INVESTIGATION OF STRESSES IN A CONCRETE GRAVITY DAM UNDER COMBINED LOADINGS OF SEISMIC AND FLOOD WAVES

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Abstract- This research is carried out to check the stability of a concrete gravity dam under the extreme loadings of combined seismic and flood waves. Concrete gravity dams are provided in highly seismic regions. These dams are not designed on experimental validation, but are simulated by finite element method on software. The environmental and other loadings and actions are then implemented on these simulated models and response of the system is checked. One drawback or ignorance of such system is, if a peak wave is generated and at the same time any seismic activity happens, then what will be the response of the dam, will it be stable in safe limit or not, will it survive combined loadings or not? That's why this study is based on such response prediction to evaluate the maximum stresses generated in the dam under such extreme loadings. In this study, a gravity dam is modelled on SAP2000 with finite element method. Blue Stone Dam from USA is selected and modelled on SAP2000. After that combined loadings i.e., seismic and flood wave are applied and response is predict of this simulation based model of the dam. After the successful run of the model, it is predicted that maximum stresses are generated on the top of the dam.

Keywords- Concrete gravity dam, Seismic loads, Flood wave loads, SAP2000, Finite element method

1 Introduction

Dams are obstacles that carry pounding of water or underground streams for different purposes such as power generation, storage of water, irrigation for agriculture, stabilization of flow, prevention of areas from floods, navigation, diversion of water channels and source of drinking water. The significance of these structures passes on the possibility of tragic disasters which can happen because of its failure, error in spillway design, piping through foundation, soil instability due to upstream fluctuation in water levels, poor maintenance, extreme precipitation events and flood waves, and seismic shocks and earthquakes [1]. The dynamic responses of concrete gravity dams due to earthquakes are affected by several factors. These factors include the dam's interaction with the water stored in the reservoir and foundation, sediments accumulation at reservoir's bed and non-linear behavior of dam's concrete. Recent studies indicated that the magnitude of the response of the concrete gravity dams is reduced generally due to the presence of sediments at the reservoir's bottom [2]. The concrete gravity dam's structures also face various flood wave loadings. These wave loadings occur in different scenarios including the wave loading relevant to the environmental data of the area is applied on the structural members together with gravity and buoyancy loads but without considering the wind loads (remote storm scenario) and the scenario where the load generated by extreme wave conditions, buoyancy and gravity loads are applied (extreme wave scenario) by neglecting wind load [3]. Different loadings are evaluated while design the concrete gravity dam. These loadings include earthquakes, floods, sedimentation, ice and wind loads etc. In this study the combined effects of seismic and flood waves are investigated to predict the portion of the dam with maximum stresses. Designing earthquake-resistant dams and assessing the safety of existing dams both rely on a reliable analytical method that can identify the stresses and deformations brought on by an earthquake [4]. However, when taking into account the various definitions of a strong motion duration, it is still unknown how different durations may affect the seismic analysis of gravity dams. Furthermore, no definitive conclusion about the best option for the duration of a powerful ground motion has been reached. Due to its high accuracy and cheap computational effort for computing the dynamic reactions of structures, the endurance time analysis (ETA) approach, a high-efficiency seismic performance method, is frequently employed [5]. In this study, the stresses generated due to combined loading of earthquake and flood wave are evaluated. The response of the results shows that due to these combined loadings, damage in dam will be occurred at top portion of dam.

2 Research Methodology

2.1 Model Development.

Blue stone dam located in USA is selected to conduct this study [6]. The dam is modelled on SAP2000 software with Finite Element Method. Concrete is used as material and compressive strength of concrete is selected as 5000 psi. Solid body is selected to model it instead of members, due to the fact that dam is a solid body. The height of the dam is selected as 173 feet and length of the dam is selected as 600 feet. Six joints are provided in y-direction at interval of 100 feet for each and 4 joints are provided in z-direction at an interval of 34.7 feet each. To check the validation of model, the sum of masses in x-direction and y-direction for different modes of the model is computed more than 90% and the period is computed less than 8 seconds [7]. Hence the model developed for this study has shown validation. The model of the dam is shown the *Figure 1.*

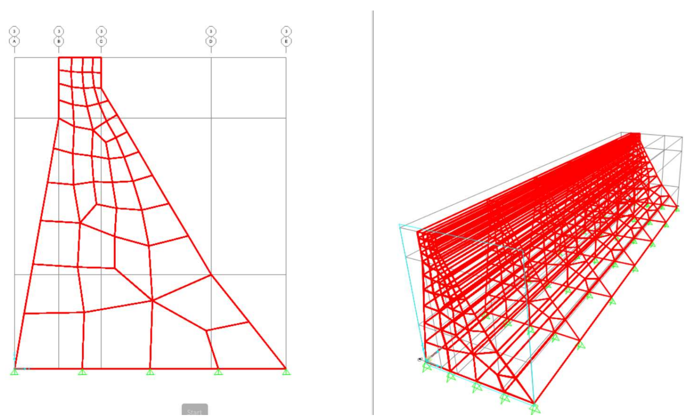


Figure 1: Model of dam developed on SAP2000

2.2 Load Definition.

For defining the load combination Time-History Analysis is used. Three earthquake loads are used and combined with peak flood wave of 6 feet height on the upstream side, in this study. Earthquake loads are downloaded from peer data base and imported in SAP2000 [6]. In this way 3 load combinations are created and model is run for these combinations. The earthquakes with magnitude greater than 6.5 are selected. The details of earthquakes used are available in *Table 1* and definition of flood wave is shown in *Figure 2.*

Table 1: Earthquakes used in this study.

Earthquake	**Year**	**Magnitude**	**Epicentre Distance (KM)**
Sitka Alaska	1972	6.68	34.61
El Centro	1940	6.95	6.09

Northridge	1994	6.61	7

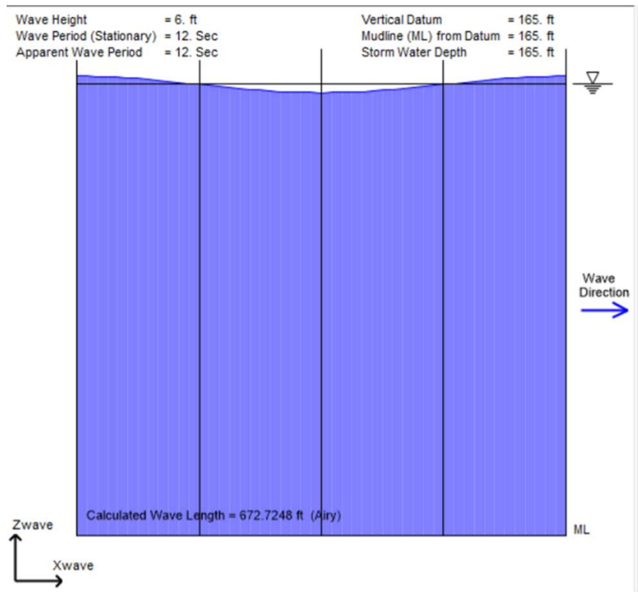


Figure 2: Definition of flood wave in SAP2000.

3 Results

The responses for the three earthquakes in combination with flood wave are represented below to check the stress contours for each case. The average of these three responses is taken to get the final results.

3.1 Stress contours of Sitka Alaska Earthquake and Flood Wave

After running the model for load combination of Sitka Alaska earthquake and flood wave, the maximum stresses developed are found at top of the dam, equal to 8400 psi. The breach point of the concrete was selected as 5000 psi during modelling. So, it is predicted that as a response of aforementioned combination, the top of the dam will be damaged initially. The results of this combined loading have shown that there is 68% increase in the stresses at the top portion of the dam. The stress contours generated due to this type of combination in z-direction and y-direction are shown in *Figure 3 a) and b)* respectively. The stresses generated for a period of 4.35 seconds are presented in *Table 2* and *Graph 1*.

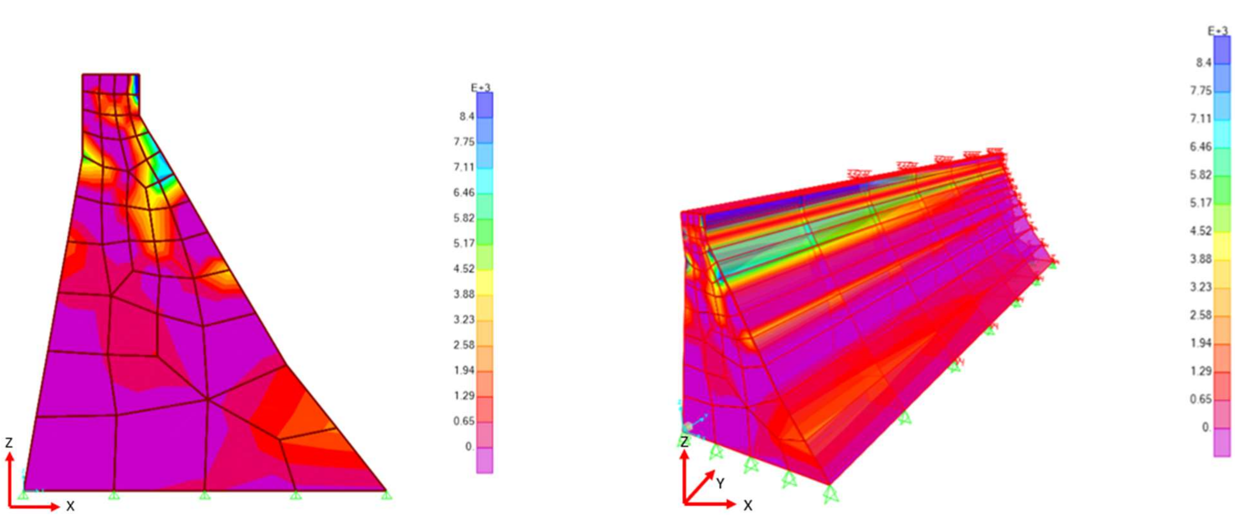
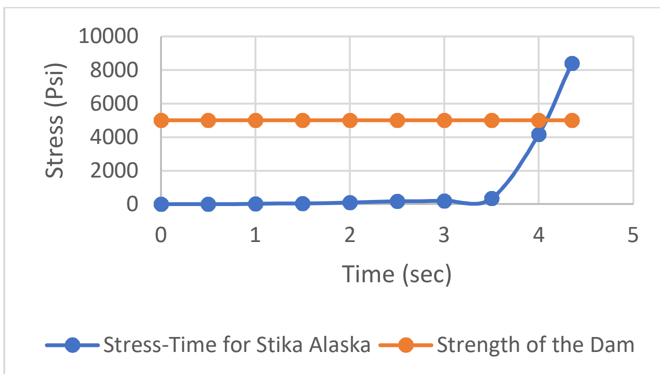


Figure 3 a): Stress contours in z-direction *Figure 3 b): Stress contours in y-direction*

Table 2: Stresses generated for a period of 4.35 seconds for Sitka Alaska Earthquake and Flood Wave

Sr. No.	Stresses (psi)	Time (Seconds)
1	0	0
2	4	0.5
3	28	1
4	52	1.5
5	104	2
6	175	2.5
7	208	3
8	347	3.5
9	4167	4
10	8400	4.35



Graph 1: Stresses generated for a period of 4.35 seconds for Sitka Alaska Earthquake and Flood Wave

3.2 Stress contours of El Centro Earthquake and Flood Wave

After running the model for load combination of El Centro earthquake and flood wave, the maximum stresses developed are found at top of the dam, equal to 7500 psi. The breach point of the concrete was selected as 5000 psi during modelling. So, it is predicted that as a response of aforementioned combination, the top of the dam will be damaged initially. The results of this combined loading have shown that there is 50% increase in the stresses at the top of the dam. The stress contours generated due to this type of combination in z-direction and y-direction are shown in *Figure 4 a) and b)* respectively. The stresses generated for a period of 4.27 seconds are presented in *Table 3* and *Graph 2.*

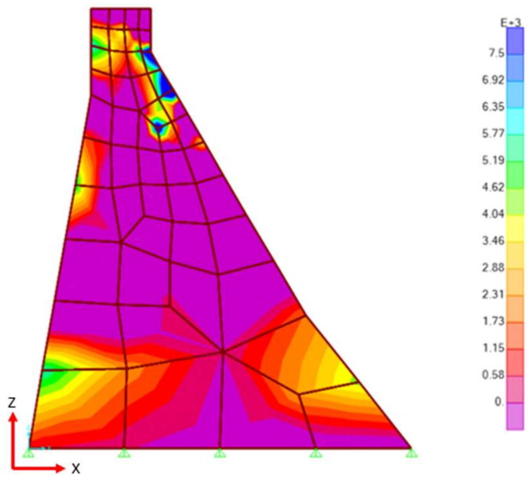


Figure 4 a): Stress contours in z-direction

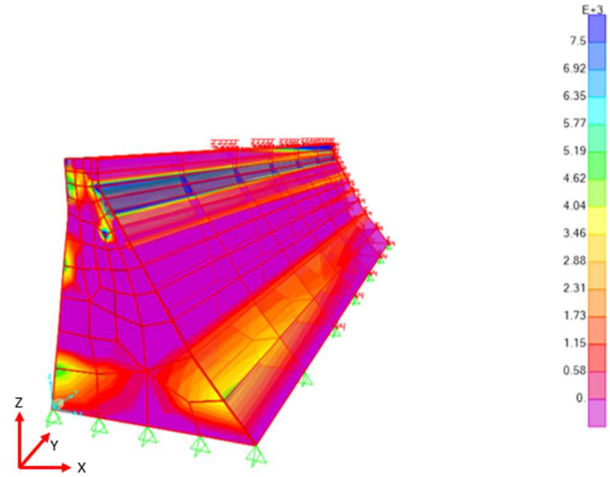
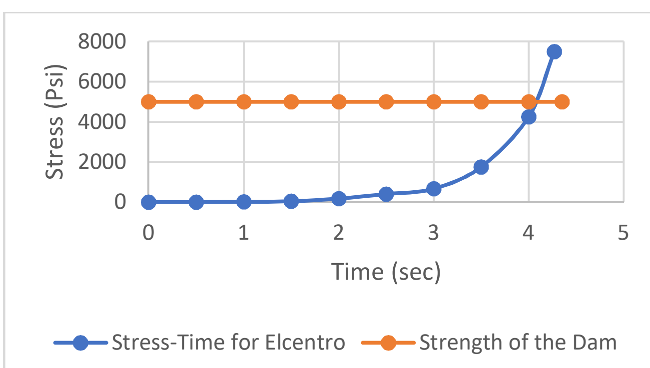


Figure 4 b): Stress contours in y-direction

Table 3: Stresses generated for a period of 4.27 seconds for El Centro Earthquake and Flood Wave

Sr. No.	Stresses (psi)	Time (Seconds)
1	0	0
2	0	0.5
3	14	1
4	39	1.5
5	175	2
6	393	2.5
7	664	3
8	1753	3.5
9	4254	4
10	7500	4.27



Graph 2: Stresses generated for a period of 4.27 seconds for El Centro Earthquake and Flood Wave

3.3 Stress contours of Northridge Earthquake and Flood Wave

After running the model for load combination of Northridge earthquake and flood wave, the maximum stresses developed are found at top of the dam, equal to 6200 psi. The breach point of the concrete was selected as 5000 psi during modelling. So, it is predicted that as a response of aforementioned combination, the top of the dam will be damaged initially. The results of this combined loading have shown that there is 24% increase in the stresses at the top of the dam. The stress contours generated due to this type of combination in z-direction and y-direction are shown in *Figure 5 a) and b)* respectively. The stresses generated for a period of 4.12 seconds are presented in *Table 4* and *Graph 3*.

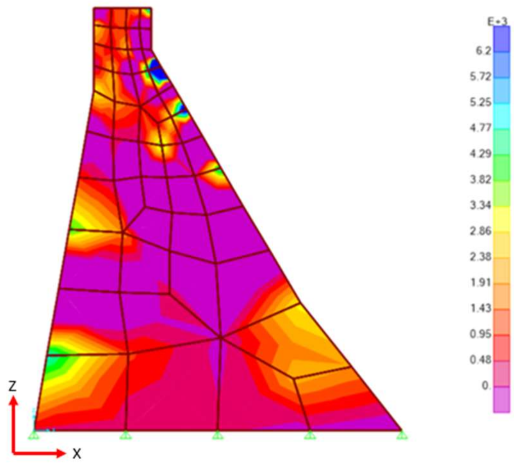


Figure 5 a): Stress contours in z-direction

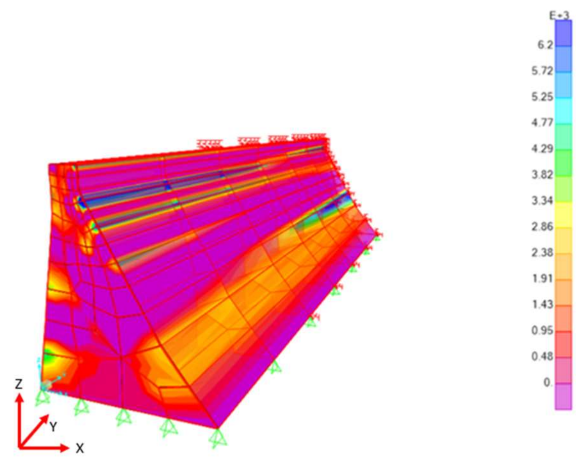
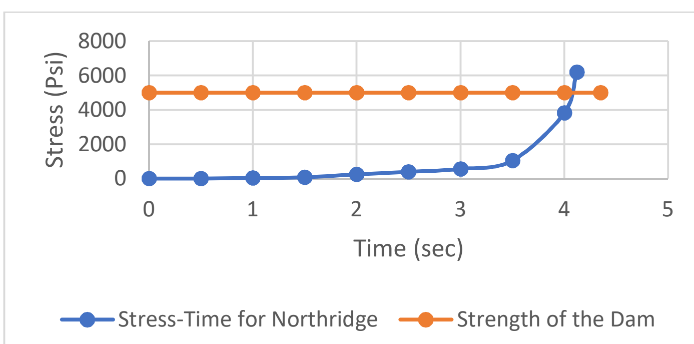


Figure 5 b): Stress contours in y-direction

Table 4: Stresses generated for a period of 4.12 seconds for Northridge Earthquake and Flood Wave

Sr. No.	Stresses (psi)	Time (Seconds)
1	0	0
2	1	0.5
3	36	1
4	66	1.5
5	248	2
6	393	2.5
7	556	3
8	1042	3.5
9	3819	4
10	6200	4.12



Graph 3: Stresses generated for a period of 4.12 seconds for Northridge Earthquake and Flood Wave

4 Practical Implementations

As this study is based on response prediction, the practical implementation of this research work can be verified by the future researchers by conducting experiments.

5 Conclusion

The results of this study have the following conclusions:

1 As an average response of three combinations, it is concluded that maximum stresses are produced at the top of the dam with strength greater that 5000 psi. Hence, the top portion of the dam will be damaged first under such type of extreme loadings.
2 Due to complex design of a concrete gravity dam, the combination of seismic and flood waves is ignored due to very less probability of such event to be occurred, but this study has shown some responses that have predicted that it should not be ignored.

The above study can also be carried out to predict the critical location of concrete gravity dams under such extreme loadings.

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