 litres per person per day, the total daily requirement will be 51200 litres (52 m^3).

If we continuously feed the filter into a storage tank, so that the hours of peak demand can be catered to, the hourly output need is 2.17 m^3/h $(52/24)^3$.We can obtain a flow rate of 0.1 $m^3/h/m^2$ by adjusting the valve (output).Therefore, the area of sand filter requires will be about 22 m^2 .

Two filters should be installed in two different cofferdams. So, while one is being cleaned/out of order, the water supply can be maintained. During maintenance, the filter that is still operating can be run at the rate of 0.2 $m^3/h/m^2$, which is still within the recommended limit (0.1 – 0.4 $m^3/h/m^2$). The raw water source is the river that supplies the hourly demand of 2.17 m^3/h. Hence, slow sand filters are normally used to clean surface water supplies like rivers and lakes.

C. Cofferdam Components

1) Sheet piling: Sheet piling is a construction product with a mechanical "interlock" at both ends of the section. These connections interlock with one another to form a continuous wall like sheeting. They are designed to create a rigid barrier for earth and water while resisting lateral pressures.

2) Bracing frame: Bracing is provided to prevent the inward movement of sheet piles.

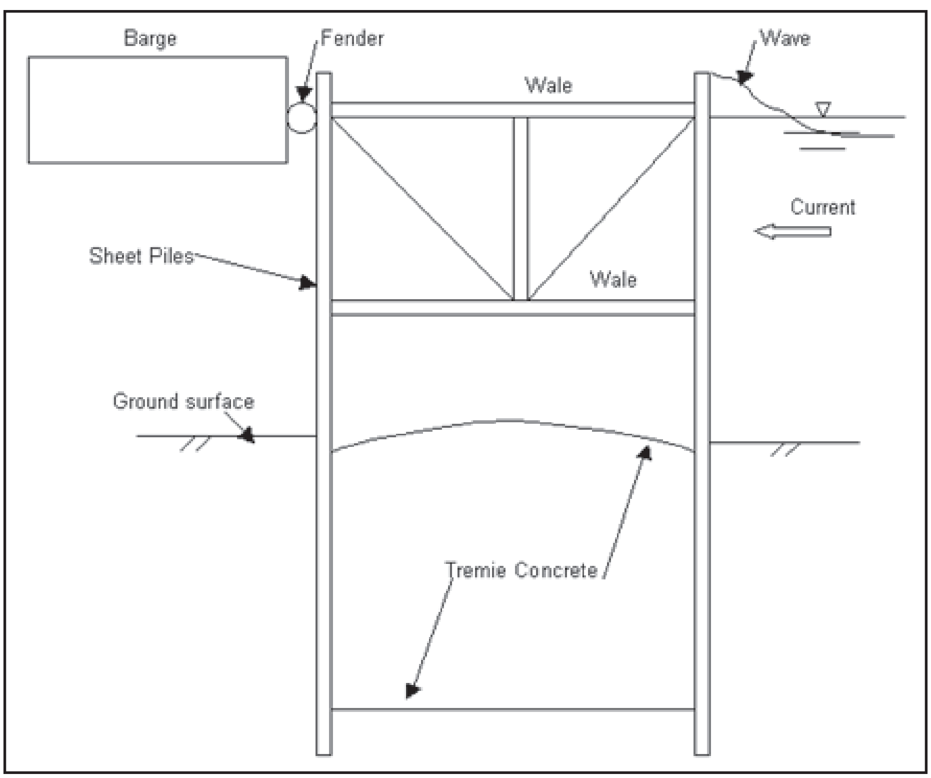

Fig. 3. Typical Cofferdam

3) Concrete seal: An underwater concrete seal course may then be placed prior to dewatering in order to seal off the water, and to resist its pressure (from the underneath portion).

V. TYPES OF LOADS ACTING ON THE COFFERDAM

A. Soil Loads

The soils impose load, both locally on the wall (of cofferdam) and globally upon the structure as a whole. Local forces cause bending in the sheets, bending in the wales, and axial compression in the struts [3].

Hydrostatic pressure

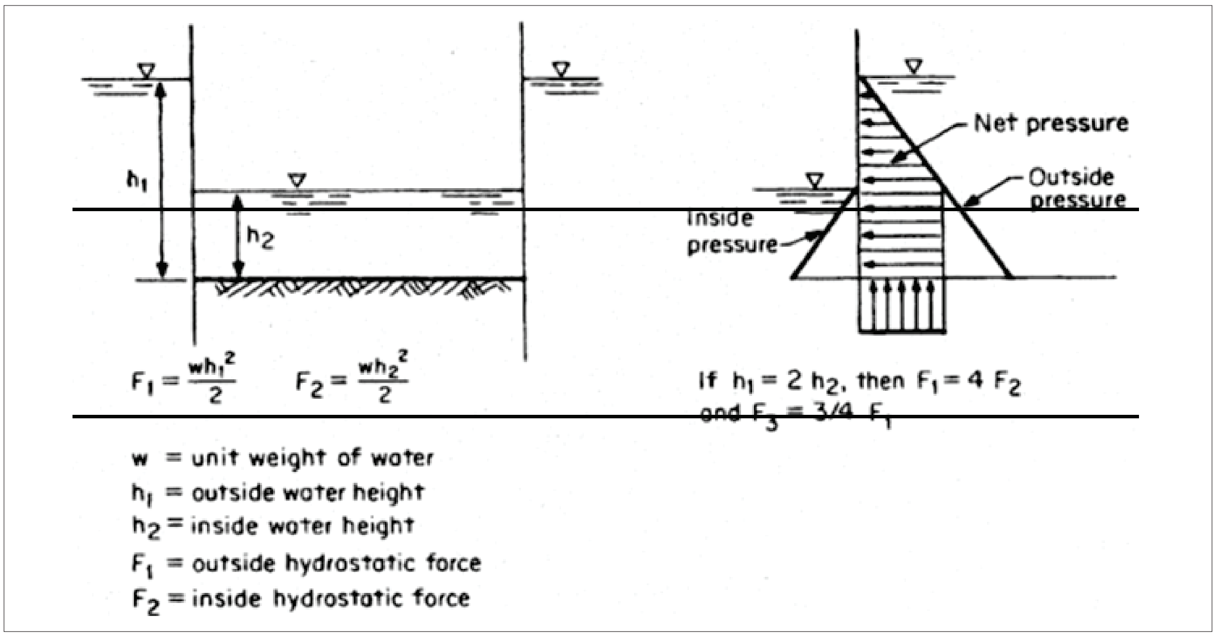

Fig. 4. Hydrostatic Force/Load (Partially Dewatered Structure)

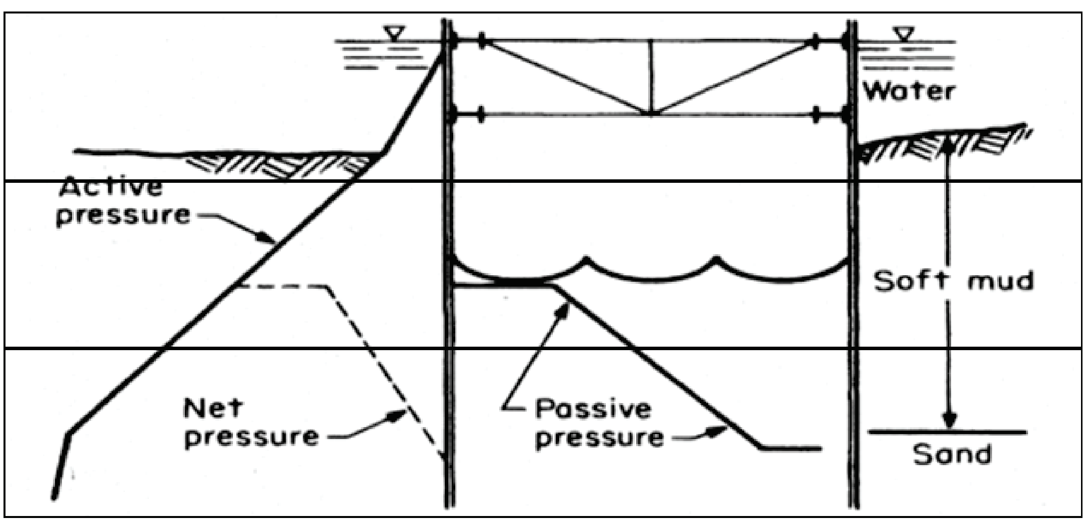

Fig. 5. SoilLoad/Force in Muds or Clays

B. Current Forces on Cofferdam

The current force consists of the force acting on the normal projection of the cofferdam as well as the drag force acting along the sides of the cofferdam.

C. Wave Forces

Waves acting are usually the result of local winds and are of short wavelength and limited in height. In some cases, the cofferdam should have minimum three feet of freeboard or higher above the designed high water elevation than the maximum expected the height of the wave. Wave forces play a significant role in large bays and lakes where the fetch is several miles.

D. Seismic Force

For very large, important and deep cofferdams in highly seismically active areas, seismic evaluation should be performed/considered [4].

VI. FACTORS GOVERNING THE TYPE OF COFFER DAM

A. Depth of Water

Low depth => Earthen dam
High depth => Sheet pile coffer dam

B. Current and Nature of Flowering of Sheet Pile

High current => Sheet pile coffer dam (higher seepage control capacity)
Low current => Earthen or any other dam (less seepage control capacity)

C. Type and Period of Work

Short duration work => Timber dam
Long duration work => Sheet pile coffer dam

VII. CONSTRUCTION SEQUENCE

For a cofferdam, such as for a bridge pier, the construction procedure follows the listed pattern.

1. Pre-dredge to remove soil or soft sediments and level the area of the cofferdam.
2. Drive temporary support piles.
3. The temporarily erect bracing frame on the support piles.
4. Set steel sheet piles, starting at all four corners and meeting at the center of each side.
5. Drive sheet piles to grade.
6. Block between bracing frame and sheets, and provide ties for sheet piles at the top as necessary.
7. Excavate inside the grade or slightly below grade, while leaving the cofferdam full of water.
8. Drive bearing piles.

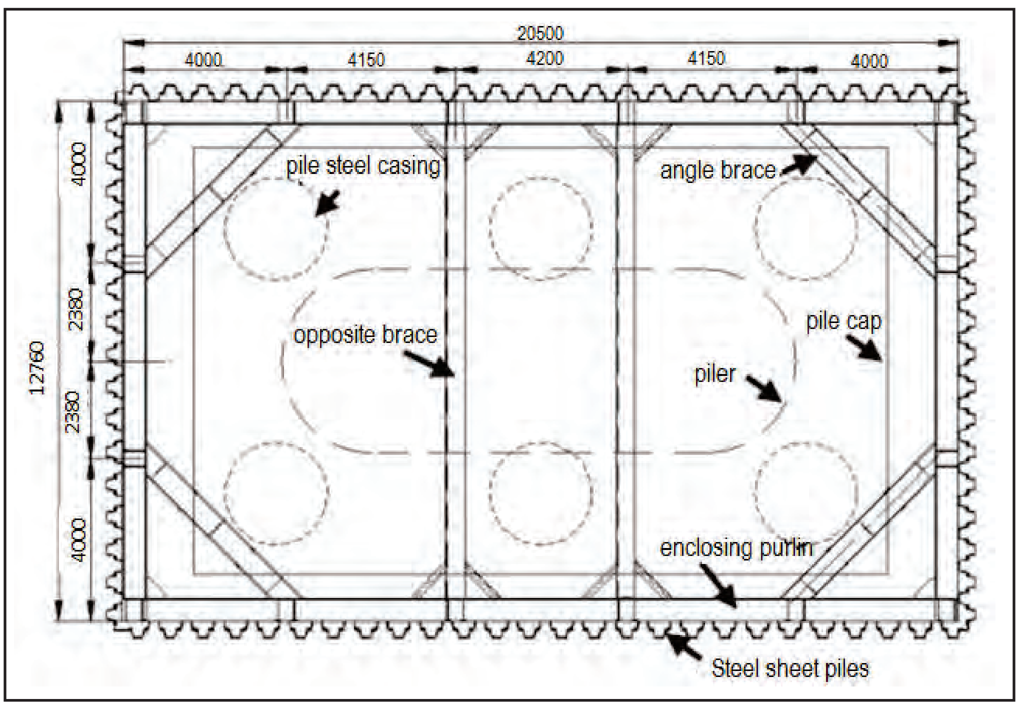

Fig. 6. Plan of the Cofferdam

9. Place rock fill as a leveling and support course.
10. Place tremie concrete seal.

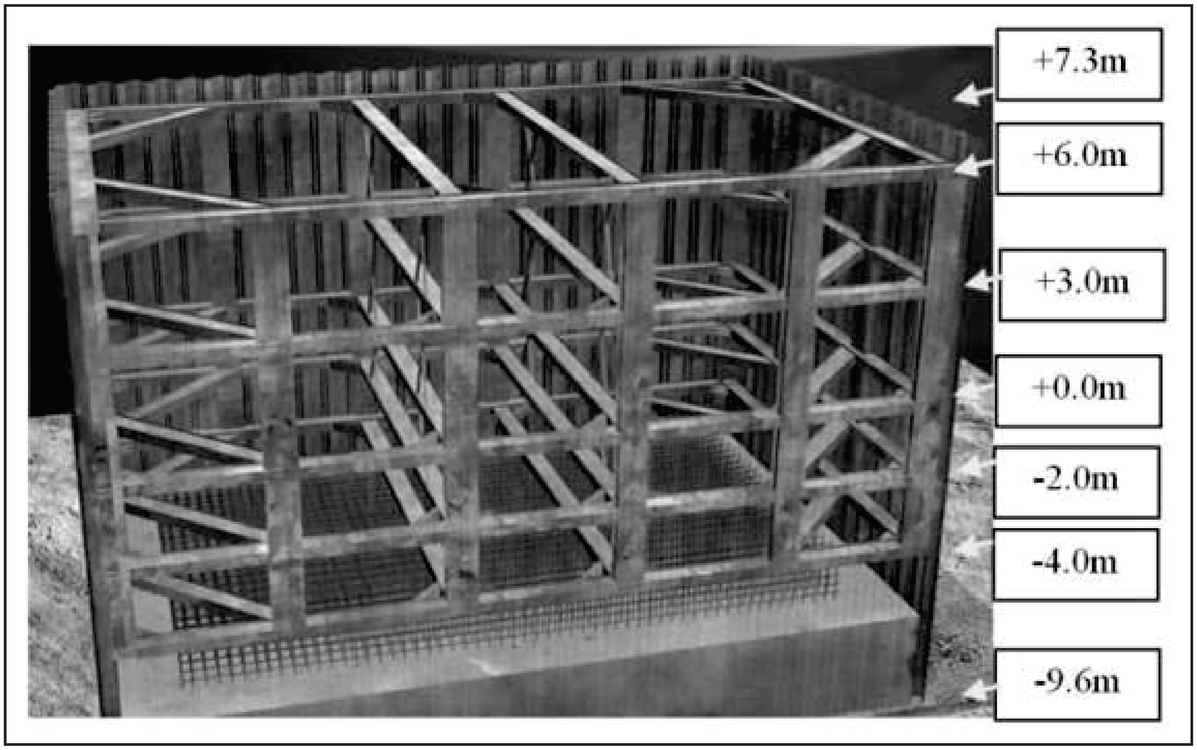

Fig.7. 3D Perspective Model

STAAD.Pro Report

Structure Type	**SPACE FRAME**	
Number of nodes	1179 Highest node	1710
Number of elements	407 Highest beam	1807
Number of plates	899 Highest plate	2047

Number of basic load cases : 2

Number of combination load cases :4

Included in this printout are results for load cases:

Type	L/C	Name

TABLE I.

Primary	1	EL X+
Primary	2	EL X-
Primary	3	
Primary	4	EL Z+ EL Z-
Primary	5	DL
Combination	6	1.5(DL+EL X+)
Combination	7	1.5(DL+EL Z+)
Combination	8	1.2(DL-EL X-)
Combination	9	1.2(DL-EL Z-)

Reactions and Moments **1.2(DL-EL Z-)**

		Horizontal	Vertical	Horizontal		Moment	
Node	**L/C**	**FX (kN)**	**FY (kN)**	**FZ (kN)**	**MX (kNm)**	**MY (kNm)**	**MZ (kNm)**
1	1:EL X+	-33.464	-86.527	-0.884	-1.820	0.152	96.562
	2:EL X-	33.464	86.527	0.884	1.820	-0.152	-96.562
	3:EL Z+	0.083	-124.566	-42.808	-125.386	-2.245	-0.134
	4:EL Z-	-0.083	124.566	42.808	125.386	2.245	0.134
	5:DL	-9.874	237.337	-17.549	-29.228	-59.296	17.758
	6:1.5(DL+EL	-65.007	226.216	-27.651	-46.571	-88.716	171.481
	7:1.5(DL+EL	-14.687	169.156	-90.536	-231.921	-92.311	26.437
	8:1.2(DL-EL X-)	-52.005	180.972	-22.121	-37.257	-70.973	137.185
	9:1.2(DL-EL Z-)	-11.749	135.325	-72.429	-185.537	-73.849	21.149
2	1:EL X+	-45.175	-8.153	-1.597	-4.968	0.196	135.918
	2:EL X-	45.175	8.153	1.597	4.968	-0.196	-135.918
	3:EL Z+	2.569	-53.607	-39.767	-136.051	-5.096	-4.953
	4:EL Z-	-2.569	53.607	39.767	136.051	5.096	4.953
	5:DL	-1.222	354.718	31.218	98.097	2.243	1.707
	6:1.5(DL+EL	-69.596	519.848	44.432	139.693	3.658	206.438
	7:1.5(DL+EL	2.020	451.667	-12.824	-56.931	-4.280	-4.869
	8:1.2(DL-EL X-)	-55.677	415.878	35.545	111.755	2.926	165.150
	9:1.2(DL-EL Z-)	1.616	361.333	-10.259	-45.545	-3.424	-3.895
3	1:EL X+	-43.766	-3.875	-0.168	-0.475	-0.519	132.838
	2:EL X-	43.766	3.875	0.168	0.475	0.519	-132.838
	3:EL Z+	-0.057	-24.347	-20.060	-87.692	-2.894	0.305
	4:EL Z-	0.057	24.347	20.060	87.692	2.894	-0.305
	5:DL	1.258	351.776	7.451	16.510	13.715	-4.013
	6:1.5(DL+EL	-63.763	521.852	10.923	24.053	19.794	193.237
	7:1.5(DL+EL	1.801	491.145	-18.915	-106.773	16.232	-5.563
	8:1.2(DL-EL X-)	-51.011	417.482	8.739	19.242	15.835	154.589
	9:1.2(DL-EL Z-)	1.441	392.916	-15.132	-85.419	12.986	-4.450
4	1:EL X+	-43.761	3.028	0.169	0.479	-0.555	132.822
	2:EL X-	43.761	-3.028	-0.169	-0.479	0.555	-132.822

	3:EL Z+	-0.563	-24.401	-19.883	-86.958	2.548	1.667
	4:EL Z-	0.563	24.401	19.883	86.958	-2.548	-1.667
	5:DL	2.315	356.915	6.520	12.382	-3.054	-7.109
	6:1.5(DL+EL	-62.168	539.915	10.034	19.291	-5.413	188.571
	7:1.5(DL+EL	2.628	498.770	-20.044	-111.863	-0.759	-8.162
	8:1.2(DL-EL X-)	-49.735	431.932	8.027	15.433	-4.330	150.857
	9:1.2(DL-EL Z-)	2.103	399.016	-16.036	-89.491	-0.607	-6.529
5	1:EL X+	-45.167	6.927	1.645	5.139	0.196	135.887
	2:EL X-	45.167	-6.927	-1.645	-5.139	-0.196	-135.887
	3:EL Z+	-3.175	-53.640	-39.506	-134.681	5.124	6.894
	4:EL Z-	3.175	53.640	39.506	134.681	-5.124	-6.894
	5:DL	4.422	364.835	3.214	8.206	0.674	-12.135
	6:1.5(DL+EL	-61.117	557.643	7.289	20.016	1.305	185.628
	7:1.5(DL+EL	1.871	466.792	-54.438	-189.713	8.696	-7.862
	8:1.2(DL-EL X-)	-48.893	446.115	5.831	16.013	1.044	148.502
	9:1.2(DL-EL Z-)	1.497	373.434	-43.551	-151.770	6.957	-6.289
6	1:EL X+	-35.365	89.102	0.914	1.903	0.178	106.235
	2:EL X-	35.365	-89.102	-0.914	-1.903	-0.178	-106.235
	3:EL Z+	-0.001	-127.749	-46.308	-139.572	1.767	0.616
	9:1.2(DL-EL Z-)	-18.950	457.806	-51.105	-148.842	6.567	61.44
15	1:EL X+	-22.730	-36.274	1.242	2.252	0.937	74.041
	2:EL X-	22.730	36.274	-1.242	-2.252	-0.937	-74.041
	3:EL Z+	-3.806	4.988	-41.126	-121.437	0.311	11.018
	4:EL Z-	3.806	-4.988	41.126	121.437	-0.311	-11.018
	5:DL	-18.696	387.827	2.603	5.840	-5.489	59.747
	6:1.5(DL+EL	-62.138	527.330	5.767	12.138	-6.829	200.682
	7:1.5(DL+EL	-33.753	589.223	-57.784	-173.396	-7.768	106.147
	8:1.2(DL-EL X-)	-49.710	421.864	4.614	9.710	-5.463	160.546
	9:1.2(DL-EL Z-)	-27.002	471.378	-46.228	-138.717	-6.214	84.917
16	1:EL X+	-22.697	35.572	-1.218	-2.200	0.951	73.927
	2:EL X-	22.697	-35.572	1.218	2.200	-0.951	-73.927
	3:EL Z+	3.569	5.540	-40.739	-120.239	-0.068	-10.149
	4:EL Z-	-3.569	-5.540	40.739	120.239	0.068	10.149
	5:DL	1.552	338.142	0.166	0.652	0.240	-6.368

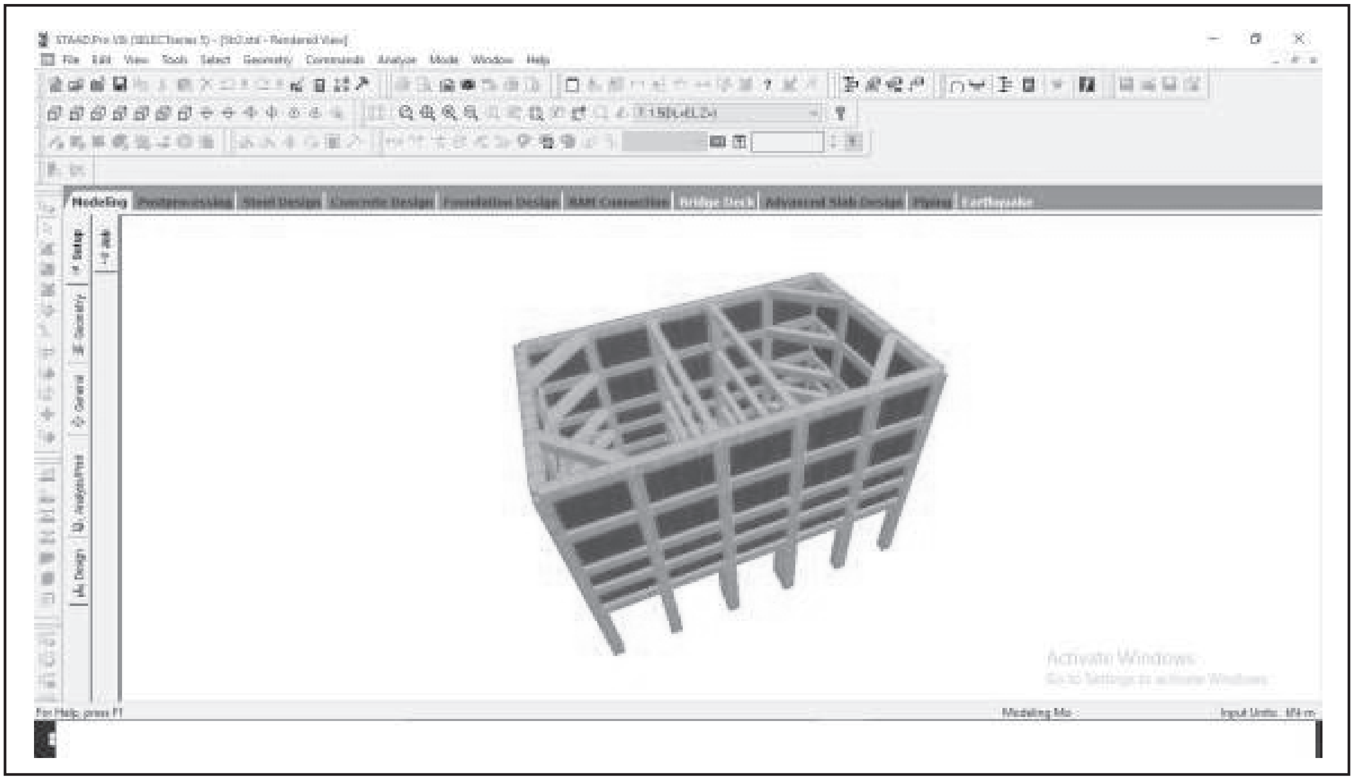

Fig. 8. Different Combinations of Load

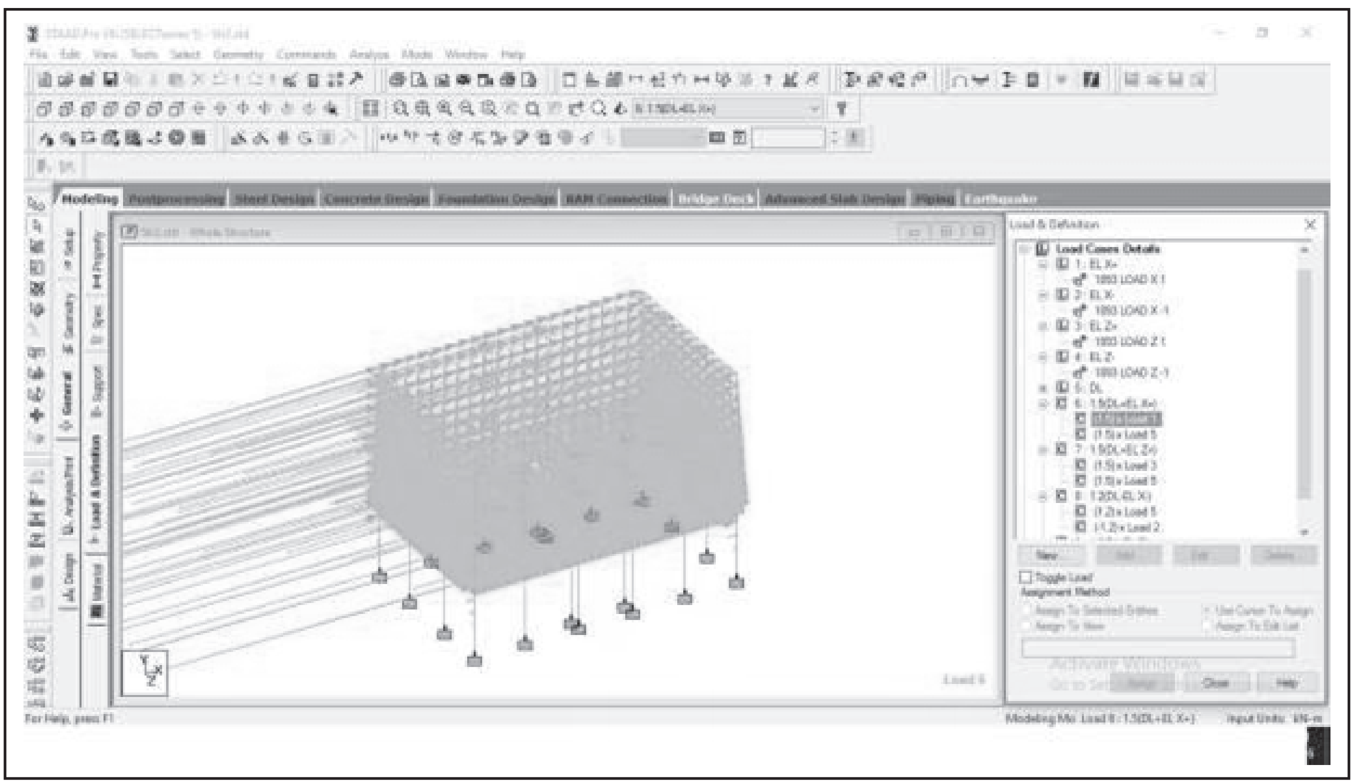

Fig. 9 (a). Analysis of Beams

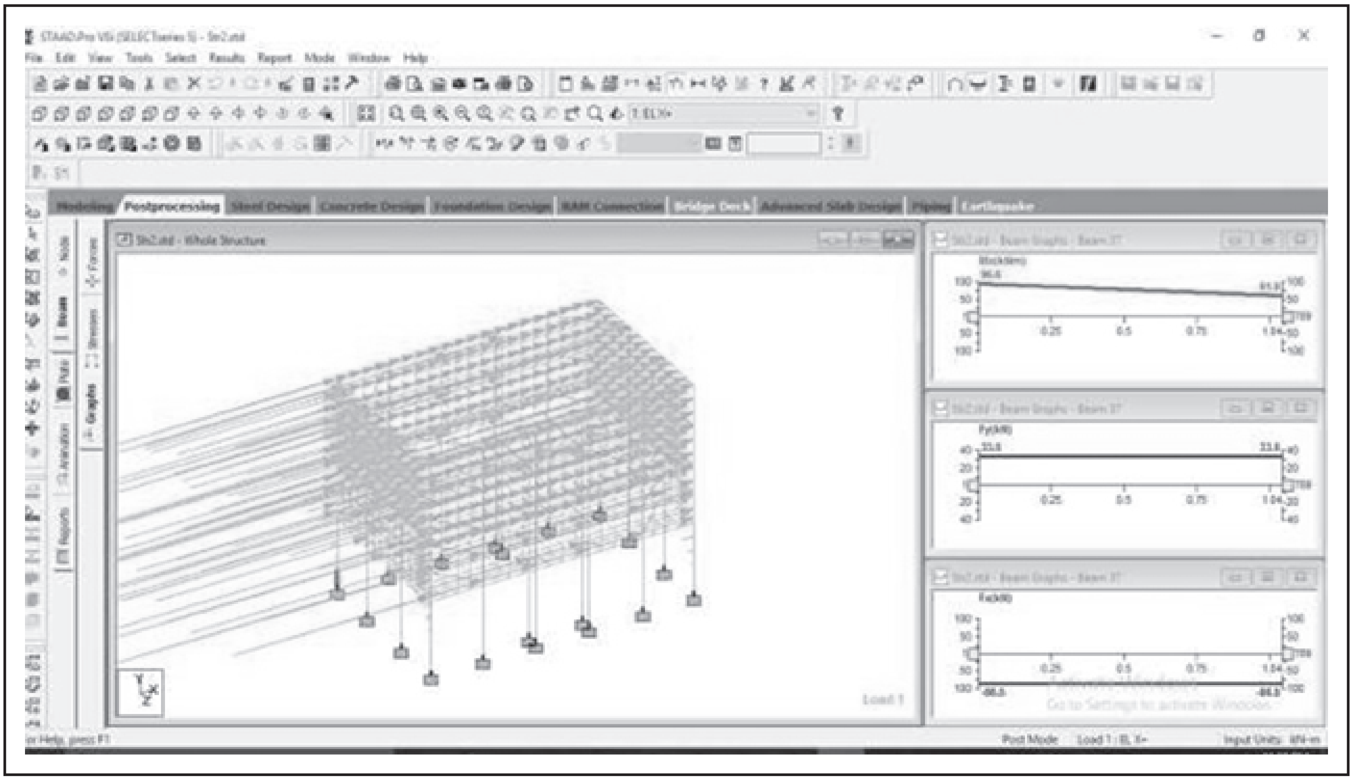

Fig. 9 (b). Analysis of Beams

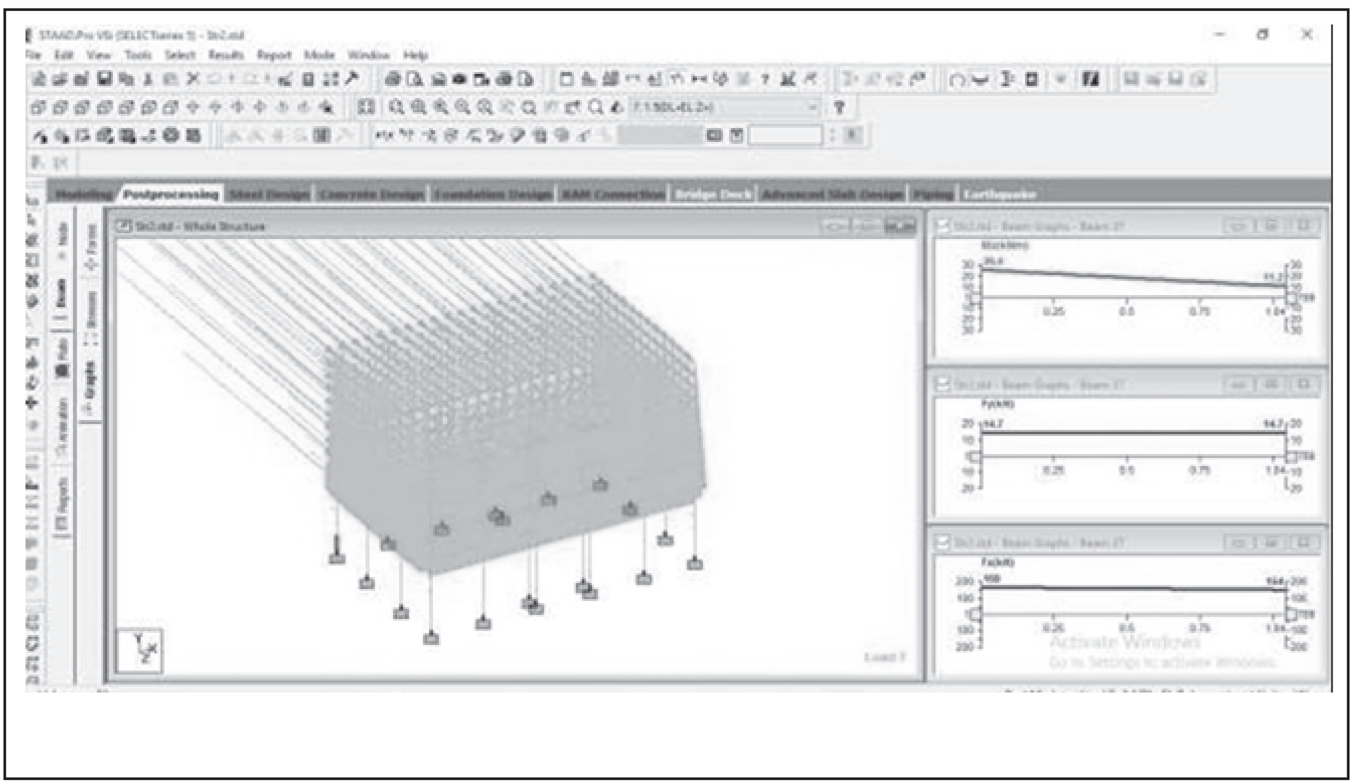

Fig. 9 (c). Analysis of Beams

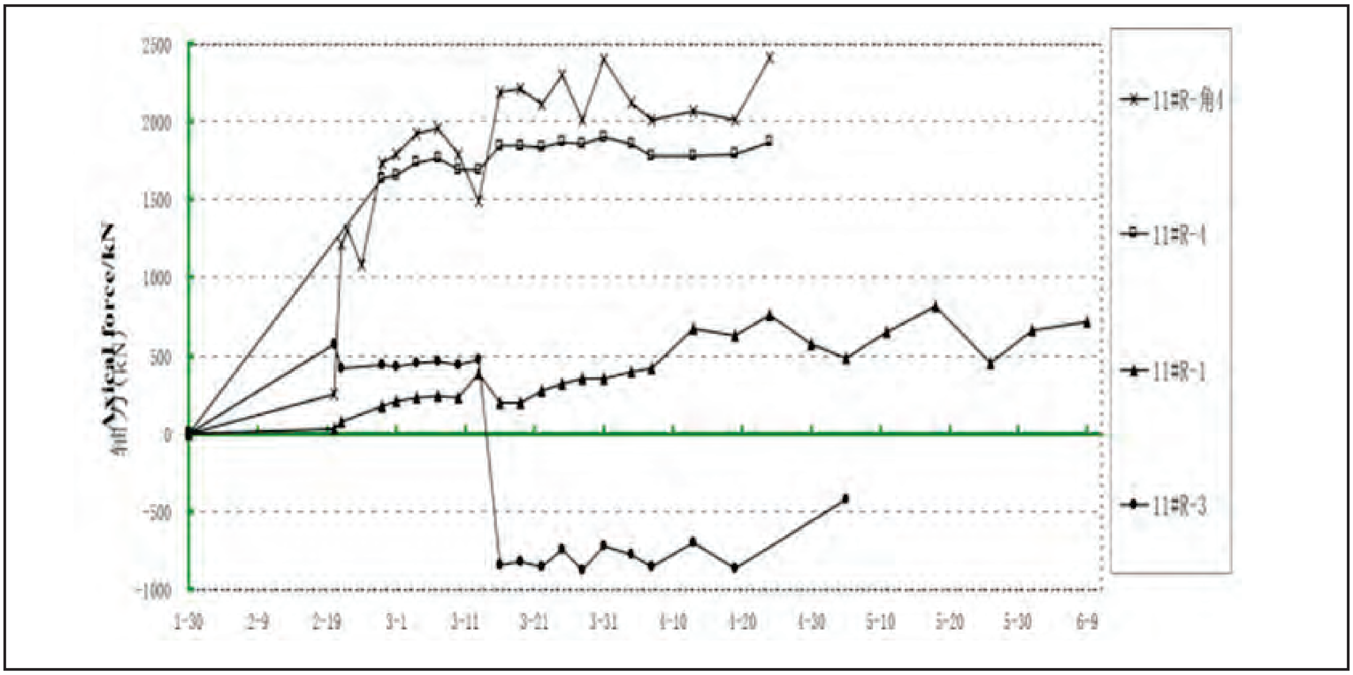

Fig. 10. Axial Force of Brace (inner side) in all Construction Processes

Market Analysis (Cost Estimation):

Grade of concrete taken: M25

Workability=0.85

Condition of Exposure: Very Severe

Degree of control: Good

Characteristic strength: 25N/mm^2

Target strength(fct)=fck+ks=25+1.65*5.3=33.745

Sand Zone taken=2

Water required=186kg/m^3 Sand required=35%

Water cement ratio=0.40

Adjustment of water and sand

Sand	Water	
w/c (0.6-0.4)	-4%	
Workability (0.8-0.85)	-	+1.5%

Net water required=188(1+1.5/100) =188.79kg = 188kg/m^3

Cement required=188/0.4=470kg

0.98*1000=[(470/3.11)+188+fa/(0.325*2.64)]

fa=556kg/m^3

648.87=0.57fc/(0.675*2.84)+0.43/(0.675*2.83)

fc=1242kg/m^3

fc(20mm) =708kg/m^3 and fc(10mm) =534kg/m^3 where, fc=weight of coarse aggregate and fa=weight of fine aggregate

Volume of treamie concrete seal=(12.76*20.5*5.6) m^3

So,

Cement required=13,769.5bags (Approximate cost=₹ 34,42,250)

Fine aggregate =308.910 m^3(Cost=₹ 2,75,000)

Coarse aggregate=689m^3(Cost=₹ 6,20,000)

Sheet pile(PZ-22 type) (Cost=₹ 29,00,000)

So, The total cost of Cofferdam (without labour cost)=₹ 72,37,250

VIII. MODEL ESTABLISHMENT (DESIGN)

Each cofferdam is a rectangle with 20.05m×12.76m in the plane using steel sheet pile (24m in length). The top elevation of steel sheet pile is +7.3m,and the bottom is -16.7m. It contains two cross braces and four angle braces in the plane, and five horizontal bracing layers in vertical section. Fig.1 depicts the plan of the cofferdam, and Fig. 2 shows 3D perspective model.

IX. ANALYSIS OF STEEL SHEET PILE COFFERDAM USING STAADPRO

In this paper, a 3D analysis software StaadPro was used to analyze the Cofferdam (Table I). Due to a different combination of load, mainly structure analysis was analyzed due to seismic, hydrostatic forces, and wave forces. The structure was found suitable, and there were no failed members.

X. CONCLUSION

A cofferdam is designed to be constructed across the Ram Nagar bridge to install bridge piers and sand filtration bed with approximately 237 interlocking sheet piles. It is a temporary enclosure constructed to allow the enclosed area to be pumped out, creating a dry work environment for major work to proceed. Enclosed coffers are commonly used for construction and repair of oil platforms, bridge piers, and other support structures built within or over water. These cofferdams are usually welded steel structures, with components consisting of sheet piles and braces. Such structures are typically dismantled after the ultimate work is completed. The sheet piles used in the project were found to be very useful in reducing the effort of de-watering by about 35% and adding stability and reliability of the cofferdams by cutting down the chances of piping in a very conducive environment. Cofferdams offer an economical and practical alternative to propping, and all anchorages are post-tensioned to 110% working load.

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