TESTS OF LOCAL VIBRATION IN THE NODE OF A TRUSS BRIDGE

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Abstract

The paper describes results of dynamic tests of a truss railway bridge. Placement of the sensors (accelerometers and tensometers) allowed detection of local vibration patterns in a node being subject to the tests. In addition that placement of deflection sensors made possible recording of main natural frequency in the tested bridge. Prevailing part of the identified vibration frequency was near the theoretically obtained natural frequencies of the structure which proves that the properly planned and conducted dynamic tests can be a good basis for verification and qualitative analysis of theoretical models.

Streszczenie

W referacie opisano wyniki badań dynamicznych dźwigara kratowego mostu kolejowego. Zastosowany w czasie badań sposób rozmieszczenia akcelerometrów i tensometrów elektrooporowych zapewnił ujawnienie lokalnych postaci drgań w badanym węźle kratownicy. Natomiast zastosowany w czasie badań sposób rozmieszczenia indukcyjnych czujników przemieszczeń umożliwił zarejestrowanie podstawowych częstotliwości drgań własnych w badanym przęśle. Zdecydowana większość ze zidentyfikowanych częstości drgań odpowiada wyznaczonym teoretycznie częstotliwościom drgań własnych konstrukcji. Tak przeprowadzone badania dynamiczne dają więc dobrą podstawę do weryfikacji i analizy jakościowej teoretycznych modeli obliczeniowych.

Keywords: **Bridge; Dynamic tests; Identification experiment; Vibration frequency; Natural frequences.**

1. INTRODUCTION

To determine dynamic characteristics of the bridge an identification experiment has to be conducted. The structure is to be subjected to an excitation. Through a set of sensors the structure dynamic response can then be measured. Appropriate number of sensors have to be placed to capture longitudinal, deflectional and torsional shapes of natural vibrations. Proper and effective placement of sensors requires a degree of experience.

It may be required to repeat the measurement and average several series of measurements. The results are usually presented in relationship to frequencies (natural and associated modes) and time, with full description of the testing process.

Next step is analysis of the results. Registered results are subjected to various numerical transformations. The results of such transformaions may appear to be more precise, but it has to be remebered that they are only as good as the precision of the measurements they are based upon, and the results should be always interpreted with a prudent caution.

Such identification experiment was performed on truss railway bridge with a span of 93 m. This is a freely supported, steel construction with track at the bottom chord. Main truss appear to be a standard Warren type truss with parallel chords (Figure 3). It is not, however a typical truss, as its bottom chords are subject to bending as a result of cross bars configuration connected in nodes and in places between them. Truss nodes are not typical either because the diagonal bars alignments cross at the top flange of the bottom chord (Figure 4). The girder therefore can be considered to be a beam subject to bending reinforced with a truss.

The main objective of the study is identification of local vibrations in the girder node. According to the test program sensors (accelerometers and tensometers) were located in a way that made possible measurements of local dynamic influences in the girder nodes. In addition to that main vertical natural frequency of structure was identified by inductive deflection sensors. This paper describes only results of dynamic tests. Theoretical analyses are shown in [1], [2] and [3].

2. TESTING EQUIPMENT

Testing equipment (Figure 1) was built in Roads and Bridges Department of The Silesian University of Technology. It consists of:

a) 1 portable computer,

b) 1 PCMCIA measurement CARD DAQCARD-AI-16XE-50,

c) 1 combined card,

d) 2 inductive displacement sensors (P),

e) 2 acceleration sensors (A),

f) 8 resistance tensometers (T).

Figure 1.
Measurement set

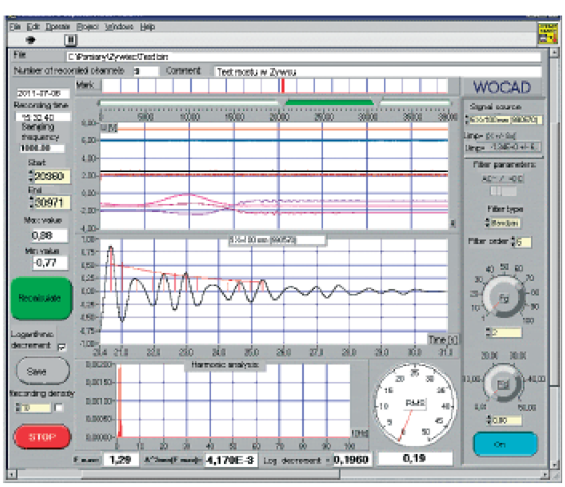

Figure 2.
Interactive panel

The measurement card is a very versatile tool. It had to be programmed for the purpose of this research. Purpose fit software was created for registration, monitoring and analysis of collected data - National Instrument's LabView graphical environment which allows use of ready – made functions and procedures prepared as so called "virtual instruments".

Figure 2 shows interactive panel for analysis. It imitates a real front plate of measurement equipment. The panel's dials and controls are operated by means of the computer keyboard and mouse.

3. FIELD TESTS

During the tests sensors reading were registered. In particular strain, displacement, acceleration and dynamic characteristic in selected points of the structure were recorded.

Two inductive sensors (Figure 3), one per girder, were installed to capture time changes of the girders deflections. Sensor P2 was installed on the left girder (looking toward Jęzor) in vicinity of node no. 4 (middle of the span). Sensor P3 on the right girder (looking toward Jęzor) – by node no. 5 (1/3 the girder span). Locations of both sensors are shown on Figure 3.

Accelerometers and tensometers were used to register local dynamic influences. Detailed survey was performed on node no. 5 of the right girder (looking toward Jęzor). The sensors were installed to register local vibrations in that particular node.

Two accelerometers A1 and A2 (Figure 4) were placed in vertical alignment, on both sides of top flange of the plate girder, close to the joint of gusset plate of node no. 5. Accelerometer A1 was attached to the inside, and A2 to the outside of the span. Eight tensometers T1÷T8 (Figure 4) served to capture changes in the structure strain. Those with odd numbers on the inside, the remaining ones on the outside. Four tensometers T1, T2, T7 and T8 were stuck horizontally close to gusset plates, in the middle of top flange of the lattice girder thickness. T1 and T2 were placed on the node 4 side, T7 and T8 on the node no. 6 side. Further 4 tensometers T3 T6 were placed vertically on gusset plated at their edges. T3 and T4 on the node no. 4 side, T5 and T6 – on the node no. 6 side.

Dynamic load was performed by crossing of a train consisting of 3 locomotives ET-41. It was an attempt to simulate a real-life situation that the bridge would be subjected to during normal operations. Test programme consisted of runs at 10, 30, 50 and 70 km/h

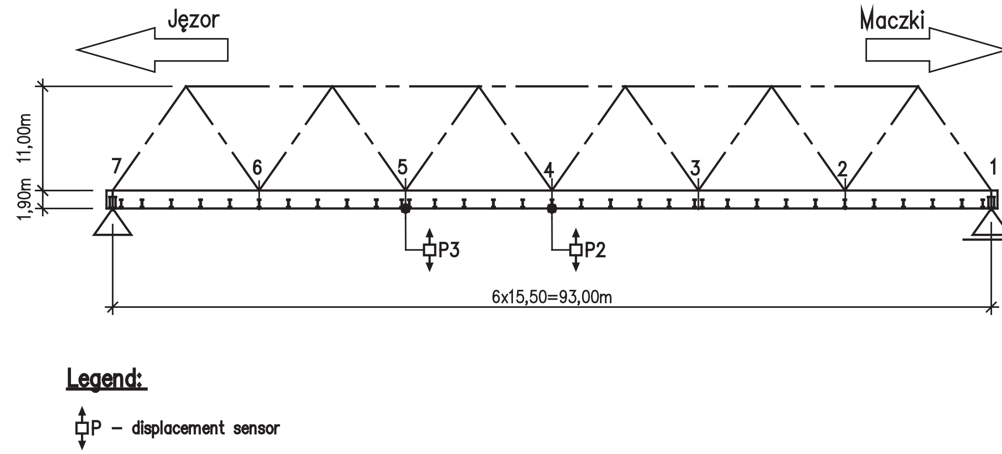

Figure 3.
Inductive displacement sensors locations

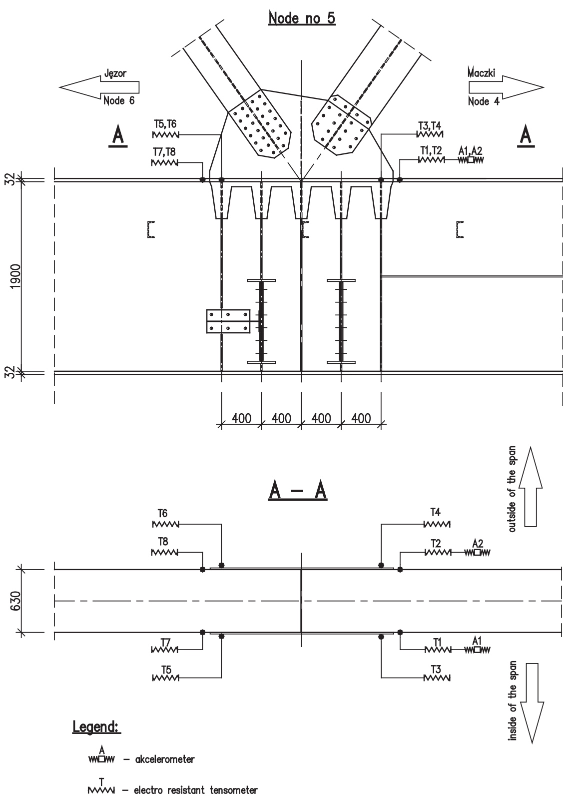

Figure 4.
Electro resistant tensometers (T) and accelerometers (A)

speeds (2.9, 8.3, 13.9, 19.4 m/s) in both directions (Maczki and Jęzor).

4. ANALYSIS OF REGISTERED DATA

Of all results registered only selected, representative set is presented herein. They were collected for load movements in both directions (Maczki and Jęzor) on the lattice girders after retrofitting. These results form a good basis for assessment of quality of theoretical calculation models, which enables verification of results of modal and time spectrum analysis [1] and [3].

Registered results of the tests are presented in the figure 5, figure 7 and figure 9. Each drawing has 4 parts, a through d. Each part has a heading, vibrogram, corresponding graph of power spectrum density (PSD) and a table with sensor id, amplitudes (Min/Max) and spread λ (Max-Min) and their changes in time t, type and order of the filter and identified, dominant frequencies of vibrations F_{max}.

4.1. Inductive displacement sensors (P)

Inductive displacement sensors (P) were used to measure changes in time of deflection of main girders. Location of the displacement sensors enabled registration of vertical modes of the girders vibrations. Figure 5 shows, as an example, deflections registered by P2 sensor over the time for 50 km/h load run toward Maczki. Drawing consists of four parts (a÷d) showing signal processing results:

a) Filter-0P. Entire reregistered record of deflections without the signal post – processing. It is impossible to visually assess the displacements. Only deflection spread λu_z (Max-Min) can be determined.

b) Filter-1P. As above, but post processed with Bessel

Table 1.
Results registered with inductive displacement sensors

Sensor	λu_z (Max-Min) [mm]	Identified F_{max} [Hz]		
	a) Filter-0P	b) Filter-1P	c) Filter-2P	d) Filter-3P
1	2	3	4	5
P2	28.94÷29.61	1.55÷2.28	1.70÷2.25	1.71÷2.37
P3	23.66÷24.58	1.78÷2.35	1.80÷2.20	2.00÷2.25

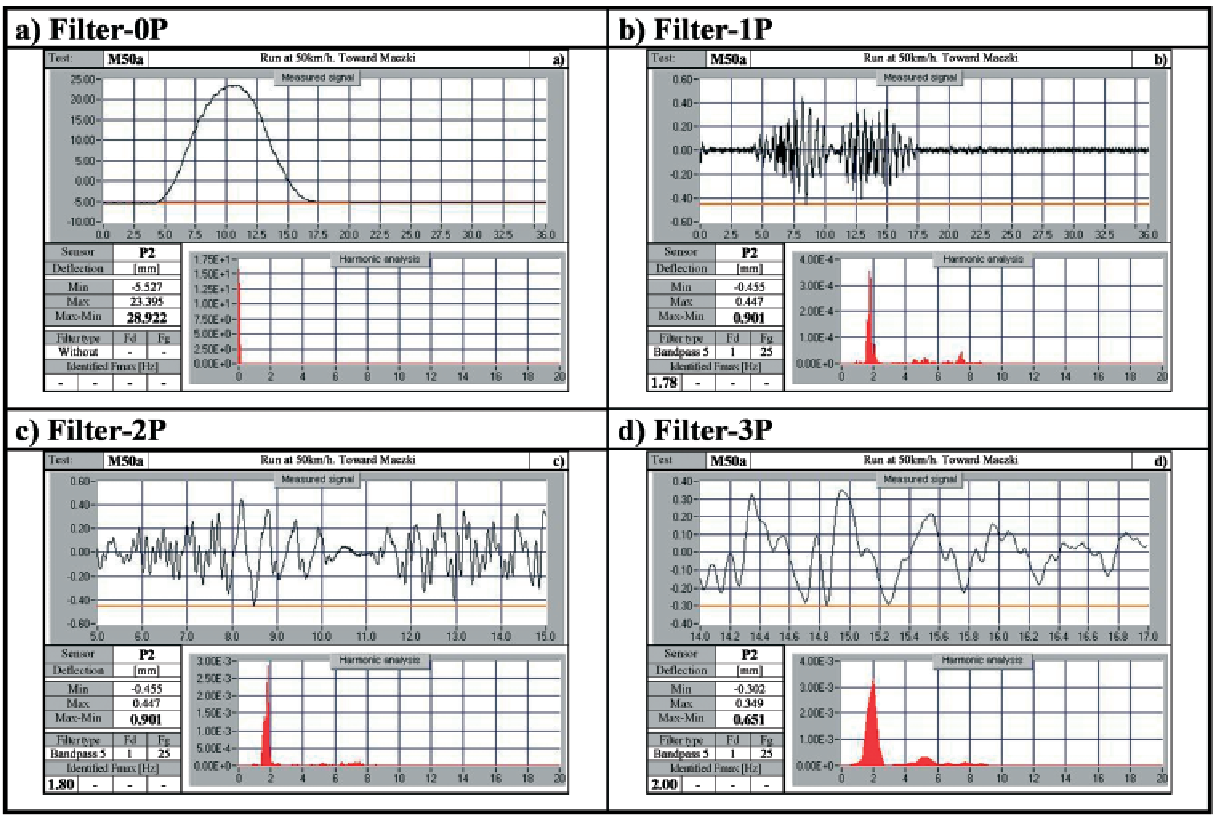

Figure 5.
Sensor P2. Run at 50km/h. Toward Maczki: a) Filter 0P, b) Filter 1P, c) Filter 2P, d) Filter 3P

band filter of 5th order, with lower frequency F_d=1 Hz and top one F_g=25 Hz. It is possible to determine dominant frequencies F_{max} and spread of deflections λu_z (Max-Min) after deduction of quasi-static signal.

c) Filter-2P. Part of registered measurement signal while the load is present on the bridge, after post processing with Bessel band filter of 5th order, with lower frequency F_d=1 Hz and top one F_g=25 Hz. It is possible to determine dominant frequencies F_{max} and spread of deflections λu_z (Max-Min) after deduction of quasi-static signal.

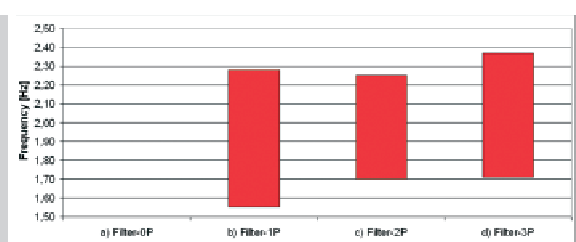

Figure 6.
Sensor P2. Range of identified second natural frequency

d) Filter-3P. Part of registered measurement signal after the load has left the bridge, after post processing with Bessel band filter of 5th order, with lower frequency F_d=1 Hz and top one F_g=25 Hz. It is possible to determine dominant frequencies F_{max} and spread of deflections λu_z (Max-Min) after deduction of quasi-static signal.

The vibrograms show how the vertical deflection $u_z(t)$ changes during the passage of the load on the main girder. Biggest spread of deflections λu_z (Max–Min) reached 29.61 mm. It was registered by P2 sensor with load traveling at 70 km/h toward Jęzor.

After post processing of the signal from P2 sensor with Bessel band filter of 5th order, with lower frequency F_d=1 Hz and top one F_g=25 Hz (graphs b, c, d) local heap can be observed. Frequencies which correspond to the heaps were identified as F_{max}. After filtering out all registered signal (part b) a very clear dominant heap of power spectrum density can be observed. Its frequency F_{max} falls between 1.55 Hz do 2.28 Hz. Similar results is obtained from analysis of measurement signal while the load is on the bridge (part c). Frequency of first F_{max} falls then into range between 1.70 Hz and 2.25 Hz. After the load leaves the bridge, however, (part d) first maximum PSD occurs with frequency F_{max} in range between 1.71 Hz and 2.37 Hz. Moreover, the P2 sensor registered another heap with F_{max} in range between 4.88 Hz and 8.73 Hz.

Figure 6 shows range of identified second natural frequency with sensor P2. All registered with inductive displacement sensors (P) values are collected in Table 1.

Deflections spans λu_z (Max-Min) is shown in column 2. Identified frequencies F_{max} are shown in columns 3 to 5.

In summing up it can be stated that after filtering out parts of b, c, d values registered by P2 and P3 first heaps appeared at frequency F_{max}, between 1.55 Hz and 2,37 Hz. In this range theoretically calculated frequency of second mode of natural vibration is located at 1,78 Hz [1]. Frequencies F_{max} for next registered heaps correspond to higher modes of natural vibrations.

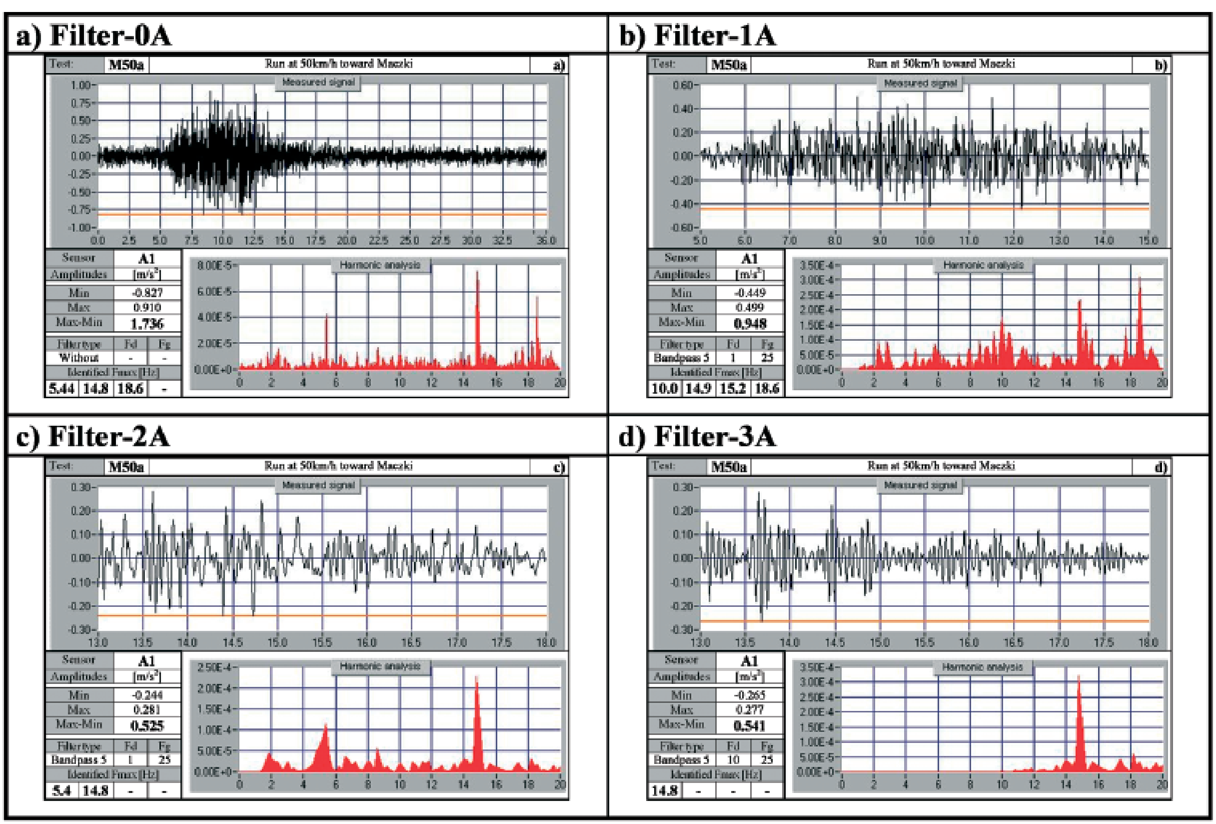

Figure 7.
Accelerometer A1. Run at 50km/h toward Maczki: a) Filter 0A, b) Filter 1A, c) Filter 2A, d) Filter 3A

Table 2.
Results registered with accelerometers (A)

Sensor	λa_z (Max-Min) [ms^2]	Identified F_{max} [Hz]		
	a) Filter-0A	a) Filter-0A	b) Filter-1A	c) Filter-2A
1	2	3	4	5
A1	1.377÷2.197	14.8÷21.2	10.0÷18.6	12.7÷18.5
A2	2.391÷4.711	13.3÷18.6	13.0÷16.4	13.6÷18.4

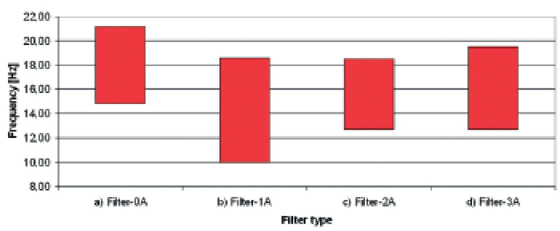

Figure 8.
Accelerometer A1. Range of identified local natural frequencies

4.2. Accelerometers (A)

Accelerometers (A) were used to measure acceleration in the places of failure which was possible thanks to the way they were placed around the critical places (Figure 4).

Figure 7 shows, as an exemple, changes in vertical accelerations a_z(t) registered with accelometer A1 in time *t* in place of failure. It pertains to load movements at 50 km/h speeds toward Maczki. Just as before each picture consists of 4 parts, a to d. The vibrogram on part a) Filter 0A of the picture shows how the vertical acceleration a_z changes in time *t*.

The measuring signal presented in part a) Filter-0A was not processed. Registered signal is non-stationary with interferences. It is difficult to conduct vibration analysis for such a signal. Local heaps, however, can be observed. It is most clearly seen with speeds of 50 km/h and 70 km/h which reveal F_{max} in ranges 4.9 Hz to 5.5 Hz and 14.8 Hz to 21.2 Hz. With speed 70 km/h toward Jęzor, range of vertical accelerations λa_z (Max-Min) reaches almost 2.2 m/s^2.

The signal postprocessing with a filter further increases analysis possibilities. Part of the signal which after post processing with Bessel band filter of 5th order, with lower frequency F_d=1 Hz and top one F_g=25 Hz (graphs b, c). Part b) Filter-1A displays local heap F_{max} in range 10 Hz to 18.6 Hz. With speed 70 km/h a heap appears at 4.9 Hz. In the part c) Filter-2A F_{max} appears in range 12.7 Hz to 18.5 Hz while in d) Filter-3A appears between 12.7 Hz and 19.5 Hz. In case d) Filter-3A the Bessel filter lower frequency is F_d=10 Hz and the higher one F_g=25 Hz.

Figure 8 shows range of identified natural frequency with sensor A1. All registered with accelerometers (A) values were gathered in Table 2. Vertical acceleration ranges λa_z (Max Min) are shown in column 2. Further four columns 3 to 6 shows identified frequencies F_{max}.

Prevailing number of local heaps occurs in vicinity of theoretically established frequencies of natural frequencies for transverse beams next to dilatation (15.7 Hz and 18.5 Hz) [1] and [3]. Identified frequencies of vibrations F_{max} in range 4.9 Hz to 5.5 Hz are most probably connected with further vertical modes of natural vibrations of the main girder. It proves accuracy of a theoretical model for the retrofitted girder [1].

4.3. Electro resistant tensometers (T)

Node number 5 on the right (looking toward Jęzor) main girder was chosen for the tests (Figure 3). Figure 4 shows locations of the tensometers (T). 8 of them were used to register changes of the structure strains, which was made possible by choice of the points the tensometers were placed.

During the tests tensometers T2 and T5÷T8 broke down. Exemplary changes of strains in time registered with tensometer T3 are shown in Figure 9. They pertain to load movements at 50 km/h speed toward Jęzor. Just as before each picture consists of 4 parts, a to d.

The signal of T3, shows in part a) Filter-0T is severely interfered. It was impossible to analyze it further. In part b) Filter-1T one can determine characteristics and range of changes and quasi static strains during the load runs. In part c) Filter-2T local heaps can be observed with frequencies F_{max} between 4.73 Hz and

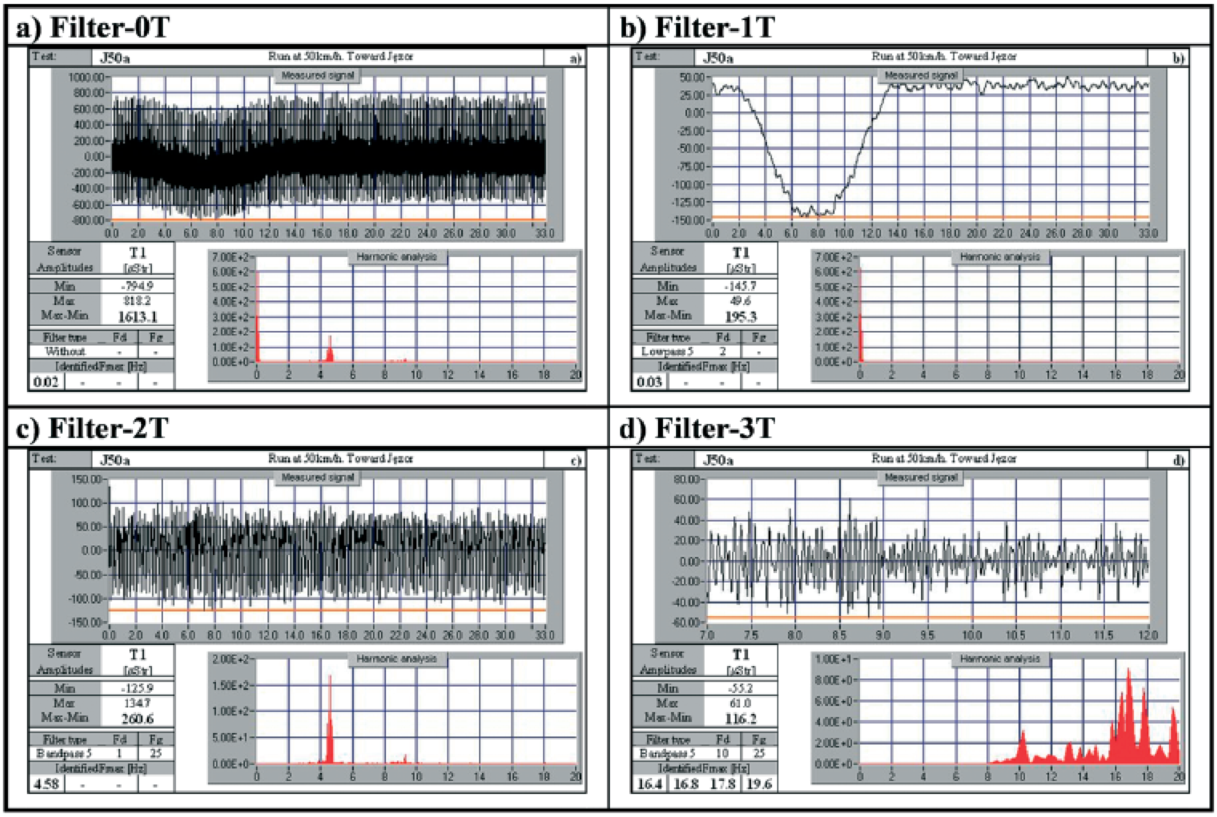

Figure 9.
Electro resistant tensometer T3. Run at 50km/h. Toward Jęzor: a) Filter 0T, b) Filter 1T, c) Filter 2T, d) Filter 3T

8.88 Hz. However, only in part d) Filter 3T, after analysis of 5 s part of registered signal in time, when the load is present on the bridge and the lower frequency of the filter is raised to F_d=10 Hz local heaps were revealed for ranges 16.0 Hz to 19.4 Hz.

Figure 10 shows range of identified natural frequency with electro resistant tensometer T3. All values registered with electro resistant tensometers (T) are collected in table 3. Strains spans λε (Max-Min) are shown in columns 2 to 5. Identified frequencies F_{max} are shown in next two columns 6 and 7.

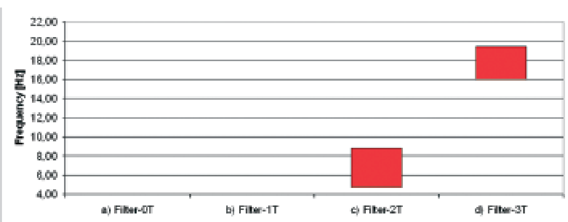

Figure 10.
Electro resistant tensometer T3. Range of identified local natural frequencies

Table 3.
Results registered with electro resistant tensometers (T)

Sensor	λε (Max-Min) [µStr]				Identified F_{max} [Hz]	
	a) Filter-0T	b) Filter-1T	c) Filter-2T	d) Filter-3T	c) Filter-2T	d) Filter-3T
1	2	3	4	5	6	7
T1	1613.1	195.3	260.6	116.2	4.58	16.4÷19.6
T3	135.3	90.7	28.9	28.5	4.73÷8.88	16.0÷19.4
T4	214.5	60.2	42.5	28.5	4.58	15.2÷18.6

Way the tensometers were placed enabled determination of local modes of natural frequencies in places of failure. After filtering according to c) Filter-2T ($1 \div 25$ Hz) heaps were identified between $4.58 \div 8.88$ Hz (Table 3). They most probably correspond to vertical modes of natural frequencies of the main girder [1]. After filtering d) Filter-3T ($10 \div 25$ Hz) heaps were revealed between $15.2 \div 19.6$ Hz (Table 3). In this range there are determined theoretically frequencies of the proper vibrations moving in the opposite directions for the cross members near the expansion joints (15.7 Hz and 18.5 Hz) [1] and [3]. That proves accuracy of the calculation model.

5. SUMMARY

It can be observed that frequency found with inductive deflection sensors (P) agrees with theoretical frequencies of 2nd mode of natural frequencies in tested span [1].

Further identification of local modes of natural frequencies was possible with accelometers. In tested span prevailing part of heaps was identified close to frequencies corresponding with theoretical natural ones for the transverse beams next to dilatation. That was further confirmed with tensometers which showed heaps close to counter laying theoretical natural frequencies.

6. CONCLUSIONS

Inductive deflection sensors (P) allowed registration of main natural vibration modes frequencies for tested span. Furthermore accelometers (A) and tensometers (T) allowed winding of local modes of vibrations of the node in tested span.

Registered frequencies correspond to theoretical natural vibration modes frequencies. That proves quality of the corresponding theoretical models [1] and [3].

Field test provide good basis for analysis of quality of theoretical calculation models. This enables verification of the obtained analysis results. In this particular case the way the sensors were placed over the structure made possible registration of the natural mode frequencies in the subject span. Identified first frequencies were identical with theoretical ones [1]. Local frequencies in the tested node were identified with tensometers and accelometers. Prevailing part of the heaps was identified next to the theoretical ones which proves quality of the model.

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