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Influence of reinforcement's inclination on bearing capacity of RS wall

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ABSTRACT: The paper presents the experimental results obtained on the small scale models of RS retaining wall loaded on its crest with the footing. The influence of reinforcement's inclination on a bearing capacity and a orientation of failure surface is tested. The data are compared with the theoretical prediction based on limit states theorems. It is shown that the reinforcement's inclination reduces the bearing capacity of the structure.

1 INTRODUCTION

In the most of reinforced soil structures the reinforcement is placed in horizontal layers. However, in soil nailing construction the inclination of the reinforcement is always recommended.

There is a lack of the papers analyzing an influence of reinforcement inclination on a bearing capacity and failure mechanism of RS (Reinforced Soil) structures in a complex manner. A few publications on that subject present contradictory results. Kitamura et al. (1988) have been describing the model tests of RS retaining wall reinforced horizontally and with reinforcement placed at the angle of 20^0 to the horizontal. They noted that the bearing capacity of construction is slightly decreased for inclined reinforcement in comparison with horizontal one. Juran et al. (1990) have presented the results of the similar model tests. They did not state the relevant influence of reinforcement inclination on critical height of RS construction. Huang et al. (1990) have considered the effect of reinforcement direction on bearing capacity of RS slope. They pointed out that the most effective direction for reinforcing members was the one which coincided with the direction of the minor principal strain in the failure zone. In numerical analysis Bang et al. (1992) confirmed that reinforcement inclination at the angle of $5 \div 20^0$ was the most effective. On the other hand, Lesniewska (1992) using the method of characteristic showed that the horizontal placement of reinforcement in RS wall was optimal. The similar conclusion was drawn by Sabhahit et al. (1995) and Sawicki (2000).

Herein are presented results of experiments in which the influence of reinforcement's inclination on bearing capacity of RS retaining walls is tested. In the next step the theoretical analysis based on the limit states tecbniques is shortly described. It is shown that the structure reinforced horizontally is the strongest, and that the inclination of reinforcement reduces the bearing capacity of RS retaining wall.

2 MODEL TESTS

2.1 *Experimental 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 aluminum plate.

Each model wall was 32 cm in height and was reinforced with ten layers of reinforcement, which were placed at equal vertical spacing of 3.2 cm. The configuration of the model is shown in Figure 1.

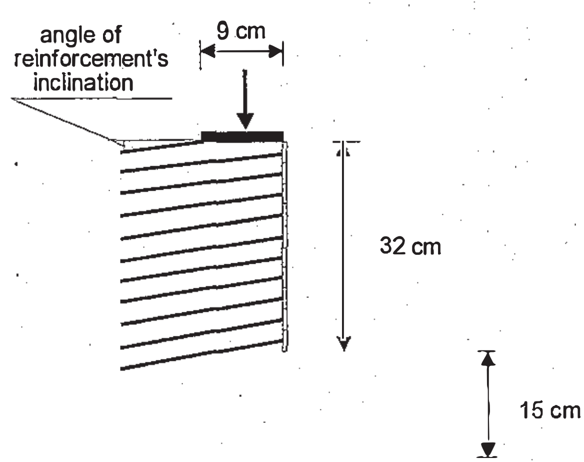

Figure 1. Configuration of the model wall.

The reinforcement used in the models consisted of aluminum strips 2.5 cm wide, 18 μm thick and 30 cm long. In each layer three strips were connected to the cardboard panels used as the wall facing (see Figure 2).

The backfill and the foundation were constructed from the sand that was rained through air by using the hopper kept at 100 cm high from the sand surfaces. The models were built on a 15 cm thick foundation. A temporary support in the form of wooden plate and platform was positioned on the top of the foundation soil in front of the wall face to keep the facing in place during construction. To obtain the required inclination of reinforcement, each of sand 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. The temporary support was then removed.

The position of reinforcement was marked near by the glass sidewall using the thin layer of colored sand. It was usefil to detect the failure surface in the model wall.

2.2 *Material properties*

The soil used as a backfill and a foundation was silica sand. Results of triaxial compression tests indicated that the soil exhibited a friction angle ϕ of 31° at confining stresses within the range expected in the models. The sand was rained through air under controlled condition to a dry density γ of 17.3 kN/m^3.

Results of tensile tests of reinforcing strips indicated that the plastic limit of reinforcement R was

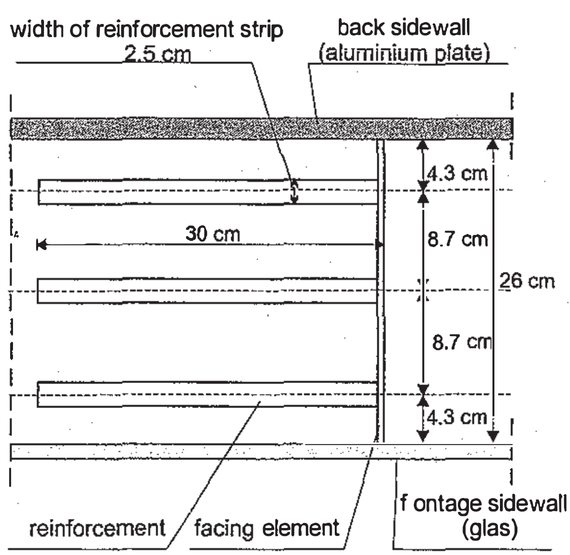

Figure 2. Arrangement of reinforcing strips in reinforcement layer.

41.6 x 10^3 kN/m^2 and the elongation at break was 4.1%. No test was performed on the interfaces between the strips and the model soil.

2.3 *Results of the model tests*

Five tests on uniformly reinforced model walls were conducted using different angle α of reinforcement inclination with respect to the horizontal: α=0^0, 5^0, 10^0, 15^0 and 20^0 (see Figure 3).

All walls were loaded at their crests using the 9 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 occurs. The applied load and vertical displacement offooting 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.

The failure zones in model constructions are presented in Figure 4. For all tests the same failure mechanisms were observed. The failure was developed along the surface from the footing edge to an intermediate point along the wall height. This mechanism was associated with tensile failure of the reinforcement. It was shown that the reinforcement inclination strongly influenced the height of failure zones.

The experimental results of the critical load, footing displacement measured at failure and the height of the failure zones are presented in Table 1, Table 2 and Table 3, respectively. These results indicate that the structure reinforced horizontally is the strongest. The increase of the angle of reinforcement inclination reduces the bearing capacity of RS model and enhances the footing displacement at failure and the height of the failure zones.

It should be noted that for little value of angle α the decrease of critical load is rather small, but for the angle α > 10^0 the reduction is significant. The bearing capacity of model wall reinforced horizontally is nearly two times greater than of the similar structure with the angle of reinforcement inclination α=20^0. Simultaneously the height of the failure zones is more than two times higher.

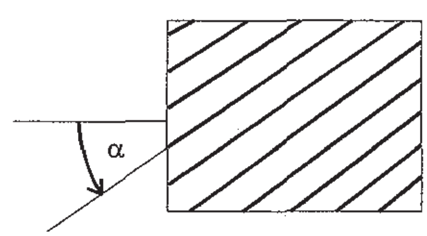

Figure 3. Orientation of reinforcement inclination.

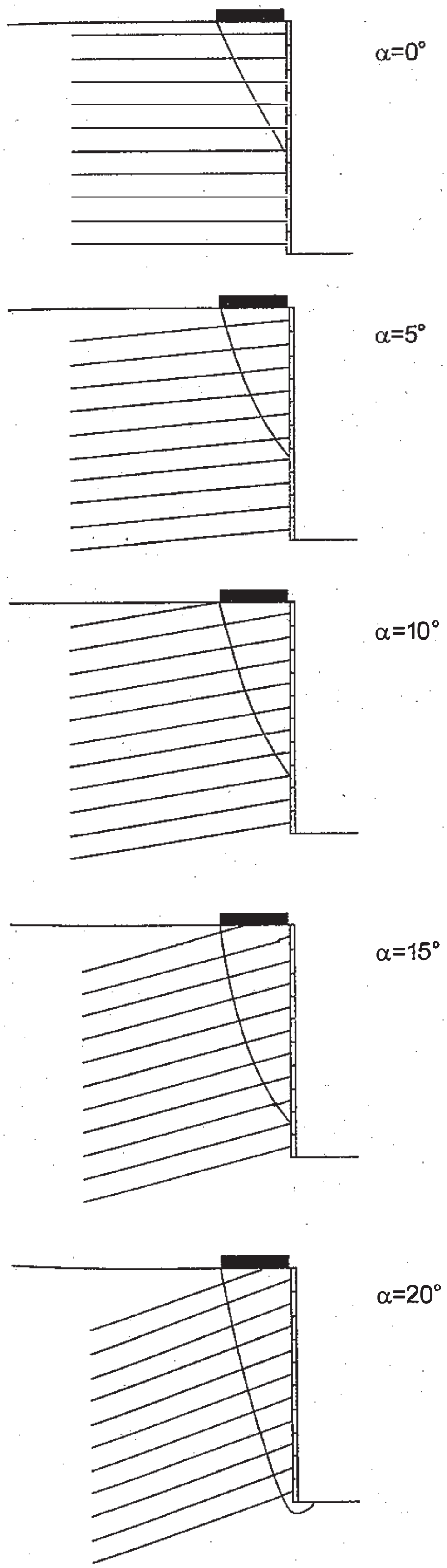

Figure 4. Failure zones in the model tests.

3 THEORETICAL PREDICTION

In this paper the influence of reinforcement's inclination on bearing capacity of RS retaining structures is analysed using limit states techniques. The homogenised rigid-plastic theory of RS proposed by Sawicki (1983) is applied. It is assumed that the reinforced soil consists of the soil matrix and unidirectional reinforcement, and that the perfect bonding between these constituents exists.

The limit states theorems enable estimating so called upper-bounds of critical load of RS retaining wall. The estimate of the critical load can be obtained from the analysis of the kinematically admissible mechanism of failure, shown in Figure 5.

The mechanism depends on slippage of the rigid wedge ABC along the planar failure surface AB. The velocity V of uniform translation is inclined at angle ϕ with respect to AB. This inclination results from the assumption about the associated flow rule. The expression for the upper-bound estimate of the critical load can be derived by equating the energy dissipated along the failure surface to the work done by external forces and self-weight forces of RS structure.

The following formula represents the upper-bound estimate of critical load:

$$p = \frac{\sigma_0 \cos(\beta - \phi)}{\sin\beta}\left[\cos\alpha \tan(\beta - \phi) - \sin\alpha\right] - \frac{\gamma a}{2\tan\beta}, \tag{1}$$

where ϕ= angle of internal friction, α= angle between the direction of reinforcement and the horizontal direction, a= width of loading area.

The strengthen behaviour of reinforcement is described by the coefficient σ_0, which indicates the

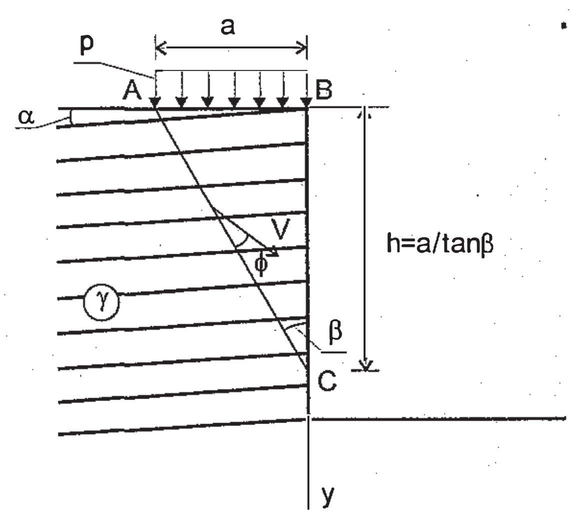

Figure 5. Kinematically admissible mechanism of failure.

tensile strength of reinforcement per unit cross section of entire structure:

$$\sigma_0 = \frac{n \cdot T}{A_c}, \tag{2}$$

where T = tensile limit force for single element of reinforcement, A_c = cross section area of construction normal to the reinforcement direction, n = number of reinforcement elements. For sheets of geotextile or geogrid σ_0 can be defined as

$$\sigma_0 = \frac{T_G}{\Delta H}, \tag{3}$$

where T_G = limit force per unit length of reinforcement and ΔH = the vertical spacing. For reinforcing bar or strips, σ_0 can be taken as

$$\sigma_0 = \frac{T_B}{\Delta H \cdot \Delta V}, \tag{4}$$

where T_B = tensile limit force of a single bar or strip and ΔH and ΔV denote horizontal and vertical spacing, respectively.

The value of unknown angle β can be obtained from the expression:

$$\frac{\partial p}{\partial \beta} = 0; \tag{5}$$

which leads to the following result:

$$\sigma_0\left[\sin^2\beta - \frac{1}{2}\tan\beta\sin(\beta+\phi)\right]\cos^2\alpha$$
$$+\sigma_0\left\{\frac{1}{2}\tan\beta\sin 2\alpha\left[\sin^2\beta + \cos^2(\beta+\phi)\right]\right\} \tag{6}$$
$$+\frac{1}{2}\gamma a\cos^2(\beta+\phi)\tan\beta = 0.$$

From the analysis of Eqs.(1) and Eqs.(6) it follows that there should be:

$$-\phi < \alpha < \phi, \tag{7}$$

$$0 < \beta < \frac{\pi}{2} - \phi. \tag{8}$$

Due to the complicated form of the expression (6) the solution of angle β can be obtained numerically for the experimental data.

4 COMPARISON BETWEEN EXPERIMENTAL RESULTS AND THEORETICAL PREDICTION

The comparison between observed and predicted results are presented in Table 1, Table 3 and in Figures 6-7.

In Table 1 and in Figure 6 the experimental results and theoretical prediction of the critical load of RS model walls with different inclination of reinforcement are compared.

Table 1. Comparison between experimental results and theoretical prediction of the critical load of RS wall.

Inclination of reinforcement	Experimental data	Theoretical prediction
deg	kN/m^2	kN/m^2
0	27.5	20.1
5	26.8	19.6
10	26.1	18.5
15	21.9	16.6
20	15.2	13.9

Table 2. Experimental results of the footing displacement measured at failure.

Inclination of reinforcement	Experimental data
deg	mm
0	6.7
5	9.1
10	9.4
15	13.5
20	11.1

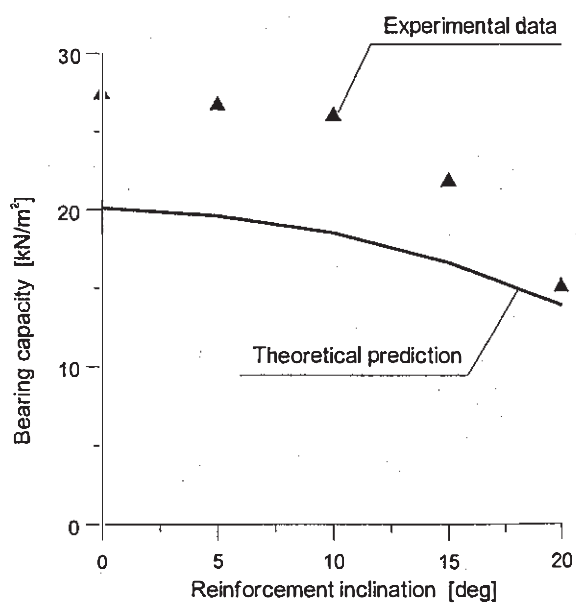

Figure 6. Comparison between experimental data and theoretical results of the critical load of RS wall.

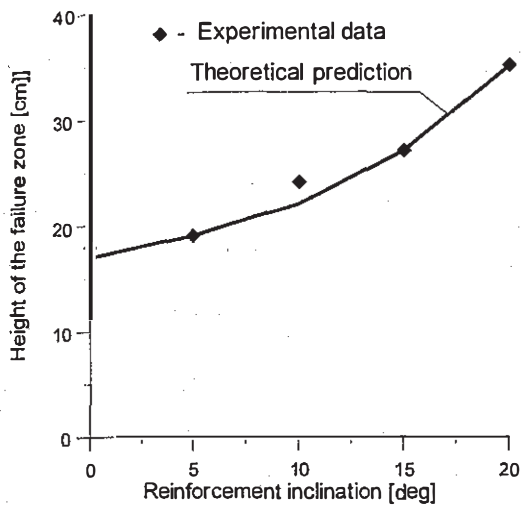

Figure 7. Comparison between observed and predicted height of the failure zone.

It is shown that the horizontal placement of reinforcement makes the structure the strongest and that the inclination of reinforcement reduces the bearing capacity of RS retaining walls.

The difference between measured and predicted critical load (of about 25 %) is probably due to boundary friction effect on the sidewall.

In Table 3 and in Figure 7 the experimental results and theoretical prediction of the height of failure zone of RS model walls with different inclination of reinforcement are compared. It is shown that the lowest value of the failure zone height corresponds to the horizontal reinforcement and that the inclination of reinforcement strongly influences the orientation of the failure surfaces.

The experimental heights of the failure zone are approximately equal to that obtained from the theoretical prediction.

Table 3. Comparison between observed and predicted height of the failure zone.

Inclination of reinforcement	Experimental data	Theoretical prediction
deg	cm	cm
0	17	18
5	19	19
10	22	24
15	27	27
20	35	35

5 CONCLUSIONS

In the paper the laboratory tests performed on the models of RS retaining walls with different reinforcement inclination are described.

Moreover the analysis based on the limit states theorems is presented. With regard to the experimental and theoretical results it is interest to note that:

1. The RS retaining wall reinforced by the horizontally placed layers is the strongest and that the reinforcement inclination reduces the bearing capacity of the structure.
2. The inclination of reinforcement strongly influences the orientation of the failure surfaces.
3. The kinematical limit approach with the failure mechanism depends on slippage of the rigid wedge along the planar failure surface gives a good estimation of the experimental results.

These conclusions support the theoretical results of Lesniewska (1992), Sabhabit et al. (1995) and Sawicki (2000). On the contrary to the other authors' suggestions about the positive effect of the reinforcement inclination on the strength of RS structures, the present study confirms the advantage of the horizontal placement of reinforcement in RS retaining walls.

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Effect of facing and construction sequence on the stability of reinforced soil wall

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ABSTRACT: A small-scale reinforced soil wall was constructed in a laboratory to investigate role of the wall facing and the effect of construction sequence on the wall. A full continuous facing wall and a block-type facing wall were introduced for test. These two different facing systems adapted different construction procedures. The model wall was built with geogrid reinforcement, sand, and facings on rigid surface. The model wall was instrumented with earth pressure gages, LVDTs, and strain gages. The experimental results have shown differences in wall behavior related to construction sequence and types of wall facing. It is found in this study that the reinforced soil wall system built with full continuous facing be the safest reinforced soil wall ever compared to the block-type facing wall. Thus, it is recommended that study for the wall system be necessary for further wide usage for the future.

1 INTRODUCTION

Recently, many types of reinforced soil wall with geogrid reinforcement and block facing have been proposed due to its simplicity of construction and economic construction procedure. However, wall deformations generated during the construction procedure are comparatively larger than those of conventional gravity retaining wall and excavated cut wall such as soil nailed wall (Jones, 1994). This is due to use of different construction procedure and construction materials. The reinforced soil wall is built usually from bottom to top. The soil nailed wall is built from top to bottom. Typically, the reinforced soil wall is vulnerable to deformations. In this study, a reinforced soil wall built with full continuous facing was investigated in order to check possibility of reducing wall deformation.

Cardoso and Lopes (1996) divided construction procedures of the reinforced soil structures into two typical types. The first one is the so-called common type of reinforced soil wall built from bottom to top with block-type facing, reinforcement and backfill soil. In this type of the wall, tension in the reinforcement is generated from the beginning of construction. On the other hand, construction of the other type of the wall may start with use of panel-type facing with aid of props in front of the wall first. After setting up the propped facing, the wall is backfilled and reinforced from bottom to top. Then the props are to be removed from the wall after backfilling. Therefore, the tension in the reinforcement is to be generated when the wall moves due to removal of the props. Different wall behavior can provide different pattern and amount of wall deformation.

In this study, a small-scale model wall reinforced with geogrid adapting different construction sequences was investigated in order to validate usage of full continuous facing wall for reducing wall deformation effectively compared to conventional reinforced soil wall.

2 DESIGN OF MODEL TEST

2.1 *Test apparatus and instrumentation*

A schematic diagram of the testing apparatus used for the tests is shown in Figure 1. The model wall was constructed by adapting two different construction sequences.

The testing apparatus consisted of external steel frames and internal soil retainer. The external steel frames include vertical and horizontal loading machines attached on them. The size of the external frames is 2.0m long, 3.0m high, and 0.8m wide. The soil retainer used for making the model wall to be filled with the Jumunjin sand was 1.2m long, 0.8m high and 0.8m wide. The bottom of the soil retainer was rigid steel slab. The vertical load is applied to the wall by a 196kN capacity of linear servo motor and screw gear. Either a constant loading rate or a constant pressure system is available in this loading machine. Total displacements of the wall were monitored by five LVDTs as shown in Figure 2.