Eng. & Tech. Journal, Vol.27, No8, 2009

Dynamic Analysis of Al-Adhaim Zoned Earthdam

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Received on: 13/4 /2008
Accepted on: 31/12 /2008

Abstract

Among external forces, the dam is subjected to earthquakes which are naturally or artificially occurring and resulting in time-varying deflections, excess pore water pressure and liquefaction at some zones in the dam.

In this paper, coupled dynamic analysis has been carried out on zoned earthdam subjected to earthquake excitation in which displacements and pore water pressures are calculated. The finite element method is used and the computer program QUAKE/W is adopted for this task.

Al-Adhaim dam which is an earthdam located near the place of intersection of Tuz Jay and the river Al-Adhaim is used as a case study. A parametric study was carried out to investigate the effect of the maximum earthquake horizontal acceleration on the general response of the dam.

It was found that as the maximum horizontal acceleration of the input motion increases, both horizontal and vertical displacement increase. In all cases, the effect of the input ground acceleration diminishes at time (60 sec.) from the time of earthquake shock. When the maximum horizontal acceleration of the input motion increases from (0.05g) to (0.2g), the horizontal acceleration predicted at a node located at the core base increases by about (200 %) while the maximum effective stress increases by about (32 %).

Keywords: Earth dams, Finite elements, Dynamic, Zoned.

التحليل الديناميكي لسد العظيم الترابي المتمنطق

الخلاصة

من بين القوى الخارجية التي يتعرض لها السد قوى الهزات الأرضية التي تكون طبيعية أو صناعية وتؤدي إلى تشوه وزيادة بضغط الماء المسامي متغيراً مع الزمن وحدوث ظاهرة التسييل في بعض أجزاء السد.

في هذا البحث تم دراسة التصرف الديناميكي المزدوج للسدود الترابية المتعرضة للهزات الأرضية والذي يتم فيه حساب الازاحات وضغط الماء المسامي. و استخدمت طريقة العناصر المحددة من خلال برنامج QUAKE / W.

استخدم سد العظيم الذي هو عبارة عن سد ترابي يقع قرب المكان الذي يلتقي به (طوزجاي) مع نهر العظيم كحالة للدراسة . تم دراسة تأثير أقصى تعجيل أفقي للهزة الأرضية على استجابة السد.

وقد وجد أنه كلما زاد أقصى تعجيل أفقي للهزة المؤثرة فان الازاحات الأفقية والعمودية تزداد. وفي جميع الحالات يتلاشى التعجيل الأرضي عند زمن (60 ثانية) من بداية الهزة الأرضية.

كما وجد أنه عند ازدياد أقصى تعجيل أفقي للحركة المدخلة من (0.05 g) إلى (0.2 g), يزداد التعجيل الأفقي المتوقع لنقطة تقع عند قاعدة اللب بمقدار (200%) بينما يزداد الإجهاد الفعال الأقصى بمقدار (32%).

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https://doi.org/10.30684/etj.27.8.14
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Introduction

For a seismic design of dam, the aim of designer is to know the force exerted on the dam structure due to the probable ground motion expected at the site, as well as to estimate the behaviour of a dam during an earthquake.

So, it is important to ensure the safety of embankment subjected to seismic loading because a number of embankment dams have failed or suffered major displacement during earthquakes in the past.

The possible ways in which an earthdam might fail during an earthquake include (Sherard, et al., 1963):

1- failure due to disruption of the dam by major fault movement in the foundation.
2- slope failures induced by ground motions.
3- loss of freeboard due to differential tectonic ground movements.
4- sliding of the dam on weak foundation materials.
5- piping failure through cracks induced by ground motions.
6- overtopping of the dam due to seiches in the reservoir.
7- overtopping of the dam due to slides or rock falls into reservoir.
8- overtopping of the dam due to failure of spillway or outlet work.

Many of potentially harmful effects of earthquakes on earth and rockfill dams can be eliminated by adopting defensive measures which render the effects non-harmful, (Seed, 1979 and Ozkan, 1998).

Dams especially those consisting of different materials (earthfill and rockfill) behave in a different manner and undergo different types of motions when subjected to an earthquake motion.

The response of the dams depends on many parameters such as, the shape of the structure, the type and intensity of the motion, the properties of the materials, etc.

Description of Al-Adhaim Dam

Al-Adhaim dam is an earthdam located at a distance of (1.5 km) in the rear of the place in which Tuz Jay and the river Al-Adhaim merge, which is considered as seismically active region in Iraq. It consists of embankment with length of (3.1 km) from the helm of a major cross-river valley (where it is 73.5 m) high and go through or underneath spending and channel spillway, and the payment of the wings in the left and right and up the embankment major backs on the left and right where appropriate height is less because of high natural land there. Al-Adhaim dam is a fill soil with sloping core, its architecture has been developed initially by Bennie and Partners company. The soil of the foundation consists of sloping layers from sandstone and marl uneven thickness, (Final Report on Al-Adhaim Dam, 1994)

Figure (1) shows the section of the dam, which has a base level of about (70 m) above the sea level, and the level at the top of dam is (146.5 m).

Al-Adhaim is a filling dam which consists of three main layers: shell, core, and filters. The thickness of this filling changes with the height of the dam where it has a greatest value at the base and gradually decreases with increase of the height. The height change of the dam depends on the height of land, which varies from a few meters rival parties and up to about (70 m) at the confluence with the metaphor of the river, and below is a brief description of the dimensions and sloping of the dam.

The shell is composed of sand and gravel in general, the width at top is (12 m), while the sloping at the upstream is

(1:2.5 vertical: horizontal) and the downstream is (1:2).

The core consists of clayey silt sliding towards the upstream of the dam with the sloping (1.1:1) and (2:1). The form of core sections is chimney and the thickness is (8 m) at elevation (143.5 m) and this thickness gradually increases until it reaches (33 m) at elevation (70 m). At elevation (70 m), the core soil merges with the marl soil at the foundation, (final report on Al-Adhaim Dam, 1994). The drainage consists of vertical and horizontal filters. The designer; Bennie and Partners, implementated the vertical filter consisting of two layers to protect the core. Table (1) shows the main properties of Al-Adhaim dam materials.

Discretization

To study the effect of earthquake on Al-Adhaim dam, the dam is analyzed using the program QUAKE /W. The finite element mesh used for the analysis is shown in Figure (2). The mesh includes higher-order quadrilateral and triangular elements. In dynamic analysis, the left and right vertical boundary conditions on nodes are assumed to be free to move in the horizontal direction but are fixed in the vertical direction. The boundary conditions along the horizontal base boundary of the foundation are assumed to be fixed in both horizontal and vertical directions. Equivalent linear model is used in the analysis. This model is actually non-linear, but it is equivalent to a linear model because it transforms the irregular earthquake shaking into equivalent uniform cycles. It is non-linear in that the secant shear modulus of soils decreases with increase of cyclic shear strain amplitude as shown in Figure (3).

The selected earthquake for the analysis is El-Centro earthquake (1940) with a period of (10 sec.).

The time of the analysis is taken as (600 sec.) with (Δt = 0.01 sec.) to investigate the behaviour of the soil for a period of time after the earthquake has stopped.

Effect of Different Maximum Horizontal Acceleration:

The mesh of the dam is shown in Figure (2) which shows the actual design of the dam.

Figures (4) to (11) show the results with maximum acceleration (0.05g). Figures (12) to (19) show the results with maximum acceleration (0.1g), while the results with maximum acceleration of (0.2g) are shown in Figures (20) to (27).

A comparison between Figures (4), (12) and (20) shows that as the maximum horizontal acceleration of the input motion increases, both the horizontal and vertical displacements increase. In all cases, the effect of the input ground acceleration diminishes at time (60 sec.) from the time of application.

A comparison between Figures (5), (13) and (21) reveals that as the maximum horizontal acceleration of the input motion increases from (0.05 g) to (0.2 g), the horizontal acceleration predicted at node (310) (shown in Figure 2) increases by about (200%) while the maximum horizontal effective stress increases by about (32%), when the maximum horizontal acceleration of the input motion is (0.05 g), the pore water pressure increases rapidly at early times reaching a value of (525 kPa) at time (292 sec.) where liquefaction takes place. The pore water pressure becomes (513 kPa) and liquefaction takes place at time (60 sec.), when the input acceleration is (0.1 g) or (0.2 g). This means that the increase in the input acceleration has no effect on liquefaction potential when the values are greater than (0.1 g). The increase in the maximum horizontal acceleration of the input motion decreases the time required for liquefaction to take place.

A comparison between Figures (5) and (6) shows that the time required for liquefaction to take place at node (310) which is located near the core base is smaller than that required for node (477) which is located near the normal water level although the maximum acceleration at node (477) is higher than that at node (310).

The same results were found for accelerations of (0.1g) and (0.2g).

Figures (7) and (15) show that at node (253) which is located in the dam's shell, the time required for liquefaction to take place is greater than that for nodes (310) and (477). On the other hand, Figures (21), (22) and (23) show that when the maximum horizontal acceleration of the input motion is (0.2g), liquefaction takes place at all nodes within the dam's shell at the same time.

It can be noticed that, although the values of pore water pressure lines in the base of foundation are greater than the upper parts of the embankments, the liquefaction starts to take place in the core and the shell before the foundation. This may be attributed to that the deeper soil is less likely to liquefy than the dam shells. These conclusions agree with those reported by NAVAC DM- 7.3, 1993. This is illustrated in Figures (9), (17) and (25) respectively.

A comparison between Figures (10), (18) and (26) shows that as the maximum horizontal component of the input acceleration increases, liquefaction zones within the dam and its foundation become larger.

It can also be noticed that the maximum stresses and pore water pressure occur at a time after the earthquake shock and not on or in the vicinity of the time of the peak ground acceleration as was concluded by conventional dynamic stress analysis. This conclusion agrees well with Ghaboussi and Wilson, (1973) who stated that the time of maximum stresses and pore pressures depends on many factors such as permeability of each zone and the presence of filters and drainage paths.

Delay in liquefaction occurrence is noticed until the earthquake has stopped which may be due to pore water pressure redistribution within the embankment and this agrees with Seed, (1979) who stated that most of the failures in embankment dams occur after the earthquake has stopped.

Conclusions:

1. As the maximum horizontal acceleration of the input motion increases, both horizontal and vertical displacement increase. In all cases, the effect of the input ground acceleration diminishes at time (60 sec.) from the time of earthquake shock for Al-Adhaim dam.
2. When the maximum horizontal acceleration of the input motion increases from (0.05g) to (0.2g), the horizontal acceleration predicted at a node located at the core base increases by about (200 %) while the maximum effective stress increases by about (32 %).
3. The increase of the maximum value of the input acceleration has no effect on liquefaction potential when the values are greater than (0.1g). The increase of the maximum horizontal acceleration of the input motion decreases the time required for liquefaction to take place.

   The time required for liquefaction to occur near the core base is smaller than that required for a point near the normal water level in spite that the maximum acceleration at the latter position is higher than in the former one.

4. When the maximum horizontal acceleration of the input motion is (0.2g), liquefaction takes place at all nodes within the dam's shell at the same time. This means that liquefaction potential increases considerably under strong earthquakes

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Table (1) Material Properties of Al-Adhaim Dam, (Final Report on Al-Adhaim Dam, 1994).

Material zone		Dynamic elastic modulus (MN/m^2)	Poisson's ratio (ν)	Density (t/m^3)
Shell		19	0.3	1.8
Core		30	0.45	2.0
Foundation	Marl	350	0.35	2.1
	Sand Stone	300	0.35	2.1

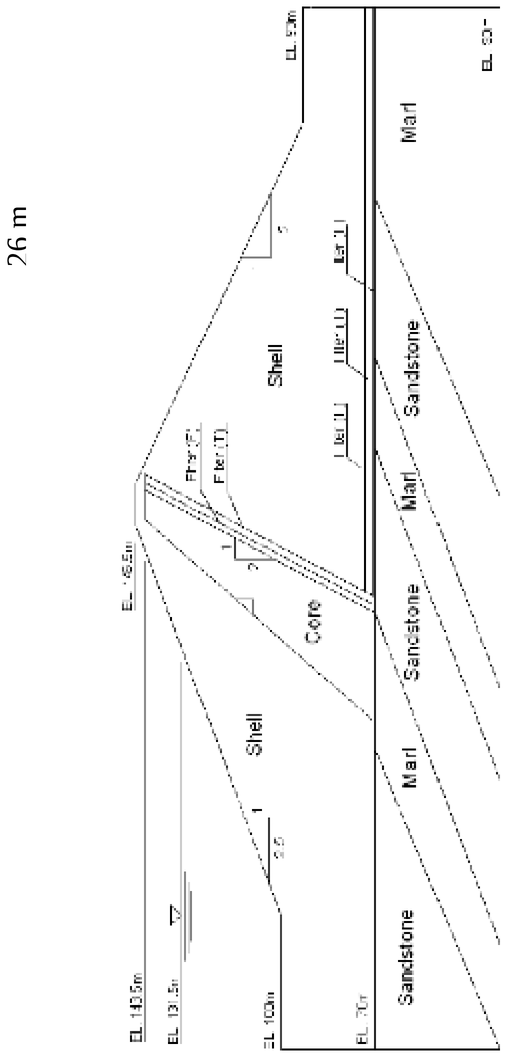


Figure (1): Al-Adhaim Dam –Typical Cross Section,(Final Report on Al-Adhaim Dam, 1994)

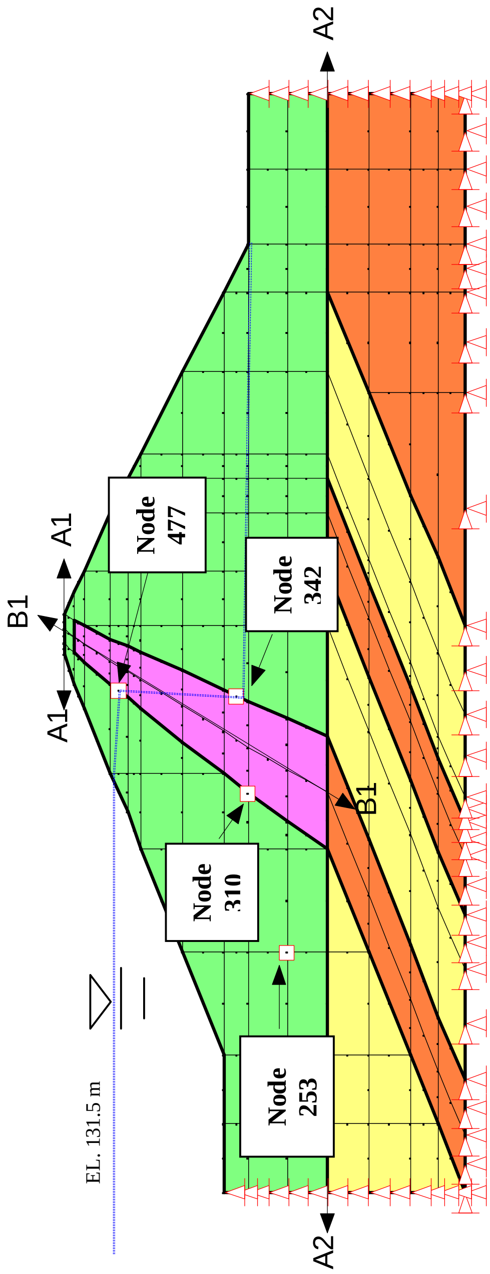


Figure (2): Finite Element Mesh for Al-Adhaim Dam.

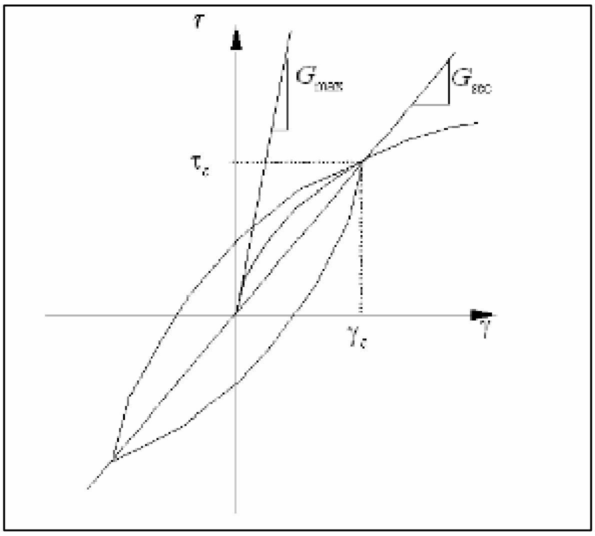
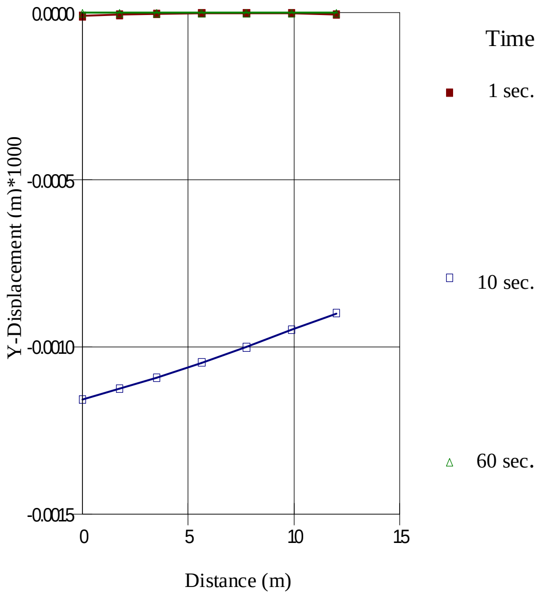
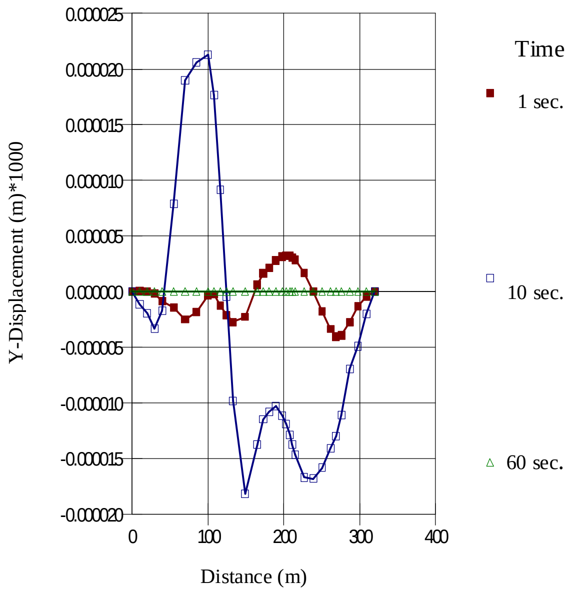


Figure (3) The Shear Modulus under Cyclic Loading Conditions, (Das, 1983).



Line (A1-A1)

(a)



Line (A2-A2)

(b)

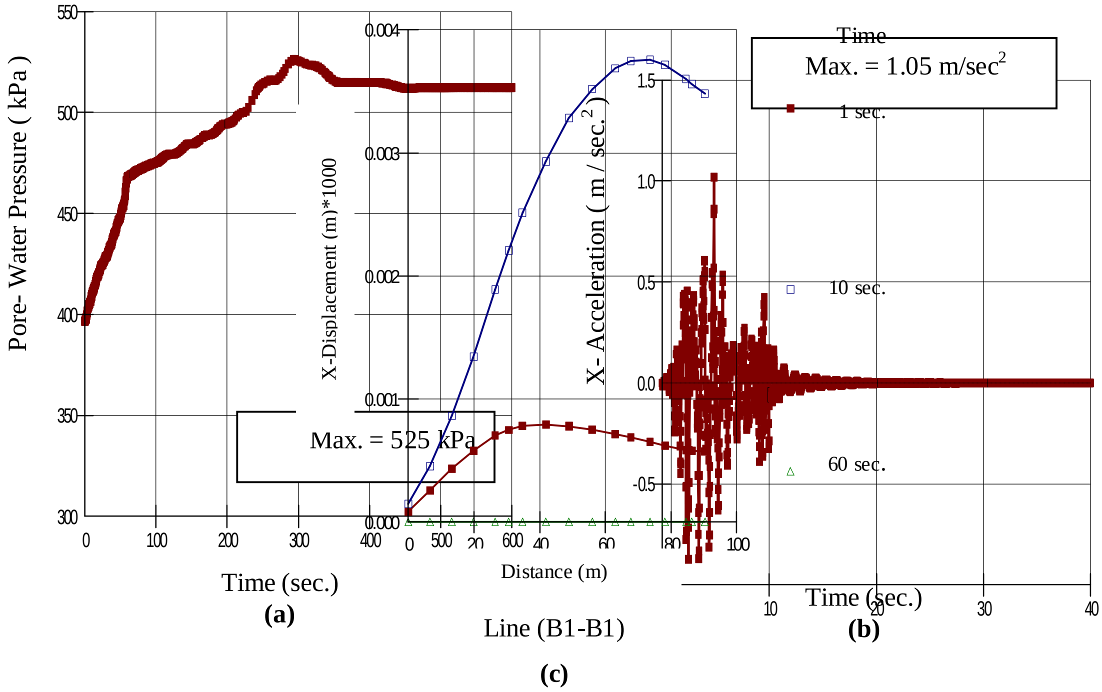


Figure (4): Earthquake Response along Different Sections of the Dam (Maximum Horizontal Acceleration = 0.05g).

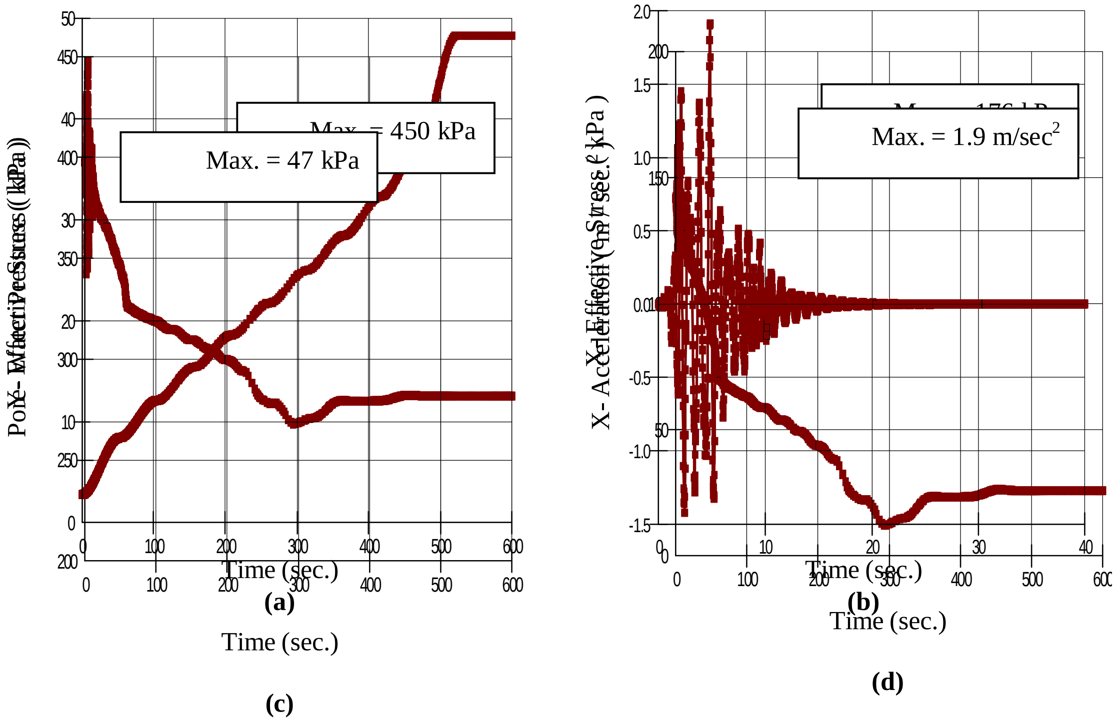


Figure (5): Earthquake Response of Node (310)
(Maximum Horizontal Acceleration = 0.05g).

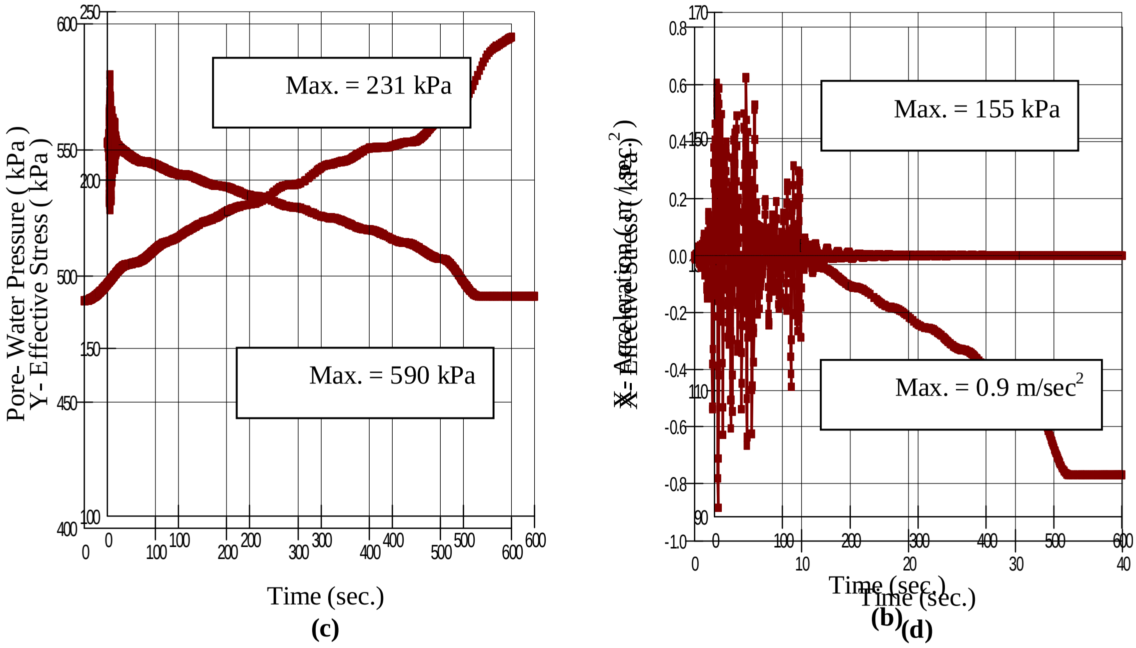


Figure (6): Earthquake Response of Node (477)
(Maximum Horizontal Acceleration = 0.05g).

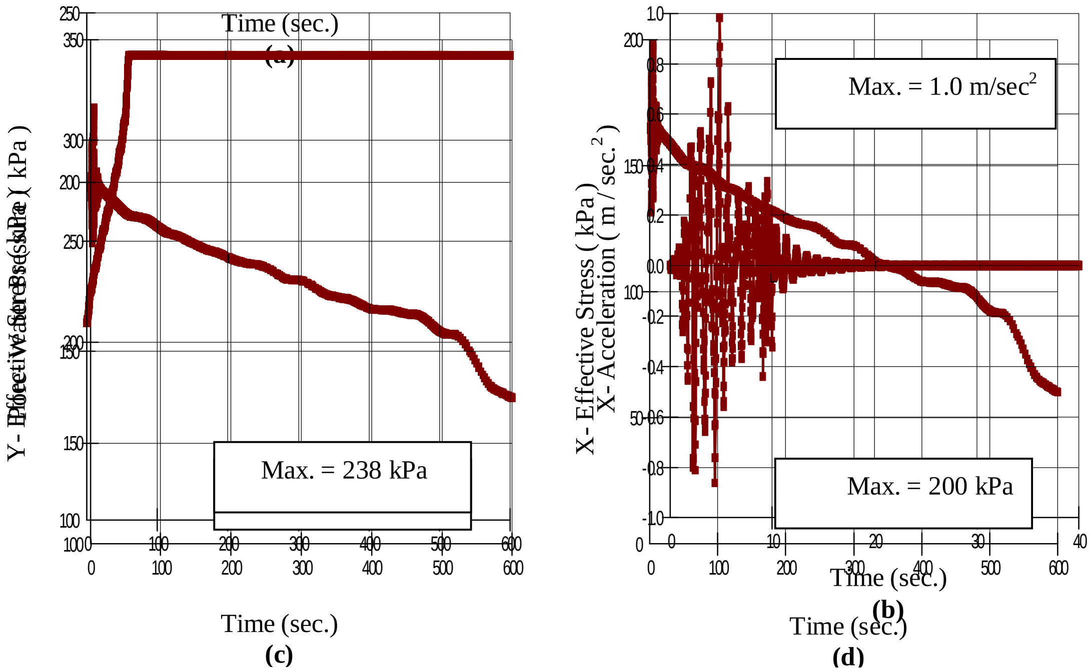


Figure (7): Earthquake Response of Node (253)
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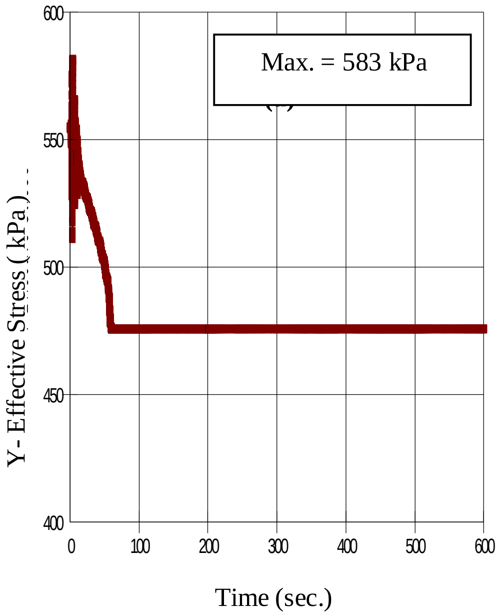
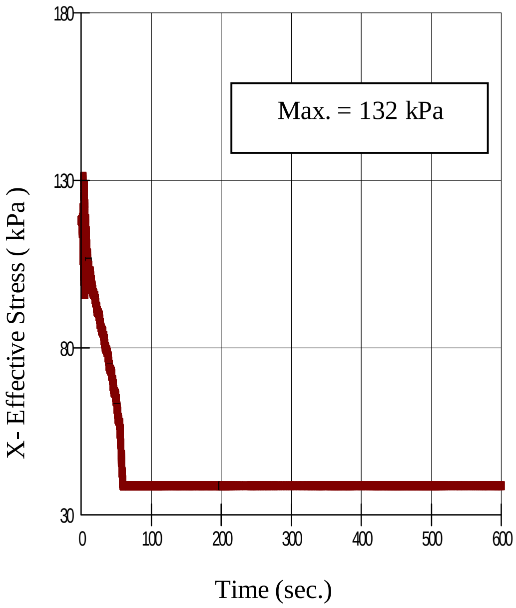
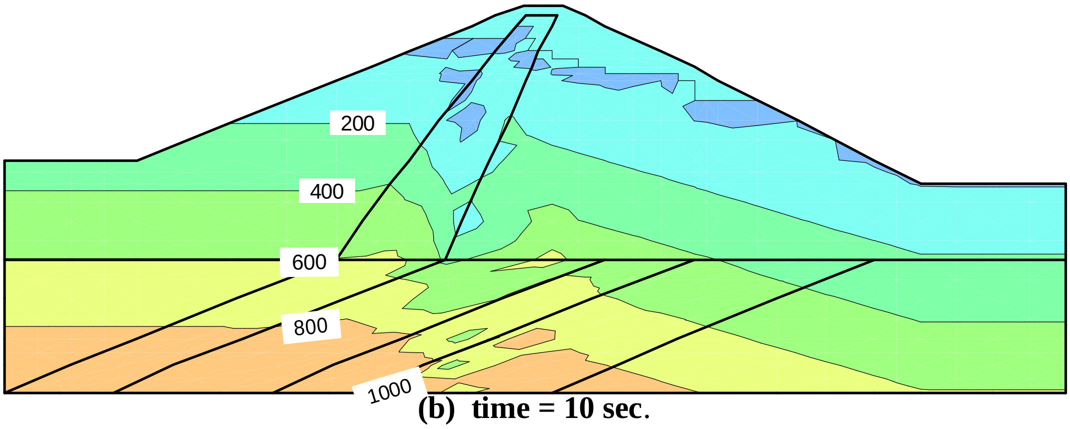


(c)



(d)

Figure (8): Earthquake Response of Node (342)
(Maximum Horizontal Acceleration = 0.05g).



(b) time = 10 sec.

(a) time = 2.14 sec.

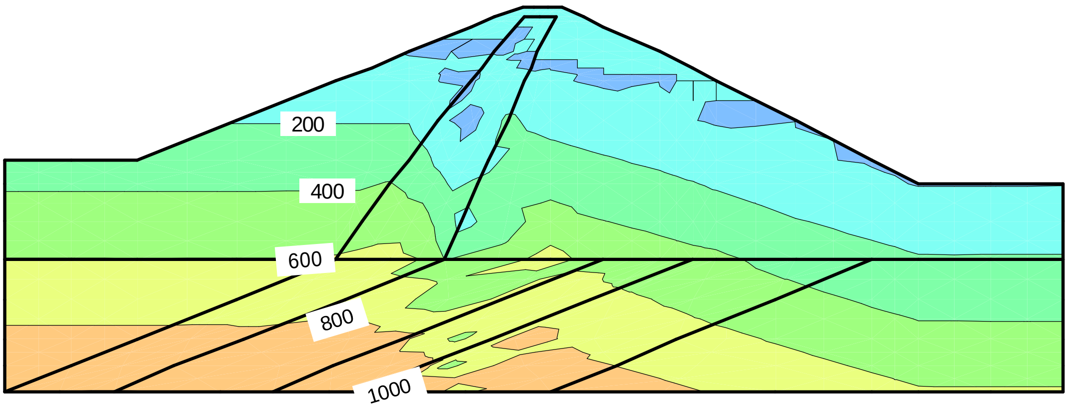
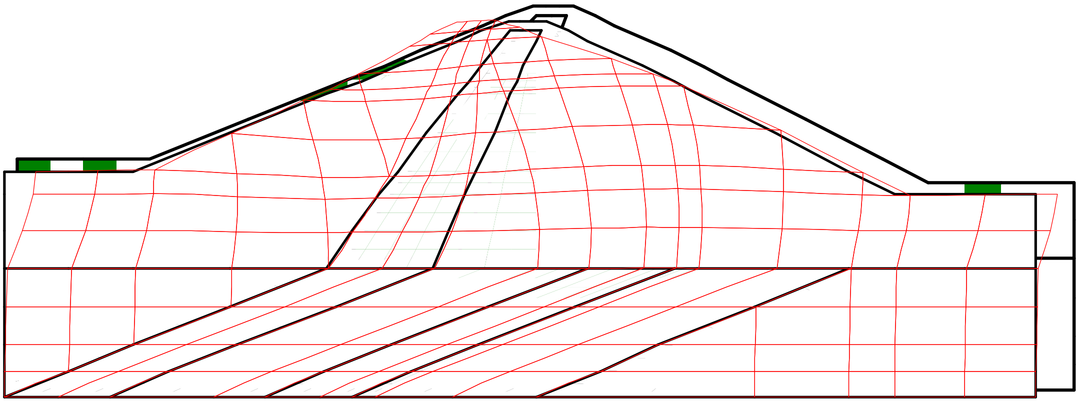


Figure (9): Contour Lines of Pore Water Pressure through the Dam at Different Times (Maximum Horizontal Acceleration = 0.05g).



(a) time = 60 sec.
(b) time = 600 sec.

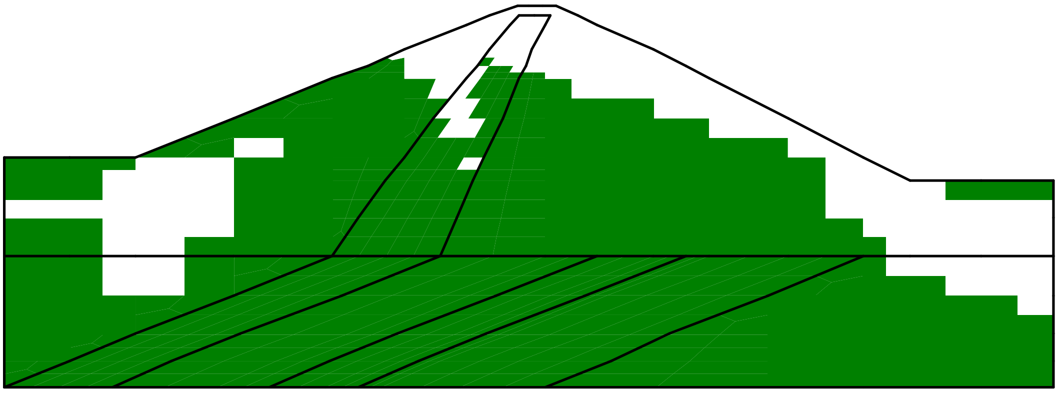
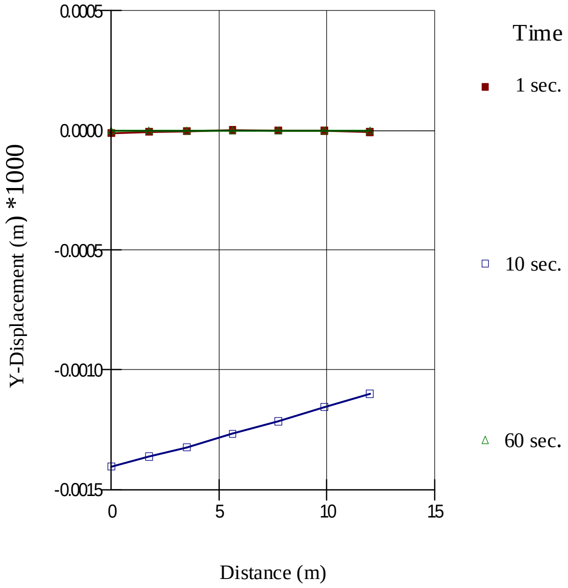


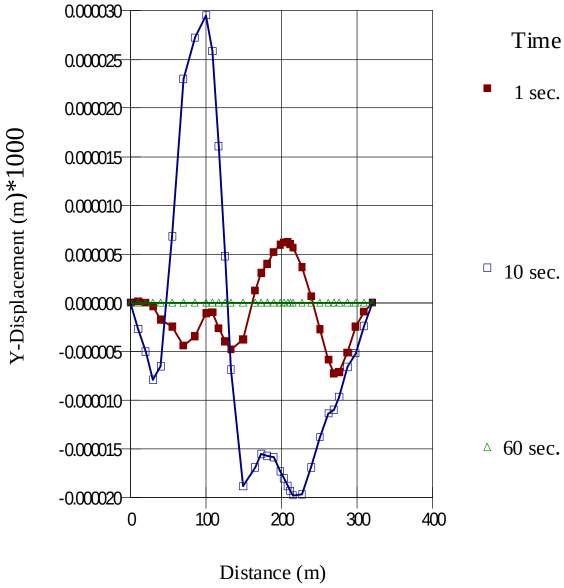
Figure (10): Propagation of Liquefaction Zones through the Dam (Maximum Horizontal Acceleration = 0.05g).

Figure (11): Deformed Shape of the Dam after 2.14 sec. (Maximum Horizontal Acceleration = 0.05g).



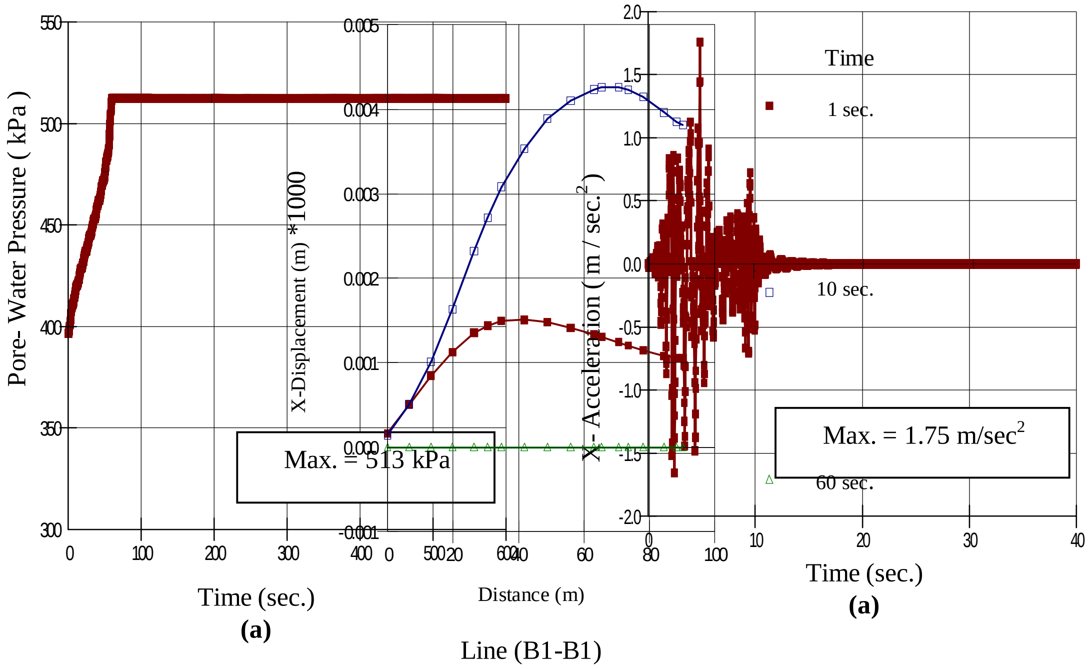
Line (A1-A1)

(a)



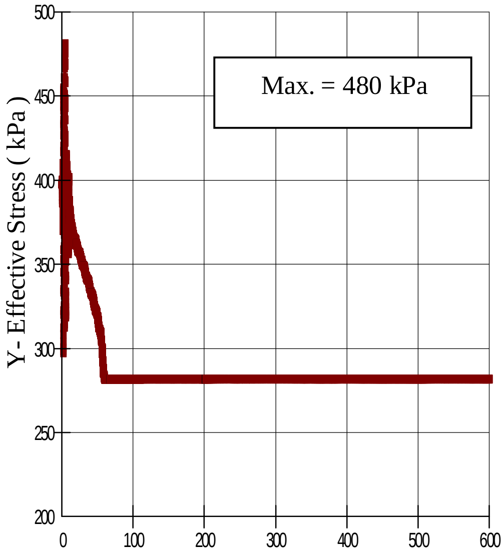
Line (A2-A2)

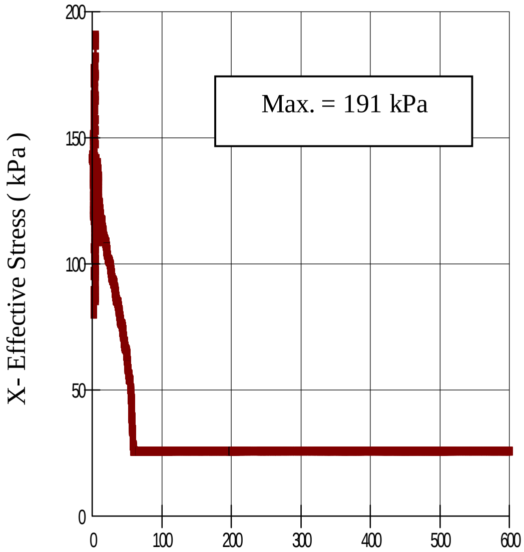
(b)



(c)

Figure (12): Earthquake Response along Different Sections of the Dam (Maximum Horizontal Acceleration = 0.1 g).

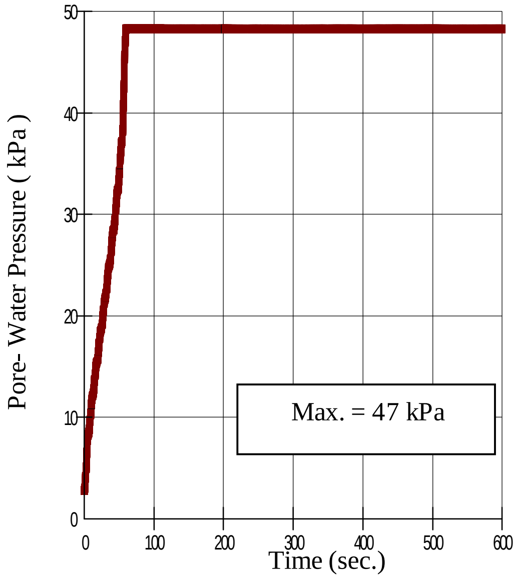




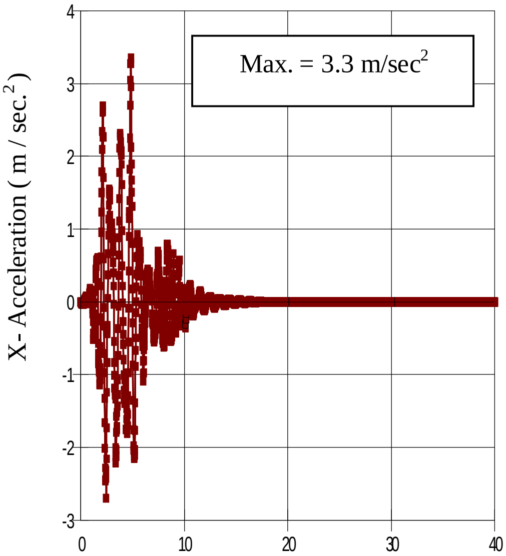
Time (sec.)
(d)

Time (sec.)
(c)

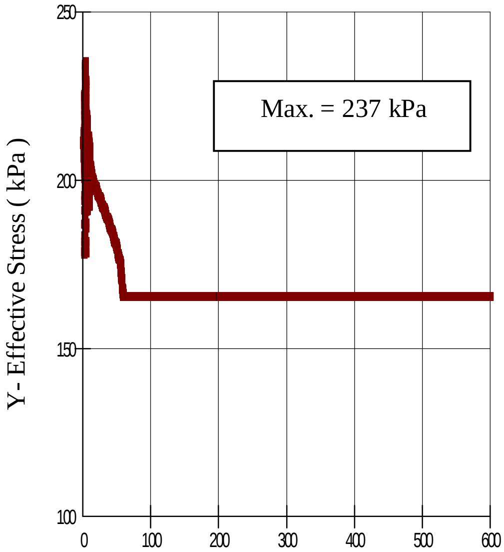
Figure (13): Earthquake Response of Node (310)
(Maximum Horizontal Acceleration = 0.1 g).

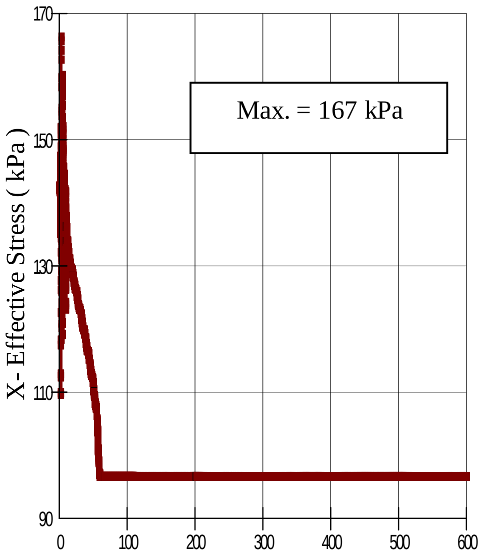


(a)



Time (sec.)
(b)

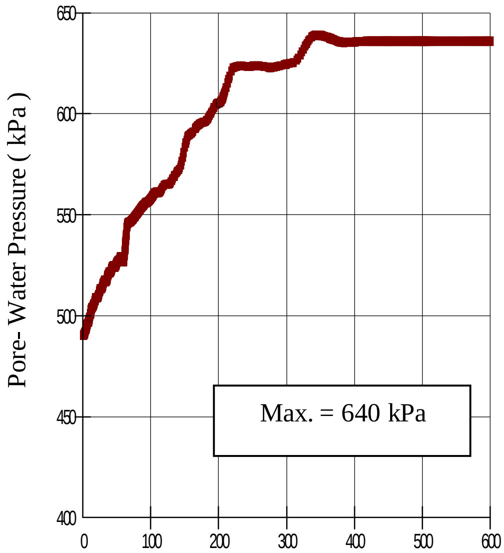




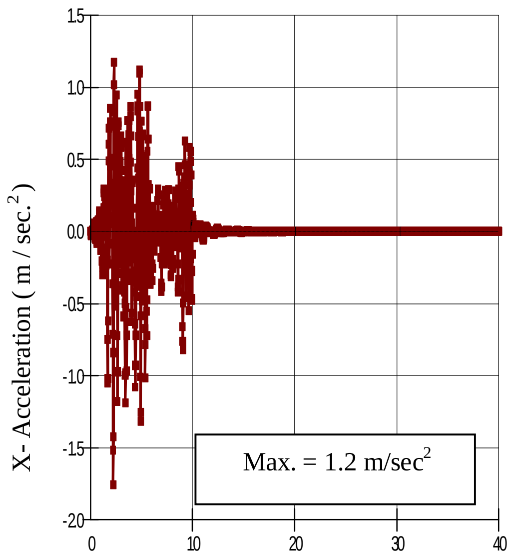
Time (sec.)
(d)

Time (sec.)
(c)

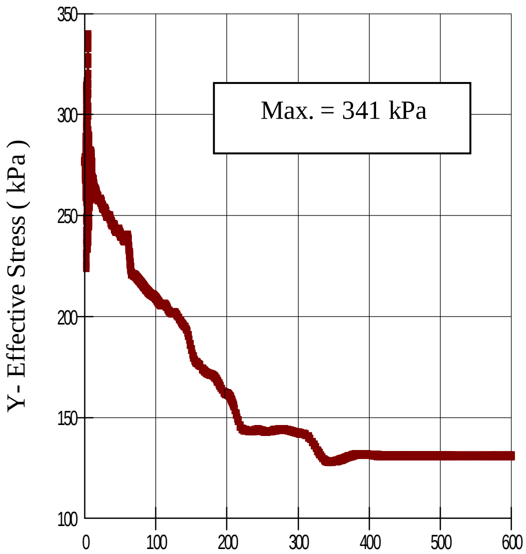
Figure (14): Earthquake Response of Node (477) (Maximum Horizontal Acceleration = 0.1 g).

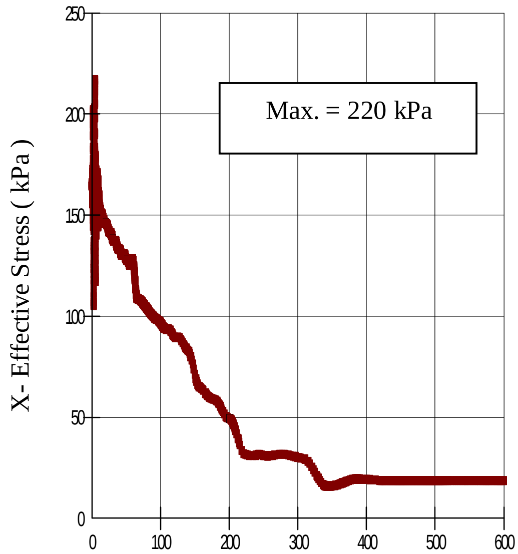


Time (sec.)
(a)



Time (sec.)
(b)





Time (sec.)
(d)

Time (sec.)

(c)

Figure (15): Earthquake Response of Node (253) (Maximum Horizontal Acceleration = 0.1 g).

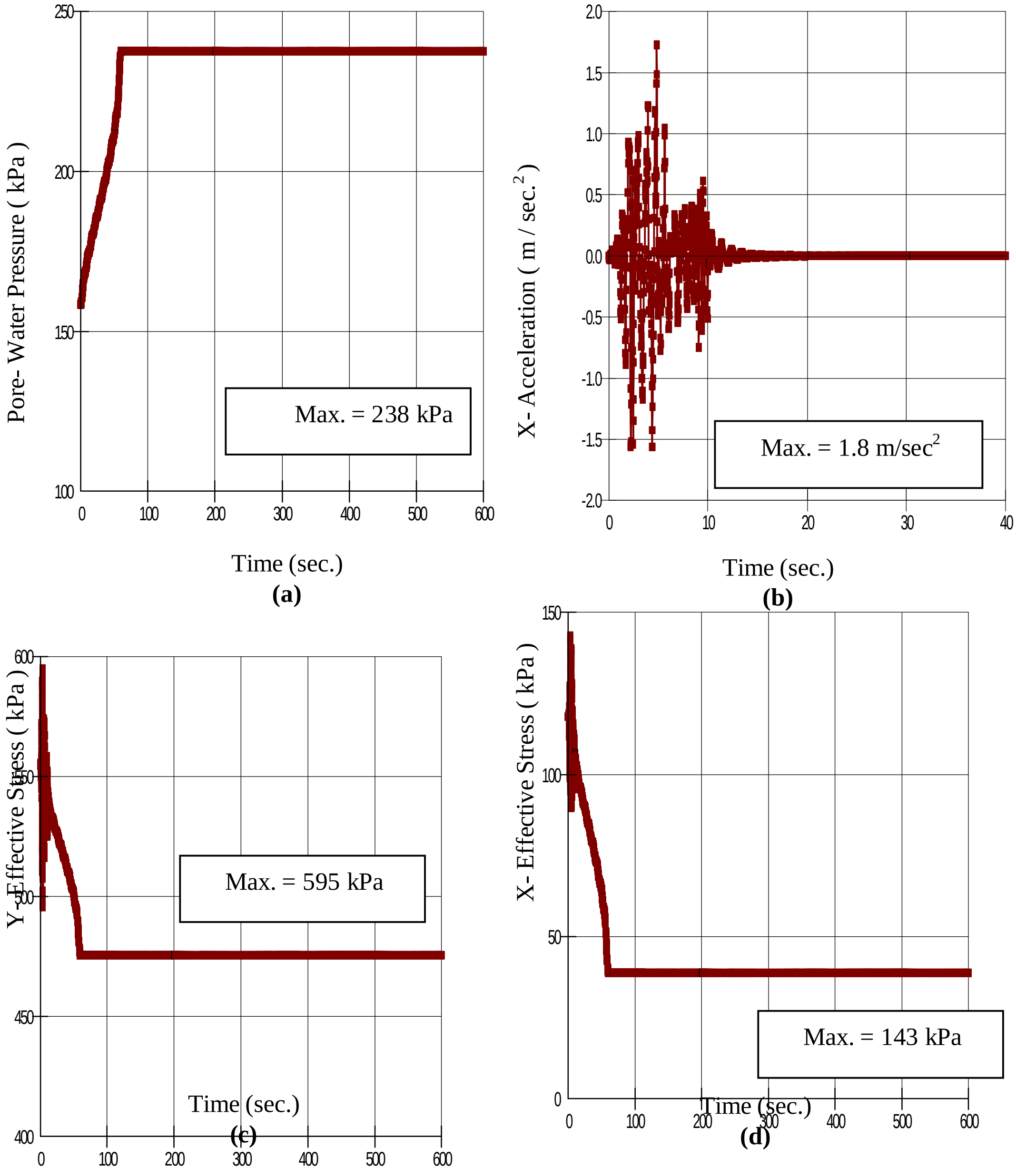
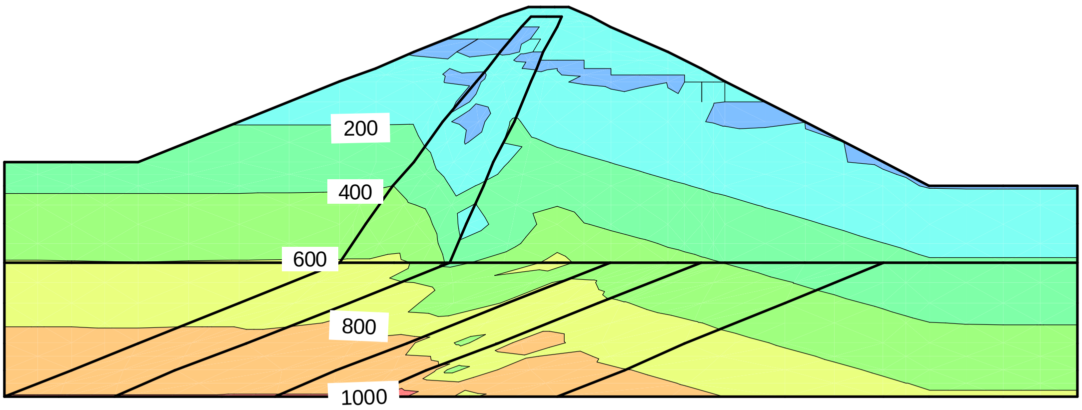
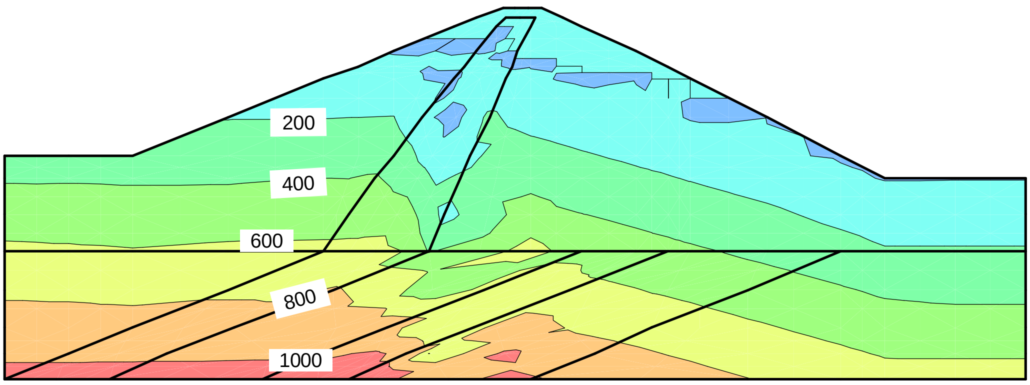


Figure (16): Earthquake Response of Node (342)
(Maximum Horizontal Acceleration = 0.1 g).

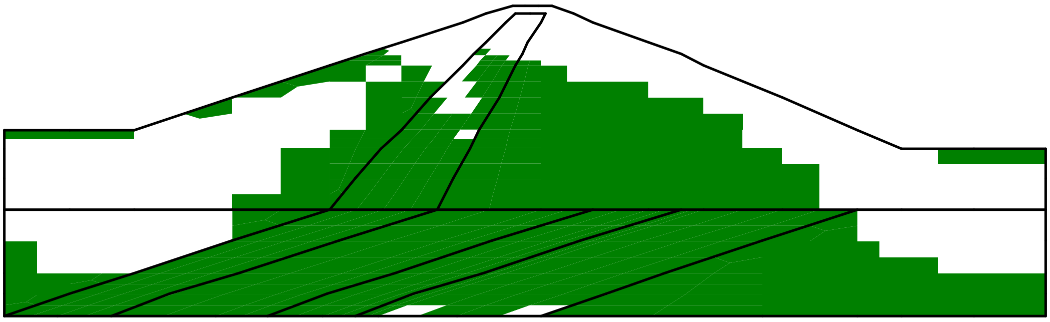


(a) time = 2.14 sec.

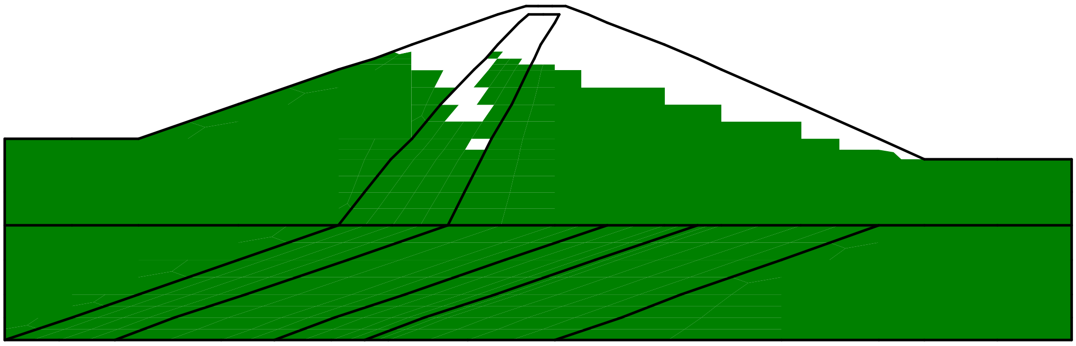


(b) time = 10 sec.

Figure (17): Contour Lines of Pore Water Pressure through the Dam at Different Times (Maximum Horizontal Acceleration = 0.1 g).



(a) time = 60 sec.



(b) time = 600 sec.

Figure (18): Propagation of Liquefaction Zones through the Dam (Maximum Horizontal Acceleration = 0.1g).

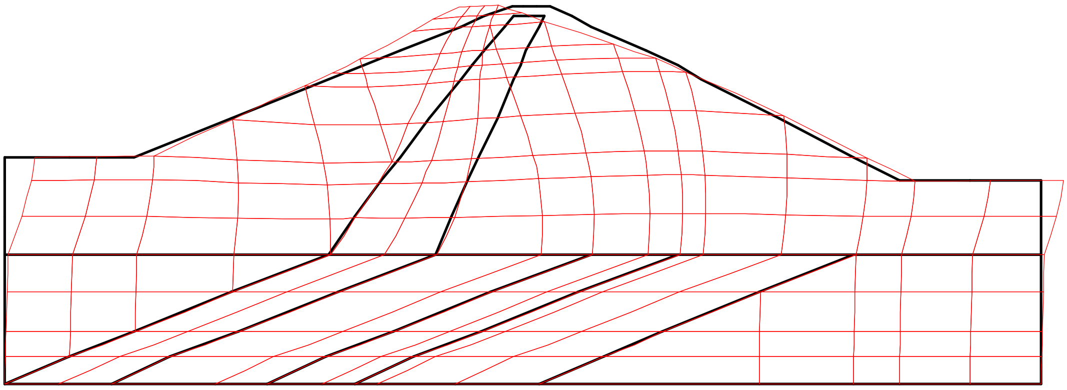
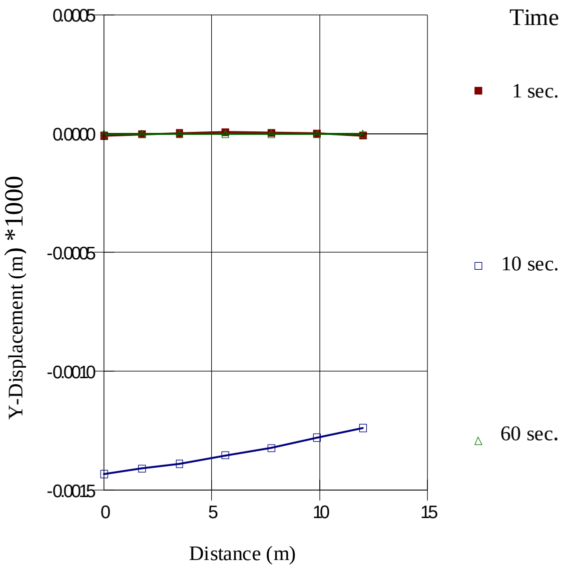
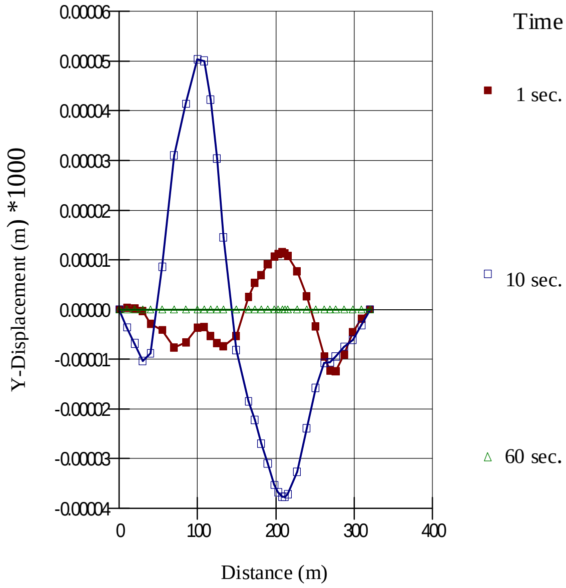


Figure (19): Deformed Shape of the Dam after 2.14 sec. (Maximum Horizontal Acceleration = 0.1g).



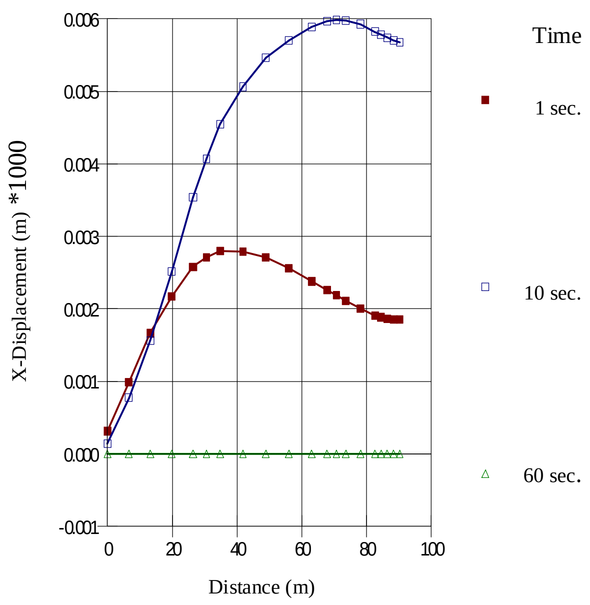
Line (A1-A1)

(a)



Line (A2-A2)

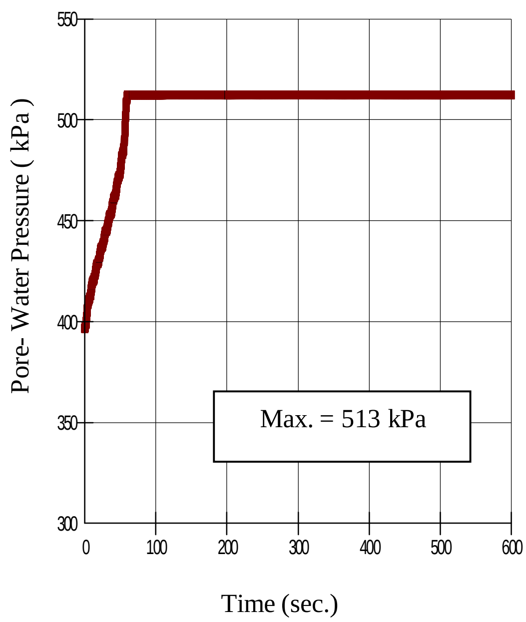
(b)



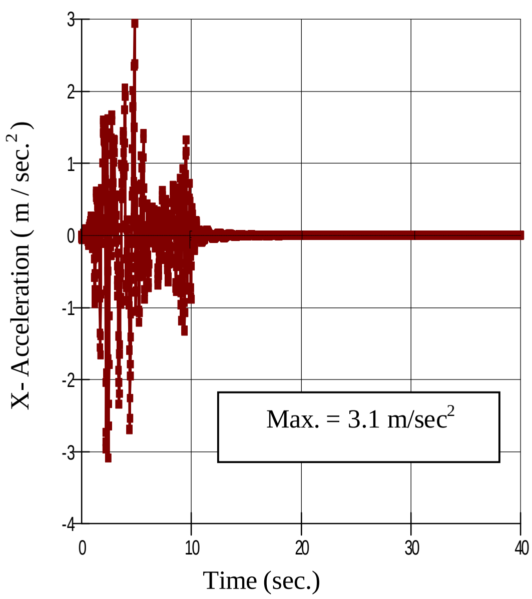
Line (B1-B1)

(c)

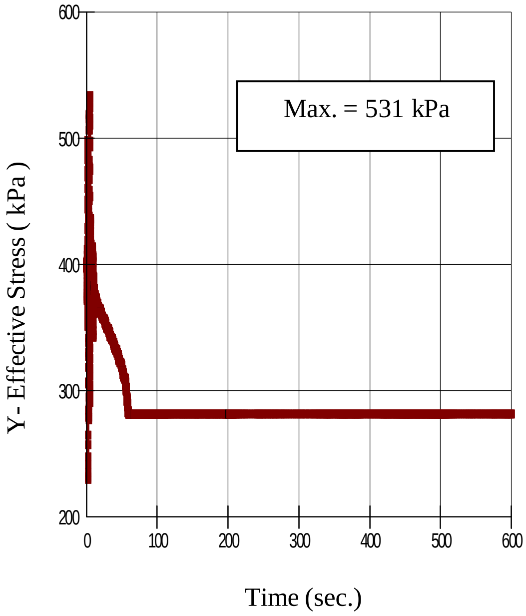
Figure (20): Earthquake Response along Different Sections of the Dam (Maximum Horizontal Acceleration = 0.2g).



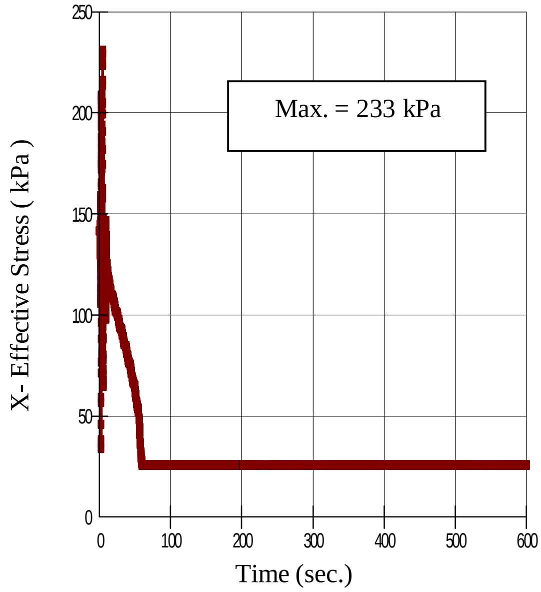
(a)



(b)

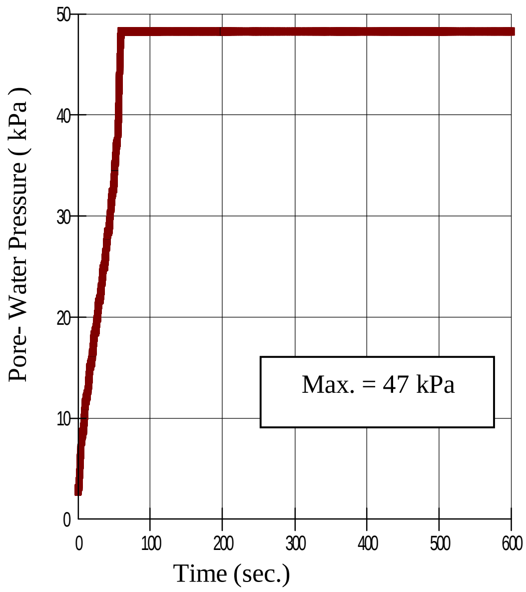


(c)

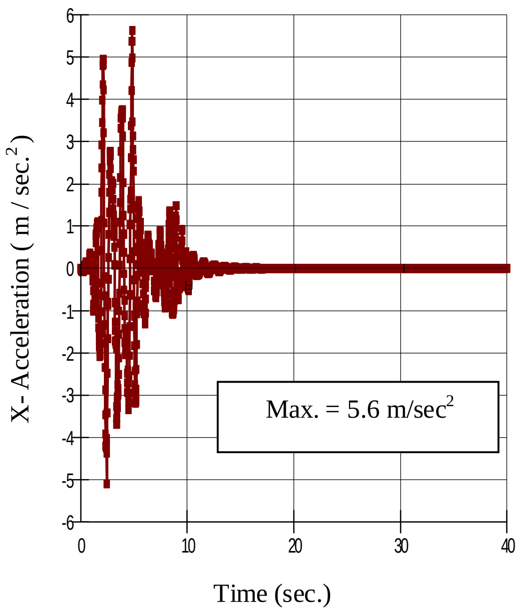


(d)

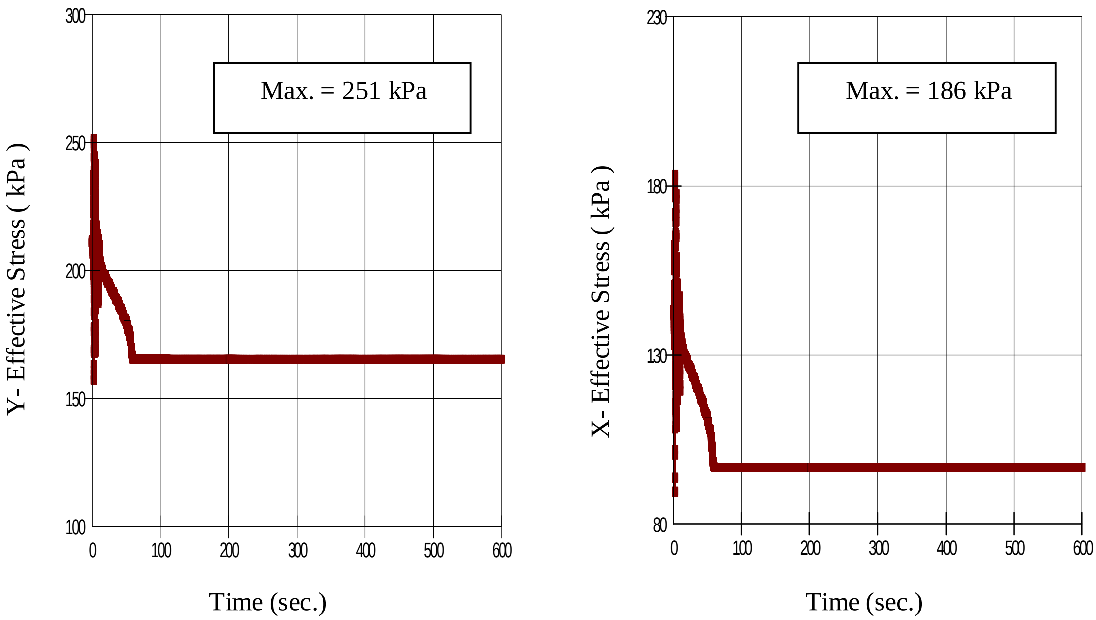
Figure (21): Earthquake Response of Node (310) (Maximum Horizontal Acceleration = 0.2g).



(a)

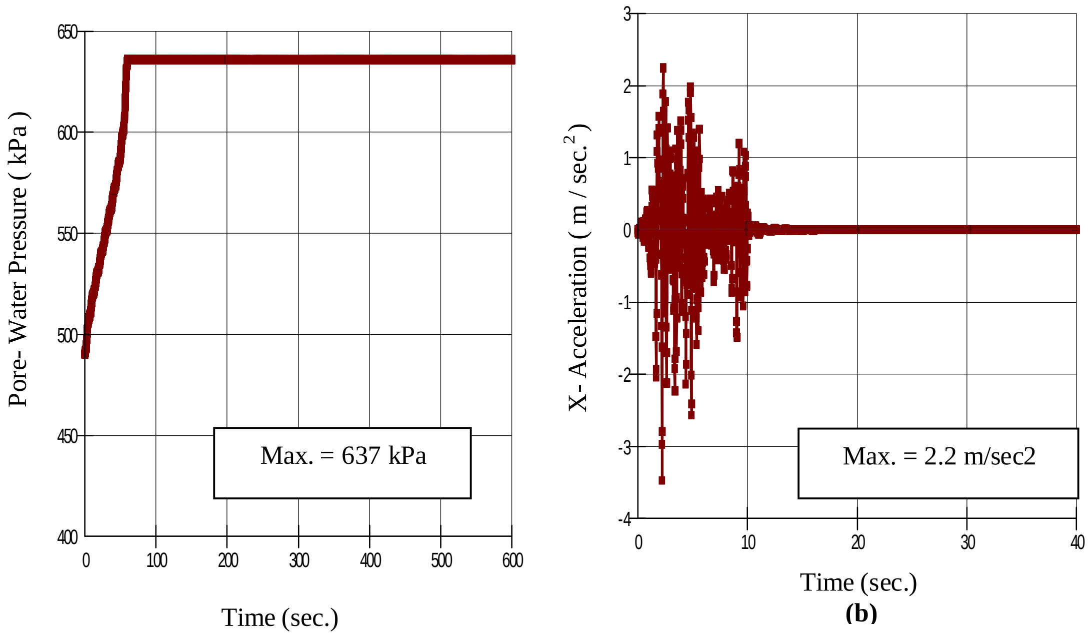


(b)

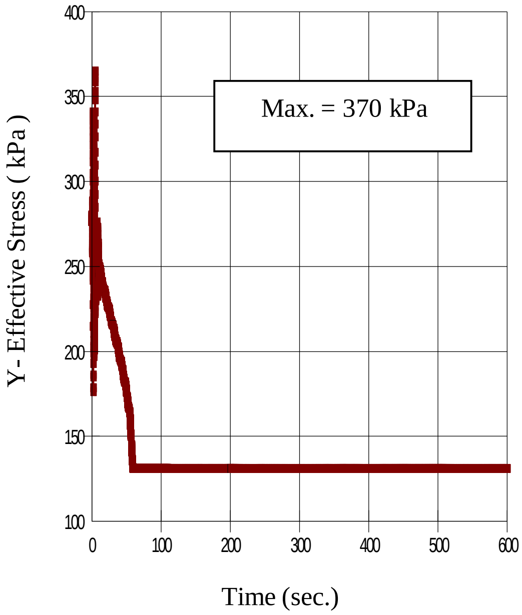


(c) **(d)**

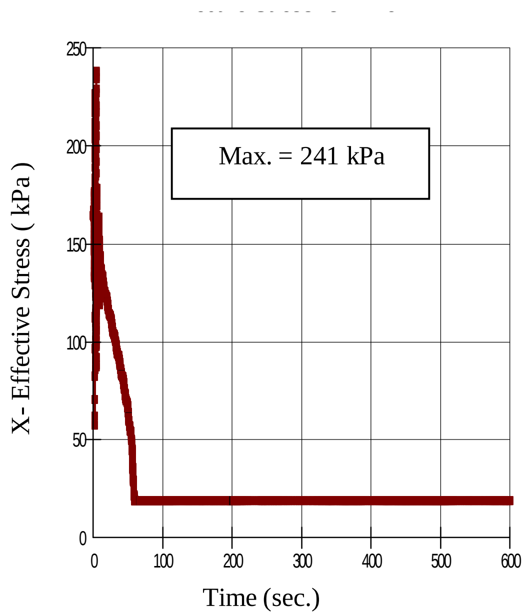
Figure (22): Earthquake Response of Node (477)
(Maximum Horizontal Acceleration = 0.2g).



(a) **(b)**

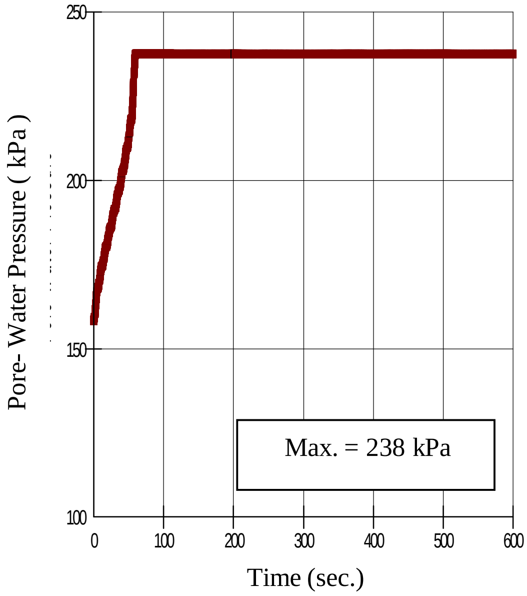


(c)

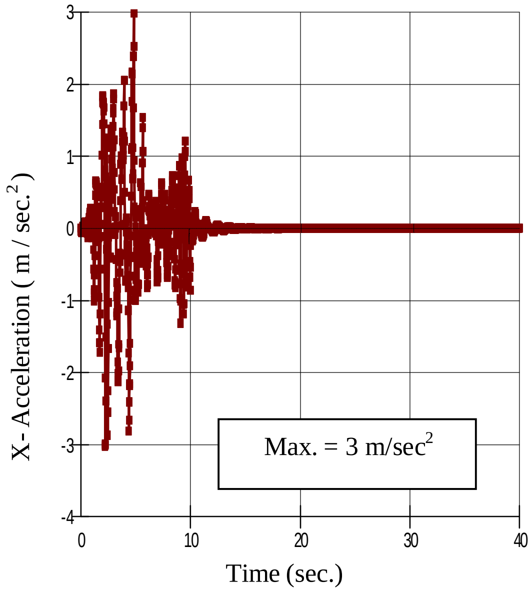


(d)

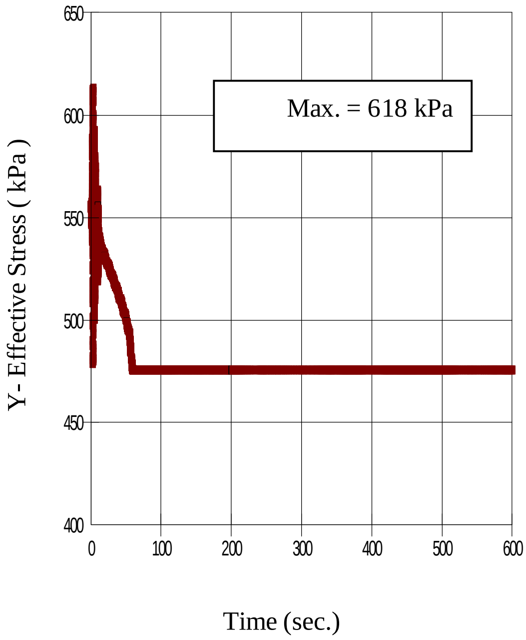
Figure (23): Earthquake Response of Node (253) (Maximum Horizontal Acceleration = 0.2g).



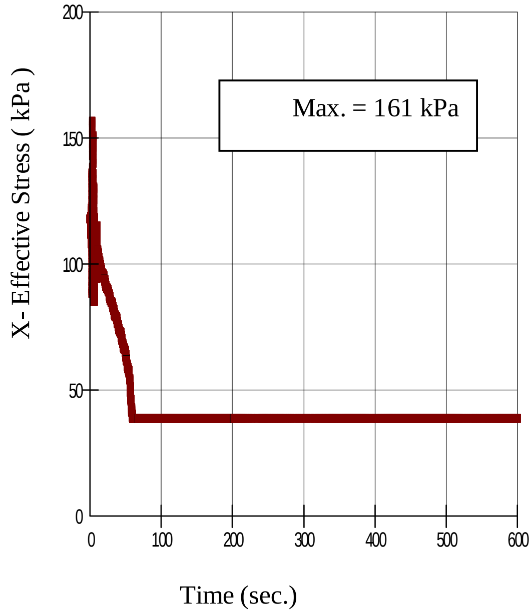
(a)



(b)

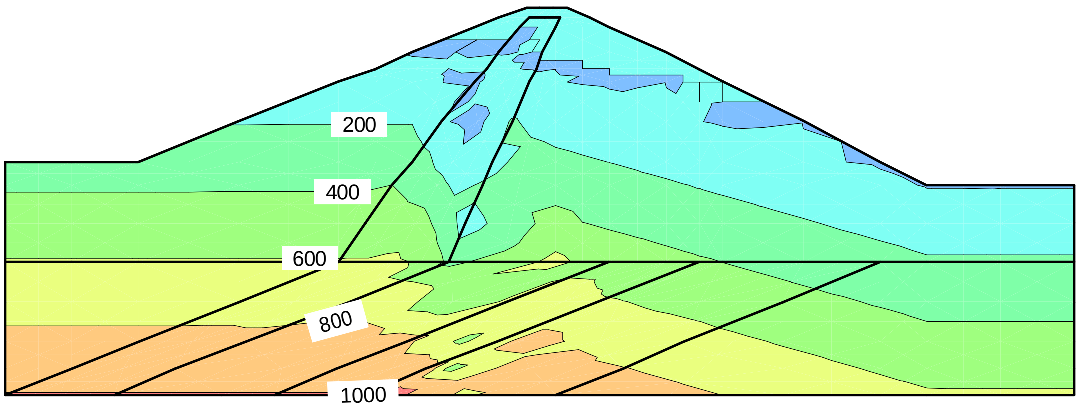


(c)

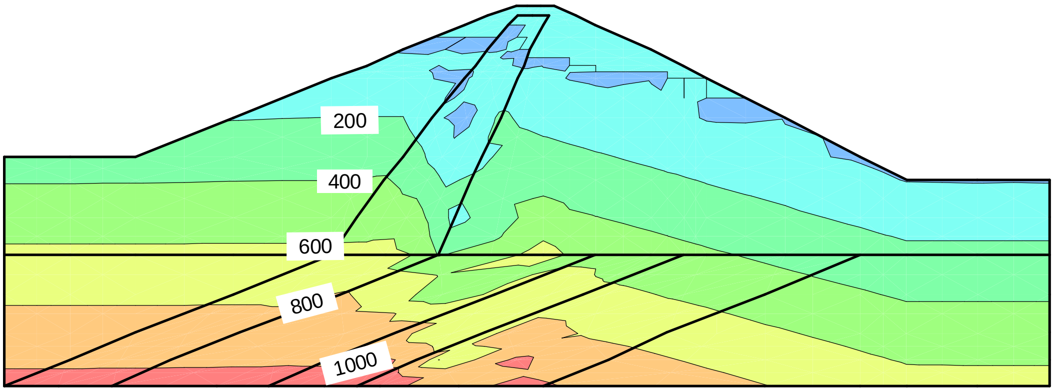


(d)

Figure (24): Earthquake Response of Node (342) (Maximum Horizontal Acceleration = 0.2g).

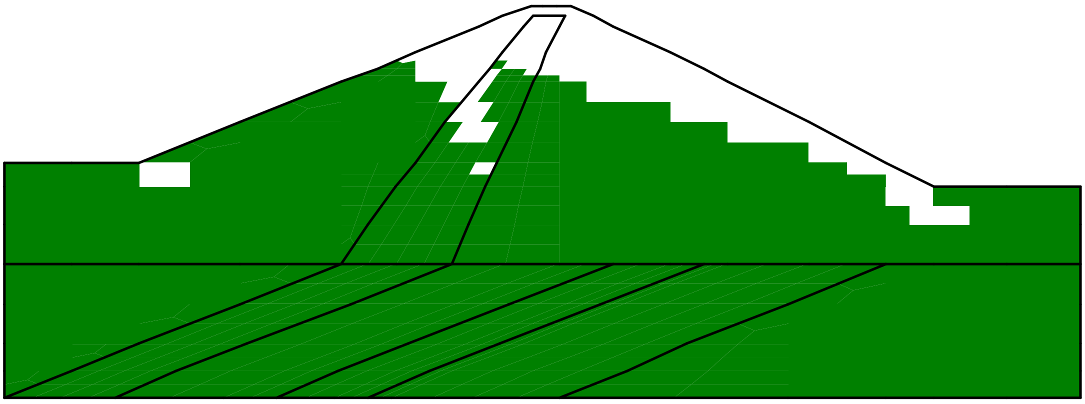


(a) time = 2.14 sec.

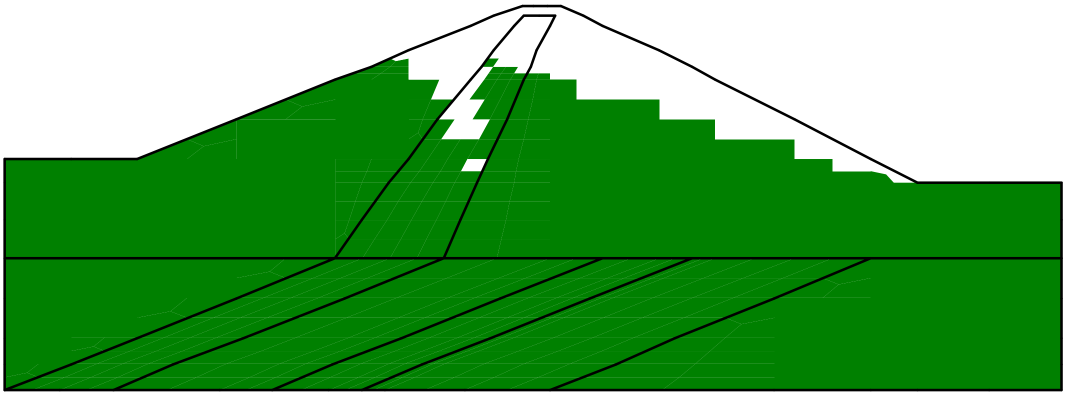


(b) time = 10 sec.

Figure (25): Contour Lines of Pore Water Pressure through the Dam at Different Times (Maximum Horizontal Acceleration = 0.2g).



(a) time = 60 sec.



(b) time = 600 sec.

Figure (26): Propagation of Liquefaction Zones through the Dam (Maximum Horizontal Acceleration = 0.2g).

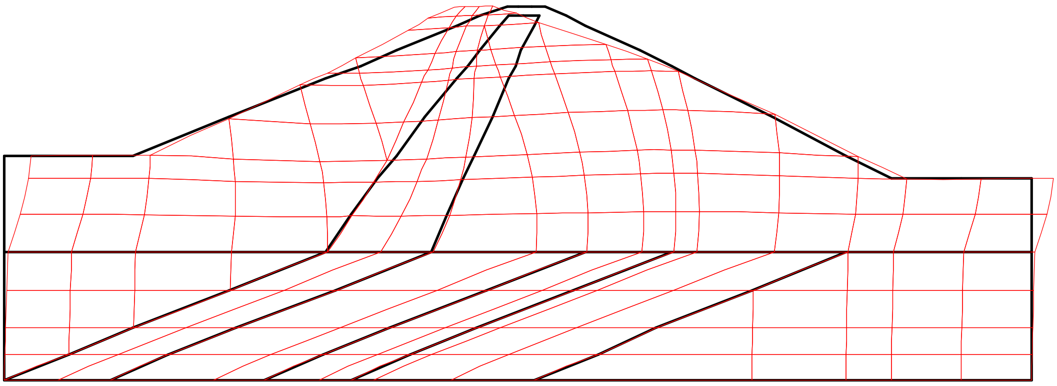


Figure (27): Deformed Shape of the Dam after 2.14 sec. (Maximum Horizontal Acceleration = 0.2g).