Spectrum Response Analysis of Concrete Face Rock Fill Dam, Case Study Bakun Dam

Behrouz Gordan[1], Azlan Adnan [2]

1. Civil Engineering Department, Islamic Azad University, Gorgan Branch, Iran

2. Engineering Seismology and Earthquake Engineering Research Group (e-seer), Universiti Technologi Malaysia 81310 Skudai, Johor, Malaysia

Email: bh.gordan@yahoo.com

Abstract

The response spectrum analysis of the Bakun dam on the east of Malaysia is evaluated in this study. The scope of study is based on two macro zone maps with probability exceeding such as 10% (500 years) and 2% (2500years) in 50 years. The response spectrum of the site is provided using ASCE7. In terms of spectrum response analysis, the Finite-Element method is applied using Ansys13 program. Based on the free vibration analysis, it can be concluded that the initial vibration mode was critical with respect to the minimum frequency. The relation between frequency and mode shape was the nonlinear trend. The maximum and minimum displacements were located on the site class (E) and (A) for both directions. This value was doubled in 2500 years in comparing to 500 years. The maximum horizontal and vertical displacements were at the crest and the upper half of upstream and downstream, respectively. The body crack was possible on the slope surface for 500 years based on the relative displacement. Consequently, the data monitoring is necessary in order to control dam.

Keywords: Spectrum, Modal, Displacements, CFRD dam, Crack.

1. INTRODUCTION

The dynamical analysis process was started after some huge damages of the earth dams. Much significant destruction during an earthquake was recorded. As a significant approach, the structural failure is a very critical aspect in the earthen dam. In the case of failure process, the basic role was based on some specific factors such as piping and overflow. Both of them are created by body crack. However, the body crack can be led by relative displacement. Therefore, reduction of the relative displacement in the structure is very important to control body crack. Besides, a construction method in earth dam is the gradual process. Therefore, the static settlement can be created during the consolidation development. Consequently, in order to generate relative displacement during an earthquake, the dynamical settlement can be made. According to the literature, the dynamical settlement is distinguished by experience and engineering opinion [1-3]. However, the prediction of dam behavior under the strong earthquake was necessary in the high seismic zones. The main concern in the design was the security while it was widely accepted that the (CFRD) performance under the earthquake was plastic deformation and settlement, but without a change of slope [4-7]. The concrete face rock-fill dam with additional challenges during an earthquake was designed while the physical face has been just a water stop and not a structural element of the dam's configuration. Therefore, the control of dam behavior is necessary at design stage. To date, the design effort is limited to avoid failure, minimize the crack making to ensure valid behavior of concrete joints. Moreover, materials are taken to avoid of the generate pore water pressures to develop in the dam’s body during and after strong seismic loading [8]. Numerous studies have been attempted to explain some methods in order to evaluate the dynamic deformation range from simple analytical tools regard the three dimensional (3D) numerical models [4, 6, 7 and 8]. In terms of numerical analysis, some case studies were investigated widely. Recently, the numerical analyses are carried out to evaluate the structure (CFRD) during dynamical load [9, 10]. In addition, the dam was safe under the strongest earthquake, while it was well designed and compacted on the rock foundations [11]. In addition, settlement analysis of the Mornos earth dam was carried out with respect to the monitoring data [12]. This paper tried to evaluate the response spectrum analysis of the Bakun dam using ASCE7. In the case of this study, there are two main purposes. Firstly, the structural behavior can be estimated by response spectrum analysis. Secondly, the step by step of the design process can be reviewed using Finite-Element

Method (FEM). It should be noted that, this analysis included two periods such as 500 and 2500 years. Both periods were developed by macro zone maps in the case of 10% and 2% of probability in 50 years ground motions in the east of Malaysia [13].

2. Bakun Dam

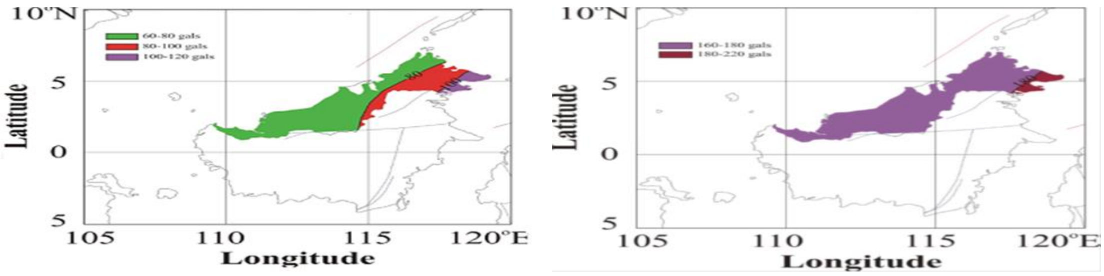
The hydroelectric dam on the river Balui in Belaga district of Sarawak in Malaysia since 1996 until 2011 was built. Respectively, the dam situation and dam perspective show in Figure 1 (a-b). There are some dams in the east of Malaysia. The location dams and stations network show in Figure 1(c). In order to distribute the station, there are two stations in the east of the map. It seems to be that, the stations in this area should increase in regards to the situation of the second highest earth dam that located in this zone.

(a) (b) (c)

Figure 1. a) Situation of Bakun dam (CRFD), b) The dam perspective before reservoir, c) Dams location of national seismological network, 8 dams and 14 stations in Malaysia

3. Peak Ground Acceleration

The peak ground acceleration (PGA) maps in Malaysia are available for two periods such as 500 years and 2500 years (Adnan et al, 2008). However, both macro zone maps for 10% and 2% probability of exceeding (PE) in 50 years ground motions in the east of Malaysia is available. It can be seen in Figure 2. In terms of the hazard level, the previous results indicated that the ground motions across the east Malaysia range between 60-120 (gal) for 10% in 50 years and 160-220 (gal) for 2% in 50 years.



(a) (b)

Figure 2: a) PGA map for 500 years, b) PGA map for 2500 years

4. Response Spectra ASCE

The input data for response spectra analysis is carried out using ASCE 7. It can be driven following below process.

4.1. Seismic ground motion parameters and site class

Both parameters S_S and S_1 are determined from the 0.2 seconds and 1.0 seconds of the spectral response accelerations, respectively. The different site classes are classified based on the soil properties. Therefore, they have categorized [A, B, C, D, E, or F] that introduced strong soil to soft condition. It should be noted that while the soil properties have not known in sufficient detail to determine the site class, site class [D] should be used unless the authority having jurisdiction or Geotechnical data determines site class [E] or [F] soils are present at the site (ASCE7). The site classification presented in Table 1.

Table 1: Site classification

Site Class	v_s	N or N_{ch}	s_u
A. Hard rock	>5,000 ft/s	NA	NA
B. Rock	2,500 to 5,000 ft/s	NA	NA
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the following characteristics: - Plasticity index PI > 20, - Moisture content $w \geq 40\%$, and - Undrained shear strength s_u < 500 psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

4.2. SITE COEFFICIENTS AND ADJUSTED MAXIMUM CONSIDERED EARTHQUAKE (MCE) SPECTRAL RESPONSE ACCELERATION PARAMETERS

The MCE spectral response acceleration for two periods ($S_{M S}$) and (S_{M1}), adjusted for site class effects, shall be determined by equations 1-2, respectively.

$S_{M S} = F_{a*} S_s$ When T=0.2 second (1)

$S_{M1} = F_{v*} S_1$ When T=1.00 second (2)

S_S = the mapped MCE spectral response acceleration at short periods of 0.20 seconds was specified 0.15 and 0.30 for 500-2500 years, respectively [14].

S_1 = the mapped MCE spectral response was acceleration in a period same 1.00 seconds. In case of 500 years or 2500 years (Adnan et al, 2005), this value 0.05 and 0.10 are respectively obtained. It should be noted that, the straight-line interpolation for intermediate values of S_S and S_1 can be used. Besides, two new parameters are shown using equation 3 and 4 in the case of acceleration spectrum curve.

$S_{D S}$ = 2/3* $S_{M S}$ (3)

$S_{D 1}$ = 2/3* $S_{M 1}$ (4)

Besides, both of the site coefficients such as F_a and F_v are driven by Table 2 and Table 3 respectively (ASCE7).

There are two key points at the top of spectrum response curve. These points are driven by both periods in equation 5 and equation 6.

$To = 0.2 * S_{D 1} / S_{D S}$ (5)

$T_s = S_{D 1} / S_{D S}$ (6)

According to equations 1-6, the acceleration spectrum curve is obtained using ASCE 2007. Figure 3 shows this curve.

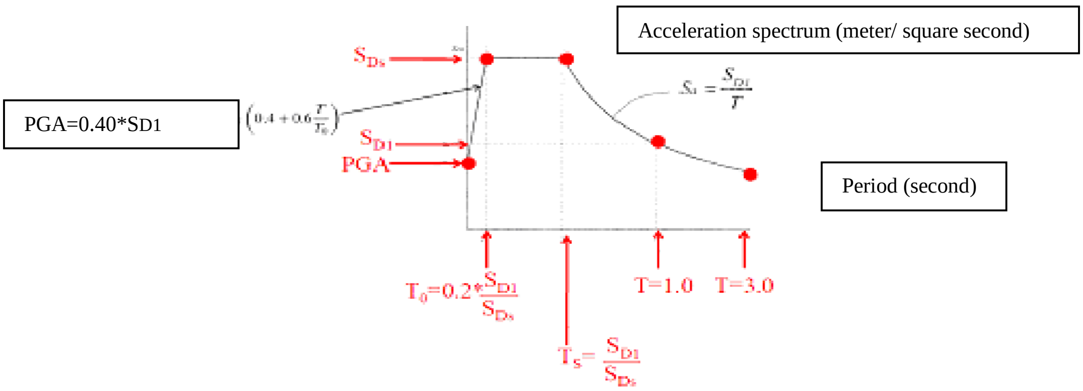


Figure 3: ASCE Acceleration spectrum curve. The period and acceleration spectrum was matched by horizontal and vertical axis

In terms of the response spectrum acceleration in Malaysia, both curves are computed and all factors are shown in tables 4-5.

Table 2: Site Coefficient, (F_a)

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at Short Period (t=0.20 s)				
	S_S = 0.25	S_S = 0.5	S_S = 0.75	S_S = 1.0	S_S = 1.25
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 (ASCE 7criteria)				

Table 3: Site Coefficient, (F_v)

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at Period (t=1.00 s)				
	S_1 = 0.1	S_1= 0.2	S_1= 0.3	S_1= 0.4	S_1=0.5
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7 (ASCE7 criteria)				

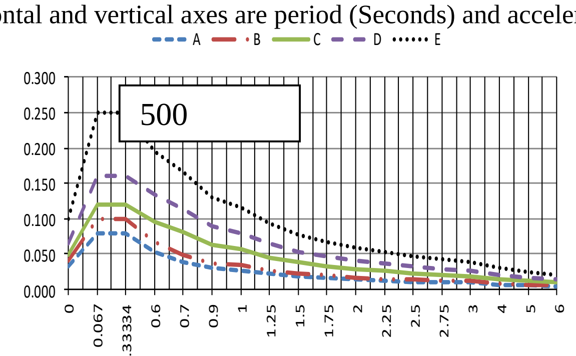
Table 4: The acceleration spectrum factors factors for return period earthquake 500 years 2500 years

500 Years	A	B	C	D	E
(F_v)	0.8	1	1.7	2.4	3.5
(F_a)	0.8	1	1.2	1.6	2.5
SMs	0.12	0.15	0.18	0.24	0.375
SM1	0.04	0.05	0.085	0.12	0.175
SDs	0.08	0.1	0.12	0.16	0.25
SD1	0.02666	0.03333	0.05666	0.08	0.11666
T0	0.06666	0.06666	0.09444	0.1	0.09333
TS	0.33333	0.33333	0.47222	0.5	0.46666

Table 5: The acceleration spectrum for return period earthquake

2500 Years	A	B	C	D	E
(F_v)	0.8	1	1.7	2.4	3.5
(F_a)	0.8	1	1.2	1.56	2.34
SMs	0.24	0.30	0.36	0.46	0.702
SM1	0.08	0.10	0.17	0.24	0.350
SDs	0.16	0.2	0.24	0.31	0.468
SD1	0.05333	0.06666	0.11333	0.16	0.23333
T0	0.06666	0.06666	0.09444	0.10	0.099715
TS	0.33333	0.33333	0.47222	0.51	0.498575

The spectrum acceleration curves for different soils are provided, as can be seen in Figure 4. In the case of measurement unit, the horizontal and vertical axes are period (Seconds) and acceleration (gravity)



2500

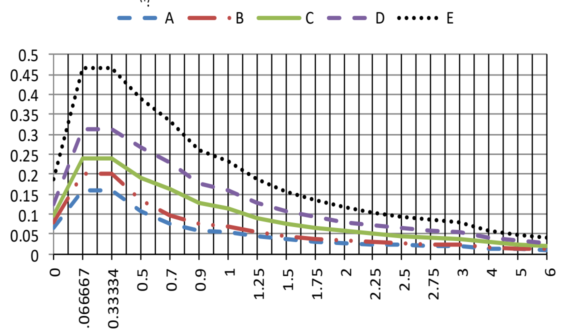


Figure 4. Acceleration spectrum, Vertical axis is acceleration, and horizontal axes is time

5. MODELING PROCESS

The modeling process was carried out following below process. The ANSYS program is based on the Finite - element method. A strong ability to compute the free vibration analysis is possible with respect to use modal analysis. In particular, it is one of the universal programs with high abilities for different analyses like response spectrum.

Moreover, other analysis like time-history is also available. Briefly, the result of free vibration analysis was used for response spectrum in this research.

5.1. ELEMENTS AND BOUNDARY CONDITIONS IN THE MODAL ANALYSIS

In the case of suitable element, solid42 in the model was applied. This element was recommended by help menu for 2D condition. The modal analysis was carried out while the model was coupled on the bedrock. Therefore, the both displacements for bedrock are assigned with zero value in order to effect of the degree of freedom.

5.2. CONFIGURATION, MATERIAL PROPERTIES OF DAM, MESH AND PROCESSING CHART

The dam is 205 meters height with a crest length of approximately 750 meters and tank volume of about 43.8 billion cube meter. To assess the road transport, the width at the crest was 12 meters. The face of rock-fill dam was built by concrete slab instead of riprap on the upstream. The different gradient was in both slopes. The upstream and downstream are located by 1.4H and 1.3H respectively, while 1v was fixed for both. The maximum section of dam with different zones shows in Figure 5. Furthermore, the concrete face with horizontal and vertical contraction joints shows in Figure 5. In terms of the material properties, the relative density and linear properties were used in this study. It is illustrated in Table 6. Based on the linear properties, the elasticity modulus and Poisson ratio for modal analysis and response spectrum analysis were used. Mesh process is possible with two methods such as regular and free based on the programming ability. Regular mesh to access the best interaction effect between different materials was used, as shown in Figure 5. Furthermore, Figure 6 shows the chart process in this study. Three steps are connected such as input data, free vibration analysis, and spectrum analysis.

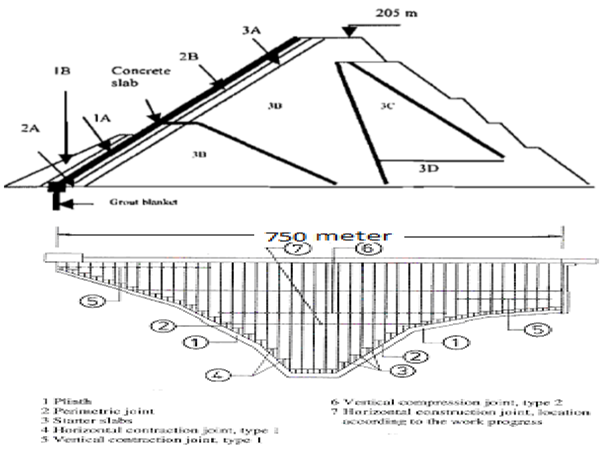
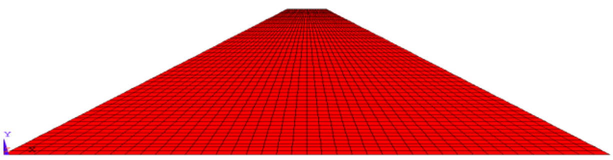


Figure 5: a) The dam section with different zones, b) Upstream face of dam,



c) Meshing

Table 6: Material properties

Zone	Elasticity modulus (Kg / m^2)	Poisson's Ratio	Relative Density (Kg / m^3)
Concrete slab Thickness (0.30m)	3.20E9	0.20	2400
2B-Cushion	3.20E7	0.30	2280
2A-Transition	1.60E9	0.30	2250
2B-Rockfill	1.00E9	0.30	2130
2C-Rockfill	1.00E9	0.30	2060
2D-Rockfill	1.00E9	0.30	2050

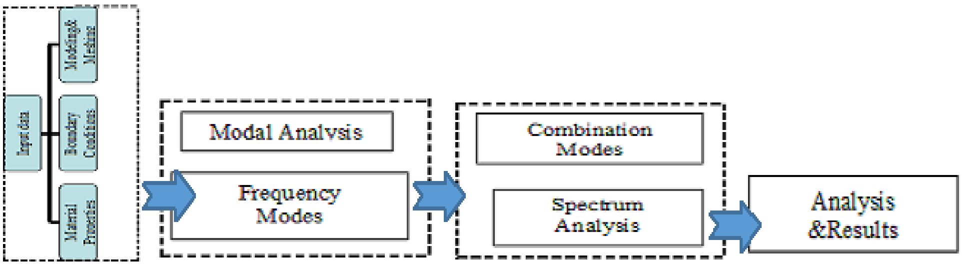


Figure 6. Chart Processing

6. ANALYSIS AND RESULTS

In the case of free vibration modes, the modal analysis was carried out using simulation. Generally, the best computational accuracy of the response spectrum was the main purpose. It was possible according to compute model with more vibration mode. In fact, the combination method is used for spectrum analysis. However, the spectrum analysis depends on the modal analysis in particular. In terms of frequency distribution, twenty vibration modes were collected as presented in Table 7.

Table 7: Frequency in twenty mode shapes of dam

Mode	Frequency	Mode	Frequency	Mode	Frequency	Mode	Frequency
1	1.222	6	3.233	11	4.775	16	5.691
2	1.823	7	3.563	12	4.961	17	5.810
3	2.152	8	3.816	13	5.051	18	6.275
4	2.658	9	4.251	14	5.464	19	6.571
5	3.182	10	4.439	15	5.661	20	6.648

The frequency trend indicated the incremental behavior when the vibration mode was increased. However, the relation between period and frequency is the reverse performance (See Equation 7). In the case of measurement unit, period is seconds and frequency is hertz.

$$T = 1 / f \qquad (7)$$

In terms of dam behavior in different vibration modes, ten vibration modes are shown in Figure 7. It can be seen that; deformation is different for each mode. Besides, displacement in both directions and frequency are shown in the above on the left side in each mode. In fact, the maximum period is obtained in the first vibration mode with respect to the minimum frequency. Therefore, frequency was dominant in the first vibration mode.

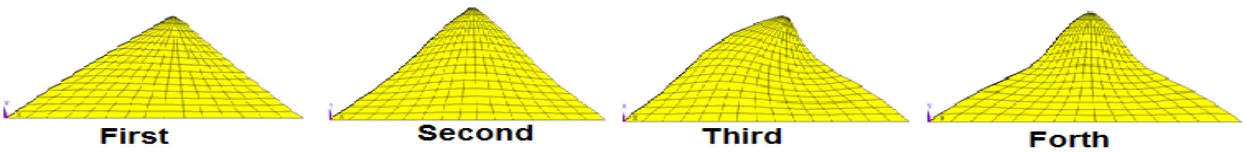


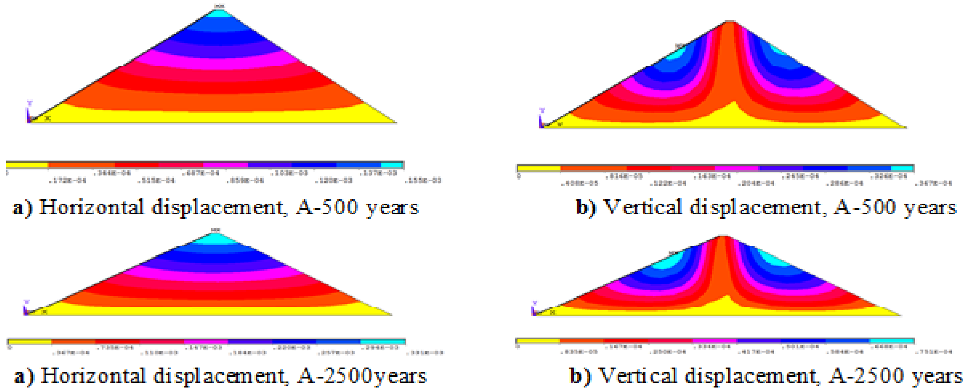
Figure 7: Different vibration modes

In addition, the frequency is expressed by equation 8 when the regression was at a high level of accuracy equal 0.997.

$$y = 1.21\ x^{0.565} \quad (8)$$

The response spectrum analysis was carried out after collection results from modal analysis, as discussed. This analysis depends on frequency as distributed in different modes.

The Spectrum analysis was computed by the combination method with high level of accuracy. The input data were applied according to the response acceleration curves that shown in Figures 7-8. However, the square root sum of squares (SRSS) method in order to combine external data from modal analysis was used. This method is one of the full applicable approaches regarding program ability (ANSYS13). As a result, displacements in both periods such as 500 years and 2500 years are shown in Figures 8 for site class A. As shown, dam displacement illustrated in both directions. However, the horizontal displacement was maximized at the crest while it was the minimum value for bedrock. In addition, this value is increased while the site condition focuses on the soft soil. Furthermore, the peak level of vertical displacement is at both slopes while it is minimized in the bedrock. As a significant result, both displacements are decreased in this area. It means that the soil amplification was carried out. Besides, maximum vertical displacement occurred in the upper half of the gradient. Moreover, the maximum horizontal and vertical displacement show in Table 8. It was found that, the horizontal displacement is more than vertical displacement, significantly.



a) Horizontal displacement, A-500 years

b) Vertical displacement, A-500 years

a) Horizontal displacement, A-2500years

b) Vertical displacement, A-2500 years

Figure 8. Distribution of displacements in different site class for 500 years returns earthquake period

Table 8: Maximum displacements in site classes (A to E) for 500 to 2500 years, measurement unit is meter.

Horizontal	**500 years**	**2500 years**	**Vertical**	**500 years**	**2500 years**
A	1.55E-04	3.31E-04	A	3.67E-05	7.51E-05
B	2.06E-04	4.12E-04	B	4.66E-05	9.36E-05
C	3.50E-04	7.02E-04	C	7.92E-05	1.59E-04
D	4.95E-04	9.90E-04	D	1.12E-04	2.25E-04
E	7.21E-04	1.44E-03	E	1.63E-04	3.28E-04

The distribution of displacement is shown in Figure 9 and Figure 10 in order to effect of the site classes (A- E). Both displacements were located more than quadruple on soft soil in comparison hard soil. The displacement ratio between both periods such as 500 and 2500 years was demonstrated double. Consequently, body cracks will be available by more probabilities due to the relative vertical displacements for 500 years. However, spectrum analysis is the prediction of dynamic behavior based on the linear method. On the other hand, one of the main concerns of the dam is the optimal utilization. It seems to be that; the installation of monitoring equipment is very useful suggestion to control dam. Finally, this project shows the design process, as can be used in the same structures step by step based on the response spectrum analysis.

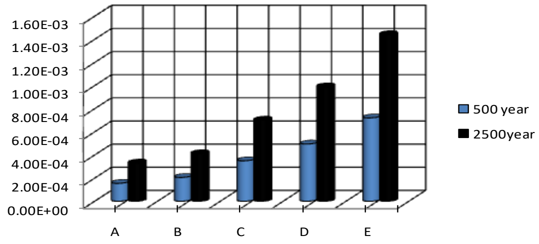


Figure 9. Maximum horizontal displacement

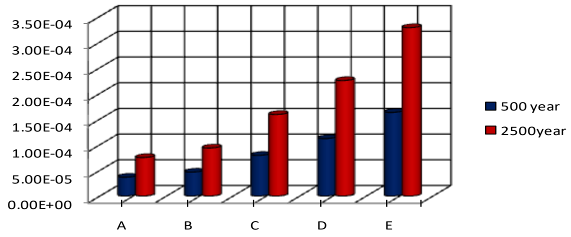


Figure 10: Maximum vertical displacement

7. CONCLUSIONS

The response spectrum analysis of the CFRD dam (Bakun dam) case study was carried out using the Finite-Element method in the present study. According to the modal analysis, the dominant frequency was in the first vibration mode with minimum values. Frequency is increased with non- linear equation in different vibration modes. In terms of response spectrum analysis, horizontal displacement was maximum and minimum at the crest and bedrock, respectively. The peak of vertical displacement was at both slopes while in the bedrock was reduced significantly. In fact, the high rigidity in the case of the displacement reduction was observed in bedrock. Besides, the maximum vertical displacement was featured on the upper half of gradient surface. Both displacements were located more than quadruple on soft soil in comparison hard soil. The displacement ratio between both periods like 500 years and 2500 years, according to 10% and 2% probability of exceeding (PE) in 50 years was demonstrated double. The body crack was possible on the slope surface for 500 years with respect to assessment of the relative displacement. Consequently, the installation of monitoring equipment is very useful suggestion in the case of dam controlling.

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