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Stability Analysis of Overflow Dam using STAAD.Pro

Ms.Varsha V Deshpande
Post graduate student – M.Tech (Civil Engineering)
PES University Banshankari III Stage,
Benagluru-560085, India

Mr. K Janardhana
Assistant Professor, Dept of Civil Engineering
PES University Banshankari III Stage,
Benagluru-560085, India

***Abstract*— Dams are important structures where safety is of utmost importance. They are complex structures subjected to various forces. Stability is one of the most important factors governing the design of dams. In this paper a 3 dimensional finite element model of an overflow dam is created using solid elements in STAAD.Pro. All the forces are calculated and applied as loads and load combinations for most adverse cases. The objective of the study is to check the stability of the dam for various load combinations mentioned in IS 6512-1984. The model is analysed considering both static and dynamic conditions. The results show that the dam is safe against overturning, sliding and uplift. The stress concentration near the trunion and the drainage gallery can be visualised.**

***Keywords*— Ogee spillway, solid elements, stability, factor of safety, stress concentration.**

I. INTRODUCTION

Concrete dams are solid structures which are built of mass concrete. The geometry, strength of concrete and shape of the dams help to resist the imposed forces acting on the dam. Spillways are hydraulic works made of concrete inserted in dams, in which the main goal is the discharge of water in order to ensure the safety of the dam. The structure should be safe against the forces such as water pressure, tail water pressure, uplift pressure, silt pressure, earthquake forces. These forces make the dam unstable and cause overturning, sliding, and tension effects on the dam. Analysis of the stability is conducted at the base of the dam and at selected planes within the dam. Analysis of the 3D Finite element dam model is performed by using STAAD.Pro. During earthquake due to ground motion an additional seismic force will act on the structure of the dam. This additional force lead to collapse of structure and affects the dynamic nature of structure it may cause the cleavage/cracks in the gravity dam. Dynamic analysis can be performed to determine the design seismic force and its distribution to difference levels along the height of the structure. The main objective of using F.E.M in this study is to evaluate the stability of the dam against various forces. The stresses are evaluated considering most adverse combinations A, B, C , D, E, F or G as per IS 6512-1984. The stresses are visualized under various combinations and checked for its stability. Provided good foundation conditions, this type of dams, when accurately projected and built, have a high degree of reliability and low maintenance costs

II. DESCRIPTION OF THE OVERFLOW DAM

In the present study, an overflow dam of height 38.5m and width 38 m monolith is considered. The overflow is made of concrete with steel gates. The model includes pier, drainage gallery and a sluice. The important data are mentioned below

Top of the dam = 215.00 m
FRL = 212.00 m
BED LEVEL = 174.5 m
Width of the pier = 3 m
Drainage gallery = 2.00x3.00 m
Density of water = 10 kN/m^3
Grade of concrete = M25
Damping = 5%

The loads such as hydrostatic force, uplift pressure, tail water pressure, silt pressure, hydrodynamic pressure are considered according to IS 6512-1984 and IS 1893-2002.

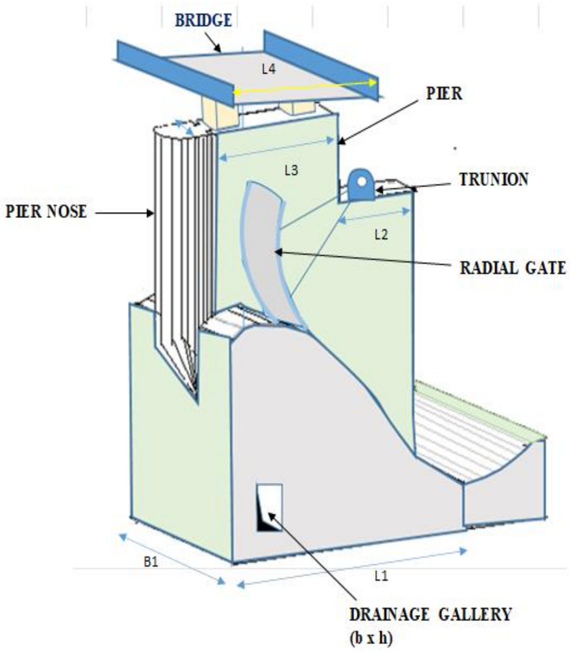

Figure 1 Dam and its components

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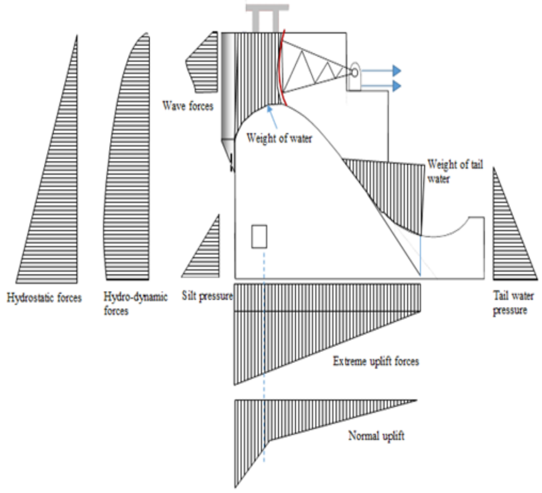

Figure 2 Forces acting on the dam

III. MODELLING OF THE OVERFLOW DAM

For solving large problems, many FE software are available such as ABAQUS, STAAD.PRO, SAP etc. In this study a 3 dimensional finite element model is created using solid elements in STAAD.Pro software. One of the main advantages of FE modelling is the possibility to set up complex models with geometry close to reality. Discretization of the elements is important for the analysis. Solid elements enable the solution of structural problems which involve three dimensional stresses. Finite element analysis provides a powerful tool when using solid elements to determine the stress distributions. It consists of 8 nodes with 3 translational degrees of freedom at each node. The boundary conditions control how the construction is supported. Here hinged support is provided at the base. The gates are modeled using plate elements having thickness of 400mm. After all the loads and load combinations are provided, the model is analyzed. Stability analysis includes safety of the dam against uplift, overturning and sliding.

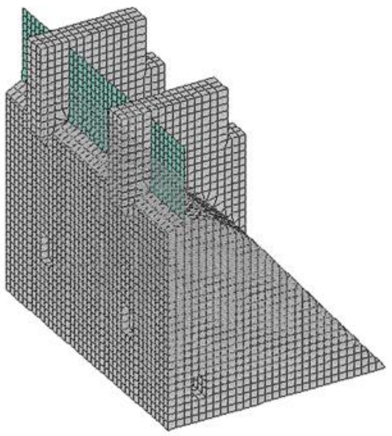

Figure 3. Finite element model of the overflow section

IV. MODES OF FAILURE AND STABILITY ANALYSIS

In order to account for stability analysis, it is important to account for different failure modes. Overturning and sliding are the most crucial factors governing stability of the structure.

Sliding: Sliding or shear failure will occur when there is a movement along any weak plane in the construction and its foundation. If the resistance against the movement is lower than the driving forces the construction will start to slide.

$$FSS = \frac{\frac{(w-u)\tan\phi}{F_\phi} + \frac{CA}{F_o}}{P}$$

Overturning: If the resultant of all the forces acting on the dam at any section passes outside the toe, the dam will begin to rotate or overturn. The factor of safety is given by:

$$\text{Factor of safety} = \frac{\text{Resisting Moment}}{\text{Overturning Moment}}$$

Resisting Moment = Moment due to pier + weir + bridge + gate

Overturning Moment = Moment due to hydrostatic force + hydrodynamic force + uplift pressure (normal and extreme)

Uplift:

The factor of safety for uplift is given by:

$$\text{Factor of safety} = \frac{\text{total vertical forces}}{\text{total uplift force}}$$

Tension: Dams have to be designed in such a way that no tension is developed anywhere. Under severe loading conditions some amount of tension may be permitted.

Compression or crushing: A dam may fail when the stresses due to compression exceed the permissible stresses and the dam material may get crushed. STAAD.Pro gives the variation of stresses along with the stress concentrations. Principal and shear stresses can also be derived from STAAD.Pro results.

V. RESULTS AND DISCUSSIONS.

In this study, hydrostatic pressure up to FRL, normal and extreme uplift pressure, tail water pressure up to level of 194.5m and hydrodynamic forces are considered. The earthquake forces are taken equivalent to 0.156 for horizontal forces and 0.05g for vertical forces, considering zone 3. The uplift is considered equal to the hydrostatic pressure at the ends. A free board of 100mm is considered. The results were directly generated from STAAD.Pro software. The variation of the stresses in the body can be indicated with different colours. The results of stability analysis which consists of check for overturning, sliding and uplift are shown in the tables

From table 1, it can be seen that the factor of safety is more than 1 in all the cases; hence it is safe against sliding.

From table 2, the factor of safety for the most crucial combination is found to be safe against uplift.

From table 3, it is seen that the factor of safety against overturning is more than 1.5 and therefore it is safe.

Table 1. Factor of safety against sliding

		B	E	G	C	F
B	29.39	29.39	29.39	29.39	29.39	29.39
L	38	38	38	38	38	38
F_y	KN	8357.595	8643.954	7183.858	8396.879	6936.785
P	KN	4680.574	6146.013	6146.013	4625.77	4625.77
$\tan_\varphi$	40°	0.84	0.84	0.84	0.84	0.84
A	m^2	1116.82	1116.82	1116.82	1116.82	1116.82
C	kN/m^2	100	100	100	100	100
F_φ		1.5	1.2	1	1.5	1
F_o		3.6	2.4	1.2	3.6	1.2

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$Fy \tan \Phi / F_g$		4680.2532	6050.7678	6034.4403	4702.25224	5826.8994
$\frac{Fy \tan \Phi / F_g}{P}$		0.99	0.9845	0.9818	1.0165	1.2596
C A/F_o		31022.77	46534.16	93068.33	31022.77	93068.33
(C A/F_o)/P		6.6278	7.5714	15.1428	6.7065	20.119
FSS		7.628	8.556	16.125	7.723	21.379

Table 2. Factor of safety against uplift

	A	D	B	E	G	C	F
Fy	12444.08 5	13287.3 27	19092.4 05	19935.6 5	19935.6 5	13194.0 85	13194.08 5
Normal	6659.9	6659.9	6659.9	6659.9	6659.9	6659.9	6659.9
Extreme	8449.625	8449.63	8449.63	8449.63	8449.63	8449.63	8449.63
FOS (normal)	1.869	1.995	2.867	2.993	2.993	1.981	1.981
FOS (extreme)	1.473	1.573	2.259	2.359	2.359	1.561	1.561

TABLE 3. FACTOR OF SAFETY AGAINST OVERTURNING

		B	E	G
Total Resisting Moment	M_R	393913.5	393913.5	393913.5
Total Overturning Moment	Mo	192977.2	216858.4	248535.7
FOS		2.041243	1.816454	1.584937

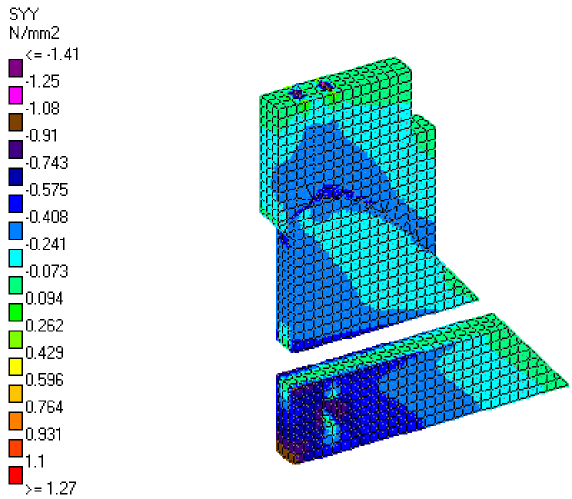

Figure 4. Normal stresses for empty case

The stress variation for empty case is shown in figure 4, where it is seen that the tensile stresses are within the permissible limits. Stress concentration can be seen near the junction of the pier and spillway and also around the drainage gallery. At the toe compressive stresses of 0.902 MPa is seen which is within the permissible stresses for concrete.

VI. CONCLUSION

- The main concern in regards of dam stability is the tensile stresses created at the heel. A small amount of tensile stresses are allowed at the heel in extreme loading conditions.
- The dam safety against all the forces as per IS 6512-1984 for all the combinations was carried out and was found to be safe and acceptable.
- Since it is a cracked section, reinforcement will be provided in cases of high tensile stresses.

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