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The measure of the propagation of vibration for the assessment of damages in a concrete beam

Key words

Fault monitoring, vibrations, concrete structure.

Słowa kluczowe

Monitorowanie usterek, wibracje, struktura betonu.

Summary

The paper considers the possibilities of using the efficiency measure of vibration propagation as a diagnostic parameter. A measure defined by using recorded test results is proposed and the method of numerical calculations is shown. Examining an example of the empirical results of a concrete beam working under bending load and submitted to impact forced vibrations, an effort to determine the degradation process level is undertaken.

The concept of the propagation measures of vibroacoustical energy is developed on the basic the observation that, in case of the process variable in time, its energy is proportional to the integrated (according to time) square of the instant value of amplitude. It is assumed that the defined measures are inversely proportional to the force of impact. A simple form of notation, suitable for numerical calculations in the time domain, is proposed.

The proposed measures can be used for performing engineering comparisons based on single value parameters. According to the results, selective sensitivity to the stage of failure development

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shown by the construction depends to some extend on a proper localisation of points of impact and vibration recordings.

In conclusion, solving diagnostic problems is possible, if the places of impact and vibration recording have been correctly located.

Introduction

The materials commonly used in construction are mostly characterised by anisotropy of their strength qualities: unquestionably higher compressive stress is more acceptable than tensile, tangential or torsional stress. However, there is a group of several elements submitted to bending, working under a complex stress (floor beams, bridge and roof spans, etc.) where the load is transmitted mostly by the steel profiles and ferroconcrete structures. Everyday the prestressed concrete becomes more frequently used, and this means that the concrete submitted to stress by the flexible distortion of steel bars placed within the concrete mass.

The supporting structures of bridges and roofs undergo, as any technical objects, exploitation wearing processes. The vehicles used in Poland often carry excessive loads, which result in the acceleration of the wear processes of the roads. According to forecasts, either replacement or major repairs of many bridges will be soon necessary, as well as building new ones. Thus, studies leading to the formulation of some efficient methods for evaluating and forecasting technical conditions of these objects are needed.

The methodology consists of registering the acceleration time process of impact–forced vibrations of a beam, the beam being supported on both ends and loaded by a static centrally applied force. This makes it possible to apply the measures of the propagation of vibroacoustic energy developed by the author [1] and check their potential in evaluating the level of damage development.

The paper develops the ideas of the author presented at the First World Congress on Engineering Asset Management [2].

The basis of research methodology

In the engineering reasoning, real constructions are usually modelled in a simplified way. The dynamic models of one or few degrees of freedom are often considered a satisfactory base for pondering on construction or practical qualities of machines and devices. However, difficulties appear when the non-linear component emerges, which is unfortunately the way the technical state of objects changes [3]. Consequently, diagnostic application of the measures based on the description of the movement of one degree of freedom is quite limited. There are different research centres developing methods of forecasting and evaluating the technical state of an object and trying to make them both efficient and well-anchored in the physical bases of analysed phenomena.

The relationship between the technical state of a mechanical system and the energy dissipated during the performance of its functional tasks has been observed [4]. It seems sensible then to search for energetic descriptors to be possibly used in the diagnostics of technical objects. Therefore, we come to the idea of defining a measure matching simplicity of expression with universal quality, and simultaneously reflecting the vibroacoustic effect of an input of determined energy [5].

It is commonly known that the average square value of the amplitude of a signal variable in time is proportional to the energy of the process characterised by the signal. We can thus examine the following relationship:

$$\mathrm{U} \sim \frac{1}{\boldsymbol{T}}\int_{0}^{\boldsymbol{T}}\left(x(t)\right)^{2}\boldsymbol{dt} \tag{1}$$

where ***x(t)*** represents the variation course of the amplitude of the examined physical quantity in time, while **U** is energy, and ***T*** is observation time.

Let us try to use the above statement in our pondering on the vibroacoustic processes. Let us also assume that a description of inputs provoking the vibroacoustic activity of the technical object is known in the form of ***F(t).*** The measure matching the energy of the observed process with the input quantity, and called the measure of propagation of vibroacoustic energy, seems to be a valid solution:

$$\mathrm{H} = \frac{\int_{0}^{\boldsymbol{T}}\left(\boldsymbol{x(t)}\right)^{2}\boldsymbol{dt}}{\int_{0}^{\boldsymbol{T}}\left(\boldsymbol{F(t)}\right)^{2}\boldsymbol{dt}} \tag{2}$$

If we replace ***x(t)*** by the course of the acceleration of vibrations physically registered (measured) for an actual point of the technical object ***a(t),*** and take ***F(t)*** as the course of the input force for the vibrations, we will be able to talk about the measure of efficiency of vibration propagation:

$$\mathrm{H}_{a} = \frac{\int_{0}^{\boldsymbol{T}}\left(\boldsymbol{a(t)}\right)^{2}\boldsymbol{dt}}{\int_{0}^{\boldsymbol{T}}\left(\boldsymbol{F(t)}\right)^{2}\boldsymbol{dt}} \tag{3}$$

The above form is particularly useful while examining the results of experimental studies when the vibrations of the object are forced by impulse. To dampen vibrations, it is enough to take the integration time ***T*** to be longer than the time needed for the vibration to disappear and the lower integration limit established for the moment of impulse input; subsequently, the above quotient will explicitly reflect the relationship between the energy of vibration movement and the particular qualities of an actual object.

One of the characteristics of numeric signal processing is operating on discrete values obtained by the discretization and quantization of an analogue signal. Then the integrating is replaced by the summation.

$$H_a = \frac{\sum_{i=1}^{N} \left(a(i) \right)^2}{\sum_{i=1}^{N} \left(F(i) \right)^2} \tag{4}$$

In the above relationship, the amplitudes of input force ***F(i)*** and vibration acceleration ***a(i)*** correspond to the values of i-th time step. The value of measurement can be calculated on the basis of a single impulse or a series of impulses; the only condition is a synchronic processing of both physical quantities used to define the measure.

Research results

For any of the values of the effectuated load, the impulse inputs and the vibration response of the object were synchronically recorded using six accelerometers located as shown in Figure 1 (points 2-7). The vibrations of the beam were activated using an impact hammer equipped with a force transducer. The points of impact are marked 1, while the arrows demonstrate the impact directions. Top values of the impulses of input reached 3-5kN.

Single numerical values of the measures of the efficiency of vibration propagation were calculated according to the relationship (4) as the average value coming from a series of 10 subsequent input impulses. The cases of impact loads in perpendicular directions were analysed separately.

The graphs in the Figures 2 and 3 show the changes in the measurements of the efficiency of vibration propagation as a function of the static load of a beam, obtained by processing the changes of input and the variation progressions of the acceleration of vibration at the fixed points of one of the six accelerators. During the registration of the vibration signals of the beam under maximum load, the sensor lead was destroyed, so the graphs illustrating the measured values for vertical strokes have been prepared for a static load under 40kN.

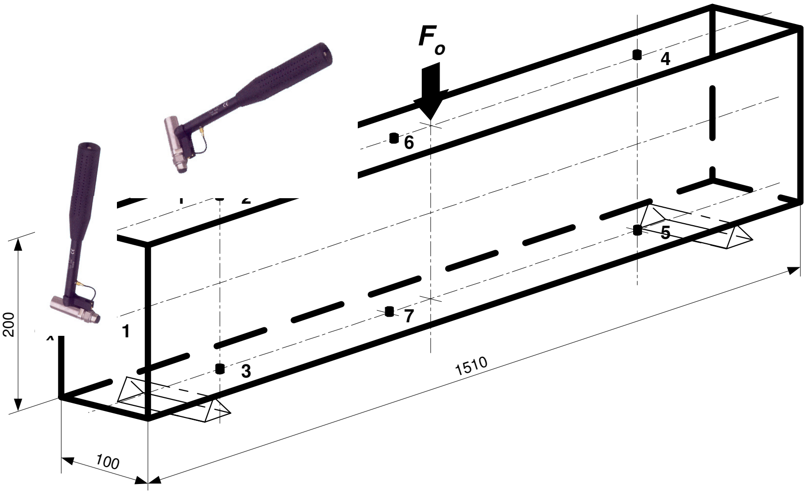

Fig. 1. The studied beam: location of accelerometers, point of load application and impulse input points

Rys. 1. Badana belka z pokazaną lokalizacją akcelerometrów, miejsca przyłożenia obciążenia oraz punktów pobudzanych impulsowo

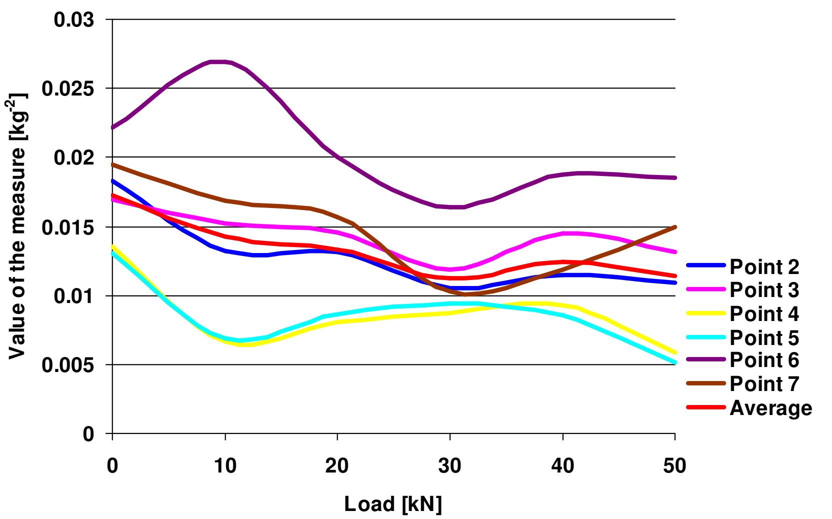

Fig. 2. Changes in the efficiency of vibration propagation for separate measurement points, horizontal input ($\boldsymbol{U_y}$)

Rys. 2. Zmiany miar efektywności propagacji drgań dla poszczególnych punktów pomiarowych, wymuszenie pionowo ($\boldsymbol{U_y}$)

The highest numerical values for measurements of the efficiency of vibration propagation were obtained for the measurement points located near the places of impact. It seems consistent that structural dampening results in lowering vibration amplitudes in the places situated within a greater distance from the source. The load input changes to some extent the way the object is supported; and in consequence, it explains the maximum without loading and decrease in the function of loading force.

The changes shown in the graphs have a monotonous character only in isolated cases which points to their potential diagnostic utility. On the other hand, there is a lack of an explicit trend in the majority of the graphs that suggests a need for deeper analysis for application.

Interpreting the graphs and relating them to the state of the object become easier if we refer to the information that the first visible cracks (break initiation) were observed under a load of 30kN. In many courses, the local extreme corresponding to this load can be seen. Quality evaluation makes it possible to relate the changes of the curve's shape to the initiation of damage.

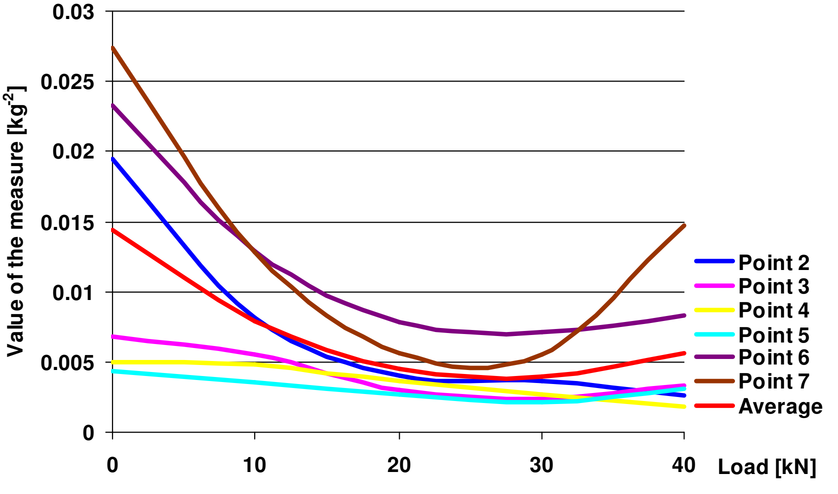

Fig. 3. Changes in the efficiency of vibration propagation for separate measurement points, vertical input (U_x)
Rys. 3. Zmiany miar efektywności propagacji drgań dla poszczególnych punktów pomiarowych, wymuszenie poziomo (U_x)

Conclusion

The conclusions based on the experiment indicate the possibility of applying the efficiency measurements of vibration propagation for exploitation diagnostics of concrete structures. Structural beams made of pre-stressed concrete are being bent under a load more frequently from day to day. Therefore, considering the information value of the efficiency measurements of vibration propagation calculated on the basis of vibrations induced by horizontally oriented impulses, we would suggest further studies.

All of the defects appearing in the exploitation process (plastic deformations, cracks, fractures, etc.) change the dynamic characteristics of the object; therefore, attempts to apply the already explained measures for evaluating the level of wear of concrete structures seem justified. Any damage results in the modification of the ways of the propagation of vibroacoustic energy, which necessarily provokes changes in the form of the structural vibrations, and consequently, a visible change in the numerical value of the measurements of the propagation of vibrations.

Due the freedom to select the location of the receptors of vibroacoustic signal (accelerometers) and the application point of inducing impulses, there is the possibility of directing the measurements towards comparing the properties of actual elements of studied structures, or their fragments.

References

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Użyteczność miary propagacji drgań do oceny uszkodzenia belki betonowej

S t r e s z c z e n i e

Referat zawiera rozważania nad możliwością zastosowania miar efektywności propagacji drgań jako parametrów diagnostycznych. Zdefiniowano propozycję miary wykorzystującej zarejestrowane wyniki badań eksperymentalnych oraz przedstawiono sposób prowadzenia obliczeń numerycznych. Na przykładzie rezultatów badań wymuszanych impulsowo drgań belki betonowej pracującej na zginanie podjęto próbę oceny stopnia zaawansowania procesów zniszczeniowych.

Do opracowania koncepcji miar efektywności propagacji energii wibroakustycznej wykorzystano fakt, że energia procesu zmiennego w czasie jest proporcjonalna do scałkowanego

po czasie kwadratu chwilowej wartości amplitudy. Założono również odwrotną proporcjonalność do energii impulsu wymuszającego. Zaproponowano nieskomplikowaną postać zapisu dogodną do przetwarzania przebiegów czasowych amplitud.

Zaproponowane miary nadają się do prowadzenia inżynierskich porównań na bazie pojedynczych wartości liczbowych. Wybiórcza wrażliwość miar na stopień degradacji konstrukcji zależy między innymi od lokalizacji przetworników pomiarowych.

Wnioski z badań wskazują na niezłe odwzorowanie początków procesu pękania pod warunkiem właściwej lokalizacji miejsc pobudzenia i odbioru sygnału drganiowego.