ISSN 2029–9990

*JOURNAL OF SUSTAINABLE ARCHITECTURE AND CIVIL ENGINEERING*

*DARNIOJI ARCHITEKTŪRA IR STATYBA*

*2013. No. 3(4)*

# Investigation of Width of Vertical Cracks in Reinforced Concrete Box-Girder Viaducts

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crossref http://dx.doi.org/10.5755/j01.sace.3.4.3277

The article examines the effect of dynamic loads on crack width of decks of prestressed reinforced concrete frame (box-girder) viaducts. The experimental measurement of the changes in width of vertical cracks of Pareizgupis viaduct resulting from the loads of moving heavy weight vehicles was made. During testing, four-axle vehicles with weights of around 40 tonnes were used and they were driven over the viaduct deck at the speed of 20–40 km/h. The stresses in prestressed reinforcement were analysed, calculated and compared to the results obtained during testing. Having evaluated theoretically the elastoplastic operation of concrete, the width of a vertical crack was measured in the middle part of the viaduct.

**Keywords:** *stressed reinforced concrete, crack width, stresses, precompression, elastoplastic deformations.*

## 1. Introduction

Bridge structures are constantly affected by dynamic loads caused by transport flows. Dynamic loads caused by moving heavy weight vehicles are one of the main problems for bridge designers. In some cases dynamic loads are more important than static loads especially when analysing the cracking of reinforced concrete bridges. Investigators (Hamed, E., Frosting, Y. 2004 and Huang, D. Z., Wang, T. L., Shahaway, M. 1993) note that the cracks in most stressed reinforced concrete bridges opened by the effect of dynamic loads and overloads. A lot of research has been done on the dynamic effect of heavy weight vehicles on uncracked prestressed concrete bridges with a double T cross-section. (Li, C. Y. 1996 and Bruni et al. 2003), however little research has been carried out on the cracked box girder bridges. When cracks appear in the beams of box-girder bridges (viaducts), linear analysis of reinforced concrete structures describing the effect of static and dynamic loads becomes invalid (Moghimi, H., Ronagh, H. R. 2007) and it is necessary to apply nonlinear analysis of reinforced concrete structures when analysing the limit states of bridge safety and operational suitability.

There are many bridges in Lithuania that have a deck with stressed reinforced concrete box girders and double T girders. In the old (operated for 20–30 years) stressed reinforced concrete box girder bridges very common damage is the cracking of girder webs shear and normal sections. Most of cracks and damage were found in stressed reinforced concrete frame box girder viaducts that had been operated for around 30 years. (Augonis et al. 2012).

Dynamic loads in the bridges and especially viaducts of old construction designed according to the Russian design code (CH-200, 1962, CH-365, 1967) have been evaluated insufficiently. This code states that dynamic coefficient should be calculated according to the length of a bridge span not taking into account the possibility of deterioration of roadway pavement, pits and deck deformations (deflections) during bridge operation. The experimental research on dynamic and static deflections of road pavement roughness of the three viaducts (Babtai, Gėluva and Pareizgupis) carried out by the authors (Zadlauskas, S., Augonis, M. 2012) showed that dynamic deflection and dynamic coefficient depended greatly on road pavement roughness. Dynamic coefficient of the viaducts with uneven roadway surface was 20–30% higher than that of the viaducts with even roadway surface. Dynamic coefficient is a very important parameter when calculating cracking moment of a structure as the deflection also. Investigators (Gomez Navaro and Lebet, 2001) note that due to the increase of cyclic loads that are formed when heavy weight vehicles move over a bridge, normal cracks open up in the tensile concrete zone. Analyzing the cracking of double T and box girders under the loads of heavy weight vehicles, the scientists (Sasaki et al. 2010) noticed that shear cracks open in the webs of double T girders due to more intensive transport flows.

This article analyses the vertical cracks opened up in the 5th segment of middle span of the Pareizgupis viaduct (Fig. 1), discusses the effect of dynamic loads on the cracked girders and presents experimental measurement of the changes in width of vertical cracks. When evaluating the elastoplastic operation of concrete (according to the nonlinear analysis of reinforced concrete structures), the stresses of prestressed reinforcement in a vertical crack zone have been calculated theoretically.

## 2. The experimental measurements of normal cracks width variation

The Pareizgupis viaduct has shear cracks (marked in green) and vertical cracks (marked in red) opened up in the middle segments (5 and 6, Fig. 2) of girder B of the middle span. The viaduct has been designed according to the Russian design code (CH-200, 1962, CH-365, 1967) which stated that the crack forming in the deck girders of reinforced concrete bridges was not allowed.

It was found out during the inspection of viaduct structure that stressed tendons were highly affected by corrosion and some wire bunches were broken in the 5th segment of girder "B" (in the location of vertical cracks) (Fig. 3).

There are 24 high-strength stressed wire bunches at the bottom of this girder with the total cross-sectional area of 113 cm$^2$. Having inspected in detail these wire bunches, it was determined that 2.5 wire bunches were broken and 2 wire bunches were greatly subject to corrosion and were released.

More than 300 heavy weight vehicles move over this viaduct per day and they affect corroded tendons additionally. In order to examine the effect of dynamic loads on the viaduct deck (especially in the cracked girder "B"), the changes in width of vertical cracks under the loads of heavy weight vehicles moving over a deck have been measured experimentally. Testing was conducted in April 2011. The changes in width of vertical cracks were measured in the place of stressed reinforcement by electronic and mechanical sensors (Fig. 4).

The widths of opened up cracks were measured before the arrangement of sensors: the width of the first crack was 0.35 mm (60 mm measurement base), the width of the second crack was 0.40 mm (35 mm measurement base), the width of the third crack was 0.50 mm (56 mm measurement base). The changes in width of viaduct vertical cracks were measured using a four-axle vehicle with the weight of around 40 tonnes and it was driven over the viaduct deck in the speed of 30 km/h. The experimental measurements of the changes in width of vertical cracks are presented in table 1.

The experimental measurements of the width changes of the second vertical crack were chosen for more detailed analysis of viaduct deck cracking. This change in crack width was measured by an electronic sensor and a mechanical indicator (precision of 0.01). They produced the same results.

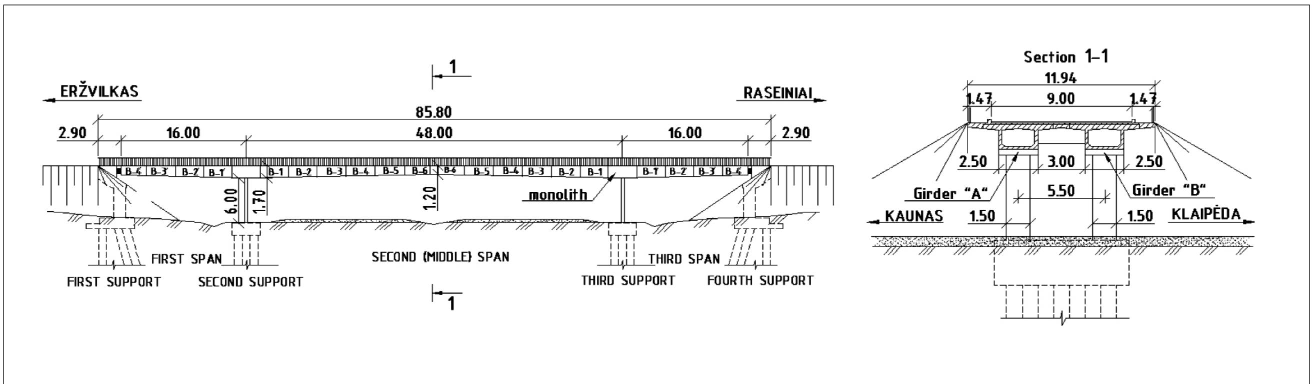


***Fig. 1.*** *The Pareizgupis viaduct plan, segment numeration and cross section in meters*

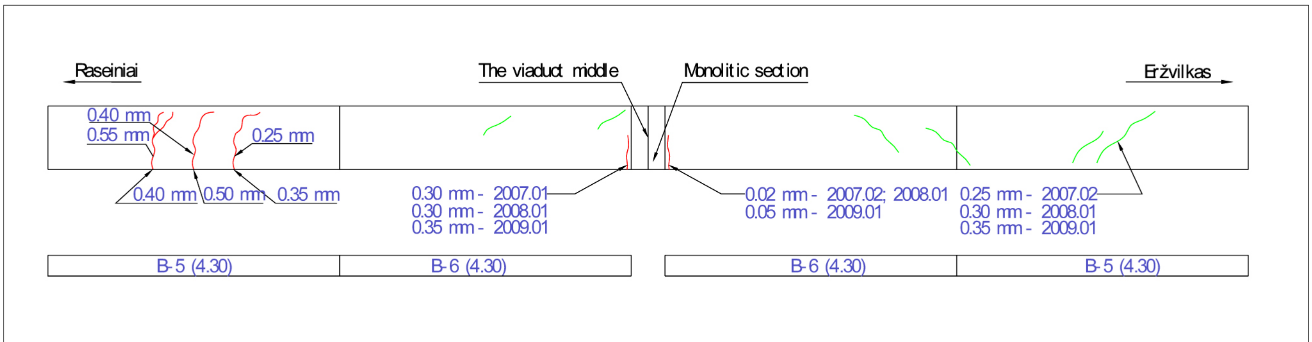


***Fig. 2.*** *Girder "B" of the Pareizgupis viaduct in Klaipėda direction. Opened vertical and shear cracks*

*__Fig. 3.__ The general view of corroded tendons in the location of opened vertical cracks*

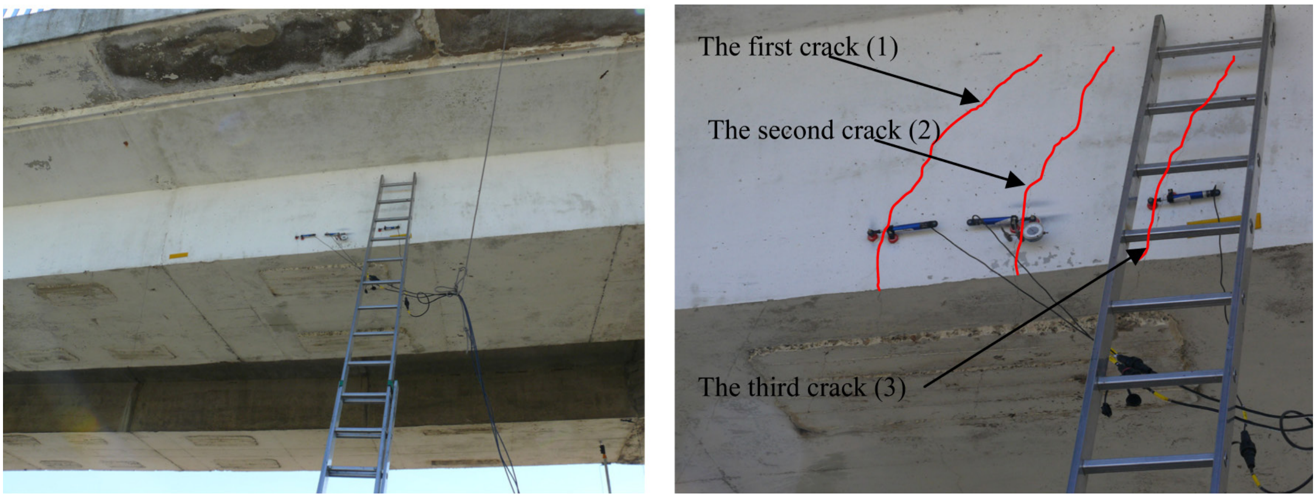


*__Fig. 4.__ Experimental measurement of the changes in width of vertical cracks*

***Table 1***. *Experimental measurement of the changes in width of vertical cracks*

| Test number | Number of axles | Weight of a vehicle, t | Speed of movement km/h | Change in width of 2 crack Δw, mm | Change in width of 3 crack Δw, mm |
|---|---|---|---|---|---|
| 1 | 4 | 40 | 30 | 0.07 | 0.09 |
| 2 | 4 | 40 | 30 | 0.06 | 0.07 |
| 3 | 4 | 40 | 30 | 0.06 | 0.07 |
| 4 | 4 | 40 | 30 | 0.07 | 0.08 |
| 5 | 4 | 40 | 30 | 0.07 | 0.07 |
| Average | 4 | 40 | 30 | 0.066 | 0.07 |

## 3. Experimental results and their analysis

When the corrosion of prestressed reinforcement and the elastoplastic operation of cracked concrete part were evaluated, the width of vertical crack and stresses in stressed tendons were calculated theoretically.

Having evaluated the initial crack width and the change in crack width obtained during testing, the width of a vertical crack is calculated according to the following formula:

$$w_{k,total} = w_{k,initial} + \Delta w \tag{1}$$

It was obtained that $w_{k,total} = 0.47\ mm$.

According to the SNiP method, the long-term vertical crack width of ~0.4mm under the self weight is obtained when ~7-8 wire bunches do not operate in the cross-section.

The effects of cyclic and dynamic loads, which are very important in bridges and viaducts, are not evaluated in this case. It has to be noted that the diameter of a wire bunch, which is reduced in proportion to the amount of corroded reinforcement, has a great influence in these calculations. If approximately 4-5 wire bunches would not operate in the cross-section (which was found during the visual inspection), the long-term width of a vertical crack (not evaluating cyclic and dynamic loads) is equal to ~0.17 mm, i. e. almost two times less than it was obtained during the inspection.

Contrary results were obtained by calculating crack width under the load of a vehicle (~40 t) standing on one girder, which produces the additional bending moment of 1.079 MNm in the cross-section. In this case, we obtain that the experimental short-term value of vertical crack width will be reached when 1.5 wire bunches will not operate. On the ground of practical measurement notice it can be accepted that around 20% of load on one girder move to the adjacent girder over a diaphragm. In this case, the crack of mentioned size would be formed when ~4–5 wire bunches are not operating. More detailed examination of the increase in stresses of both cases showed that they were equal to ~40MPa. The dependence of the change in width of vertical crack on the cross-sectional area of stressed reinforcement (evaluating the fact that load of moving heavy weight vehicle is carried by 1 or 2 or 1.2 girders) is presented in Figure 5.

Using the experimental values relative deformations in stressed tendons are calculated as follows:

$$\varepsilon = \Delta l / l = 0.002 \qquad (2)$$

Having calculated tensile stresses in stressed tendons under the loads of heavy weight vehicles (not evaluating the effect of tensile concrete) according to the relative deformations, we obtain:

$$\sigma_s = \varepsilon \cdot E_s = 0.002 \cdot 180000 = 360\ MPa\ .$$

Thus, the obtained value differs from the calculated value by 9 times.

In order to check the accuracy of results, the increase of stresses in reinforcement only under a transport load (not taking into consideration the operation of tensile concrete) was calculated additionally (Fig. 6).

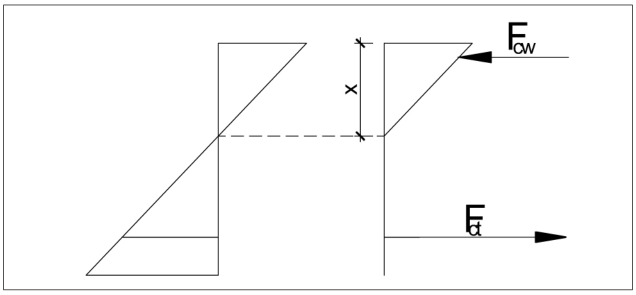


***Fig. 6.*** *The design scheme of stresses in reinforcement not taking into consideration the operation of tensile concrete*

The tension stiffening was not evaluated for the reason of small measurement base. The space between cracks is ~500 mm and measurement base – 40 mm. So, the influence of tensile concrete would not affect the result significantly.

Stresses in reinforcement are equal to ~100 MPa not taking into consideration the effect of a diaphragm and ~80 MPa when evaluating the effect of a diaphragm. Therefore, we cannot evaluate the state of stresses in reinforcement on the ground of the width of short-term crack determined experimentally.

It has to be noted that the calculations of crack width were also made in the interval in which the crack cannot open up theoretically; thus, the produced results cannot be totally accurate.

The increase of stresses in reinforcement of ~300 MPa theoretically is obtained when 7–8 wire bunches are broken (in the examination of girder 1) under the total bending moment of 7,659 MNm (from a decking and a truck).

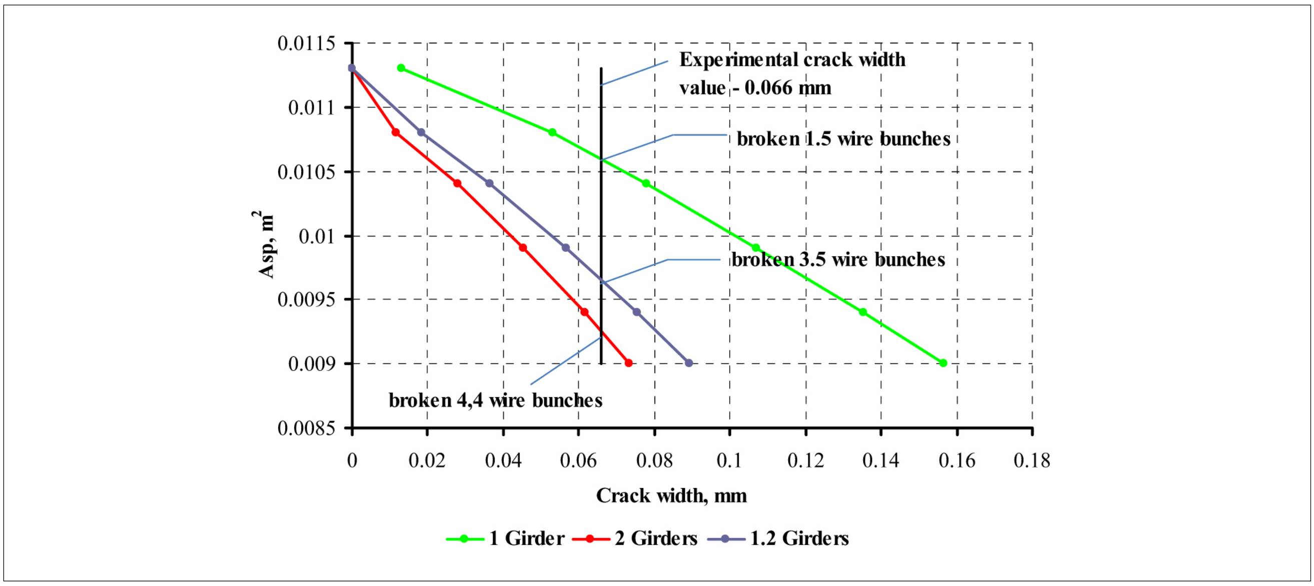


***Fig. 5.*** *The dependence of vertical crack width on the cross-sectional area of stressed reinforcement*

## 4. Conclusions

- Having performed the experimental measurements of the changes in width of vertical cracks of the Pareizgupis viaduct under the loads of moving heavy weight vehicles, it was found out that the crack width increased by around 0,066 mm.
- It is not possible to evaluate the potential level of prestressed reinforcement corrosion based on the width of long-term vertical crack determined experimentally because cyclic and dynamic loads are of great importance in this case.
- On the ground of the width of short-term vertical crack determined experimentally, the potential level of prestressed reinforcement corrosion was calculated theoretically. It was obtained that, after evaluating the possible effect of a diaphragm in the section, 4–5 wire bunches do not operate, which was found out during the inspection.

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Received 2013 01 31

Accepted after revision 2013 05 20


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