Static and Dynamic Behavior Analysis of Neka Dry Dock Walls, A Case Study

Mojtaba Heidari[1] and Mahmoud Hassanlou Rad[2]

[1] *Dept. of Civil Engineering , Islamic Azad University, Kermanshah Branch, Kermanshah, Iran*
[2] *Dept. of Civil Engineering , Islamic Azad University, Zanjan Branch, Zanjzn, Iran*
Email: mojiran@gmail.com

ABSTRACT :

Special details of Neka dry dock such as geotechnical conditions, seepage phenomenon, different construction stages, different loads during construction, operation and earthquake, special geometry of embedded sheet piles, the repair ability assessment after earthquake and defects of exist empirical and theoretical methods dictated the use of stronger tools and noble methods to structure analyze and design. In this paper, brief results of analysis and the used special methods are presented. The analyses were carried out using geotechnical software named PLAXIS, considering the all mentioned parameters to optimize the final design. Despite, the analyses were controlled using geotechnical software named FLAC. The results of two mentioned softwares showed an acceptable compatibility with a fewer difference. Therefore, a suitable assessment of internal structural forces, dynamic deformations and structure repair ability after fully time history analysis was carried out.

KEYWORDS: dry dock, retaining wall, steel sheet pile, time history, Neka

1. INTRODUCTION

The analysis and design of special geotechnical structures and their dynamic behavior, has a particular importance regarding to defects of theoretical and empirical methods. These deficiencies are emphasized in dynamic soil and structure interaction that different loads in staged construction affect the structural elements forces. Also seepage and its effect on pore water pressure affect the effective stresses and consequently the total stability of structure is under question. Pseudo static and spectral methods are exist as the simple methods in order to consider of horizontal earthquake loads. In case of geotechnical buried structures such as dry dock and so, pseudo static method has some defects such as prediction disability of residual earthquake displacements and boundary condition limitations. Also the spectral method has no specified use in geotechnical structures. Thus, it is needed to utilize a powerful tools and methods in order to consider the all mentioned conditions together and to estimate the residual earthquake displacements.

Some staged construction and loading cases were carried out to analyze and design of Neka dry dock walls as anchored steel sheet pile (SSP). The mentioned geotechnical structure was subjected to static and seismic conditions during construction and operation. SADRA Ship Building Complex is located in SADRA Ship Building Complex, south-eastern coast of Caspian Sea (Neka- Iran). This paper presents brief results of static and pseudo static analyses and also fully dynamic (time history) analyses results. The analyses were performed using PLAXIS finite element software and controlled by FLAC finite difference software. It should be noted that the dynamic analysis of dry dock retaining walls was carried out for level two of earthquake with the period of 475 years and in case of operation (after construction).

2. PRIMARY CONDITIONS, LOADING AND OTHER CHARACTERISTICS

Some assumptions in selection of construction conditions and primary parameters have been supposed in analysis and design of dry dock structural elements as follow:

2.1. Construction Conditions

Some construction stages were assumed as follow to reduce effective pressure on SSPs and to achieve the required depth in a dry area after cofferdam construction against sea water entrance into the site and soil improvement against liquefaction:
1) lowering groundwater table down to 5m in depth, 2) excavation to depth of 5m, 3) driving and anchoring of SSPs, 4) backfill of walls up to ground surface, 5) excavation in front of SSPs to foundation floor in depth of 13m, and 6) construction of concrete foundation with 2m thickness.

2.2. Loading Cases

Different loads in staged construction and also operation of dry dock is as follow:
Live load during construction LL=0.5 t/m^2
Live load during construction LL=0.5 t/m^2 and earthquake coefficient K=0.12 for pseudo static analysis
Live load during operation LL=2.5 t/m^2
Live load during operation LL=0.5 t/m^2 and earthquake coefficient K=0.22 for pseudo static analysis
Live load during operation LL=0.5 t/m^2 and time history earthquake acceleration analysis by means of four existing acceleration time histories for dry dock site. It should be noted that existing acceleration time histories were obtained from recorded information in two stations prepared by SADRA Co. (Iran Marine Industrial Company) and one of them has been shown in Figure 1 [1].

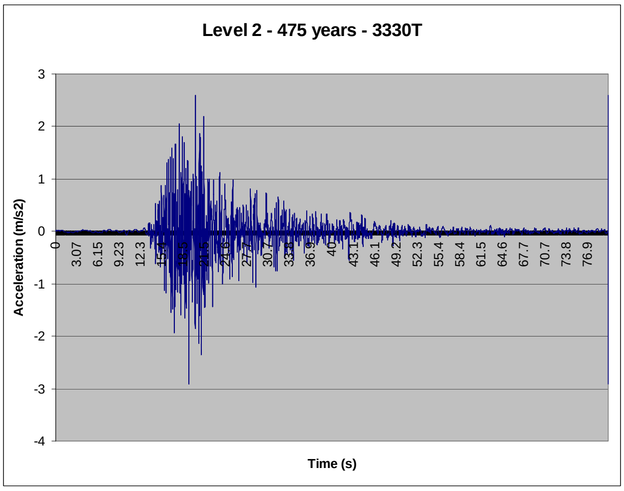

Figure 1 Acceleration time history in Neka site

2.3. Soil Layers Geotechnical Parameters

According to site investigation and results of five borehole logs in project area, soil layers characteristics were obtained by means of in situ tests (permeability and SPT) and laboratory tests (classification, consolidation, triaxial and direct shear test and permeability) and have been presented in table 2.1.

2.4. Dry Dock Characteristics

The area of Neka dry dock is 40m x 250m and in figure 2 its section has been shown after excavation and construction of dock floor slab. Structural elements characteristics for analysis of dock model have been shown in figures no. 3, 4 and 5 that include of properties of concrete dock floor slab, SSPs and anchor rods.

Table 2.1 Soil layers physical and mechanical properties [2]

Description	Silty sand (0-10m)	Silty sand (10m-23m)	Silty clay (23m-27)	Silty sand (27m-60m)	Unit
Undrained angle of friction (φ_u)	-	-	*0-5*	-	Degree
Undrained cohesion (C_u)	-	-	*0.5-0.7*	-	Kg/cm^2
Drained angle of friction (φ_d)	*29-31*	*31-33*	*28-30*	*33-35*	Degree
Drained cohesion (C_d)	*0-0.1*	*0-0.1*	*0-0.1*	*0-0.1*	Kg/cm^2
Modulus of elasticity (E)	*130-230*	*200-250*	*120-180*	*250-350*	Kg/cm^2
Density (γ)	*1.95-2.1*	*1.95-2.1*	*1.9-2.0*	*2.0-2.1*	Gr/cm^3
Poison's ratio (υ)	*0.3*	*0.3*	*0.4*	*0.3*	-
Compression index (C_c)	-	-	*0.2*	-	-
Swelling index (C_s)	-	-	*0.02*	-	-
Over consolidation ratio (OCR)	-	-	*1.0*	-	-

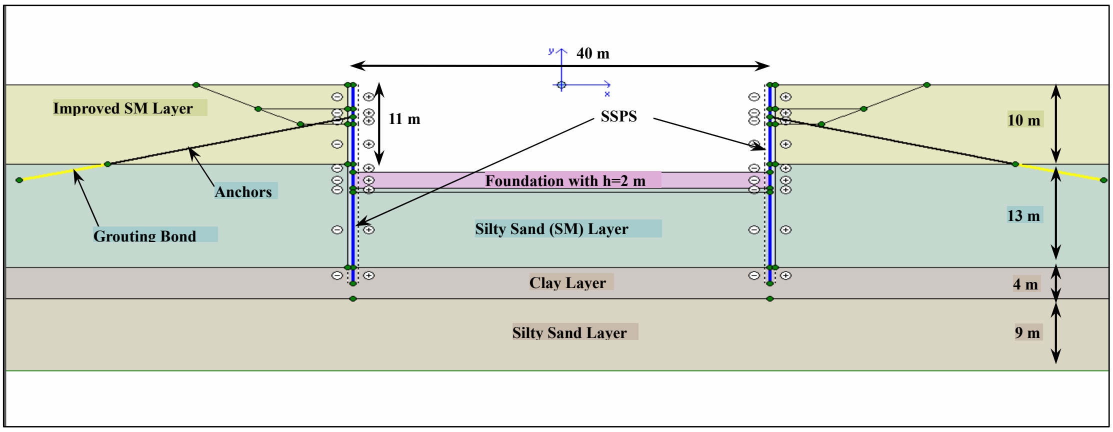

Figure 2 Dry dock geometry and soil stratification

Number	Identification	γ_{dry} [kN/m^3]	γ_{wet} [kN/m^3]	ν [-]	E_{ref} [kN/m^2]
7	Concrete 2m-EL	25.0	25.1	0.20	2E7

Figure 3 Dock floor concrete slab properties

Number	Identification	EA [kN/m]	EI [kNm^2/m]	w [kN/m/m]	ν [-]
7	HZ975B14/AZ18	6.8859E6	8.9233E5	2.57	0.25

Figure 4 Properties of steel sheet piles (SSP) as retaining wall

Number	Identification	EA [kN]	$\lvert F_{max}\rvert$ [kN]	L_s [m]
4	Anch D=5 cm - EL.PL.	4.1213E5	800.0	1.00

Figure 5 Anchors properties

3. STATIC AND PSEUDO STATIC ANALYSIS

Dynamic analysis is carried out after static analysis with considering mentioned staged construction. For achieving this purpose, PLAXIS finite element code was utilized in dry dock analysis with the ability of modeling soil-water environments and soil-structure interaction, and also water seepage through soil and the analysis of stress-deformation according to soil behavior models. PLAXIS analysis results were checked by similar program named FLAC that is based on finite difference method and comparison out put has been presented in the following.

3.1. Modeling in PLAXIS and FLAC [3, 4]

Mesh generation of soil in PLAXIS is based on triangular elements and in FLAC is based on square elements. Beam element for SSP and axial element for anchor were used in both soft wares. Simulation of connection between soil and structural elements (soil-structure interaction) consist of interface elements in both program. By mentioned feature and use of smaller soil strength in interfaces (about 60% of ultimate strength), slip surface between soil and structure occurs before soil failure. Mohr-Coulomb failure envelop was used for soil with elastic perfectly-plastic behavior. An area with 400m x 36m dimension was used in plane strain condition in model to avoid effects of model boundaries on the analysis results, and 36m depth as bedrock depth was selected because of prepared acceleration time history on it.

3.2. Groundwater Seepage

Groundwater flow study has been done due to two reasons: 1) discharge determination of seeped water through soil into the dock and 2) consideration of unbalance pressure effects on sheet piles and soil mass. A seepage analysis is performed in each staged construction of dock and before stress-deformation analysis to consider unbalance pressures affected on SSPs because of water flow in soil. Mentioned unbalance pressure has been shown in figure 6 after a seepage analysis.

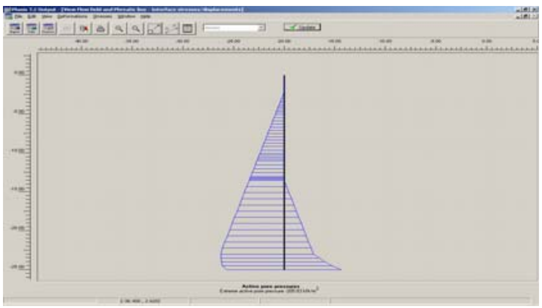

Figure 6 Unbalance water pressure on a sheet pile after seepage analysis

3.3. Static Analysis

As mentioned above, it is needed to define of stresses and deformations generated by dry dock construction before time history analysis. Thus, a static analysis was carried out considering staged construction in regard to excavation and groundwater levels. In this model, horizontal and vertical deformations on the horizontal boundary and horizontal deformation on the vertical boundary were set to zero to define static boundary conditions. Groundwater table is 2m below ground surface before dock construction. Maximum value of SSP deformation is equal to 16.5cm in depth of 11m below surface that occurs after dock floor excavation and before floor concrete slab construction. It is notable that maximum horizontal deformation of dock related to its depth is equal to 1.5% that is according to standard [5]. Deformed geometry of Neka dry dock is shown in figure 7.

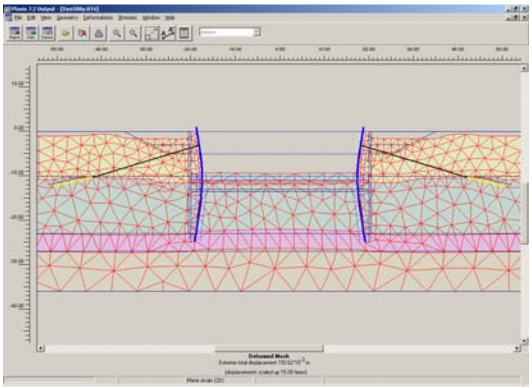

Figure 7 Deformed mesh after excavation and dock floor construction (scaled to 15 times greater)

3.4. Pseudo Static Analysis

In pseudo static method, a coefficient of peak ground acceleration (PGA) as equivalent horizontal force applies on soil and structure together to consider of earthquake effect on dock stability. Reduced validity of this method and uncertainty in use of its results were observed according to following reasons during analysis:
1) The whole mass of soil and dock structures trends to move in direction of applied horizontal force and selection of different distances of boundaries from dock, affects on analysis results such as anchor force, bending moment and displacement of SSP, stress and strain of soil mass. It means that the farther boundaries puts more mass of soil against applied horizontal force and increases the structural element forces and also a near boundary produces smaller structural forces.
2) Another problem of pseudo static method is loading on whole section of the model (about 400m) in one direction, but in real earthquake only a limited area as big as earthquake wavelength is loaded and moved in one direction and this direction is variable during earthquake.
The reason of mentioned problems is special buried form of symmetric dock structure and it is not very important in other geotechnical structures such as embankment dams, retaining walls, etc. with limit length that are made on the ground surface. Therefore, it seems necessary to utilize an exact time history analysis to study of dynamic behavior of dock.

4. FULLY DYNAMIC (TIME HISTORY) ANALYSIS

In addition to mentioned problems in pseudo static method, other analytical, empirical and semi-empirical methods prepare different results and have no ability to consider staged construction. Also in these methods, residual structural displacement after earthquake and failure mechanism is not predictable that is important to show structure operation in seismic conditions. Thus, in this research, fully dynamic analysis was used as a relatively exact method in prediction of structure response to earthquake in each moment of earthquake time. Earthquake loading on structure should be applied as time history of acceleration, velocity, displacement or stress or force on bedrock to simulate dynamic loading on real structure. In this research acceleration time history was used for project area. After that, different parameters such as time history of acceleration, velocity and displacement in different points of soil and structure and also structural bending moments and forces during analysis were recorded to study of dynamic behavior of dry dock and soil structure interaction.

4.1. Dynamic Boundary Conditions

It is necessary to select of correct dynamic boundary conditions to achieve a correct modeling of real conditions and to obtain valid results. Thus, dynamic boundary conditions were selected as energy absorbent and free boundary (like semi-infinite natural ground) to avoid reflection of earthquake waves into the model after reception to these boundaries. Also, selected earthquake acceleration time history was affected on the bedrock (lower horizontal boundary) to apply earthquake acceleration on the model.

4.2. Damping selection

Rayleigh damping used in dynamic analysis that define in Eqn. 4.1.

$$C = \alpha M + \beta K \tag{4.1}$$

That C is damping matrix, M is mass matrix, K is stiffness matrix, α is damping constant relative to mass and β is damping constant relative to stiffness. In FLAC program, the values of α and β calculates according to Eqn. 4.2 and Eqn. 4.3 by definition of minimum critical damping ($\xi_{\min}$) and minimum frequency of model ($f_{\min}$). In PLAXIS software the values of α and β define directly as input data after calculation by Eqn. 4.2 and Eqn. 4.3.

$$\alpha = \xi_{\min}\omega_{\min} \tag{4.2}$$

$$\beta = \xi_{\min} / \omega_{\min} \tag{4.3}$$

According FLAC manual recommendation, minimum critical damping is located in range of 2% to 5% for geological materials and in this research is selected as $\xi_{\min} = 0.02$. Also, it is not very important to exact definition of α and β in models that is possible to create plastic zones during earthquake, because energy dissipation under plastic conditions is much bigger than elastic conditions based on damping and mentioned coefficients [4]. Minimum frequency of soil and structure was defined based on free motion analysis of model under its weight that this value was obtained equal to 0.8 Hz with both software PLAXIS and FLAC (Eqn. 4.4).

$$f_{\min} = \frac{1}{T_{\max}} = \frac{1}{1.2\sec} = 0.8Hz \tag{4.4}$$

T_{max} (sec.) is maximum period of model based on free motion analysis of model under its weight.

4.3. Dynamic Analysis Results

After static analysis, existing displacements were set to zero to study net seismic displacements. In this paper, critical results of dynamic analysis have been presented based on four recorded acceleration time history in project area [1]. In figure 8, horizontal displacement of bedrock level, top and bottom of SSP and dock floor has been shown during earthquake obtained by PLAXIS. According to this figure, difference between pure dynamic displacements of mentioned levels is zero before earthquake but at the end of analysis, it is equal to 5cm between bedrock and top of SSP that is named residual horizontal displacement. Also in figure 8, maximum bending moment of SSP and anchor force have been shown with some values in other moments of earthquake. Brief results of dynamic analysis of Neka dry dock have been presented in table 4.1.

Table 4.1 Brief results of dynamic analysis of Neka dry dock

Software	Maximum Experienced Bending Moment in SSP (t.m/m)	Maximum Experienced Anchor Force (t /m)	Max. Displacement of Top of SSP During Earthquake (cm)	Max. Residual Displacement of Top of SSP After Earthquake (cm)
PLAXIS	***218***	***80***	***16.1***	***5.1***
FLAC	***187***	***80***	***13***	***4***

It is better to correct input acceleration time history to the base line that bedrock displacement sets to zero. But it is notable that if this correct does not carry out, any error will not affect on analysis results.

In figure 9, recorded acceleration time history by FLAC has been shown in three points consist of bedrock, dock floor and top of SSP during earthquake. It should be noted that, comparison of results of two geotechnical software PLAXIS and FLAC in dynamic analysis of Neka dry dock increases the reliability in using their outputs because of the same behavior of soil and structure in two software, closeness of their results and each other confirmation.

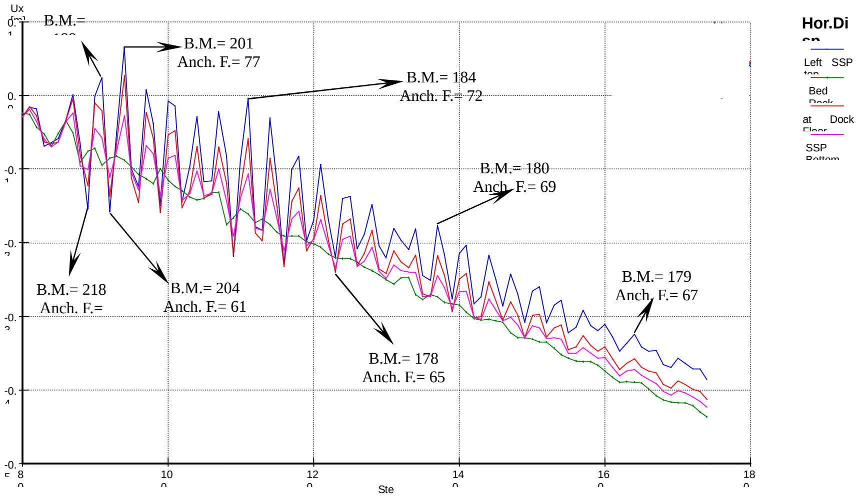

Figure 8 Disp. of different points and some bending moment (t-m/m) and anchor forces (t/m) during earthquake

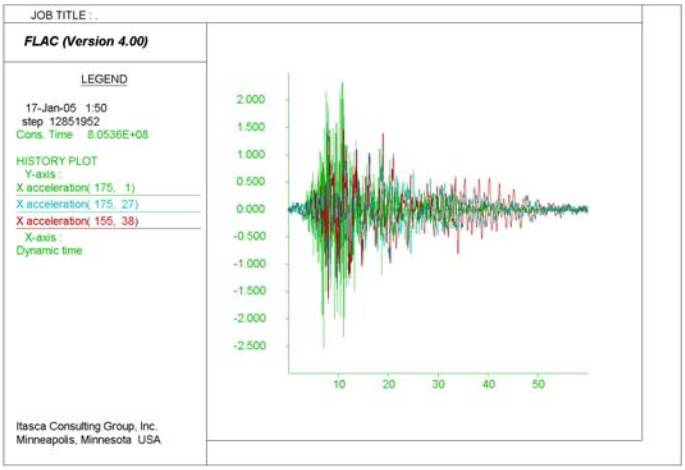

Figure 9 Recorded acceleration time history in three points of bedrock, dock floor and top of SSP

5. CONCLUSION AND INTERPRETATION OF RESULTS

Main factors representing dynamic behavior of dry dock are time history of displacement and bending moment of SSP, axial forces of anchor and maximum values of them, shear strains and plastic zones in soil because of earthquake loading. Investigation results of dynamic behavior of Neka dry dock under earthquake loading are presented as below:

1) The values of maximum residual displacements of SSP (5.1cm at the end of dynamic analysis) are according to standard [5] and in the range of repair ability of special structure of Neka dry dock.

2) The maximum bending moment of 218 t.m/m is acceptable based on the capacity (277 t.m/m) of selected

section (HZ975B-14/AZ 18) for SSP in earthquake loading. It should be noted that the location of maximum bending moment in height of SSP is almost same during static and dynamic conditions.

3) Maximum values of bearable anchor axial forces were restricted to 80 t/m based on the axial bearing capacity of anchors. It means that anchor axial forces of 80 t/m during earthquake destroys the connection between soil and grout bond of anchor's end and anchors loses their roles in stability of SSP until reduction of loads. Therefore, the SSPs will be responsible for keeping the total stability because of increasing in displacements and consequently bending moments. According to analysis, except some moments of earthquake loading, recorded anchors axial forces is less than 75 t/m and increased displacements and bending moments due to disoperation of anchors remains in the safe side and allowable range for dock structure.

4) Acceleration time history of top of SSPs relative to input acceleration time history on bedrock is another factor representing the dynamic behavior of dry dock. At the beginning of earthquake with greater acceleration applied on bedrock, recorded acceleration on the top of SSPs have smaller values that show the energy absorbance and damping in soil. After that, reduction in amplitude of input acceleration on bedrock increases the recorded acceleration on the top of SSPs and illustrates acceleration amplification in soil. On the other hand, at the beginning of earthquake with great amplitude of acceleration and induced large strains, plastic zones are created in soil and the ability of earthquake wave transfer to upper soil layers is demolished. Also, in the range of weaker acceleration, the model vibrates in elastic conditions and amplification of earthquake waves is observed.

5) In spite of plastic zones are experienced by the soil in limited areas and maximum residual shear strain that exceeds to 5% in some regions, any failure mechanism is not formed in the model and total soil-structure system is remained in the safe side.

ACKNOLEDGMENT

This is a great appreciate to Khak Baft Consulting Engineers' staffs especially Mr. G. Sanaee, Mr. G. Fazaee and Mr. M. Hoseini regarding to prepare of data and equipments for this research.

REFERENCES

[1] SADRA Company. (2004). "Report on Seismotectonics, Seismic Hazard and Seismic Response Analysis of Bedrock for NEKA Site (South of Khazar Sea)".
[2] Mandro Consulting Engineers. (2004). "Final Report Soil Investigation and Geotechnical Studies at the Site of Dry Dock for SADRA Ship Building Complex".
[3] PLAXIS Finite Element Code for Soil and Rock Analyses, Version 7.2. (1998). User Manual, Rotterdam, Netherlands.
[4] Itasca Consulting Group. (2001). "FLAC 2D. Fast Lagrangian Analysis of Continua in 2 Dimensions", Version 4.0, User Manual, Minnea Police: Itasca.
[5] PIANC, International Navigation Association. (2001). "Seismic Design Guidelines for Port Structures".
[6] The Overseas Coastal Area Development Institute of Japan. (2002). "Technical Standard and Commentaries for Port and Harbor Facilities in Japan".
[7] CIRIA C580. (2003). "Embedded Retaining Walls Guidance for Economic Design", London.
[8] Steven L. Kramer. (1997). "Geotechnical Earthquake Engineering".