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Seismic risk analysis of dam reservoir system

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General Note

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ABSTRACT

A gravity dam is an artificial solid concrete barrier holds water by the brute force of its weight. Dam failure can cause loss of life, property damage, cultural & historic losses, and environmental as well as social impacts. The performance of a dam under both static and earthquake forces is very crucial for its endurance. In the proposed presentation five sections of Sunkesula gravity dam monoliths located in Prakasem district, state of Andhra Pradesh are considered for the dynamic analysis. The earthquake responses of the dam monoliths for reservoir wet conditions are evaluated by Response Spectrum method and Finite Element Analysis. Influence of damping factors given in the IS :1893, on the responses of the above dam sections are initially studied and found that the principal stresses at heel & toe and crest displacements are stable at 5% damping. Considering the 5% damping the dam monoliths responses are evaluated on dam – reservoir system. The hydrodynamic pressure on the dam is applied as per the Westergaards concept of added mass. Dam sections are descritized as triangular & quadrilaterals elements. It is observed that in all the cases the compressive stresses are below the permissible stress where as the tensile stress are found at heel portions.

Key words: Gravity dams, Response spectra, Earthquakes, Damping.

1. INTRODUCTION

One of history's worst dam failure happened in the year 1979 in India. When the Machhu Dam II on the Machhu River collapsed in the western part of Gujarat. This led to inundation in the industrial city of Morbi located near by the dam site and surrounding rural areas destroying thousands of homes and lives. In the past over forty dam bursts have taken place in India, and there have been shown that earthquake hazard continues to be a serious threat to dams. These disasters have raised concerns over the issue of dam safety and design of the 4900 large dams and the several thousand small dams in India. The response of a dam subjected to seismic loading, exhibits a combined effect of the interaction among dam, reservoir and foundation systems. Hence, in order to evaluate the safety of dams, it is necessary to study the various aspects influencing the seismic response of a concrete gravity dam (B.Sing and P.Agrawal 2009). A response spectrum analysis procedure, which estimates the peak response directly from the earthquake design spectrum, is available for the preliminary phase of design and safety evaluation of concrete gravity dams (Arnkjell Lokke and Anil K. Chopra 2015). In the response spectrum analysis the governing parameters are the modal characteristics, damping ratio and hydrodynamic pressures. Dam water interaction and reservoir bottom adsorption modify the natural vibration period and the damping ratio of the equivalent SDF system representing the fundamental vibration mode response of the dam (Gregory Fenves, A.M and Anil K. Chopra). Although sophisticated techniques were proven to efficiently handle many aspects of dam reservoir interactions, their use requires appropriate expertise and specialized software. For practical engineering applications, simplified procedures are still needed to globally evaluate the seismic response of gravity dams, namely for preliminary design or safety evaluation purposes (Benjamin Miquel, Najib Bouaanani, 2010).In this work the Finite Element method is demonstrated by considering the practical data of an existing non over flow dam at Veligonda in the state of Andhra Pradesh, India with various valid assumptions. The dam was designed and constructed by conventional design procedure through consideration being given to five plane sections (pertains to the dam heights 63m, 46m, 35m ,13m and 8m). The structural responses of the above five sections using response spectra mentioned in the IS code 1893 are derived for the influence of reservoir pressure, uplift pressure and hydrodynamic pressure. Each dam sections are descritized conveniently by three and four – noded quadrilateral isoperimetric elements. Incompressibility of reservoir water is assumed and hydrodynamic effects are incorporated through the proposal of Westergaards theory. The statistics and analysis about peak displacement, principal stress, of the feature points of the dam, can conclude the safety of dam (Yang Lu, Li Shi-Min). Also the entire range of damping factor included in the earthquake response spectrum in IS: 1893 taken up and investigated the influence with a view to achieve a rational conclusion regarding the damping factors (Sashikiran.K and Manjulavani.K, 2015).

2. METHODOLOGY

The combined influence of the amplitudes of ground accelerations, their frequency components and the duration of ground motion on different structure is conveniently represented by a response spectrum, and is a plot of the maximum response against each possible period of vibration of the structure and its damping characteristics. It is customary to describe an actual earthquake shock through a set of curves referred to as earthquake response spectra .Each curve represents response spectra for a particular damping. Housner has investigated response spectra of four major earthquakes in the world .On the basis of his analysis he has proposed, generalized earthquake response spectra referred to as average spectra. In the absence of specific knowledge regarding the design earthquake it is customary to treat Housner spectra as design earthquake response spectra. IS 1893 also recommends the same. For the proposed work the same average acceleration spectra is considered for the analysis of considered dams.

3. CASE STUDY

To demonstrate the effectiveness of the analysis procedure presented in this work, the response of Sunkesula dam proposed across the natural gaps formed in Veligonda reservoir project, located in Prakasem district, Andhra Pradesh is considered. The Veligonda Project envisages drawl of 43.50 TMC of Krishna water from foreshore Srisailam reservoir through a tunnel and link canal. The water is stored in the reservoir called the Eastern Nallamalaisagar at about 12 Km NW of Markapur town by constructing dams across saddles near Sunkesula ,Gottipadia and Kakarla villages to store 60.5 TMC of waters to provide Irrigation facilities in upland areas of Prakasem, Nellore and Kadapa districts of Andhra Pradesh. The location details of the Sunkesula dam is shown in Fig.1 Also the maximum section of the dam monolith with the details of levels are shown in Figure 2.

Geometry and Idealizations

A two dimensional conventional finite element model is created using both triangular and quadrilateral elements. The finite element idealizations of the five dam sections of Sunkesula dam are shown in Figure 3 and their discretization numerical data is provided in Table 1. The material properties of the dam monoliths considered in the analysis are Modulus of Elasticity Ed = 0.25×10^8 kN $/m^2$, and Poisson's ratio $\gamma = 0.15$. Density of concrete $\rho = 25$ kN/m^3.

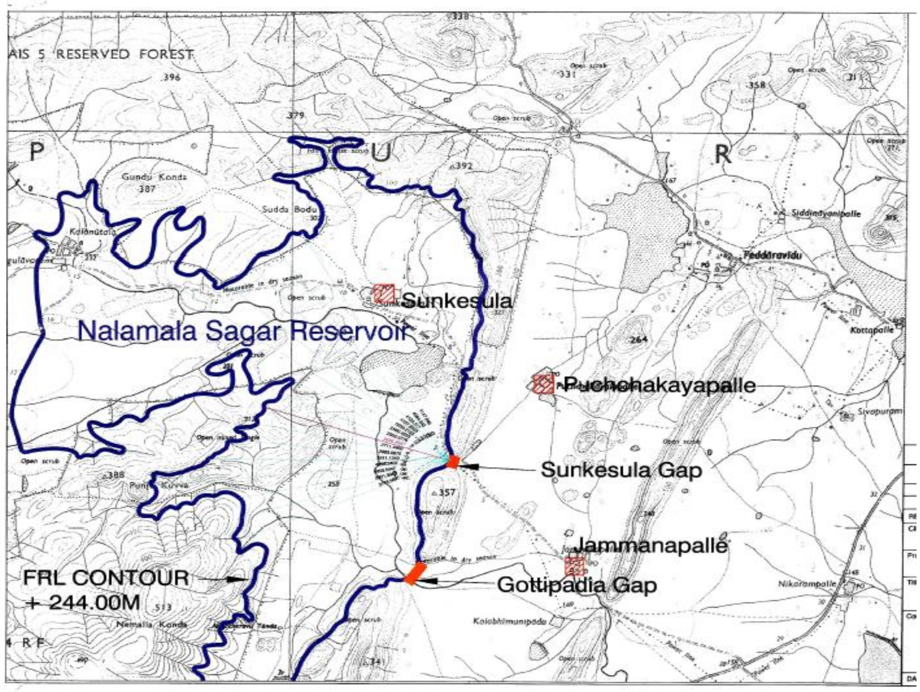

Figure 1 Location map of Sunkesula gravity Dam

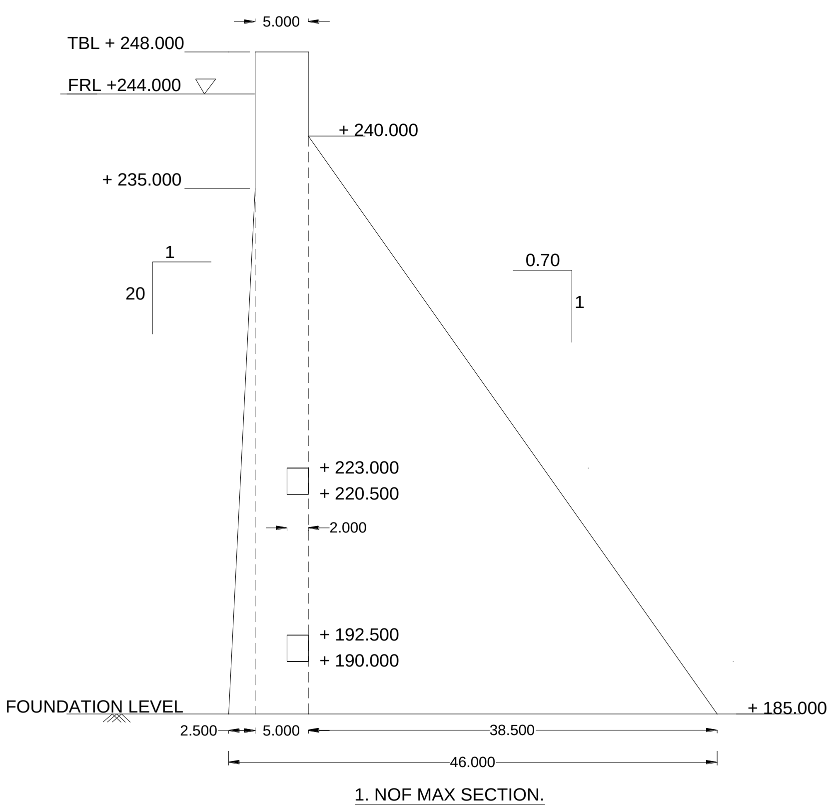

Figure 2 Maximum section of dam monolith (63m height)

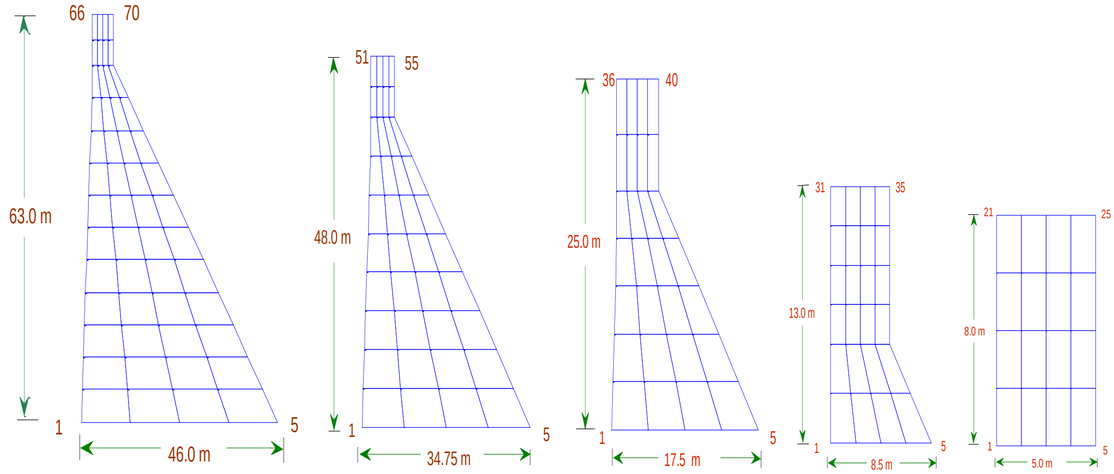

Figure 3 Finite element idealization adopted for the five sections of Sunkesula dam

Table 1 Numerical data

S.no	Section height(m)	No of nodes	No of Elements
1.	63.0	70	52
2.	48.0	55	40
3.	25.0	40	28
4.	13.0	35	24
5.	8.0	25	16

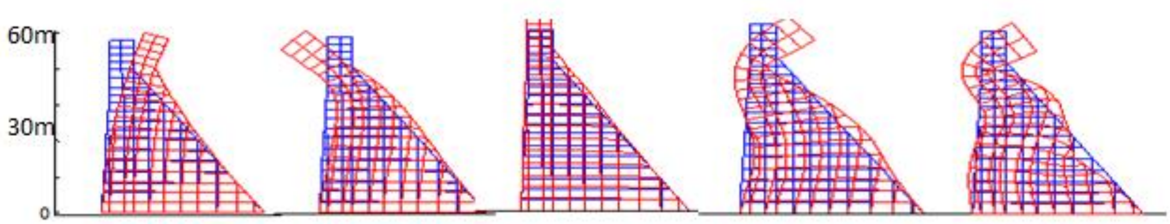

Figure 4 Modal characteristics of 63.0m section of Sunkesula dam for frequencies w_1 to w_5.

Structural response

The response spectrum analysis on Sunkesula dam is conducted through linear plane stress finite element analysis. The modal features for the first five modes (w_1 to w_2) of the natural vibrations are selected and some are assumed to satisfy requirements of the modal characteristics. It is emphasized that these are derived through considerations being given only to the body of the dam ignoring the presence of reservoir water. The structural response is derived for the possible maximum stress development where in the static influence of the reservoir pressure, uplift pressure and hydrodynamic pressure are considered. The modal characteristics of maximum height 63.0 m dam are fully described in Fig. 4.

4. RESULTS

The presentation of results aims at the following features.

1.Response details in consideration to five damping ratios for reservoir empty and reservoir full conditions, in terms of horizontal deflection at the top of the dam and principal stresses at the heel and toe of the dam considering 63.0 m height without foundation are shown Figure 5 to 9.

2.Stress contours for 63.0m dam height are shown in Figure 10 to 11. Details of the stresses for the five cases arrived are given in the Table 2

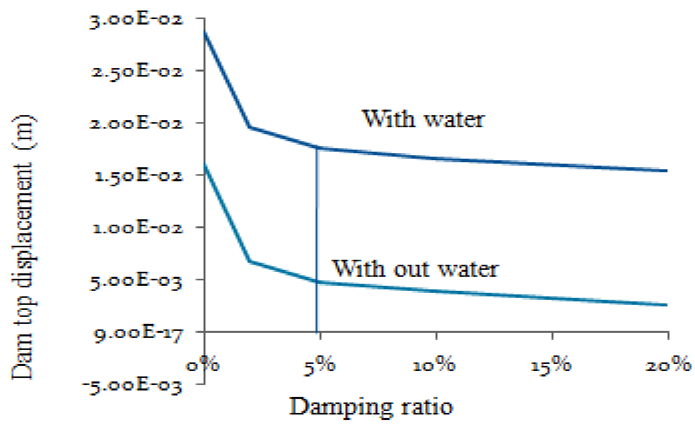

Figure 5 Damping ratios Vs Dam top displacement

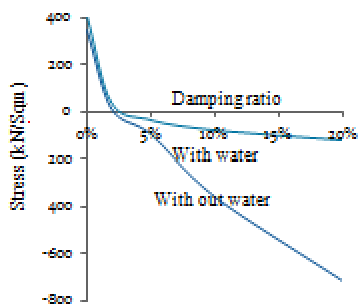

Figure 6 Damping ratios Vs Smin for heel

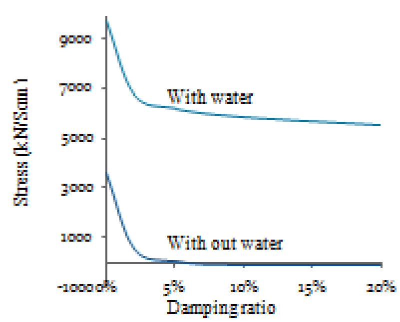

Figure 7 Damping ratios Vs Smax for heel

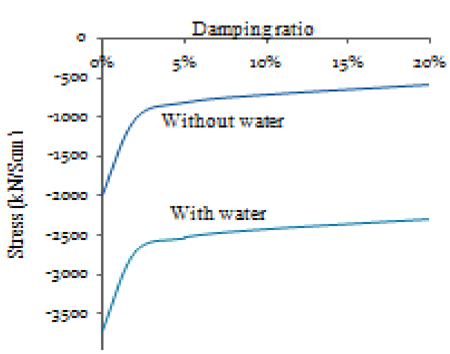

Figure 8 Damping ratios Vs Smin for heel

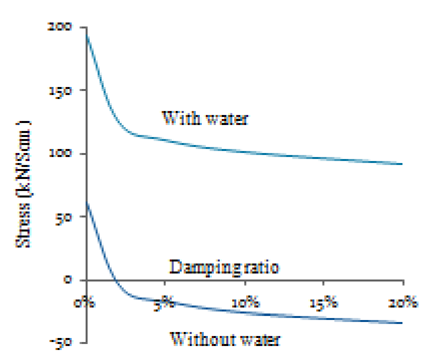

Figure 9 Damping ratios Vs Smax for heel

Smin=Minor Principal Stress. Smax=Major Principal Stress

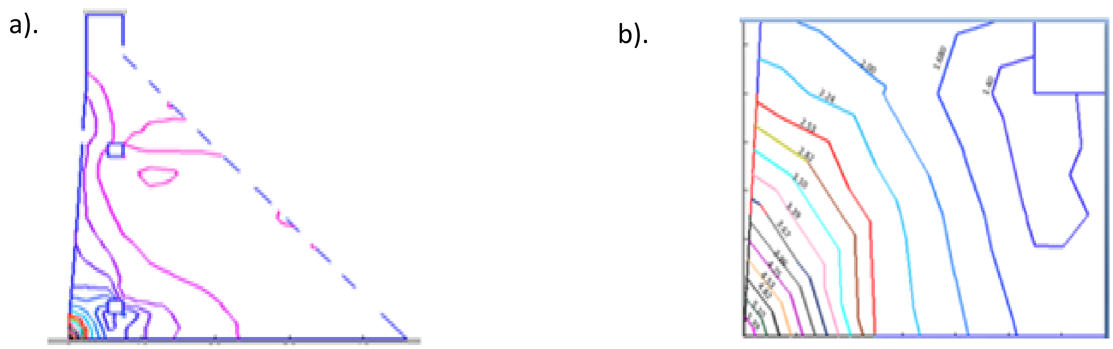

Figure 10 a) Contours of Major Principal Stress for 63m ht dam. b) Enlarged view at heel

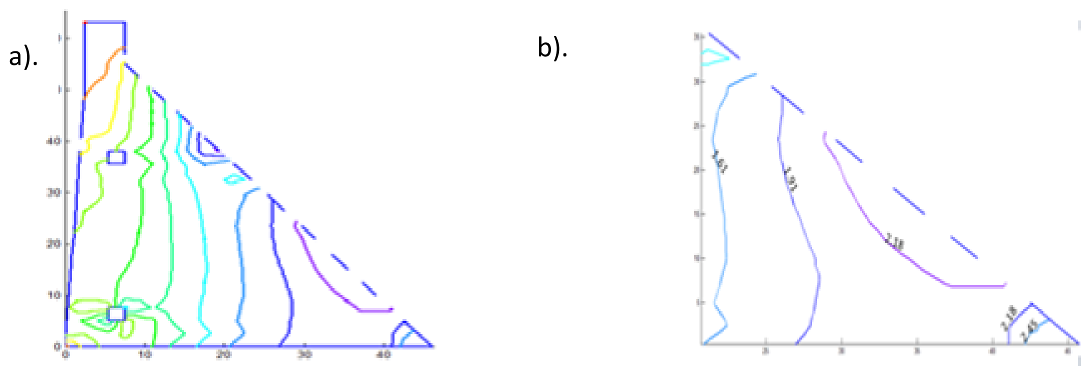

Figure 11 a).Contours of Minor Principal Stress for 63m ht dam. b).Enlarged view at toe

Table 2 Stresses of dam sections for normal load operation with earthquake

S.no.	Dam heights	Major Principal stress(N/mm^2)		Minor principal stress(N/mm^2)	
		Tension @ heel	Compression @ toe	Tension @ heel	Compression @ toe
1.	63.0 m	5.39	0.044	0	2.45
2.	48.0 m	3.55	0.020	0	1.91
3.	25.0 m	0.956	0.015	0	0.788
4.	13.0 m	0.349	0.010	0	0.519
5.	8.0 m	0.101	0.010	0	0.379

5. DISCUSSION

1.The figures 5 to 9 show that the dam top deflection and magnitude of stresses at both toe and heel of the dam sections are gradually varying from 0 to 5 % damping. However beyond 5% damping, changes in the stress response are not much evident.

2.As shown in the table.2 at toe, for all the dam heights both major and minor principal stresses are in compression only. Whereas the tensile stresses are found at heel and are increasing with the dams heights. Stress contours as shown in figure. 9 & 10 represents the same results for a dam of 63m height.

6. CONCLUSION

The following conclusions are drawn from the basis of the detailed investigations carried on the Sunkesula gravity dam.

1. At 5% damping the deflection of the dam top and stress at heel and toe are changing from non linear to linear. Therefore it is quite in order to assume 5% damping as the design parameter in the analysis of dams.
2. The compressive stresses are found far below the permissible stresses in the dam monoliths.
3. The tensile stresses and the area of tension zone at heel increase with increase in the height of the dam (may cause failure) and the same are to be attended in the further refinement process.

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