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Dynamic Analysis of Concrete Faced Rockfill Dam Using Finite Element Method

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Abstract: This study reports a brief study on linear dynamic analysis of Bakun Concrete Faced Rock fill Dam (CFRD). The analysis was conducted in order to determine the performance and behavior of the dam under seismic excitation. The dam was modeled as two-dimensional and developed based on the design drawing that is obtained from Sarawak Hydro Sdn. Bhd. The dynamic analysis of the dam is conducted using finite element analysis software package LUSAS 14.0 and the dam has been analyze as a plain stress problem with a linear consideration. A set of historic data, with Peak Ground Acceleration (PGA) of about 0.50 g is used as an earthquake excitation. The natural frequency and mode shape up to fifth mode of the dam has been obtained from the analysis to show the differences of the stress and deformation between each mode. The maximum horizontal and vertical stress of the Bakun dam was found and the distribution of them was discussed in form of contours. The deformation of the dam were also been discussed by comparing the maximum displacement for each mode shaped.

Key words: Dynamic analysis, finite element method, earthquake performance, dams, structural dynamics

INTRODUCTION

Dam is a structure that acts as a barrier to hold water or retain the water. In general, dam has been built since many years ago and there are >45000 dams around the world. One of the countries that have lots of dam structure is China with over 22000 of large dams. Most of the dams were built for the irrigation purposes and almost all the large dams were used to produce electricity. There are many dams purpose other than produce electricity such as flood control, supply water to the cities and river navigation. There are also dams that are built to serve multipurpose providing two or more benefits at once. The Bakun Dam main civil work was originally started around 2002 by Malaysia-China Hydro Joint Venture (MCHJV) and there are about 3000 of workforce at the site during the peak of the construction period. There are experts, engineers, specialist and consultants worldwide are involved in this mega-project. Bakun Dam is 205 m high with a length of crest of 750 m, a base width of 573 m, a crest width of 12 m and the volume of fill is about 16.71 mm^3. The reservoir surface area of the Bakun Dam is nearly 70000 ha equivalent to the size of Singapore. The finite element method is an approximate analysis technique which basically consists of dividing a structure into a number of parts called elements (Norshariza and Mohamad, 2005). Lee *et al.* (2015) and Taghizadeh *et al.* (2015) also adopted finite element method to study the performance of their structure as well. Each node may have one or more degree of freedom which is defined as independent displacements used to describe the movement of each node. The number and type of elements should be selected so that the deformed shaped of the structure can be effectively represented. Deformations within the elements are assumed to follow predefined functions known as shape functions. The finite element method is the best method used in analyzing the internal forces of elements by solving differential equation obtained through their discretization in space dimensions (Adedeji, 2008). Norshariza and Mohamad (2005) stated that the finite element method is an approximate analysis technique which basically consists of dividing a structure into a number of parts called elements. Each node may have one or more degree of freedom which is defined as independent displacements used to describe the movement of each node. The number and type of elements should be selected so that the deformed shaped of the structure can be effectively represented. Deformations within the elements are assumed to follow predefined functions known as shape functions. Bathe (1996) claimed that finite element method is a numerical method that can be used to solve different kinds of engineering problem in the stable, transient, linear or non-linear cases. De Salvo and Swanson stated that by using the programs with interactive graphical facilities, it is possible to generate

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finite element models of complex structures with considerable ease and to obtain the results in a convenient, readily assimilated form.

Many researcher stated that earthquake or seismic loads are the major dynamic loads being considered in the analysis and design of dams especially in earthquake prone areas. They are of kinematic origin and owe their existence to vibration caused in the structure by the movement of the earth's surface during an earthquake. They have random characteristics and are regarded as deterministic in practical calculations to simplify the design model (Major, 1980; Seed, 1981; Alembagheri, 2016). Parish and Abadi (2009) shows the deformation of the dam by applying dynamic loading at the base of the foundation layer as a velocity excitation.

MATERIALS AND METHODS

Research background: This study involved the modeling of concrete faced rockfill Bakun Dam located in Sarawak, Malaysia on the Balui River. The study comprised of several tasks in finite element modeling and involves a modeling technique for dynamic analysis using a computer program. This research starts with obtaining and understanding the literature review concerned with the related research topic followed by collection of the dam data, understanding the finite element using LUSAS 14.0, building and analyse a model by developing a two dimensions finite element model with the LUSAS 14.0 and finally obtains the result and conclusion based on the analysis. Rock-fill dams are embankments of compacted free-draining granular earth with an impervious zone. To prevent internal erosion of clay into the rock fill due to seepage forces, the core is separated using a filter. Chin (2004) stated that Concrete Faced Rock Fill Dam (CRFD) is a good permeability of dam, even if the leakage become large the dam would not easily collapse. CFRD has a wide base and imposed lower stresses on the ground compared to concrete dams for similar in height. Their fill is plastic and can accommodate deformations such as settlement. CFRD structures are considered safer compared with the concrete dam especially in seismic area.

Bakun dam is one of the rock fill type in Malaysia. It is over 205 m high making it the second tallest Concrete Faced Rock Fill Dam (CRFD) in the world. The Bakun dam is still in the ongoing process and it is estimated to complete around the year of 2010. It is located in Sarawak, Malaysia on the Balui River and expected to generate 2400 MW of electricity once completed. Figure 1 shows the location of Bakun Dam in Sarawak.

The Bakun Dam main civil work was originally started around 2002 by Malaysia-China Hydro Joint Venture (MCHJV) and there are about 3000 of workforce at the site during the peak of the construction period. There are experts, engineers, specialists and consultants worldwide are involved in this mega-project. Bakun Dam is 205 m high with a length of crest of 750 m, a base width of 573 m, a crest width of 12 m and the volume of fill is about 16.71 mm^3. The reservoir surface area of the Bakun Dam is nearly 70000 ha equivalent to the size of Singapore. The purpose of the Bakun Dam is to generated electricity and supplies it around the Malaysia. However, most of the supplies were said will be supplied to the Peninsular Malaysia and not East Malaysia where the dam is located.

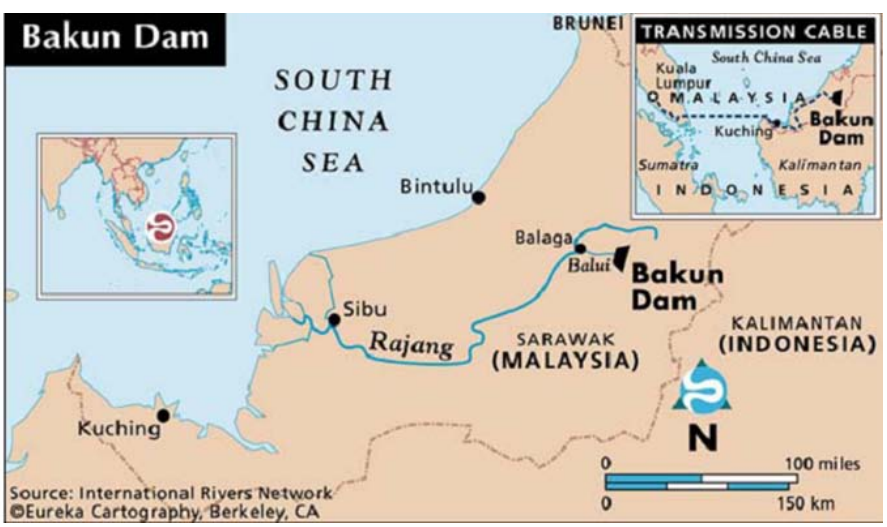

Fig. 1: Bakun dam located on the Balui River at Sarawak, East Malaysia

RESULTS AND DISCUSSION

Modal analysis: The main dynamic analysis is performed by using a modal approach or analysis due to the weight of the dam and the horizontal component of the ground motion. The seismic excitation that has been used in the analysis is obtained from the El-centro time history data and presented in Fig. 2. The original data of an earthquake motion recorded from PEER, 1998 is the El-Centro Earthquake in Imperial building. The earthquake happened in 1940 with the magnitude 7.1 of the Richter scale and ground acceleration 0.35 g with respectively rock soil profile for the geology site specific. The time history data consist of 2829 points with 5658 of total time duration for 0.02s of time step (Seed, 1981). The result obtained from the Modal analysis is the natural frequency and the mode shape of the Bakun Dam under certain seismic excitation or loading. There is no limitation to the mode shape of the dam but in this study, there are only five different mode shapes of the dam is presented with different natural frequency each. The purpose is just to show the dam deformation under the seismic excitation. The natural frequency of the first five modal shapes is presented in Table 1.

It is noticed that there is only a slightly difference in the natural frequency for each mode. This will makes the mode shape or the deformation of the dam change too little for each frequency and will be difficult to see the comparison between each shape.

Deformation analysis: The deformation level for each dam occurs due to the assignation of the dynamic loading during the analysis. It can be seen that the deformation of dam are significantly to the horizontal direction with difference displacement each. Figure 3 shows the maximum displacement due to seismic excitation.

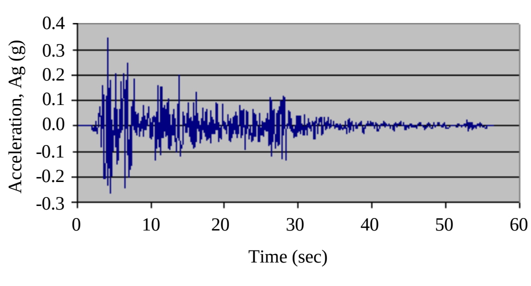

Fig. 2: El-centro time history analysis (Ismail, 2009)

Table 1: Natural frequency of dam

No. of mode shape	Natural frequency (hz)
1	5.56946
2	7.15231
3	9.26785
4	10.0336
5	11.5452

The maximum displacement for each mode shape has been shown in Table 2. The deformation level for each dam occurs due to the assignation of the dynamic loading during the analysis. It can be seen that the deformation of the dam are significantly to the horizontal direction with difference displacement each. Figure shows the maximum displacement due to seismic excitation. Figure 3 shows mode shape 5 with 1.37 mm maximum displacement.

Stress analysis: The dynamic analysis shows the stress in the dam structures when subjected to the dynamic loading. The purpose of this stress analysis is to determine whether the dam can safely withstand the specified forces. Table 3 shows the normal stress and shear stress of the dam due to the seismic excitation. The stress of the dam is shown in contours in order to visualize the distribution of the stress.

Figure 4-7 shows the normal and shear stress contours for mode shape 1 and 5, respectively. Figure 4 shows the maximum stress about 114.83 kN/m^2 at node 1293 and -90.42 kN/m^2 of minimum stress at node 638 under dynamic loading. 617.98 kN/m^2 of maximum stress at node 1293 and -483.95 kN/m^2 at node 1059 was shown in Fig. 5.

Figure 6 shows the maximum stress about 86.28 kN/m^2 at node 708 and -75.19 kN/m^2 of minimum

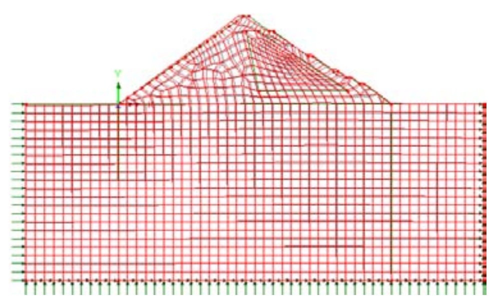

Fig. 3: Mode shape 5 (max. displacement = 1.37 mm)

Table 2: Maximum displacement of dam

No. of mode shape	Displacement (mm)
1	0.26
2	0.31
3	0.88
4	0.56
5	1.37

Table 3: Maximum normal stress and shear stress of dam

No. of mode shape	Normal stress (kN/m^2)	Shear stress (kN/m^2)
1	114.83	86.28
2	145.86	109.82
3	345.36	208.53
4	427.67	293.99
5	617.98	468.42

node 1085 under dynamic loading. 468.42 kN/m^2 of maximum stress at node 691 and -489.50 kN/m^2 at node 1086 was shown in Fig. 7. It is noticed that for each mode shape there are different in the maximum and minimum stress. It is due to the variable of the time history data which is the acceleration of the earthquake. The maximum stresses obtained from the analysis need to be compared with the material allowable capacity in order to determine whether the stress exerted on the dam can withstand the seismic loading. The stress allowable capacity of the greywacke stone was around 1040 KN/m^2 as shown in Table 4. It can be seen that the normal stress and shear stress exerted by the dam does not exceeded the allowable capacity of the material.

Table 4: Allowable capacity

Parameters	Values
Normal stress (maximum)	617.98 KN/m^2
Shear stress (maximum)	468.42 KN/m^2
Allowable apacity	1040 KN/m^2

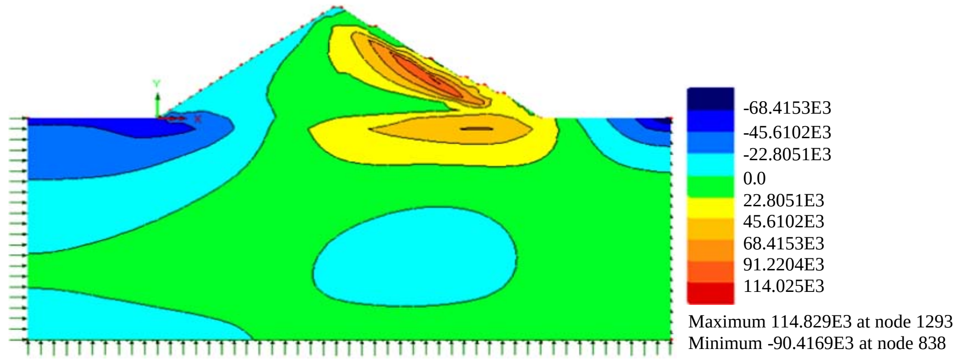

Fig. 4: Mode shape 1 (Normal stress = 114.83 kN/m^2)

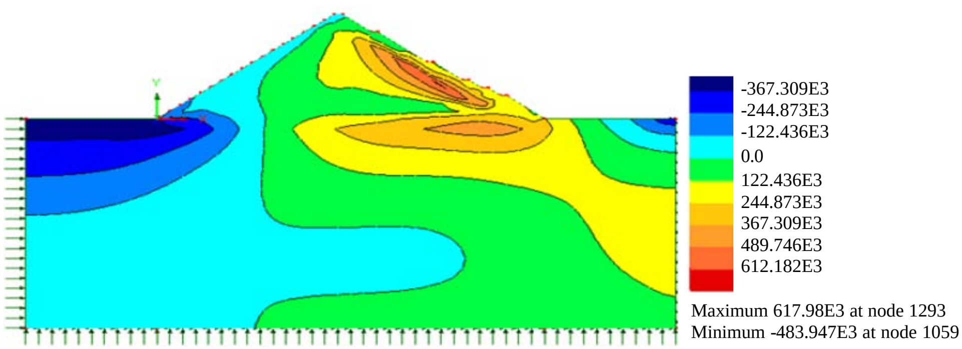

Fig. 5: Mode Shape 5 (Normal stress = 345.36 kN/m^2)

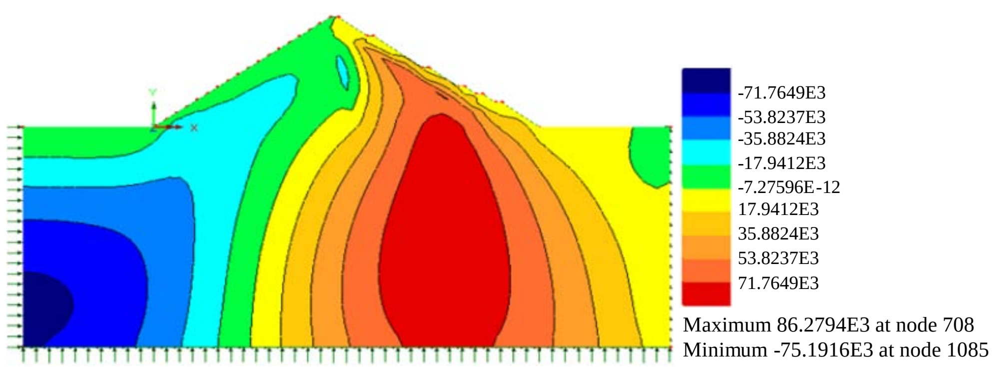

Fig. 6: Mode Shape 1 (Shear stress = 86.28 kN/m^2)

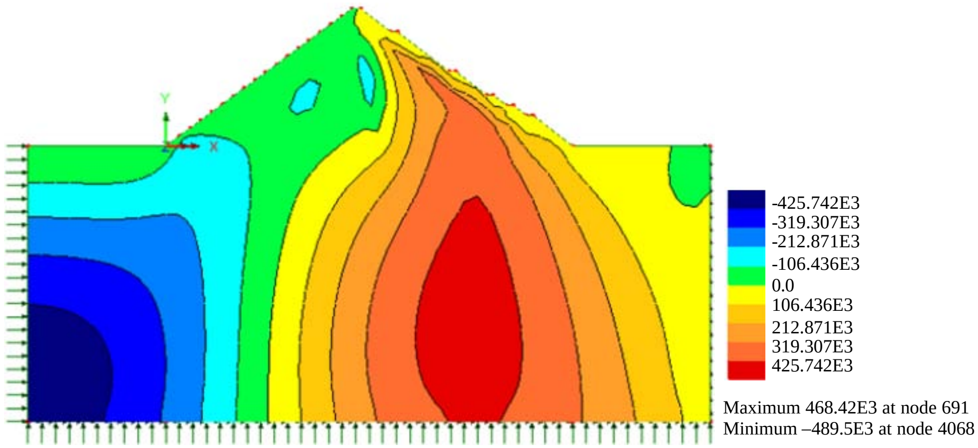

Fig. 7: Mode Shape 5 (Shear stress = 468.42 kN/m^2)

CONCLUSION

An earthquake analysis of concrete faced rock fill dams which is referred to as modal analysis and stress analysis has been used in order to find the performance and the behavior of the dam. The method has been described previously and the procedure is implemented in a computer program LUSAS 14. The analysis of the concrete faced rock fill dam which is Bakun Dam is considered as linear dynamic analysis and is carried out by utilizing 5 modes of shape for the dam. Based on the dynamic analysis the performance of the dam can be considered as a satisfactory result due to the acceptable maximum displacement value which is 1.37 mm in the mode shape 5. The stress behavior of the dam was also satisfactorily acceptable because the dam normal and shear stress which is 617.98 and 468.42 kN/m^2, respectively does not exceed the allowable stress capacity which is 1040 kN/m^2. The result obtained from the linear dynamic analysis conducted in this project was also shown that the LUSAS 14 Software was capable in analyzing the seismic response.

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