Comparison of Methods for Measuring Deflection and Vibration of Bridges

P. Kuras [a,*], T. Owerko [a], Ł. Ortyl [a], R. Kocierz [a], P. Kohut [b], K. Holak [b], K. Krupiński [b]

[a] Department of Engineering Surveying and Civil Engineering, AGH University of Science and Technology, 30 Mickiewicza Av., 30-059 Kraków, Poland - (kuras, owerko, ortyl, kocierz)@agh.edu.pl
[b] Department of Robotics and Mechatronics, AGH University of Science and Technology, 30 Mickiewicza Av., 30-059 Kraków, Poland - (pko, holak)@agh.edu.pl, krzysiek.krupinski@wp.pl

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ABSTRACT:

Continuous exploitation of bridges causes their progressive consumption. Periodic observations can help to control safety of such structures. Reliable description of behaviour of the bridge under load requires the use of method, which enables observation of many points simultaneously. The paper presents a comparison of deflection and vibration measurements performed on span of a steel bridge designed for tram traffic. Measurements were carried out during normal traffic. It was assumed to obtain the data necessary to determine the span deflection and vibration. Deflection measurements were carried out independently by two systems using different techniques: radar interferometry and digital image correlation. In both cases it is possible to measure many points on the structure simultaneously. Additionally, a set of accelerometers was installed on structure in order to measure vibrations. Vibrations were determined also by the ground-based interferometric radar. This novel measuring device operates on the basis of stepped-frequency continuous wave modulation and microwave interferometry technique. It allows to determine deformation and vibration frequency of the object through non-invasive observation of its behaviour at a frequency of up to 200 Hz. The authors present the comparison of test load results obtained by two systems and analysis of dynamics.

1. INTRODUCTION

1.1 Load testing of bridges

Diagnosis of bridges requires to develop the reliable assessment of the bridge condition. It is a complex process requiring extensive knowledge of the tested structure. Among many sources of information used in the engineering diagnosis, the results of load testing are of particular importance (Ryall, 2010). They are obtained by performing load tests or tests during operation.

Static and dynamic load tests are performed during commissioning. Studies are carried out in accordance to the design load, using a controlled load precisely located on the structure. On the other hand, tests during operation are conducted as short-term extemporary studies or long-term monitoring studies with randomly changing operational loads.

The results of bridges under static loads are a useful tool to assess the correctness of work and condition of structures. Regular repetition of tests during operation allows the comprehensive assessment of changes in the static properties which indicate the appearance of damages, often difficult to detect by other methods.

A separate problem is the study of structures under dynamic loads. On the basis of changes in dynamic characteristics of structures many types of defects may be detected, including structure deformation, destruction and loss of material, loss of material continuity and change of position. Parameters, that allow the defects detection, are: changes of natural vibration frequencies, mode shapes and damping characteristics, progressive in time. In addition to detecting defects, studies are being conducted on the possibility of locating defects based on the results of dynamic tests (e.g. Maia et al., 2003).

Procedures for systematic research of bridge structures under operational loads are usually designed individually for each object as a comprehensive system to monitor its condition. The concept of each system must take into account the importance of the monitored structure, structure type, operational conditions and the observed rate of degradation processes. For this reason, techniques used to observe the response of structure under load are very diverse.

1.2 Overview of measuring methods

Ko & Ni (2005) present wide range of monitoring systems being installed on bridges. Typically, a basic group of information about the behaviour of bridge structures are the results of displacement measurements. Surveying techniques are commonly used, both electro-optical and satellite (Watson et al., 2007). Techniques that use displacement transducers are also applied (Paultre et al., 1995). During measurements of velocity and acceleration of vibration, accelerometers and strain gauges are often applied (Paultre et al., 1995), as well as displacement transducers.

A significant disadvantage of above mentioned measurement methods is the necessity of direct access to the structure in order to install sensors and other additional devices. Moreover, these methods provide only discrete information on the current position of the object. To get full information about the position of the structure, it is necessary to install a number of sensors or make measurements at many points. This paper presents two

* Corresponding author

non-invasive techniques, which allow the displacement measurements (in this case: deflection of viaduct span) at many points simultaneously.

The first technique is radar interferometry. It is widely used for imaging changes the earth's surface by satellites (Gens & van Genderen, 1996). Recently it is also being used in ground-based imaging. It can provide information about the movements of surface such as slopes or landslides (Pieraccini et al., 2006) and also enable the static and dynamic tests of engineering structures like bridges (Gentile, 2010).

The second technique is the digital image correlation. It does not require the complicated optical system, so that it has a lot of applications. Yoneyama et al. (2007) present its application to the load testing of bridge construction, proving the accordance with results of measurements made using displacement transducers. Kohut et al. (2010) developed vision-based system for measurements of civil engineering structures. This system was used in the described experiment.

2. GROUND-BASED INTERFEROMETRIC RADAR

2.1 Description of system

The IBIS (Image by Interferometric Survey) system was developed by the Italian company IDS in order to monitor movements of land masses and engineering structures. The IBIS-S version is applied to measure displacements of buildings, of which one dimension is significantly larger than others, i.e. tall buildings, towers or bridge structures (Fig. 1).

Figure 1. IBIS-S radar during work

The IBIS-S system consists of:

– radar unit – an active radar which generates, transmits and receives electromagnetic waves from K_u band (of about 17 GHz frequency),
– notebook with the software which controls operation of the radar and communicates with radar via USB interface,
– two transmitting and receiving antennas ("horns") of defined radiation characteristics,
– 12 V battery pack enabling field work.

Radar is equipped with antennas of different characteristics. Their use is dependent on the size of the area occupied by the observed object. Antennas of maximum gain of 23.5 dBi are used for observation of a narrow scene – the intensity of the signal sent to the horizontal angle of ±5° (and vertical angle of ±5.5°) is equal to the half of the axial signal intensity (Tab. 1). These antennas were used in the described experiment. Their characteristics is shown in Fig. 2.

Maximum gain	Antenna beam width at -3 dB	
	horizontal	vertical
23.5 dBi	**11°**	**10°**
20 dBi	17°	15°
15 dBi	29°	25°
13.5 dBi	38°	18°

Table 1. Characteristics of IBIS antennas

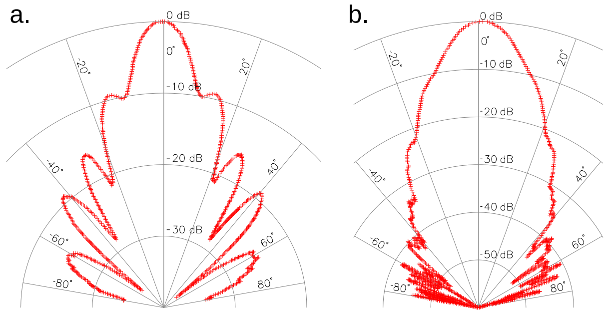

Figure 2. Plane patterns of antenna of 23.5 dBi maximum gain: a. horizontal, b. vertical

The bandwidth used by the radar is $B = 300$ MHz. It allows to obtain the maximum resolution $\Delta R = 0.5$ m. The concept of resolution shall be understood as the minimum distance between two points on the structure at which they may be considered as different points. This means the opportunity to observe points on the structure separated by not less than 50 cm along the radial direction, i.e. direction of wave propagation (Fig. 3). If the distance is less than ΔR, points will be treated as one. The distance is taken along the direction of wave propagation. The interval of ΔR is called a range bin.

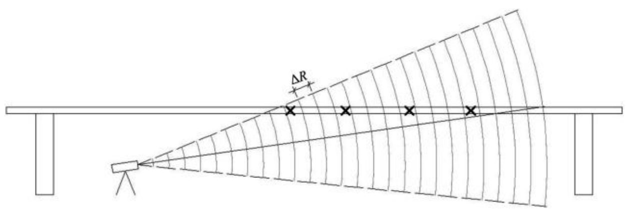

Figure 3. Concept of range resolution

Parameters that allow to use the IBIS-S radar to measure the displacements are:

– recording frequency of all observed points position: up to 200 Hz (Gentile & Bernardini, 2008),
– measurement range: up to 1000 m (Gentile, 2010),
– accuracy of the radial component of displacement: 0.1 mm (Pieraccini et al., 2004).

2.2 Radar techniques

The IBIS-S system operates basing on two radar techniques:

– microwave interferometry,
– stepped-frequency continuous wave modulation.

2.2.1 Microwave interferometry technique allows to achieve high accuracy of displacement measurement. Displacement of a point is calculated based on the phase difference of waves received by the receiver at different times (Fig. 4). Movement of the point in the direction of electromagnetic wave propagation induces a phase shift between the signals reflected from the surface of the object. The value of displacement *d* along the direction of wave propagation can be written as:

$$d = \frac{\lambda \cdot \Delta\varphi}{4\pi} \tag{1}$$

where λ = wavelength
$\Delta\varphi$ = phase shift

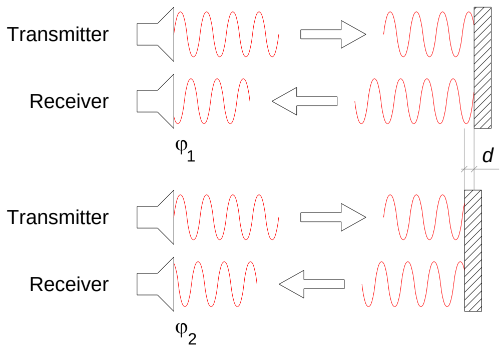

Figure 4. Concept of interferometric measurement

2.2.2 Stepped-frequency continuous wave (SFCW) modulation technique allows to avoid the need to install many measuring devices on the structure. The relevant output signal processing allows to obtain an image displacement of many points (virtual sensors) on the structure. In fact, measurements are made on small "inhomogeneities" of the structure, on which the wave is scattered. In cases, when the specific points must be observed, it is possible to use radar beam reflectors.

Radar signal has the form of a short pulse. The shorter duration τ of pulse, the higher measurement resolution ΔR can be obtained. This is due to equation (2). The relationship between pulse duration τ and used microwave bandwidth B can be written as $\tau \cdot B = 1$, hence the radar resolution equals (3).

$$\Delta R = \frac{c\tau}{2} \tag{2}$$

$$\Delta R = \frac{c}{2B} \tag{3}$$

where c = speed of light

Increasing the resolution of measurement is achieved by reducing the value of τ or increasing the value of B. SFCW radars, instead of using short pulses, reach the wide bandwidth through the stepped, linear increase of discrete frequency values Δf. Bandwidth can be expressed as:

$$B = (N-1) \cdot \Delta f \tag{4}$$

where N = number of different frequencies within the bandwidth B (Fig. 5)

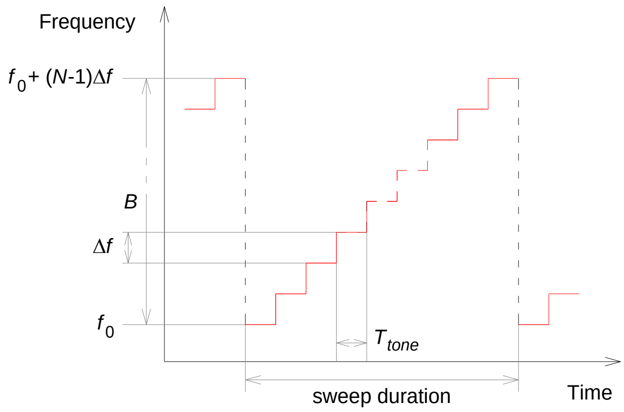

Figure 5. Relation between frequency and time in SFCW modulation

3. VISION-BASED MEASUREMENT SYSTEM

3.1 System description

The vision-based measurement system provides monitoring of static states of civil engineering constructions such as displacements, deflections and deformations. The measurement device consists of a one or more high resolution digital camera and the software embedded in MS-Windows operating system. Other elements of the device are the lighting system and the set of intensity markers. 2D displacement field of a construction is obtained as a result of processing and analysis of images acquired before and after structure's deformation under the load. The method makes it possible to capture the consecutive images of an object from different viewpoints. The measurement can be carried out in characteristic points of the construction or along its entire span in the case of the dense measurement. The system works automatically with minimal intervention of an operator.

The software performs construction deflection measurement using camera drivers for remote image acquisition, image processing algorithms for preparing acquired images and vision algorithms to calculate deflection value. Two operation modes are available for the software: on-line and off-line. In the first case, an user specifies the date and time range of the measurement and then the system works fully automatically. The off-line mode provides analysis of the images registered by other devices and in different measurement sessions. The live-view makes it possible to observe in real time how the change of camera parameters influences the quality of acquired photographs, which may be useful during positioning the camera and tuning its working configuration parameters. The software has embedded tools for camera calibration and scale coefficient calculation from special markers or the certified length standards. The result browser module carries out the visualization of calculated curves of deflection, storing of the data, automatic reporting. The additional feature of the software is detection of exceeding of allowed level of maximum deflection and sending alerts to client by e-mail or SMS.

Advantages:

- simplicity of the measurement – acquisition of two images of the construction,
- global measurement of an object deformation – dense sensor's network is not necessary,
- 2D measurement of displacement fields – possibility of deflection course curve to be obtained using images of the construction taken before and after deformation from two distinct points in space,
- application of commonly available digital camera (so called digital SLR camera),
- the software provides easy analysis and interpretation of results.

3.2 Overview of developed measurement method

The method of the non-contact measurement of civil engineering constructions' in-plane deflection consists of three major steps (Uhl et al., 2011). In the first step, a rectification of images acquired from distinct points of view, not coincident with the reference one is performed by means of the homography matrix **H**. The detection and matching of the coplanar markers is carried out by the system automatically. In the following step, the deflection of a construction is calculated using the normalized cross correlation coefficient (NCC). Sub-pixel feature detection techniques were introduced in order to increase the accuracy of the measurement. In the final step, the scale coefficient is computed with the help of a circular intensity pattern with a known diameter or length standards. The developed algorithm is presented in Fig. 6.

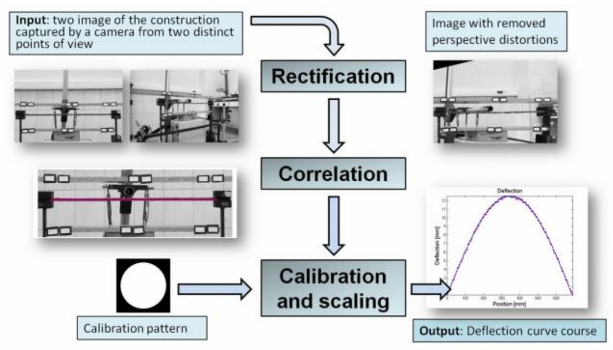

Figure 6. Developed algorithm of the in-plane deflection measurement

Image registration is a method of stitching two or more images taken at different times, from distinct points of view or by using different imaging devices. In this work, the homography mapping was introduced in order to align two images acquired from distinct points of view.

Image rectification is a process of projective distortions reduction by means of the homography transformation. Four pairs of coplanar corresponding points are sufficient for the computation of matrix **H** if none three of them are collinear. The set of corresponding points used for the homography computation consist of vertices of rectangular markers, which are placed on the structure. Markers must be coplanar with the plane of the construction and cannot change their position as it deforms. Coordinates of the corresponding points on both images are calculated by the automatic corner detector. In the first step, rectangles are detected on images by means of contour processing and shape filtering methods. Exact positions of each of markers' vertices are determined by the sub-pixel improvement of the detector. As the alternative for the aforementioned method of feature matching, image patch correspondence matching based on binary codes recognition has been developed. When the homography mapping between two images of a construction is calculated, projective distortions of the particular plane of the object are removed from the image.

The normalized cross correlation coefficient (NCC) is applied for the computation of the in-plane displacement field. In the developed method, the reference image of the unloaded construction is divided into intensity patterns whose position are computed by means of the NCC coefficient. The displacement vector for each of the measurement points is computed as a difference between positions of the pattern on two images of the construction: taken before and after application of a load.

In order to express a deflection curve in metric units, calibration of the system is necessary. It is performed by a circular intensity pattern with a known diameter. Optionally, full camera calibration is carried out in order to obtain intrinsic parameters, which are necessary for the reduction of radial and tangential lens distortions.

4. FIELD TEST

The measured structure was a 28 m long span of a steel viaduct (Fig. 7). During tests the viaduct was subjected to operational loads, caused by passing trams. A several passages, that causes the span deflection, has been recorded.

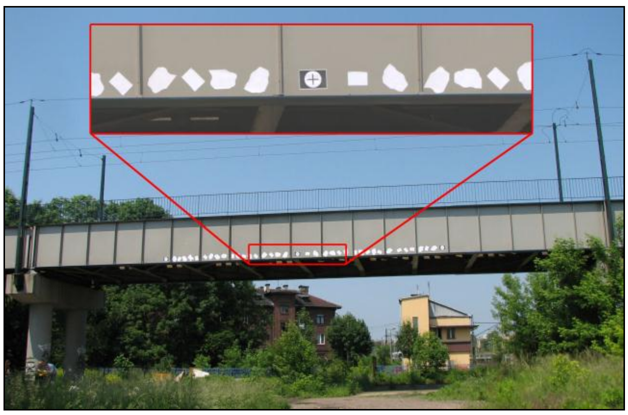

Figure 7. The tested viaduct

Location of the structure and measurement systems is presented in a plan (Fig. 8). The symbols CAM1 and CAM2 indicate location of two digital cameras implementing the vision-based technique. On the surface of monitored object measurement markers have been attached as well as three calibration markers (M1, M2, M3) consisting of white circle and black crosses inside used for determining scale coefficient. Measurement have been performed using two Canon EOS 5D Mark II SLR cameras mounted on tripods and laptop with installed Wiz2D software. Both SLR cameras have been situated in the distance of 24.6 m from the object. The first camera was equipped with Canon EF 24÷70 mm f/28 L lens set to work with 70 mm of focal length. Field of vision for this camera spanned 13.5 meters. The second camera was equipped with telephoto lens (Canon

EF 100÷400 mm f/4.5÷5.6 L) set to 400 mm focal length. The camera was used for monitoring smaller fragment of construction of length 2.32 m.

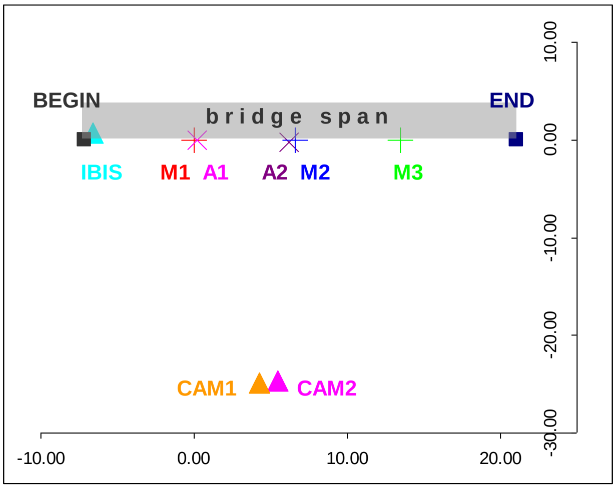

Figure 8. Location of the viaduct and devices (axes unit: m)

The symbol IBIS in Fig. 8 means the position of the radar. It was set about 5.5 m under the span, near the pillar. After illuminating the scene the range profile was generated (Fig. 9). The graph shows the intensity of reflected signal, expressed as signal-to-noise ratio (SNR), depending on the span length. The highest peak was obtained for a distance of 12.8 m from the beginning of the span, which is almost in the middle. Most of the other peaks have been identified as cross beams, visible in Fig. 1, which reflect the radar wave.

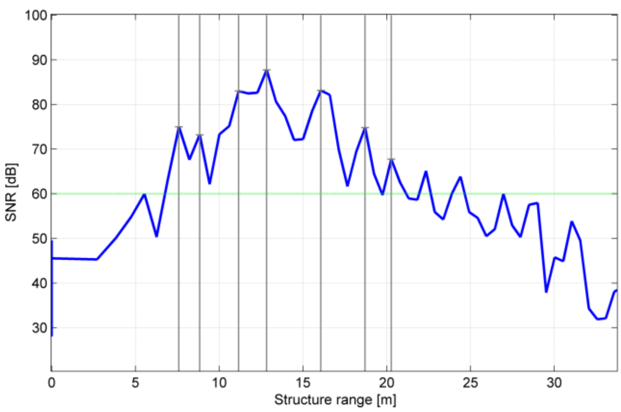

Figure 9. Range profile of observed scene

The symbols A1 and A2 in Fig. 8 indicate location of two accelerometers, used in vibration test. They were attached to the steel structure by means of magnets.

5. ANALYSIS OF RESULTS

5.1 Radar interferometry results

Displacements were analyzed at 7 points of span, located in the central part. Information about the position of points and the intensity of the reflected signal is contained in Tab. 2.

Point no.	Distance from span beginning [m]	SNR [dB]
Rbin 19	7.6	75.0
Rbin 21	8.8	73.2
Rbin 25	11.2	83.0
Rbin 28	12.8	87.7
Rbin 34	16.1	83.1
Rbin 39	18.7	74.8
Rbin 42	20.3	67.7

Table 2. Points observed by radar

Examples of vertical displacements of points Rbin 19 and Rbin 28 are shown in Fig. 10. Fig. 10a presents the deflection recorded for a typical tram passage, while Fig. 10b shows the maximum recorded deflection, measured during passing of two trams at the same time.

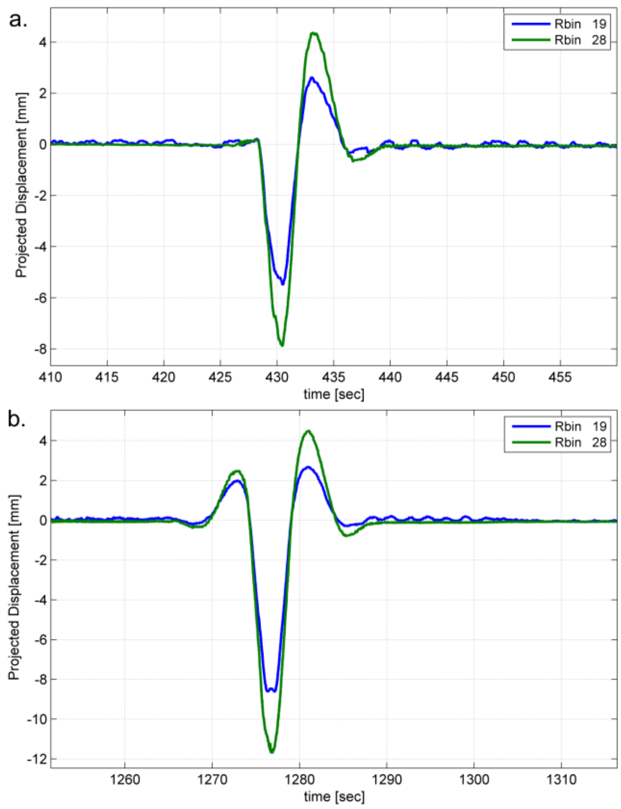

Figure 10. Vertical displacements of two points

5.2 Results comparison

In Tab. 3a and 3b a set of measurements performed by both systems during a sample tram passing (no. 4) is presented. Almost the same points were measured – their location is shown in the top rows of both tables. Due to the high frequency of radar recording data (100 Hz), information about the displacement of points was averaged for 0.25-second intervals in order to compare results (Tab. 3a). In the case of vision-based method the intermediate deflection values were interpolated in time (Tab. 3b). The maximum values of deflection for each point are bold in both tables.

Time [s]	Measured points (from beginning of span) [m]						
	7.6	8.8	11.2	12.8	16.1	18.7	20.3
	Deflection [mm]						
...	...						
1.50	-3.89	-4.41	-5.33	-5.49	-5.66	-5.78	-5.35
1.75	-4.59	-4.97	-6.01	-6.41	-6.65	-6.63	-6.35
2.00	-4.89	-5.46	-6.75	-7.08	-7.34	-7.49	-7.07
2.25	**-5.22**	**-5.81**	**-7.10**	**-7.67**	**-7.97**	**-7.83**	**-7.53**
2.50	-4.96	-5.39	-6.70	-6.99	-7.25	-7.41	-6.98
2.75	-3.80	-4.34	-5.62	-5.88	-6.12	-6.50	-6.01
3.00	-2.31	-2.63	-3.54	-3.89	-4.03	-4.37	-4.07
3.25	-1.02	-1.11	-1.63	-1.81	-1.88	-2.09	-2.02
3.50	0.28	0.41	0.29	0.35	0.37	0.29	0.14
...	...						

Table 3a. Radar measurements during tram passing

Time [s]	Measured points (from beginning of span) [m]						
	7.7	8.8	11.5	12.9	16.2	18.7	20.4
	Deflection [mm]						
...	...						
1.50	-4.67	-4.92	-5.62	-5.60	-5.43	-4.96	-3.97
1.75	-5.13	-5.42	-6.33	-6.25	-6.07	-5.68	-4.79
2.00	**-5.61**	**-5.92**	**-7.11**	**-6.99**	**-6.77**	**-6.31**	-5.34
2.25	-5.50	-5.77	-6.94	-6.85	-6.76	-6.24	-5.36
2.50	-5.30	-5.52	-6.49	-6.54	-6.63	-6.21	**-5.40**
2.75	-4.27	-4.46	-5.35	-5.48	-5.69	-5.49	-4.70
3.00	-3.68	-3.46	-4.78	-4.74	-4.99	-5.22	-4.42
3.25	-0.49	-0.09	-1.01	-1.14	-1.32	-1.47	-1.40
3.50	0.87	-0.67	0.34	0.05	0.27	-0.35	-0.36
...	...						

Table 3b. Vision-based measurements during tram passing

Such observations were collected for 8 tram passages (Tab. 4). For each passage the maximum deflection for both methods (marked as R – radar technique and V – vision-based technique) was calculated, as well as differences between them (Δ). Moreover, for each set of Δ values the minimum and maximum values were calculated (Δ_{min} and Δ_{max}). Maximum values of span deflection are bold in Tab. 4. The minimum difference between two techniques equals 0.08 mm, while the maximum difference achieves 1.37 mm.

Fig. 12 shows the shape of span in the moment of maximum span deflection during a sample tram passing (no. 4). The graphs were obtained with two different techniques. In Fig. 11 deflection of each observed points on the span during the same tram passing is presented in time domain. These results are also obtained with both techniques.

Differences between deflections from both techniques calculated for the measurements made every 0.25 s were used to evaluate the average differences between the techniques and their standard deviations. Passages of 8 trams were taken into account. These values are calculated for all of 7 measured points and summarized in Tab. 5.

Tram no.	Technique	Measured points [m]							Δ_{min} Δ_{max}
		7.6	8.8	11.2	12.8	16.1	18.7	20.3	
		Maximum deflections [mm]							
1	R	-8.64	-9.24	-11.12	-11.53	**-11.61**	-10.70	-10.56	
	V	-9.70	-11.02	-11.25	**-11.69**	-11.15	-10.30	-8.83	0.13
	Δ	1.06	1.78	0.13	0.16	-0.46	-0.40	-1.73	1.78
2	R	-3.96	-3.56	**-4.34**	-4.25	-4.33	-4.22	-3.94	
	V	-4.02	-4.39	-4.77	-5.19	**-5.54**	-5.36	-5.05	0.05
	Δ	0.05	0.82	0.43	0.94	1.21	1.14	1.11	1.21
3	R	-5.15	-5.58	-6.64	-7.03	**-7.09**	-6.86	-6.46	
	V	-6.49	-6.40	-6.93	**-7.01**	-6.77	-6.00	-5.06	0.02
	Δ	1.34	0.82	0.29	-0.02	-0.32	-0.86	-1.40	1.40
4	R	-5.22	-5.81	-7.09	-7.67	**-7.72**	-7.27	-7.03	
	V	-5.80	-6.12	**-7.41**	-7.28	-7.05	-6.54	-5.53	0.31
	Δ	0.58	0.31	0.32	-0.39	-0.68	-0.73	-1.50	1.50
5	R	-5.21	-5.82	-6.91	-7.30	**-7.36**	-7.08	-6.69	
	V	-5.68	-6.01	-6.24	**-6.25**	-5.96	-5.01	-4.10	0.19
	Δ	0.46	0.19	-0.67	-1.05	-1.41	-2.06	-2.59	2.59
6	R	-3.44	-3.31	-3.97	-3.87	**-4.00**	-3.85	-3.60	
	V	-2.91	-3.10	-3.64	**-3.72**	-3.47	-3.40	-2.98	0.15
	Δ	-0.53	-0.22	-0.32	-0.15	-0.53	-0.45	-0.62	0.62
7	R	-5.55	-6.29	-7.49	-8.01	**-8.11**	-7.64	-7.38	
	V	-5.81	-6.40	**-6.74**	-6.70	-6.39	-5.44	-4.46	0.11
	Δ	0.26	0.11	-0.75	-1.32	-1.72	-2.21	-2.92	2.92
8	R	-5.22	-5.90	-6.95	-7.41	**-7.47**	-7.17	-6.81	
	V	-5.84	-6.15	-6.40	**-6.45**	-6.19	-5.34	-4.38	0.25
	Δ	0.62	0.25	-0.55	-0.96	-1.28	-1.83	-2.43	2.43

Table 4. Values of vertical deflections of 7 measured points and differences between techniques results

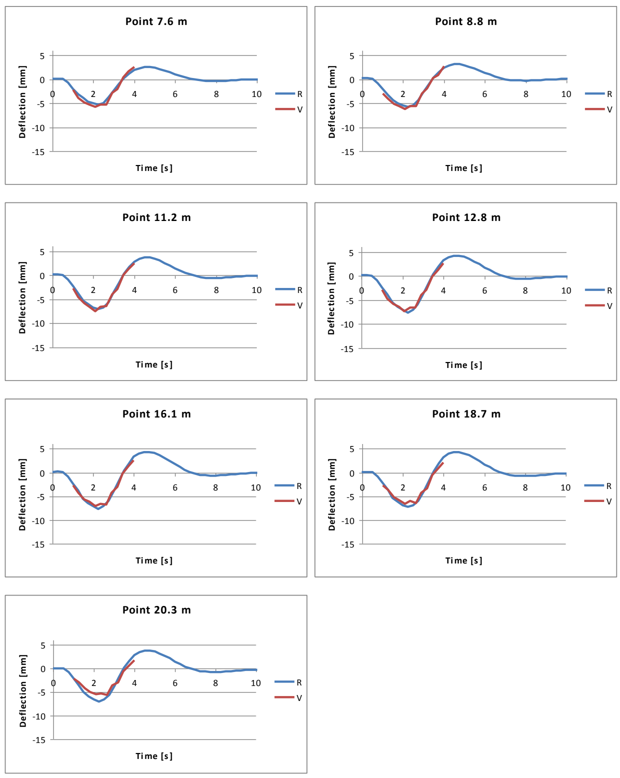

Figure 11. Graphs of vertical deflections of 7 measured points for tram passing no. 4

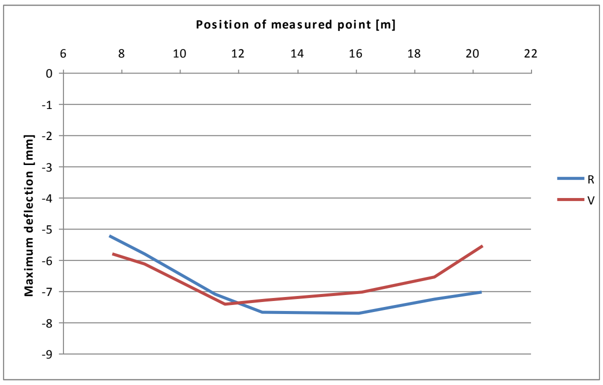

Figure 12. Moment of maximum span deflection during tram passing no. 4

	Measured points [m]						
	7.6	8.8	11.2	12.8	16.1	18.7	20.3
Average of differences [mm]	0.16	0.16	-0.23	-0.31	-0.65	-1.05	-1.35
Standard deviation [mm]	0.42	0.40	0.28	0.32	0.40	0.58	0.69

Table 5. Vision-based measurements during tram passing

The measurements results show good agreement between two techniques. The maximum disagreement achieves nearly 3 mm. However, the farther on the span is located the observed point, the difference of deflection is greater. Probably, reasons for this phenomenon should be found in rules of interferometric radar operation. On the structure illuminated by radar it is impossible to identify the particular point being measured. If the reflection occurs from the element on the top of the span (not the bottom, as it was assumed), the result of deflection may be overestimated.

Moreover, radar measures only the component of radial displacement d_R (Fig. 13), which serves to calculate the vertical deflection d_V. For the calculation it is necessary to know D and H values, which can be simply measured using land surveying techniques. The farther position of the point on the span, the smaller the d_R/d_V ratio. Then the d_V value is more affected by the measurement uncertainty. This dependence is particularly inconvenient when measuring low bridge structures.

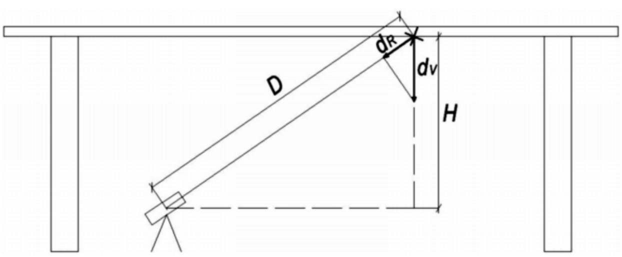

Figure 13. Relation between radial and vertical displacement

5.3 Vibration test

After the tram passage, that is after the end of forcing load, the bridge span vibrates for some time with the natural frequency. Vibrations are dampened until their complete disappearance. To determine the dynamic characteristics of vibrating span the high accuracy of measurement and high sampling frequency have to be assured. These measurement conditions are met by the interferometric radar. The comparative measurement of vibration was provided by the accelerometers. One of them was located in the middle of span, where the strongest deflection were expected.

Fig. 14 shows the response of the span mid-point to the passing tram which forced the span vibration. Response to static load is presented in Fig. 14a. Since the end of load (1288 s) dynamic response reveals as vibration with natural frequency. Fig. 14b shows damping vibration. The natural frequency of less than 0.01 mm displacement amplitude is observable until approximately 1334 s (Fig. 14 c).

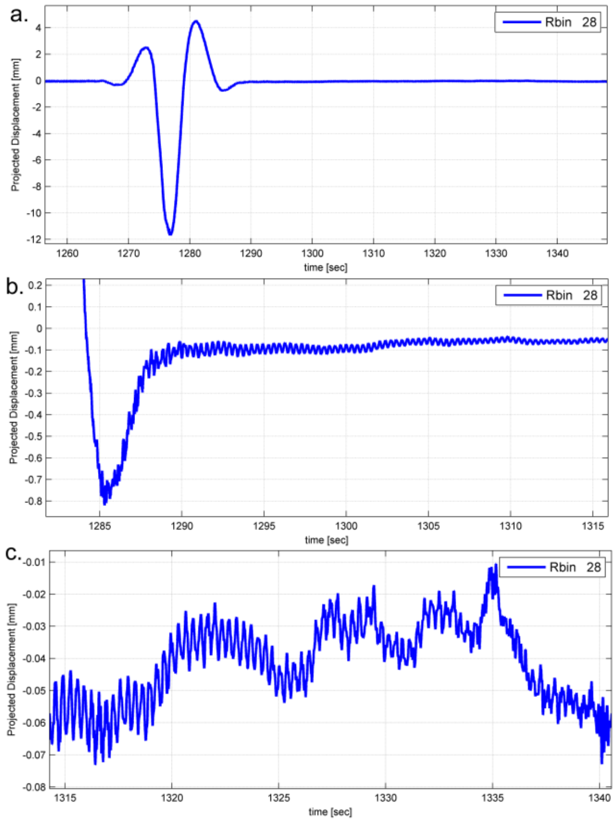

Figure 14. Vibration of the middle span point after tram passing no. 1

Spectral analysis enables to determine natural frequencies based on recorded values of displacement, velocity or acceleration. Natural frequencies of span were estimated based on displacement measurements using the interferometric radar. In order to compare results, values of acceleration, measured by accelerometers, were double integrated. However, ISO (2010) recommends to avoid integration (or differentiation) process and perform the measurement of interesting value directly.

On the basis of obtained displacements, the discrete Fourier transform (DFT) was calculated to obtain the natural frequencies. The interval, when both interferometric radar and accelerometers were working, lasted for 30 s and covered the maximum span deflection during train passage no. 1. Fig. 15 contains the frequency spectrum acquired with radar measurements, while Fig. 16 presents the results of DFT obtained on the basis of accelerometer data.

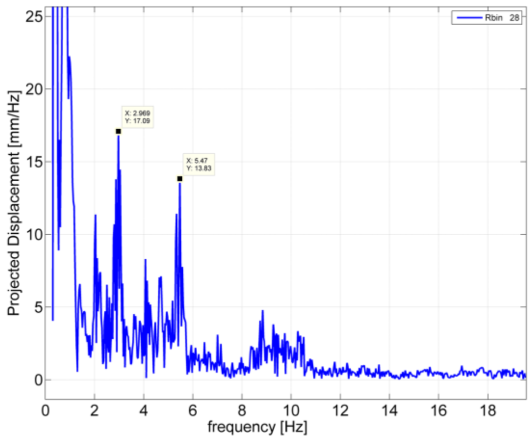

Figure 15. Spectral analysis based on radar measurements

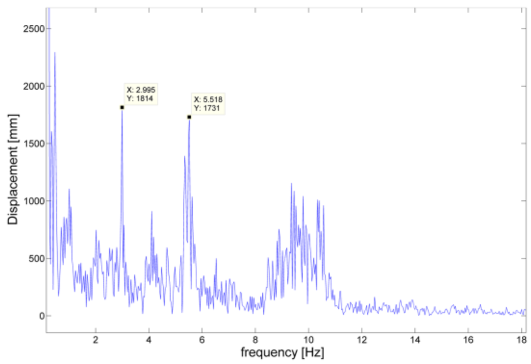

Figure 16. Spectral analysis based on accelerometer data

6. CONCLUSIONS

The performed research allows to determine the applicability of vision-based technique and radar interferometry to measuring the engineering structures deformation. The first technique enables measurement of displacement fields representing in-plane deflection of a construction. 2D deformation of the whole construction or its regions is being measured. Among structures that can be measured, there are: bridges, footbridges, chimneys, viaducts, girders, ceilings, halls, masts, wind turbines, buildings, machines and devices.

Results obtained from radar interferometry technique are consistent with the results of comparative tests, both for static and dynamic. However, it should be noted that this technique can be used to measure much larger structures with high accuracy.

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