*Maintenance, Monitoring, Safety, Risk and Resilience of Bridges and Bridge Networks – Bittencourt, Frangopol & Beck (Eds)*


# Traffic load effects on dynamic bridge performance

I.Paeglite &J.Smirnovs & A.Paeglitis
*Department of Roads and Bridges, Riga Technical University, Riga, Latvia*

ABSTRACT: Bridge performance is affected by bridge material, bridge system, loading type and other internal and external factors. A moving truck generates a dynamic response which is greater than static because of the interaction between the moving vehicle and bridge structure hence it can accelerate deterioration process of the bridge. To evaluate the influence of the passing truck, structural codes require that static live load is multiplied by dynamic amplification factor (DAF) or is a built-in value of a live load model. Road surface deterioration of existing bridges influence bridge performance hence DAF from field measurements can be higher than values specified in design codes that target new bridges. The paper presents and discusses a research about traffic load effect on the bridge structure. Results show that uneven pavement condition significantly increases DAF values for low vehicle speed.

## 1 INTRODUCTION

In recent years traffic volume on the Latvian roads has significantly increased. Although there is a restriction on an axial load of 11,5 t and special permit is necessary if heavy vehicle axle load exceeds 13 t, proportion of overweight transport is increasing. Many bridges in the main roads has been built more than fifty years ago hence it is important to make a proper inspection of structures and determine cause of the increasing deterioration of the bridge condition.

Traffic load on the bridge has a stochastic nature hence to predict an exact loading on a bridge is almost impossible. Probabilistic methods are used to find the most probable loading. Weight-in-motion (WMA) systems installed on roads have been used to record real traffic data including axle number and axle weight on the vehicle. WIM system was installed in Latvia in 2002 in the crossing of the roads A4 and A6 hence it was possible to obtain first data about traffic composition. In 2011 sensors were found totally destroyed by the traffic. These data were analysed by Paeglitis.An. (2012) and traffic contents obtained.

Although traffic contents are important information, bridge load carrying capacity is more influenced by effect that loading cause on the structure. Traffic load is a dynamic load hence it is important to understand dynamic behaviour and possible effects from moving vehicles. The dynamic load is time varying and depend on various criteria like: vehicle type, vehicle weight, axle configuration, bridge material, bridge span length, road roughness and transverse position of the truck on the bridge.

This paper presents results of 3 bridge dynamic load tests performed from 2009 to 2012.

## 2 DYNAMIC LOAD

Dynamic force induced by the vehicle-bridge interaction plays a significant role in the design of a bridge. Dynamic load results in an increase of the bridge deformations that are described by DAF, it shows how many times static load should be increased to cover additional dynamic effects was studied by 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 was studied by Cebon (1999). It decreases bridge lifetime and increase the maintenance cost of the structure.

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).

EN 1991-2 (2003) do not exactly indicate how dynamic load should be evaluated in the design, but there dynamic effect is accounted by multiplying the static live load by DAF or are a built-in value of a live load model. In general, in codes, the DAF is given as a function of the bridge span length. However, the obtained load test results showed DAF dependence on the road surface conditions 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 was analysed by Cantero, Gonzalez, O`Brien (2009). The DAF values used in the EN 1991-2 (2003) for 2-line bridge roadway are presented in the figure 1.

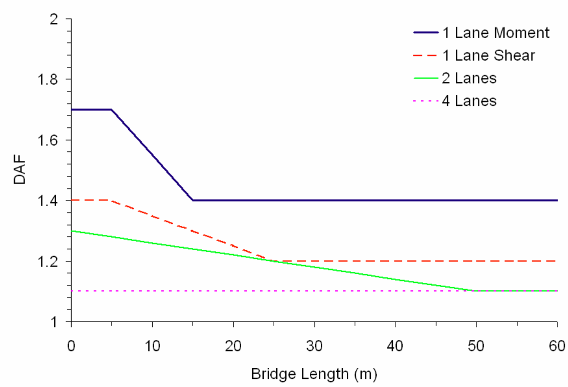


Figure 1: DAF – dynamic amplification factor built-in in the EN 1991-2 (2003) Bruls, Calgaro (1996).

## 3 DYNAMIC TESTING METHODS

Dynamic effects on the bridge can be indicated by different dynamic parameters. Most common dynamic parameters are DAF, bridge natural frequency and damping ratio.

These parameters can be found from experimental measurements. In past 15 years development in modal analysis methods has led to Operational modal analysis (OMA) for civil engineering structures. Using this method is enough with ambient vibration on the bridge to find mode shapes, natural frequencies and damping ratios. This method was studied by Brincker (2000).

DAF, natural frequency and damping can be determined also from deflection measurements that was used in experiments performed in this research.

National standard LVS 190-11 "Bridge inspection and load testing" in Latvia require a new bridge with non-standard structure to be tested with live load. This testing consists of static and dynamic load testing. The dynamic load tests gives information about the natural frequency and damping of the bridge including the variations of the DAF.

As a dynamic load a loaded truck with weight about 30 t is used. The passage of a loaded truck makes the most real dynamic effect on the structure hence it gives the reasonably accurate dynamic results. Dynamic properties of the bridge were found from the vibration response diagrams.

The dynamic responses were obtained by vibration sensor Noptel PSM-200. An example of the obtained vibration response is given in figure 2. The transmitter can be placed at a distance of 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.

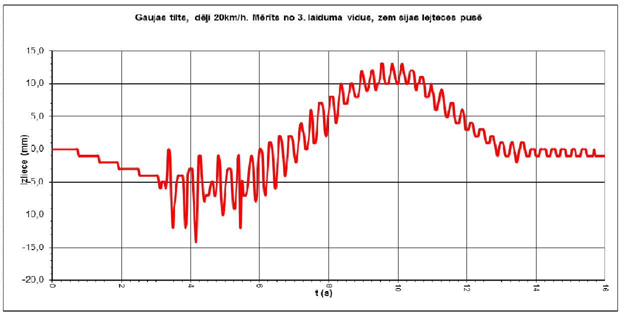


Figure 2: The Vibration response diagram obtained by the Noptel PSM-200

The dynamic load test includes the vehicle driving over two different roadway conditions - even and uneven pavement. 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.

## 4 DYNAMIC EFFECTS

Bridge design codes like EN 1991-2 and AASHTO (1996) consider DAF as most useful parameter for design purposes; hence DAF is introduced in the bridge design codes. 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) .

Other important parameter is bridge natural frequency that strongly depends on the span structural system, cross section type and material, construction type, bearing conditions and others parameters.

Damping of the structure was determined from vibration response diagrams.

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

## 5 DESCRIPTION OF THE BRIDGES

Two new composite bridge and one steel bridge dynamic parameters designed according to EN 1991-2 (2003) load model LM1 are discussed in this paper.

*Bridge over Venta River (transport channel) in Ventspils.*

Bridge consists of 4 spans with length 39 m, carriageway width 12,11 m. Bridge elevation and cross section and first mode shape are given in figures 3,4 and 5 respectively. Cross section consists of 6 plate girders that are bolted together with cross girders. Bridge load testing was performed in 2010. Deflections were measured in the middle of the bridge. FE model constructed as a plate-beam 3D system.

Figure 3: Bridge over Venta River elevation

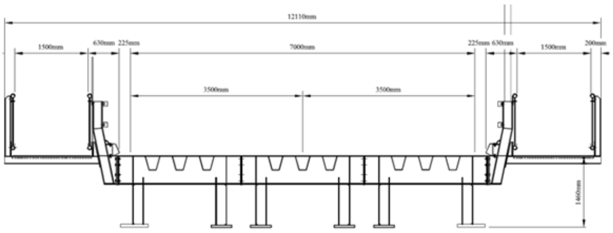

Figure 4: Bridge over Venta River cross-section

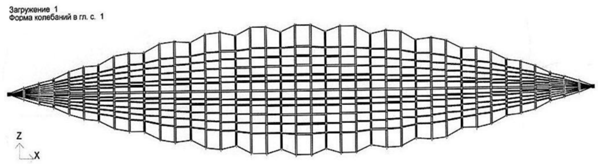

Figure 5: Fist mode shape

*Bridge over Venta in Ventspils (span 8-9)*

Bridge consists of 9 spans with different length. Loaded span length 32,7 m, carriageway width 19,2m. Bridge elevation and cross section and first mode shape is given in figures 6,7 and 8 respectively. Cross section consists of 9 plate girders and concrete deck. Bridge load testing was performed in 2010. Deflections were measured in the middle of the bridge. FE model constructed as a plate-beam 3D system.

Figure 6: Bridge over Venta River

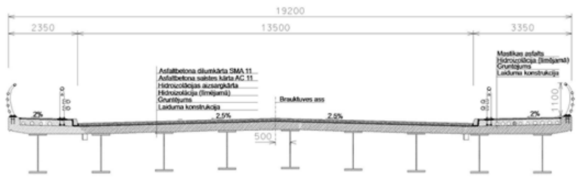


Figure 7: Bridge over Venta River cross section

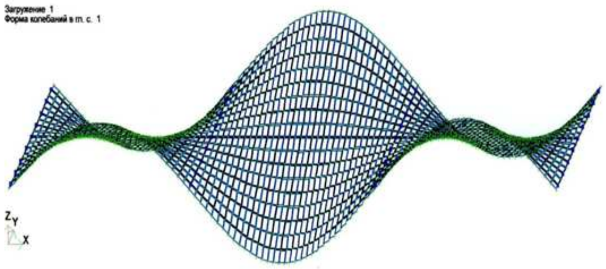

Figure 8: First mode shape of bridge over Venta River

*Bridge over Gauja in Valmiera*

Bridge consists of 3 spans – 27,22m + 36,27 + 27,22m. Loaded span length 36,27 m, carriageway width 13,0m. Bridge elevation and cross section and first mode shape is given in Figures 9,10 and 11 respectively. Cross section consists of 2 plate girders and concrete deck. Bridge load testing was performed in 2012. Deflections were measured in the middle of the bridge. FE model constructed as a plate-beam 3D system.

Figure 9: Bridge over Gauja River

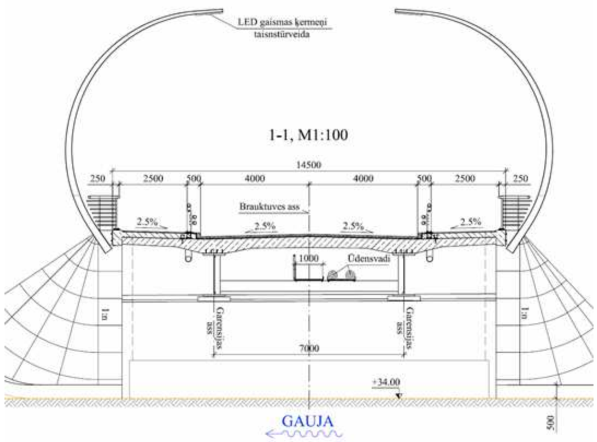


Figure 10: Bridge over Gauja River cross section

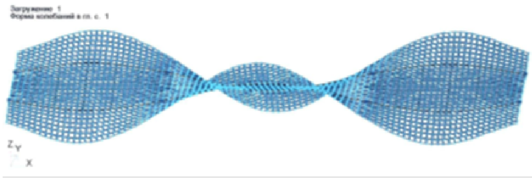

Figure 11: 1st and 2nd mode shape of bridge over Gauja in Valmiera.

## 6 DYNAMIC CHARACTERISTICS

### *6.1 Natural frequency*

Natural frequencies for structures were calculated using FEM software LIRA and calculated for first mode shapes are given in table 1. Figure 12 shows natural frequency correlation with bridge span length. For all bridges measured natural frequency is between 2 and 4 Hz that is recommended value for 1$^{st}$ mode frequency. Moreover, for all bridges except bridge in Valmiera, measured natural frequency exceed calculated first mode shape frequency but does not exceed second mode shape. It can be noted, that bridge in Valmiera has non uniform cross section beams and hence structure is more slender and can perform in a more elastic mode.

Table 1. Natural frequency of the bridges

| Nr. | Bridge | Natural frequency measured, Hz | 1$^{st}$ mode Natural frequency calculated, Hz |
|---|---|---|---|
| 1. | Bridge over Venta (transport channel) in Ventspils | 2,9 | 2,62 |
| 2. | Bridge over Venta in Ventspils (span 8-9) | 3,5 | 3,1 |
| 3. | Bridge over Gauja in Valmiera | 3,6 | 2,95 |

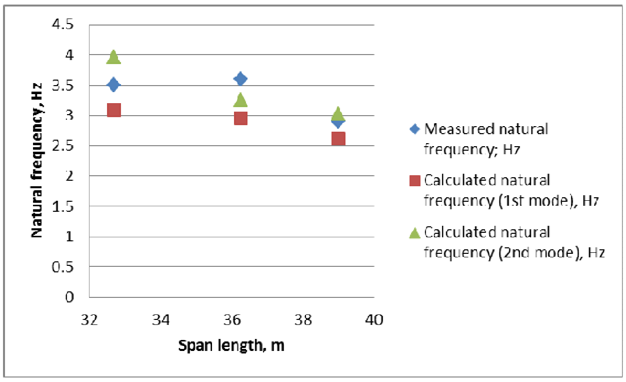


Figure 12: Calculated and measured natural frequency dependence on span length.

### 6.2 *Dynamic amplification factor*

Figure 13 shows DAF values for selected bridges. Values that were measured when 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. For bridge in Valmiera with span length 36 m, difference between DAF value for even and uneven pavement is significant. This increase in DAF can be caused by more elastic system as there are only 2 girders.

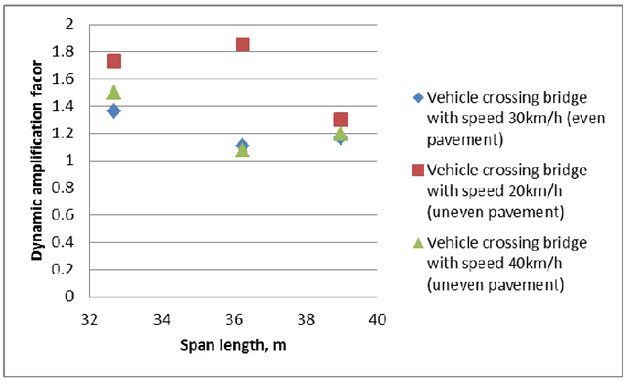


Figure 13: DAF dependence on span length.

Figure 13 also show that the span length is not the only parameter that influences DAF values for a bridge and there are many other factors that need to be considered when DAF is being determined.

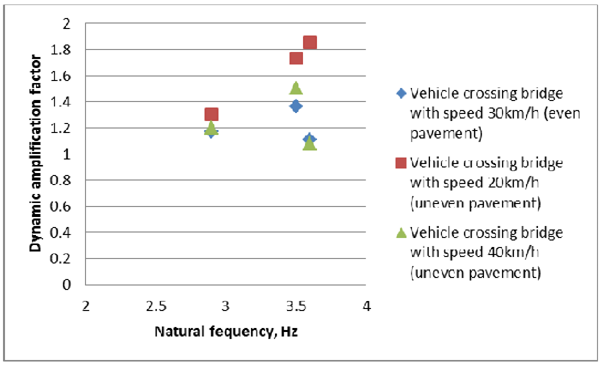


Figure 14:. DAF dependence on natural frequency

Figure 14 show that for composite bridges there is no correlation between DAF and natural frequency, but there is tendency for vehicle passing bridge with 20 km/h over uneven surface to increase DAF. Figure 13 and figure14 show that for uneven pavement DAF values increase, also this value significantly depend on the vehicle speed. For lower speeds DAF values are higher hence it much more influence bridge load carrying capacity.

Fig. 15 show that for vehicles with weight up to 40 t there in not much correlation with DAF values. However for vehicles with weight over 35 t DAF tend to decrease.

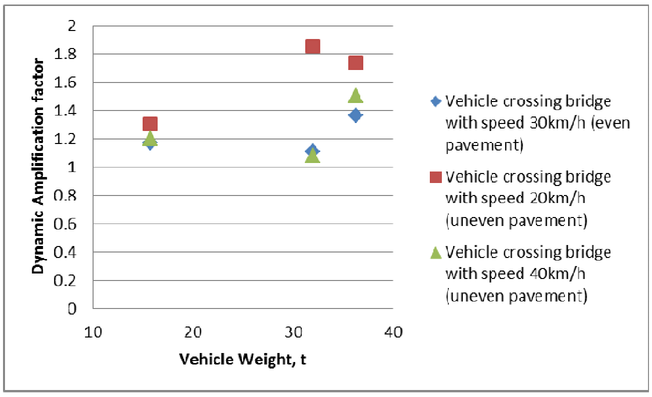


Figure 15: DAF dependence on vehicle weight.

## 7 CONCLUSIONS

Results show that for bridge dynamic response carriageway surface condition is a very important factor. Deteriorated bridge surface and heavy vehicles can significantly increase DAF values hence accelerating deterioration process of the structure.

Results also show that natural frequency correlated with DAF - for higher natural frequency values DAF values increased for vehicle speed 20km/h over uneven pavement surface.

Overall DAF values for even pavement were within 1,0 and 1,4 and are in the range proposed in the EN 1991-2 (2003). Hence proposed values are reasonable for good pavement condition.

## AKNOWLEDGMENT

The research leading to these results has received the funding from Latvia state research programme under 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)

Brincker,R., Zhang,L., and Andersen P. (2000). Modal identification from ambient responses using frequency domain decomposition, Proc., 18th Int. Modal Analysis Conference, Society of Experimental Mechanics, Inc.,Bethel, Feb.,San Antonio, Tex., 625 – 630.

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)

Paeglite I, Paeglitis A, (2013) The Dynamic Amplification Factor of the Bridges in Latvia. // Journal Procedia Engineering,2013, pp. 851-858., 10.1016/j.proeng.2013.04.108

Paeglitis An., Paeglitis Ai. (2012.) Investigation and upgrading of a historical multispan arch masonry Bridge. In: Biondini, F., Frangopol, D., M. (Eds). Bridge Maintenance, Safety, Management, Resilience and Sustainability. ISBN: 978-0-415-62124-3, Taylor&Francis Group, London, 1086-1093.

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.