NUMERICAL SIMULATION AND DYNAMIC ANALYSIS OF THE CONCRETE DIAPHRAGM WALL

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ABSTRACT

As a temporary structure, Concrete Diaphragm Wallhas been widely used to counteract excavation problems in Iran not only in urban areas, but also in mountainous and coastal areas. This continuous barrier can be used in different soil types and it is able to resist lateral earth pressure, but its large deformation is a serious concern for the use of this structure in the geotechnical engineering. Dynamic behaviour of concrete diaphragm wall underlying earthquake is evaluated through fully coupled nonlinear effective stress dynamic analyses. Each model was subjected to three ground motion events obtained by scaling the amplitude of the Tabas (1978), Manjil (1990), and Bam (2003)earthquakes.

Effects of nonlinear soil structure interaction(SSI) and a diaphragm wall can be simulated with the application of interface elementsusing *FLAC* program package. The results revealed that Concrete Diaphragm Wall has a better performance in clay soils compared to the granular soils. Investigation of the horizontal displacement over the concrete diaphragm wall has demonstrated that the maximum displacement occurred during strong motions and it is depended to earthquake characteristics.

INTRODUCTION

Any large-scale excavation requires retaining structures (such as diaphragm walls) to be installed before soil excavation is commenced. Although the influence of excavation work on the surrounding ground and on existing structures has been commonly evaluated through numerical simulation, the main interest focuses on the influence of the excavation process on these areas after retaining structures are installed in the soil. In other words, numerical simulation of the excavation process has generally been carried out under the assumption that the construction of retaining structures prior to excavation will not affect in situ stress conditionsArai et al. (2008).

In the past decades, considerable research has been conducted to study earthquake related retaining wall problems. These investigations can be broadly divided in two categories, namely, theoretical studies and experimental studies. Theoretical studies include analytical and numerical methods. Experimental studies include shaking table tests performed under earth's gravity (1g), seismic centrifuge tests, and any rare occurrences of field testing. Most analytical and design procedures such as the ones suggested by Mononobe

(1929) and Okabe (1924), Matsuzawa etal.(1985), and Ishibashi and Madi (1990) are generally based onsemi-empirical methods or involve simplistic assumptions.

In most numerical methods, complex theories involving soil/water interaction incorporating elasto-plastic constitutive models are used. Therefore, such analytical, design, and numerical methods need to be verified.

Although recent advances in physical model experiments (Gang Zheng et al. (2014)) and computational modelling of liquefaction-induced ground deformation (Chang-Yu Ou et al. (2013) and Gordon Tung-Chin Kung (2009) and Kung et al. (2007) and Arai et al. (2008)) are quite promising, but challenges still remain on this critical problem.

In this paper, for the precision in the assessment of the Concrete Diaphragm Wall at a site, three factors affecting the safety and cost of the design are evaluated: Trenches height, soil type and the characteristics of the earthquake. Results of the analyses are interpreted in order to improve understanding of the Concrete Diaphragm Wall response.

MODEL GEOMETRY AND SOIL PROPERTIES

A series of numerical analyses are carried out to investigate various factors affecting the seismic performance of Concrete Diaphragm Wall.The Mohr–Coulomb model was used to simulate the nonlinear soil behaviour. The model is based on the plane strain conditions and is formulated in terms of effective stresses. The Concrete Diaphragm Wall was modelled as a linearly elastic material, by using beam element with bending stiffness of $E_c I = 3\times10^6 kN.\mathrm{m}^2$ (American Concrete Institute (ACI) 2008). Table 1 presents the soil and Trenches parameters used in the model.

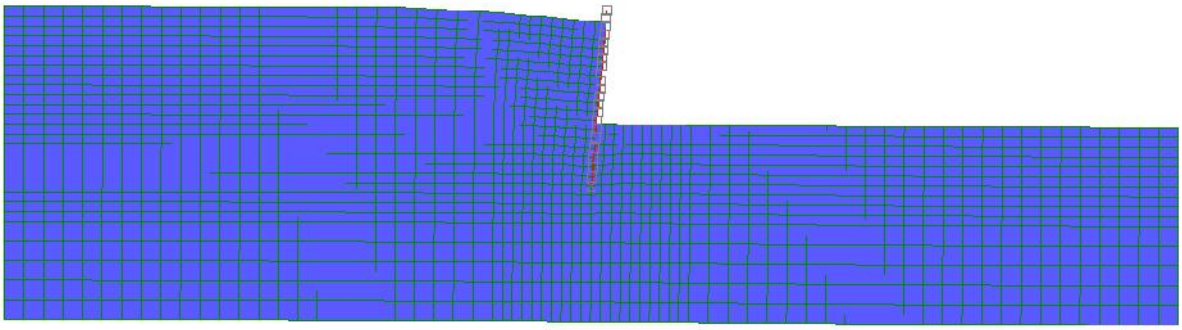

Figure 1. Schematic illustration of the concrete diaphragm wall subjected to earthquake.

Trenches are from 4 to 6 meters height and are excavated in 40 to 60 meter lengths (Figure 1.).Each model was subjected to three ground motion events obtained by scaling the amplitude of the Tabas (1978), Manjil (1990), and Bam (2003) earthquakes (Figure 2.)

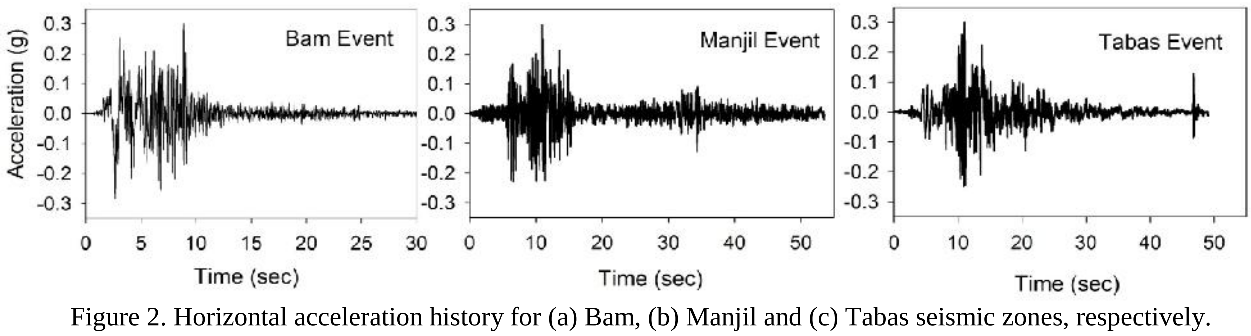

Figure 2. Horizontal acceleration history for (a) Bam, (b) Manjil and (c) Tabas seismic zones, respectively.

A series of realistic earthquake motions (Table 1.) were applied to the base of the model (Figure 1.).

The interfaces between the concrete diaphragm wall and soil were modelled as linear spring-slider systems, with interface shear strength defined by the Mohr–Coulomb failure criterion.

The relative interface movement is controlled by interface stiffness values in the normal k_n and the tangential k_s directions. Based on the recommended rule-of-thumb estimates for maximum interface stiffness values given by Itasca consulting group (Itasca), k_n and k_s were set to ten times of the equivalent stiffness of the neighboring zone. The apparent stiffness (expressed in stress per distance units) of a zone in the normal and tangential directions is:

$$k_{n(\max)} = k_{s(\max)} = 10 \times \max\left[\frac{K + 4G/3}{(\Delta Z)_{\min}}\right] \quad (1)$$

Where K and Gare the bulk and shear modules of soil zone, respectively (Table 1), and $\Delta Z_{\min}$ is the smallest dimension of an adjoining zone in the normal direction.

Table 1 summarizes the interface stiffness properties used in the foundation simulations after adjustment from values calculated by using Eq. (1).

Table 1.Soil and foundation data for deterministic analysis

Soil property	**Soft clay**	**Loose sand**
moist unit weight, γ (kg/m3)	1400	1600
Bulk modulus, K (Mpa)	3.3	8.3
Shear modulus, G (Mpa)	1.1	3.8
Relative density, Dr (%)	30	30
Internal friction angle, ϕ (degree)	20	30
Dilation angle, ϕ (degree)	-	-
Drained cohesion, C (kPa)	18	-
Poisson' ratio,(υ)	0.35	0.3
Concrete Diaphragm Wall data		
Diaphragm Wall, B_{wall}(m)		1
Young'modulusconcrete,E_c(kPa)		3.6×10^7
unit weight, γ (kg/m)		2300
$K_{n\ (Interface)}$, (Pa)/m		1×10^7
$K_{s\ (Interface)}$, (Pa)/m		5×10^6

The initial geostatic stress for steady state in a free field is one of the primary values related to grid zones which forces the model to reach equilibrium by performing mechanical calculations. In the static analysis, the soil–structure system was under gravity loading only; the base boundary was fixed in all directions and the side boundaries were fixed in x direction.

Table 2. Earthquake Data for the Parametric Analysis

Earthquake motion parameters/component	**Bam(2003)**	**Manjil(1990)**	**Tabas(1978)**
Date of occurrence	2003	1990	1979
Maximum horizontal acceleration (MHA)	0.3g	0.3g	0.3g
Predominant period (sec)	0.2	0.16	0.2
Bracketed duration (sec)	25.63	52.73	44.79
Significant duration ($D_{5\text{-}95}$) (sec)	7.75	29.23	18.73
Time of MHA (t_p (sec))	8.87	10.19	11.01
PGV/PGA (sec)	0.158	0.08	0.138
Arias intensity	1.143	1.23	1.358
Energy flux ($J.m^{-2}.sec^{-1}$)	1151	715	5549
M_w	6.5	7.3	7.4

RESULTS AND DISCUSSION

The values of maximum horizontal displacement for the diaphragm wall are presented for various wall height and soils in Fig. 3.The results revealed that Concrete Diaphragm Wall has a better performance in clay soils compared to the granular soils during the three mentioned events. Investigation of the horizontal displacement over the concrete diaphragm wall has demonstrated that the maximum displacement occurred during strong motions and it is depended to earthquake characteristics.

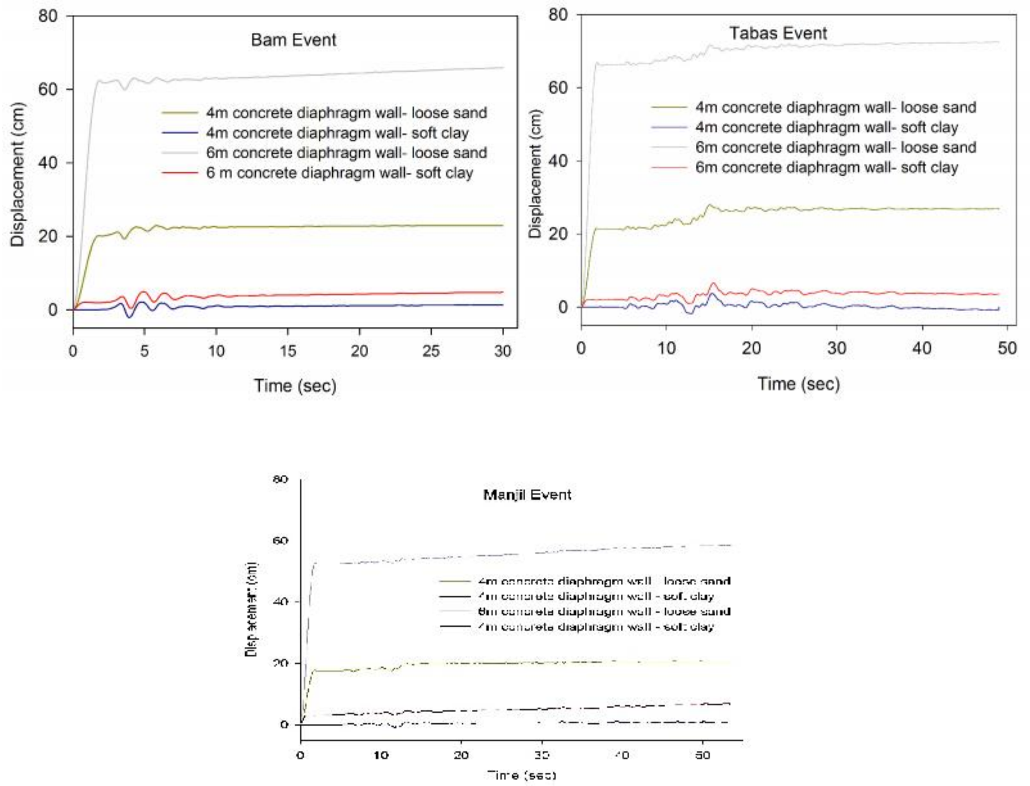

Figure 3. Time history of the lateral displacement of highest point of the concrete diaphragm wall for Bam and Tabas and Manjil earthquakes.

In the region of moderate to high seism city, if the height of the Concrete Diaphragm Wall is more than 4 meters, the seismic performance of the wall should be inspected.

Although reducing the wall thickness resulted in a decrease in the vertical and lateral section strength forces of the wall, the horizontal displacement over the concrete diaphragm wall is predicted to slightly increase.

In addition, the reduced total earth pressure on the excavated side of the diaphragm wall above approximately 1/2 of the maximum the original earth pressure on both sides of the diaphragm wall and the different earth pressure on the excavated and retained sides of the diaphragm wall ledto the rotation of the diaphragm wall into the excavation, especially in loose sand.

CONCLUSIONS

The main findings on lateral movements of Concrete Diaphragm Wall examined by a two-dimensional finite difference code(FDM) analysis are as follows:

The results revealed that Concrete Diaphragm Wall has a better performance in clay soils compared to the granular soils. Investigation of the horizontal displacement over the concrete diaphragm wall has demonstrated that the maximum displacement occurred during strong motions and it is depended to earthquake characteristics. In the region of moderate to high seism city, if the height of the Concrete Diaphragm Wall is more than 4 meters, the seismic performance of the wall should be inspected.

In addition, the reduced total earth pressure on the excavated side of the diaphragm wall above approximately 1/2 of the maximum the original earth pressure on both sides of the diaphragm wall and the different earth pressure on the excavated and retained sides of the diaphragm wall led to the rotation of the diaphragm wall into the excavation, especially in loose sand.

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