Plate load test of base taken from coal ash and slag mixture in experimental tray and on experimental section of embankment

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Abstract. The soil study in experimental trays has a number of advantages in comparison with field experiments. It is easier to create the required conditions in the laboratory, it is possible to exclude the superfluous factors influence on the experiment course. However, in a reinforced concrete tray of insufficient size, a special stressed state is created, which influence on the test results is to be taken into account additionally. The paper discusses the results of two experimental studies on the ash and slag mixture (ASM) modulus of elasticity determination: one was carried out in the experimental section of base from the ash and slag mixture; the second - in the experimental tray filled with the same ash and slag mixture. Both experiments were carried out using the same method of stamp test at the same moisture content and the compaction coefficient of the ASM. Based on the test results, the analysis of deformation parameters, determined in different conditions, is carried out. The dependences of the change in the modulus of elasticity on the moistening degree of the ASM are analyzed.

1. Introduction

Stamp tests (plate load test) are the main and most common type of research in assessing the bearing capacity of the roadbed in the Russian Federation. Tests in full-scale conditions make it possible to obtain values of the modulus of elasticity, in which the mold walls influence which the soil is placed in is excluded, it is possible to use the stamp size that is close to the imprint of the assumed temporary load. However, due to the need to build a pilot section, the cost and laboriousness of testing in full-scale conditions is high. Therefore, the comparison of the ash and slag mixture test results (ASM), as anthropogenic soil in the tray and in natural conditions, is an important, yet unresolved problem.

Another problem that impedes full-scale testing is that it is not always possible for a real object to realize the planned experimental conditions, namely: to change the material density and moisture content. And also to exclude factors influencing the course of the experiment: humidity and air temperature, the presence of precipitation, the impact of transport, etc.

In such a situation, it is logical to use experimental trays. In the laboratory it is much easier to simulate the required conditions, however, during an experiment in a rigid tray of limited dimensions, a special stressed state is created in the tested soil bases, which influence on the experimental results requires additional studies to determine the this factor influence degree.

In foreign works [1-5], as a rule, research is limited to the definition of the California bearing ratio (CBR) capacity, which, despite its simplicity and convenience, does not allow modeling in software
complexes using the finite element method [6-8]. The procedure for determining CBR also does not take into account the possibility of natural soil drainage [9]. The stress level under the stamp during the CBR test is much higher than the stresses arising in the constructions [10]. Therefore, the CBR use is not always justified.

At the same time, there are a number of dependencies [11-16] linking CBR and modulus of elasticity, but neither in practice nor in publications there is a clear difference between the elastic modulus determined by different techniques (stamp, laboratory, acoustic, etc.) [17]. At the same time, the values of these modules can vary from 2 to 4 times. Therefore, in this paper, studies are presented to make it possible to compare the stamp test of the base from the ASM in the tray and in full-scale conditions. These studies allow us to answer the question: is it possible to replace the full-scale tests of the base from the ASM with their laboratory analogue.

2. Experimental Plan

Elastic modulus estimation in full-scale conditions was carried out on the experimental section constructed from the ASM of Omsk TPP-4. The cross section is a mound with a height of 1.20 m with roadway width of 4.0 m. Two test cycles were carried out at the pilot site: during the construction phase, before the pavement and five years after its construction.

The first test cycle was conducted in 2013 according to the methodology of E.V. Kosterin [18]. During the test, a rigid stamp with a diameter of 330 mm was installed on the surface of the roadbed at three points of the site. The load was transferred via a hydraulic cylinder with a force of up to 40kN, which was installed in truck sprung part. The load was monitored by a manometer using the calibration "pressure-load" calibration curve obtained during the hydraulic cylinder calibration.

The second test cycle was performed in 2017 according to the method which recommended by the Rosavtodor [19]. Tests were carried out at four points of the roadbed. Cuttings in the coating and the base dimensions of 400 by 400 mm were made before the tests. For the second cycle of stamp tests, a rigid press-stamp PS-050С with a diameter of 330 mm was used, loaded with a hydraulic cylinder with a force of up to 50 kN.

The press-stamp was also installed in the sprung part of the loaded car. Displacement indicators were fixed to a steel beam, which does not allow movement under the influence of wind, loads and accidental touches to it. The load on the stamp was applied, as indicated in [19], the load control was carried out using an electronic dynamometer DEP/ 3-1D-50S-2. After testing the roadbed with natural humidity, its water saturation was carried out by feeding water through the hose to the well. The test procedure is shown in Figure 1a.

Modulus of elasticity evaluation in laboratory conditions was carried out in an experimental tray with dimensions of 6.0x3.0x1.0 m filled with ash and slag mixture of Omsk TPP-4. The tray walls are made of reinforced concrete with a thickness of 100 mm, which prevents the strut in the testing course. In the experiment course, the tray was filled with an ash-and-slag mixture 800 mm from the bottom, the compaction was carried out in four layers.

The tests in the experimental tray were carried out in a similar manner to the second cycle of stamp tests at the test site. The only exception was that the tray had a specially equipped anchor system for fastening the press stamp and placing the sensors of the watch type. In the testing process, the tray was also humidified by the ASM. The testing process is shown in Figure 1b.

The embankment and the tray were kept for at least 24 hours from the moistening moment to distribute the water evenly in the massif. The ASM moisture control was carried out by [29] by sampling after the tests. Sampling was carried out by vertical drilling of the earthen cloth with a hand drill with a screw 16 mm in diameter. Samples for the moisture content determination were taken from a depth of 100, 400 and 700 mm. For each point, at least three samples were taken from each depth. After the selection, the hole was tamped with ASM using a specially made rammer with a diameter of 15 mm.

During the experiment on the pilot site, the following feature was noted. When the ASM was moistened, water loss was not only due to partial evaporation, but also due to a significant moisture
drainage into the underlying layers. Despite the low ASM permeability (0.02 m / day), the moisture content of this material fell from 46% to 30% by weight during the day, which confirms the previously proposed position [20] on the rapid discharge of excessive moisture from the ASM, close to the optimum moisture content. For this reason, in full-scale experiments, we were unable to achieve the degree of ASM humidification in excess of 0.80 of the maximum molecular moisture capacity.

Figure 1. (a) Stamp test at the test site. (b) Tests in the experimental tray.

Under experimental tray conditions, it was possible to achieve maximum ASM water saturation by filling the tray bottom to a level of 50 mm with water, which corresponds to the full ASM moisture capacity.

3. Results and discussion
All tests were performed for ASM compaction coefficient of 0.95. The study results obtained during the stamping tests, depending on the ASM moisture content, are shown in Figure 2.

Figure 2. Modulus of elasticity ASM depending on its moisture content.

It can be seen from the graph in Fig. 2 that the elastic modulus values for all experimental conditions are close to each other (the approximation error does not exceed 8% between the dependencies). So modulus of elasticity magnitude, defined in the tray, is similar to the value obtained on the experimental embankment. The effect of the reinforced concrete bottom and tray walls was minimal. ASM layer depths of 800 mm using a stamp with a diameter of 330 mm are sufficient to attenuate excess voltages by 95%.
This agrees with the problem solution of stress formation under a rigid stamp built on the Boussinesq’s theories in the modification of Frolich [21], Love [22], Kandaurov [23] and to a lesser extent Badanin's solution [24] for the broken structure soil with parameters of mechanical properties similar to the investigated ASM.

According to the above solutions, the stresses at a depth of 800 mm in this soil amount to 3-12% of the maximum under the surface of the die, which practically does not affect the experiment course. The calculation results are shown in Figure 3.

![Figure 3. Stresses distribution along the rigid stamp axis.](image)

Since, as is known from [25], the condensed ASM transmits stresses in the horizontal direction much less than in the vertical direction. Consequently, the distance to the boundary of the tray in the horizontal direction was excessive, which allowed to avoid concentration of stresses.

In general, the obtained data, although they say about the accuracy of the conducted tray tests, but indicate the need to use experimental trays with a depth of at least 800-1000 mm, which will allow greater results convergence. The tray dimensions in the horizontal direction can be reduced (but only in the test case of not reinforced with geosynthetic materials soil).

In addition to the main results, all the data were statistically processed to obtain a general relationship describing the change in the ASM modulus of elasticity with increasing moisture content. These data were compared with the publications of other specialists.

As we mentioned earlier, in the works of foreign specialists there is no differentiation into different elastic moduli, therefore, it is not possible to compare the values of the theoretical deformation moduli calculated through the CBR parameter. However, since there is a direct relationship between CBR and the modulus of elasticity, it can be argued that the dependence forms will be of a similar nature [11-16]. Therefore, it is possible to compare the theoretical modulus of elasticity dependence forms on the ASM moisture content obtained earlier abroad with our data.

Our studies show a significant moisture content effect on the load-bearing capacity of the ASM base. Similar results of the influence of moisture content on ASM modulus of elasticity were noted in Pandian [4], Toth et al [3] and in our article [25].

Pandian in his work defined the CBR (the Californian bearing ratio) of different ASM types when they were saturated. He received a significant reduction in load-bearing capacity when soaked. The decrease in the ASM modulus of elasticity with increasing moisture content is also confirmed by the Toth et al experiments [3], in which a decrease in the load-bearing capacity of this technogenic soil with a water saturation of 1.43-1.99 times, depending on the test conditions, is found. As a whole, this correlates with the results of our studies.
Thus, we have confirmed a steady drop in the ASM load-bearing capacity (E) when it is wetted. It should be noted that such a high water ASM saturation (above 0.8) was performed artificially (in the laboratory), from the experimental conditions. Under actual conditions, water is discharged from the ASM array to a relative humidity level of 0.75-0.80.

Moisture content values of 1.0 (complete water saturation) imitate the embankments dumping "on water". Our studies allow us to confirm sufficient load-bearing ASM capacity presence, even in this case. However, unlike the experience of India and Poland (DREDGDIKES Project) [26-29], the climatic features in Russia will not allow the construction of a high-quality earthen cloth with excessive ASM moisture without performing measures to protect it from frost heaving.

4. Conclusions.
According to the research results, the following conclusions are made:
- the numerical values of the modulus of elasticity obtained in the laboratory and in the field conditions are almost identical, which indicates the possibility of using a considerable size experimental chute for carrying out tests with sufficient accuracy;
- for greater tests convergence in the tray and in the test area, the depth of the tray must be at least three diameters of the stamp used;
- we confirmed the dependence character of the load-bearing ASM capacity on humidity in relation to Ekibastuz coals ASM burning;
- the results of the moisture content influence study on the base ASM elasticity modulus showed that this man-made soil can be used for the embankments erection and on the flooded areas, but it is necessary to take into account the base bearing capacity possible loss within the moisture capillary rise (1.2-1.4 m).

References
[1] Collins R J and Srivastava L 1989 Use of Ash in Highway Construction: Delaware Demonstration Project Final Report Electric Power Research Institute Report No. GS-6540 (Palo Alto, CA) p 126
[2] Brendel G F and Glogowski P E 1989 Ash Utilization in Highways: Pennsylvania Demonstration Project Electric Power Research Institute Report No. GS-6431 (Palo Alto, CA) p 132
[3] Toth P S, Chan H T and Cragg C B 1988 Coal ash as structural fill with special reference to Ontario experience Canadian Geotechnical Journal 25 pp 694–704
[4] Pandian N S 2004 Fly ash characterization with reference to geotechnical application Journal Indian Institute of Science 84 pp 189–216
[5] Martin J P, Collins R A, Browning J S and Biehl F J 1990 Properties and use of fly ashes for embankments Energy 116 (2) pp 71–86
[6] Boldyrev G G, Aref'ev D V and Gordeev A V 2010 Determination of soil deformation characteristics using various laboratory methods Inzh. Izysk 8 pp 16–23
[7] Popa H and Batali L 2010 Using Finite Element Method in geotechnical design. Soil constitutive laws and calibration of the parameters. Retaining wall case study WSEAS Transactions on applied and theoretical mechanics 5 (3) pp 177–186
[8] Jiki P N, Agber J U and Osadebe N N 2012 Finite element evaluation of bearing capacity parameters for soils in the University of Agriculture, Makurdi Indian J. Innovations Dev. 1 (3) pp 121–126
[9] Boldyrev G G 2008 Methods for the determination of mechanical properties of soils. The state of the question (Penza: Penza State University of Architecture and Construction) p 695
[10] ASTM 1883-16 Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils (West Conshohocken: ASTM International) p 14
[11] Heukelom W and Foster C R 1960 Dynamic Testing of Pavements J. of the Soil Mechanics and Foundations Division 86 SM1 pp 1–28
[12] Heukelom W and Klomp A J G 1962 Dynamic Testing as a Means of Controlling Pavements During and After Construction Proc. of 1st Int. Conf. on Structural Design of Asphalt Pavements pp 495–510

[13] Green J L and Hall J W 1975 Nondestructive Vibratory Testing of Airport Pavements Volume I: Experimental Test Results and Development of Evaluation Methodology and Procedure Federal Aviation Administration Report No. FAA-RD-73-205-1 (Vicksburg: National Technical Information Service) p 214

[14] Witzczak M W, Qi X and Mirza M W 1995 Use of Nonlinear Subgrade Modulus in AASHTO Design Procedure J. of Transportation Engineering 121 pp 273–282

[15] Powell W D, Potter J F, Mayhew H C and Nunn M E 1984 The Structural Design of Bituminous Roads Transport and Road Research Laboratory TRRL Laboratory Report 1132 (Berkshire: Department of Transport) p 62

[16] Putri E E, Rao N S V K and Mannan M A 2012 Evaluation of Modulus of Elasticity and Modulus of Subgrade Reaction of Soils Using CBR Test J. of Civil Engineering Research 2 pp 34–40.

[17] El-Kasaby E 1991 Estimation of Guide Values for the Modulus of Elasticity of Soil Bulletin of Faculty of Engineering, Assiut University 19 pp 1–7

[18] Kosterin E V 1993 Methodical instructions to the laboratory work "Determination by stamping tests of the modulus of deformation of the sand base and the distribution of stresses in it" (Omsk: SibADI) p 12

[19] IRMD 218.5.007-2016 Methodical recommendations for determining the modulus of elasticity of pavement using a static hard stamp (Moscow: Informavtodor) p 24

[20] Ivanov E V 2015 Substantiation of application of ash and slag mixtures for construction of an earthen cloth taking into account a water-heat regime (Omsk: SibADI) p 165

[21] Frolich O K 1934 Druckverteilung im Baugrunde (Wien: Springer) p 188

[22] Aleksandrov A S 2015 Improving the calculation of road structures for shear resistance. Part 1. Status of the issue (Omsk: SibADI) p 292

[23] Kandaurov I I 1988 Mechanics of Granular Media and Its Application in Civil Engineering (Leningrad: stroiyzdat) p 280

[24] Badanin A N, Bugrov A K and Krotov A V 2012 The determination of the first critical load on particulate medium of sandy loam foundation Magazine of Civil Engineering 9(35) pp 29–34

[25] Sirotyuk V V and Lunev A A 2017 Strength and deformation characteristics of ash and slag mixture Magazine of Civil Engineering 6 pp 3–16

[26] Sinha A K, Havanagi V G, Mathur S and Guruvittal U K 2010 Investigation and design of pond ash road embankment 2nd Int. Conf. on CPT pp 3–49

[27] Ossowski R and Gwizdala K 2017 Mechanical properties of a dike formed from a soil-ash composite Procedia Engineering 172 pp 816–822

[28] Sikora Z and Ossowski R 2013 Geotechnical Aspects of Dike Construction Using Soil-Ash Composites Procedia Engineering 57 pp 1029–1035

[29] Bałachowski L and Sikora Z 2013 Mechanical properties of fly ash - dredged material mixtures on laboratory test Studia Geotechnica et Mechanica 25 pp 3–11