Friction at Upper and Lower Faces and Tension in Reinforcing Sheets

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ABSTRACT: The friction on the upper and lower faces of the reinforcing mats were obtained by analyzing two reinforced soil retaining walls. One of which had inextensible steel mesh and the another had extensible polymer grid. Generally speaking, the friction on the upper face acts in the forward direction and the friction under the lower face acts in the backward direction, and their distribution are not the same. The difference between the upper and lower faces results in the tension of the mat. The friction near the face of the wall acts in the forward direction. Soil constants related to deformation are closely related to not only stability but also deformation of the retaining walls. Thus, the possibility of establishing new design methods for providing deformation of the retaining walls by taking into account of soil constants during and after the construction is discussed.

1 INTRODUCTION

Figure 1 illustrates a retaining wall with reinforcing mats. The earth pressure distribution on the 2 vertical sections at the back face of the retaining wall and the tails of the reinforcing mats are assumed to be triangular. Values of the earth-pressure coefficients of both sections are k_1 and k_2 and k_1 is larger than k_2. The wall height is denoted H,unit weight of the backfill soil γ and M1 to M5 are the reinforcing mats. The amount of the friction is equal to the difference of the earth pressures on the two sections. The soil body on the mat gives a frictional force to the upper face of the mat. Then, the sliding of the mat is kept back by the backward frictional force exerted by the lower soil body. The shear distribution on the surfaces is not uniform. The values of frictional stresses acting on the upper and lower faces of an element of the mat are not the same in magnitude and in direction. The tension in the mat is the vector sum of the frictional forces on the upper and lower faces. The values of frictional forces are obtained by back-analyzing from the measured data of the actual reinforced soil retaining wall. The first example is at a retaining wall which was constructed by using welded steel wire mats. The second one is at a steep slope by using polymer grid mats.

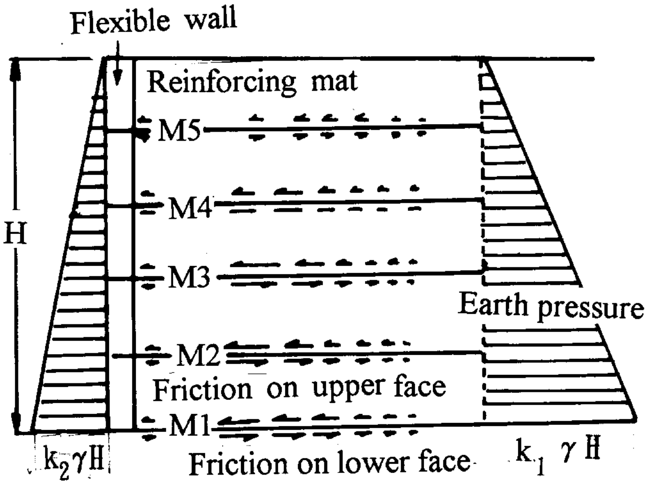


Fig. 1 Retaining wall with reinforcing mat.

2 RETAINING WALL USING STEEL MATS

Professor L.R. Anderson and others have constructed a retaining wall consisted of welded wire mats placed between successive layers of backfill. The mats bend up at the front to form the face of the wall. The plan and section of the wall are illustrated in Fig. 2. The 15-m high section of the wall was constructed using 13.41m long mats. The mat had a vertical spacing of about 0.5m. The longitudinal mats spaced about 15cm centers and the transverse wires were spaced on about 23cm. The diameters of the longitudinal wires were 6, 7.6, 8.84 and 9.93mm depending on the wall hight. Tension was measured in the longitudinal wires at the locations marked G1, G2, --- G15. The distribution of tension forces in the longitudinal wires is shown in Fig. 3. For the purpose of calculating frictional force on the upper and lower faces of the mats, datas from the measurement of the actual retaining walls accumulated by the author in the past were used. Figure 3 shows that the maximum tension force in the wires occurs at the distance of 1.5 to 2 m behind the wall. The tension force decreases gradually as the distance from the wall increases. The tension force becomes almost 0 at the location about 6 m from the wall for M1 and M2. On the other hand, the tension force at the rear ends is still large for the upper mats. The tension is fluctuating at some points influenced by properties of backfill and the other conditions. This gives effect on the distribution of the friction. The backfill soil behind the point showing 0 tension shows no lateral deformation. But the soil in the region showing tension in the wires expands horizontally, and the earth pressure decreases in this region. As an example, the result of analysis for M3 is given in Fig. 4. The total sum of the tension from the uppermost mat to the mat just above the M3 are obtained by interpolation. The value of coefficient of earth pressure behind the point of maximum tension is assumed to be 0.5. Therefore, the total earth pressure becomes 733.8 kN/m. The earth pressure between the wall and the point of maximum pressure is assumed to decrease linearly. The maximum frictional force is 228.0 kPa at the lower face between G1 and G2. As the vertical stress at this point is 235.7 kPa, the apparent frictional angle is 44 degrees. The strain in the wire, which corresponds to horizontal strain of the soil, is very small as shown in Fig. 3. It means that no appreciable expansion occured in the soil behind the point of maximum tension, and the backfill in this region is stable. The backfill between the wall and the point of maximum tension is retained by the front wall.

3 POLYMER GRID RETAINING WALL

As an example of polymer grid retaining wall, the steep slope embankment reported in this International Conference is taken up here. (Itoh, M. et al 1994) The mats used for the retaining wall gives elongation of 1% in response to tension of 10 kN/m. As the elongation of the mat is nearly equal to the lateral deformation of the soil at the interface, the lateral deformation of the backfill soil can be obtained by the elongation of the mat. Earth pressure and deformation in the backfill were monitored for this retaining wall, though it was not sufficient. Horizontal and vertical strains and stresses in the backfill are estimated by the observed records refering to the other case records in the past. The following equations for the plane strain are used to the analysis.

$$\varepsilon_h = \frac{\sigma_h}{E} - \frac{1}{mE}\left\{\frac{1}{m}(\sigma_h + \sigma_v) + \sigma_v\right\} \cdots\cdots (1)$$

$$\varepsilon_v = \frac{\sigma_v}{E} - \frac{1}{mE}\left\{\frac{1}{m}(\sigma_h + \sigma_v) + \sigma_h\right\} \cdots\cdots (2)$$

Where σ_h=horizontal stress
σ_v=vertical stress
ε_h=horizontal strain
ε_v=vertical strain
m =Poisson's ratio
E =modulus of linear deformation

The values of E and m were obtained by the laboratory tests. But they were not directly available. On the contrary, those values were back-calculated by the data obtained on site. The earth pressure at the back of the sandbags was measured by the earth pressure gages. The earth pressure at the plane passing the tail end of the mats has the one smaller than the so called earth pressure at rest. Because this plane moved forward during and after the construction. The immovable region can be determined by extrapolating the records of horizontal displacement measured. Figure 5 illustrates the polymer grid retaining wall. A comparison of the values between Case 1 at the end of construction and Case 2 after 5 months can be done by Table 1. Total amount of frictional forces on the each faces are the same but the distribution of frictional force are different in intensity and even direction in some parts. The largest friction appears in Case 2. It can be said, at least, that the difference of friction between the upper and the lower surfaces results in the form of strain of the mat. The values of ε_h, ε_v, σ_v, E and m in the equations (1) and (2) may be obtained by the experiment like this. Table 2 gives the values of E and m. The E values decreased remarkably after 5 months. The values of m also changed. The percolation of water should be the cause of change of those values. Assuming the shear parameters c and ϕ decreased from 40 kPa and 20 degrees to 20 kPa and 20 degrees, the friction for the Mat 3 is revised as shown at the bottom in Table 1. If the values of m, E and k during and after construction are determined by investigation, horizontal deformation settlement and tension in mats will be calculated at the time of design. There are three cases of rupture for retaining walls.

(1) rupture of the backfill,
(2) breakage of mats,
(3) sliding at the mat surfaces.

These conditions of rupure can possibly be estimated by accumulating case histories along the procedure presented

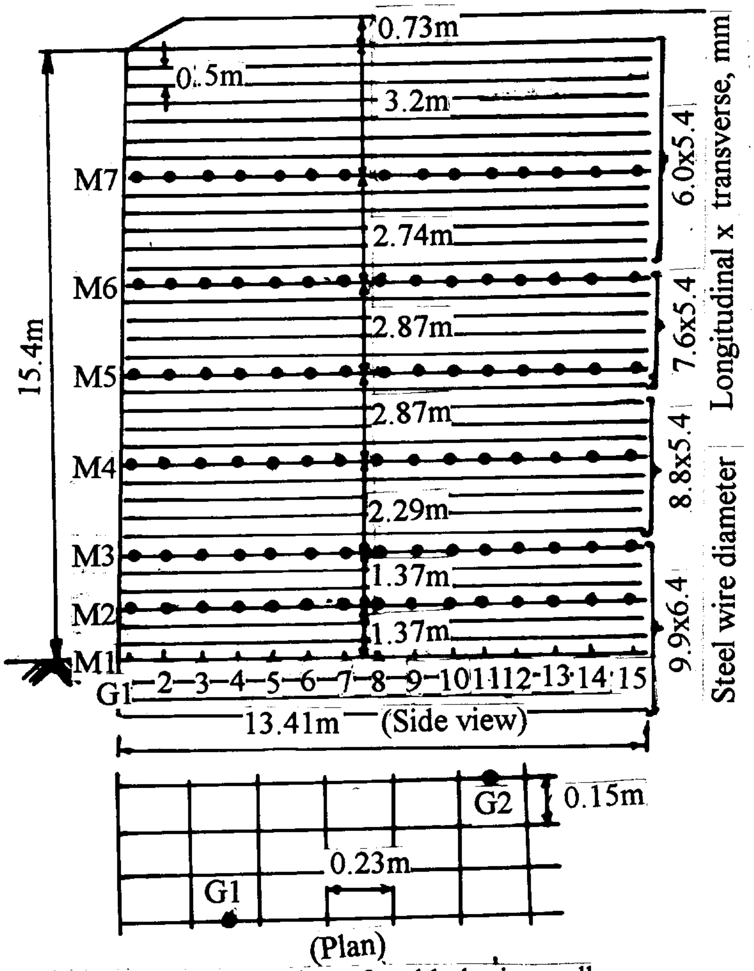


Fig.2 Section and plan of welded wire wall (After Anderson et al 1987)

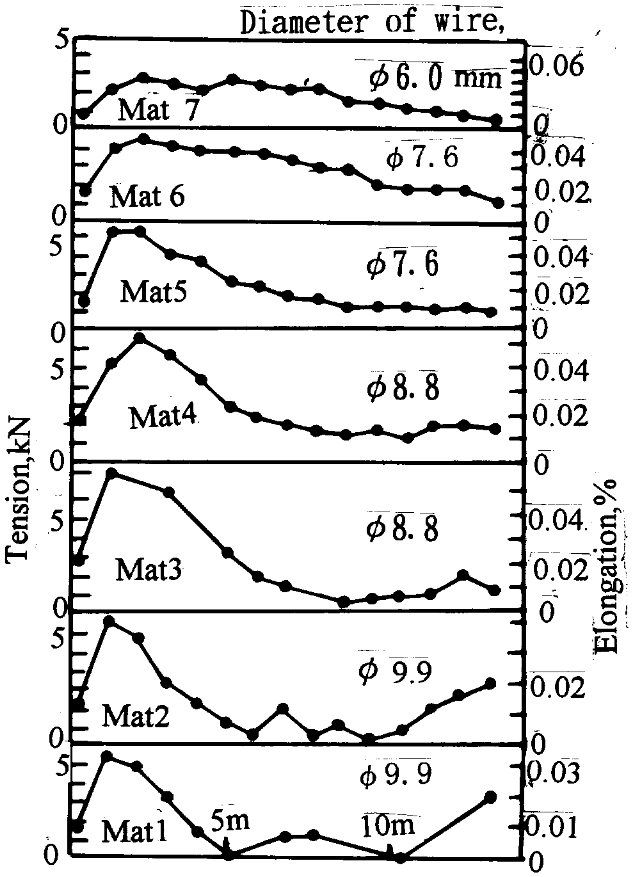


Fig.3 Distribution of tension force and elongation in the longitudinal wires.

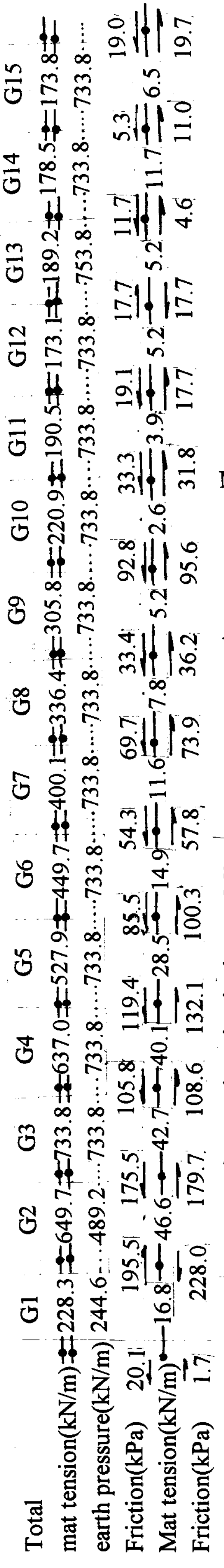
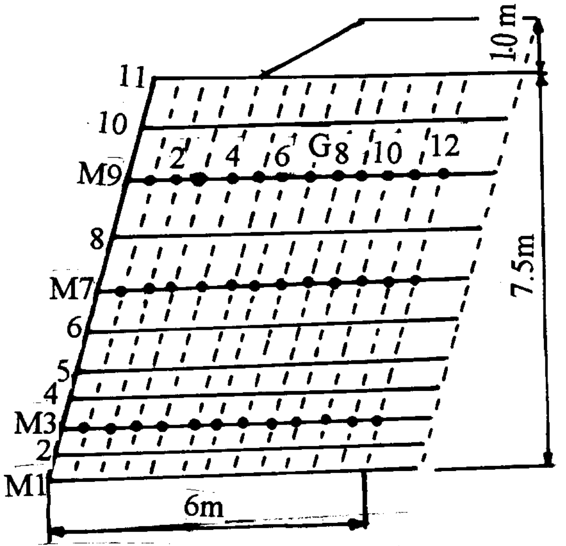


Fig.4 Friction on the upper and lower faces and tension in the mat,M3.



• Location of wire strain gage
M9,7and 3 were measured

Fig. 5 Section of polymer grid retaining wall

Table 2 Poisson's ratio and modulus of linear deformation of backfill soil.

	Case 1		Case 2	
	m	E	m	E
M9	2.81	4.46	2.88	0.28
M7	2.73	6.12	2.55	0.71
M3	3.50	1.43	3.21	0.19

m:Poisson's ratio
E:Modulus of linear deformation, MPa
Case1:At the end of construction(May 9)
Case2:After 5 months (October 12)

Table1 Friction on upper and lower faces for polymer grid reinforced retaining wall.

		G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	
M 9	U.Case1	←4.58	←4.64	←0.98	←5.80	←3.06	←1.84	←3.06	←3.10	←3.74	←1.62	←2.12	←3.72	←0.28
	U.Case2	←3.50	-0.62→	-3.88→	←3.48	←9.26	←6.38	←5.32	←2.58	-1.16→	←5.44	←9.04	←4.02	←4.11
	L.Case1	←1.40	5.04→	2.66→	5.02→	4.10→	1.36→	4.34→	3.60→	3.58→	0.90→	2.90→	0.88→	2.69→
	L.Case2	←13.2	←23.9	←13.9	17.5→	19.0→	7.60→	8.96→	←11.0	←3.16	21.5→	16.0→	←4.70	15.00→
M 7	U.Case1	←7.72	←13.4	←3.62	←12.7	←11.9	←9.26	←7.84	←11.1	←11.8	←8.20	←5.76	←6.44	←3.36
	U.Case2	←7.20	-11.9→	-38.6→	←10.4	←28.3	←47.5	←30.2	←5.62	←2.00	←7.72	←32.1	←26.2	←18.36
	L.Case1	5.34→	6.02→	3.42→	15.4→	12.7→	10.7→	7.54→	12.4→	12.8→	7.56→	6.60→	4.82→	5.39→
	L.Case2	0.00	←34.5	←62.4	2.38→	40.3→	61.8→	33.9→	13.0→	9.44→	13.6→	35.8→	23.6→	24.01→
M 3	U.Case1	←8.02	←21.3	←15.8	←69.2	←57.4	←42.0	←43.0	←36.0	←41.0	←39.8	←35.4	←29.2	←5.7
	U.Case2	←6.12	←2.10	-46.3→	-45.4→	←32.8	←59.1	←49.7	←105.0	←54.8	←46.0	←35.3	-37.0→	←94.4
	L.Case1	1.22→	17.0→	15.0→	70.8→	18.2→	46.4→	43.6→	38.2→	42.8→	40.4→	36.2→	39.2→	6.1→
	L.Case2	←1.64	←16.2	←44.0	←42.4	34.1→	62.5→	49.5→	110.0→	55.9→	46.3→	39.6→	←40.2	98→
M* 3	U.Case2	0.00	0.00	-28.0→	-28.0→	←34.0	←46.0	←48.0	←52.0	←54.0	←56.0	←59.0	←60.0	←50.0
	L.Case2	←8.00	←18.0	←26.0	←25.0	35.0→	49.0→	48.0→	58.0→	55.0→	56.0→	62.0→	57.0→	44.0→

Note:Unit kPa,U:Friction on upper face,L:Friction on lower face,

Case1:At the end of construction (May 8),Case2:After 5 months (October 8),

in this paper, which can be used for design.

4 CONCLUSIONS

This paper is described by concentrating in the analysis of the upper and lower faces of the reinforcing sheets, and two examples of the retaining walls by inextensible steel mesh and extensible polymeer grid mats. If well documented records are accumulated by conducting analysis like this, a more advanced design methods with regard to change of soil properties induced by the change of moisture content will be established in the future.

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REFERENCES

Anderson, L.R., K.D. and Harding, O.T.(1987) Performance of a 50-foot high welded wire wall,Soil Improvement - A Ten Year Update ASCE Geotechnical Publication No.12, Joseph Welsh, 281-308.

Itoh, M., Itoh, A, Shirasawa, M., Kumagai, K., Fukuoka, M.(1994) Well documented case record of reinforced retaining wall, Proceedings of the 5th Conference of the IGS, Singapore.

Fukuoka, M.(1984) Research on static earth presuure on retaining walls, Proceedings of Conference on Case Historics in Geotechnical Engineering, University of Missouri-Rolla, USA, II-655-664.

Fukuoka, M., Imamura, Y., Morita, S.(1987) Failure of a retaining wall caused by heavy rain, Proceedings of International Conference on Structural Failure, Singpore,20-38.

Fukuoka, M.(1990) On the mechanism of reinforcing retaining walls reinforced with net, Proceedings of the 5th Symposium on Geosynthetics,Tokyo, 47-52.