DESIGN AND ANALYSIS OF GRAVITY DAM BY USING STAAD PRO

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Abstract - *This paper presents the stability analysis of the Masonry dam. The dam structures that were built in past years are analyzed manually. As the years pass because of no proper maintenance the efficiency of the dams may be decreased. For a better understanding of the stability of the dam structure, we are using modern techniques like different software and analysis programs. So to find out the stability of the dam we are using STAAD PRO software for a better understanding of the gravity dam.*

Key Words: **Stability Analysis, Gravity Dam, Seismic Forces, Hydro-Static forces,Staad Pro**

1.INTRODUCTION

Any structure that is built will experience numerous strengths like self-weight, wind, seismic, uplift weight constrain, and other minor forces. A gravity dam is a strong structure that is made up of concrete or brickwork. It acts as a water-holding structure and holds a huge sum of water by making a reservoir on its upstream side. That's why a gravity dam is built over a stream to hold water. The cross-segment of the gravity dam is around triangular and has a pinnacle at best and most extreme width at foot. Different strengths are acting on the gravity dam such as hydrostatic pressure, residue pressure, wave pressure, ice pressure, wind pressure, self-weight of the dam, elevated pressure and seismic forces, etc. The area of the dam is outlined in such a way that it would stand up to all these powers acting on it from different bearings beneath the impact of its possessed self-weight. Gravity dams are moreover called strong gravity dams since they are inflexible as well as strong and no bowing stresses are actuated at any point on a dam structure.

1.1 Literature Review

Title of Research	Author	Objective of Research	Case Study	Review
Analysis of Pressures on Nagarjuna Spillway	M V S S Giridhar, Madaka Madavi, Ramaraju Anirudh, E Ramakrishna Goud	To determine the pressure forces acting on the dam	Nagarjuna Sagar Dam	Water pressure is the major pressure rather than the remaining pressures
Design and Stability Analysis of Gravity Dam using STAAD Pro	Gaurav Sharma Abhay Joshi	To analyze the gravity dam using STAAD Pro	Example Problem	Mentioned, acquired forces, moments, deflections, element, and node count are used.

Study on the dam and reservoir, analysis the failures of dam	Mohith Kumar Bharati Mani Sharma Mr.Nazrul Islam	To study the reservoir and avoid the failures of the dam	Review Paper	Highlighted the different general aspects of dams, their types, and the cause of failure. And giving the data previously failed the dam in the world.
Dam-reservoir interaction analysis using finite element model	M.Pasbani Khiavi A.R.M. Gharabaghi K.Abide	Analysis of Dam reservoir by using Finite Element Method	Sefidrud Dam	Comparing responses related to two states of far-field boundary condition and analytical solution one can conclude that on condition of avoiding extra computational effort.
Design and Modal Analysis of Gravity Dams by Ansys Parametric Design Language	Shiva Koshari Mohammad Heydari	Analysis of Gravity Dam by using Ansys Parametric Design Language	Example Problem	An efficient procedure is developed to model the geometric shape of concrete gravity dams considering dam-reservoir-foundation rock interactions by employing real values of the geometric variables.
Analysis of Dam Behavior by Statistical Models: Application of the Random Forest Approach	Ahmed Belmokre Mustapha Kamel Mihoubi David Santillán	Analysis of Dam by models to Predict the deflections.	Tichy Haf arch dam	The performance of the RFR model is better than the traditional HST and HTT models, and the ANN approach. The RFR models predict recorded movements at the four pendulums more accurately than the other approaches.

1.2 Objective

From the above journals that we have refered says about the pressure distribution, analysis of dam, forces acting on the dam, failures of dam etc. Through them we concluded that the stability analysis of the dam is in following three cases and stability requirements on sliding, overturning, compression and tension. We are going to perform stability analysis of a masonry dam by manually and using STAAD Pro software and determine the forces, moments, principle stresses, shear stress acting on the masonry dam.

2. Methodology

2.1 Weight of Dam: The weight of the dam body and its establishment is the major standing up to constrain. The unit length of the dam is considered in the two-dimensional examination of a gravity dam. The cross area of the dam is partitioned into rectangles and triangles. The weight of each along with their center of gravity can be decided. The add up to the weight of the dam acting at the middle of gravity of the dam will be spoken to by the resultant of all these downward forces.

Self-weight Sw = lbh.ρc.g
Where ρc is density of masonry = 2300 kg/m^3

2.2 Water Pressure: Water pressure is a level constraint that acts on the dam in a triangular shape. No pressure is applied by the water at the surface of the reservoir and the water applies the most extreme sum weight to the dam at the foot (at the toe).

Water Pressure **=** ½ γw.h^2 acts on $h/3$ tallness from the water base.

2.3 Uplift Pressure: Water leaks through the breaks, pores, and gaps of the establishment fabric. Because of the breaks, pores, and gaps of the establishment, the water leaks through the foot joints of the dam structure and the establishment of the dam. The uplift pressure depends on the tallness of the water, if the water level is greatest at that point the uplift pressure is too extreme and if the uplift pressure is least at that point the uplift pressure is moreover least. The uplift pressure at the toe is calculated by γw.h.

Where γw = Thickness of water 9.81 kn/m^2

2.4 Seismic Pressure Force: It is due to essential, auxiliary, rare, and cherished waves on earth's outside. The wave's moment increasing velocities to establishments causes development. The concentration of soil shake at a put is the degree of the quality of shaking amid seismic tremor and it is prosecuted by a number concurring to the altered Mercalli scale (M.S.K).

For the calculation of escalated soil shudder India was separated into five zones as per IS 1893-1984 they are Zone 1, Zone 2, Zone 3, Zone 4, and Zone 5. Afterward, it is reexamined into four zones as per Is 1893-2002 they are Zone 2, Zone 3, Zone 4, and Zone 5. Nagarjuna Sagar dam comes beneath Zone 2. The seismic drive is calculated by Cm.γh.γw.h

where Cm = Weight coefficient
γh = Even seismic coefficient
γw = Thickness of water
h = Stature of the dam

2.5 Silt Pressure: When the water is streamed from the upstream side to the downstream side, the residue gets kept at the upstream side of the dam. The pressure coming from the residue kept and weight are considered in expansion to the weight and pressure of water. The weight of residue acts vertically on the slant and weighs evenly. It is computed by the Rankin's equation.

Silt pressure Psilt = 1/2 γsub h^2 ka.

Where ka is the coefficient of the residue = 1−sin Ø/1+sin Ø
Ø It is the point of the inside grinding of soil.

2.6 Wave Pressure: Waves are created on the surface of the store because of wind. This causes pressure on the dam. Wave weight depends on the stature of the wave.

Pw = 2.4 γw. Hw

2.7 Overturning Stability: The overturning stability is calculated by calculating the vertical force and level constrain acting on the gravity dam. By taking moments over the toe, which forces are contradicting the dam to topple like self-weight this moment as ideal moments (Mf) and the forces which are attempting to upset the gravity dam like water weight, elevate weight, wave weight, residue weight, etc., this minute as contradicting moments (Mo). The upsetting strengths ought to be more than 2, if it is less than 2 the dam is not safe.

Overturning moment = Mo/Mf. > 2

2.8 Sliding Force: Sliding will misfortune the stability of the gravity dam. Overabundance sliding happens amid the time of seismic tremor. Sliding constraints allude to the withdrawal between the dam establishment and shake. It is calculated by the frictional drive and level powers on the dam, it ought to not be less than 1.5.

Sliding force = frictional force/flat constrain on dam > 1.5

2.9 Compression and Tension: For the most part, dam structures are built by utilizing materials like concrete and stone work. The compression and tension are very typical and these depend on the forces acting on it. Concurring with the material utilized for the development of structure the values of compression and tension vary.
Formulae utilized for the calculation of compression and tension:

- At Heel = $\Sigma V/B(1-6e/B)$
- At toe = $\Sigma V/B(1+6e/B)$

where ΣV = Whole of Vertical Forces
B = Base width of dam
e = Unpredictability (b/2-x)

3. STAAD Procedure

Open STAAD pro software and select the new project file. Now select the space option and give length units in meters and force units in kilonewtons. Now select the add new beam option and then click finish. Now add node points and give dimensions to draw the cross-section of the gravity dam. By giving the node numbers join the node points to one another. Now assign support at the ends of the gravity dam by selecting the support option in the general tab. Give the support as fixed on both ends supports. Now select load and definition and give dead load and live load for the gravity dam. Assign the self-weight of the dam in dead load and hydrostatic force on the upstream side and uplift pressure from the downward as live load. Also, assign the material of the gravity dam as masonry and give its density. Now select the translational repeat option give the global direction as Z- -the axis and give step spacing. Now select the four-node plate option and join the nodes of the dam section by joining four nodes. Likewise, join all the remaining plates using the four-node plate option. Now select all the cross-sections and select the plate cursor. Now perform analysis to get the result of the gravity dam. After performing a run analysis go to the postprocessing tab to find the stresses and moments in the gravity dam.

4. Case Study

Nagarjuna Sagar Dam is the world's biggest brickwork dam which is built over The Stream Krishna. The dam is built between 1955 to 1967. The dam interfaces the Palnadu area of Andhra Pradesh and the Nalgonda area of Telangana. The dam makes a water supply where the water is collected and it is provided to the encompassing locale named Palnadu, Guntur, Nalgonda, Prakasam, Khammam, Krishna, and parts of West Godavari. The provided water is utilized for both water systems and household purposes. It is moreover a source of electric era for the national grid.

The net capacity of the store behind the dam is up to 11.472 billion cubic meters, its successful capacity is 6.92 cubic kilometers. It is 124 meters (407ft) stature from its establishment and 1600 meters (5200ft) long with 26 surge doors. The estimate of each surge door is 13 meters in width and 14 meters in stature. It is worked by both Andhra Pradesh and Telangana states.

Beneath the administering of Nizam the British engineers did the studying work for the dam over the Krishna Stream in the year 1903. The development of the extension was introduced by Prime Serve Jawaharlal Nehru on 10th December 1955. Raja Vasireddy Ramagopala Krishna Maheswara Prasad given one hundred and ten million GBP in 1952 and 22,000 ha (55,000 sections of land) of arrive for the development of the extend. The dam was built under the design administration of Kanuri Lakshmana Rao.

The water from the supply was discharged into the cleared out and right bank canals by Prime Serve Indira Gandhi on 4th Eminent 1967. The dam was chosen for the advancement of a water aerodrome beneath UDAN Conspire in 2022.

Table – 1: Specifications of Dam

Specifications	Values
Length of dam	1600m
Height of dam	106.78m
The top width of the dam	9.2m
The bottom width of the dam	97.4m
The slope on the downstream side	1 in 0.75
The slope on the upstream side	1 in 20
Maximum flood level	106.78m
Galleries	71.05m (from toe)

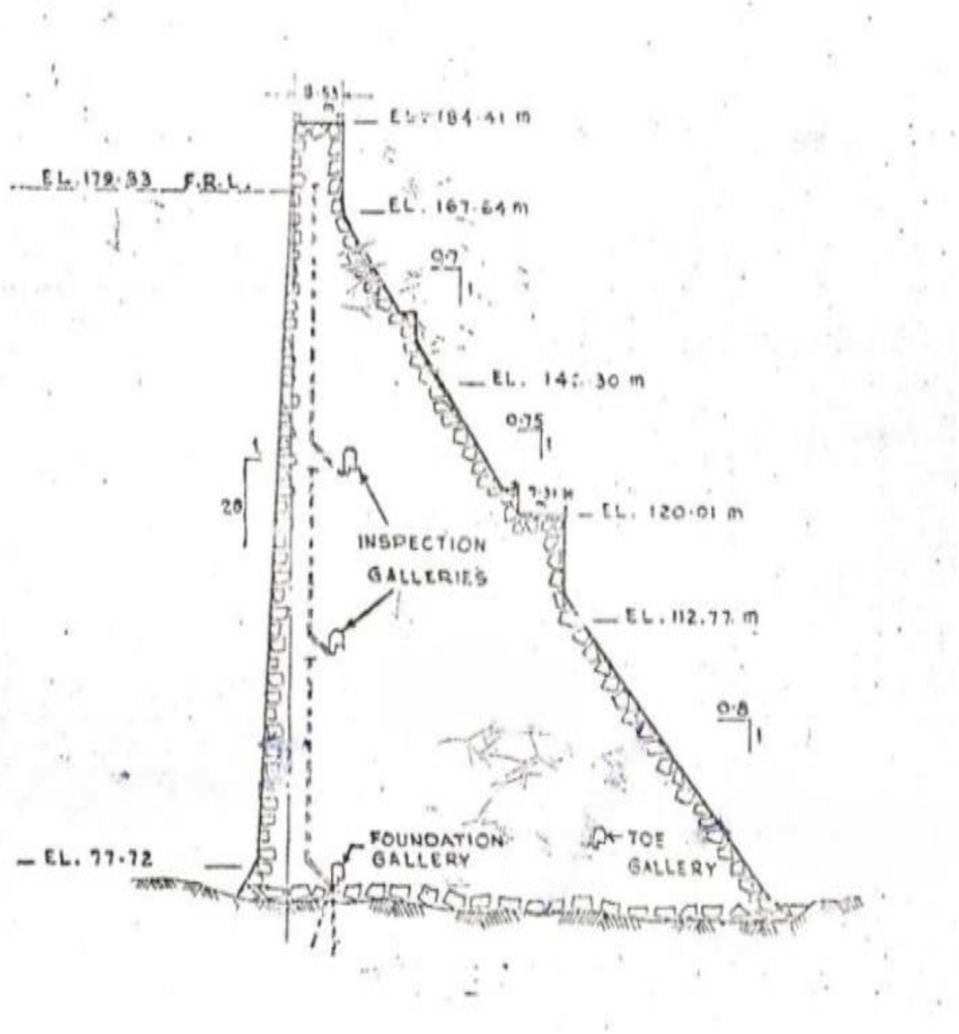


Fig -1: Cross Section of a Gravity Dam (Source: G V Gopal Rao article, Google Image)

4.1 Design of dam structure

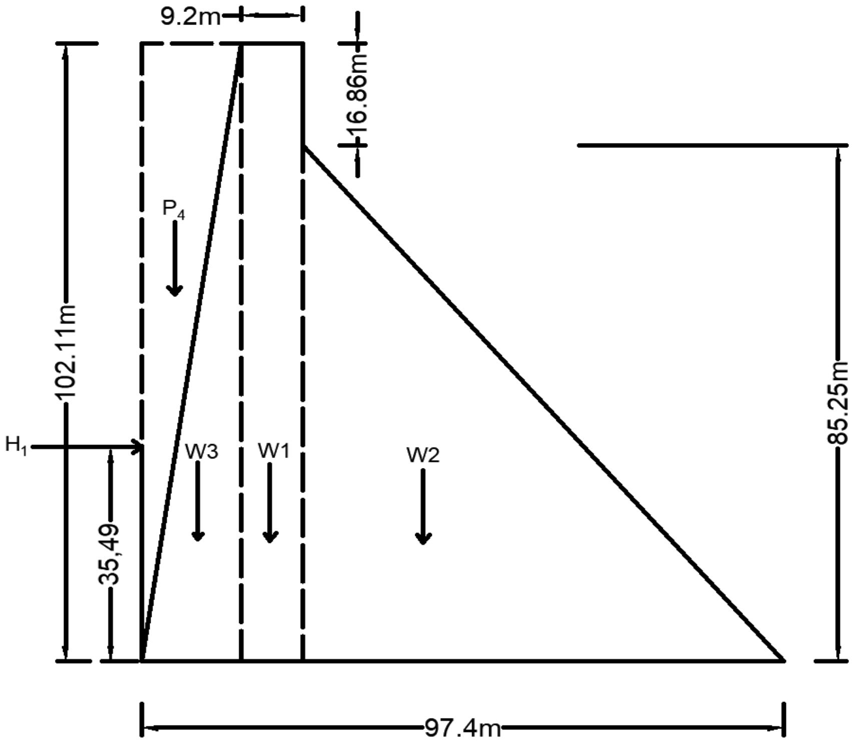


Fig-2: Cross Section of Dam

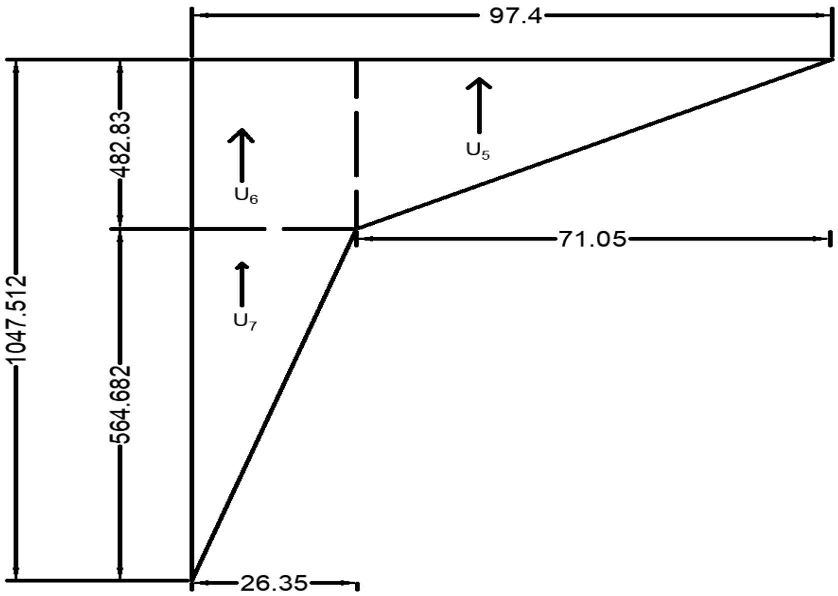


Fig-3: Uplift Pressure Diagram

5. Calculations & Results

TABLE 2. STABILITY CALCULATIONS NEGLECTING SEISMIC FORCES

Item	Description	Forces (KN)		Lever arm (M)	Moment at Toe (KN-M)		Remarks
		Vertical	Horizontal		Positive(+ve)	Negative(-ve)	
W1	**Selfweight of Dam** 9.20 x 106.78 x 1 x 23	22594.648		77.65	1754.474×10^3		Reservoir Empty Condition
W2	1/2 x 73.05 x 89.92 x 23	75539.544		48.7	3678.775×10^3		
W3	1/2 x 15.5 x 106.78 x 23	18603.745		87.3	1624.107×10^3		
	Sum	$\sum V_1 = 116737.9$		Sum	7057.356×10^3	0.00	
					$\sum M_1 = 7057.356 \times 10^3$		
P4	**Water Pressure Force** 1/2 x 15.15 x 106.78 x 9.81	7934.9		92.35	732.788×10^3		The Reservoir Full With no Uplift
H1	$1/2 \times 106.78^2 \times 9.81$		55926.66	35.593		1990.616×10^3	
	Sum	$\sum V_2 = 124672.8$	55926.66	Sum	$+7790.144 \times 10^3$	-1990.616×10^3	
					$\sum M_2 = 5799.528 \times 10^3$		
U5	**Uplift Pressure Force** 1/2 x 71.05 x 482.83	-17261.172		47.367		817.61×10^3	Reservoir Full With Uplift
U6	482.83 x 26.35 x 1	-1722.5705		84.225		145.1×10^3	
U7	1/2 x 564.282 x 26.35	-7439.685		88.62		659.304×10^3	
	Sum	$\sum V_3 = 98249.8$		Sum	$+7790.144 \times 10^3$	-3612.63×10^3	
					$\sum M_3 = 4177.514 \times 10^3$		

Case 1. Reservoir Empty Condition

When the reservoir is empty, as it were the weight of the dam will be acting as a force. Other forces namely water pressure and uplift will be zero. The resulting force $\sum V_1$ and resulting moment $\sum M_1$ for this case has been worked out in Table 1.

Position of resultant from toe:

$$e = \frac{\sum M_1}{\sum V_1} = \frac{7057.356 \times 10^3}{116737.9} = 60.45m$$

Its distance from the center is

$$e = \frac{b}{2} - x = \frac{97.4}{2} - 60.45 = -11.75m$$

Normal compressive stress at the toe:

$$p_n = \frac{\sum V_1}{b}\left[1 + \frac{6e}{b}\right] = \frac{116737.9}{97.4}\left[1 + \frac{6(-11.75)}{97.4}\right] \qquad = 331.01\frac{kN}{m^2}$$

Normal compressive stress at heel:

$$p_n = \frac{\sum V_1}{b}\left[1 - \frac{6e}{b}\right] = \frac{116737.9}{97.4}\left[1 - \frac{6(-11.75)}{97.4}\right] \qquad = 2066.07\frac{kN}{m^2}$$

Principal stress at toe:

$$\sigma_1 = p_n\, sec^2\emptyset \qquad where\ tan\emptyset = 0.75\ and\ sec^2\emptyset = 1.562$$

$$\sigma_1 = 331.01 \times 1.5625 = 517.20\frac{kN}{m^2}$$

Principal stress at heel:

$$\Sigma = p_n\, sec^2\theta \qquad where\ tan\theta = \frac{15.15}{106.78} = 0.142\ and\ sec^2\theta = 1.02$$

$$\Sigma = 2066.07 \times 1.02 = 2107.39\frac{kN}{m^2}$$

Shear stress at the toe:

$$\tau = p_n\, tan\emptyset = 331.01 \times 0.75 = 248.26\frac{kN}{m^2}$$

Shear stress at heel:

$$\tau = p_n\, tan\theta = 2066.07 \times 0.142 = 293.38\frac{kN}{m^2}$$

Note that there cannot be any sliding or overturning when the reservoir is empty.

Case 2. Reservoir full with no uplift: In some cases, values of stresses at the toe and heel are worked out without considering uplift as the vertical powers are most extreme in this case.

The values of vertical forces $\sum V_2$ and moments $\sum M_2$ have been worked out in Table 1 where the $\sum V_2$ and $\sum M_2$ speak to the entirety of forces and entirety of moments of all forces when the reservoir is full but when uplift is not acting.

Position of resultant from toe:

$$x = \frac{\sum M_2}{\sum V_2} = \frac{5799.528 \times 10^3}{124672.8} = 46.51m$$

Its distance from the center is

$$e = \frac{b}{2} - x = \frac{97.4}{2} - 46.51 = 2.19m$$

Normal compressive stress at the toe:

$$p_n = \frac{\sum V_2}{b}\left[1 + \frac{6e}{b}\right] = \frac{124672.8}{97.4}\left[1 + \frac{6\times 2.19}{97.4}\right] \quad = 1452.69\frac{kN}{m^2}$$

Normal compressive stress at heel:

$$p_n = \frac{\sum V_1}{b}\left[1 - \frac{6e}{b}\right] = \frac{124672.8}{97.4}\left[1 - \frac{6\times 2.19}{97.4}\right] \quad = 1107.32\frac{kN}{m^2}$$

Principal stress at toe:

$$\sigma_1 = p_n\ sec^2\emptyset \qquad where\ tan\emptyset = 0.75\ and\ sec^2\emptyset = 1.5625$$

$$\sigma_1 = 1452.69 \times 1.5625 = 2269.83\frac{kN}{m^2}$$

Principal stress at heel:

$$\Sigma = p_n\ sec^2\theta - p\ tan^2\theta\ where\ tan\theta = \frac{15.15}{106.78} = 0.142\ and\ sec^2\theta = 1.02$$

$$\Sigma = 1107.32 \times 1.02 - 9.81 \times 106.78 \times 0.02 = 1108.52\frac{kN}{m^2}$$

Shear stress at the toe:

$$\tau = p_n\ tan\emptyset = 1452.69 \times 0.75 = 1089.52\frac{kN}{m^2}$$

Shear stress at heel:

$$\tau = -(p_n - p)\ tan\theta = -(1107.32 - (9.81 \times 106.78)) \times 0.142 = -8.49\ kN/m^2$$

Here there is no uplift pressure in this condition. Hence, the factor of safety against sliding and overturning is not worked out. These are considered when uplift pressure acts.

Case 3. Reservoir full with uplift: Values of vertical forces $\sum V_3$ and moments $\sum M_3$ have been worked out in Table 1.

Position of resultant from toe:

$$x = \frac{\sum M_3}{\sum V_3} = \frac{4177.514\times 10^3}{98249.8} = 42.52m$$

Its distance from the center is

$$e = \frac{b}{2} - x = \frac{97.4}{2} - 42.52 = 6.18m$$

Normal compressive stress at the toe:

$$p_n = \frac{\sum V_2}{b}\left[1 + \frac{6e}{b}\right] = \frac{98249.8}{97.4}\left[1 + \frac{6\times 6.18}{97.4}\right] \quad = 1392.74\frac{kN}{m^2}$$

Normal compressive stress at heel:

$$p_n = \frac{\sum V_1}{b}\left[1 - \frac{6e}{b}\right] = \frac{98249.8}{97.4}\left[1 - \frac{6\times 6.18}{97.4}\right] \quad = 624.71\,\frac{kN}{m^2}$$

Principal stress at toe:

$$\sigma_1 = p_n\, sec^2\emptyset \qquad where\ tan\emptyset = 0.75\ and\ sec^2\emptyset = 1.5625$$

$$\sigma_1 = 1392.74 \times 1.5625 = 2176.16\,\frac{kN}{m^2}$$

Principal stress at heel:

$$\sigma = p_n\, sec^2\theta - p\, tan^2\theta \quad where\ tan\theta = \frac{15.15}{106.78} = 0.142\ and\ sec^2\theta = 1.02$$

$$\sigma = 624.71 \times 1.02 - 9.81 \times 106.78 \times 0.02 = 616.25\,\frac{kN}{m^2}$$

Shear stress at the toe:

$$\tau = p_n\, tan\emptyset = 1392.74 \times 0.75 = 1044.55\,\frac{kN}{m^2}$$

Shear stress at heel:

$$\tau = -(p_n - p)\, tan\theta = -(624.71 - (9.81 \times 106.78)) \times 0.142 = 60.03\ kN/m^2$$

Calculation of Factor of Safety:

The factor of Safety against Overturning = $\frac{\sum M(+)}{\sum M(-)} = \frac{7790.144 \text{ x } 103}{3612.63 \text{ x } 103}$ = 2.16 > 1.5

The factor of Safety against Sliding = $\frac{\mu \sum V_3}{\sum H} = \frac{0.3\times 98249.8}{55926.66}$ = 0.53 < 2

Shear Friction Factor = $\frac{\mu \sum V_3 + b.c}{\sum H} = \frac{0.3\times 98249.8 + 97.40\times 2800}{55926.66}$ = 5.40 > 4

Safety against sliding according to IS 6512-1984:

Taking $F_\varphi = 1.5$ and $F_e = 3.6$ for load combination B,

$$F = \frac{\frac{\mu \sum V}{F\varphi} + \frac{cb}{F_e}}{\sum H} = \frac{\frac{0.3\times 98249.8}{1.5} + \frac{2800\times 97.4}{3.6}}{55926.66} = 1.706 > 1 \quad \text{Hence safe.}$$

Case-4: Stability check of a dam by considering seismic forces

TABLE 3. ADDITIONAL FORCES AND THEIR MOMENTS DUE TO EARTHQUAKE

Item	**Description**	**Forces (KN)**		**Lever arm (M)**	**Moment at Toe (KN-M)**		**Remarks**
		Vertical	**Horizontal**		**Positive(+ve)**	**Negative(-ve)**	
	Inertial force due to the earthquake on the weight of the dam						The inertial force acting at C.G. is considered to be acting upwards
$\sum V_1$	$\sum V_1 \times \propto v$	-2334.758		60.455		141147.84	
W_1	$W_1 \times \propto h$		903.785	53.39		48253.08	
W_2	$W_2 \times \propto h$		1510.790	29.973		45282.908	
W_3	$W_3 \times \propto h$		372.074	35.593		13243.229	
P_e	**Hydrodynamic pressure**		2176.31			95695.92	
	Total	$\sum V$ =-2334.758	$\sum H$ =4962.95			$\sum M$=-343.623x10^3	
	The sum of forces and moments from the previous table	$\sum V_3$ = 98249.8	H =55926.66		+7790.144x10^3	-3612.63 x10^3	
	Sum	$\sum V_4$ = 95915.042	$\sum H$ =60889.61		+7790.144x10^3	-3956.253x10^3	
					$\sum M_4$ = 11746.397x10^3		

From (IS 1893-1984)

$$\propto_h = 2 \propto_o$$

Where,

$\propto_o$ varies from 0.02 to 0.08

$\propto_h$ varies from 0.04 to 0.16 for Zone (II) to Zone (V)

Therefore, $\propto_o$ = 0.02 (Zone II)

$\propto_h = 2 \times 0.02 = 0.04$

Vertical seismic co-efficient ($\propto_v$) = 0.5 $\propto_h$

= 0.5x0.04 = 0.02

For the worst condition consider that:

(a) Horizontal earthquake acceleration acts upstream.

(b) Vertical earthquake acceleration acts downwards.

Hydrodynamic pressure due to water caused by earthquakes can be found in Zanger's formula. Since the slope is up to middle depth, the approximate value of e can be found by joining the heel to the upstream edge,

$$\text{Tan}\,\theta_1 = \frac{15.15}{106.78} = 0.14 \qquad \text{or } \theta_1 = 8.075°$$

$$C_m = 0.735 \times \left(1 - \frac{8.075°}{90°}\right) = 0.670$$

At base $C = C_m$

Therefore,34 $p_e = C_m \times \alpha_h \times w \times h = 0.670 \times 0.04 \text{ x } 9.81 \text{ x } 106.78 = 28.07 \text{ kN/m}^2$

Total pressure $force\ F_e = 0.726 \times p_e \times h = 0.726 \times 28.07 \times 106.78 = 2176.31kN$

Moment due to this force at the base,

$$M_e = 0.299 \times p_e \times h^2 = 0.299 \times 28.07 \times 106.78^2 = 95695.92 \text{ kN-m}$$

Calculation of forces and moments due to inertial earthquake force is done in the tabular form (Table 2). This Table is to be prepared in continuation of the previous Table (Table 1) made without considering earthquake forces.

Values of vertical forces $\sum V_4$ and moment $\sum M_4$ have been worked out in the Table 3.

Position of resultant from toe:

$$x = \frac{11746.397 \text{x} 10^3}{95915.042} = 122.467$$

Hence the resultant does not lie within the middle third. Its distance from the center is

$$e = \frac{b}{2} - x = \frac{97.4}{2} - 122.467 = -73.767m$$

i.e., the resultant falls to the right of the center.

Normal compressive stress at the toe:

$$p_n = \frac{\sum V_4}{b}\left[1 + \frac{6e}{b}\right] = \frac{95915.042}{97.4}\left[1 + \frac{6 \times -73.767m}{97.4}\right]$$

$$= -3490.134kN/m^2$$

Normal compressive stress at heel:

$$p_n = \frac{\sum V_4}{b}\left[1 - \frac{6e}{b}\right] = \frac{95915.042}{97.4}\left[1 - \frac{6 \times -73.767m}{97.4}\right]$$

$$= 5459.642\ kN/m^2$$

Principal stress at the toe is

$$p_n\ sec^2\emptyset = -3490.134 \times 1.5625 = 5453.33\frac{kN}{m^2}$$

Principal stress at heel:

$$\sigma_1 = p_n\ sec^2\theta - (\ p + p_e\ )\ tan^2\theta$$

$$\sigma_1 = 5459.642 \times 1.02 - (9.81 \times 106.78 + 28.07) \times 0.02$$

$$\sigma_1 = 5547.323\frac{kN}{m^2}$$

Shear stress at toe:

$$\tau = p_n\ tan\emptyset = -3490.134 \times 0.75 = -2617.6\frac{kN}{m^2}$$

Shear stress at heel:

$$\tau = -(p_n - (\ p + p_e\ )\ tan\theta$$

$$\tau = -(5459.642 - (9.81 \times 106.78 + 28.07)) \times 0.142$$

$$\tau = -622.54\ kN/m^2$$

Calculations of Factor of Safety:

The factor of Safety against Overturning = $\frac{\sum M(+)}{\sum M(-)} = \frac{7790.144\text{x}10^3}{3956.253\text{x}10^3}$ = 1.96> 1.5

The factor of Safety against Sliding = $\frac{\mu \sum V_4}{\sum H} = \frac{0.3\times95915.042}{60889.61}$ = 0.47 < 2

Shear Friction Factor = $\frac{\mu \sum V_4 + b.c}{\sum H} = \frac{0.3\times95915.042+97.40\times2800}{60889.61}$ = 4.95 > 4

Safety against sliding according to IS 6512-1984:

Taking $F_\varphi = 1.5$ and $F_e = 3.6$ for load combination B,

$$F = \frac{\frac{\mu \sum V}{F\varphi}+\frac{cb}{F_e}}{\sum H} = \frac{\frac{0.3\times95915.042}{1.5}+\frac{2800\times97.4}{3.6}}{60889.61} = 1.27 > 1$$

Hence safe.

Table-4: Node Points Table in STAAD

Node	X m	Y m	Z m
2	-15.150	0.000	0.000
3	82.250	0.000	0.000
4	0.000	106.780	0.000
5	9.200	106.780	0.000
6	9.200	89.920	0.000
7	-2.392	89.920	0.000
8	-15.150	0.000	13.000
9	82.250	0.000	13.000
10	0.000	106.780	13.000
11	9.200	106.780	13.000
12	9.200	89.920	13.000
13	-2.392	89.920	13.000
14			

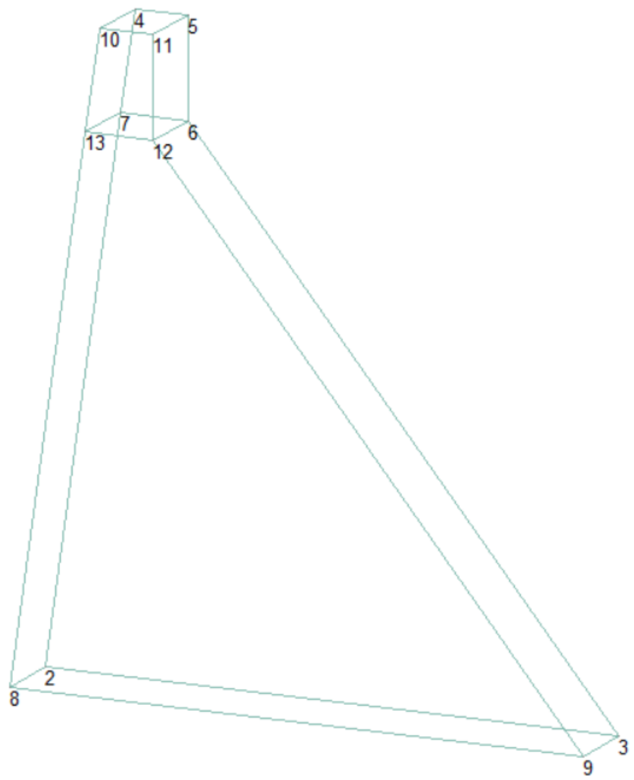


Fig-4: Dam with Node Points

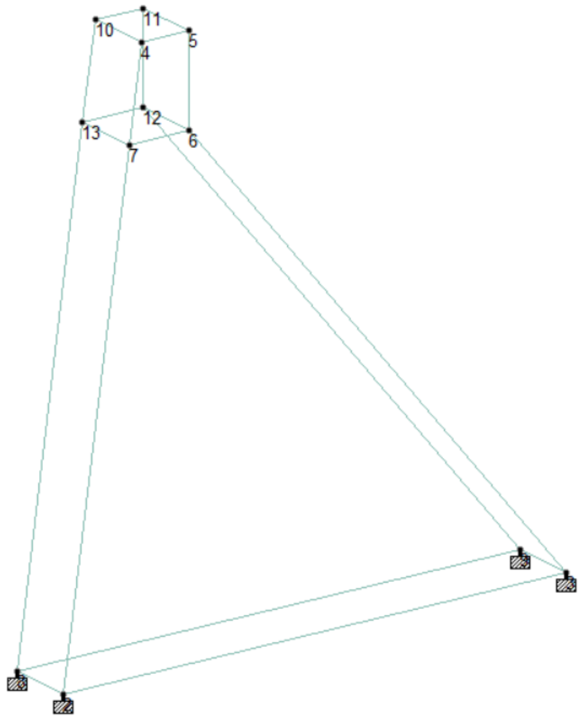


Fig-5: Dam with Supports

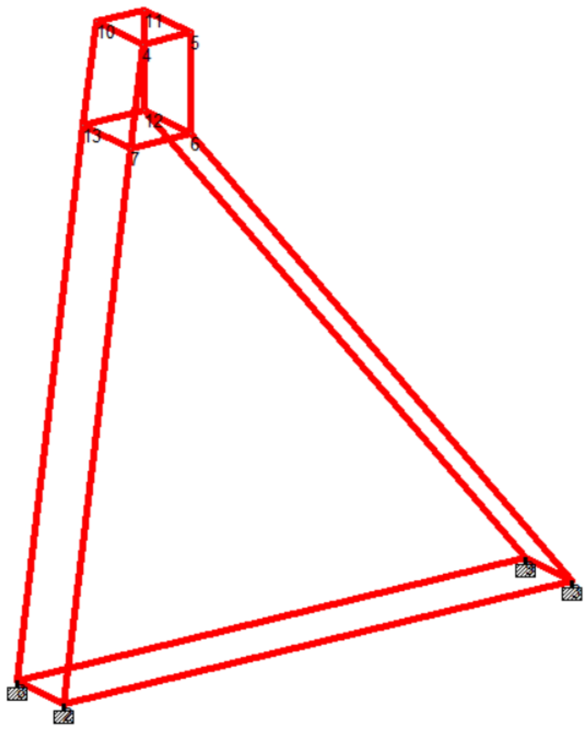


Fig-6: Dam with its Self-Weight

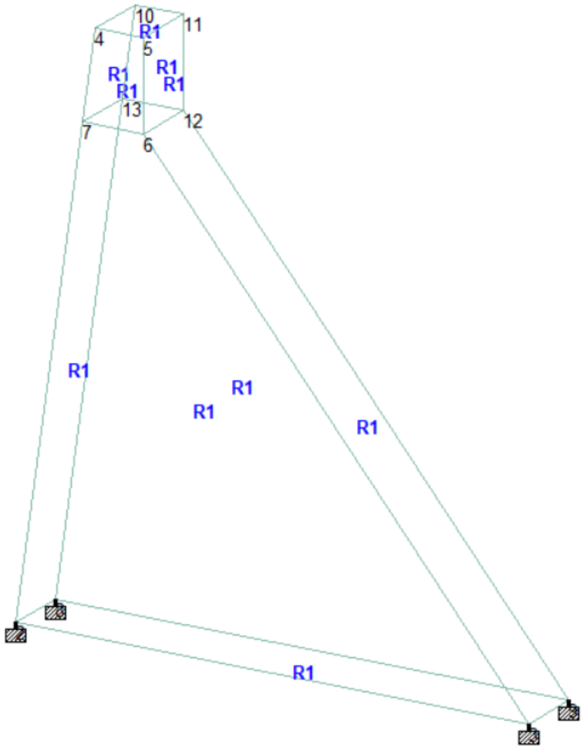


Fig-7: Dam with its Property

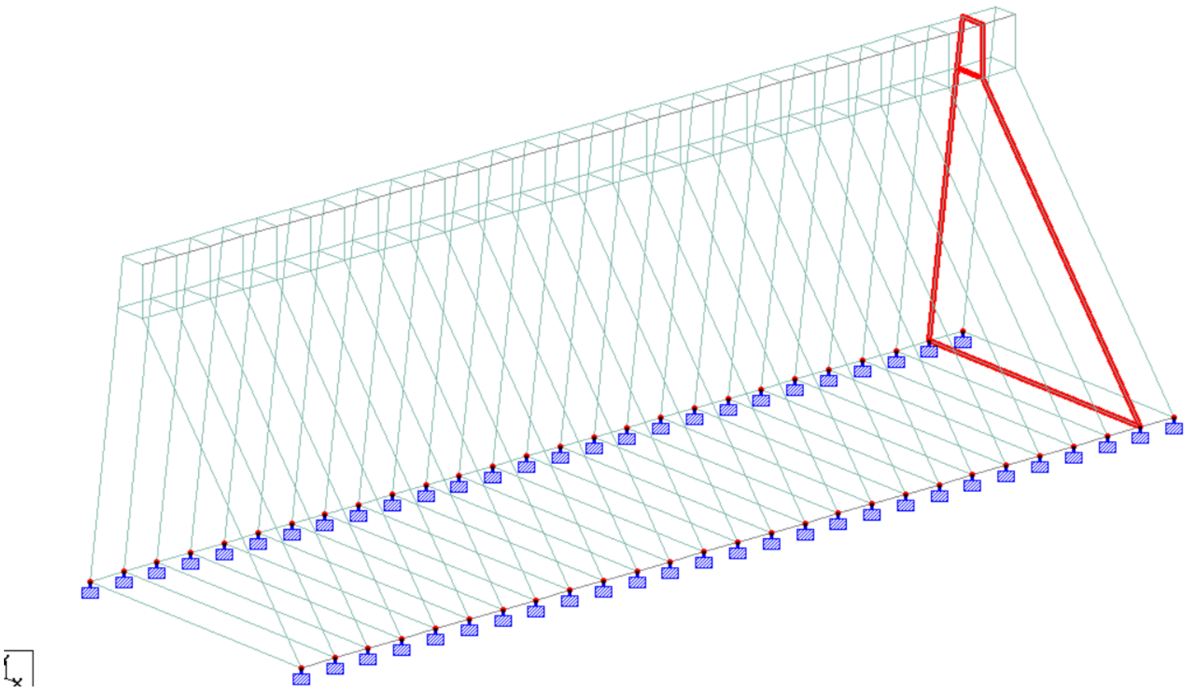


Fig-8: Total Length of Dam

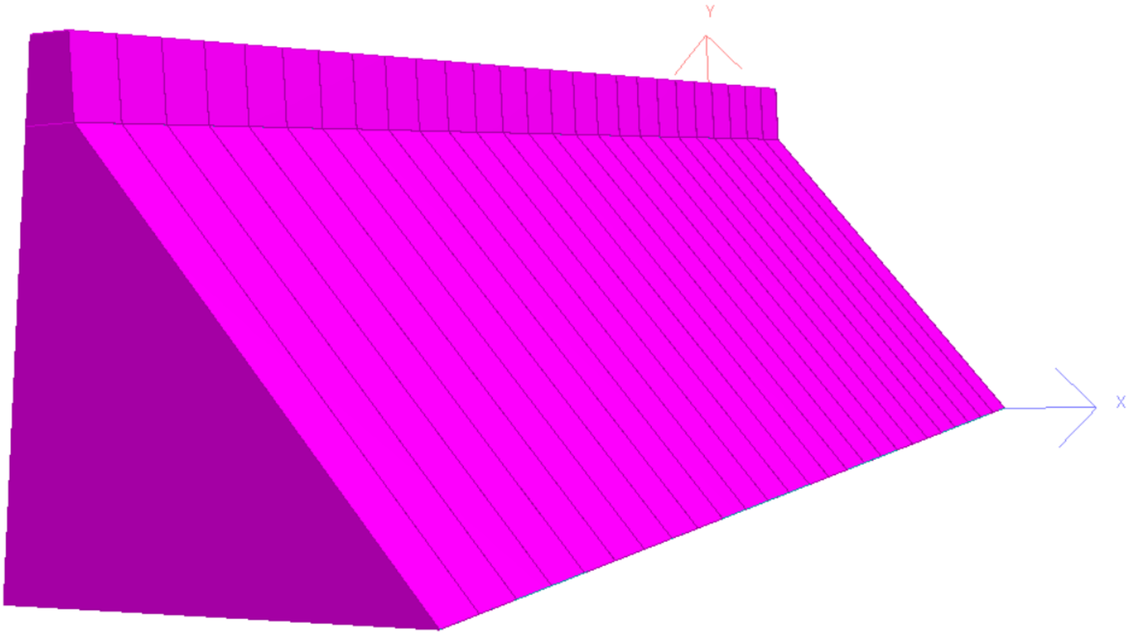


Fig-9: Rendered view of Dam

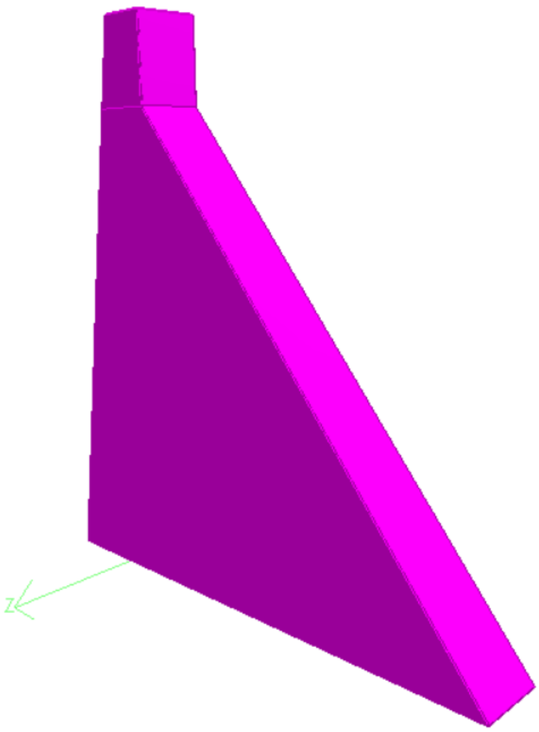


Fig-10: Rendered view of a gate

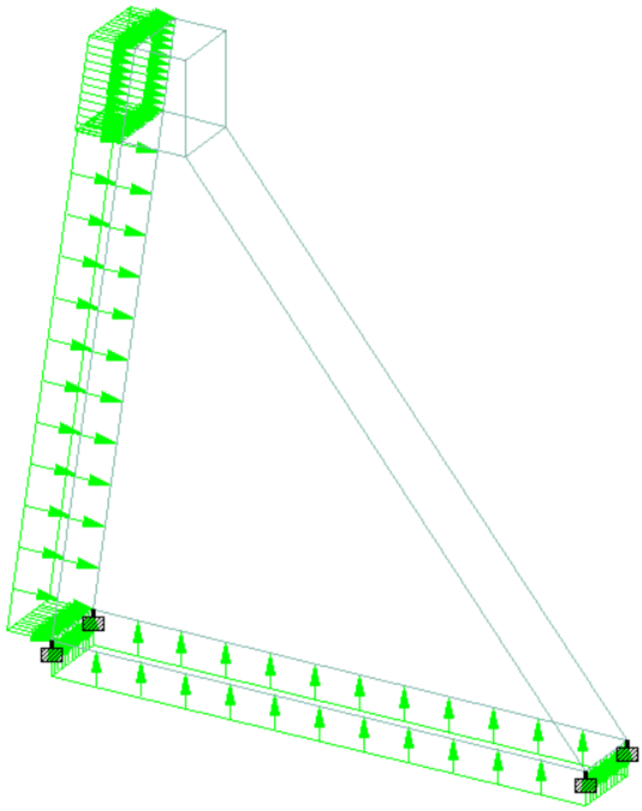


Fig-11: Dam structure Acting forces on it

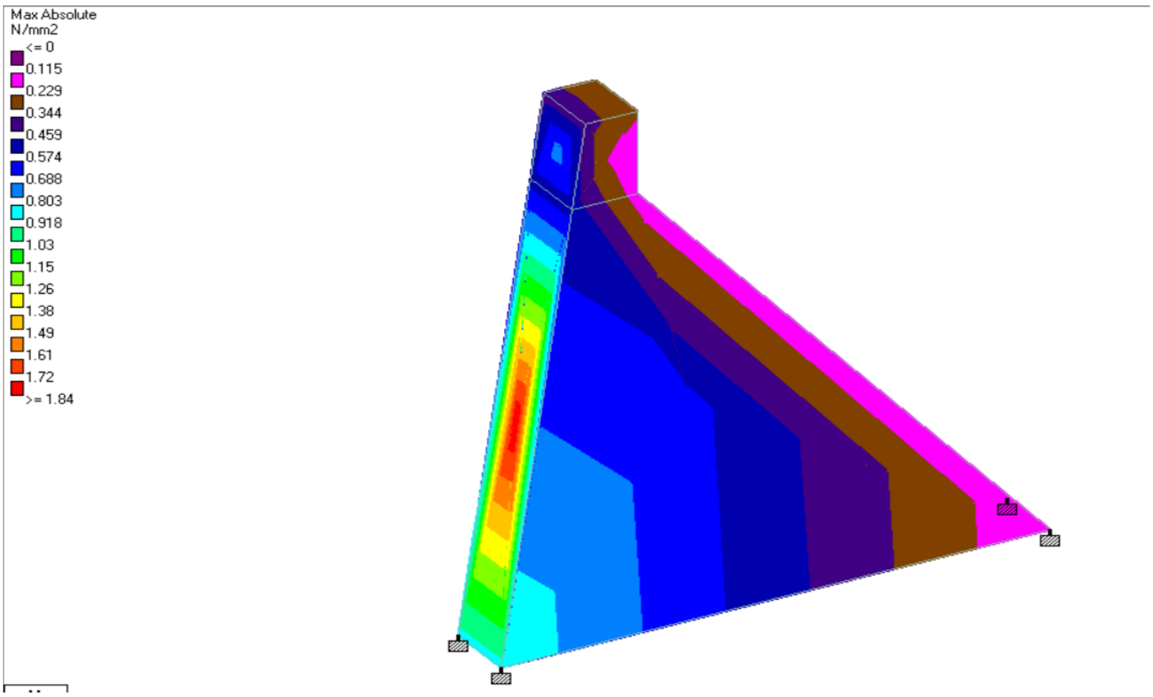


Fig-12: Animation of max absolute pressure on a gate of dam Dead load

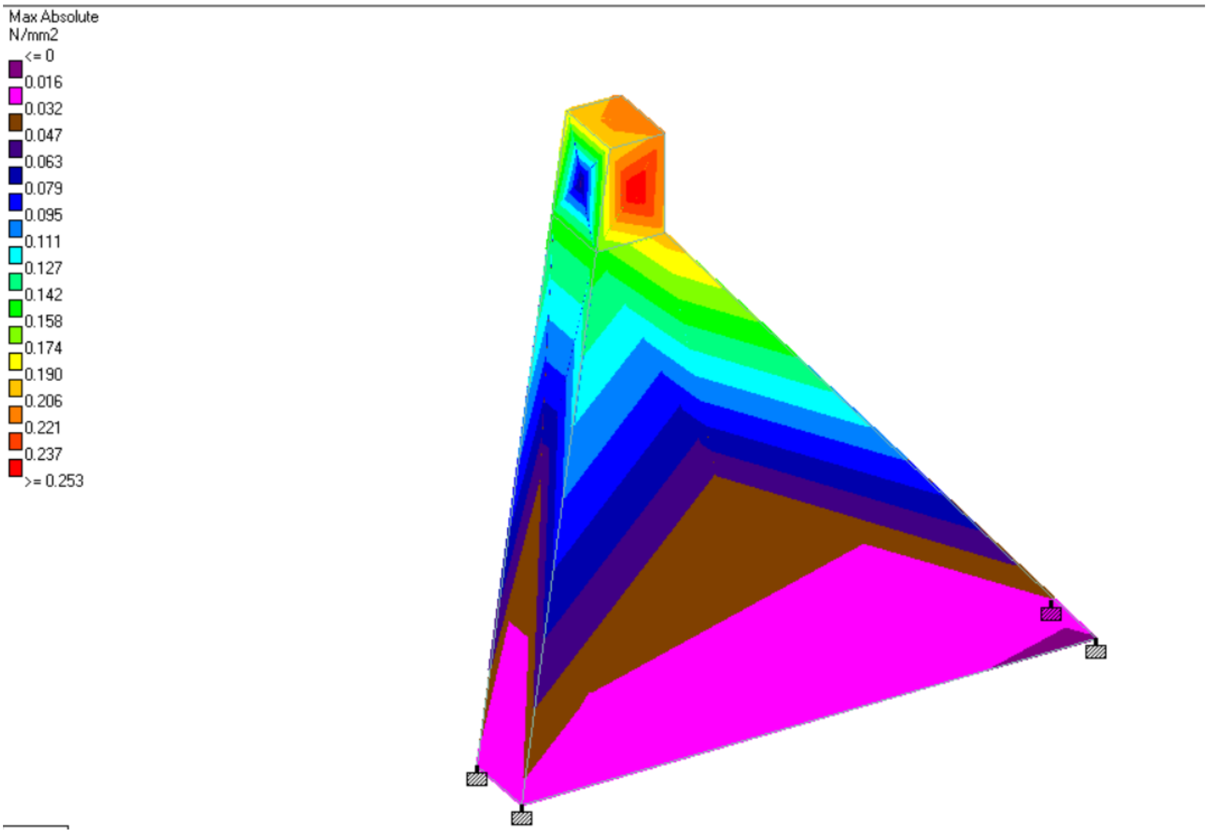
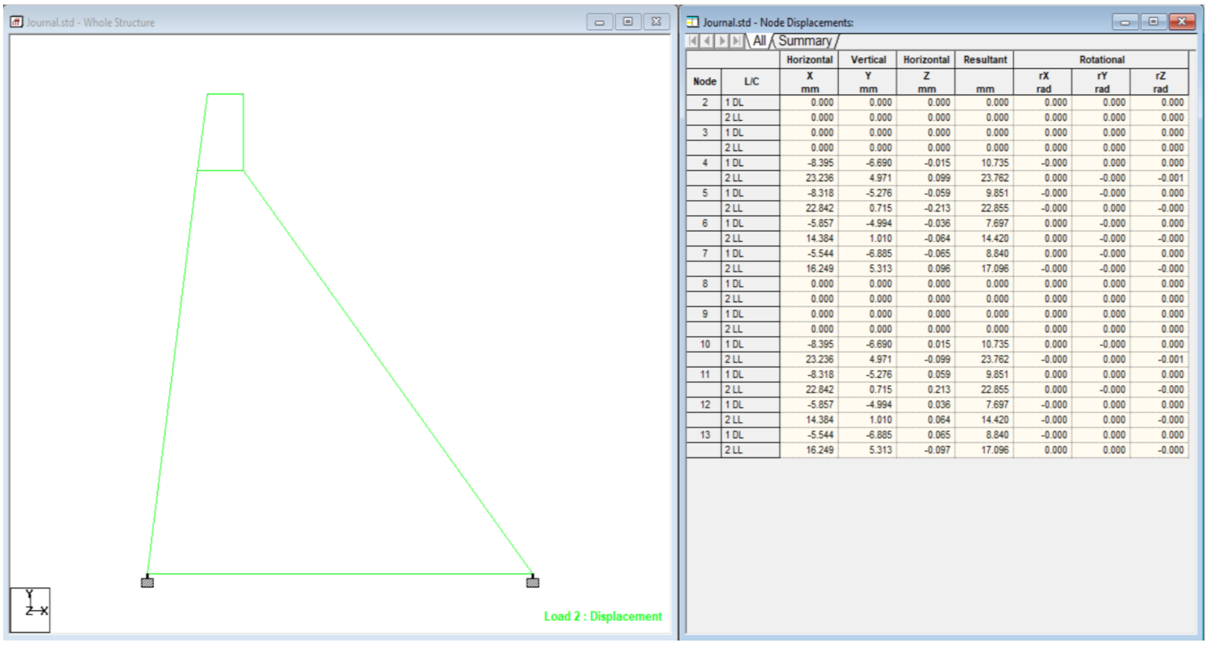


Fig-13: Animation of max absolute pressure on a gate of dam Live load



		Horizontal	Vertical	Horizontal	Resultant	Rotational		
Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
2	1 DL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2 LL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	1 DL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2 LL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	1 DL	-8.395	-6.690	-0.015	10.735	-0.000	0.000	0.000
	2 LL	23.236	4.971	0.099	23.762	0.000	-0.000	-0.001
5	1 DL	-8.318	-5.276	-0.059	9.851	-0.000	-0.000	0.000
	2 LL	22.842	0.715	-0.213	22.855	-0.000	0.000	-0.000
6	1 DL	-5.857	-4.994	-0.036	7.697	0.000	-0.000	0.000
	2 LL	14.384	1.010	-0.064	14.420	0.000	-0.000	-0.000
7	1 DL	-5.544	-6.885	-0.065	8.840	0.000	-0.000	0.000
	2 LL	16.249	5.313	0.096	17.096	-0.000	-0.000	-0.000
8	1 DL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2 LL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	1 DL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2 LL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	1 DL	-8.395	-6.690	0.015	10.735	0.000	-0.000	0.000
	2 LL	23.236	4.971	-0.099	23.762	-0.000	0.000	-0.001
11	1 DL	-8.318	-5.276	0.059	9.851	0.000	0.000	0.000
	2 LL	22.842	0.715	0.213	22.855	0.000	-0.000	-0.000
12	1 DL	-5.857	-4.994	0.036	7.697	-0.000	0.000	0.000
	2 LL	14.384	1.010	0.064	14.420	-0.000	0.000	-0.000
13	1 DL	-5.544	-6.885	0.065	8.840	-0.000	0.000	0.000
	2 LL	16.249	5.313	-0.097	17.096	0.000	0.000	-0.000

Fig-14: Node Displacement Table

Table 5: Summary of Forces and Moments

Journal.std - Support Reactions:

All | Summary | Envelope

		Horizontal	Vertical	Horizontal	Moment		
Node	L/C	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
2	1 DL	-714.208	52145.934	1596.219	-1284.987	161.813	210.07022E
	2 LL	-20862.521	-5539.678	-1814.829	4115.442	-621.711	141.98417E
3	1 DL	714.216	34232.277	604.426	-220.228	-240.951	-209.84062E
	2 LL	-6416.434	24532.680	1595.264	-361.889	-381.953	-142.00692E
8	1 DL	-714.237	52145.891	-1596.219	1284.990	-161.812	210.07008E
	2 LL	-20862.488	-5539.649	1814.826	-4115.453	621.712	141.98389E
9	1 DL	714.229	34232.262	-604.426	220.228	240.951	-209.84050E
	2 LL	-6416.407	24532.648	-1595.261	361.887	381.951	-142.00664E

Journal.std - Statics Check Results

L/C		Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
1	Loads	0.000	-172.75636E	0.000	1.12292E6	0.000	-4.05165E6
	Reactions	-0.000	172.75636E	0.000	-1.12292E6	-0.150	4.05165E6
	Difference	-0.000	-0.000	0.000	-0.021	-0.150	0.529
2	Loads	54557.853	-37986.001	0.000	246.90900E	354.62603E	-4.20343E6
	Reactions	-54557.853	37986.001	-0.000	-246.90898E	-354.62591E	4.20343E6
	Difference	0.000	-0.000	-0.000	0.016	0.113	-0.386

6. Discussions

- From manual calculations hence the stability analysis of the dam is ok.
- From STAAD the obtained moments are given in Table 5 above.
- In STAAD we performed analysis for a single gate width of 13m and height 106.7m.
- From figure-11 represents the forces (Water Pressure, Uplift Pressure, Self-Weight) acting on one gate width of the dam.
- Figure 12&13 is the animation of pressure distribution on the dam due to forces acting on it.
- Figure 14 shows the displacement of the dam due to various pressures acting on it.

7. Conclusions

This paper presents the stability analysis of a masonry dam in both manually and by using STAAD Pro. In manual calculations the stability analysis against water pressure, uplift pressure and seismic pressure is ok. In STAAD Pro we performed analysis for one gate width of dam and obtained results are shown in the above figures and tables. As we conclude that by using new technique and software's it is easy to perform analysis comparing to manual procedures and the results are accurate, thereby it is easy to analyse or design of any complicated structure by using advanced software's which reduce time and human effort.

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