Analysis of a Group of Failing Retaining Walls and Remediation Measures

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ABSTRACT

This study investigates the reasons of excessive movements of a group of reinforced-concrete retaining walls with a total length of over 300 meters, constructed in 2000 in Kocaeli, Turkey. The contractor had documented the construction stages in sufficient detail. Evaluation of available documents, field observations and engineering analysis has shown that the factor of safety for the walls was around one. In other words, the walls were slowly failing. Engineering errors on calculation of earth pressures and the use of wrong backfill were identified as the primary reasons. The factor of safety of the failing walls was significantly improved by using the combination treatment of backfill replacement, base enlargement, post-construction shear key enclosure and drainage improvement.

INTRODUCTION

This study investigates the reasons of excessive movements of a group of reinforced-concrete retaining walls with a total length of over 300 meters, constructed in 2000 in Kocaeli Turkey. The walls comprise over 40 different types and each wall type has a drawing and construction notes independently. Shortly after the construction was completed, excessive wall movements were observed by the engineers, but the cause for the movements was not agreed by the contractor and the client.

Investigations include field observations, interviews with the involving parties, review of existing documents and engineering analysis based on the collected information. The information available is first documented along with the findings during field observations. Second, results of the engineering analysis are presented and subsequently the reasons of the failures are identified. Finally, remediation measures are presented.

AVALIBLE INFORMATION

Construction Phase

The contractor had documented construction stages well. Wall types fall into two categories: standard cantilever made out of reinforced concrete such as Walls 23 and 41 and cantilever with a console in the middle such as Wall 30. Pictures taken during construction stage of Wall Type 30 are shown in Fig. 1.

Field Observations

During the field visit, it was observed that some of the walls, particularly type 23, 30 and 41, have excessive movements. A simple displacement monitoring mechanism based on measuring the distance between the wall surface and a post was in place. However, the post was placed very close to the retaining wall. The post was moving along with the moving backfill. As a result, the measurements made over time were not indicative of the actual wall displacements; hence, they were not valuable.

Wall type 23 was 8,3 meters high, wall type 30 was 16 meters high, and wall type 41 was 9,4 meters high as shown in Figs. 2 through 4. The primary displacement mode of the wall type 30 was translation. Wall type 23 and 41 had combination of rotation and translation. The maximum wall displacements observed was about 10 cm.

During the field visit, it was also interesting to see that a resident was growing vegetables as hobby on the backfill of the wall types 23 and 41 as pictured in Fig. 5. Interviews with the involving parties revealed that additional backfill of clayey organic soil about 1 meter high was added on the original backfill by this resident.

The field visit also showed that there were no cracks in the concrete. Concrete samples had been taken previously and found that the compressive strength was 35 MPa, exceeding the design value of 30MPa. Therefore, the primary failure mechanism was due to insufficient evaluations of geotechnical conditions.

a) Foundation excavation

b) Lower part construction

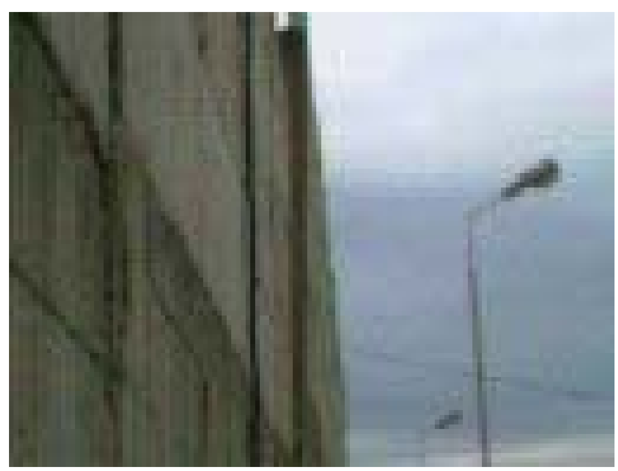
c) Middle console

d) Construction near completion

Fig. 1. Construction of wall type 30.

Fig. 2. Picture of failing wall type 30.

a) Outer surface



b) Close view of outer surface

Fig. 3. Pictures of failing wall type 23.

Fig. 4. Picture of failing wall type 41.

Fig. 5. Vegetation growth on the backfill of wall types 23 and 41.

Backfill

It was understood that the soil excavated from the foundation was used as backfill material. This was because of the fact that construction drawings have vague specifications about the backfill material, which gave way to the use of excavation material as backfill instead of a clean backfill. If the excavated material is treated as silty sand or gravel, the coefficient of active earth pressure can be estimated as 0.4 from Clough and Duncan (1991) with a unit weight of 18 kN/m^3.

Foundation Soil

Foundation soil was graywacke throughout the site as can be seen in Fig. 1.a. No laboratory testing was conducted for the site soils. However, Graywacke is an unweathered rock and it can be described as cemented with usual strength of medium (8000 psi or 50 MPa) to very high (over 32000 psi or 200 MPa) according to Peck et al. (1974).

The friction coefficient between the retaining wall and graywacke against sliding can be assumed 0.55 from Stephenson (1995). Because the strength of concrete was 30 MPa, and the strength of the greywacke is significantly higher than the strength of concrete, the bearing capacity was not a problem.

Earth Pressure Calculations

The documents reviewed showed that lateral earth pressures for the walls with a middle console had been calculated erroneously. Design engineer had assumed that the lateral earth pressure just beneath the middle console starts from zero as shown in Fig. 6. This method of calculation may be acceptable for the material design of the walls. The existence of middle console cannot reduce the total lateral load because the backfill extends significantly away from the inner side of the wall.

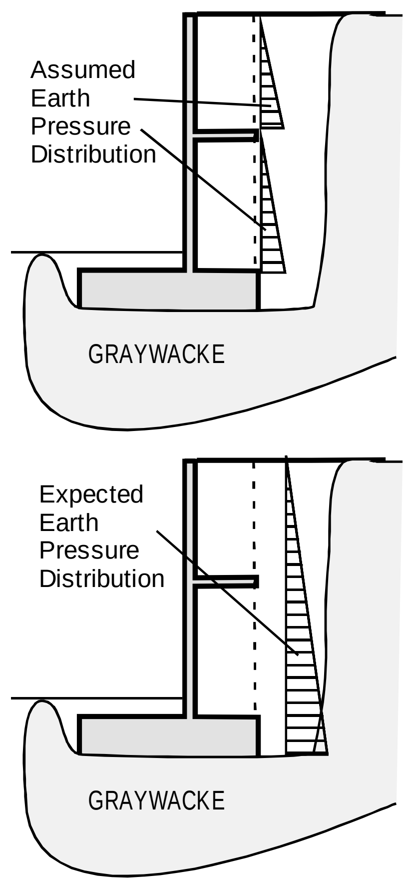


Fig. 6. Assumed and expected earth pressure distributions

Summary of Factors Contributing to Failure

Observations, interviews and review of existing documents during the field visit revealed that the causes failing mechanism include the following:

1. There were no cracks in the concrete, indicating that structural failure is not a concern and the failure mechanism was due to insufficient evaluations of geotechnical conditions.
2. During the design stage, the design engineer had passed away and another engineer had completed the design, resulting in loss of some information, which had led to faulty design for some of the wall types.
3. Vague specification about the backfill material gave way to the use of excavation material as a backfill instead of a clean backfill.
4. Properties of clean backfill were used in the analysis, but excavated soil was used as backfill. As a result earth pressure coefficients were misrepresentative.
5. Plant and vegetation growing on the neighboring land brought in significant amount of water which aggravated the pore pressures exerted on the wall due to wrong backfill selection.
6. Engineering errors were made on calculation of earth pressures. For walls with a console in the middle, the designer had assumed that earth pressures for the lower portion of the wall starts from zero at the console independent of the soil above it.
7. Drainage was achieved by pipes placed at the bottom of the backfill, not by weep holes. Because the backfill contained significant amount of fines, drainage was slow, which, in turn, adding extra water pressures on the wall and contributing to excessive movements.

BACK ANALYSIS

Based on the available information summarized above, earth pressures were calculated and the factor of safety against sliding and rotation was calculated for wall types of 23, 30 and 41. During the analysis, the friction between the foundation soil and the base of the wall was represented by $\delta=22^0$ and $\tan\phi=0.4$ and the backfill material was represented by Ka=0.4. The factor of safety calculated for these conditions are shown in Table 1.

Table 1. Factor of Safety (FS) Calculated For Existing Conditions

Wall Type	Against sliding	Against overturning
23, 41 and like	~1	~1
30 and like	~1	1.6

The results of the analysis supports the field observations that displacements for wall type 23, 41 and like were mostly rotational and sliding and for wall type 30 and like were mostly translational. It was concluded that the reason of the excessive movements was because the walls were near failure. In other words, the walls were actually failing slowly and eventually a total failure was inevitable unless remedial measures were taken.

REMEDIAL MEASURES CONSIDERED

A number of remedial measures were evaluated in order to improve the factor of safety of the failing walls. Remedial measures considered include the following:

- Raising ground line in front of wall
- Backfill replacement
- Base enlargement
- Anchor blocks
- Micro piles
- Shear key
- Drainage improvement

Raising Ground Line

Raising ground line permanently in front of the wall would have increased the passive pressures significantly and it would have been the cheapest solution. This would require raising the ground level of the client's yard for walls types 23 and 41, and raising the ground line on the neighboring parcel for wall type 30. Neither of which was feasible. As a result, this alternative was eliminated.

Backfill Replacement

As explained above, most of the walls were backfilled with soil from excavation. Replacing all of the backfill with free-draining would have not been cost effective. As a result clean backfill replacement was used only for walls chosen to improve with base enlargement

Base Enlargement

As Table 1 shows, wall type 23, 41 and likes suffer from low factor of safety values for both sliding and rotating. Enlarging the base would improve both values and could be done on either side of the base. It has been decided to enlarge the base on the backfilled side for wall types 23 and 41 and since the existing backfill has to be removed, backfill replacement with clean sand had also been used.

Anchor Blocks

Anchor blocks would require excavation on the backside of the walls and attaching anchor rods to the walls. This would have increased both the sliding and the rotational safety. Constructability without interrupting regular activities of the client was a concern. As a result, the cost benefit ratio for this alternative was high. For these reasons, this alternative was abandoned.

Micro piles

Adding a row of micro piles in front of the walls would certainly improve the sliding resistance significantly. However, this alternative would be the costliest among all. Therefore, micro piles were not recommended.

Shear Key

Instead of micro piles, a shear key out of reinforced concrete could be constructed just in front of the walls and it could be anchored to the foundation of the existing walls in order to increase the sliding resistance. This alternative was perfectly suited to wall type 30 because the sliding safety was of primary concern. Hence, it was successfully implemented.

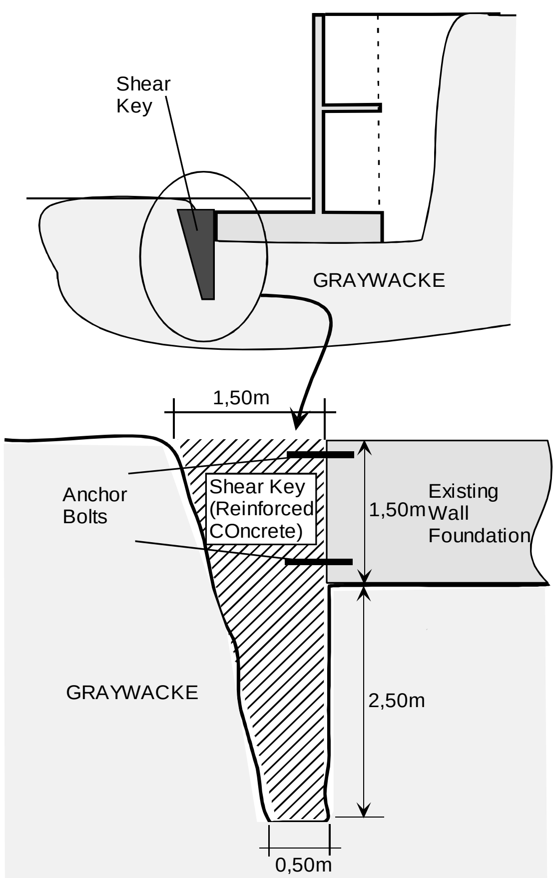


Fig. 7. Adding Shear Key in front of Wall

Drainage Improvement

Water entry into the backfill was reduced by adding a layer of geotextile and clayey soil layer at the top of the backfill. Replacing backfill with clean sand has significantly improved the drainage where backfill replacement was implemented.

RESULTS AND CONCLUSIONS

After the causes were identified the factor of safety of the failing walls were significantly improved by using the combination treatment of backfill replacement and base enlargement for wall types 23, 41 and alike and by using post-construction shear key for wall type 30 and alike. Measures for drainage improvement were also taken. The remedial measures were successful and cost effective. This case will serve as a good example of frequently observed poor geotechnical practice but superior structural practice.

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