ELASTIC FOUNDATION EFFECTS ON THREE DIMENSIONAL ARCH DAMS

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Abstract: Dynamic effects on an arch dam should be taken into account together with gravity and hydrostatic pressure for the most critical conditions. This study presents three-dimensional linear earthquake response of an arch dam. Different soil parameters and ground motion accelerograms are used in the finite element analyses. The Type 3 double curvature of an arch dam which is one of the five type models suggested in Arch Dams Symposium organized in England in 1968 is considered in this paper. All numerical analyses are carried out by SAP2000 program for empty reservoir case. In the scope of this study, modal analyses and modal time-history analyses are performed using three dimensional finite element model of the arch dam and arch dam-foundation interaction systems. According to numerical analyses, maximum horizontal displacements and principle stresses are shown by height and also evaluated earthquake for various soil conditions and earthquakes. Besides this study clearly appears that the soil conditions are very effective on the dynamic response of an arch dam.

Keywords: Type 3 Arch dam, Finite element method, Modal time-history analyses, Static and dynamic analysis.

Introduction

It is not possible that continuing life without water. Therefore, humanity have efforted to situate around water resourses from past to now. On the other hand, settlements away from water supplies were not available every time and every place to water. Because the settlers needed to water storing and dams for drinking, using and irrigation in proceeded eras. Thanks to dams, producing hydro-electric power is a significant place at the world today also. On the other side, enabling flood control supplies safety areas of settlement to downstream, agriculture and industry. Also, dams regulates regime of flow and average of downstream flow even dry seasons.

In our country dams which have been builted up until now, consist of %75 earthfill dams, %17 rockfill dams and only %2 arch dams . Arch dams transfer pressure of water to slopes via arch. Arch dams have thinner sections than compare with concrete gravity dams and it causes saving concrete. Generally, arch thickness has to be smaller than %60 height of arch. When the thickness of arch section rises, arch gravity and concrete gravity dam must be considered (Ozsoy, 2007). Constructing of arch dam is more beneficial to produce water energy if only suitable valley status and foundation ground conditions are available. However, disadvantage of arch dam is that analyses and design process are more complex than other alternative dam types. Besides, qualification of the slopes must carry the effect is obligatory. To construct an arch dam, valley must have high potential bearing capacity of foundation and slopes.

At first these dam types were built with stone wall or cut stone after producing concrete, they are planned as a concrete. Collapse ratio of arch dams is less than all other dam types (Ağıralioğlu, 2005).

Eeffect of Forces on Arch Dams

The most important factor of arch dams projects is that calculation of effect forces on dams is determined truly. Effected forces on arch dams;

1) Self weight of arch dam
2) hydrostatic water pressure
3) hydrodynamic water pressure
4) change of temperature
5) equivalent seismic load
6) silt pressure
7) ice pressure
8) wind pressure
9) wave pressure

Model and Analysis Stages

Three dimensional finite element model of arch dam was planned by SAP 2000. Following stages were monitored while creating model by SAP 2000.

1) Three dimensional solid geometrical model was created by SAP 2000.
2) Material properties of the model was assigned (concrete, weight per unit of volume, poission's ratio, compressive strength, tensile strength, elasticity modulus)
3) Dam body and foundation properties were defined.
4) Foundation and slopes were performed as fixed support or pin support according to firm soil or weak soil
5) Combinations of load and loads used for analyses were defined.
6) Records of acceleration components used for time history analysis were done.
7) Analysis were solved under records of strong motion and self weight dam.
8) Maximum and minimum principal stresses and displacements occured on dam body were determined.
9) Dimensioning were evaluated according to analysis results.

Method

In this study, finite element method was used for modelling and analysis. Dam body was divided 204 finite elements. Size of finite element mesh was selected as small as possible in order to get realistic results. Analysis type is linear, loading type is time history, the time history type is modal. Time history analysis method can be used in order to calculate more correct values of displacements, stresses and shear forces. Time history earthquake analysis is used to avoid from many limitations response spectral and investigate buildings under ground motion effects.

When finite element mesh of dam foundation were created, soil-structure interaction and shape of slopes were taken into account. Soil depth from dam base is 120 m. Three dimensional finite element model of 3. type dam comprises of eight nodal elements. Three degree of freedom was defined every nodal point as displacements of directions x, y and z. Three dimensional finite element model has 263 nodal points and 204 number of solids. Linear analysis performed on time history, archs component of dam is assumed monolitic, homogen and isotropic under ground motion. Nodal points where join points of concrete blocks were ignored. Acception of rigid foundation makes solution of dam-foundation interaction problems easy. In the case of dam settlement upon a rock area or extra hard soils, assuming foundation as a rigid may provide more sufficient results. However, if strength of foundation ground is low, assuming foundation as a rigid contrary solutions occured.

Based on finite element method of arch dam analysis programs takes into account massless foundation condition (Tan, 1995). Dam foundation size must be one or two times of dam height provides sufficient approach on downstream and upstream parts of dam. The farest boundary nodal points of foundation rock, which were used finite element method, are assumed to be fixed. The main idea of massless foundation assumption is preventing resonance at the low frequencies obtained from dam-foundation system (Dowling, 1987). Disadvantage of this approach is that damping of material and propagation are not considered. A dynamic analysis must include these dampings because of the load effection on dam. Five different soil parameters were determined to sand stone using required resources. Soil models were categorized. Young's modulus, poission ratio and weight densities were determined. According to real acceleration datas tensile behaviour and displacements of soil were investigated.

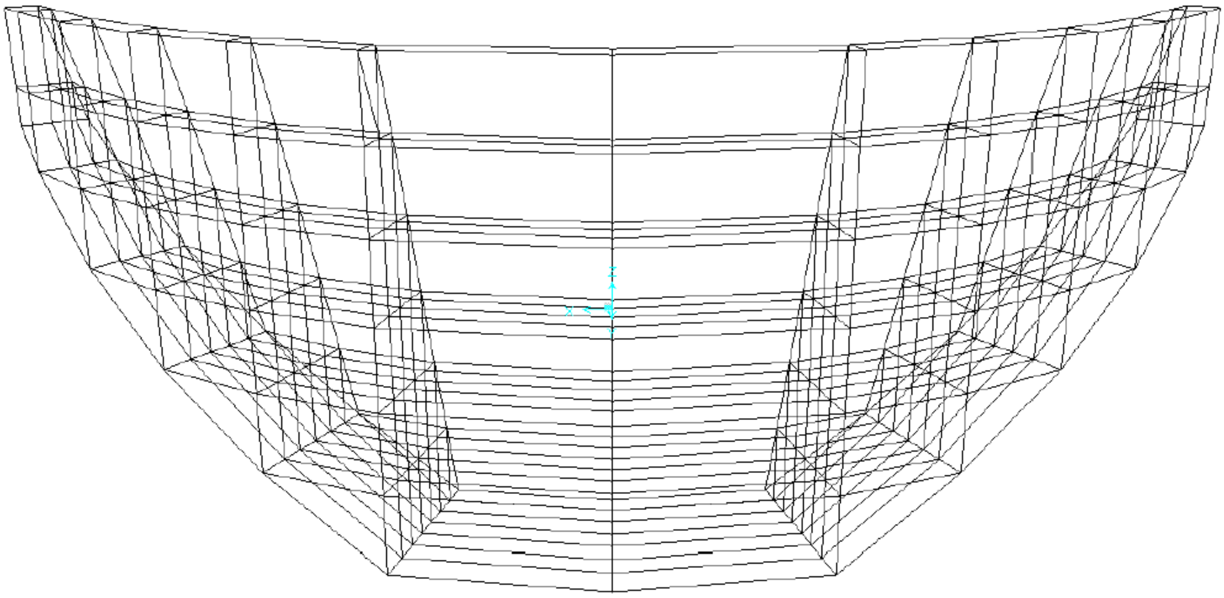


Figure1. In the event embedded foundation that finite element mesh of three dimensional arch dam

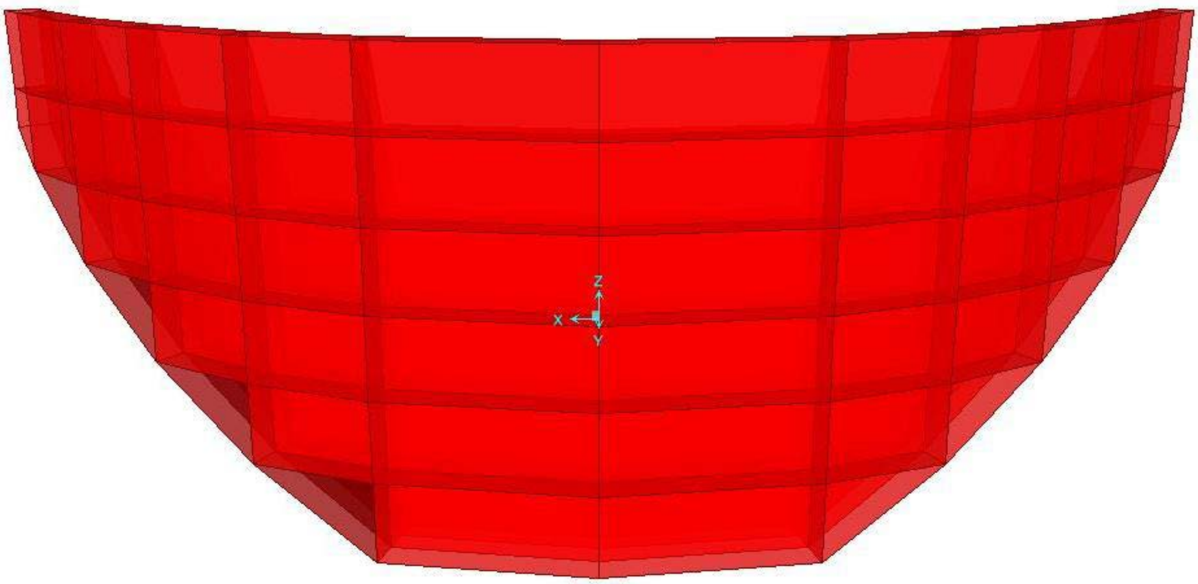


Figure 2. Finite element model of three dimensional type 3 arch dam

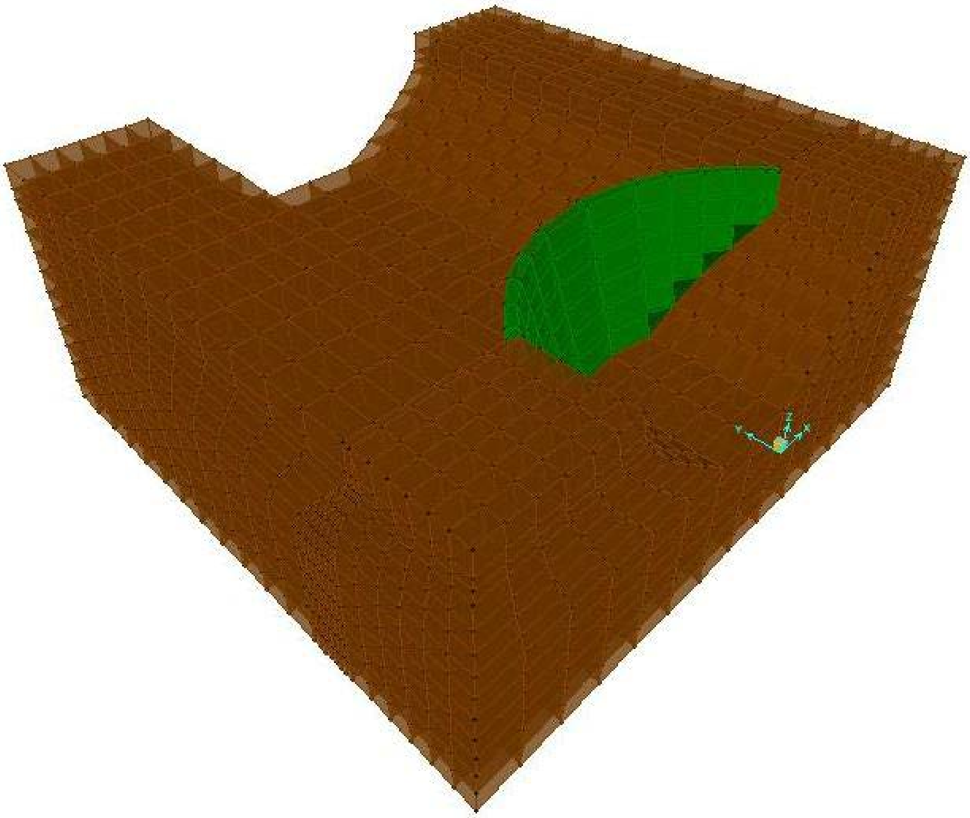


Figure 3. Model 1 three dimensional finite element model of arch dam-foundation

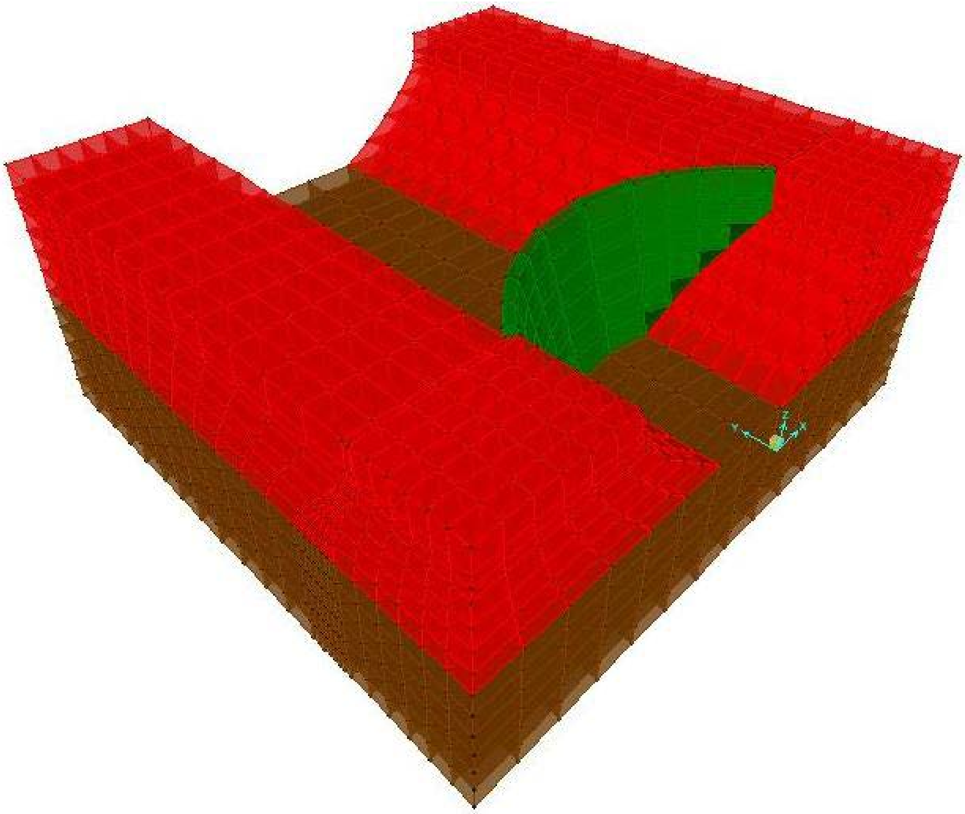


Figure 4. Model 2 three dimensional finite element model of arch dam-foundation

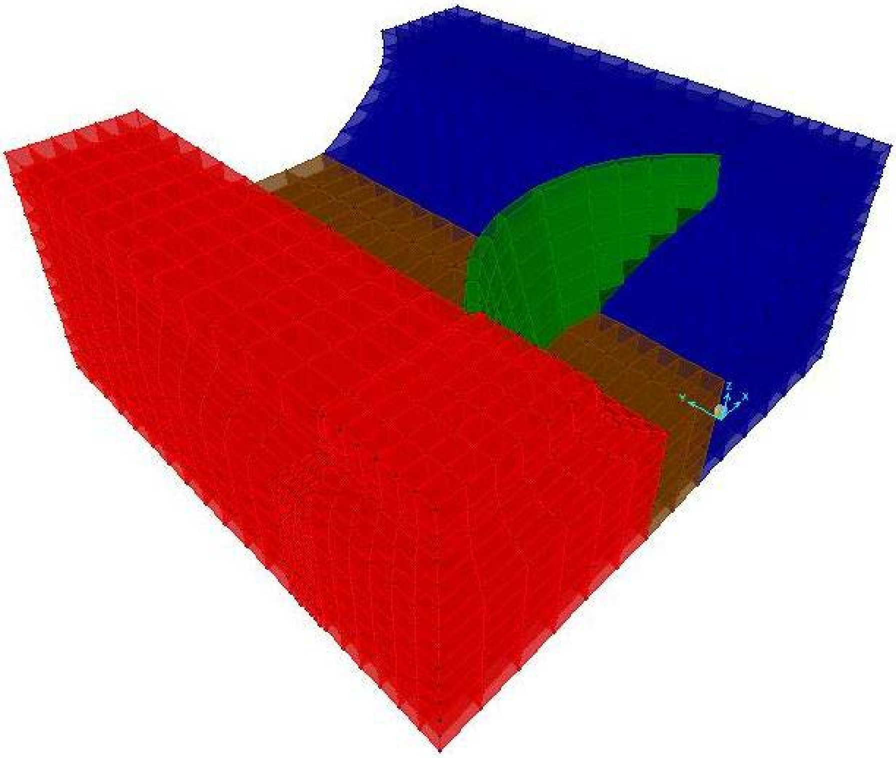


Figure 5. Model 3 three dimensional finite element model of arch dam-foundation

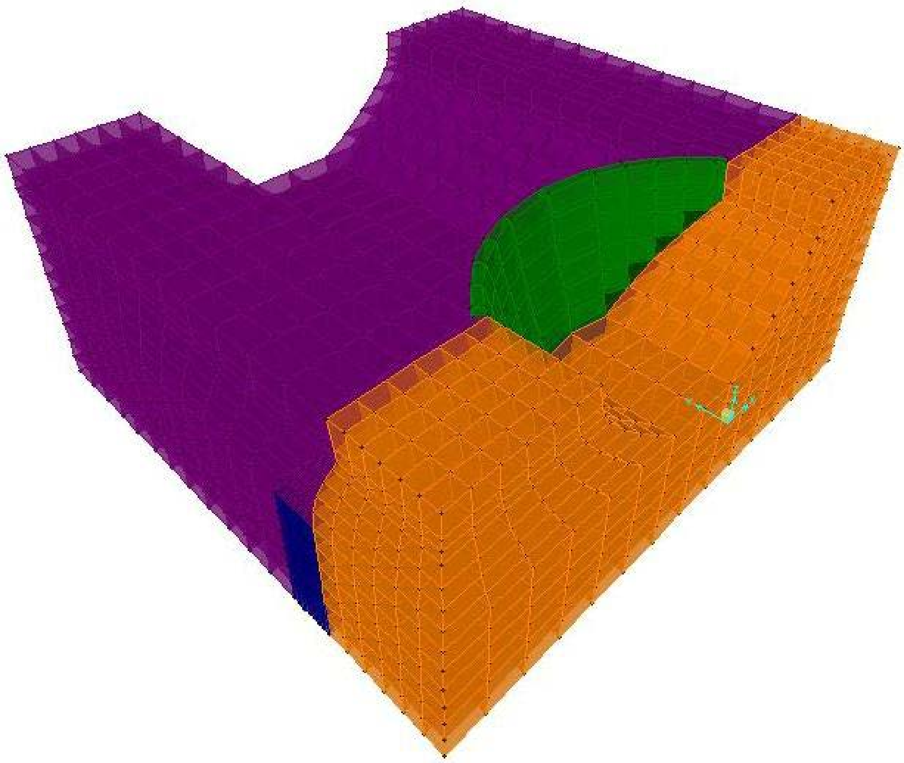


Figure 6. Model 4 three dimensional finite element model of arch dam-foundation

Static Analysis

Static analysis was done for empty reservoir, as a three dimensional rigid and elastic foundation conditions were taken into account. Displacements and principal stresses obtained from downstream and upstream faces were investigated throughout dam height.

Dynamic Analysis

Acceleration-time spectrum obtained by Housner was used to investigate behaviour of an arch dam to earthquake. Earthquake force were actted on dam west-east, north-south and up directions. % 5 damping ratio was used in calculations. First thirty seconds of earthquake takes into account since the time of solution analysis too much time. Linear analysis was conducted by Newmark method and step by step integration technique. 0.1 second was selected time step for integration. The analysis was done for empty reservoir situation. First six mods were taken into account natural frequency and mods of dam under hydrodynamic influence.

Linear Analysis of Arch Dams in Time-History

3. type of double curved arch dam was analyzed under several loadings. Three dimensional linear dynamic analysis was executed by taking into account different ground motions and self weight. After arch dam model was composed, identification loads, material properties of soil and dam concrete were defined. Analysis was conducted for different soil types, ground motion and empty reservoir condition. Modeling of foundation was created as sound or rigid rock and poor bearing soil. Empty reservoir condition was investigated to take into account self weight, different ground motion and soil types

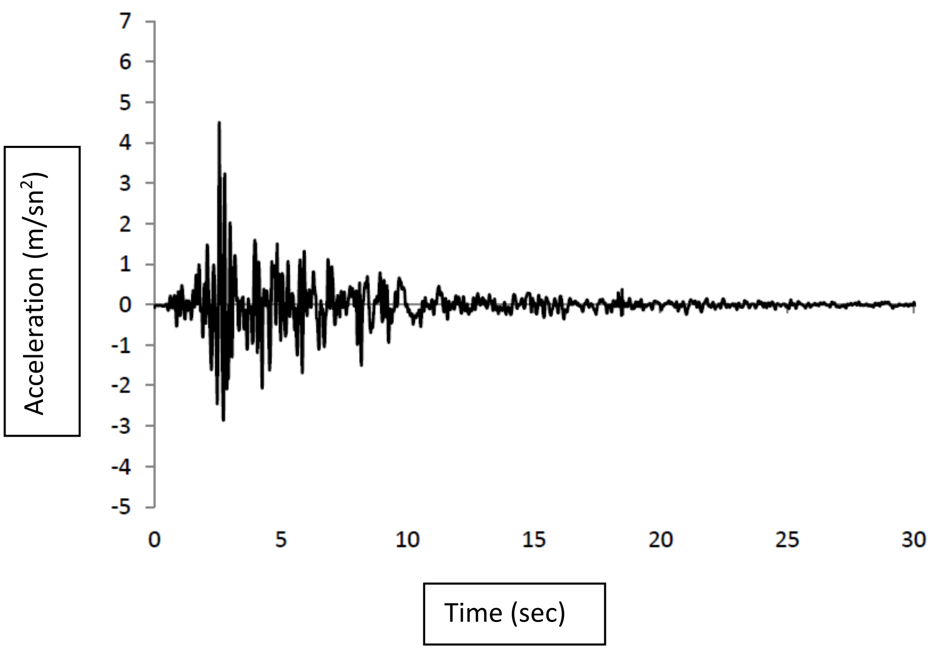
Figure7. Evaluated analysis results of nodal points on dam body shape

Table 1. Determined loading conditions according to different ground motion which used in dynamic analysis

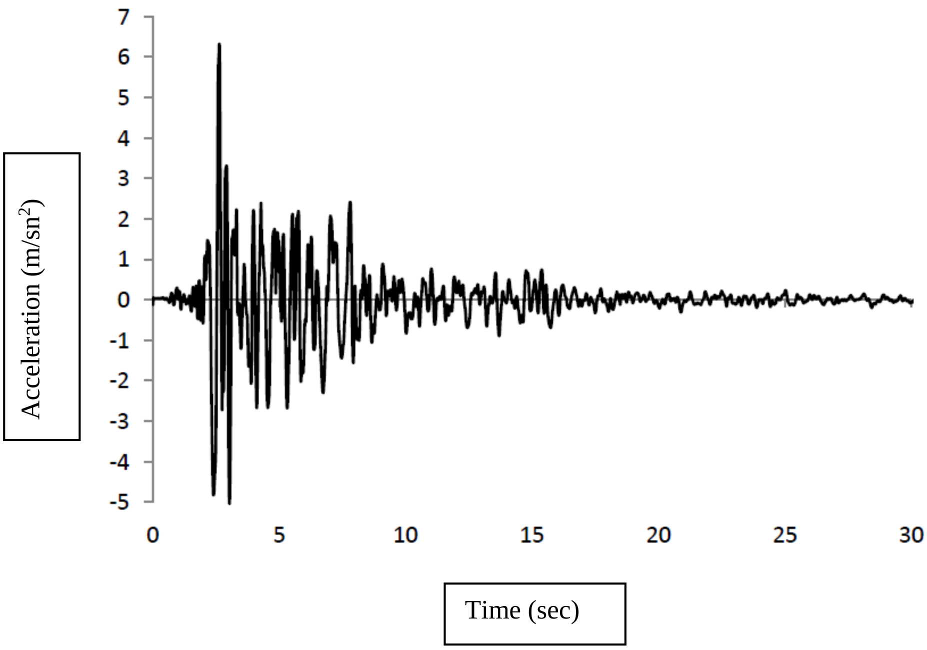
Loading Condition	Group Name	Dynamic Loading Groups
1	Near Fault	Diffirent Ground Motion
2	Far Field Fault 1	Diffirent Ground Motion
3	Far Field Fault 2	Diffirent Ground Motion

Table 2. Different ground motions and properties used in the linear analysis on time history

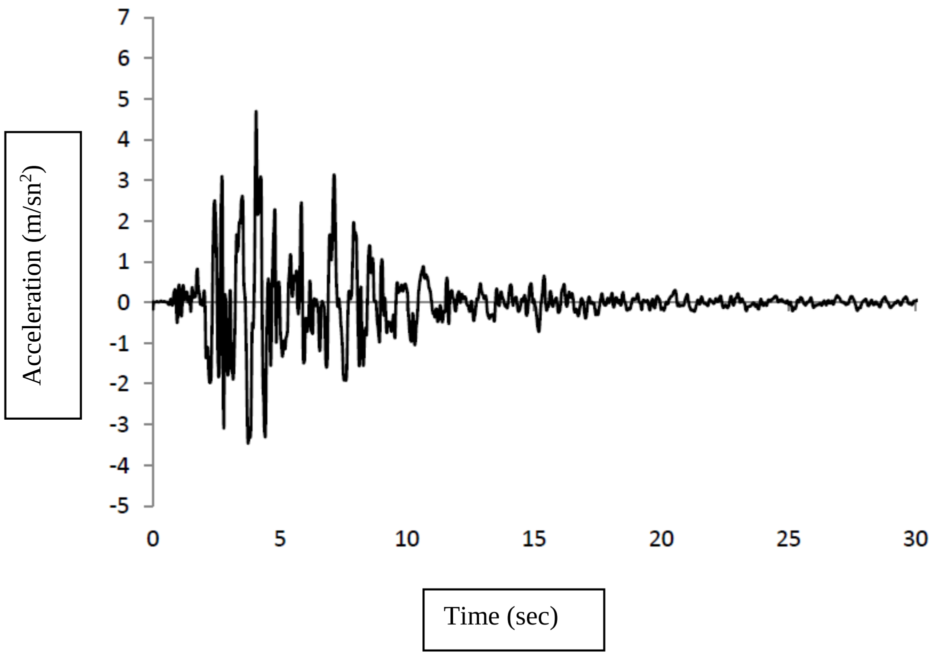
Faults	Components	Moment Magnitude	Ground Velocity (cm/s)	Ground Acceleration (g)	Focal Distance (km)
Near Fault	North-South	6.9	17.7	0.455	5.1
	East-West		55.2	0.644	
	Up		45.2	0.479	
Far Field Fault 1	North-South	6.9	5.6	0.115	24.2
	East-West		16.4	0.226	
	Up		16.6	0.323	
Far Field Fault 2	North-South	6.9	4.4	0.032	93.1
	East-West		17.3	0.124	
	Up		14.2	0.106	



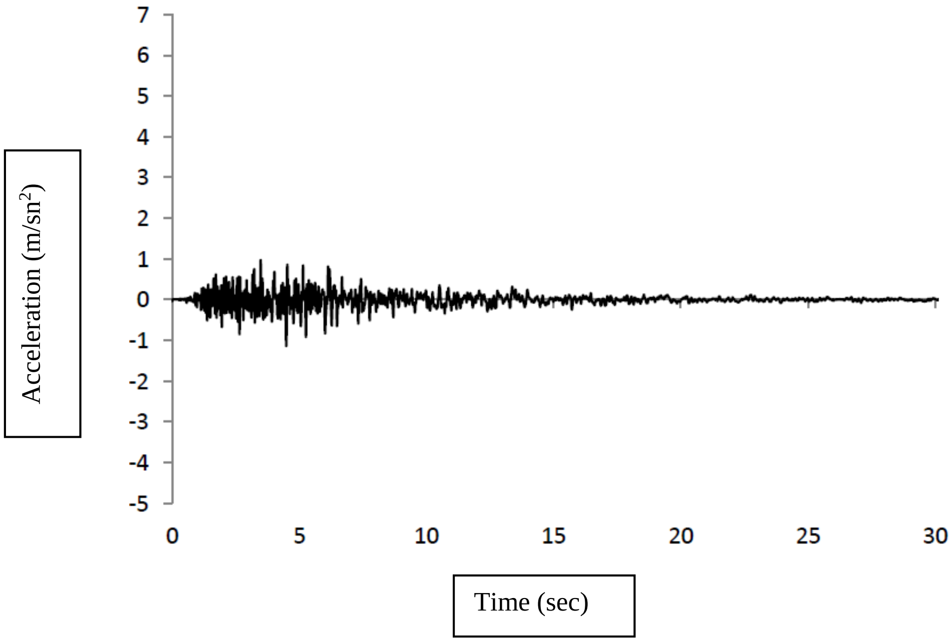
Graphic 1. Acceleration-Time graphic of west-east components of Loma Prieta Earthquake for near fault



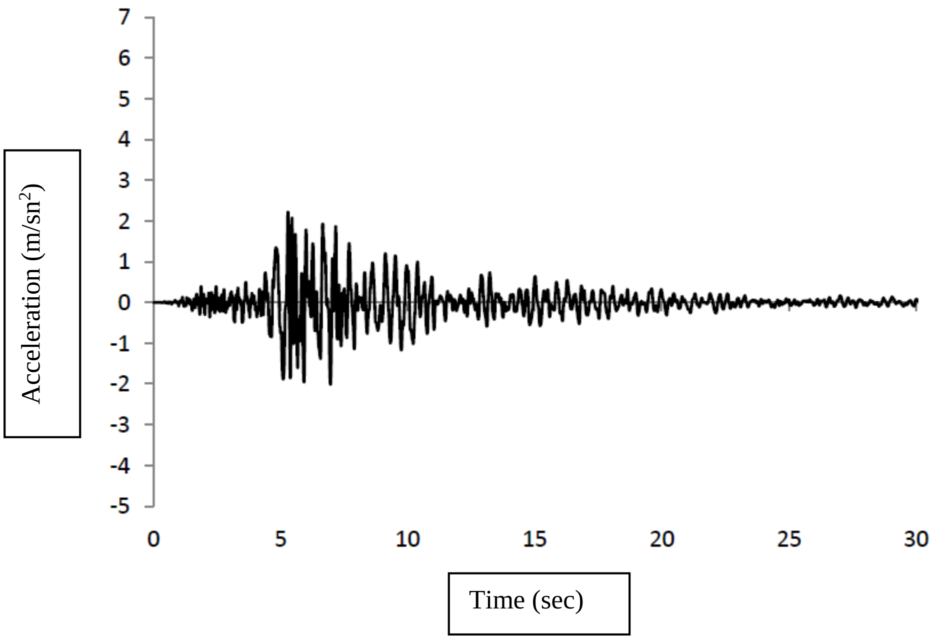
Graphic 2. Acceleration-Time graphic of north-south components of Loma Prieta Earthquake for near fault



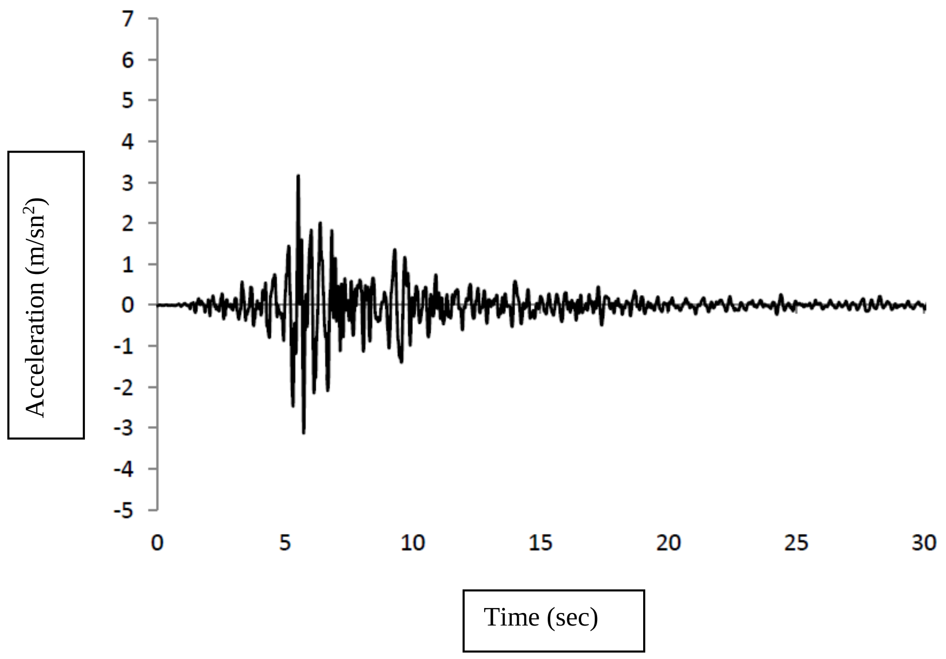
Graphic 3. Acceleration-Time graphic of up components of Loma Prieta Earthquake for near fault



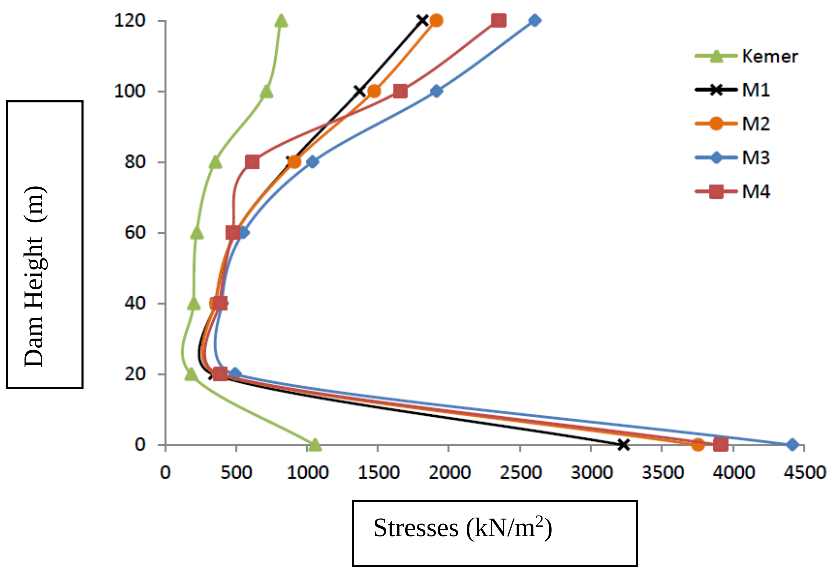
Graphic 4. Acceleration graphic of west-east component of Loma Prieta Earthquake for far field fault 1



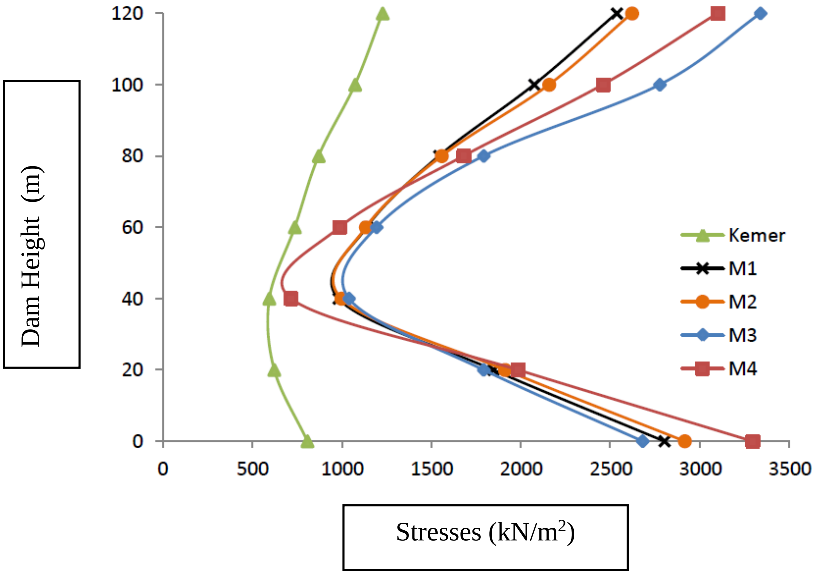
Graphic 5. Acceleration graphic of north-south component of Loma Prieta Earthquake for far field fault 1



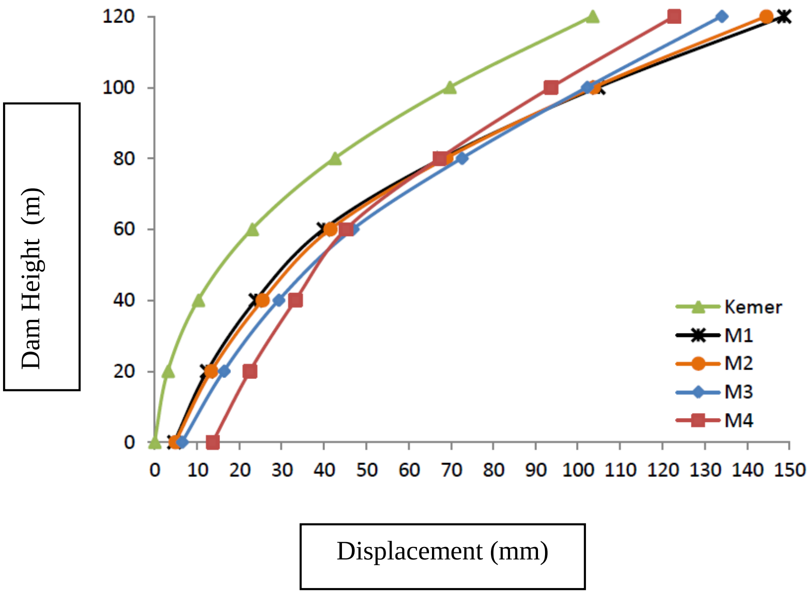
Graphic 6. Acceleration graphic of up component of Loma Prieta Earthquake for far field fault 1



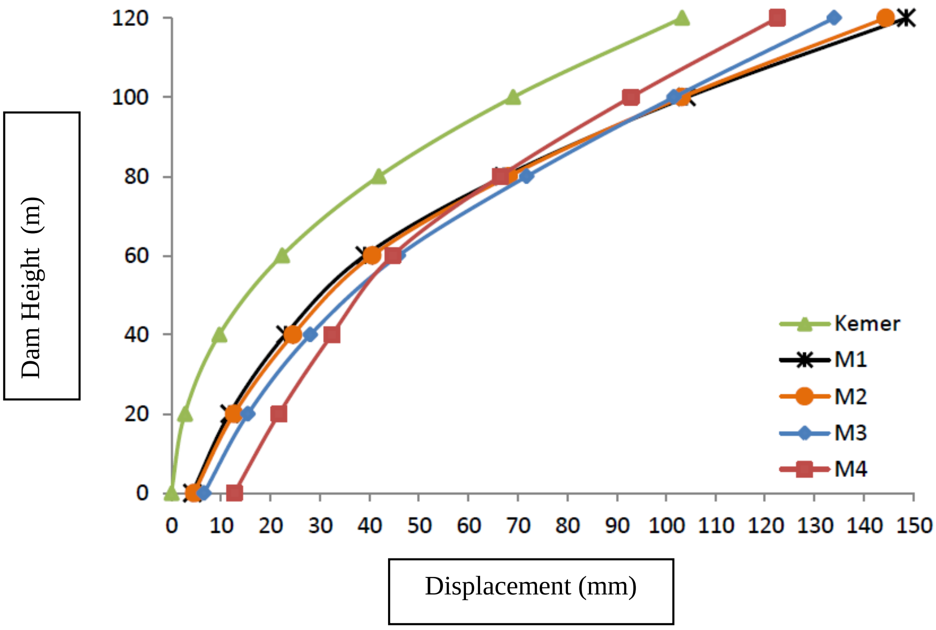
Graphic 7. Stresses changing throughout dam height on upstream face for empty reservoir condition



Graphic 8. Stresses changing throughout dam height on downstream face for empty reservoir condition



Graphic 9. Displacement changing throughout dam height on upstream face for empty reservoir condition



Graphic 10. Displacement changing throughout dam height on downstream face for empty reservoir condition

Results

Results of static analysis show that maximum displacements occured up direction. Maksimum displacement obtained from model 4. The worst unfavorable foundation and slopes conditions were designed at Model 4. The maximum tensile stress was occured at downstream side of Model 4's crest. Maksimum compression stress was occured approximately equal for all models. Maximum compression and tensile stress obtained from dynamic analsis is shown Model 3 which both slopes having different material properties. Tensile stress developed at downstream face of dam crest, compressive stress occured at upstream face of dam foundation. The biggest displacements took place at crest point in all static and dynamic analysis.

According to analysis, existence of soil affects dam behavior significantly. Therefore, dam-soil interaction must consider in static and dynamic analysis. Arch dam, which was projected according to linear analysis, must investegated to nonlinear analysis.

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