DYNAMICAL INVESTIGATION OF A FOOTBRIDGE IN WRONKI NEAR POZNAŃ

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SUMMARY

The objective of this paper is to present results of dynamical tests of a footbridge in Wronki near Poznań in Poland and clearly summarize them. The investigated footbridge, with asymmetrical arch and the main span 90.0 m long, is an example of original architecture and interesting structural solutions.

A lot of dynamic tests were performed. The research schedule included normal live loads and vandal actions to the footbridge. Normal live loads tests examined the influence of various kinds of the pedestrian activity on the footbridge's behaviour as: walking, jogging or fast running. Vandal type of excitation consisted of synchronized walking or running and rhythmical half-crouching. The main aim of the vandal live loads was to check structure's safety and behaviour in the extreme dynamic conditions.

Keywords: *Arch Footbridge, Dynamical Behaviour, Tests.*

1. INTRODUCTION

Statical and dynamical proof load tests of the footbridge in Wronki near Poznań were carried out in 2014 [1]. The footbridge with asymmetrical arch and the main span 90.0 m long constitutes an interesting example of a design solution [2], which might be a landmark of one of the biggest cities in Poland. Characteristic of the investigated structure, a range and results of the dynamical tests are described in this paper.

2. CHARACTERISTIC OF THE INVESTIGATED FOOTBRIDGE

The footbridge was designed as consisted of two structural parts. The first one, located over the main current of the Warta River, is the arch structure (Fig. 1). The deck is made of an orthotropic plate with steel cantilevers and a box main girder, which is a tie-beam of the arch. The deck is connected to the asymmetrically inclined arch with plate girder hangers and steel rods. In side spans of this part of the structure, the deck is a reinforced concrete slab supported on steel cantilevers.

Fig. 1. *View of the structure over the main current of the Warta River.*

The second part of the footbridge (Fig. 2) is situated over inundation area of the river and is constructed as a beam structure, made of steel I-bar beams, braced by cross-beams. In a connection place of both parts of the footbridge the deck is widened. The idea of this solution was to create an observation deck.

Fig. 2. *View of the structure over the inundation area of the Warta River.*

The total length of the footbridge is 206.40 m. The spans in the first part (arch part) are 2.75 + 22.70 + 90.00 + 20.22 m long, whereas in the second one (beam part): 18.44 + 25.20 + 19.30 m. The width of the footbridge is equal to 3.00 m. Structural steel type S355, structural concrete C40/50 and reinforcement steel BSt500S/B500Sp was used.

The decks of both parts are connected with a hinge. Due to this fact and also different static schemes (arch over the main current of the Warta River and multi-span beam over the inundation area of the river), in dynamical investigations both parts of the structure are treated independently. The tests results of the arch part of the structure are presented in this paper.

3. RANGE OF DYNAMICAL INVESTIGATION

Dynamical proof load tests were carried out after statical investigation of the structure. Forty pedestrians took part in dynamical tests. According to the proof load test project [3] 6 schemes of vibrations excitations were implemented:

Scheme D1 – identification of natural frequencies of the structure;

Scheme D2 – walking of a group of pedestrians;

Scheme D3 – synchronic walking of a group of pedestrians with a step frequency 1.9 Hz (path rate was controlled by using of a metronome);

Scheme D4 – synchronic walking of a group of pedestrians with a step frequency compatible with natural frequencies of the footbridge;

Scheme D5 – running of a group of pedestrians;

Scheme D6 – synchronic half-crouching of a group of 10 pedestrians.

Accelerations of vibrations were measured in points PV1, PV2, PH1, PH2 and PH6, whereas in a point NA1w1 strain was measured (measurements points are presented in Fig. 3).

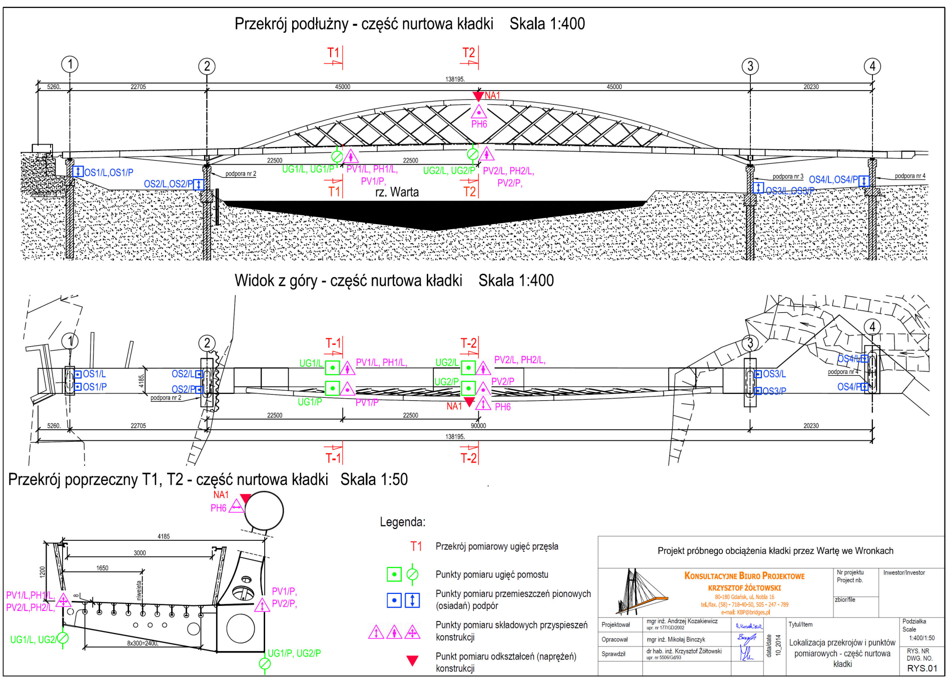


Fig. 3. Scheme of location of measurements devices (arch part of the structure) [3] – side view, top view and cross-section of the footbridge (PV – measurement of vertical vibrations, PH – measurement of horizontal vibrations, NA – measurement of strains).

Walking and running schemes were carried out in groups of 10, 20, 30 and 40 pedestrians, according to investigation procedures [4]. Examples of schemes are presented in Fig. 4.

Fig. 4. *Walking and running of a group of pedestrians with a free path rate.*

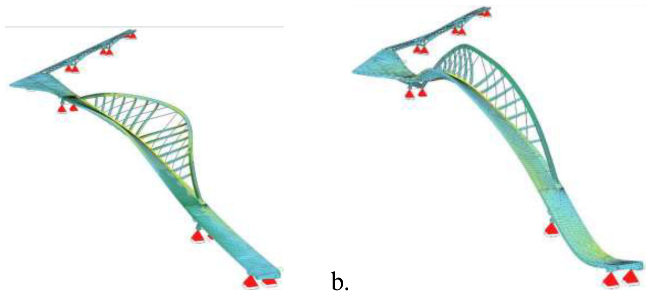
The main aim of dynamical investigations was to identify natural frequencies of the footbridge and compare them with results obtained from a computational model. Moreover, it was to register accelerations of the deck and compare them with recommended accelerations limits, as well as to register strain of the arch and evaluate safety of the structure in conditions of dynamical vibrations.

Accelerometers by HBM Hottinger Baldwin Messtechnik GmbH (type B12/200), with SPIDER8 amplifier and CATMAN program (version Express 4.5), as well as electric resistance wire strain gauges were used for the tests of the footbridge (Fig. 5).

Fig. 5. *Accelerometer B12/200 – measurement of vertical and horizontal accelerations of the deck (on the left) and measurement of horizontal accelerations of the arch (on the right).*

4. IDENTIFICATION OF VIBRATIONS FREQUENCIES

The first two determined in the proof load test project [3] modal shapes with calculated corresponding frequencies are presented in Fig. 6.



a. b.

Fig. 6. *Modal shapes of the deck in the arch part: a. the first modal shape (f = 1.57 Hz), b. the second modal shape (f = 2.13 Hz) [3].*

Experimentally identified frequencies are presented in Tab. 1. These frequencies were determined by analyzing vibrations signals registered in a scheme D1. The example of registered signal is presented in Fig. 7 in a time and frequency domain.

Table 1. *Calculated and identified frequencies of deck's vibrations.*

Frequency	Calculation	Investigation
f_1 [Hz]	1.57	1.56
f_2 [Hz]	2.13	2.41

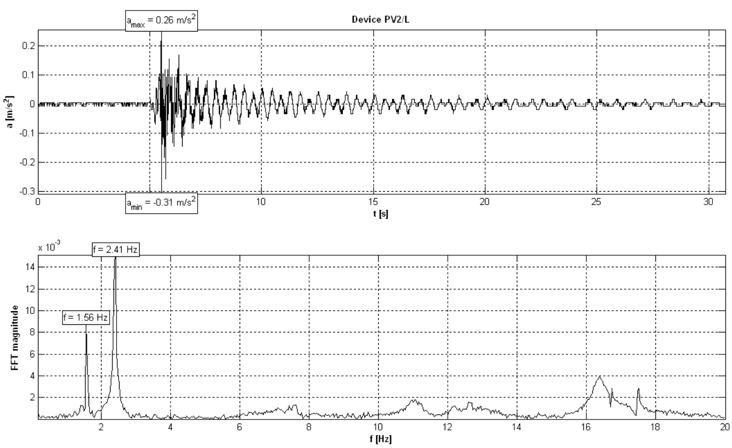


Fig. 7. *Identification of the 1st and the 2nd frequency of the footbridge (scheme D1).*

5. RESULTS OF DYNAMICAL TESTS

Extreme accelerations of vibrations and values of strains of the arch, which were registered during dynamical proof load tests, are presented in Tab. 2.

Table 2. *Accelerations and strains registered during dynamical tests.*

No.	Scheme	Description of a scheme	No. of pedestrians	Deck		Arch	
				a_V [m/s^2]	a_H^D [m/s^2]	a_H^A [m/s^2]	ε [10^{-6}]
1	D2	Walking	10	0.16	0.05	0.13	4.56
			20	0.25	0.08	0.16	8.64
			30	**0.34**	**0.12**	0.22	12.72
			40	0.32	0.11	**0.26**	**15.12**
2	D3	Synchronic walking (f = 1.9 Hz)	10	0.30	0.09	0.20	6.00
			20	0.31	0.11	0.26	11.76
			30	0.57	0.17	0.36	16.32
			40	**0.59**	**0.18**	**0.47**	**18.72**
3	D4	Synchronic walking (f = 1.56 Hz)	10	0.25	0.14	0.61	10.56
			20	0.40	0.19	0.94	17.28
			30	0.37	0.21	0.94	19.20
			40	**0.43**	**0.26**	**1.11**	**24.48**
4	D5	Running	10	0.60	0.20	0.30	8.40
			20	0.70	0.41	0.62	13.44
			30	**0.89**	**0.44**	0.62	**16.56**
			40	0.81	0.40	**0.67**	16.08
5	D4	Synchronic running (f = 2.41 Hz)	10	0.81	0.24	0.33	13.44
			20	1.10	0.37	0.51	16.08
			30	1.31	0.33	0.61	18.24
			40	**1.35**	**0.41**	**0.68**	**22.80**
6	D5	Sprint	10	0.57	0.21	0.32	7.20
			20	1.09	**0.40**	**0.83**	12.48
			30	**1.14**	0.33	0.82	**16.80**
			40	1.03	0.38	0.81	14.64
7	D6	Synchronic half-crouching (f_1)	10	**0.50**	**0.34**	**1.52**	**21.36**
8	D6	Synchronic half-crouching (f_2)	10	**1.28**	**0.41**	**0.58**	**20.40**

Notations used in Tab. 2:

a_V – maximum acceleration of vertical vibrations of the deck in the arch part of the structure, registered by devices PV1 and PV2,

a_H^D – maximum acceleration of horizontal vibrations of the deck in the arch part of the structure, registered by devices PH1 and PH2,

a_H^A – maximum acceleration of arch vibrations, registered by device PH6,

ε – maximum value of arch strains, registered by device NA1w1.

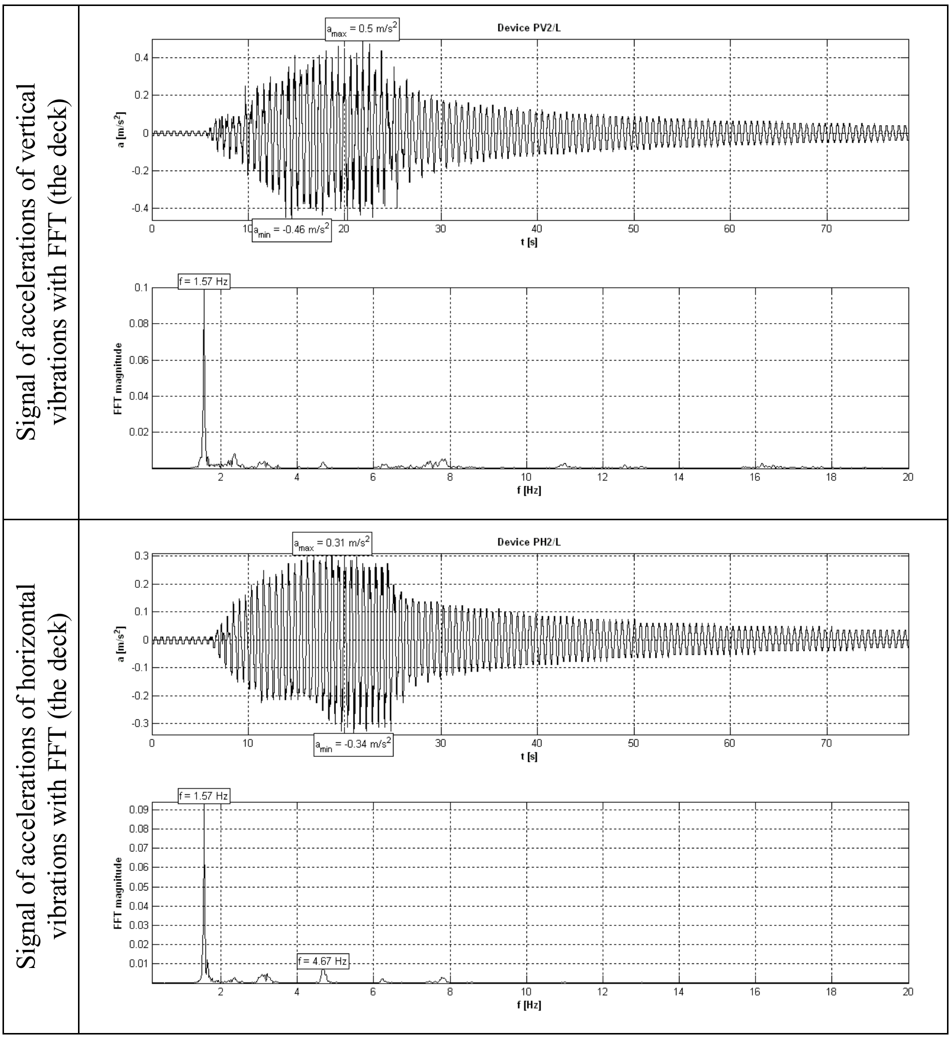


Fig. 8. *Inducing of vibrations by half-crouching with frequency f_1 (the deck).*

Examples of registered signals of the deck vibrations in vertical and horizontal directions in scheme D6 are presented in Fig. 8. Signal of the arch vibrations in a horizontal direction and signal of strain registered in the same scheme by strain gauge sensor (NA1w1) is presented in Fig. 9. Signals are presented in time and frequency domain.

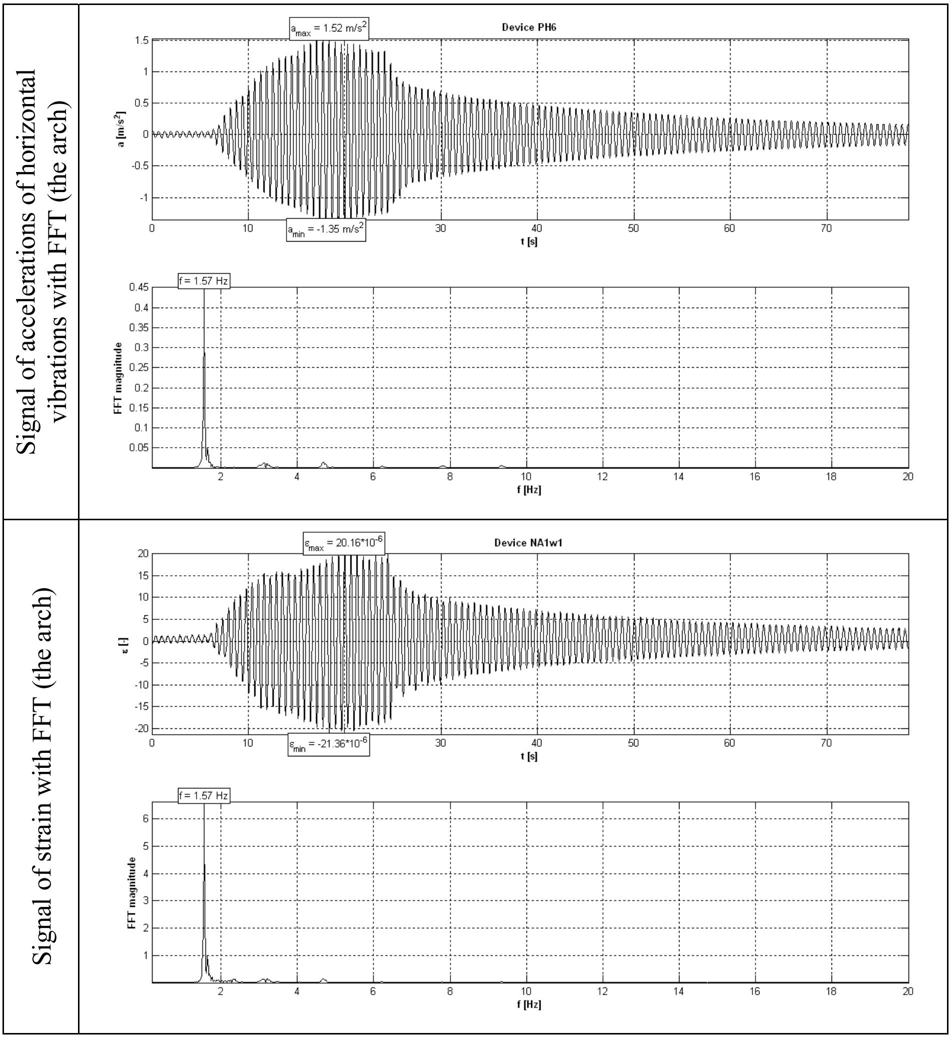


Fig. 9. *Inducing of vibrations by half-crouching with frequency f_1 (the arch).*

6. CONCLUSION

The investigation of considered footbridge shows that very good compatibility between the results obtained using the computational model and results of experimental tests of the structure is achieved. Calculated natural frequency of flexural vibrations of the bridge is 1.57 Hz, while the value obtained experimentally is 1.56 Hz. This proves that the model of the structure was correct.

The maximum value of the vertical vibrations acceleration induced by walking persons without synchronization is 0.34 m/s^2. This value does not exceed 0.70 m/s^2 [5], [6], [7], [8], which is generally recognized as a limit value of vibrations in relation to usage comfort on footbridges. Then it may be concluded that the structure meets usage comfort.

The maximum value of the vertical vibrations acceleration induced by people running without synchronization is 1.14 m/s^2, which should be regarded as a satisfactory value.

The criterion of the footbridge load capacity in dynamical conditions were checked by comparing values of stresses and displacements measured in the dynamic tests with design values. In relation to the arch part of the structure the criterion taken into account was not exceeding values of the design stresses in the arch. The maximum value of strains is $24{,}48 \cdot 10^{-6}$, that corresponds to 5.0 MPa. This result is much lower than the calculated value of the stresses due to statical proof load tests (in scheme U2, in a measurement point NA1w1 calculated value of stresses is 32.7 MPa). These strains results lead to the statement that the safety of the structure in conditions of dynamic influences is fulfilled (including vandal actions on the structure).

Analyzed structure was an interesting subject for research because of the unusual design solutions and its main span length. Applied final design solutions provide the relevant dynamic characteristics and correct behaviour under pedestrian load. The footbridge is an example of the original architecture of the structural system which does not require the use of additional vibrations damping devices.

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