REPLACEMENT OF DAMAGED CONCRETE PAVING BLOCKS

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SUMMARY

Surface damage (spalling) of new concrete paving blocks, which were cast into the square and streets of an old part of the town of Samobor, Croatia has appeared very soon after embedding. Damage was caused by freeze-thaw cycles during the first winter. The only criterion that cast paving blocks had to satisfy was 28-day compressive strength of 50 MPa. Damaged surfaces have been spread over the whole renovated area and, therefore, it was decided in favor of complete replacement of damaged paving blocks with new ones. The newly produced paving blocks had to have, along with required mechanical properties, better durability properties for described aggressive environment.

In this paper replacement of damaged concrete paving blocks is described as well as their quality control Mechanical and durability properties of newly produced concrete paving blocks were tested .in accordance with existing Croatian standards, in particular dimensions, volume and dry density, thickness of surface abrasion layer, compressive strength, bending strength, abrasion and impact resistance and freeze-thaw resistance with/without using deicing salts.

1. INTRODUCTION

Use of concrete paving blocks in construction of traffic areas is increasing during the last several decades in the world, as well as in Croatia. Concrete paving blocks are most frequently used in building and renovation of municipal pedestrian areas and less loaded traffic areas. Development of production and embedding technology of concrete paving blocks has improved their mechanical and durability properties. Therefore they are lately increasingly used for high-load traffic areas such as airports and industrial objects.

There are numerous examples dating from the end of last century where the only technical criterion of achieving improved durability properties of concrete paving blocks was higher 28-day compression strength (>40 MPa). However, in many cases achieving of higher compression strength was not a guaranty of improved concrete paving blocks durability, especially in cases when paving blocks were exposed to freeze-thaw cycles with/without using deicing salts and in cases of extreme abrasion. Replacement of damaged concrete paving blocks with those of better durability properties was then the only possible solution.

This paper describes a case study of replacing app. 6000 m^2 of damaged two-layer concrete paving blocks within mostly pedestrian area of the main square and approaching streets of the old historical part of the town of Samobor, 20 km away from Zagreb, capital of Croatia. Furthermore, quality control of newly produced/embedded concrete paving blocks is given. Within the quality control, along with mechanical properties determined by the project, paving blocks had to satisfy additional durability properties.

2. CONDITION OF DAMAGED CONCRETE PAVING BLOCKS

The King Tomislav Square is located in the old, historical part of the town of Samobor. Therefore, city council has decided that, during the renovation of that part of the town in 1999, areas of square and approaching streets should be paved with material similar to natural stone paving blocks. Two-layer concrete paving blocks, with thickness of 8 cm, have proved to be the best solution for that demand. These paving blocks have been embedded in modules of 1 m^2, and every module was consisted of 10 blocks of different size (Fig. 1).



Figure 1. Concrete paving blocks module

Concrete paving blocks were embedded in construction of Samobor's main square, according to main project, on adequate support layer. They had to satisfy only one technical criterion: the 28-day compression strength of 50 MPa. Prior testing, carried out in laboratory conditions, has proved that embedded paving blocks were satisfying that criterion. Nevertheless, very soon after embedding, only one winter afterwards, surface damages appeared on paving blocks. These damages were spalling and crushing of upper abrasion layer and edges. The cause of these damages was freeze-thaw cycles during the winter together with using deicing salts (Bijen, 2003). One of the possible reasons of caused damages is that paving blocks were embedded during winter time, only few days after producing and therefore immediately exposed to freeze-thaw influence before reaching required 28-day strength.



Figure 2. View of the King Tomislav Square in Samobor

With the purpose of evaluating the state of damaged concrete paving blocks, the whole square area was examined (Fig. 2). Evaluation included visual examination of paving blocks surfaces with the purpose of revealing visible characteristic defects. Visible defects were crushing and spalling of surface, crushing and falling of edges, surface cracks and dirt stains. In order to evaluate the state of concrete paving block damage, degrees of damage have been defined in table 1.

Table 1. Defined damage degrees

Degree level	Damage description	Damage depth (mm)
0	Without spalling	0
1	Slight spalling	0-1
2	Medium spalling	1-4
3	Strong spalling	4-10

According to the results of damage degree evaluation (Table 2) it is visible that approximately 50 % of square's total surface had damages of 2nd or 3rd degree and the rest had damages of 0 and 1st degree. Damages of 1st degree have occurred as dirt stains, surface unevenness and minor cracks and damages of 2nd and 3rd degree as spalling, crushing of surface while stepping on it and minor or severe crushing of edges (Fig. 3). Damages were of higher intensity on surfaces exposed to weather conditions, on places for temporary stopping and parking of vehicles as well as on surfaces along the main road crossing by the square. Damages on surfaces located next to the objects, where paving blocks were not directly exposed to weather condition influence, were of smaller intensity and their state was much better.

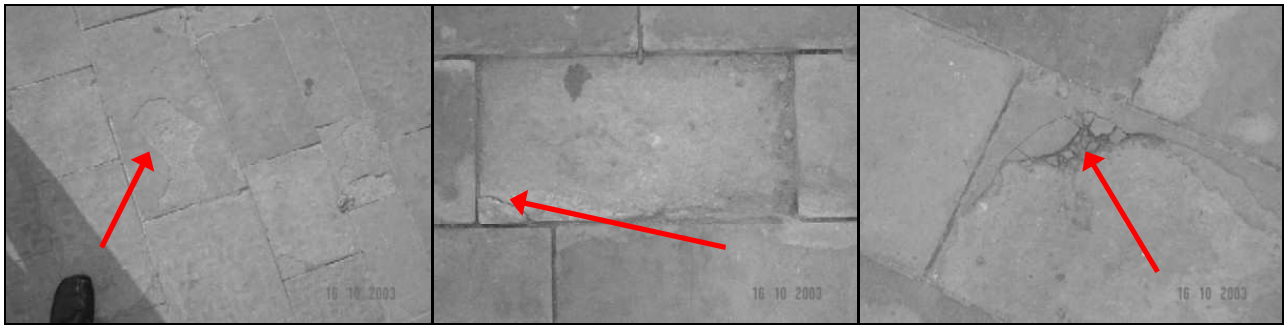

Figure 3. Visible damages on concrete paving blocks

Table 2. Distribution of surface damages by degrees

Damage degree	Area of damaged surfaces (m^2)	Percentage of damaged surfaces (%)
0	300	5
1	2520	42
2	1980	33
3	1200	20
TOTAL	6000	100

3. REPLACEMENT OF DAMAGED CONCRETE PAVING BLOCKS

Because of a high damage rate it was decided to replace concrete paving blocks on the whole square area. The replacement started in 2003. For this purpose two-layer concrete paving blocks of the same view and dimensions with improved composition of concrete mixture were used in order to achieve better durability properties. In paving block production two types of concrete mixtures were used. Concrete mixture for lower layer consisted of 370 kg of cement per cubic meter of concrete and of dolomite aggregate of 8 mm maximum grain size. Mixture for upper abrasion layer consisted of 470 kg of cement per cubic meter of concrete and of diabase aggregate of 3.2 mm maximum grain size. Volume of water added into concrete mixture depended on required consistency. The only difference between two mixtures was percentage of added black pigment in upper abrasion layer, 1.25 or 2 % of cement mass. Maximum amount of black pigment was limited to 2% of cement mass because prior testing showed greater loss of strength of abrasion layer if the black pigment was added in larger amount (Ukrainczyk, 1994). Paving blocks were embedded in square construction by method shown on Figure 4.

Continuously, during the replacement, quality control of newly produced concrete paving blocks has been carried out, according to control schedule and additional technical criteria that paving blocks had to satisfy (Table 3). According to additional technical criteria, main durability properties that paving blocks had to satisfy were abrasion resistance, freeze-thaw resistance with and without using deicing salts and impact resistance (Ukrainczyk, 2001).

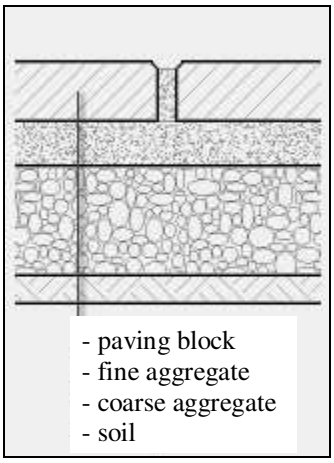

Figure 4. Concrete paving block construction method – cross section

Quality control of concrete paving blocks was carried out according to existing Croatian standards. Frequency of sample taking for tests that were carried out depended on quantity of produced paving blocks and intensity of production. During the quality control, for some tested properties (e.g. freeze-thaw resistance with using deicing salts); new standards were brought, harmonized with European (EN) standards. However, as the quality control was in its 2nd year of carrying out, it was decided to continue using old standards till ending complete repair of damaged surfaces.

Table 3. Technical criteria for two-layer concrete paving blocks

Property	Test method	Criteria
Dimensions	HRN EN 1339	maximum deviation: - length and width ± 2mm - thickness and diagonals difference ± 3mm
Abrasion layer thickness	HRN EN 1339	minimal 4mm
Visual appearance	HRN EN 1339	- without visible defects of abrasion layer - without delaminating between two layers
Volume mass	HRN B.B8.010	$\geq$ 2.15 g/cm^3
Compression strength	DIN 18 501	$\geq$ 50 MPa
Bending strength	HRN EN 1339	- average value $\geq$ 5 MPa - individual values $\geq$ 4 MPa
Water absorption	HRN B.B8.010	$\leq$ 6% of mass
Impact resistance	Procedure developed on Faculty of civil engineering in Zagreb	resistance on impact energy of 50 J
Abrasion resistance by grinding	HRN EN 1339	volume loss $\leq$ 18cm^3/50cm^2
Freeze-thaw resistance without using deicing salts	HRN U.M1.016	compression strength loss $\leq$ 25% after 100 cycles
Freeze-thaw resistance with using deicing salts	HRN U.M1.055	weight loss $\leq$ 1 kg/m^2 after 50 cycles

3.1 Dimensions of concrete paving blocks (HRN EN 1339)

Dimension measurements (length, width, thickness, diagonals difference) were carried out on every paving block from particular series. Measurements were carried out on 4 places on every paving block, and as a result average value of all measurements was taken. During all measurements requested technical criteria were satisfied.

3.2 Abrasion layer thickness (HRN EN 1339)

Measurements of abrasion layer thickness were carried out also on every paving block from particular series. On each sample measurement was carried out on places where the minimum abrasion layer thickness was visually determined. In this case requested technical criterion was also satisfied in all measurements carried out.

3.3 Visual appearance (HRN EN 1339)

Concrete paving block was set in position similar to its position in construction. On the daylight, on the distance of approximately 2 m, the existence of possible defects was detected. By visual examination, in each examined series, it was determined that all concrete paving blocks satisfy technical criterion.

3.4 Volume mass (HRN B.B8.010)

By measuring mass and volume of each sample of concrete paving block its volume mass was calculated, and in all cases of measurements the technical criterion was satisfied.

3.5 Compression strength (DIN 18 501)

Compression strength test method was taken from existing German (DIN) standards because the new European (EN) standards do not include it. Procedure for testing compression strength was pressing two steel plates of dimensions 8x16x5 cm into paving block on a compression machine with controlled force growth (Fig. 5). Plates were placed below and above tested paving block on previously leveled surfaces. Compression strength was calculated as ratio between break force and area of steel plates (8x16 cm).

Criteria for evaluation of achieved compression strength were in accordance with Croatian Regulation for concrete and reinforced concrete (PBAB, 1987), paragraph 46, criterion 1. Produced concrete satisfies requested class of compressive strength if all test results satisfy sub criteria mentioned below:

$$m_3 \geq f_{ck} + k_1 \quad (1)$$

$$X_1 \geq f_{ck} - k_2 \quad (2)$$

where:

f_{ck} – concrete characteristic compressive strength– in this case from technical criteria f_{ck}=50 MPa,

m_3 – average value of three consecutive test results (MPa),

X_1 – smallest value of three consecutive test results (MPa),

k_1=3 MPa, k_2=3 MPa – constants used for established production.

Statistical processing of test results (Table 4) showed large dissipation of produced paving block's compression strength through high standard deviation (6.05 MPa). Standard deviation (σ) of compression strength test results is usually index of equally distributed concrete production.

Based on calculated standard deviation, it can be concluded that tested concrete paving blocks were produced in out dated production with poor mechanization or with modern mechanization with little or none of production control influence (Ukrainczyk, 1994). This was particularly visible in case of season influence on concrete compression strength test results. During summer concrete compression strength used to reach values above 60 MPa, and during winter only 40 MPa. Therefore, in minor number of cases technical criteria for compression strength was not satisfying.

3.6 Bending strength (HRN EN 1339)

A technical criterion for bending strength has been satisfied in all cases of testing. Bending strength was determined by testing samples of paving blocks to action of concentrated force in the middle of span (Fig. 6) under controlled force increase:

$$\sigma_S = \frac{3 \cdot P \cdot l}{2 \cdot b \cdot t^2} \quad (3)$$

where:

P – break force (N),

l – testing span (mm),

b, t – dimensions of sample's cross-section (mm),

σ_S – bending strength (MPa).

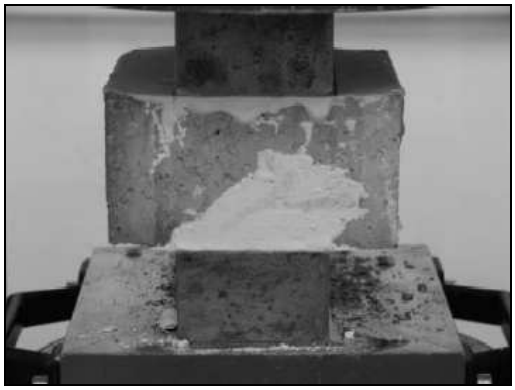

Figure 5. Compression strength testing



Figure 6. Bending strength testing

3.7 Water absorption (HRN B.B8.010)

Measurements of water absorption were carried out on small samples of paving blocks whose mass was between 150 and 350 g. Water absorption was represented as total amount of absorbed water till complete saturation state. It was displayed in percentage of mass of totally dry sample and it always satisfied given technical criteria.

3.8 Impact resistance

Because of lack of any defined test method in existing Croatian and European standards, impact resistance of concrete paving blocks was tested based on the method developed on the Faculty of Civil Engineering in Zagreb. This test method was developed within work participation of RILEM Technical Committee TC 184 IFE and European project Eureka E! 2345. Testing procedure consisted of prior embedding of paving block sample on crushed stone base similar to one used in real construction (Fig. 4). After that, paving block was exposed to dropping of 10 kg heavy ballast from the height of 0.5 m on a drawn grid in order to achieve impact energy of 50 J (Fig. 7). Serious damages of paving block should not have occurred during testing (Stirmer, 2004). While testing only surface damages on upper abrasion layer of paving block have occurred (concavities, surface cracks). In minor number of cases larger cracks have occurred, even sample breaking. Cause of that was test method that is testing of sequence of neighboring points close to sample edges (Fig. 8). Therefore, concrete paving blocks have not satisfied technical criterion.



Figure 7. Impact resistance testing

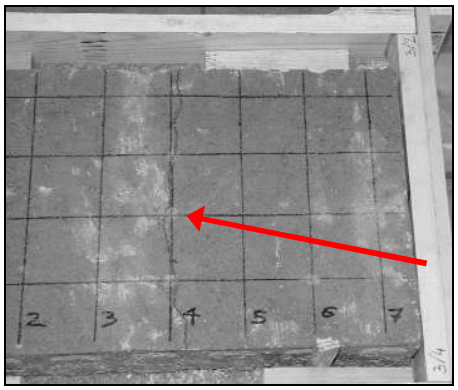

Figure 8. Impact damage (crack)

3.9 Abrasion resistance by grinding (HRN EN 1338)

Abrasion resistance by grinding was one of the main properties that paving blocks had to satisfy. Samples of 50 cm^2 area were tested to abrasion by grinding according to Bohme test on rotating plate

on which abrasion sand, defined by standard, was added (Fig. 9). Before starting the testing samples were submitted to pre cycles. Afterwards, testing for each sample lasted for 16 cycles. Every cycle consisted of 22 rotations of round steel plate. Result was displayed as a loss of volume during testing by grinding against the area of tested sample. During all measurements requested technical criteria was satisfied.

3.10 Freeze-thaw resistance without using deicing salts (HRN U.M1.016)

One cycle of freeze-thaw action consisted of putting the sample under influence of freezing temperature of –20 ± 2°C in duration of 4 hours and defrosting it in water under temperature of 20 ± 2°C during another 4 hours. Before and after ending the testing, compression strength, by pressing two steel plates of dimensions 8x16x5 cm into sample, was determined (Fig. 5). Just before testing the compressive strength, the upper and lower sample surfaces were leveled. Compression strength of tested samples after 100 cycles was not aloud to be less than 75% of compression strength of the check samples. In other words, compression strength was not aloud to drop more than 25% on samples tested on freeze-thaw resistance without using deicing salts. Tested concrete paving blocks did not satisfy that criterion and that is visible from statistically processed results (average value and standard deviation). Also, this property of paving blocks was closely connected to compression strength, and it was logical that if criterion of compression strength was not satisfied, criterion of freeze-thaw resistance without using deicing salts would not be satisfied too.

Table 4. Processed results of control tests of concrete paving blocks

Tested property	Unit	Number of samples tested	Average value	Standard deviation	Variation coefficient (%)
Compression strength	(MPa)	51	53.56	6.05	11
Bending strength	(MPa)	30	7.20	0.72	20
Water absorption	(% of mass)	35	5.12	0.70	7
Abrasion resistance by grinding	(cm^3/cm^2)	24	12.23	2.13	17
Freeze-thaw resistance without using deicing salts	(MPa)	21	36.28	7.29	20
Freeze-thaw resistance with using deicing salts	(kg/m^2)	21	0.021	0.007	36

3.11 Freeze-thaw resistance with using deicing salts (HRN U.M1.055)

Before testing, the silicone frame of approximate 15 mm height was placed on samples of paving blocks. Within those frames, on a sample surface, 3% NaCl solution was poured in 3 mm height (Fig. 10). One cycle of testing consisted of putting the sample under influence of freezing temperature of –20 ± 2°C in duration of 16 to 18 hours and defrosting it under temperature of 20 ± 2°C during another 6 to 8 hours. After every 5 cycles and after ending testing (after 50 cycles) the mass of spalled material on sample surface was measured. Furthermore, the depth of upper abrasion layer damage was analyzed. Test results showed that tested samples of concrete paving blocks had, after 50 cycles, damages of 0 or 1st degree and weight loss lower than given in technical criteria. It was concluded that paving blocks have required freeze-thaw resistance with using deicing salts.

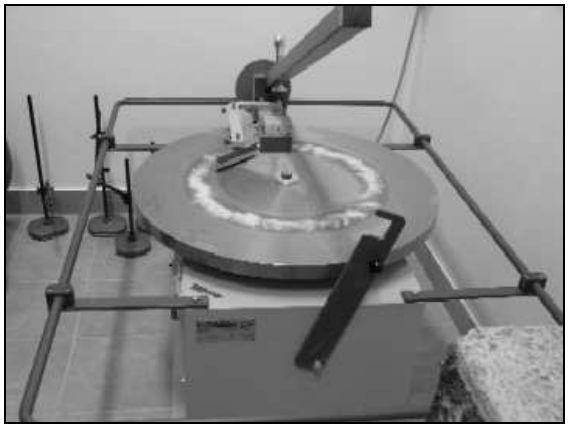

Figure 9. Abrasion resistance testing

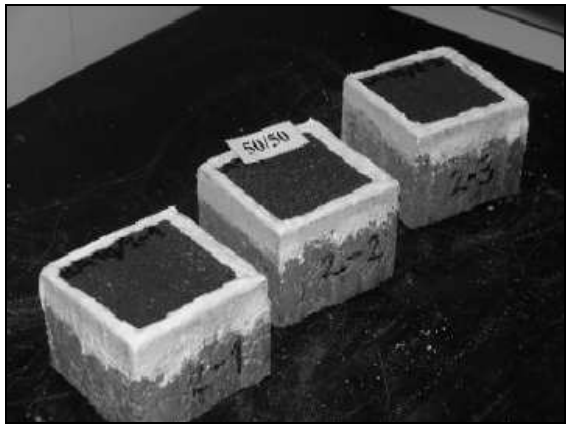

Figure 10. Samples tested on freeze-thaw resistance with using deicing salts

4. CONCLUSIONS

According to showed and described results of quality control of newly produced concrete paving blocks for King Tomislav Square in Samobor, it can be concluded that replacement of damaged surfaces was successfully carried out. By improved durability properties of concrete mixture and more rigorous production and embedding quality control, requested properties of concrete paving blocks were achieved. Completely undamaged surfaces of embedded paving blocks, after already few years of use and few winter periods with severe, freezing temperatures, are proof for that statement.

5. ACKNOWLEDGMENT

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