Estimate of Seismic Displacement of the Hump-Back Block Type Gravity Quay Wall

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Abstract

Quay wall is one of the key elements in harbor facilities and equipment, so collapse or any abrupt movement caused by an earthquake may result in irreparable economic and social losses in national, and even international, level. This type of quay wall has been popular in construction of moorings and ships in transportation industry as well as importation and exportation. In the recent years, there has been a concern about the stability of gravity quay walls in earthquakes of level 2 (MCE), which has changed the concept of design with concentration on performance evaluation. Based on this design, quay wall is allowed to displacement only to a limited extent in this level, so that the wall is changeable and maintains its performance.The present essay first studies the seismic displacement of hump-back block type quay wall in earthquake of level 2. The study has been conducted by using finite element method in numerical manner and behavior of hump-back quay wall has been analyzed in parametric way. The results denote that in cases where the seabed is soft and loose, gravity quay wall show very much settlement and rotation toward the sea and considerable displacment in foundation soil.

Key words: Quay wall, Hump-back, Seismic displacement, Dynamic analysis,

1. Introduction

Gravity Quay walls are the most common type of construction for docks because of their durability case of construction and capacity to reach deep seabed levels. The design gravity Quay walls requires sufficient capacity for three design criteria; sliding , overturning and allowable bearing stress under under the base of the wall. Although the design of gravity Quay walls is reasonably well understood for static loads, analysis under seismic loads is still in being developed. (PIANC 2001)

In a hump – back wall , increasing lateral earth pressures at deeper elevations of the wall are reduced by the land ward. Leaning rear face of the while the cost, weight, and mass of the wall are reduced by using a seaward leaning rear face at shallower elevation where lateral earth pressures are smaller (Sadrekarimi et al 2008) the stability of a hump – back retaining wall in comparison to that of a vertical – back wall is also improved as the center of gravity of the wall is drawn land ward (by appropriate land ward offset of the precast concrete blocks) and there by the stabilizing moment is increased and a higher friction is developed between the wall's base and the foundation seabed soil.

Therefore , several studies on quay walls. (Sherif and Fang 1984)(Ghalandarzadeh 1998) (Dakolas and Gazetas 2008). (Sato etal 2000) found that the fluctuating components of the dynamic thrust acting on quay walls and the inertia force of the wall were acting in opposite directions while the excess pore pressure developed in the back fill soil was small.

(Kim etal 2004) proposed a model to Estimate the magnitude and phase variation of the dynamic thrust on the back of the quay wall they evaluated the fluctuating and non fluctuating components of the dynamic thrust separately and confirmed the behavior of their model by two shaking table tests. They found that the mononobe – Okabe method overestimated the dynamic thrust as much as 4.5 times for large excess pore water pressures. (Mononobe and Matsuo 1929),(Okabe 1924) .

2. Description of the Region and Quay walls

This quay wall is used to transmit gas and petrochemical products to ships. The body of this quay consists of 10 concrete block placed on each other in gravity way, with the height of 20 m. Draught depth of this quay wall is 16 m, while dredging balance is +16CD and deck balance is +6CD. (Fig.1) shows geometrical profile of the quay wall.

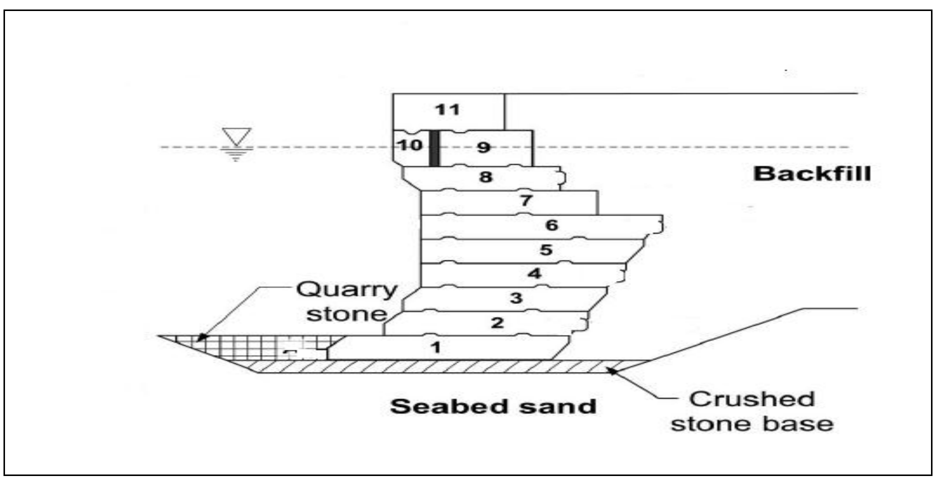

Fig1: Geometrical profile pars port quay wall

2.1. Geotechnical Conditions of the Region

Geotechnical studies were carried out in order to identify underground texture in quay area of Pars petrochemical port. The results indicate that quay wall area has various soil texture. According to these studies, layers of underground texture of this region in an area of 300 meters is as follows:

The first layer is very compressed sand together with silt, gravel and rubble. The second layers is very compressed graveland silt, with a hard silt lens layer below it. The fourth layer until the end of boreholes consists of sand, gravel and silt. Standard penetration test (SPT) was carried out in different depths and physical identification and soil strength tests were made on the samples. Soil layers details are shown in the (Tables 1~2).

E (MPa)	ν	Φ (deg)	C (kPa)	γsat (kNm3)	Layer thickness (m)	Layer surface in relation to water free level	Layer
30	0.30	35	0	20	3	-14 ~ -17	I
75	0.30	40	0	21	3	-17~ -20	II
120	0.30	45	0	21	4	-20~ -24	III
15			15				IV
20	0.45	0	20	20	2	-24~ -26	
30	0.30	35	0	20	3	-26~ -29	V
150	0.30	45	0	21	>20	-29 -E.O.B1	VI

Table 1. Strength parameters of soil layers

E (MPa)	ν	Φ (deg)	γ_{sat} (kNm3)	γ_{dry} (kNm3)	Grain size	Explanation	Layer
100	0.30	40	20	18	5-50 mm	Backfill	I
310	0.30	40	20	18	30-50mm	Rock fill below the wall	II
30	0.30	35	20	17	----	Natural land	III

Table 2. Strength parameters of the materials behind and below the wall

3. Numerical Modeling

Block type quay wall has been constructed by placing 10 concrete blocks on each other in gravity manner, with the height of 20 meters, in such a way that there is no fastening between the blocks and their connection is of friction type.

In view of high length compared with width and height, plane strain analysis type is used. This method is used for structures with nearly steady profile and tension status in vertical line. Since earthquake duration is short and very fast, studies are made only in this limited time period without consideration to post-earthquake behavior and analyses have been made in undraining conditions. Mohr-Kolomb behavioral model has been used as behavioral model of

the soils, and 15-node element which calculates hardness matrix in 12 points has been used for networking of the environment.
Behavioral model of the concrete used in wall's blocks is of linear elastic type with the weight of γ_{con}=24 KN/M3 and G=25 Gpa.
Standard fixity default in plane strain analysis mode gives horizontal fixity to vertical boundaries and complete fixity to horizontal boundaries. Also, left and right boundaries are energy absorbent which is used to avoid false reflections.
Material damping in a soil is generally caused by its viscous properties friction and the development of plasticity. However, in Plaxis the soil models do not include viscosity as such. Instead, a damping term is assumed, which is proportional to the mass and stiffness of the system (Rayleigh damping) , such flat:

$$C = \alpha M + \beta k \qquad (1)$$

Where C represents the damping, M the mass, K the stiffness and α (Alpha) and β (Beta) are the rayleigh coefficients.
The rayleigh damping coefficients α and β can be determined from at least two given damping ratios ξ_i that correspond to two frequencies of vibration ω_i. The relation ship between α, β, ξ_i and ω_i can be presented as

$$\alpha + \beta w_i^2 = 2 w_i \xi_i \qquad (2)$$

Interface element has been used between quay wall and backfill, between bottom block and seabed and between all the blocks.
In Plaxis, the stress – strain behavior at soil – structure interface is simulated by elastic – perfectly plastic model the model parameters at the soil. Structure inter face can be modeled from the soil with a correlating factor called interaction coefficient or interface strength , R_i or R_{int}.
(Fig.2) shown the models built block type gravity quay wall for dynamic analysis together with their details in PLAXIS.

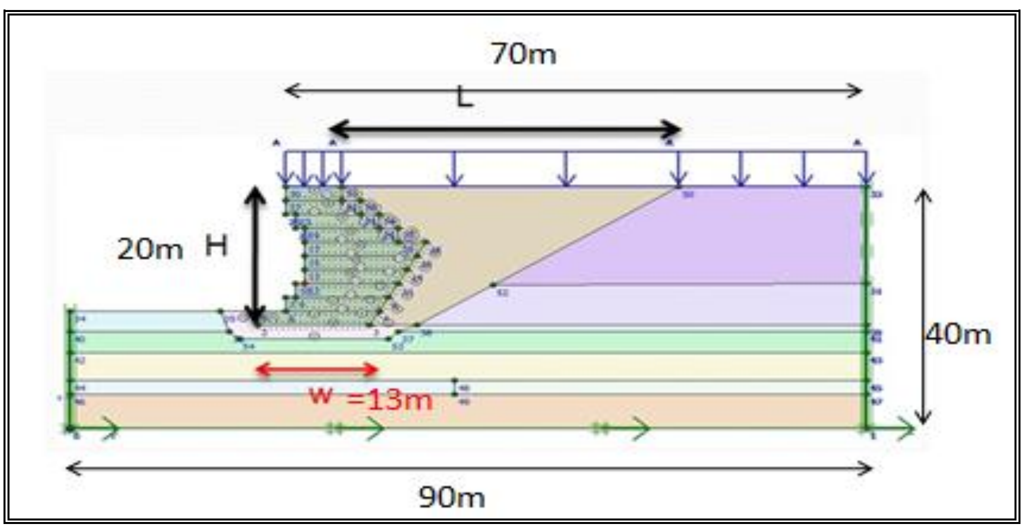

Fig.2: Profile of the quay wall in numerical model (PLAXIS)

The most perfect way for evaluation of dynamic behavior of soil structures is full nonlinear time history dynamic analysis. The structure's behavior in every moment of earthquake is analyzable. This method is not still very popular due to its complicatedness and needed long time, but many of designers use it for final control of design.
In loading time, surchage in ordinary conditions is 4 (ton/m2) according to different recommendations (PIANC, OCDI 2001) [11,12]. Quay wall surchage value in time of earthquake is considered 50% of the value in ordinary conditions (static). In dynamic loading, however, since design is based on performance and according to (OCDI 2002) recommendation that earthquake level 2 (MCE) should be used in dynamic analysis, all acceleration records have been scaled PGA=0.42g in earthquake level 2.
According to Japan's OCDI standard, analysis in level 1 is based on acceptable stability and efficiency and in level 2 is based on reparability and reusability until effective lifetime of the project. The selected acceleration records are shown in the (Table3).

Earthquake	Registration place	PGA
Kocaeli (Turkey), 1999	Sakaria	0.7g
Kobe (Japan), 1995	Kjm	0.82 g
Northrige (USA), 1994	Sylmar hospital	0.65g
Northrige (USA), 1994	Sepulvada va	0.749 g
Lomaprieta (USA), 1989	Emeryville	0.25 g
Northrige (USA), 1994	Sylmar convertor	0.82 g
Friulli (Italy), 1976	-----	0.48 g

Table3**.** Ground motion inputted

To make a comparison between the results of dynamic analysis, horizontal displacement of the first block from top of both quay walls has been used as seismic response of hump-back quay wall.
(Table 4) presents full information achieved by dynamic analysis of the quay wall (QW) for all acceleration records together with allowed values

earthquake / parameters	Kobe kjm	Northrige sylmarcon	Northrige sylmarhos	Northrige sepulveda	Kocaeli sakaria	Lomaprieta emery vill	Friulli Italy	Allowed value
H.displacement of the top wall(cm)	**33.3**	**35.7**	**40**	**39.3**	**60.8**	**87.5**	**14.8**	**100-110 (cm)**
H.displacement of the base wall(cm)	**29.3**	**29.3**	**34.3**	**30.8**	**58.6**	**85.7**	**14.3**	**-**
Difference top and base	**4**	**6.4**	**5.7**	**8.5**	**2.2**	**1.8**	**0.5**	**-**
Rotation (degree)	**0.2**	**0.32**	**0.29**	**0.43**	**0.11**	**0.1**	**.02**	**1.5-5**
V.displacement of the top(cm)	**14.3**	**11.8**	**15.7**	**12.1**	**14.3**	**32.1**	**3.2**	**-**

Backfill settlement(cm)	**20.1**	**18.6**	**26.6**	**15.1**	**27.1**	**77**	**12.1**	**-**
Relative displacement of the two blocks	**0.4**	**0.65**	**0.7**	**0.67**	**0.9**	**2.5**	**0.35**	

Table 4 . Information achieved by dynamic analysis of the quay wall (QW)

4. Study on the effect of relative density(Dr) of the seabed and backfill

In view of the fact that earthquake has caused considerable damages to the world's quays such as Kobe in Japan (1995) and Drince port during Kocaeli earthquake (1999), the effect of compression of seabed and backfill in four different cases was studied under dynamic analysis of block wall QW, because it is necessary to evaluate the effect of seabed relative compression in seismic design, especially in saturation conditions.

To evaluate this parameter, acceleration record of Loma Prieta earthquake in Collaritos station has been used. The results are shown in (Figs. 3~4).

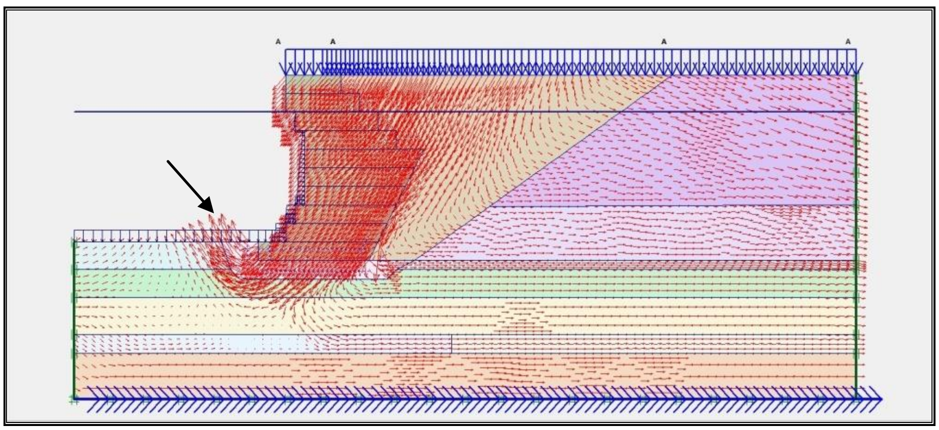

Fig. a: Loose foundation/seabed condition(QW2)

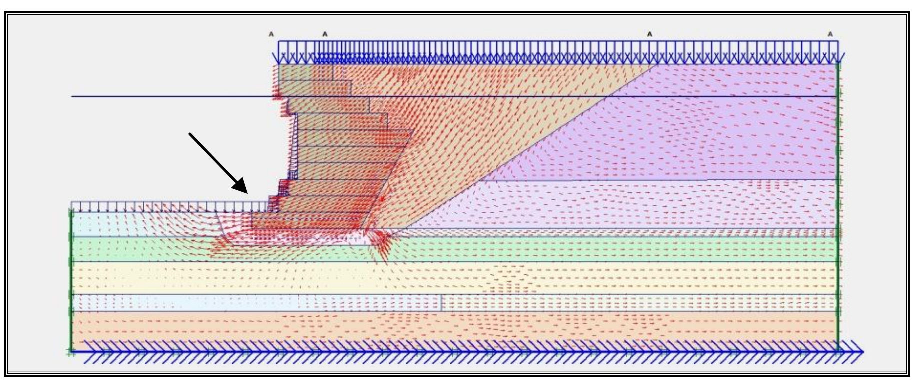

Fig. b: Densefoundation/seabed condition(QW2)

Fig.3 : Plot displacement QW2 after earthquake in diffrent Dr

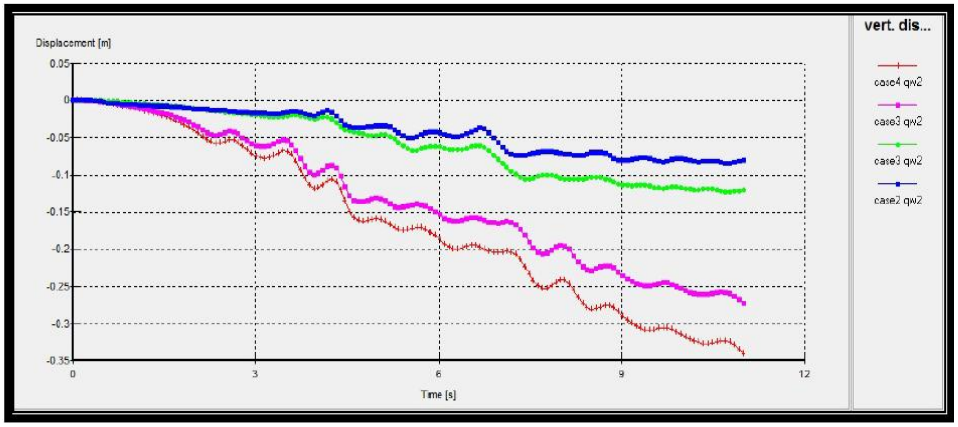

Fig.a: Vertical displacement

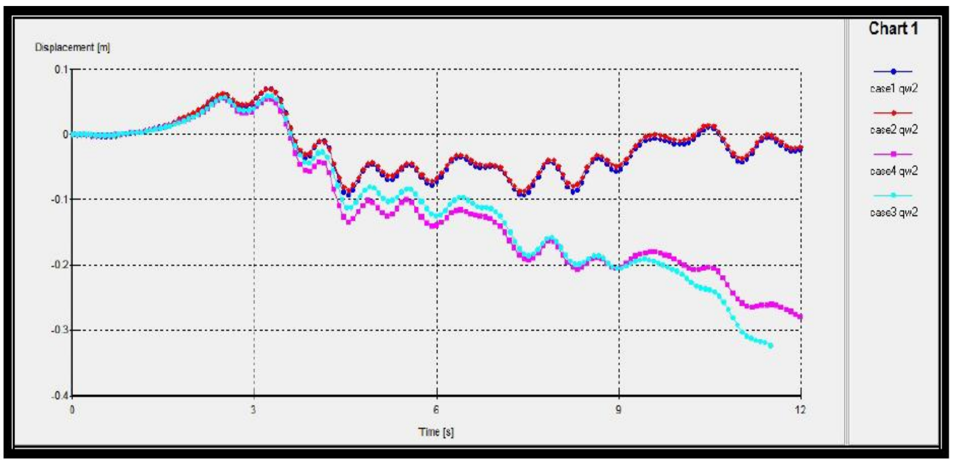

Fig.b: Horizontal displacement

Fig.4:Horizontal and vertical disolacement of quay wall in different cases

Rotation (grade)	displacement (cm)		Backfill	Seabed	Mode
	Vertical	Horizontal			
0.05	12.1	2.5	Dense	Dense	Case 1
0.025	8.2	2.1	Loose	Dense	Case 2
-0.18	34	34.1	Loose	Loose	Case 3
-0.15	27.3	28	Dense	Loose	Case 4

Table5. Full information achieved by Plaxis in different analyses of seabed and backfill compression of Wall

The quay wall (QW) with six sloped blocks and higher weight, if located on soft seabed, sinks like the first type wall and pushes the backfill in front of it, causing much more settlement compared with when seabed is very dense (Figs. 3~4) . In the case of soft seabed, the wall often moves toward the sea but rotates toward the land. The negative sign of rotation means rotation towards land.

However, when the seabed is dense, the wall completely moves, sliding with the least rotation. In this case, the second type wall often moves toward the sea. (Table 4)

5. Conclusions

1. Design base performance of block type quay wall modeled with an approach to earthquake level 2 in order to study quay wall performance in terms of stability and reusability after occurrence of earthquake. The results indicate that block quay wall resists earthquake level 2 showing acceptable performance in accordance with standards and regulations.

2. The study on the effect of relative compression of seabed and backfill, for which a dynamic model was developed in Plaxis, indicates that when seabed is compressed and backfill has relatively less compression, the best mode in wall movement and rotation is achieved. When the seabed is loose and back fill has relatively high compression, we will have the highest amount of movement and rotation.

3.Improving the foundation while the backfill remained loose caused slightly smaller residual deformation of the hump back than when both the foundation and backfill were improved.

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