Effect of Oval Shape Tunnel on Existing Buildings Under Seismic Loading

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***Abstract*—- This paper deals with analysis of the time history response of the soil profile surrounding tunnel during earthquakes. The analysis presented illustrates the behavior of buildings due to oval shape tunneling under seismic loading condition. Generally tunnels have a fairly high safety against earthquakes. However, at the earth surface the reaction to the earthquake action may lead to more complicated consequences. The proposed approach can also be used for estimation of dynamic load influence on development of differential settlement for nearby structure. the impact of the earthquakes on underground and ground structures and it can be evaluated, whether the amount of variations in displacements are in the allowable ranges, and what measures are needed to save the structures in case of excessive displacement A real tunnel model which is subjected to earthquake forces was considered and for the purpose of analysis modified numerical program MIDAS 2D was used**

Keywords— *Tunnel, excavation, superstructure, Earthquake, MIDAS 2D, Displacement*

I. INTRODUCTION

One of the most important factors affecting the design of the structures is the impact of the seismic loadings on the design displacements. Whereas, the influences of the near structures on the existing buildings, which sometimes can cause great changes in forces and displacements. Thus, the induced displacement in the adjacent buildings due to newly constructed underground tunnel will be investigated in this study. The behavior of the super structures, such as buildings, bridges, under seismic conditions is highly affected by the underlying soil layer. So far, extensive studies have been carried out to know the impact of the earthquakes on underground and ground structures and it can be evaluated, whether the amount of variations in displacements are in the allowable ranges, and what measures are needed to save the structures in case of excessive displacement. Different shapes of tunnels are shown in figure1.

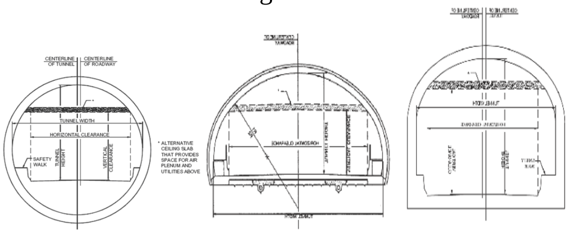


Fig.1: Circular, Horseshoe and Curvilinear (Oval) Tunnel (FHWA, 2005a)

II. ENGINEERING APPROACH TO SEISMIC ANALYSIS AND DESIGN

Earthquake effects on underground structures can be grouped into two categories, a) ground shaking and, b) ground failure such as liquefaction, fault displacement, and slope instability. Ground shaking, refers to the deformation of the ground produced by seismic waves propagating through the earth's crust. The major factors influencing shaking damage include: i) the shape, dimensions and depth of the structure ii) the properties of the surrounding soil or rock iii) the properties of the structure and iv) the severity of the ground shaking, Seismic design of underground structures is unique in several ways. For most underground structures, the inertia of the surrounding soil is large relative to the inertia of the structure. Measurements of the seismic response of an immersed tube tunnel during several earthquakes show that the response of a tunnel is dominated by the surrounding ground response and not the inertial properties of the tunnel structure itself. The focus of underground seismic design, therefore, is on the free field deformation of the ground and its interaction with the structure. The emphasis on displacement is in stark contrast to the design of surface structures, which focuses on inertial effects of the structure itself. This led to the development of design methods such as the Seismic Deformation Method that explicitly considers the seismic deformation of the ground. Many researchers present a review on the seismic behavior and design of underground structures in soft ground with an emphasis on the development of the Seismic Deformation Method. The behavior of a tunnel is sometimes approximated to that of an elastic beam subject to deformations imposed by the surrounding ground.

III. NUMERICAL PROGRAMME

The numerical program reported herein, that involves a real tunnel model which is subjected to earthquake forces are considered. A tunnel of 6.91 m diameter and overburden depth of 18m, 22m and 26m was considered. Soil strata consist of four alternating layers top clay, weather rock, soft rock and hard rock. The left and right structures are placed at a distance of 10 m and 15 m from the center of tunnel and the height of structures are 15m and 21m respectively. A typical cross section shows the information about strata, the alignment of tunnel and other related details in Fig. 2

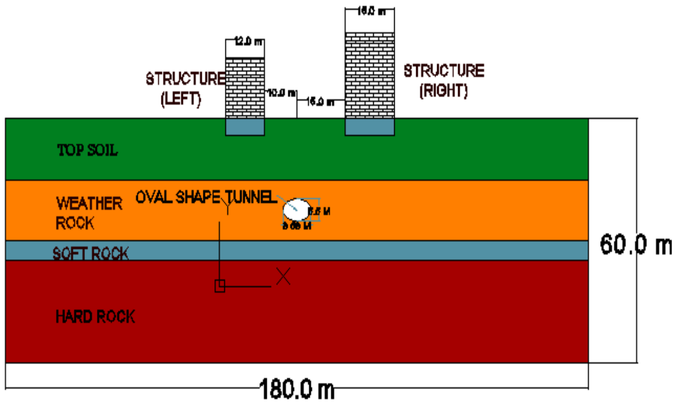


Fig. 2: Ground Profile and The Positions of the Existing Structures and Tunnel in the Selected Model.

A. *Material*

The material properties of the formation and that of the tunnel lining are listed in Table 1 and Table 2 respectively.

TABLE I : MATERIAL PROPERTIES OF GROUND MEDIUM

Depth (m)	DryUnit Weight (kN/m)	Poisons Ratio (µ)	Elastic Modulus *E* (kN/m^2)	Angle of Friction Ø	Cohesion *C* (kN/m^2)
15	18	0.3	40000	33	28
15	21	0.3	200000	37	40
5	24	0.27	1350000	37	100
25	26	0.2	8900000	55	500

TABLE II: MATERIAL PROPERTIES OF STRUCTURAL MEDIUM.

Sr. No	Material Type	Modulus of Elasticity (kN/m^2)	Poisons Ratio (µ)	Unit Weight (kN/m^3)
1	Structure	20000000	0.2	25
2	Soft Shotcrete	5000000	0.3	24
3	Hard Shotcrete	15000000	0.3	24

B. *Time History Data*

A set of input acceleration time history had been selected from data base records as shown in fig.3 and 4. The finite element software MIDAS GTS 2D has been used to perform two dimensional dynamic analyses.

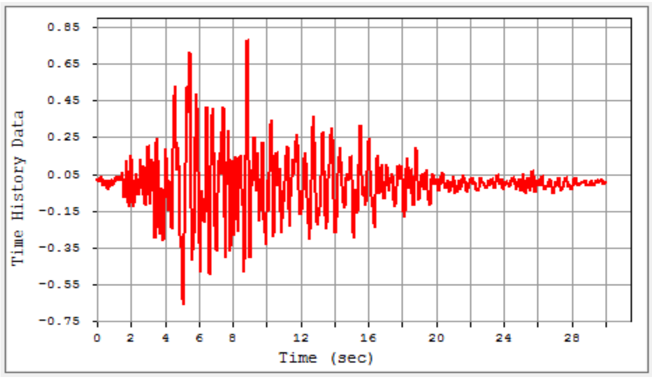


Fig.3: Time History Load Function of T2-I-2(1995,Hyougoken_South,EW) Earthquake.1

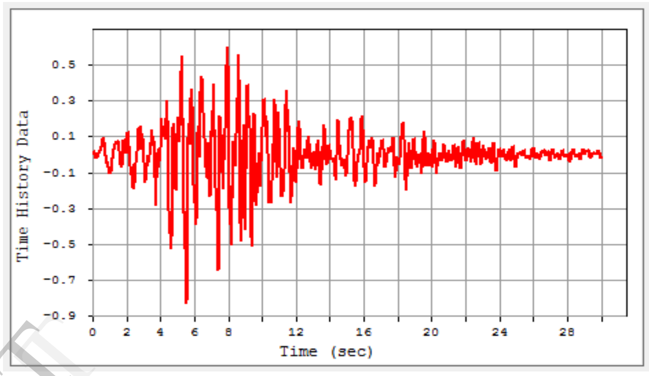


Fig 4: Time History Load Function of T2-I-1(1995,Hyougoken_South,NS) Earthquake.2

II. NUMERICAL ANALYSIS

The behavior of building due to tunneling under seismic loading had been studied using MIDAS 2D (GTS) software. Initially the analysis had been carried out only for Oval shape single tunnel with and without seismic loading at different depth. Then twin tunnel of different spacing with different seismic loading at different depth and analysis was carried out.

A) *Case Details*

The numerical analysis presented hear was used to examine the effect of dynamic loads on the stability of nearby structures particularly buildings, tunnels and especially due to earthquakes. Vertical and horizontal displacements were estimated to examine the behavior of structure under following cases, as mentioned in table.3

TABLE III: DIFFERENT CASE DETAILS.

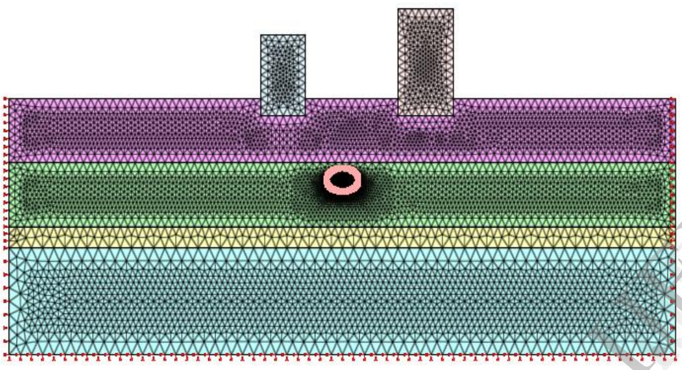
Case I	18 m depth
Case II	22 m depth
Case III	26 depth

B) Computational Soil Models of Tunnel.

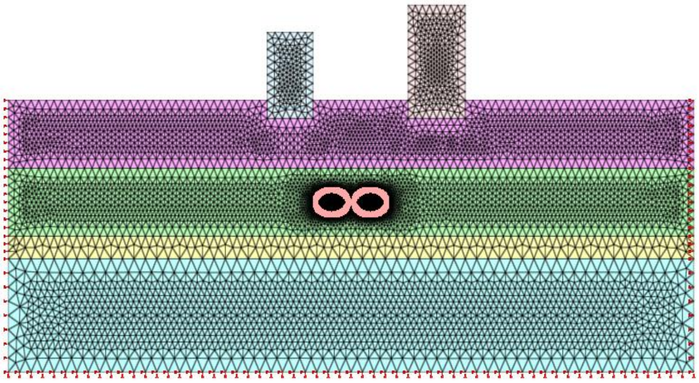
The soil model dimensions were chosen keeping in view the width of tunnel excavation, ground conditions and neighboring structures. The model should encompass 3 to 4 times the width of tunnel excavation on each side of the tunnel and more than 2 to 3 times the tunnel height below the tunnel and above the tunnel up to ground surface, except for the cases where elastic boundary conditions (boundary elements, infinite elements, etc.) are assigned. Engineering judgment should be used if the depth of the ground above the tunnel is very deep in such a case, modeling to the ground surface may not be necessary.

C) *Computational MIDAS 2D models for Oval Shape Tunnel.*

The models for single and twin oval shape tunnel in MIDAS 2D with and without seismic loadings are shown in Fig.5



a) Single Tuneel



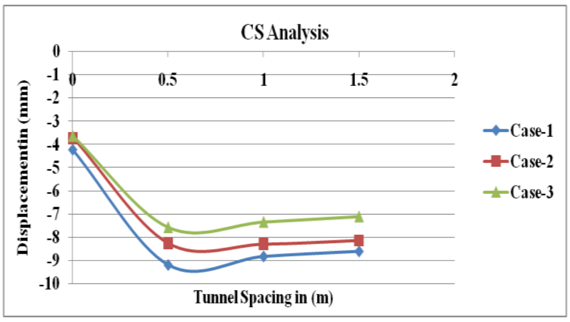
b) Twin Tuneel

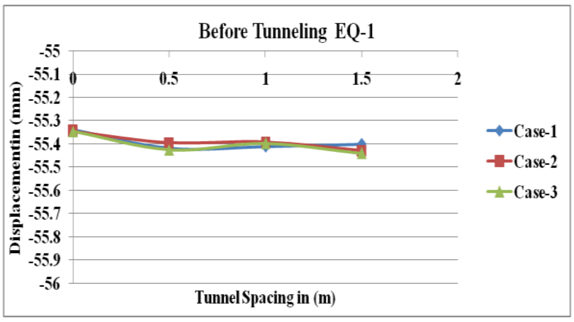
Fig. 5: The finite element mesh of the numerical model for single and twin tunnel.

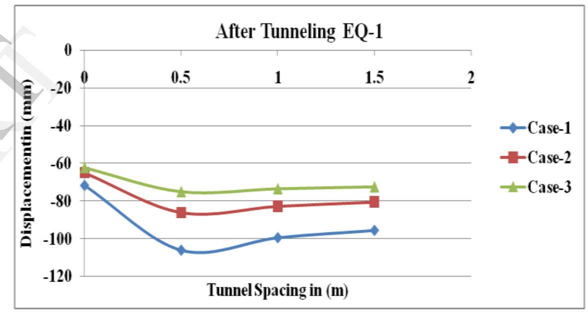
IV. RESULTS AND DISCUSSION

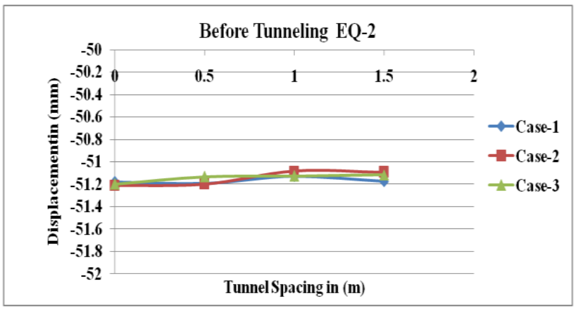
From the results obtained by analysis of tunnel in given strata, a vertical displacement and horizontal displacement curves are obtained in MIDAS 2D as shown in fig. 6 and 7.

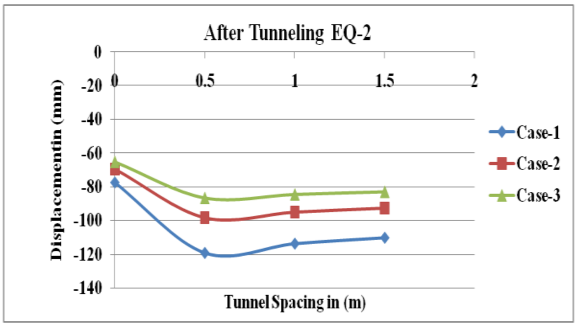
STRUCTURE-1











STRUCTURE-2 STRUCTURE-1

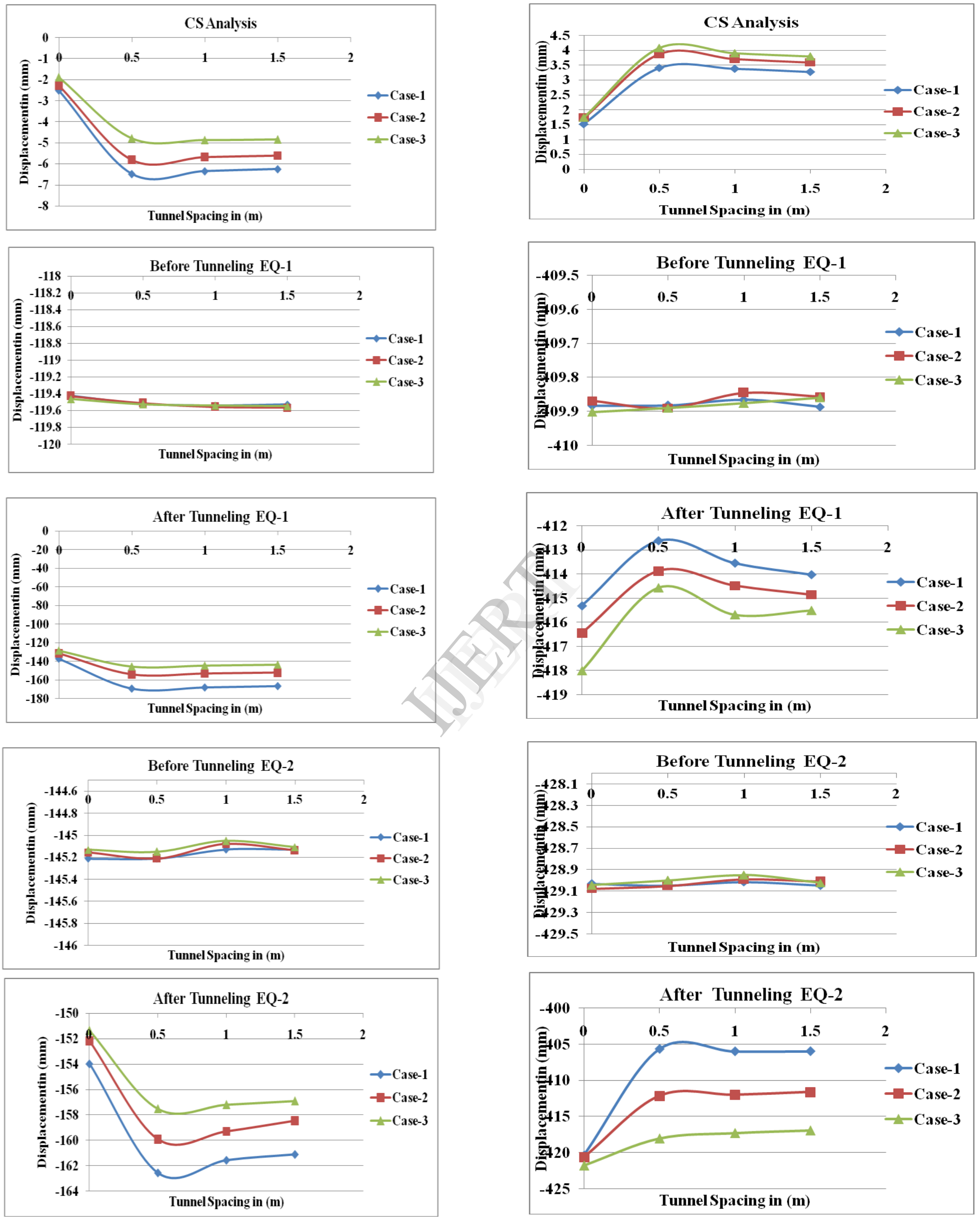


Fig.6 Vertical Displacement graphs for Earthquake. (EQ1) and (EQ2) before and after tunneling.(Stucturer-1&2)

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STRUCTURE-2

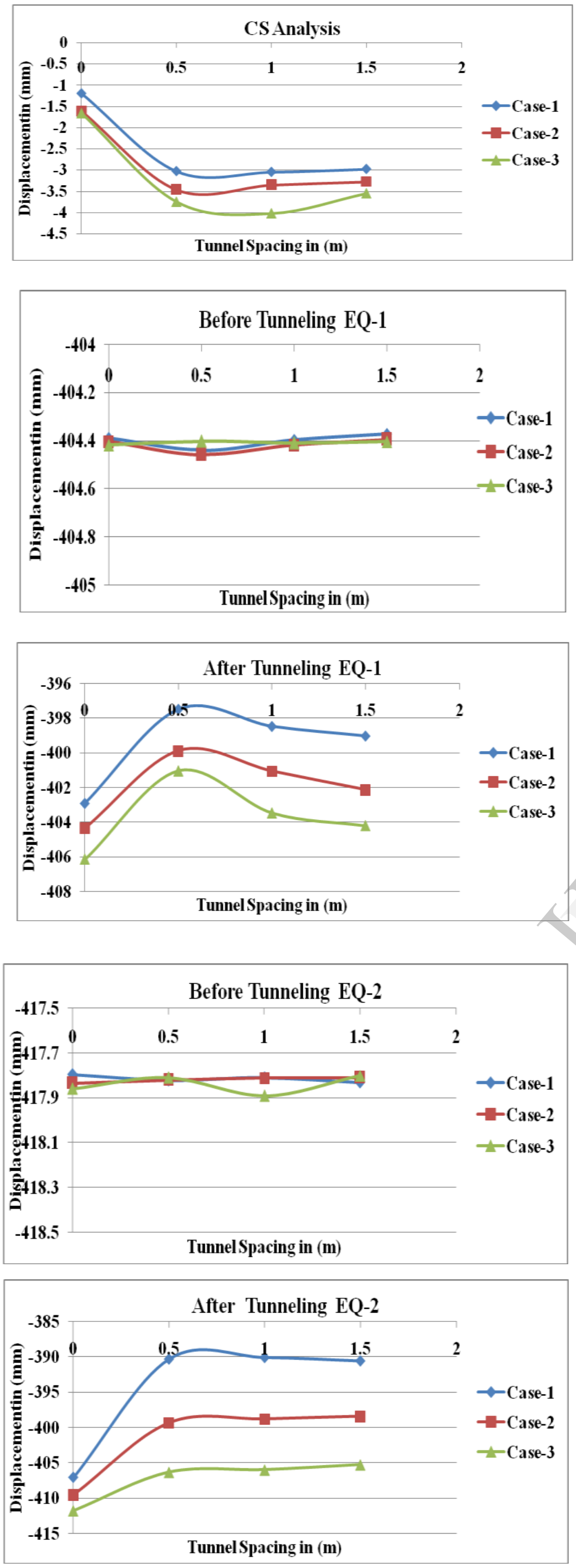

Fig.7Horizontal Displacement graphs for Earthquakes (EQ1) & (EQ2) before and after tunneling. (Structure-1&2)

Summery

The dynamic analysis of model before and after excavation of the underground tunnel (case I, case II and case III) using Time History Load Function of T2-I-2 (1995, Hyougoken_South, EW) and T2-I-1 (1995, Hyougoken_ South, NS) Earthquakes were carried out. The adjacent buildings were considered to be 5 and 7 stories. Based on result analyses the variations of the vertical and horizontal displacements of building versus different single and twin tunnel spacing are calculated and given in table IV and V. The percentage variations of the maximum differential displacements after excavation of the tunnel are also presented in the same table.

According to table IV and V, the maximum percentage of variations of the vertical displacement after excavation of tunnel is about 47.69% and 57.11% and horizontal displacement after excavation of tunnel is about -1.76% and -7.06% for Earthquake-1 &2 respectively.

TABLE IV: VERTICAL DISPLACEMENT FOR DIFFERENT CASES.

Case Studied	Vertical Displacement For Eq1		Vertical Displacement For Eq2	
	Change In Max Differential Displacement For Eq1	%Change In Max Differential Displacement For Eq1	Change In Max Differential Displacement For Eq2	%Change In Max Differential Displacement For Eq1
Structure 1				
Single Tunnel	16.40	22.86	26.16	33.82
Twin Tunnel 0.5m Spacing	50.53	47.69	68.15	57.11
Twin Tunnel 1 M Spacing	43.92	44.22	62.69	55.08
Twin Tunnel 1.5m Spacing	40.06	41.96	59.10	53.59
Structure 2				
Single Tunnel	-17.63	-12.86	8.75	5.68
Twin Tunnel 0.5m Spacing	-49.55	-29.31	17.37	10.68
Twin Tunnel 1 M Spacing	-48.31	-28.78	16.45	10.18
Twin Tunnel 1.5m Spacing	-46.90	-28.18	15.99	9.92

TABLE V: HORIZONTAL DISPLACEMENT FOR DIFFERENT CASES.

Case Studied	Horizontal Displacement For Eq1		Horizontal Displacement For Eq2	
	Change In Max Differential Displacement For Eq1	%Change In Max Differential Displacement For Eq1	Change In Max Differential Displacement For Eq2	%Change In Max Differential Displacement For Eq1
Structure 1				
Single Tunnel	5.43	1.31	-8.66	-2.06
Twin Tunnel 0.5m Spacing	2.73	0.66	-23.40	-5.77
Twin Tunnel 1 M Spacing	3.68	0.89	-23.03	-5.67
Twin Tunnel 1.5m Spacing	4.14	1.00	-23.08	-5.69
Structure 2				
Single Tunnel	-1.48	-0.37	-10.75	-2.64
Twin Tunnel 0.5m Spacing	-6.98	-1.76	-27.57	-7.06
Twin Tunnel 1 M Spacing	-5.95	-1.49	-27.78	-7.12
Twin Tunnel 1.5m Spacing	-5.37	-1.34	-27.31	-6.99

V. CONCLUSIONS

The effect of the underground tunnel excavation on the existing building under seismic loading has been studied and investigated. From the results obtained, it is observed that
i) The vertical displacement varies from 22.86% to 57.11% for structure 1.
ii) The vertical displacement varies from 2.68% to29.31% for structure 2.
iii) The horizontal displacement varies from 0.66% to 5.77% for structure 1.
iv) The horizontal displacement varies from 0.37% to6.99% for structure 2. Therefore it is need to be considering vertical displacement while designing tunnel.

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