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METHODOLOGY AND SYSTEM FOR LONG-TERM MEASUREMENTS OF VIBROACOUSTIC PARAMETERS IN MINING-AFFECTED AREAS

Abstract

Mining operations, both those conducted currently and in the past in densely populated urban areas generate well known adverse effects, both on the natural environment and on technical substance located in them. This entails a straightforward question of human safety and methods to mitigate these negative consequences.

To be able to make reliable assessment of vibroacoustic climate, including that existing in residential buildings, it is necessary to perform measuring tasks in the form of continuous monitoring of two types of related parameters: vibrational and acoustic. This means designing and building a continuous monitoring system. A version developed at the Department of Technical Acoustics, Laser Technology and Radiometry is described in the paper.

The proposed System for Continuous Measurements of Noise and Vibration (SCMNV) is based on combining two subsystems, the first of them designed to perform measurements of acoustic parameters, and the other the measurements of tilt and vibration of building structures. Subject to control by such a complex monitoring system are various structures affected by underground mining, e.g. cultural heritage objects, such as churches, castles, and public objects (hospitals, schools, etc.). Joint (usually inter-related) effects of past and current mining and heavy road and railway traffic are also controlled.

The acoustic parameters are being effectively measured through using the System for Continuous Noise Measurement (SCNM), while tilt and vibration by using the Laser Tilt and Vibration Measuring System (LTVMS). Some measuring situations need using additional vibration measuring equipment. For this purpose, a POLYTEC PSV-400 scanning laser Doppler vibrometer is used.

Metodyka i system długookresowych pomiarów parametrów wibroakustycznych na terenach objętych wpływami górniczymi

Streszczenie

Operacje górnicze zarówno bieżące, jak i przeszłe, prowadzone na gęsto zaludnionych obszarach zurbanizowanych, generują dobrze znane skutki negatywne zarówno dla środowiska naturalnego, jak i dla zlokalizowanej na nich substancji technicznej. Pociąga to za sobą natychmiastowe pytanie o bezpieczeństwo ludzi i metody zredukowania tych negatywnych skutków.

Dla właściwej oceny wibroakustycznej, uwzględniając klimat istniejący w budynkach mieszkalnych, konieczne jest wykonanie zadań pomiarowych w postaci ciągłego monitoringu dwóch typów parametrów z nim związanych: wibracyjnego i akustycznego. Oznacza to zaprojektowanie i zbudowanie systemu do ciągłego monitoringu. Jego wersja opracowana w Zakładzie Akustyki Technicznej, Techniki Laserowej i Radiometrii została opisana w niniejszym artykule.

Zaproponowany System do Ciągłych Pomiarów Hałasu i Wibracji (SCPHW) oparto na kombinacji dwóch podsystemów, z których pierwszy jest przeznaczony do wykonywania pomiarów parametrów akustycznych, a drugi do pomiarów wychyleń i drgań struktur budowlanych. Obiektem kontroli przy użyciu takiego złożonego systemu monitoringu są różne struktury poddane wpływom podziemnej dzia-

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łalności górniczej, np. obiekty dziedzictwa kulturowego, takie jak: kościoły, zamki, a także obiekty użyteczności publicznej (szpitale, szkoły itp.). Kontrolowane są również łącznie (zwykle powiązane ze sobą) skutki przeszłej i bieżącej działalności górniczej oraz skutki używania ciężkiego transportu drogowego i kolejowego.

Parametry akustyczne są efektywnie mierzone z wykorzystaniem Systemu do Ciągłego Pomiaru Hałasu (SCPH), natomiast wychylenia i drgania – przy użyciu Systemu Laserowego do Pomiarów Drgań i Wychyleń (SLPDW). Niektóre sytuacje pomiarowe wymagają zastosowania dodatkowego wyposażenia do pomiarów wibracji. Do tego celu jest wykorzystywany dopplerowski skaningowy wibrometr laserowy POLYTEC PSV-400.

INTRODUCTION

The most accurate representation of the current state, in terms of vibroacoustics, is offered by the measuring method that relies on making, in parallel, measurements of the sound level and vibration in specified locations, in defined time and meteorological conditions. For this type of studies, one uses, most often, the results of monitoring-type measurements. To be classified as measurements of this type, they should meet the following conditions:

- cyclical character,
- unification of methodologies,
- unification of equipment,
- unification of interpretation.

The principal tasks belonging to such kind of measurements are as follows:

- providing reliable information on the current state and degree of pollution of individual components of the environment to allow effective realisation of protection tasks, including technical safety,
- analysing processes taking place in the natural environment and objects located in it,
- informing people on possible hazards,
- providing information on predicted consequences of using the environment.

Presented in the paper is the System for Continuous Measurements of Noise and Vibration (SCMNV), developed in the Department of Technical Acoustics, Laser Technology and Radiometry. To realise the tasks as specified above, it has been made as combination of two subsystems, the first of them designed to perform measurements of acoustic parameters, and the other the measurements of tilt and vibration of building structures, in particular located in the regions subjected to underground mining conducted currently and in the past.

1. SYSTEM FOR CONTINUOUS MEASUREMENTS OF NOISE

System for continuous measurements of noise is a subsystem of the SCMNV. It is used for providing all needed acoustic parameters to be measured during complex evaluation of the environmental characteristics in the surroundings of the object endangered with the risk of excessive noise levels.

1.1. System for measurements of acoustic parameters SCNM

The acoustic parameters are being effectively measured through using the System for Continuous Noise Measurement (SCNM) developed in the Central Mining Institute's Technical Acoustic Laboratory (Lipowczan, Kompała 2004; Lipowczan, Bartmański, Kompała 2005). The SCNM system is designed for longterm noise measuring and monitoring in wide areas, for the needs of assessment of noise propagation in outdoor environment and associated risk. It consists of a set of autonomous measuring devices provided with digital memory (Fig. 1). They enable to measure and record sound level samples at several measuring points simultaneously, located on a wide area, and this significantly increases the effectiveness and reliability of acoustical data acquired during activities connected with the assessment of acoustic climate.

a) b)

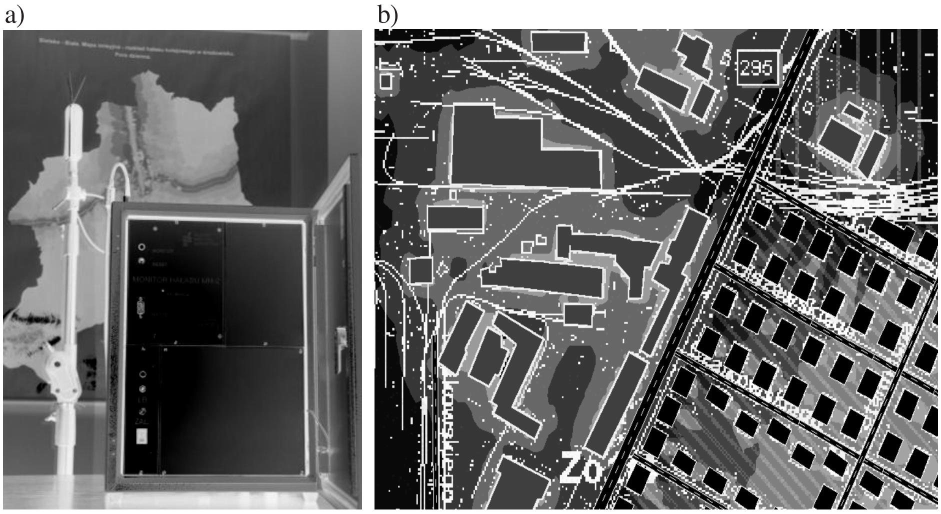

Fig. 1. System for Continuous Noise Measurement (SCNM) (a) and an example of acoustic map obtained with the use of this system (b)

Rys. 1. System do Ciągłego Pomiaru Hałasu (SCPH) (a) i przykład mapy akustycznej wykonanej z jego użyciem (b)

The team supervising the work of the SCNM system performs reading of recorded results with the use of movable computer. The results collected in a database enable to analyse the observations in particular measurement points and, at the stage of digital modelling, determining the space distribution of noise level within the area under investigation. The research results form a tool supporting decision processes with respect to methods and means of noise reduction at the endangered areas.

2. SYSTEM FOR CONTINUOUS MEASUREMENTS OF TILTS AND VIBRATIONS

Tilt and vibration of the building structure are continuously measured with the use of Laser Tilt and Vibration Measuring System (LTVMS) being a product of the Central Mining Institute's Laser Technology Laboratory.

The operational principle of the CMI-developed laser tilt sensor and measurement versions have been sufficiently widely described in the authors' publications and patents [3–10]. The LTVMS system is used for determining tilts and vibrations of the constructional element of the object under investigation.

2.1. Constructional and technical characteristics of the sensor of the LTVMS system

The general structure of the sensor with a liquid wedge is illustrated in Fig. 2a, while the general overview at measuring position *in situ* in Fig. 2b.

The laser tilt sensor for continuous recording of the behaviour of structures is composed of the light transmitter section, glass cell containing the liquid and signal detection circuit cooperating with the amplifier, signal transmission, power supply and data acquisition systems. The transmitter assembly, cell and detection circuit are firmly fastened to the analysed object through levelling head and base. The transmitter assembly is made with the use either of a diode laser or LED provided with the light collimating system. All are contained in one casing.

a) b)

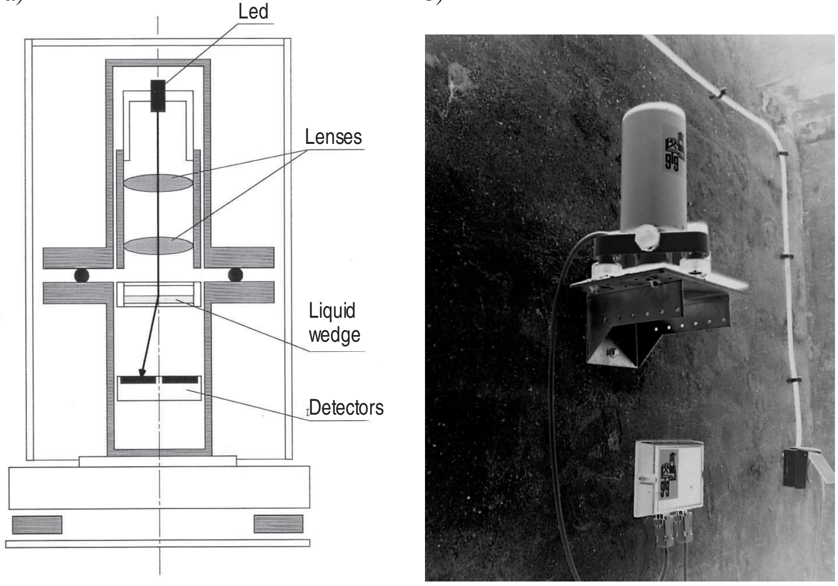

Fig. 2. Schematic of laser sensor with liquid wedge (a) and the laser sensor at measuring position *in situ* (b)

Rys. 2. Schemat czujnika laserowego z klinem cieczowym (a) oraz czujnik laserowy na stanowisku pomiarowym *in situ* (b)

The beam detection unit contains a quadrant detector attached to a separate holder and positioned at a specified distance under the cell. The cell contains the liquid with precisely known both the index of refraction and decrement of vibration damping.

The measurement parameters and technical characteristics of the sensor can be collected as follows:

- measurement range $\pm$ 5 mm (with the possibility to be adjusted from 2 to 50 mm/m),
- resolution $\pm$ 0.02 mm/m,

- vibration frequency to be measured < 10 Hz,
- power consumption < 2 W,
- galvanic separation between the transmitter and receiver circuits (only in the intrinsically-safe version of the device) – 4.5 kV,
- autonomous transmitting-supplying line (intrinsically-safe version) – L < 1500 m,
- weight of the measurement-transmission assembly – 2 kg (intrinsically-safe version – 10 kg).

As it has been already mentioned above, that the sensor is being made in two versions: normal and intrinsically-safe.

In the normal version, the system is composed of the laser tilt sensor, measuring amplifier and analog or digital recorder.

In the methane explosion-hazard zones, the intrinsically-safe version of the instrument is used (approved by Polish High Mines Inspectorate, № GX-179/97).

The sensor elements are contained in dust-and-waterproof casing (type IP54).

2.2. Measurement method and examples of recording of the effects at building structures in the Upper Silesia Coal Basin

The structures (objects) located in mining-influenced zones are liable to various deformations differing in their kind and size. The deflection from the vertical direction, when kept within the limits defined by the standards, is a condition of their safe operation. This deflection can proceed gradually or to be of periodical and dynamic character. Uneven subsidence, shock and vibration can result from other causes, apart from mining operations. These are, as an example: hydro-geological, climate and road traffic.

For many endangered objects and engineering structures, continuous measurements are required with the use of continuous recording of amplitudes and directions of the changes.

The measurement results, in a form of a graphic printout provide a full pattern of the changes both in terms of the deflection values and their directions, and the time of their occurrence (Fig. 3). The operation principle is based on determining the deflection of the laser beam from its initial vertical position after it has passed through the liquid wedge. There are no movable parts in the instrument.

The layer of the liquid is an absolute reference system in the measurements. The displacement of the beam spot on the photodetector is a function of the inclination angle assumed by the liquid level when the instrument (i.e. the controlled structure) is tilted, and index of refraction of the liquid.

The electrical signal is, in turn, a function of the illuminated quadrant segments of the detector. After being amplified, it is fed into a PC through A/D card for processing.

An analysis of the measurement data obtained by using the sensor system will allow the following:

- identification of factors influencing the stability of the object,
- decision-taking about applying building protection measures or others.

a) b) c)

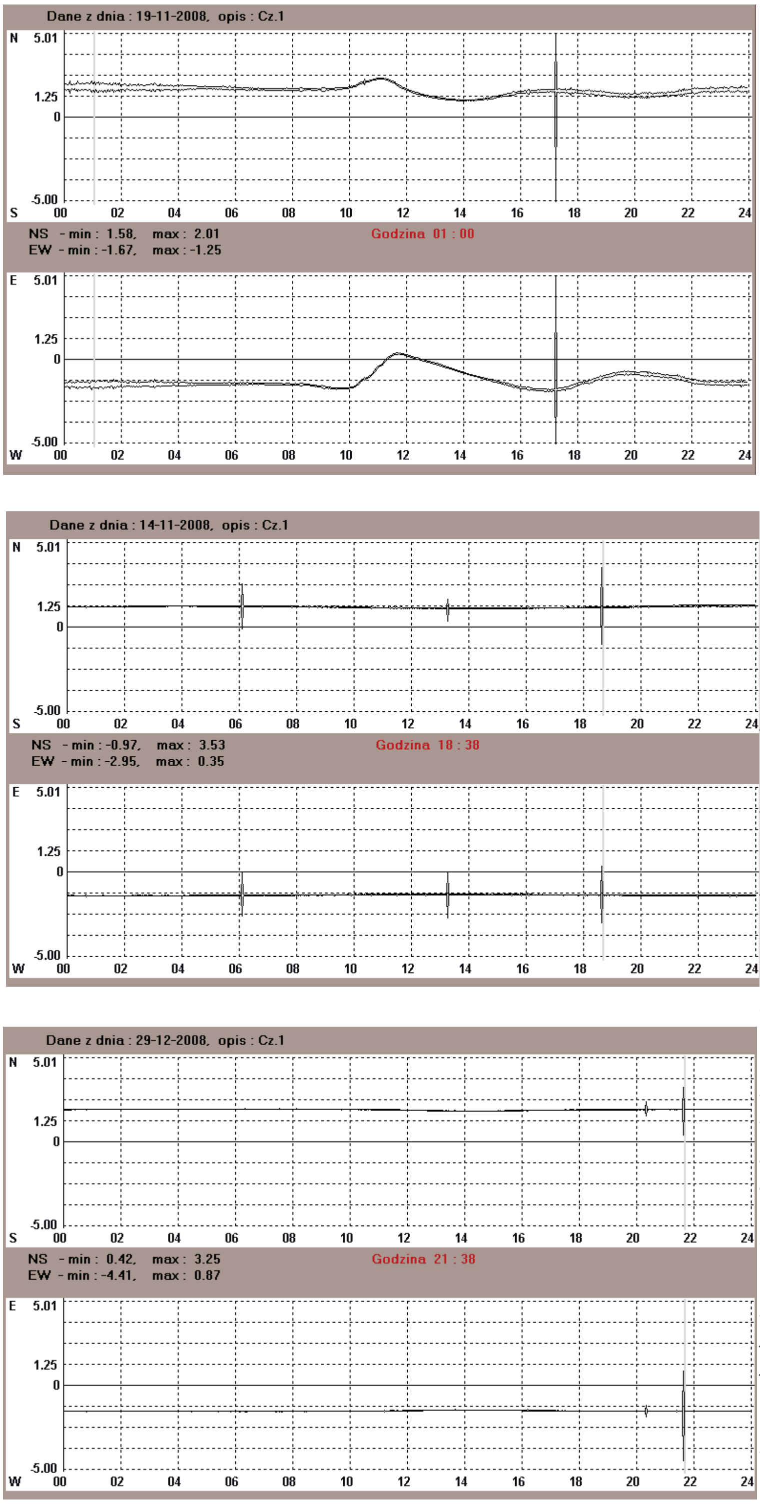

Fig. 3. Examples of changes of tilts: a – strong twenty four-hour changes of church tower tilt affected by varying weather conditions and strong changes being an effect of underground tremor, b – minor twenty four-hour changes of tilt superimposed by strong changes caused by 3 underground tremors, c – one stronger with a weaker precursor

Rys. 3. Przykłady zmian wychyleń: a – silne dobowe zmiany wychyleń wieży kościoła, na które nałożyły się zmienne warunki atmosferyczne oraz silne zmiany wywołane wstrząsem podziemnym, b – dobowe niewielkie zmiany wychyleń, na które nałożyły się silne zmiany wywołane 3 wstrząsami podziemnymi o zbliżonej amplitudzie, c – jedno silniejsze wychylenie poprzedzone słabym prekursorem

The examples presented in Fig. 3 demonstrate applications of the laser tilt and vibration sensor located in monumental structures in the mining-influenced areas, namely the medieval castle of Będzin (14-th century) and church (19-th century) in the town of Rydułtowy, both Upper Silesia region, south Poland. The first one is influenced mainly by post-mining occurrences, the other by currently conducted mining, right under the structure. The subsequent figures demonstrate various effects observed at the church.

Figure 3a presents strong twenty four- hour changes of church tower tilt affected by varying weather conditions, and with superimposed very strong momentary change of tilt caused by an underground rockburst. Figure 3b shows minor twenty four hour changes of tilt superimposed by three minor momentary changes of tilt caused by underground rockbursts. Figure 3c presents twenty four hour changes of tilt superimposed by one stronger momentary change of tilt caused by underground rockburst, preceded by a weaker precursor (c). In this picture, they are also accompanied by wind effects, especially manifesting themselves during the night time.

Weather conditions, especially temperature differences (e.g. produced by illumination of one part of the structure) can cause remarkable changes of the tilt. Such an example is also presented in Fig. 3a, presenting the effect of the sun beginning at 10 am.

One of the conclusions which can be drawn on the basis of the above discussed examples is the necessity to have reliable information about the vibrational reaction of the monitored object as a whole. Therefore, the next step is to apply a method of modal analysis to give effective assessments of the conditions of the construction structure under consideration.

3. MEASUREMENTS WITH THE USE OF SCANNING LASER VIBROMETER SYSTEM

Occasionally, additional measurements are being made using a POLYTEC PSV-400 scanning laser vibrometer (Fig. 4). Associated with the LTVMS system, it enables to obtain data for an effective assessments of the conditions of the construction structure under consideration.

CONCLUSIONS

On the basis of the above presented material, the following conclucions can be drawn:

1. Current underground mining and post-mining activities manifest themselves as various effects on the structures located on the surface.
2. The authors routinely conduct measurements of low-frequency vibration and tilt of the structures located on mining-influenced areas such as dwelling houses, industrial objects and others, including in particular monumental structures. In parallel, acoustic parameters are measured in these locations.
3. Both short-duration (“shocks”) and long-term phenomena are typically observed. The measuring information obtained in such locations with the use of the CMI-

developed laser tilt sensor forces the necessity to supplement these data with a method enabling to examine the vibrations of the structure as a whole. Laser vibrometry has been choosen as this supplementary method. The extended information provides the basis to apply effective protection measures.

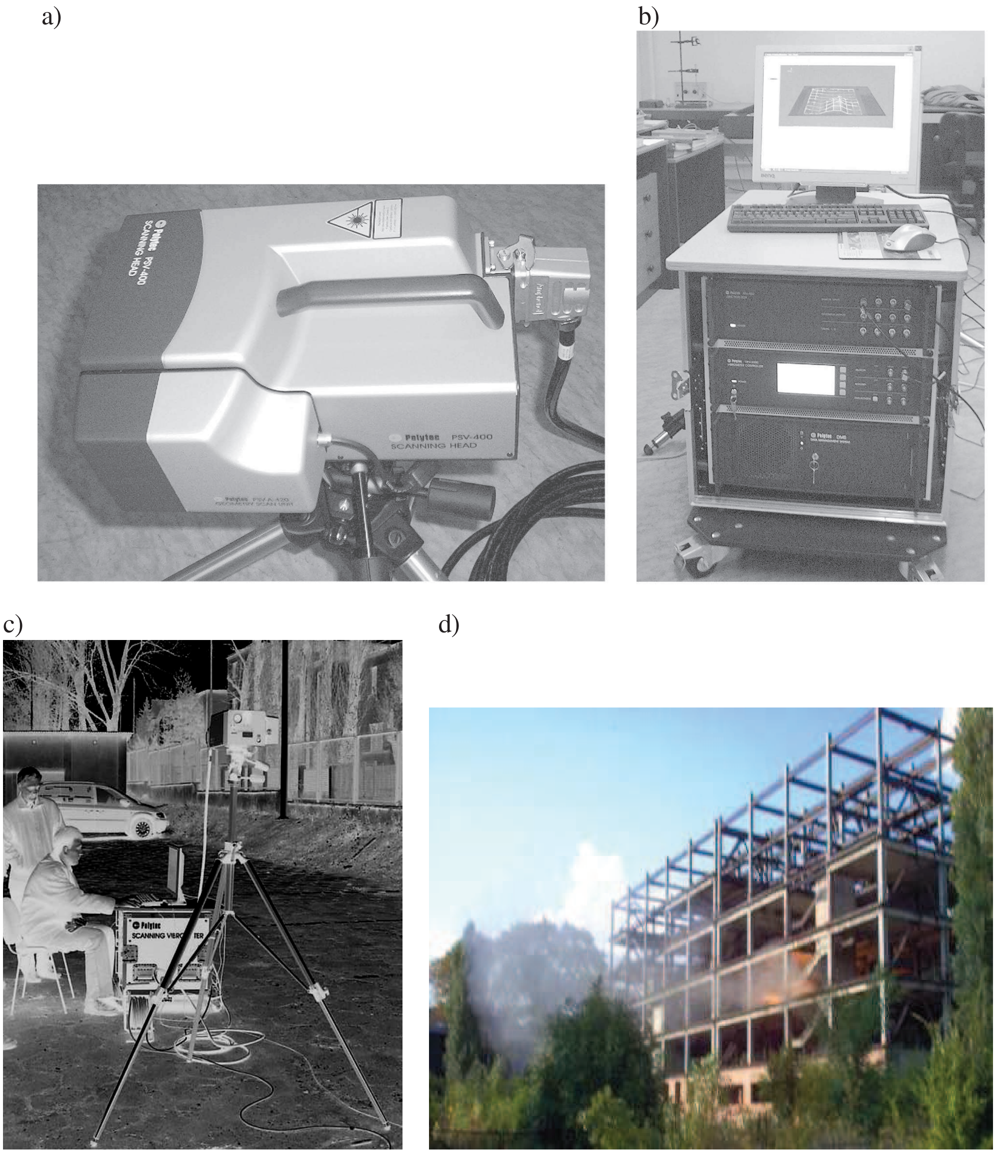

Fig. 4. POLYTEC PSV-400 scanning laser vibrometer in the laboratory – laser scanning head (a) and controlling and data analysing system (b). The same measuring set located against a building structure (c) whose vibrations were forced with the use of rocket engines (d)

Rys. 4. Laserowy wibrometr skaningowy POLYTEC PSV-400 w laboratorium – laserowa głowica skanująca (a) oraz system sterowania i analizy danych (b). Ten sam zestaw pomiarowy rozmieszczony naprzeciw badanej struktury budowlanej (c), której drgania wymuszane były z wykorzystaniem silników rakietowych (d)

4. The effectiveness of the assumed protection measures should be again analysed by long-term measurements using laser tilt sensors.
5. The presented methodology and instrumentation can be directly transferred to measurements of the structures subjected to effects generated by other similar causes, like seismic ones.

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