SLOVAK JOURNAL
OF
CIVIL ENGINEERING

2003/1 PAGES 11 – 25 RECEIVED 8. 4. 2002 ACCEPTED 15. 11. 2002

K. GRÜNNER, T. DURMEKOVÁ,
P. WAGNER

EXPLOITATION POSSIBILITIES OF THE TUNNEL`S MUCK AS A CONSTRUCTION MATERIAL

Karol Grünner, PhD., Assoc. Prof.

Research field: Road materials properties, Road pavements, Construction technology
Address: Department of Transportation Engineering – Road Research and Scientific Laboratory, Faculty of Civil Engineering, Slovak Technical University,
Radlinského 11, 813 68 Bratislava

Tatiana Durmeková, RNDr.

Research field: Engineering geology, Rock material properties
Address: Department of Engineering Geology, Faculty of Natural Sciences, Comenius University,
Mlynská dolina G, 842 15 Bratislava

Peter Wagner, PhD., Assoc. Prof.

Research field: Engineering geology, Rock material properties, Geological investigation for tunnels
Address: Department of Engineering Geology, Faculty of Natural Sciences, Comenius University,
Mlynská dolina G, 842 15 Bratislava

ABSTRACT

One of the most important problems connected with the construction of the highway and road sections with the tunnel structures is a proposal of the optimal utilisation of the muck from the pilot galleries and tunnels. Though the requirements to rock material utilisation as a construction material are regulated by various standards, a muck from underground works seems usually as a heterogeneousic mixture of the rock material (from lithological and grain size point of view) without any uniform standard methodical procedures for its evaluation. The authors describe the method for the special-purpose evaluation of a muck aimed as a recommendation offor various ways of its utilisation in civil engineering. This method is demonstrated on the evaluation of the muck from the pilot gallery for the Višňové tunnel (northern Slovakia).

KEY WORDS

- *muck*
- *building stone*
- *aggregates,*
- *properties of rock material,*
- *lithological and size heterogeneity of rocks,*
- *materials valuation*

1 INTRODUCTION

The building of a highway network in Slovakia is taking place. Several tunnels that represent very important highway structures in the mountainous areas of Slovakia and that will be built for the protection and creation of a healthier environment represent part of a large-scale programme of highway construction in Slovakia. The whole length of the projected tunnel sections is about 30 km [1]. In the case of bi-directional traffic, this represents about 60 km of tunnels. In spite of various corrections and new projected ideas, it is clear that tunnel structures are essential in highway construction in Slovakia. This fact follows from the present state of the preparations for the tunnel construction - since the realisation of the pilot gallery, one tube of the Branisko tunnel has been driven; the pilot galleries for the Ovčiarsko tunnel (south of the town of Žilina) and partly for the Horelica tunnel (near of the town of Čadca) have been finished and the pilot gallery for the longest Slovak highway tunnel, Višňové (east of Žilina), and one tube of the Horelica tunnel are presently driven.

Based on the set of geological, engineering-geological, hydrogeological, geotechnical and technological problems connected with tunnel construction, the question of the optimal utilisation of muck has great importance. Because the estimated volume of muck from the projected tunnels is more than 10 mil. m^3 [2], resolving its optimal utilisation as a construction material amounts to an important economic effect (if we take into consideration that the price of material resources is about 43 % of the total costs of construction [3]) and also helps to protect the environment of the broader area around the tunnel.

At the same time, a specific characteristic of the rock environment of Slovak tunnels must be emphasised. All tunnels and galleries driven in Slovakia up to now have been realised in a very lithological-

2003/1 PAGES 11 – 25

ly and structurally heterogeneous rock environment. Therefore, this environment is unsuitable for the utilisation of muck as a construction material. The only exception was a central part of the Branisko tunnel, which was driven in crystalline rocks suitable for exacting forms of utilisation as a construction material. From this point of view it was evaluated according to competent standards [4]. The entrance portions of the Branisko tunnel, as well as the pilot galleries of the Ovčiarsko and Horelica tunnels, were driven in the very heterogeneous environment of Paleogenic flysh rocks, the properties of which are unsuitable for utilisation as a construction material. From the same point of view, a great part of the rocks were proved unsuitable during the driving of the pilot gallery for the Višňové tunnel. In addition to the unsuitable parts of the Paleogene claystones and sandstones from the west tunnel opening, a line of the tunnel crosses wide parts of tectonically deteriorated Mesozoic and crystalline rocks (from the west and east tunnel openings), the utilisation of which as a construction material is very limited.

On the basis of the facts shown during the driving of the pilot galleries and the expected increase in problems with the utilisation of the muck after tunnel driving, the Department of Engineering Geology, Faculty of Natural Sciences, Comenius University in Bratislava conducted a preliminary evaluation of the quality of the muck from the pilot gallery for the Ovčiarsko tunnel and for the west opening of the Višňové tunnel gallery [5, 6, 7]. The obtained knowledge demonstrates the necessity to improve the methodology for the evaluating muck by using current laboratory methods and the requirements of existing and prepared standards, as well as the technological possibilities for muck separation. All these methodological problems are discussed in the introductory parts of this paper, and the results of the rock material's evaluation from the part of Višňové tunnel's pilot gallery are summarised in the concluding sections.

2 PROBLEMS WITH THE SPECIAL PURPOSE EVALUATION OF MUCK

The muck dug from underground structures belongs among rocks used for the production of aggregates (the volume of the soils used in the construction of roads and dams or industrial structures is not important from a practical point of view). The aggregates are defined as an incoherent granular material with the maximum size of the particles, at 125 mm.

The grain size composition of the muck depends on the underground work structure driving method:

- in the case of using a tunnel boring machine (TBM), the size criterion of muck is usually suitable for aggregate definition. Nevertheless, the aggregate obtained by this method is less suitable as a construction material because of the unfavourable shape of the rock fragments (unsuitable for use in concrete production) and its fine grain size. Some experience from abroad shows that in certain cases, blasting driving was preferred to a TBM as a method for procuring more suitable muck for utilisation as a construction material [8, 2],
- if the underground structure is driven by classical methods (using blasting, digging and the carriage of the muck), the character of the muck is very heterogeneous, and its composition depends on the physical state of the rock mass (density and character of the discontinuities), the technology of the blasting works and the method of muck transport. In this case the muck dug from the underground structure is a mixture of building stone and aggregates, usually with an admixture of soils. A uniform methodology for an evaluation of the properties and utilisation of such a rock mixture has not been developed yet.

Because a considerable part of the underground works realised during the construction of the highway network in Slovakia has been driven by the classical methods, it is necessary to carry out an evaluation of the properties and the proposed utilisation of the muck on samples corresponding to this driving method. Technological samples (weight of about 50 kg) are used for these purposes. Such a type of sample has a sufficiently representative character (a technological sample consists of several portions of material sampled from the quasi-homogeneous sections of a underground work). Nevertheless, the basic problem of a technological sample evaluation - its heterogeneity - must be underscored. Besides the basic size heterogeneity (a mixture of building stones, aggregates and soils where an application of current standards is impossible), the analysis of the sample is complicated by the significant lithological heterogeneity (for example, in a flysh environment, the presence of solid blocks of sandstones in a matrix of claystones or the reverse) and also by the heterogeneity of the physical state of the rocks (solid and intensively tectonically deteriorated rocks of the same lithological type, etc.).

Based on the elicited facts it is possible to use several methods to evaluate rock material:

- to separate the individual parts of the material (building stones, coarse aggregates, fine aggregates, soils) or the various lithological or deteriorated types of rocks and to test and evaluate them individually. This method requires creating several dumps of the rock material, which complicates the progress of the driving. An application of this method is difficult during current practical driving - the muck is usually showered on the dump without any separation, and a dump of rock mixture is created,
- to concentrate attention on the most unsuitable parts of a rock mixture and consider them as representative of the analysed section. Using this method, relatively good-quality parts of the rock environment could be underestimated, which leads to economic losses.

SLOVAK JOURNAL
OF
CIVIL ENGINEERING

2003/1 PAGES 11 – 25

The process of the evaluation of rock material properties is also complicated by some other facts - the muck weathers very quickly in dumps (especially those consisting of semi-solid rocks) and, in the case of the higher content of some clayey minerals, the character and physical and mechanical properties of the rock mixture change quickly. Therefore, in the process of evaluating rock material the time factor must be considered - the properties of the material dug and transported immediately afterwards to a laboratory may be significantly different from the properties of material dug at the same time from the same part of the gallery, but placed on the dump. The time of changes rock material properties may be relatively short (in the case of claystones and similar semi-solid rocks, it only takes several months).

After taking into consideration all the facts affecting muck properties, we used a method of separation and evaluation of muck as a crushed aggregate in the testing of heterogeneous technological samples. Laboratory tests of samples with the majority of the particles bigger than 125 mm were realised on the crushed lumps. This led to the necessity to modify the excavated rock material - to crush the large particles of the building stone. Moreover, because of the lithological character of the large particles (they were usually claystones, sandy limestones and dolomites), their use as a building stone was not likely.

In the process of selecting the most important properties for the evaluation of the muck as a construction material, we at first used requirements corresponding to the valid Slovak Technical Standards (STN). Simultaneously, we also took into consideration these properties and their tests, which were sufficiently representative for the characterisation of the physical state of the rock material and are widely used in engineering geological and road construction practice. Moreover, we had to take into consideration possibilities for the performance of individual tests regarding the technical equipment of the laboratory.

3 SELECTION OF THE PROPERTIES FOR A SPECIAL-PURPOSE EVALUATION OF THE MUCK

The muck obtained during the driving of underground works is a very heterogeneous mixture of rock material, the major part of which has particle size of aggregates and soils. Also, individual blocks, the size of which corresponds to quarry stones, occur. Grain size heterogeneity is usually complicated by important lithological heterogeneity. Therefore, the material obtained from the muck has after various types of treatment (for example crushing, grading), various properties which allow for different possibilities of its utilisation as a construction material. Each utilisation purpose has to correspond to certain requirements named in the standards.

A review of various ways of utilising muck in civil engineering practice is presented in the next chapter together with the basic requirements for aggregate quality.

3.1 Methods of utilising muck in civil engineering

Inland and foreign engineer-designers are aware of the importance of the maximum utilisation of muck from tunnels. This problem is usually solved in an early stage of preparations for underground construction. In analysing some examples from abroad, Klepsatel and Ledényiová [2] describe the case of the Gotthard tunnel in Switzerland, where about 5,4 million tons of muck is planed to be used in concrete mix for tunnel lining construction and 9,0 million tons into the embankments near the tunnel opening. Another amount of the muck will be used for an arrangement field or sold to local residents and only 0,3 million tons will be placed in dumps. Brtáň [3] describes the volumes of aggregates, necessary for the projected highway section construction in Slovakia. He individually appraises the volumes of aggregates for the embankments, pavements and various types of the monolithic and torcrets concrete for the buildings (bridges, supporting and retaining walls, tunnel linings, etc.) according to the qualitative requirements.

The range of possibilities for utilisation of the modified muck in civil engineering is very broad. Nevertheless, it is generally possible to create the next gradation based on an assessment of the muck according to the desired quality parameters (in order from the most demanding to the less demanding parameters):

- Utilisation for construction layers of transport constructions.
  Quality requirements for aggregates generally increase in the direction from a subgrade to the surface of transport constructions. The aggregates of the highest degree of quality are used in the upper layers (the wearing courses of the pavements) and in railway beds. According to the criterion of rock solidity, the aggregates of andesites, quartzites, limestones, various types of igneous rocks and similar lithological types in a good physical state are suitable. Lesser requirements are given for the quality of aggregates for base courses, which create the subbase layers of a roadway.
- Utilisation for various types of concrete.
  Avery wide range of requirements for the properties of aggregates used as a filling for concrete exists. We can say that concrete used for the wearing courses of pavements (concrete or asphalt) requires a high quality of crushed aggregates, which are strong and resist climatic and traffic effects.
- Utilisation for embankments.
  This method of utilising muck is the most usual because of the lower requirements for the quality of dug material. The requirements for the adaptation of the muck are lower, too. Various technological embankment solutions (for example, „sandwich“ types)

2003/1 PAGES 11 – 25

permit using material of a lower quality into the body of the embankment and, in this way, using the maximum volume of the dug material.

Material of the lowest quality may be used for an arrangement field. Only particularly sensitive rock material (usually clays and claystones with an unstable volume) is deposited in artificial dumps. If the muck's properties are verified early and the method of driving and depositing the muck is well thought out, only a small part of the dug material has to be deposited in artificial dumps - even in the case of tunnels driven in a rock environment with muck unsuitable for utilisation.

3.2 Basic criteria limiting the utilisation of aggregate in civil engineering

The criteria of the utilisation of aggregate for various purposes in civil engineering are summarised in several technological and material standards. The basic method of utilisation may be determined according to the material standards - STN 72 1510, 72 1511 and 72 1512. While in the STN 72 1510 and 72 1511 standards the terminology, classification and basic regulations are summarised, in STN 72 1512, the technical requirements for the quality of fine and coarse aggregates, gravels and crushed gravels are stated. In this standard, coarse aggregates are categorised into five qualitative classes (from A to E). The technological standards follow up this division and state the requirements for individual construction layers or building works, depending on the necessary quality or climate conditions affecting the structure. Therefore, the requirements summarised in STN 72 1512 are based on the process of evaluating muck obtained from aggregates. The only exception is a lithological type of dolomite, which is considered a questionable material due to its slacking. The requirements for the utilisation of dolomitic aggregates in concrete are described in STN 72 1475. The dolomitic aggregates are categorised into two qualitative classes (I. and II.) according to this standard.

The chief determining properties for the categorisation of aggregates into qualitative classes are: particle size distribution, oversieve and undersieve, percentage of particles with an unsuitable shape, content of washed away and heterogeneous particles, the hydrophility coefficient (for fine aggregates), the sulphur content, the resistance to fragmentation using the Los Angeles test, frost resistance, the value of polished stone, water absorption, the clay content and the resistance to fragmentation by the impact test. The limiting values of these properties for the defined qualitative classes of the aggregates are summarised in STN 72 1512. Generally, it is possible to state that for more exact purposes (constructional concrete, wearing courses), the aggregates of classes A or B (and under some conditions also C) are suitable. Aggregates of lower classes may be used for the subgrade layers of pavements, embankments and arrangement fields.

The procedures for determining the mentioned properties are described in standards STN 72 1170 to STN 72 1185. In the introductory stage of the decision making about the possibilities for the rock material we used, out of the large set of tests described in these standards, only the tests which were possible to be performed in commonly equipped road laboratories or rock mechanics laboratories. The selection of the type of test is affected by the next assumption - if any of the preliminary tests exceeds the standard's values of a tested property, the evaluated material is unsuitable for utilisation in engineering constructions and, in such a case, the performance of the whole set of laboratory tests is not necessary.

The requirements for the evaluation of the decisive properties for specific purposes are summarised in different standards. The utilisation of aggregates for transport construction, which are tightly connected with tunnel constructions, allow for many types of technologies (STN 73 6121 to 73 6127). Similarly, utilisation of aggregates for various types of concrete which are usually a part of transportation work is described too.

Utilisation of the aggregates for embankments and other purposes is evaluated analogously. Nevertheless, a majority of the standards describing utilisation of the material for embankments only deal with the evaluation of soil material (STN 72 1002, STN 73 6133, STN 73 3050, STN 73 3055). Because the required properties are obtained from common tests, which are well-known in the practice of soil mechanics (for example, tests on determining an apparent density, a liquidity limit, the organic matters content, relative strength CBR, etc.) and because of the specific features of the special purposeful assessment of soils, these problems are not analysed in the paper.

At present, the European Standards (EN) and International Standards (ISO) are incorporated into the Slovak Standards system (STN). With the regard to the present state of STN, the most significant changes will concern the testing procedures for some aggregate properties [9, 10]. New standards for mixtures and their processing, as well as standards for the utilisation of aggregates for mortar, concrete, roads and pavements have been prepared in connection with the completion of the set of the European Standards for aggregate testing. Other standards will describe the requirements for aggregates with asphalt binding, as well as hydraulically cemented and non-binding light aggregates. At present parallel Slovak (STN) and European (STN EN) standards till 1 July 2004 in the aggregate testing sector are valid.

Experience from the engineering geological and geotechnical practices shows that a good description of the physical state of rocks (and indirectly the possibilities for their utilisation) requires the study of more properties than is stated in STN 72 1512. Moreover, this fact results from the comment of STN 72 1511 where an extensive set of tests for determining the various properties of aggregates is mentioned. First of all, the tests for determining the physical properties of rock

SLOVAK JOURNAL OF CIVIL ENGINEERING

2003/1 PAGES 11 – 25

material (apparent density, real density, porosity and water absorption) are mentioned and also a few tests for determining the mechanical properties (strength, rarely deformation) are described. The tests characterising the resistance of rocks against the effect of weather conditions and traffic are required, too. The practical application of evaluating rock material according to the whole set of mentioned properties is described, for example, by Ďurkovič and Malinovský [11]. The utilisation of these properties firstly for the physical state of rock evaluation (for example the degree of weathering) is illustrated in various research papers.

After summarising the requirements for the rock material properties in the standards and based on other experience, we created a sequence and content for testing muck samples. This methodical proposal concerns the possibilities of using equipment of the Road Research Laboratory, Department of Transportation Engineering, Faculty of Civil Engineering, Slovak Technical University and the Laboratory of Rock Mechanics at the Department of Engineering Geology of the Faculty of Natural Sciences, Comenius University in Bratislava. The results of the tests allow, in the very first stage of an evaluation, an indication of the possibilities of using the tested material for a certain purpose.

4 METHODOLOGY OF LABORATORY TESTING OF A MUCK

At first the samples of aggregates collected in the rock mechanics laboratory and obtained by a classic way of muck driving from the first part of the Višňové tunnel (from the side of the west portal), were subdivided on the basis of their granularity, lithological composition and the physical state of their components. The introductory mineralogical analysis permitted not only the definition of the precise name of a rock and its composition, but also the comparison of the clayey content with the requirements of some standards. This was followed by a complex of laboratory tests oriented towards determining basic physical, mechanical and other properties of the rock material. Some tests routinely used in our laboratory practice were supplemented by other tests used in foreign countries. The properties of samples with a significantly high content of fine particles were determined by methods usually used in soil mechanics; these tests are not mentioned in this article. When using standard tests, the authors have commented only on the results of the tests achieved and their importance. They describe in detail only tests that are not included in the Slovak Standards for rock material properties.

4.1 Mineralogical analyses

The mineralogical analyses of the samples were done by research workers of the Geological Institute, Faculty of Natural Sciences, CU, from the section for the Identification of Minerals. They used four methods: manometric analysis, thermal analysis, and optical microscopy of the undissolved remainder and also partial X-ray diffractometry [12, 13]. The thermal and X-ray analyses were used mainly for the identification of clayey minerals. The manometric analysis was applied for the qualitative and quantitative interpretation of carbonate minerals, and the visual study was used for determining the heavy and light elements of the rock.

The results of the manometric analysis provided the following data: the amount of calcite, dolomite, undissolved remainder, the amount of CaO, MgO and CO_2, and the so called difference (this means the amount of non-carbonate minerals dissolved in HCl without releasing CO_2). Unfortunately, it is impossible to determine from the analysis which minerals are present in the undissolved remainder. These can be sulphates or clayey minerals (mainly montmorillonite), Fe^{3+} oxides, Fe-chlorite, etc. Manometric analysis permits determining the exact lithological name of the rock.

The amount of carbonate minerals in the tested samples was also proved by the results of the thermal analysis. It is also possible to identify, besides carbonates, clay from the thermal records (difractograms). Based on the exothermic reactions, the presence of Fe^{3+}, the amount of organic matter or the occurrence of pyrite can be determined in the sample.

For the qualitative assessment of the clay content, X-ray diffraction analysis, either conducted by an analysis of the samples in natural conditions or after saturation with glycerol, is more suitable.This method unambiguously confirms the facts determined by the thermal analysis. It is possible to differentiate, for instance, chlorite and smectite and identify other clayey minerals or confirm the occurrence of quartz and feldspars.

Some basic minerals in undissolved remainders of the samples could be identified by visual study (microscopically). In the samples from the Višňové pilot gallery, for instance, minerals such as quartz, feldspars, limonite, pyrite, heavy minerals (tourmaline, zircon, apatite, rutile, garnet, magnetite) and mica were determined.

4.2 Methods used in the laboratory testing

4.2.1 *Laboratory tests of the physical properties of the rock material*

The following basic physical properties of the rocks were studied: dry apparent den-sity, real density, water absorption and porosity.

- *Apparent density (in dry state)* ρ_V (g.cm^{-3}) was determined using irregular form samples with a weight of about 150 to 200 g according to the STN 72 1154 and STN ISO 6783 standards. The values of the apparent density appropriately characterise the physical condition of a testing material (lower values in comparison with the standard values indicate deteriorated or weathered material).

SLOVAK JOURNAL OF CIVIL ENGINEERING

2003/1 PAGES 11 – 25

- *Real density* ρ (g.cm^{-3}) was determined by the pyknometric method after crushing and grinding the samples to fine particles and after sieving on thin sieves (STN 72 1154). From a practical point of view, real density is a property which enables calculate the porosity value.
- *Porosity P* (%) illustrates the state of the rock material accurately. Generally, the porosity of fresh hard rocks is less than 1 %; porosity above 10 % usually means a higher degree of weathering or degradation of rock the material (understandably, these values are only informative and depend mainly on the lithological type of the rock).
- *Water absorption (weight of water absorption) N* (%) was determined as an increasing weight of the sample after gradual pouring of water and saturation to a constant mass (STN 72 1155, STN ISO 6783). The value of the water absorption belongs among the important criteria for evaluating the utilisation of aggregates according to some standards. Regarding the utilisation of aggregates for concrete, water absorption is a measure of their ability to take water from a fresh concrete mixture.
- *Water absorption (volume of water absorption)* N_0 (%) is a parameter calculated from the mean values of the dry apparent density and the values of the weight of the water absorption (STN 72 1155).

A water absorption test provides accurate results only in rock types that conserve their integrity upon contact with water. Otherwise, the test cannot be performed; actually, it provides no objective results. In that case, the water absorption test can only compensate as a test of the disintegration of the rock that describes the behaviour of rock material in contact with water.

4.2.2 *Laboratory tests of the mechanical properties of rock material*

Only the Point Load Test was applied from the complex of tests. The results of the test offer a good correlation with the uniaxial compressive strength.

- *Point load test (PLT)* helps determine the strength of rocks on irregular fragments very quickly. During the test, the resistance of a rock against compressive loading applied using two coaxial platens with standard dimensions is recorded.

The result of the Point Load Test is a value known as the Index $Is_{(50)}$ (MPa). According to Bieniawski [14], the correlation coefficient most used between the value $Is_{(50)}$ and the value of the uniaxial compressive strength σ_c is 24. ($\sigma_c = 24 \,.\, Is_{(50)}$ [MPa]).

Values of $Is_{(50)}$ less than 2 MPa characterise the low strength, values between 2 and 4 MPa characterise medium strength and values above 4 MPa respond to the high strength of a rock.

4.2.3 *Laboratory tests of the durability properties of rock material*

Point load testing is possible to carry out on samples with a natural water content (immediately after collecting the samples), on dried samples, on constant mass saturated samples and on samples after 25 cycles of the frost resistance test. A comparison of the values obtained from the point load testing on samples in different states helps to deduce the range of factors affecting a rock strength - it leads to the properties characterising the resistance of the rock material.

- *The coefficient of softening* K_1 (STN 72 1163) expresses the reduction of the strength of the saturated samples. It can be calculated from a comparison of the average values $Is_{(50)}$ of saturated and dried samples. Sufficiently resistant rocks usually have a value of K_1 near 1. STN 72 1860 standard requires a value of K_1 greater than 0,85 for aggregates of the first quality class.
- *The coefficient of freezing* K_2 (STN 72 1156) expresses the reduction of the strength of samples after 25 cycles of freezing and thawing. In this case, according to STN 72 1860, the rocks of the first quality class have to have a value of K_2 greater than 0,75.
- *Frost resistance* characterises the ability of rocks to resist to climate changes during the winter season. The saturated samples are exposed alternately freezing and thawing 25 times (one cycle takes 24 hours). The frost resistance of the tested material is expressed by the *loss of weight after freezing* S_z (%) parameter.

The frost resistance test is very exact and models the repeated unfavourable effect of climate changes to a rock.

- *The slake durability test (SDT)* characterises the durability of a rock by the *slake durability index* I_d. The test is carried out using special ELE equipment. It was developed at the Imperial College of Science and Technology in London and accepted by the International Society for Rock Mechanics as standard equipment for evaluating rock resistance against various effects in natural conditions and engineering practice, too.

The tested sample consists of 10 representative fragments of the rock, approximately of an equal size, giving a total weight of 450 to 550 g. During the test the sample is placed in a small rotating, perforated drum with 2 mm standard mesh. The rock fragments are exposed to fragmentation for a period of 10 minutes, with effect of liquid (the drum is placed in a water tank).

The slake durability index is calculated as a percentage of the sample weight before and after the test according to the equation:

$$I_d = B/A \,.\, 100 \qquad (\%)$$

where A is the weight of the dried sample before the test in g,
B the weight of the dried sample after the test in g.

Gamble [15] recommends carrying out this test in two 10-minute cycles and, based on the results, he advises assessing the durability of rock according to a six-degree scale (table 1).

The record of the SDT results also contain, besides the numeric value of the slake durability index I_d, data about the nature of the liquid used, the character of the remainder retained in the drum and the character of the material passing through the drum.

SLOVAK JOURNAL OF CIVIL ENGINEERING

2003/1 PAGES 11 – 25

Tab. 1 *Classification scale of rock resistance based on SDT results*

Class of rock resistence	Values of I_d [%]	
	After one 10-minutes cycle	After two 10-minute cycles
1 Extremely high	> 99	> 98
2 High	98 – 99	95 – 98
3 Relatively high	95 – 98	85 – 95
4 Average	85 – 95	60 – 85
5 Low	60 – 85	20 – 60
6 Very low	< 60	< 20

The slake durability test is mainly recommended for rock material containing clayey minerals (claystones, mudstones etc.).

- *The Los Angeles fragmentation test* permits expression of the resistance of rock against disintegration and crushing. During the test the amount of rock material passed through a 2 mm sieve is determined; the material originated during the fragmentation of the tested sample in a fragmentation drum together with steel balls and after passing the prescribed number of turns (according to STN 72 1175).

4.2.4 *Laboratory tests of the physical and mechanical properties of aggregates*

Material obtained from the gallery was collected from the dump containing muck. According to the standards, the bulk sample was prepared as a mixture of sampling increments. The bulk sample was - according to defined laboratory methodology - reduced to subsamples. The subsamples were the base for laboratory sample preparing. The test portions, as well as the test specimens (in the event more than one statement of a property was needed) were prepared for each test according to the instructions of the relevant standards. The tests, the results of which are summarised in Tables 2 to 6, were conducted on samples prepared in such a manner.

The methods of working with the laboratory tests used are described in the relevant standards.

4.2.5 *Some laboratory tests of aggregates used in foreign countries*

From tests used for determining aggregate properties in Canada and the USA, we applied tests of aggregate adsorption and frost resistance [16, 17].

- *The adsorption test* is an indirect method for determining the relative content of clayey minerals in rock material. The substance of the test consist of the adsorption of bipolar molecules of water on the surface of pores, which are generally negatively charged. The occurrence of clayey minerals in hard or soft rocks is indicated by higher adsorption of the water. Experimentally, after many years of experience, the critical value of adsorption of 1 % has been determined [16]. Rock material with an adsorption value above this limit contains a lot of clayey minerals, and its suitability for engineering construction purposes is either limited or totally useless.

The test is carried out on irregularly shaped samples with a particle size of about 10 - 20 mm. The total weight of the sample is about 500 g. After washing the sample in a stream of water, drying and weighing, is it inserted to an air-tight box with a moisture content of 98 %. The sample should be placed in a ventilated vessel (for instance, in copper mesh). After 72 hours, the sample is taken out of the box and weighed. The adsorption A is calculated according to:

$$A = (m_a - m_s)/m_s \,.\, 100 \qquad (\%)$$

where m_s is the weight of the dried sample before testing,
m_a is the weight of the saturated sample after testing.

- *Frost resistance in a 3 % solution* of NaCl is a widely used standard test. It consists of five freezing and thawing cycles (1 cycle takes 24 hours). The reason of using so expressive shortened procedure comparing with procedures used our country consist in the aggressiveness of the 3 % solution of NaCl (which simulates the situation on roads using spread salt during the winter season).

The test is carried out on aggregates with a particle size of about 10 - 20 mm. The washed sample (the amount is about 500 g) is dried (five hours at 105 °C), weighed and saturated with water for 24 hours. Then it is inserted into a resealable bottle or glass together with a 3 % solution of NaCl. The solution should cover 1/3 of the sample's height. The bottle is closed hermetically and inserted into a freezing box (temperature of about –18 °C) in a laying-down position. The freezing takes 16 hours and the thawing 8 hours. The defrosted sample is again inserted into the box in a different position 90° from the previous one. This permits the solution to act on all the particles evenly. After finishing the last cycle, the sample is washed in a stream of water and sieved on a sieve with a mesh of 10 mm. The sample is dried (five hours at 105 °C) and weighed. The difference between the weight of the sample before the testing and after the testing is the *loss of weight* M_z which is calculated using the equation:

$$M_z = (m_s - m_z)/m_s \,.\, 100 \qquad (\%)$$

where m_s is the weight of the sample before the testing in g,
m_z the weight of the remainder on a sieve with a 10 mm mesh in g.

In Canada, the limit value of this parameter is about 10 % for the utilisation of aggregates as a construction material.

SLOVAK JOURNAL
OF
CIVIL ENGINEERING

2003/1 PAGES 11 – 25

5 EVALUATION OF THE MUCK FROM PART OF THE VIŠŇOVÉ PILOT GALLERY

The complex of laboratory tests described in the preceeding part of the paper was applied to evaluate the muck from the Ovčiarsko and Višňové pilot tunnels. The results obtained were compared with some requirements for the quality of aggregates used for various purposes in civil engineering.
The whole pilot gallery at Ovčiarsko is driven in Paleogenic flysh beds; the material upcast is, in general, suitable to some extent for utilisation in civil engineering. Because the results obtained of the quality of muck from the Ovčiarsko pilot gallery have already been published [18], the results of the investigation of the properties of the muck from the Višňové pilot gallery are presented in this paper. The Višňové pilot gallery is being driven from both sides. Fifteen samples collected from the west entrance to 2,625 km (samples 1V to 15V) and one sample from the east side (100V - 3,071 km) have been tested up to the present in our laboratories.

5.1 Brief description of the geological conditions

The route of the Višňové tunnel is situated in the very heterogeneous geological environment of the core mountain of Lúčanská Malá Fatra. Just the western mouth of the tunnel is in the Paleogenic sediments of the „Žilinská kotlina“ basin. The projected length of the tunnel is 7, 469 km. Most of the length of the tunnel will be driven in the crystalline rocks of the core of the Malá Fatra massif.
The initial 115 m of the pilot gallery from its western mouth has been driven in the flysh strata of the „Žilinská kotlina“ basin, which consists of claystones, siltstones, sandstones, and shales, with a predominance of claystones. The strata moreover, are, in a part near a portal broken by slope deformations (up to 60 m from the portal). There are also manifestations of neotectonic faults, plication and bedding cleavage in further parts of the tunnel [19]. The paleogenic sediments are most damaged at a tectonic contact with the Mesozoic complex at the standpoint 0,0996 - 0,1148 km from the western portal. Mesozoic suits - Jurassic sedimentary formations of the Krí na nappe (limestone and dolomite, marlstone, claystone and evaporite) and Triassic Tatricum cover unit (carbonates, quartzites, siliceous sandstones and conglomerations) constitute the next part of the tunnel from 0,115 km to approximately 1,4 km. Further in the gallery, Paleozoic rocks from the core of the Malá Fatra mountains (granites, biotite diorites, granodiorites and biotite gneisses) occur. From the eastern tunnel's mouth, only crystalline rocks occurre (granite, tonalite, migmatite, gneiss xenolite, quartzite veins and lamprofyre dykes up to 1 m thick). Hence, the pilot tunnel is driven in very inhomogeneous conditions, not only from the lithological point of view, but also with regard to the degree of tectonic deterioration.
The NATM (New Austrian Tunneling Method) is used from the western portal of the gallery, while a TBM (Tunnel Boring Machine) is used from the eastern portal.

5.2 The results of the laboratory testing

The samples for the laboratory research were collected simultaneously while the pilot gallery was being driven. The first two samples, 1V and 2V, were collected from the Paleogenic strata; samples 3V to 10V represented Mesozoic rocks. Other samples represent rocks from the crystalline core (11V to 15V and a sample from the eastern part of the gallery, marked as 100V).

Tab. 2 *The results of the manometric analysis of the samples from the Višňové pilot gallery*

Sample identification	Calcite [%]	Dolomite [%]	Undissolved rest [%]	Difference [%]	CaO [%]	MgO [%]	CO_2 [%]
1VA	88,17	0	11,10	0,73	49,40	0	38,77
1VB1	20,64	0	78,23	1,13	11,56	0	9,08
1VB2	17,02	0	80,75	2,23	9,54	0	7,48
2V	11,51	9,10	77,93	1,46	9,22	1,99	9,40
3V	41,70	0	29,77	28,53	23,36	0	18,33
4V	0	99,21	0,7	0,42	30,17	21,69	47,35
5V	0	85,53	10,78	3,69	26,00	18,70	40,83
6V - pink	2,12	94,80	1,75	1,33	30,02	20,72	46,18
6V- grey	93,41	0	4,10	2,49	52,34	0	41,07
7V	0	85,08	5,87	9,04	25,87	18,60	40,61
8V	0	99,57	0,43	0	30,28	21,77	47,52

SLOVAK JOURNAL OF CIVIL ENGINEERING

2003/1 PAGES 11 – 25

The results of the mineralogical analysis are given in Table 2. An accurate localisation of the muck sampling from the first tunnel part, the lithology of the rocks and the average values of the properties determined are provided in Table 3.

According to the results of the laboratory tests, the material of the crystalline rocks has similar properties. Samples 12V and 14V (Table 3) show the representative values of the basic properties for this group of samples (11V to 15V and 100V). Because the material of the crystalline rocks is generally suitable for civil engineering purposes, its testing as a rock material is insufficient. Therefore, two representative samples of granitic rocks (15V and 100V) were chosen for laboratory tests of the aggregates. Sample 15V was obtained from the western part of the gallery, driving by the classic method, and sample 100V from the eastern part, driving by the TBM.

From a lithological point of view sample 15V mainly consists of porphyritic granodiorite with aplite veins present. Part of the sample consists of fine-grained gneiss. The sample was collected from the dump pile in September, 2001. Because the material in the dump is impure owing to the water used during the driving, the grain size analysis was conducted by sieving in dry and wet conditions. The results of the sieving analysis, which was performed according to STN 72 1183, are summarised in Table 4.

The differing results of the dry and wet sieving indicate, that during the process of driving a large amount of fine and silt grains adhere to the coarse grains. As a result, washing the aggregates obtained from the dump pile is necessary.

Besides the sieving analysis, the basic tests of the physical and mechanical properties of size 8-16 mm aggregates were conducted. The results of the tests are in Table 5.

Sample 100V (3,071 km from the eastern portal) is representative of the granitic material driven by TBM. From a lithological point of view the 100V sample is medium-grained granite to granodiorite. The sample was collected from the dump pile near the eastern portal. Because machine tunnel driving creates scaled form aggregates, crushing the samples in the laboratory was necessary. The results of the laboratory tests are summarised in Table 6. Because of the high proportion of scaled grains, the size analysis of sample was not performed.

5.3 Proposed utilisation of muck for engineering purposes

A simple assessment of the suitability of muck as a construction material is, with regard to its extreme heterogeneity and the large complex of qualitative standard requirements, very difficult. Therefore, we used a simplified method - the method of elimination, which is based on a comparison of the results of the tests used with the requirements of the standards for the specific use (from the highest quality material for constructional concrete and wearing courses of pavements, over material of a lesser quality for subgrade layers of pavements, embankments and terrain arrangements, to material unsuitable for use). In cases, when some of the evaluated properties of the rock material do not respond to the requirements for utilisation for some purpose, the evaluated muck is moved to a lower quality class. It is necessary to say that our division of the muck into quality classes has only an advisory character. The muck used for a determined purpose must be tested by laboratory tests that are strictly required by competent standards.

Another problem is the actual technology of driving, transporting and, most of all, the method of deposition of the muck. The deposition of the muck has great significance for the evaluation of the highly heterogeneous and unsuitable rock material excavated from a Paleogenic flysh environment. The properties of excavated material with high a clay content change very quickly due to the effect of climate factors. Material decomposes, and in the case of unseparated storage, it has an unfavourable effect on the relatively more useful rocks. Then, over a short period, a dump of deposited aggregate changes to unsuitable rock with an unstable volume. However, it is not possible to separate individual portions of the muck during the driving; therefore, in the preferential evaluation of the muck, the presence of materials with more negative properties is asserted.

The above mentioned facts were taken into consideration in the proposed utilisation of the muck dug from the western side of the Višňové pilot gallery (the part of the gallery 0,8081 km from the western portal).

Based on the conducted tests, it can be seen that only muck represented by samples 4V, 6V and 8V can be taken into consideration for use in concrete. Because these samples are mainly comprised of dolomites (except for sample 6V which is a mixture of dolomites and limestones), we can use the requirements of STN 72 1475. Because the analysis of the particle size distribution of the collected samples has not been done, we can make our statement only with regard to some standard requirements.

With regard to the clay content the purest is the rock material represented by samples 4V (the undissolved remainder is only 0,7 %, and it does not contain clayey minerals) and 8V1 (the undissolved remainder is 0,43 % and it contains only quartz, biotite and pyrite - Table 2). Both samples also comply with the requirement of the L.A. fragmentation test (value of K_0 is less than 40 % - Table 3). With regard to the tests result, the samples represent a material of low porosity and water absorption, which is also suitable according to foreign experience (the value of the adsorption is less than 1 %, and value of the frost resistance is less than 10 %). The strength tests have demonstrated that the strength of these two samples is the highest, although the PLT results of sample 4V have a high dispersion of the values. Moreover, sample 4V was very sensitive to water and

SLOVAK JOURNAL OF CIVIL ENGINEERING
2003/1 PAGES 11 – 25

Tab. 3 *Average values of some determined properties of the samples from the west part of Višňové pilot gallery*

Sample identification	Stand-point [km]	Lithology of rock	Apparent density ρ_V [g.cm^{-3}]	Real density ρ [g.cm^{-3}]	Porosity P [%]	Water absorption N [%]	Frost resistance S_z [%]	Adsorption A [%]	Frost resistance in NaCl [%]	Durability SDT class	Point load test PLT $I_{s(50)}$ [MPa]	Coefficient of softening K_1	Coefficient of freezing K_2	L. A. fragmentation test K_0 [%]
1VA	0,000 - 0,0292	Sandy limestone	2,41	2,703	10,8	4,38	5,8	0,4	25,5	-	2,99	1,06	0,66	-
1VB1	0,000 - 0,0292	Sandy claystone	2,27	2,598	12,6	5,54	31,2	-	-	-	0,9	0,72	0,48	-
1VB2	0,000 - 0,0292	Claystone	2,38	2,652	10,3	decom-position	-	3,4	56,5	3 - 4	1,22	-	-	-
2V	0,0823	Claystone	2,40	2,628	8,7	decom-position	-	3,9	45,5	3	1,35	-	-	-
3V	0,2527	Clayey limestone	2,63	2,721	3,34	decom-position	-	2,5	70,0	4	-	-	-	-
4V	0,342	Dolomite	2,83	2,842	0,42	0,28	0,86	0,05	0,55	1 - 2	3,23	0,41	0,37	23,39
5V1	0,3894	Dolomite	2,83	-	14,64	0,22	-	1,53	33,9	1	2,72	1,21	-	-
5V2	0,3894	Alterate dolomite	2,39	2,800	14,64	decom-position	-	-	-	6	-	-	-	-
6V	0,6906	Dolomite Limestone	2,73	2,824	3,33	1,16	0,62	0,09	12,26	2	2,16	1,27	1,00	26,04
7V	0,744 - 0,746	Dolomite	2,40	2,816	14,77	decom-position	-	0,6	55,0	4	0,95	-	-	-
8V1	0,8081	Dolomite fresh	2,81	2,852	1,48	0,51	-	0,03	2,0	-	3,84	1,20	-	32,35
8V2	0,8081	Dolomite weathered	2,74	2,852	3,92	1,10	-	-	-	3	-	-	-	-
12V	1,8468 - 1,8537	Granite	2,67	2,694	0,89	0,31	0,07	-	-	1	3,85	0,64	0,60	-
14V	2,4253	Grano-diorite	2,68	2,711	1,14	0,52	0,17	-	-	1	2,57	0,62	0,50	-

SLOVAK JOURNAL OF CIVIL ENGINEERING

2003/1 PAGES 11 – 25

Tab. 4 *Sieving analysis results of the aggregates from the west portal of the Višňové pilot gallery (sample 15V, km 2,625)*

Test sieve [mm]	Retained on a sieve [%]						Passing sieve [%]	
	Dry sieving			Wet sieving			Dry sieving	Wet sieving
	sample 1	sample 2	average	sample 1	sample 2	average		
63	4,25	2,46	3,36	4,22	2,42	3,32	96,64	96,68
45	11,06	15,16	13,11	10,90	14,98	12,94	83,53	83,74
32	25,07	26,41	25,74	24,83	26,06	25,45	57,79	58,29
22	19,24	28,01	23,62	19,07	27,85	23,46	34,17	34,83
16	14,68	14,80	14,74	14,55	14,65	14,60	19,43	20,23
11	11,71	6,02	8,87	11,61	5,93	8,77	10,56	11,46
8	6,20	1,92	4,06	6,16	1,89	4,02	6,50	7,44
6	2,03	0,69	1,36	2,01	0,77	1,39	5,14	6,05
4	0,77	0,27	0,52	0,76	0,27	0,52	4,62	5,53
2	0,92	0,37	0,64	0,94	0,38	0,66	3,98	4,87
1	0,58	0,52	0,55	0,61	0,56	0,58	3,43	4,29
05	0,83	0,84	0,84	0,86	0,87	0,87	2,59	3,42
025	0,91	0,85	0,88	0,99	0,93	0,96	1,78	2,46
0125	0,70	0,68	0,69	0,83	0,80	0,81	1,02	1,65
009	0,37	0,23	0,30	0,52	0,37	0,45	0,72	1,20
passing	0,68	0,77	0,72	1,14	1,35	1,20	-	-

	Dry sieving	Wet sieving
Content of particles max. 0,5 mm [% of weight]	2,59	3,42
Content of particles max. 2 mm [% of weight]	3,98	4,87
Washed away particles [% of weight]	0,34	0,67
Heterogeneous particles [% of weight]	0,00	0,00
According to requirements of STN 72 1512, for category	B	B

frost effects (the low values of the coefficients of the softening and freezing). Nevertheless, it is possible to say that the results of the tests conducted did not exceed any of the requirements which would exclude samples 4V and 8V1 from utilisation as filling material for concrete or for construction layers of pavements. For a definitive assessment, it is necessary to conduct all the tests according to the standard. Sample 8V contains material of a lesser quality (8V2) which could affect the possibilities for its use for the mentioned purposes.

Sample 6V represents a mixture of limestones and dolomites. This means, that for its evaluation, the requirements of Standard STN 72 1512 must be taken into consideration, too. When considering the mineralogical composition, the sample does not contravene the standard limits of clayey mineral content and therefore complies with the demands of the L.A. fragmentation and frost resistance tests. The sample does not comply, however, with the Canadian requirements of frost resistance in NaCl, and the determined porosity (3,3 %) is relatively high. The strength values are low - they are at the level of a conventional limit between hard and soft rocks. After testing for the other properties required by the standards, it cannot be eliminated the using of this rock material for concrete of lower quality.

The assessment of material for lower layers of pavements was processed similarly, according to Standards STN 72 1512 and 72 1475 for class C or II. It is necessary to say that there is a greater content of dolomite material in the tested samples which constitutes a disintegrated and crumbly material; therefore, its utilisation for constructional layers of pavements could be limited.

The rock aggregates which do not comply with the above-mentioned requirements can be used for embankments or, in the case of another negative property (for instance, high sensitivity in contact with water, decomposition), it is possible to build it into central parts

SLOVAK JOURNAL
OF
CIVIL ENGINEERING

2003/1 PAGES 11 – 25

Tab. 5 *Results of the laboratory tests of the aggregates (the western part of the Višňové pilot gallery, sample 15V)*

Test type	Tested according to	Test results	Requirement of STN 72 1512 for category		Requirement of STN 73 6129 for TDZ[1] I a II
			A	B	
Particle size distribution: oversieve [% of w.] undersieve [% of w.] passing next smaler sieve [% of w.] content of particles less than 0,09 mm [% of w.]	STN 72 1172 STN 72 1183	 table 4 1,20	 max. 10 max. 10 ----- -----	 max. 10 max. 15 max. 5 -----	 ----- ----- ----- max. 1,0
Polished stone value, f_{OK}	STN 72 1182	0,48	min. 0,50	min. 0,48	min. 0,50
Resistance to fragmentation by LA test, K_O [% of w.]	STN 72 1175	28,9	max. 25	max. 30	max. 20
Resistance to wear (micro-Deval), Q_O [% of w.]	STN EN 1097 - 1	13,4	-----	-----	max. 20 CVVL criterion[2]
Frost resistance, $Q_{m,25}$ [% of w.]	STN 72 1176	1,2	max. 3	max. 4	max. 3,0
Natrium sulphate test, $Q_{t,5}$ [% of w.]	STN 72 1176	-	max. 8	max. 10	-----
Content of particle with shape index 3 and more, $b_{i,3}$ [% of w.]	STN 72 1172	15,0	max. 25	max. 35	max. 20
Particle density: real, ρ [g.cm^{-3}] apparent, ρ_V [g.cm^{-3}]	STN 72 1171 2,681 2,631	 ----- -----	 ----- -----	 ----- -----	
Water absorption, N [% of w.]	STN 72 1174	0,84	max. 1,5	max. 1,5	-----
Porosity, P [% of w.]	STN 72 1171	1,88	-----	-----	-----
Washed away particles [% of w.]	STN 72 1173	0,67	max. 0,7	max. 1,0	-----
Heterogeneous particles [% of w.]	STN 72 1180	0,00	max. 0,25	max. 0,25	-----

Note: [1] Class of traffic load (TDZ)
[2] Criterion used in the Road Research and Scientific Laboratory (CVVL), STU

Tab. 6 *Results of the laboratory tests of the aggregates (the eastern part of the Višňové pilot gallery, sample 100V)*

Test type	Tested according to	Test results	Requirement of STN 72 1512 for category		Requirement of STN 73 6129 for TDZ[1] I a II
			A	B	
Polished stone value, f_{OK}	STN 72 1182	0,49	min. 0,50	min. 0,48	min. 0,50
Resistance to fragmentation by LA test, K_O [% of w.]	STN 72 1175	25,28	max. 25	max.0 30	max. 20
Resistance to wear (micro-Deval), Q_O [% of w.]	STN EN 1097 - 1	10,4	-----	-----	max. 20 CVVL criterion[2]
Frost resistance, $Q_{m,25}$ [% of w.]	STN 72 1176	1,7	max. 3	max. 4	max. 3,0
Natrium sulphate test, $Q_{t,5}$ [% of w.]	STN 72 1176	-	max. 8	max. 10	-----
Content of particle with shape index 3 and more, $b_{i,3}$ [% of w.]	STN 72 1172	71,0	max. 25	max. 35	max. 20
Water absorption, N [% of w.]	STN 72 1174	0,87	max. 1,5	max. 1,5	-----
Washed-away particles [% of w.]	STN 72 1173	-	max. 0,7	max. 1,0	-----
Heterogeneous particles [% of w.]	STN 72 1180	0,00	max. 0,25	max. 0,25	-----

SLOVAK JOURNAL OF CIVIL ENGINEERING

2003/1 PAGES 11 – 25

of embankments. On the basis of the test results, utilisation for embankments is assumed in samples 1VA (with high values of porosity and absorption capacity and relatively low values of frost resistance), 1VB1 (the sample with low frost resistance) and 8V2 (with relatively high porosity). According to the values of the properties, the material represented by these samples may be placed under protective layers only.

The extreme sensitivity in contact with water of samples 1VB2, 2V, 3V, 5V2 and 7V (all the samples disintegrated in water), which was also confirmed by SDT (Table 3) in some cases, leads to the statement that the material of these samples is suitable only for central parts of embankments or for simple terrain arrangements and restoration.

The division of the tested samples according to their utilisation for various engineering purposes is summarised in Table 7. As it is impossible to store the dug material separately during the drilling work, it will probably be used as material of a lower quality only. It must be underscored once again that it is necessary to carry out a complex of tests required by the corresponding standards before using the selected rock type for a particular purpose.

The other situation came after the driving in the crystalline rock mass (after a stand-point approximately 1,500 km from the western portal of the pilot gallery). The crystalline rocks (granite, granodiorite) dug from this and from the eastern part of the gallery have different properties as they are Paleogenic and Mesozoic rocks. The test results summarised in Tables 4, 5 and 6 refer to the fact that crystalline rocks will be capable far better utilisation than muck from the first western section of the gallery.

The tested samples 15V and 100V satisfy the requirements of the standard STN 72 1512 „Normal weight aggregates for building purposes. Technical requirements.“ for class B of coarse aggregates, and also according to their polishing resistance. The tested samples also satisfy all the requirements of the standard STN 73 6121 „Road building. Asphalt pavement courses.“ According to this standard the lowest class B for aggregates into asphalt layers is required.

According to the requirements of STN 73 6121, „Asphalt pavement courses“, and also according to STN 73 6129 „Sprays and surface dressings“ it is possible to use the rock material of the tested samples for asphalt pavement courses and for surface dressings of less-encumbered wearing courses of roads with traffic load of the classes of traffic load III to V.

Generally, according to STN 73 6121 to 34 it is possible to evaluate samples 15V and 100V as aggregates, which are suitable for current road sections in the classes of traffic load III to V, all construction layers and concrete and railroads, as well.

6 DISCUSSION AND CONCLUSION

Besides the general proposal for utilisation of the muck from selected parts of the Višňové pilot gallery for construction purposes we discovered several interesting facts, in terms of basic methodological knowledge and application of the results of the muck's laboratory tests. Simultaneously, it was confirmed that the results obtained by one type of test only cannot be sufficiently representative (for example, the comparison of the results of the SDT with disintegration of sam-

Tab. 7 *Suitability of the tested muck for various engineering purposes*

The purpose of the muck's utilisation	Sample identification	Note
For concrete, wearing courses of pavements and railroads	4V, 6V, 8V1, 9V	Suitability is necessary to be verified by other tests of properties according to STN 72 1512 and 72 1475 and evaluated according to STN 73 6121 to 73 6128.
For subgrade layers of pavements and railroads	4V, 6V, 8V1, 9V	Suitability is necessary to be verified by other tests of properties according to STN 72 1512 and evaluated according to STN 73 6124 - 27 and the standard TN 72 1514.
For embankments (probably only into parts protected from the direct effect of climate factors)	1VA, 1VB1, 5V1, 8V2, 10V	Suitability depends on the results of additional tests of the properties and on the technological project of the embankment.
Into the internal part of embankments or as a lesser-quality component	1VA, 1VB1, 5V1, 8V2, 10V, 1VB2, 2V, 3V, 5V2, 7V	Suitability depends on the results of additional tests of the properties and on the technological project of the embankment.
Deposition to dumps or utilisation in a simple arrangement field	1VB2, 2V, 3V, 5V2, 7V	

SLOVAK JOURNAL
OF
CIVIL ENGINEERING

2003/1 PAGES 11 – 25

ples in water during the adsorption test was unexpected - samples 1VB2 and 2V disintegrated in water, but their slake durability index was relatively high).

The series of tests show the suitability of the short frost resistance test (not only from the time-saving viewpoint, but also in the case of materials that disintegrate in water, the frost resistance test in NaCl solution was conducted - see sample 1VB2). The adsorption test helps to identify clayey minerals in the muck indirectly.

Though the described method of muck evaluation is not definitive and its application depends on several facts (however, some of them cannot be affected by the authors of laboratory tests - for example, separate dumping of the muck), we assume that for a first decision about the possibilities of utilising the muck, the engineer-designer obtains valuable information which has to be validated by further tests. The laboratory test results also demonstrated that the utilisation of dug rock material must be evaluated depending on the driving method. Various methods of driving affect the cleanliness and particle shape index of the dug material. The method of classic driving used from the western part of the gallery is more suitable even when partially polluted grains are obtained. It is evident that the utilisation of such muck (mainly, tested granodiorite) can fully substitute for rocks exploited from quarries with minimal costs necessary for the treatment of dug rocks stored in dumps.

ACKNOWLEDGEMENTS

The paper was developed thanks to VEGA Grant Project No. 1/7127/20 and 1/0323/03 at the Faculty of Civil Engineering, Slovak Technical University in Bratislava, and No. 1/7364/20 and 1/9159/02 at the Faculty of Natural Sciences, Comenius University in Bratislava. The authors thank the VEGA agency for its kind support.

REFERENCES

1 **BRTÁŇ, F.:** *Tunelové objekty vo výstavbe diaľníc na území SR*. (Tunnel structures in the construction of highways at the territory of Slovak Republic). In: Tunely pre tretie tisícročie. Prievidza, 1996, pp. 45 - 54 (Slovak)

2 **KLEPSATEL, F., LEDÉNYIOVÁ, T.:** *Využiteľnosť rúbaniny z tunelov*. (Utilisation of the muck from tunnels). In: Výroba kameniva *2000. Bratislava, 2000, pp. 127 - 130 (Slovak)

3 **BRTÁŇ, F.:** *Kamenivo pre výstavbu diaľníc*. (Aggregates for highway construction). In: Výroba kameniva *98. Stará Lesná, 1998, pp. 21 - 27 (Slovak)

4 **HATALA, J., ĎUROVE, J., VAVREK, P. and MARAS, M.:** *Predpokladané vlastnosti kameniva vyrobeného z hornín kryštalinika tunela Branisko*. (Expected properties of aggregates produced from crystalline rocks of the Branisko tunnel). In: Geotechnika 97 - Základ moderných technológií výstavby. Podbanské, 1997, pp. 204 - 206 (Slovak)

5 **HYÁNKOVÁ, A., WAGNER, P.:** *Laboratórne zhodnotenie rúbaniny z prieskumnej štôlne pre tunel Ovčiarsko*. (Laboratory evaluation of the muck from the pilot gallery for the Ovčiarsko tunnel). Manuscript, Katedra inž. geológie PRIF UK, Bratislava, 1998, 21 p. (Slovak)

6 **WAGNER, P., DURMEKOVÁ, T.:** *Laboratórne zhodnotenie rúbaniny z prieskumnej štôlne pre tunel Višňové - úsek 0,0 až 115,0 m od západného portálu*. (Laboratory evaluation of the muck from the pilot gallery for the Višňové tunnel - Section from 0,0 to 115,0 m from the west portal). Manuscript, Katedra inž. geológie PRIF UK, Bratislava, 1999, 16 p. (Slovak)

7 **WAGNER, P., DURMEKOVÁ, T.:** *Laboratórne zhodnotenie rúbaniny z prieskumnej štôlne pre tunel Višňové - úsek 252,7 až 810,0 m od západného portálu*. (Laboratory evaluation of the muck from the pilot gallery for the Višňové tunnel - Section from 252,7 to 810,0 m from the west portal). Manuscript. Katedra inž. geológie PRIF UK, Brati-slava, 2000, 16 pp., (Slovak)

8 **KLEPSATEL, F.:** *Rúbanina z tunelov - stavebné kamenivo, či nežiadúci odpad?* (The muck from tunnels - construction aggregate or undesireable waste?). In: Výroba kameniva *98, Stará Lesná, 1998, pp. 69 - 72 (Slovak)

9 **GRÜNNER, K.:** *Súčasný stav normalizácie v oblasti kameniva u nás*. (Present state of standardization in the aggregate sector in Slovak Republic). In: Výroba kameniva *98. Stará Lesná, 1998, pp. 113 - 116 (Slovak)

10 **GRÜNNER, K., ROMANCOVÁ, I.:** *Implementácia EN z oblasti kameňa a kameniva do sústavy STN*. (Implementation of European Standards from the sector of building stone and aggregate into the system of Slovak Technical Standards). In: Výroba kameniva *2000. Bratislava, 2000, pp. 65 -71 (Slovak)

11 **ĎURKOVIČ, M., MALINOVSKÝ, E.:** *Kamenivo z banských a priemyselných odpadov na stavebné účely*. (Aggregate from mining and industrial waste for construction purposes). In: Výroba kameniva *98, Stará Lesná, 1998, pp. 73 - 80 (Slovak)

12 **TURANOVÁ, L.:** *Laboratórne metódy výskumu minerálov a hornín. II. Manometrická analýza, stanovenie hustoty*

SLOVAK JOURNAL
OF
CIVIL ENGINEERING

2003/1 PAGES 11 – 25

a optické štúdium. (Laboratory methods for mineral and rock research. II. Manometric analysis, determination of density and optical study). In: Biológia - ekológia - chémia, vol. 3, Bratislava, 1998, pp. 28 - 30 (Slovak)

13 **TURANOVÁ, L.:** *Laboratórne metódy výskumu minerálov a hornín. III. Termická a röntgenodifrakčná analýza*. (Laboratory methods for mineral and rock research. III. Thermal and X-ray - diffractometry analysis). Biológia - ekológia - chémia, vol. 2, Bratislava, 1999, pp. 26 - 27 (Slovak)

14 **BIENIAWSKI, Z. T.:** *The point load test in geotechnical practice*. In: Engineering Geology, vol. 9, 1975, pp. 1 - 11

15 **GOODMAN, R. E.:** *Mechanika skaľnych porod*. (Rock mechanics). 1. vyd. Strojizdat, Moskva, 1987, 232 pp., ISBN (Russian)

16 **HUDEC, P. P.:** *Porovnanie kanadských a slovenských metód hodnotenia vhodnosti kameňa do stavebných konštrukcií*. (Comparison of Canadian and Slovak methods of evaluating the suitability of stone for building construction). In: Mineralia Slovaca, vol. 27, 1995, no. 2, pp. 145 - 152 (Slovak)

17 **ONDRÁŠIK, M.:** *Vplyv zamrznutej vody v póroch na rozpínanie kameniva*. (The effect of freezeing water in pores on the expansion of aggregate). In: Výroba kameniva *2000. Bratislava, 2000, pp. 101 - 107 (Slovak)

18 **HYÁNKOVÁ, A., WAGNER, P: and ONDRÁŠIK, M.:** *Posúdenie vlastností rúbaniny z tunela Ovčiarsko*. (Evaluation of muck properties from the Ovčiarsko tunnel). In: Geológia a životné prostredie. Bratislava: Vyd. D. Štúra, 1998, pp. 22-24 (Slovak)

19 **MATEJČEK, A., ONDRÁŠIK, R.:** *Vplyv geologického prostredia na výber trasy tunela Višňové*. (The effect of the geological environment on the selection of the Višňové tunnel line). In: Environmentálna geológia. Herľany, 1999, pp. 8 - 13 (Slovak)

20 Slovak Technical Standards (STN), International Standards (ISO, P ENV), special railroad standards (TN) mentioned in the paper:
STN 72 1001; 72 1002; 72 1154 to 72 1156; 72 1163; 72 1170 to 72 1183; 72 1185; 72 1475; 72 1510 to 72 1512; 72 1860; 73 2400; 73 3050; 73 6121 to 73 6129; 73 6133;
STN ISO 6782 (72 1171); 6783 (72 1171); 7033 (72 1174);
STN P ENV 206 (73 2403); TN 72 1514: *Technické a ekologické podmienky na dodávanie materiálu do konštrukcie koľajového lôžka a podkladných vrstiev podvalového podložia (GR ŽSR)*, (Technical and ecological conditions for delivery of material for the construction of rail supports and subgrade layers of railway sleeper supports), 2000