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BEHAVIOR OF RETAINING WALLS CONSTRUCTED IN THE SATURATED CLAY AND WATER-SATURATED SAND SOILS UNDER THE DYNAMIC LOADS

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Abstract

Since the main purpose of building retaining walls is to hold up the slopes, the calculations are important during the design process. Although static loads that affect retaining walls are generally taken into consideration, dynamic effects should also be marked in our country located in the earthquake zone. Within the scope of this study, stability checks were performed by taking the effects to the retaining walls subjected to static and dynamic loads and wall designs were also made.

In this study, behavior of retaining walls constructed in saturated clay soil and water-saturated sand soil have been determined under static and dynamic loads. Analyses of static and dynamic behavior of gravity and cantilever walls have been done by Plaxis 2D software packet program. The heights of the walls are selected such as 5.0 m, 10.0 m and 15.0 m. Active earth pressures are calculated by using Rankine active earth pressure theory. Factor of safeties such as overturning, sliding and bearing capacity are selected as 2.0, 1.5 and 3.0, respectively. Three different earthquake loads such as Van, Turkey, Petrolia-California, USA and Volcano-Hawaii, USA are chosen to determine the dynamic behavior of walls. Records of earthquake loads were taken from “United States Geological Survey” (USGS) official web site. Format of earthquake records is “strong motion CD” (.smc) due to Plaxis 2D software packet program.

The results of analyses done in the saturated clay showed that 5.0 m and 10.0 m heights of retaining walls can be safely constructed in the earthquake zones having the magnitude up to 7.0. 15.0 m height of retaining walls cannot be safely constructed due to the insufficient wall dimensions. The results of analyses done in the water-saturated sand soil showed that 5.0 m height of retaining walls can be safely constructed in the earthquake zones having the magnitude up to 7.0. While the 10.0 m height of retaining walls can be safely constructed in the earthquake zones having magnitude of 6.0, it cannot be constructed in the earthquake zones having magnitude of 5.0 due to the earthquake acceleration. While the 15.0 m height of retaining walls can be safely constructed in the earthquake zones having magnitude of 6.0, it cannot be safely constructed in the earthquake zones having magnitude of 5.0 and 7.0.

Keywords: Retaining Wall, Clay Soil, Sand Soil, Dynamic Load, Static load, Plaxis 2D Program.

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SUYA DOYGUN KİLLİ ve KUMLU ZEMİNLERDE İNŞA EDİLEN İSTİNAT DUVARLARININ STATİK VE DİNAMİK DAVRANIŞLARI

Öz

İstinat duvarların yapılış amacı genel olarak şevleri tutmak olduğu için tasarımda hesaplamalar önem taşımaktadır. Genellikle istinat duvarlarına etki eden statik yükler göz önünde bulundurulsa da deprem bölgesinde yer alan ülkemizde dinamik etkiler de dikkate alınmalıdır. Bu çalışma kapsamında istinat duvarların statik ve dinamik yükler altında maruz kalacağı etkiler dikkate alınarak stabilite kontrolleri yapılmış ve duvar tasarımları yapılmıştır.

Bu çalışmada; farklı tür ve boyutlardaki istinat duvarlarına etki edecek olan geri dolgu malzemesinin, doygun kil ve kötü derecelenmiş kum olması durumunda duvarların statik ve dinamik yükler altındaki deformasyonları incelenmiştir. Statik ve dinamik yük analizleri Plaxis 2D paket programı kullanılarak yapılmıştır. İstinat duvarları; ağırlıklı ve konsol olmak üzere 2 farklı türde ve yükseklikleri 5.0m, 10.0m ve 15.0m olmak üzere 3 farklı yükseklikte tasarlanmıştır. Duvarlara etki edecek olan aktif basınç değeri Rankine aktif basınç teorisi ile bulunmuştur. İstinat duvarlarının devrilmeye karşı, kaymaya karşı ve taşımaya karşı güvenlik sayıları sırasıyla 2.0, 1.5 ve 3.0 olarak alınmıştır. Statik yükler altında dengede olan istinat duvarların dinamik yükler altında nasıl davrandığını anlamak için 3 farklı büyüklüğe sahip olan Van, Türkiye; Petrolia-California, ABD ve Volcano-Hawai, ABD depremleri kullanılmıştır. Deprem kayıtları “United States Geological Survey” (USGS) sitesinden alınmıştır. Bu kayıtlar Plaxis 2D paket programında kullanılması için “strong motion CD” (.smc) uzantısına sahiptirler.

Doygun killerde yapılan analiz sonuçları, büyüklüğü 7.0'a kadar olan deprem bölgelerinde 5.0m ve 10.0m yüksekliğinde istinat duvarlarının güvenle yapılabileceğini ama 15.0m yüksekliğindeki istinat duvarları yetersiz duvar boyutları nedeniyle güvenli bir şekilde yapılamayacağını göstermiştir. Suya doygun kum zeminde yapılan analiz sonuçları ise, büyüklüğü 7.0'a kadar olan deprem bölgelerinde 5.0m yüksekliğinde istinat duvarlarının güvenle yapılabileceğini göstermiştir. 6.0 büyüklüğündeki deprem bölgelerinde, 10.0m yüksekliğindeki istinat duvarları güvenle yapılabilirken, 5.0 büyüklüğündeki deprem bölgelerinde deprem ivmesinden dolayı yapılamamaktadır. 15.0m yüksekliğindeki istinat duvarları 6.0 büyüklüğündeki deprem bölgelerinde güvenle yapılabilirken, 5.0 ve 7.0 büyüklüğündeki deprem bölgelerinde güvenli bir şekilde yapılamamaktadır.

Anahtar Kelimeler: İstinat Duvarı, Killi Zemin, Kumlu Zemin, Dinamik Yük, Statik Yük, Plaxis 2D Program.

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1. INTRODUCTION

Retaining walls are constructed to resist lateral earth pressures on sloped surfaces [1]. They are generally divided into two categories such as cantilever and gravity walls. Stability checks of retaining walls can be generally done according to overturning, sliding and bearing capacity. There are many theories to calculate the active earth pressure which acts to the retaining wall. These theories can change according to weight of wall, friction between the soil and the wall surface and the unit weight of soil. Rankine earth pressure theory does not consider the friction between the soil and wall surface. Therefore, it is simple than Coulomb theory and widely used. Active pressure can also be calculated by using graphical method of Cullmann theory as well [2].

Earthquake load can cause displacements and stability failures on the wall in the earthquake zones. Therefore, theories are developed to find excessive earth pressures under the earthquake forces. Especially, Mononobe-Okabe equations are mostly preferred. In this theory, earthquake acceleration is used to find excessive earthquake loads which act to the wall [1].

Many researchers studied static and dynamic behavior of retaining walls in the literature. These studies considered the soil slope and the soil type behind the wall. Studies showed that wall displacements decrease with increasing wall rigidity. Besides, foundation soil properties of retaining wall are also important for the overturning and sliding of the wall [3, 4, 5, 6]. When the periods and amplitudes of soil and dynamic loads coincide, wall can displace so much [3, 7]. The behavior of sheet pile, concrete slurry wall or rigid reinforced concrete wall is different under the dynamic loads [7]. Cavalera and Lipani [8] investigated the behavior of geosenthetics under the dynamic loads.

Using finite element method in the analysis has an advantage of time and calculation [9]. Gursoy and Durmus [10] investigated linear and non-linear behavior of reinforced concrete cantilever retaining walls under dynamic loads. Li et al. [11] modelled lateral soil pressure acting to the wall. Cakır [12] investigated the interaction between the soil and wall under the dynamic loads. Harraz et al. [13] investigated the behavior of cantilever retaining wall under the dynamic loads. They used FLEX program and developed numerical model by using 2D finite element program to analyze the behavior of gravity wall constructed in dry sand [14]. Other numerical methods are developed by using FLAC [15]. Gazetas et al. [16] developed numerical model by using ABAQUUS for the

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plane-unit deformation case.

Deformation controlled analysis mainly consider earthquake acceleration and deformation amount of structure after the earthquake. Newmark [17] and Kramer [7] showed that deformation controlled analyses is suitable for the displacements of the retaining walls under the seismic conditions. The deformation of earth fill dams under the earthquake loads is developed by sliding the soil block on the plane. Richards and Elms [18] suggested Newmark model based on modified new model considering originally seismic slope stability to design gravity wall.

Some researchers gave limit deformation values for retaining walls under the earthquake loads [19]. Limit deformation values in the horizontal direction are 300.a_{max} (mm) and 250.a_{max} (mm) according to Eurocode [20] and AASHTO [21], respectively, where, a_{max} is the maximum earthquake acceleration. Wu and Prakash [22] gave the limit deformation value of 0.02H in the horizontal direction and this deformation reaches 0.1H, failure occurs, where H is the wall height. DAS [1] gave the settlement amount of 5-7 cm for strip footings. JRA [23] suggested differential settlement of 10-20 cm for strip footings. Rafnsson and Prakash [24] analyzed combination of shear and vibration considering soil rigidity, geometrical and material damping under lateral soil movement and also developed new model. Wu [25] investigated gravity retaining wall chancing the wall heights from 4 m to 10 m under the earthquake loads. He investigated the deformations of 8 m wall height and 4.6 m wall width retaining wall subjected to El-Centro earthquake. Sandzevicins et al. [26] studied retaining wall constructed on hydro-structures. They determined that the limit deformation of retaining wall is about one-fifth of the wall height.

In this study, the behavior of cantilever and gravity retaining walls constructed in the saturated clay soil and water-saturated sand soil under the earthquake loads is investigated. Dynamic behavior of walls is simulated by using Plaxis 2D Dynamic Modulus program.

2. MATERIAL and METHOD

2.1. Retaining Wall Design

In this study, Plaxis 2D Program is used to determine the displacements and stability checks. Plaxis 2D program is commercially available finite element program that is commonly used in geotechnical engineering applications in Turkey.

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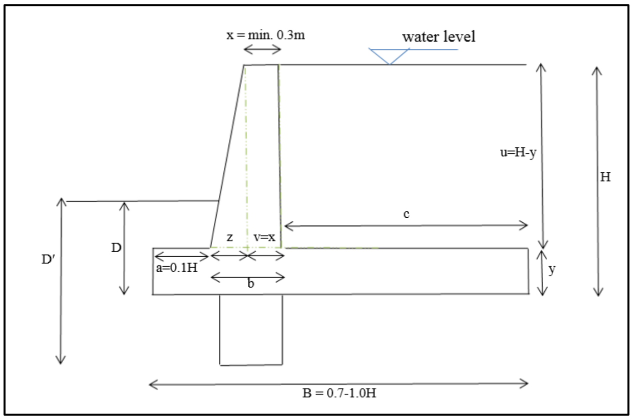

Figure 1. Design Parameters of the CRW

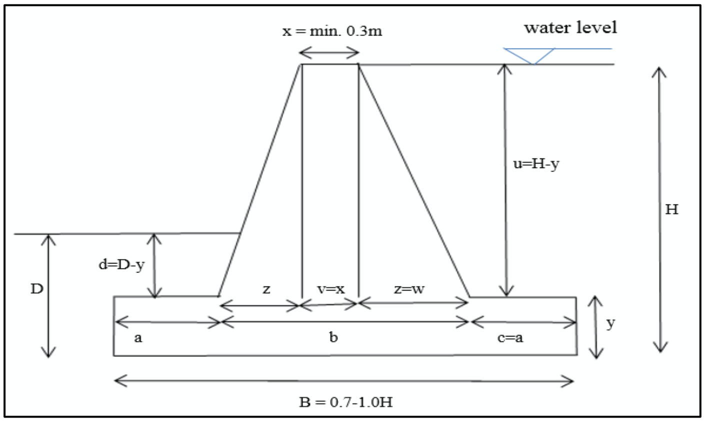

Figure 2. Design Parameters of the GRW

Design parameters of the walls are determined in the model. Factor of safeties are chosen minimum 2.0, 1.5 and 3.0 for overturning, sliding and bearing capacities, respectively. Rankine earth pressure theory is used for the earth pressure calculations. Mayerhoff theory is used for the bearing capacity calculations. The wall heights are chosen 5 m, 10 m and 15 m. Water level behind the wall is same as the wall height shown in figures 3 and 4. Design parameters of cantilever and gravity walls are given in Fig. 1 and Table 1 and Fig. 2 and Table 1, respectively [27, 28].

Table 1. Design Parameter Values of the Retaining Walls

	Cantilever Retaining Walls			**Gravity Retaining Walls**		
	Model-A	**Model-B**	**Model-C**	**Model-A**	**Model-B**	**Model-C**
Wall Height H (m)	5.0	10.0	15.0	5.0	10.0	15.0
Foundation Length B	4.0	9.5	12.5	5.0	10.0	15.0
Key Depth D' (m)	1.85	4.0	6.75	--	--	--
Frost Depth D (m)	0.75	1.5	2.5	1.4	3.5	5.5
x (m)	0.5	1.0	1.5	1.0	3.0	5.0
a (m)	0.5	1.0	1.5	0.4	0.5	0.5
b (m)	0.5	1.0	1.5	4.2	9.0	14.0
c (m)	3.0	7.5	9.5	0.4	0.5	0.5
d (m)	0.25	0.5	1.0	0.6	1.5	1.5
u (m)	4.5	9.0	13.5	4.2	8.0	11.0
v (m)	0.5	1.0	1.5	1.0	3.0	5.0
y (m)	0.5	1.0	1.5	0.8	2.0	4.0
z (m)	0.0	0.0	0.0	1.6	3.0	4.5
w (m)	--	--	--	1.6	3.0	4.5

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Mononobe-Okabe theory can be used to calculate lateral earth pressures considering earthquake loads in the literature. However, these equations given below cannot be practical and rarely used. Some packet programmes are also widely used instead of these equations. Because these programmes are much more practable and faster than the equations. Lateral earth pressures and factor of safeties for cantilever and gravity walls are given in Tables 2 and 3, respectively.

$$k_h = \frac{horizontal\ component\ of\ earthquake\ acceleration}{g} \quad (1)$$

$$k_v = \frac{vertical\ component\ of\ earthquake\ acceleration}{g} \quad (2)$$

$$\bar{\beta} = \tan^{-1}\left(\frac{k_h}{1-k_v}\right) \quad (3)$$

$$K_a = K_a(\alpha', \theta') = \frac{cos^2(\phi - \theta')}{cos^2\theta'\ cos\,(\delta + \theta')\left\{1 + \left[\frac{\sin(\emptyset + \delta)\ \sin(\emptyset - \alpha')}{\sin(\delta + \theta')\ \cos(\theta' - \alpha')}\right]^{1/2}\right\}^2} \quad (4)$$

$$P_{ae} = \left[\frac{1}{2}\ \gamma H^2(1 - k_v)\right]\left[K_a(\alpha', \theta')\right]\left[\frac{\cos^2\theta'}{\cos\bar{\beta}\ \cos^2\theta}\right] \quad (5)$$

Table 2. Lateral Earth Pressures and Factor of Safeties for Cantilever Retaining Wall

Natural Soil	**Saturated Clay**			**Water-Saturated Sand**		
Cantilever Retaining Wall	Model A	Model B	Model C	Model A	Model B	Model C
Active Earth Pressure, P_a (kN/m)	110.0	610.0	1535.0	149,75	500	1347,75
$F.S._{overturning}$	2.02	3.0	2.3	2,71	3,39	3,68
$F.S._{sliding}$	1.5	1.5	1.5	1,96	1,95	2,06
$F.S._{bearing\ capacity}$	8.3	9.3	8.2	3,12	3,01	3,36
Excessive Load due to the Earthquake Load, P_{ae} (kN/m)	111.0	442.0	993.0	111.0	442.0	993.0

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Table 3. Lateral Earth Pressures and Factor of Safeties for Gravity Retaining Wall

Natural Soil	Saturated Clay			Water-Saturated Sand		
Gravity Retaining Wall	**Model A**	**Model B**	**Model C**	**Model A**	**Model B**	**Model C**
Active Earth Pressure, Pa (kN/m))	110.0	610.0	1535.0	149,75	500.0	1347,75
F.S.overturning	3.7	3.9	4.1	4.98	5.22	5.35
F.S.sliding	1.5	1.5	1.5	1.87	1.94	1.95
F.S.bearing capacity	3.7	3.2	3.0	5.84	4.77	4.34
Excessive Load due to the Earthquake Load, P_{ae} (kN/m)	111.0	442.0	993.0	111.0	442.0	993.0

Earthquake records of the City of Van, Turkey, Petrolia-California, USA and Volcano-Hawaii, USA are used for the dynamic analysis. Latest great earthquake is occurred in the city of Van in 2011 and its magnitude is M_w=7.2. Strong ground motion records are taken from "United States Geological Survey" (USGS) official web site. Properties of the earthquakes are given in Table 4.

Tablo 4. Properties of Earthquakes

Earthquake	Volcano-Hawaii, ABD	Petrolia-California, ABD	Van, Türkiye
Earthquake Magnitude (M_w)	4.90	5.87	7.20
Episantr Distance (km)	84.3	71.7	200.0
Date	08/2013	02/2010	10/2011
Place	Hawaii	California	Van

2.2. Properties of Materials Used in the Design

Concrete properties of retaining wall used in the Plaxis 2D packet program are given in Table. 5. Natural soil properties which act to the walls given in Table 6. Foundation soil under the retaining wall is chosen as a dense sand having internal friction angle of 30°, unit weight of 20 kN/m^3 and cohesion of 10 kN/m².

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Table 5. Parameters of Walls in the Models

Model	Material Type	Unit Weight (kN/m^3)	Elasticity Modulus (kN/m^3)	Poisson Ratio
Concrete	Non-Porous	24.00	2E+7	0.2

Table 6. Soil Properties Used in the Models

Soil Properties	Soil-I	Soil-II	Soil-III	Soil-IV	Soil-V	Soil-VI
Soil Type	Very soft	Soft	Medium	Loose	Medium	Dense
Saturated Unit Weight, γ_{sat} (kN/m^3)	17,0	17,0	17,0	16,0	16,0	16,0
Poisson Ratio, υ	0,2	0,25	0,3	0,2	0,25	0,3
Elasticity Modulus, E (kN/m^2)	2050	4050	5500	15000	17500	20000
Internal Friction Angle, Ø (°)	5	5	5	30	35	40
Cohesion, c (kN/m^2)	10	20	40	0	0	0
Saturation Degree, S (%)	100	100	100	100	100	100

3. ANALYSIS of MODELS

3.1. Displacements of Retaining Walls under the Static Loads

Horizontal and vertical deformations of retaining walls under the static loads given in Tables 7 and 8, respectively. Chaning the shear strength parameters of soil cannot much affect the deformations considering 5 m, 10 m and 15 m height of walls. Cantilever and gravity walls can be designed with minimum design parameters under the static loads. However, it is suggested that vertical deformations of 15 m height of walls constructed in the saturated clays can be checked in the design process. Because, vertical deformations of walls are greater than limit deformations.

Horizontal and vertical deformations of gravity walls with different heights are less than that of cantilever walls. Limit horizontal displacements of wall is considered as 0.02H. Limit vertical displacements of wall is considered as 5-7 cm. Deformations under the static loads considering all

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wall heights, except 15 m height of cantilever wall constructed in the saturated clay and sand soil do not exceed the limit values under the static loads. When the heights of walls increase for both type of walls, deformations also increase. Both deformations of walls decrease with increasing the strength of soil. Both type of walls are safe in the horizontal direction according to the limit values. However, Deformation values of cantilever retaining wall of 15 m height are in the limits in the vertical direction.

As a result, 5 m and 10 m height of retaining walls constructed in the both soils are safe under the static loads. Cantilever length of wall is extended to satisfy safety against sliding and therefore, deformations of 15 m height of cantilever wall constructed in the saturated clay are high due to the non-uniform distributions of vertical deformations. Because, Plaxis 2D program gives the maximum deformation of one point on the cantilever part of the wall. Therefore, 15 m height of cantilever wall is not safe. It can be suggested that 15 m height of cantilever walls can be constructed either with counterfort wall or gravity wall.

Tablo 7. Horizontal Displacements of Retaining Walls Under the Static Loads

		Horizontal Displacements of Retaining Walls (u_x) (cm)					
		Soil					
Height of Wall	**Type of Wall**	**Soil-I**	**Soil-II**	**Soil-III**	**Soil-IV**	**Soil-V**	**Soil-VI**
5 m	Gravity R.W.	0,580	0,550	0,530	0,15	0,13	0,12
	Cantilever R.W.	0,500	0,60	0,650	0,94	0,87	0,83
10m	Gravity R.W.	1,340	1,260	1,220	0,42	0,37	0,33
	Cantilever R.W.	2,260	2,710	2,840	3,14	2,92	2,73
15 m	Gravity R.W.	2,270	2,140	2,080	0,69	0,62	0,55
	Cantilever R.W.	6,840	7,010	7,490	5,78	4,59	3,60

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Tablo 8. Vertical Displacements of Retaining Walls Under the Static Loads

		Vertical Displacements of Retaining Walls (u_x) (cm)					
		Soil					
Height of Wall	**Type of Wall**	**Soil-I**	**Soil-II**	**Soil-III**	**Soil-IV**	**Soil-V**	**Soil-VI**
5 m	Gravity R.W.	0,600	0,590	0,580	0,030	0,020	0,020
	Cantilever R.W.	2,390	2,400	2,410	0,220	0,170	0,160
10m	Gravity R.W.	1,380	1,370	1,360	0,080	0,070	0,060
	Cantilever R.W.	5,950	5,970	5,980	1,210	1,100	1,040
15 m	Gravity R.W.	1,890	1,820	1,790	0,140	0,120	0,100
	Cantilever R.W.	12,850	12,810	12,820	1,740	1,470	1,240

3.2. Horizontal Displacements of Retaining Walls under the Dynamic Loads

Limit deformations used in this study are 300. $amax$ (mm) according to Eurocode (1994) and 250. a_{max} (mm) according to AASHTO (2002), where a_{max} is the maximum horizontal design acceleration. Wu and Parakash (1999) gave the limit horizontal deformation of 0.02 H and this deformation value exceeds 0.1H, failure occurs in the wall. Limit and maximum deformation values in the horizontal direction under the dynamic loads are given in Table 9 and Table 10, respectively.

Table 9. Limit deformation Values in the horizontal direction under the dynamic loads

Name of Earthquake and Maximum Acceleration	Eurocode	AASHTO
Volcano-Hawaii M_W=5.0 a_{max}=140 cm/sn^2	4,2 cm	3,5 cm
Petrolia-California M_W=6.0 a_{max}=45 cm/sn^2	1,3 cm	1,1 cm
Van M_W=7.0 a_{max}=180 cm/sn^2	5,4 cm	4,5 cm

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Table 10. Limit and Maximum Deformations in the Horizontal Direction According to the Wall Height

Wall Height(m)	Limit Deformation 0,02H (cm)	Maximum Deformation 0,1H (cm)
5.0	10.0	50.0
10.0	20.0	100.0
15.0	30.0	150.0

3.2.1 Retaining Walls Constructed in the Saturated Clay Soil

Maximum deformations of both retaining walls under the earthquake magnitude of M_W=5.0, M_W=6.0 and M_W=7.0 are given in Tables 11, 12 and 13, respectively.

3.2.1.1. Earthquake Magnitude of M_W=5.0

5 m height of both cantilever and gravity retaining walls are safe according to for both earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction and limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of walls are safe according to the limit deformations of 5-7cm.

10 m height cantilever retaining wall are not safe according to the earthquake acceleration limit deformations in the horizontal direction given by AASHTO and Eurocode. However, they are safe according to the limit deformations with respect to the wall height of 0,02H. 10 m height of gravity retaining walls are safe according to for both earthquake acceleration limit deformations in the horizontal direction and limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are safe according to the limit deformations of 5-7cm.

15 m height of cantilever retaining walls are not safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However, they are safe according to the limit deformations with respect to the wall height of 0,02H. 15 m height of gravity retaining walls are safe according to earthquake acceleration limit deformations given by AASHTO

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and Eurocode in the horizontal direction. In the vertical direction, they are not safe according to the limit deformations of 5-7cm.

3.2.1.2. Earthquake Magnitude of M_W=6.0

5 m height of cantilever retaining walls are not safe according to earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However they are safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are safe according to the limit deformations of 5-7cm.

10 m height of both cantilever and gravity retaining walls are not safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However, both types of walls are safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are safe according to the limit deformations of 5-7cm.

15 m height of both cantilever and gravity retaining walls are not safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However, both types of wall are safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are not safe according to the limit deformations of 5-7cm.

3.2.1.3. Earthquake Magnitude of M_W=7.0

5 m height of cantilever retaining walls is not safe according to earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However it is safe according to the limit deformations with respect to the wall height of 0,02H. 5 m height of gravity retaining walls is safe according to earthquake acceleration limit deformations in the horizontal direction and the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are safe according to the limit deformations of 5-7cm.

10 m height of cantilever retaining walls is not safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However, it is safe according to the limit deformations with respect to the wall height of 0,02H. 10 m height of gravity retaining walls is safe according to the earthquake acceleration limit deformations in the horizontal

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direction and the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are not safe according to the limit deformations of 5-7cm.
15 m height cantilever retaining walls is not safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However, it is safe according to the limit deformations with respect to the wall height of 0,02H. 15 m height gravity retaining walls is safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction and the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are not safe according to the limit deformations of 5-7cm.

3.2.2. Retaining Walls Constructed in the Water-Saturated Sand Soil

3.2.2.1. Earthquake Magnitude of M_W=5.0

5.0 m height of both cantilever and gravity retaining walls are safe according to for both earthquake acceleration limit deformations given by Eurocode in the horizontal direction and limit deformations with respect to the wall height of 0,02H. However, 5 m height of both cantilever and gravity retaining walls are not safe according to for both earthquake acceleration limit deformations given by AASHTO. In the vertical direction, both types of wall are safe according to the limit deformations of 5-7cm.
10.0 m height cantilever and gravity retaining walls are not safe according to the earthquake acceleration limit deformations in the horizontal direction given by AASHTO and Eurocode). However, they are safe according to the limit deformations with respect to the wall height (0,02H). In the vertical direction, both types of wall are safe according to the limit deformations of 5-7cm.
15.0 m height of cantilever and gravity retaining walls are not safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However, they are safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, they are not safe according to the limit deformations of 5-7cm.

3.2.2.2. Earthquake Magnitude of M_W=6.0

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5.0 m height of cantilever and gravity retaining walls are not safe according to earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However it is safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are safe according to the limit deformations of 5-7cm.

10.0 m height of both cantilever and gravity retaining walls are not safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However, both types of wall are safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are safe according to the limit deformations of 5-7cm.

15.0 m height of both cantilever and gravity retaining walls are not safe according to the earthquake acceleration limit deformations by AASHTO and Eurocode in the horizontal direction. However, both types of wall are safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are not safe according to the limit deformations of 5-7cm.

3.2.2.3. Earthquake Magnitude of M_W=7.0

5.0 m height of cantilever and gravity retaining walls are not safe according to earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. However it is safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are not safe according to the limit deformations of 5-7cm.

10.0 m height of cantilever and gravity retaining walls are not safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. Also they are not safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are not safe according to the limit deformations of 5-7cm.

15.0 m height of cantilever and gravity retaining walls are not safe according to the earthquake acceleration limit deformations given by AASHTO and Eurocode in the horizontal direction. Also they are not safe according to the limit deformations with respect to the wall height of 0,02H. In the vertical direction, both types of wall are not safe according to the limit deformations of 5-7cm.

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Table 11. Maximum Deformations of Retaining Walls Under the Dynamic Load (M_w=5.0)

		Displacements of Retaining Walls (cm)											
		Soil											
Wall Height	**Wall Type**	**Soil-I**		**Soil-II**		**Soil-III**		**Soil-IV**		**Soil-V**		**Soil-VI**	
		u_x	u_y	u_x	u_y	u_x	u_y	u_x	u_y	u_x	u_y	u_x	u_y
5 m	Gravity	0,70	2,51	0,65	2,54	0,65	2,55	3,51	3,20	3,50	3,20	3,50	3,20
	Cantilever	2,63	3,09	2,51	3,04	2,1	3,03	3,56	3,21	3,55	3,21	3,55	3,21
10 m	Gravity	1,63	6,77	1,37	6,80	1,56	6,82	6,12	7,40	6,12	7,40	6,12	7,40
	Cantilever	5,06	6,09	6,47	6,15	6,35	6,13	7,56	6,44	7,56	6,44	7,60	6,44
15 m	Gravity	2,69	14,18	2,67	14,14	2,42	14,11	9,18	11,01	9,18	10,95	9,18	10,95
	Cantilever	11,94	12,81	12,89	12,71	12,77	12,71	11,40	9,57	11,37	9,57	11,34	9,57

Table 12. Maximum Deformations of Retaining Walls Under the Dynamic Load (M_w=6.0)

		Displacements of Retaining Walls (cm)											
		Soil											
Wall Height	**Wall Type**	**Soil-I**		**Soil-II**		**Soil-III**		**Soil-IV**		**Soil-V**		**Soil-VI**	
		u_x	u_y	u_x	u_y	u_x	u_y	u_x	u_y	u_x	u_y	u_x	u_y
5 m	Gravity	0,64	3,03	0,66	3,00	0,63	3,00	1,58	1,60	1,58	1,60	1,58	1,60
	Cantilever	4,92	2,5	5,29	2,54	4,64	2,48	1,58	1,60	1,58	1,60	1,58	1,60
10 m	Gravity	1,60	7,12	1,62	6,80	1,47	7,05	3,16	3,36	3,16	3,36	3,16	3,36
	Cantilever	6,83	6,14	8,57	6,16	8,45	6,17	3,24	3,32	3,26	3,30	3,26	3,30
15 m	Gravity	2,82	14,06	2,70	14,06	2,60	14,02	4,74	4,77	4,74	4,77	4,74	4,77
	Cantilever	12,34	12,88	13,04	12,77	13,36	12,76	4,74	4,77	4,74	4,86	4,74	5,04

Tablo 13. Maximum Deformations of Retaining Walls Under the Dynamic Load (M_w=7.0)

		Displacements of Retaining Walls (cm)											
		Soil											
Wall Height	**Wall Type**	**Soil-I**		**Soil-II**		**Soil-III**		**Soil-IV**		**Soil-V**		**Soil-VI**	
		u_x	u_y	u_x	u_y	u_x	u_y	u_x	u_y	u_x	u_y	u_x	u_y
5 m	Gravity	1,47	9,51	1,38	9,55	1,38	9,58	10,81	10,78	10,81	10,78	10,81	10,78
	Cantilever	24,07	9,95	22,09	10,00	23,53	10,05	10,82	10,80	10,81	10,80	10,81	10,80
10m	Gravity	3,14	13,01	3,17	13,02	2,07	12,95	21,64	21,80	21,62	21,74	21,62	21,70
	Cantilever	29,25	12,43	28,81	12,53	28,23	12,59	21,74	26,62	21,74	25,18	21,74	25,04
15 m	Gravity	5,19	21,91	5,02	22,03	4,83	21,91	32,61	32,64	32,55	32,64	32,52	32,67
	Cantilever	30,54	19,32	30,93	19,30	30,36	19,30	33,09	38,34	32,76	32,76	32,73	32,73

4. CONCLUSIONS

Both types of retaining walls having 5.0 m wall height constructed in the saturated clay soil and water-saturated sand soil are safe under the 5.0 and 6.0 magnitudes of earthquakes for the horizontal deformation limit of 0.02H and vertical deformation limit of 5-7 cm. After the dynamic analysis, deformations of 5.0 m height of gravity wall has less deformations than that of cantilever wall. Deformations in the horizontal direction of cantilever retaining wall having 5.0 m wall height are greater than that of gravity wall. However, it is determined that deformations in the vertical direction for both types of retaining walls are more or less same.

5.0 m height of gravity wall constructed in the saturated clay soil is safe under the 7.0 magnitude of earthquake for the horizontal deformation limit of 0.02H, however it is not safe for the vertical deformation limit of 5-7 cm. 5.0 m height of cantilever wall constructed in the saturated clay soil is not safe under the 7.0 magnitude of earthquake both for the horizontal deformation limit of 0.02H and for the vertical deformation limit of 5-7 cm.

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Deformations in the horizontal direction of cantilever wall having 10.0 m wall height constructed in the saturated clay soil are higher than that of gravity wall. However, deformations in the horizontal direction of cantilever wall having 10.0 m wall height constructed in the saturated sand soil are almost same that of gravity wall. Deformations in the vertical direction for both types of retaining walls are more or less same under the 5.0 and 6.0 magnitudes of earthquakes. Deformations in the vertical direction of both walls having 10 m wall height constructed in the both types of soil found in the limit of 5-7 cm.

Deformations in the horizontal direction of cantilever wall having 10.0 m wall height are higher than that of gravity wall under the 7.0 magnitude of earthquake. Deformations in the vertical direction of both types of retaining walls constructed in the saturated clay are more or less same.

10 m height of both walls constructed in the saturated clay soil is safe under the 7.0 magnitude of earthquake for the horizontal deformation limit of 0.02H, however it is not safe for the vertical deformation limit of 5-7 cm. 10.0 m height of both walls constructed in the water-saturated sand soil is not safe under the 7.0 magnitude of earthquake both for the horizontal deformation limit of 0.02H and for the vertical deformation limit of 5-7 cm.

Deformations in the horizontal direction for both type of retaining walls having 15.0 m wall height constructed in the saturated clay soil and water-saturated sand soil are not under the limit deformation of 0.02H, except that of wall constructed in the saturated clay soil. High deformations is due to the liquefaction occurred in the water-saturated sand soil.

Deformations in the vertical direction for both types of retaining walls having 15.0 m wall height constructed in the both soils exceed the limit deformation of 5-7 cm under the 7.0 magnitude of earthquake.

As a result, if the limit deformation values in the horizontal direction depending on the wall height (H) and 5-7 cm limit deformations in the vertical direction are considered, following conclusions can be drawn for the both walls constructed in the saturated clay soil.

5.0 m and 10.0 m heights of both cantilever and gravity walls can be safely constructed in the risk cases of earthquakes of magnitudes 5.0 and 6.0. 5.0 m and 10.0 m heights of both cantilever and gravity walls cannot be safely constructed in the risk cases of earthquakes of magnitudes 7.0. Because, limit deformations in the vertical direction are exceeded. Therefore, extra precautions are

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needed for construction of walls. 15 m height of both cantilever and gravity walls cannot be safely constructed in the risk cases of earthquakes of magnitudes 5.0, 6.0 and 7.0 due to exceeding the limit deformations in the vertical direction. Extra precautions are needed for construction of wall. As a result, if the limit deformation values in the horizontal direction depending on the wall height (H) and 5-7 cm limit deformations in the vertical direction are considered, following conclusions can be drawn for the both walls constructed in the water-saturated sand soil.

5.0 m heights of both cantilever and gravity walls can be safely constructed in the cases of earthquakes of magnitudes 5,0 and 6,0. 10.0 m heights of gravity walls can be safely constructed in the cases of earthquakes of magnitudes 5,0 and 6,0. While 10.0 m height of cantilever wall can be constructed safely in the case of earthquake magnitudes of 6.0, vertical deformation of the wall is greater than the limit value of 5-7 m in the case of earthquake magnitudes of 5.0. This is due to the high earthquake acceleration of magnitude Mw=5 is greater than that of Mw=6. Therefore, soil improvement is needed to construct the wall. 15m height of both cantilever and gravity walls can be safely constructed in the cases of earthquakes of magnitudes 6,0. However, 15m height of both cantilever and gravity walls cannot be safely constructed in the cases of earthquakes of magnitudes 5,0 due to the high settlement of wall. 15m height of both cantilever and gravity walls cannot be safely constructed in the cases of earthquakes of magnitude 5,0 due to the high vertical and horizontal displacements of wall.

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