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Parametric study of the behavior of concrete block quay walls, considering near-field records, the case of Pars petrochemical port

*Pouya madanipour[1], Mahdi dehghanirenani[2] and Hamid zafarani[3]

[1]Sadra Institute, Tehran, Iran

[2] Group of Civil Engineering, Project Management Dept ,National Petrochemical Company, Tehran, Iran

[3]International Institute of Earthquake Engineering and Seismology, Tehran, Iran

[1]pooya_874@yahoo.com

ABSTRACT

This paper is focused on a parametric study of the effect of cohesion in a silt layer of soil on the behavior of quay walls under the combined effect of horizontal and vertical components of earthquake. The wall used in this study is a crookback gravity wall which utilizes its own weight to resist against soil's active pressure, lateral pressure, and gravity. The studied quay is the Southern Pars Quay(Asaluyeh), located 4 km from a known active reverse fault. The effect of the vertical component that can cause instability in gravity structures cannot be ignored in the near-field region. Here, the ABAQUS software has been used. Some simplifications were necessary due to the complexity of the model. For instance, the effect of free water is considered using the Westergaard added mass approach, and the soil conditions are assumed to be such that liquefaction does not occur. The vertical and horizontal components used in the study are the near-field data from the Tabas (M7.4), and the Bam (M6.5) earthquakes. The results of the analysis show that under the assumptions of this study, the effect of variations in the cohesion of the silt layer, and the vertical component are negligible.

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[1] Graduate Student

[2] Assistant Professor

[3] Assistant Professor

1. Introduction

With the increasing use of retaining structures, additional fees should be charged for construction of these structures. Taking into account the placement of the structures in the vicinity of the water saturated porous media and the complex behavior of quakemotions, makes it necessary to investigate the exact function of them in order to design more economical and more efficient ones. The quay walls can be classified in terms of wall type andflexibility. The quay wall examined here, in terms of type, is weighting and in terms of flexibility s rigid. There are many factors that play arolein the design of quay walls e.g. soil and water pressure, watersuctionforcecreatedbythe earthquakeandtheverticaland horizontalcomponents ofthe earthquake (inertia force of the wall). Since the Kobe, Japan earthquake in 1995 severelydamaged gravity type quay walls in the Kobe port, severalresearchers have analyzed the causes of the damages by modeltests and theoretical methods.Theproblemaddressed inthis paperistheeffectofnear-field characteristics of earthquakemotiononthequay wall seismic behavior. Specific characteristics of near-field motions introduce newproblems into the design of structures and special conditions. Alarge long-periodpulse andlarger vertical component (in comparison with the far-field regions)canbenotedas specific characteristics of the near-field regions. The traditional assumption of 2/3 for the ratio of vertical to horizontal components of earthquake motion will no longer be hold. There are near-field records (e.g. the Bam station record during the 2003 Bam earthquake, M6.5) in which the vertical to horizontal ratio has exceeded one (i.e. vertical acceleration>horizontal acceleration). According to the regulations of the Coastal Area Development Institute of Japan (OCDI), ifthevertical componentislessthan 70% of the horizontal one, then it will be less than10% effectivein theresultantforceexerted on thewalland can be ignored. However, if the verticalcomponentexceeds thehorizontalcomponent(e.g. like the near-field record of Bam earthquake), it should be consideredin thecalculations. The Pars Petrochemical Port site, located ~2 km fromthe ‘Zagros Mountain Front’ active reverse fault; taking account of near fault aspects in the design of such an important structure system is necessary. Here, a parametric study is performed to analyze the effect of different soil characteristics and recorded near-field ground motion on the seismic stability of quay walls of the Southern Pars Quay. The petrochemical coastal harbor blocks rest freely on each other resulting in a greater impact of the vertical component on the wall system behavior. The main reason for this is that the walls are gravity type and stability of the walls are due to their self-weight, as a result, at the time of the earthquake, vertical component of motion would reduce their weight, and eventually walls may become unstable. Care must be taken that the wall blocks have not been tied into the adjacent block. This reduces the integrity of the coastal blocks together, and will causes/allows the components of retaining wall to act individually.

2. Seismic analysis and performance evaluation

The purpose of the analysis performance-based design, seismic behavior of offshore structures with legal values (displacements, stresses, shape, flexibility and strain), and generally for the higher levels of performance, further analysis potency is required.

Analytical selective methods should have analysis potency in the performance seismic evaluation. There are a variety of analytical methods to assess local site effects, liquefaction potential and seismic response of offshore structures. The analytical methods based on the degree of complexity and analytical potencies are classified as follows:

I. Simplified Analysis: Appropriate for evaluating approximate threshold values shape changes and the values of response elastic and in order to estimate the permanent displacement induced seismic loading.
II. Simplified dynamic analysis: suitable for assessment of shape changes, stress, and strain plasticity based on the assumed failure mode.
III. Dynamic Analysis: modes of failure and for the evaluation of displacement, stress and strain plasticity.

Critical damage structures as the regulation of Japan according to the table 2.

Table.1 types of analysis related to performance grades

Level performance	Type of analysis		
Level C	■		
Level B	░	■	
Level A	░	░	■
Level S	░	░	░

Index:

Preliminary design	░
Standard/final design	■

Table.2 Structural damage criteria in Japanese standard

Type of retaining walls	Water depth	
	Shallower than 7.5 m	Deeper than 7.5 m
Gravity quay wall	Horizontal displacement	Horizontal displacement
- No repair needed for operation	0 to 0.2 m	0 to 0.3 m
- Partial operation allowed	0.2 to 0.5 m	0.3 to 1.0 m
Sheet pile quay wall	Horizontal displacement	Horizontal displacement
- No repair needed for operation	0 to 0.2 m	0 to 0.3 m
- Partial operation allowed	0 to 0.3 m	0.3 to 0.5 m

Table.1 is shown as the most appropriate type of analysis for each of the functional areas. This table was prepared on the basis of the structures with higher performance levels should be evaluated with more sophisticated methods. According to Table 1, the simpler methods for preliminary design, selection of design or analysis of seismic behavior is appropriate.

3. Check situ or in-situ stresses and dynamic

In the first step, to verify the performance of the software, we will consider in-situ stresses (static). For this purpose, the model was evaluated by Pynvt et al, (Fig.1) in the form of software ABAQUS(Fig. 1) is modeled. Materials properties have been used in tables.3 and 4 and the analysis of the seismic profile Table.5 and Fig.2 respectively. In the sides we use damper to absorb the energy of seismic waves which is from the outside .

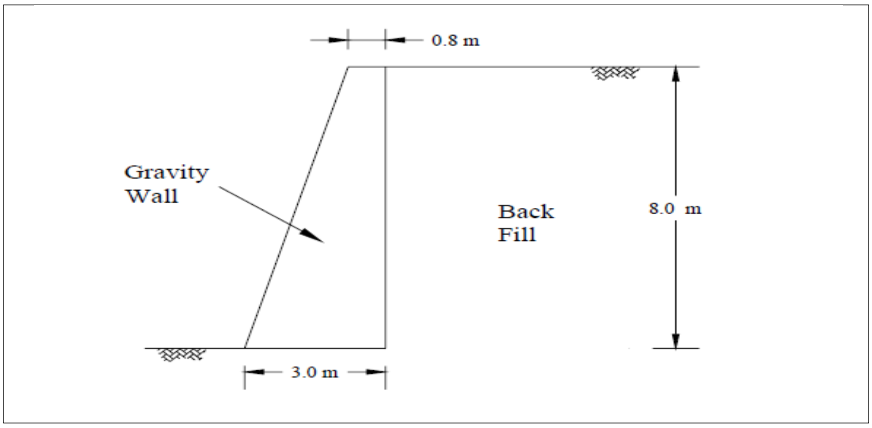

Fig.1 Dimension of gravity wall

Table.3 properties of concrete

Parameters	Value
Elastic modulus of concrete (MPA)	30,000
Density (Kg/m^3)	2406
Poisson's ratio	0.2

Table.4 properties of clay

Parameters	Value
Poisson's ratio	0.34
At-rest pressure coefficient	0.53
Drained cohesion (KN/m^2)	10
Effective friction angle	28
Elastic modulus(MPa)	30.00
Density(Kg/m^3)	1835

Table.5 Ground motion

Earthquake	Station	PGA(g)	Significant duration (s)
Chi-Chi(1999)	CHY 006N chi-chi	0.35	26.03

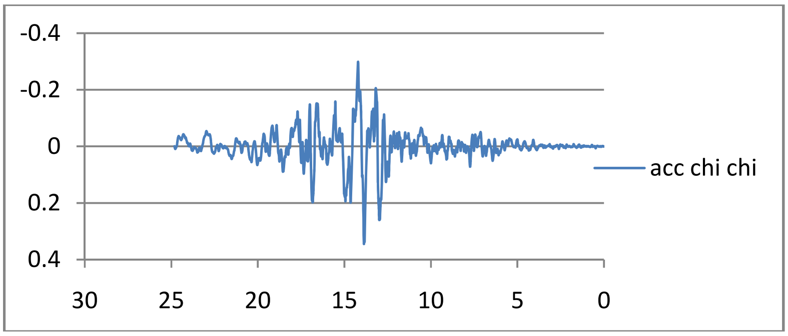

Fig. 2 Chi-Chi (1999) acceleration time-history

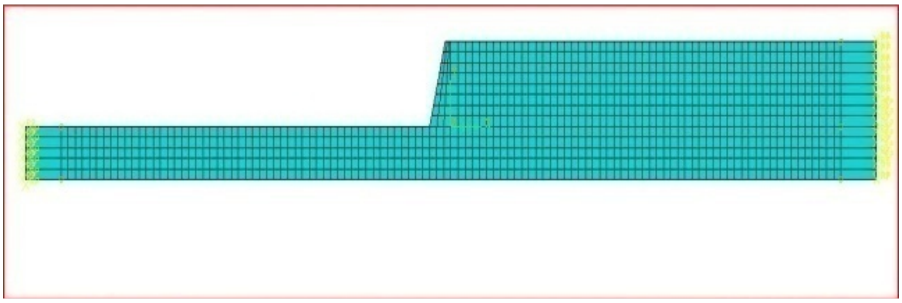

Fig. 3 Finite element mesh for gravity wall

In Figures.4 and 5 the output results compared between the outputs of the Diana and ABAQUS in dynamic mode (horizontal stresses in wall height) shown less than 10% difference and endorsed the performance and accuracy of the software.

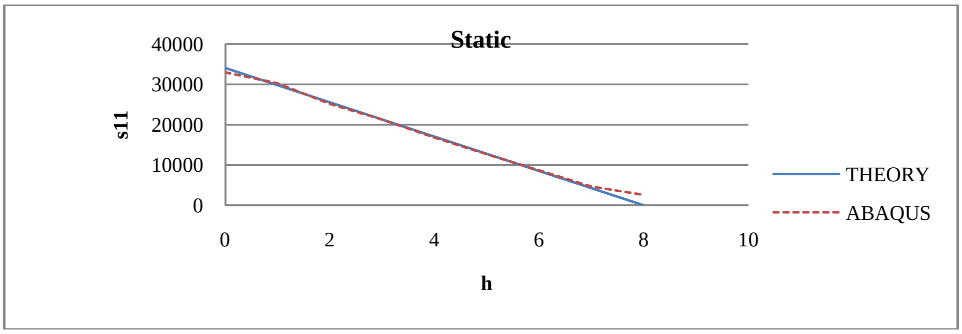

Fig. 4 Comparison of pressures along the gravity wall at the end of the static analysis

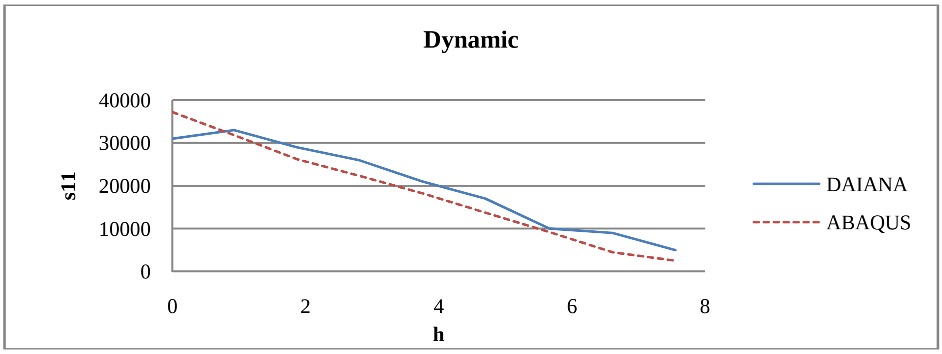

Fig.5 Comparison of pressures along the gravity wall at the end of the dynamic analysis

4. Basic model

The basic model of the form figures.6 and 7 is made. To obtain damping coefficients Rayleigh soil , a frequency analysis is performed first. Obtaining the frequencies of structures for a fixed damping ratio, damping coefficients can obtained. After the frequency analysis , Rayleigh attenuation coefficients should be attributed to soil analysis and dynamic place to be. The first two natural frequencies of the structure after frequency analysis, 6.632 and 8.71 radians per second and Rayleigh damping factor values are obtained as follows.

$\alpha = 0.39$
$\beta = 0.006$

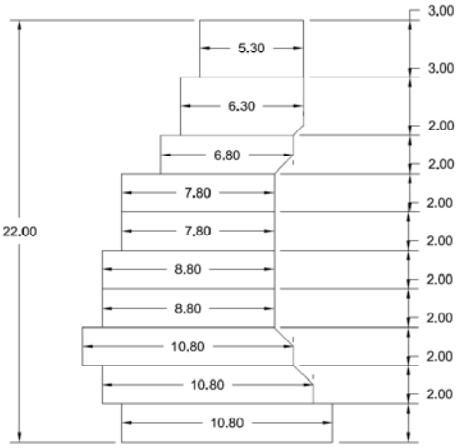

Fig.6 modeling of concrete blocks in ABAQUS (m)

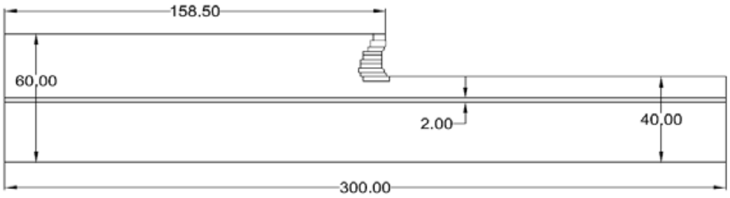

Fig.7 Dimension of model (soil and quay wall)

Specification of concrete, soil and silt layers used in the Tables.6 ,7 and 8 are given. To modeling of soil behavior , Drucker - Prager modeling behavioral is used and according to the following relations of behavioral modeling data Mohr - Coulomb become to model behavior Drucker - Praker. Soil profiles chosen such that the liquefaction model is not going to happen.

$$\tan\beta = \frac{3\sqrt{3}\tan\emptyset'}{\sqrt{9+12\tan^2\emptyset'}} \emptyset' = 37^{\circ} \rightarrow \beta = 44/56^{\circ} \qquad (1), \quad d = \frac{3\sqrt{3}C'}{\sqrt{9+12\tan^2\emptyset'}} C' = 0 \rightarrow d = 0 \qquad (2)$$

Table.6 properties of concrete

Parameters	Value
Elastic modulus of concrete (MPA)	30,000
Poisson's ratio	0.2
Density (Kg/m^3)	2406

Table.7 properties of clay

Parameters	Value
Poisson's ratio	0.3
Effective friction angle	37
Elastic modulus(MPa)	10.00
Density(submerged unit weight soil) (Kg/m^3)	1100

Table.8 properties of silt

Parameters	Value
Poisson's ratio	0.35
Effective friction angle	15 , 20 , 25
Elastic modulus(MPa)	10.00
Density(submerged unit weight soil)(Kg/m^3)	1100

Instead of modeling the soil, removed water from soil and Westergaard added mass method is used to the regulation of Japan and ports design and Marine Structures in Iran, if the permeability coefficient is more than 10^{-3} meters per second for calculating lateral earth pressure during earthquakes, submerged specific gravity should be used. So instead of gravity of the specific saturated, submerged unit weight soil is used in modeling to obtain the lateral effective stresses. Westergaard has suggested formula is as follows:

$$M_i = \frac{7}{8}\rho_\omega\sqrt{H(H-Z_i)}A_i \qquad (3)$$

Where H is the total depth of water , Z is the height above the bass of the quay wall, and A is the tributary area of the node.

The water pressure on the other side of the wall is 70% of its value at the sea wall. As a result, the mass values obtained for each block separately is provided in the table.9.

Table.9 Added mass of the side wall

NO	Height of the center block of the seabed	added mass valve the sea(Kg)	added mass valve the soil(Kg)
1	1	13255	9278
2	3	14430	10101
3	5	17674	12371
4	7	20408	14285
5	9	22817	15971
6	11	24995	17496
7	13	26997	18898
8	15/5	28861	20203

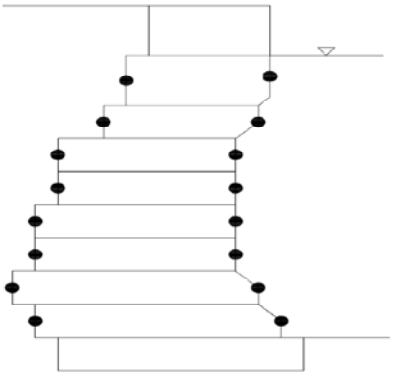

Fig.8 Locations added mass placed on the quay

Boundary conditions at different stages are different which described separately.

A) static stage (in situ) : side's boundaries (x = 0) is closed in both directions as well as the lower boundary of the horizontal and vertical closed (x=0,y=0)

B) Dynamic phase : side's boundaries are free and only the dampers are placed at the sides, Also, to reduce boundary effects, horizontal stresses created by the static stages in both sides with the pressure in contrast to produced static stresses are reduced. Earthquake acceleration is applied to both the horizontal and vertical the floor or bottom border. Also regulations as well as Japan, the coefficient of friction between the concrete and the concrete is 0.5 and between soil and concrete as well as 0.5 is considered.

Dampers have an important role in the accuracy of the data. Two perpendicular dampers in each node is defined in the sides of model, damper in the perpendicular to the surface absorbs long-wave model, and the damper which is in line with the lateral border absorbs the shear waves. Values of the damping dampers according to Eq.4 and Eq.5 is calculated as follows.

$$C_s = \rho.A.V_s \quad (4)$$

$$C_p = \rho.A.V_p \quad (5)$$

$$V_p = \sqrt{\frac{E}{\rho}} \quad (6)$$

$$V_s = \sqrt{\frac{G}{\rho}} = \sqrt{\frac{E}{2(1+\mu)\rho}} \quad (7)$$

ρ = density, *A* = area, *Vs* = shear wave velocity, *Vp* = compression wave velocity, *Cp* = coefficient of pressure dampers, *Cs* = coefficient of shear dampers, *G* = shear modulus, *E* = modulus of elasticity.

C_p=331662, C_S=205688

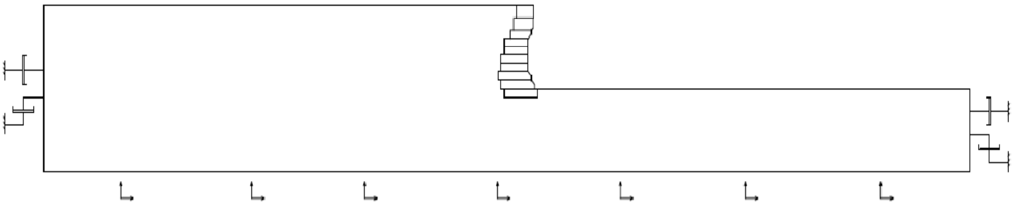

Fig.9 Placement of dampers and seismic acceleration

Selective accelerograms was for the dynamic analysis of recorded earthquakes in Bam and Tabas. Lysmer (1973) has recommended that the size of the elements in finite element mesh are one-eighth to one-tenth of the wavelength of the highest frequency. For this purpose, earthquake records using filtered software SeismoSignal and the highest frequency of 15 Hz is selected. So the recommended maximum size of the elements according to Lysmer should be (Eq. 8 and 9) 1.2 m, then the size of a mesh element is selected one meter.

$$\lambda = \frac{V_S}{f} \quad (8) \qquad , \Delta l \leq \frac{V_S}{\Gamma f_{max}} \quad (9)$$

λ= Wavelength, f= Frequency, f_{max}= Maximum frequency, V_s= Shear wave velocity, Δl= Mesh size, Γ= A multiple of 8 or 10

Table .10 PGA reduction after filtering to 15 Hz, Tabas earthquake

TABAS		
component	PGA(g)	PGA after filtering
LN	0.836	0.839
TR	0.852	0.949
UP	0.688	0.585

Table .11 PGA reduction after filtering to 15 Hz, Bam earthquake

BAM		
component	PGA(g)	PGA after filtering
I	0.776	0.856
T	0.582	0.56
V	0.987	0.84

Element types used in the mesh is CPE4 which the specification of this elements is 4-node plane strain constant. The nodal number of mesh elements is 9341 and the number of elements is 8991.

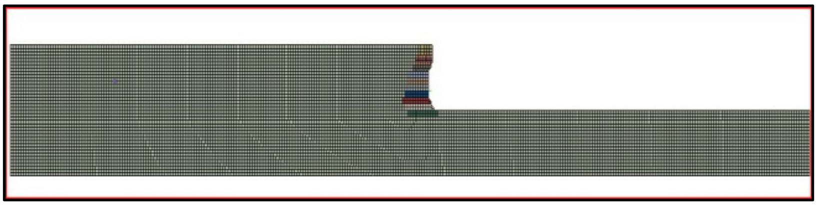

Fig.10 How to mesh

5. Analysis results :

The analysis time is dependent on several factors, including the type of analysis (implicit or explicit), the size of the mesh elements, dimensions and modeling when applied depends. For example, in a record time of Bam earthquake, It lasted 3 hours. Results output divided into two parts, moving walls in static and dynamic modes. For in-situ stresses, static analysis is carried out that displacement of the wall on both vertical and horizontal is the fig.11 and fig.12 .

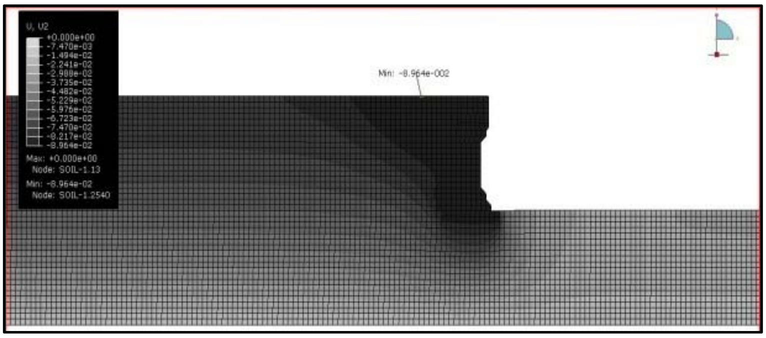

Fig.11 X movement and friction angle at 20

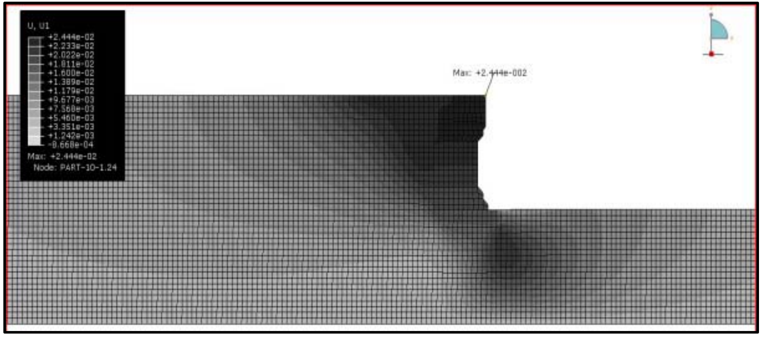

Fig.12 Y movement and friction angle at 20

Wall displacement after Tabas and Bam earthquakes, for each component individually is shown below, It is noteworthy that each of these analyzes is under the horizontal and the vertical component. It should also be noted that the displacement caused by the static displacement generated in the first stage and the second stage is the dynamic displacement.

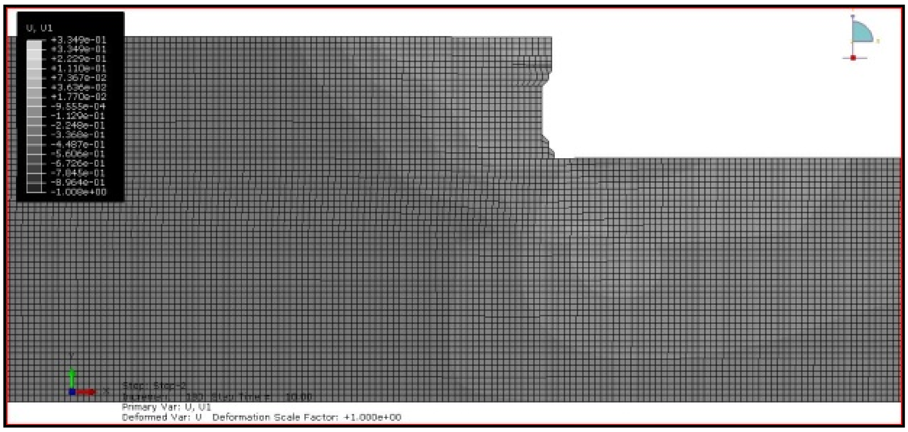

Fig.13 Displacement in X direction under acceleration Bam earthquake, elements of T, V and friction angle of 20 degrees silt layer

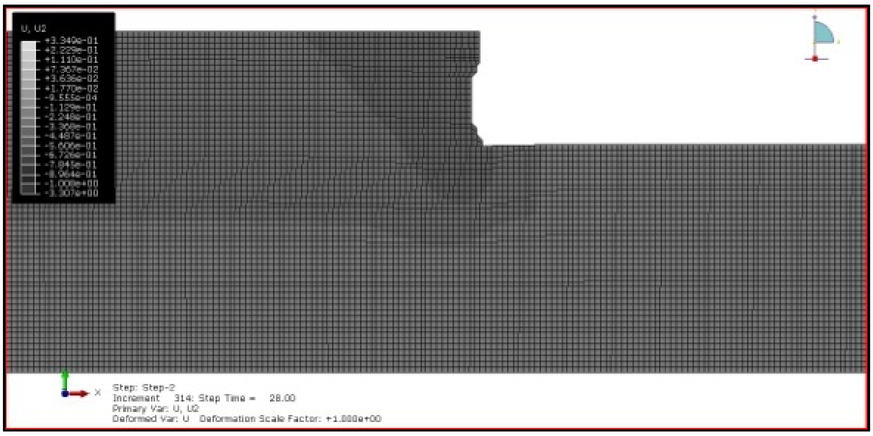

Fig.14 Displacement in Y direction under acceleration Tabas earthquake, elements of LN, UP and friction angle of 20 degrees silt layer

The displacement of the wall under the horizontal and vertical components during the quake as the following figures for various friction angles obtained from the silt layer.

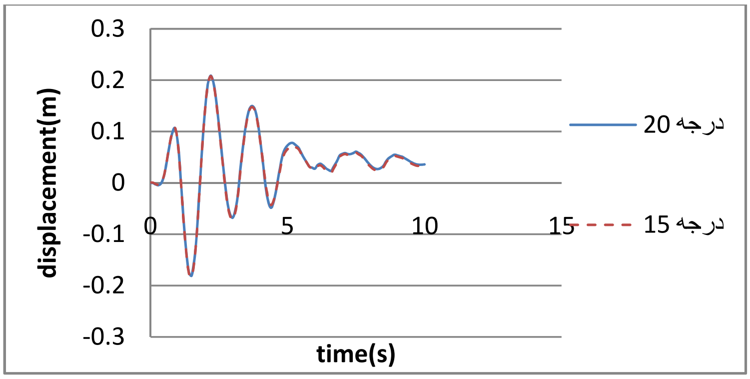

Fig.15 the wall displacement in the X direction under Bam earthquake (the components of T, V) For the friction angle of 15 and 20 silty layer

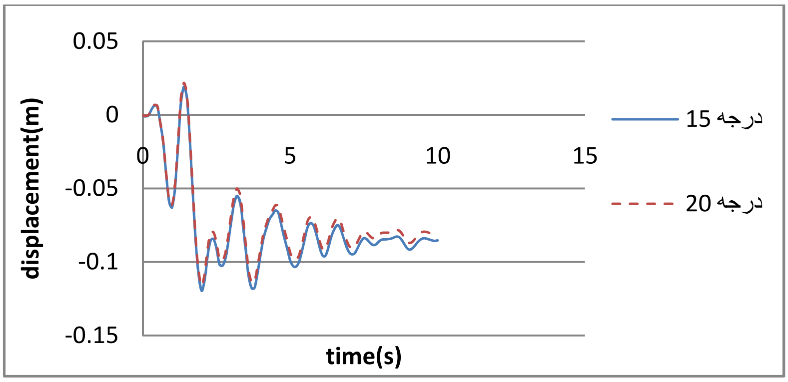

Fig.16 the wall displacement in the Y direction under Bam earthquake (the components of T, V) For the friction angle of 15 and 20 silty layer

6. Results and Discussion

As shown in the above charts and forms, displacement under the vertical component seismic in the structure is very low. Also the silt layer beneath the wall friction angle does not affect the transfer wall. The maximum displacement of Bam earthquake is 20 cm and based on the regulations Japan (Table. 2) Structure mode is not out of service. In this paper, a series of conditions of soil analysis is simple, for example water in the soil behind the wall and sea water with added mass are equivalent with the Westergaard , also the soil type is chosen that liquefaction conditions of the soil is not created. This simplification is possible in order to show the stability of the wall, which should be examined more carefully. It may be noted that in different circumstances for soil and water has been modeled in this paper, the results of this study may not be true.

7. References

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