COMPARISON OF CEMENT STABILIZED PAVEMENT STRUCTURE BASE COURSES PREPARED WITH NATURAL GRAVEL AND CRUSHED STONE MATERIAL

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Abstract

A series of different types of soil, sand, natural or fractioned gravels and crushed stone material may be used for the construction of cement-stabilized base courses. However, in Croatia, natural gravel and crushed stone are the most often employed materials in cement stabilized base courses in pavement structures. Both of these types of granular stone materials, as well as cement stabilized mixtures prepared with them, fully satisfy the quality criteria stipulated by valid technical regulations. One of the key factors that influences the choice of the type of material is the relief or terrain configuration where the future road route will pass. In cases where the route passes through mountainous, or hilly regions, extensive geotechnical works are required during executon of cuts, tunnels and side cut or slope cuts. In karst regions of Croatia, these works normally produce a significant amount of quality stone material, of mostly carbonate origin (limestone, dolomites), which may be utilized in construction of pavement structure courses. If the amount of material obtained by route excavation is insufficient, special permits are needed to open borrow pits. In lowland parts of Croatia, such as alluvial plains of Sava and Drava rivers, gravel is the most available material, so it naturally follows that cement-stabilized base courses are usually made with natural gravel. In any case, the objective is to shorten transport distances from the gravel source to the site, and thus reduce transport costs and use as much material from the site as possible. This paper examines the differences between mix designs with gravel and those with crushed stone in terms of physical and mechanical properties, grain size distribution and preparation. It conveys practical experience in placing of mixtures and course curing. It also gives recommendations on implementation of particular types of granular stone material with respect to construction site particularity.

1 Suitability of granular stone material for the construction of cement stabilized base courses

The most important tests carried out to establish whether granular stone material is suitable for preparing cement stabilized mixtures are the following:

- Grain size distribution
- Optimum moisture and maximum dry density with the addition of binders and
- Physical and mechanical properties

For the purposes of grain size distribution analysis of different materials, 5 typical grain size distribution curves for gravel i.e. crushed stone materials are examined in this paper [1]. In order to analyze optimum moisture content, maximum dry density and physical and mechanical properties of materials, 7 different samples were observed [2]. All examined samples were obtained for testing that was carried out as a part of quality monitoring of materials and mixtures produced during construction of major traffic routes (motorways and state roads) in different parts of Croatia, from Slavonia through Zagreb region and Zagorje to Gorski Kotar.

1.1 Grain size distribution and production of granular stone materials

Figure 1 shows 5 typical grain size distribution curves for gravel, i.e. crushed stone material.

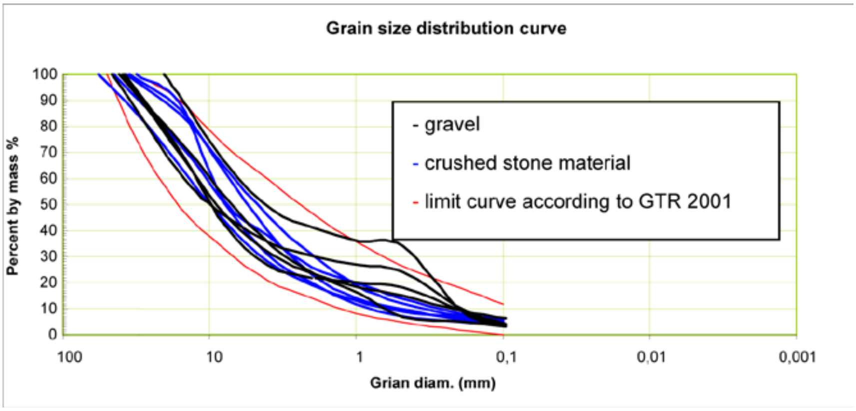

Figure 1 Grain size distribution of granular stone materials

It is clear that all shown grain size distribution curves, with certain deviations, fall within prescribed limits [3]. Some gravel materials show a significantly greater proportion of medium and coarse sand, or fine gravel. This is typical for gravels of the alluvial plains of Drava River. Empirically, it can be said that, during exploitation (extraction from the borrow pit) gravels vary less in terms of grain size distribution than crushed stone in production phase (crushing). Also, it can be stated that they are "cleaner", or have a smaller proportion of fine grains, which is shown in Table 1 (particle proportion is less than 0.02mm). However, screening is often necessary in order to remove oversizes, which may be numerous at times. In case of gravel, time equired for the material to stay deposited should be taken into account, so that excess water gathered during exploitation is drained. In terms of crushed stone production, the proportion of oversizes can be controlled by adjustment of crushing plant. During periods of increased precipitation, production difficulties might occur due to reduced efficacy of overburden removal system at the entry of raw material into the crushing plant.

1.2 Optimum moisture and maximum dry density and the impact of the moisture of mixture on placeability

Optimum moisture and maximum dry density of granular materials to be used in cement stabilized mixtures is determined using the so called modified Proctor compaction test. During testing, a binder is added to granular stone material in the proportion which is, based on experience, expected to be optimal in terms of required properties for cement-stabilized base course, according to the type of material and its grain size distribution. Table 1, which compares essential properties of granular stone material and mixtures prepared with binders of the same strength class (42.5), clearly shows that the two types of materials observed do not differ significantly in terms of optimum moisture content, whereas it can be said that dry density is somewhat greater in crushed stone materials.

Table 1 Properties of granular stone materials

Tested property	Property	Test method	Unit	Assessment criteria according to GTR of 2001	Type of stone material	
					Gravels	Crushed stone material
Density	density	HRN U.B1.014	Mg/m^3	/	2.718	2.739
Grain size distribution analysis	non-uniformity coefficient	HRN U.B1.018	/	15-50	25.50	28.08
	proportion of particles smaller than 0.02mm	HRN U.B1.018	mass%	/	1.4	2.7
	maximum grain diameter	HRN U.B1.018	mm	<63	50	42
Proctor compaction test	optimum moisture, w_{opt}	HRN U.B1.038	%	/	4.1	3.7
	maximum dry density	HRN U.B1.038	Mg/m^3	/	2.207	2.247
Load bearing capacity	maximum dry density	HRN U.B1.042	Mg/m^3	/	2.164	2.239
	95% of value of maximum dry density	HRN U.B1.042	Mg/m^3	/	2.034	2.127
	California bearing ratio	HRN U.B1.042	%	at least 40/80	48.6	120
Physical and mechanical properties	grain shape	HRN U.B1.048	%	maximum 40	15.74	9.51
	water absorption	HRN U.B1.031	%	maximum 1.6	1.14	0.64
	frost stability by Na_2SO_4 method	HRN U.B1.044	%	maximum 12	1.35	3.17
	grain friability	HRN U.B1.037	%	maximum 7	3.09	1.69
	wear and impact resistance of grains	HRN U.B1.045	%	maximum 45	23.61	24.03

Proper moisture content in the mixture may have a great impact on good placeability of material. Too little moisture may result in lower dry density of the course, and during extremely dry periods and in the absence of surface course bond which will become overdried for the final placing, so the cement bonding process will be significantly impaired. Too much moisture will create problems in placing. Too moist mixtures are hard to place, and they have poor compactness. Under machinery wheels, the layer becomes “rubberized”and rutting occurs. This happens more often in gravel and crushed stone mixtures that contain a greater share of fine particles and clay. Clay particles have an increased capacity to absorb moisture and it is more difficult to release it.

1.3 Physical and mechanical properties of the course

In terms of physical and mechanical properties of gravel and crushed stone materials examined in this paper [2], all samples meet the criteria required by valid construction regulations in Croatia [3]. Nevertheless, some differences were noted. Mean values of physical and mechanical properties of observed samples show a slightly greater share of grains of unfavourable shape, higher water absorption, the share of worn grains and greater frost stability of grains in gravel materials when compared to crushed stone (Table 1). Wear and impact resistance tests of grains according to Los Angeles method are almost equal for both types of material compared in this paper. (Table 1).

2 Production of cement stabilized mixtures

Each continuous production of cement stabilization preceded by preparation of the initial job mix formula, or mix design. The mix design serves to prove by laboratory testing that a cement stabilized mixture, with the right components (certain granular stone material, cement and manufacturer and water from a particular source) can be made, which is able to fulfil the requirements of valid Croatian technical regulations [3]. Compressive strength and optimum proportion of cement were observed in 7 mix designs prepared with gravel and 7 mix designs prepared with crushed stone, by means of basic statistical parameters [4]. Table 2 shows that cement-stabilized mixtures prepared with gravel should contain a greater cement quantity in order to achieve the same, or somewhat lower compressive strengths, as mixtures prepared with crushed stone.
Since the proportion of cement is small in both cases (from 1.5% to 2.5%), even small oscillations of cement quantity can affect the essential characteristics of the produced mixture (compressive strength). In this respect, mixtures that contain greater cement quantities have an advantage, since the mentioned oscillations are reduced in proportion to greater cement quantity, and these are definitely mixtures with gravel. Rounded gravel grains have a positive effect on extended service life of individual parts of the plant for the preparation of cement stabilized mixtures (mixing blades, conveyer belt etc.)

Table 2 Compressive strengths and cement proportion in mixtures according to mix designs

Mix design			
Gravel		**Crushed stone**	
Cement proportion according to mix design (%)	**Compressive strength after 28 days (MN/m²)**	**Cement proportion according to mix design (%)**	**Compressive strength after 28 days (MN/m²)**
/	HRN EN 13286-41	/	HRN EN 13286-41
2.0	4.4	1.8	4.2
1.6	3.3	1.7	4.0
2.3	4.7	1.8	5.6
1.6	3.6	2.0	3.0
2.2	2.8	1.5	4.0
2.5	4.8	1.6	4.2
2.2	4.7	1.8	4.7
min/max			
1.6/2.5	2.8/4.8	1.5/2.0	3.0/5.6
mean value			
2.1	4.0	1.7	4.2

3 Placing of cement-stabilized mixtures

Placing of cement stabilized base courses involves spreading of cement-stabilized mixtures (usually by means of blade grader or paver), course compaction to the required compaction level, clearances and course geometry. Segregation of material is a problem that often occurs in both crushed stone and gravel cement stabilized mixtures. Segregation intensity is proportional to the share of coarse grains, or oversizes in the mixture. Therefore, it is important to take the quantity of oversizes into account during material production. Segregation occurs already at the production stage, during depositing, transport, unloading, spreading and placement of material. Segregation within the course (Fig 2) can represent a serious problem, especially in extreme cases when it extends over the entire course thickness. Segregation is mostly local association of single-sized material with a significant number of voids, with low internal friction between grains. Segregated parts of the course are unstable, i.e. have low bearing capacity, so they represent a threat to the load bearing capacity of the entire pavement structure, if they are not remediated. It may be stated that, due to rounded grains, gravel is more prone to segregation than crushed stone of similar grain size distribution. This is particularly true of certain Sava gravels which contain less coarse and medium sand (e.g. "Petruševac" and "Čiće" gravels)

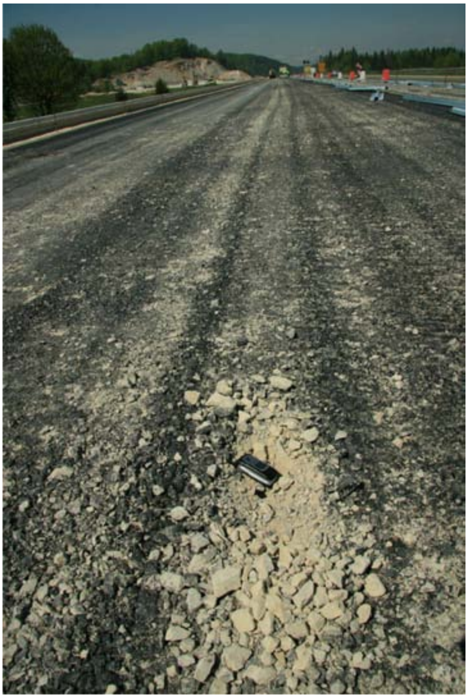

Figure 2 Damaged course on the segregated surface

Unlike Sava gravels, gravels from the alluvial plain of Drava River, have a greater proportion of medium and coarse sand, or fine gravel, which is favourable for the reduction of material segregation. However, for these materials, a variety of compaction means should be used as well as more energy into final compaction, to achieve sufficient level of surface compaction. Due to specific grain size properties of these materials and low internal friction between rounded grains, under steel vibratory rollers, gravel is dispersed along the surface instead of being compacted, so pneumatic-tired rollers or combined rollers should be used, in order to mix in the material into the course. Compactors are also used for surface compaction at times. Placing of crushed stone material requires simpler compaction methods. In fact, on smaller (e.g. some urban) construction sites, and sites with lighter works dynamics, only one heavier vibratory roller (>10T) is employed for compaction of fill layers and all courses of pavement structure, apart from asphalt layers, and a vibratory plate for fixing up of edges and details (water inlet, expansion joints etc.). It can generally be said that less energy is needed for compaction of cement stabilized mixture made with different grain size distributions of crushed stone, than for some gravel types. Certain experiences show that in terms of proper profile geometry of the course placed, crushed stone material is more favourable than certain types of gravel. This is particularly expressed in placing of courses thicker than 20cm (25 or 30cm). Due to lower friction between rounded grains during compaction of edge parts of the course, material may be pushed outwards, or the course might become thinner towards the edges. In terms of cross section geometry, it can result in foundering of course edges. Naturally, this can be prevented by pre-compaction of edge parts of the course with several passages by a lighter roller, but it requires additional engagement for compaction and greater attention in execution. Good results in terms of correct profiles are obtained by technology of placing cement stabilized mixture in two layers, even in usual thicknesses (20cm). Thinner courses are less deformed at edges, and the final course can correct potential defects of the first course. Except in mixing plants for the preparation of cement stabilization, the mixtures may be prepared at the site of placement. The so called “mix in place” technology includes spreading, sprinkling with binders, mixing, profiling and compaction of courses in situ. For that purpose, heavy machinery, such as cement loader, recycling or milling machine and water tank pass over the compacted placed course made of non-bounded granular materials. Crushed stone materials show greater stability in case of passage of heavy machinery along the edge parts of the course, which is especially important in treatment of the lower edge part of greater cross slope.

4 Course curing

After placement of cement stabilized base course it is necessary to cure the course for 7 days before the next course of pavement structure is placed, in such a way that no traffic passes over the course, i.e. that the course surface is maintained moist. In practice, it is often impossible to shut down all site traffic during course curing. Therefore, it is permitted that lighter delivery vehicles, smaller loading machinery, truck cranes etc. pass over the course. In extreme cases, when it is assessed that the necessary site traffic will significantly degrade the course, and especially when circumstances require that the road is opened for traffic as soon as possible, and there is positive experience with the quality of cement stabilized mixture, the asphalt course is placed on cement stabilized base course immediately after its placement. This type of site traffic (lighter construction site traffic) or placing of asphalt layers (movements of paving machines and tipping lorry with fresh asphalt), before the bonds in the course are achieved, might cause local surface course degradation. Experience shows that under these conditions, due to better grain interlocking, crushed stone sustains the mentioned loads better than gravels.

5 Conclusion

Both gravel and crushed stone materials can be used in production of high quality cement stabilized mixtures, i.e. quality cement stabilized base courses. Owing to recent major projects of motorway construction, Croatia has an extensive experience in production, placing and curing of cement stabilized base courses prepared with both types of granular stone material, in different climate areas and under different climatic and site circumstances. The paper comments on some of the properties of materials and mixtures both from site experiences and on the basis of specific laboratory testing results. It is difficult to draw general conclusions and say that one material is better, more favourable or that it gives better results than others, since experiences vary considerably. When it comes to use of gravel and crushed stone materials, the most important thing is to select, or produce materials of optimum grain size composition, and to reduce their oscillations to the minimum during production. In terms of design and production of cement stabilized mixtures, it can be concluded that most mixtures made of gravel material require the addition of greater cement quantity (an average of 2.1%, and in some cases up to 3%) in order to attain equal properties as crushed stone mixtures (an average of 1.7% and in some cases up to 1.1% of cement). The paper demonstrates that the basic difference between gravel and crushed materials, and in placed courses made with them, lies in the morphology of crushed grain, or the capacity of rough grain surfaces obtained by crushing to interlock and bond better. The recommendation is that crushed materials should be given preference in construction sites where passage of lighter traffic or placing of asphalt courses of the pavement structure over freshly placed cement stabilized base course cannot be avoided.

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