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Dynamic Amplification Factors of Some City Bridges

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***Abstract*—**Paper presents a study about dynamic effects obtained from the dynamic load testing of the city highway bridges in Latvia carried out from 2005 to 2012. 9 prestressed concrete bridges and 4 composite bridges were considered. 11 of 13 bridges were designed according to the Eurocodes but two according to the previous structural codes used in Latvia (SNIP 2.05.03-84**)**. The dynamic properties of the bridges were obtained by heavy vehicle passing the bridge roadway with different driving speeds and with or without even pavement. The obtained values of the Dynamic amplification factor (DAF) and the bridge natural frequency were analyzed and compared to the values of built-in traffic load models provided in Eurocode 1. The actual DAF values for even bridge pavement in the most cases are smaller than the value adopted in Eurocode 1. Vehicle speed for uneven pavements significantly influence Dynamic amplification factor values.

***Keywords*—**Bridge, dynamic effects, load testing, dynamic amplification factor.

I. Introduction

URBAN areas have many bridges and overpasses that are subjected to everyday traffic and heavy vehicle loads. As urban areas get more populated number of vehicles increase, but infrastructure in most cases is not being upgraded. This is why it is important to understand bridge structure behaviour and possible effects from the moving vehicles. Effects from heavy truck loads on the bridges are important because it can determine load carrying capacity of the structure. Heavy vehicles on damaged road surface create dynamic loads that increase overall load on the bridge structure.

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. With calculation methods it is almost impossible to correctly model the real behavior of the bridge structure, because there are many factors that have to be included; hence a load testing of a similar bridge structures can give useful information about possible structure behavior.

Purpose of this study is to find if the Dynamic amplification factor (DAF) values tor existing structures exceed in codes proposed and see if there is any correlation between DAF values and bridge span length, vehicle weight and natural frequency.

A. Loads

Every day overweight vehicles require permits to cross existing bridges, but there is very little information available about dynamic effects caused by those heavy vehicles. It is necessary to know if crossing an old bridge will not excite the bridge too much and cause serious damage to the structure. Allowed axle load in European Union is 11,5t per axle but in Latvia special permit is necessary if a heavy vehicle axle load exceeds 13 t or total weight of 52t.

Traffic contents are different in the city and on the major highways. Highway bridges outside the city are subjected to more heavy vehicles because of the fright corridors, city bridges, however, are more subjected to lighter vehicles, but the amount of vehicles crossing the bridge is much higher. City bridges are also subjected to different vibrations caused, for example, from trams. For city bridges important factor is acceleration, because of the pedestrians crossing the bridges every day.

This paper presents 13 bridge dynamic load test result performed from 2005 to 2012. For two bridges dynamic load testing had been performed twice, hence it was possible to compare obtained results.

B. Dynamic Effects

Dynamic effects on the bridge can be indicated by different dynamic parameters. Most common used dynamic parameters are dynamic amplification factor (DAF), bridge natural frequency and bridge acceleration. DAF is used in structural codes to cope with dynamic effects. The DAF of a bridge is defined as the maximum total load (including dynamic part) effect divided by the maximum static load effect [1]:

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

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

Many studies have been dedicated to the investigation of the influence of the DAF on the bridge behavior [4]-[6], [8]. The DAF is an important parameter in the design of the highway bridges and should be taken into account by the evaluation of the bridge load carrying capacity. The value of the DAF depend on many factors: bridge span length and natural frequency, vehicle speed, weight and dynamic characteristics, the condition of the bridge structures – roadway roughness, expansion joint's condition and others.

In the Structural Codes the dynamic effects of all the vehicles on all bridges are taken into account by multiplying the static live load by DAF or are 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, vehicle weight and passing speed.

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In the *Eurocode 1* (*EN 1991-2:2003 Actions on structures. 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 [3]. The DAF values used in the Eurocode 1 for 2-line bridge roadway are presented in Fig. 1.

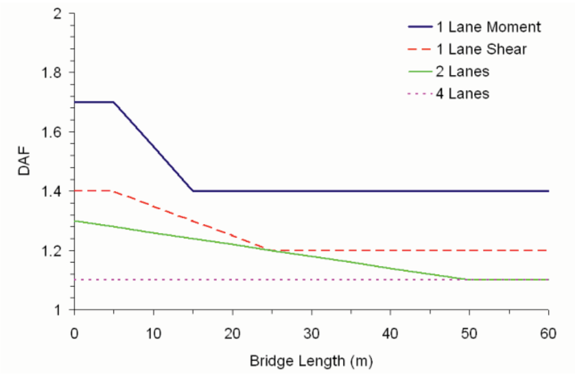

Fig. 1 DAF – dynamic amplification factor built-in in the Eurocode 1 [2]

Bridge natural frequency strongly depends on the span structural system, cross section type and material, construction type, bearing conditions and others parameters.

Natural frequency for two to three span structures can be found if the stiffness and mass of the structure is given:

$$f = \frac{\pi}{2 \cdot L^2} \sqrt{\frac{EI}{m}} \tag{2}$$

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

For considered bridges natural frequency and period was calculated using FEM software LIRA model. In most cases measured bridge natural frequency did not reach calculated first mode bridge natural frequency.

II. Description of the Bridges Considered

Nine of the selected bridges were *prestressed concrete bridges* with the span length varying from 20,5m – 58,2 m. Bridges are located in the largest cities of Latvia where the traffic value is high. Basic parameters of the bridges are given in Table I.

Selected four *steel composite bridges* are with span length varying from 24,5m to 110 m. Main parameters of the bridges are given in Table II.

First two mode shapes were calculated and compared with results obtained from data received in load testing.

III. Description of the Dynamic Load Testing

The load tests of the bridges in Latvia are carried out according to the requirements of the national standard *LVS 190-11 "Bridge inspection and load testing."* The dynamic load tests provide information about the natural frequency, damping of the bridge and variations of the DAF depending on the vehicle speed.

TABLE I
Selected Prestressed Concrete Bridges Main Characteristic Values

Nr.	Bridge	Span length (m)	Bridge width (m)	Natural frequency measured, Hz	1st mode Natural frequency calculated, Hz
1.	Bridge over River Lielupe in Jūrmala	58,2	23,27	3	-
2.	South bridge overpass 4-3	32	19,3	2,38	2,11
3.	South bridge overpass 5-1	24	8,32	2,75	3,27
4.	South bridge overpass 5-2	24	8,32	3,7	3,38
5.	South bridge overpass 7	24	9,32	2,75	3,39
6.	Bridge over River Jugla on Brivibas avenue	22,16	31	2	3,53
7.	South bridge overpass 2nd part E1-3K	35,9	13,2	2,25	2,4
8.	Bridge over Pedele river in Valka	20,5	15	5,3	4,47
9.	Bridge over Meža avenue in Riga	38	11,5	4	4,69

TABLE II
Selected Composite Bridges Main Characteristic Values

Nr.	Bridge	Span length (m)	Bridge width (m)	Natural frequency measured, Hz	1st mode Natural frequency calculated, Hz
1.	South bridge (803m)	110,0	24,25	0,8	0,47
2.	Bridge over city Channel in Liepāja (discontinouse system)	24,5	15,1	4	4,43
3.	Bridge over Venta in Ventspils	40	19,2	-	3,1
4.	Bridge over Gauja in Valmiera	36,27	13	3,6	2,95

Loaded trucks are used to model real behaviour of the bridge. Heavy truck weight is usually about 25 t.

Instruments were placed in the middle of the spans to obtain maximum deflection values. Displacement and accelerations were collected from selected points. Dynamic properties of the bridge were found from the vibration response diagrams [8].

Fig. 2 Vehicle driving over planks paced on the road surface

The vibration responses were obtained by vibration sensor Noptel PSM-200. Example of the obtained vibration responses are given in Fig. 3. For Noptel PSM-200 the transmitter can be at a distance of 1 to 350 meters from the receiver, depending on the environmental conditions.

As a vibration inducer were used vehicles passing the bridge roadway with speeds of 20km/h and 40 km/h.

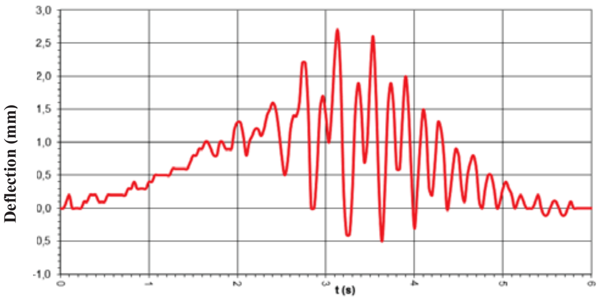

Fig. 3 The Vibration response diagram obtained by the Noptel PSM-200

The dynamic load test include the vehicle driving over two different roadway condition - even roadway pavement and uneven. Uneven pavement is used to model damages (damaged pavement or ice caused bumps) on it. The bumps in the pavement surface are formed with timber planks approximately 5 cm high and 10 cm wide installed on the path of the vehicles. The distance between the planks is approximately 3 to 3,5 m. but it depend on the distance between vehicle axles.

IV. Results

A. Prestressed Concrete Bridges

8 bridges considered were recently built and designed according to Eurocodes, except a bridge over River Lielupe in Jurmala. This bridge was renovated in 2005 and was originally designed according to previous structural codes used in Latvia (SNIP 2.05.03-84). There was a remark in the previous report that bridge is vulnerable to dynamic loads. After reconstruction results showed that bridge structure has become stiffer.

All overpasses considered has similar prestressed concrete cross section hence results are very close. Fig. 6 shows natural frequencies measured and calculated for the bridges showed in Table I. For considered bridges measured natural frequency is lower than calculated. Exception is an overpass 5-2 that has higher natural frequency than calculated 1st mode shape frequency; hence it shows that originated natural frequency caused different mode shape. Fig. 5 shows Overpass 5-2 1st vibration mode shape. This overpass is set on very high supports hence it is subjected also to horizontal movements hence the mode shape differ from all other bridges considered. Fig. 4 shows the Overpass 5-2 situated in the 3rd level of the junction.

Fig. 4 South bridge overpass 5-2

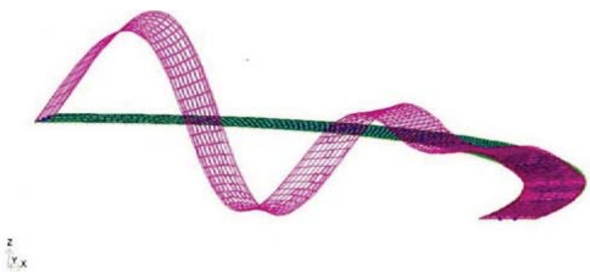

Fig. 5 South bridge overpass 5-1. Vibration 1st mode shape

Analyzing results obtained from the dynamic load testing, majority of the natural frequency values were in the range – from 2 to 4 Hz. Fig. 6 shows natural frequencies for considered bridges placed in Table I. Natural frequencies are lower than calculated except two bridges. First one is already discussed Overpass 5-2 and second is Bridge over river Pedele.

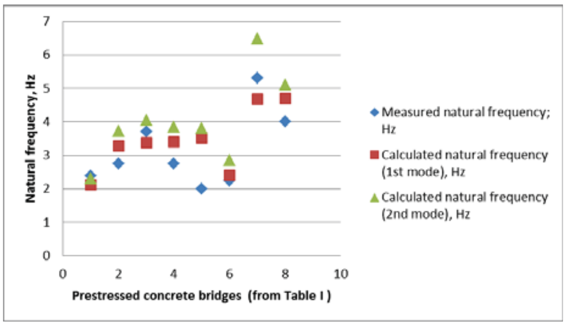

Fig. 6 Natural frequencies for considered Prestressed concrete bridges

Fig. 7 shows DAF dependence on vehicle weight. It can be seen that there are not much correlation between these two parameters.

In Fig. 8 is shown DAF dependence on span length. These results show that there is no correlation between these two parameters.

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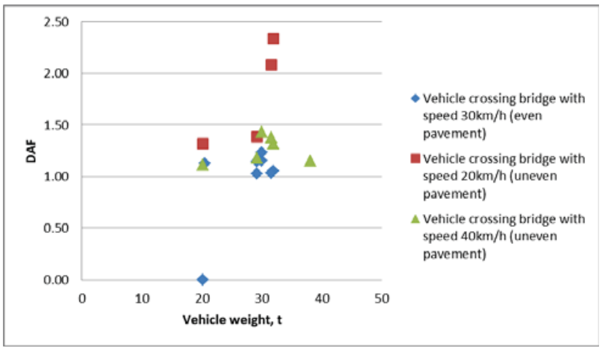

Fig. 7 DAF dependence on loaded vehicle weight

DAF values used in Eurocode are from 1,0 to 1,4, but Fig. 9 shows that if the pavement is uneven and vehicle is driving with very low speed (here 20km/h), then DAF values are much higher than used in Eurocode [7]. Hence it shows that bridge structures are very sensitive to uneven pavement and to assure bridge structure durability it is very important to make sure that there are no potholes or other damages on the bridge pavement.

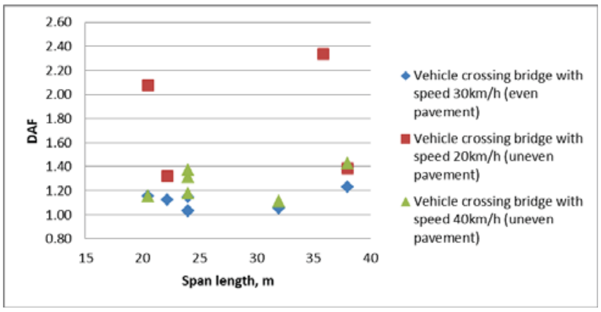

Fig. 8 Dynamic Amplification factor (DAF) dependence on the span length

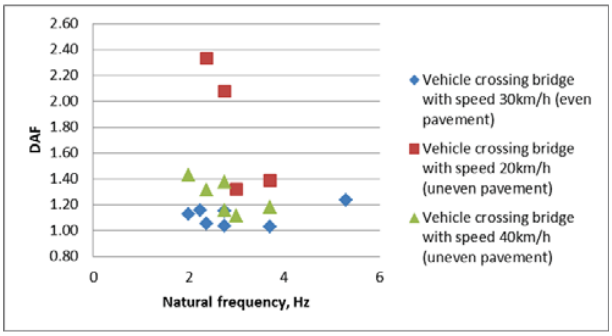

Fig. 9 Dynamic Amplification factor (DAF) dependence on the bridge natural frequency

Fig. 9 shows DAF value dependence on the bridge natural frequency. Tendency show that for lower natural frequency DAF tend to be higher, but for higher natural frequencies these values are lower.

B. Composite Bridges

Only 4 composite bridges were considered. Bridge over city channel in Liepaja is the only bridge with discontinuous system hence results cannot directly be compared with results of continuous bridge systems, but Fig. 10 shows that natural frequency values for discontinuous system were higher than for continuous systems.

Obtained natural frequency values were higher than for prestressed concrete bridges, but they were not higher than 4 Hz.

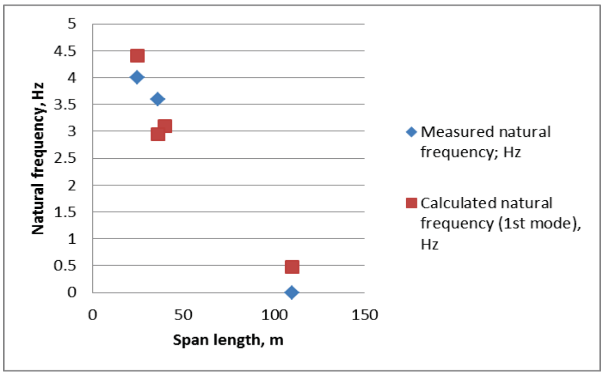

Fig. 10 Calculated and measured natural frequency dependence on span length

Fig. 11 shows DAF values for composite bridges. These values were inside the range 1 and 1,4 used in Eurocode 1991, however DAF values that were obtained for vehicle driving with speed 20km/h over uneven surface were much higher than recommended. Same tendency was observed for prestressed concrete bridges.

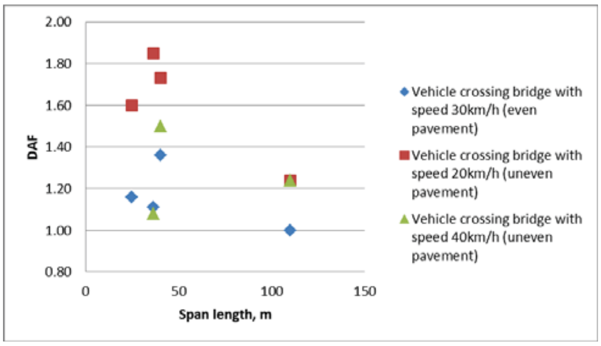

Fig. 11 DAF dependence on the span length

Fig. 12 shows that for vehicles with weight up to 40 t there in not much correlation with DAF, however for bridge with span length more than 100 m and vehicles with total weight of 80 t DAF values are much lower.

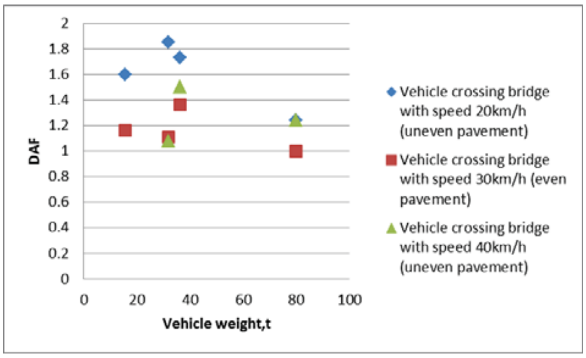

Fig. 12 DAF dependence on the vehicle weight

V. Conclusions

Obtained results show that for bridges road surface condition is a very important factor. If road condition is very bad with potholes or ice in the winter, then heavy traffic driving with low speed can cause a lot of damage. Hence it is important to maintain city infrastructure in good condition, especially road surface because traffic can cause much faster deterioration of the structure.

Bridge natural frequency did not correlate with the bridge span and vehicle weight hence these parameters are not significant for bridge natural frequency. However there were correlation between natural frequency and DAF - for higher natural frequency values DAF values were smaller.

Overall DAF values for even pavement were within 1,0 and 1,4 and are in the range proposed in the Eurocode 1. Hence proposed values are reasonable for good pavement condition.

Acknowledgment

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