# DYNAMIC EFFECTS CAUSED BY THE VEHICLE-BRIDGE INTERACTION

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## ABSTRACT

*This paper presents research on the interaction between a bridge and a vehicle moving over it. A vehicle moving over a bridge causes dynamic effects that can be indicated by different dynamic parameters like – natural frequency, bridge logarithmical decrement, bridge acceleration and dynamic amplification factor (DAF). The dynamic amplification factor is the most widely used parameter included in design codes, because it shows amplification of the static effects on a bridge structure. The results show that a bridge carriageway's condition significantly influences DAF.*

**Key words:** bridge, vehicle-bridge interaction, dynamic amplification factor

## INTRODUCTION

Dynamic force induced by vehicle-bridge interaction plays a significant role in the design of a bridge. Dynamic vehicle-bridge interaction results in an increase of bridge deformations that are described by DAF, it shows how many times static load should be increased to cover additional dynamic effect (Fryba 1996).

Dynamic vehicle load on a bridge depends on the dynamic properties of the vehicle, dynamic properties of the bridge, vehicle speed and bridge surface roughness. Although additional dynamic load usually does not lead to major bridge failures, dynamic vehicle load can cause problems that later contribute to fatigue, surface wear rapid deterioration and cracking of concrete that leads to reinforcement corrosion (Cebon 1999). It decreases bridge lifetime and increases the cost of maintenance for the structure.

This paper presents 4 composite bridge dynamic load test results performed from 2009 to 2014.

## MATERIALS AND METHODS

### Loads

To evaluate bridge dynamic response it is very important to know the moving load and bridge parameters. Evaluation methods of the moving load over bridges and possible solutions have been analysed by Fryba (1999), Law, Chan and Zeng (1997). The dynamic load is time varying and depends on various criteria like: vehicle type, vehicle weight, vehicle axle configuration, bridge material, bridge span length and road roughness.

EN 1991-2 (2003) does not exactly indicate how dynamic load should be evaluated in the design, but the dynamic effect is accounted by multiplying the static live load by the DAF or is a built-in value of a live load model. In general codes, the DAF is given as a function of the bridge span length. However, the obtained load test results showed the DAF dependence on the road surface conditions, vehicle weight and passing speed.

In the EN 1991-2 (2003) Actions on structures, Part 2 Traffic loads on bridges, the load models have built-in DAF values, which depend only on the shape of the influence line and bridge length (Cantero, Gonzalez, O`Brien 2009). The DAF values used in the EN 1991-2 (2003) for a 2-lane bridge roadway are presented in Fig.1.

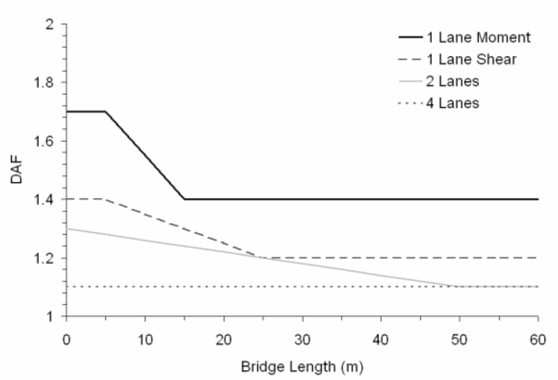


**Figure 1.** DAF – dynamic amplification factor built- in values in the EN 1991-2 (2003) (Bruls, Calgaro 1996)

### Vehicle – bridge interaction

Two sets of equations can be used to express the bridge-vehicle interaction: one for the vehicle and another for the bridge. The two systems interact with each other through contact forces - the forces induced at the contact points between the wheels and the pavement surface of the bridge. This problem is non-linear and time-dependent due to the fact that the contact forces may move from time to time, while their magnitudes do not remain constant as a result of the relative movement of the subsystems (Anon 1992). Because of the nonlinearity of the problem, the mathematical calculation of the dynamic response is very complex, hence a live scale load testing is used to find the dynamic properties of the bridge structure.

### Dynamic load testing

The national standard *LVS 190-11 "Bridge inspection and load testing"* in Latvia requires a new bridge with non-standard structure to be tested with live load. This testing also includes the dynamic testing of the bridge. The dynamic load tests give information about the natural frequency and damping of the bridge including the variations of the DAF.

As a dynamic load a loaded truck with an approximate weight of 30 t is used. The passage of the loaded truck creates the most real dynamic effect on the structure, hence giving reasonably accurate dynamic results. Dynamic properties of the bridge were found in the vibration response diagrams. The vibration responses were obtained by the vibration sensor Noptel PSM-200. Examples of the obtained vibration responses are given in Fig. 2. The transmitter can be at a distance from 1 to 350 meters from the receiver, depending on the environmental conditions. As a vibration inducer vehicles passing the bridge roadway with speeds of 20km/h and 40 km/h are used.

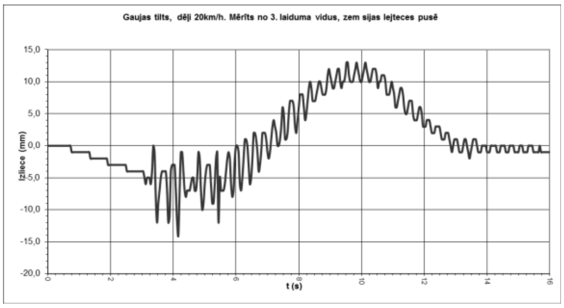


**Figure 2.** The Vibration response diagram obtained by the Noptel PSM-200

The dynamic load test includes the vehicle driving over two different roadway conditions - an even and uneven pavement. The uneven pavement is used to model damages (damaged pavement or ice caused bumps) on the bridge pavement surface. The bumps in the pavement surface will be formed with timber planks approximately 5 cm high and 10 cm wide installed on the path of the vehicles. The length of the planked roadway depends on the length of the span and could cover approximately 2/3 of it. The distance between the planks is approximately 3 to 3.5 m.

### Dynamic effects

The dynamic effects on the bridge can be indicated by different dynamic parameters. Most common dynamic parameters are the DAF, bridge natural frequency and bridge span acceleration. Bridge design codes like EN 1991-2 and AASHTO (1996) consider the DAF as the most useful parameter for design purposes; hence DAF is introduced in the bridge design codes. The DAF for a bridge is defined as the maximum total load (including dynamic part) effect divided by the maximum static load effect (Brady, O'Brien, Znidaric 2006):

$$DAF = \frac{\varepsilon_{(dyn)}}{\varepsilon_{(stat)}} \qquad (1)$$

where $\varepsilon_{(stat)}$ – maximum static response (stress, strain or deflection), $\varepsilon_{(dyn)}$ – maximum dynamic response (stress, strain or deflection) .

Another important parameter is a bridge's natural frequency that strongly depends on the span structural system, cross section type and material, construction type, bearing conditions and other parameters.

A natural frequency for two to three span structures can be found if the stiffness and mass of the structure is given (Beards 1996):

$$f = \frac{\pi}{2 \cdot L^2} \sqrt{\frac{EI}{m}} \qquad (2)$$

where, L is – span length, EI is – structure stiffness, m is – mass of the span.

For considered bridges natural frequency and period was calculated using FEM software LIRA model.

## RESULTS AND DISCUSSION

Four new composite bridge's dynamic parameters designed according to EN 1991-2 (2003) load model LM1 are discussed in this paper. Bridge parameters are given in Table 1.

### Natural frequency

Natural frequency for structures was calculated using FEM software LIRA and calculated results for the first mode shape are given in Table 1. Fig. 3 shows natural frequency correlation with bridge span length. For all bridges measured the natural frequency is between 2 and 4 Hz that is the recommended value. Moreover, for all bridges except the bridge in Valmiera, the measured natural frequency exceeds the calculated first mode shape frequency but does not exceed the second mode shape. It can be noted, that the bridge in Valmiera has non uniform cross section beams and hence the structure is more slender and can perform in a more elastic mode.

**Table 1**

**Composite bridge parameters**

| Nr. | Bridge | Span length (m) | Bridge width(m) | Natural frequency measured, Hz | 1st mode Natural frequency calculated, Hz |
|---|---|---|---|---|---|
| 1. | Bridge over Venta (transport channel) in Ventspils | 19.5 | 12.11 | 2.9 | 2.62 |
| 2. | Bridge over Venta in Ventspils (span 8-9) | 40 | 19.2 | 3.5 | 3.1 |
| 3. | Bridge over Gauja in Valmiera | 36.27 | 13.00 | 3.6 | 2.95 |
| 4. | Bridge over Mūsa in Bauska | 43.5 | 15.00 | 2.83 | 2.95 |

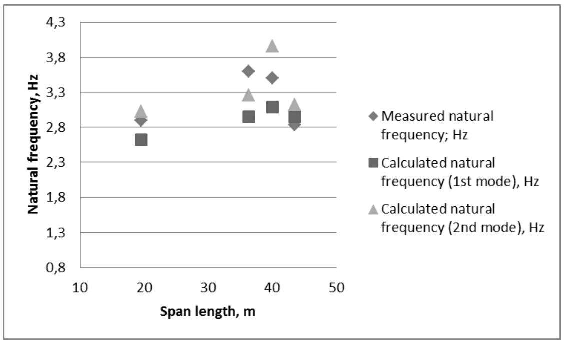


**Figure 3**. Calculated and measured natural frequency dependence on span length

Figure 4 shows first and second mode shape of bridge over Gauja in Valmiera.

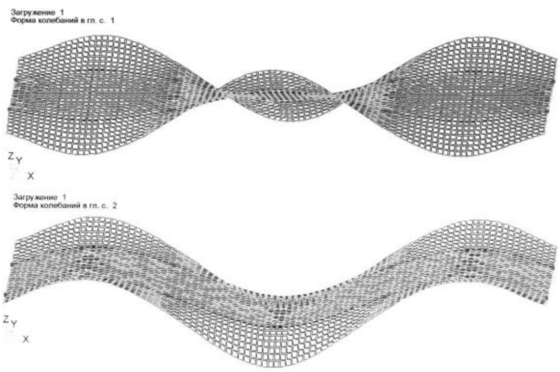

**Figure 4.** 1st and 2nd mode shape of bridge over Gauja in Valmiera

**Dynamic amplification factor**

Figure 5 shows DAF values for selected composite bridges. The values that were measured when the vehicle was driving over an even pavement are inside the range 1 and 1.4 used in EN 1991-2 (2003), however DAF values that were obtained for vehicle driving with speed 20km/h over uneven surface were much higher than recommended.

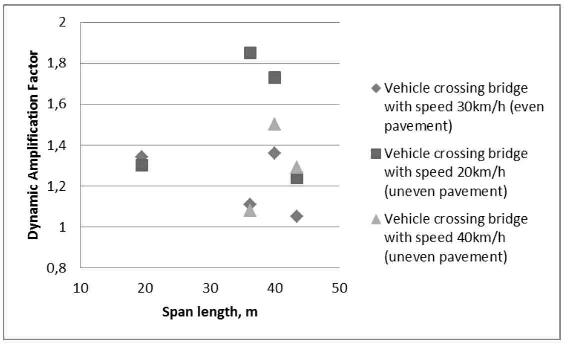


**Figure 5.** DAF dependence on span length

Figure 5 also shows that the span length is not the only parameter that influences the DAF values for a bridge and that there are many other factors that need to be considered when the DAF is being determined.

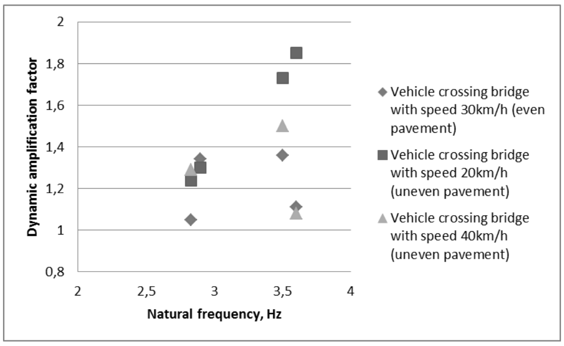


**Figure 6.** DAF dependence on natural frequency

Figure 6 shows that for composite bridges there is no correlation between the DAF and natural frequency, but there is a tendency for vehicles passing a bridge with 20 km/h over an uneven surface to increase the DAF. Fig. 5 and fig.6 show that for an uneven pavement the DAF values increase, also this value significantly depends on the vehicle's speed. For lower speeds the DAF values are higher, hence it has much more of an influence on the bridge load carrying capacity.

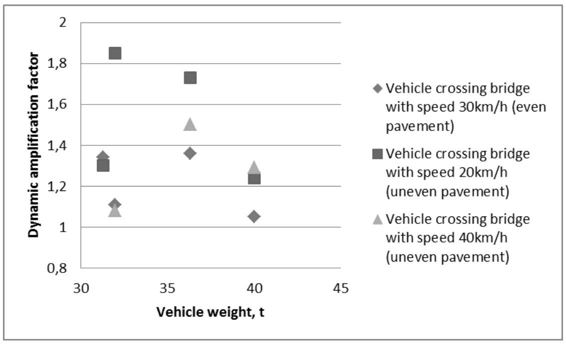


**Figure 7.** DAF dependence on vehicle weight

Figure 7 shows that for vehicles with a weight up to 40 t there is not much correlation with the DAF values. However for vehicles with a weight over 35 t, DAF tends to decrease.

## CONCLUSIONS

1) Results show that for the bridge dynamic response, the carriageway surface condition is a very important factor. Deteriorated bridge surfaces and heavy vehicles can significantly increase the DAF values thus accelerating the deterioration process of the structure.
2) Results also show that natural frequency correlated with the DAF - for higher natural frequency values the DAF values increased for the vehicle speed of 20km/h over an uneven pavement surface.
3) Overall the DAF values for an even pavement were within 1.0 and 1.4 and are in the range proposed in the EN 1991-2 (2003). Hence the proposed values are reasonable for good pavement condition.

## ACKNOWLEDGMENT

The research leading to these results has received funding from the Latvia state research programme under the grant agreement "INNOVATIVE MATERIALS AND SMART TECHNOLOGIES FOR ENVIRONMENTAL SAFETY, IMATEH".

## REFERENCES

AASHTO (1996) *Standard Specification for Highway bridges*, American Association of State Highway and Transportation, Washington, D.C.

Anon, A. (1992) *Report of the OECD Working group IR2 on the Dynamic Loading of Pavements*, OECD, Paris, France.

Beards, C. F. (1996) *Structural vibration: analysis and damping*, Butterworth – Heinemann publications, p. 150–152.

Brady, S. P.; O'Brien, J. O.; Znidaric, A. (2006) Effect of vehicle velocity on the dynamic amplification of a vehicle crossing a simply supported bridge, *Journal of Bridge Engineering* 11(2): 241–249. http://dx.doi.org/10.1061/(ASCE)1084-0702(2006)11:2(241)

Bruls, A.; Calgaro, J. A.; Mathieu, H.; Prat, M. (1996) *ENV1991 – Part 3: the main models of traffic loads on bridges: background studies*. IABSE Colloquim, Delft. The Delft: IABSE, 215–228.

Cantero, D.; González, A.; O'Brien, E. J. (2009) Maximum dynamic stress on bridges traversed by moving loads, *Proceedings of the ICE – Bridge Engineering* 162(BE2): 75–85. http://dx.doi.org/10.1680/BREN.2009.162.2.75

Cebon, D.(1999*). Handbook of vehicle-road interaction*, London: Taylor & Francis.

European standard. Eurocode 1991-2. (2003) *Actions on structures - Part 2: Traffic loads on bridges*. EN 1991-2:2003.

Fryba, L. (1996). *Dynamics of Railway Bridges. 2-nd ed.*, London: Thomas Telford. http://dx.doi.org/10.1680/dorb.34716

Fryba, L. (1999). *Vibrations of Solids and Structure Under Moving Loads*, 3-rd.ed., London: Thomas Telford.

LVS 190-11:2009 "Bridge inspection and load testing"(in Latvian)

S. S. Law, T. H. T. Chan, and Q. H. Zeng. (1997) Moving force identification: a time domain method, *Journal of Sound and Vibration, vol. 201, no. 1*, pp. 1–22.