EXPERIMENTAL STUDY ON PRE-FAILURE BEHAVIOUR OF REINFORCED WALL

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ABSTRACT: The paper presents the experimental results of the vertical reinforced soil wall displacements under the sustained load located on the top of the model. The model wall, performed on small-scale, was reinforced with eleven layers of reinforcement. Six strips of reinforcement were placed in each layer. The facing of the model was made of wooden panels. The fine sand was used as a backfill and a foundation material.

The experimental investigations consisted of two stages. During the first stage (for thirty months) the deformations were measured under constant load.

During the second part the sustained load was increased step by step until model failure occurred. Horizontal and vertical displacements at the wall facing were measured during the process.

The scope and character of deformations, obtained during the two stages of the experiment, were compared and conclusions are formulated in this article. The average results from two performed experiments are published.

1 INTRODUCTION

Some papers provide information about the long-term behaviour of retaining walls reinforced with geosynthetics. For example, interesting studies of deformations of full-scale structures (walls and slopes) are presented by: Bathurst (1991,1992), Itoh et al. (1994), Nakajima et al. (1996), Vaslestad (1996). The authors, among other data, present information about long-term deformations of monitored constructions. Their behaviours were observed under constant load (for the whole time).

During another type of experiments (for example: Benigni et al., 1996) the RS walls are gradually loaded. Their displacements were measured during the process.

The experimental programme presented in this paper summarised the two above described procedures. It consisted of two parts. During the first thirty months deformations at the surface of the experimental reinforced wall were monitored under constant load. After this period the structure was gradually loaded up to the failure. Its behaviour (horizontal and vertical displacements) were monitored during the process. Two experiments were performed and their average results are published in this article. They were a part of the research programme which was performed in Institute of Hydro-Engineering to investigate and theoretically describe the deformations of different types of RS retaining walls (Kazimierowicz-Frankowska, 2003a; Kazimierowicz-Frankowska, 2003b).

2 MODEL TESTS

The following general conditions were accepted during the experiment:

2.1 *Experimental set-up*

The investigations were performed in the experimental box: height 22cm, width 24cm, length 35cm (see Figure 1). The model wall was reinforced with eleven layers of reinforcement, which were placed in equal vertical spacing of 2 cm.

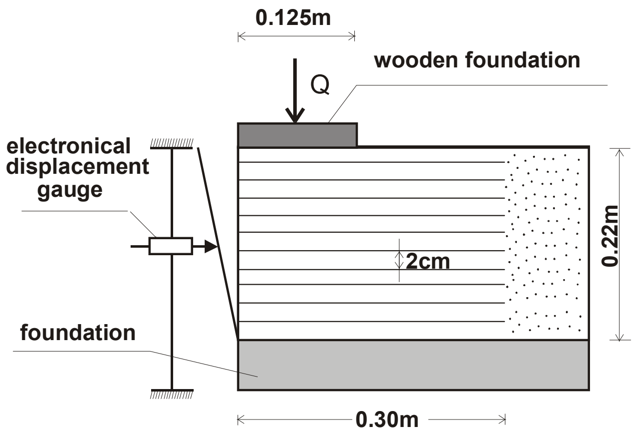

Figure 1 The experimental wall – longitudinal section.

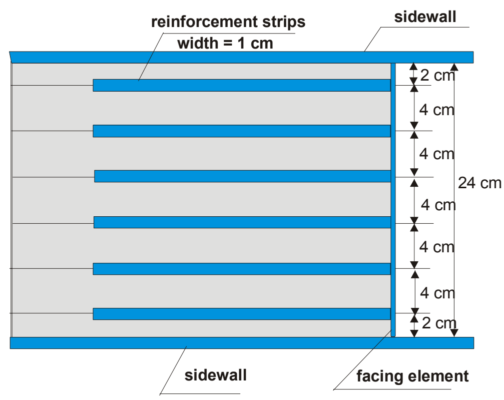

Figure 2 The arrangement of the reinforcement layer.

The reinforcement in each layer consisted of six 1 cm wide strips (compare with Figure 2). The backfill was rained through air by using the hopper kept at 100cm above the sand surfaces. Each of the soil layer was flattened by the grader. After it, the layer of reinforcement was placed on the sand (six strips) and then, the next sand layer was rained in the similar way.

The wall facing was built with eleven (each 2 cm height) wooden panels. The reinforcement strips were fixed to the panels. The temporary support with the form of wooden element was used to prevent the facing deformation during the wall construction. The wooden foundation was placed on the top of the wall (compare with Figure 1) and the load was put on it.

2.2 *Materials*

2.2.1 *Reinforcement*

The polyester fabric was selected as reinforcement. It had the following basic mechanical parameters: the tensile strength – 1.52 kN/m and the elongation at ultimate tensile strength – 10.05% - both obtained as the average results of 20 tensile tests. The tests were performed in machine direction.

2.2.2 *Back-fill*

The fine, silica sand was used as the backfill and the foundation. Its basic parameters were the following: friction angle $\varphi = 31.5^0$ (obtained from triaxial compression test), relative density – 0.96, void ratio – 0.56, average particle size – 0.25, dry density - $\gamma = 17.2 kN/m^3$.

2.3 *Measurements*

The main aim of the experiment was to measure the horizontal deformations at the surface of the model wall under the sustained load, which was located on the top of the structure. The displacements of 132 points regularly located of the wall facing (at 12 points of each of 11 wooden facing panels) were monitored by using electronic displacement gages.

Additionally the simple measurements of the vertical displacements of the experimental structure were performed. Two gages were fixed to the wooden foundation (on the top of the structure) and they showed its vertical movement during the experiment .

The investigation programme consisted of two stages.

2.3.1 *First stage of the experiment*

The constant load Q = 98 N was applied during the whole time (21 672 hours) of the stage. After completion of the construction of the model wall, the rigid wooden foundation was placed on the top of the structure. Then the temporary support of the wall was dismantled and the following series of measurements were performed:

- 1st (initial) measurement - before loading of the wall
- 2nd measurement - just after loading of the model
- simultaneous measurements – their frequency was individually selected, adequately to the observed movements
- final measurement - 21672 hours after loading the structure.

The above described measurement procedure was used during monitoring of horizontal and vertical deformations of the experimental wall.

2.3.2 *Second stage of the experiment*

The aim of this part of the experiment was to measure the displacements of the experimental wall under increasing level of loading and to determine the experimental value of the failure load.

The loading was added step by step (in equal rate of values) and it was put on the top surface of the wall. It was changed in the range from 98 N to 785 N.

The following eight levels of loading were applied:

- 1st stage of load Q = 98 N (time duration 26742 h – 1st stage of the experiment),
- 2nd stage of load Q = 196 N (time duration 24h),
- 3rd stage of load Q = 294 N (time duration 0.2h),
- 4th stage of load Q = 392 N (time duration 0.2h),
- 5th stage of load Q = 491 N (time duration 24h),
- 6th stage of load Q = 589 N (time duration 0.2h),
- 7th stage of load Q = 687 N (time duration 24h),
- 8th stage of load Q = 785 N (time duration 0.1h).

The first value of the load (98 N) was equal the level of load which was applied during the first stage of the experiment. The last one (785 N) caused the total destruction of the experimental wall. The failure was observed within 5 minutes after application of the load.

The measurements were performed immediately after placing the additional load. The 2nd, 4th ,5th , 7th stages of loading were applied immediately after finishing the previous series of measurements. The 3rd , 6th and 8th ones – after 24 hours duration of the previous stages of loading. The scope of the wall facing displacements during this time periods (for three different levels of loading) were compared.

3 DISCUSSION OF THE EXPERIMENTAL RESULTS

3.1 *Displacements under constant loading*

The measured horizontal deformations of model wall during the first stage of experiment are presented in Figure 3. Each mark, showed in this Figure, was obtained as the average result of displacements of 12 points which position was monitored during experiment.

It is visible that the maximum displacements appeared in the top layers of the wall. The minimum deformations occurred at the foot of the RS model structure. The displacements at the upper part of construction had the tendency to grow with time.

After the immediate displacement of the surface, which was the “answer” for the loading impact, the position of the lower part of the construction (approximately 3-4 wooden facing elements) practically remained unchanged. The rates of horizontal movements were the greatest immediately after applying of the load and became progressively smaller in time.

Figure 4 shows the results of vertical displacements measured on the top surface of the wall. The observed movements were intensive in the first period of the experiment (approximately for the first 1000 hours after loading). After this time the curve which shows the vertical displacement in time, tend to horizontal asymptote and the measured values of deformations stayed constant.

By the end of this stage the maximum values of measured displacements were: about 0.30cm – horizontal movement and about 0.32cm – the vertical one.

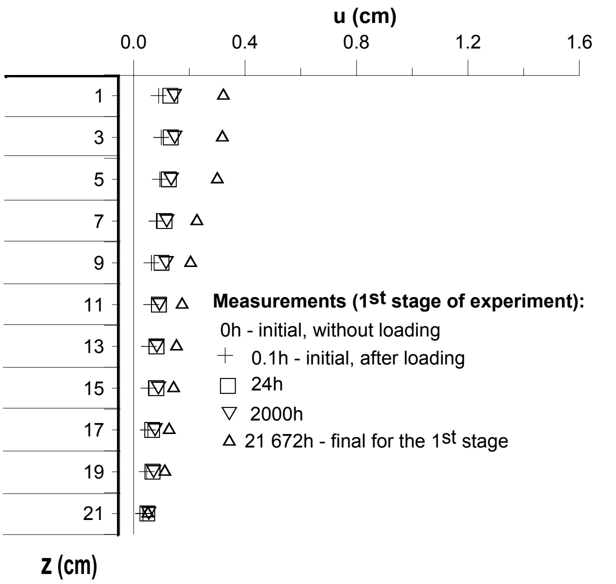

Figure 3 Horizontal displacements during 1 stage of experiment.

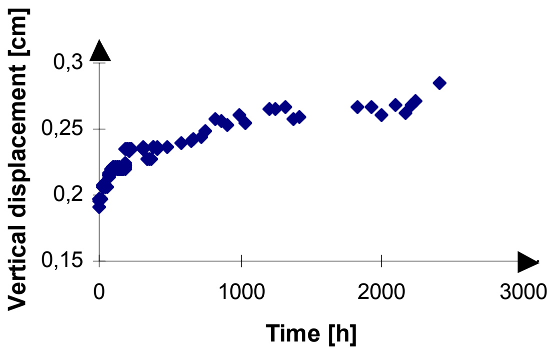

Figure 4 Vertical displacements during the first 2500 hours of experiment.

3.2 *Displacements under the increasing loading and failure load*

The horizontal displacements at the wall face, measured during application of the increasing loading are presented in Figure 5 (the summary results obtained for the whole monitored points at the surface of the wall) and in Figure 6 (movement of 4 selected facing elements, which were located in the top, middle and bottom part of the experimental model).

It is visible, that similarly to the first stage of the experiment, the largest movements were measured in the top part of the wall. However, it is possible to select two different stages of wall facing horizontal displacements. During the first one (corresponding the levels of loading in the range: 98 N – 392 N) the maximum displacement occurred in the top facing element (first below the sustained loading). During the pre-failure stage of deformations the maximum horizontal movement was observed 3 cm below the loading area (second facing panels). The similar tendency was observed by Benigni et al. (1996). They described behaviour of RS wall performed in natural scale.

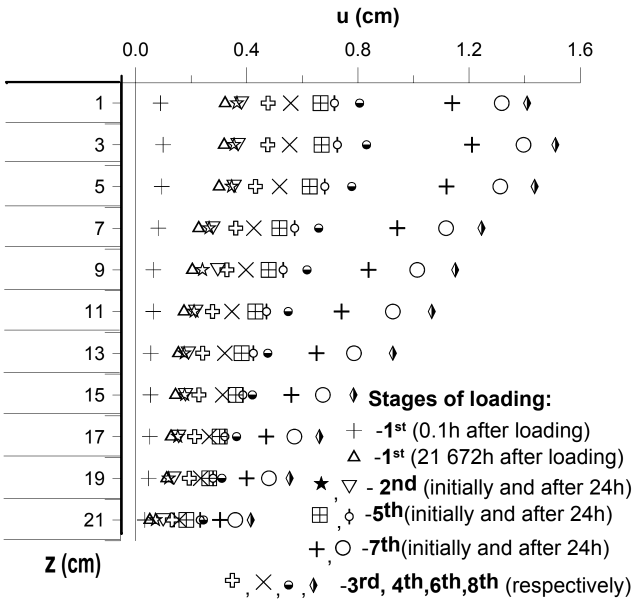

Figure 5 Horizontal displacements under following levels of loading.

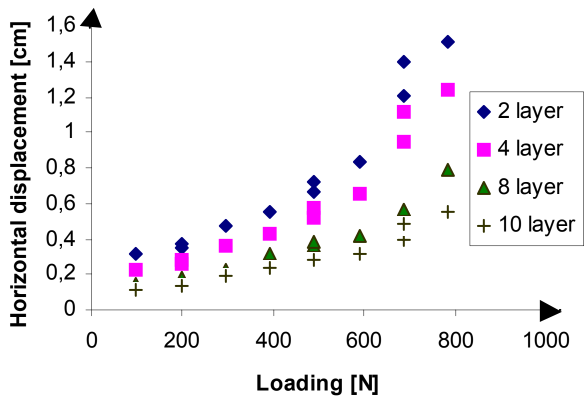

Figure 6 Horizontal displacements of the selected facing panels.

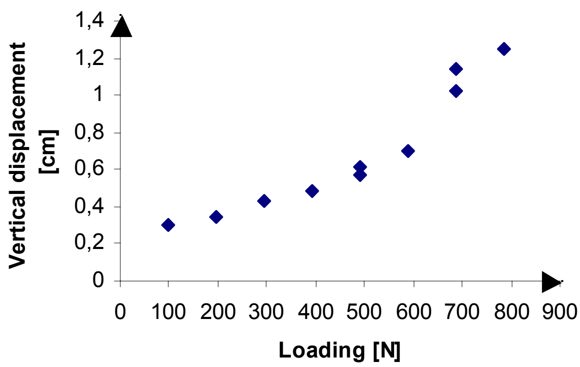

Figure 7 Pre-failure vertical displacements of the model wall . Second stage of the experiment.

Figure 7 presents the average (from two points) vertical displacement measured on the surface of the rigid foundation placed on the top of the model wall. The deformations grow linearly with the following stages of loading (in the range between 98 N and 589 N). The very “strong” reaction (increasing of horizontal and vertical deformations) after application the 7^{th} level of loading was observed.

Figure 8 shows the rate of horizontal displacements during 24 hours under three different levels of loading. It is easy to note that there was practically no difference between initial and final (after 24 hours) position of wall facing, when the 2^{nd} stage of loading was applied. Very little movement (average 0.04cm) was observed within the 5^{th} stage of loading. It was nearly the parallel displacement along the whole height of construction. The substantial deformation (average 0.17cm) was observed, when the 7^{th} stage of loading was applied.

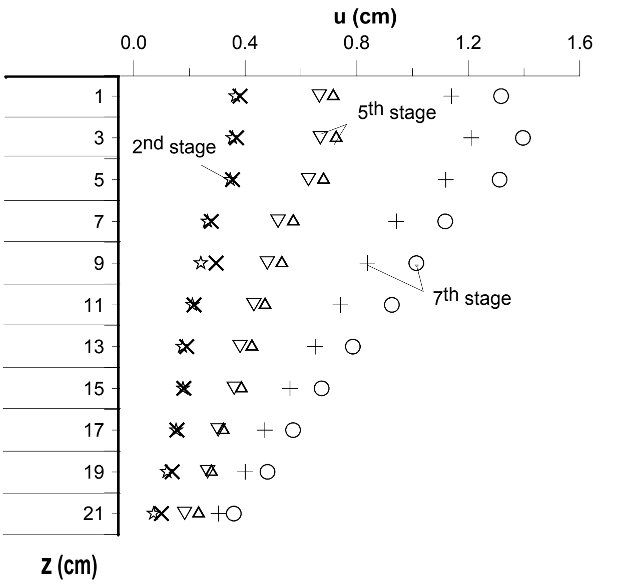

Figure 8 Horizontal displacements during 24 hours – for 3 different levels of loading.

The failure load (785N) was lower than its estimations (lower - p_l and upper - p_u) obtained using the theory of limit states (Sawicki, 2000):

$$p_l = \sigma_0 \tan^2\left(45^0 + \varphi/2\right) - \gamma H \ , \qquad (1)$$

$$p_u = \sigma_0 \tan^2\left(45^0 + \varphi/2\right) - \gamma H/2 \ , \qquad (2)$$

where σ_0 is the coefficient which indicates the tensile strength of reinforcement per unit cross section of construction. For reinforcing strips σ_0 is defined as:

$$\sigma_0 = \frac{T_B}{\Delta H \cdot \Delta V} \ , \qquad (3)$$

T_B is the tensile strength of a single strip and ΔH and ΔV denote horizontal and vertical spacing, respectively. φ denotes angle of internal friction, γ - unit weight of RS, H – height of RS structure.

The above results may suggest that the loading of the structure during the first stage of the experiment (21672h) strongly caused the decrease of the bearing capacity of the model wall. It was the initial experiment and the experimental programme will be continued. After finished the following (basic) series of experiments the theoretical analysis will be done.

4 CONCLUSIONS

Considering the results of the above described experimental research the following conclusions can be formulated:

- The largest horizontal displacements of model wall occurred in the top part of the structure.
- During the first stage of the experiment and for the first period of the second one (for loading in the range: 98 N – 392 N) the same shape of horizontal deformations were observed. The maximum movements were measured directly below the loaded area – in the top facing element. They decreased down the height of the wall and may be linearly approximated (for a specific time).
- During the pre-failure stage of experiments (for loading in the range: 491N - 785 N) the shape of horizontal displacements changed and the largest horizontal movement was noted 3 cm below the top of the construction.
- The average experimental results measured immediately before the wall failure were as follows: the maximum horizontal deformation: 1.51cm, the maximum vertical deformation: 1.25cm.
- The experimental failure load was lower than its lower bound estimation obtained using the theory of limit states.
- The theoretical analysis of the experimental wall deformations required a separate treatment. The proposed analytical method of calculation of the determinations of the horizontal displacements is presented in previous publications (Kazimierowicz-Frankowska, 2003a).

5 REFERENCE

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