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Design of Kawlewada Dam and its Components

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Abstract: This paper presents the design and stability analysis of Kawlewada dam (a concrete gravity dam situated in kawlewada village of gondia district) and its components. Through, the demanding years, it has been observed that failures of dams due to many factors are common. So, it is the essential to analysis the various components, parts of dam against all its modes of failures, forces acting on it, uncontrollable disasters such as earthquake, disaster, etc. For this, the preliminary data of the dam required for design, such as control levels, dimensions, crest width, base width, etc. was collected through the Inspection Engineer, posted at Dhapewada Lift Irrigation Office, Tirora, Dist. Gondia. On the basis of collected data the elementary profile and practical profile of dam was estimated, further all the major and the minor force forces acting on dam were calculated, stability analysis of designed dam against all modes of failure and for various load combinations was carried out in STAAD PRO software and was checked for permissible limits. Design of spillway, stilling basin and earthen dam was also carried out for the designed dam. Further, canal originating from the dam and carrying water to culturable command area was also designed by taking care of peak discharge as required by crops.

Keywords: Gravity Dam, Kawlewada Dam, Analysis of Dam in STAAD PRO, Spillways, Stilling Basin, Canals, Earthen Dam

I. INTRODUCTION

The gravity dam is constructed with the concrete or masonry. The purpose of the dam is to store, hold water and to control the floods, to supply water to households, irrigation, energy generation, livestock water supplies, pollution control etc., Dams are generally classified according to the type of material used in construction, the way dam resist the loads, type of the structure etc. The materials used for construction of dams include earth, rock, tailings from mining or milling, concrete, masonry, steel, timber, miscellaneous materials and any combination of all these materials.

II. METHODOLOGY

A. Elementary Profile of a Gravity Dam.

An elementary profile of a gravity dam is the theoretical shape of its cross-section when it is subjected to only three main forces, viz. self-weight, water pressure, and uplift pressure. Moreover, the elementary profile has zero top width and no free board. The right-angle triangle is the most suitable section for the theoretical profile. For reservoir empty condition, a right-angled triangular profile as shown in fig. 1, will provide the maximum possible stabilizing force against overturning, without causing any tension in the base. In this case, the only force is due to the self-weight of the dam acting at a distance of B/3 from the upstream face of the dam and hence satisfies the middle third rule. The elementary profile is hypothetical because an actual gravity dam has some minimum top width and free board, and it will also be subjected to forces other than the three main forces considered in the elementary profile.

Base Width of Elementary Profile –

The base width of the elementary profile is to be determined under following two criteria –

1) *Base Width with No Tension Basis:* When reservoir is empty, for no tension to develop, the resultant should act at the inner third point A. For the full reservoir condition, let R be the resultant of all forces acting on the dam, for no tension at the heel, the resultant R must pass through the outer middle third point B as shown in fig. 1. The maximum value of eccentricity (e) is B/6 when the resultant R passes through the point (B) Taking the moment of all forces about B and equating it to zero, we get $W.B/3 - U.B/3 – P.H/3 = 0$
2) *Base Width for No Sliding:* For no sliding to occur, the forces causing sliding should not be greater than the forces resisting sliding. In the limiting condition the two forces must be equal and opposite. It is usually assumed that the sliding is resisted by the friction only thus,

$$\mu\Sigma V = \Sigma H$$

where, u is the coefficient of friction.

The minimum base width required for the elementary profile should be greater of the two values obtained from the equations (i) and (ii).

However generally equation (i) is used to calculate base width.

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B. Practical Profile of a Gravity Dam.

The elementary profile cannot be adopted as such. Some modifications have to be incorporated, to make it adaptable in practice.

Certain changes will have to be made in the profile in order to cater to the practical needs. These needs are

1) Providing a straight top width, for road construction over the top of the dam.
2) Providing a free board above the top water surface, so that water may not spill over the top of the dam due to wave action, etc.

As, the addition of these two provisions cause the resultant force to shift toward the heel. As the R_f is shifting toward the heel so, tension will develop at the Toe. In order to avoid the development of the tension at the toe, we have to add some concrete at the upstream side.

So, now profile can be checked for the stability analysis of the Gravity Dam

It is not determined by comparing the height of the dam with limiting condition of dam. If, Height of the dam is less than,

$H < \frac{f}{\gamma_w(Sc+1)}$ .Then, Dam will be low gravity dam, otherwise it will be high gravity dam.

Some important term to consider during the design of practical profile of the gravity dam.

Freeboard calculation:

1. If, height of wave that is h_w is given,

Freeboard = 1.5* h_w.

2. If, height of wave is not given

Freeboard = 4 – 5% of h.

Top width of the Dam can from economic criteria as 14% of h

a = 14% of h.

C. Forces Acting on Gravity Dam

The forces that act on the dam are the following:

1) Weight of the dam
2) Horizontal hydrostatic pressure due to water
3) Uplift pressure due to water percolated under the dam
4) Earthquake pressure
5) Wind pressure
6) Ice pressure
7) Wave pressure
8) Pressure due to silt deposited on U/S face.
9) Water pressure at tail water side.

Out of above eight forces, acting on the dam, first three forces are the major forces that are considered in the design. All other forces are not of much significance and are considered only under specific conditions. Water pressure is major load of gravity dam which is calculated by hydrostatic pressure law. We separate water pressure in two cases which are explain below. If the tailwater present on the downstream side, that means it is also developed pressure and acts on the dam. Therefore, tail water pressure is also calculated by hydrostatic pressure law.

TABLE I
Classification Of Forces Acting On Dam

MAJOR FORCES	MINOR FORCES
Weight of the dam	Silt pressure
Uplift pressure	Wave pressure
Water pressure	Wind pressure
Water pressure at tail water side	Earthquake pressure
	Ice pressure

D. Natures of The Forces and Moments

Once the forces are calculated, we have to consider the effects of this forces. For this, first of all we have to calculate the moments at any point of the dam (heel or toe). Here we have to analyse every aspect of the dam. Such as horizontal and vertical forces, overturning and resisting moments. So by taking into account all considerations and assumptions, the following things are to be calculated orderly.

1) Summation of horizontal forces
2) Summation of vertical forces
3) Total overturning moments
4) Total resisting moments
5) Net moment
6) Lever arm and eccentricity.

Table II. Moment Calculation Table

Name of the Force	Magnitude Of Force (KN)	Distance from toe (m)	Moment about toe (KN. m)	Nature of Moment	Sign taken

The extension of above table can be used for comprehension of moments properly.

E. Modes of Failures

Failure is unacceptable for dams because not only it is financially costly, but people's lives are put at risk. Despite having the goal to avoid any type of failure, unfortunately, it still may occur due to different reasons. The United States has seen numerous incidents for different size dams where lives were sadly lost. By extending our research and finding out how we can prevent this from occurring we may be able to prevent these accidents from occurring in the future. However, to start this process one must be familiar with the different failure types and look at related case scenarios, which may help us with coming up with a solution through empirical observation.

Failure of gravity dam occurs due to overturning, sliding, tension and compression. A gravity dam is designed in such a way that it resists all external forces acting on the dam like water pressure, wind pressure, wave pressure, ice pressure, uplift pressure by its own self-weight. Gravity dams are constructed from masonry or concrete. However, concrete gravity dams are preferred these days and mostly constructed. The advantage of gravity dam is that its structure is most durable and solid and requires very less maintenance.

1) *Overturning Of Dam About The Toe:* The horizontal forces such as water pressure, wave pressure, silt pressure which act against the gravity dam causes overturning moments. To resist this, resisting moments are generated by the self-weight of the dam. If the resultant of all the forces acting on a dam at any of its sections, passes through toe, the dam will rotate and overturn about the toe. This is called overturning failure of gravity dam. But practically, such a condition does not arise and dam will fail much earlier by compression.

$\therefore$ FOS = M_R/M_O

The value of F.S. against overturning should not be less than 1.5.

2) *Sliding Failure of Gravity Dam:* When the net horizontal forces acting on gravity dam at the base exceeds the frictional resistance (produced between body of the dam and foundation), The failure occurs is known as sliding failure of gravity dam.

$$\therefore \text{FOS} = \mu\sum V/\sum H$$

The value of coefficient of friction varies from 0.65 to 0.75. The value of F.S. should always be greater than one.

3) *Gravity Dam Failure due to Compression:* A gravity dam may fail by the failure of its material, i.e. the compressive stresses produced may exceed the allowable stresses, and the dam material may get crushed. If the compressive stress developed anywhere in the dam exceeds the safe permissible limit, the dam may fail by crushing of the dam itself or of foundation. The maximum compressive stress can develop at toe when reservoir is full of water. If reservoir is empty the maximum compressive stress is likely to develop at the heal of the dam. The magnitude of maximum compressive and minimum compressive stresses can be found out by using following equation.

$$P_n\text{=Vb(1+6eb)}$$

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4) *Failure due to Development of Tension:* Both cement concrete and masonry, are very weak in tension. Hence from safety point of view the tension is not allowed to be developed in the dam anywhere. We know that minimum compressive stress in the dam. The nature of this stress remains Negative sign of this stress indicates that nature of this stress is tensile rather than compressive. Hence as soon as e exceeds b/6 tension is developed in the dam and dam fails by opening of the joints, as concrete and masonry are almost nil in tension. When reservoir is full of water, tension is likely to develop at heal and when reservoir is empty tension is likely to develop at Toe of the dam.

III. ANALYSIS OF DAM IN STAAD PRO

A. About the Software.

1) STAAD or (STAAD Pro) is a structural analysis and design software.
2) STAAD Pro is one of the most widely used structural analysis and design software products worldwide.
3) It can make use of various forms of analysis from the traditional static analysis to more recent analysis methods like p-delta analysis, geometric non-linear analysis, Pushover analysis (Static-Nonlinear Analysis) or a buckling analysis.
4) STAAD Pro can be used for analysis and design of all types of structural projects from plants, buildings, and bridges to towers, tunnels, metro stations, water/wastewater treatment plants and more.
5) STAAD Pro is interoperable with applications such as RAM Connection, AutoPIPE, SACS and many more engineering design and analysis applications to further improve collaboration between the different disciplines involved in a project.

B. Finite Element Method.

1) Finite element models are used for linear elastic static and dynamic analyses and for nonlinear analyses that account for interaction of the dam and foundation.
2) The finite element method provides the capability of modeling complex geometries and wide variations in material properties.
3) The stresses at corners, around openings, and in tension zones can be approximated with a finite element model.
4) Two-dimensional, finite element analysis is generally appropriate for concrete gravity dams.
5) It should be noted that actual structure response is three dimensional therefore, a land selected should review the analytical and realistic results to assure that the two-dimensional approximation is acceptable and realistic.
6) For long conventional concrete dams with transverse contraction joints and without keyed joints, a two-dimensional analysis should be reasonably correct.
7) Structures located in narrow valleys between steep abutments and dams with varying rock module which vary across the valley are conditions that necessitate three-dimensional modelling.

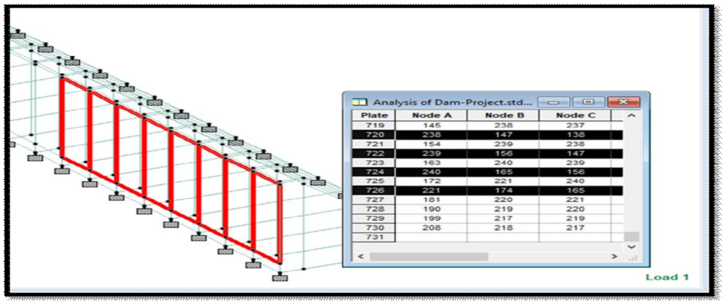
C. Procedure Adopted for Analysis.

1) *Step - 1:* Creation of nodal points based on the positioning of plan.

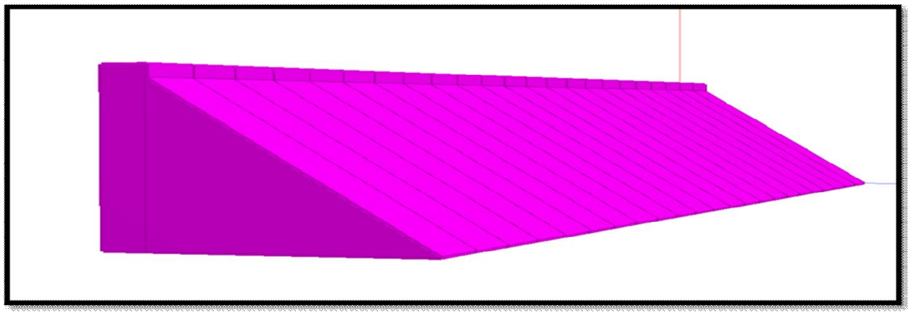
Analysis of Dam-Project.s...

Node	X m	Y m	Z m
1	0.000	0.000	0.000
3	0.000	26.230	0.000
4	0.000	27.230	0.000
5	4.000	27.230	0.000
7	4.000	25.230	0.000
8	29.500	0.000	0.000
9	4.000	0.000	0.000
10	0.000	0.000	8.000

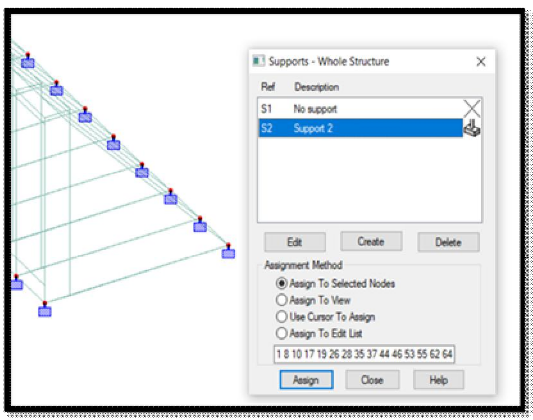
2) *Step - 2:* Creation of plates between node points.

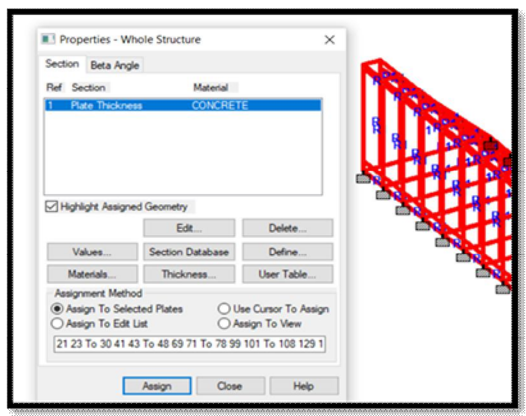


3) *Step - 3:* Viewing 3D view of structure.

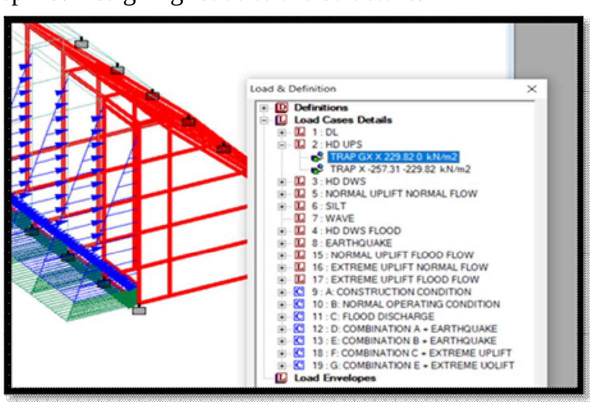


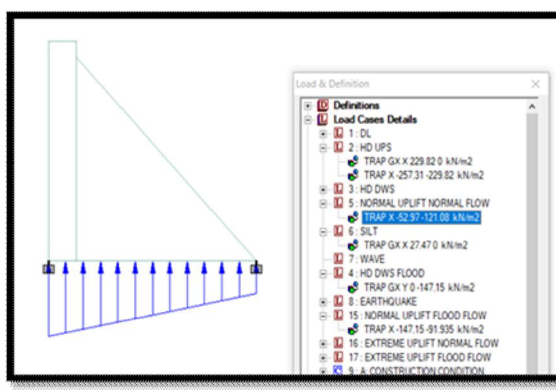
4) *Step - 4:* Supports and property assigning.



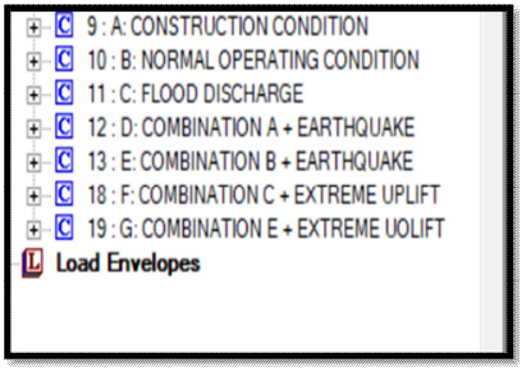


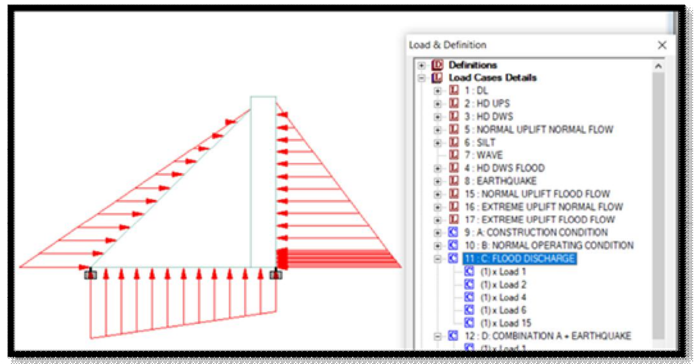
5) Step - 5: Assigning loads to the Structure.



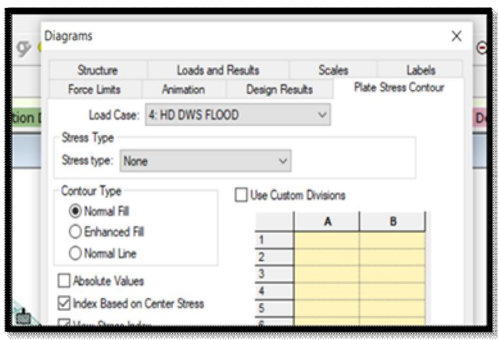


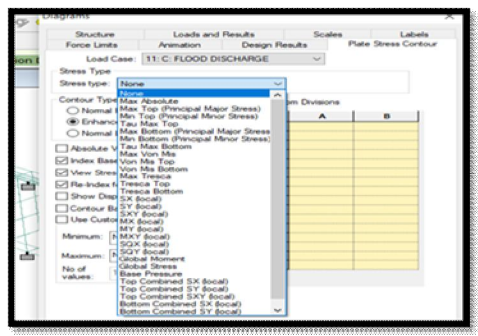
6) Step -6: Assigning of load combinations.





7) *Step-7:* Save and run the file.
8) *Step-8:* View and Print the results required.





IV. DESIGN OF SPILLWAY

"Spillways are structures constructed to provide safe release of flood waters from a dam to a downstream area".

Types of Spillways

1) Drop Spillway
2) Ogee Spillway
3) Siphon Spillway
4) Chute or Trough Spillway
5) Shaft Spillway
6) Side Channel Spillway

A. Design of Ogee Spillway Profile

Computation of design head over the crest of spillway

$$Q = C_d \times L_e \times H_e^{\frac{3}{2}}$$

Approximate value of H_e, for a value of effective length can be worked out.

1) Up Stream Slope

The upstream face of the dam and spillway is proposed to be kept vertical

Effective length of the spillway (Le) can be work out as

$$L_e = L - 2(NK_p + K_a)H_e$$

2) Downstream Profile

The downstream profile for vertical upstream face is given by equation

$$X^{1.85} = 2 \times H_d^{\,0.85} Y$$

$$Y = \frac{X^{1.85}}{2 \times H_d^{\,0.85}} = Y = \frac{X^{1.85}}{2 \times 2.5^{0.85}}$$

3) Upstream Side Profile:

The upstream side profile may be design as per giver equations,

$$Y = \frac{0.724(X + 0.27H_d)^{1.85}}{H_d^{\,0.85}} + 0.126H_d - 0.4315H_d^{\,0.375}(X + 0.27H_d)^{0.625}$$

V. DESIGN OF STILLING BASIN

Stilling Basins: A stilling basin is a basin-like structure in which all or a part of the energy is dissipated. In a stilling basin, the kinetic energy causes turbulence and it is ultimately lost as heat energy. The stilling basins commonly used for spillways are of the hydraulic jump type, in which dissipation of energy is accomplished by a hydraulic jump.

The basins are usually provided with special appurtenances including chute blocks, sills and baffles piers.

1) *Chute Blocks:* Are used to form a serrated device at the entrance to the stilling basin. Their function is to furrow the incoming jet and lift a portion of it from the floor producing a shorter length of jump than would be possible without them.
2) *The Sill:* Is usually provided at the end of stilling basin. Its function is to reduce further the length of the jump and to control scour. The sill has additional function of diffusing the residual portion of high velocity jet that may reach the end of the basin.
3) *Baffle Piers:* Are blocks placed in the intermediate position across the basin floor. Their function is to dissipate energy mostly by impact action. They are useful in small structures with low incoming velocities. They are unsuitable where high velocities make cavitation possible.

A. Types of stilling Basins

The type of stilling basin mostly suitable for a location mainly depends upon the initial Froude number and the velocity of the incoming flow.

Following types are the most commonly used in practice,

1) U.S.B.R. stilling basins
2) Indian standard basins
   - Type 1
   - Type 2
   - Type 3
   - Type 4

Indian standard type 1 basin:

- provided when Froude number less than 4.5.
- such a case usually occurs on weirs barrages and low dams.
- The basin is provided with chute blocks, basin blocks and dentate sills.
- The basin blocks may not be used if the velocity of flow exceed 15 m3/s.

Indian standard type 2 basin:

- Provided when the Froude number is greater than 4.5.
- Usually required in case of spillway of medium and high dams.
- The basin is provided with chute block, basins blocks and dentate sill.

B. Design Steps to Follow.

1) *Step -1:* Calculation discharge over crest of spillway

$$Q = \frac{2}{3} \times C_D \times H^{\frac{3}{2}} \times \sqrt{2g}$$

2) *Step 2:* Calculation of pre jump depth (y_1)
3) *Step 3:* Calculate the post jump depth (y_2):

$$y_2 - \frac{y_1}{2}(\sqrt{1 + 8F_r^{\ 2}} - 1)$$

4) *Step 4:* Calculate normal depth or tailwater depth (y_0):

$$Q = A \times V = By_0 \times \frac{1}{n} R^{2/3} \sqrt{S}$$

5) *Step 5:* Calculate critical depth (y_c)

$$y_c - (\frac{q^2}{g})^{\frac{1}{3}}$$

6) *Step 6:* Applying checks
7) *Step 7:* Selection of stilling basin: depending on Froude number and velocity at the toe of spillway.

VI. DESIGN OF EARTHEN DAM

An earthen dam is a dam built up by compacting the successive layers of earth across the river with a central impermeable layer; catchments are possible to accumulate most of the soil, foothills on the upstream and downstream sides.
These dams are constructed from earthen materials such as gravels sand, silt and clay.

1) Step 1- Deciding top width.

   W= 0.55(H) $^{1/2}$ +H/5

   Where, H=height of dam.

2) Step 2- Provision of Free board.

Free board is the vertical distance between horizontal crest of embankment & reservoir level. Sufficient Free board is to be provided so that there is no possibility that embankment being overturned.

3) Step 3- Providing Casing or outer shell
   1) Its Function is to protect central core of dam
   2) It is made up of pervious soil & provided in both upstream & downstream
   3) Slope maintained on both sides is decided on type of soil used, height of dam, foundation condition.

4) Step 4- Central impervious core.

Sometimes there is chance of seepage occurrence due to capillary action of water, to prevent this the height of central core should be minimum 1m more than maximum reservoir level.

5) Step 5-Design of berms

Berms are provided to observe condition of slope protection and for maintenance & repair work purposes

Berms are provided on downstream side with a width of berms = 2m at a height interval of 10 to 15m.

6) Step 6- Design of filters

Filters are provided between impervious zones of fine-grained Soil & Pervious zone of coarse-grained Soil to prevent the migration of soil grains from former to later due to seepage of water. It must be pervious than fine grained soil.

VII. DESIGN OF CANALS

A. Design Steps of Canal.

1) Step 1- Find water requirement for crops like Rice, Wheat, Vegetable, Fodder
2) Step 2- Find area to be irrigated in growing each crop.
3) Step 3- Find average Duty for each crop
4) Step 4- Calculate outlet discharge required for each crop =A/D
5) Step 5- Decide the design discharge.
   Discharge is maximum of kharif, rabi or Zaid seasons.
6) Step 6- Assume suitable value of side slope & coefficient of roughness.
7) Step 7- Calculate velocity using manning's equation.
   $v = 1/n*R^{2/3} * S^{1/2}$
8) STEP 8- Calculate Area using equation Q= A*V.
9) STEP 9 – Assume suitable b/d ration and calculate values of b & d (breadth and depth).

VIII. CONCLUSIONS

The Gravity dams are the lifesaving mega structures which are mainly used for irrigation, hydroelectric power generation, water supply, animal enhancement etc.., a concrete gravity dam has to maintain its stability by its own weight. The strength of the material is important when the concrete gravity dam is analyzed for stability and the seismic pressure for different load combinations. This paper accounts for design and stability analysis of concrete gravity dam under different load of failures for various load combinations using STAAD PRO software. STAAD PRO provides facility to analyze gravity dam for every possible stress that can act on the dam (Ex- Absolute maximum stress, shear stress, normal stress, etc.) along with displacement and B.M. A well-designed spillway provides facility to dispose surplus flood water from reservoir ensuring no damage to dam. Stilling basin act as energy dissipator which prevents scouring of river bed on downstream side due to high kinetic energy of water flowing. An earthen dam is provided to confine and divert the storm water runoff. It is also used to increase infiltration, detention and retention facilities. A Canal designed by taking care of peak discharge act as lifeline for crops in that area. Thus, a well-designed dam project ultimately leads to development and welfare of people serving agriculture, fisheries, transportation etc., and have generally benefit to cost ratio above 1.

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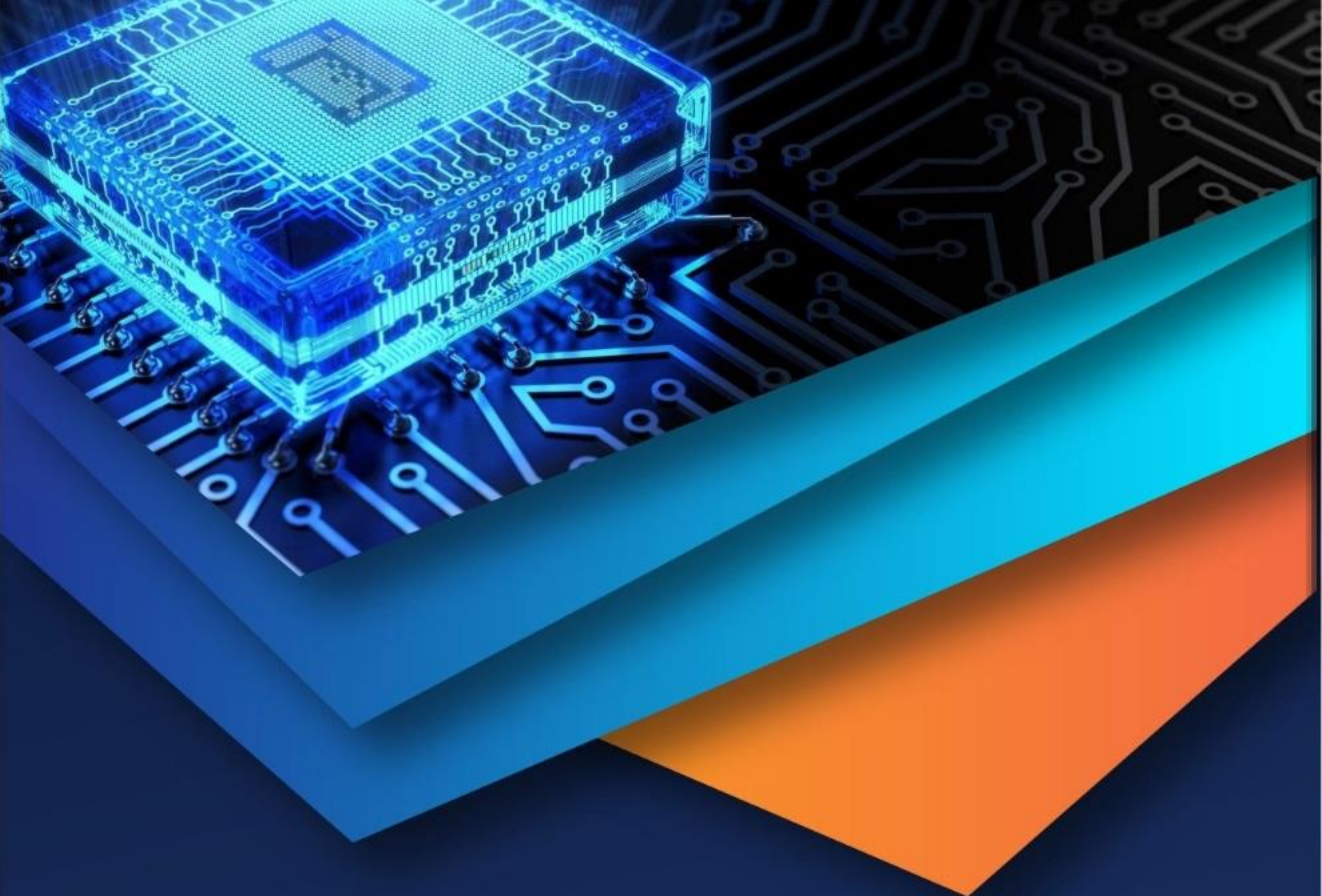

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