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Thin-Wall Retaining Structure Operation with Reinforced Soil Backfill Using Fly Ash

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The results of the retaining wall structures with different backfilling options are presented. Issues related to feasibility study of design and materials selection of retaining structures are considered. Estimated cost and estimated labour intensity of erection of each structure were calculated and conclusions were made on the efficiency of retaining wall structures operation.

Key words: retaining structures, reinforced soil, geosynthetic material, fibre reinforcement, fly ash, transportation load

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НАУЧНАЯ СТАТЬЯ
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Работа тонкостенной подпорной конструкции с обратной засыпкой из армированного грунта с использованием золы-уноса

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Представлены результаты работы конструкций подпорных стен с различными вариантами обратной засыпки. Рассмотрены вопросы, связанные с технико-экономическим обоснованием выбора конструкции и материалов подпорных сооружений. Рассчитаны сметная стоимость и сметная трудоемкость возведения каждой конструкции и сделаны выводы об эффективности эксплуатации конструкций подпорных стен.

Ключевые слова: подпорные конструкции, армированный грунт, геосинтетический материал, фиброармирование, зола-уноса, транспортная нагрузка

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INTRODUCTION

Retaining walls are used for the vertical planning of difficult terrains with large differences in levels and for the construction of many underground structures such as tunnels, canals, and cellars. The retaining structures are widely used in hydraulic and transport engineering. Also, they are effectively used as foundations for bridge crossings, viaducts, flyovers, overpasses, and embankments [1, 2].

The choice of design and materials of retaining structures must be technically and economically reasonable. Reinforced soil retaining walls are often used effectively. Reinforcing soils improves their physical and mechanical properties, increases their load-bearing capacity, and reduces their deformability. The economic effect is achieved by reducing the amount of work and the cost of delivering the materials [3-7].

In model tests [1, 8] we obtained data on the effectiveness of reinforcing sandy soil backfill retaining wall with horizontal geosynthetic elements, namely geotextile and geogrid. The efficiency criterion was taken to be the reduction of the horizontal movements of the retaining wall with reinforced soil backfill, relative to the horizontal movements of the retaining wall with conventional soil backfill. Thus, the use of polyamide mesh (as a geogrid analogue) as a reinforcing material was 36.3% and the use of non-woven synthetic material (as a geotextile analogue) was 41.7%.

Nowadays, the development of the construction industry is directly linked to the implementation of new construction technologies and the use of new building materials. Furthermore, in some cases, in order to achieve the greatest economic and environmental benefits, it is possible to replace 'conventional' materials with the waste product. It is very interesting to conduct research when fly ash reinforced with basalt fibres is considered as backfill for the retaining wall [9, 10].

EXPERIMENTAL PART

Fly ash is a fine material obtained from the combustion of solid fuels in thermal power plants. In Russia, more than 70% of electricity is generated by burning coal, so it is an important task to explore the use of this waste product.

The basalt fibre is a waste product from the production of basalt fibres during the extraction process, which in turn is one of the most promising materials as a reinforcement for concrete.

To determine the physical and mechanical properties of the fly ash without reinforcement and with fibre reinforcement, a series of experiments were conducted on a single-plane shear instrument.

Fly ash with a relative humidity of W = 22% without reinforcement was used as the material under study; basalt fibres of 13-15 mm in length were used as reinforcement materials. Reinforcement was 1% by mass. Samples of the materials are shown in Fig. 1.

The test results are shown in Table 1.

Table 1. Strength test results

Parameter	Fly ash without reinforcement	Fly ash with basalt fibre reinforcement
Specific adhesion, kPa	18.4	39.0
Angle of internal friction, degrees	35.6	27.0

The analysis of the values showed that fibre reinforcement of the fly ash increases the grip but decreases the angle of internal friction. The use of basalt fibres as a reinforcing material increased adhesion by 112% and reduced the angle of internal friction by 24%.

The horizontal displacements under constant load were determined by the finite element method. The finite element method makes it possible to create a numerical model of the research object taking into account the natural stress state and the complex layering of soils, changes in their strength and strain characteristics during the construction and operation of structures and calculate simultaneously two limit states.

a

b

Fig. 1. Material samples: *a* – fly ash; *b* – ash with basalt fibres

A computer simulation of the retaining wall was performed to test the effectiveness of different backfill options for the retaining structures. PLAXIS software, widely used for geotechnical calculations, was used for numerical modelling of the structure [6].

We chose a five-metre retaining wall as our model; the preliminary dimensions are assigned on the basis of the retaining wall design guidelines. We determined the load application point according to GOST 32960-2014; the temporary moving load we gave a uniformly distributed load intensity of 75.6 kN/m, according to GOST 32960-2014.

The basic dimensions of the retaining wall are shown in Fig. 2.

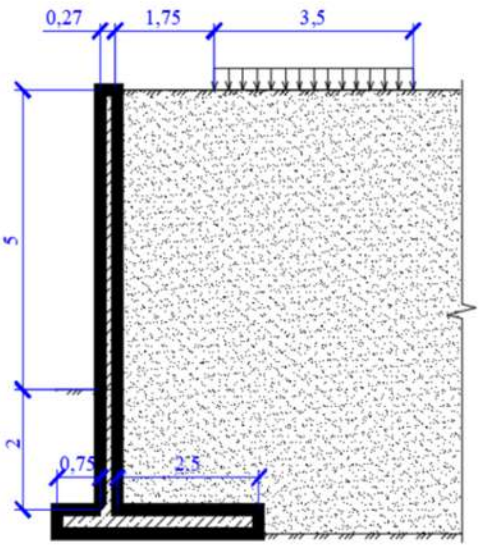


Fig. 2. Material samples: *a* – fly ash; *b* – ash with basalt fibres

The facing is additionally buried two metres into the ground and rests on a 1.0-metre-wide foundation. The alternative is a monolithic solid retaining wall 1.0 m thick with sandy soil backfill.

The following options are considered as types of backfill:

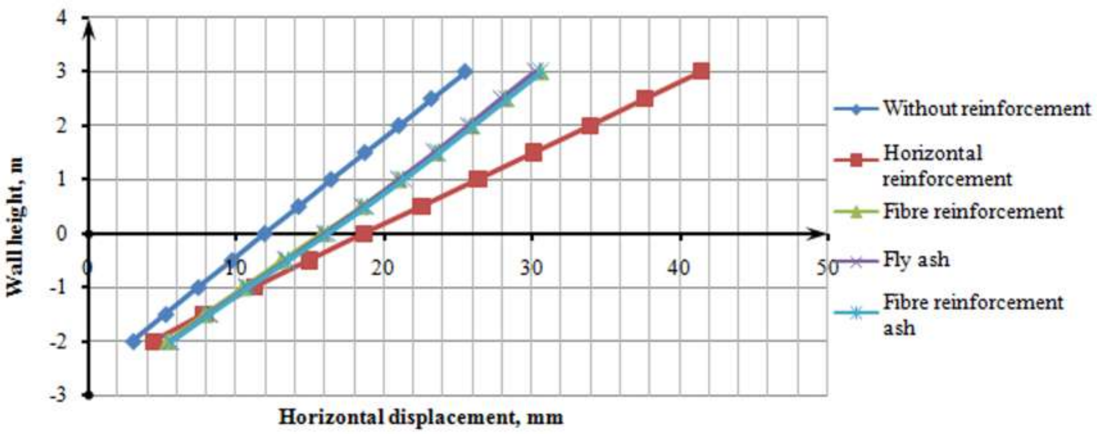
- sand backfill without reinforcement;
- sand backfill with horizontal reinforcement with non-woven geosynthetic material every 50 cm of height;
- sand backfill reinforced with the discrete polypropylene fibres at a rate of 1% fibre by weight of sand;
- backfill using fly ash;
- sand backfill reinforced with the discrete basalt fibres at a rate of 1% fibre by weight of sand.

The Mora-Coulomb model was used for the calculation. Calculation was performed for fixed load according to GOST R 52748-2007 item 4.5, item 5.2.2. The location of the load on the collapsing prism was taken according to SP 35.13330.2011 item 6.12.

RESULT AND DISCUSSION

The calculation results for the horizontal displacement of the retaining wall from its own weight of soil are shown on Fig. 3*a*, and of the applied load on Fig. 3*b*.

a



b

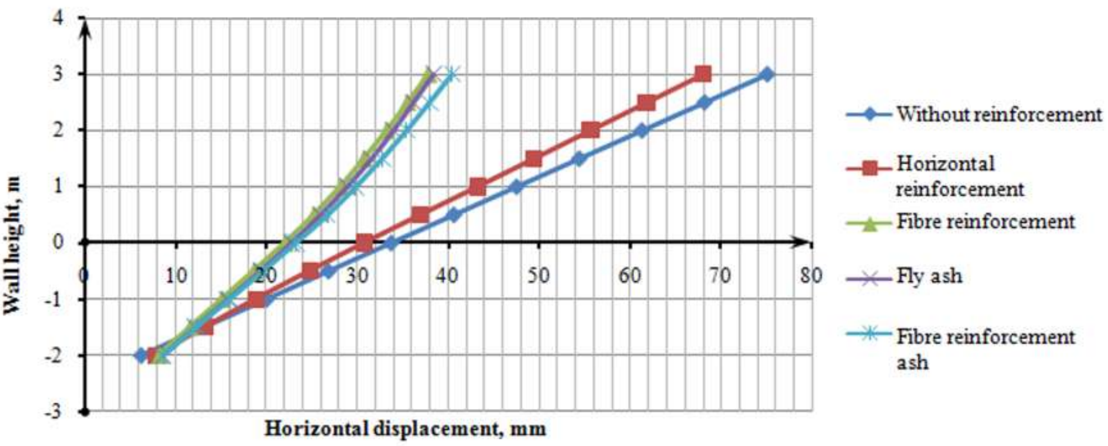


Fig. 3. Horizontal displacement values at the different points along the retaining wall height when acting by its own weight of soil (*a*) and temporary load on the collapsing prism (*b*)

According to the results, the absence of temporary loading causes the minimum horizontal displacement of the wall top, which is 25.5 mm, for the solid retaining wall. The maximum horizontal displacement (41.4 mm) is observed for a reinforced soil retaining wall with geotextile horizontal interlayers. The other backfill options result a displacement of 30.2-30.6 mm.

In the case of a temporary load applied to a collapsing prism, the maximum horizontal displacement of the top point of the wall is 75.1 mm and can be observed at the solid retaining wall. The displacement value of a reinforced soil wall with the geotextile reinforcement decreased by 9.5% relative to a solid retaining wall; the displacement value of the fibre reinforced sand backfill decreased by 49.7%; the displacement value of fly ash backfill decreased by 49.0%; the displacement value of the fibre reinforced fly ash backfill decreased by 46.2%.

When considering the impact of the temporary load on the overall deformation of the retaining wall - the increment of horizontal displacement under the temporary load is in the case of the designing of:

- the traditional retaining wall - 49.6 mm;
- the ground reinforcement with geotextile - 26.6 mm;
- the fibre-reinforced soil - 7.2 mm;
- the fly ash backfill is 8.1 mm;
- the fibre-reinforced ash - 9.8 mm.

The PLAXIS software package mentioned above was used to calculate the retaining structure (Fig. 4).

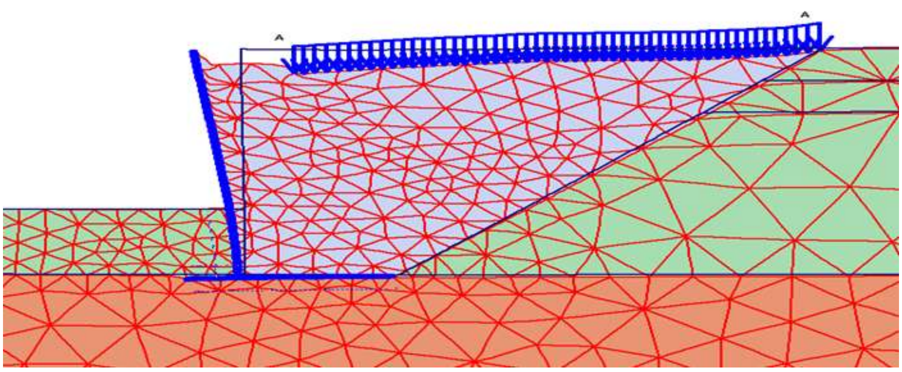


Fig. 4. Calculation results for a retaining wall with load imposed

One of the main factors for choosing technologies and materials for the construction of structures under study, along with their reliability, is their cost. The issues of cost-effective use of resources - material, technical, human - are particularly acute in the current conditions of a market economy. The economic evaluation of the retaining wall structures with different backfill options was determined in accordance with the "Methodology for determining the cost of construction products in the Russian Federation" MDS (Guidance Documents in Construction) 81-35.2004.

The estimated cost per running metre of a retaining wall with the different reinforcement options is presented and the results of the estimated labour requirements are shown below (Figures 5, 6).

Taking into account the criterion of reducing the estimated cost of works, the cost effectiveness of horizontal reinforcement made of the geosynthetic materials was 49.45%, the cost effectiveness of sand reinforcement with discrete polypropylene fibres was 38.2%, the use of fly ash as backfill material was 55.3% and that of basalt fibre reinforced ash was 39.1%.

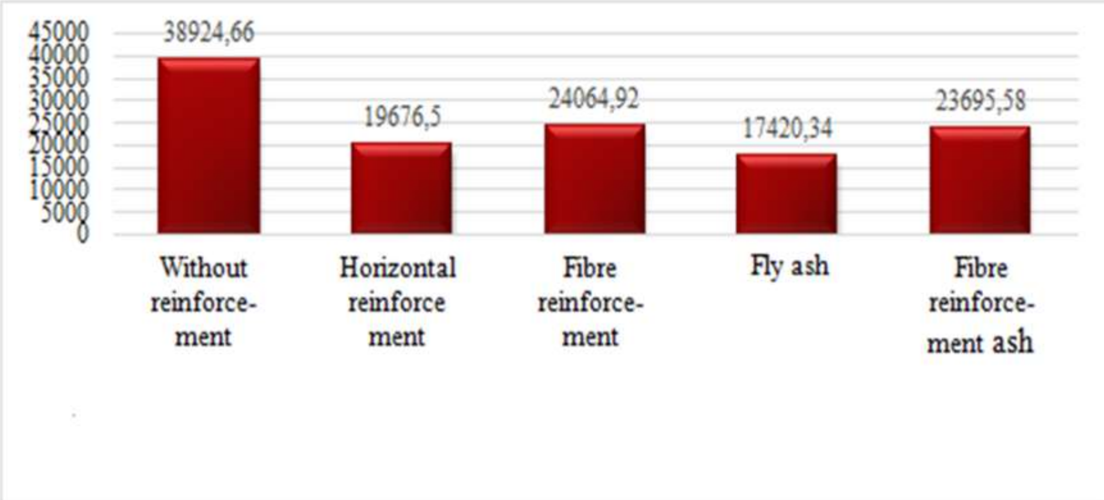


Fig. 5. Calculation of the estimated cost of the work, Rub.

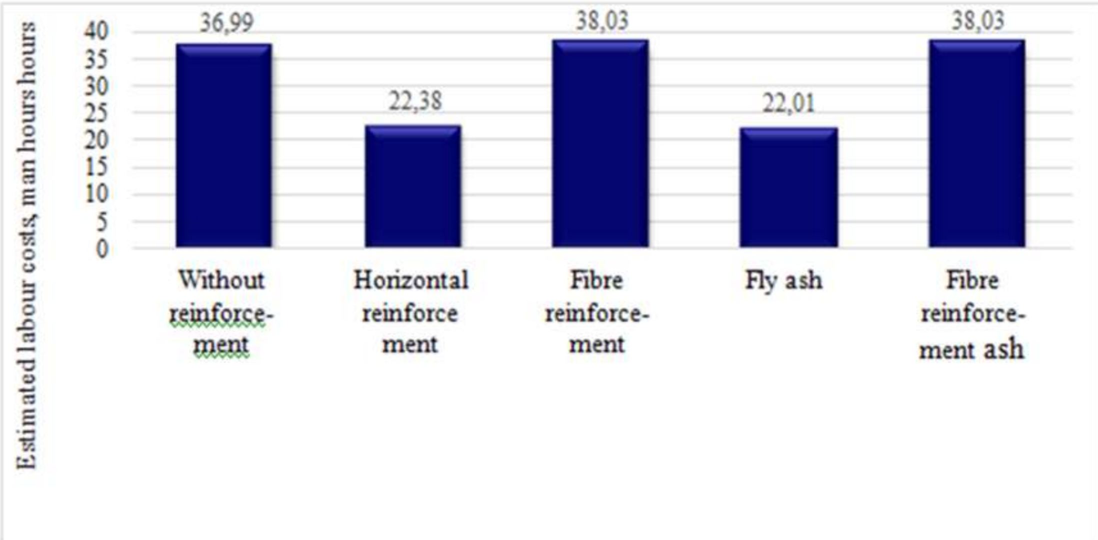


Fig. 6. Calculation of estimated labour costs

The calculations for determining the estimated labour costs have shown that using fibre reinforcement increases the estimated labour costs by 2.8% compared to a retaining wall without the reinforcement. Using of fly ash reduces the estimated labour intensity by 40.5%; reinforcing the sandy soil with non-woven geosynthetics reduces the estimated labour intensity by 39.5%.

CONCLUSION

1. The use of fly ash for retaining the wall constructions stands out as a promising direction to improve the strength and deformation characteristics of soils.

2. When comparing the estimated labour intensity of the work, the most advantageous method is the use of fly ash and horizontal reinforcement. Reinforcing the ground or ash with the fibres is more time-consuming than building a retaining wall without reinforcement.

REFERENCES

1. **Kashapova, K.R. & Kleveko, V.I.** (2016). Results of model tests to determine horizontal deformations of reinforced soil retaining walls, *Vestnik PNIPU. Prikladnaya ekologiya. Urbanistika,* (4), pp. 128-140 (in Russian).
2. **Kashapova, K.R.** (2015) Modelling of reinforced ground foundations of bridge crossings by finite element method, *Aktual'nye napravleniya nauchnyh issledovanij XXI veka: teoriya i* praktika, (7-1), pp. 460-463 (in Russian).
3. **Liu, H., Wang, X. & Song, E.** (2011). Reinforcement load and deformation mode of geosynthetic-reinforced soil walls subject to seismic loading during service life, *Geotextiles and Geomembranes,* 29(1), pp. 1-16.
4. **Haza, E., Gotteland, Ph. & Gourc, J.P.** (2000) Design method for local load on a geosynthetic reinforced soil structure, *Geotechnical and Geological Engineering,* 18(4), pp. 243-267.
5. **Mendonca, A., Lopes, M.L. & Pinho-Lopes, M.** (2003) Construction and post-construction behaviour of a geogrid-reinforced steep slope, *Geotechnical and Geological Engineering,* 21(2), pp. 129-147.
6. **Ling, H.I., Yang, S., Leshchinsky, D., Liu, H. & Burke, C.** (2010) Finite-element simulations of full-scale modular-block reinforced soil retaining walls under earthquake loading, *Journal of Engineering Mechanics – ASCE,* 136(5), pp. 653-661.
7. **Shapiro, D.M. & Tarasov, A.A. (**2014) Analytical models of beds of inclined structures and retaining walls of reinforced soils, *Soil Mechanics and Foundation Engineering,* 51(4), pp. 181-187.
8. **Kashapova, K.R.** (2016). Planning of model experiments to study retaining walls reinforced with horizontal geosynthetic interlayers, *Vestnik Permskogo nacional'nogo issledovatel'skogo politekhnicheskogo universiteta. Stroitel'stvo i arhitektura,.* (1), pp. 30-38 (In Russian).
9. **Burgonutdinov, A.M., Istomina, K.R. & Kleveko, V.I.** (2019) Study of retaining structures with reinforced soil backfill, and fiber reinforced fly ash backfill, *Transport. Transportnye sooruzheniya. Ekologiya,* (3), pp. 15-22 (in Russian).
10. **Kuznetsova, A.S. & Ponomarev, A.B.** (2015) Planning experiment for studying the stress-strain state of a loaded massive of fibro-armed soil behind a retaining wall, *Vestnik Permskogo nacional'nogo issledovatel'skogo politekhnicheskogo universiteta. Stroitel'stvo i arhitektura,* (1), pp. 135-148 (in Russian).

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СПИСОК ИСТОЧНИКОВ

1. **Кашапова К.Р., Клевеко В.И.** Результаты модельных испытаний по определению горизонтальных деформаций армогрунтовых подпорных стен // *Вестник ПНИПУ. Прикладная экология. Урбанистика.* 2016. №4. С. 128-140.
2. **Кашапова К.Р.** Моделирование армогрунтовых устоев мостовых переходов методом конечных элементов //*Актуальные направления научных исследований XXI века: теория и практика.* 2015. № 7-1 (18-1). С. 460-463.

3. **Liu H., Wang X., Song E.** Reinforcement load and deformation mode of geosynthetic-reinforced soil walls subject to seismic loading during service life // *Geotextiles and Geomembranes.* 2011. Vol. 29, № 1. P. 1-16.
4. **Haza E., Gotteland Ph., Gourc J.P.** Design method for local load on a geosynthetic reinforced soil structure //*Geotechnical and Geological Engineering.*2000. Vol. 18, № 4. P. 243-267.
5. **Mendonca A., Lopes M.L., Pinho-Lopes M.** Construction and post-construction behaviour of a geogrid-reinforced steep slope // *Geotechnical and Geological Engineering.* 2003. Vol. 21, № 2. P. 129-147.
6. **Ling H.I., Yang S., Leshchinsky D., Liu H., Burke C.** Finite-element simulations of full-scale modular-block reinforced soil retaining walls under earthquake loading // *Journal of Engineering Mechanics- ASCE*. 2010. Vol. 136, № 5. P. 653-661.
7. **Shapiro D.M., Tarasov A.A.** Analytical models of beds of inclined structures and retaining walls of reinforced soils // *Soil Mechanics and Foundation Engineering.* 2014. Vol. 51, № 4. P. 181-187.
8. **Кашапова К.Р.** Планирование модельных экспериментов по исследованию работы подпорных стен, армированных горизонтальными геосинтетическими прослойками // *Вестник Пермского национального исследовательского политехнического университета. Строительство и архитектура.* 2016. № 1. С. 30-38.
9. **Бургонутдинов А.М., Истомина К.Р., Клевеко В.И.** Исследование работы армогрунтовых подпорных конструкций с обратной засыпкой из армированного грунта, а также с использованием обратной засыпки из фиброармированной золы уноса // *Транспорт. Транспортные сооружения. Экология*. 2019. № 3. С. 15-22.
10. **Кузнецова А.С., Пономарев А.Б.** Планирование эксперимента по исследованию напряженно-деформированного состояния нагруженного массива фиброармированного грунта, находящегося за подпорной стеной // *Вестник Пермского национального исследовательского политехнического университета. Строительство и архитектура.* 2015. № 1. С. 135-148.

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