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APPLICATION OF RECYCLED AGGREGATES IN PAVEMENT BASE COURSES

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Abstract

Guidelines for sustainable development stipulate protection of non-renewable sources of natural aggregates, which means creating the best and most cost-efficient application of all available resources.
Very large quantities of natural aggregates are used in civil engineering; a significant part of those quantities is particularly used for purposes of road building. Natural aggregates which are used in large quantities in road building are crushed stone, excavated gravel, and river gravels and sands.
Such a continual demand for natural materials depletes natural sources, and the costs of procurement and transportation in areas with scarce good quality aggregates significantly increase building costs. Therefore, waste materials may be significant as an alternative in road building in a number of ways.
Large quantities of waste materials are a product of demolition of buildings, and particularly re-deposition of such materials has been recognized as a possibility for preservation of natural sources of materials, such as reduction of energy required for the production of natural aggregates and a manner in which it is possible to reduce the surface size of the landfill where waste material is deposited. In some European countries it is even the standard alternative for road building and maintenance, especially if the country has scarce natural aggregates.
The paper describes examples of successful incorporation of material which is a product of removal of existing buildings at two sites in residential areas Španska-Oranice in Zagrebu and Sopnica-Jelkovec in Sesvete (in Croatia). Recycled construction material was embedded into pavement base courses of road at the same site where it was "produced". Tests of modulus of compressibility of the deposited base courses were carried out, and the obtained results had higher values than the values of the modulus of compressibility required by the design.

Keywords: recycled aggregate, properties, modulus of compressibility, unbound base course

1 Introduction

According to the guidelines for sustainable development, non-renewable sources of natural aggregates should be protected. Extraction of natural aggregates has been presented as depletion of the aggregates themselves, but also of the natural environment from which the aggregates are extracted. Exploitation procedures also result in various adverse effects [1] which bring about visual changes of the environment, increased heavy traffic flow on existing roads with insufficient bearing capacity, noise, dust, and vibrations.
Very large quantities of natural aggregates from excavations are used in civil engineering; a significant part of those quantities is used particularly for the purposes of building of roads

and bridges. Therefore, application of waste materials and industrial by-products has multiple significance as an alternative in road building. In industrially developed countries some alternative materials have been used for a number of years. American studies and lessons learned [2], [3], indicate that there are as many as 19 different types of waste material and industrial by-products which may be useful if used in various layers of pavement base courses and embankments.
In the wide array of alternative materials that may be used in road building, construction waste has a special place and significance.

2 Construction waste

Construction waste is a material that is a product of building of new buildings or demolition of existing buildings, and which, depending on the composition, may be re-used in building by application in specific methods of recycling. The composition of construction waste depends on the place of "origin", so the material originating from removal of a section of a road contains asphalt, concrete, cement-bound material, sand, gravel, and crushed stone. Material originating from removal of buildings in building construction is composed of bricks, mortar, wood, concrete, reinforcing, glass, shingles, tiles.
Construction waste has very high usability in road building, depending on its origin and composition and provided corresponding recycling technologies are used. Approximately 80% of the material from construction waste may be re-used in unbound and stabilized base courses, as aggregates in asphalt and concrete pavements, as aggregates in manufacturing of various concrete elements for slab paving or drainage, as the basic or added material in the construction of embankments. Material received from recycled construction waste very clearly belongs to the category of recycled aggregates because it already contains the natural aggregate which can be re-used.
Some European countries such as Germany, Sweden, Denmark, Great Britain, and the Netherlands have years of (positive) experience in the application of various alternative materials, in particular recycled aggregates. Recycled construction waste in those countries accounts for more than 80% of produced construction waste. Particularly successful in "re-use" of waste materials is the Netherlands, which uses almost all available recycled aggregates in road building. In comparison, Croatia recycles 7% of the total produced quantities of construction waste, which is approximately 2 mill. tons per annum.
With respect to the origin, i.e., various compositions of construction waste, the possibilities of application of recycled aggregates depend on sorting and elimination of impurities:
Recycled aggregate from concrete is obtained by removal and crushing of concrete pavement of a road or airport and buildings. Crushed concrete is used in construction of pavement structure layers: unbound base courses, stabilized cement layers, as aggregate in concrete mixtures, in construction of road embankments or in road maintenance [2], [3], [4] and is considered a part of construction waste with the highest and most frequent application in civil engineering in general.
Recycled aggregate from cement-stabilized layers represents a good quality granular material, to which all the conditions valid for the material for the preparation of unbound base courses apply. This aggregate may be stabilized (again) by cement and it can be deposited into the upper pavement base course.
Recycled aggregate from crushed brick depends on the type of brick and mortar, and the most frequent application is in unbound base courses or as filling material.
Recycled aggregate obtained from crushed demolition waste due to its properties cannot be applied in pavement structures, but can be used as an addition to the material for construction of embankments.
Material from old asphalt pavement has a significant recycling potential. Approximately 95% of the old asphalt material is natural aggregate coated with bitumen binder. Such crushed

material may be used in the construction of embankments, in non-bound and stabilized pavement layers, as an addition in the production of new asphalt mixtures in asphalt plants, or in the procedure of recycling bituminous overlay on the construction site.
One of the drawbacks for a wider application of all types of waste materials in civil engineering is the lack of existence of the corresponding standards, regulations, and recommendations, so in the practice so far standards or regulations for standard materials have been used. "Encouragement" for use of alternative materials as a substitute for the traditional ones are definitely the steps made in drafting regulations, in particular for application of recycled aggregates [4], [5].
The text below describes construction of traffic surfaces in residential areas Španski-Oranice in Zagreb and Sopnica-Jelkovec in Sesvete in 2004. Recycled aggregate was obtained by removal of existing buildings and then it was incorporated into unbound base courses. It was also the first application of a recycled aggregate into pavement structures in the Republic of Croatia.

3 Application of recycled aggregates in pavement structures

Demolition of buildings is undertaken to free space for new construction or use of a specific space for other purposes, which may be motivated by economic, technical, safety, or environmental reasons.
For purposes of investors in the course of 2003 and 2004 buildings at the Sopnica-Jelkovec site in Sesvete and buildings on the premises of military barracks in Španski-Oranice in Zagreb were demolished in order to free up the existing surfaces for new purposes. Those sites are very interesting from the point of view of demolition, recycling, and application of recycled material, and also because the subject works were carried out seven years ago, when the awareness of the application of recycled materials in Croatia was not very high.

3.1 Site I: Sopnica-Jelkovec in Sesvete

Pursuant to the Agreement with the Agency for Legal Transactions and Real Estate Mediation, the Ministry of Public Works, Reconstruction, and Construction, commenced building of a residential area at the Sopnica-Jelkovec site for the Social Housing Program (POS). The building of the new residential area included the surface size of 37 ha in the area of the cadastral municipality Sesvete.
The total surface of the project is approximately 37 ha, and the area covered with the size of 32 ha has two basic spatial elements: a corridor of boundary roads (approximately 3 ha) and the inner area (approximately 29 ha).
At the space of the former pig farm there were a total of 65 facilities divided in two sectors (two functional units). The A sector included the administration building with sanitary facilities, a warehouse and a workshop, an approach ramp and weighbridge (a total of 4 facilities). Within the B sector there were the remains of the farm buildings (a total of 54) of which remained only the floor tiles, foundation structure and, in places, the remains of basic structure.
At the site of the former pig farm there were 65 building structures with the total surface size of 72,900 m2 that needed to be removed. Of most of the building structures (a total of 54) there remained only the floor tiles and foundation structure. All the facilities were removed together with flooring panels and foundations.
Access roads, plateaus, and paths were also planned to be removed, as well as the greenery on the western part of the site.

Figure 1 Sopnica-Jelkovec Site: Existing State of Play (a) and Removal of Buildings (b)

3.2 Site II: Španski-Oranice in Zagreb

The closure of the military barracks at the Španski-Oranice site created a possibility for this exceptionally valuable space to be included mostly into the built area, primarily as residential area of the western part of the city of Zagreb. The site included 54 building structures foreseen for removal with the total gross surface size of 26,000.00 m² or total gross volume of 113,000.00 m³. Access roads, plateaus, and paths were also foreseen for removal. Within the site it was foreseen that the overall internal installation networks would be removed: water supply, sewage, telecommunications, and electric grid.
The inventory (furniture), equipment, stored goods, devices, and facilities formerly used in technological processes (boiler rooms, transformer station, gas station, aggregate station) were removed from all the buildings, so that only pertinent parts of building structures without the facilities for specific purposes were left for demolition.

Figure 2 Site II – Španski-Oranice: Removal of Floor Tiles (a) and Recycling of Material (b)

3.3 Removal of buildings

In the course of the procedure of demolition of buildings, from the very phase of the preparation of a Removal design, it was necessary to take all the required measures so that the material originating from demolition would be systematically collected and recycled in the place of origin and used again later on.
The removal of buildings consisted of a number of activities such as:

- Disposal of devices and facilities formerly used in technological processes and hazardous waste
- Cutting the buildings off all the communal infrastructure connections.
- Performing the protection of structures or parts of buildings not foreseen for demolition.

- Dismantling, which included dismantling of equipment, installations, and other parts of the buildings which could be removed separately
- Demolition of buildings

3.4 Recycling of material originating from demolition

Recycled material (or recovery of material, see the Waste Act [6]) includes the procedures of treatment and re-use of construction material originating from demolition. Activities of recycling of construction material may be divided into two basic groups:

- recycling in the phase of the preparation of a building structure for demolition – sorting and separation of materials with use value in the as – found state (wood, metal) and separation of material that needs to be disposed separately to prevent permanent environmental pollution (plastic, glass, bitumens),
- recycling of material after demolition – crushing, purification and sifting of material originating from demolition (crushers, devices for water or air treatment, separation screens, etc.).

Figure 3 Sopnica-Jelkovec Site: Recycling of Material on Site (a) and Recycled Material (b)

After performing the works of removal of existing buildings of the former military barracks, the material originating from removal was recovered and incorporated into blanket courses of the future temporary roads.

The contractor for the works on the removal of buildings, recycling of the material originating from removal, and incorporation of the material into pavement base courses was the Vinkovci-based company EURCO [7], [8].

Tests were conducted for the modulus of compressibility of the pavement base course by means of a circular plate Φ300mm to standard HRN U.B1.046 by the Civil Engineering Institute of Croatia (IGH). A total of 24 tests of modulus of compressibility were carried out, of which 3 tests on the formation soil and 21 tests on the base course. The attained values of modulus of compressibility on the base course were Ms=54 MN/m2 to Ms=75 MN/m2, which was higher than the minimum value of the required modulus of compressibility according to project documents, Ms=50 MN/m2. A part of the test results is shown in Table 1.

The volume of material incorporated into the pavement base course which was obtained by recycling of material originating from demolition on the Sopnica-Jelkovec site was 19,000.00 m3, and on the Španski-Oranice site its volume was 11,000.00 m3.

Figure 4 Disposition of Recycled Material on the Sopnica-Jelkovec Site

Table 1 Modulus of Compressibility Ms Tests Results on the Sopnica-Jelkovec Site

Broj probe	Datum ispitivanja	Stacionaža	Ispitani sloj	Potrebni Ms (MN/m2)	Ispitani Ms (MN/m2)
15/4	12.2.2004	0+070	Materijal koln. konstrukcije	50	60
16/5	12.2.2004	0+164	Materijal koln. konstrukcije	50	58
17/6	11.2.2004	0+116	Materijal koln. konstrukcije	50	75
18/7	11.2.2004	0+261	Materijal koln. konstrukcije	50	40
19/6	12.2.2004	0+261	Materijal koln. konstrukcije	50	55
20/7	12.2.2004	0+049	Materijal koln. konstrukcije	50	59
21/8	12.2.2004	0+130	Materijal koln. konstrukcije	50	63
22/9	12.2.2004	0+030	Materijal koln. konstrukcije	50	67
23/10	12.2.2004	0+220	Materijal koln. konstrukcije	50	56
24/11	12.2.2004	0+075	Materijal koln. konstrukcije	50	54

On the Španska-Oranice site, 15 modulus-of-compressibility tests were carried out on the base course, on two occasions. The test results are illustrated in Table 2. During the first test the values of the modulus of compressibility attained were lower than the minimum required modulus according to project documentation Ms=50MN/m2. After an additional site establishment and rolling of the layer tests were repeated and values of the modulus of compressibility attained were Ms=51MN/m2 to Ms=88 MN/m2.

Table 2 Modulus of Compressibility Ms Tests Results at the Španska-Oranice Site

Broj probe	Datum ispitivanja	Stacionaža	Ispitani sloj	Potrebni Ms (MN/m2)	Ispitani Ms (MN/m2)
1	15.12.2003	0+067	Tampon	50	48
2	13.2.2004	0+067	Tampon	50	58
3	15.12.2003	0+020	Tampon	50	31
4	13.2.2004	0+020	Tampon	50	81
5	13.2.2004	0+085	Tampon	50	61
6	15.12.2003	0+350	Tampon	50	55
7	13.2.2004	0+490	Tampon	50	81
8	15.12.2003	0+080	Tampon	50	43
9	13.2.2004	0+080	Tampon	50	65
10	15.12.2003	0+080	Tampon	50	87
11	13.2.2004	0+138	Tampon	50	88
12	15.12.2003	0+130	Tampon	50	38
13	13.2.2004	0+130	Tampon	50	52
14	15.12.2003	0+050	Tampon	50	41
15	13.2.2004	0+050	Tampon	50	51

4 Conclusion

In the course of removal of buildings there is originated, pursuant to the Regulation on the Categories, Types, and Classification of Waste and Hazardous Waste, a category on non-hazardous construction waste, which may be prepared by using procedures of separation of other ingredients and primary recycling, for use as a convenient secondary material in construction works. Since the waste management strategy encourages the use of such kind of secondary materials, in order to reduce the negative environmental impacts of permanent disposal of such kind of useable secondary materials on landfills, such a manner of construction waste management contributes to sustainable development. Positive experiences with the application of recycled aggregates described in this paper should be used as a role model and should be an incentive for its greater use in civil engineering.

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