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Reinforcement stiffness effect on the behaviour of retaining wall – experimental tests

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ABSTRACT: This paper presents the results of experiments performed on the small scale models of RS retaining wall loaded on its crest with the footing. The influence of reinforcement's stiffness on failure mechanism, maximum external load and the deformation of construction is tested. It is shown that the reinforcement stiffness strongly influences the deformation and the settlement of construction and affects the ultimate external load.

1 INTRODUCTION

It is well known, that the longitudinal stiffness of reinforcement has a marked effect on the behaviour of reinforced soil (RS) structures. The application of extensible reinforcement may cause the deterioration of wall performance: increase of lateral movement of the wall face and appearance of other unacceptable deformation. Hence in the most of RS retaining walls the condition of non-excess of the serviceability limit state imposes the use of stiff (inextensible) reinforcement. However, in some temporary constructions the serviceability limit state needs not to be checked. In these cases it is possible to apply, in acceptable limits, the extensible reinforcement e.g. nonwoven geotextiles, which are much cheaper then the stiffer geogrids or woven geotextiles. However, there is a lack of data on the influence of extensible reinforcement on the maximum surcharge load and the failure mechanism of RS structure.

The studies of the effect of reinforcement stiffness on the load-deformation characteristics of the reinforced wall have been performed. Huang et al. (1994) investigated two model walls with the same dimensions, but reinforced with two various types of material. The reinforcement stiffness differed significantly, while the ultimate strength was similar. The surcharge load was applied uniformly on the crests of construction using synthetic air bag system. The results showed that the structure deformability was strongly influenced by the reinforcement stiffness.

Herein the results of similar experiments are presented, in which the influence of reinforcement's stiffness on failure mechanism, ultimate value of external load and the deformation by of RS model are tested. In contrast to the Huang's et al. (1994) tests where the uniform surcharge load was applied, the model walls are loaded using the rigid footing located on their crests. The results confirm significant influence of reinforcement stiffness on the structure deformation. Both the footing displacement at the wall crest and the settlement of the model base measured at failure in the tests with extensible reinforcement are much higher than those where the stiff reinforcement is applied. It is also shown that the critical load of the model wall with extensible reinforcement is higher than that with the stiffer strips.

2 EXPERIMENTAL SET

2.1 *Material properties*

The same sand was used in the experiments as a backfill and as foundation soil. It was cohesionless, fine, uniform, dry silica sand. Results of triaxial compression tests indicated that the soil exhibited a friction angle ϕ_{tr} of 29° at confining stresses within the range expected in the experiments. When the model was constructed, the sand was rained through air under controlled condition to a dry density γ of 17 kN/m^3.

In the experiments the stiff and extensible reinforcement was applied. The 10 μm thick aluminium foil as the stiff reinforcement was used. The cotton bandage as the extensible reinforcement was chosen. It was knitted structure in the form of 5 cm wide strips.

To compare the stiffness and ultimate strength of both types of the reinforcement the in air uniaxial wide-width tensile tests were performed. The width of all reinforcement samples was 5 cm and their gauge length was 2 cm. The specimens were tested at a constant strain rate of 14% per minute.

The stress-strain curves of reinforcing strips obtained in tensile tests are shown in Fig. 1.

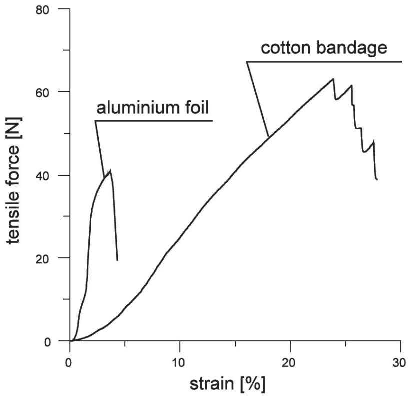


Figure 1. Results of stress-strain tests on aluminium foil and cotton bandage (stiff and extensible reinforcement).

Results of tensile tests of aluminium foil indicated that the failure tensile force was $T_f = 40.8$ N and the strain at failure was $\varepsilon_f = 3.7\%$. The failure characteristics for bondage strips were: $T_f = 63.1$ N and $\varepsilon_f = 23.9\%$. The results confirm correctness of the stiff and extensible reinforcement applications with classification presented by Hung et al. 1994 (stiff reinforcement: $\varepsilon_f < 20\%$, extensible reinforcement: $\varepsilon_f > 15\%$).

2.2 *Testing method*

The model walls were constructed in strong box with an inner dimension of 66 cm long, 50 cm high and 26 cm wide. To reduce the friction effect the frontage sidewall was made of glass and the opposite sidewall was covered with a smooth aluminium plate. The frontage glass sidewall unables the observation and recording of the failure mechanism and orientation of failure surfaces by photo camera.

Each model wall was 23 cm in height and was reinforced with 12 layers of reinforcement, which were placed at equal vertical spacing of 1.9 cm. The configuration of the model is shown in Fig. 2.

The reinforcement used in the models consisted of 30 cm long strips. In each layer 3 strips were connected to the cardboard panels forming the wall facing (see Fig. 3).

To compare the experimental results properly, in both model walls the same global strength of reinforcement should be applied. Therefore the appropriate width of aluminium strips was chosen to

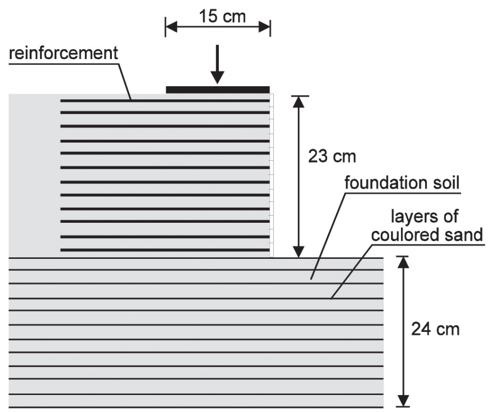


Figure 2. Configuration of the model wall.

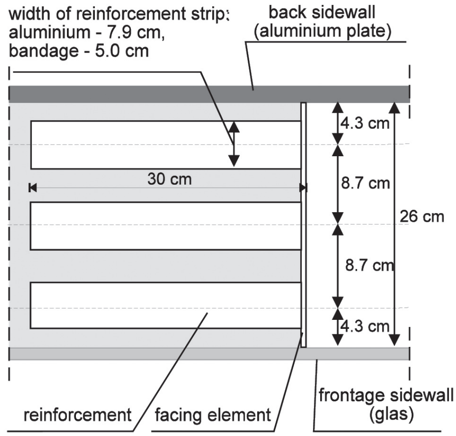


Figure 3. Arrangement of reinforcing strips in reinforcement layer.

reach the same tensile limit load as in extensible reinforcement. Finally 7.9 cm wide aluminium belts and 5 cm wide bandage strips were used as stiff and extensible reinforcement, respectively.

The models were built on a 24 cm thick foundation. The backfill and the foundation were constructed from the same sand that was rained through air by using the hopper kept at 100 cm high from the sand surfaces. A temporary support was positioned on the top of the foundation soil in front of the wall face to keep the facing in place during constructing. To obtain the required vertical distance between the reinforcement, each of sand the layer was flattened with the grader. Then the layer of reinforcement was placed on the exposed portion of sand. Next layer of soil was placed, in turn, on it, and this process was repeated for successive layers, until the model wall reached the desired height. Then the temporary support was removed.

During constructing, the position of reinforcement was marked near by the glass sidewall using the thin layer of colored sand. In the same way the layers in the foundation sand were marked. It was helpful to detect and record the failure surface and the deformation of the subsoil.

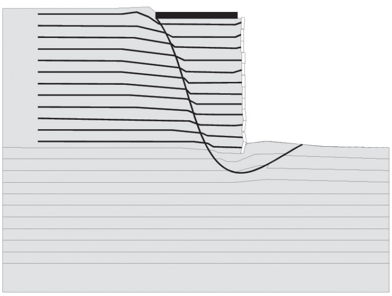
The model walls were loaded at their crests using the 15 cm wide smooth rigid strip footing. The footing base was loaded at a constant vertical displacement rate of 3.3 mm/min, until model failure occurred. The applied load and vertical displacement of footing were measured using data acquisition system. The deformation of the wall during loading was observed through the glass sidewall. The failure mechanism and the orientation of failure surfaces, detected by means of colored sand were recorded by photo camera.

3 RESULTS OF THE TESTS

To analyse influence of reinforcement's stiffness on the failure mechanism and ultimate load two tests on RS model walls with stiff and extensible reinforcement were conducted. In each experiment vertical load was applied to footing plate until the model failure had happened.

In the test with stiff reinforcement an increase of external load referred to relatively small deformation of construction, even close to the failure (see Fig. 4a). The failure line developed rapidly just only in the post failure process (Fig. 4b).

(a)



(b)

Figure 4. Model with stiff reinforcement. (a) deformation close to failure, (b) deformation after failure.

In the test with extensible reinforcement an increase of external load corresponded to comparatively large deformation. In this case the two slip lines were observed. The first, internal line came out at the beginning of the loading process. The another, external line appeared just after the failure (Fig. 5). In all tests the similar failure mechanisms were observed. The failure was developed along the surface beginning in the footing edge and passing through the subsoil beneath the model base.

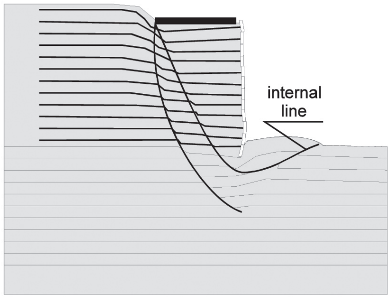


Figure 5. Failure zone in the model with extensible reinforcement.

A significant increase of a lateral movement of the wall face could be observed when the extensible reinforcement was used. However, in both tests regardless of the reinforcement stiffness, the height of failure zones, limited of the slip line passing beneath the model base, was nearly the same.

After the experiments the models were disassembled to examine the reinforcement. It turned out that the failure mechanism was associated with rupture of reinforcement. The cuttings of a strip corresponded to the observed failure lines.

The results of the critical load P_f, footing displacement measured at failure d_f and the settlement of the model base d_{fb} are presented in Table 1.

The load-footing displacement relationship is presented in Fig. 6.

Table 1. Experimental results.

Reinforcement	P_f (N)	d_f (mm)	d_{fb} (mm)
stiff	4.50	10.2	9
extensible	5.41	30.6	30

Both the footing displacement at the wall crest and the settlement of the model base measured at failure in the tests with extensible reinforcement were three times higher than that with the stiff reinforcement. It was shown that the critical load of the RS retaining wall with extensible reinforcement was about 20% higher than that with the stiffer reinforcing strips.

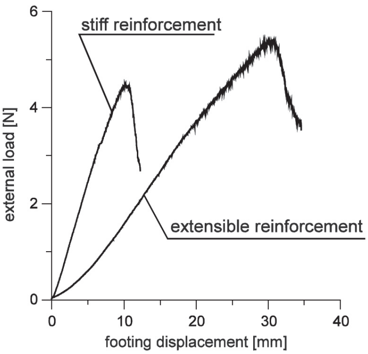


Figure 6. Configuration of the model wall.

4 CONCLUSIONS

In this paper the laboratory tests performed on the models of RS retaining walls with stiff and extensible reinforcement are described. Model walls of the same height are reinforced with layers of equal vertical spacing. The width of the reinforcement strips is chosen to reach the same tensile strength in all constructions. Walls are loaded at their crests using the smooth rigid strip footing. The results unable to recognise the influence of reinforcement's stiffness on: failure mechanism, external load and the deformation of construction. It is shown that the reinforcement stiffness strongly influences the deformation and the settlement of construction and affects the ultimate external load.

It is worth to note that:

– the increase of reinforcement stiffness enlarges the deformation, outward movement and settlement of construction and enhances the footing displacement at failure,
– the ultimate external load in structure reinforced with extensible reinforcement is a bit larger that in the stiffer one.

The results presented herein have coincided with those reported by Huang et al. (1994) for uniform loading on the crest of the wall.

REFERENCES

Huang, C.C., Cheng, C.Y., Hsia, S.H. and Hsu, S.P. (1994). "Reinforcement Stiffness on Load-Deformation Characteristics of Reinforced Wall", Proceedings of 5th International Conference on Geotextiles, Geomembranes and Related Products, Vol. 1, pp. 197-200.

Van Santvoort, G.P. T.M. (1994). "Geotextiles and Geomembranes in Civil Engineering", Balkema, Rotterdam, Brookfield.

Walters, D.L., Allen, T.M. and Bathurst, R.J. (2002). "Conversion of Geosynthetic Strain to Load Using Reinforcement Stiffness", Geosynthetics International, Vol. 9, Nos. 5-6, pp 483-523.

