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Dynamic and Static Analysis of Deep Excavation of Poligon Station in İzmir Metro Line

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Abstract - In this paper, the deep excavation stages of Poligon Station which is the located along the Üçyol–Fahrettin Altay subway line was modeled numerically. Although some parts of the metro line were constructed, some parts of metro line are currently under construction in İzmir. The Poligon Station is carried out with a surrounding diaphragm wall and top-down construction method. The foundation mat and four slabs of the station building are used as support elements. The excavation depth of the station is 18 meters. The soil properties of the numerical model were obtained engineering boreholes and laboratory tests. Lateral soil displacements were measured with inclinometers installed in the nearby soil layers. Displacements which were measured from inclinometers and obtained from numerical modeling were compared. Beside the static analysis, the Poligon station of the metro line was analyzed with a model earthquake. 16.12.1977 İzmir Earthquake (Ms=5.5, amax=0.21g) was used as a model earthquake for dynamic analyses. In addition, effects of changing the properties of the soil on computed results were numerically investigated using the software Plaxis.

Keywords: Deep Excavation, Top-Down Construction, Soil Deformation, Numerical Modeling.

I. Introduction

İzmir Metro passes through places which were completed housing and large number of problematic soils. There are 20–50 year–old buildings along the line of subway. These buildings have high-risk of damage due to excavation works. For example, in 2006–2008 during the subway construction on Hatay–Üçyol route, some buildings (Ateş Apt. etc.) were damaged due to deep excavations and tunnel constructions. Consequently, contractor had to paid high cost for remediation of buildings. This experience shows that importance of field investigations, selection the construction method and deep excavations required to be carefulness.

Deep excavation is one of the most important problems in geotechnical engineering. Deep excavations can be selected such as high building foundations construction and subway construction. Soil properties, ground water level, vertical or horizontal soil deformations which can affect the nearby buildings are important points for selection or designing of the deep excavation method [1] . Soil deformations which lead to damages nearby buildings and this is the most important matter of the deep excavations [2]. Deformation of the excavations in the İzmir subway construction must be estimated with high accuracy and they must be restricted because of buildings on subway line are relatively old and these old buildings on the subway line can be easily damaged.

In this study, Poligon Station which is a part of the second stage of İzmir Subway was analyzed with finite element method. Station was analyzed both static and dynamic aspect. Depth of the excavation of Poligon Station is 18 m. The construction method of the station is up–down construction method. Excavation and structure of the station were modeled with Plaxis 8.2 [3] software which uses finite element method. Displacements which were obtained from numerical modeling and measured from inclinometers were compared. In the dynamic analysis, 16.12.1977 İzmir earthquake was used as a model earthquake. In addition, deformations were calculated for different soil parameters. In this way, the effects of soil parameters on the deformations with different soil parameters were investigated. This investigation was performed because of soil and rock properties have high varieties along the subway line.

II. Soil Properties of The Study Area and. Numerical Modeling

The Poligon Station is in the center of İzmir and located so closely to the sea. Station is located under Fahrettin Altay – Üçyol road and there are apartment buildings very closes in both sides of the station. Apartment buildings consist of six – eight flats. The position of the station and apartment buildings are shown in Figure 1. Inclinometers were installed boreholes which were located outside soils of the stations along the metro line. The distance of the inclinometer borehole from diaphragm wall of the Poligon Station is 2.0 meter. Inclinometer locations can be seen in Figure 1.

According to the boreholes and soil investigation in the region, two main units were observed as given in Figure 2. First soil unit is clay and it lays upper level of the soil profile. Thickness of the clay layer is about 5 m around the station. Sand stone is second unit and it lays below the clay layer [4], [5].

Properties of the clay layer on the top are brown-colored and it contains fine to medium grained gravel. Sandstone unit is gray and yellow-brown colored. Sandstone is low-medium weathering and well hardened. The Sandstone has medium-high strength [6], [7]. The main properties of the clay and sandstone are given in Table 1

Figure 1. Location of the Poligon Station, inclinometer borehole and buildings

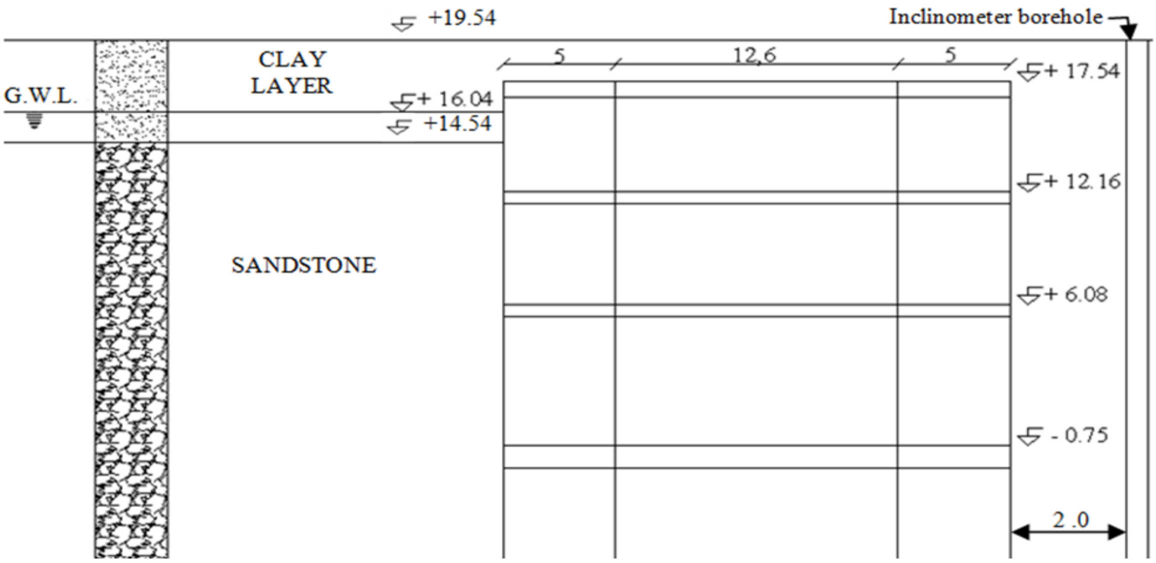

Figure 2. Soil profile and cross-section of the Poligon Station (dimensions are meter)

Table 1. Soil properties of around the station (Aksoy et all. 2006, Onargan et all. 2006)

Soil	γ_n (kN/m^3)	γ_{sat} (kN/m^3)	υ	E (kN/m^2)	c (kN/m^2)
Clay	20	22	0.20	198000	13
Sandstone	22	27	0.35	10125000	120

Length and width of the Poligon Station are 128 meters and 25 meters respectively. Station is being constructed as three parts. Length of each part is about 40–45 meter. Top-down construction method was selected for the construction. The excavation depth is approximately 18.0 meter. Diaphragm walls were designed as a part of structure of the station. Length of the diaphragm walls 24.60 meter. The station consists of three stairs. Currently, only upper stairs of the station were completed. The station will be buried end of the construction and ground surface will be used as a road.

The finite element model of the station was constituted with Plaxis software. In the numerical analysis, surcharge loads of buildings and traffics on the road are taken into account as 45 kPa and 15 kPa respectively. Soil parameters which were used for the analyses are given in Table 2. Properties of the construction elements are given in the Table 3. Each construction stage was defined in the model as described in Figure 3.

Table 2. Soil properties of around the station (Aksoy et all. 2006, Onargan et all. 2006)

Units	Model	ϕ (°)	E_{ref} (kN/m²)	c_{ref} (kN/m²)	Ψ (°)	υ	K_o^{nc}	γ_n (kN/m³)	γ_{sat} (kN/m³)
Clay	Hardening	38	6.6x10^4	13	7	0.35	0.38	20	22
Sandstone	Hardening	45	3.375x10^6	120	7	0.20	0.30	22	27

Table 3. Construction elements properties in numerical model

Construction elements	Type	EA (kN/m)	EI (kNm²/m)	w (kN/m/m)	υ
Diaphragm wall	Elastic	31800000	2639400	24.0	0.20
Column	Elastic	126900000	2639400	24.0	0.20
Upper slab	Elastic	24200000	1291675	24.0	0.20
Intermediate slabs	Elastic	18150000	544500	14.4	0.20
Foundation mat	Elastic	60500000	6100000	48.0	0.20

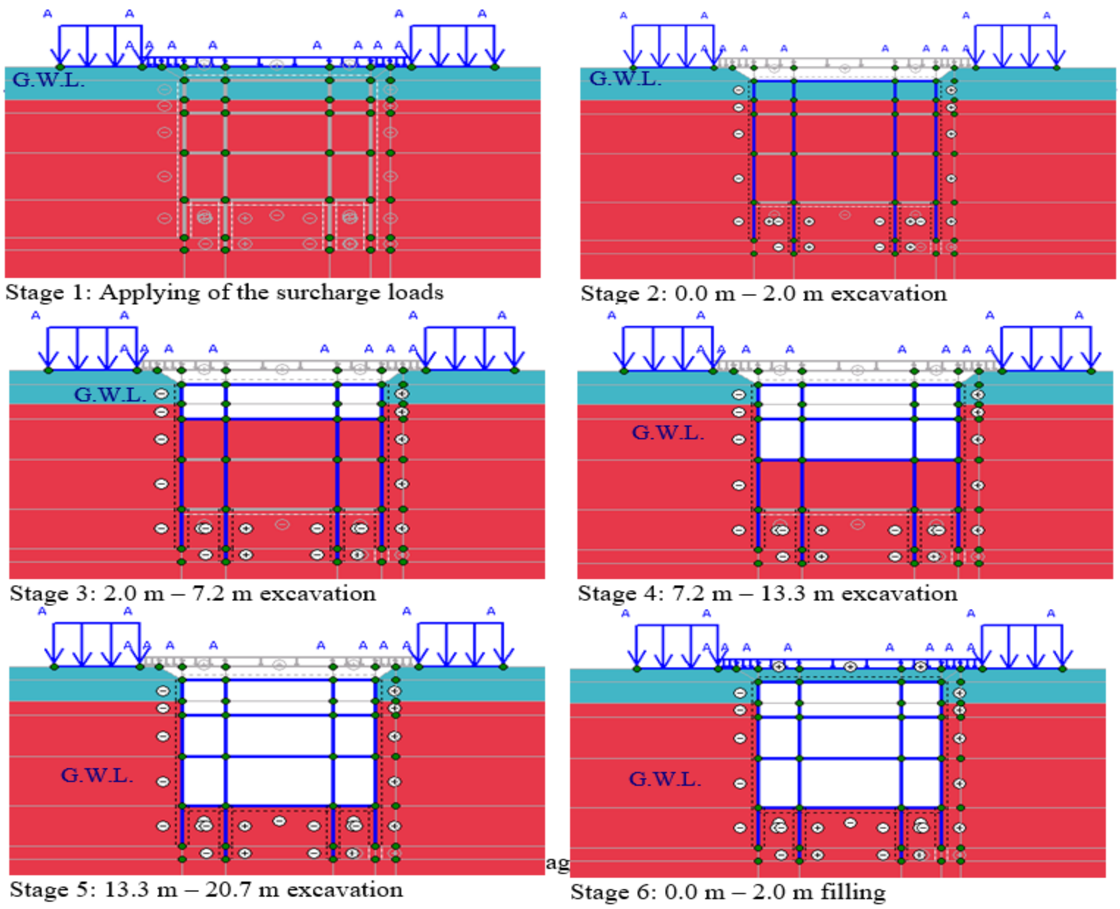

Figure 3. Construction stages of the finite element model

In addition to static analysis, dynamic analysis of the Poligon Station was carried out for after construction period. 16.12.1977 İzmir Earthquake (Ms=5.5) was used in dynamic analysis. The acceleration record of the 1977 Earthquake can be downloaded from the National Strong Motion Database of Türkiye. The recording station in Poligon district provided a strong motion record on the rock site. The location of the station was quite close to the İzmir Fault and Poligon station.

It is a few kilometers away from the İzmir fault which have major earthquake risk for the İzmir city. This record station was shut down in 1991. The maximum acceleration during 1977 İzmir earthquake value was recorded as 0.39g by seismograph of the station. The acceleration record was corrected by [8]. Maximum acceleration of the corrected acceleration record is 0.21g. In this work corrected version of the acceleration records was used. Corrected acceleration record is shown in Figure 4.

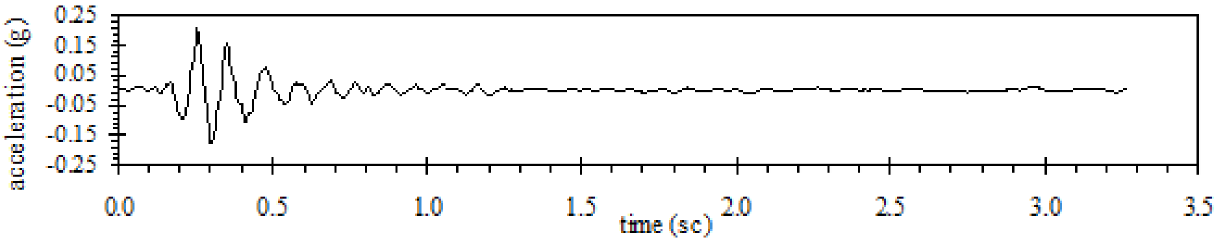

Figure 4. Corrected acceleration record of 16.12.1977 İzmir Earthquake (North-East Component)

III. Evaluations of The Numerical Modeling Results

The subway station is under construction and it is in the third stage at present time. The third stage of the construction can be seen in Figure 3. Excavation of the fourth stage of construction has not yet been started. Therefore, the inclinometer readings include end of the third stage deformations. Calculated horizontal deformations and inclinometer readings are given in Figure 5 for the end of third stage. In the numerical analyses, maximum lateral displacement for the end of third stage was calculated as 0.51 mm. At the same location maximum, lateral displacement was measured as 0.21 mm by inclinometer. As it is seen from Figure 5, calculated lateral displacements with numerical model and inclinometer readings are close to each other. Calculated vertical and lateral displacements for the end of excavation (end of stage 6) are given in Figure 6 and Figure 7 respectively.

Maximum lateral displacement of the diaphragm wall during construction was estimated 0.3 mm from numerical analysis. Also, maximum swelling of the foundation mat was estimated as 0.3 mm from numerical analysis. During the construction, estimated maximum shear forces and bending moments of the construction elements are given in Table 4. The all values in the Table 4 remain on the safe side, and any problem was not occurred until the end of third stage of the station construction

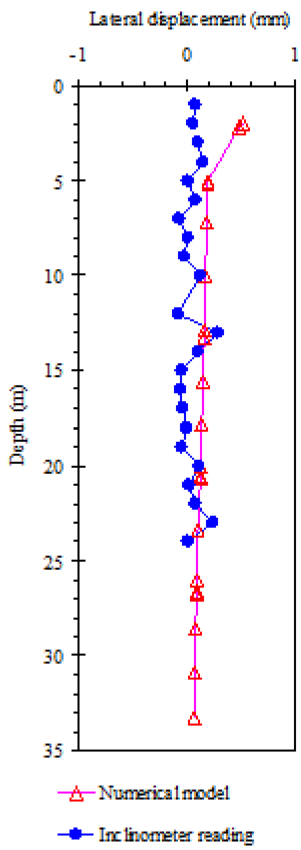

Figure 5. The graphical comparison of the lateral displacements in the soil between inclinometer readings and numerical model for the end of third construction stage

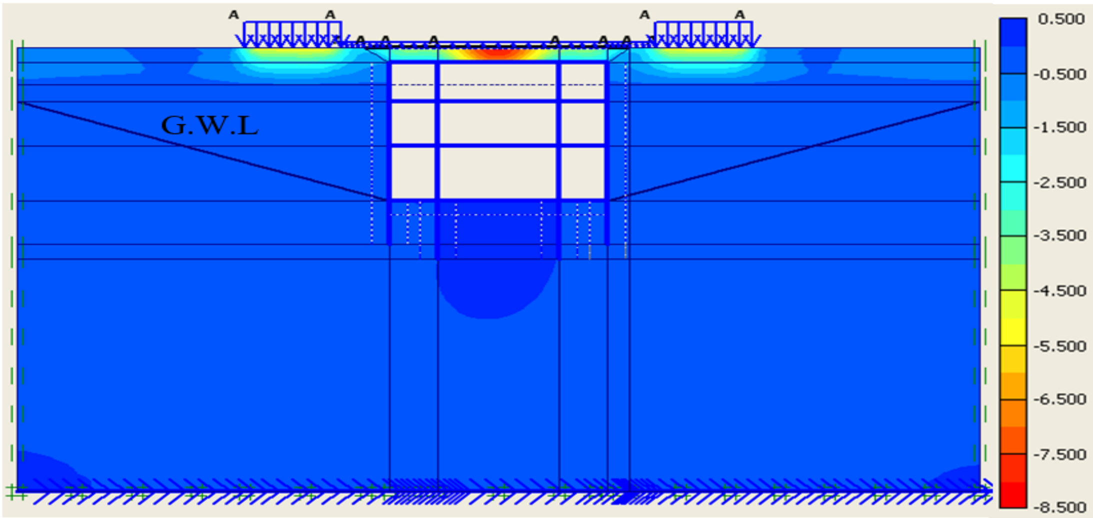

Figure 6. Vertical displacements of the numerical model (mm)

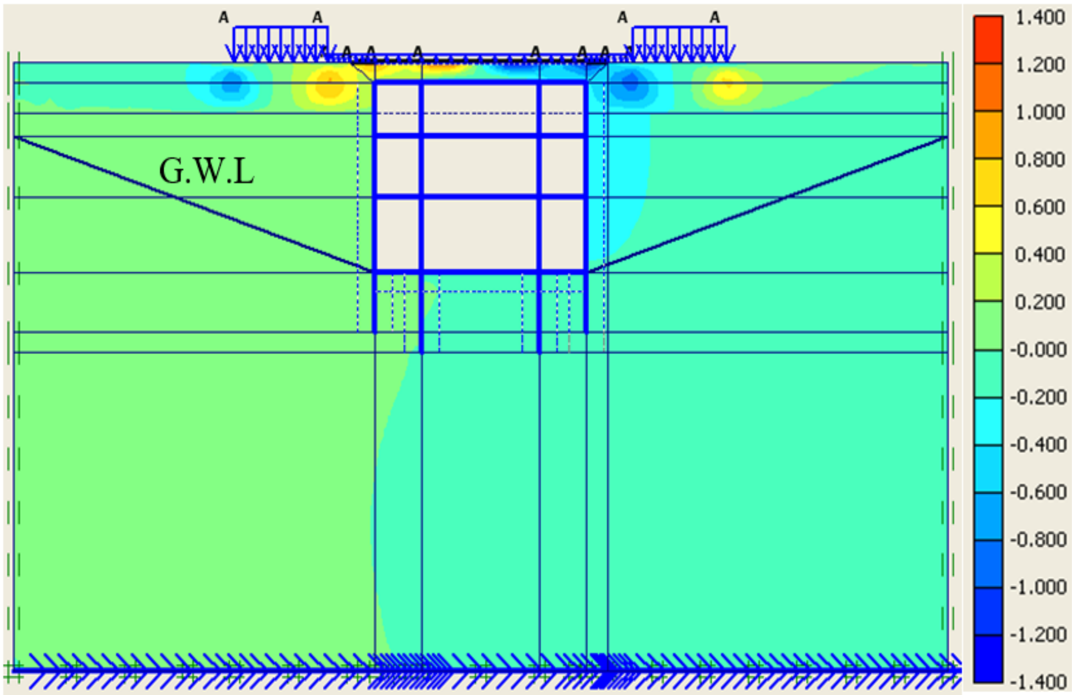

Figure 7. Lateral displacements of the numerical model (mm)

Table 4. Calculated deformations and forces in the construction elements for all construction stages

	Maximum Lateral Displacements (mm)						Maximum Vertical Displacements (mm)					
Construction stage :	1	2	3	4	5	6	1	2	3	4	5	6
Diphragm wall	-	-0.2	-0.2	-0.3	-0.3	-0.3	-	-0.7	-0.6	-0.7	-0.8	-0.9
Upper slab	-	-0.2	-0.2	-0.2	-0.2	-0.3	-	-0.7	-2.2	-2.0	-2.0	-5.2
1. Intermedied slab	-	-	-0.1	-0.2	-0.2	-0.2	-	-	-0.2	-1.8	-1.7	-1.8
2. Intermediate slab	-	-	-	-0.1	-0.3	-0.3	-	-	-	0.2	-1.8	-1.9
Foundation mat	-	-	-	-	-0.2	-0.2	-	-	-	-	0.3	0.2
	Maximum Shear Forces (kN/m)						Maximum Bending Moments (kNm/m)					
Construction stage :	1	2	3	4	5	6	1	2	3	4	5	6
Diphragm wall	-	6	108	188	391	386	-	20	-80	-137	-327	-323
Upper slab	-	101	-162	-161	-161	-498	-	165	-316	-320	-321	-969
1. Intermedied slab	-	-	-125	-97	-97	-97	-	-	57	-200	-201	-204
2. Intermediate slab	-	-	-	239	-97	-97	-	-	-	107	-199	-198
Foundation mat	-	-	-	.-.	677	714	-	-	-	-	435	521

Subway line and its stations lie on different rocks and soils types such as low or high weathering rock, soft clay, stiff clay, loose sand, dense sand, clay-sand soil etc. [4], [6], [7]. Soil characteristics and properties on the subway line vary place to place. Therefore, numerical analyses were performed with different soil parameters. So that effects of the soil properties on the deformations and forces were investigated with numerical model. For this purpose, 5 different analyses were carried out with different soil parameters. The soil parameters were chosen as 0.5E and ϕ, E and ϕ, 2E and ϕ, E and (ϕ+7^o), E and(ϕ+7^o). Variation of the lateral displacements on the diaphragm wall with elasticity modulus (E) and internal frictional angle (ϕ) of the soil are given with Figure 8.a and Figure 8.b respectively. Maximum lateral displacement on the diaphragm wall for 0.5E, E and 2E are occurred as 0.49 mm, 0.35 mm and 0.22 mm respectively. On the other hand, lateral displacements on the same wall for (ϕ-7^o), ϕ, and (ϕ+7^o) were occurred as 0.36 mm, 0.35 mm and 0.34 mm respectively. Vertical deformations on the foundation mat for elasticity modulus and internal frictional angle were occurred as 0.47 mm for 0.5E, 0.24 mm for E, 0.12 mm for 2E, 0.20 mm for (ϕ-7o), 0.24 mm for ϕ and 0.28 mm for (ϕ+7^o). Vertical deformations on the foundation mat according to elasticity and internal frictional angle are given in Figure 9.a and Figure 9.b. As seen in, elasticity modulus of the soil has more effect than internal frictional angle of the soil. Displacements both of vertical and horizontal are occurred very restricted because of the main soil type of the excavation is stiff and low weathering sandstone [2], [4], [7].

In addition to static analysis, the Poligon station was analyzed aspect earthquake loading. The seismograph in the Poligon Meteorology Station and Poligon Subway Station are very close to each other and both are on the similar soil type (Kuruoğlu 2004). Therefore, it is assumed that any earthquake which will be produced by İzmir Fault has same effects on the Poligon Subway and seismograph stations. The other assumption is 1977 İzmir Earthquake can represent probably earthquake which will be produced by İzmir Fault [9], [10], [11]. Due to these assumptions, 1977 İzmir Earthquake was selected as a model earthquake and any attenuation relationship for the earthquake was not used. Corrected acceleration record of the 16.12.1977 İzmir Earthquake (Ms= 5.5) which was produced by İzmir Fault was used as a model acceleration record for earthquake analysis (Figure 4). Calculated maximum horizontal and vertical displacements of the construction elements for the earthquake analysis are given in Table 5. Estimated maximum shear forces and bending moments due to earthquake loading are given in Table 5. All values both deformations and forces remain in the safe side.

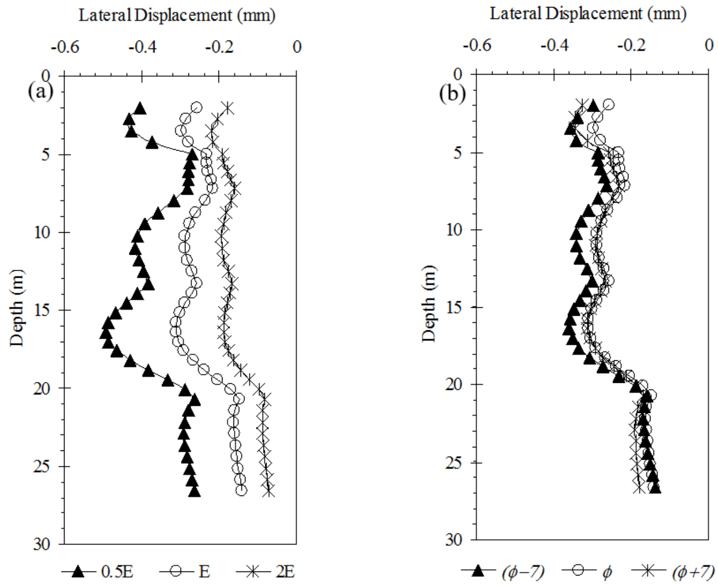

Figure 8. Elasticity modulus (E) and internal frictional angle (ϕ) effects on lateral displacements of the diaphragm wall

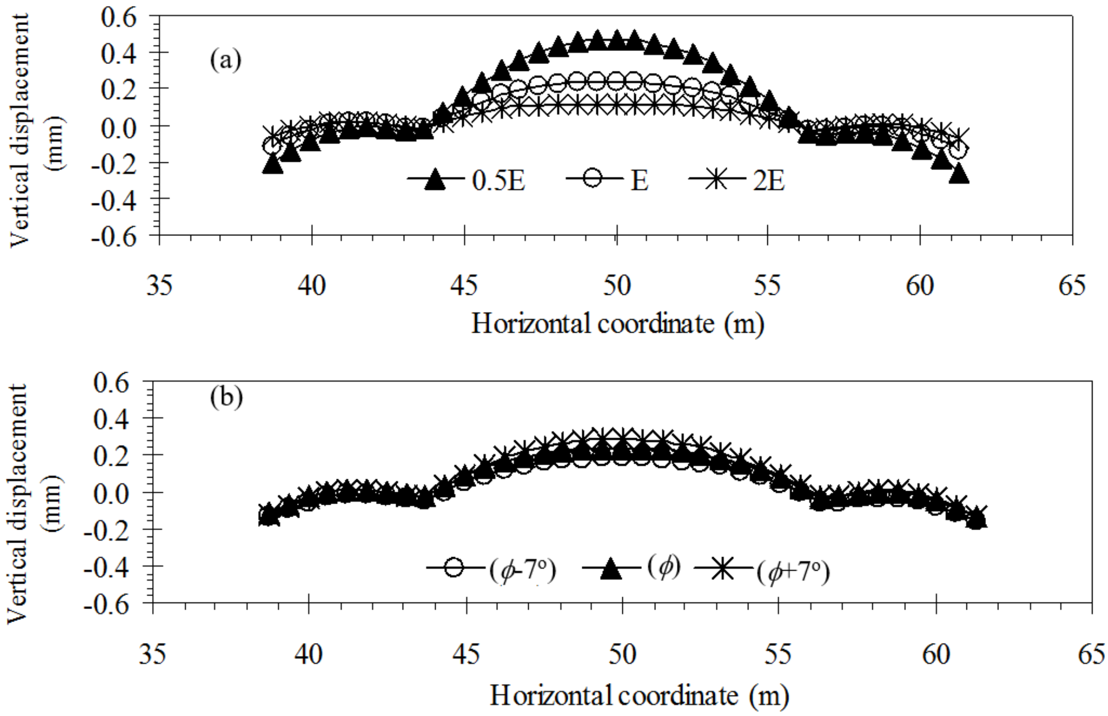

Figure 9. Elasticity modulus (E) and internal frictional angle (ϕ) effects on the vertical displacements of the foundation

Table 5. Calculated lateral and vertical displacements for the earthquake analysis

Structural elemnts	Maximum Shear Forces (kN/m)	Maximum Bending Moments (kNm/m)	Maximum Displacements (mm)
Upper slab	497.6	969.1	0.30 (Vertical)
Diaphragm wall	391.4	326.6	0.47 (Horizontal)
Foundation mat	714.5	521.0	0.39 (Vertical)

IV. Conclusions

In this study, Izmir Subway Poligon Station which is built with top-down constraction method and diaphragm walls have been analyzed by finite element with static and dynamic aspects. The following conclusions are reached as a result of the analyses.

soil parameters have significant effects on the deformations and forces [1]. Soil parameter must be carefully determined to accurately estimation of the soil-structure behavior especially for deep excavations [12].

The results of analyses show that the selection of top–down construction method is the right choice for Izmir Metro Poligon Station. Analysis and in-situ measured values are compatible with each other. The construction continues without a problem in terms of poligon station and nearby buildings.

Elasticity modulus of the soils is more effective than internal friction angle aspect displacement on the diaphragm wall and swelling of the foundation mat.

The İzmir Fault is most important fault aspect the earthquake risk for İzmir [10]. Also, İzmir Fault is nearest fault to Poligon station of the subway. 16.12.1977 İzmir Earthquake acceleration record was selected in order to represent to probable earthquake will be struck in the future to Poligon station. Results of the dynamic analysis, it seems that, earthquakes (Ms≤5.5) with maximum acceleration value ≤0.21g has not a risk for the Poligon Station.

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