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Full Length Research Paper

Evaluation of a collapsed anchored bored pile retaining system by using finite elements method

Devrim ALKAYA* and Burak YEŞİL

Pamukkale University, Faculty of Engineering, Department of Civil Engineering, Denizli, Turkey.

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This study evaluates and investigates a collapsed retaining system constituted with anchored bored files, with the aim of presenting an example for the damages caused by the errors made in a project and construction phase. For determining the reasons for the collapse occurred in retaining system, field evaluations were implemented, calculations in the project were checked through and re-analyses were made. 19 m anchored bored piles were used to implement a safe 16.1 m depth excavation. The retaining system was figured out by using finite elements and Mohr-Coulomb and Hardening Soil surface model via Plaxis software. The collapsed supporting system was re-solved with finite elements and the results were compared with by the designer of investigated project. It is obtained that the expected deformation is about 28 cm by Mohr-Coulomb Model and is about 112 cm by Hardening Soil Model although this value calculated by the designers was 1.53 cm. Results showed that the main reason for collapsing the anchored system is a miscalculation of expected deformation.

Key words: Anchor, bored piling, deep excavation, finite elements method, retaining.

INTRODUCTION

For enabling the vertical formation of the excavation and preventing the possible damages that would occur in the surrounding buildings, roads, and other existing structures, it is necessary to build excavation supporting systems. As a result of the errors made during the design and construction of supporting systems, unexpected deformations which damage the structures surrounding the excavations, are encountered. The extent of the damage depends on the occurring movements near the excavation. Therefore, selection of a safe retaining system, which limits the movements of the soil, is of a vital importance.

It is a necessity to support the excavations in order to sustain the safe implementation of groundwork (CHSR, 1974). For enabling the vertical formation of the excavation and preventing the possible damages which would occur in the surrounding buildings, roads, and other existing structures, it is necessary to build excavation supporting systems. The excavations that are deeper than 6 m are accepted as deep excavations (Terzaghi and Peck, 1967; Tomlinson, 2001).

The safe functioning of the supporting system of a deep excavation depends on many factors. These factors can be listed as; healthy implementation of soil surveys, correct interpretation of soil parameters, accurate selection of retaining project, structural elements' dimensions, anchor type, attentive application, and control of site investigation. Many studies exist related to the design of deep excavations and collapses occurred in these systems.

Finno (1991) examined the soil movements in a soft clay deep excavation and stated that surrounding structures and construction activities, which could change the soil stress values, should also be taken into consideration when calculating the movement values.

Wong and Broms (1989) conducted a research by using the finite element method and revealed that wall rigidity and distance between the lateral supports were important for the stability.

Swanson and Larson (1990) investigated a collapse that occurred in a metro project and found out that the collapse occurred as a result of using the undrained shear force bigger than its actual value in the calculations.

Steiner and Pedrozzi (2001) observed that surcharge loads occured near the deep excavations as a result of the truck cranes used in the excavations and these loads

*Corresponding author. E-mail: devrimalkaya@hotmail.com. Tel: +90 258 2963354. Fax: +90 258 2963382.

Figure 1. Non-deformed Condition of the Excavation Site

increased the anchor loads. In order to show the inefficiency and miscalculation of expected deformations in a retaining system projects, any one method may not be enough to obtain those values. Thus, the main of this study is to calculate the retaining projects with more than one method such as hardening soil surface and Mohr-Coulomb. Moreover, this study investigates the possible affect of collapsing retaining projects by which erroneous evaluation of geotechnical specifications of the soil, groundwater level, additional force effect caused by the existing buildings surrounding the excavation, and the inaccurate selection of anchor system. Furthermore, a collapsing incident that occurred in the supporting system of a deep excavation in Istanbul was evaluated and the reasons for the collapse were investigated.

CALCULATION METHODS OF DEEP EXCAVATION RETAINING SYSTEMS

An encased retaining system consists of pile-plank walls, king-post wall, spaced bored pile walls, shear bored pile walls, and diaphragm walls. With these systems, which could be implemented embedded and with anchored supports, 30 to 35 m deep excavations could be implemented (Keleşoğlu and Özkan, 2005). The selection of retaining system, which is related to the conditions such as excavation depth, soil conditions, distance of the surrounding structures from the excavation, groundwater condition etc., is generally implemented by using anchors/supports.

The methods, used for designing an encased deep excavation retaining systems can generally be classified into four major groups (Sağlam, 2006); which are "limit stability", "beam on elastic foundation"- in which beam and surface of the retaining system is modeled with arches-, "pseudo-finite elements", and "finite elements/finite differences" methods.

Alkaya and Yeşil (2010) pointed that empirical and tension-based methods are purposive as regards to design but have limited capacity. Furthermore, deformation- based methods and finite elements programs are defined as more accurate and possible to use for every type of soil condition. On the other hand, Goh (1994) stated that the major difficulty of deformation-based methods was caused by the estimation of free soil displacement values.

With the use of professional programs, which utilize finite elements and finite differences methods, by modeling structure-soil interaction more realistically, it is possible to consider the construction phases of a retaining system. By this means, it becomes possible both to estimate the wall moment, shear force, and displacement values in every phase of construction, and the displacements of surrounding structures and soil displacements values in the designing phase; and thus, expected deformations can be calculated (Sağlam, 2006).

The process steps of designing of a retaining system are as follows; investigation of the excavation surroundings, soil surveys, geotechnical evaluation, retaining project design, building control, instrumental observation, and determination of the legal problems.

INFORMATION REGARDING THE CONSTRUCTION SURROUNDINGS AND STRUCTURE

The construction site is included in the master plan of Esenyurt district in Istanbul province (Figure 2). It is planned to build a 30.50 m high reinforced concrete structure with 3 basement storeys. The excavation site area is 2346 m^2. One side of the excavation site is adjacent to the road. Approximately 4 m embankment load exists on the road. The other 3 sides are empty (Figure 1). The road was built by using reinforced earth method. The final excavation level is -18.80 m.

GEOTECHNICAL SPECIFICATIONS

The site and laboratory works, to determine the geotechnical specifications of the soil, was conducted by a private company. Geological units belonging to the Çukurçeşme formation was encountered in the site. Çukurçeşme formation consists of sand

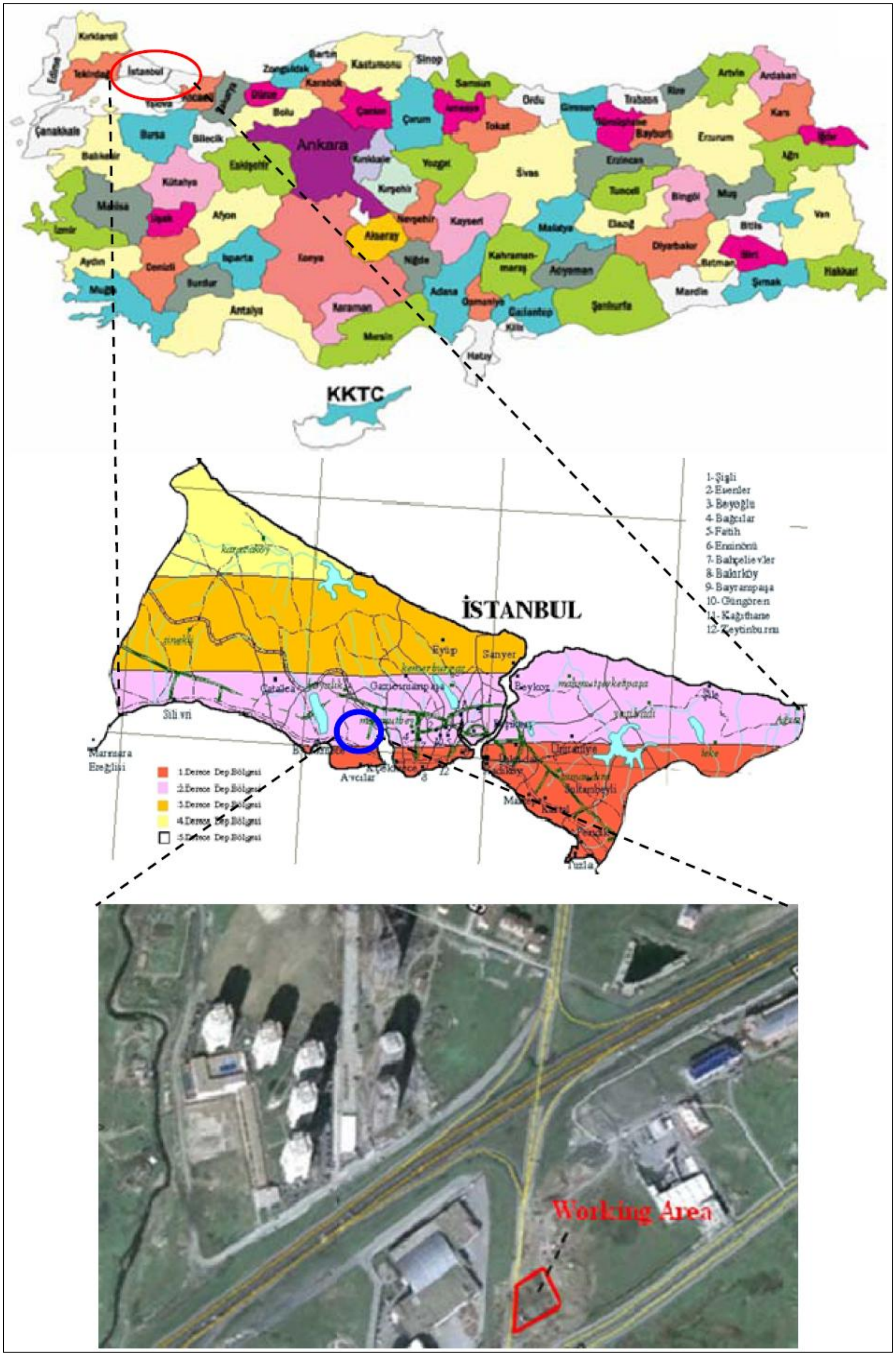

Figure 2. Working Area (Istanbul/TURKEY) (Google Earth, 2011)

Table 1. Results of Laboratory Test (Alaner and Mermer, 2009)

Drill No	Depth (m)	Gravel (%)	Sand (%)	Silt+clay (%)	Atterberg limits (%)			Soil Class (TS 1500, 2000)	w_n (%)	γ_n (kN/m^3)	γ_k (kN/m^3)	Triaxial Compression Test		Shear Box Test	
					L_L	P_L	I_P					c (kN/m^2)	ϕ (°)	c (kN/m^2)	ϕ (°)
DW1	8.00-8.50	15	18	67	33	15	18	CL	20	19.10	--	--	--	66	12
DW1	15.00-15.50	4	7	89	61	25	36	CH	27	19.00	14.96	13	10	--	--
DW2	13.00-13.50	2	23	75	49	21	28	CL	26	19.23	15.26	94	9	--	--
DW2	16.00-16.50	2	20	78	48	21	27	CL	27	19.43	15.30	100	10	--	--
DW3	18.00-18.50	6.5	31	62.5	43	16	27	CL	32	18.28	13.85	--	--	32	13
DW4	8.00-8.45	5	21	74	44	17	27	CL	--	--	--	--	--	--	--
DW4	12.00-12.50	3.50	19.50	77.00	49	21	28	CL	27	19.43	15.30	98	8	--	--
DW5	25.00-25.50	0.00	2.00	98.00	58	29	29	CH	30	19.34	14.88	112	11	--	--

Table 2. Results of SPT Test (Alaner and Mermer, 2009)

Soil Profile (Clay)	Drill No	SPT No	Test Interval (m)	N_{30}	Drill No	SPT No	Test Interval (m)	N_{30}
		SPT-1	1.50 - 1.95	13		SPT-1	1.50 - 1.95	2
		SPT-2	3.00 - 3.45	18		SPT-2	3.00 - 3.45	5
		SPT-3	4.50 - 4.95	16		SPT-3	4.50 - 4.95	7
		SPT-4	6.00 - 6.45	24		SPT-4	6.00 - 6.45	8
		SPT-5	7.50 - 7.95	36		SPT-5	7.50 - 7.95	10
		SPT-6	9.00 - 9.45	26		SPT-6	9.00 - 9.45	19
		SPT-7	10.50 - 10.95	42		SPT-7	10.50 - 10.95	25
	DW-2	SPT-8	12.00 - 12.45	29	DW-3	SPT-8	12.00 - 12.45	20
		SPT-9	13.50 - 13.95	36		SPT-9	13.50 - 13.95	18
		SPT-10	15.00 - 15,45	38		SPT-10	15.00 - 15.45	26
		SPT-11	16.50 - 16.95	44		SPT-11	16.50 - 16.95	36
		SPT-12	18.00 - 18.45	50		SPT-12	18.00 - 18.45	34
		SPT-13	19.50 - 19.95	49		SPT-13	19.50 - 19.95	32
		SPT-14	21.00 - 21.45	R		SPT-14	21.00 - 21.45	30
		SPT-15	22.50 - 22.95	R		SPT-15	22.50 - 22.95	38

and gravel with banded silts and clay in patches (Alaner and Mermer, 2009).

5 drilling procedures, with varying depths of between 22 and 30 m, were implemented. Site and laboratory test results are presented in Tables 1 to 3. From the drilling logs, the soil section was determined as clay soil. Because effective values are used in Plaxis

Table 3. Results of Pressiometer Test (Alaner and Mermer, 2009)

Drill No	Depth (m)	Ep (MPa)	PL	PL*	Depth (m)	Ep (MPa)	PL	PL*
DW5	1	12	0.79	0.65	17	20	1.48	1.48
	2	12	0.79	0.65	19	20	1.48	1.48
	5	12	0.79	0.65	21	30	1.66	1.48
	7	16	1.04	0.88	23	30	1.66	1.83
	9	16	1.04	0.88	25	32	2.00	1.83
	11	16	1.04	1.24	27	32	2.00	2.00
	13	16	1.04	1.24	29	36	2.32	2.02
	15	20	1.48	1.24				

Table 4. Design Parameters and Calculation Results of the Collapsed Retaining System

γ_n (kN/m^3)	c (kN/m^2)	ϕ (^{o})	Bored pile diameter θ (cm)	Anchor root length	α (^{o})	Anchor intervals (m)	The depth of excavation D_f (m)	Horizontal distance between anchors D (m)	Road load (kN/m^2)	Moment (kNm/m)	Displacement (cm)
19.10	0	30	65	8 m	15	1.60	16.10	2.50	20.00	72.10	1.53

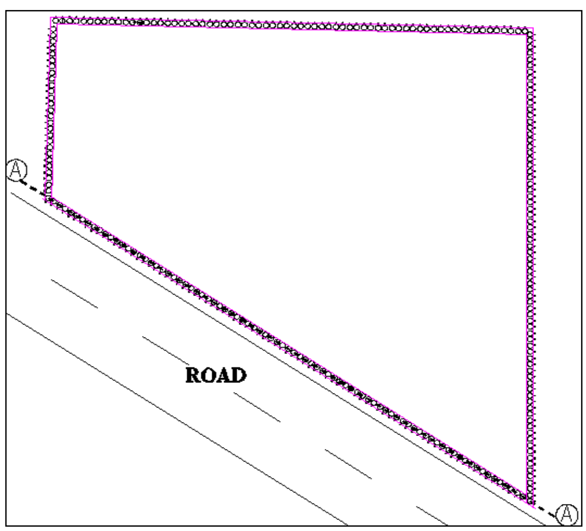

Figure 3. Bored Pile Plan

program, cohesion and angle of internal friction values in Table 1 are effective values.

RETAINING PROJECT

The soil data, pile diameter, anchor root length, moment and displacement values obtained, which are used by the retaining project planned by the designer firm, are presented in Table 4. Figures 3 to 5 show geometrical properties of retaining system. Bending moment value and shear force distributions calculated by the designer firm, on the other hand, are presented in Figure 6.

THE COLLAPSE OF RETAINING SYSTEM

No instrumental observation was implemented regarding the

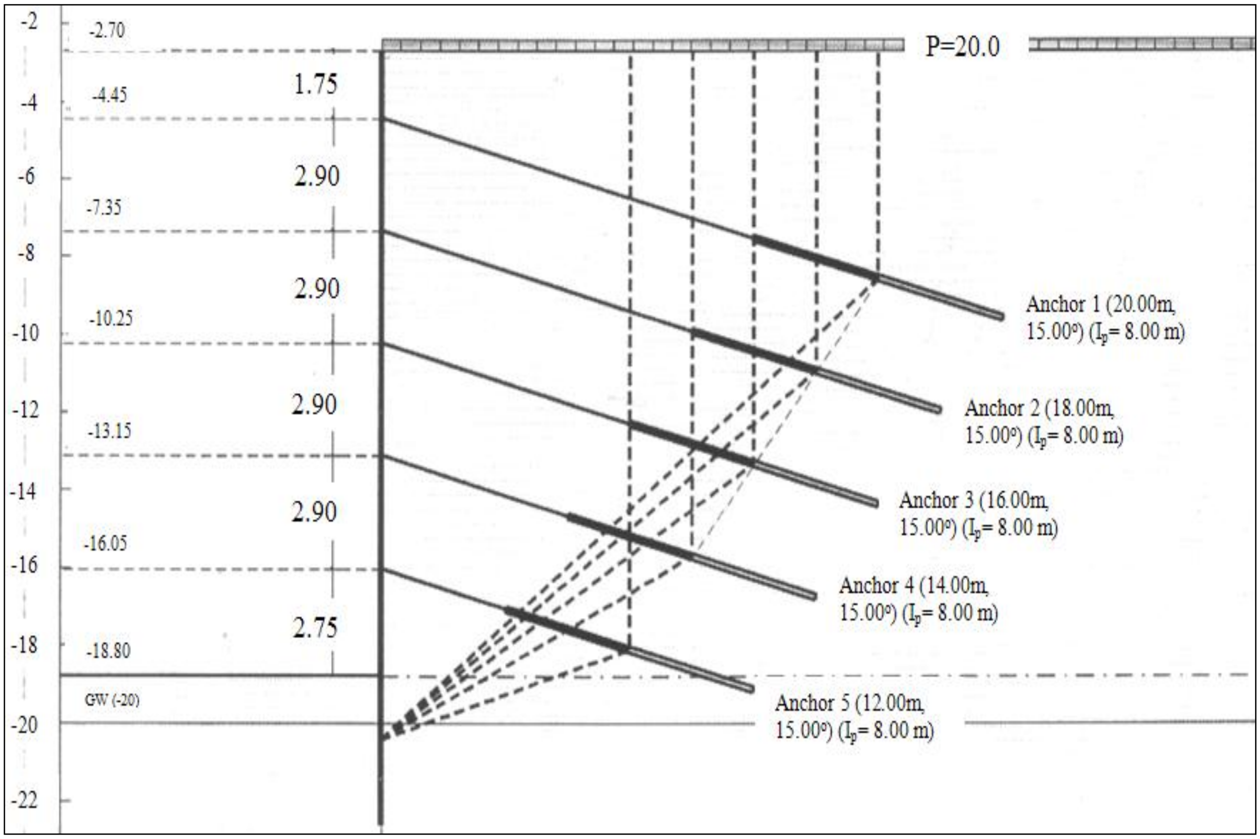

Figure 4. Road Elevation of the Excavation Site A-A section

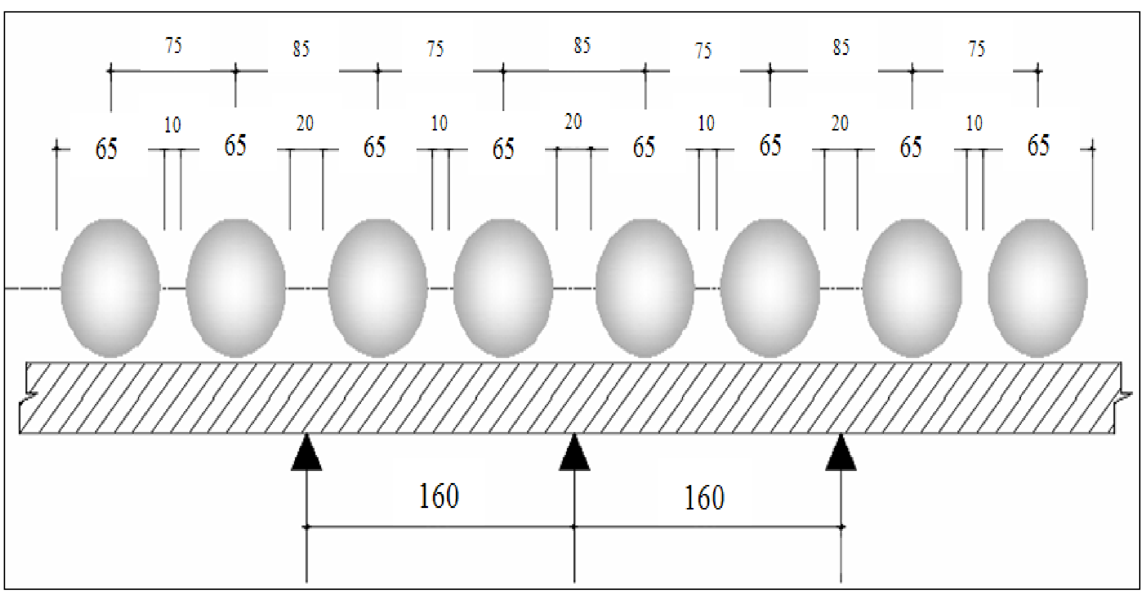

Figure 5. Pile and Anchor Modulation Plan

deformation of the excavation by the designer firm. Cracks on the reinforced earth road embankment of the highway, which is an elastic structure, and problems in the retaining system were distinguished. These cracks and deformations on the coating

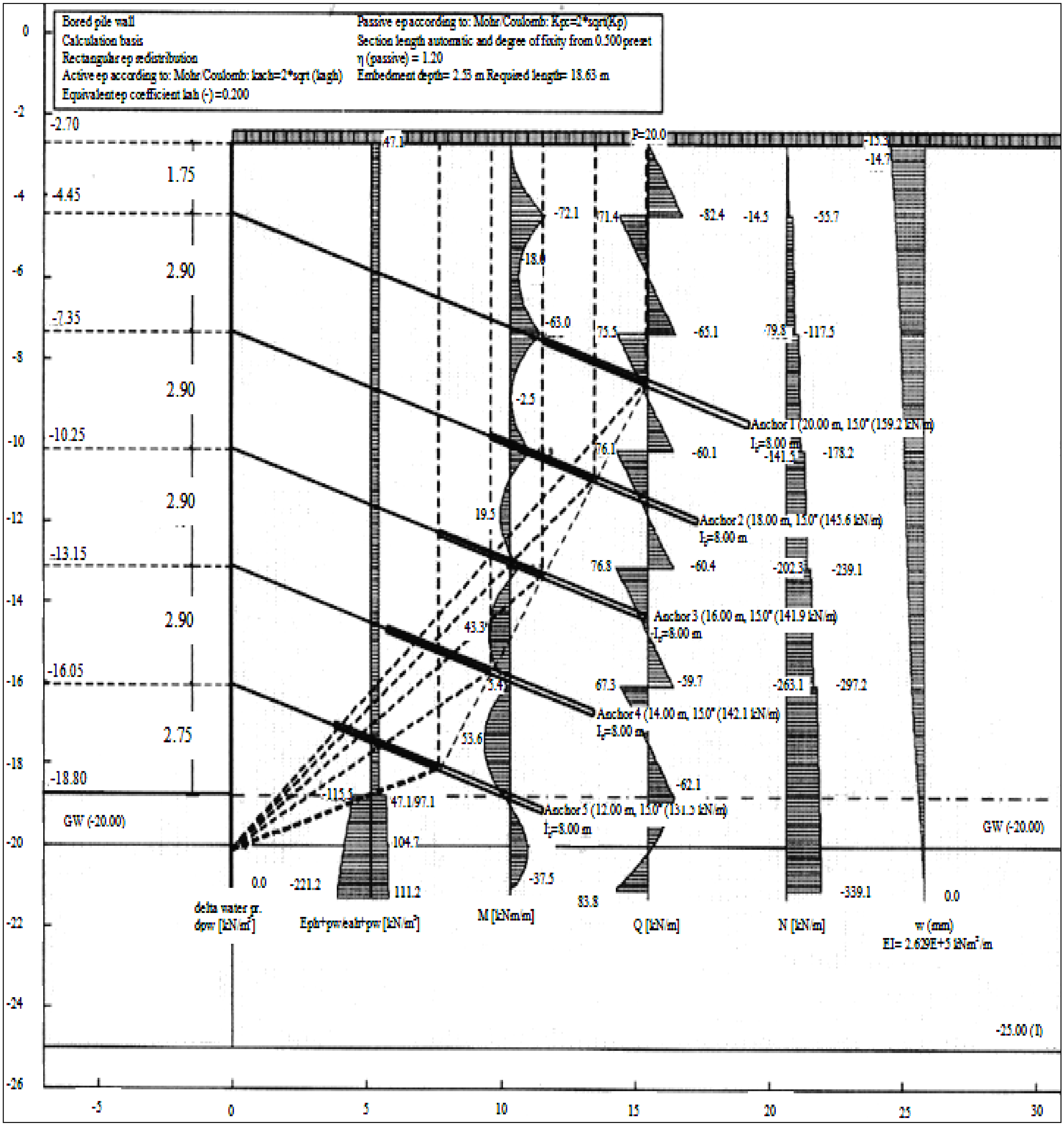

Figure 6. Moment, Shear, Normal Load, and Bending Rigidity Distributions of Collapsed Retaining System

started to appear due to the occurrence of deformation in the retaining system more than the calculated value by the designer firm (Figures 7 and 8).

As the first step, the occurred cracks were closed by filling them with concrete (Figure 9). The cracks gradually expanded as a result of the continuing deformation; and the road was closed to the traffic.

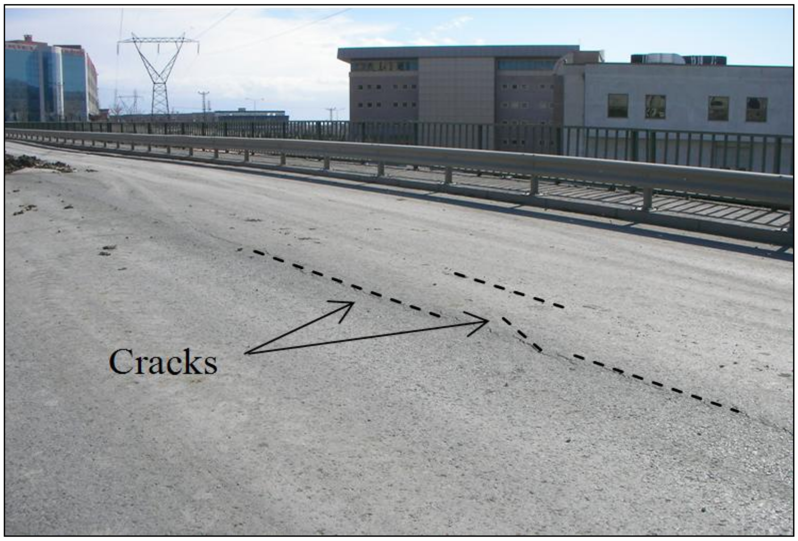

Figure 7. Deformations Occurred on the Road Embankment

Figure 8. Expansions of the Cracks on the Road Embankment

Figure 9. Filling of the Cracks with Concrete

Figure 10. The Backfill Procedure

Figure 11. Encounter with Groundwater

Figure 12. Collapsed Bored Piles

The backfilling procedure was implemented, in the meantime, to prevent the down throw of retaining system. Since the collapse was not expected, the backfilling procedure was implemented too late (Figure 10).

In the controls conducted, it was determined that some sections of the anchors were scraped and became dysfunctional. Water, at 11 to 12 m depth, was encountered inside the soil (Figure 11). In the soil survey, the groundwater level was determined as 20 m. Nevertheless, groundwater was encountered during the excavation after the retaining implementation. Deformations, due to the water pressure and dysfunctioning of anchors, were increased; and, ultimately, bored piles were overturned and collapsed (Figure 12).

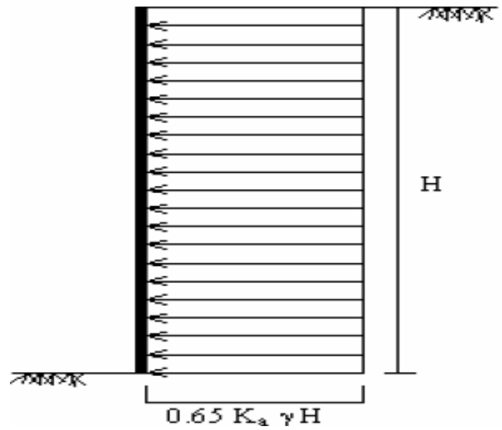

Figure 13. Lateral Soil Pressure Distributions Suggested by Terzaghi-Peck for the Noncohesive Soils (Terzaghi-Peck, 1967)

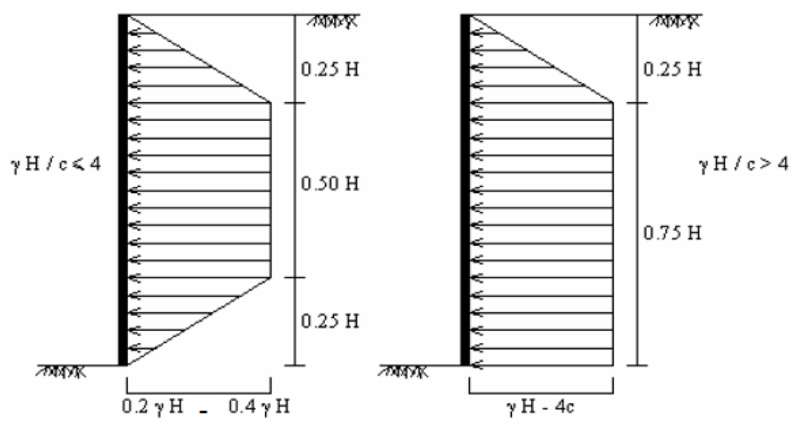

Figure 14. Lateral Soil Pressure Distributions Suggested by Peck for the Cohesive Soils (Peck, 1969)

Table 5. Calculation Results of Shear Force Parameters and Active Stress

	Calculation Method	**Shear Force Parameters** c (kN/m^2)	ϕ (°)	**Active Soil Stress (kN/m)**
Collapsed Retaining Project	Mohr–Coulomb	0	30	820
Control Calculations 1	Terzaghi-Peck	0	30	1060
Control Calculations 2	Peck	32	13	2500

DETERMINING THE CAUSE OF COLLAPSE

As the result of site investigations, it was determined that the soil was rigid and dense clay. Nonetheless, in the existing project design phase lateral soil pressure was calculated by taking the angle of internal friction value as 30° and neglecting the cohesion effect.

The road embankment, with approximately 4 m height, located on the side of collapse, was not taken into consideration during the calculation phase of existing project. In the existing project, Mohr – Coulomb method was used for the lateral soil pressure calculations. The active stress obtained in the calculations was found out as 820 kN/m. Peck (1969)'s and Terzaghi - Peck (1967)'s lateral soil pressure distribution suggestions, according to the soil types, that are taken up by the retaining system are presented in Figures 13 to 14.

By using the shear force parameters, obtained by the soil survey and the assumption that the soil was noncohesive, lateral soil stresses were calculated; and they were compared with the values of the existing project (Table 5).

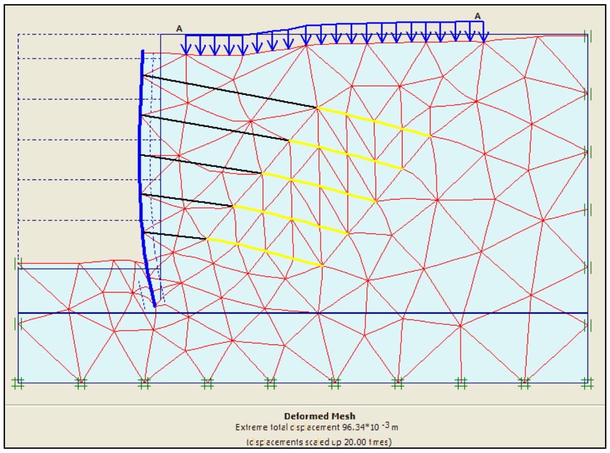

Figure 15. Deformed Shape

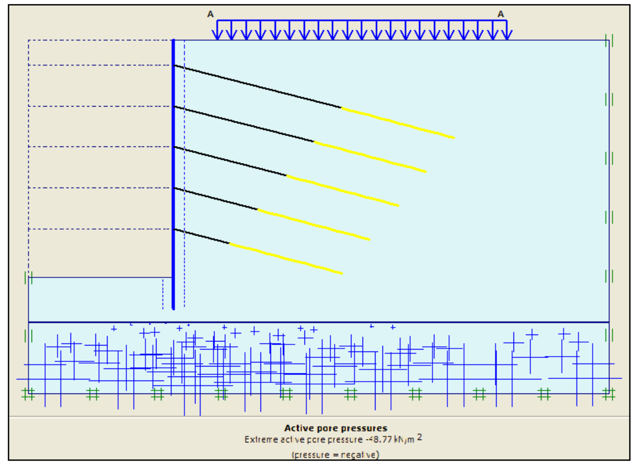

Figure 18. Active Pore Pressures

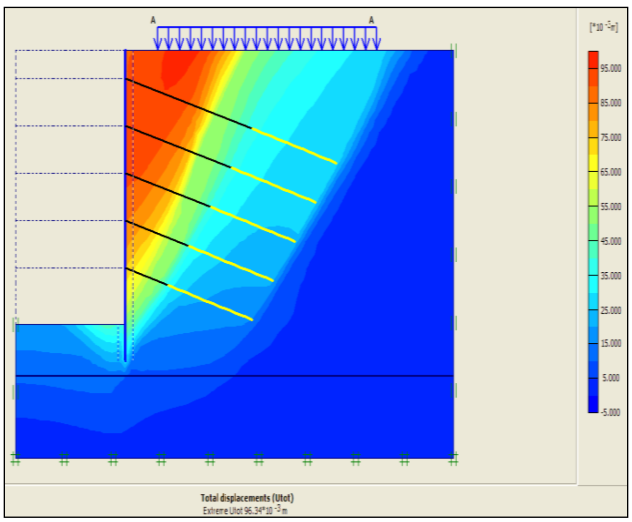

Figure 16. After The Analysis of Total Displacement

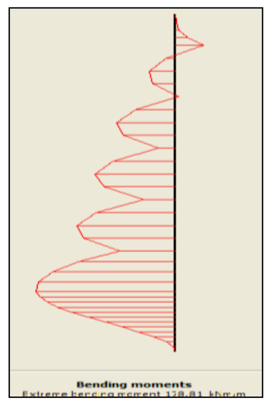

Figure 19. Bending Moment (ϕ=30^o, c=0 and H_w=20 m)

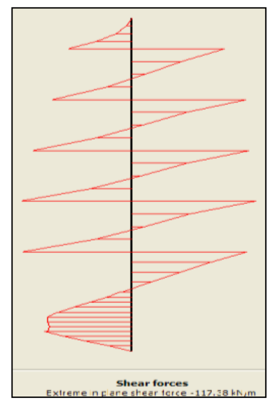

Figure 20. Shear Force (ϕ=30^o, c=0 and H_w=20 m)

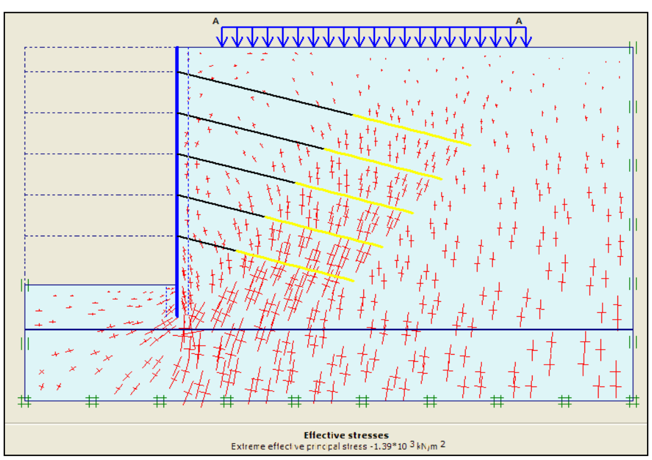

Figure 17. Effective Stresses

ANALYSIS OF ANCHORED RETAINING BY USING FINITE ELEMENTS METHOD

In this study, by using the soil assumption used in the design of the collapsed retaining and dimensions of the retaining structure (Tables 4 to 8), excavation and retaining structure were modeled with finite elements method used by Plaxis program (Vermeer and Brinkgreve, 1998) and the system was analyzed.

Deformed shape is presented in Figure 15. As a result of the analyses, the biggest displacement value was calculated as 9.5 cm (Figure 16). The biggest bending moment and shear force values were found, respectively, as 178.81 and 117.38 kN/m (Figures 19 to 20). The biggest value of stress taken up by the anchor, on the other hand, was calculated as 255.00 kN/m. Effective stress and active pore pressure are presented in Figures

Table 6. Specifications of the Soil Used in the Project (Alaner and Mermer, 2009)

Soil type	Material type	Model Utilized	k_x, k_y (m/day)	E (kN/m^2)	ν	(G_s)	H_w (m)
Clay	Drained	Mohr-Coulomb	0.001	100000	0.35	1.25	20

Table 7. Specifications of the Retaining System Implemented in Project

Concrete class	Material type	θ (cm)	Reinforcement	Ø (mm)	A_s (cm^2)	EI (kNm^2/m)	EA (kN/m)	w (kN/m/m)
C25	Elastic	65	BÇIII 420	Ø18/16	40.715	120000	200000	8.3

Table 8. Specifications of the Anchor Implemented

Length (m)	EA (kN/m)	Material	α
8.0	200000	Elastic	15

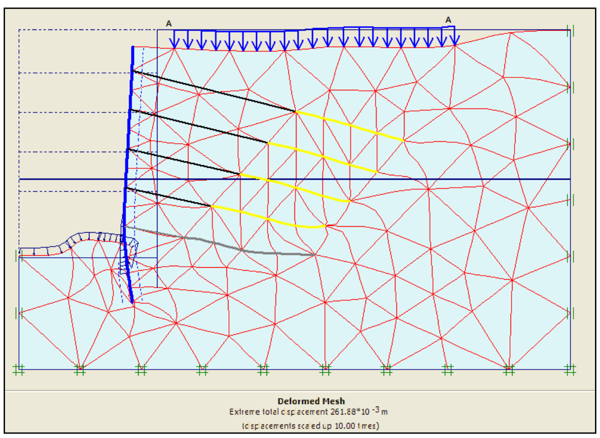

Figure 21. Deformed Shape

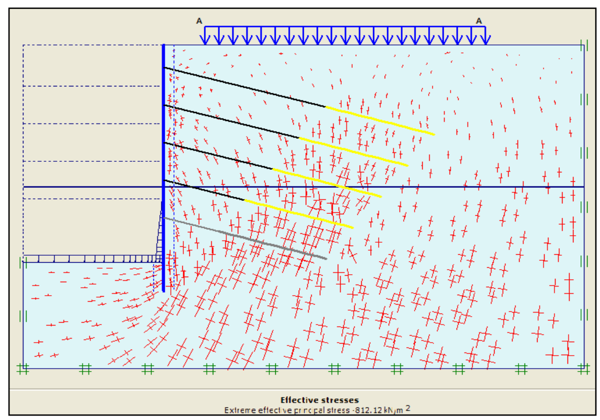

Figure 23. Effective Stresses

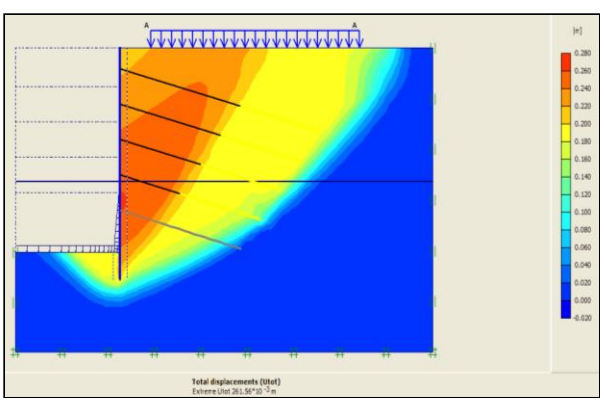

Figure 22. After The Analysis of Total Displacement

17 and 18.

The soil conditions of the investigation area, and retaining system and anchor specifications were summarized in Tables 6 to 8.

It was determined that groundwater level was identified inaccurately during the soil survey; and this level was found out to be at 11 m depth from the soil. There is water in excavation pit. By taking the angle of internal friction and cohesion, respectively, as 13° and 32 kN/m^2 as the soil data, the analyses were conducted again (Mohr Coulomb). As the result of analyses, the maximum displacement value was calculated as 28 cm (Figures 21 to 24). The biggest bending moment and shear force values were found, respectively, as 392.09 and 206.22 kN/m (Figures 25 and 26). In this analysis, retaining was

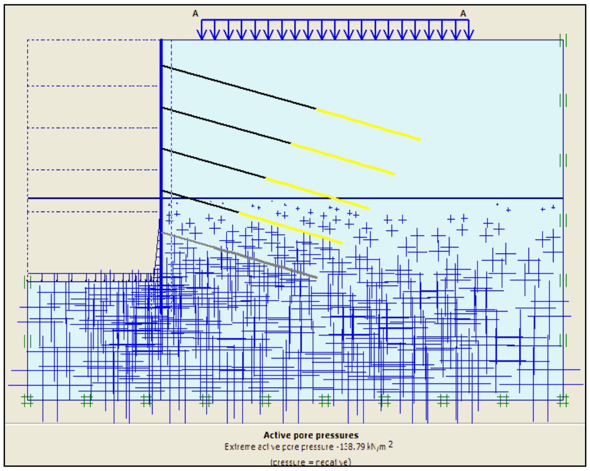

Figure 24. Active Pore Pressures

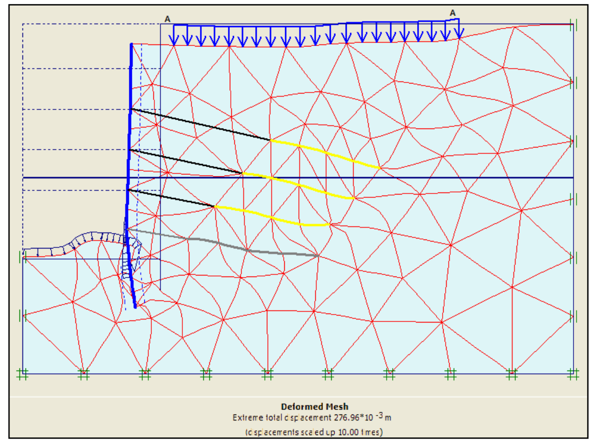

Figure 27. Deformed Shape

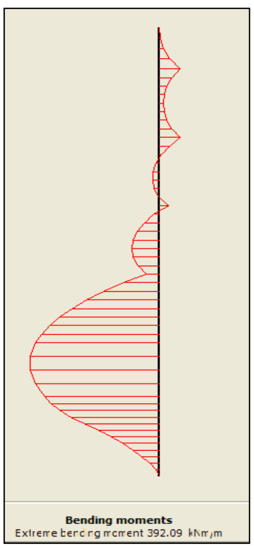

Figure 25. Bending Moment (ϕ=13^o, c=32 kN/m^2 and H_w=11 m) (Mohr – Coulomb Method)

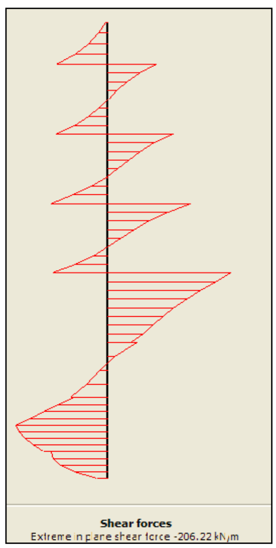

Figure 26. Shear Force (ϕ=13^o, c=32 kN/m^2 and Hw=11 m) (Mohr – Coulomb Method)

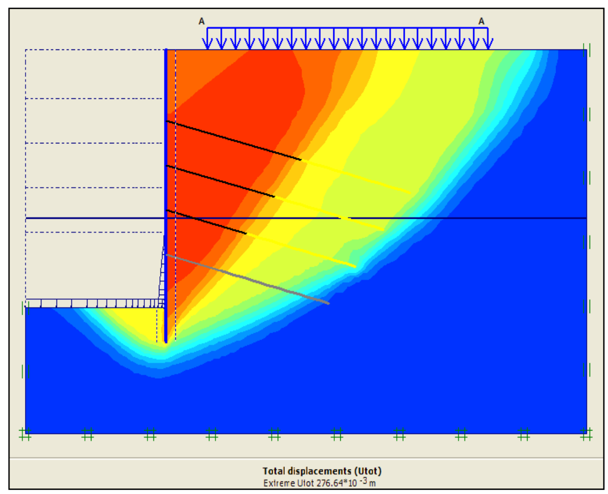

Figure 28. After The Analysis of Total Displacement

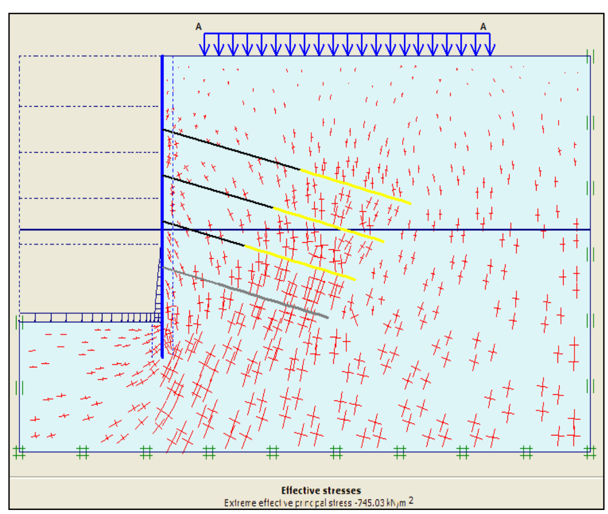

Figure 29. Effective Stresses

detected to be collapsing. The biggest value of stress taken up by the anchor, on the other hand, was calculated as 331.20 kN/m. As the result of the analysis, a soil collapse warning was received.

In the site investigations, some of the first row anchors were determined to be emptied before the collapse due to the difficulty of anchoring in the clay soils and insufficient injection acceptance of the clay soil, and became dysfunctional. For revealing the deformations in case of first row anchors' dysfunctioning, the scraping of the first row anchors were modeled by using finite elements method (Figures 27 to 30). The biggest bending

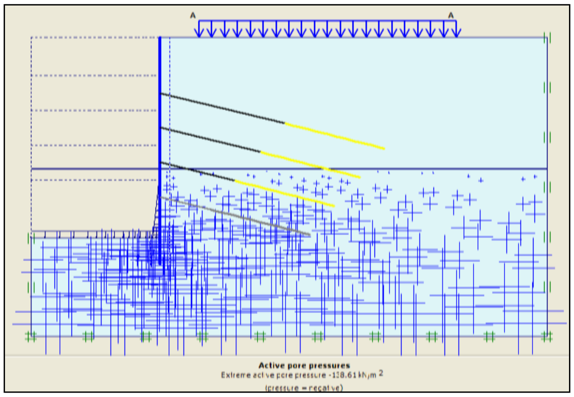

Figure 30. Active Pore Pressures

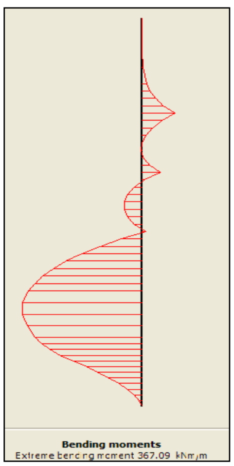

Figure 31. Bending Moment (ϕ=13^o, c=32 kN/m^2 and H_w=20 m)

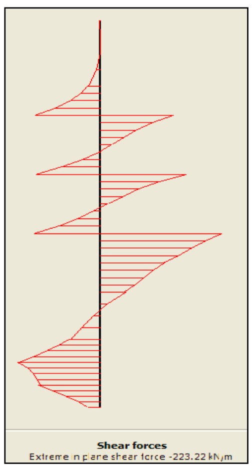

Figure 32. Shear Force (ϕ=13^o, c=32 kN/m^2 and H_w=20 m)

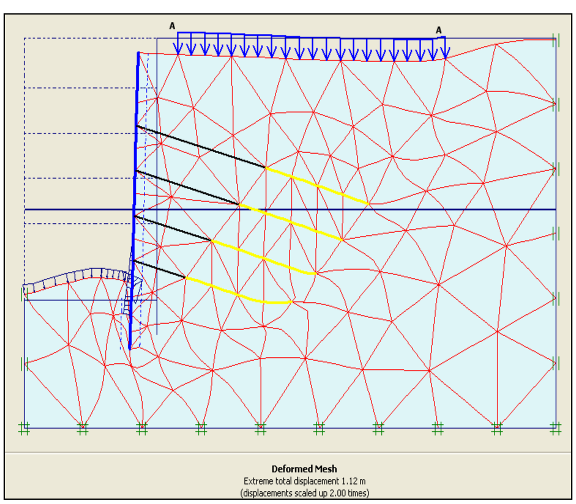

Figure 33. Deformed Shape

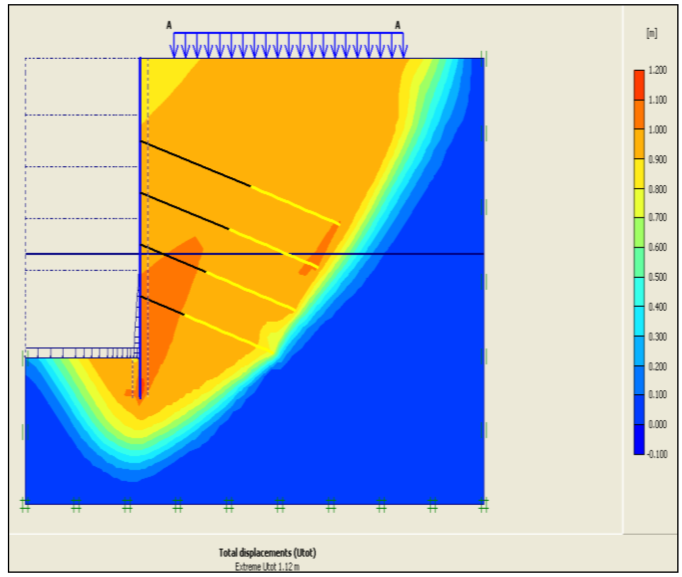

Figure 34. After The Analysis of Total Displacement

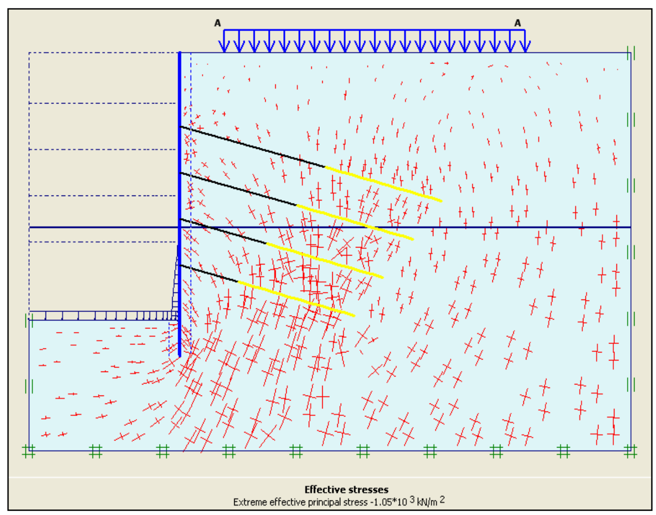

Figure 35. Effective Stresses

moment and shear force values were found, respectively, as 367.09 and 223.22 kN/m (Figures 31 to 32). The retaining system was detected to be collapsing in this analysis. The biggest value of stress taken up by the anchor, on the other hand, was calculated to be 384.00 kN/m. The unexpected increase in the values of forces taken up by anchors, made the anchors dysfunctional. This condition caused the collapse of retaining system.

The analyses were conducted by hardening soil methods (Schanz et al., 1999). As the result of analyses, the maximum displacement value was calculated as 112 cm (Figures 33 to 36). The biggest bending moment and shear force values were found, respectively, as 404.96

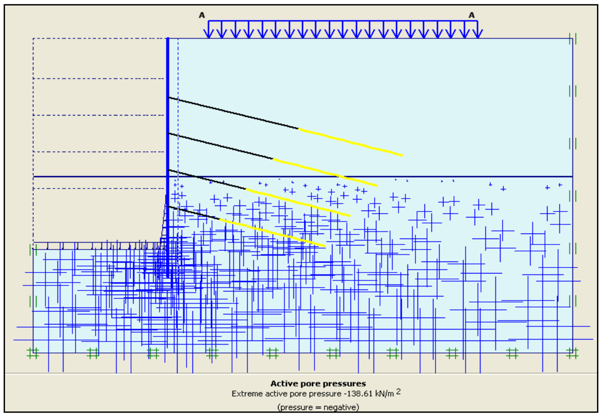

Figure 36. Active Pore Pressures

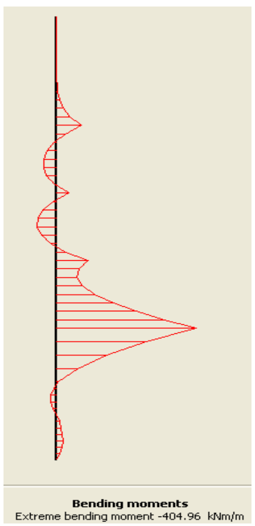

Figure 37. Bending Moment (ϕ=13^o, c=32 kN/m^2 and H_w=11 m) (Hardening Soil Method)

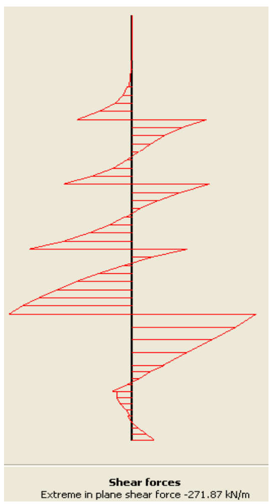

Figure 38. Shear Force (ϕ=13^o, c=32 kN/m^2 and H_w=11 m) (Hardening Soil Method)

and 271.87 kN/m (Figures 37 and 38). In this analysis, retaining was detected to be collapsing. The biggest value of stress taken up by the anchor, on the other hand, was calculated as 400.00 kN/m. As the result of the analysis, a soil collapse warning was received.

The shearing force parameters, obtained by the soil assumption and soil survey implemented by the designer of the project, and finite elements method analysis results, which used the groundwater level value determined during the construction, were compared. The anchor forces were calculated by modeling the scraping of the first row anchors (Table 9).

The reasons for the collapse of anchored bored pile system can be listed as;

1. The groundwater level value was erroneously determined. It could not be figured out that the level was closer to the surface.
2. According to the soil survey report, although it was found that the soil was clayey, the angle of internal friction and cohesion value were, respectively, as 13° and 32 kN/m^2, the values for angle of internal friction and cohesion were taken as 30° and 0, respectively, in the calculations.
3. The effect of reinforced earth road embankment, which is located at the side of the excavation site, was not considered during calculation phase of the project.
4. In the clay soils, a successful anchor implementation could not be implemented in the first excavation step.
5. No instrumental observation was conducted in the excavation region.
6. The number of lateral support was not enough, and the socket length was insufficient.

RESULTS AND RECOMMENDATIONS

This study investigated the possible collapsing parameters of the retaining projects. Application of the Mohr-Coulomb and hardening soil method were applied to the example project. The following results can be drawn from this study.

It is obtained that the displacement value of 1.53 cm, calculated by the designers of project, was the main reason of collapsing. Other reasons were erroneous selection of surrounding buildings in which the first row anchors of the side could not be implemented successfully. Shear force parameters and groundwater level values to be selected according to the investigation of soil survey, 28 cm displacement was calculated (Mohr Coulomb), 112 cm displacement was calculated (Hardening Soil); and it was determined that the retaining structure would collapse.

For the retaining structures which would be exposed to long-time soil stress or be continuously permanent, adequate safety numbers should be used. When designing the deep excavation projects, environmental effects and effects of the existing structures should be considered. The lateral soil pressures, taken up by the retaining system, should be determined for the most inimical situation. The surcharge loads, caused by the machines around the excavation site, should also be taken into account. With the use of accurate soil data, it becomes possible to accurately model by using finite elements, or other methods, in the analyses. Like in the project investigated, inaccurate soil data or analysis approach do limit the validity of analysis. With the instrumental observations conducted in the excavations, the validity of analysis and possible dangers should be checked. Appearance of the displacements at the predicted level would show that the excavation and retaining project were successfully implemented.

Table 9. Calculation Results

	Used Method	ϕ (°)	c (kN/m^2)	H_w (m)	Anchor force$_{max}$ (kN/m)	Bending moment$_{max}$ (kNm/m)	Maximum shear force (kN/m)	Maximum displacement (cm)
Collapsed Retaining		30	0	20	254.00	72.10	82.40	1.53 (No collapse)
FEMA (Project assumption)		30	0	20	255.00	178.81	117.38	9.50 (No collapse)
FEMA (Actual situation)	Mohr - Coulomb	13	32	11	331.20	392.09	206.22	28.00 (Collapse warning)
FEMA (Anchors scraped)		13	32	11	384.00	367.09	223.22	- (Collapse warning)
FEMA (Anchors scraped)	Hardening Soil	13	32	11	400.00	404.96	271.87	112.00 (Collapse warning)

The conducted studies revealed that using anchors would be an effective method for decreasing the displacements. The injection should be implemented by making sure of its success; by keeping outside of the inclination angle of anchors and slip circle. The test load bearing experiments of anchors should be implemented at discretion. Likewise, the capacity of the material should be determined by conducting the necessary controls and experiments.

Regarding the retaining systems, it is compulsory to comply with the TS 3168-EN 1536, TS EN 1537 standards, respectively, about the bored piles and soil anchors in Turkey.

Finally, the most important factor for the successful implementation of deep excavation is the faultless application of geotechnical research. After obtaining information about the soil, the selection of excavation system becomes significant. The basis for the deep excavation is reaching the acceptable displacement level, according to the provisions of the excavation, and selecting the most economical, as well as feasible, support system for enabling the stability. Every excavation should be approached and analyzed according to their specific site conditions. The optimum support system should be selected by evaluating all the criteria.

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