Ground Embankment Model Testing Reinforced by Geosynthetic Elements

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ABSTRACT
The article presents the results of trough (model) tests of a soil embankment subject to static loading. The framework of the work program are two models of a soil embankment are subjected to static tests: without reinforcement elements and using reinforcement elements from geosynthetic material. The test results are presented in graphical and tabular form. A qualitative and quantitative analysis of the load-fall curve is carried out.

RESUMEN
El artículo presenta los resultados de las pruebas de comedero (modelo) de un terraplén de suelo sujeto a carga estática. El marco del programa de trabajo son dos modelos de terraplén de suelo que se someten a pruebas estáticas: sin elementos de refuerzo y utilizando elementos de refuerzo de material geosintético. Los resultados de la prueba se presentan en forma gráfica y tabular. Se realiza un análisis cualitativo y cuantitativo de la curva carga-caída.

1. INTRODUCTION

The use of geosynthetic materials as reinforcement elements to strengthen the earth embankments has a great world practice and wide application, and in recent years, its intensive implementation in Kazakhstan in the field of road construction and slope stability has been observed. The severe conditions of climatic data in Kazakhstan, such as frozen-thawing soils is also a big influence to stability of foundations (Zhussupbekov et al. 2012). Especially, it is a lot of deformations by freezing-thawing to constructions of infrastructures, low-rising buildings and so on (Zhussupbekov et al. 2018). In Kazakhstan, it is important to do laboratories investigations for more detailed determinations of frost susceptibility in the slopes and embankments (Zhussupbekov A. & Shakhmov Zh. 2015).
Geosynthetic materials could be in the form of fabrics and nonwovens which has high usage for around 50 years. Especially, material as geogrid is widely used in reinforcing of steep slopes , walls, bridge abutments, embankments on soft soils and covering of tailing ponds (Ziegler, 2018). Reinforcement of the soil embankment implies the use of reinforcement elements to increase the overall stability of the structure and the mechanical properties of the soil embankment. Nevertheless, the issue of qualitative design primarily depends on the correct calculation, the choice of the design scheme, the evaluation of the effect of reinforcement elements on the overall stability of the embankment (Shin & Young, 2006).
The pilot tests were carried out in the laboratory of the Karaganda Industrial State University in June 2014.
The tests were conducted with the aim of:
- evaluation of the stress-strain state of the embankment at different loading values;
- evaluation of the effect of reinforcement elements on the general stability of the soil embankment model.
Experimental studies on models are performed by the method of equivalent materials and have as their goal the study of the work of a soil embankment model loaded with static pressure of different sizes, as well as the effect of reinforcement elements on the external and internal stability of the structure.

2. METHODOLOGY

There several methods for calculation and design of slope stability of embankments. Stability of slopes depend on soil type such as cohesive or disperse type. The main tendency for stability of slope or embankment is normative coefficients should be more than designed coefficients:

$$\gamma_{st} \geq \gamma_{st,n}$$

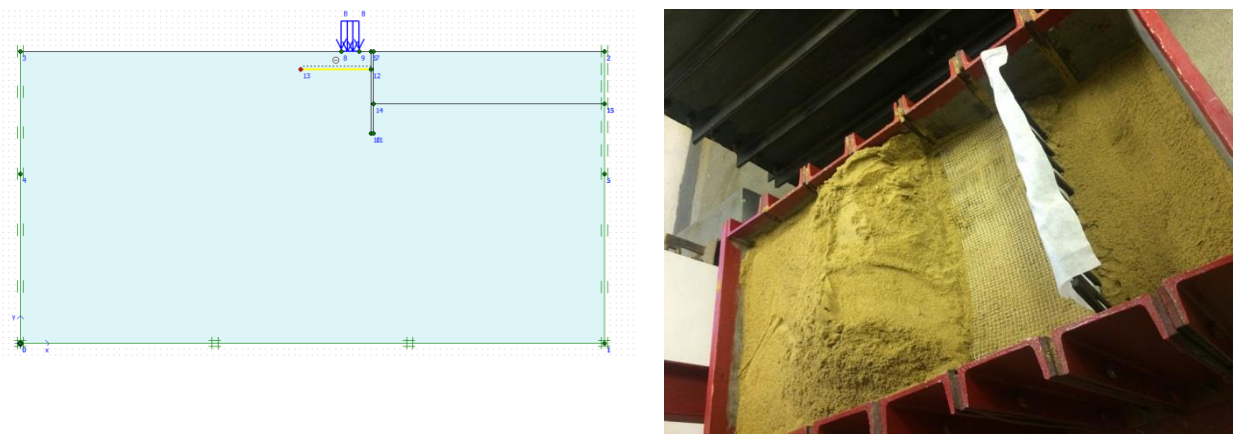
where, $\gamma_{st,n}$- normative coefficient of stability, γ_{st}- designed coefficient of stability.

The complex of research included the following steps:
1. Numerical modeling of reinforced and unreinforced soil embankment with the usage of a geogrid and a different stepped pile.
2. Model tests of reinforced and unreinforced soil embankment with the usage of a geogrid and a different stepped pile.

The general concept of numerical and model testing is shown in the figure 1.

Numerical modeling | Model test

A) Model of a unreinforced soil embankment



B) Model of a reinforced soil embankment

Figure 1. Concept of research

Precast concrete driven piles (14 m of length, 40x40 cm of cross-section) were used as supporting slope structure. Numerical simulation was carried out in Plaxis 2D, in a plane strain. When carrying out model tests, the law of dynamic similarity was used to select the model components (soil, geosynthetic, geogrid, piles, etc.) [3]. Model tests were carried out at a scale of 1:40.
For the initial constructive solution, the following decision has accepted:
1. The use of piles with a length of 14 meters, section 40x40 centimeters, with pile span of 1 m;
2. Application of the geogrid 150x150 mm, with an axial strength EA (deformation of 2%) 200000 MPa, with different pile spans;
3. Preliminary location of the geogrid is taken with a step of 1.5 meters along the height of the RS.

2.1 NUMERICAL ANALYSIS

The complex of research works by numerical modeling is includes following:

1. Determination of the optimal location (zone of the placement) of geosynthetic reinforced elements along the height of the RS;
2. Analysis of the joints of geosynthetic elements at specified locations, with the goal to determine optimal solution
3. Analysis of the application of several geosynthetic grids (from 5 to 1 with a span of 25 centimeters) in the chosen optimal location;
4. Investigation of the dependence of the reinforcement length (the solution of the problem 3) adopted to reduce the number of piles (span increments).

The last problem in the plain strain could be realized by reduction of pile stiffness and increase the soil pressure.

Figure 2 (on the left) shows the locations of geosynthetic grids, with a step of 1.5 meters along the height of the RS. Calculations of the slope stability of the RS have been carried out for each location separately, in order to identify the shortest length of reinforcement. Calculations showed that the optimal geolocation solution correspond to the positions B and E, where the reinforcement length is 8 m in both.

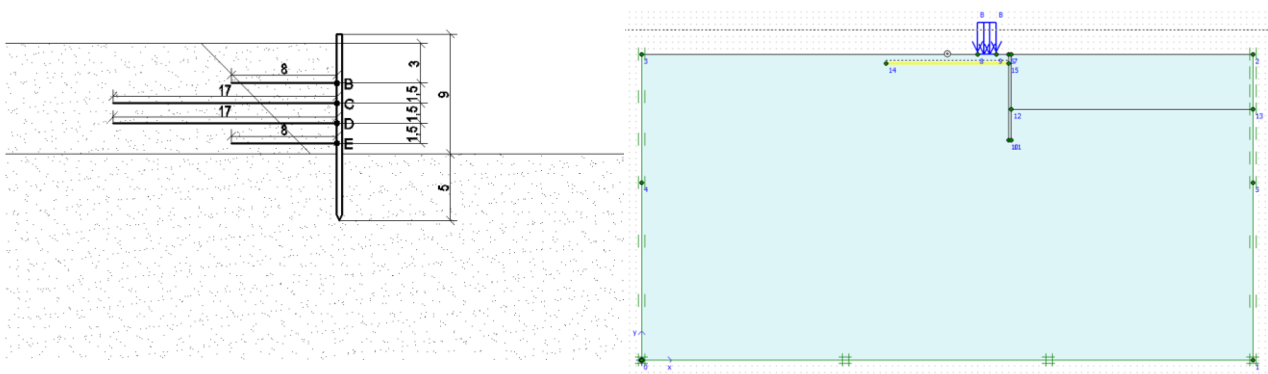


Figure 2. Location and design scheme

Next, the joint work of the geogrid in two locations B and E had been made(Problem 2). The general principle of the calculation is determination of the lowest total length of geogrids (joint work B and E) under the same criteria of RS reliability and stability. The solution of the problem is represented by the following algorithm: E (n) + B (8-n) ... + B 8-n + 1) or B (8-n-1) ... until the stability condition of the RS is satisfied.

The results of the research showed that the optimal solution is the individual work of the geogrid either in the E location or in the B location. Since all the combinations have shown the need for a longer geogrid length (total length over 8 m). The results are presented in Figure 3, where vertical axis - the geogrid length along E, horizon axis - the geogrid length along the B.

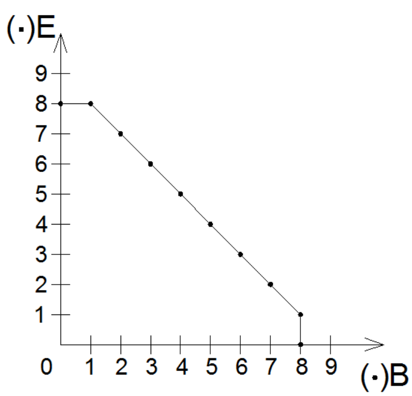


Figure 3. Analysis of the joint work of geosynthetic reinforcement elements in locations B and E

Since the locations B and E are symmetrical, it is possible to notice identical work of the reinforced geo-elements. At the same time the point B is 3 meters from surface and the point E is 6 meters from the surface, therefore we come to the conclusion about the rationality of using the geogrid in location B. That is, from the point of view of the production technology for geogrid construction, this constructive solution will be most economical.

The next task of the research (Task 3) is analysis of the group work of several geogrids are nearby chosen location B. The span of the group geogrids is 25 cm (Figure 4).

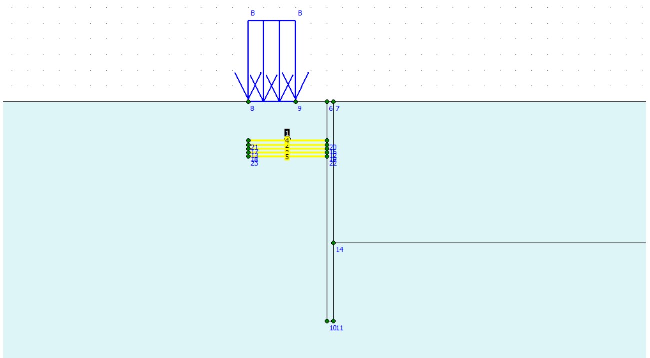


Figure 4. Design scheme of the task 3

Analysis of this task showed that the application of only 10 geogrids of 5 m length (with a span of 25 cm) leads to the get of the necessary stability and reliability of the RS. That, the use of group geosynthetic elements is ineffective. Therefore, choosing only one geogrid layer with a length of 8 m, located in point B.

The next step (task 4) is to find the dependence between the reinforcement length and piles number on the point B. This task can be realized in Plaxis by reducing the stiffness of the pile EA and increasing the soil pressure on the retaining wall.

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Table 1 presents the calculated stiffness of piles and soil pressure depending from changing the pile span.

Table 1. Stiffness of piles and soil pressure depending from changing the piles

№	Span of pile, m	EA, kN/m²	ρ, kN/m³
1	2	1,500E+07	32
2	3	1,000E+07	48
3	4	7,500E+06	64
4	5	6,000E+06	80
5	6	5,000E+06	96
6	7	4,200E+06	108
7	8	3,750 E+06	124
8	9	3,333 E+06	140
9	10	3,000 E+06	156
10	11	2,727 E+06	172
11	12	2,250 E+06	188
12	13	2,307 E+06	204
13	14	2,142 E+06	220
14	15	2,000 E+06	236

The results of the calculations showed that the increment in the length of the geogrid with increasing pile span is not significant. Therefore, the most economical, in terms of material and labor, usage of the maximum pile span. However, this increase of pile span (15 m) requires additional research: an assessment of the RS facing and it`s work between the piles.

2.2 LABORATORY MODELING

The complex of model tests included following:
1. Model testing of a RS without geosynthetic reinforcement elements (geogrid);
2. A series of model tests of a RS with a geogrid for various piles spans.

Each test was carried out using a static load applied to the roadbed as a point load, until the ground embankment collapsed completely. The mixture was used as the equivalent material. An elastic polymeric material was used as a model of roadway. A polymer grid with aperture of 1.25 cm was used as reinforced material. Flexible geotextile was used as facing element of the RS. Models of piles are made of wood covered with bitumen. A series of model tests with multilevel pile span had been made, table 2.

Table 2. Model test of RS

№	Test series	Span of piles, in nature (m) /in the model (cm)	
1	RS without reinforcement	2 m	5 cm
2	Reinforced RS	2 m	5 cm
3	Reinforced RS	4 m	10 cm
4	Reinforced RS	6,8 m	17 cm
5	Reinforced RS	10,6 m	26,5 cm
6	Reinforced RS	21,2 m	53 cm

The materials for the model are selected on the basis of the general law of dynamic similarity, taking into account the simultaneous action of gravity and internal stresses (Tanaka T. at all., 2015).

After substituting the corresponding values for the model and natural soil, we obtain the linear scale of the modeling:

$$m_C = c_M / c_H \cdot \gamma_H / \gamma_M = 0.9/38 \cdot 19/17{,}7 = 1/40 \qquad (1)$$

Consequently, the linear scale of the model and the object is determined by the ratio of the strength properties (cohesion) of loam and equivalent material and is equal to 1:40.
The material of the soil basement is represented by a mixture consisting of 97% fine quartz sand and 3% spindle oil by weight. The oil allows to model cohesive soils. Parameters of soils and equivalent material are presented in Table 3.

Table 3. Soil and equivalent material parameters.

The name of soils and model material	Unit weight, γ, (кN/m3)	Cohesion, c, (кPa)	Angle of internal friction, φ, (degree)	Modulus of deformation, E, (MPa)	Poisson's ratio ν
Physical and mechanical parameters of the natural dam					
Loam	19,0	38	38	27	0,35
Physical and mechanical parameters of the natural dam					
Equivalent material	17,7	0,90	21	0,26	0,25

It is necessary only one parameter of reinforced element modeling is axial strength, which can be fined by following equation:

$$\mathrm{EA} = \mathrm{T} \cdot \mathrm{t} \cdot \mathrm{t_g} \frac{\mathrm{W_g}}{\mathrm{s}} \quad , \qquad (2)$$

Where EA – axial strength, kN/m; t – thickness of reinforced element, m; T – tensile force, kN/m; tg – thickness of geogrid rod, mm; Wg – width of geogrid rod, mm; s – space between the rods of geogrid, mm.
The axial strength of one rod of natural geogrid is 51 kN/m, then axial strength of 1 m reinforcement is follow: 51 ·5=255 kN/m (where 5 is a number of rods per 1 m of natural dam). Final parameters of the model geogrid are follow: diameter of the rod is 0.8mm, cross section is 0,524·10-6 m, and axial strength of equivalent 1/40 m of model is EA=100,48 kN/m, where 1/40 is a scale of natural to model dam (Lukpanov R.E., 2016).
The tests were carried out in accordance with the test program. Each test was carried out until the overall stability of the retaining structure was exhausted. Thus, a quantitative comparison of the loads (before collapse) will give a general conception of the soil embankment strenghening (percentage, compared to the unreinforced).
Figure 5 shows picture of the collapse of the retaining structure for various tasks (without reinforcement and reinforcement with different pile spans).


Unreinforced (2m)


Reinforced (2m)


Reinforced (4m)


Reinforced (6,8m)


Reinforced (10,6m)


Reinforced (21,2m)

Figure 5. Modeling of the RS

The test results are summarized in a graphical and tabular form. The graph shows the dependence of the pile span and the maximum load at which the retaining structure collapsed. The table shows the comparison of absolute values and the percentage with the results of the first test (without reinforcement).

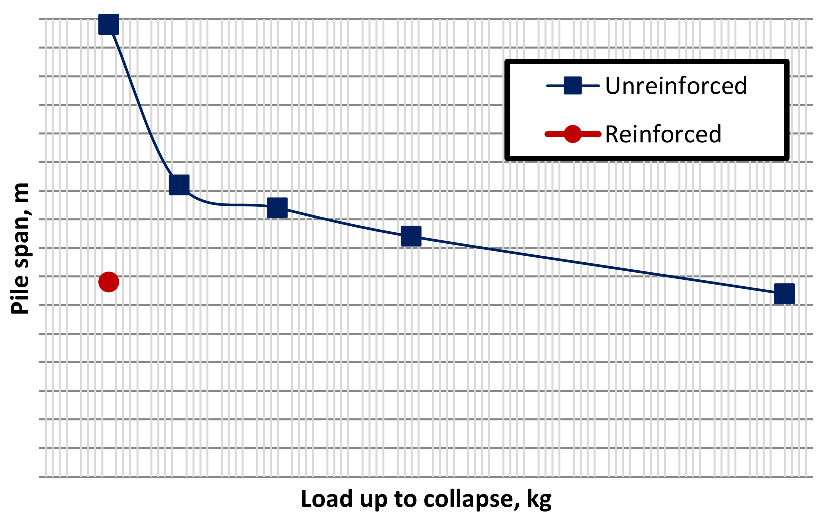

Figure 6. Dependence of load and pile span

Conclusions

In general, the results of the research showed the effective use of geosynthetic reinforced material, as an element of soil strengthening.

The results of numerical analysis showed that the most optimal design solution would be the use of a single layer of a geosynthetic reinforcement element: 8 m long, 3 m from the surface. The results of model tests also showed the effectiveness of the geogrid. The reinforced retaining structure maintains 2.32 times the static load than the non-reinforced one. The application of the geogrid allows increasing the pile span by 10 times (21,2 / 2 = 10,6). In general, the analysis of the choosing optimal pile span (with a view to reduce the material expenditure) showed a tendency to minimize costs with increasing pile span, but requires additional research, as long as a number of questions related to the choice of the facing material and its works are arise.

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