Shutenko L., doctor of science, professor
Syerikov Y., candidate of science, professor
Zolotov M., candidate of science
Kharkiv National Academy of Municipal Economy
Ukraine

Estimation of crack formation in concrete in bridge constructions using ultrasonic impulse method

The investigation results of crack formation process in structural reinforced concrete elements of bridge constructions using ultrasonic impulse method have been described. The dependence of amplitude and frequency characteristics of an information signal when increasing the amount of cracks parameters in concrete has been revealed and described in the article.

The investigation of the process of crack formation and development in bridge reinforced concrete constructions, their bearing capacity is considered to be a very important task allowing the forecast of their reliability and durability. The urgency of solving the problem can be stipulated from the economic point of view, i.e. the necessity of maximum use of the existing units and determining the terms of maintenance work.

The analysis of solving such problem at the stage of its setting makes it possible to conclude that the operation process of such reinforced concrete elements is affected by static, dynamic loads and climatic conditions. Moreover, the influence of mentioned above factors is known to stir up the process of crack formation in concrete, i.e. leads to consecutive relative changes of its physical and mechanic and structural characteristics.

The application of destructive methods for control over concrete quality in construction elements is considered not to be possible from the technical point of view and the methods of visual estimation are known to be labor consuming and not very reliable allowing observation of cracks only with visual depth of opening.

Physical basis and the experience of using nondestructive methods of control over the quality of concrete structure allow solving this problem on their basis [1, 2]. The analysis of the potential of nondestructive methods using elastic wave parameters for estimation of such concrete characteristics shows that ultrasonic impulse method has considerable promise for such investigation [1].

In the case under consideration rather high sensitivity of the ultrasonic impulse method to relative changes of physical and mechanic characteristics of materials has been used for control over the process of crack formation in reinforced concrete elements of bridge constructions. The control methods have been based on the principles of control over the reliability of concrete and reinforced concrete products under load [1].

The essence of the method lies in the fact that reliable concrete properties, its bearing capacities are investigated through the measurement of the speed of ultrasonic vibration (V) spreading in the investigated products under premeditated influence of outer rationed load (Pi) with the reciprocal P = 20…60 % from the maximum (P_{max}), perceived by the material (fig.1).

Under the influence of outer force (P_i) irreversible structural flaws changing elastic waves spreading speed (V) because of the increase of their pathway from radiating to

receiving transformer when rounding these flaws are known to appear in concrete of a product, construction or erection.

The dependence of magnitudes *P*i and *V*i correlated with physical and mechanic characteristics of concrete is considered to be expressed in the following way:

$$\Delta V_j = V_1 - V_2 = F(E_{qi1}; E_{qi2}; G_{qi1}; G_{qi2}; S_{qi1}; S_{qi2});$$

$$E_{qi1}, G_{qi1}, \rho_{i1}, \eta_{i1}, S_{qi1}, V_1 \in \psi_{i1}/P_1,$$

$$E_{qi2}, G_{qi2}, \rho_{i2}, \eta_{i2}, S_{qi2}, V_2 \in \psi_{i2}/P_2;$$

where ΔVj – the change of ultrasonic vibration spreading speed, occurring when microcracks in concrete appear.

V_1 – the speed of ultrasonic vibration spreading in concrete under load P_1;

V_2 – the speed of ultrasonic vibration spreading in concrete under load P_2;

$E_{qi} \in E_q$, $G_{qi} \in G_q$, $\rho_i \in \rho$, $\eta_i \in \eta$ - differential quotient indices of dynamic moduli of elasticity of the first and second kind, structural characteristics of a product flaws, concrete density;

ψ_i - differential index of the aggregate of physical and mechanic properties of concrete in a product, influencing the magnitude Vi;

P_{dectr} - the value of destructive load;

P_{max} - the value of maximum load, perceived by a product (construction, erection);

P_1, P_2 - the values of applied load on the product under investigation;

$P_1 < P_2 < P_{max} < P_{dectr}$ - correlation of loads.

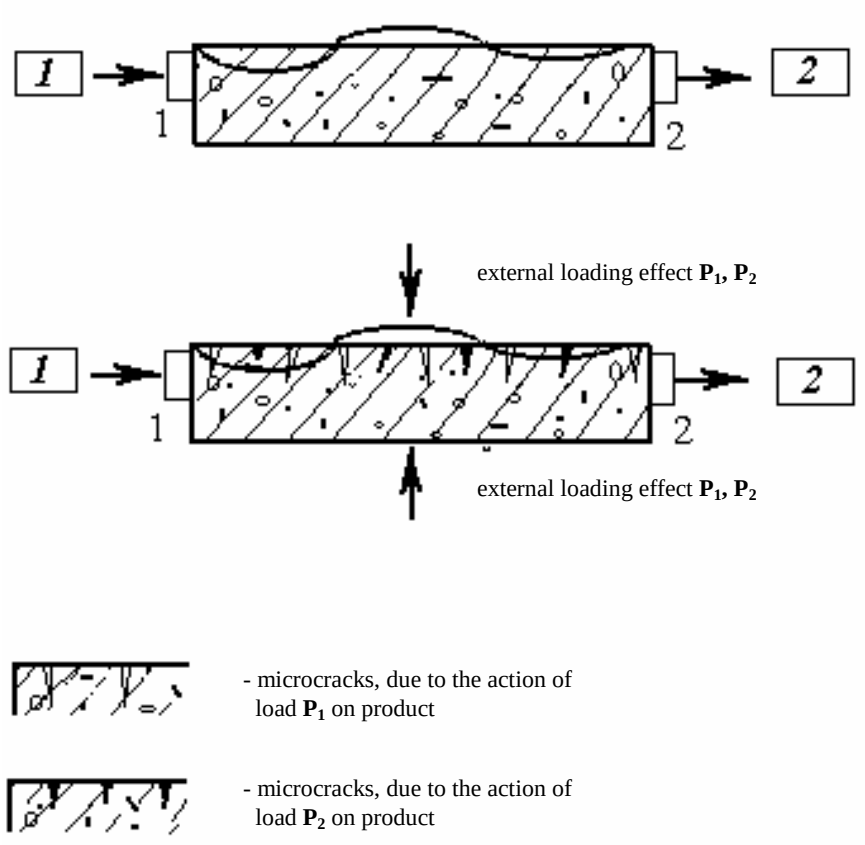

Fig.1. The scheme of concrete reliability control under load using ultrasonic impulse method: 1 – radiating ultrasonic piezzo and elastic transformer; 2 – receiving ultrasonic transformer; 1 – impulse influence of an elastic wave; 2 – receiving an information signal.

Using this method the speed of ultrasonic vibration spreading is measured in an unloaded product (V_0) and at two load values (P_1) and (P_2) accordingly (V_1) and (V_2). In this case the direction of elastic waves spreading when determining the speed (V_1) and (V_2) is to be perpendicular to the action of an outer load (Pi).

By the values of relative changes of parameters (Vi) using special diagrams [1] auxiliary coefficients are determined and the value of maximum load (P_{max}) perceived by a product is calculated.

The main advantage of this method is the possibility to investigate physical and mechanic properties of concrete without preliminary experiments for formation of correlation dependences ”the speed of ultrasonic vibration spreading – concrete density”.

In the case under investigation nondestructive control over the process of crack formation in reinforced concrete structures of bridge constructions is based on the use of information concerning structural properties of concrete changing owing to natural dynamic and static forces. Such control allows revealing the zones of cracks or other damage in constructional reinforced concrete elements.

So, the methods of nondestructive testing are based on the analysis of correlation in the system “static or dynamic load – concrete structure – ultrasonic information signal parameters”. Mathematical model describing correlation in such system is based on the solution of nonlinear task of elastic waves spreading.

The methods of control are based on measurement of a complex of information signal characteristics in the passage of elastic waves through construction concrete. An impulse active location is used.

Physical basis of ultrasonic impulse method and field physical testing show that such characteristics as spectral, information signal amplitude and the speed of elastic wave spreading [3, 4, 5] are considered to be the most informative for estimation of the process of cracks formation in concrete of reinforced concrete structures of bridge constructions.

When diagnosing constructional reinforced concrete elements with flaws and without them, physical experiments allowing revealing adequate changes in spectral signal characteristics have been carried out. The increase of spectral constituents intensity in the area of low frequencies has been observed.

It has been elucidated that the changes in spectrum of forced elastic vibration increase not only with the increase of static outer influence capacity, but also at different levels of concrete crack formation at constant outer influence capacity. In some cases the zones of flaws in the investigated constructions have been identified on the parameters of changes in spectra.

The following investigations are necessary for increasing reliability of determining cracks location: storing data base of statistic information; carrying out comparative analysis of faulty and flawless state of concrete structure in constructions.

The results of physical experiments showed that spectrum characteristics, changing under the influence of deforming stress increase being the basis of faulty structure development are considered to be the most informative parameters.

The development of a crack formation process in constructions concrete is observed if the process of stress increase and concentration is considered as the behavior of a dynamic system with hierarchic levels, each of which is realized in formation of connected flaws operated by outer forces on the construction. The equilibrium of such system can be unstable and broken under changes of outer force parameters (dynamic or static). In this case the process of its development is considered as discrete sequence of hierarchic phase passages from integral flawless concrete structure to consecutive stages of development and buildup of cracks of different hierarchic levels. This process is finished by final stage of destruction at Pi = Pdestr.

Thus, in this case an irreversible process of flaws development in concrete occurring at the stage of nonmolecular cracks (microcracks formation) is known to develop as the sequence of physical discrete states. The passages between these states occur in the form of a cascade of stepped unstable states of a system “static or dynamic load – concrete structure, which are formed at a definite value of outer load and corresponding elastic deformation of concrete, correlating with the moments of spasmodic increase of flaws.

In this case each following state of concrete structure in a construction is known to depend on the previous one. In other words, the flaws of a hierarchic level “y” appear from flaws of a lower level “x - w”, where w – arbitrarily expressed as a state of concrete without cracks.

So, discrete increase of scattering centers amount and decrease of elastic wave power are observed. In this case concrete structure is considered as the change of some nonlinear acoustic parameter regarding to elastic wave characteristics. If nonlinear acoustic parameter doesn’t exceed some conventional unities the speed of elastic wave spreading, its damping and spectral characteristics are not subjected to any changes. In this connection nonlinear theory and corresponding changes can not be considered as the basis for judging the level of flaws in concrete at such stage.

At the same time, when flaws concentration ranges up to rather high values depending on initial physical and mechanic concrete characteristics the effects of their collective behavior influencing corresponding information signal characteristics occur.

Each following structural level of faulty medium the parameters of which are connected with the previous one appears when the level of elastic deformation increases. In this case the development process of concrete structure faulty formation is considered as movement on the sites of a hierarchic structure in which the passages to the following faulty medium level are connected with the lower deformation levels.

Physical experiment was carried out in the following way. When studying the structural reinforced concrete element of bridge construction the place with three cracks, originated from one top, have been found out. Deformation increase was conditioned by the change of static and dynamic loads when operating tower erection. A seamy method of active ultrasonic location has been used.

Functional scheme of control and measurement system used in the experiment is presented in fig.2.

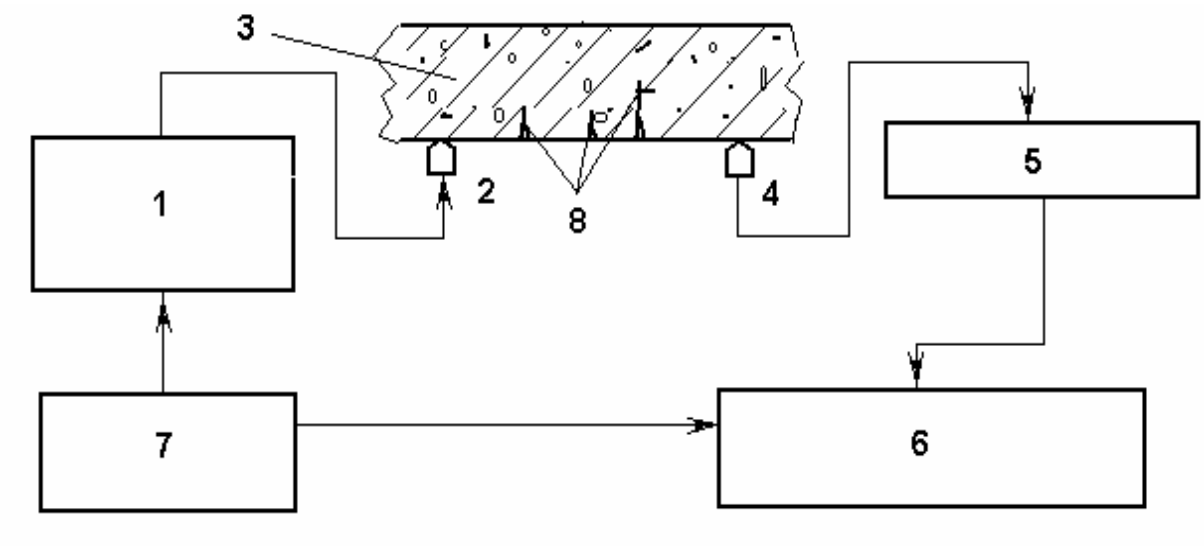

Fig. 2. Structural scheme of control and measurement system for investigating the process of crack formation in reinforced concrete structural elements of bridge constructions

Electric impulses are fed from the generator of sounding impulses 1 to the radiating electric transformer 2. With the help of the transformer ultrasonic elastic vibration is introduced into the concrete of the investigated structural element of bridge construction 3. Ultrasonic information signal arrives at receiving piezzo-electric transformer 4, then it is strengthened by the intensifier 5 and fed to the block of information processing 6. The speed of elastic wave spreading and damping coefficient are measured and spectral characteristics are analyzed in the block of information processing. Synchronization of a measurement device work is made in the block of automated mechanisms 7. 8 – microcracks in concrete of the investigated constructional element.

Amplitude and frequency characteristics of information signals observed in the process of investigating reinforced concrete structural element of bridge construction as static load increases are presented in fig.3.

The comparative studies of the given spectra show the change of their spectral constituents caused by cracks growth.

Thus, field measurement of spectral characteristics of information signals with increased crack formation in concrete of a construction under the influence of static and dynamic loads are considered to confirm the possibility of control over the process of crack formation using ultrasonic impulse method with discrete measurement, spread in time. As a result, the possibility of forecasting reliability and determining the terms of maintenance work occurs.

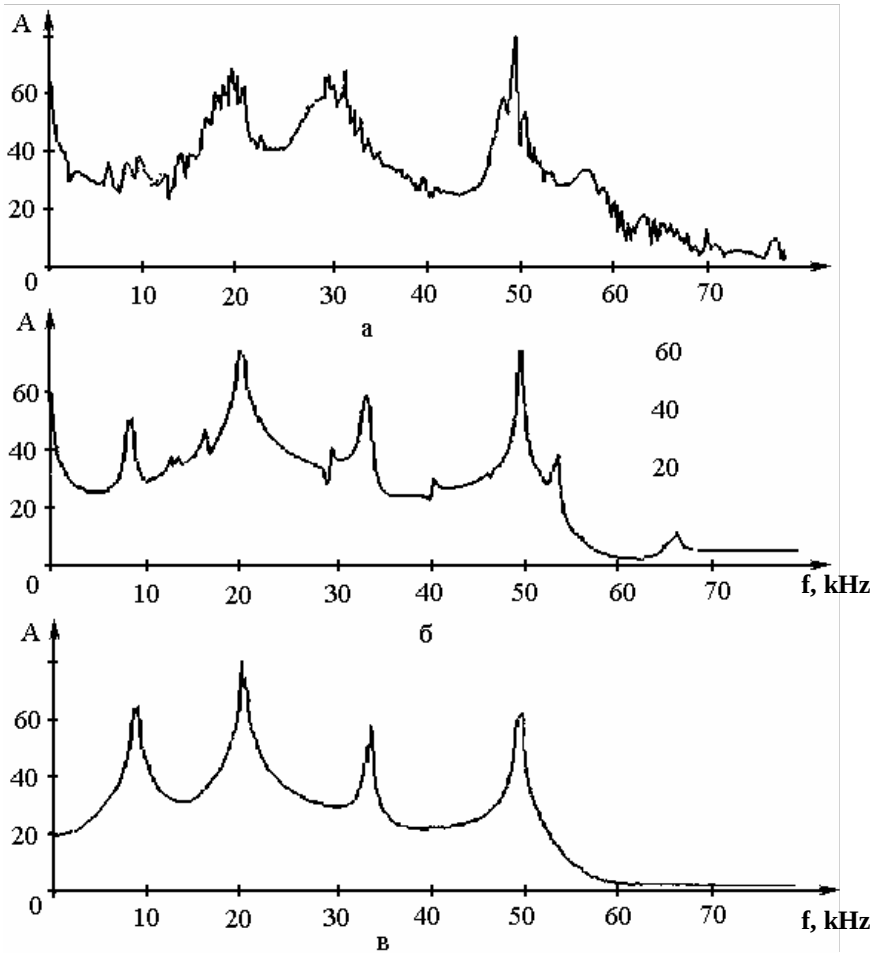

Fig.3. Amplitude and frequency characteristics of information signals when investigating reinforced concrete structural element of bridge construction

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