# Optimization of Geometric Shapes of Gravity Dam using STAAD Pro

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*Abstract*— Concrete gravity dams are important lifeline structures and represent the fragrance of people's standard of living. These are very complex structures and subjected to various types of forces both static and dynamic in nature. Optimization techniques plays an effective role in structural design in which the structure can be designed in such a way that the area and volume can be optimized and hence the requirement of the materials can be effectively reduced and thus it minimises the cost of construction. In the present study, 3 different geometrical shape (cross section) of non-overflow section is considered and a two dimensional (2D) Finite Element models are created. All major load/forces are calculated and applied as primary load cases and load combinations are generated for the most adverse load combination A, B and C as per I.S 6512-1984, using Finite Element software STAAD pro V8i. The stress contour pattern and behaviour under various load combinations are evaluated and stress distribution is visualised. The maximum displacement of the dam crest is observed for the various load combinations. A comparative study is made between conventional and STAAD pro analysis for maximum principal stress and shear stresses at heel /toe/ in dam body for the various load combinations as per I.S. Codal guide lines for dam with fixed base.

***Key words:*** Optimization, STAAD Pro V8i, Displacement, Principal Stress, Shear Stresses

## I. INTRODUCTION

Optimization techniques plays an effective role in structural design in which the structure can be designed in such a way that the area and volume can be optimized and hence the requirement of the materials can be effectively reduced and thus it minimises the cost of construction. It is an important means to save investment at the same time factor of safety and stability of the structure need to be ensured without compromise. They are several optimization techniques available to optimize a structure. Gravity dam is a hydraulic structure that is constructed using rigid materials. Construction of concrete gravity dam is quite common and optimizing its size can result significant reduction in the construction materials. The external forces acting on the gravity dam are entirely resisted by the weight of the dam itself. The main advantages of gravity dam are, it can be constructed up to any height, failure of gravity dam gives sufficient warning and moreover it requires least maintenance. Although it has several advantages it has a disadvantage that the requirements of material to construct gravity dam is very high which ultimately lead to high cost of construction. Optimize the shape of the gravity dam using differential evolution such that to minimize the cross-sectional area of the dam and reduce the material requirements so that construction cost is economized.

## II. LITERATURE REVIEW

Dr. K. Rama Mohan Rao.et.al (2014), in their paper non overflow 63m height of gravity dam considered and two dimensional finite element model created. All load combinations are considered according to IS 6512-1984. Analysis did by static and dynamic load consideration, using STAAD pro software. Conclusions stated that at normal loading conditions, compression stresses shows at heel point of dam with foundation condition and tensile stress shows at heel point of dam with foundation fixed base condition. Maximum displacement at crest level shows in dam with foundation compared to dam with fixed base. Vemula siva nagendra babu.et.al (2016), in their paper is of the gravity dam height 110m for which Equivalent static analysis and dynamic analysis by using time history method is carried out. Here Finite Element Approach is used to analyse the dam which is proved to be the realistic for such structures. A comparison is done between the equivalent static approaches of seismic analysis with dynamic analysis by using time history.

## III. METHODOLOGY

In this chapter the details about the analysis of fixed base 3 different geometrical shape of concrete gravity dam models are considered. But height, top width and bottom width of the dam are same in all 3 models. Varying only upstream and downstream side slope (batter). Two dimensional (2D) FE Models are created using STAAD pro software. And also used Auto CAD Software. The analysis is carried out using the software STAAD pro V8i. This chapter mainly discusses the methods of analysis of structure. STAAD pro is one of the most used and user friendly program of the computers and structures, graphical user interface. Creating the model, modification of the model, analysis and output results can be obtained within single interface.

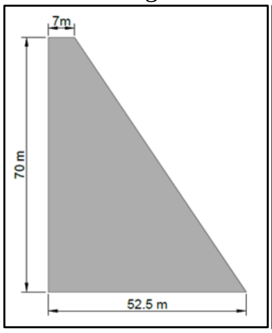


Fig. 1: Model 1

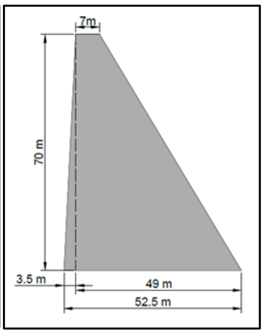


Fig. 2: Model 2

Following are the methodology steps,

1) Model description
2) Plate element
– Geometry modelling considerations
3) Importing cad models in staad.pro for modelling

– Import geometry
4) Forces acting on a gravity dam
– Self-weight of dam
– Hydraulic pressure (water pressure)\
– Uplift pressure
– Silt pressure
– Load combinations
5) Analysis of the structure

## IV. MODEL DESCRIPTION

Height of concrete gravity dam: 70.00 m, Base width of gravity dam: 52.50 m, Top width of dam: 7.00 m, Maximum water height (H): 66.00 m, Free board: 4.00 m, Height of bottom level gallery: 12.00 m, Height of top level gallery: 38.00 m Dimension of gallery: 2 x 2 m, Grade of concrete: M20, Unit weight of water (ω): 9.81 kN/m$^3$, Young's Modulus of Elasticity (E): 21.7185 kN/mm$^2$, Poisson's Ratio (μ): 0.7, Density of concrete: 24 kN/m$^3$, In the STAAD models, created number of plates in the model 1 is 520. Model 2 plates are 530 and model 3 plates are 453.

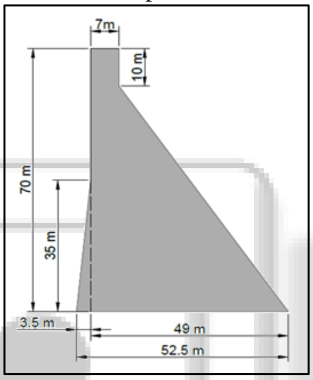

Fig. 3: Model 3

All models are created by 4 node quadrilateral plate element with the thickness of 1m. Assigning material as concrete. Plate dimension taken as maximum 2 m x 2 m.

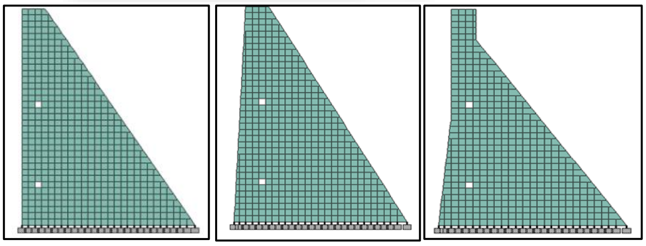
Fig. 4: 2D view of model 1, 2 & 3

### A. *Hydraulic pressure (water pressure)*

– Water Pressure is the most major external force acting on a gravity dam.
– On upstream face pressure exerted by water is stored up to the full reservoir level. The upstream face may either be vertical or inclined.
– On downstream face the pressure is exerted by tail water. The downstream face is always inclined.

The hydrostatic pressure applied on upstream face of the dam, the pressure values are entered in STAAD models.

ω x H = 9.81 x 66 = 647.46 kN/m$^2$, The hydrostatic pressure applied as an in order plate loads – hydrostatic. And take edit option on each plate, node 2 and 3 variation along element are edit it as 0. Because, required only one direction of in plane trapezoidal load.

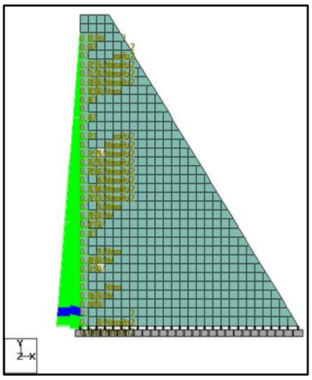
Fig. 5: Hydraulic pressure distribution in STAAD pro

### B. *Uplift Pressure*

– The water stored on the upstream side of the dam has a tendency to seep through the soil below foundation.
– While seeping, the water exerts an uplift force on the base of the dam depending upon the head of water.
– This uplift pressure reduces the self-weight of the dam.
– To reduce the uplift pressure, drainage galleries are provided on the base of the dams.

In the uplift pressure also same method follows as water pressure. But uplift pressure on upward bottom face of dam along the base width are applied in STAAD models. ω x H = 9.81 x 66 = 647.46 kN/m$^2$, The uplift pressure applied as an in order plate loads – hydrostatic. Selected bottom (one full row) side plates, entered the calculated force value. Click on interpolate along global axis X and direction of pressure GY, Add.

### C. *Silt Pressure*

The river brings silt along with it. The silt load deposited to an appreciable extent when dam is constructed. According to Indian standard (IS: 6512-1984) the silt pressure and water pressure exist together in sub merged silt. Horizontal 'silt and water pressure' is assumed to be equivalent to that of a fluid weighing 13.34 kN/m$^3$. The additional forces due to silt alone are computed by taking $\gamma_s$ = 13.34 - 9.81 = 3.53 kN/m$^3$. The horizontal silt pressure applied on upstream face of the dam, means up to 30 m height (h) in STAAD models. $\gamma_s$ x h = 3.53 x 30 = 105.9 kN/m$^2$. The silt pressure applied as an in order plate loads – hydrostatic. Selected upstream side plates, entered the calculated force value. Click on interpolate along global axis Y and direction of pressure GX, Add.

### D. *Analysis of the Structure*

1) After the CAD model is imported to STAAD, the model is created and it is assigned with properties, support and loading.
2) Then the model is analysed for the given load combination.
3) The analysis results and the corresponding graphs are shown in the next chapter.
4) Following are the considered load combinations,

– Reservoir empty condition: Only self-weight of the dam, dam completed but no water in reservoir and no tail water.
– Reservoir full with no up lift: Reservoir is full, considered self-weight, water pressure and silt pressure.

– Reservoir full with up lift: Reservoir is full, considered self-weight, water pressure, silt pressure and uplift pressure.

## V. RESULTS AND DISCUSSION

This chapter deals with the comparison of different results obtained from the analysis. The comparison of results are done for 3 models with different load combinations. From the results obtained from analysis again comparison of different parameters like principal stress and in plane shear stress is carried out and tabulated. Plate stress output is considered in the STAAD pro, there particularly taken displacement, principal stress and in plane shear stress. At the crest level of the gravity dam models as taken 4 node points, taken displacement of all 4 nodes. Considered maximum displacement value for each model according to load combination in X&Y direction. The title SXY gives in plane shear stress.

### A. *Displacement*

| Displacement (mm) | | | | | | |
|---|---|---|---|---|---|---|
| Type of model | Reservoir empty | | Reservoir full with no uplift | | Reservoir full with uplift | |
| | X Direction | Y Direction | X Direction | Y Direction | X Direction | Y Direction |
| Model 1 | 3.627 | 3.045 | 2.738 | 1.235 | 2.759 | 1.221 |
| Model 2 | 2.903 | 2.669 | 1.119 | 1.628 | 1.141 | 1.613 |
| Model 3 | 3.519 | 2.657 | 4.421 | 1.038 | 4.443 | 1.026 |

Table 1: Displacement of model 1, 2&3 for different conditions

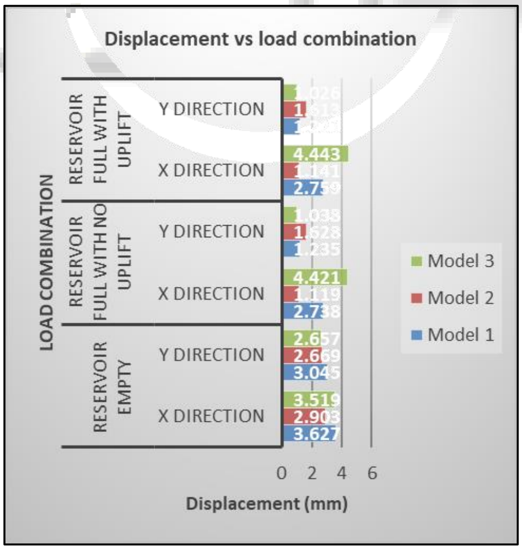


Fig. 6: Displacement of model 1, 2&3.

### B. *Principal Stress*

| Principal stress (N/mm²) | | | |
|---|---|---|---|
| Model no. | Empty condition | Without uplift | With uplift |
| Model 1 | 2.36 | 1.37 | 1.32 |
| Model 2 | 2.17 | 1.27 | 1.27 |
| Model 3 | 1.74 | 1.31 | 1.27 |

Table 2: Principal stress values of model 1, 2 &3

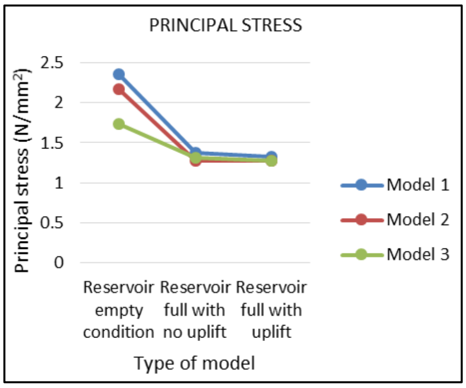


Fig. 7: Principal stress values for different condition.

### C. *Shear Stress*

| Shear stress (N/mm²) | | | |
|---|---|---|---|
| Model no. | Empty condition | Without uplift | With uplift |
| Model 1 | 0.484 | 0.597 | 0.595 |
| Model 2 | 0.494 | 0.483 | 0.484 |
| Model 3 | 0.451 | 0.561 | 0.562 |

Table 3: Shear stress values for model 1, 2&3.

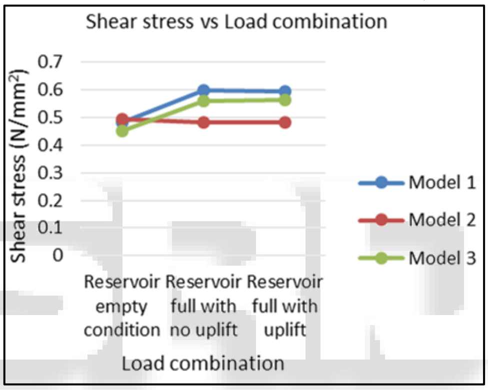


Fig. 8: Shear stress values for different condition.

## VI. CONCLUSIONS

Based on the analysis the following conclusions are drawn.

1) As per displacement results, when reservoir empty condition, model 1 shows maximum displacement at crest level is 3.627mm in x-direction. Reservoir full with no uplift condition, model 3 is shows maximum displacement at crest level is 4.421mm in x-direction. Reservoir full with uplift condition, model 3 is shows maximum displacement at crest level is 4.443mm in x-direction. However, the maximum displacement is very negligible value.
2) As per principal stress results, when reservoir empty condition, model 3 shows maximum principal stress is 1.74 N/mm² at heel point, it is comparatively less than model 1&2. Reservoir full with no uplift condition, model 3&2 are shows same maximum principal stress is 1.3 N/mm² at near toe. Reservoir full with uplift condition, model 3&2 are shows same maximum principal stress is 1.27N/mm² at near toe, it is comparatively less than model 1. However, model 3 shows less principal stress compared to model 1&2. So, concluded that model 3 is optimum model.
3) As per in plane shear stress results, when reservoir empty condition, model 3 is shows maximum shear stress is 0.451N/mm² at heel point, it is comparatively less than

model 1&2. Reservoir full with no uplift condition, model 2 is shows maximum shear stress is 0.483N/mm$^2$ and in the reservoir full with uplift condition also same value shows at toe.

4) Finally all three models are compared to each other, self-weight of the model 3 is 43274.402 kN which is lesser than model 1&2. So finally concluded that model 3 is optimum geometrical shape for the gravity dam.

### A. *Future Scope*

1) Comparative study can be done with adoption of different degree of upstream side slope of the gravity dam.
2) Most of gravity dam fails by improper design of foundation, so advanced foundation design required.
3) Low gravity dam analysis and design required for mini hydroelectric power plant. Because, in future all types of non-renewable sources may completely nil, then definitely gravity dam will get scope for structures to produce renewable energy like hydroelectric power generation.

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