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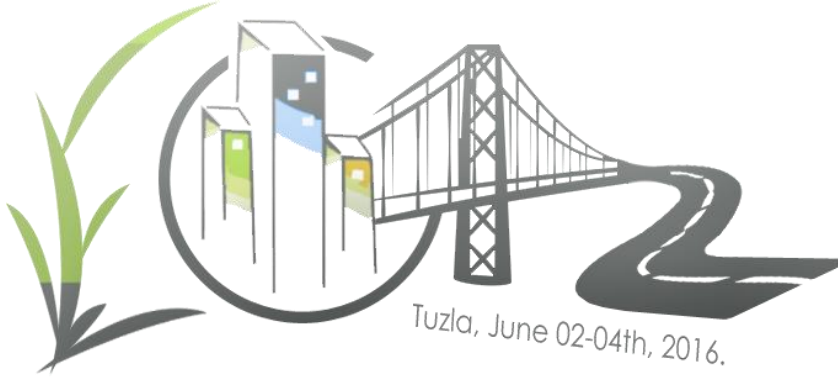

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3rd International
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TEST METHODS OF HYDRO-ABRASIVE RESISTANCE OF CONCRETE IN HYDRAULIC STRUCTURES

Summary: *Hydro-abrasion represents a concrete surface damage caused by the impact of water-borne solid particles and effects of hydraulic forces on the concrete. Erosion of concrete of hydraulic structures is a long-term process, and it usually develops over a period of several months or even years before the damage can be assessed. Because of the complexity of the problem, a large number of parameters must be taken into consideration when abrasion resistance of concrete is researched. A very important factor is the choice of the kind of abrasion stress which will be used in the research. Apart from that, when choosing the research methodology, it is necessary to find a sensible balance between complexity of the model and practicability. In this paper, some of the testing methods of hydro-abrasive resistance of concrete were presented, with the critical review of the advantages and disadvantages of the testing equipment, in terms of simulated approximation of abrasion in natural environment.*
Key words: *hydro-abrasive resistance, concrete, wear, damage, methods of examination*

METODE ISPITIVANJA HIDRO-ABRAZIVNE OTPORNOSTI BETONA KOD HIDROTEHNIČKIH KONSTRUKCIJA

Sažetak: *Hidro-abrazija predstavlja oštećenje površine betona nastalo usled udara čvrstih čestica nošenih vodom i dejstva hidrotehničkih sila na beton. Erozija betona kod hidrotehničkih konstrukcija je dugotrajni proces i razvija se obično u periodu od nekoliko meseci ili čak godina, pre nego što se oštećenje može oceniti. Zbog složenosi problema, mora se u obzir uzeti veliki broj paramtara prilikom istraživanja otpornosti betona prema habanju. Veoma je bitan odabir naprezanja habanjem koje će se koristiti pri ispitivanju. Osim toga, prilikom izbora metodologije ispitivanja potrebno je naći razuman balans između kompleksnosti modela i praktične izvodljivosti. U ovom radu su prikazane neke metode ispitivanja hidro-abrazivne otpornosti betona, sa kritičkim osvrtom na prednosti i nedostatke uređaja za ispitivanje u pogledu približnosti simuliranja habanja u prirodnim uslovima.*
Ključne reči: *hidro-abrazivna otpornost, beton, habanje, oštećenje, metode ispitivanja*

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1. INTRODUCTION

Durability of hydraulic engineering structures in most part depends on the resistance of concrete surface to mechanical abrasion. The abrasive wear of concrete in hydraulic structures is most often caused by the action of water-borne particles (silt, sand, gravel and other solid particles) rolling and eroding the concrete surface during hydraulic processes. Abrasive-erosive concrete damage represents a continuing issue in maintenance of hydraulic structures and necessitates taking this process into account when designing the structures and choosing the concrete mixtures. The order of magnitude of damage is several centimeters, but in some cases it can be significantly higher after only several years of abrasive action. Weak abrasive-erosive actions do not represent a big problem, but very pronounced actions may endanger the structural integrity of concrete, as well as the functionality of the structure [1].

The choice of testing methodology of concrete resistance to abrasive wear is very important. Erosion of concrete of hydraulic structures is a long-term process, and it usually develops over a period of several months or even years before the damage can be assessed. For this reason the accelerated concrete abrasion methods are necessary. Several studies, performed on the basis of the accelerated tests, have been published until now. Majority of equipment for testing of abrasive resistance of concrete described in professional literature was used for simulating mechanisms of sand blasting [2-4] and grooving with dry friction [5-7]. Many papers [8-10] and test methods according to ASTM standards [11] describe research performed in the conditions similar to natural environment impacts, using equipment allowing a concrete abrasion process based on aggregate and water mixture model. Momber and Kovačević [12] also applied the accelerated water jet test method for hydraulic concrete wear test. Momber [13] performed tests of accelerated cavitation on concrete by means of a cavitation chamber. For solving the problems in this study, the method of abrasive water jet could be applied for a very rapid wear of concrete by a mixture of water and solid particles moving at high velocity. The same researchers applied this method for parametric study of concrete abrasion [14] and for research of hydro-abrasion of mortar and concrete by means of acoustic emission [15]. A very complex test of behavior of concrete exposed to accelerated abrasive jet was presented in the paper [16]. In the general case, the construction of the equipment for testing of concrete abrasion by pressurized jets does not allow movement of a total of granular composition of water abrasive. Most often, acting as the abrasive, a mixture of fine fractions of sand and pressurized water is used to act upon the concrete surface at high velocity. It should be pointed out that it is difficult to formulate a universal and general criterion of acceptable damage level for hydraulic structures. When analyzing the various tests results, only those results based on the same friction mechanisms during samples abrasion can be compared. These mechanisms are described with four basic external parameters related to the grain in the water jet: mineralogical composition (hardness), size, velocity and glancing angle at which the jet hits the sample. Change of one of these parameters causes change of abrasion mechanisms and renders the comparative analysis of test results impossible. Laboratory simulation of abrasion process in the conditions similar to the natural makes the correct assessment of concrete abrasive resistance possible.

The paper provides a short description of some test methods, with a critical review of advantages and shortcomings of testing devices in terms of being as true to simulation of abrasive wear in natural conditions as possible.

2. ABRASIVE WEAR METHOD IN A TANK

Yet another method for simulation of concrete damage is abrasion wear in a tank [17,18]. The test specimen is leant against a rod which is connected to a driveshaft on its bottom end. This system is immersed in a tank which is filled by the mixture of water and abrasive. Due to the driveshaft rotation, the mixture in the tank homogenizes, figure 1 left. The abrasive from the mixture hits the concrete specimen at high velocity, and one of the reasons for the high velocity is the eccentric position of the driveshaft in the tank. Due to the continuing impact of the abrasive from the mixture, the concrete specimen sustains damage.

Kunterding [18] developed a modified procedure for abrasive wear testing in a tank, where the concrete specimen is exposed to the action of coarse particles in water, figure 1 right. There is a screw on the driveshaft, which, as the driveshaft spins, transports the abrasive (gravel) up, towards the cylindrical concrete specimen having diameter of 150 mm and height of 50 mm. Abrasion is performed by the abrasive impacting the lower end of the concrete specimen and falling to the bottom of the tank, where the screw collects it and sends it upwards to impact against the concrete sample again, and so on. The abrasive impact velocity is set to be 6 m/s. The system temperature ranges between 20°C and 200°C. The test lasts 90 minutes, whereby every 30 minutes the abrasive is replaced. The concrete specimen loss of mass after the test is the parameter employed for wear assessment.

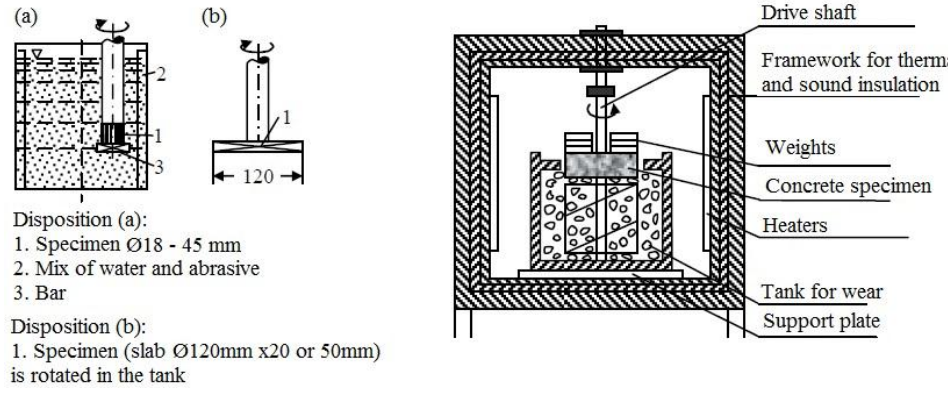

Figure 1. Diagram of the abrasive wear method in a tank according to Uetz [17], left and according to Kunterding [18], right

This testing method can hardly simulate the actual concrete wear conditions caused by the action of hydraulic abrasion. The abrasive used in the test is partially similar to the actual one. The time of exposure to abrasive action is limited to 90 minutes, which is not sufficient for a serious assessment of concrete wear resistance.

3. ABRASIVE WEAR METHOD ACCORDING TO ASTM C 1138

The procedure of concrete abrasive resistance test according to ASTM C1138 [19] the so called, underwater test was developed by Liu [20] for the needs of assessment of resistance of concrete surfaces subjected to the action of abrasive from water of hydraulic

structures, such as dam lakes, overflows, etc. The test device consists of a cylindrical steel tank having diameter of 305 mm and height of around 457 mm, water agitation paddles and 70 steel grinding balls, figure 2. The concrete specimen having diameter of 305 mm and height of around 100 mm is placed on the bottom of the tank. The Steel tank is filled with water up to the designed height, and the steel balls are placed on the surface of the test sample. The agitation paddle immersed in water spins at 1200 revolutions per minute, stirs water and moves the steel balls which impact the concrete surface. The test lasts 6 times 12 hours, which is duration of one period of testing, the total being 72 hours. The assessment parameter of the concrete resistance to wear is the average depth of the damage.

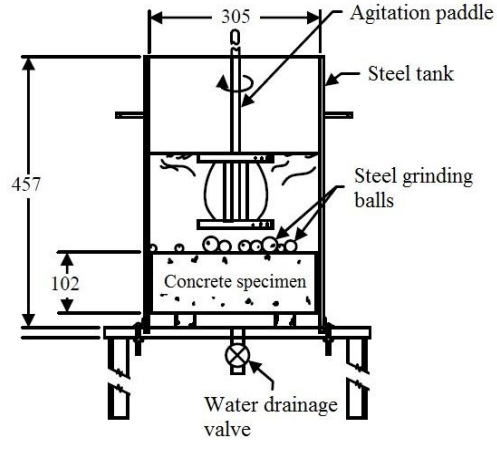

Figure 2. Diagram of the abrasive wear method according to ASTM C1138 [19] and Liu [20], dimensions are in mm

In case of this testing method, the damage occurs due to sliding or impacting of steel balls against the concrete surface. The steel balls used in the tests do not fully correspond to the abrasion in water in actual conditions. The testing lasts excessively long, and for serious research it is necessary to utilize multiple devices.

4. AUSTRIAN ABRASIVE WEAR METHOD USING A DRUM

Huber and Rozinski [21] developed a method of testing the concrete wear resistance using a drum. The drum has an approximate diameter of 1 m and it rotates about the horizontal axis at a speed of around 46 revolutions per minute. The drum rotation direction is changed at each half an hour. The abrasive employed is quartz sand having grain diameter up to 50 mm. The drum is filled with 30 liters of water. The test specimen plates have dimensions 47 × 47 cm and they are attached to the drum wall. Due to the drum rotation, concrete plates pass through the mixture of water and abrasive, which causes their wear. The entire test lasts 24 h. The damage created during the laboratory test is equivalent to the damage sustained in natural conditions in a period of 10 years.

This test method fairly realistically simulates the natural conditions in which hydro-abrasive concrete wear takes place. However, there are numerous downsides, such

as limited thickness of the test plate. The limited plate thickness means that the maximum dimensions of the aggregate grains used for making concrete are also limited. In addition, large test plates are heavy and difficult to handle during fitting in and removing from the drum. At intensive testing, the plates may break. Also, the abrasive does not fully correspond to that occurring in practice. The change of the load attack angle is not provided in this test.

5. BANIA ABRASIVE WEAR METHOD

The wear drum according to the Bania method [8] consists of a horizontal cylinder having diameter of 1,55 m and the length of 2,28 m, figure 3. An axle holds 36 rods used to attach concrete test specimens. The specimens can be cylindrical, having diameter of 80 mm and the height of 80 mm or cubical, with a side length of 100 mm. An electric motor spins the axle with perpendicularly fitted rods and test specimens. Rotation speed can vary, and the maximum one is 50 revolutions per minute. Mixture of water and abrasive consists of 300 kg of gravel, of the following fractions: 2/4 mm, 4/8 mm and 8/16 mm and 300 liters of water. Concrete samples pass through the mixture of water and abrasive and in this way, wear is effected by a combination of rubbing of abrasive over the surface of the specimens and by impact of abrasive on the surface of concrete specimens. Time of exposure of concrete samples to abrasive action is not strictly defined and can be varied (the long-term experiments performed by Bania lasted 120 hours). Assessment of concrete abrasive resistance in this case is based on the determination of the loss of mass.

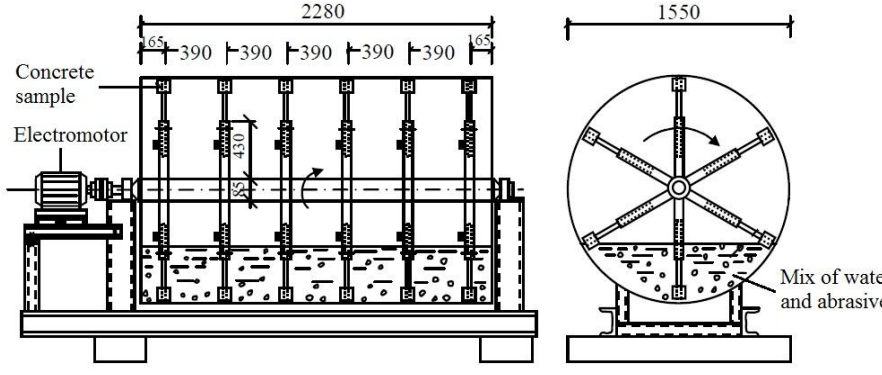

Figure 3. Diagram of Bania abrasive wear method [8], dimensions are in mm

This wear test method to a great extent simulates natural conditions. The basic deficiency are small dimensions of test samples. It should be mentioned that his device was used by [22-23] for wear tests of his specimens.

6. WATER AND SAND JET ABRASIVE WEAR METHOD

This concrete abrasive wear method was used by Liu et al. [24-25] on the occasion of testing of hydro-abrasive resistance of various kinds of concrete. The testing device consists of a sheet metal basin, having dimensions 2500×1800×1500 mm, figure 4. The

basin is one-third filled with water. Abrasive added to the water is quartz sand with the maximum grain size of 5 mm. Abrasive content in the mixture is 400 kg/m^3. The relative homogeneity of the water and abrasive mixture is provided by the mixing blades which are located in the basin, and powered by the pump mixer. Also, there are four pumps inside the basin, which collect the water and abrasive mixture from several places. The mixture drawn by the pumps is collected into a pipe which ends in a rectangular nozzle having dimensions 200×10 mm through which a test concrete plate is sprayed – the plate is located below the nozzle, but above water. The velocity of water and abrasive at the nozzle is controlled and amounts to 10 m/s which corresponds to the pressure of 0,17 MPa. Water temperature is kept at 30°C. The attack angle of the mixture jet and concrete plate can vary, but usually an angle of 45° is used. Concrete test plate has dimensions 200×200×50 mm and it is situated 200 mm below the nozzle. The time of exposure of the specimen to hydro-abrasive action is 180 minutes. Assessment of abrasive resistance of concrete is performed on the basis of the loss of mass of the specimen in a unit of time (g/min).

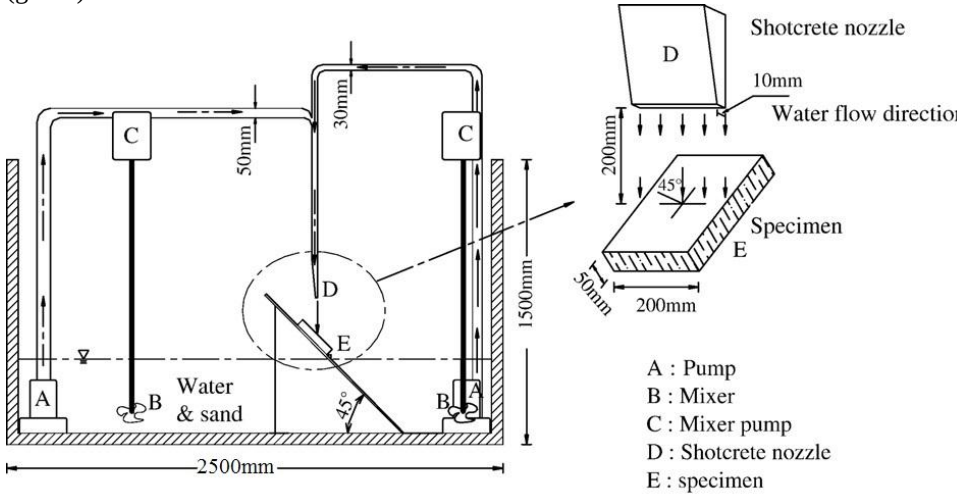

Figure 4. Diagram of the abrasive wear method using a jet of water and abrasive mixture [24-25]

This abrasive testing method to a great extent simulates the actual natural conditions. The attack angle of the water and sand jet mixture on the concrete plate can vary, abrasive concentration in the mixture can vary as well as the test duration time. The basic downside is the small surface area of wear, which is limited by the nozzle opening. Also, the abrasive grain size is limited to 5 mm. It is difficult to provide homogeneity of the water-sand mixture and the constant speed, i.e. pressure of the jet during testing. A similar device, partially modified and adapted to different test conditions was used in the research at the Faculty of Civil Engineering and Architecture of Niš [26-29].

7. CONCLUSION

In general, because of the complexity of the problem, a large number of parameters must be taken into consideration when abrasion resistance of concrete is researched. A very important factor is the choice of the kind of abrasion stress which will

be used in the research. In addition, when choosing the research methodology, it is necessary to find a sensible balance between complexity of the model and practicability. In particular, the following conditions should be considered when choosing the abrasive test method which will simulate the actual conditions:

- Abrasion wear conditions being simulated in the controlled laboratory conditions should, to a great extent, coincide with the conditions in practice,
- Mixture of water and abrasive used in the tests should correspond to the actual situations in practice,
- The principal parameters affecting the abrasion wear process in practice should also be dominant during the laboratory testing, which must be facilitated by the construction of the testing device,
- Construction of the device should facilitate varying of the attack angle between the abrasive and surface of the tested specimen,
- Abrasion wear test should be short and simple to perform,
- The measured abrasion wear damage results must be easy to reproduce.

Realistic simulation of hydro-abrasive wear of concrete surfaces is not simple. There is a small number of concrete abrasive resistance testing methods which are standardized and implemented internationally. However, there are methods which were not classified within any national or international standard, but which can be used for the assessment of concrete behavior under various forms of abrasive stress.

8. ACKNOWLEDGEMENTS

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