STATIC ANALYSIS ON ROAD CONCRETE CLASS BcR 4.5 AND BcR 5.0

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Abstract: *The reliability of the products, determined by measuring and estimating quality characteristics, plays a decisive role in the strategy of the economic evolution. In the execution of rigid road clothing, traditional materials are used, which are found in nature (stone, sand, cover aggregate etc.). Blended with binders, the resulting structures must respect specific well-established resistors, obtained in special production stations. In order to determine the quality of any material used in practice, first of all, it is necessary to run tests on it in laboratories equipped with specific apparatus.*

This paper presents a comparative study on the bending behaviour of the road concrete class BcR-4.5 and BcR-5.0, on the KD-KL 300/R hydraulic dual piston test machine. The bending strength was calculated, under the action of different forces, comparing the experimental values with the values obtained from a finite element analysis.

Keywords: *road concrete, FEM analysis, bending analysis*

1. Introduction

Ensurance regarding the durability of concrete structures represents a vital issue for the national economy, and concrete, as a composite building material, obtained after certain recipes by mixing aggregates with binders, various additives and water, still has a vast usage in practice, due to its multiple advantages, such as: high durability, good behaviour in static and dynamic actions, reduced maintenance costs compared to other structural elements, resistance to environmental actions etc. [Proca, 2012], [Dumitraș, 2014].

Structural elements of concrete industrial constructions can often be subjected to mechanical loading of variable intensity in relation to the time [Baciu, 2017], [Chira, 2014], however, since the Regulation NE 012/1 (CP 012/1) entered into force, concrete can be designed, produced and put into opera, being more resilient, more durable and at the same time, more efficient, in terms of embedded energy, according to the new binding national regulations, harmonised with the European regulations [NE 012/1, 2007], [HeidelbergCement, 2017].

At the same time, concrete cement road clothing for rigid road structures must be designed to ensure the framing of the concept of sustainable development, by applying new technological solutions, but also the development of design, sizing, simulation and testing principles [Ilinoiu,2004].

The general conditions to be met when preparing, transporting, putting into work and controlling the quality of concrete in the making of road clothing with cement concrete shall be applied to modernisations or reinforcements of public roads, industrial platforms, parking places, trails, roads and airport platforms, for which technical prescriptions in force, specific to these works, are to be respected [NE 014, 2002], [Cojocaru, 2013].

Compressive and bending strength are the main criteria for assessing the quality of a concrete. Knowledge of compression strength gives sufficiently precise indications on resistance to other demands, as well as on the other physical and mechanical properties of concrete [Mohamad, 2016], [Tan, 2019], [De Oliveira, 2008]. The strength of concrete to bending also depends, in addition to the quality of concrete, on other factors, such as:

testing conditions, shape and dimensions of the specimen, method of manufacturing and storage, loading speed etc. In order for the values obtained to be comparable and reproducible, finite element analysis can be carried out, to which the loads must strictly comply with the conditions of determination laid down in the international standards [Goh, 2014], [Indriyantho, 2014], [Oh, 2018], [Viswanathan, 2014].

2. Road concrete. Technical characteristics

Concrete, as a mixture of aggregates (sand and cover aggregate), cement and water and possibly some additions intended to confer special properties, can be classified after several criteria, the most common being after the apparent density, Table 1.

Table 1: *Classification of concrete by density*

Density category of concrete	*Apparent density, [kg/cm^3]*
Very heavy concrete	>2.500
Concrete with normal density	2.001….2.500
Light concrete	<2.000

Depending on the density of the element in which is poured, the concrete mark shall be established, defined as the compressive strength of concrete. [daN/cm^2], established 28 days after preparation and kept under specific conditions. At the same time, account must also be taken of a series of characteristics, ever since its state of fresh concrete: the proportions in which the different components must be located; consistency - corresponding to the various building elements in which it is poured; The analysis as a result of which is found whether the concrete out of the pan mixer has the projected composition etc. In order to determine the mechanical properties of concrete it is necessary to manufacture the transverse test specimens and compression test piece, which undergo bending or compression tests, as appropriate.

The manufacturing process of the test pieces is carried out with fresh concrete, and their test is made after it has hardened, 28 days after pouring concrete.

The test pieces that are made to determine the mechanical strength of concrete are of three shapes: cubes, cylinders and prisms. The most common are the cube-shaped ones with the 150 mm side, as well as the prism type. They serve to determine both compressive strength and bending strength, being advantageous when aggregates can be used with a maximum diameter of 25 mm. Removable patterns are used for manufacturing test pieces. The compressive strength of the concrete is expressed by the strength classes related to the characteristic strength, measured on the cylinder, f_{ck}, or on the cube, $f_{ck,cube}$, EN 206-1. The strength values for the usual concrete are presented in Table 2.

Table 2: *Concrete strength characteristics (EN 1992-1-1): f_{cm} – average compressive strength; E_{cm} – Young's modulus*

Type	*C12/15*	*C16/20*	*C20/25*	*C25/30*
f_{ck} *[MPa]*	*12*	*16*	*20*	*25*
$f_{ck,cube}$ *[MPa]*	*15*	*20*	*25*	*30*
f_{cm} *[MPa]*	*20*	*24*	*28*	*33*
E_{cm} *[GPa]*	*27*	*29*	*30*	*31*
Clasa	*C30/37*	*C35/45*	*C40/50*	*C45/55*
f_{ck} *[MPa]*	*30*	*35*	*40*	*45*
$f_{ck,cube}$ *[MPa]*	*37*	*45*	*50*	*55*
f_{cm} *[MPa]*	*38*	*43*	*48*	*53*
E_{cm} *[GPa]*	*33*	*34*	*35*	*36*

Usually, for road concrete, the road-mix shall be chosen for which, with the minimum dosage of cement, the bending and compression strength of concrete are higher or at least equal to the resistance after 28 days, after the preparation, Table 3.

Table 3: *Resistance classes of road concrete*

Class	*Bending strength - prism 150x150x600mm [N/mm^2]*	*Average bending strength -cubes, l=150mm [N/mm^2]*
BcR 5.0	5.5	50
BcR 4.5	4.9	44
BcR 4.0	4.4	39
BcR 3.8	3.8	34

3. Experimental equipment

3.1 Materials used

The road concrete is made out of natural road-mix aggregates and quarry, water, cement and additives. The materials used in the composition of the road concrete, BcR 4.5 and BcR 5.0, are presented in Table 4 and Table 5.

Table 4: *Composition characteristics of road concrete class BcR 4.5*

Material quantities at 1 m^3 dry concrete		
Components	*Dry aggre-gates [Kg]*	*Water [l]*
CEM I 42.5 R	400	-
Water	-	164
Aditive AIR G100 (0.15%)	0.6	-
Aditive FLUID FTM (0.90%)	3.6	-
Sort 0/4 mm (41%)	758	38
Sort 4/8 mm (17%)	320	6
Sort 8/16 mm (22%)	415	6
Sort 16/25 mm (20%)	377	-
Green concrete density [kg/cm^3]	2438	

Table 5: *Composition characteristics of road concrete class BcR 5.0*

Material quantities (per 1 m^3 dry concrete)		
Components	*Dry aggre-gates [Kg]*	*Water [l]*
CEM I 42.5 R	420	-
Water	-	165
Aditive AIR G100 (0.15%)	0.63	-
Aditive FLUID FTM (0.90%)	3.78	-
Sort 0/4 mm (41%)	745	37
Sort 4/8 mm (17%)	315	6
Sort 8/16 mm (22%)	408	6
Sort 16/25 mm (20%)	370	-
Green concrete density [kg/cm^3]	2427	

- *FTM* - superplasticizer fluid
- *AIR G100* - air entrainer/mixed with water

Specimens are prism-shaped, made of fresh concrete, with dimensions of 150x150x600 mm, using removable metallic patterns. The required volume of a specimen must be at least 5/4 of the volume of the patterns.

Vibratory compaction of the specimens is made using a vibrant table with a frequency of about 3000 vibrations per minute and an amplitude of 0.35 mm.

Whatever the purpose of taking the specimens, they shall be kept during the first 24 hours in the pattern in which they were poured out. After this term, the specimens are carefully dismantled, by removing the patterns, taking care not to take off the edges.
The characteristics of the retention regimes indicated are high humidity (water) and normal humidity (air), Figure 1.

Figure 1: *Keeping specimens after dismantling.*

3.2 Work equipment

The concrete testing machine designed for specimens is a dual piston hydraulic test press, Figure 2.

Figure 2: *The concrete testing machine with KL 300/CE dual piston KL 300/CE.*

This is equipped with two concentric hydraulic pistons, which can be actuated separately. One of the pistons, the largest, develops a force reaching up to 3000 kN, and the specimens that can be tested are cubes, cylinders and prisms, and the smallest develops a force of 300 kN and can be tested cement prisms, ballast cylinders and stabilized soil road. This solution allows a double measurement scale using a single test room.

For safety reasons the hydraulic system has 2 pressure valves, calibrated so that no piston would develop forces higher than those laid down in the technical requirements.

3.3 Research methodology

Specimens, with the same moisture state that they had in the storage environment, shall be subjected to testing. The specimens shall be located on the bearings of the press in such a way that the forces transmitted through the knives of the device act perpendicularly to the casting plan, Figure 3.

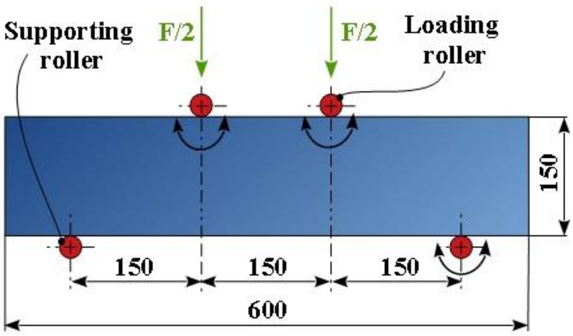

Figure 3: *The physical principle of bending stress.*

It shall be controlled that both the press and the knives of the device are in contact with the concrete on the entire width of the specimen, after which the loading starts, so as to produce an increase in the effort of 0.05 ± 0.01 N/mm^2, Which leads to a load application speed of about 250 N/s to the breaking point of the prisms. A single test was performed on a prismatic specimen of 150x150x600 mm. Bending strength is the arithmetic mean of 3 determinations that are performed on a series of prismatic specimens, made of the same concrete. The speed of application of the load is about 250 N/s to the breaking point of the prisms.

4. Determination of bending strength of concrete specimens class BcR 4.5 and BcR 5.0

The bending strength of the road concrete is calculated considering the elastic behaviour of the stretched area to the breaking point, on the specimens of 150x150x600 mm:

$$R_{inc} = \frac{M}{W_{el}} = \frac{\frac{F \cdot L}{6}}{\frac{B \cdot H^2}{6}} = \frac{F \cdot L}{B \cdot H^2} \text{ [N/mm}^2\text{]} \qquad (1)$$

where: M is the bending moment [N·mm]; W – strength modulus, accepting the hypothesis of elastic behaviour of the stretched area to the breaking point [mm^3]; F – breaking force, read on the screen of the press [N]; L – the unsupported length (450 mm); B – cross-sectional width (150 mm); H – mean height of the cross-section (150 mm). The result is rounded to 0.1 N/mm^2. Stretching strength by bending for road concretes can be determined by the relation:

$$R_t = 0.875 \cdot \frac{F \cdot L}{B \cdot H^2} \text{ [N/mm}^2\text{]} \qquad (2)$$

The test is carried out at the ambient temperature of 20°C ± 5°C and a relative humidity of 65%, the apparatus used being the compression test machine KL 300/EC. The concrete specimen is positioned between the press pans, so that the application is applied perpendicular to the casting direction, Figure. 4.

Figure 4: *Specimen subjected to bending test.*

Also, the specimen is centered towards the lower plate to a degree of accuracy of ± 1% of the specific dimensions of the plate. Force is constantly applied, without shocks and continuously 0.6 ($N/mm^2 \cdot s$) ± 0.2 ($N/mm^2 \cdot s$). When using manual order testing presses, it corrects any trend in speed variation by decreasing it as it punctually approaches the breaking point.

4.1 Determination of bending strength of the concrete specimens class BcR 4.5

To check the correct framing in the strength class of the road concrete, the bending strength of the specimens in BcR 4.5 is calculated. In consequence, 6 results from different series were taken into account, Table 6, Figure 5.

Table 6: *Bending strength of the road concrete class BcR 4.5*

No.	*Applied force, F [kN]*	*Strength, R_{inc} [N/mm²]*
1.	41.25	5.52
2.	45.01	6.01
3.	46.51	6.22
4.	48.75	6.51
5.	52.50	7.01
6.	54.10	7.20

Figure 5: *Bending test– BcR 4.5.*

The achievement of the road concrete class BcR 4.5 is checked based on the 6 results of the bending strength, Table 6:

- sum of results values [N/mm²]

$$\sum R_{inc} = 5.52+6.01+...+7.01+7.20=38.47$$

- sum of squares of results values [N/mm²]

$$\sum R_{inc}^2 = 5.52^2+6.01^2+...+7.01^2+7.20^2=248.64$$

- standard deviation, S [N/mm²]:

$$S=\sqrt{\frac{1}{6-1}\left(248.64\text{-}\frac{1}{6}\cdot 38.47^2\right)}=0.887$$

- average strength, R_{inc} [N/mm²]:

$$\overline{R_{inc}}=\frac{\sum R_{inc}}{n}=\frac{38.47}{6}=8.64$$

- characteristic strength, R_{inc}^k [N/mm²]:

$$R_{inc}^k = 8.64-0.875\cdot 0.887=7.86$$

4.2 Determination of bending strength of the concrete specimens class BcR 5.0

In order to check the correct framing in the strength class of the road concrete, the bending strength of the samples in BcR 5.0 is calculated. In consequence, 6 results from different series were taken into account, Table 7, Figure 6.

Table 7: *Bending* strength *of road concrete class BcR 5.0*

No.	*Applied force, F [kN]*	*Strength, R_{inc} [N/mm²]*
1.	45.01	6.02
2.	48.11	6.41
3.	52.51	7.00
4.	53.25	7.90
5.	56.25	7.50
6.	61.75	8.10

Figure 6: *Bending test– BcR 5.0.*

The achievement of the road concrete class BcR 5.0 is checked based on the 8 results of the bending strength, Table 7:

- sum of results values [N/mm²]

$$\sum R_{inc} = 6.02+6.41+...+7.50+8.10=42.93$$

- sum of squares of results values [N/mm²]

$$\sum R_{inc}^2 = 6.02^2+6.41^2+...+7.50^2+8.10^2=310.60$$

- standard deviation, S [N/mm²]:

$$S=\sqrt{\frac{1}{6-1}\left(310.60\text{-}\frac{1}{6}\cdot 42.93^2\right)}=1.536$$

- average strength, R_{inc} [N/mm²]:

$$\overline{R_{inc}}=\frac{\sum R_{inc}}{n}=\frac{42.93}{6}=7.16$$

- characteristic strength, R_{inc}^{k} [N/mm²]:

$$R_{inc}^{k} = 7.16 - 0.875 \cdot 1.536 = 5.81$$

5. Finite element analysis of the demands of road concrete specimens classes BcR 4.5 and BcR 5.0

For the finite element analysis [Beznea, 2012], [Beznea, 2019], it is considered the case of road concrete specimens BcR 4.5 and BcR 5.0., using the COSMOS/M licensed software.

The numerical analysis was made for paralelipipedic blocks with dimensions of 150x150x600 mm, considered simple at the distance of 75 mm from the free ends and the length of support of 450 mm, Figure 7.

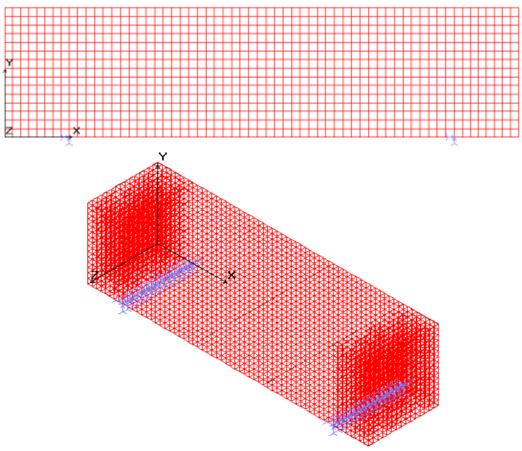

Figure 7: *The FEM BcR 4.5 and BcR 5.0 analysis - defining the boundary conditions.*

Concrete specimens were modelled with 5 elements of volume and discretized with SOLID-type elements. A number of 13725 SOLID-type elements were used in order to discretize the 5 volumes, Figure 8.

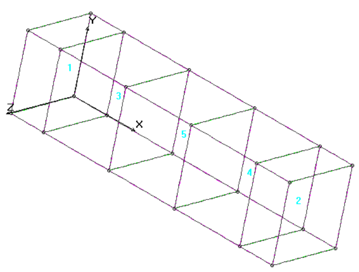

Figure 8: *FEM BcR 4.5 and BcR 5.0 modelling using 5 elements of volume.*

The loading was carried out with evenly distributed linear loads, their values being presented in Table 6 for road concrete class BcR 4.5, respectively, Table 7 for road concrete class BcR 5.0, Figure 9.

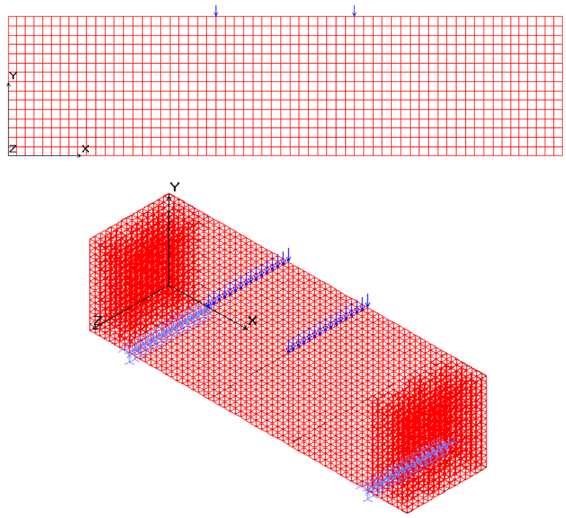

Figure 9: *The FEM BcR 4.5 and BcR 5.0 analysis - defining the loadings.*

Establishing the boundary conditions, and applying the loads, will define the deformation of the concrete specimens, Figure 10.

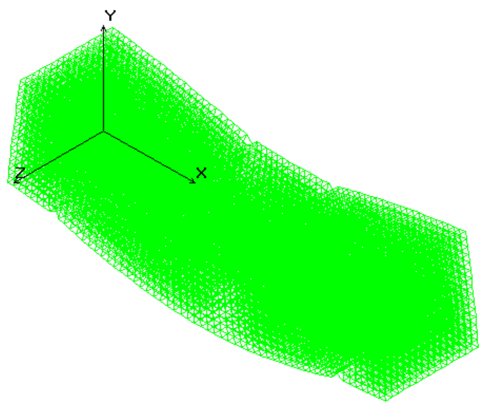

Figure 10: *The deformation of the specimen under the action of loading and boundary conditions*

5.1 FEM analysis of the road concrete class BcR 4.5

Following the design and static structural analysis with finite element for the case of road concrete specimens class BcR 4.5, the values of deformations and maximum loads are defined in Table 8.

Table 8: *State of deformations and loads - BcR 4.5.*

No.	*Applied force, F [kN]*	*Equivalent load [N/mm²]*	*Maximum displacement [mm]*
1.	41.25	3.67	0.0062
2.	45.01	4.01	0.0068
3.	46.51	4.14	0.0071
4.	48.75	4.34	0.0074
5.	52.50	4.67	0.0079
6.	54.10	4.82	0.0082

The displacement map with a loading of 48.75 kN, BcR 4.5 is presented in Figure 11, and in Figure 12 - the map of equivalent Von Mises loads.

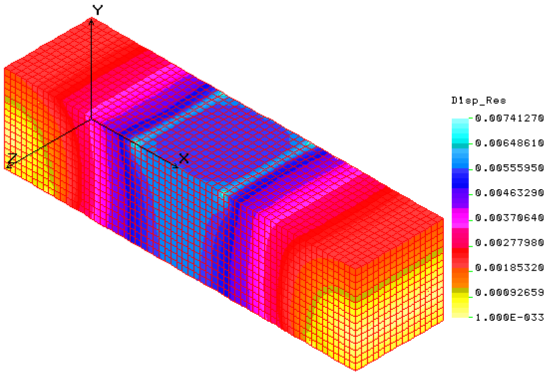

Figure 11: *Variation map of maximum displacement for F=48.75 kN, BcR 4.5*

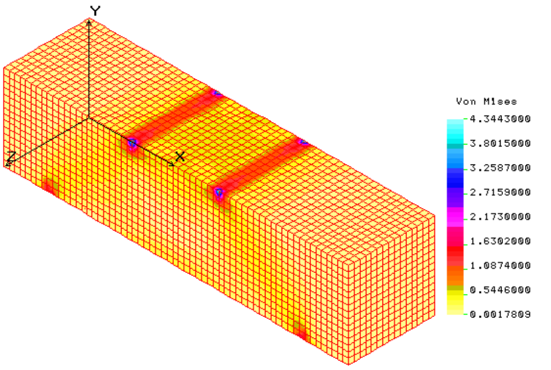

Figure 12: *Variation map of the equivalent load for F=48.75 kN, BcR 4.5*

5.2 FEM analysis of road concrete class BcR 5.0

Following the design and static structural analysis with finite element for the case of road concrete specimens class BcR 5.0, the values of deformations and maximum loads are defined in Table 9.

Table 9: *State of deformations and loads - BcR 5.0.*

No.	*Applied force, F [kN]*	*Equivalent load [N/mm²]*	*Maximum displacement [mm]*
1.	45.01	4.01	0.0056
2.	48.11	4.28	0.0061
3.	52.51	4.67	0.0066
4.	53.25	4.74	0.0067
5.	56.25	4.96	0.0070
6.	61.75	5.51	0.0078

The displacement map with a loading of 48.75 kN, BcR 4.5 is presented in Figure 13, and in Figure 14 - the map of equivalent Von Mises loads.

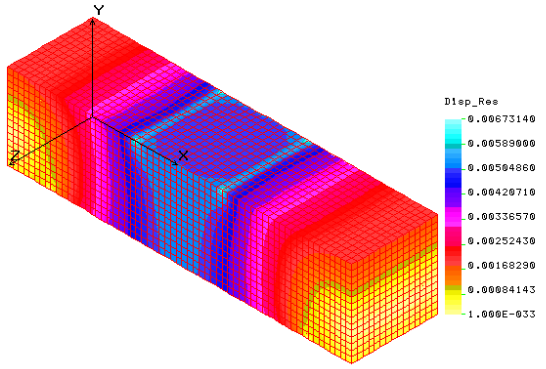

Figure 13: *Variation map of maximum displacement for F=53.25 kN, BcR 5.0*

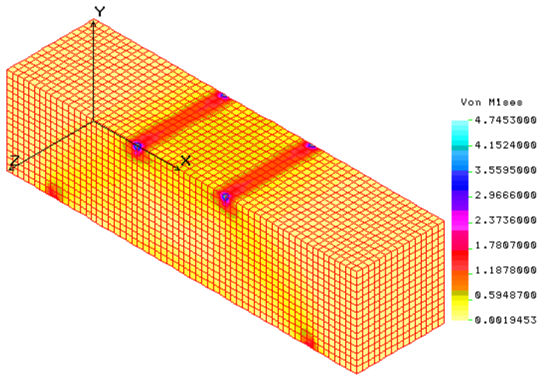

Figure 14: *Variation map of the equivalent load for F=53.25 kN, BcR 5.0*

6 Conclusions

- In the case of the analysed road concrete, corresponding to the BcR 4.5 class, the value of the characteristic strength is above the class value set out in the normative table:

R_{inc}^{k} =7.86 > 4.9 N/mm²

- For the second case, the analysed concrete corresponds to the BcR 5.0 class, since the value of the characteristic strength is higher than the value of the class laid down in normatives:

R_{inc}^{k} =5.81 > 5.5 N/mm^2

- The FEM modelling does not include highlighting the cracks occurring with the increased force applied, the maximum displacements presenting decreased values;

- Differences are observed, however, between the values of the experimental scheme and the values obtained by FEM modelling, differences that can be attributed to the non-homogeneous structure of the road concrete.

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