Load Testing Results of new Road Bridges In Bosnia and Herzegovina

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ABSTRACT

In this paper the results of load testing of several new road bridges constructed in Bosnia and Herzegovina are presented. Load testing of new road bridges with spans larger than 15m, prior to setting them into operation, is obligatory according to regulations in Bosnia and Herzegovina. Load testing, according to regulations, consists of static and dynamic tests, and is performed according to instructions given in the regulations.

The test results then have to be compared with the results obtained by the theoretical design model, which is also given in this paper.

INTRODUCTION

As mentioned above, all road bridges with spans larger than 15m, need to be tested after completion in order to check their behaviour by comparing tests results with the results obtained by the design model for the same test load.

The results of tests conducted on six new bridges constructed on motorway, corridor Vc, in Bosnia and Herzegovina, are given in this paper.

The purpose of this overview is to compare the obtained test results from the different bridges, designed by different designers and constructed by the different contractors, in order to investigate the quality of new bridges that are now being built in Bosnia and Herzegovina.

Also, some problems regarding bridge testing are stated in this paper.

The bridge is considered to be suitable for use if following demands are fulfilled:

- measured deflections are less than calculated ones
- permanent deflections are less than 15-25% of the maximum deflection, depending on the bridge type
- dynamic amplification factor is in the range predicted in the design
- natural period of the bridge is in the range of the theoretical value

In order to obtain above results, both static and dynamic tests needs to be performed on the bridge, using test load with efficiency between 50% and 100% with respect to the design load multiplied with the dynamic coefficient

All results given in this paper are obtained in 2012 and 2013 by the Civil Engineering and Mechanical Faculty of "Dzemal Bijedic" University from Mostar, Bosnia and Herzegovina [2], [3].

TESTING PROCEDURE

The procedure for testing of bridges with test load is given in Yugoslavian standard from 1984 [1], which is still active in Bosnia and Herzegovina.

This standard also gives information about the type of test load and the rules for analysis of the results, both for road and railroad bridges.

In general, for all new bridges, standard prescribes normal, short-term static and dynamic test load, which is applied on completely finished bridge structure, according to the prepared test program. Test program gives information about the location and the value of the test load, as well as the locations for measuring and calculation of expected deflections and deformations.

For road bridges test load normally consists out of two to four trucks loaded according to the preliminary calculations and the efficiency demands given in the standard. Prior to the test every axle of the vehicles is weighted and the distances between the axles are measured.

As mentioned above testing is divided into static and dynamic tests, in which the following measurements are conducted:

- Measurements of deflections in all spans before, during and after the test load in order to obtain maximum and accumulated deflection of the structure for the static test load.
- Measurements of deflection and natural period of the bridge for dynamic test load in the shortest span.

Dynamic test load is produced by driving one truck over an 5cm obstacle placed in the center of the shortest span which produces an impact on the structure and the dynamic deflection. The truck continues to go across the bridge creating a vibration of the structure from which the natural period of the structure is determined after the truck left the bridge.

Measured dynamic deflection is divided with the static deflection obtained from the same truck to calculate the dynamic amplification factor.

All measured values are then compared with the calculated ones using the same test load and the structural properties of the bridge.

BRIDGEs description

General information about the tested bridges is given in Table 1.

Table 3 Tested bridges information

Bridge	Type	Spans (m)	Width (m)
1	Prestressed	20+2x25+3x22.5+2x27+20	12,16
2	Prestressed	20+25+25+20	12,40
3	Prestressed	20+25+25+20	12,40
4	Prestressed	20+25+25+20	9,90
5	Reinforced concrete	16+20+20+16	9,20
6	Composite	25+4x30+25	9,35

Spans of all bridges are slabs except for composite bridge, were I beam girders were used. Bridges 2 and 3 are identical twin bridges on motorway, while others are crossing over motorway.

TEST RESULTS

In order to obtain test results for listed bridges, different test load was applied, as given in Table 2.

Table 2 Test load

Bridge	No. of Axles	No. of trucks	Truck weight (kN)	Efficiency (%)
1	4	4	370	65
2	4	4	330	70
3	4	4	330	70
4	4	2	490	72
5	4	2	490	90
6	3	4	260	52

The same test load was applied for bridges 2 and 3, as well for bridges 4 and 5, because these bridges were tested at the same time. Looking at the efficiency of the test load it is clear that it is almost impossible to achieve test load equal to the design load, because of the limitation of the axle load in regular trucks, as well as the distances between the axles.

Measurements for the static test load was conducted using a high precision geodetic leveling method with 0.1mm accuracy, and for the dynamic test, measurements were conducted using a accelerometers and displacement sensor both connected to Spider 8 amplifier device. Also strain gauges were used in some cases, although it is not obligatory according to standard.

Maximum measured and calculated deflections due to static load are shown in Table 3 for each bridge.

Table 3 Maximum deflections

Bridge	Measured deflection (mm)	Calculated value (mm)	Permament deflection (mm)	Ratio between permanent and maximum value
1	5,87	6,72	0,95	16,18%
2	4,90	5,02	0,40	8,16%
3	5,00	5,02	0,90	18,00%
4	2,90	3,73	0,50	17,24%

5	4,10	4,30	0,50	12,19%
6	10,00	11,19	1,00	10,00%

Based on the results given in Table 3, it is clear that the behavior of all bridges is the same like the behavior predicted in the design, as well as that the value of accumulated deflection is less than allowed, which corresponds to the demands given in the standards.

Also, it is important to say that all bridges have retain their initial stiffness during load tests which is proven by taking the design stiffness into account when calculating test load deflections which shows good correlation with the measured values.

However, it is also important to mention that the determination of the permanent deflection after the completion of the test is very difficult for small spans due to low values of the deflections and measurement error of the geodetic devices. Therefore it is very useful to make control measurements with different devices whenever it is possible, but especially on bridges with smaller spans.

One of the main purposes of dynamic testing is to determine dynamic amplification factor, which is calculated as a ratio between static and dynamic deflection. The values of static and dynamic deflection in time are given in following Figures 1 to 6. In this Figures deflection is measured in mm, and time is displayed in seconds.

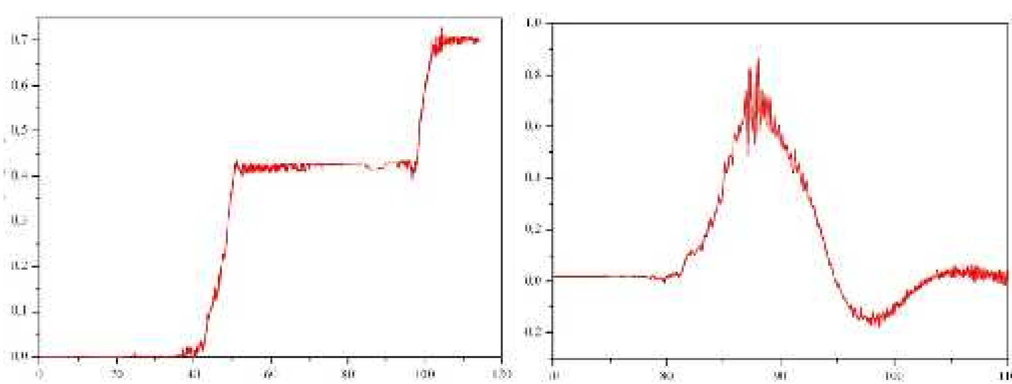

Figure 1 Static and dynamic deflection for bridge 1

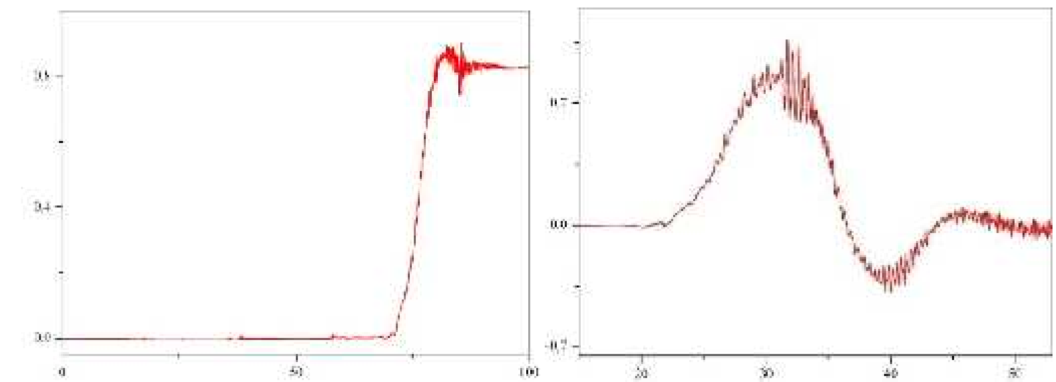

Figure 2 Static and dynamic deflection for bridge 2

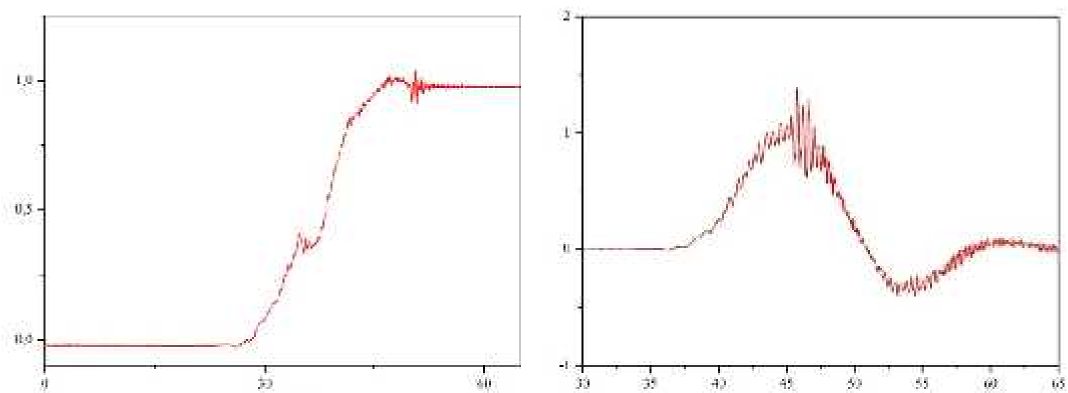

Figure 3 Static and dynamic deflection for bridge 3

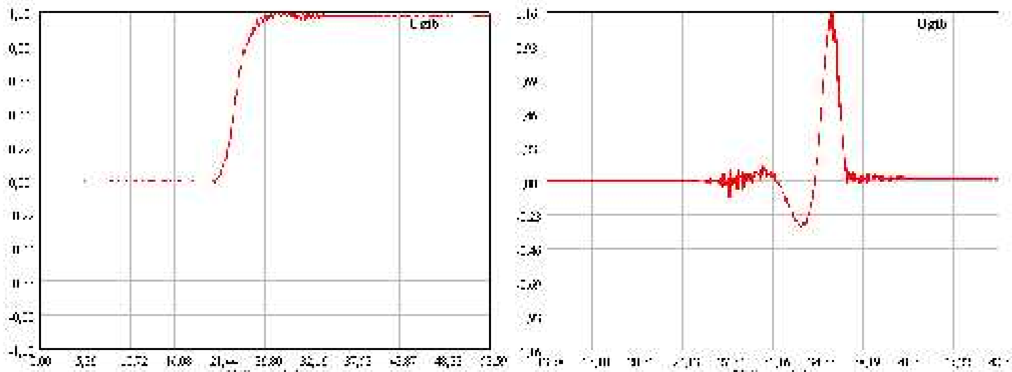

Figure 4 Static and dynamic deflection for bridge 4

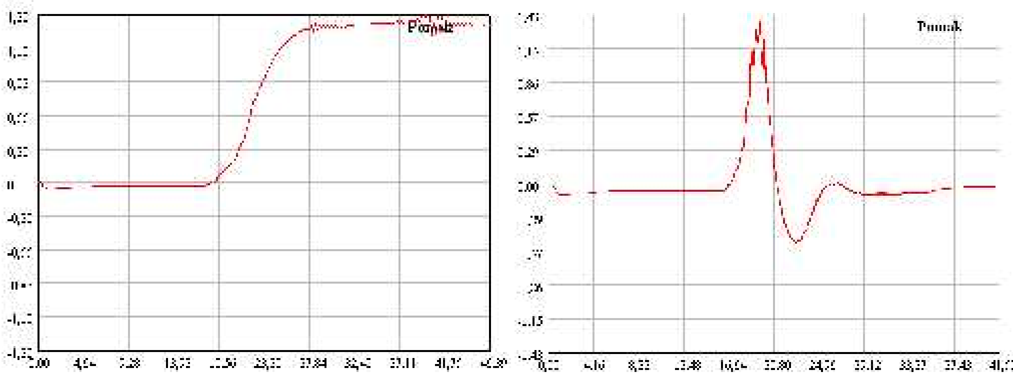

Figure 5 Static and dynamic deflection for bridge 5

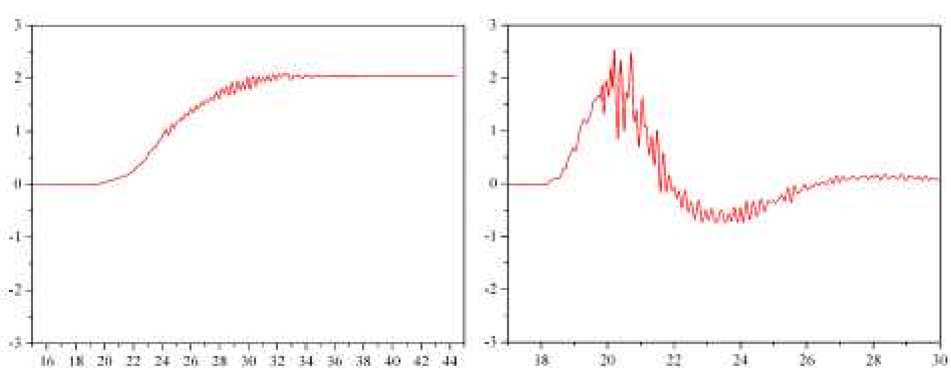

Figure 6 Static and dynamic deflection for bridge 6

Each of these deflections was measured in the shortest span of the bridge, since the highest dynamic amplification factor is obtained there, according to the regulations.

Dynamic amplification factor is obtained in the design using the following equation:

$$k_d = 1{,}4 - 0{,}008 \cdot l \qquad (1)$$

Where l is the span of the bridge.

Based on the measurement results showed in Figures 1 to 6 it is possible to calculate the dynamic amplification factor and to compare it with the value from the design, Table 4.

Table 4 Dynamic amplification factors

Bridge	Static deflection (mm)	Dynamic deflection (mm)	Dynamic amplification factor	Design value k_d
1	0,701	0,86	1,227	1,24
2	0,90	1,05	1,16	1,24
3	0,95	1,15	1,21	1,24
4	1,07	1,16	1,08	1,24
5	1,30	1,43	1,10	1,27
6	2,036	2,32	1,139	1,16

As seen in Table 4, dynamic amplification factors calculated from measured deflections are in the range of amplification factors predicted in the design process.

Beside the dynamic amplification factor, during dynamic test, the natural period of the bridge is also determined, using accelerometer placed also in the shortest span of the bridge.

Accelerometer is used to measure the bridge acceleration, during, and after the dynamic impact of the truck, which can be shown in the diagram, Figure 7.

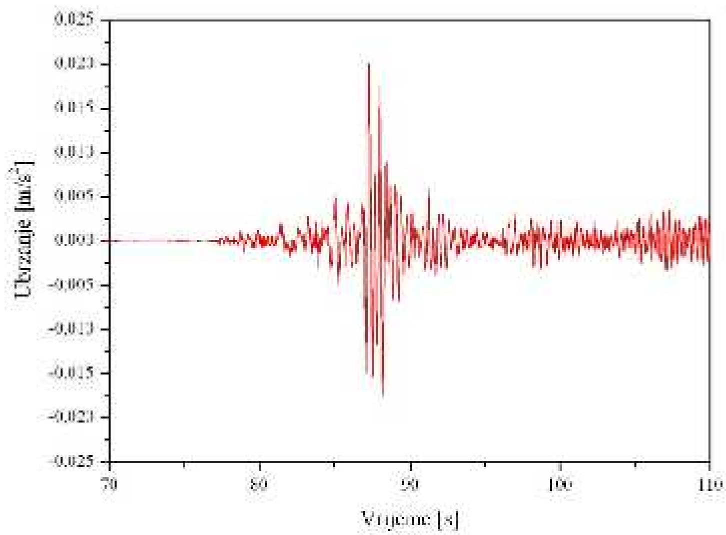

Figure 7 Typical diagram of bridge acceleration

Natural period of the bridge or fundamental vibration frequency of the bridge is determined by displaying the measured acceleration in frequency domain, Figure 8.

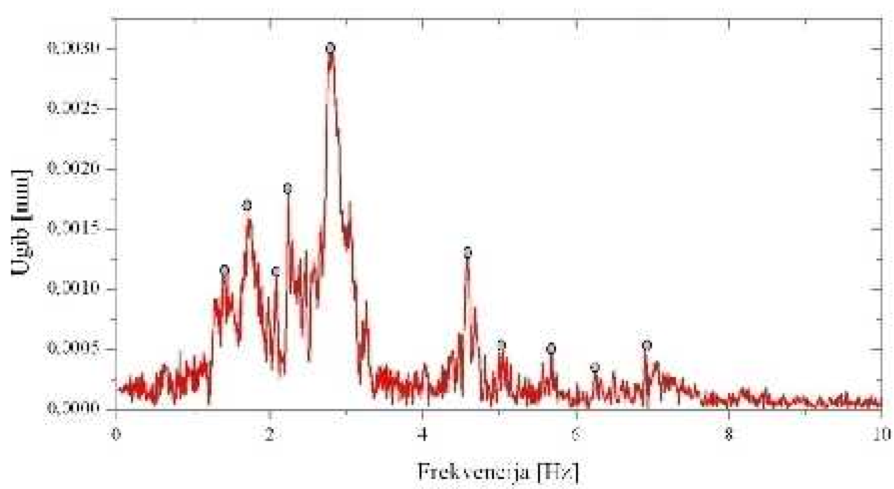

Figure 8 Typical diagram of vibration frequencies

These measured frequencies are then compared with the values obtained from the design model, Table 5.

Table 5 Fundamental vibration frequencies

Bridge	Fundamental vibration	f_1 (Hz)	f_2 (Hz)	f_3 (Hz)

	frequencies			
1	measured	1,4	1,7	2,1
	calculated	0,85	1,11	1,2
2	measured	1,36	2,07	2,52
	calculated	1,27	1,52	2,0
3	measured	1,30	2,49	3,21
	calculated	1,27	1,52	2,0
4	measured	1,7	2,0	2,3
	calculated	1,621	1,92	3,65
5	measured	2,4	3,4	3,8
	calculated	2,09	4,25	4,62
6	measured	2,6	2,9	3,4
	calculated	2,81	2,97	3,23

Based on the results given in Table 5 it can be concluded that the measured values are in the range of the theoretical values obtained in the design model. However, theoretical values calculated using the design model, are depended on the soil stiffness which is very difficult to determine accurately. Therefore, it is important not to misjudge the measured values of the fundamental vibration frequencies due to potential errors in the values of the soil stiffness.

CONCLUSION

Results for all bridges presented in this paper show that the bridges are suitable for use, since they meet the requirements given by the standards. However in same cases when the results are very near the limit values, special consideration is necessary not to misjudge the results due to measurement errors or errors in the design model.

This is mostly the case for bridges with smaller spans (between 15 and 20m) were the values of deflections are smaller and therefore the measurement errors, when given as percentages, become higher. In this cases some of the demands given in standards might not be fulfilled, which means that the bridge needs to be tested again or repaired if it failed the test again.

In order to avoid these mistakes it is recommended, if possible, to make double measurements using more precise and reliable measuring devices such as displacement sensors mounted below the bridge using scaffolding. In most cases this is only possible in the end spans, which are also the shortest ones in most cases, so it is sufficient to make control measurements only in those spans.

Measurements of strains makes sense only in steel parts of the bridge, since the exact value of modulus of elasticity for concrete is often unknown and therefore it is impossible to accurately calculate the stress from strains measurements.

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