40. MEZINÁRODNÍ KONFERENCE EXPERIMENTÁLNÍ ANALÝZY NAPĚTÍ
40th INTERNATIONAL CONFERENCE EXPERIMENTAL STRESS ANALYSIS
3. – 6. VI. 2002, PRAHA/PRAGUE, CZECH REPUBLIC

# VIBRATION MEASUREMENT OF HIGHWAY BRIDGES
# MERANIE VIBRACIÍ MOSTOV NA POZEMNÝCH KOMUNIKÁCIÁCH

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*Abstract: The bridge structures are subjected during the service life to the effect of moving load and time variable load with variable frequency composition. The response of bridge structures on the effect of such load is conditioned not only by the character of the load but by the dynamical properties of the structure, too. The analysis of dynamical properties of a structure, that characterize its dynamical individuality, is an integral part of the complex dynamical analysis of the structure. The diagnostic of dynamic properties is in fact the combination of analytical, numerical and experimental procedures. This contribution is dedicated to the methodology of experimental investigation of bridge response on the effects of paraseismic excitation due to traffic and to the possibility to use the obtained results for diagnostic of dynamic characteristics of a bridge. The level of vibrations under various kinds of traffic and transfer characteristics are followed.*

**Key words**: experimental measurement, bridge structure, moving load, natural frequencies, dynamical analysis

## 1. Introduction

Natural frequencies, natural modes, frequency response functions pictured as amplitude – frequency or phase – frequency characteristics and damping are the basic dynamic characteristics of every dynamic system. These characteristics exactly define the dynamic individuality of the system and determine how the system will react under various dynamic excitation. Identification of these characteristics is a combination of analytical, numerical and experimental procedures. Some characteristics can be obtained also numerically (natural frequencies, natural modes, frequency response functions) another only by experimental way (damping). From the today's point of view the so called "modal analysis" is much more effective method [1], [2]. The application of this method requests adequate experimental equipment. Partial information can be obtained also by simpler method. For example natural frequencies and amplitude – frequency characteristics can be obtained from the analysis of the structure response on the stochastic excitation that represents the widely spectral random process.

## 2. Basic theoretical assumptions

Frequency response function $H(i\omega)$ is a complex function and can be written as a vector sum of real part $R(\omega)$ and imaginary part $I(\omega)$

$$H(i\omega) = R(\omega) + i.I(\omega)\,, \tag{1}$$

or

$$H(i\omega) = \left|H(i\omega)\right|.e^{i\varphi}\,, \tag{2}$$

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where $|H(i\omega)|$ is absolute value or magnitude of frequency response function and represents the amplitude of response of the system excited with simple harmonic function. In equation (2) $\varphi$ represents phase shift of frequency function, that is phase of response $r(t)$. Equation for $r(t)$, with respect to equation (2), can be expressed as

$$r(t) = |H(i\omega)|.e^{i\varphi}.e^{i\omega t} = |H(i\omega)|.e^{i(\omega t+\varphi)}. \tag{3}$$

Frequency spectrum of output signal can be obtained by multiplying the frequency response function times frequency spectrum of input signal

$$R(i\omega) = H(i\omega) . F(i\omega) . \tag{4}$$

Introduction of power spectral density functions of input signal $S_F(\omega)$ and output signal $S_r(\omega)$ enable to write this dependence in the form

$$S_r(\omega) = |H(i\omega)|^2 .S_F(\omega) , \tag{5}$$

where $|H(i\omega)|^2$ can be defined as a power response factor [3]. Mechanical system selects from the power spectral density of load by the power response factor only frequencies close to natural frequencies of the system and reaction is mainly on these frequencies (natural filtration of the system).

## 3. Experimental technique

For the measurements of vibration intensity due to transport the measuring line by the *Fig. 1* is usually used on the Department of Structural Mechanics University of Žilina.

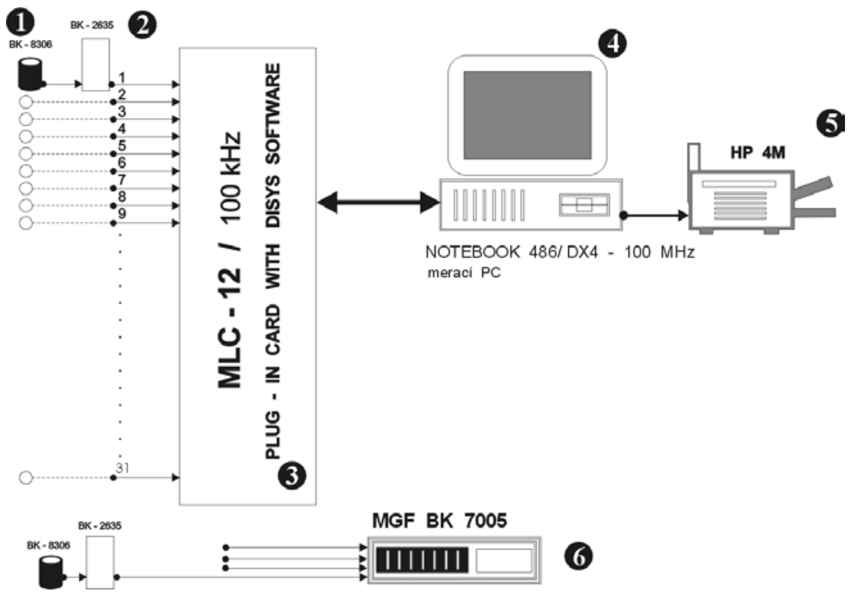


*Fig. 1 Measuring line*

For the registration of vibration the accelerometers of Brűer-Kjaer BK 8306 are usually use. Electrical signal is amplified by the charge amplifier of the type BK 2635. The charge amplifier works as the low pass filter too. Than the signal is lied on the tape recorder BK 7005 or via analogue – digital interface to a computer. All the analysis is than carried out by the computer. For the analysis of the measured data the computer program DISYS or DAS 16 are usually used. The results of calculation can be printed by printer or plotted by the plotter.

## 4. Experimental measurement and its analysis

This paper presents some results of bridge vibration induced due to road traffic passing along the street under the bridge. The bridge construction is proposed as the four-span reinforced concrete structure. The lengths of spans are 24,00 + 2 x 32,00 + 24,00 m. The cross section is box with variable thickness of walls and plates. The concrete B 40 as the material is used.

The acceleration of motion in vertical and horizontal direction was investigated in selected points of the structure. The first point was situated on the border of pavement under the bridge. The second point was situated up on the bridge pavement above the column number 3 and the third was situated in the middle of the third bridge span, *Fig. 2*. The horizontal accelerometers were situated perpendicularly on the longitudinal axis of the bridge.

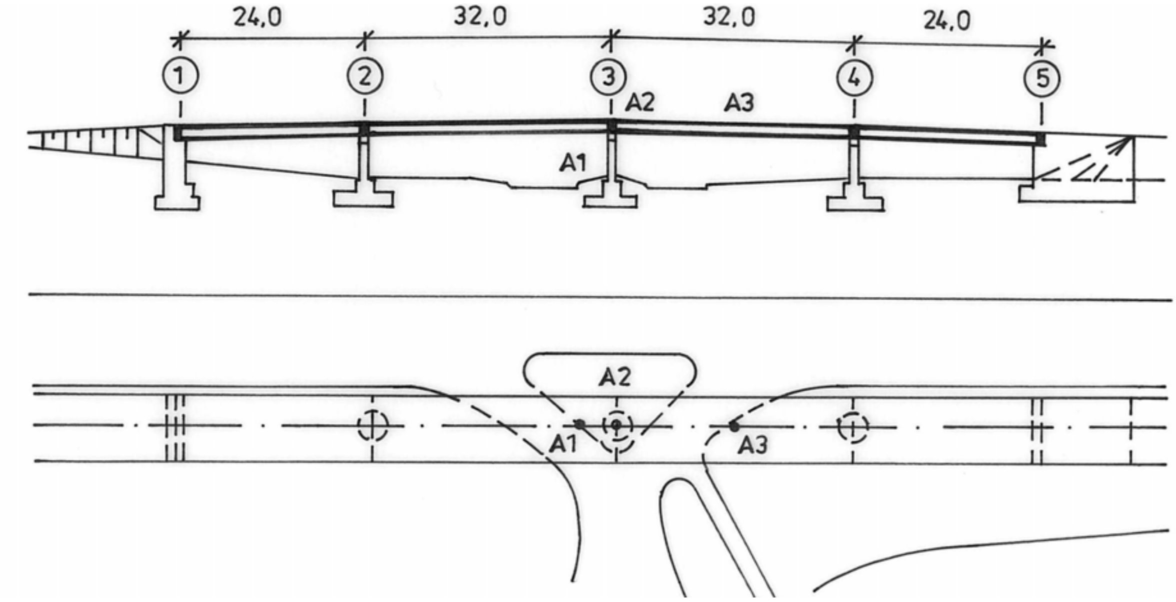


*Fig. 2 Disposal drawing*

The values of accelerations in selected points induced by various transport means are in *Tab. 1* and *Tab. 2*.

*Tab. 1 Accelerations in selected points, vertical direction*

| Means of transport | Vertical accelerations in [m.s$^{-2}$] | | |
|---|---|---|---|
| | AY1 | AY2 | AY3 |
| cars | 0,01434 | 0,00558 | 0,02678 |
| light lorries | 0,04468 | 0,01536 | 0,05192 |
| buses | 0,04379 | 0,01548 | 0,07045 |
| heavy trucks | 0,07033 | 0,01511 | 0,03186 |

*Tab. 2 Accelerations in selected points, horizontal direction*

| Means of transport | Horizontal accelerations in [m.s$^{-2}$] | | |
|---|---|---|---|
| | AX1 | AX2 | AX3 |
| cars | 0,03771 | 0,00952 | 0,00812 |
| light lorries | 0,06004 | 0,01015 | 0,01066 |
| buses | 0,05966 | 0,01421 | 0,01523 |
| heavy trucks | 0,01823 | 0,00672 | 0,01231 |

Power spectral density functions (PSD) of accelerations can be obtained by the numerical analysis of vibration records. From the power spectral density functions the transfer functions (power response factors $|H|^2$) between individual measure points are derived. Peaks of these functions are found at frequencies corresponding to natural frequencies. PSD of vertical accelerations in the points 1, 3 are pictured in the *Fig. 3*. Power response factor $|H|^2$ between points 1, 2 and 1, 3 are in the *Fig. 4*. Similar results for horizontal direction of vibration are plotted in the *Fig. 5* and *6*.

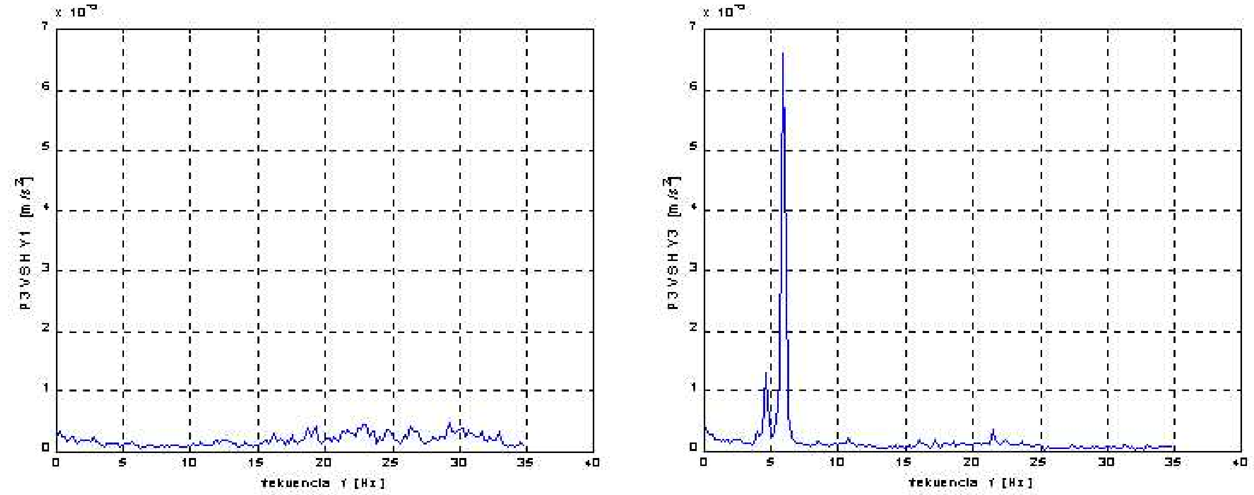

*Fig. 3 Power spectral densities of vertical acceleration in the points 1 and 3*

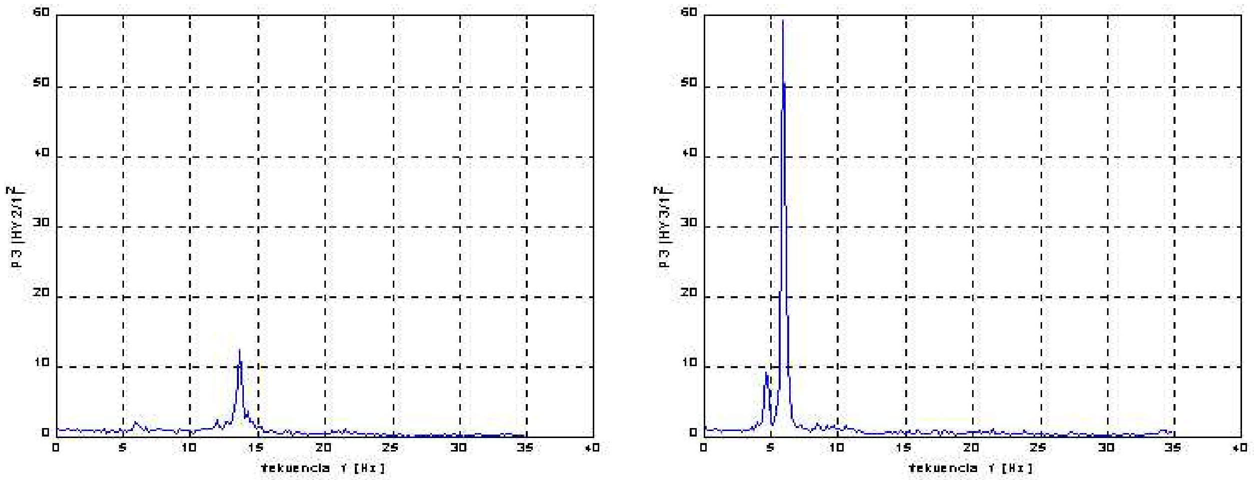

*Fig. 4 Power response factor $|H|^2$ between points 1, 2 and 1, 3 in vertical direction*

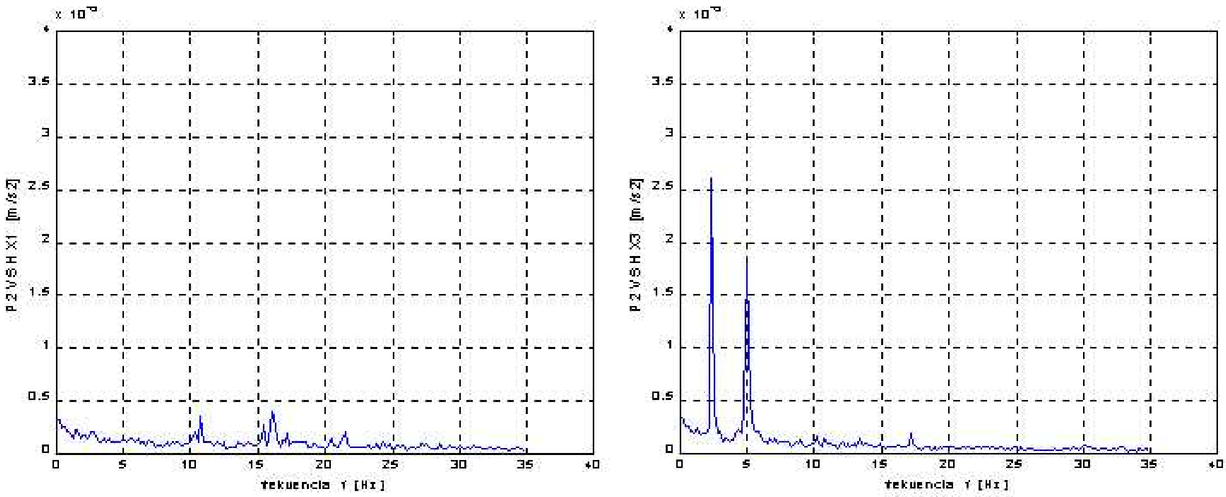

*Fig. 5 Power spectral densities of horizontal acceleration in the points 1 and 3*

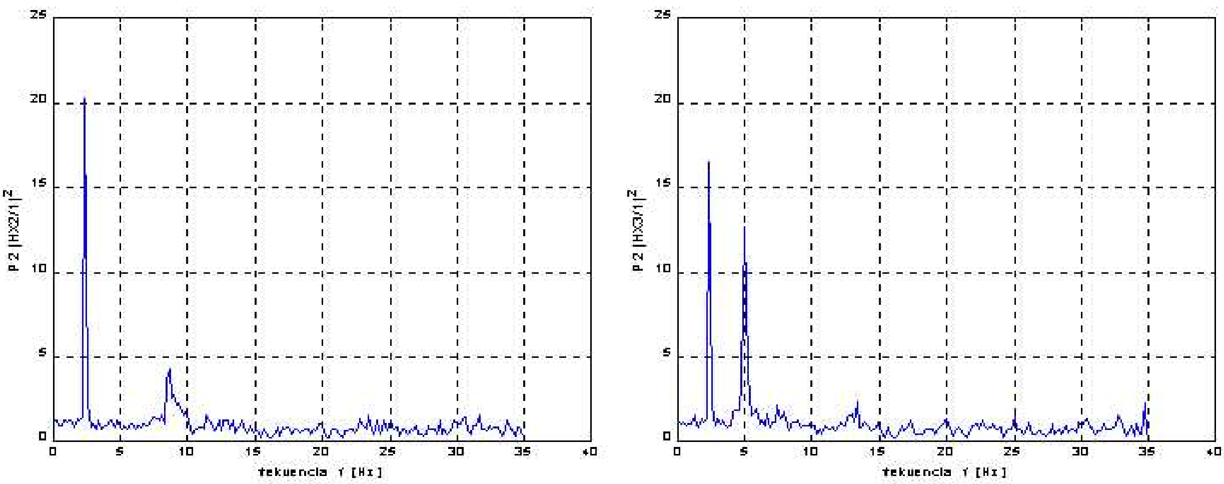

*Fig. 6 Power response factor* $|H|^2$ *between points 1, 2 and 1, 3 in horizontal direction*

## Conclusions

The questions of natural earthquake are in the Slovak republic analysed by many authors [4], [5], [6], [7], [8]. Less attention is dedicated to the analysis of paraseismic problems due to traffic, especially to the experimental investigation of vibration intensity of structures. Various transport means induce various intensity of acceleration on the pavement under the bridge and on the pavement on the bridge, as we can see from the *Tab. 1* and *2*. The lowest values of vertical accelerations were induced on the pavement under the bridge by passing cars and the highest ones by passing heavy trucks. In opposite heavy trucks induced the lowest values of horizontal accelerations and light lorries and buses induced the highest ones. Cars induced the lowest accelerations and buses induced the highest accelerations on the bridge pavement in horizontal and vertical direction. Buses induced even higher values of acceleration then heavy trucks in both directions.

Response of the pavement under the bridge and response of the bridge structure depend on the mechanical properties of subsoil and mechanical properties of bridge structure. Mechanical properties of bridge structure are very well defined by natural frequencies, natural modes and by frequency response functions. They define the dynamical individuality of the system. The image about frequency composition of vibration is very well described by the power spectral density functions. They described not only frequency composition of vibration but the distribution of the whole dispersion too. The bridge responds markedly on such frequency compositions of load, which correspond to its natural frequencies, even in such case if these frequency compositions of load have very low power. In opposite the response of the bridge on the frequency compositions of load with high power is small if the frequencies of load do not correspond to natural frequencies of the bridge. Some demonstrations of results are on the *Fig. 3 - 4*.

The results of experimental measurements confirm very well the results of numerical analysis as we can see from the *Tab. 3* where we compare the numerically and experimentally obtained values of natural frequencies.

*Tab. 3 Comparison of calculated end experimentally obtained natural frequencies*

| Vertical bending vibration | | | Horizontal bending vibration | | |
|---|---|---|---|---|---|
| *j* | computation | experiment | *j* | computation | experiment |
| 2 | 4,396 | 4,492 | 1 | 2,,425 | 2,344 |
| 4 | 6,057 | 6,055 | 3 | 4,526 | 4,883 |
| 6 | 8,321 | - | 7 | 8,929 | 8,594 |
| 8 | 9,193 | - | 9 | 15,241 | - |

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