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ANALYSIS OF DYNAMIC RESPONSE OF FOOTBRIDGE VEVEŘÍ ON PEDESTRIAN LOAD

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Abstract: *The paper deals with dynamic response of footbridge Veveří which is induced by the movement of people. Measurement of response induced by the movement of people was carried out on this footbridge. Graphs of acceleration in chosen points in time were results of measurement. The pedestrians who cross footbridge in specific numbers and in different types of walk were source of vibrations. On site measurements were compared with calculations of individual load states.*

Keywords: Footbridge, Dynamic analysis, Vibration serviceability of footbridges, Damping, stiffness, Dynamic force, Force model, Walking force, Natural frequencies and vibration modes.

1. Description of Measurement

The response of the bridge deck is recorded for walk of one, two, four, six and sixteen pedestrians. The pedestrians move either unorganized (free walk) or organized (synchronized walk).

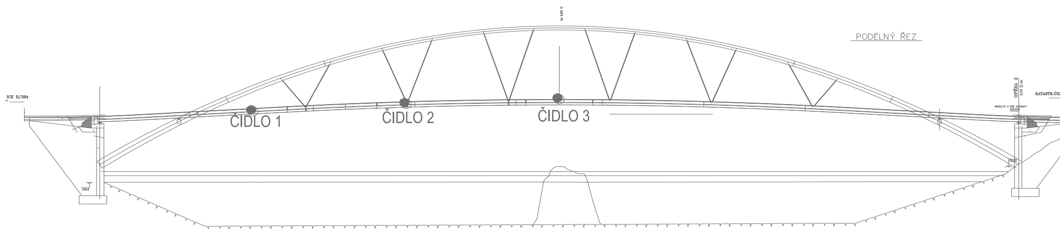

Fig. 1: Scheme of accelerometer placement on footbridge.

Two sets of measurement were carried out. Each set contained several load states. Main difference between sets is in positions of sensors (Kala et al., 2012a). The first set has placing of sensors on three places of bridge deck. The acceleration in vertical direction was recorded.

2. Introduction and Aims

Large attention was devoted to computations of dynamic response of footbridge in recent years. The response is assessed in terms of vibration influence on structure but also and above in terms of influence on pedestrian. Recent experiences showed necessity to check response of structure on a pedestrian walk comfort. Acceleration and size of oscillation are assessed. If these variables are exceeded, a certain degree of discomfort is felt by pedestrian. In worst case it can come to disabling of walk. The goal of paper was verify conformity computations of dynamic response with measurement in-site. Size of the conformity is a key to assess dynamic response in terms of pedestrian comfort. Measurement in-site, which serves to calibrate computational model, was available in this case. These details are not available in construction time. Executed conformity of results of numerical analysis with measurement can show which parameters of structure and calculation are the most important to reach exact results.

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Tab. 1: Load states for the first set of measurement.

Set of measurement 1								
N. Measurement	**N.of person**	**Type of movement**	Transition time	Speed	Stride lenght	frequency	Stride lenght	frequency
			[s]	[m.s-2]	[m]	[Hz]	[m]	[Hz]
1	2	fast walk	62	1.616	0.8	2.020	0.840	1.924
2	2	synchronized brisk walking	60	1.670	0.8	2.088	0.706	2.365
3	6	normal walk	84	1.193	0.8	1.491	0.723	1.650
4	6	synchronized walk with stomping	68	1.474	0.8	1.842	0.719	2.050
5	16	normal walk	91	1.101	0.8	1.376	0.605	1.820
6	16	synchronized walk	72	1.392	0.8	1.740	0.631	2.207

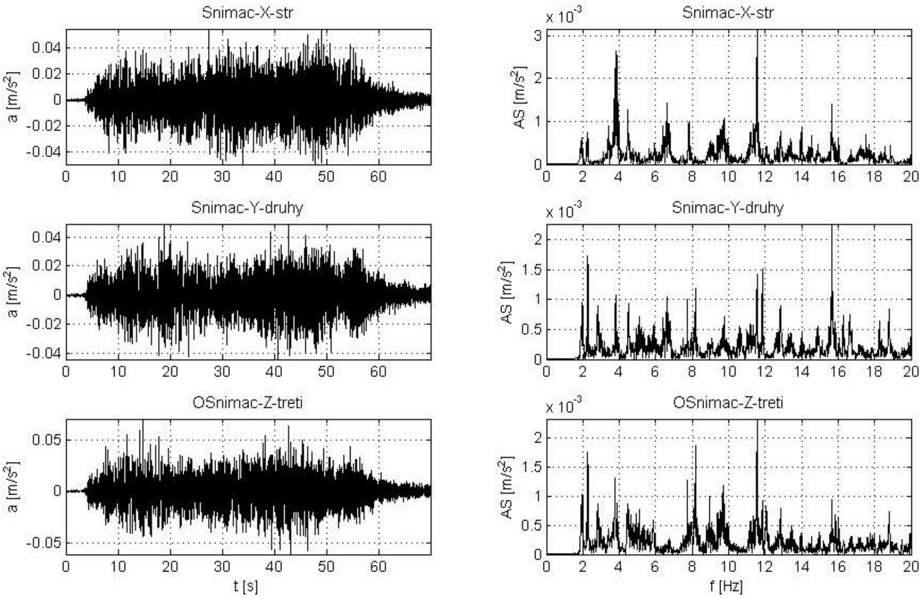
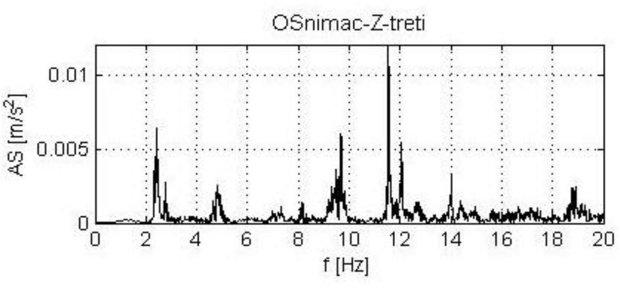


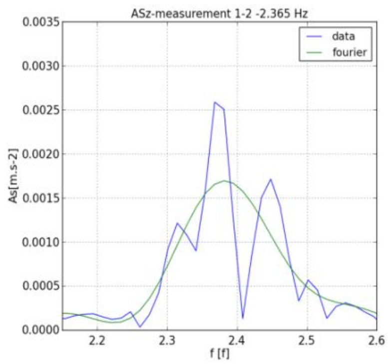
Fig. 2: Record of dynamical response of footbridge – measurement 1-1, left side describes acceleration in time, right side describes frequencies.

Tabs. 1 and 2 show list of measured cases dynamical response of footbridge. Two details for step frequency are in the table. Each is related to different length of step. First value step frequency is calculated on the base length of step 0.8 m.

It is given by equation, v = 0.8xf [m.s^{-2}]. Length of step is determined by measurement for normal walk. The second value was calculated for specific case of measurement. Walk velocity was determined from graph of acceleration. This graph shows also time to pass over the footbridge. Frequency was determined from frequency representation of record measurement. This is the first peak in the graph.



a)



b)

Fig. 3: a) Record of dynamical response – measurement 1-2, frequency zone;
b) Detail with step frequency.

Tab. 2: Load states for the second set of measurement.

Set of measurement 2									
N. Measurement	**N.of person**	**Type of movement**	Transition time	Speed	Stride lenght	frequency	Stride lenght	frequency
			[s]	[m.s-2]	[m]	[Hz]	[m]	[Hz]
1	2	fast walk	66	1.518	0.8	1.898	0.787	1.930
2	2	synchronized brisk walking	53	1.891	0.9	2.101	0.834	2.268
3	1	normal walk	34	2.947	1	2.947	1.053	2.800
4	1	running	27	3.711	1	3.711	1.088	3.410
5	4	normal walk	41.7	2.403	0.9	2.670	0.910	2.640
6	4	running	27	3.711	1	3.711	1.108	3.350
7	6	normal walk	77.7	1.290	0.8	1.612	0.713	1.808
8	6	synchronizovaná chůze	72	1.392	0.8	1.740	0.710	1.961
9	16	normal walk	85.8	1.167	0.8	1.459	0.686	1.701
10	16	synchronized walk	80	1.253	0.9	1.392	0.653	1.917
11	7	lateral excitation - vandalism	40					2.140
12	16	lateral excitation - vandalism	30					1.760

Modal analysis was performed to description behaviour of structure in dynamical load. Lower stiffness is evident in horizontal direction upright to longitudinal axis of footbridge. Mode shapes and corresponding eigen frequency are shown on Fig. 4. This result is given by configuration of structure support system (Kala et al., 2012b). The bridge deck is suspended by ropes to arcs which have large stiffness in vertical direction.

Damping, which is caused by dispersion of mechanical energy, was considered uniform and constant damping. Damping model for numerical analysis was modeled by Rayleigh damping. Damping value was determined from the damping ratio $\xi = 0.007$.

Tab. 3: Load states for the second set of measurement.

Modal structure charakteristic		
No.	Frequency	Shape description
1	1.321	Lateral
2	1.68	Lateral
4	2.764	Vertical
6	4.044	Vertical

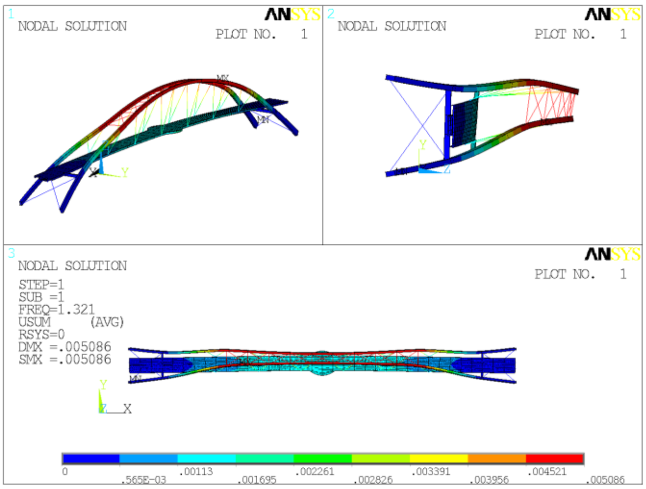


Fig. 4: Mode shape of structure with frequency 1.321 Hz.

3. Evaluation of Dynamical Response – Numerical Analysis Result

Process of response in graph on the left side shows acceleration in chosen point for given direction. Longitudinal direction is marked as “x”, transverse “y” and vertical “z”. Corresponding step frequency and step length are marked on the top of graph.

Dependence acceleration in time is on the left side, Fourier transformation to frequency zone is on the right side.

Process of response which is from the first measurement set is only for vertical direction.

Numerical analysis is in appropriate conformity with measurement. Large result difference which is in the middle time response can be ascribed to method of computation. Although the model is taking into account flexible supports, the bridge deck is softening (Kala et al., 2012c). Regardless it is not possible to completely eliminate large amplitude, when the pedestrians (represented by the forces) cross the chosen point.

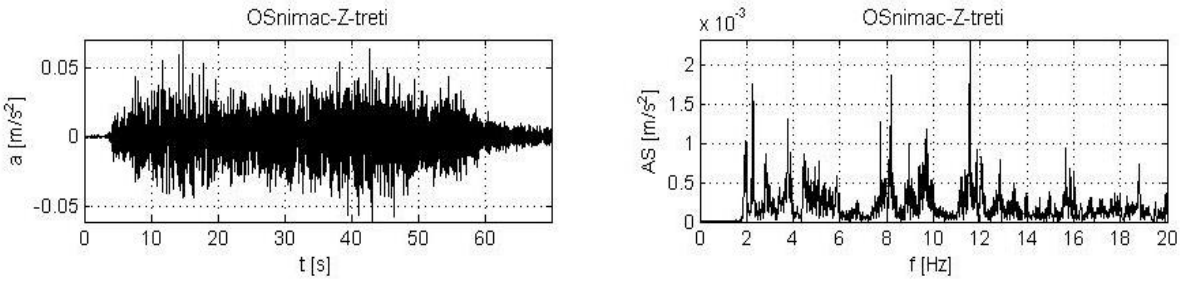


Fig. 5: Measurement record 1-1, walk, direction „z“.

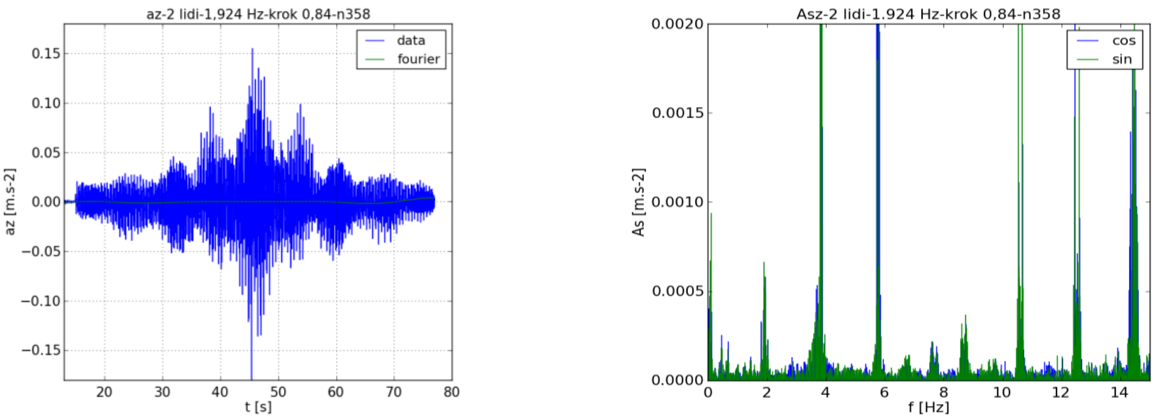


Fig. 6: Walk 2 pedestrians, f = 1.924 Hz, step 0.84 - direction "z".

The graph, which shows transformation of result in time dependency to frequency zone, confirms correctness step frequency. Step frequency is 1.924 Hz for this case. Conformity of values is especially in frequency 1.924 Hz and further in frequency 3.84 Hz. This fact is confirmed by the most significant part of the first two members Fourier series for step force.

4. Conclusion

The paper presents measurement of dynamical response of bridge structure and comparison with results of numerical analysis. Result differences between measurement and computation are given by the damping model. Presented comparison measurement and computation demonstrates appropriate conformity of results. This fact proves good prediction of behavior of structure loaded by the movement of pedestrians.

Acknowledgement

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