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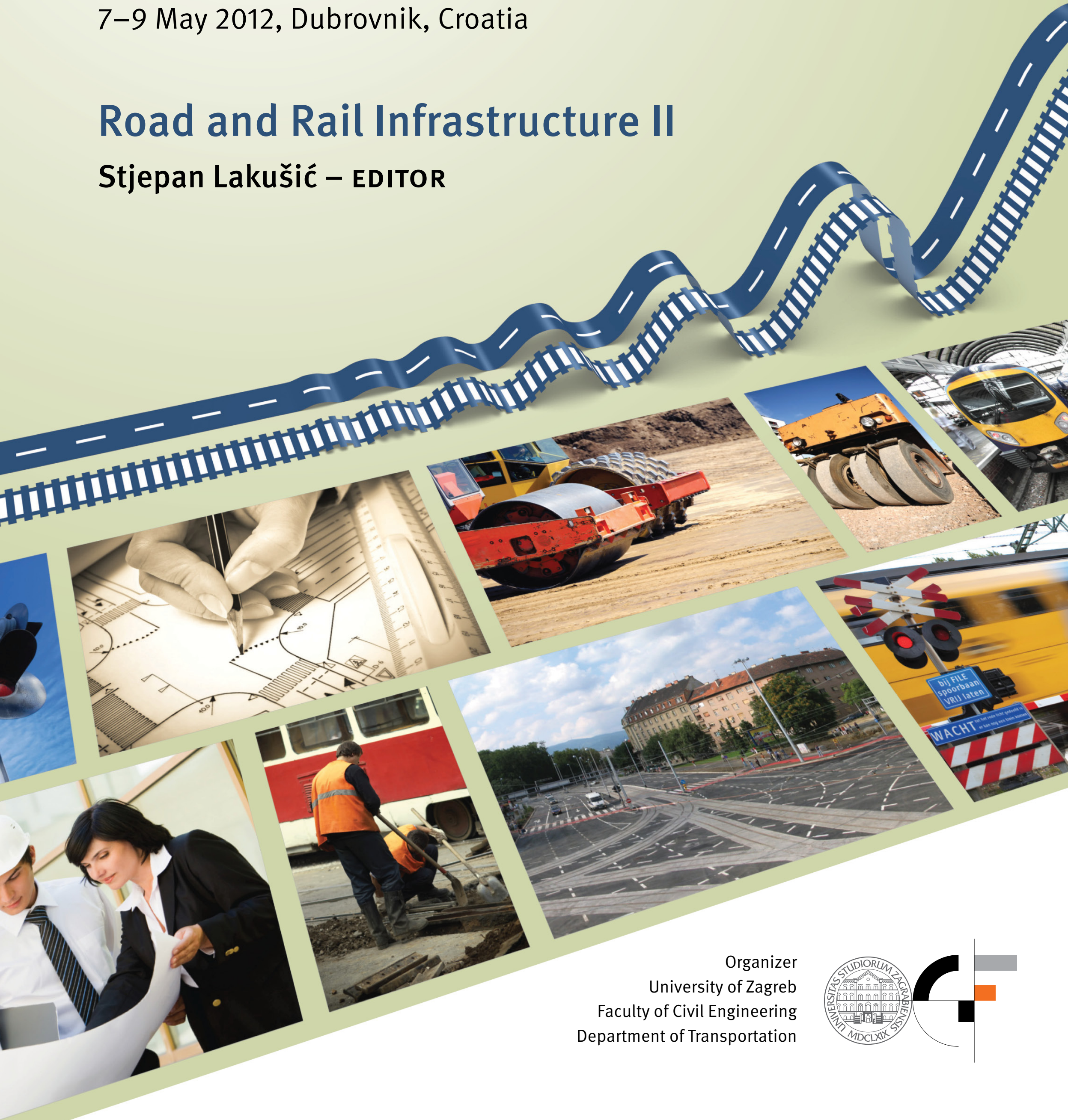
# Road and Rail Infrastructure II

**Stjepan Lakušić – EDITOR**





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# SOME EXPERIENCES IN PRODUCTION OF CONCRETE MIXES DESIGNS FOR CONSTRUCTION OF CORRIDOR X IN SERBIA

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## Abstract

The construction of road infrastructure of the Corridor X through Serbia, according to design documents, required concretes of a variety of classes and special properties. Depending on the type of structures and their structural elements (piles, bridges, tunnels) the concrete class ranged from C 25/30 to C 45/55. The special properties required were: resistance to frost, resistance to simultaneous action of frost and defrosting salts and water tightness. Overall, those are concrete mixtures which can be designed relatively easily with quality materials. In practice, however, a problem occurred, as the contractor required using of the materials, i.e. aggregates, from the nearest locations. Experience acquired in those concrete mixes design once again confirmed how large impact aggregates have on concrete properties. As a result, many aggregates from the local screening plants were not adequate choice in mixing of the concretes having the required properties. The paper presents the mix designs for concrete, designed with various aggregates, as well as the properties of concrete in fresh and hardened states.

*Keywords: aggregate, mix design, fresh concrete, hardened concrete*

## 1 Introduction

Aggregate, on average, occupies around three quarters of concrete volume, and therefore impacts the properties of fresh and hardened concrete by means of its own characteristics. The aggregate's share in the cost of 1 m3 of concrete is around 50%, the river aggregate being less expensive than the crushed one. Lately, there is a tendency to decrease and limit borrowing of aggregate from the river courses for hydrological, environmental and other reasons.
The properties of aggregate tested for the purpose of proving its suitability for concrete mixing are numerous and in general, they can be divided into: mineralogic-petrographic, chemical, physical and mechanical.
One of the earliest parameters of aggregate quality that draw attention of numerous researchers (Fuller, Bolomey, Fourie, Leviant, Popovics, Valet, EMPA Institute etc.) is the particle size distribution. For production of concrete, in principle, the grading has to be chosen in such a way so that fine particles fill in the space between the coarse grains, then even finer particles fill in the remaining space and so on approximately until the cement fineness is reached. Cement paste is supposed to fill in all the remaining space and to envelop the aggregate grains in a thin film. After hydration, the cement rock should bind all the aggregate grains into one compact mass. Prescription of a single 'ideal' grading curve is exaggeration, and it is known that grading curves lie in a wider area [1].
Mineral aggregates used for concrete mixing are considered basically inert, that is, chemically inactive in concrete. However, they can sometimes contain substances which are detrimental

for concrete, if their amount is above the certain limits. Such substances are called harmful matters.
One of the harmful matters which is very often present to a certain extent, is the fine particles. This term comprises those particles of aggregate passing through the sieve with 0.09 mm square mesh openings. Fine particles in aggregate can be present in dispersed – unbound form, as clay lumps or as an layer ('clay film') on the surface of coarse aggregate grains. As for the content of fine particles, the crushed aggregate can very often be less favorable than the river one, because in the crushing process a large quantity of such particles is generated – rock flour, which adheres to the surface of coarse grains, or is simply present in the unbound state. If used for production of ordinary cement concretes, the crushed aggregate needs to be washed [2, 3].
Excessive presence of fine particles can affect workability of fresh concrete, contribute to increased shrinkage of concrete, reduce its durability, reduce the content of air entrapped in concrete [4]. The aggregate whose surface is to a considerable extent enveloped by the layer of fine particles is not favorable for production of cement concrete because there will be no sufficiently strong bond between the cement rock and the aggregate grains which results in lower strength of concrete. Simultaneously, at the interface between the aggregate grains and cement rock a transit zone is created, containing multitude of capillary pores [5]. The water transport occurs through the transit zone, or in other works, the concrete is water permeable. Such concrete has low strength to other adverse impacts: freezing and thawing, defrosting salt action, chemical aggressiveness etc. Fine particles have large surface and they are capable of binding a large quantity of water. For this reason, the aggregate which contains a large quantity of fine particles requires a larger quantity of water for the purpose of making the concrete of identical consistency in respect to the clean aggregate. The excess water which does not take part in cement hydration evaporates later, and due to this the concrete has higher porousness, lower density, lower compressive strength and poorer other characteristics [6].
Porousness of the aggregate, its water tightness and absorption affect the potential of binding of the aggregate for cement paste, concrete resistance to frost action, chemical stability and wear resistance. Due to aggregate water absorption there is a certain loss of workability of fresh concrete mass, particularly in the first 15 minutes [7].
The results of aggregate tests by the Los Angeles method show high agreement with the achieved compressive strength of concrete and resistance of aggregate and concrete to wear. For these reasons, the resistance to simultaneous crushing and wear in the Los Angeles machine was determined for all the aggregates used for the making of concrete. In this paper is presented the experience acquired in designing concrete mix designs for concretes intended for construction of structures (piles, bridges, tunnels etc.) of Corridor X (highway E 75).

## 2 Materials used for making concrete

It should be emphasized at the outset, that the choice of the material for making concrete was made by the party that ordered the mix designs, which was primarily concerned by the financial considerations. For this reason, the basic choice was focused on the closest screening plants, i.e. quarries. The list of aggregates which were tested, and which underwent the preliminary laboratory tests is provided in table 1.
Regardless of the found deficiencies of certain aggregates, at the contractor's demand, all the requested concrete tests were carried out. The final concrete mix designs were made with the aggregate no. 5 and no. 4 with certain corrections, table 1.

**Table 1** **Table 1**
The list of aggregates used for making concrete.

| No. | Aggregate name | Aggregate type | Found Deficiencies |
|---|---|---|---|
| 1. | Europetrol, Vranje | Screened from the South Morava river | Coefficient LA 38, aggregate grain surface enveloped by fine particles |
| 2. | Momin Kamen, Vladičin Han | Screened crushed dacite | High porousness (above 5%), water absorption around 2% |
| 3. | 5D, Vranje | Screened from the South Morava river | None, small capacity of the separation facility |
| 4. | Saba Belča, Bujanovac | Screened crushed limestone | Poor particle size distribution, high content of fine particles |
| 5. | MD GIT, Brestovac near Niš | Screened from the South Morava river | None (selected for production of concrete) |

For making concrete, the following CEM II cements were used: Titan PC 20M(V–L) 42.5N, Titan PC 35M (V–L) 42.5R and Titan PC 20S 42.5N. All cements met the requirements in terms of suitability for making concrete according to EN norms and they had fairly uniform characteristics. Concrete for construction of structures along the highway, apart from the required compressive strengths (C 25/30 to C 45/55) had to have other properties: capacity of maintaining long term consistency in summer conditions (S3 to S4), resistance to frost action (M100 to M150), resistance to simultaneous action of frost and defrosting salt and resistance to action of pressurized water (V3). In relation to that, numerous chemical admixtures by various manufacturers have been tested, as given in the table 2. As in the case of other materials, the choice of chemical admixtures was made by the contractor. After all tests, the chemical admixtures chosen for making concrete were Sika Viscocrete 3070 and Sika Aer.

Table 2 Table 2
List of chemical admixtures used for making concrete.

| No. | Manufacturer | Chemical admixture designation | Primary purpose (according to the manufacturers' technical specifications) |
|---|---|---|---|
| 1. | Sika | Viscocrete 4000 BP (Hyperplasticizer) | Maintaining of consistency in extreme summer conditions, higher final strengths |
| | | Viscocrete 3070 (Hyperplasticizer) | For moderate maintaining of consistency and transport, for summer season, for waterproofing |
| | | Sika Plast 20C (Superplasticizer) | For maintaining consistency and transport of concrete for application in summer season |
| | | Sika Aer (Air entraining) | Increases resistance to frost and resistance to defrosting salt |
| 2. | Ruredil | Ergomix 140 (Plasticizer) | Reduces water demand, increases compressive strength |
| | | Monolit (Air entraining) | Increases resistance to frost and resistance to defrosting salt |
| 3. | Isomat | Adium 130 (Superplasticizer) | Reduces water demand, facilitates longer maintain of consistency |
| | | Porolit – LM (Air entraining, superplasticizer) | Reduces water demand, increase workability, increases frost resistance and resistance to defrosting salt |
| 4. | Ading | Fluiding M1M (Superplasticizer) | For transport concretes, for concreting at high temperatures |
| | | Poročinitelj (Air entraining) | Increases resistance to frost and resistance to defrosting salt |

## 3 Properties of fresh and hardened concrete

Around 40 concrete mixtures were made. The most of them, as many as 23, referred to class c 25/30 concrete which except the required strength had to have certain previously mentioned properties. Fresh concrete underwent the slump test, density and entrapped air content, and the fresh concrete underwent compressive strength tests and the density. In table 3, there are concrete mixtures compositions, and in table 4 are provided some of the measured values of the properties of fresh and hardened concrete. In table 3, in column 1 there are ordinal numbers under which they were filed in the laboratory.

**Table 3** **Table 3**
Quantities of material in kilograms for 1 m3 of class C 25/30 concrete.

| No. | Type, number of fractions and quantity of aggregate | Quantity of cement and w/c ratio | Type and quantity of admixtures [% of cement mass] |
|---|---|---|---|
| 237 | Europetrol (4) 1845 | 380 0.44 | Viscocrete 4000 0,8%, Aer 0,03% |
| 238 | Europetrol (4) 1845 | 380 0.44 | Viscocrete 4000 0,8%, Aer 0,025% |
| 239 | Europetrol (4) 1845 | 380 0.44 | Viscocrete 4000 0,8%, Aer 0,02% |
| 243 | Europetrol (4) 1845 | 380 0.50 | Ergomix 140 1,2%, Monolit 0,1% |
| 245 | Europetrol (4) 1830 | 400 0.50 | Viscocrete 3070 0,8%, Aer 0,015% |
| 246 | Europetrol (4) 1830 | 400 0.50 | Viscocrete 4000 0,65%, Aer 0,015% |
| 247 | Europetrol (4) 1830 | 400 0.50 | Ergomix 140 1,2%, Monolit 0,1% |
| 258 | Europetrol (3) 1780 | 390 0.50 | Viscocrete 3070 (1,2%) |
| 259 | Europetrol (3) 1780 | 390 0.48 | Ergomix 140 (1,4%) |
| 260 | Europetrol (4) 1820 | 400 0.50 | Fluiding M1M 1,0%, Poroč. 0,09% |
| 261 | Europetrol (3) 1760 | 400 0.473 | Fluiding M1M 1,2%, Poroč. 0,09% |
| 262 | Europetrol (4) 1830 | 400 0.50 | Adium 130 0,7%, Porolit-LM 0,03% |
| 263 | Europetrol (3) 1760 | 400 0.498 | Adium 130 0,7%, Porolit-LM 0,05% |
| 268 | 5D (3) 1800 | 400 0.42 | Viscocrete 3070 1,0%, Aer 0,015% |
| 269 | 5D (3) 1760 | 400 0.45 | Sika Plast 20C 1.6%, Aer 0,015% |
| 270 | Momin K. (3) 1810 | 380 0.486 | Viscocrete 3070 1,0%, Aer 0,015% |
| 271 | Momin K. (3) 1740 | 400 0.55 | Sika Plast 20C 1.2% |
| 272 | Momin K. (4) 1760 | 400 0.50 | Viscocrete 3070 1,2% |
| 273 | Momin K. (3) 1740 | 400 0.534 | Viscocrete 3070 1,0% |
| 275 | Saba Belča (3) 1735 | 400 0.513 | Viscocrete 3070 0,85% |
| 277 | Saba Belča (3) 1736 | 400 0.501 | Viscocrete 3070 0,85%, Aer 0,015% |
| 278 | MD GIT (4) 1800 | 360 0.462 | Viscocrete 3070 0,8%, Aer 0,01% |
| 281 | Saba Belča (3) 1736 | 400 0.468 | Viscocrete 3070 0,85% |

Table 4 Table 4
Measured values of fresh and hardened class C 25/30 concrete.

| Concrete mixture designation | Consistency class (slump) | Entrapped air content [%] | Density of fresh concrete [kg/m³] | Compressive strength after [N/mm²] |
|---|---|---|---|---|
| 237 | S3 (100 mm) | 4.2 | 2410 | 41.1 |
| 238 | S3 (110 mm) | 3.5 | 2410 | 42.6 |
| 239 | S3 (120 mm) | 3.2 | 2410 | 42.3 |
| 243 | S3 (100 mm) | 4.5 | 2424 | 41.26 |
| 245 | S4 (170 mm) | 4.5 | 2406 | 40.0 |
| 246 | S4 (180 mm) | 4.6 | 2394 | 39.0 |
| 247 | S2 (90 mm) | 6.2 | 2354 | 35.8 |
| 258 | S4 (190 mm) | - | 2384 | 33.1 |
| 259 | S4 (180 mm) | - | 2399 | 33.1 |
| 260 | S3 (120 mm) | 2.6 | 2405 | 34.6 |
| 261 | S1 (20 mm) | 2.6 | 2404 | 38.1 |
| 262 | S1 (40 mm) | 2.5 | 2422 | 34.2 |
| 263 | S1 (40 mm) | 4.0 | 2388 | 30.7 |
| 268 | S3 (130 mm) | 4.5 | 2318 | 39.2 |
| 269 | S1 (130 mm) | 4.5 | 2302 | 31.0 |
| 270 | 0 mm | - | 2314 | 49.9 |
| 271 | S2 (60 mm) | - | 2280 | 40.6 |
| 272 | S4 (160 mm) | - | 2322 | 35.9 |
| 273 | S3 (110 mm) | - | 2265 | 36.3 |
| 275 | S4 (200 mm) | - | 2357 | 44.7 |
| 277 | S3 (150 mm) | 4.5 | 2340 | 44.1 |
| 278 | S4 (190 mm) | 4.0 | 2300 | 38.1 |
| 283 | S1 (40 mm) | - | 2368 | 39.6 |

## 4 Discussion of obtained results

The majority of concrete mixes were made with river screened aggregate from the upper course of the South Morava river, Europetrol (table 3, no's. 237 to 263) screening plant. This aggregate had a number of deficiencies, of which high value of Los Angeles coefficient (38, grade 'B') and envelopment of aggregate grain surface by fine particles particularly stand out. Notwithstanding, the contractor insisted to make concrete mixes, as the screening plant was immediately next to the highway section under construction. Along with the previously mentioned elements, the concrete mixes were made with chemical admixtures of as many as four manufacturers (table 2). The reason for this was the contractor's attempt to find the least costly solution.
Due to the poor quality of the mentioned aggregate, the dosage of cement were considerably high, and the same holds for the dosage of chemical admixtures which was at the top recommended limits (regardless of the manufacturer). The concrete mixes which were made

with the dosage of cement of 400 kg/m3 of concrete were intended for construction of piles, as required by the design documents.
Fresh concrete exhibited bleeding and quick loss of consistency. For many concrete mixtures, compressive strengths were not satisfactory after 28 days (less than 38 N/mm2). In terms of time, four months were spent for preliminary tests prior to rejecting the aggregate as a material suitable for production of concrete.
Afterwards, the screened river aggregate from the upper course of the South Morava river from the screening plant 5D, was sent to the laboratory, which met all the quality conditions. With this aggregate, in a very short time a concrete mix for construction of piles was made, with all the required properties ((tab. 3 and tab. 4, no. 268). The problem, however, was not solved, because the screening plant turned out to have small capacity, which could not satisfy the dynamics of construction works.
For this reason, production of concrete mix designs continued, with the crushed screened dacite from the Momin Kamen quarry. This quarry was not operational for a number of years. Even though the required strengths could be obtained with this aggregate, it had been known that it had featured high porousness and insufficient resistance to frost action. There was a problem as well with the required (S3 to S4) slump value. When such consistency was achieved, then the compressive strengths after 28 days were not satisfactory and vice versa.
Eventually, the crushed screened limestone from the quarry Saba Belča and river screened aggregate from the medium course of the South Morava river MD GIT screening plant, of Brestovac near Niš were sent to the laboratory. The crushed limestone aggregate had a very poor particle size distribution (high share of finer or coarser grains in fractions), so by designing the fraction mix, this problem was somehow overcome. Fraction 0/4 mm was replaced by the corresponding fraction of the river aggregate. When making concrete C 25/30 with the river screened aggregate MD GIT there were no problems (tab. 3 and tab. 4, no. 278). Eventually, for making concrete for production of piles, crushed screened limestone was chosen, and for other structures, the screened river aggregate MD GIT.

## 5 Conclusion

On the basis of the experience acquired when designing concrete mix design for construction works of the section of the Corridor X highway, a number of conclusions was drawn.
The contractor requested a large number of preliminary tests in concrete works preparation period, which is extraordinary compared to the requests of national (Serbian) companies. The aim of this action was to find out the most cost–efficient solution – concrete mix design.
The activities related to production of mix designs, which have been presented in this paper, confirmed earlier theoretical and practical knowledge that the aggregates which have as much as one property which does not meet the prescribed quality requirements cannot be used for making a good and cost–efficient concrete. This assertion is confirmed by the fact that in almost all presented examples the dosages of cement and chemical admixtures were extraordinary high.
The chemical admixtures irrefutably have a large impact on properties of fresh and hardened concrete. However, in the situation when one of the concrete components, in this case aggregate, does not meet the prescribed quality requirements, the effects of chemical admixtures are severely limited. The quantity of chemical admixture is around the maximum recommended limits, with no prominent or expected effect.
The final conclusion, which is generally known, is that the economically acceptable concrete of required properties can be obtained only when all the concrete components meet the prescribed quality conditions.

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