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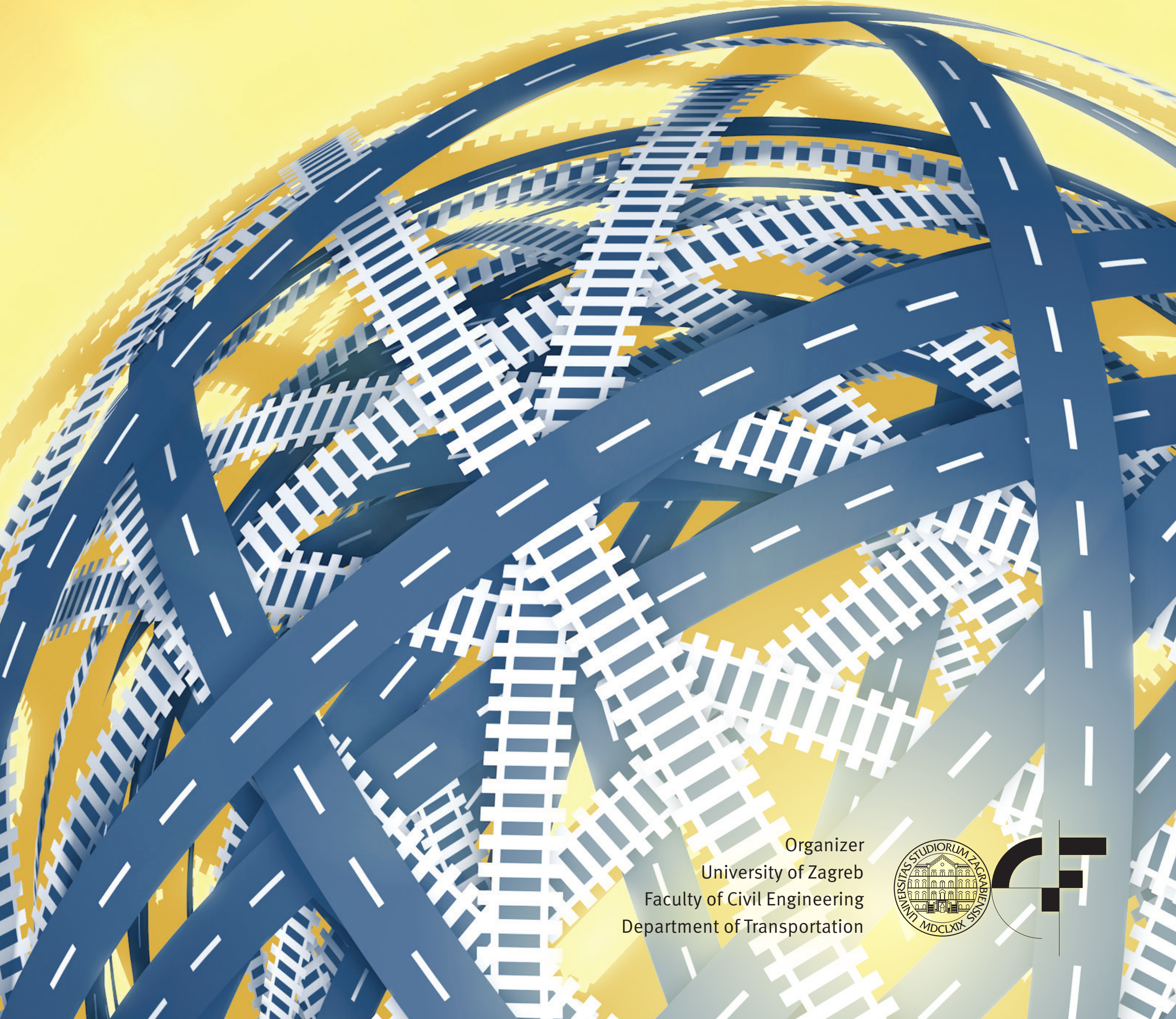
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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EFFECT OF MOISTURE CONTENT AND FREEZE-THAW CYCLES ON BEARING CAPACITY OF RAP/NATURAL AGGREGATE MIXTURES

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Abstract

Unbound granular base layer plays a significant role in the overall performance of the pavement structure. It provides structural support for the upper pavement layers, contributes to load distribution and acts as frost protection layer. Traditionally this layer is built with high quality natural aggregate. However, as the sources of natural aggregates are becoming increasingly scarce, engineers are examining the possibilities of using recycled materials. The most widely used recycled material in pavement construction is reclaimed asphalt pavement (RAP) and its possible application in unbound granular base layer has been investigated since the mid-1990s. Previous studies confirmed that RAP can be a suitable replacement for natural aggregate, but there is major concern regarding the impact of seasonal variations in environmental factors on its properties.
The paper analyses effect of changing moisture conditions and freeze-thaw cycling on bearing capacity of natural aggregate (limestone and gravel) and its mixtures with varying RAP percentages (20, 35 and 50%). Bearing capacity was determinate by laboratory CBR tests on samples prepared by modified Proctor compaction at optimal moisture content. Three samples for each mixture were prepared and tested after different curing conditions. First sample was tested immediately after compaction, second after 96 hours soaking in water and third after 14 freeze-thaw cycles. Base on the obtained results it can be concluded that the impact of changes in moisture content and freeze-thaw cycling is largely depended on the type of natural aggregate. Increasing RAP content for mixtures with limestone decreases their sensitivity to changes in moisture content and freeze-thaw cycling. For mixtures with gravel increasing RAP content increases their sensitivity to changes in moisture content and does not affect their sensitivity to freeze-thaw cycling.

Keywords: unbound granular layer, bearing capacity, reclaimed asphalt pavement, moisture content, freeze-thaw cycling

1 Introduction

Natural aggregates are by far most widely used materials in construction. Approximately 20% of annual aggregate production in Europe, that amounts 2.6 billion tons, is used in the construction of transport infrastructure. Most of the aggregates, about 87%, come from quarries and gravel pits, while the rest comes from marine dredged and industry (5%) or by recycling construction and demolition materials (8%) [1]. Such trend in aggregate production and transport infrastructure construction leads to increase depletion of natural aggregate resources. At the same time, we are faced with disposal of large quantities of construction and demolition (C&D) waste, which in 2012 amount 33% of total waste generated in EU [2]. Because of the

large amounts of C&D waste that are generated and its high potential for reuse (up to 90%) [3] it is necessary to explore new ways for its utilization. Among C&D waste materials one of the most often used recycled materials in pavement construction is reclaimed asphalt pavement. Reclaimed asphalt pavement (RAP) is primary used as replacement for natural aggregate in asphalt mixtures. However, with regard to upper limits of RAP allowed in asphalt mixtures as well as other requirements placed on asphalt mixtures there are still significant amounts of RAP that cannot be utilized in this manner [4]. To avoid disposal of RAP to limited landfills engineers are investigating its possible application in unbound granular base layer as a replacement for natural aggregate. Research conducted so far indicate that use of RAP in unbound base layer is technically viable alternative [5, 6]. However, despite the increased acceptance of RAP/natural aggregate mixtures as unbound base material, limited information's and conflicting reports are available regarding the effect of seasonal frost conditions on RAP properties [7, 8]. Most of research is based on the comparison of materials resilient modulus values before and after freeze-thaw conditioning. Wu [9] and Attia and Abdelrahman [10] reported that resilient modulus of RAP increases after freeze-thaw cycles. It was assumed that the main reason for increase in resilient modulus was decreased in moisture content during sample conditioning and/or testing. In contrast to them, Bozyurt et al [7], Soleimanbeigi et al [8] and Shadivy [11] reported decrease in resilient modulus after freeze-thaw cycles as a result of particle degradation and progressive asphalt-binder weakening. Because of differences in materials and freeze-thaw conditioning, as well as in methods used to determine resilient modulus it is not possible to make a comparison between conducted researches.
The objective of research presented in paper is to evaluate effect of moisture content and freeze-thaw cycling on bearing capacity of RAP/natural aggregate mixtures. The CBR values of mixtures were determinate on samples at optimum moisture content, water saturated samples and samples exposed to freeze-thaw cycles.

2 Experimental considerations

Laboratory test program was divided in three parts; design of RAP/natural aggregate mixtures, determination of compaction characteristics and determination of California bearing ratio on samples exposed to different curing conditions.

2.1 Mixture design

Research was conducted on mixtures of natural aggregate and reclaimed asphalt pavement. In the mixtures type of natural aggregate (crushed limestone or river gravel) and percentage of RAP (0%, 20%, 35% and 50%) were varied.
In order to obtained mixtures that meet CRO requirements [12] for unbound base aggregate portion of RAP was replaced with different fractions of crushed limestone or river gravel. Since the bearing capacity and sensitivity to frost action is strongly influenced by gradation, two distribution curves were selected for designed mixtures, one for mixtures of RAP with crushed limestone (labelled LRAP%) and other for mixtures of RAP and river gravel (labelled GRAP%). According to designed composition eight mixtures were produced and their particle size distribution was determined in accordance with HRN EN 933-1 [13]. Results of particle size distribution test and CRO gradation requirements are shown in Table 1. In addition to particle size distribution, geometrical characteristics of the mixtures such as maximum particle size (d_{max}), coefficient of uniformity (C_u) and percentage of fines (‹ 0.02 mm) were also determined (Table 2).

Table 1 Mixtures particle size distribution and CRO gradation requirements

Mixture label	LRAP0	LRAP20	LRAP35	LRAP50	GRAP0	GRAP20	GRAP35	GRAP50	CRO req.
Sieve size [mm]	**Percentage passing [%]**								
31.5	100	100	100	100	100	100	100	100	73-100
22.4	91.64	94.23	94.80	92.03	93.57	91.96	91.75	90.61	-
16.0	83.25	83.03	81.74	76.74	84.09	80.27	81.14	78.69	54-90
8.0	70.46	66.75	61.88	54.37	61.54	60.34	61.74	61.33	40-75
4.0	52.49	47.24	47.24	41.93	40.52	42.66	44.64	44.13	29-60
2.0	34.68	30.57	31.88	28.81	30.15	31.15	30.10	31.36	20-48
1.0	20.80	18.07	18.44	17.13	25.50	25.75	23,00	24.65	13-38
0.500	12.89	11.18	11.25	10.28	22.04	22.05	19.02	20.57	7-28
0.250*	8.49	7.34	7.27	6.61	11.90	12.34	9.76	11.41	3-20
0.125*	6.03	5.13	5.03	4.56	1.92	2.26	1.58	2.14	2-15
0.063	5.46	4.69	4.66	4.20	0.89	1.14	1.10	1.14	-

*CRO requirements regulates passing through sieve size 0.2 and 0.1 mm

Table 2 Mixtures geometrical characteristics

Mixture label	LRAP0	LRAP20	LRAP35	LRAP50	GRAP0	GRAP20	GRAP35	GRAP50
d_{max} [mm]	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5
$C_u = d_{60}/d_{10}$	16.87	15.76	17.78	20.83	34.12	35.88	29.65	33.29
Fines [%]	3.28	‹3.28	‹3.28	‹3.28	‹0.89	‹1.14	‹1.10	‹1.14

As it can be seen in Table 1 all mixtures meet CRO gradation requirements. Maximum particle size for all mixture was 31.5 mm which is less than the maximum allowed 63 mm. Coefficients of uniformity were between 15 and 50 for mixtures with crushed limestone, i.e. 15 and 100 for mixtures with river gravel. Maximum percentage of fines (‹ 0.02 mm) was 3.28% which is within tolerance limits of CRO specifications. Based on presented results it can be concluded that in terms of particle size distribution and geometrical characteristics RAP/natural aggregate mixtures are suitable for application in unbound base layers.

2.2 Compaction characteristics

Compaction characteristics, optimum moisture content (OMC) and maximum dry density (MDD) were determinate by modified Proctor compaction test according to HRN EN 13286-2 [14]. Given the maximum particle size of 31.5 mm, mixtures were compacted with a 4.5 kg rammer in large Proctor mould (B). Results of modified Proctor test are shown in Table 3.

Table 3 Mixtures optimum moisture content and maximum dry density

Mixture label	LRAP0	LRAP20	LRAP35	LRAP50	GRAP0	GRAP20	GRAP35	GRAP50
OMC [%]	3.8	4.9	4.6	5.2	2.4	2.9	3.3	3.6
MDD [Mg/m^3]	2.16	2.13	2.06	2.04	2.22	2.15	2.11	2.12

As it can be seen in Table 3, increase in RAP content results in increase of optimum moisture content and decrease of maximum dry density for all mixtures regardless to the type of natural aggregate. Increase in optimum moisture content may be due to increase in percentage of fines during compaction [15] and decrease in maximum dry density is a result of lower specific gravity of RAP than natural aggregate [16].

2.3 Laboratory CBR test

Laboratory CBR test was conducted in accordance with HRN EN 13286-47 [17], on samples compacted by modified Proctor method at optimum moisture content. For each mixture three samples that were exposed to different curing times and conditions before testing were prepared (Fig. 1).

Figure 1 CBR samples at different stages of conditioning (left, middle) and testing (right)

First sample was tested immediately after compaction as to determine CBR value at optimum moisture content. Second sample was placed in an immersion tank filled with water, at room temperature (20 ± 2 °C). Pressure gauge was mount on the CBR mould to measure sample vertical expansion, e.g. swelling (Fig. 1, left). Sample was then left to soak in water for 96 hours during which expansion was recorded for every 0.05 mm. On completion of soaking sample was removed from a tank and allowed to drain for 15 minutes before testing. Third sample was placed in cooler with automatic program for freezing and thawing cycles (Fig. 1, middle). One cycle consisted of freezing at -15 °C for 16 hours and 8 hours of thawing at +20 °C. In thawing stage cooler was filled with water to a height of about 5 cm to simulate capillary rise of water. After 14 cycles sample was removed from cooler and left to thaw for 24 hours at room temperature before testing. During 24 hours of thawing, end caps were place on the mould and sealed with tape to prevent water loss by evaporation.

3 Results and analysis

The results of CBR test for all tested mixtures and curing conditions are summarised in Table 4. As it was expected from previous studies [15, 16, 18] the CBR value of the mixtures decreases with an increase in RAP content and the rate of decrease depended on the type of natural aggregate. The effect of sample conditioning, changes in moisture content and exposure to freeze-thaw cycles, on bearing capacity of tested mixtures will be analyzed separately.

Table 4 Results of CBR test

Mixture label	LRAP0	LRAP20	LRAP35	LRAP50	GRAP0	GRAP20	GRAP35	GRAP50
CBR_{OMC} [%]	185	74	44	36	110	85	73	53
CBR_{96h} [%]	129	62	40	27	75	53	44	29
CBR_{FT} [%]	117	54	31	22	28	17	14	12

3.1 Effect of moisture content

Change in moisture content of the samples from optimum to saturate resulted in decrease of CBR value (ΔCBR_{MC}) for all tested mixtures. This decrease was calculated as:

$$\Delta CBR_{MC} = \left(1 - \frac{CBR_{96h}}{CBR_{OMC}}\right) \times 100[\%] \quad (1)$$

Where:
CBR_{OMC} – is CBR value of samples tested at optimum moisture content,
CBR_{96h} – is CBR value of samples tested after 96 hours soaking in water.

Effect of moisture content on CBR value largely depends on the type of natural aggregate (Fig.2). For mixtures with crushed limestone the largest decrease was obtained on those without RAP, followed by the reduction in decrease for mixtures with 20% and 35% of RAP, and slightly increases for mixtures with 50% of RAP. On mixtures with river gravel smallest decrease was obtained for mixtures without RAP followed by continuous increase with increase in RAP content.

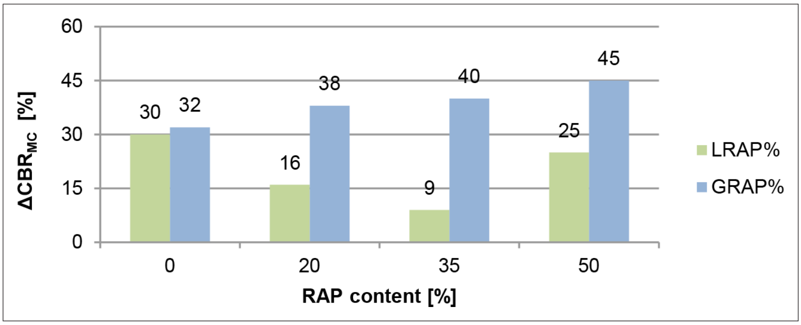

Figure 2 Decrease of CBR value caused by change in moisture content in relation to RAP content

3.2 Effect of freeze-thaw cycles

Exposure of samples to freeze-thaw cycles resulted in decrease of CBR value (ΔCBR_{FT}) for all tested mixtures. The decrease was calculated as:

$$\Delta CBR_{FT} = \left(1 - \frac{CBR_{FT}}{CBR_{OMC}}\right) \times 100[\%] \quad (2)$$

Where:
CBR_{OMC} – is CBR value of samples tested at optimum moisture content,
CBR_{FT} – is CBR value of samples tested after 14 freeze-thaw cycles.

As it is shown on Fig. 3, decrease in CBR value largely depends on the type of natural aggregate. For mixtures with crushed limestone the largest decrease was obtained on mixtures with 50% of RAP and the lowest on those with 20%. Mixtures with 20% and 35% of RAP had slightly lower decrease in CBR value compared to 100% crushed limestone mixtures. For all RAP/river gravel mixtures decrease in CBR value after freeze-thaw cycles was of a comparable level regardless of RAP content.

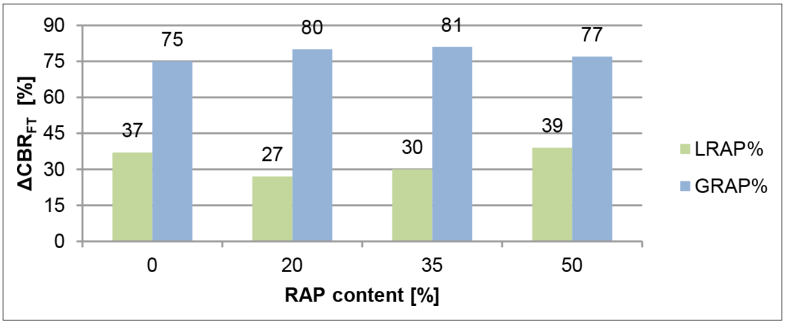

Figure 3 Decrease of CBR value caused by freeze-thaw cycles in relation to RAP content

4 Conclusion

Application of RAP in unbound base layers would result in significant economic benefits, substantial reduction in RAP material disposed on landfills and preservation of natural aggregate resources. A major concern in using RAP as an unbound base layer is influence of changing seasonal conditions on its properties. To investigate the effect of change in moisture content and freeze-thaw cycling on RAP/natural aggregate mixtures laboratory CBR test was performed on mixtures of natural aggregate (limestone or gravel) with varying RAP percentages (0, 20, 35 and 50%) exposed to different curing conditions.

Both, the effect of change in moisture content and the effect of freeze thaw cycles on mixtures bearing capacity largely depended on type of natural aggregate. RAP/crushed limestone mixtures were less sensitive to change in moisture content compared to crushed limestone mixture without RAP. For RAP/river gravel mixtures increase of RAP content resulted in an increased sensitivity of mixtures to changes in moisture content. Regarding the effect of freeze-thaw cycles it can be concluded that RAP/crushed limestone mixtures are less sensitive to freeze-thaw cycles if the RAP content is below 50%. For RAP/river gravel mixtures freeze-thaw cycles resulted in reduction of bearing capacity with an average 80% decrease of CBR value. This decrease was not affected by change in RAP content.

RAP/crushed limestone mixtures are suitable for the application in unbound base layers since they are less sensitive to changes in moisture content and freeze-thaw conditioning. However, as these mixtures have lower bearing capacity than mixtures without RAP, their main application would be for low volume roads with thinner asphalt layer where unbound base layers are more exposed to freeze-thaw cycles. Application of these mixtures in high volume roads requires additional testing as well as adjustment of current technical regulations in the field of unbound base layers.

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