Acoustic Testing of Reinforced Concrete Structure Corrosion

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Abstract. The rebar condition influences profoundly the properties of horizontal structures. Note that the occurrence of corrosion in the bulk cannot be observed from the outside in many cases. This is why studies of non-destructive methods allowing the researchers to detect the degree of corrosion for the built-in rebars are being paid much attention currently.

An acoustic method, known as Impact-Echo method, providing for the internal structure damage evolution and degree detection, appears to be a convenient method to monitor the building structure condition the defect detection, identification and location are constituents of the diagnosis of the object technical condition.

The paper deals with the study of dominant frequencies of an Impact-Echo method response signal obtained from a reinforced concrete beam with a steel rod diameter of 8 mm. Tension pulse was produced in the centre of the concrete beam and detected in opposite position of the concrete beam. Dominant frequencies of the response signal will be the main criterions for the reinforced concrete rebar corrosion progress. The article presents the results of measurements obtained after 24 months controlled degradation in aqueous NaCl solution. The results were compared with measurements of electrical resistance of reinforcing steel by using the Thomson double bridge.

It is obvious that the measurement of electrical resistance of reinforcement is a sensitive method for assessing the state of corrosion of reinforcing steel in reinforced concrete structures, and so it can be used to compare the results of corrosion monitoring using acoustic methods. We observed a strong correlation between these two changes.

Based on the above results, the frequency inspection method can be recommended as an efficient tool to evaluate the steel rebar corrosion condition.

The non-destructive testing methods make it possible to timely identify the occurrence and development of defects in materials and thus ward off the failure or even the breakdown of structural units consisting of mechanically or thermally stressed, or corrosion affected parts.

1. Introduction

Using of Impact-Echo method from the group of acoustic methods for non-destructive testing allows detection of micro-defects in the structure of the material [1] which allows monitoring the condition of internal structure. This method appears to be a convenient method to monitor the building structure condition, defect detection, identification and location which are constituents of the technical condition diagnosis [2, 3]. The non-destructive testing methods is possible to use for timely identification of the occurrence and development of defects in materials and thus ward off the failure or even the breakdown of structural units of construction which are mechanically strained or thermal stressed, or affected by corrosion [4, 5]. The frequency inspection (Impact-Echo method) belongs to the family of non-destructive testing methods and can be applied in many branches, among others also in civil engineering [6, 7]. The new measurement method to assess the degree of corrosion was based on using the acoustic properties [8 – 12].

2. Experimental

2.1 Preparation of samples

We studied a concrete beam which was reinforced with one standard reinforcing bar passing through the centre of the beam. The length of bar was 400 mm and the diameter 8 mm. For preparation of the beam was used concrete mixture in composition 400 kg of cement CEM II/B - S 32.5 and 1400 kg of sand Želešice with fraction of aggregate 2 mm - 4 mm and 225 l of water. Concrete has been modified on a vibration table. After casting the concrete, the concrete samples were kept in the forms at room temperature for 24 hours and and subsequently they were demolded and placed in water for 28 days. Then were the samples dried at room temperature for next 28 days.

The samples were degraded using accelerated corrosion caused by chlorides. The specimens were immersed into a 5 % water solution of NaCl for 16 hours, to be subsequently placed into a drier, whose internal air temperature was kept at 40 °C, for 8 hours. These cycles were repeated after 24 months.

2.2 Measurement of Impact-echo method

A short-time mechanical impulse (a hammer blow) is applied to the specimen under test to be detected by means of piezoelectric sensors placed on the specimen surface. The impulse is reflected by the surface but also by micro-cracks and defects of the specimen under investigation. Thus originating resonance frequency is determined by means of frequency analysis. Dominant frequencies can be determined from the response by means of Fourier transformation.

The 360x50x50mm concrete beam with a 8 mm diameter steel rebar have been studied. To generate the exciting impulse, a steel hammer hit the specimen surface. An MIDI piezoelectric sensor was used to pick up the response, the respective impulses being fed into the input of an oscilloscope TiePie engineering Handyscope HS3 two-channel with resolution 16 bits.

The piezoelectric sensor was placed at the centre of longitudinal side of the concrete beam and the hammer hit on the opposite side in the direction of the transverse axis. The impulse response was recorded by an oscilloscope, and afterwards analyzed by means of an SW package called TiePie Multi Channel software.

2.3 Resistance measurement

Thomson double bridge was used for resistance measurement. The Thomson double bridge measurement accuracy depends on the accuracy of the resistors used, the bridge sensitivity and various interferences. The measurement accuracy will be virtually affected by the accuracy of the bridge arm resistors only, provided the bridge sensitivity is sufficient and the interferences are suppressed by suitable measurement methodology. By using the Thompson double bridge can be measured very low resistance which allows obtaining very accurate results.

3. Result and discussion

3.1 Impact-echo method

In the Fig. 1 is seen the time course of signal response of the sample No. 20 before the start of degradation and the Fig. 2 shows plot of the frequency spectrum for the sample No. 20 before degradation. The sensor is placed at the centre of longitudinal side of concrete beam and the hit is made at the opposite side of concrete beam in the centre side in the transverse direction. A spectral component of frequency of f_1=7033 Hz is dominant for this spectrum. Response signal of the same sample after 24 months shows the Fig. 3. In the Fig. 4 we can then see the change of frequency spectrum for the sample No. 20 after 24 months controlled degradation in aqueous NaCl solution. The original dominant frequency is shifted to the value of f_2=7319 Hz.

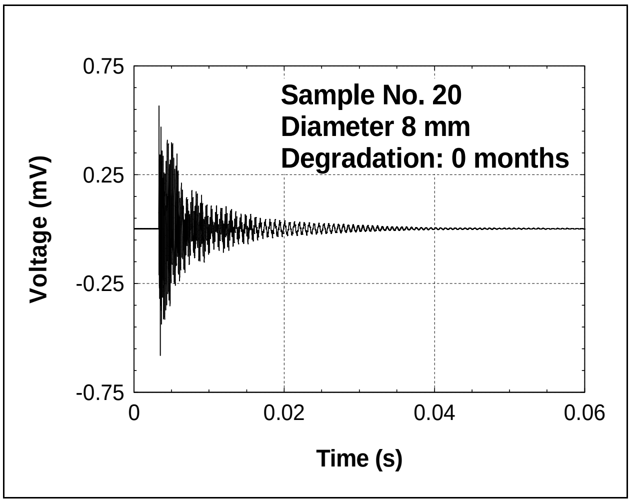

Fig. 1. Sensor output versus time plot for the sample No. 20 before degradation

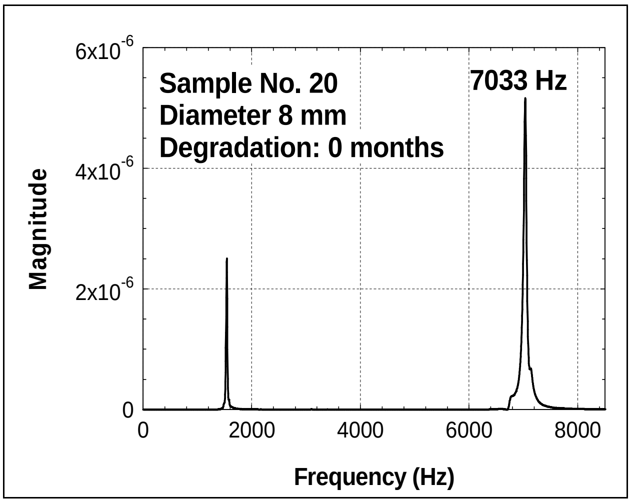

Fig. 2. Frequency spectrum for the sample No. 20 before degradation.

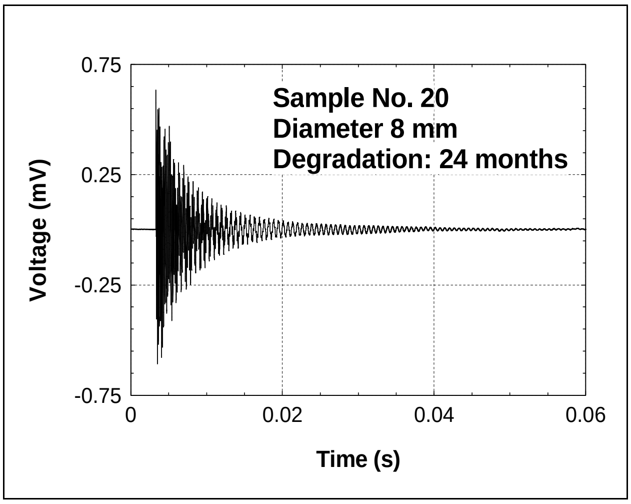

Fig. 3. Sensor output versus time plot for the sample No. 20 after 24 months of degradation.

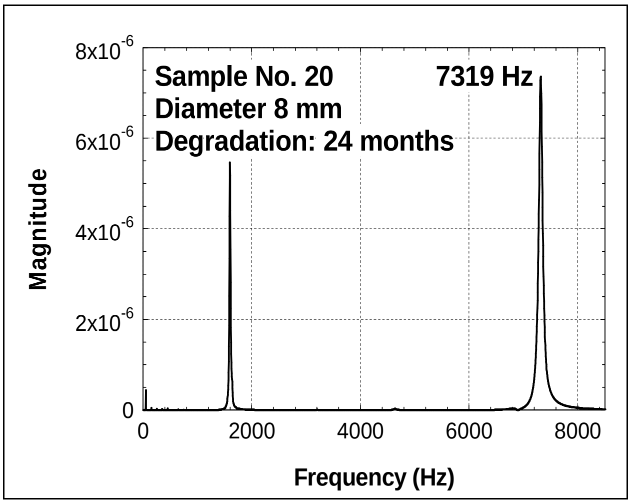

Fig. 4. Frequency spectrum for the sample No. 20 after 24 months of degradation.

In Fig. 5 we can observe the modification of the dominant frequency during 24 months of controlled degradation in aqueous solution of NaCl. The frequency changed from f_1=7033 Hz to f_2=7319 Hz, which meant Δf=286 Hz change and therefore 4.1 %. The graph shows the rapid increase of the dominant frequency in the first six months of degradation. Other changes of the dominant frequency are more gradual.

In addition to dominant frequency, damping coefficient λ was also monitored. The damping coefficient was calculated from exponential equation $A = A_o e^{-\lambda T}$. This coefficient show significant rise of the values during the first six months degradation too as presented in the Fig.6. The damping coefficient is changed from $\lambda_1 = 21.6\ s^{-1}$ to the $\lambda_2 = 24.8\ s^{-1}$, it is $\Delta\lambda = 3.2\ s^{-1}$ change, by 14.8 %.

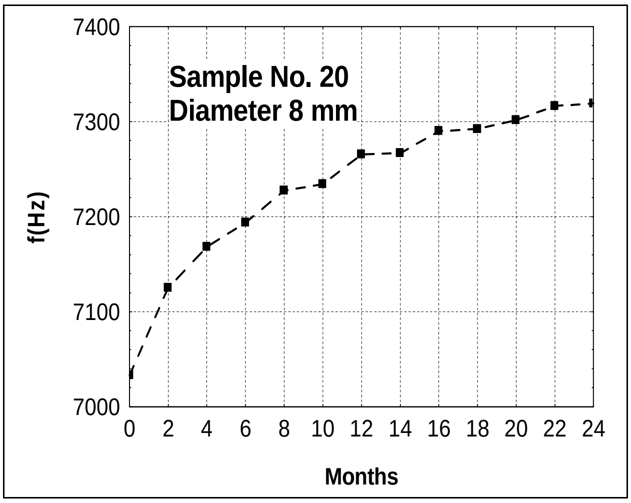

Fig. 5. Change of dominant frequency at sample No. 20 during the 24 months degradation.

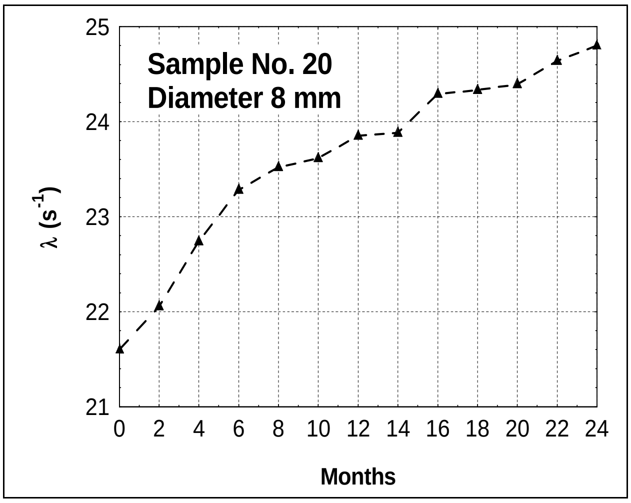

Fig. 6. Change of at damping coefficient sample No. 20 during the 24 months degradation.

3.2 Electrical resistance

Fig. 7 shows the results of monitoring changes in resistance of reinforcing steel No. 20 with a diameter of 8 mm within 24 months of controlled degradation. Measurements were performed using a Thomson double bridge, which made it possible to measure very small resistances. The initial value of electrical resistance changed during the controlled degradation from value $R_1 = 1.17$ mΩ to value of $R_2 = 1.29$ mΩ. After 24 months there was a change of electrical resistance of $\Delta R = 0.12$ mΩ. This represents a change of 10 %.

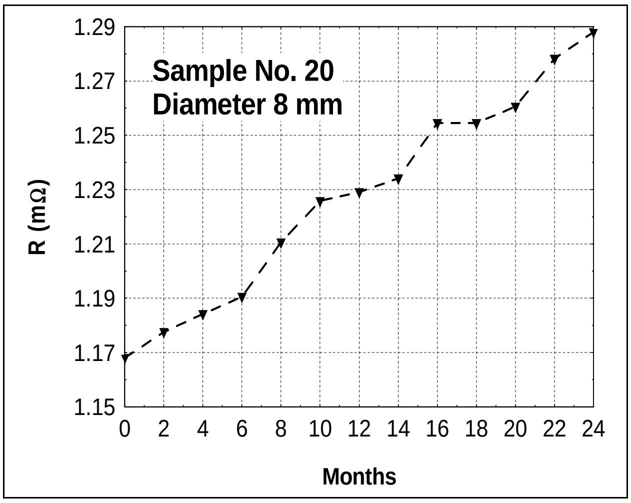

Fig. 7. Change of resistance of steel at sample No. 20 during the 24 months degradation.

4. Conclusion

The paper deals with the study of dominant frequencies and the damping coefficient which are obtained from response signal by using Impact-Echo method and these results are compared with measurements of electrical resistance of reinforcing steel by using the Thomson double bridge.

The results were measured on a reinforced concrete beam with a steel rod diameter of 8 mm. Tension pulse was produced in the centre of longitudinal side of the concrete beam in the direction of the transverse axis and detected in opposite position of the concrete beam. Dominant frequencies showing changes of the response signal are the main criterion for the reinforced concrete rebars corrosion progress. The article presents the results of measurements obtained after 24 months controlled degradation in aqueous NaCl solution.

The results are represented by specific sample No. 20 for illustration. The change of frequency spectrum took place during the degradation. The dominant frequency was shifted and damping coefficient was changed too. For example, the sample No. 20 show the change of the frequency from f_1 = 7033 Hz to f_2 = 7319 Hz, it means Δf=286 Hz change which is 4.1 %. The damping coefficient changed from $\lambda_1 = 21.6\ s^{-1}$ to the $\lambda_2 = 24.8\ s^{-1}$, it is $\Delta\lambda = 3.2\ s^{-1}$change, by 14.8 %.

The results obtained by studying the state of corrosion by acoustic method Impact-Echo was compared with results obtained by measuring the electrical resistance of steel reinforcement bars. Measurements were carried out using a double Thomson bridge which allowed the measurement of a very small resistance. The value of the resistance for sample No. 20 changed from R_1 = 1.17 mΩ to R_2 = 1.29 mΩ. During 24 months of degradation, the electrical resistance of reinforcing steel increased by ΔR = 0.12 mΩ ie 10 %.

Based on the above results, the frequency inspection method can be recommended as an efficient tool to evaluate the condition of corrosion of reinforced concrete. It is obvious that the measurement of electrical resistance of reinforcing steel is a sensitive method for assessing the state of corrosion of reinforcing steel in reinforced concrete structures and so it can be used to compare the results of corrosion monitoring using acoustic methods. We observed a strong correlation between these two parameters.

The non-destructive testing methods are possible to use for timely identification of the occurrence and development of defects in materials and thus ward off the failure or even the breakdown of structural units of construction which are mechanically strained or thermal stressed, or affected by corrosion.

Acknowledgements

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Introduction

An acoustic method, known as Impact-Echo method, provides information about the internal structure and the damage. It appears to be a convenient method to monitor the building structure condition and the defect detection.

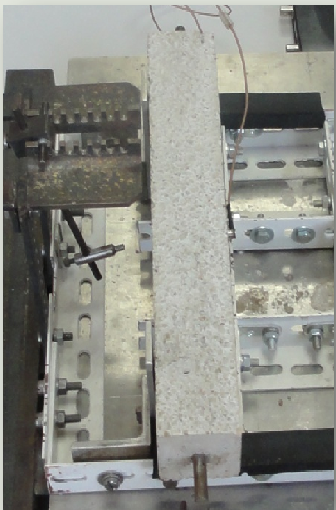
Preparation of samples

Reinforcing steel: bar length:400 mm, bar diameter:8 mm.
Concrete mixture: 400 kg of cement CEM II/B S 32.5
1400 kg of sand Želešice with fraction of aggregate 2 - 4 mm
225 l of water.
Degradation: accelerated corrosion caused by chlorides
placement into a 5 % water solution of NaCl for 16 hours
drying into a drier with 40 °C, for 8 hours



Impact-echo method

A short-time mechanical impulse is applied to the centre of side of the concrete beam and the piezoelectric sensor is placed on the opposite side. The impulse response was analyzed by Fast Fourier Transformation, when were observed the changes dominant frequency.

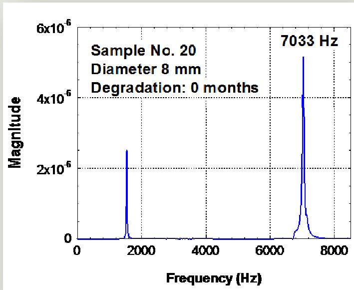


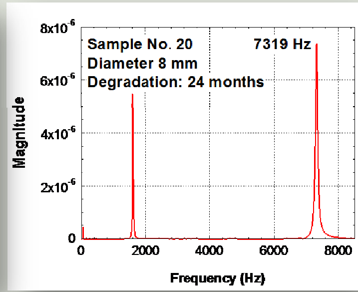
Electrical resistance

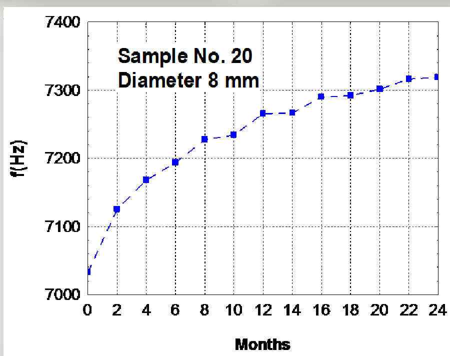
Thomson double bridge was used for resistance measurement. It allows measured very low resistance thus obtaining very accurate results.

Result and discussion

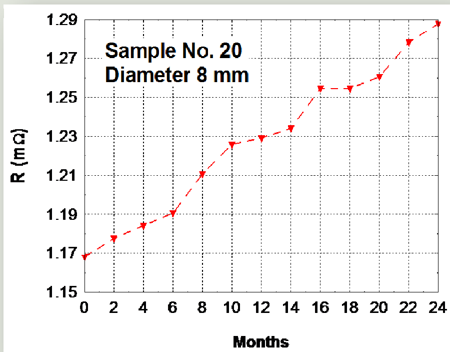
The dominant frequency changed from f1 = 7033 Hz to f2 = 7319 Hz, it means Δf=286 Hz change which is 4.1 %.







The value of the resistance changed from R1 = 1.17 mΩ to R2 = 1.29 mΩ, the electrical resistance of reinforcing steel increased by ΔR = 0.12 mΩ ie 10 %..



Conclusion

The results obtained by acoustic method Impact-Echo and by measuring the electrical resistance of steel reinforcement bars demonstrate the Impact-echo method can be recommended as an efficient tool to evaluate the condition of corrosion of reinforced concrete.

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