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Design and Analysis of Arch Dam with AutoCAD, ANSYS and Google Earth Software: A Case Study

Shashank Nayan[1], Arijit Kumar Banerji[2], Md Asif SK[3]

B. Tech, Civil Engineering, BCREC, Durgapur, India[1]

Assistant Professor, Department of Civil Engineering, Dr. B. C. Roy Engineering College, Durgapur, India[2]

Assistant Professor, Department of Civil Engineering, Coochbehar Government Engineering College, India[3]

Abstract: In this research, a site is chosen for construction of dam, and its geotechnical data has been collected through online state government websites. It included topographical feature of the site, type of rock, soil, annual flow of river, annual rainfall. A narrow valley between the border of states Bihar and Jharkhand have been found through Google Map application software and we found the river Mohana flows throughout this valley. The abutment which is best suited for holding arms of the arch dam has been found here. Then Canon dimensions are known from google earth software. After it elementary dimension of the proposing arch dam is calculated using some empirical formulas [5]. These dimensions are plotted in AutoCAD worksheet and by joining these points we got the design. Most of the layout plans are taken from google earth software which may vary to the actual context of the realm. Each and every geo-co-ordinate with precision is noted down. Finally, a finite element analysis software which is ANSYS, is used for the checking the stability of structure. It included calculation of equivalent stress and total displacement. This computational analysis software shows the simulation of stress generated under different loading condition. We have done this case study as there is not a single IS (Indian Standard) code for "Arch Dam Design" and we haven't proper methodology for this type of construction. We found that by using three different kind of advanced software (AutoCAD, ANSYS & Google Earth) we could propose or plan for construction of this hydraulic structure. After verification of the results obtained in the pre-investigation we could go further by doing actual survey, geotechnical testing, making lab reports etc. It would be time and money saving opportunity for an engineer to do all the basic calculation sitting in front of screen which would minimise the risk of a wrong decision.

Keywords: Storage reservoir, AutoCAD, ANSYS, Double Curvature Arch Dam, Google Earth

I. INTRODUCTION

An arch dam is a concrete dam that is in shape of curved spoon. It is designed to resist hydrostatic pressure by the arch action. It is most suitable for narrow gorges or canyons with steep walls of stable rock to support the structure and stresses. Through google earth we have searched so many sites. [10]In general, arch dams are classified based on the ratio of the base thickness to the structural height (b/h) as: Thin, for b/h less than 0.2,Medium-thick, for b/h between 0.2 and 0.3Thick, for b/h ratio over 0.3.Another classification with respect to their structural height are: Low dams up to 100 feet (30 m),Medium high dams between 100–300 ft. (30–91 m),High dams over 300 ft. (91 m).

Site Exploration: The site is located at the boundary of states Bihar and Jharkhand. It is about 35 km away from Gaya and 30 km from Hazaribagh. The river crossing through the valley is Mohana originating from Chatra district of Jharkhand. The Mohana originates on Korambe Pahar on the Hazaribagh plateau near Bendi village, 19.3 kilometers from Hazaribagh. It drains the upper part of the plateau. The Mohana then runs north past Itkhori, descends into the Gaya Plains, and crosses the Grand Trunk Road / NH 2 at the foot of the Danua pass. Near Itkhori it intersects the Chatra-Chauparan Road with its wide and sandy channel. 3.2 kilometers below Bodh Gaya it unites with the Lilajan (Niranjana) to form the Falgu. When it goes past the Barabar Hills, it again takes the name of Mohana, and divides into two branches.

Fig. 1 Google earth image of site location

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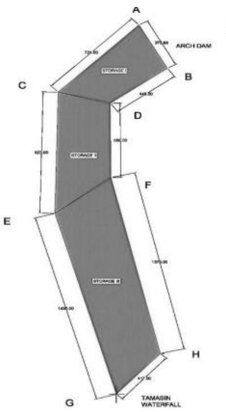
II. GEOTECHNICAL REPORT

- **Waterfall :**In the long range of hills south of the border of Gaya district, well inside Chatra district, there are two waterfalls of the Mohana. The first at Tamasin is at the head of deep valley where the river plunges abruptly down a high steep face of black rock in to a shady pool below and then dashes down a gloomy gorge of strangely contorted rock. Tamasin is 26 kilometers (16 mi) from Chatra town. This waterfall is near about Armedag having geological co-ordinates latitude 24°20'25.02"N and longitude 85° 5'46.00"E
- **Mohana River** Origin of River: Korambe Pahar, Hazaribagh , Origin place: Bendi Village ,Plateau: North-Chotanagpur Plateau ,Sub- Plateau: Hazaribagh Plateau (lower Hazaribagh Plateau)
- **Types of Rock**: Archaean metamorphic rocks, Schist, Gneisses, Granites, Quartzite, Meta basic granites. Strength of Rock: Hard and Soft, Black hard Rock, Can Hearted Rock and Miconites Color Of rock: Black, Filler and grey .
- **River Basin**: Damodar Climate: The district receives an annual rainfall of 1250 mm in rainy season. In summer season rainfall 1-2 mm. Temperature-25 degree, on summer it goes to 46 degrees maximum, in winter 2 -3 degree
- **Availability of Material**: Easily Available, many cement bricks and steel industries are situated around site. Spillway Size and Location: Less populated and distributed in two ways after some distance of site. So, there is no problem of evacuation of water during rainy season on emergency.
- **Earthquake Zone:** Zone –III, Moderate damage Risk Zone, MSKVII, IS Code Assign 0.16 for Zone 3 Other Consideration:
- **Site characteristic**: V-shaped Valley Type of Soil: Alisol, Ecetisol and . The width of the valley is 400.39 m and the height of the valley is 99.99 m, so b/h ratio is 4.003 which is less than 6. The valley is in V shape with slope 45° having central angle 130°33'.The parameters at this site tells that a medium thick arch dam could be possible here.

Reservoir Planning: The figure (Fig. 2) shows the plan layout of storage reservoir. It has been plotted in CAD worksheet, showing co-ordinates of the reservoir. The reservoir is being divided into three units for easier calculation. Storage-1, Storage-2 and Storage-3. The SG-1 & SG-2 is the deepest and the SG-3 is the longest one. The catchment areas are being calculated by area command. Storage Area has 1,89,890.588 sq.m, Storage area-2 has catchement 2,54,476.595 sq.m and Storage area-3 has 5,33,120.240 sq.m



COORDINATES OF STORAGE		
Sl.. No	Latitude	Longitude
A	24°22'24.72"N	85°05'20.89"E
B	24°22'13.99'N	85°05'27.26"E
C	24°22'08.10"N	85°05'2.69"E
D	24°22'05.35"N	85°05'14.43"E
E	24°21'38.11"N	85°05'01.85"E
F	24°21'46.98"N	85°05'14.58"E
G	24°20'53.39"N	85°05'15.77"E
H	24°21'03.47"N	85°05'25.68"E

STORAGE CALCULATION

NO.	AREA (sq.m)	CAPACITY (cu.m)
1.	189890.588	1768061.07
2.	254476.595	6400860.93
3.	533120.240	4875034.35

Fig. 2 Survey Plan Layout of Reservoir

Water Containment: These graphs are from collected from the google earth. The X-axis represent the distance from the reference point and Y-axis shows the elevation above the sea level. Although contouring is done before construction of the dam using total station and field measuring equipment. we have found out an approximate contour profile for the site chosen.

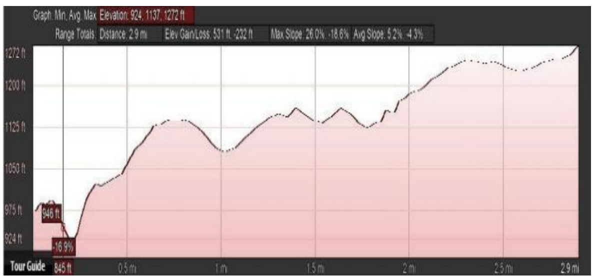


Fig. 3 Upper Rock Bed Contour

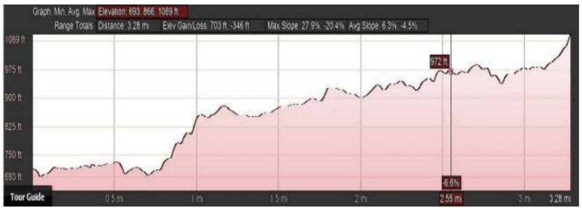


Fig. 4 Lower River Bed Contour

This figure (Fig. 5) tells about water containing capacity of the reservoir and arch dam. The elevation profile data of river bed (lower) and rock bed (upper) are taken from the google earth. These graphs are being inserted in cad sheet and by superimposing these graph we got the water containment profile. The brown color shows the river bed level, the area below blue line shows the water containment, and green area shows the valleys along the river. The red picture shows the orientation and positioning of the arch dam. The structure is positioned where B/H ratio is less than 0.5. (B-Breadth of the valley and H -height of the valley at that site.) **Note:** 1mile = 1609 meters

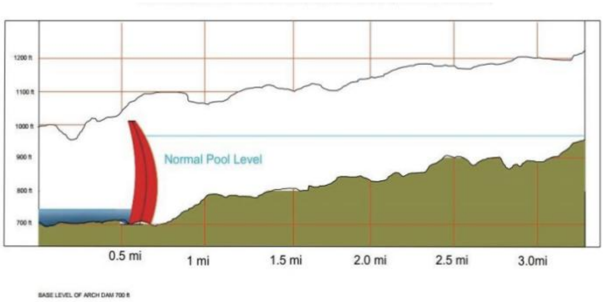


Fig. 5 Water Containment Profile of River Bed and Upper Rock Bed

III. DESIGN OF DOUBLE CURVATURE ARCH DAM

Canon Calculations: The canon location is first determined by the parameters fulfilling the possibility of holding the abutment. The canon rock should be so strong to uphold the structure. Then after knowing the co-ordinates (Fig. 2.0), we find out L_1 and L_2 of the canon. Where L_1 is straight line distance at crest elevation between abutments excavated to sound rock and L_2 is straight line distance at 0.15H above base between abutments excavated to sound rock. Where H is assumed height of dam. USP- Upper Stream Projections, DSP-Downstream Projection.

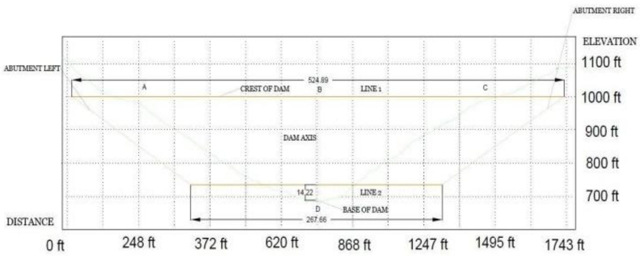


Fig.6 Calculation Sheet for Canon

Elementary Profile [5]: Double curvature arch dam with constant center is designed here. Empirical formulas for Crown Cantilever Thickness: The shape of the crown cantilever is defined by three thicknesses, upstream projections (USP) and downstream projections (DSP) at the crest, at the base, and at 0.45 H elevation by the following empirical formulas (Fig. 2.0) Data collected from rock-river bed elevation profile, L_1 = 524.88 m, L_2= 267.65 m.

Crest thickness $T_{c:}$ 0.01. (H+ 1.2L_1) ⇨ 0.01(94.84 +1.2 ×524.88) ⇨ 7.246, U.S.P =0.0, DSP = 7.426

Thickness at base: T_B ⇨ ⇨ $\left\{ \mathbf{0.0012H.L_1.L_2.}\left(\left(\frac{\mathbf{H}}{\mathbf{400}} \right)^{\frac{\mathbf{H}}{\mathbf{400}}} \right)^{\frac{\mathbf{1}}{\mathbf{3}}} \right\}$

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$$\Rightarrow \left\{ 0.0012 \times 94.84 \times 524.88 \times 267.66 \left(\left(\frac{94.84}{400} \right)^{\frac{94.84}{400}} \right)^{\frac{1}{3}} \right\}$$

$$\Rightarrow \sqrt[3]{\{0.0012 \times 94.84 \times 13321026.1 \ \times 0.710\}}$$

$\Rightarrow (11349.51)^{1/3}$ » 22.456 » 22.46 (Approx)

At Base, USP: 0.67 TB = 0.67 × 22.46 = 15.05 m

DSP: 0.33TB = 0.33× 22.46 = 7.41 m

Thickness at 0.45 H: $\mathbf{T_{0.45H} = 0.95\ T_B}$

⇨ 0.95 × 22.46 ⇨ 21.337

Height = 42.67 Min DSP =0.0, Max. DSP = 21.337

Note: These empirical formulas are valid from range, Crest -0.91 – 25.6032 m; Base – 1.5 – 199.34m. And the values obtained are within limit, so it can be accepted.

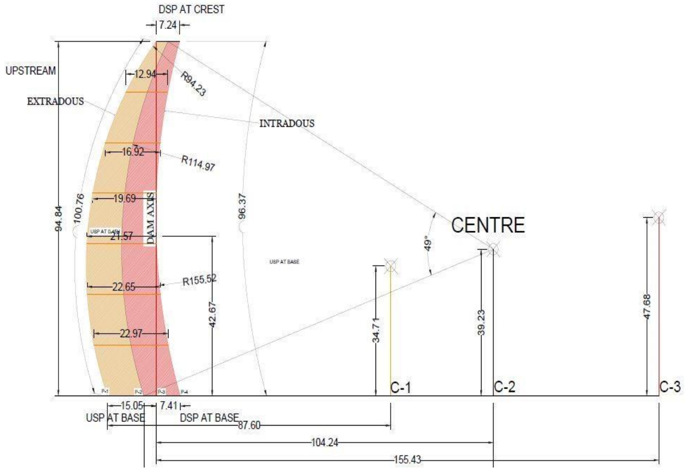

Fig 7 Elementary Design of Double curvature arch dam

IV. LOAD CALCULATIONS

The loads are applied in ANSYS mechanical as an input parameter of the functions available in static structural. These are hydrostatic pressure, wind pressure, uplift pressure, gravity load, earthquake load etc.

Gravity Load: It is the self-weight of the structure. It is not well defined in case of arch dam structure. It is dependent on the construction type whether cantilever or horizontal arches.

Table I

Acceleration	**X**	**Y**	**Z**
m/s^2	-9.81	0	1.2

Hydrostatic Pressure: The pressure generated by the river water on the upstream face. Hydrostatic acceleration has three components in X, Y, Z. The hydrostatic acceleration data has been adjusted with water-depth pressure formula. **Note:** Fluid density-1000 kg/m^3, symbol "e" in table mean exponent of ten.

Table II

Hydrostatic Acceleration	**X**	**Y**	**Z**
m/s^2	-6.85	0	1.2

Table III

Pressure	**Min.**	**Max**
ANSYS	2.909e+5	9.18e+5
Math Calculation	1.32e+5	9.30e+5

Wind Pressure: The wind pressure is calculated according to IS 875, under surface effect parameter acting toward downstream face.

TABLE IV

V_b(m/s)	K_1	K_2	K_3	K_4	P_z = (pa)$0.6V_z^2$
39	1.0	1.26	1.0	1.0	1448.84

Earthquake Load: According to IS 1893, the earthquake acceleration has been applied here in terms of fraction of acceleration due to gravity. **Note:** Silt Pressure and uplift pressure has not been calculated due to lack of data.

TABLE V

Seismic acc.	X(0.5g)	Y(0.2g)	Z(0.1g)
m/s^2	-4.905	1.962	0.981

V. STRUCTURAL ANALYSIS

ANSYS is a finite element analysis software, used in solving complex problem in engineering. There are so many forces or load acting on the structure simultaneously which creates difficulty in solving equilibrium equation and any slight deviation in calculation will produce major deflection in the result. We have to calculate so many possibilities of nature's entities which would affect the stability and life of the structure. For example, change in wind pressure, atmospheric pressure, temperature, solar radiation hydrostatic pressure, uplift pressure, silt pressure etc. Accounting these factors, we could easily simulate and know different results like stress, strain produced. without actual creating the model and situation. We have used static structural analysis engine. The CAD model which was designed earlier is imported in the ANSYS space claim. The concrete properties have been feed in engineering data. All the material properties are again given in this workspace and after verification of dimension detail, mass properties, material, then it is transferred to mechanical solver. Element size about 10 m is chosen and meshing is done. Then support applied at abutments and base, different loads (hydrostatic, wind pressure), environmental conditions have been assigned to the existing model. After this in solution section different results are obtained like as equivalent stress, stress intensity and total deformation. **Note:** Special attention should be considered about direction of applied load.

Model Description: Geometry has great influence in safety and economy of arch dams. Traditionally, shape design of an arch dam is based on the experience of the designer, model tests and trial and error procedures. To get a better shape, the designer should select several alternative schemes with various patterns and modify them to obtain a number of feasible shapes. The best shape considering the economy of design, structural considerations, safety, etc. is selected as the final shape. The shape of the dam obtained in this way is feasible but not necessarily optimum or even good.

Table VI Model Description

Material	
Assignment	Concrete
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	82.826 m
Length Y	221.43 m
Length Z	94.837 m
Properties	
Volume	4.4031e+005 m^3
Mass	1.0127e+009 kg
Centroid X	59.123 m
Centroid Y	-111.72 m
Centroid Z	41.176 m
Moment of Inertia Ip1	4.6127e+012 kg·m^2
Moment of Inertia Ip2	1.0374e+012 kg·m^2
Moment of Inertia Ip3	4.3601e+012 kg·m^2
Mesh	

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Nodes	3035
Elements	500
Size(m)	10

Table VII Concrete Properties

Young's Modulus Pa	2.73e+10	**Bulk Modulus** pa	1.52e+10
Poisson's Ratio	0.20	**Shear Modulus** pa	1.41e+10
Density kg/m^3	2300	**Thermal-Strain Reference** $^\circ$C	22
Ultimate Strength Compressive	3e + 07	**Specific Heat** J kg^{-1}C^{-1}	879

Equivalent Stress: Equivalent stress is often used in design work because it allows any arbitrary three-dimensional stress state to be represented as a single positive stress value. This is the most important result in analysis of arch dam. The stress generated at abutments (supports) and base is higher which means that support should have sufficient strength to resist the stress generated.

Table VII

Unit	Minimum	Maximum	Average
N/m^2	54151	7.717e+6	2.895e+006

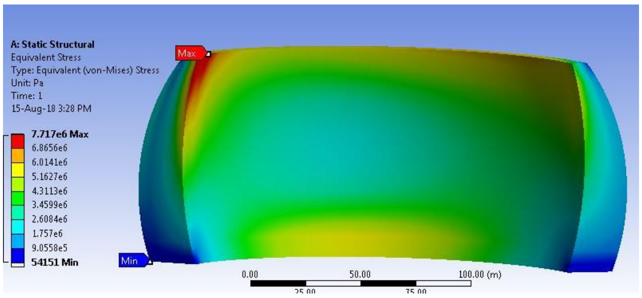

Fig.8 Equivalent stress generation on downstream face

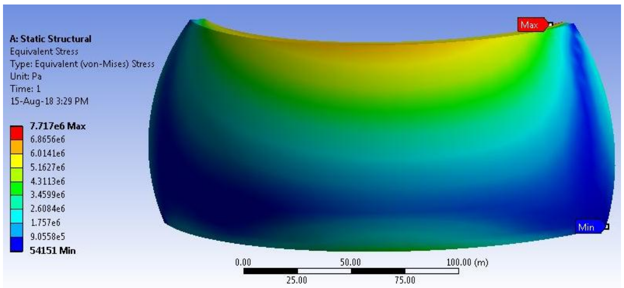

Fig.9 Equivalent stress generation on upstream face

The maximum stress generated is 7.17 N/mm^2 and average stress is 2.89 N/mm^2. Hence permissible value of concrete strength required should be 10 N/mm^2 and considering the factor of safety for existing dam which is 2.0 under normal working condition (compressive), so ultimate strength of concrete required is 20 N/mm^{2}or M20.

Total Deformation: Total deformation is the resultant deformation of the model in X, Y, Z axis. This parameter tells about geometrical change in shape of the arches. The red area shows maximum deformation as it is in the crest of the dam. It would result in slight tilting of the crest mid part towards downstream face

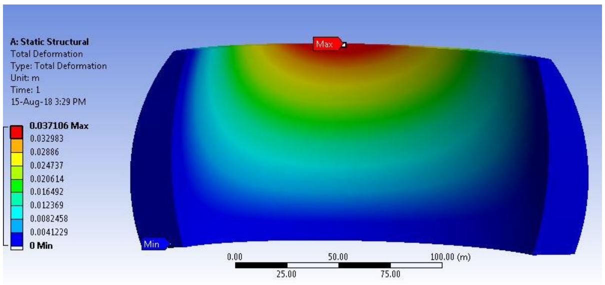

Fig.10 Total deformation generated on downstream face

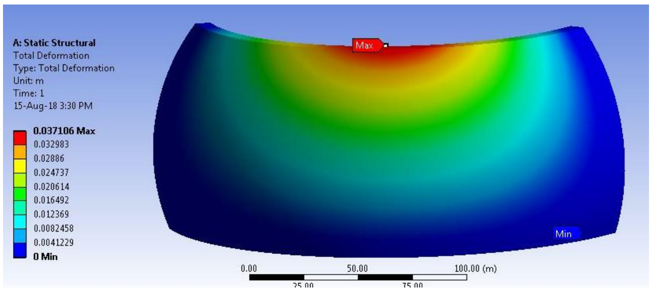

Fig.11 Total deformation generated on upstream face

Table VIII

Unit	Minimum	Maximum	Average
m	0.	3.710e-02	9.005e-03

VI. CONCLUSION

By equivalent stress result we could easily choose grade of cement required which can resist the load acting on the structure. We could easily check the total deformation whether they are in limit or not. If we have to go for further analysis, we could build a prototype or working model and by testing it on small scale we could easily predict the future possibility of the hydraulic structure. It is the simplified method for planning of arch dam which can be used further for making DPR (Detailed Project Report) and doing geotechnical investigation & experiments if required. We could also calculate the cost of structure and could compare with other hydraulic structure cost.

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