APPLICATION OF INDUCTION SENSORS FOR MEASUREMENT OF VERTICAL DISPLACEMENTS OCCUREING DURING BRIDGE LOAD TESTS

Stanisław Mroziński
Faculty of Mechanical Engineering
University of Technology and Life Sciences in Bydgoszcz

Jan Gadomski, Maria Gadomska
Faculty of Civil and Environmental Engineering
University of Technology and Life Sciences in Bydgoszcz

1. INTRODUCTION

A bridge before being put into use undergoes fatigue tests which involve test of static and dynamic loads [Ryżyński A., 1983]. Assessment of the object real characteristics requires familiarity with the problems of displacement and strain and frequency as well as the amplitude of vibrations. Knowing the purpose of the test and application of its results it is necessary to choose proper methods, measurement equipment and the way of the results elaboration.

According to regulations, norms and instructions concerning tests of static loads it is necessary to measure the bridge span deflection and vertical displacement of its supports. These tests determine the way of the control points arrangement on the tested object. In case of application of geodetic methods, bench-marks have to be determined – and at least two datum points have to be set up on each side of the bridge. These bench-points must fulfill the condition of mutual stability. Determination of vertical displacements is performed with the use of geometric leveling. It is a very difficult task as there is usually a big number of points to be measured. High frequency of measurements also provides difficulties due to the object location near watercourses, negative influence of physical conditions and also vibrations caused by riding vehicles. Measurement during live load is not an easy task, either. Dynamic impacts cause that stress in the bridge structure elements, including their strain, is higher with moving vehicles than in case of static load of the same value, that is, very slow introduction of vehicles and placing them on the bridge immovably [Bęben D., Mańko Z., 2010]. Clock sensors [Pradelok S., Będkowski P., 2007], tensometric ones [Skrzypczak I., Klich R., 2007] or induction inertia ones [Bęben, Mańko Z., 2010] can be used for dynamic tests. Preparation of measurement stations for performance of tests by means of sensors is more difficult than preparation of the object for geodetic measurements.

Preparation of measurement stations for measurements by means of sensors requires stable foundation (ferroconcrete plates) and a vertical post supported on this foundation. It is required to provide the post with stability through fixing the post bottom to the foundation and use of guy ropes for stabilizing the post top. In order to provide access to the sensor fixed on the post top, a separate structure has to be erected. Two examples of measurements for test loads: by geometric leveling and with the use of induction sensors – measurements were performed simultaneously, will be presented. Bridges of different structures were objects of tests.

2. TESTED OBJECTS

2.1. Ferroconcrete flyover over a channel

The flyover load-carrying structure is a three- span ferroconcrete plate of 1.05 to 1.16 width. The span length 15.00+ 20.00 + 15.00m, width – 22.30m, obstacle crossing angle 75°. Extreme supports are ferroconcrete bridgeheads, whereas intermediate supports are two rows of ferroconcrete posts (four in every row) with diameters equal to 1m.

Six loaded trucks with total weight 300±5kN were the test load. Static tests were performed according to 6 variants in 3 phases. For particular variants, loads were applied with the use of four or six trucks.
Points depicted in figure 1 were observed during static tests.

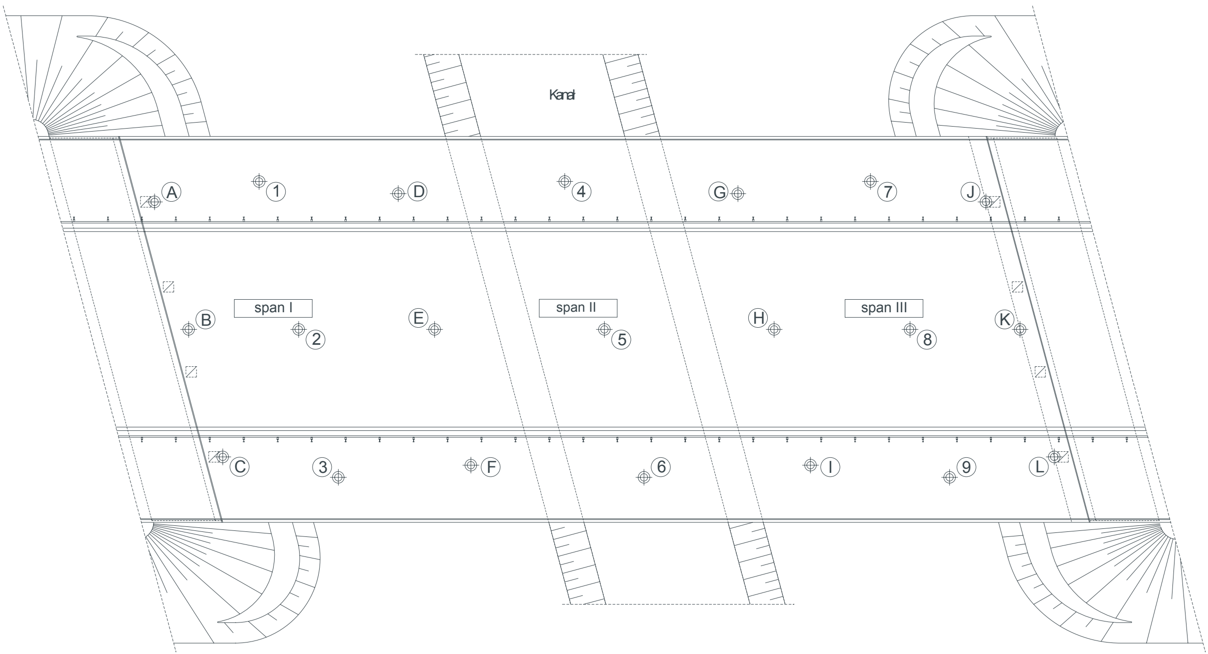


Fig. 1. Scheme of control points arrangement.

Four leveling instruments were used for geodetic measurements, two on every side of the bridge. Two spans were monitored during each load variant and two points on spans (points 4, 6 - span II and points 7, 9 - span III) by means of induction sensors of displacement.
The measurement range of induction sensors was ±5 and ± 50mm. ESAM Traveler Deflection measurement set was used for performance of the measurements. This set consists of a measurement card and technologically advanced strain meter bridge, and

a well developed control and data processing software. ESAM system makes it possible to perform measurements with maximum frequency up to 250000 samples per second. The results of tests for one span, loaded using two methods for one load variant, have been presented as an example. The results for test load of span III are shown in table 1.

Table 1. Results of test load of span III

Load variant	Measurement	Point 7			Point 9		
		Deflections [mm]			Deflections [mm]		
		before test	load	after test	before test	load	after test
I	geodetic	0	0.4	0.00	0	0.5	0.2
	sensors	0	0.44	0.01	0	0.47	0.04
II	geodetic	0	0.3	0.00	0	0.4	0.00
	sensors	0	0.30	0.01	0	0.43	0.01

As it results from the table, there are no differences between the results obtained from geodetic measurements and the sensors. It should be noticed that the survey points were very close to each other for both measurements.

Dynamic loads

Measurements were performed only by means of sensors, on the bridge under a dynamic load, on its two spans, in four points (4, 6, 7, 9). Dynamic tests involved parallel rides of two trucks with the speed 10, 30 and 50 km/h and rides of one truck through two speed breakers with diameter 6x10cm situated across the ride direction. In figure 2, exemplary results of measurements for the trucks riding at speed equal to 30km/h.

On the basis of an analysis of the charts shown in figure 2, it is possible to say that the bridge deflections in survey points depend on the moving vehicle position. The vehicle ride through span II and speed breaker 1 causes deflections in survey points 6 and 7, and a slight elevation in points 7 and 9. The area near the speed breaker 1 (sensor 6) is affected by a larger deflection. The situation changes when the vehicle continues to move through span III and speed breaker 2 which is situated on it. The bridge deflection appears in points 7 and 9, whereas, measurement points which are on span II, undergo a slight elevation at the same time. According to expectations, the bridge deflections in effect of the vehicle ride through span II (points 5 and 6) are definitely higher than deflections of span III (points 7 and 9). Temporary values of the bridge deflection recorded during the vehicle ride were also used for an analysis of the bridge free vibration frequency after the ride of through speed breakers 1 and 2.

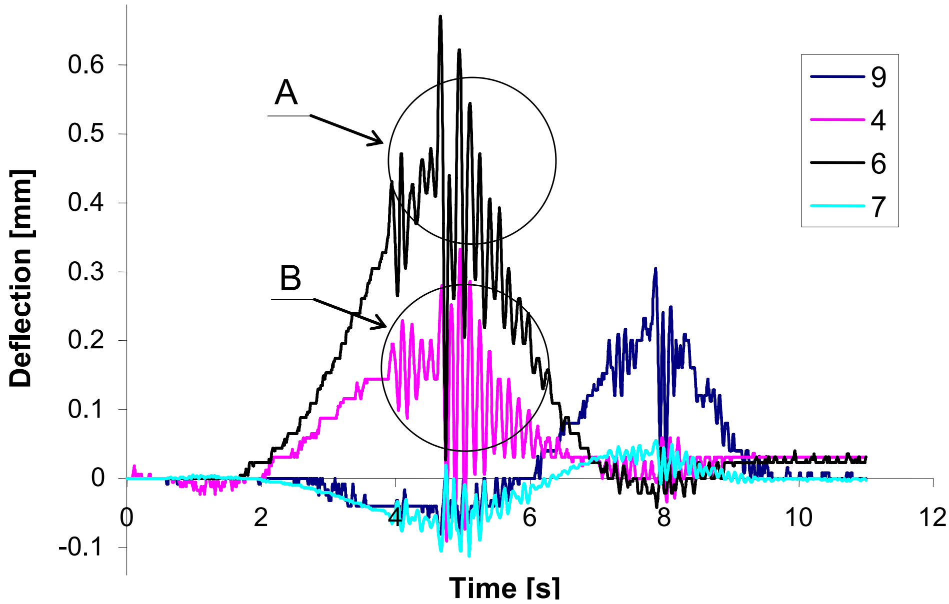
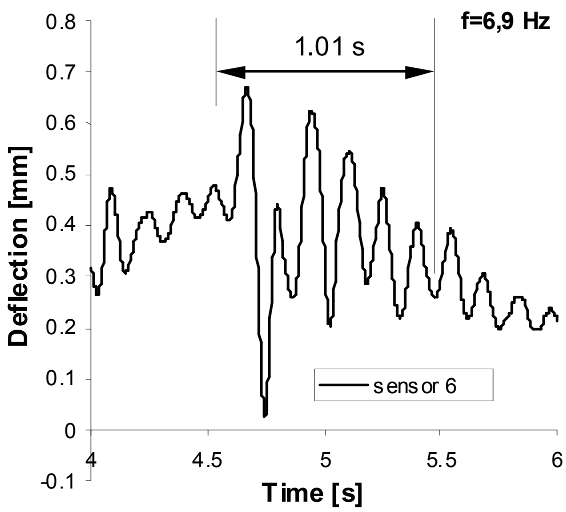


Fig. 2. The bridge deflections during the vehicle ride through speed breakers.

For this purpose, a number of full sinusoidal vibrations during one second were calculated. There was made an analysis of vibrations after the vehicle ride through speed breaker 1. The mode of operation for determining the vibration frequency has been accounted for in fig. 3, where fragments „A" and „B" of graphs of deflections recorded in points 4 and 6 (fig.2) have been presented.

a)



b)

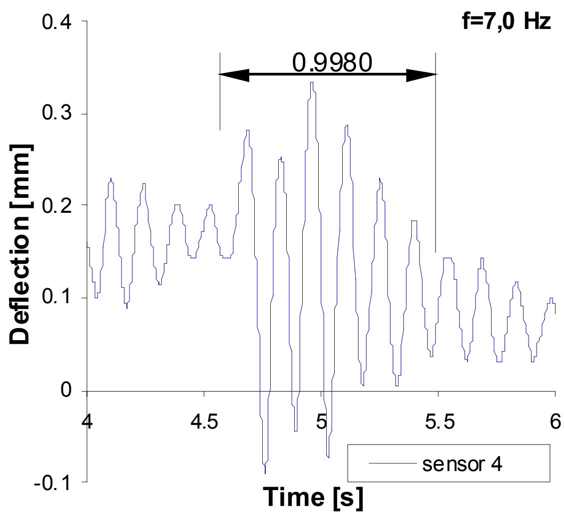


Fig. 3. Vibrations of the flyover after the vehicle ride:
a) detail A-sensor no. 6,
b) detail B-sensor no. 4.

On the basis of an analysis of the graphs, it is possible to find occurrence of the flyover vibration damping. Its reflection is an increase in the vibration amplitude in both survey points of deflection. According to expectations the flyover free vibrations frequencies f occurred in points 6 and 4 and were very similar. Vibration frequency

values recorded in points 7 and 9 were also similar. The obtained results of deflection measurements and vibration frequencies confirmed correctness of the accepted method for measurement of the flyover deflections caused by dynamic load.

2.2. Steel-ferroconcrete bridge

The bearing structure of the object is a one span, free-supported plate with span 22m. consisting of a steel grid connected with a ferroconcrete plate. The steel grid consists of 710 high beams. On the grid there is a ferroconcrete plate of thickness 0.18 to 0.29m. Its width is 16.60m The bridge is located on a horizontal curve with radius 150 m and a vertical curve with radius 600 m. The bridge supports are two ferroconcrete bridgeheads situated on piles.

Check points for geodetic measurements were situated in the upper part of the bridge, whereas, sensors were fixed under the bridge. A sketch of the survey points arrangement, have been presented in figure 4.

a) **b)**

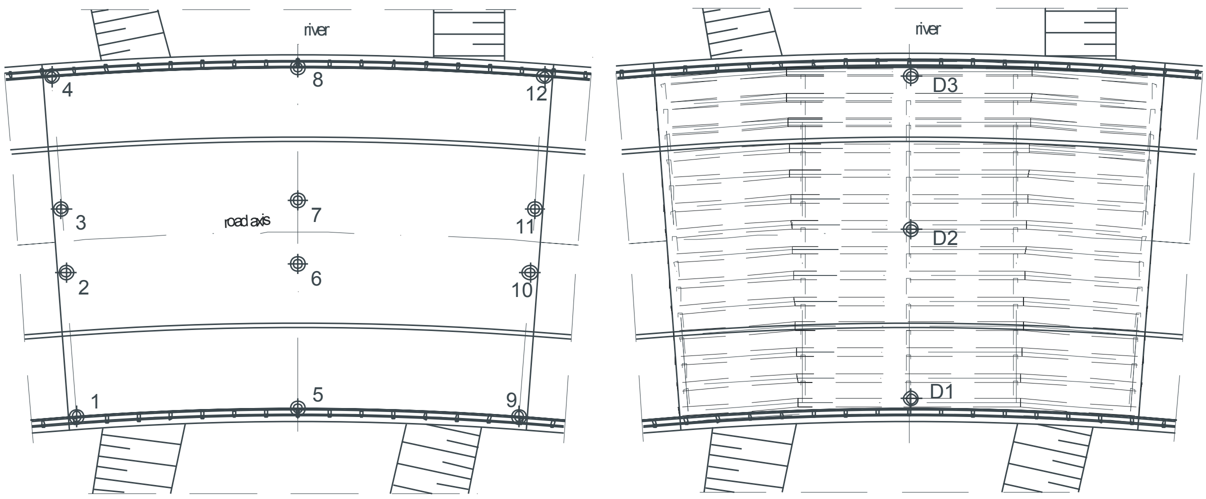


Fig. 4. A sketch of the survey points arrangement
a) on the bridge upper surface
b) on the lower surface of the steel grid girder shelves.

For test loading, 6 trucks were used with total mass 300kN. While static loading, two arrangement variants were applied (6 trucks in each).
Measurement results for points 5, 6/7, 8 and D1, D2, D3 have been shown in table 2.

Table 2. Results of displacement measurement with the use of geodetic method and induction sensors

Load variant	Measurement	Survey points								
		5 – D1			śr. 6/7 – D2			8 – D3		
		Deflections [mm]			Deflections [mm]			Deflections [mm]		
		before test	load	after test	before test	load	after test	before test	load	after test
I	geodetic	0	5.3	0.1	0	14.7	0.6	0	8.8	0.4
	sensors	0	6.4	0.2	0	15.5	0.9	0	9.9	0.6
II	geodetic	0	2.6	0.1	0	6.9	0.2	0	4.2	0.0
	sensors	0	3.1	0.0	0	7.1	0.2	0	4.6	0.1

The fact that the survey points on the bridge and under it were not situated above each other caused differences in results. Points under the bridge D were shifted toward the middle of the object in the direction of the arrows shown in figure 5.

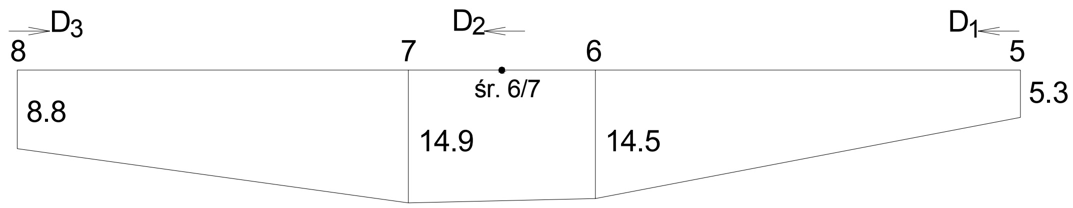


Fig. 5. Position of survey points in a cross-section and displacement.

Dynamic loads

During a dynamic test there were simultaneous rides of two trucks at the speed of 10, 30, 50 km/h. and a ride of one truck through a trunk at the speed of 30 km/h. In figure 6, there have been presented results of measurements obtained for rides of vehicles at different speeds.

On the basis of an analysis of the deflection charts (fig. 6) it can be said that regardless of the vehicle ride speed, the bridge deflections in the same survey points were comparable. In order to illustrate the observation formulated in table 3, maximum values of deflections recorded in particular points for different truck speeds, have been compared. The slight differentiation of maximum deflection values for particular speeds can be considered to be purely accidental.

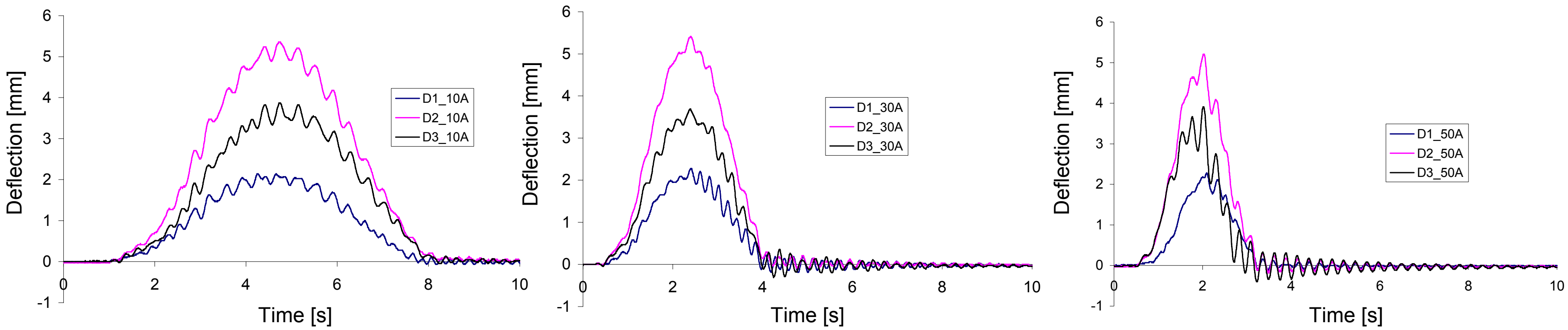


Fig. 6. The bridge deflection during a ride of vehicles with different speeds.

Table 3. Maximal deflection values

Ride speeds [km/h]	The bridge maximal deflections in survey points [mm]		
	D1	D2	D3
10	2,1	5,4	3,9
20	2,3	5,4	3,7
30	2,3	5,2	3,9

The bridge largest deflections always occurred in the point situated in the middle part of the bridge D3, in point D2 slightly smaller deflections were recorded, and the smallest ones in point D1. After each ride of a truck, the bridge vibrations were observed. They are visible on the deflection courses presented in figure 6.

3. CONCLUSION

Practical static and dynamic tests revealed high consistence of measurement results for both methods in case of static loading. Geodetic methods can be used for determination of displacements of a higher number of points, whereas, using sensors the number of points is limited merely to their existing number. Also, preparation of measurement stations poses more difficulties than installing bench marks –survey points for geometric leveling.

During dynamic tests, only a measurement by means of sensors reflects the course of the phenomenon. Results of these measurements allow to calculate dynamic coefficients, depending on the kind of the element, dynamic load scheme, speed of vehicles loading and other parameters being of interest for the constructor.

Simultaneous examination of all the spans for different load variants would be an optimal solution. Unfortunately, due to the number of geodetic devices and observers it was not possible. However, by means of a larger number of sensors, a simultaneous performance of measurements would be possible with the same accuracy and with the same service.

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