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Performance of a steel strip reinforced wall

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ABSTRACT: The measured and calculated performance of a steel strip reinforced wall is reported. The wall was constructed by using the principle of reinforced earth (Vidal 1969) with a length of 60 m and a maximum height of 12 m. The used reinforcement strips had a length of 10 m, and vertical and horizontal spacing of 0.75 m. The backfill material within reinforced soil mass was sandy gravel. The measured wall base settlement was less than 100 mm, and the lateral displacement at the top of the wall was about 15 mm at the end of the construction. The plane strain finite element method was used to analyze the behavior of the wall. The analysis results suggest that using the assumption of at rest earth pressure for design the retaining wall with very stiff reinforcement is reasonable. The location of the maximum tension force is close to the wall face and generally agreed with current design assumption. However, at working stress state, the active and passive zone in reinforced soil mass can not be clearly noticed. Also, the pullout soil/reinforcement interaction pattern is not developed in most area and the interaction pattern between soil and reinforcement is controlled by the wall displacement pattern.

1 INTRODUCTION

For design the reinforced earth structure, the basic thing needs to be determined is the location to place the reinforcement and the amount of reinforcement needs to be used, which is related to the failure mechanism and earth pressure distribution in the earth structure. In reinforced soil mass, the failure mechanism and stress state are not only influenced by the properties of soil but also the properties of the reinforcement and soil/reinforcement interaction. Although, some guidelines have been proposed for design the reinforced retaining wall, for validating or improving the methods, more field performance data are required. Therefore, report the field data and comparing the field behavior with existing theory can provide basic information for developing the earth reinforcement technique.

The behavior of a steel strip reinforced wall with a length of 10 m and maximum height of 12 m is reported in this paper. The field condition and construction procedure are described first. Then, the measured and analyzed (by finite element method) performance of the wall is presented. Finally, the behavior of the wall is compared with existing theory for reinforced wall design and the discussions are made on the coefficient of lateral earth pressure, location of potential failure surface, and soil/reinforcement interaction pattern.

2 FIELD CONDITION AND CONSTRUCTION PROCEDURE

A car driving center is under construction in Numaz, Shizuoka Prefecture, Japan. Since the ground was slightly inclined (about 5%), a reinforced retaining wall about 60 m long with a maximum height of 12 m was constructed to level the ground. The soil profile at the construction site consists of top 10 to 20 m deluvium loam layer underlain by stiff tuff-breccia deposit (base rock). The main material of the loam layer is volcanic clay from Fuji mountain. According to the mechanical properties, the loam layer can be further divided into top, middle, and lower layers with standard penetration test (SPT) N value of 4, 5, and 7, respectively. The SPT N value for tuff-breccia deposit is about 50. Site investigation indicated that up to 23 m depth, no under ground water was observed.

The foundation of the wall was excavated to the base rock and refilled by sandy gravel. Used reinforcement was galvanized steel strip with the dimensions of: 5.1 mm in thickness, 60.0 mm in width, and 10 m in length. Both vertical and horizontal center to center spacing between reinforcement strips was 0.75 m. The facing was constructed by 1.5 m by 1.5 m concrete panels with a thickness of 0.2 m. Each panel contained 4 reinforcement strips. The retaining wall was constructed with a base width of 25 m and top width of 10 m. Sandy gravel was used as backfill.

The face of the wall was vertical and the back side had a 1:1.5 (H:V) slope. The wall was constructed by 90 days with 16 layers of reinforcement. For each reinforcement layer, the construction procedure was as follows:

(1) place the facing panel;

(2) place the backfill and compacted to the elevation of reinforcement strip. The backfill was compacted in 0.25 m layers by a vibration compactor (8 ton) and near the wall face (0.5 m) was compacted by hand compactor; and

(3) place the reinforcement strip.

The quality of the sandy-gravel backfill was controlled by California Bearing Ratio (CBR), and measured CBR value was about 61.2 %. After the completion of the wall, the area behind the wall was filled by locally available loam within 46 days. The grain size distributions of both sandy gravel and loam backfills are shown in Fig. 1. For this site, during construction, the newly placed facing panel was controlled to be on designed location. In other words, the lateral displacement oflower layers had not effect on the position of newly constructed panel.

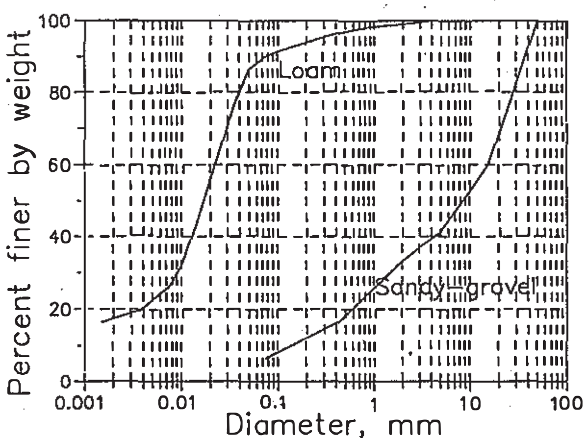


Fig. 1 Grain size distribution curves

3 OBSERVED AND ANALYZED RESULTS

3.1 Field measurement

The settlement plates and lateral displacement marks were installed to monitor the deformation of the wall and backfill soil. The available measured data are: (1) top and bottom wall settlement, (2) top wall lateral displacement at end of construction, and (3) settlement of loam backfill. For the foundation of the wall, construction of the wall caused a settlement of about 70 mm, and about 15 mm during backfilling. At the highest section, the top of the wall moved about 15 mm forward after the completion of construction. However, the relatively large settlement was occurred in loam backfill area. The details of measured data will be presented together with finite element analysis results in following section.

3.2 Finite element analysis

Unfortunately, there were no measurement on reinforcement tension force for this project. In order to investigate the stress state within the reinforced soil mass and the tension force mobilized in the reinforcement, the plane strain finite element analysis was used. The highest section (12 m) was chosen for analysis. In finite element modelling, the reinforcement strip was modelled as bar elements. Joint elements were placed at soil/reinforcement and soil/face panel interfaces to simulate the possible relative movement. The facing was modelled as solid elements and the modulous was adjusted to consider the joints between facing panels. The construction process was closely simulated. First, the initial stress in the ground was set up by gravity analysis. Then, the construction of foundation, wall, and backfill was simulated by placing the corresponding elements layer by layer. The finite element mesh and the material zone are shown in Figs. 2 and 3, respectively. The steel strips, facing panels, and base rock were

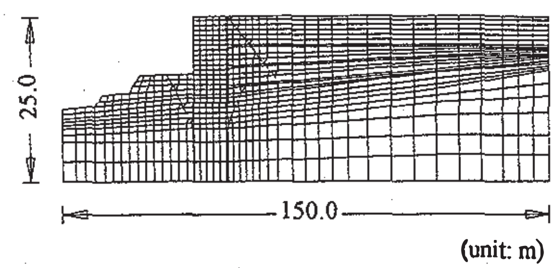


Fig. 2 Finite element mesh

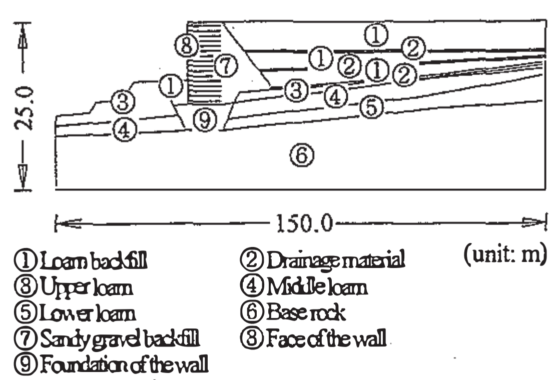


Fig. 3 Material zone

treated as elastic material. The properties of the backfill were represented as elastic-perfect plastic material with Mohr-Coulomb failure criterion. The deluvium loam was modelled by an elasto-plastic model (Sekiguchi and Ohta 1977). The material parameters are given in Table 1. The loam layer was in an overconsolidated state with a maximum vertical consolidation stress of 200 to 250 kPa.

Table 1. Model parameters for subsoil, backfill, and facing

No	Soil	κ	λ	ϕ' (°)	e_0	E (MPa)	ν	γ (kN/m³)
1	Loam backfill			35		1.0	0.3	18
2	Drainage material			35		1.5	0.3	18
3	Upper loam	0.40	0.06	40	2.5		0.3	18
4	Middle loam	0.35	0.05	40	2.3		0.3	18
5	Lower loam	0.30	0.04	40	2.1		0.3	18
6	Base rock					35.0	0.3	20
7	Sandy gravel backfill			40		10.0	0.3	18
8	Face of the wall					250.0	0.2	22
9	Foundation of the wall			40		20.0	0.3	18

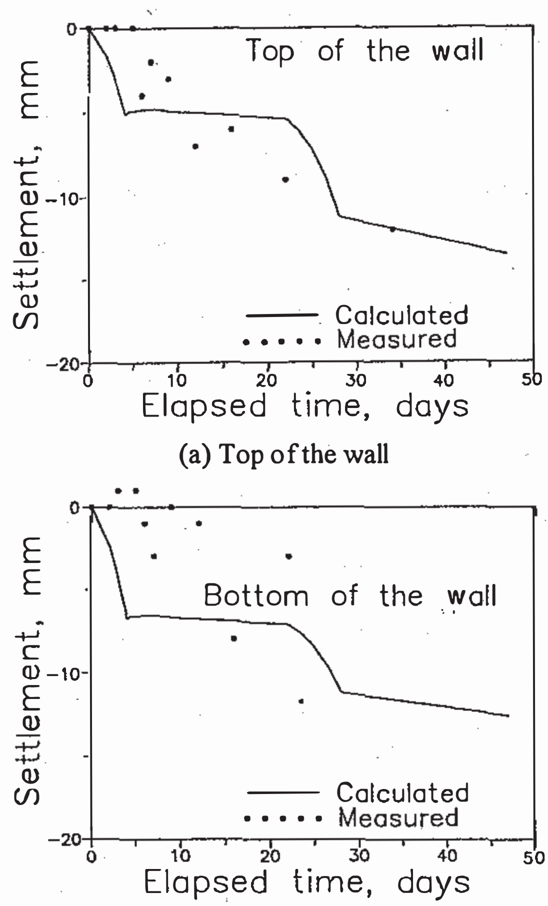
The material number is corresponding to Fig. 2.

In plane strain analysis, the reinforcement was simulated as a continued sheet with a equivalent thickness (area equivalent) of about 0.4 mm. The Young's modulous (E) of the steel strip was $2.1 \cdot 10^8$ kPa. The behavior of joint was represented by elastic perfect plastic model with Mohr-Coulomb failure criterion. The adopted parameters were: shear stiffness (k_s) of 100 MPa/m, apparent adhesion (C_a) of 10 kPa, and the interface friction angle (δ) of 40°. A rather high interface friction angle was used because the strip was ribbed. The soil parameters were determined by referring to field SPT N value, laboratory unconfined compression test and consolidation test results, and adjusted by comparing the measured wall and backfill deformation with calculated results.

3.3 Comparing the measured and calculated deformation

The calculated wall and backfill deformations are compared with measured data in terms of settlement and lateral displacement of the wall, and settlement of backfill. This comparison also provides a check on analysis method and parameters used.

(1) Settlement of the wall. At the end of the wall construction, the foundation of the wall settled about 70 mm, and it was closely fitted by finite element analysis. The comparison of top and bottom wall settlement during backfilling (after completion of the wall) is given in Figs. 4 (a) and (b). It can be seen that the analysis simulated the field data reasonably well.



(a) Top of the wall

(b) Bottom of the wall

Fig. 4 Settlement of the wall

(2) Lateral displacement of the wall. Fig. 5 shows the calculated wall lateral displacement with one point of measured data. Since the high stiffness of the reinforcement, the lateral displacement of the wall was small. The maximum value occurred at about 5 m above the base of the wall with a value of about 40 mm. As mentioned previously, during the construction, the newly placed wall facing panel was located on original designed position and which had an effect on wall lateral deformation pattern. The backfilling caused a maximum increase of the wall lateral displacement of about 25 mm.

(3) Backfill settlement. Figs. 6 (a) to (d) show the backfill settlement at a location of 30 m away from the wall face and at deferent depth. Except S2 (Fig. 6 (b)), the analysis simulates the field data well. The relative larger settlement of the loam backfill influenced the deformation of reinforced soil mass, and therefore the tension force mobilization in reinforcement, which will be discussed in below.

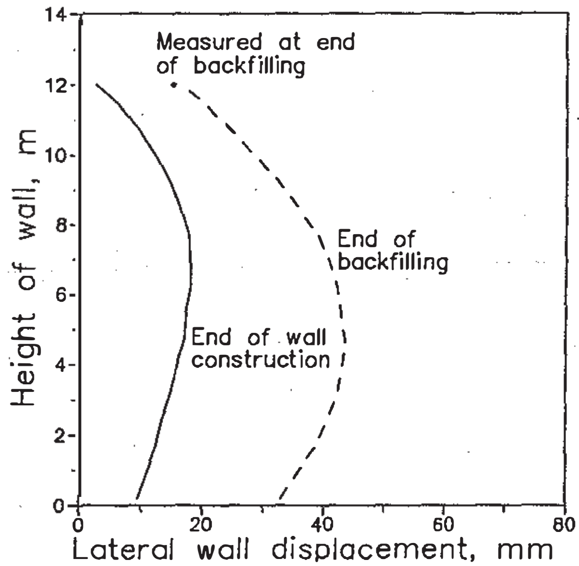
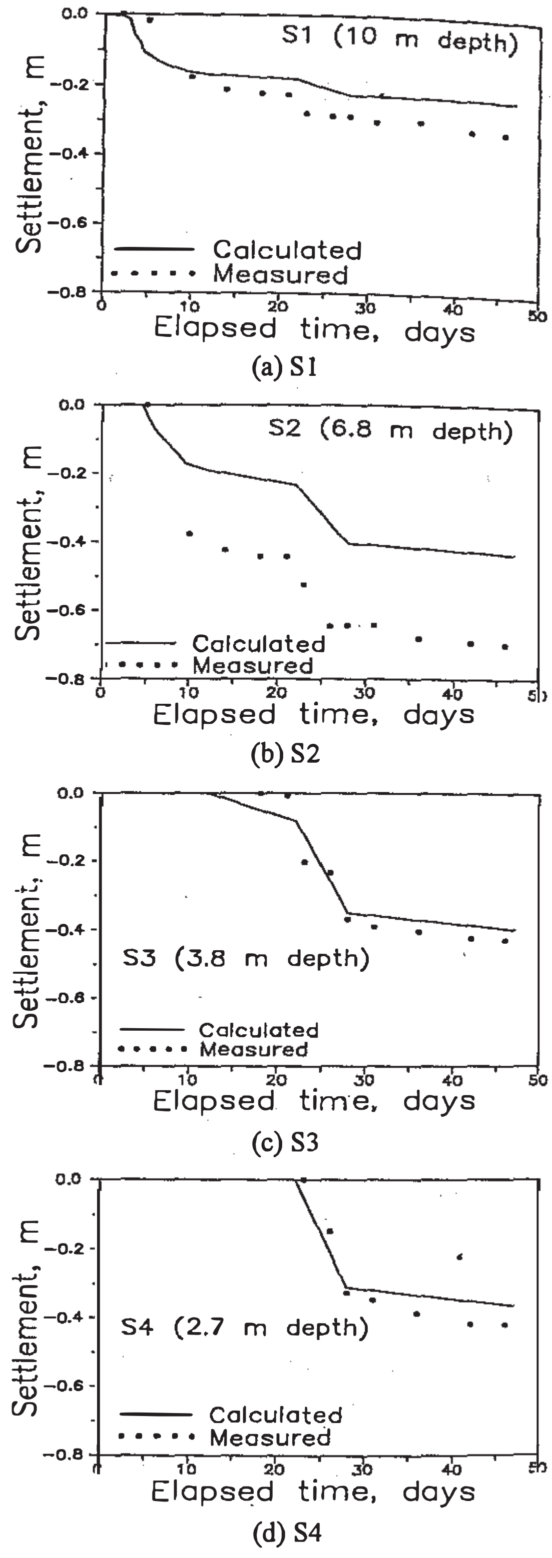


Fig. 5 Lateral wall displacement

3.4 Analyzed tension force in reinforcement

(1) Maximum tension force. The calculated maximum tension force variation with depth is shown in Fig. 7. Giving data are for two cases, namely, at end of the wall construction and after backfilling. At rest and active earth pressure lines are included for comparison. K_0 of 0.43 is estimated from assumed Poisson's ratio, and K_a of 0.27 is calculated by using a ϕ' of 35° (1-sin(35°)=0.43). Generally, the mobilized tension force is between at rest and active cases. For stiff reinforcement, it is normally assumed that the tension force in reinforcement is close to at rest earth pressure. The slightly lower reinforcement tension force can be partially explained as: (1) strong facing panel resisted a part of lateral earth pressure, (2) at near the foundation, the part of lateral earth pressure in reinforced mass was distributed to the foundation soil, and (3) the compaction effect was not considered. Also the deformation of the foundation was basin shaped, and it had a bending effect on reinforced mass, top in compression and bottom in extension (Bergado et al 1995), and this explains the relative lower tension force in upper part at end of the wall construction. The larger tension force in upper layer after backfilling was caused by the relative large settlement of backfill, which dragging the reinforced mass downward and the tension force mobilized at the end of the reinforcement as shown in Fig. 8. From Fig. 8, it can also be seen that after the backfilling, the location of maximum tension force is about 3 m away from wall face except for top layers which is influenced by backfill settlement as explained above. This is roughly agreed with the assumption that for very stiff reinforcement, the potential failure surface is about 0.3H (H is the height of wall) away from wall face (Anderson et al 1987; Schlosser and Buhan 1990). However, at the bottom of the wall, the potential failure surface seams not clearly developed at working stress level.



(a) S1

(b) S2

(c) S3

(d) S4

Fig. 6 Backfill settlement behind the wall

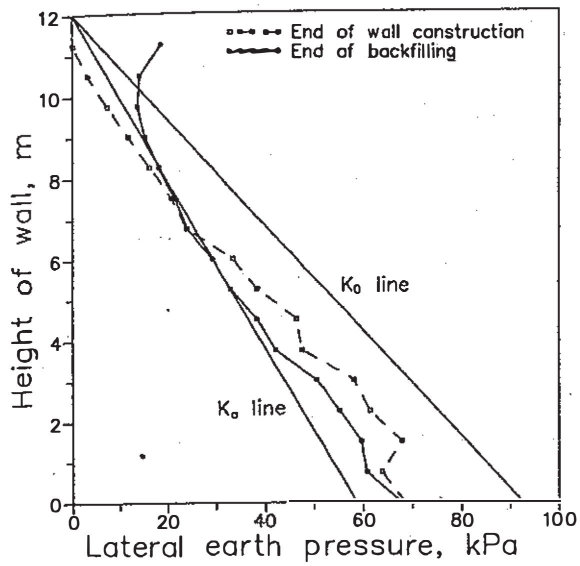


Fig. 7 Maximum tension force in reinforcement

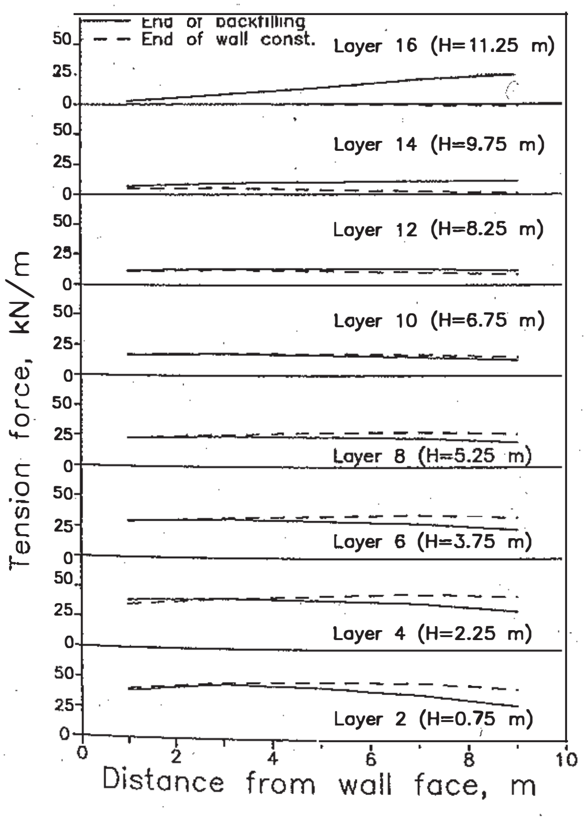


Fig. 8 Tension force distribution in selected reinforcement

(2) Interface shear stress. Soil/reinforcement interface shear stresses are analyzed to investigate the interaction pattern between the reinforcement and soil. Fig. 9 shows calculated results at the completion of construction. It indicates that at working stress level, in most area, the pullout interaction pattern is not developed. The interaction pattern is controlled by the deformation pattern of the reinforced soil mass. Roughly, below the maximum lateral displacement point (see Fig. 5), the shear stress on interface is positive and above that point it is negative. The definition for the sign of interface shear stress is sketched in Fig. 9.

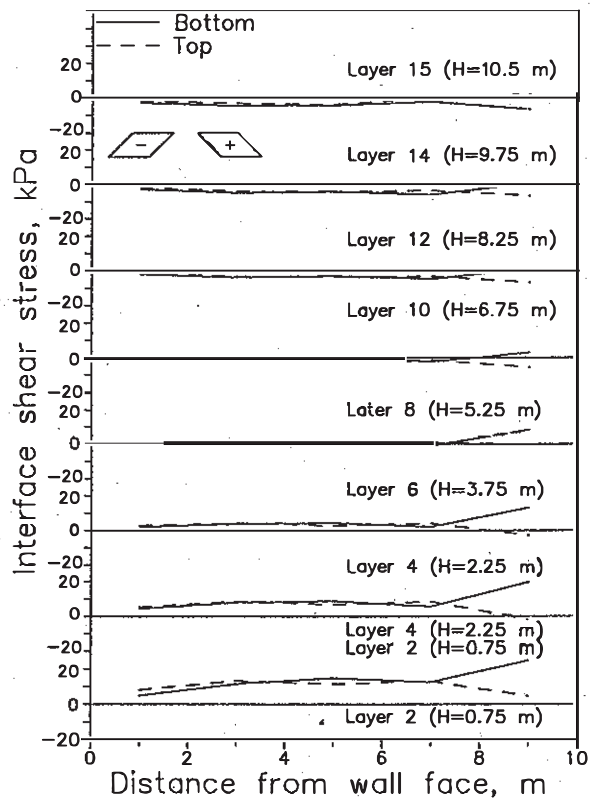


Fig. 9 Soil/reinforcement interface shear stress on selected location

In limit equilibrium design, it is assumed that the reinforced soil mass can be subdivided into two zones by potential failure surface, namely: active zone and resistant zone. However, the analysis results of this study indicate that at working stress state, the active and resistant zone can not be clearly identified. It suggests that for design the reinforced earth structure, considering the deformation pattern at working stress state is necessary.

4 CONCLUSION

The measured and analyzed performance of a steel strip reinforced wall is reported. The settlement of the foundation of the wall was about 70 mm during wall construction and increased to about 85 mm after backfilling. The lateral displacement at top of the wall was 15 mm. The calculated maximum lateral displacement of the wall was about 40 mm and occurred at the middle height of the wall. Based on the analysis results, following comments can be made.

The mobilized maximum tension force in reinforcement is between at rest and active earth pressure. This suggests that for design the retaining wall with very stiff reinforcement, using at rest earth pressure is reasonable. Also the location of maximum tension force is generally agreed with existing theory. However, at working stress state, the active and resistant zone in reinforced soil mass can not be clearly noticed.

At working tress state, the pullout soil/reinforcement interaction pattern is not developed in most area and the interaction pattern is controlled by the wall displacement pattern.

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