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USE OF DIGITAL IMAGE CORRELATION FOR THE TESTS OF FRAGMENTED MATERIALS

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ABSTRACT

An important feature in road construction is the behaviour of materials under applied load, which consequently determines the mechanisms of material degradation and the permissible range of stresses and strains to prevent a premature failure of road layers in the pavement structure.

Materials bound with binders or various non-cohesive materials are most often applied to build the structural layers of road surfaces. The nature of the used materials is crucial for the durability of a pavement structure composed of layers with different properties. Advanced measurement methods are applied to determine the properties of these materials. The article presents the results of laboratory tests on a non-cohesive material placed in a large-sized box that was gradually loaded. In order to optimize design solutions, the behaviour of the tested material under load was analysed using a modern digital image correlation technique.

Keywords: advanced measurement method, digital image correlation (DIC), fragmented material, road construction.

INTRODUCTION

Road structures are constructed as a package of layers. The features of each of the layers exert influence on the durability of an entire road structure. The layers are made of bound or unbound materials. Laboratory tests dedicated to designing road structure are restricted in the aspect of describing the work of layered road structure, together with the changing conditions of work and the evolution of the features of materials occurring over time. Field studies on test segments and large-scale outdoor-use equipment dedicated to research into road structure similarly represent computational models and changes occurring in a road structure. Applying the advanced measurement methods for research into the work of road structure, in situ and laboratory models, results in acquiring new knowledge on the work of road structures. Owing to the application of new research methods, new opportunities arise within the scope of designing, together with the optimization of road structures, maintaining the principles of sustainability, and the assessment of the usefulness of the materials in various and complex conditions of work. A modern method of measurement, which is still being developed, is the Digital Image Correlation (DIC). This is an optical method not involving any contact with a tested item and taking advantage of the images of a sample surface for the measurement of shape, displacement and deformation. The images are recorded with the application of devices recording the image at various times, states and loads on a sample. In the further course, the analyses of the image are conducted with the application of matching algorithms based on correlations. These methods find application in numerous fields of science and industry, including laboratory tests also such as those conducted on materials, both bound and unbound (Figures 1 and 2) (Alhakim et al. 2023, Kapor et al. 2023, Walotek et al. 2021, Khatami et al. 2019, Sutton et al. 2009).

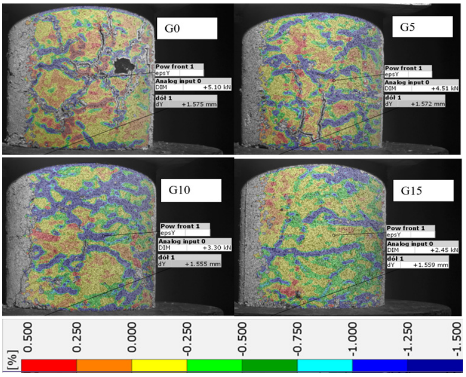

Figure 1 *Example of bound mixture (Walotek et al. 2021)*

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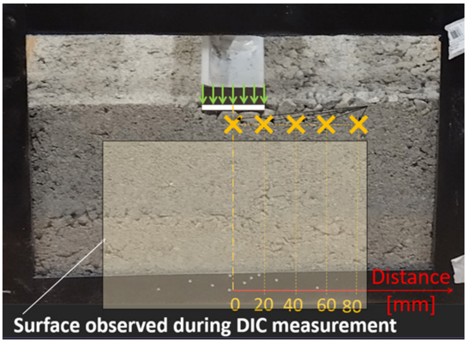

Figure 2 *Model of an unbound mixture*

MATERIALS AND METHODS

In the course of research, the attention was focused on the selection of mixture of aggregates, which, in its either natural of improved state, will find application in the further program of research, and will make it possible to assess the application of the DIC method in laboratory tests for the supporting the work on designing road constructions. For research, materials of natural origin, with contrastive colours on their surfaces, required in the case of recording the surface of a sample by devices dedicated to generating the model of a surface, were applied. As the qualitative model, an artificial random pattern on the surface of a rectangular rubber sample subjected to research was applied (Figures 3 and 4). The research was conducted in several variants. At the first stage, the research was performed using the DIC method on rectangular granite cubes (Figures 5 and 6). In the further course, the research was conducted on a loose/unbound material, placed in a large-sized box. Research into an unbound material in a large-sized box is treated as a primary one. For research, based on a series of research into a natural granite aggregate, having the grain-size distribution of 0/11.2 and the suitable properties of grain-size distribution was selected. An aggregate having the optimum water content was placed in a research chamber and its density was increased. The aggregate consists of a granite rock, owing to its mineral composition, which ensures a naturally pattern necessary for creating a model of the surface of a sample by research devices. To load the sample, a weighting system, which consisted of a hydraulic actuator, an element transmitting the load on the surface of a sample, dial gauges recording the value and the even degree of settlement, dynamometer with a deformation gauge, and also a rigid frame system, being the counterpart of a counterweight, were prepared (Figure 6). The research stand, together with a sample, was prepared in a manner that prevented external impacts on the course of research. The image was recorded with the application of the DIC ARAMIS 3D system. In particular, preventive measures were taken against the impact of vibration, optical phenomena, temperature and moisture on the obtained results of research.


Figure 3 *Coated pattern*

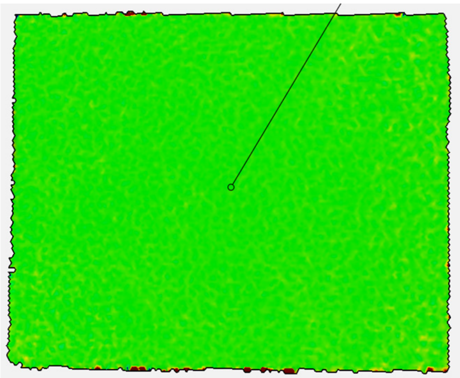
Figure 4 *Model of the surface of a rectangular rubber*

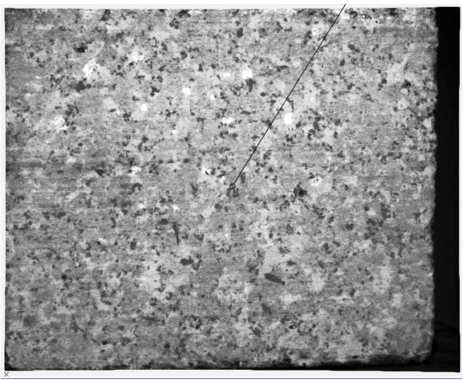
Figure 5 *Surface of a rectangular granite*

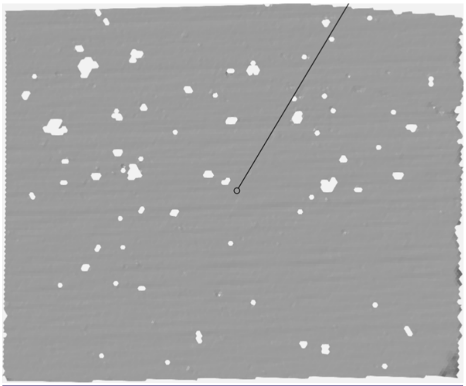

Figure 6 *Model of the surface of a rectangular granite*

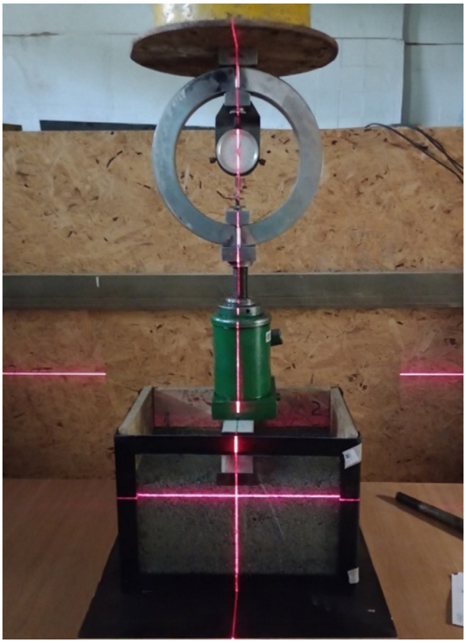

Figure 7 *Research stand dedicated to unbound material using loading the surface with the application of a hydraulic actuator*

RESEARCH

The sample was exposed to a load identical to that in the case of a rigid board under the static load with the application of the VSS method, which is one of the methods applied for the acceptance of the layers of the road structure and layers of embankment (Mackiewicz and Krawczyk, 2015). The load on the model was vertical. Taking into consideration the location of the load and method of research, the analysis of the behaviour of the sample may be conducted in a plane strain. The load on the surface of a sample was conducted in two stages: primary and secondary. Before the beginning of research, a so-called referential image was recorded (this term applies to the state of the sample before applying the load). In the further course, applying the load was commenced and continued until the value of pressure on the surface of a sample reached 125 kPa. After load had been achieved, together with the stabilization of the values of settlement, measured with the application of a dial gauge on the element transmitting the load, the load was increased to 250 kPa. Next, the load value was raised to 375 kPa, and after stabilization of displacement, the load was fully removed from the sample. In the further course, the sample was exposed to secondary load according to the same procedure as in the case of the primary load. The scheme of the load and the values of settlement depending on the distances from the axis of load are presented in a chart (Figure 8). Based on the results, the recordings of the images of the surfaces of a sample with the application of the DIC ARAMIS 3D devices, data that were applied to generate the map displacements, were obtained. These data served, among others, to conduct a reverse analysis, the purpose of which was to determine the parameters of a constitutive model. At this stage of the analysis of the results, attention was focused on the phenomenon of the partial loss of the surfaces of the model on the maps of displacement generated by the DIC. As it is presented in Figures 9 and 10, together with an increase in deformations accompanying an increase in the load, the phenomenon of the loss of the surface of a model occurs. The difference between changes in the surface of the generated model concerning the referential one amounted to no more than 28%. The phase of removing the load was marked by an increase in the surface generated by research devices. The zones of the loss of the surface of a model in the phases of primary and secondary load are assumed to be similar within the area of the occurrence of the high value of displacement.

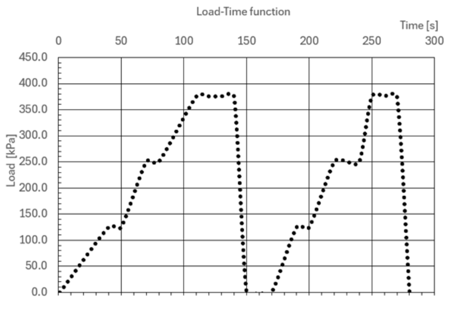

Figure 8 *Function of load in time*

Figure 9 *Map of the displacements of primary load reaching the value of 125 kPa*

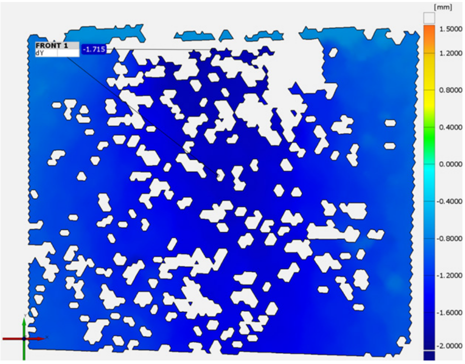

Figure 10 *Map of the displacements of primary load reaching the value of 375 kPa*

ANALYSIS

Change in the surface, the map of the displacement of which is created by the DIC system, determines the quality of data, which can be subjected to further analysis. The quality of the image acquired by the system is described by the model area factor. This describes the proportions of the model surface, under a set load, to the surface of the referential model (before applying the load). The value of the factor amounting to 1.000 means generating a model encompassing the entire surface, whereas the parameter having the value of 0.000 means the total loss of the surface in proportion to the referential model. The loss of the area in proportion to the maximum displacement values of the researched model made of a granite aggregate having the grain-size distribution of 0/11.2 is presented in the chart (Figure 11). A decrease in the value of the factor of the surface matching an increase in displacements is noticeable.

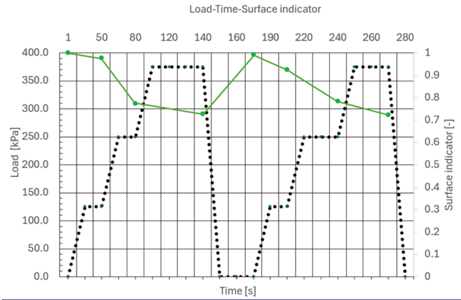

Figure 11 *Correlation between the lost surface of the model, the load and time*

An opposite phenomenon is observed in the course of the phase of removing the load; in the course of stress relieving the material, an increased value of this factor is observed. The phenomenon of the loss of surface is bound with the features of the sample, such as density, moisture, the colour of the aggregate, porousness, and also factors resulting from applying the load. The load is accompanied by the rotation of grains and their mutual displacement, which is connected with the manner of generating the model of the surface based on points plotted on the surface of a sample.

CONCLUSIONS

The analyses of the surfaces of various materials having different properties and being in different conditions make it possible to formulate conclusions relevant to the preparation of a research stand dedicated to research into granular materials with the application of the DIC method. The conditions of research conducted with the application of the DIC method constitute an important factor exerting influence on the quality of research. It is important to restricting optical phenomena on the surface of the sample and devices, taking under consideration a special case of the application of a transparent partition, For example: changes in the moisture of a material, changes in temperature and air flow on the research stand, and external vibration exerting influence on the sample (and more). Extending the scope of measurements conducted with the application of this method (DIC), complementing it with other advanced methods of measurement such as, for instance, fibre sensors, and also constructing outdoor-use model for laboratory research, will make it possible to conduct a more comprehensive analysis and the assessment of the work of a laboratory model, and representing the actual construction of a road structure.

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