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# Application of dominant frequency for nonlinear dynamic analysis of embankment during an earthquake

**Behrouz Gordan, Azlan Adnan**

***Abstract*— In terms of embankment analysis, huge damages were reported in embankments under strong earthquakes. Due to nonlinear dynamic analysis of embankment during an earthquake, one of the main factors is dominant frequency. Based on technology development using finite element programs, numerical methods were used to assess frequency. The aim of this study is evaluation of dominant frequency in the embankment for different situations such as configuration and soil properties. For this purpose, Ansys13 program based on Finite-Element Method (FEM) was applied to compute dominant frequency using modal analysis. Response spectrum analysis and nonlinear analysis are belonging to the dominant frequency. This paper presents two main purposes. Both effects such material property and dam configuration on dominant frequency were investigated in this study. The amplitude of dam height was in the range of 30 meter to 90 meter. As a result, dominant frequency curve were plotted for different condition to use. They were very applicable for spectrum analysis and computing the Rayleigh damping coefficient in terms of nonlinear dynamic analysis. Consequently, the low impact was found on dominant frequency by using both parameters such as different slopes and Poisson's ratio. The major effects were subjected to structural height, elasticity modulus, and relative density, respectively**

***Index Terms*— Modal analysis, Dominate frequency, Embankment, Soil properties.**

## I. Introduction

Dynamic behavior of embankment indicated that, destructive damage was observed during the strong earthquake. In this category, some types of damage were reported such as body cracks, piping within dam body, and overflow phenomenon. Significantly, the failure process is possible after overflow. However, the dynamic analysis of embankment was begun after losing dam in some cases. In this context, the assessment of dominant frequency (DF) is one of the basic data that required for different purposes. In terms of frequency application for linear analysis, different vibration modes were required for response spectrum analysis. In addition, it was very important factor to access Rayleigh damping coefficient in terms of dam analysis regarding nonlinear method. Finally, the control of resonance phenomena through the initial phase of design process is possible using dominant frequency. In the case of dynamic analysis, literature review indicated that, the 'Pseudo-static method' was applied between 1920 to 1960. This method was very simple, without computing both effects such as slope deformation and soil properties of the foundation. However, the sliding block method was applied based on deformation characteristics [1]. With especial respect to other methods, 'Shear beam model' was popular method [2]. After that, the inhomogeneous shear beam model was evaluated [3]. It was observed that, the shear modulus of the earth dams and rock fill dams was variable factor so increased with 2/3 power of depth from the crest. The finite-element method for two-dimensional analysis was carried out to estimate dynamic response of the embankment [4]. They have assumed that, this behavior consisted of linearly elastic, homogeneous and isotropic materials. In general, quick development of computer programs is a good advantage to access the useful data in the earthquake engineering research. Finite-Element Method (FEM) and Finite-Difference Method (FDM) developed by academician researchers, as can be much appreciated. They were successful in order to investigate some aspects such as nonlinear, inelastic, non-homogeneous, and anisotropic behavior of materials under seismic loads. The dynamic analysis of earthen dam with respect to distribute frequency was compared for both conditions such as two-dimensional and three-dimensional [5]. A motion characteristic of the compacted earth dam under small earthquake excitation was represented [6]. Two methods were presented to evaluate the dominant frequency in the dam, such as RFRS and RRS. Y. The dynamic behavior of the earth dam for different material stiffness was performed using FLAC 3D and "equivalent linear" method to obtain the dominant frequency [7]. The effect of core on dynamic response of earth dam during earthquake was studied to obtain the relationship between the first natural frequency and seepage phase [8]. In short, literature review indicated that, the maximum displacement during dynamic loading was found at the crest. Interaction between structure and foundation was a very important factor to deform dam body during earthquake. It is worth noting that, the first vibration mode shape was very effective to distribute displacement using response spectrum analysis regarding linear method. For nonlinear analysis, the control of resonance is one of the main concerns. This is possible using dominant frequency. Dominant frequency is one of the basic factors in order to compute Rayleigh damping coefficient for time history analysis. The aim of this study is focused on the computing of dominant frequency in the embankment, for designing in the first phase according to some applications that mentioned earlier. As a scope of study, based on different physical property of the soil, some parameters were used such as relative density, elasticity modulus, and Poisson's ratio. In

**Behrouz Gordan:** The Head of Civil Engineering Faculty, Science and Culture University of Iran, Hamedan branch Tel: 00989354520278

**Azlan Adnan:** The Head of Engineering Seismology and Earthquake Engineering Research Group (e-seer), Universiti Technologi Malaysia 81310 Skudai, Johor, Malaysia

addition, the amplitude of dam height was between 30-90 meters in this study.

## II. MODELING PROCESS

The modeling process consisted of some subdivision such as introducing program, elements, boundary conditions, mesh, and material properties. They are explained in details below.

### *A. Introduce Software*

ANSYS is one of the comprehensive programs in engineering applications. This program was produced using Finite- element method. A strong ability to compute free vibration analysis is possible. In particular, this software is one of the universal programs with high abilities with respect to different analyses. Not only modal analysis but also other analysis such as response spectrum and transient analysis are available [9]. Therefore, this program is widely utilized in the different academic centers of the world.

### *B. Elements and Boundary conditions*

In order to use element for numerical analysis, Solid 42 was used for dam body. In addition, this element was suggested by HELP menu. In terms of the boundary conditions, dam was coupled on the bedrock. Therefore, displacements were used zero for both direction of the bedrock. For free vibration analysis, It was the main assumption for degree of freedom [10].

### *C. Parameters of models, soil property, and mesh*

Table 1 shows the parametric dimensional of models.

**Table.1:** Amplitude of the model dimension

| | | |
|---|---|---|
| H=30-90 m | w = 5.00 m | $\alpha = 30^\circ$, $\alpha = 35^\circ$, $\alpha = 40^\circ$, $\alpha = 45^\circ$ |

The amplitude of height for simulated embankments was between 30 to 90 meters. The crest wide five meters was used based on minimum space for compaction performance. The effect of different gradients on distribution of the dominant frequency was evaluated using four slopes. Figure 1 shows the parametric dimension in simulated models. In addition, simulated models were coupled by rigid foundation (bedrock) with plane strain (2D analysis)

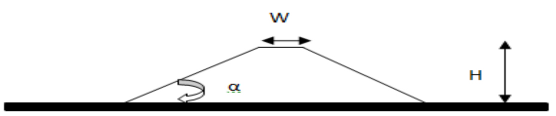



**Fig.1:** A parametric dimensional of models

Six models were analyzed to evaluate two functions such as relative density and material properties (elasticity modulus and Poisson's ratio). The first function was carried out using models 1 to 4 with different value of relative density while the linear properties were constant in order to identify the effect of mass on the dominate frequency. In addition, Poisson ratio in model 5 was bigger than other models. Furthermore, model 6 indicates the effect of elasticity modulus on dominant frequency, based on comparison between model 6 and model 4. Soil properties were utilized [11] with respect to parametric study. It should be noted that, the measurement unit was kilogram over the cube meter for relative density and kilogram over the square meter for elasticity modulus. In addition, all models were simulated using different slopes (30, 35, 40, and 45 degree), as presented in the Table 1. Hence, the effect of embankment slopes on the distribution of dominate frequency was studied. Table 2 shows soil properties, which was used in this study.

**Table.2:** Material Properties

| Models | Relative Density | Elasticity Modulus | Poisson Ratio |
|---|---|---|---|
| Model1 | 1700 | 1 E 6 | 0.30 |
| Model2 | 1800 | 1 E 6 | 0.30 |
| Model3 | 1900 | 1 E 6 | 0.30 |
| Model4 | 2000 | 1 E 6 | 0.30 |
| Model5 | 2000 | 1 E 6 | 0.45 |
| Model6 | 2000 | 0.5 E 6 | 0.30 |

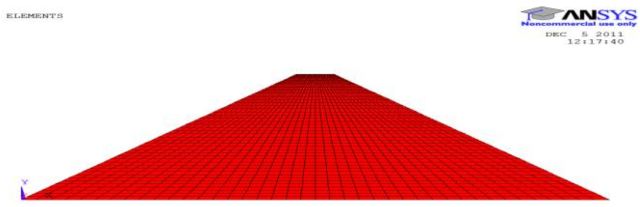
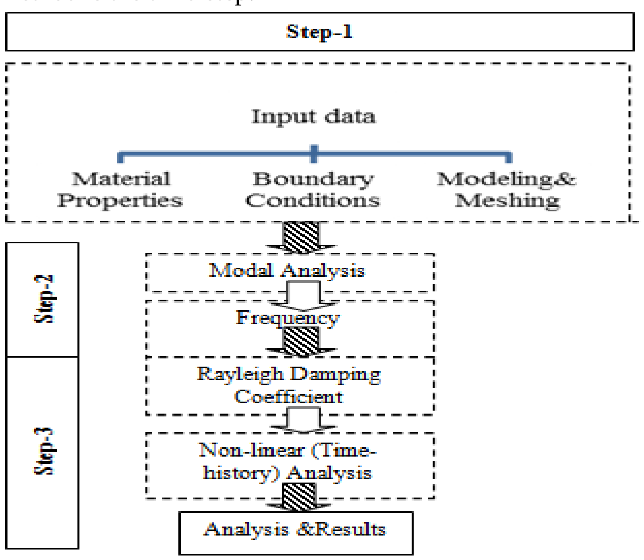



**Fig.2:** The regular mesh of the model with 30 m height and $\alpha = 40^\circ$

In the case of the high level of accuracy as explained previously, Figure 2 shows the regular mesh that was used in this study.

### *D. Flow chart of data collection for dynamic analysis*

Figure 3 shows the flow chart of data collection for nonlinear dynamic analysis. As shown in this figure, the first step is input data. After that, free vibration analysis is the second step. Finally, nonlinear analysis using time history method is the third step.




**Figu.3:** Flow Chart processing of nonlinear dynamic analysis using Time –history method

## III. RESULTS ANALYSIS

Based on results in this study, the frequency was minimum value in the first vibration mode. In addition, the increase of structural height led to smaller period. However, the dominate frequency was reduced. Based on the compared results in models 1 to 4, the amplitude of dominant frequency was very small. This value was slowly reduced when dam height was more than 30 meter and less than 70 meters. The mass effect was insignificant factor when dam height was more than 80 meters. In fact, the increase of mass with respect to similar stiffness led to the slow reduction of the frequency when the structural height was less than 70 meters.

It is also revealed that, the decrease of modulus elasticity led to the increase period value, significantly. In addition, the smallest effect on the frequency was exposed using different slopes. This behavior was found in all models. However, it was insignificant for model height more than 80 meters. Figures 4 (a to g) show the distribution of dominant frequency in different height in terms of some effects such as slope, mass, and modulus elasticity.

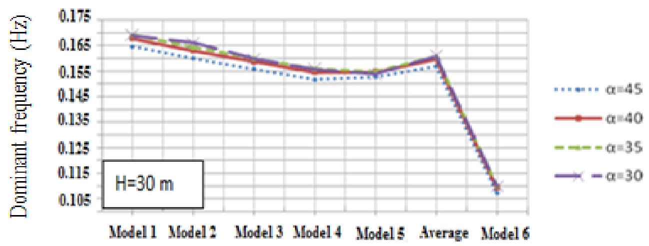



**Fig.4-a:** Dominant frequency of the first mode for H=30m in models with different slope

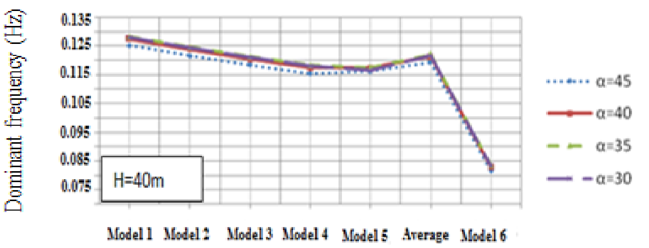



**Fig.4-b:** Dominant frequency of the first mode for H=40m in models with different slope

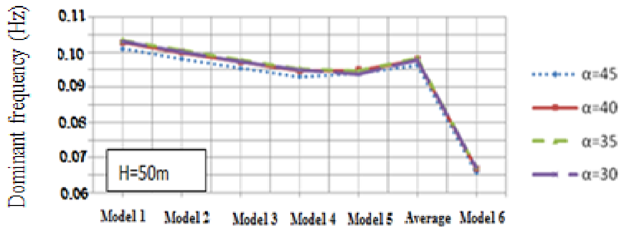



**Fig.4-c:** Dominant frequency of the first mode for H=50m in models with different slop

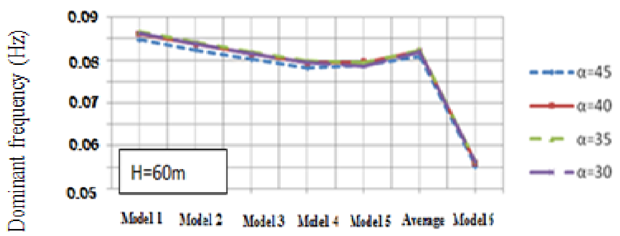



**Fig.4-d:** Dominant frequency of the first mode for H=60m in models with different slope

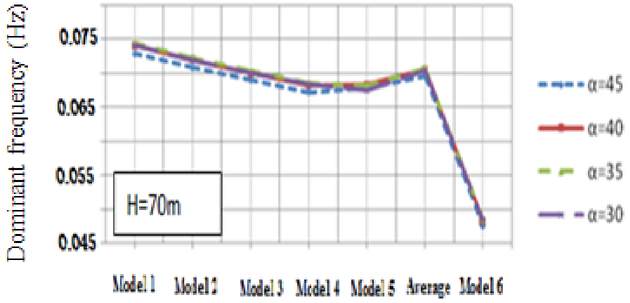



**Fig.4-e:** Dominant frequency of the first mode for H=70m in models with different slope

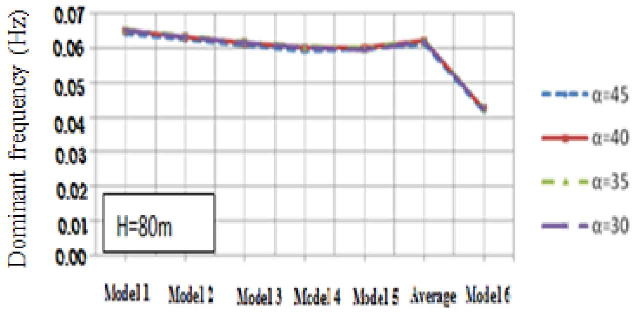



**Fig.4-f:** Dominant frequency of the first mode for H=80m in models with different slope

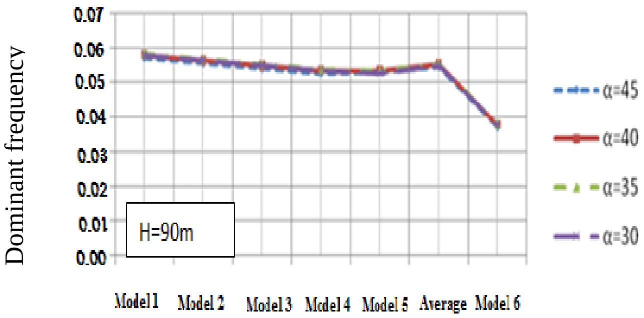



**Fig.4-g:** Dominant frequency of the first mode for H=90m in models with different slope

Furthermore, the comparison of the results between models 4 and 5 shows that, the insignificant effect on dominate frequency was observed for different Poisson's ratios. However, the major effect was related to the elasticity modulus. Figure 5 shows the relationship between the height of the embankment and dominant frequency. In this case, logarithmic formula was extracted with regression 0.998. In addition, Figure 6 shows the same situation for model 6.

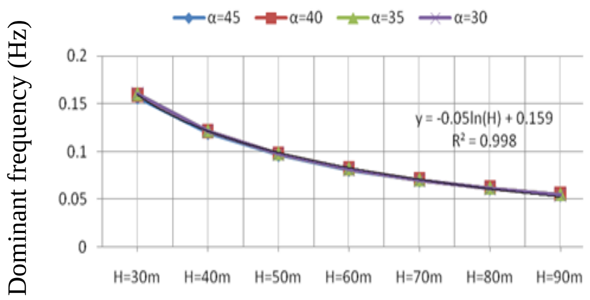



**Fig.5:** Dominant frequency (Model 5) of the first mode for different height of embankment (30-90 m) and different slope

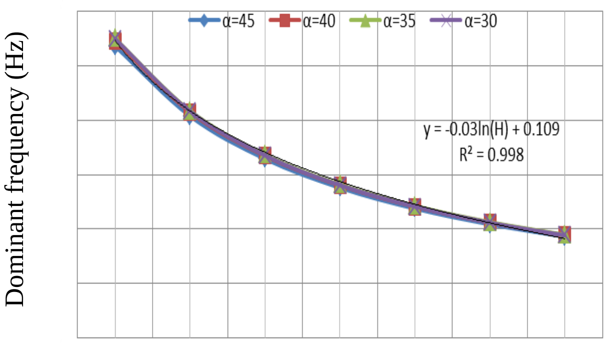



**Fig.6**: Dominate frequency of the first mode for different height of embankment (30-90 m) and different slope in model 6

According to the table 2, the modulus ratio was double. This ratio was introduced between models 1 to 4, and 6. Moreover, the compared results between model 5 and model 6 were illustrated in Figure 7. It was found; the structural height was the main factor to distribute frequency. Besides, the low modulus (model 6) shows the minimum frequency and maximum structural period.

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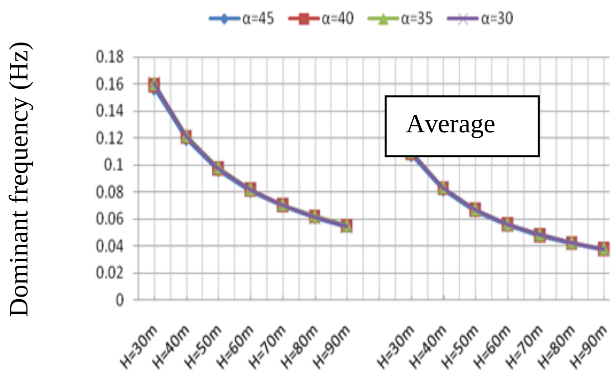


**Fig.7:** Comparison of the dominant frequency between models 5-6

Consequently, distribution of the dominant frequency in different modes indicated that, the first vibration mode was minimum value, as called dominant frequency. Figures 8.a to 8.e show the vibration mode shape for five modes.

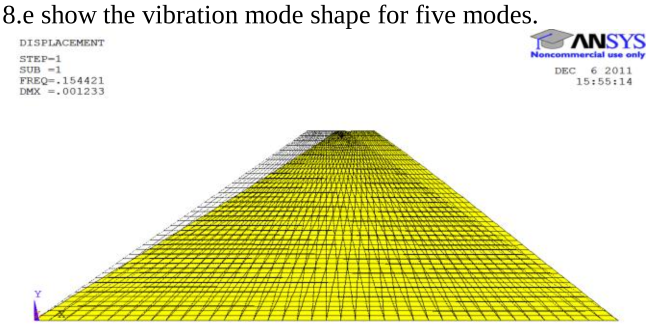


**Fig.8-a:** Mode shape 1 (H=30, α=$40^{\circ}$)

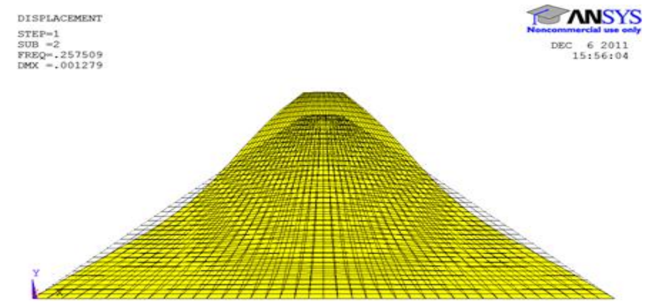


**Fig.8-b:** Mode shape 2 (H=30, α=$40^{\circ}$)

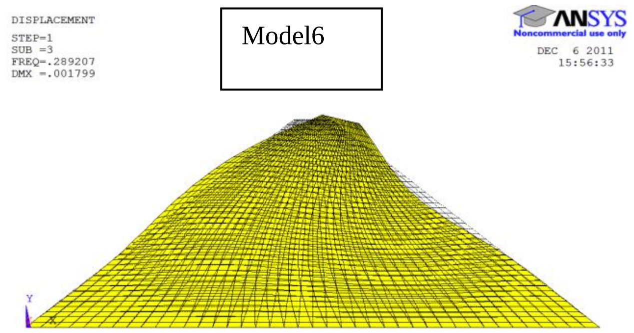


**Fig.8-c:** Mode shape 3 (H=30, α=$40^{\circ}$)

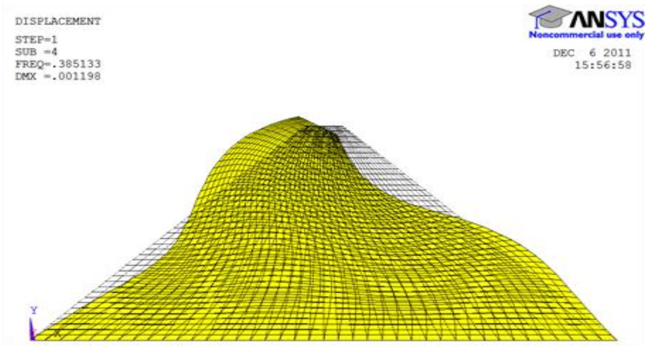


**Fig.8-d:** Mode shape 4 (H=30, α=$40^{\circ}$)

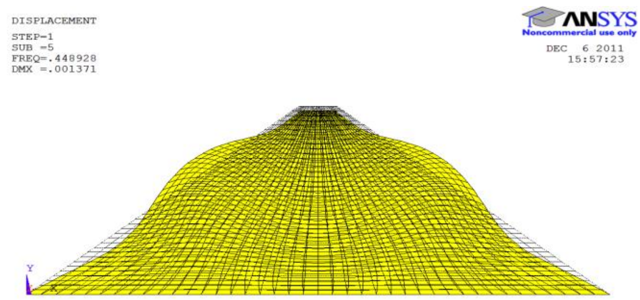


**Fig.8-e:** Mode shape 5 (H=30, α=$40^{\circ}$)

It was revealed that, the first vibration mode shape was very important to evaluate resonance. In addition, the maximum displacement occurred in the mode shape 4. It should be noted that, the relationship between vibration mode and maximum displacement was an indirect trend. Moreover, it should be mentioned that, the higher number of vibration mode were very effective factor for response spectrum analysis in order to increase the accuracy in estimating dam performance during dynamic loading. Figure 9 and 10 illustrate the displacement contours for horizontal and vertical direction, respectively.

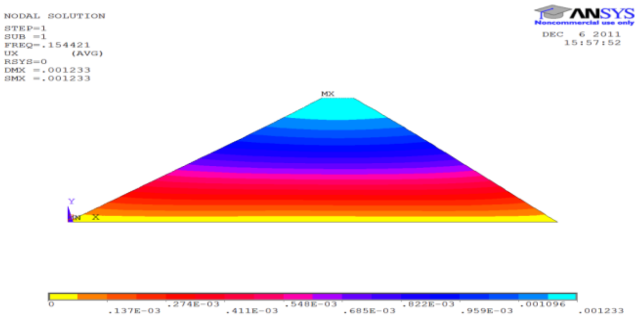


**Fig.9:** Horizontal displacement contour-Mode 1, (H=30, α=40°)

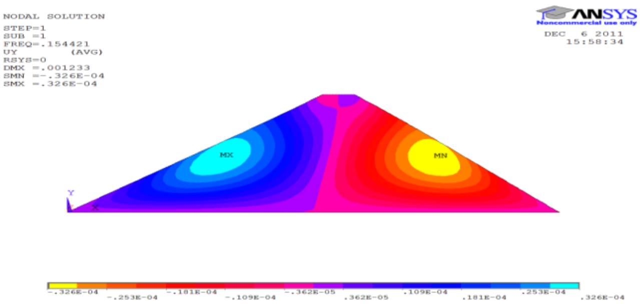


**Fig.10:** Vertical displacement contour- Mode1, (H=30, α=40)

Distribution of displacement in horizontal and vertical direction for the first vibration mode was illustrated in these contours as mentioned earlier. As a result, horizontal displacement was more than vertical displacement. The maximum displacement was revealed at the crest. The vertical displacement was very small. The maximum and minimum vertical displacements occurred in upstream and downstream, respectively. A body crack during strong earthquake was possible based on relative displacement between both slopes. In terms of recommendation for next studies, modal analysis of the earth dam with different zones is recommended.

## IV. CONCLUSION

Modal analysis of embankments was carried in this study. Structural height was between 30-90 meters. Dominant frequency in the embankment were computed using finite element with plane strain method (2D). The effect of configuration and material properties on the distribution of dominate frequency (DF) was investigated. As a result, frequency was minimized in the first vibration mode. Dominate frequency curves were plotted for different configuration of the embankment. In terms of curve application, they were very useful for response spectrum analysis regarding linear method and Rayleigh damping coefficient regarding nonlinear analysis. Consequently, configuration with different slopes and Poisson's ratio were at very low impact on distribution of (DF). The maximum effect respectively was related to the structural height, elasticity modulus, and mass.

## ACKNOLEDGMENT

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**Behrouz Gordan:** The Head of Civil Engineering Faculty, Science and Culture University of Iran, Hamedan branch, Tel: 00989354520278

**Azlan Adnan:** The Head of Engineering Seismology and Earthquake Engineering Research Group (e-seer), Universiti Technologi Malaysia 81310 Skudai, Johor, Malaysia