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An Example of Cement Stabilization Application in Railway Systems (Aladdin-Adliye Tramway)

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ABSTRACT

The subbase and base layers of the road and railway should be designed to be the most economical and should provide criteria such as bearing capacity, settlement and permeability during service life. Today, cement stabilization is widely used in improving the soil properties when the criteria are not met. In this study, the quality control tests of stabilized filling and cement stabilization applied in the construction area of Konya Aladdin-Adliye tramway line and application details of cement stabilization along the route have been given. At the quality control experiments of stabilized materials and the preparation of cement mixture, the points specified in the Technical Specifications for Highways (TSH) have been taken into consideration. Due to the presence of the tramway route in a historic area, it was not allowed to improve by deep excavation and requested to make an improvement so as not to deform the historic remains. Plate loading tests were carried out for the current situation at certain intervals along the route. In locations where have high values of settlement, soil properties have been improved by cement stabilization. The most important factor in cement stabilization is to find the most suitable cement and water ratio. For this reason, in order to determine the appropriate cement ratio according to the TSH, the optimum water content of the material used in stabilize layer has been determined. By considering this value, mixtures were prepared at different cement ratios and the mixture was compressed in CBR mold to obtain cylinder samples. The unconfined compressive strengths of the these samples were measured and the cement-to-water ratio was obtained which provided the upper and lower unconfined compressive strength limits specified in the TSH. Improvement was made in the route base layer using a cementitious mixture with the determined optimum cement-water ratio. After the application, samples were taken, quality control experiments were carried out.

Keywords: Cement stabilization, Railway systems, Technical Specifications for Highways

1. INTRODUCTION

The soil used as the subbase and base in the road construction must have certain characteristics as an environment that safely carries the loads. Traffic loads transferred to the base should not cause any deformation on the soil and these loads must carry safely by the soil. The physical properties, the behavior under load, the carrying capacity, the settlement criteria, the permeability and the swelling potential of the soil etc. should provide the desired values. Nowadays, soil stabilization methods are widely used in cases where the soil environment cannot provide these properties. Soil stabilization methods are applied in two ways as surface and deep stabilization. For structures such as roads and railways, surface improvements are often sufficient. The surface improvement is applied in two ways as mechanical and additive improvement. The soil properties are improved by using additive materials such as cement, lime, fly ash, etc. Improvement with cement is advantageous compared to other additives because it is easy, economical and fast to apply. In particular, it improves the bearing capacity and permeability properties of the soil. Thus, by improving the soil properties, benefits are also gained in terms of road performance, service life, maintenance cost and margin.

Until today, many studies related to cement stabilization, one of the oldest stabilization methods have been done [1]. Cement stabilization has been commonly applied to all non-organic soils [2, 3]. It is seen that the results obtained with cement stabilization on silty soils are as good as the results obtained with coarse-grained soils [4]. The effects on soil properties of cement admixtures have been investigated in cement-treated soils [5, 6]. Behavior between internal structure and engineering properties of cement improved marine clay has been investigated [7]. Laboratory tests were performed on soil samples with different cement ratios to obtain the appropriate cement ratio [8]. California bearing ratios of weak soil stabilized with a cement ratio of 4% to 16% were found and the relationship between the cost of stabilization and the cost of flexible superstructure stabilized with cement was presented [9]. The improvement effect of Portland cement used in the sulfate-affected soils was investigated experimentally [10]. The improvement of the sediment soils in İzmir Gulf with lime and cement has been investigated experimentally and improvements in the composition and consistency of the soil have been obtained [11].

There are basically two alternatives in improving soil properties by surface stabilization. In the first alternative, the inadequate properties of the soil are improved by digging in place or by compressing or mixing them at certain rates with the additives. In the second alternative, the inadequate soil is completely removed by stripping up to the depth of improvement. The appropriate stabilized soil is laid directly and compacted or the stabilized soil is mixed with the additive material at certain ratios and spread by compression. The choice of these alternatives depends on such criteria as cost, time, soil properties and the location of the construction site. In this study, uncontrolled filling area with inadequate properties detected on the Aladdin-Adliye tramway route was removed. Stabilized filling layer and cement stabilized soil layers which were meet the desired criteria were formed instead of the lifted layer. In the scope of the study, quality control tests of cement and stabilized filling materials used along the tramway line have been given. Due to the fact that the line is located in a historic area, it is not allowed to open observation well or apply deep recovery methods. For this reason, cement stabilization method which is one of the surface improvement methods has been applied along the tramway line. In determining the optimum cement ratio and performing other quality control tests, the conditions specified in the Technical Specifications for Highways (TSH)-Section 402 [12] have been taken into consideration. The laboratory and field tests carried out within the scope of the study were carried out at KTO Karatay University Civil Engineering Department laboratory.

2. MATERIAL AND METHODS

2.1. Stabilization Applications in Construction Site

The tramway line between Aladdin and Adliye is constructed as 6323m and is shown in Figure 1. The soil properties along the tramway route have been investigated and in some parts, uncontrolled filling and soil with low organic content have been observed. After peeling off this layer of 40-60cm thickness on the surface of the soil, a stabilized filling layer of 30cm thickness and cement stabilized layer of 20cm thickness on this layer were formed along the line. In the plate loading test made on the natural soil in the route between Alaaddin-Mevlana given in Figure 2, it is seen that there is a large amount of uncontrolled filling and remains and too much soil settlement under excessive loads.

Figure 1. Aladdin-Adliye tramway route

Figure 2. Alaaddin-Mevlana Museum tramway route

Since there was no possibility of deeper stripping of the area, it was not excavated more deeply, and a three-stage improvement was applied after stripping 50-70cm of thickness on the route so as not to damage the historic remains in this area.

1. Stage: Stabilization material with a thickness of 30cm on the excavation base was laid in optimum water content and laid down in two layers with a cylinder in accordance with

the criteria of compaction. The control of the compaction is carried out by the sand cone method and plate loading tests.

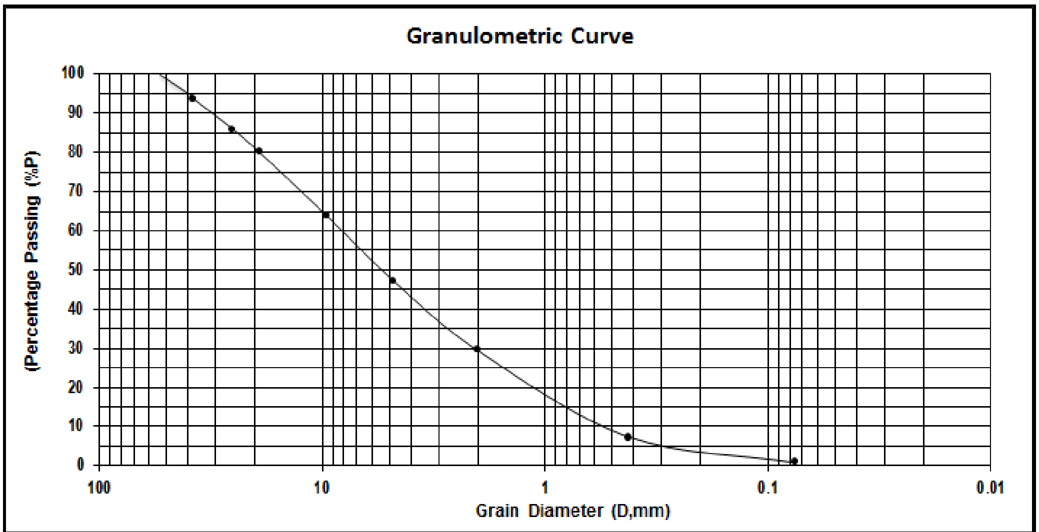
2. Stage: On the stabilized filling layer, the stabilization layer is laid with 20cm thickness cement, whose mixture ratios are determined in accordance with TSH, and compacted in a single layer with suitable cylinder. The control of the compaction is measured by the plate loading test.
3. Stage: Due to the large amount of historical remains and uncontrolled fillings between Aladdin and Mevlana, a 20cm thick reinforced mat foundation is made on the cement stabilization layer for uniform distribution of different superstructure loads and minimization of different settlement, thus ensuring that vehicles and other loads are transferred to the soil in a safer way.

2.2. Stabilize Material Properties

Table 1 shows the index properties of stabilized filling and cement stabilize used in the tramway line, determined by laboratory tests. Figure 3 shows the granulometric curves of the stabilized filling material and the granulometric curves of the cement stabilize material is given in the Figure 4. It has been found that the components of both materials (sand, gravel and fine material proportions) and other material properties generally provide the limit values specified in Section 402 of TSH.

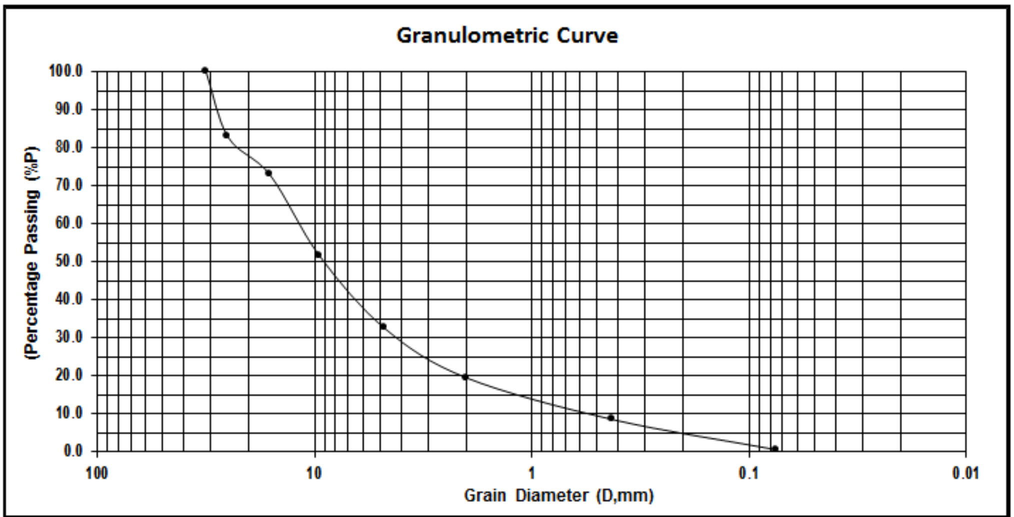
Table 1. Material properties

	Stabilized filling material	Cement stabilize material
Optimum water content, w_{opt} (%)	6.2	5
Maximum dry unit weight, γ_{dmax}(kN/m^3)	22	24.6
Gravel (%)	53	67
Sand (%)	46	32
Clay-Silt (%)	1	1
Soil class (USCS)	GW	GW
Liquid limit (%)	NP	NP
Plastic limit (%)	NP	NP



SOIL	GRAVEL	SAND %	SILT %	CLAY %	D_{60}	D_{30}	D_{10}	C_U	C_C
	53	46	1		8	2.0	0.5	17	1

Figure 3. Granulometric curve of stabilized filling material



SOIL	GRAVEL	SAND %	SILT %	CLAY %	D_{60}	D_{30}	D_{10}	C_U	C_C
	67	32	1		12	4.1	0.6	20	2

Figure 4. Granulometric curve of cement stabilize material

2.3. Determination of the Optimum Cement Ratio

In TSH, unconfined compressive strength (q_u) of the cement-bonded granular base layer to be used in road construction is required to be;

$$3.43\ N/mm^2 \leq q_u \leq 5.39\ N/mm^2$$

Experiments have been carried out in the laboratory to determine the cement ratio to provide this condition. Mixtures of cement-stabilize material prepared at different cement ratios were compacted in a modified proctor mold as specified in TSH. In the 15.24cm diameter and 17.78cm height CBR mold, the samples that compressed to 7 layers and 62 strokes per layer were removed from the following day, stored covered in a moist environment to complete the 7-day cure. The samples completed the 7-day cure were broken in the pressure press to determine their unconfined compressive strengths. In preparing the samples, the water content (w) was chosen as 3% and the unconfined compressive strengths of the samples are given in Table 2.

Table 2. Cement mixture ratio unconfined compressive strength values

Test No	Cement ratio (%)	Unconfined compressive strength (N/mm^2)
1	4.2	11.73
2	3.8	9.46
3	3.4	8.02
4	3.0	6.70
5	2.4	4.56
6	2.0	2.81

When Table 2 is examined, it is preferable to use 2.4% cement to obtain unconfined compressive strength between the limits specified in TSH. In the cement stabilization along the tramway route, the mixture prepared in the concrete plant with water content of 3% and cement ratio of 2.4%, is laid and then the mixture is compressed with 12 tons capacity vibratory cylinder. Mixing samples were taken periodically during application. The received samples were compressed in the CBR mold as specified in TSH and left to the cure, and the compressive strengths were measured after curing. The strength graphs of five samples prepared with the mixture taken from 2 + 820 km are given in Figure 5. When the graph is examined, it is seen that the strength values obtained are within the lower and upper limits specified in the specification.

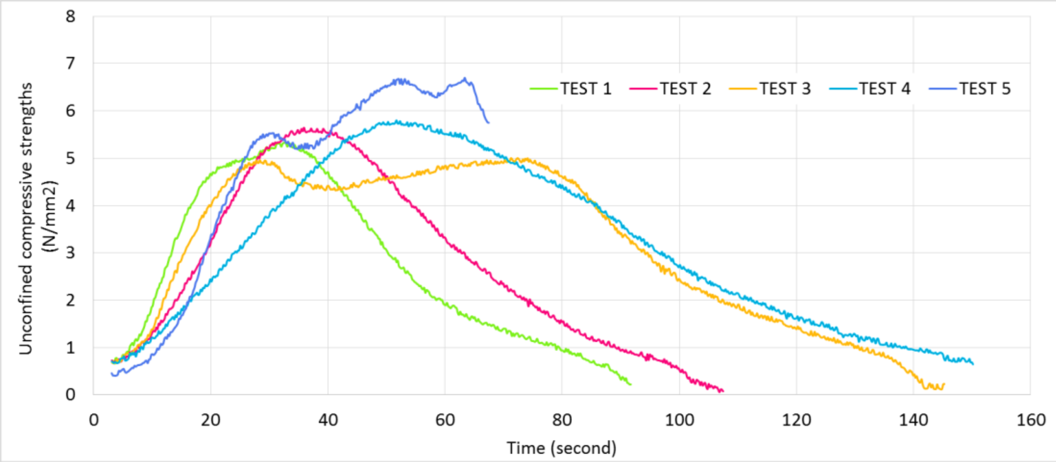


Figure 5. Unconfined compressive strengths

3. RESULTS AND DISCUSSION

3.1. Quality (Compress) Control of Stabilized Filling

Stabilized filling material is laid in the area where the Adliye Tramway Warehouse has been constructed, and compressed with a 12 ton vibratory cylinder. The composition parameters of the materials used in the filling are given in Table 1 (w_{opt}=6.2%, γ_{kmax}=22kN/m^3). Compression control was carried out by sand cone method at 12 points randomly selected in the field where mechanical stabilization at 30cm thickness is made. The determined relative compaction values from the compression control are given in Table 3. In the table, the average relative compaction value is 95.4% and this value provides the minimum 95% compactness requirement for the road subbase layer in TSH.

Table 3. Compression control values of stabilized filling

Test No	Natural unit weight, γ_n (kN/m^3)	Water content, w (%)	Field dry unit weight, γ_{df} (kN/m^3)	R_c (%)
1	22.7	3.1	22.0	95.7
2	22.5	4.1	21.6	94.0
3	23.0	3.6	22.2	96.6
4	24.0	3.8	23.1	100.0
5	23.1	3.2	22.4	97.4
6	21.0	1.8	20.6	89.5
7	23.8	2.7	23.2	100.0
8	21.0	2.0	20.5	89.3
9	21.9	2.4	21.4	93.0
10	22.2	3.2	21.5	93.7
11	23.0	4.0	22.1	95.9
12	24.3	3.0	22.5	97.8
Average Relative Compaction, Rc (%)				95.4

3.2. Plate Loading Tests

Around 70cm thickness base excavations were made along the route between Alaaddin-Mevlana. It has been determined that there is variable thickness of approximately 720m uncontrolled filling when the excavation area and the excavation soil examine in the route between Aladdin and Mevlana. The thickness, type and distribution of the filling material were not fully determined because opening of the observation well was not permitted. In this area, plate loading test was performed according to TS 5744 [13] at 5 different points (0+079m, 0+213m, 0+266m, 0+410m, 0+710m) to determine the strength-settlement properties of the excavation base (Figure 6). The graph showing the change between the settlement and the base pressure of the plate loading tests at the test points is given in Figure 7.

The estimated ultimate bearing capacity (q_s), safe bearing capacity (q_a), modulus of elasticity (E) and coefficient of subgrade reaction values from the experimental data of the plate loading experiment on these five points are given in Table 4. Safety number has been taken as Fs=3.5 while safe bearing capacity is computed.

It is seen that the geotechnical parameters given in Table 4 are very variable in the uncontrolled filling layer whose thickness and other properties are unknown. Thus, the reinforced concrete base slab (mat foundation) was applied in order to spread load of the tramway to uniform in a wider and reducing the different settlement in the area.

Figure 6. Plate Loading Experiment

Table 4. Results of plate loading experiment

	q_s (kPa)	q_a (kPa)	E (kN/m^2)	kv (kN/m^3)
0+079m	185	50	3965.0	18500
0+213m	560	160	11797.0	55047
0+266m	470	130	11952.0	55770
0+410m	260	70	5400	26000
0+710m	320	90	6100	32000

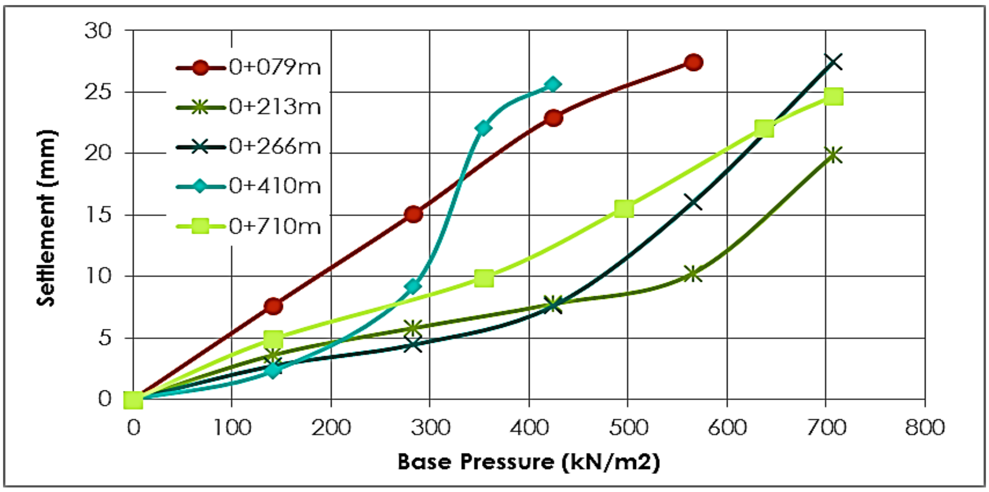


Figure 7. Base Pressure–Settlement relationship

3.3. Mat Foundation Design

In the analyzes made by using the SAP 2000 program, loading combinations were determined according to the case that the tramway vehicle load on the mat foundation of 7.8mx60m base size is in 4 different regions (Figure 8).

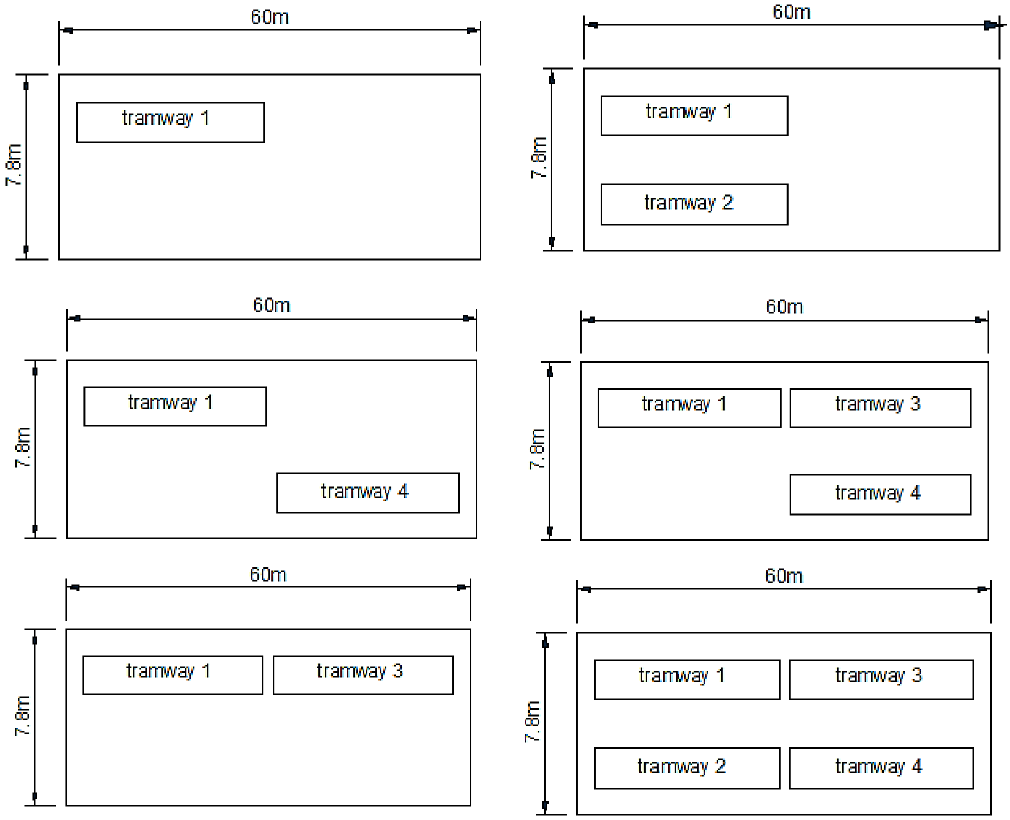


Figure 8. Base Slab Plate Load Combinations

Tramway weight is increased by dynamic increment factor considering factors such as wind load, brake load and temperature difference. The total weight of concrete taken together with the weight of the tramway is increased 1.5 times. In the SAP 2000 model, C30 / 37 concrete and S420 reinforcement were used. Figures 9 and 10 also show M_{11} and M_{22} moment distributions for the most unfavorable cases for 3D modeling. Figures 11 and 12 show the cut and moment diagrams of the 2D model, respectively.
Using the results obtained from the modeling, it is suggested to use double row reinforcement mesh on a 20cm thick mat foundation to provide the necessary reinforcement area in both directions. Loads from the vehicle will be transferred to the soil with maximum 50kN/m^2 load with the mat foundation spread over wide area. This value provides the average bearing capacity obtained from the plate loading test results.

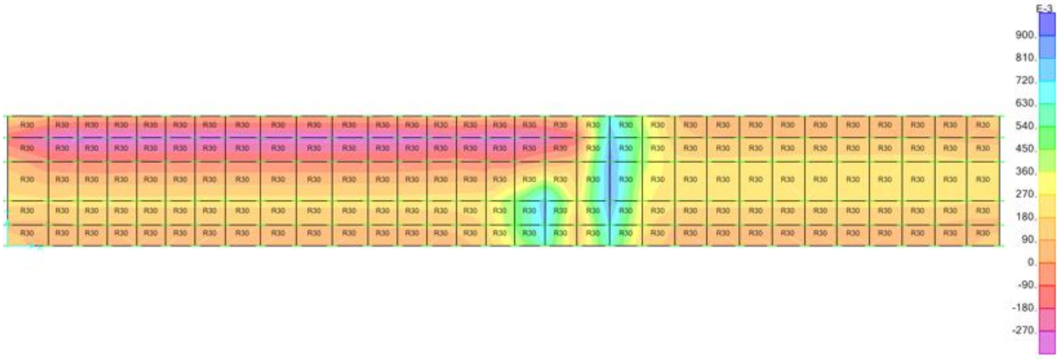


Figure 9. M11 moment distribution

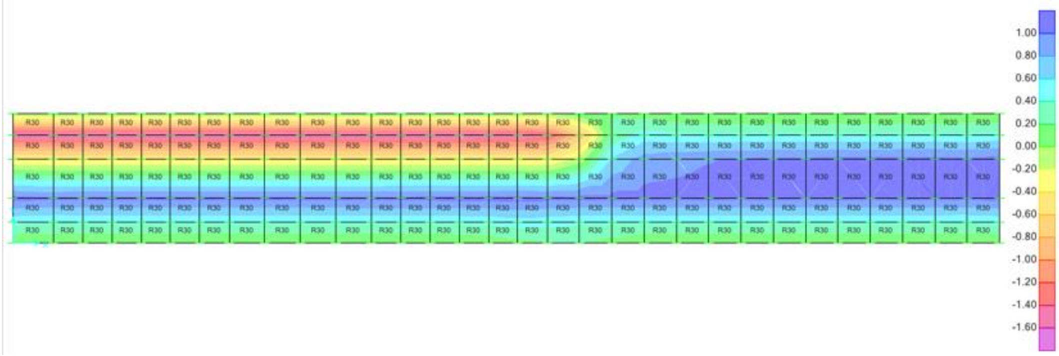


Figure 10. M22 moment distribution

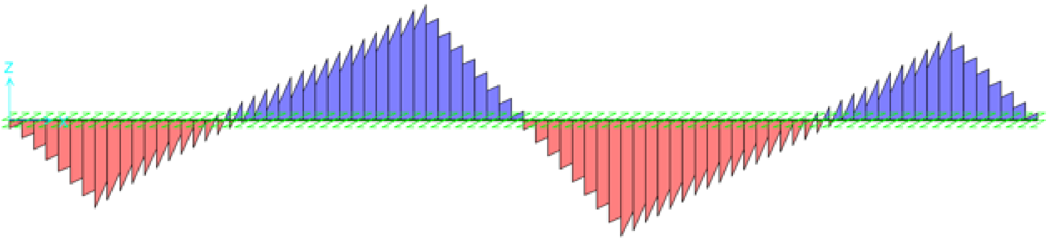


Figure 11. Typical cross-section cutting diagram

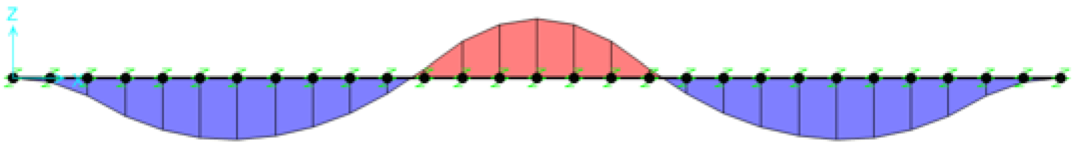


Figure 12. Typical cross-section moment diagram

4. CONCLUSION

There is an uncontrolled filling layer in the soil of Konya Aladdin-Adliye tramway line construction site, whose thickness, components and properties are not known precisely. Since deep excavation and deep stabilization are not allowed due to the presence of historic remains in the area, in order to minimize the problems that may be encountered due to settlement, bearing capacity and permeability, 50-70 cm thick stripping process followed by 30 cm thick stabilized filling and 20 cm thick cement stabilized filling layers were formed. In addition, a 20cm thick mat foundation was applied between Aladdin-Mevlana, where the uncontrolled filling thickness and intensive the historical remains could be excessive. It was determined sufficient improvement was provided on soil of the tramway line from the results of plate loading test and sand cone test made before and after improvement. It is not expected that there will be a problem that will prevent the use of the line since it is possible to prevent surface waters from entering the route by proper drainage system.

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