EVALUATION OF CONCRETE HOMOGENEITY IN MASSIVE STRUCTURAL ELEMENT OF HYDROELECTRIC POWER PLANT BY MEANS OF NONDESTRUCTIVE IMPULSE RESPONSE METHOD

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Abstract
When erecting concrete structures one may notice defects, in the form of inhomogeneities (due to improper concrete compaction), in some areas of the structural elements. Since they occur on the surface such defects are easily detectable. It is, however, difficult to detect defects occurring inside structural elements. Nondestructive test methods can be useful for this purpose. This paper presents tests of concrete homogeneity inside a structural element constituting a concrete wall of the hydroelectric power plant suction pipe, carried out using the nondestructive impulse response method. The results of the tests showed that this method can be successfully used to identify concrete zones characterized by inhomogeneity (honeycombing) inside massive structural elements.

Key words: concrete, nondestructive tests, impulse response method

1. Introduction
Concrete is one of the most widely used construction materials. All kinds of structures and structural elements are built from concrete. It owes its widespread use to the availability of its constituents, the relatively low costs of its production and the fact that it can be used in various atmospheric conditions and to erect structural elements and structures by different methods [1].

In construction practice quite often in some areas of concrete structural elements defects in the form of concrete inhomogeneity appear. Defects of this kind particularly often affect massive structural elements, which has a significant bearing on their durability, compressive strength and voids index. There are many kinds of concrete inhomogeneity, but the most common is the so-called honeycombing, i.e. zones of concrete characterized by different degrees of compaction, formed as a result of the improper compaction of the concrete. As opposed to defects occurring on the surface of structural elements, the internal defects are difficult to detect. They may appear only in the course of service, whereby a repair is required to remove them. Therefore nondestructive test methods are increasingly used to evaluate the homogeneity of concrete in building structures [2-5]. The state-of-the-art acoustic impulse-response method is particularly suitable for this purpose. The method is described in detail in [6-10].

This paper presents the testing of the homogeneity of concrete in a massive structural element, i.e. the concrete wall of the suction pipe in a hydroelectric power plant, by means of the impulse response method.
2. Range of tests

The impulse response measuring apparatus was used to test a massive structural element constituting the concrete wall of a hydroelectric power plant suction pipe. The about 1000 mm thick structural element was made of grade C25/30 concrete with 32 mm maximum aggregate grading, reinforced with smooth rebars made of A-I St3S steel. Altogether tests were carried out in 80 testing areas. In each testing area a 3 x 4 to 11 x 5 grid of measuring points was marked. The distances between the points of the grid amounted to about 50 cm. The total number of measuring points was about 2000. In each of the measuring points an elastic wave was produced in a nondestructive way by means of a special calibrated hammer with a rubber end. The ambient temperature, measured using a Trotec T200 for quick checking relative air humidity in the vicinity of the measuring point, was 23°C±2°C while the relative humidity amounted to 82%±5%. At the same time the signal was being recorded in the graphic form, using a geophone, as shown in fig. 1. Then the data were transformed to produce four maps of such characteristic parameters as average mobility, stiffness, mobility slope and voids index. Since average mobility and stiffness are the parameters used in this method exemplary tests results in the form of distribution maps of these parameters are presented below.

![Testing of massive structural element, i.e. concrete wall of hydroelectric power plant suction pipe, by means of impulse response apparatus.](image1.png)
3. Exemplary test results and their analysis

Below, exemplary results of the tests of the massive structural element constituting the concrete wall of the hydroelectric power plant suction pipe are presented for two experimental cases. In case no. 1 no concrete inhomogeneity occurs. In case no. 2 zones of concrete characterized by different degrees of compaction (honeycombing) were detected. The test results in the form of maps of average mobility and stiffness and histograms of the parameters, obtained by the impulse response method for experimental cases 1 and 2 are presented in respectively Sections 3.1 and 3.2. Case 1 occurred in 55 of the 80 testing areas.

3.1. Experimental case 1

In experimental case 1, mobility is constant in the whole testing area while stiffness may change only locally. An example here is testing area 10. A map and a histogram of average mobility for this area are shown in fig. 2 while a map and a histogram of stiffness are shown in fig. 3.

Fig. 2. Map of average mobility (a) and histogram of average mobility (b) for concrete wall of suction pipe in testing area no. 10.
As it appears from figs 2a and 3a in most of the measuring points average mobility is in a range of 5-10 N⋅m/s, i.e. it is within the average, while between measuring points 1-2, 1-3, 1-4, 2-4, 3-3, 3-2 and 2-2 (row no.-column no.) stiffness ranges from 0.4 to 0.8 (above the average). In the other measuring points, stiffness is in an interval of 0-0.4, i.e. it is within the average. As it appears from the histograms of the parameters, shown in figs 2b and 3b, the average mobility and the average stiffness amount to respectively 7.51 m/s*N and 0.19. The maps of average mobility and stiffness and their histograms for the suction pipe concrete wall in testing area 10 indicate that no concrete inhomogeneity occurs in this area.

3.2. Experimental case 2

In experimental case 2, different values of the two main parameters, i.e. average mobility and stiffness, are obtained. An example here is testing area no. 3. A map and a histogram of average mobility are shown in fig. 4 while a map and a histogram of stiffness are shown in fig. 5.
As it appears from figs 3a and 4a, between measuring points 1-2, 1-3, 1-4, 2-2, 2-4, 3-4, 3-3 and 3-2 (the first digit stands for the row number and the second digit for the column number) average mobility is in a range of 4-6 N·m/s, i.e. it is above the average, while stiffness is in a range of 0-0.6. Within measuring point 4-6, average mobility ranges from 8 to 10 N·m/s (it is much below the average) while stiffness ranges from 0 to 0.2 (it is below the average). In the other measuring points, average mobility is in a range of 2-4 N·m/s (it is below the average) while stiffness is in a range of 0.6-1.0 (it is above the average). As it appears from the histograms of the parameters, shown in figs 2b and 3b, the averages of average mobility and stiffness amount to respectively 3.94 m/s·N and 0.32. The local increase in average mobility and the low value of stiffness indicate that the material is deformable, which may be evidence of the existence of zones characterized by different degrees of compaction (honeycombing) in this area. The low values of stiffness also indicate poorer quality of the concrete in these testing points in comparison with the other testing points. The presented maps of average mobility and stiffness and the histograms of the parameters for the concrete suction pipe wall in testing area no. 3 indicate that concrete inhomogeneity (honeycombing) occurs in this area.
4. Conclusion

Exemplary tests of concrete inhomogeneity in a massive structural element, constituting the wall of the suction pipe in a hydroelectric power plant, by means of the nondestructive acoustic impulse response method have been presented.

The tests have demonstrated that the impulse response method can be successfully used to evaluate the inhomogeneity of concrete in this kind of structures with massive structural concrete elements. Using this method one can discern zones of concrete differing in their degree of compaction.

The nondestructive tests showed that in 55 of the 80 testing areas no concrete inhomogeneity occurs, whereas in the other 25 areas concrete inhomogeneities in the form of zones characterized by different degrees of compaction (honeycombing) occur. Such inhomogeneities may form as a result of improper compaction of concrete or due to the use of aggregate with grading much exceeding the design specifications.

References