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**IMPACT-ECHO METHOD APPLICATION ON THE DETECTION OF  
CAVITIES IN MASSIVE CONCRETE STRUCTURES OF NPP  
REPAIRED BY INJECTING MASS.****Š. Morávka \***

**Summary** Nuclear power plants are duty to certify their security for renewal of operating license. Security can be significantly affected by defects of ageing reinforced concrete structures. Advanced Impact-Echo method seems to be very hopeful to do in-service inspections such structures. Just these in-service inspections are included in the first priority group of specific technical issues according to the recommendations of OECD-Nuclear Energy Agency, Commission on Safety of Nuclear Installation in the field of ageing management. This paper is a part of extensive project and continues a number of foreign papers about Impact-Echo method by Pečínka, Morávka, Voldřich (2004–07), and some papers in Czech as well. It will bring a method description and main result survey of numerical modeling of detection of grouted (repaired) voids in massive concrete structures. Cavities are filled by grouting polyurethan compound CarboPur WF. We try to find out if it would be possible to confirm by Impact-Echo method, whether the injected cavities were fulfilled completely. Experimental verification of these numerical predictions on real scale (1:1) specimens in NRI Řež will be follow.

**1. Introduction**

Just in-service inspections of reinforced concrete structures having thick section and with not directly accessible areas are included in the first priority group of specific technical issues according the recommendations of OECD-Nuclear Energy Agency, Commission on Safety of Nuclear Installation in the field of ageing management.

Advanced Impact-Echo method, according to ASTM C 1383 - 98a, (1998) consists in the locating of void's position according to the elastic wave reflections between the void or inhomogeneities and surface. Generally, it is possible to go by two ways. The matter of technique in the first approach (in frequency domain, exactly according to the referenced ASTM) is the fact that the frequency of wave reflections between the void and surface (or between two surfaces) depends on the depth of the void. Knowing the wave propagation velocity and by using the discrete fast Fourier transform we can identify the dominant frequency and hence compute void's depth (or thickness of the wall).

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In the second way (in time domain) the voids can be localized simply by the transient wave reflection from the discontinuities and inhomogeneities, according the amplitude, shape and time arrival of reflected waves. This technique is not so common, but it can give next useful results, e.g. Anish Kumar et al. (2002) or Yiching et al. (2004).

It is very difficult, even impossible, to detect surface crack and/or to set its depth and inclination by the first way (in the frequency domain). We, unlike the most authors, e.g. Dr. Schubert's group in Fraunhofer Institute, Dresden (2003-4), try to detect crack and voids in the time domain. There were tested the capabilities of Impact-Echo for the detection and localization of reinforcing rods Morávka, Voldřich (2003) and Pečínka, Morávka, Voldřich, (2004) and numerical simulations of detection of perpendicular cracks on the both surfaces – accessible as well as inaccessible Morávka, Voldřich (2004a) and Pečínka, Morávka, Voldřich, (2004). Next, the depth effects of cracks perpendicular to the surface were tested in Morávka, Voldřich (2004b) and Pečínka, Morávka, Voldřich, (2005a, b). The localization of the closed crack inside the wall was modeled as well, Morávka, Voldřich (2004b), Pečínka, Morávka, Voldřich, (2005a, b). Many simulation and discussion were done about the oblique cracks detection and trying set its inclination angle and depth Morávka (2005, 2006a) and Pečínka, Morávka, Voldřich, (2005c and 2006). Localization and setting orientation of the large cavities in different positions were simulated in Morávka (2006b, 2007a).

As noted above, we generally focus on usage of Impact-Echo method in the time domain mode. But in cases, where the defect has one face (or, at least a part of its surface) parallel to the wall surface, we can identify multiply wave reflections between void and wall surface very well. Therefore we confirmed detection in frequency domain as well. The comparison and good agreement of the both of approaches was shown in Morávka (2006b, 2007a, b)

The cavities in the thick concrete can raise form different reasons. E.g. some extraneous body can get into mixture during concreting or concrete can be compacted insufficiently. There exist various techniques of repairing. This paper (and Morávka 2007c as well) concerns to repairing (filling) cavities by grouting polyurethan compound CarboPur WF from Minova International (see technical report in ref.). We test in these papers if it is possible to find out by Impact-Echo method, whether the injected cavity were perfectly filled by CarboPur WF. This material is mixed from two components before application and, in addition, the compound is being filled into cavities with water addition (Fig. 1 a). The water evokes foaming of the compound, which depend on the water amount (see Fig 1 b). Some water can occur into cavity before. Therefore the foaming can be unequal and it is exactly not predictable. So, it is very hard to estimate, if it will be possible by acoustic wave reflection to distinguish between free surface and surface of properly filled cavity.



**Fig. 1 a), b).** Application of the CarboPur WF mixture into form only. Specimen after foaming-up and hardening. Photos of experiments from project colleagues in NRI Řež.



the large models with more than 182,000 elements. These computations are more time extensive than previous, e.g. papers Morávka (2005 and 2006), because the number of operations responds to third power of the mass matrix size = approx. number of elements.

The element size results, that the shortest wave being able to propagates in such model without numerical amplitude attenuation, has wavelength  $\lambda_{\min} = 30 \text{ mm}$ . It responds to so called cut-off-frequency at, approximately, 140 kHz. Frequency band of numerical simulation is in the same way restricted by time integration step size as well. Therefore, it is suitable to choose spatial and time discretizations such “fine”, that the both frequency limitations will be “similar”. Moreover, we could not use elements of varying size for this type of problems (different cut-off-frequencies and wave dispersions, spurious wave reflections, etc.). These all facts above lead to very extensive and time consuming computations. For more details see e.g. Okrouhlík et al. (1976), Brepta (1982 and 1985), Morávka (1999).

Time integration step with regard to the element size was chosen  $\Delta t = 3.5 \text{ } \mu\text{s}$ . Time integration consists of 143 steps and it is executed up to time  $t = 500.5 \text{ } \mu\text{s}$ , from where the results starts to be devaluated by the wave reflections from the specimen borders.

### 2.3. Integration method

The Newmark integration method has been chosen for time discretization. The Newmark coefficients were slightly modified from their basic version, to  $\beta = 0,275625$  and  $\gamma = 0,55$ . By this way the moderated numerical damping was introduced. It suppresses spurious higher frequencies namely, but still keeping unconditioned method stability.

The opinions on usage suitability of explicit or implicit formula for transient processes are different. One step computation by explicit method (like central difference) consumes less computation time, but to reach the same accuracy the shorter time step is needed. It is suitable to choose the time integration method with regards to the spatial discretization type. The spatial discretization with full (consistent) mass matrix used here and time discretization by Newmark method lead to partial elimination spurious effects of the both discretizations, see e.g. Morávka (1999).

### 2.4. Materials

Concrete mixture according to the technical report about concreting at the NPP Dukovany (see references) consists of sand with 4 mm grains and aggregates up to 16 mm sized. It is possible to consider concrete to be *homogeneous*, because the shortest wavelength  $\lambda_{\min} = 30 \text{ mm}$  is greater. Next, the concrete is made by casting, so it can be considered as *isotropic*. And finally, test loadings are very small, so it will be enough use the *elastic* model. Mechanical properties respond to the concrete B30 (NPP Dukovany) according to that time standard ČSN 73 12 01.

Fill-in mass CarboPur WF from Minova International (see references) is synthetic resin based on polyurethan. It is mixed from two components (A, B) and water before application. Due to water presence the mixture froths and final foam expands into all corner of cavity being repaired.

### 2.5. Excitation

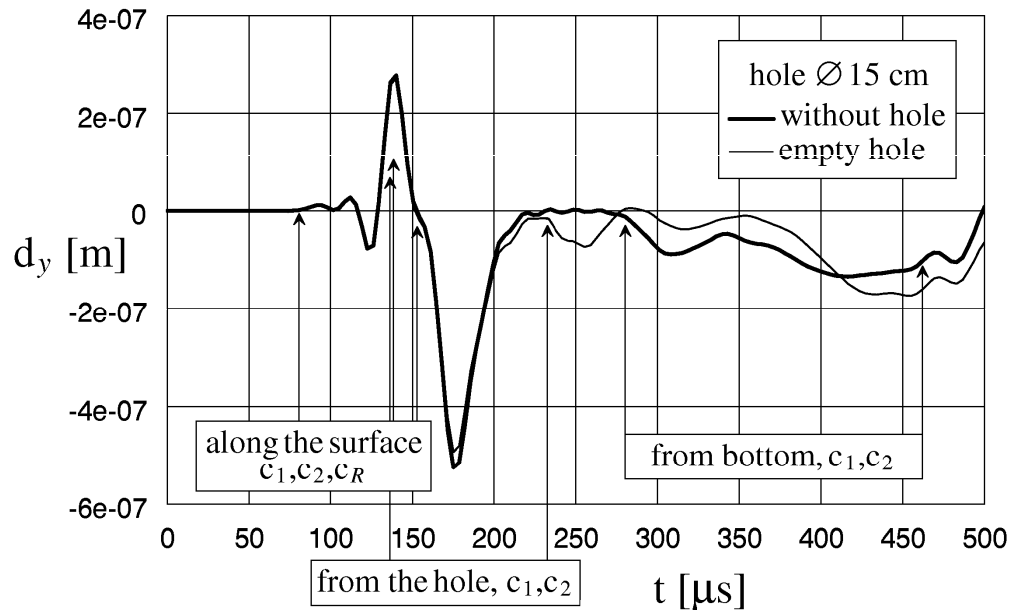
It is realized by impact of experimental hammer. According to impactor size and velocity we estimate impact at force 5,000 N taking time  $36 \text{ } \mu\text{s}$ . It seems the considerably weaker impact will be enough for real experiments.

### 3. The Results of Numerical Simulations.

We will test, if it is possible to confirm by Impact-Echo proper fulfillment of a fixed cavity. We computed three sets of tasks – a specimen without any flaw, specimen with three drilled holes and specimen with holes filled by CarboPur WF.

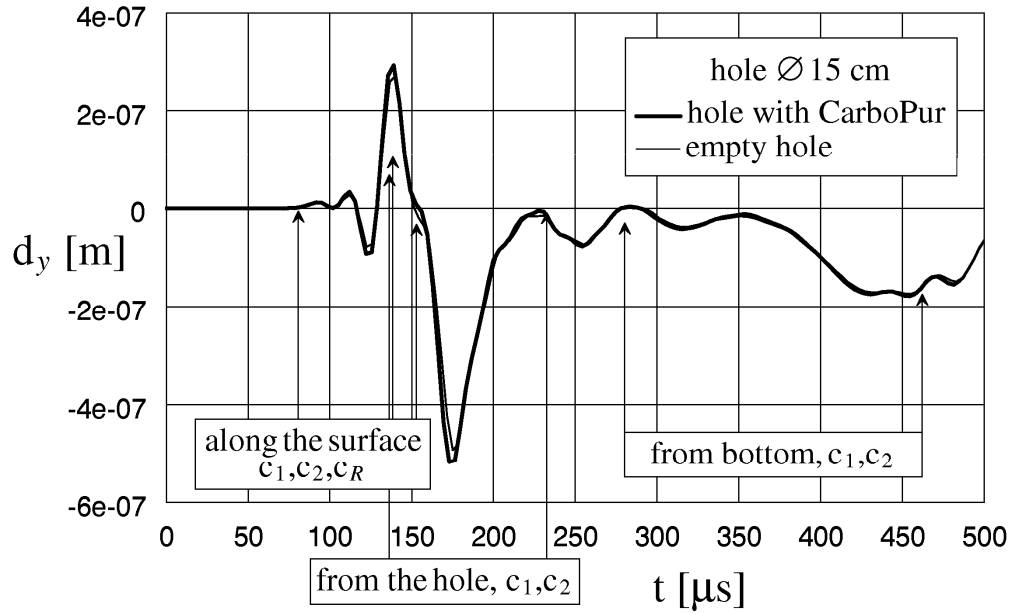
Here we have exposed some results, where the utmost difference between these three models could be expected. Time histories of displacement perpendicular to surface were taken near the biggest central hole (diameter 15 cm, in depth 29.5 cm). The excitation point and the position of transducer for these examples are located on the same surface at the opposite side of this hole (both approx. 16 cm from the hole, being measured on the surface). By such way, the maximal reflection from hole's surface will be detected (like ray reflection).

On the fig.3 we can see a comparison of responses a body without any cavity and specimen with drilled holes. The thick curve responds to the specimen without any hole and thin one responds to the specimen with empty holes. The both curves are quite identical upon the surface wavefronts passing, up to time 233  $\mu\text{s}$ , when the shear wave reflection (not dilatation wave!) from the top surface of hole arrived. Since this time the curves differ, see fig. 3. We have found out here similar findings like detecting the concrete-steel boundary, see Moravka, Voldřich (2003 and 2004a), i.e. just the shear wave face brings the first substantial information.



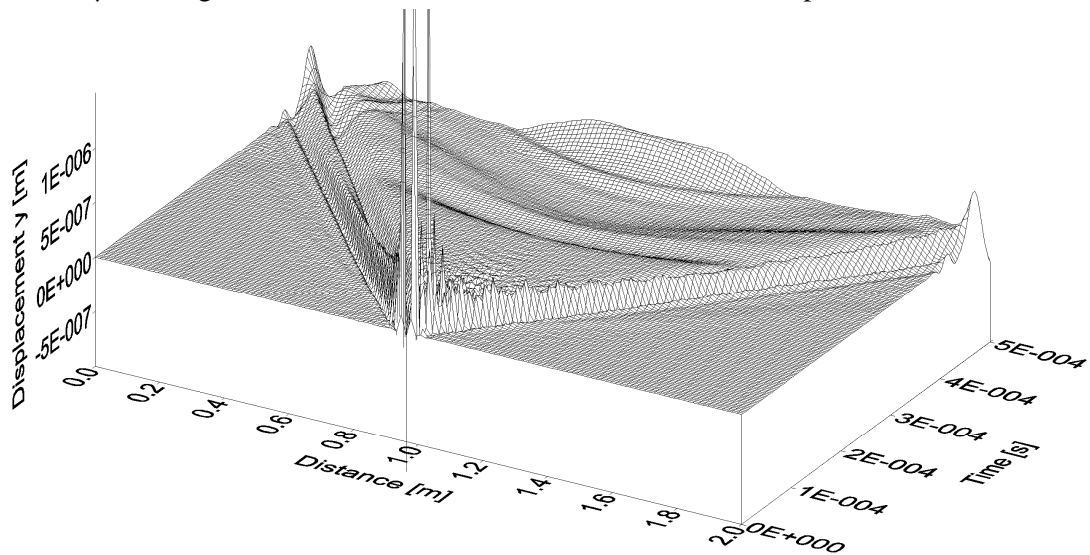
**Fig. 3.** Time histories of displacement perpendicular to surface for full-concrete specimen and for reflection from empty central hole.

The similar comparison of two curves we can find on the fig. 4 follows. The positions of excitation and sensing are the same as previous, but responses of the specimen with empty holes (thin curve) and specimen with holes filled by CarboPur WF (thick curve) are compared here. It is apparent on the first sight, that the differences are quite neglectable. It doesn't make possible to distinguish between wave reflections from CarboPur-concrete boundary and reflection from free concrete surface. So-called acoustic impedance ( $E/\rho$  ratio) of concrete and CarboPur foam are very different, whilst foam behaves similar to free boundary concrete-air.



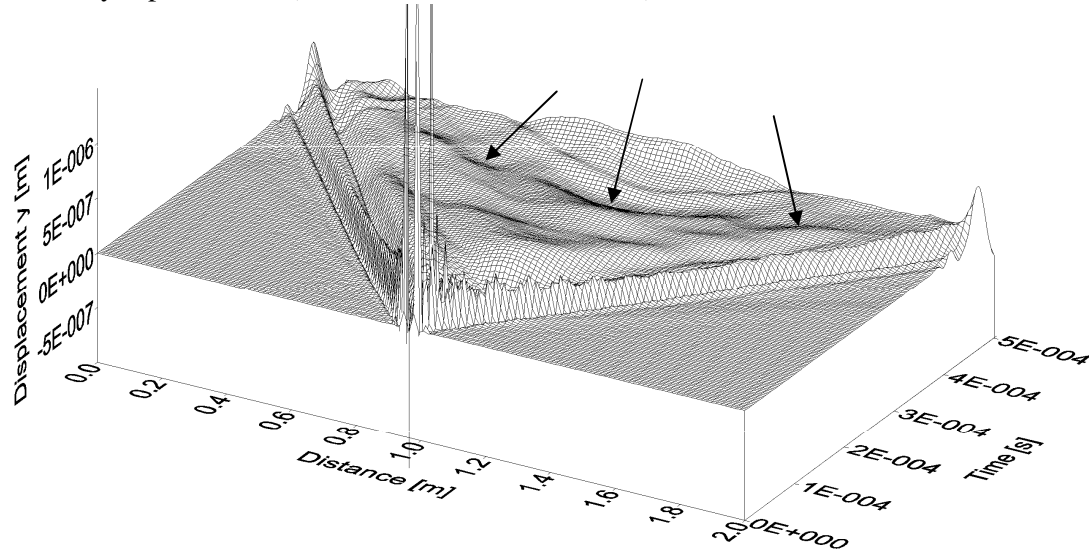
**Fig. 4.** Time histories of displacement perpendicular to surface for reflection from the central empty hole and the same hole filled with CarboPur WF foam.

The next two figures (Fig. 5 and Fig. 6) represent two sets of responses on excitation in the centre of specimen (above the hole diameter 15 cm). The face axis “Distance” is geometrical position from the specimen’s edge. We take time histories of displacement perpendicular to surface from all of 134 nodes on this 2 meters line going cross the whole specimen (perpendicularly to the three drilled holes). In such way we can display global response to set of excitation in one figure. Two triangular areas ahead are divided by dilatation wave front. But it cannot be visible in this scale, because deflections caused by dilatation wave are relatively very small. The outstanding wavefront belongs to the fronts of shear wave and surface Rayleigh wave. Their wavefronts partly coincide each other, as their velocities are similar. The deflected line behind the Rayleigh wave face at the time approx. 270-300  $\mu$ s belongs to the dilatation wavefront reflection from the specimen’s bottom.



**Fig. 5.** Responses to the excitation in middle of the specimen taken from all nodes on 2 m line going through the specimen. Specimen without any hole.

The figure 6 is similar to Fig.5, but response of specimen with empty holes is depicted here. We can see all the wave fronts as in the fig 5. Only the reflection of dilatation wave from bottom is overlaid by the reflections of shear wavefronts from the holes, see arrows. If we animate this figure moving the excitation position, we can easily distinguish the reflection from every separate hole (will be shown on conference).



**Fig. 6.** Responses to the excitation in middle of the specimen taken from all nodes on 2 m line going through the specimen. Specimen with empty holes.

It wouldn't be useful to display the next figure with responses of specimen with holes filled by CarboPur here. It looks nearly exactly like the figure 6 - response of the body with empty holes.

#### 4. Conclusions

It is really complicated task for various diagnostic methods to confirm proper filling of the cavities. Ultrasound and georadar don't succeed as well. Radiography also probably won't distinguish empty space from CarboPur foam. The Impact-Echo method is very simply applicable and therefore it was suitable to try it on this task as well. But unfortunately it must be submitted, that Impact-Echo method is not able, in practice, distinguish cavity filled by CarboPur foam from empty or partly empty cavity. It is not possible to confirm repairing success and verify proper cavity filling reliably by this way. These numerical predictions will be verified on real (1:1) specimens in NRI Řež.

Just starting work concerns to the cracks caused by the steel reinforcing corrosion. The corrosive products have up to seven time larger volume then pure steel. It results in a high pressure and share strain, which can lead up to the concrete damage.

The experimental measurements on real specimens in NRI Řež (scaled 1:1) by various diagnostic methods are parts of the project as well. There were (or will be) realized measuring by ultrasound (Inset Liberec and Civil Faculty TU Brno), optically by Moire method (Institute of Thermomechanics Prague), optically by pulse ESPI method (Music Faculty, Academy of Performing Arts Prague), radiography (Civil Faculty of TU Brno) and by Impact-Echo (using licensed B&K sensor and originally designed transducer and exciter as well).

Within the frame of whole project the techniques of automated excitation and response scanning are developed, including own devices design.

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