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INTERPRETATION OF SITE SPECIFIC SEISMIC HAZARD ANALYSIS, IN PERMANENT SHORING DESIGN, A CASE STUDY

Onur EKLI[1], Ismail Emrah KILIC[2], Mehmet AKAR[3], Hilmi Turan DURGUNOGLU[4]

ABSTRACT

The use of seismic isolators in design of important government buildings in Turkey is increased after the major Kocaeli earthquake in 1999, (M_w=7.6). The isolators are usually placed at the ground level of the building and the basement floors of these buildings are designed without the beneficial effect of the seismic isolators. Before the design period, the site specific hazard analysis for the sites of these buildings is also requested.

The Okmeydanı Training and Research Hospitals is an existing building in the European side of Istanbul, however the building is not satisfying the expectations of the government in terms of serviceability after major earthquake that is expected to occur in 50 years period with %2 probability. Therefore the hospital buildings are planned to be renewed. The seismic isolators are used in superstructure design of the Okmeydanı Training and Research Hospital are placed over the foundation level which is approximately 20m lower than the natural ground level. Therefore a there is need for permanent shoring design 20m height in a very seismically active region in which the recommended design acceleration is a_h=0.31g. This paper would be focusing on the interpretation of the site specific seismic hazard analysis and improvement of design stages and also problems occurred later on in application period and solutions suggested.

Keywords: shoring, permanent, design, seismic

1. INTRODUCTION

After the major Kocaeli earthquake in 1999, (M_w=7.6), to take the necessary precautions against the risk of having a major earthquake in Istanbul, major government buildings are re-evaluated with greater understanding and increased consciousness of potential seismic risks and buildings are re-constructed where necessary. The reconstruction project of Okmeydanı Research and Training Hospital is one of these major projects. The hospital is requested to be designed for maximum credible earthquake (MCE), which has a 2% probability of exceedance in 50 years and return period of 2475 years. The construction methodology includes firstly the utilization of recreational sites belonging to the existing hospital for the construction of new buildings. Secondly during construction, preventing the disturbance of health services continuum in the old buildings. Finally after the completion of new buildings and commencement of health services in these buildings, and then the demolishment of old buildings will be executed and construction of additional buildings and recreational areas will be done in those areas will be completed.

[1]Civil Engineer, M.Sc., Zemin Etud ve Tasarım A.S., 34794, Alemdag, Cekmekoy, Istanbul, TURKEY; onur.ekli@zetas.com.tr
[2]Civil Engineer, PhD., Zemin Etud ve Tasarım A.S., 34794, Alemdag, Cekmekoy, Istanbul, TURKEY; emrah.kilic@zetas.com.tr
[3]Civil Engineer, B.Sc., Zemin Etud ve Tasarım A.S., 34794, Alemdag, Cekmekoy, Istanbul, TURKEY; mehmet.akar@zetas.com.tr
[4]Prof., Department of Civil Engineering, Bogazici University, 34342 Bebek, Besiktas, Istanbul, TURKEY; durgunoglut@zetas.com.tr

For the purpose of seismic risk analysis of the Project, a site specific seismic hazard study has been done in 2011. Since the Okmeydanı Research and Training Hospital is only 22km away from the Main Marmara Fault and structural design performance criteria of the Hospital dictates that, the building shall be designed for maximum credible earthquake, it is decided to use seismic isolators in structural design. The important decision was about the level of these seismic isolators, after discussion of the issue among the alternative levels, the isolators were decided to be placed just above the foundation level (approx. +80.0m levels where ground level is +100.0m). After this decision is made, a challenging geotechnical problem occurred involving 20m high permanent retaining system that will be designed for maximum credible earthquake for assuring the building performance.

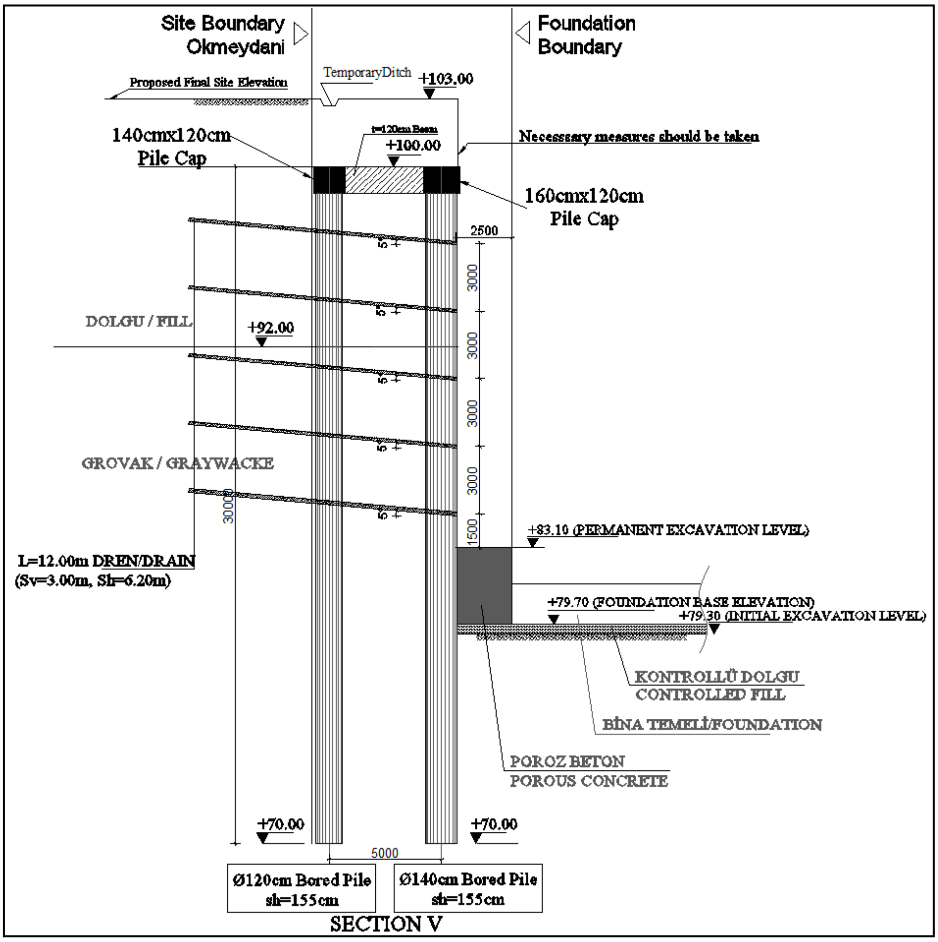

Figure 1 A Typical Section of the Preferred Retaining System Alternative

1.1 Retaining System Selection

The cross section view of the section is given in Figure 1, due to the high fill thickness found in subsoil investigations in most of the construction area, the long term performance of anchors was arguable. The long term maintenance requirements for the anchors during service life of the building are also a major issue in the decision of utilization of passive and prestressed anchors. Finally for some of the sections, the anchors need to be drilled out of the site boundary which is not possible without permission of neighboring site owners and even the permissions are taken, it is considered as a potential risk.

After presentation of possible alternatives with anchors and without anchors, the Client decided to use a cantilever system with a high initial cost but very little/no maintenance requirements. The cantilever solution for a 20m high retaining system with high seismic design requirement was only possible because of a min. of 6.0m - 7.0m of area belonging to the Client exists for the retaining system placement which is enough for two rows of piles, but not enough for anchors.

2. SITE SPECIFIC HAZARD ANALYSIS

2.1 Hazard Assessment and Ground Motion Parameters

In this Project, the probabilistic seismic hazard analysis (PSHA) study, elaborated in Erdik et al. (2003 and 2004), employed by the Earthquake Engineering Department of Kandilli Observatory and Earthquake Research Institute for the assessment of the seismic hazard in various projects, is utilized.

The codes with international standing (as stated in the tender specifications for the design of the hospital) for the design of seismically isolated buildings consist of single-mode and multi-mode equivalent linear methods and the response history analysis methods as encompassed in IBC (2006), EC8 – CEN (2005), FEMA 440 (Applied Technology Council, 2005), ASCE 7-05-ASCE (2005), NEHRP (2003), FEMA-356 (2000) are used in the analysis.

In the design process two levels of earthquake ground motion given below are taken into consideration;

- Design Basis Earthquake (DBE): Design earthquake is defined as the site dependent ground motion with 10% probability of exceedance in 50 years.
- Maximum Credible Earthquake (MCE): Maximum credible earthquake is defined as the site dependent ground motion with 2% probability of exceedance in 50 years.

To reflect the effects of the local site conditions on the ground motions the spectral accelerations (SA) for T=0.2 sec and T=1.0 sec have to be modified according to the site coefficients given in IBC (2006) and NEHRP (2003) provisions. These amplified spectral accelerations are later used in the construction of the standard shape of the response spectrum. The standard shape of the response spectrum is taken equal to the so-called "Uniform Hazard Response Spectrum" provided in IBC (2006) and NEHRP (2003) provisions. This spectrum, which is employed to assess the demand on structures, is approximated with the site-specific short-period (S_{ms}) and medium-period (S_m) spectral accelerations as illustrated in Figure 2. S_{ms} and S_m are represented by the calculated S_A at T=0.2 sec and T=1.0 sec respectively.

The design basis ground motion parameters, quantified in terms of peak ground acceleration (PGA) and 5% damped spectral accelerations at 0.2 sec and 1.0 sec ($S_A(0.2)$ and $S_A(1.0)$) and the associated 5% damped design basis response spectra that correspond to 2% and 10% probabilities of exceedance in 50 years for the Okmeydanı Training and Research Hospital site are provided as in Table 1 Probabilistic Peak Ground and Spectral Accelerations at Reference Soil. According to geotechnical survey report provided by Zemin Etüd ve Tasarım A.Ş. (2011), the corresponding NEHRP (2009) site class of "B/C" boundary is assigned to the hospital site. Table 1 provides the DBE and MCE level design basis response spectra.

Table 1 Probabilistic Peak Ground and Spectral Accelerations at Reference Soil based PSHA study by Erdik et al. (2003 and 2004)

	DBE 475 year (10%/50)	**MCE 2475 year (2%/50)**
SA(T=0.2s) Ss	0.95g	1.30g
SA(T=0.2s) S1	0.39g	0.70g
PGA=0.4Ss	0.38g	0.52g

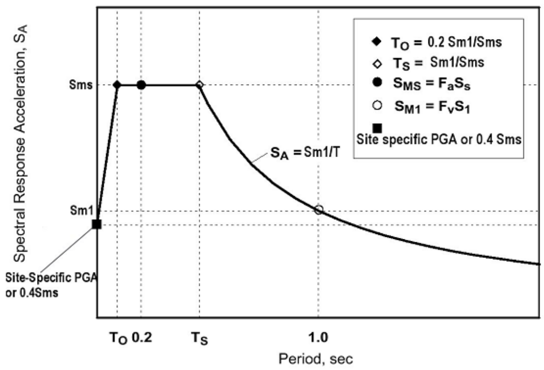

Figure 2. Standard Shape of the Response Spectrum (NEHRP, 2003)

The permanent shoring structure of Okmeydanı Training and Research Hospital must be designed at MCE level and the building importance factor has to be taken as I=1.0 in order to satisfy immediate occupancy performance level after the earthquake. For design purposes of the retaining system, pseudo static methods are utilized with appropriate stability considerations. For the verification of pseudo static methods, non linear analysis in time domain are conducted with appropriate acceleration time data later on for this paper.

For design purposes Turkish Earthquake Code (TERC 2007) (2007) is used as main design code and Eurocode 8 Part 5 (2003) regulations can be referred with below earthquake parameters (pseudo static coefficients).

C_h = 0.3(I+1)0.52=0.31; I=1.0 (TERC 2007) (1)

C_v = 2/3C_h= 0.21 (TERC 2007) (2)

k_h = α(S/r) = 0.52 (1/1)=0.52 (Eurocode 8 2003) (3)

k_v = ±0.5k_h= 0.26 (Eurocode 8 2003) (4)

In the equations 5.18 and 5.19 of Federal Highway Administration regulation (FHWA-IF-03-017 2002) coefficients given according to allowable permanent wall displacement should not be used for retaining structures higher than 15m and for cases where the peak ground acceleration (PGA) values are higher than 0.3g. Okmeydanı Research and Training Hospital satisfies both conditions and the coefficients are calculated as follows:

A_m = (1.45-A)A=(1.45-0.52)0.52=0.48 (FHWA-IF-03-017 2002) (5)

k_h = 0.5A_m to 0.67A_m =0.24 – 0.32 (FHWA-IF-03-017 2002) (6)

For the calculation of kv any equation is not suggested in (FHWA-IF-03-017 2002) code but it can be calculated regarding the general approach.

k_v = 2/3k_h= 0.16 - 0.21 (7)

As a conclusion, in this study it is suggested to design the permanent shoring structures of the Okmeydanı Training and Research Hospital according to the base acceleration that has a 2% probability of exceedance in 50 years. And for these shoring structures, it is suggested to obtain stresses and displacements that are generated at the level of 2% / 50 years earthquake level, with nonlinear finite element analysis in time domain. In these analyses it is ensured that the obtained displacements do not exceed the minimum damage level and satisfy the immediate occupancy performance level. For verification analysis the PLAXIS software is used.

2.2 General Calculation Methodology and Static Analysis

Uncontrolled fill unit is seen in first 5.0m beginning from ground level (between +100.0m / +92.0m elevation). Below uncontrolled fill layer, greywacke layer is seen down to pile base elevation (between +92.0m /+70.0m elevation). It is also assumed that proper drainage measures will be taken inside the permanent excavation area. At the main structure area, groundwater level is assumed as at the elevation of 86.8m. According to the subsoil conditions and the geometry of the site & excavation, critical sections are defined and analysed. Selected soil/rock parameters is summarized in Table 2 to be used for the stability calculations performed in drained conditions. For the calculation of the soil parameters correlations with standard penetration test results and unconfined compression test results from core samples taken from graywacke were used.

Table 2. Brief Soil/Rock Parameters Defined in Plaxis.

Identification	**Units**	**Fill**	**Graywacke**
Soil Model		Hardening Soil	Mohr-Coulomb
γ_{unsat} / γ_{sat} kN/m^3	kN/m^3	18.0 / 19.0	24.0 / 25.0
E_{oed}^{ref}	kN/m^2	10.0E3	-
E_{ur}^{ref} / E	kN/m^2	30.0E3	500.0E3
ν (nu)	-	0.3	0.25
cref	kN/m^2	1.0	25.0
φ (phi)	°	25.0	35.0
ψ (psi)	°	0.0	5.0

2.3 Seismic Analysis

The seismic analysis study is comprised of pseudo-static analysis and non linear time history analysis approaches, finite element analysis program Plaxis is utilized for both approaches. Pseudo-static analysis is performed with the pre-defined acceleration (A_h=0.31g, A_v=0.21g) for the rigid retaining system, that is applied horizontally and vertically in both directions by defining two total multiplier stages. The target factor of safety in seismic analysis is 1.0. For the verification of pseudo static analysis with nonlinear time history method horizontal and vertical pseudo static accelerations are also applied individually for this article.

Nonlinear time history analysis is performed via Plaxis as prescribed displacements applied towards the bottom support of the model (this line is fixed in both directions both during dynamic analysis prescribed displacements has priority). Absorbent boundaries are assigned to the side boundaries of the model with horizontal fixities, to simulate the soil as semi infinite medium. Considering the report of related with “Seismic Design Criteria Final Design of Okmeydanı Training and Research Hospital” (Erdik 2013), the ground motion time histories are developed for the random horizontal and vertical components of the target spectra using the NEHRP 2003 regulations. Vertical design spectrum is assumed as 2/3 of the Horizontal Design Spectrum. The main purpose of generating spectrum compatible time histories is to generate realistic acceleration time-histories whose response spectra closely match a smooth design response spectrum. Three acceleration time history records are selected for verification study as shown in Table 3.

The input “acceleration-time history” data is applied to the model from the base boundary with “prescribed displacement-dynamic” command of the Plaxis. The prescribed displacement is applied in both in positive and negative horizontal directions. Along the lateral boundaries viscous boundaries (dampers) are used for dynamic case instead of fixities to ensure that pressure waves are absorbed at boundaries without rebounding. Although special measures are utilized (viscous boundaries) to avoid disturbances due to wave reflections, the model boundaries are still placed far from the region of interest. (+90m to -90m).

Table 3. Time histories that are selected for verification

Earthquake	Fault Mech.	Components	Closest Dist. (km)
1979, Imperial Valley, US M= 6.53	Strike Slip	H-SUP135	24.61
1999, Duzce, Turkey M=7.14	Strike Slip	MDR000	34.30
1992, Landers, US M=7.28	Strike Slip	BRS000	34.86

For time history analysis acceleration records in the relevant table are applied horizontally. Figure 3 illustrates the horizontal acceleration input values from Plaxis and also these records are applied in the reverse direction on the same plane.

For research purposes the PGA of Imperial Valley earthquake is artificially increased to 0.31g by multiplying the amplitude of acceleration records with a certain factor (1.535) to be able to achieve the target PGA. The resultant artificially increased earthquake is applied to investigate the behaviour of the structure when the PGA of time history record is equal to the pseudo-static method. Results of the pseudo-static and time history analysis are given in Table-4 including maximum displacements, moments and shear forces developed on the retaining structures under seismic forces.

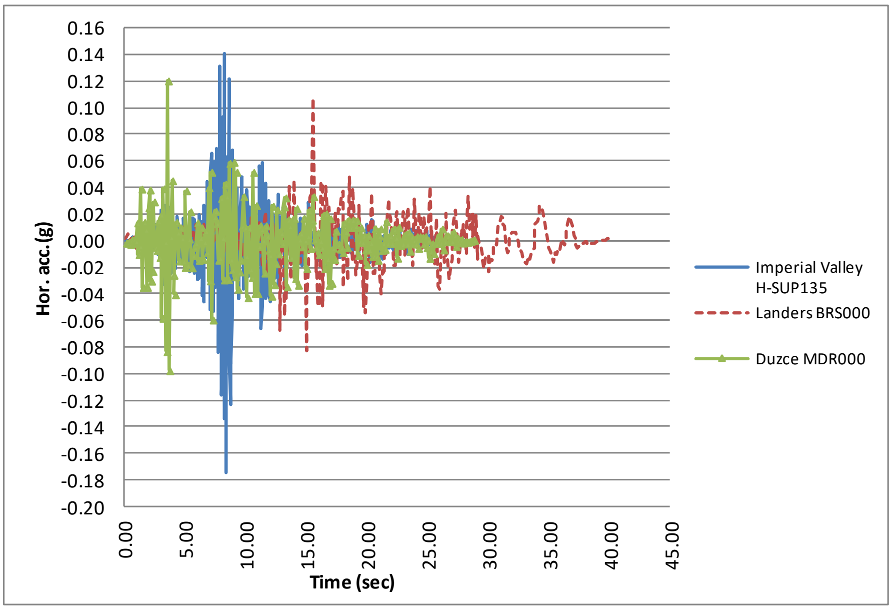

Figure 3. Acceleration time history records of selected earthquakes

3. CONCLUSION

In the content of the Okmeydanı Hospital Project, according to the site specific seismic hazard study, pseudo-static analysis are performed in design stage and later on dynamic analysis are performed to compare the results with design. The findings are presented in Table 4.
3 earthquakes that are used in site specific seismic hazard study are selected by authors for dynamic analysis and 1 of these 3 records has been amplified to the PGA level of the pseudo static earthquake.

Results are showing the following:
In terms of deformation the pseudo static calculation is conservative with respect to the actual earthquakes i.e 8.84cm instead of 17.5cm however the analysis with the amplified earthquake resulted in higher deformation i.e 22.9cm instead of 17.5cm.

In terms of sectional forces used in design of piles the pseudo static calculation is conservative with respect to actual earthquakes the max. ratio is reaching up to the 92% of the allowable sectional force. However the amplified earthquake resulted in slightly higher sectional forces than allowable capacities given in design reaching as high %120 percent of the design value.

In conclusion, calculations in design stage are verified by dynamic analysis by using actual earthquake data. The amplification of earthquake data up to the peak ground acceleration used in pseudostatic analysis, proved to give more conservative results compared to the actual design.

Table 4. Calculation Results.

			Calculated Displacements				Calculated Sectional Forces			
Model Type	Loading Explanation	PGA_{hor} (g)	Φ140 ux(cm)	Φ140 uy(cm)	Φ120 ux(cm)	Φ120 uy(cm)	Φ140 moment (kNm)	Φ140 shear (kNm)	Φ120 moment (kNm)	Φ120 shear (kNm)
Pseudostatic Analysis	-EX-EY	-0.31	17.5	2.2	17.4	2.2	3467	879	1260	182
			7.1	2.1	7.4	2.2	-2119	-1239	-2231	-319
Allowable Sectional Capacities as per Design			NA	NA	NA	NA	3650	1329	2251	695
			NA	NA	NA	NA	3650	1329	2251	695
Dynamic Analysis	Duzce MDR000	0.12	8.71	0.7	8.71	0.7	2545	496	1064	148
		-0.11	0.7	0.6	0.7	0.7	-1868	-959	-1983	-354
Dynamic Analysis	Duzce (-)MDR000	-0.12	8.84	0.7	8.84	0.7	2526	525	1099	152
		0.11	0.7	0.6	0.7	0.7	-1971	-946	-2067	-376
Dynamic Analysis	Imperial Valley H-SUP135	0.15	8.7	0.7	8.7	0.7	2352	473	1021	141
		-0.20	0.7	0.6	0.7	0.7	-1867	-1030	-2014	-357
Dynamic Analysis	Imperial Valley (-) H-SUP135	-0.15	8.63	0.7	8.63	0.8	2458	561	994	146
		0.20	0.7	0.6	0.7	0.7	-1832	-963	-2002	-341
Dynamic Analysis	Landers BRS000	0.13	8.24	0.7	8.24	0.7	2576	484	1046	151
		-0.10	0.7	0.6	0.7	0.7	-1835	-1084	-1920	-355
Dynamic Analysis	Landers (-) BRS000	-0.13	8.14	0.7	8.14	0.7	2562	667	1003	166
		0.10	0.5	0.6	0.5	0.6	-1794	-1138	-1195	-341
Dynamic Analysis	Imperial Valley (1.535)H-SUP135	0.22	10.25	0.7	10.25	0.8	3192	897	1268	144
		-0.31	0.7	0.6	0.7	0.7	-2222	-1262	-2458	-438
Dynamic Analysis	Imperial Valley (-1.535)H-SUP135	0.31	22.84	-1.3	22.83	0.3	3671	590	1634	236
		-0.23	0.9	-1.4	1.1	0.3	-2793	-1069	-2711	-332

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