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ScienceDirect

Procedia Engineering 00 (2016) 000–000

Procedia Engineering

www.elsevier.com/locate/procedia

Modern Building Materials, Structures and Techniques, MBMST 2016

Dynamic behavior of pre-stressed slab bridges

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Abstract

In last 10 years pre-stressed in-situ slab bridges has become one of the used bridge deck type for new bridges in Latvia. This structure is used for overpasses on road junctions where height of the bridge deck and space under the superstructure is limited by the levels of roads. This research show and discuss dynamic test results performed from 2008 to 2015. One reinforced concrete (RC) and three pre-stressed RC slab bridges were tested. One ribbed RC and three pre-stressed RC ribbed slab bridges were tested. Results show that for PRC bridges span/depth ratio correlate with damping ratio- higher span/depth ratio show decrease in damping ratio. For even pavement condition DAF values are lower than 1,4 .

Peer-review under responsibility of the organizing committee of MBMST 2016.

Keywords: bridge; dynamic; load testing; pre-stressed slab;

1. Introduction

Pre-stressed in-situ slab bridges in last 10 years have been used for overpasses on road junctions where height of the bridge deck and space under the superstructure is limited by the levels of roads. Because of the technology that has developed and become more economical, this type of bridge is easy and fast to build.

Reinforced concrete (RC) slab bridge is one of the simplest and widely used bridge types in Latvia however this type is limited by high self-weight (for longer spans) and span length. Although this might be a good solution, the real deflection is very much unknown value because it changes according to the amount of cracking in the slab. Since RC slabs tend to crack it reduces moment of inertia and hence increases the deflection. It leads to a well needed pre-camber. [1]

Pre-stressed concrete (PRC) slabs do not have problem with unnecessary deflection, moreover these slabs tend to deflect upwards. The only limits are span/depth ratio that is defined by bending stress and economy since the cost of the structure rises with slenderness. A span/depth ratio of 30 is commonly used for spans up to 21 m. In-situ twin rib bridges are a very good solution for spans 20 to 45 m and are economical and fast construction solution.[1]

Behavior of a slab bridge is influenced by the traffic load. Traffic load on the bridge has a stochastic nature hence to predict a very accurate 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 in-stalled 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. [2]

Although traffic contents are important information, bridge load carrying capacity is more influenced by the effect that loading cause on the structure. Traffic load is a dynamic load hence it is important to understand dynamic behavior and possible effects

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Peer-review under responsibility of the organizing committee of MBMST 2016.

from moving vehicles. The dynamic load 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 8 bridge dynamic load tests performed from 2008 to 2015.

2. Dynamic load

Dynamic force induced by the vehicle plays a significant role in the design of a bridge. Dynamic load results in an increase in bridge deformations that are described by dynamic amplification factor (DAF), it shows how many times static load should be in-creased to cover additional dynamic effects. This was studied by scientist Fryba. [3]

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. [4] For RC slab bridges additional dynamic load can cause large deflections and deterioration. For PRC slabs this may not be the biggest problem, but very large DAF can introduce cracks in bridge deck.

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 an-lysed by Fryba [5] and Law, Chan and Zeng [6].

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, previously obtained bridge load test results showed DAF dependence on the road surface conditions and passing speed [7].

In the Eurocode 1991-2 “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 analyzed by Cantero, Gonzalez, O`Brien[8] . Eurocode 1991-2 “Actions on structures, Part 2 Traffic loads on bridges” gives DAF value for 2-line bridge roadway [9].

3. Testing and measurement

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 [10].

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.

A loaded truck is used as a dynamic load with weight around 30 t and 3 axles. 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 Fig.1. The transmitter can be placed at a distance of 1 to 350 meters from the receiver, depending on the environ-mental conditions.

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

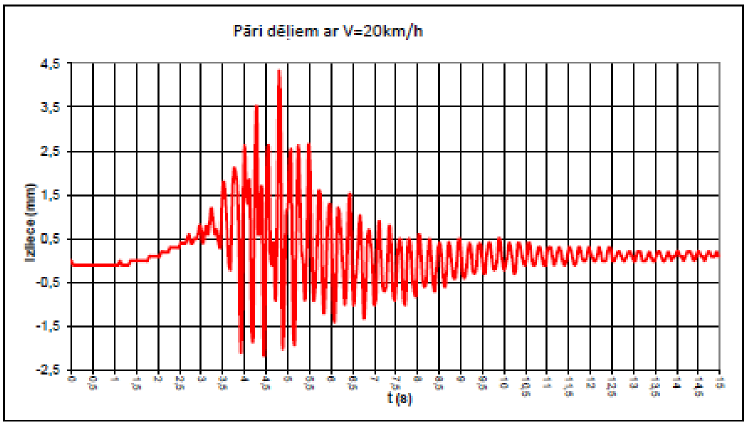


Fig.1. The vibration response diagram obtained by the Noptel PSM-200.

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 in-stalled 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. Description of the bridges

In this paper one RC and three PRC slab bridges and one ribbed RC and three ribbed PRC slab bridges were analyzed.

4.1. Uniform height slab bridges

Bridge over Lauce River on road P87 Bauska- Aizkraukle

Continuous three span bridge with the longest span of 11,4 m and carriageway width 8 m. Bridge superstructure is a RC simply supported slab with uniform thickness on 0,5 m. Span/depth ratio of 23. Bridge was designed using FEM software LIRA. It is a new bridge and concrete class is C40/50 XF4. Bridge cross section is given in Fig.2. Maximum DAF was found when vehicle crossed bridge with speed 20km/h over uneven pavement.

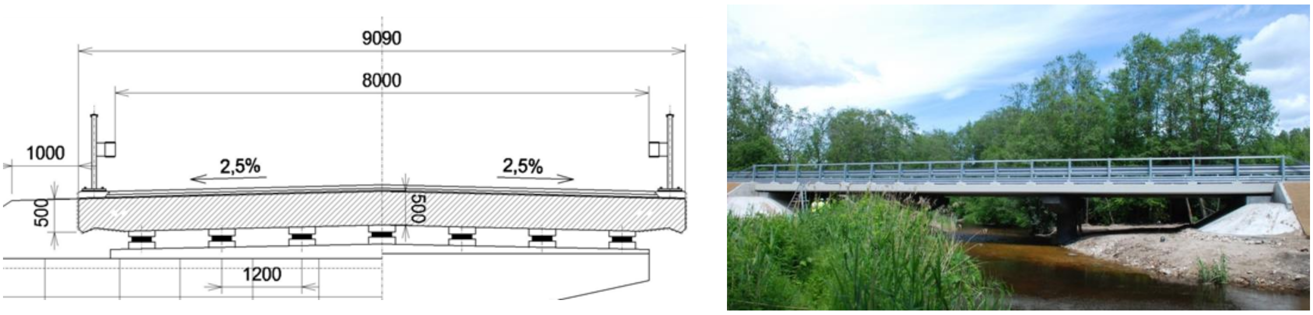


Fig. 2. Cross section and elevation of bridge over Lauce River on P87 Bauska–Aizkraukle. FE model constructed as a plate-strut 3D system.

Bridge on Road A12 over Railway Rīga - Rēzekne

Continuous three span PRC bridge with the longest span of 34 m and carriageway width 10,5 m. Bridge superstructure is a PRC simply supported slab with side cantilevers and a slab height of 1,4 m. Span/depth ratio of 24. Bridge was designed using FEM software LIRA. It is a new bridge and concrete class is C40/50 XF4. Bridge cross section is given in Fig.3 Maximum DAF was found when vehicle crossed bridge with speed 20km/h over uneven pavement.

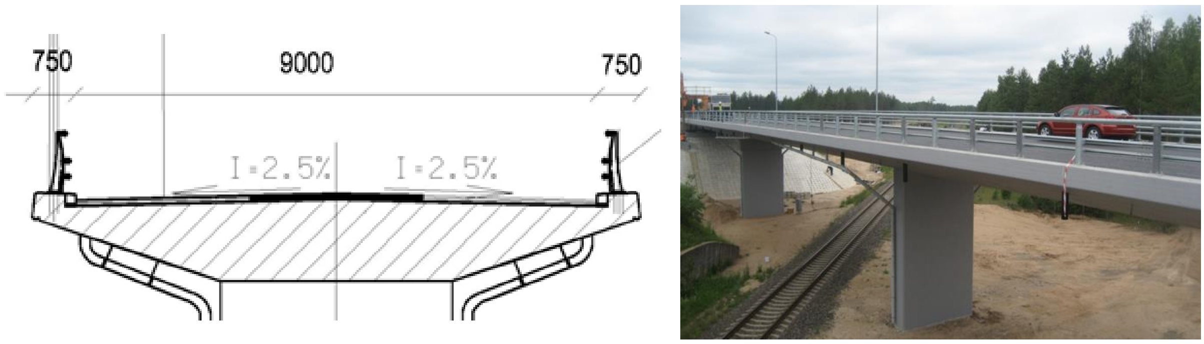
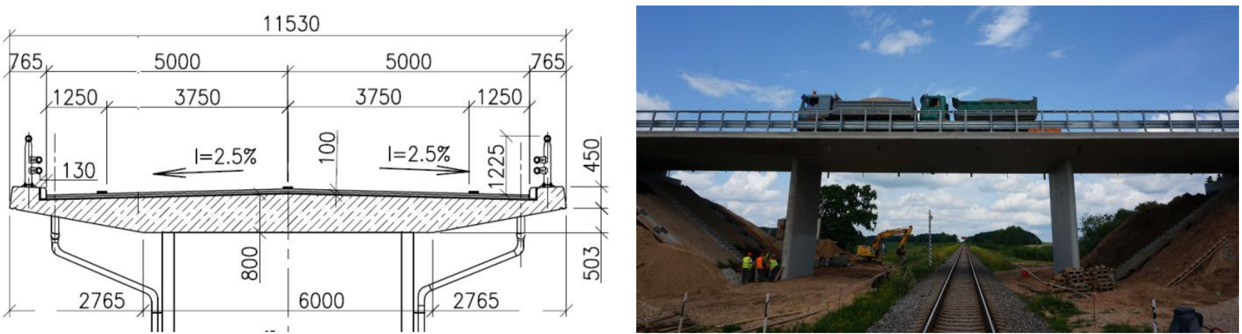


Fig. 3. Cross section and elevation of bridge on road A12 over Railway Rīga - Rēzekne. FE model constructed as a plate-strut 3D system.

Bridge over Railway Jelgava - Tukums on road A9 Rīga - Liepāja

Continuous three span PRC bridge with the longest span of 18 m and carriageway width 11,53 m. Bridge superstructure is a PRC frame slab with side cantilevers and a slab height of 0,8 m. Span/depth ratio of 23. Bridge was designed using FEM software LIRA. It is a new bridge and concrete class is C40/50 XF4. Bridge cross section is given in Fig.4 Maximum DAF was found when vehicle crossed bridge



with speed 20km/h over uneven pavement.

Fig. 4. Cross section and elevation of bridge over Railway Jelgava - Tukums on road A9 Rīga - Liepāja. FE model constructed as a plate-strut 3D system.

Overpass over Railway Riga - Krustpils km 95,21

Continuous three span PRC bridge with the longest span of 22,5 m and carriageway width 13 m. Bridge superstructure is a PRC frame slab with side cantilevers and a slab height of 0,9 m. Span/depth ratio of 25. Bridge was designed using FEM software LIRA. It is a new bridge and concrete class is C40/50 XF4. Bridge cross section is given in Fig.5 Maximum DAF was found when vehicle crossed bridge with speed 20km/h over uneven pavement.

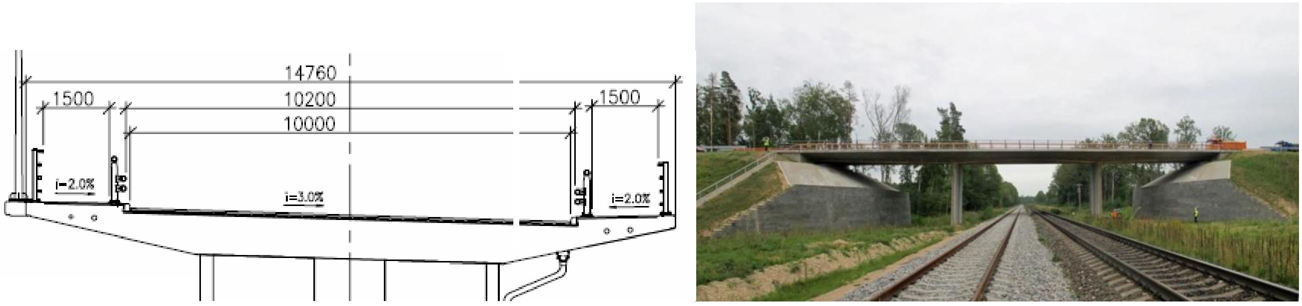


Fig. 5. Cross section and elevation of bridge over Railway Riga - Krustpils km 95,21. FE model constructed as a plate-strut 3D system.

4.2. Ribbed slab bridges

Bridge over River Dīvāja on road A6

Continuous voided three span PRC bridge with the longest span of 25,5 m and a carriageway width of 15,0 m. Bridge superstructure is a simply supported PRC ribbed slab with 2 ribs with height of 1,3 m. Span/depth ratio of 20. Bridge was designed using FEM software LIRA. It is a new bridge with concrete class C40/50 XF4. Bridge cross section is given in Fig.7 Maximum DAF was found when vehicle crossed bridge with speed 20km/h over uneven pavement.

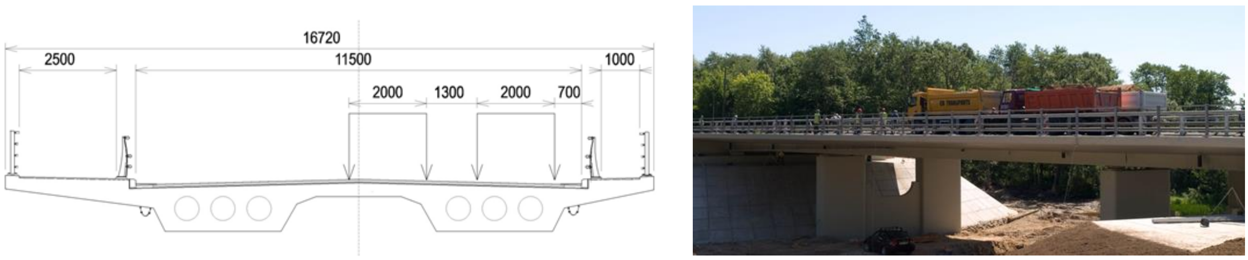


Fig. 7. Cross section and elevation of bridge over River Dīvāja on road A6. FE model constructed as a plate-strut 3D system.

Overpass on road A6 Riga -Belarus border

Continuous four span RC bridge with the longest span of 19,5 m and a carriageway width of 11,43 m. Bridge superstructure is a RC ribbed slab frame with 3 ribs with height of 1,0 m each. Span/depth ratio of 20. Bridge was designed using FEM software LIRA. It is a new bridge and concrete class is C40/50 XF4. Bridge cross section is given in Fig.7 Maximum DAF was found when vehicle crossed bridge with speed 40km/h over uneven pavement.

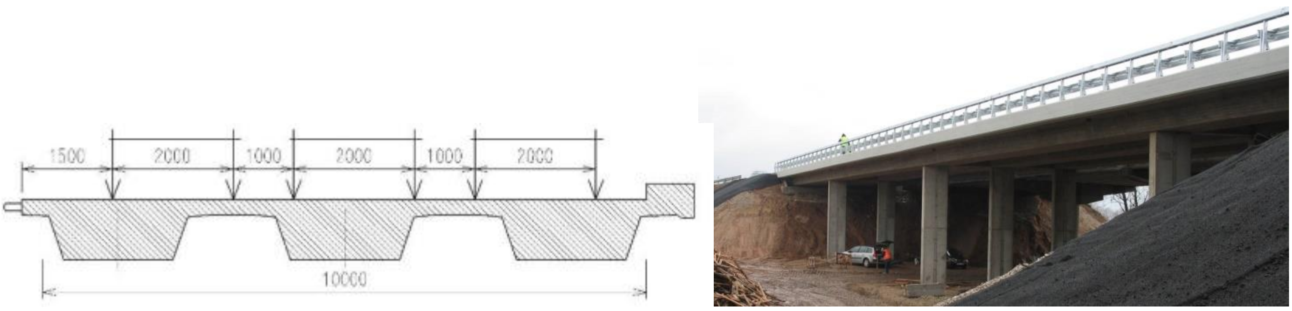


Fig. 7. Cross section and elevation of bridge on road A6 Riga -Belarus border. FE model constructed as a plate-strut 3D system.

Overpass on road P8 over road E22

Continuous four span PRC bridge with the longest span of 27,4 m and a carriageway width of 11,45 m. Bridge superstructure is a PRC ribbed slab frame with 2 ribs with height of 1,1 m each. Span/depth ratio of 25. Bridge was designed using FEM software LIRA. It is a new bridge and concrete class is C40/50 XF4. Bridge cross section is given in Fig.8 Maximum DAF was found when vehicle crossed bridge with speed 40km/h over uneven pavement.

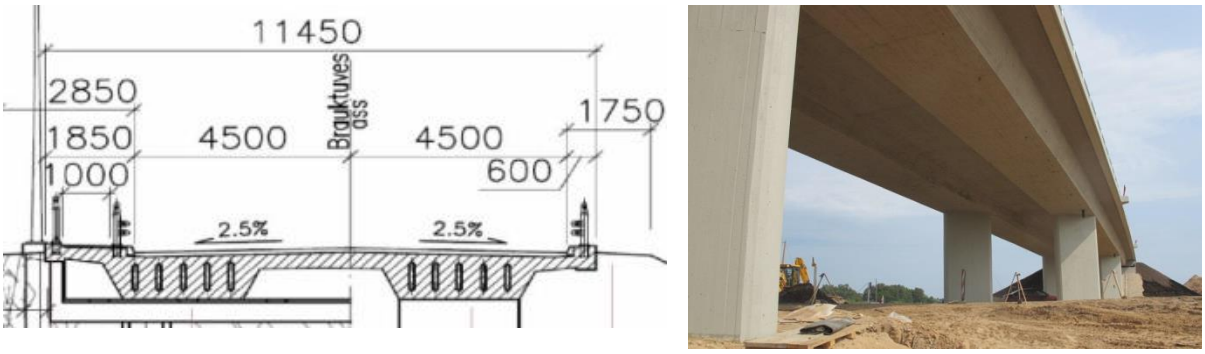


Fig. 8. Cross section and elevation of bridge on road P8 over road E22. FE model constructed as a plate-strut 3D system.

Overpass on road E22 over road V920

Single span PRC frame bridge with the span length of 30 m and a carriageway width of 19,5 m. Bridge superstructure is a PRC ribbed slab with 3 ribs of 1,1 m height. Span/depth ratio of 27. Bridge was designed using FEM software LIRA. It is a new bridge and concrete class is C40/50 XF4. Bridge cross section is given in Fig.9 Maximum DAF was found when vehicle crossed bridge with speed 20km/h over uneven pavement.

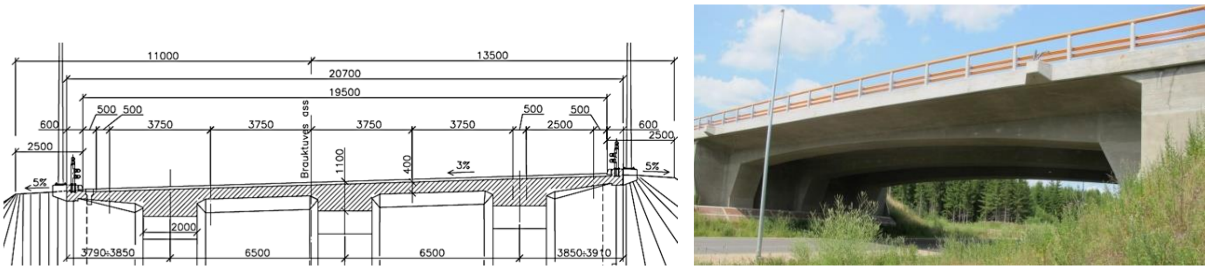


Fig. 9. Cross section and elevation of bridge on road E22 over road V920. FE model constructed as a plate-strut 3D system.

5. Results

Obtained results were compared considering bridge type. Correlations between DAF, measured natural frequency and damping ratio were analyzed. In Table 1 are shown bridge dimensions and some results.

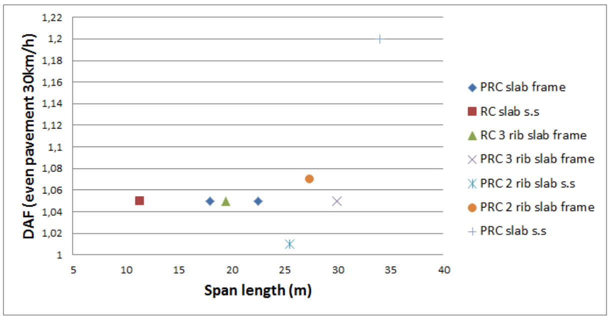
Fig.10 show correlation between DAF for even pavement and span length. For PRC slab bridge DAF is higher than for other bridge types. Span/depth ratio for this bridge is not as high as for other bridges although but high DAF could be explained as relatively wide cantilevers on both sides of the slab cross-section. Foe even pavement DAF is less than 1,4 that is built in value in Eurocode 1991-2.

Fig. 11 show correlation between natural frequency and span length. For PRC bridges natural frequency decreases with increasing span length for all types of PRC bridges. Damping ratio is much higher for simply supported slab bridge, but span/depth ration correlate with damping ratio for ribbed PRC bridges. Increase in span/depth ratio show decrease in damping ratio.

Table 1. Bridge dimensions and test results.

Bridge	Span length (m)	Width (m)	Height (m)	Span/ depth ratio	Structure	Nr. of ribs	Calculated 1st mode natural frequency, Hz	Measured natural frequency, Hz	Maximum DAF
Bridge over Lauce River	11,41	8	0,5	23	Simply supported (s.s) RC slab	1	8.88	9	2
Bridge on Road A12	34	10,5	1,4	24	Simply supported (s.s)PRC slab	1	2.45	3	1,5
Bridge over Railway Jelgava - Tukums	18	11,53	0,8	23	PRC slab frame	1	5,23	5,5	1,9
Overpass over Railway Riga - Krustpils	22,5	13	0,9	25	PRC slab frame	1	4,3	5	3,5

Bridge over River Dīvāja	25,5	15	1,3	20	Simply supported (s.s) PRC ribbed slab	2	5.68	7.3	2
Overpass on road A6	19,5	11,3	1,0	20	RC ribbed slab frame	3	5.56	6	2
Overpass on road P8	27,4	11,45	1,1	25	PRC ribbed slab frame	2	3,93	4	1,3
Overpass on road E22	30	19,5	1,1	27	PRC ribbed slab frame	3	4,8	4,9	5



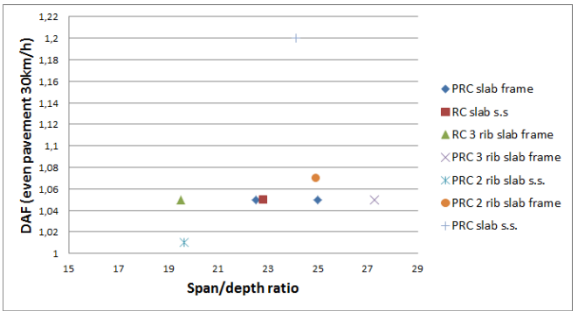
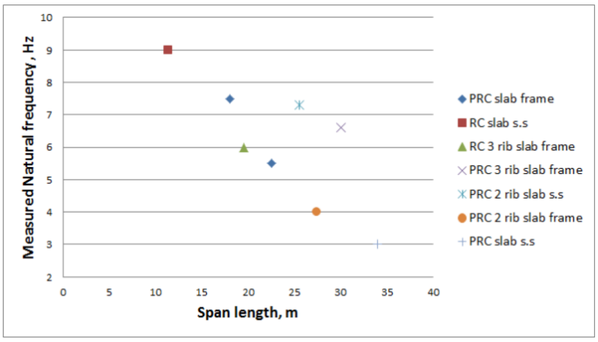


Fig. 10. Correlation between DAF (for even pavement) and span length (left side figure) and span/depth ratio (right side figure).



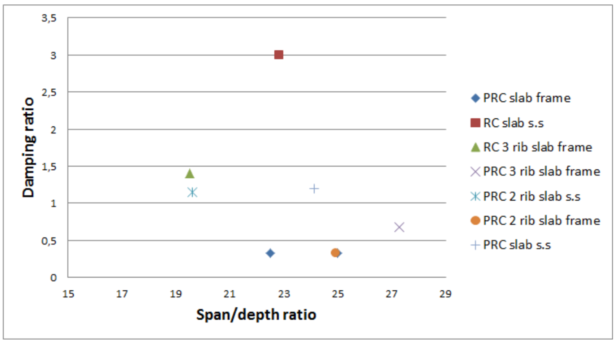
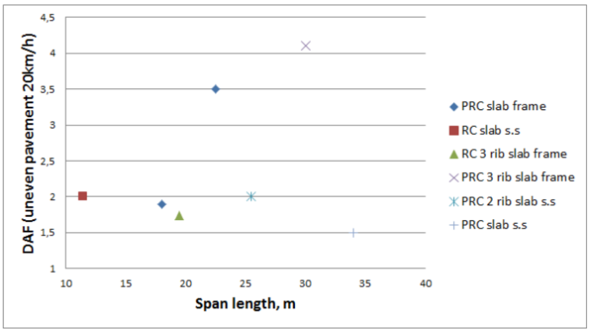


Fig. 11. Correlation between natural frequency and span length (left side figure), correlation between damping ratio and span/depth ratio (right side figure).

Previous research about bridges in Latvia show that lower vehicle speed on uneven pavement show higher DAF values [7] hence this conclusion was verified for PRC bridges. Fig.12 shows DAF for uneven pavement with vehicle speed of 20km/h. For 2 bridges DAF is higher than 2, moreover both of these bridges has a one-sided lope in cross-section. Hence it shows that this kind of bridges has much higher DAF than straight bridges.



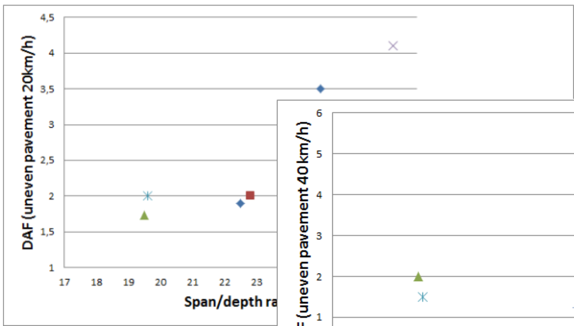


Fig. 12. Correlation between DAF (uneven pavement 20km/h) and span length (left side figure) and DAF and span/depth ratio(right side figure).

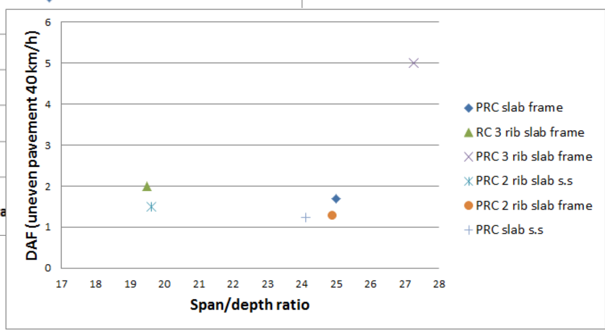


Fig. 13. Correlation between DAF (uneven pavement 40km/h) and span/depth ratio (left side figure). DAF (uneven pavement 20 km/h) and natural frequency.

Fig.13 shows correlation between DAF for uneven pavement with vehicle speed 40km/h. Results show that for PRC slab bridges DAF is lower than 2 and in most cases lower than 1,4 however PRC 3 rib slab frame bridge shows increase in DAF for higher speed. It shows that for PRC bridges with a slope dynamic properties are higher than for other types of PRC bridges hence bridge dynamic is an important factor.

6. Conclusions

Pavement evenness and vehicle speed correlate and results show that for speed of 20km/h DAF can increase up to 2. However PRC bridges in plan radius or with one sided slopes can have DAF up to 5. For PRC bridges span/depth ratio correlate with damping ratio- higher span/depth ratio show decrease in damping ratio. For even pavement condition DAF values are lower than 1,4 .

Acknowledgements

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

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