Seismic Response of Concrete Gravity Dam in Afghanistan

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Abstract - *Gravity dam is a structure that maintains their stability against all loads that coming on this structure from the geometric shape, mass and strength of concrete. The earthquake design resistance of concrete gravity dam structure is more important to have a safe dam during his life. The concrete gravity dams should perform satisfactorily during seismic events. For this purpose there are different methods available for stability analysis of concrete gravity dam under seismic loading. As in Afghanistan no specific seismic design codes is available at present. So the main aim of present work is to perform a complete 3D seismic analysis of concrete gravity dam using PGA (peak ground acceleration) of Afghanistan Cities. For present analysis four different cases were selected with and without opening for drainage gallery. The complete seismic analysis of concrete gravity dam is presented in this paper including static, modal, harmonic and response spectrum analysis using ANSYS software.*

***Key Words*: Seismic Response, ANSYS, Gravity Dam, Afghanistan**

1. INTRODUCTION

There are a large number of concrete gravity dams worldwide. Some of the dams are in seismically active areas. Safety of dam during and after an earthquake is an area of current concern in present work. The failure of a dam during an earthquake may be catastrophic in terms of loss of life and financial loss. The analysis of dams is a complex problem due to the dam reservoir and dam foundation interaction. In addition to the static water pressure, the dam is subjected to dynamic forces from the reservoir when the system is subjected to earthquake ground motion. Concrete gravity dams are preferred these days as they can be constructed with ease on any dam site, where there exists a natural foundation strong enough to bear the enormous weight of the dam. Md. Hazrat Ali, Md.RabiulAlam(2011), "Comparison of design and analysis of concrete gravity dam", the main aim of their study is to design high concrete gravity dams based on the U.S.B.R. recommendations in seismic zone II of Bangladesh, for varying horizontal earthquake intensities from 0.10 g - 0.30 g with 0.05 g increment to take into account the uncertainty and severity of earthquake intensities and constant other design loads, and to analyze its stability and stress conditions using analytical 2D gravity method and finite element method. Shiva KHOSRAVI and Mohammad Mehdi HEYDARI (2013), "Design and modal analysis of gravity dams by ANSYS parametric design language", In their paper they find the optimal shape of concrete gravity dams including dam-water-foundation rock interaction, model of 2-dimensional finite elements that include the dam, reservoir and foundation is provided using the finite element software ANSYS. Yoshikazu yamaguchi, Robert hall , Takashi sasaki , Enriyuematheu ,Ken-ichikanenawa , Anjanachudgar and Donald Yule (2004), "Seismic Performance Evaluation of Concrete Gravity Dam", This paper is prepared by engineers of Japan and United States and the decrease about the effect of nonlinear dynamic analysis in seismic evaluation problem in Japan and united states. A lot of research is carried out for the analysis of gravity dams for different parameters but very less research is done for seismic analysis of gravity dam especially in Afghanistan, as no specific seismic design codes are available at present. The objective of present work is to perform 3D analysis of concrete gravity dam for seismic analysis for PGA (peak ground acceleration) of Afghanistan. 3D analysis using ANSYS software for concrete gravity dam with and without opening for two different cities of Afghanistan i.e. Kabul and Herat as both have a different seismic coefficient is done.

In this section, we analyze the gravity dam under earthquake by ANSYS Software and for analysis, two sections were considered a) gravity dam without opening b) gravity dam without opening. For a complete study of the seismic response of 3D concrete gravity dam, following analysis are done.

- Static Structural Analysis
- Modal Analysis
- Harmonic Response
- Response Spectrum

For analysis two cities of Afghanistan PGA (peak ground acceleration) were selected. Four cases were considered for analysis they are-

Table -1: different cases of study

Case 1	Analysis of the section without opening in Kabul city
Case 2	Analysis of the section without opening in Herat city
Case 3	Analysis of the section with opening in Kabul city
Case 4	Analysis of the section with opening in Herat city

1.1 Element Description

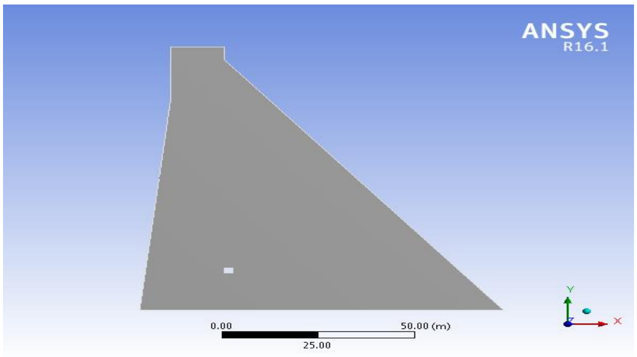
Main task in finite element analysis is selection of suitable elements. Numbers of checks and convergence test are made for selection of suitable elements from different available elements and to decide the element length. SOLID 186 is used for analysis using ANSYS software. SOLID186 is a 3D homogeneous structural solid element that exhibits quadratic displacement behavior with 20-Node and three degrees of freedom at each node i.e. translations in the nodal in X-, Y- and Z-directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities.

2. Sectional Properties

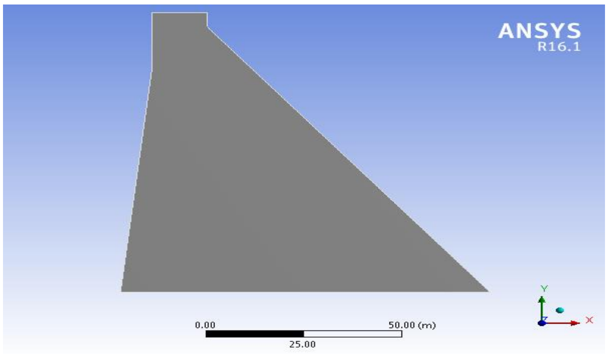
The section of gravity dam should be chosen in such a way that it is the most economic section and satisfies all the conditions and requirements of stability. The cross section of the dam is selected after convergence to check the stability. This dam has 100 m height and 96 m width. The cross section of dam with and without opening is given in figure 1. Following material properties were considered for analysis-

Table-2: Material Properties

Concrete	Mass density of concrete	2400 kg m-3
	Yong modulus of concrete	3.1027E+10
	Poison ratio	0.2
	Compress yield strength of concrete	1.26 E+07pa
	Tensile ultimate strength of concrete	3E+06pa
Water	Mass density of water	1000 kg m-3



a) With Opening



b) Without Opening

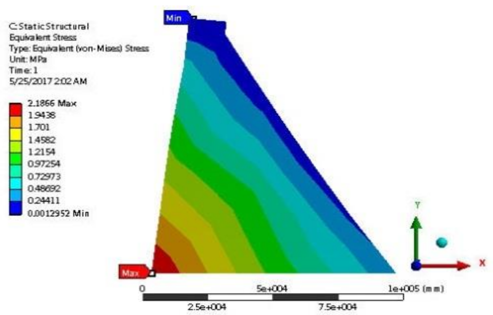
Fig -1: Cross-section of Gravity Dam

3. Finite Element Analysis

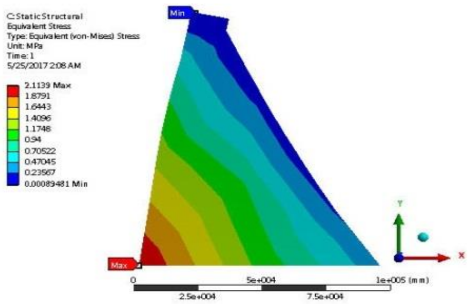
First, the model was imported in workbench, followed by four types of analysis i.e. 1) static structural 2) modal analysis 3) harmonic response 4) response spectrum. For 3D analysis two cities of Afghanistan PGA (peak ground acceleration) were selected-
1) Kabul by PGA 48 %g
2) Herat by PGA 28% g

3.1 Result of Static Structural Analysis

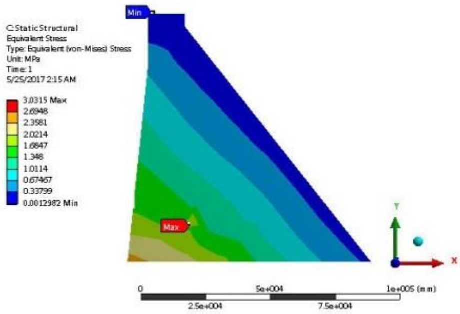
1) Maximum Equivalent Stress



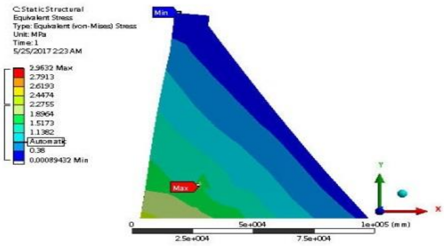
a) Case 1



b) Case 2



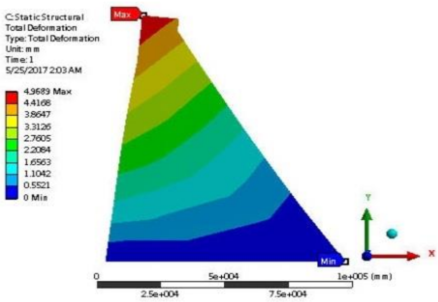
c) Case 3



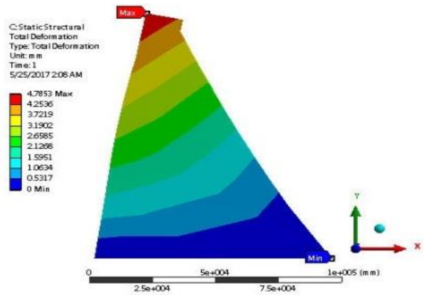
d) Case 4

Fig -2: Maximum Equivalent Stresses

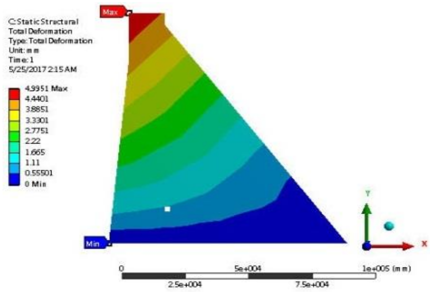
2) Maximum Deflection



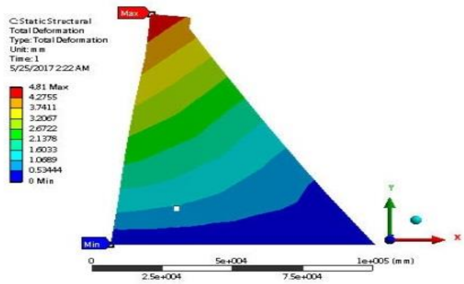
a) Case 1



b) Case 2



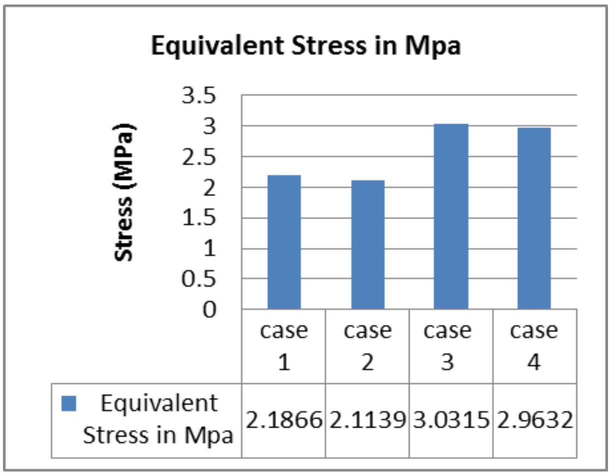
c) Case 3



d) Case 4

Fig -3: Maximum Deflections

Chart -1: Comparing Maximum Equivalent Stresses of four cases



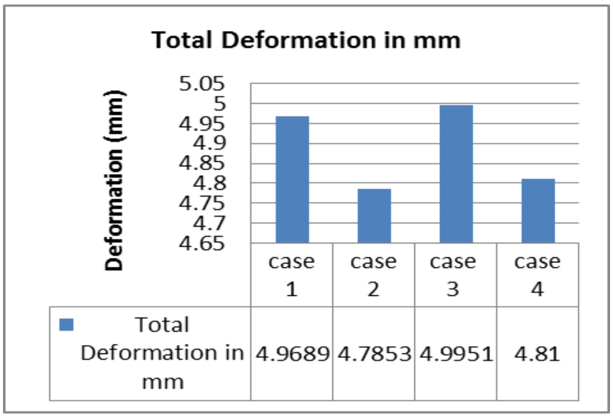


Chart -2: Comparing Maximum Deflections of four cases

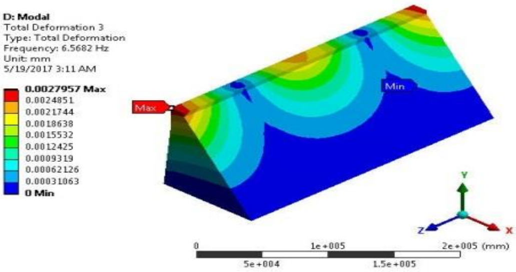
Table -3: Static Structrul analysis results

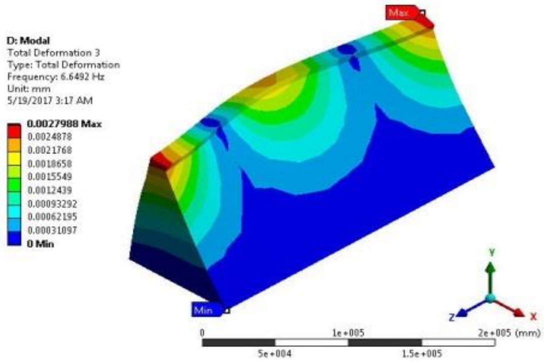
Different Cases	Total Deformation	Equivalent Stress	Normal Stress	Shear Stress	Maximum Principal Stress
Case 1	4.9689 mm	2.1866 MPa	0.43184 MPa	0.32874 MPa	2.5716 MPa
Case 2	4.7853 mm	2.1139 MPa	0.43432 MPa	0.31385 MPa	2.4894 MPa
Case 3	4.9951 mm	3.0315 MPa	0.54894 MPa	1.1209 MPa	2.9884 MPa
Case 4	4.81 mm	2.9632 MPa	0.53289 MPa	1.0964 MPa	2.9461 MPa

3.2 Results of Modal Analysis

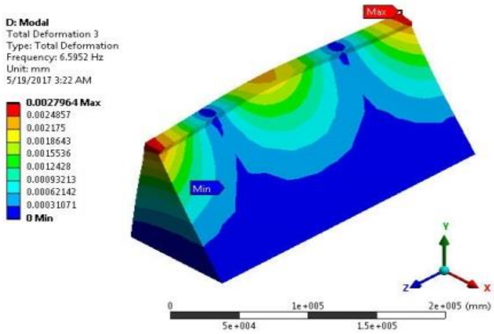
A modal analysis is a technique used to determine the vibration characteristics of structures-a) natural frequencies (At what frequencies the structure would tend to naturally vibrate) b) mode shapes (In what shape the structure would tend to vibrate at each frequency) c) mode participation factors (The amount of mass that participates in a given direction for each mode Most fundamental of all the dynamic analysis types.)

a) Case 1(mode 3)

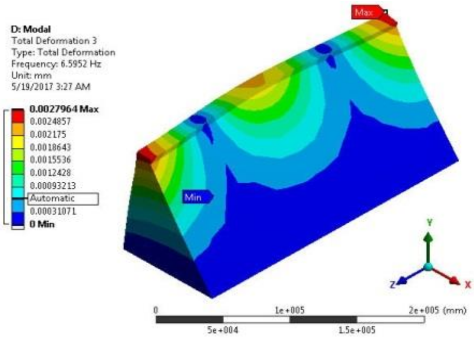




b) Case 2(mode 3)



C) Case 3(mode 3)

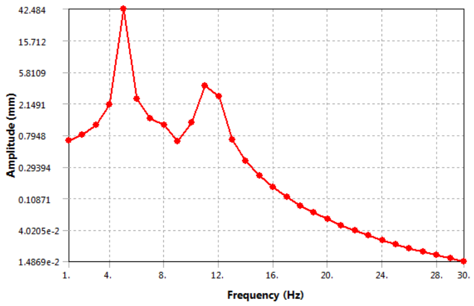


d) Case 4(mode 3)

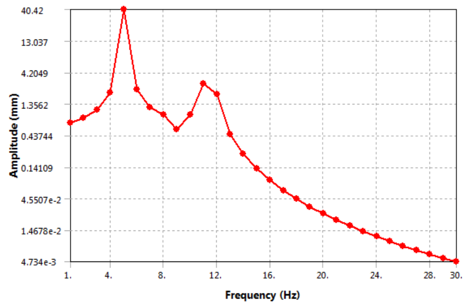
Fig -4: The 3rd Mode shapes for four cases

3.3 Results of Harmonic Response

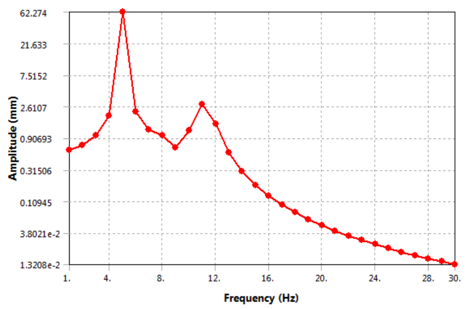
Harmonic response is a technique to determine the steady state response of a structure to sinusoidal (harmonic) loads of known frequency.



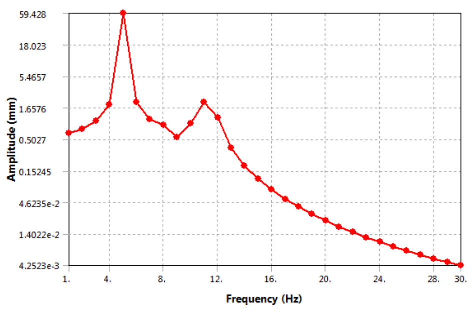
a) Case 1



b) Case 2



c) Case 3

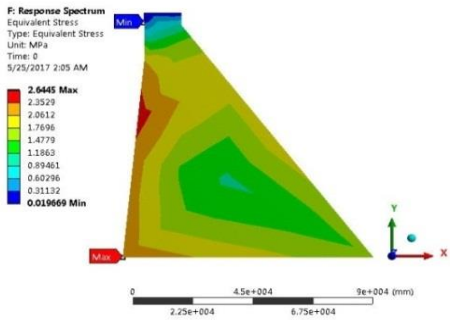


d) Case 4

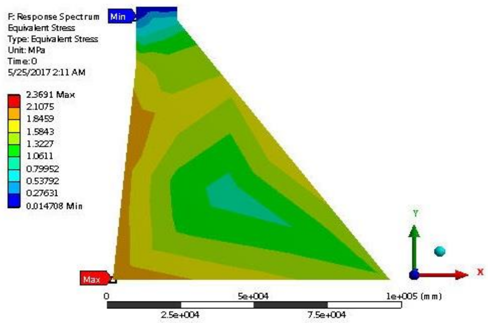
Chart -3: Frequency Response of modes in Y axis

3.4 Result of Response Spectrum

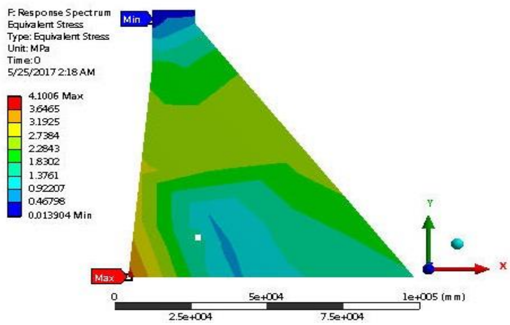
In using the response spectrum method of seismic analysis there are computational advantages for prediction of member forces and displacements in structural systems. The method involves the calculation of only the maximum values of the displacements and member forces in each mode of vibration using smooth design spectra that are the average of several earthquake motions.



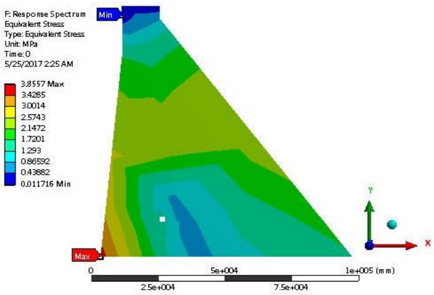
a) Case 1



b) Case 2

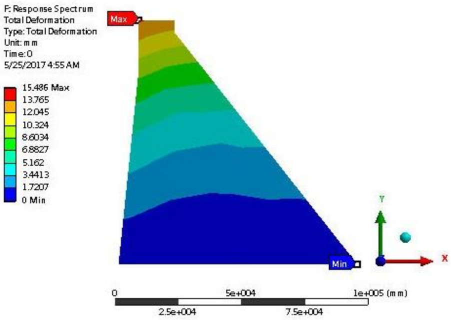


c) Case 3

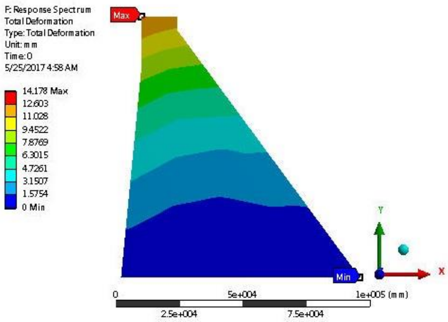


d) Case 4

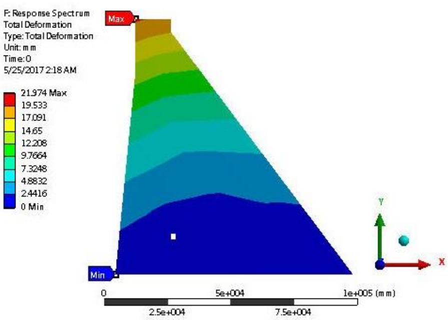
Fig -5: Response Spectrum stresses



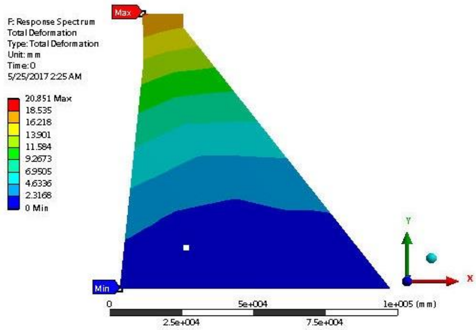
a) Case 1



b) Case 2



c) Case 3



d) Case 4

Fig -6: Deformation due to Response Spectrum

Table -4: Response Spectrum analysis results

Different Cases	Total Deformation	Equivalent Stress	Normal Stress	Shear Stress
Case 1	15.486 mm	2.6445 MPa	0.82557 MPa	1.1526 MPa
Case 2	14.178 mm	2.3691 MPa	0.74712 MPa	1.0261 MPa
Case 3	21.974 mm	4.1006 MPa	1.2634 MPa	1.8447 MPa
Case 4	20.851 mm	3.8557 MPa	1.1924 MPa	1.7117 MPa

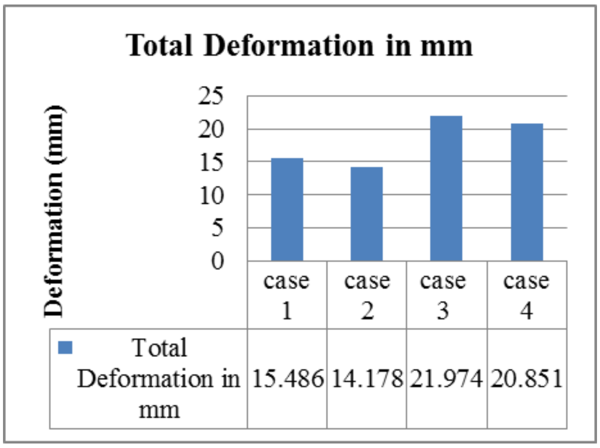


Chart -4: Comparing Maximum Deflections of four cases

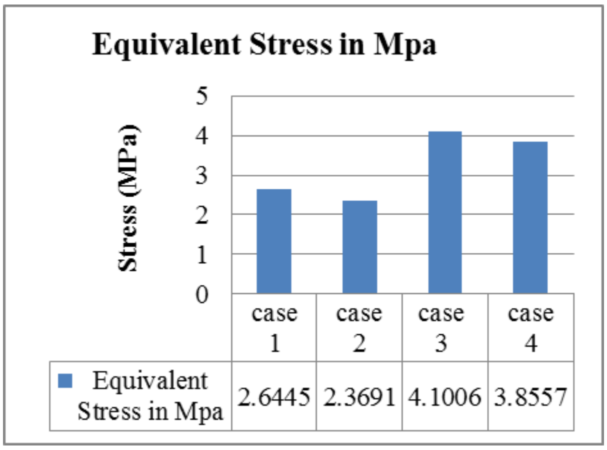


Chart -5: Comparing Maximum Equivalent Stresses of four cases

4. Conclusion

3D analysis of concrete gravity dam is performed using ANSYS software. Based on the findings, the following conclusions can be made.

1. Static Structural Analysis

1. In the static analysis, the maximum stresses are found at heel for case 1 and case 2, but as we introduce opening in case 3 and case 4, the maximum stresses are around the opening.
2. The maximum deformation is obtained at crest along upstream for all four cases.
3. The maximum values of stresses and deformation are observed in case 3(dam with opening in Kabul City).

2. Modal Analysis

1. In the modal analysis, in every mode the maximum deformations are observed at the crest of the dam.
2. In modal analysis are performed for 10 modes, In case 1 and case 2 the values are same for deformation and frequencies and case 3 and case 4 are having same values.
3. We must complete modal analysis for use modal to dynamic analysis in other words; modal analysis is the first step of dynamic analysis.

3. Harmonic Response

1. In harmonic response, the maximum deformation is observed around downstream and upstream section near change in cross-section area.
2. From Fig 6, it is clear that the Harmonic Response (dynamic behavior) of all four cases are same, but the maximum values of amplitude were observed in case 3.

4. Response Spectrum

1. In Response Spectrum case 1 and case 2 are safe in crushing because equivalent stresses are less than 3 MPa.
2. In case 3 and case 4 of Response Spectrum analysis both are not safe in crushing.

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