DESIGN AND ANALYSIS OF GRAVITY DAM –A CASE STUDY ANALYSIS USING STAAD-PRO

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Abstract

A gravity dam is a solid structure, made of concrete or masonry, constructed across a river to create a reservoir on its upstream. The section of the gravity dam is approximately triangular in shape, with its apex at its top and maximum width at bottom. The section is so proportioned that it resists the various forces acting on it by its own weight. In this paper analysis of dam is carried out using Staad.Pro software. Staad.pro is widely used for multi-storied buildings with beam and columns. However Staad.Pro can analyse any type of element such as, plate, shell or solid in addition to beam members. So, in the software with suitable data, dam is modelled with solid elements. Result of stresses and stress contours are described at the end of paper. The objective of paper is to have a direction of analysis of dam considering solid elements using STAAD.Pro.

INTRODUCTION

Dams constructed out of masonry or concrete and which rely solely on its self weight for stability fall under the nomenclature of gravity dams. Masonary dams have been in use in the past quite often but after independence, the last major masonry dam structure that was built was the N*agarjunsagar Dam* on river *Krishna* which was built during 1958-69. Normally, coursed rubble masonry was used which was bonded together by lime concrete or cement concrete. However masonry dam is no longer being designed in our country probably due to existence of alternate easily available dam construction material and need construction technology. In fact, gravity dams are now being built of mass concrete, whose design and construction aspects would be discussed in this chapter. There are other dams built out of concrete like the Arch/Multiple Arch or Buttress type. These have however not been designed or constructed in India, except the sole one being the arch dam at *Idukki* on river *Periyar*. In India the trend for concrete dam is only of the gravity type and therefore the design other types of concrete dams have not been discussed in this course. Interested readers may know more about such dams from standard books on the subject like Engineering of Large Dams by Henry H. Thomas, Volumes I and II published by John Wiley and Sons (1976). A slightly outdated publication, Engineering of Dams, Volumes I, II and III by W P Creager, J D Justin, and J Hinds published by John Wiley and Sons (1917) has also been long considered a classic in dam engineering, though many new technologies have do not find mention here.

It is important to note that, it is not just sufficient to design a strong dam structure, but it is equally important to check the foundation as well for structural integrity. For concrete dams, the stress developed at the junction of the base becomes quite high, which the foundation has to resist. Usually concrete gravity dams are constructed across a river by excavating away the loose overburden till firm rock is encountered which is considered as the actual foundation. Nevertheless not all rocks are of the same quality; they vary with different geological materials and the process by which they have been formed over the years. For example, the hills of the Himalayan range of the mountains are considered geologically young, as well as weaker than the massif of the Deccan plateau. The quality of foundation not only affects the design, it also guides the type of dam that would be suited at a design site. Hence, discussions on the ground foundation aspects have been introduced in this lesson as well.

Design of concrete gravity Dam sections

Fundamentally a gravity dam should satisfy the following criteria:

1. It shall be safe against overturning at any horizontal position within the dam at the contact with the foundation or within the foundation.
2. It should be safe against sliding at any horizontal plane within the dam, at the contact with the foundation or along any geological feature within the foundation.
3. The section should be so proportional that the allowable stresses in both the concrete and the foundation should not exceed.

Safety of the dam structure is to be checked against possible loadings, which may be classified as primary, secondary or exceptional. The classification is made in terms of the applicability and/or for the relative importance of the load.

1. Primary loads are identified as universally applicable and of prime importance of the load.
2. Secondary loads are generally discretionary and of lesser magnitude like sediment load or thermal stresses due to mass concreting.
3. Exceptional loads are designed on the basis of limited general applicability or having low probability of occurrence like inertial loads associated with seismic activity.

Technically a concrete gravity dam derives its stability from the force of gravity of the materials in the section and hence the name. The gravity dam has sufficient weight so as to withstand the forces and the overturning moment caused by the water impounded in the reservoir behind it. It transfers the loads to the foundations by cantilever action and hence good foundations are pre requisite for the gravity dam.

The forces that give stability to the dam include:

1. Weight of the dam
2. Thrust of the tail water

The forces that try to destabilize the dam include:

1. Reservoir water pressure
2. Uplift
3. Forces due to waves in the reservoir
4. Ice pressure
5. Temperature stresses
6. Silt pressure
7. Seismic forces
8. Wind pressure

The forces to be resisted by a gravity dam fall into two categories as given below:

1. Forces, such as weight of the dam and water pressure which are directly calculated from the unit weight of materials and properties of fluid pressure and
2. Forces such as uplift, earthquake loads, silt pressure and ice pressure which are assumed only on the basis of assumptions of varying degree of reliability. In fact to evaluate this category of forces, special care has to be taken and reliance placed on available data, experience and judgement.

Objectives

1. Method to calculate fundamental period and design base shear.
2. Vertical distribution of base shear along the height of the dam.
3. To analyse the dam by using staad-pro.

LITERATURE REVIEW

IIT, Kharagpur (2010) broadly classified dams according to construction materials. The classification is as follows; 1) Embankment dams - These are dams constructed of natural materials excavated or obtained from the vicinity of a dam site. The two main types of embankment dams include: 2) Earth-filled dams – This dam uses compacted soil for constructing the bulk of the dam. It is constructed primarily by selecting engineering soils compacted uniformly and intensively in thin layers at a controlled moisture content. This dam may be homogeneous where only one type of soil is available and the dam height is low or may be zoned where more than one type of soil material is used. They are the most economical type of dam and utilizes materials, usually available locally, that do not require a high degree of processing. However, these dams are highly susceptible to erosion and require consistent maintenance. Also, soil importing may be required if the soils in the area or not clay soils. 3) Concrete dams – Use of mass concrete in dam constructed started due to the ease of construction and to suit complex designs, like having a spillway within the dam body. Mas concrete can be strengthened by the use if additives like slag, pulverized fuel ash inorder to reduce temperature induced problems or avoid undesirable cracking and total cost of the project.

Types of concrete dams include: i) Arch dams – these types of dams have considerable upstream curvature in plan and rely on an arching action on the abutments through which of the water loads is passed onto the walls of the river valley ii) Buttress dams – these types of dams consist of a continuous upstream face supported at regular intervals by buttress walls and the downstream side. iii) Gravity dams – A gravity dam is one which depends entirely on its own weight for stability. It may be constructed of masonry or of concrete. Other classifications of dams include

2.1.1 Based on function and use (i) Storage dams (or conservation) dams: These are dams constructed to store excess flood water during the rainy season when there is a large flow in the river to be utilized later during the period when the flow in the river is reduced and is less than the demand. The water stored in the reservoir formed in the upstream is used for a number of purposes, such as irrigation, water supply and hydropower.

(ii) Diversion dam: A diversion dam is constructed for the purpose of raising the water level and divert water of the river into an off-taking canal (or a conduit) or a conveyance system where it may be used as run-off river hydroelectric scheme, water supply or irrigation.

2.1.2 Hydraulic design, (i) Overflow dams: An overflow dam is designed to act as an overflow structure. The surplus water which cannot be retained in the reservoir is permitted to pass over the crest of the overflow dam which acts as a spillway. The overflow dam is made of a material such as masonry or cement concrete which does not erode by the action of overflowing water. (ii) Non-overflow dams: A non-overflow dam is designed such that there is no flow over it. Excess water is not allowed to flow over the top of the dam and a separatespillway away from the body of the dam is provided to dispose of the excess flood water.

The procedure is as outlined below:

i) Collect the stream flow data at the reservoir site during the critical dry period. Generally, the monthly inflow rates are required. However, for very large reservoirs, the annual inflow rates may be used.

ii) Ascertain the discharge to be released downstream to satisfy water rights.

iii) Determine the direct precipitation volume falling on the reservoir during the month.

iv) Estimate the evaporation losses which would occur from the reservoir. The pan evaporation data are normally used for the estimation of evaporation losses during the month.

v) Ascertain the demand during various months.

vi) Determine the adjusted inflow during different months as follows: =

+ − − vii) Computation of the storage capacity for each month. = −

The storage would be required only in those months in which the demand is less than the adjusted inflow.

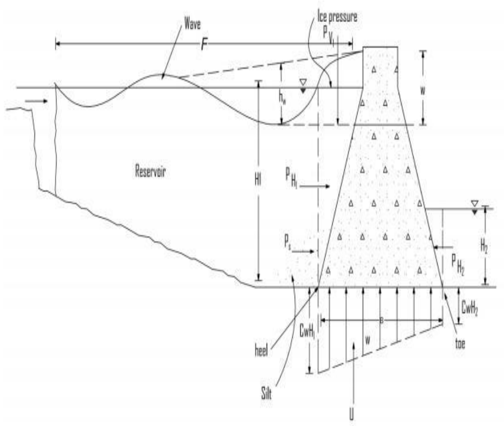


Figure 3.2 – Forces Acting on a Gravity Dam

Design specifications and methodology

Design specifications

Height of the dam = 90mts

Length =50mts

Base width=85 mts

Concrete grade=M40

Steel grade-FE500

Road width =10mts

Water flow distance= 10mts

METHODOLOGY

STAAD or (STAAD.Pro) is a structural analysis and design computer program originally developed by Research Engineers International in Yorba Linda, A. In late 2005, Research Engineer International was bought by Bentley Systems. An older version called Staad-III for windows is used by Iowa State University for educational purposes for civil and structural engineers. The commercial version STAAD.Pro is one of the most widely used structural analysis and design software. It can also make use of various forms of dynamic analysis from modal extraction to time history and response spectrum analysis.

The dam body is modeled in STAADpro using the SOLIDisoparametric finite elements with eight nodes. Each node has three translational degrees of freedom. The stiffness matrix of the solid element is evaluated by numerical integration with eight Gauss – Legendre points. The dam is analyzed for several basic loads and load combinations possibly met with during its service. These are enlisted in table 1 below. The stresses induced are checked for all the combinations and the dimensions are so framed that the factor of safety mentioned above is maintained. The base of the dam is to rest on rock and the extra excavation into be filled with concrete of same strength, the foundation rock of approximately equal to the height of dam is modeled around and below the foundation level.

The present study undertaken deals with time history method of dynamic analysis. Time history is available only for X direction, so in order to apply forces in different angles, the structure has to be rotated with incidence angle from 0 to 90 degrees, with an increment of 10 degrees and column forces have been investigated in all cases. Further in order to find the accurate angle the interval of one degree is used. The columns have been divided into three main categories, including corner, side and internal (middle) columns and the results are compared.

<u>Design in staad</u>

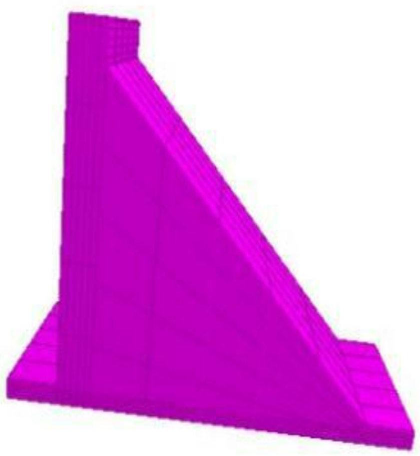


Figure 3.1 shows the 3d construction in staad

Figure 3.2 shows the staad in put plan

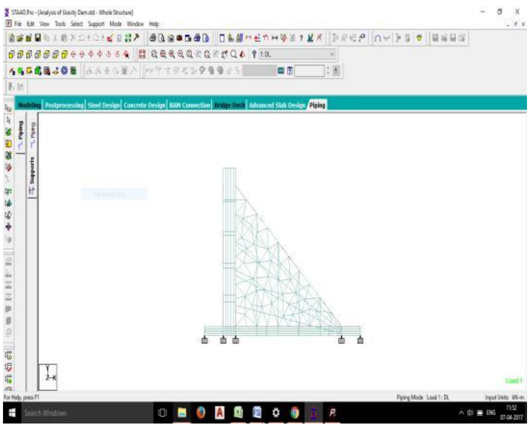


Figure 3.3 shows the elevation of dam

ANALYSIS INPUT AND RESULTS

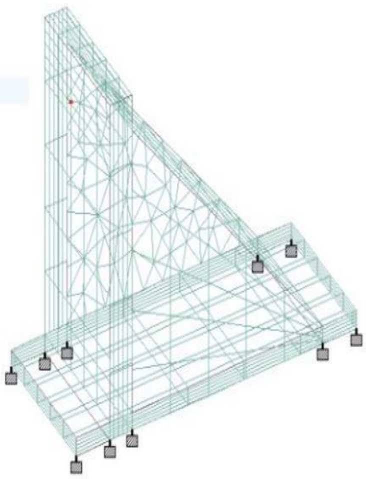


Figure 4.1 shows the support areas in staad

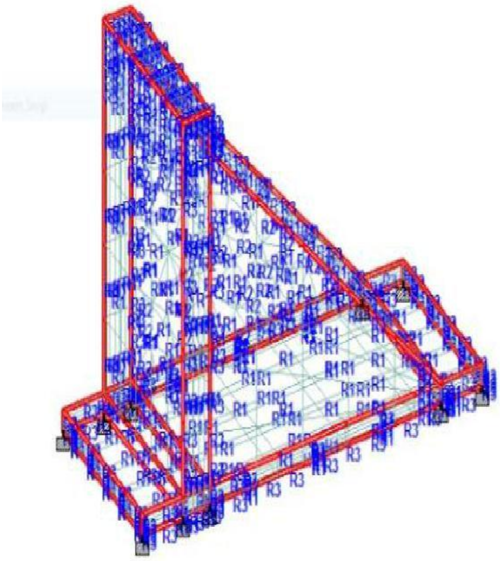


Figure4.2 shows the geometry of the dam

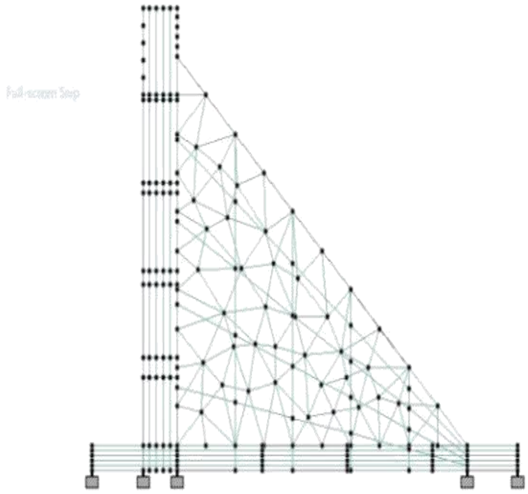


Figure 4.3 shows the piping geometry

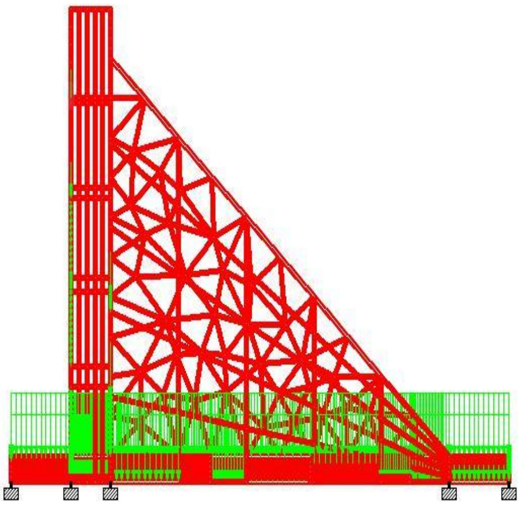


Figure 4.4 shows piping assignments and dead load conditions i.e self weight

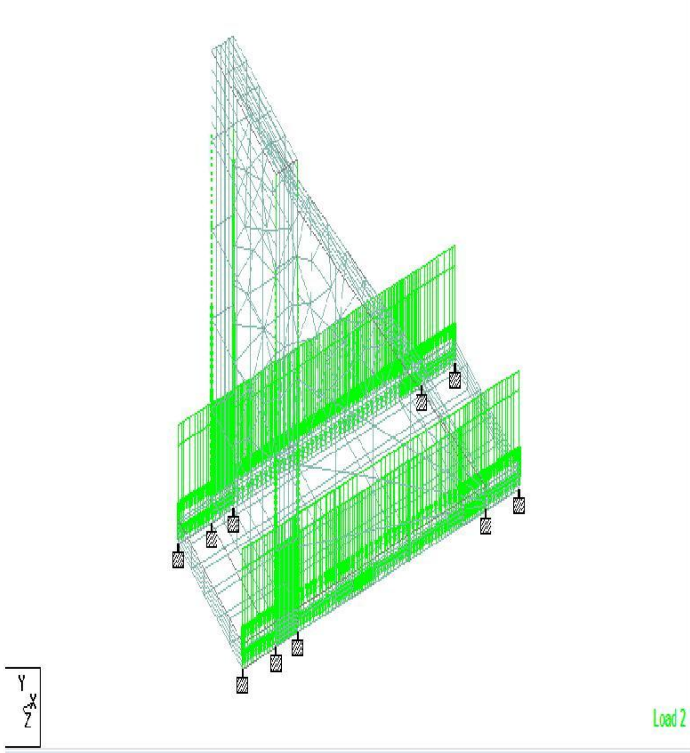


Figure 4.6 shows the load assignment IS codes

Job Information

Engineer Checked Approved

Date: 07-Apr-17

Structure Type SPACE FRAME

Number of Nodes 441 Highest Node 441
Number of Elements 257 Highest Beam 665
Number of Plates 444 Highest Plate 701
Number of Basic Load Cases 1
Number of Combination Load Case 3

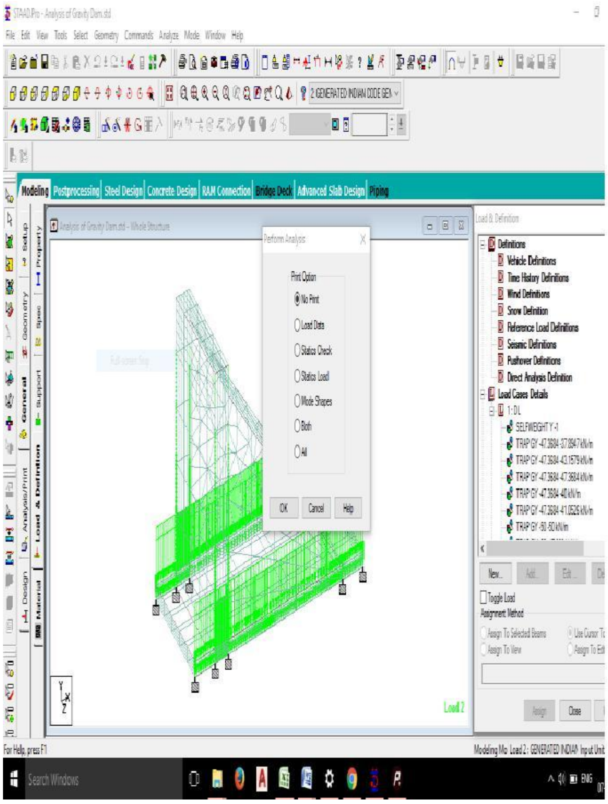


Figure 4.7 shows analysis input data assignments

Analysis of Gravity Dam.std ...

Node	X m	Y m	Z m
1	0.000	0.000	0.000
2	0.000	90.000	0.000
3	10.000	0.000	0.000
4	10.000	90.000	0.000
5	95.000	0.000	0.000
6	10.000	80.000	0.000
7	0.000	0.000	50.000
8	0.000	90.000	50.000
9	10.000	0.000	50.000
10	10.000	90.000	50.000
11	95.000	0.000	50.000

Analysis of Gravity Dam.std ...

Beam	Node A	Node B	Property Refn
1	1	34	3
2	3	434	3
3	6	404	3
4	1	318	3
5	2	298	3
6	1	36	3
7	2	29	3
8	3	151	3
9	4	350	3
10	5	90	3

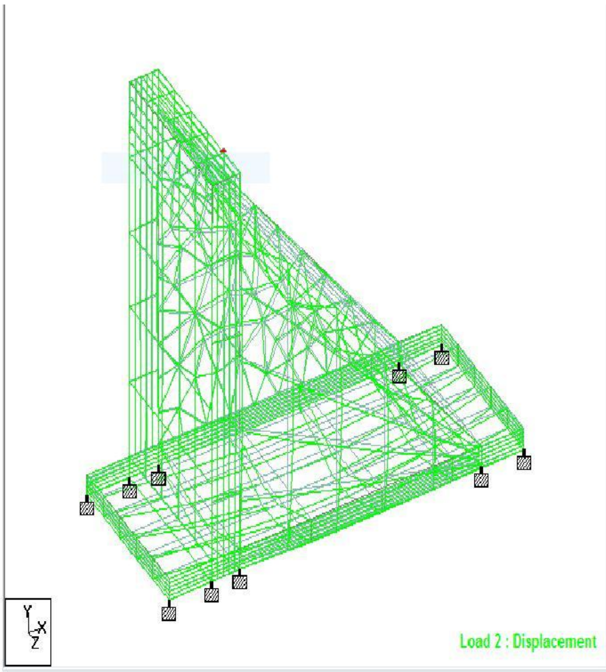


Figure 4.8 shows displacement

All / Summary

		Horizontal	Vertical	Horizontal	Resultant	Rotational		
Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
1	1 DL	1.306	-19.291	-32.795	38.070	0.000	-0.004	-0.00
	2 GENERATE	1.959	-28.936	-49.193	57.106	0.001	-0.006	-0.00
	3 GENERATE	1.567	-23.149	-39.354	45.685	0.000	-0.005	-0.00
	4 GENERATE	1.175	-17.362	-29.516	34.263	0.000	-0.003	-0.00
2	1 DL	42.770	-27.771	-52.793	73.400	-0.000	-0.000	-0.00
	2 GENERATE	64.155	-41.656	-79.190	110.101	-0.000	-0.000	-0.00
	3 GENERATE	51.324	-33.325	-63.352	88.081	-0.000	-0.000	-0.00
	4 GENERATE	38.493	-24.994	-47.514	66.060	-0.000	-0.000	-0.00

Analysis of Gravity Dam.std - Beam Relative Displacement Detail:

All Relative Displacement / Max Relative Displacements

Beam	L/C	Dist m	x mm	y mm	z mm	Resultant mm
1	1 DL	0.000	0.000	0.000	0.000	0.000
		4.500	-0.049	-0.000	1.327	1.328
		9.000	-1.044	-0.000	1.659	1.961
		13.500	-1.518	-0.001	1.162	1.912
		18.000	0.000	0.000	0.000	0.000
	2 GENERATE	0.000	0.000	0.000	0.000	0.000
		4.500	-0.073	-0.000	1.990	1.992
		9.000	-1.566	-0.000	2.489	2.941
		13.500	-2.277	-0.001	1.743	2.867
		18.000	0.000	0.000	0.000	0.000

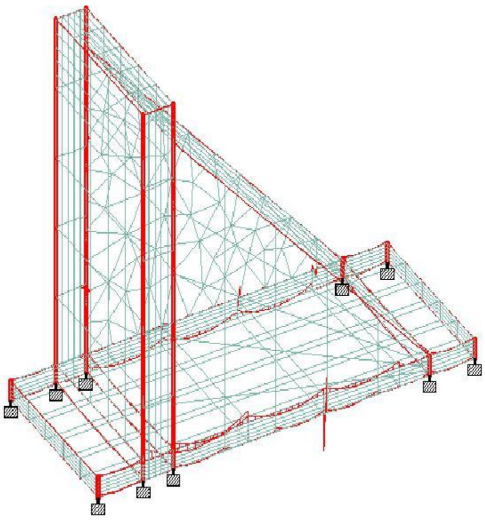


Figure4.9 shows bending

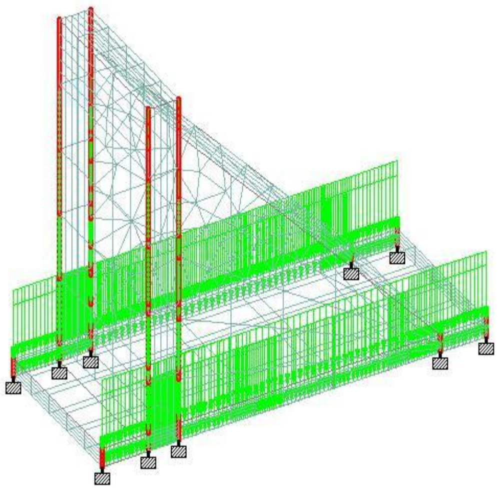


Figure 4.10 shows displacement along axis

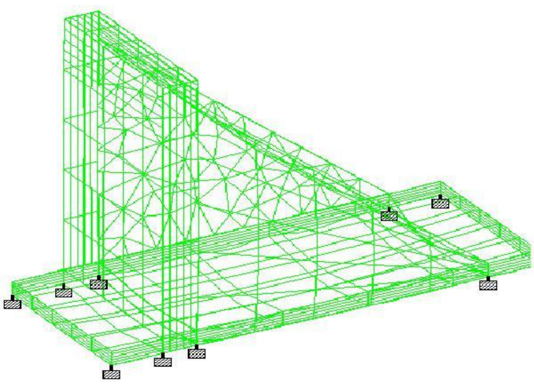


Figure 4.11 shows displacement conditions for load assignment

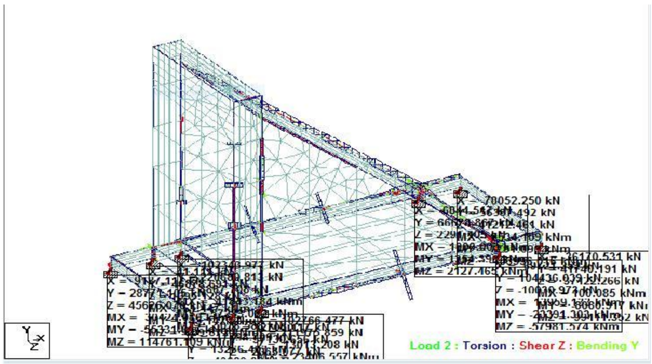


Figure 4.13 shows torsion, shear along Z bending along Y

		Horizontal	Vertical	Horizontal	Moment		
Node	L/C	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
17	1 DL	-27.407	31252.461	730.085	40.964	130.094	-539.914
	2 GENERATE	-41.111	46878.691	1095.128	61.447	195.142	-809.872
	3 GENERATE	-32.889	37502.957	876.102	49.157	156.113	-647.897
	4 GENERATE	-24.667	28127.213	657.077	36.868	117.085	-485.923
18	1 DL	68229.320	147.12055E	5911.805	-27895.455	38188.719	-3385.726
	2 GENERATE	102.34398E	220.68081E	8867.708	-41843.184	57283.082	-5078.588
	3 GENERATE	81875.188	176.54467E	7094.167	-33474.547	45826.469	-4062.871
	4 GENERATE	61406.387	132.40848E	5320.624	-25105.908	34369.848	-3047.153
19	1 DL	-4563.011	44452.578	1527.603	666.669	836.264	1418.310

Analysis of Gravity Dam.std - Statics Check Results

L/C		Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
1	Loads	0.000	-565.29742E	0.000	14.30031E6	0.002	-20.48570E6
	Reactions	-0.008	565.29742E	0.005	-14.30031E6	-0.248	20.48570E6
	Difference	-0.008	-0.002	0.005	-0.098	-0.247	-0.096

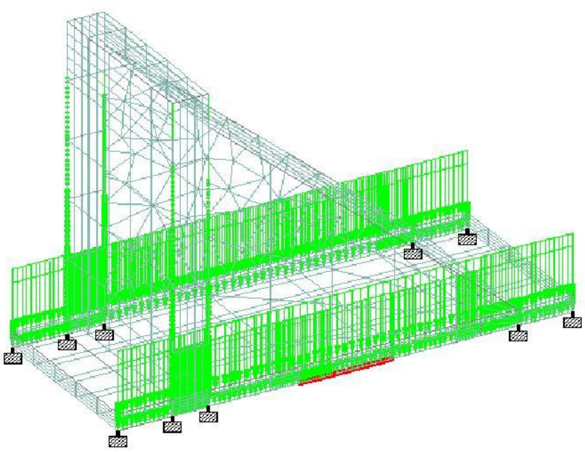
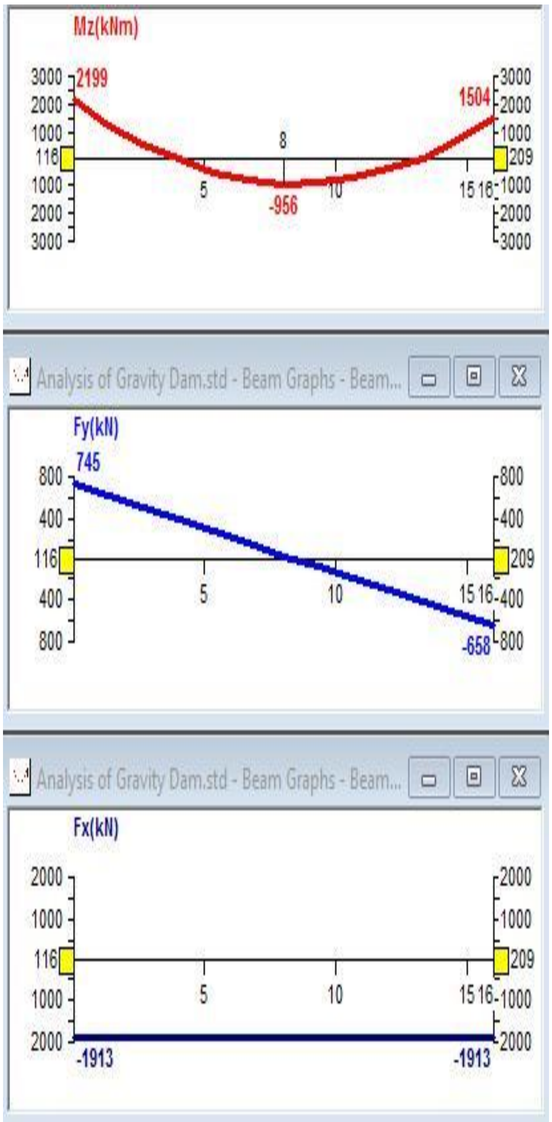


Figure 4.15 shows post processing



Graph shows the beam displacement along axis

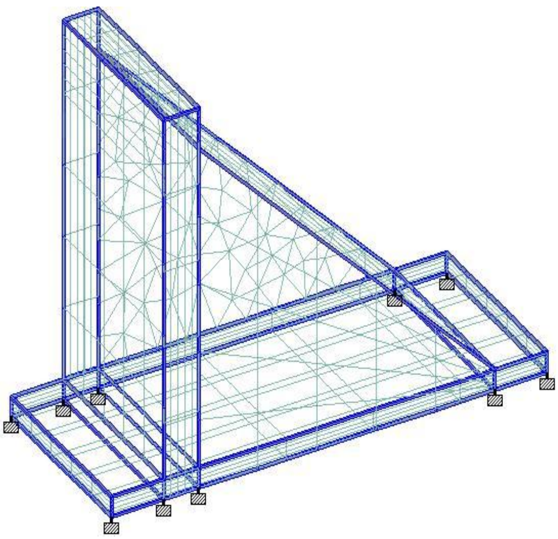


Figure 4.16 shows the membrane and bending

LIVE LOAD ANALYSIS

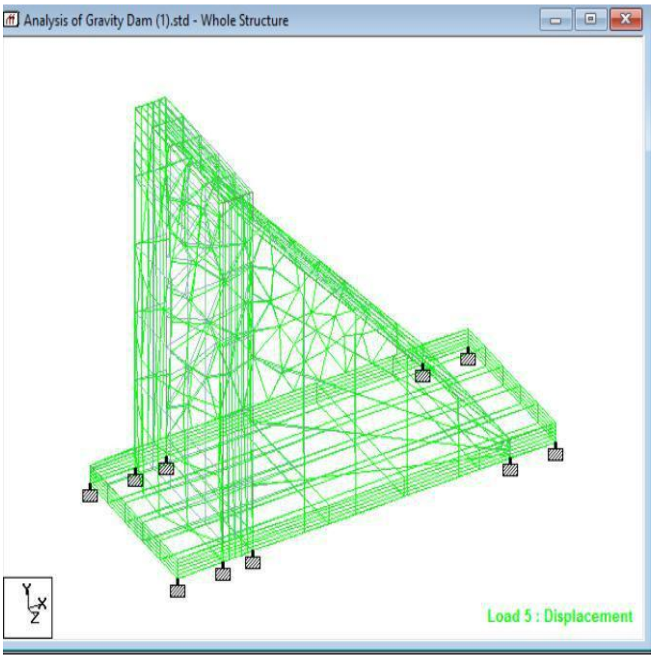


Figure 5.16 shows live-load analysis

Analysis of Gravity Dam (1).std - Node Displacements:

All / Summary

		Horizontal	Vertical	Horizontal	Resultant	Rotational		
Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
1	1 DEAD LOA	1.306	-19.291	-32.795	38.070	0.000	-0.004	-0.00
	2 WL+X	0.002	0.014	0.074	0.076	-0.000	0.000	-0.00
	3 WL-X	-0.002	-0.014	-0.031	0.034	0.000	-0.000	0.00
	4 WL+Z	-0.031	-0.089	11.120	11.120	0.000	0.001	0.00
	5 LIVE LOAD	-0.424	-1.984	-33.843	33.903	-0.000	-0.015	0.00
	6 WL-Z	0.031	0.091	-11.248	11.249	-0.000	-0.001	-0.00
	7 GENERATE	1.322	-31.913	-99.957	104.936	0.000	-0.028	0.00
	8 GENERATE	1.060	-25.514	-79.876	83.858	0.000	-0.022	0.00

Analysis of Gravity Dam (1).std - Beam Relative Displacement Detail:

All Relative Displacement / Max Relative Displacements

Beam	L/C	Dist m	x mm	y mm	z mm	Resultant mm
1	1 DEAD LOA	0.000	0.000	0.000	0.000	0.000
		4.500	-0.049	-0.000	1.327	1.328
		9.000	-1.044	-0.000	1.659	1.961
		13.500	-1.518	-0.001	1.162	1.912
		18.000	0.000	0.000	0.000	0.000
	2 WL+X	0.000	0.000	0.000	0.000	0.000
		4.500	0.002	0.000	0.000	0.002
		9.000	0.000	0.001	-0.000	0.001
		13.500	-0.002	0.000	-0.001	0.002
		18.000	0.000	0.000	0.000	0.000

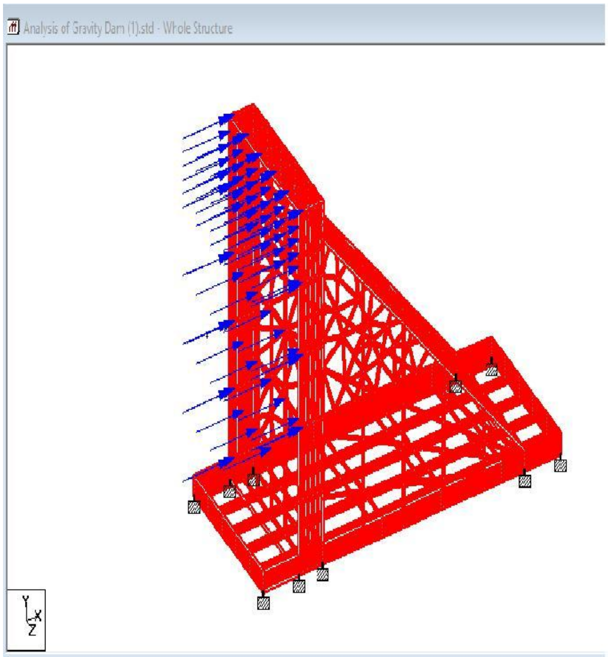


Figure5.18 wind direction x with 15KN-.m

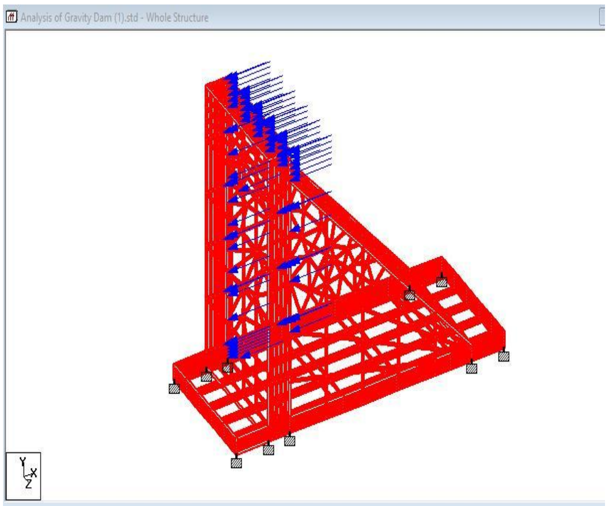


Figure5.19 wind direction -x with 15KN-.m

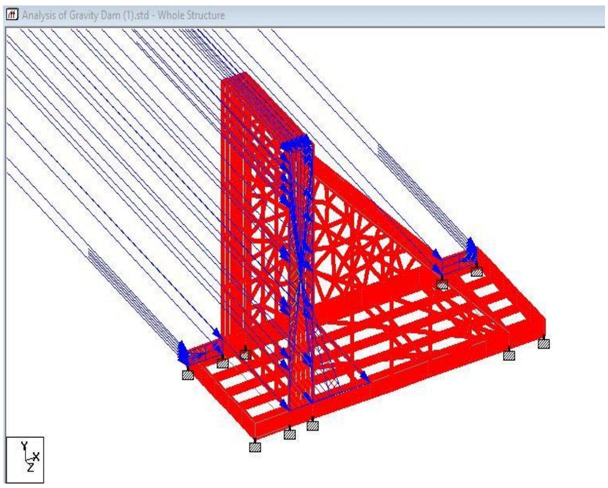


Figure5.20 wind direction z with 15KN-.m

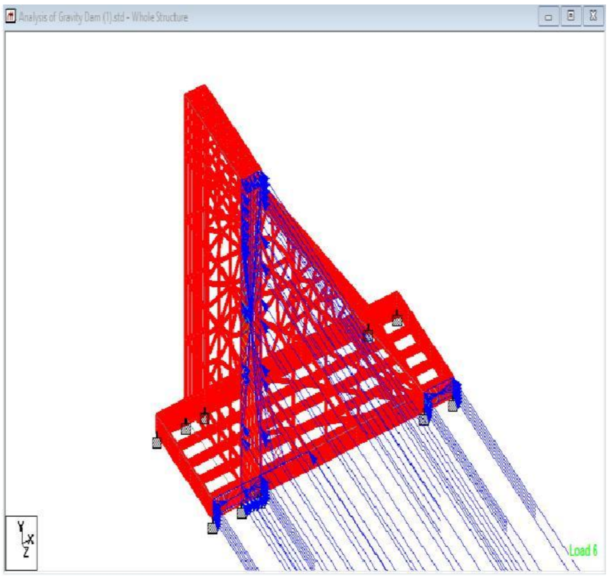


Figure5.20 wind direction -z with 15KN-.m

Discussions

The load conditions and final deflection results are given below

ISOTROPIC CONCRETE
E 2.17185E+007
POISSON 0.17 DENSITY 23.5616
ALPHA 1E-005
DAMP 0.05
END DEFINE
SELFWEIGHT Y -1 LIST 1 TO 701

Conclusions

The dam has been analysed with CODE-IS -6512-1984, the variable deflection found very less approximately 0.002mts which can be considered as negligible.

After performing the analysis the errors found to be zero that means the design of the structure is considerable and the standard loads are taken for analysis of live and wind loads.

Staad –pro given results have to be optimised practically to implement structure finalization in future.

From the modeling and analysis the results can be concluded as per the following points:

1) Maximum stress in dam with openings is 4193.257 KN/m2 and without openings it is 3117.744 KN/m2.

2) The dam without openings the maximum stresses are concentrating near u/s face ranges from 0.59 N/mm2 to 0.977 N/mm2.

3) Dam with openings, Maximum stress concentrated around the openings are 4.13 N/mm2.

4) So far earthquake forces static loading is given as per the STAAD.Pro definitions and command and not manually, however dynamic analysis is not considered in this paper.

5) There are some uncertainties still prevailing regarding stability at support conditions.

References

[1] Karuna Moy Ghosh,"Analysis and Design Practice of Hydraulic Concrete Structure" PHI Learning Private Limited

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[3] Bentley, " STAAD.Pro" www.bentley.com/en-US/Products/STAAD.Pro

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