23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

INFLUENCE OF COMPRESSIVE STRESS ON SHEAR FORCE DISTRIBUTION IN BRIDGE DECK SLABS

R. Vida[*]**, J. Halvonik**[**]

Abstract: *Shear resistance is a long-term problem of reinforced concrete structures. It is also one of the decisive checks for bridge deck slabs assessment. In contrast with bending failure (which is ductile), the shear failure is brittle, which makes it even more dangerous and therefore undesirable. This paper deals with concentrated loads acting on a bridge deck slab and their transverse distribution to the support. The main focus is laid on the question whether compression force (either caused by prestressing or by the compression in the top parts of the cross section under bending moment) has any influence on the distribution of shear forces in a bridge deck slab.*

Keywords: Shear force, Distribution, Compression, Bridge slab.

1. Introduction

Bridge deck slabs are subjected to different types of loading, compared to common slabs in buildings. This fact results in a different behavior of the structure. The loads acting on a bridge deck slab are a combination of distributed loads on a large area and concentrated loads on a small part of the structure.

According to Lantsoght et al.(2012), the behavior of slab under uniformly distributed load is very similar to a beam loaded by continuous load and the common methods for calculating the shear resistance of beams lead to satisfactory results. On the other hand, slabs under concentrated loads act different and the internal forces caused by this load tend to spread over certain width (Rombach et al., 2008, Lantsoght et al., 2012,).

One of the parameters that influences the ability of the slab to transfer the local load in transverse direction is the cracking pattern of the slab (Lantsoght et al., 2010). This leads to a question, whether the prevention of cracks due to compressive stress in the slab can lead to a change in the internal forces distribution.

2. Bridge Loads and Internal Forces

A common highway bridge shall be designed in such a way that it is able to withstand all actions introduced in relevant standards, e.g.in EN 1991-1-1 or EN 1991-2. Some of these loads are similar to the ones in buildings, such as the self- weight, the weight of carriageway surfacing, kerbs, parapets, crash barriers, noise barriers and other bridge furnishing. These loads are usually uniformly distributed and cause a steady flow of internal forces in the bridge slab.

An important part of load acting on a bridge is produced by vehicles. According to EN 1991-2, these effects are substituted by load models, e.g. LM1, which represents effects of trucks and cars in real traffic on European roads in the year 2000. The model LM1 (shown in Fig. 1) consists of two parts:

- Uniformly Distributed Load (UDL) (q_{ik})
- Tandem System (TS), consisting of two axles with axle load Q_{ik} and the wheel size 0.4 x 0.4 m.

---

[*] MSc. Radoslav Vida: Department of Concrete Structures and Bridges, Slovak University of Technology, Radlinskeho 11, 810 05 Bratislava; SR, radoslav.vida@stuba.sk

[**] Prof. MSc. Jaroslav Halvonik: Department of Concrete Structures and Bridges, Slovak University of Technology, Radlinskeho 11, 810 05 Bratislava; SR, jaroslav.halvonik@stuba.sk

The TS causes a variable flow of internal forces in plane members (such as slabs). The difference in the flow of internal forces can be seen in Fig. 2.

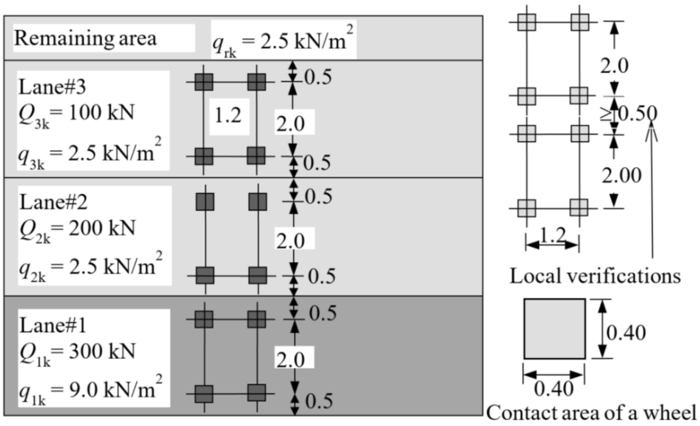

Fig. 1: Load Model LM1, according to EN 1991-2.

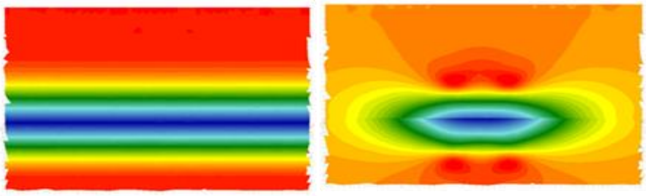

Fig. 2: a) steady flow of internal forces caused by UDL; b) variable flow of internal forces caused by TS.

3. Description of the Analyzed Structure

For the analysis, a typical highway bridge cross-section from the mid of 80s in Bratislava was chosen (Fig. 3). Only the left side cantilever has been analyzed. The length of the cantilever is 2.7 m, with variable thickness from 240 to 500 mm. The web of the box section supporting the cantilever is 460 mm thick. The depth of the inner slab changes from 500 mm near the web to 200 mm in the middle part of the slab.

The reinforcement of the cantilever slab is provided by 4 ϕ 22 + 4 ϕ 16 per meter, which means 25.3 cm^2 per meter. Considering the concrete cover of 30 mm, the effective depth of the slab is 459 mm and the reinforcement ratio 0.0055 at the web-slab connection. The concrete C 35/45 and steel B 420B were used.

The loads caused by traffic are considered according to EN 1991-2, as described in chapter 2. Other (permanent) loads consist of self-weight, kerbs and parapets – 10.4 kN/m and carriageway surfacing 100 mm – 2.4 kN/m^2.

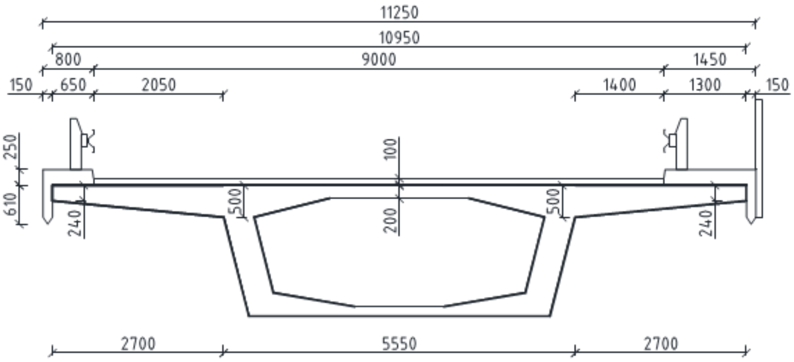

Fig. 3: Cross-section of the analyzed bridge deck.

All internal forces have been calculated on a 3D finite element model using quadrilateral area elements. This model was subjected to both linear (marked LA) and nonlinear (marked NA) analysis (taking into account the cracked concrete and the provided reinforcement) with the partial safety factors equal to 1.35 for both permanent and variable loads.

The compressive stresses in the slab which prevent the development of cracks in concrete can be obtained in two ways. The first is longitudinal prestressing, which should lead to compressive stress in all parts of the cross section. As for the second way, the longitudinal bending moment caused by the loads on the bridge also creates compressive stress in the top parts of the cross section. For this to happen, the cross-section must of course be located between the supports, in the area with a positive bending moment.

Different levels of compressive stresses have been introduced into the analysis. The first level was without additional compressive force. For the second and third level, compressive stress of 1 MPa and 4 MPa respectively, were introduced.

Two locations of the TS were selected for the analysis. The first (marked as 1. position) is in the distance *d* from the face of the web, for the maximum shear force and the second (marked as 2. position) creates the maximum bending moment in the control section.

4. Results of the analysis and summary

Figs. 4 – 7 show the shear force along the section at the face of the web caused by a design combination of loads acting on the cantilever slab. Each figure shows shear forces with compressive stress of three levels (0, 1 and 4 MPa). Since the LA does not cover the stress conditions of the member, there is no difference in shear forces for various levels of compressive stress.

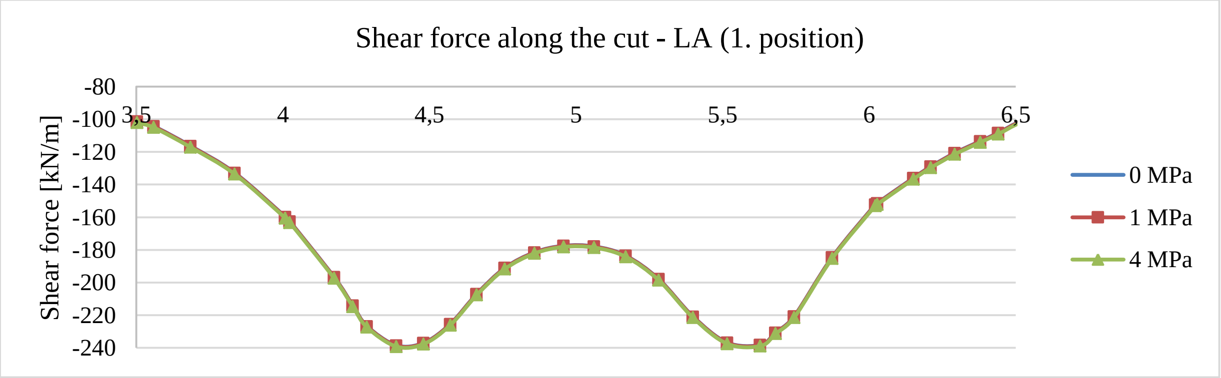

Fig. 4: Shear force along the control section (linear analysis, 1. position).

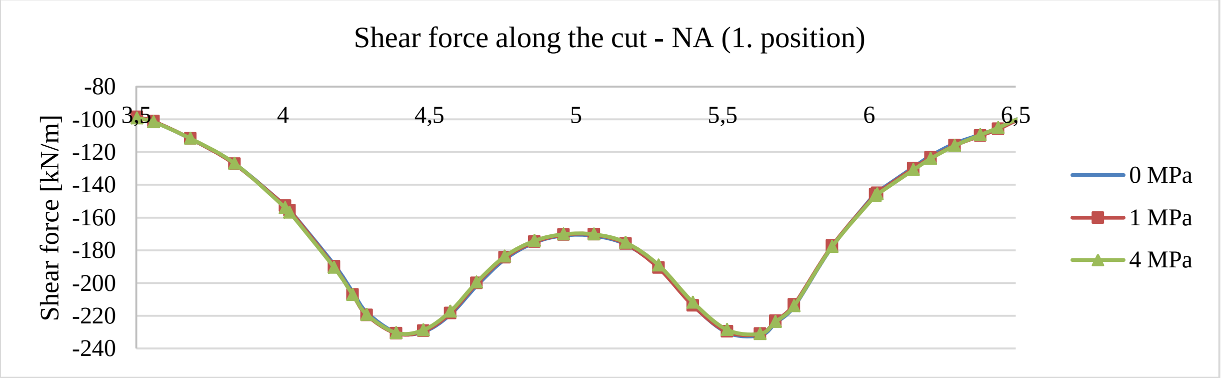

Fig. 5: Shear force along the control section (non-linear analysis, 1. position).

As could be expected, the different positions of the TS load lead to different distribution of shear forces. For the position near the web of the cross-section, two peaks are clearly visible, caused by the two wheels of the load model. For the second position, there is only one maximum value, because the shear force can distribute more evenly to a wider effective width.

In Figs. 4 and 5 a difference between LA and NA can be seen, mainly in the maximum shear force. The shear force obtained from NA is 4 % lower than from LA. For this position of the load, the compression stress does not have any influence on the shear force distribution.

For the second position of the load, only slight difference between LA and NA for no compression stress state is visible. The distribution of the shear force is a little bit different, but the maximum shear force is equal. On the other hand, the addition of compressive force into the analysis helps, as the distribution of the shear force is smoother, more evenly distributed along the effective width of the slab. The peak shear force is also slightly lower, with the difference of around 4 %.

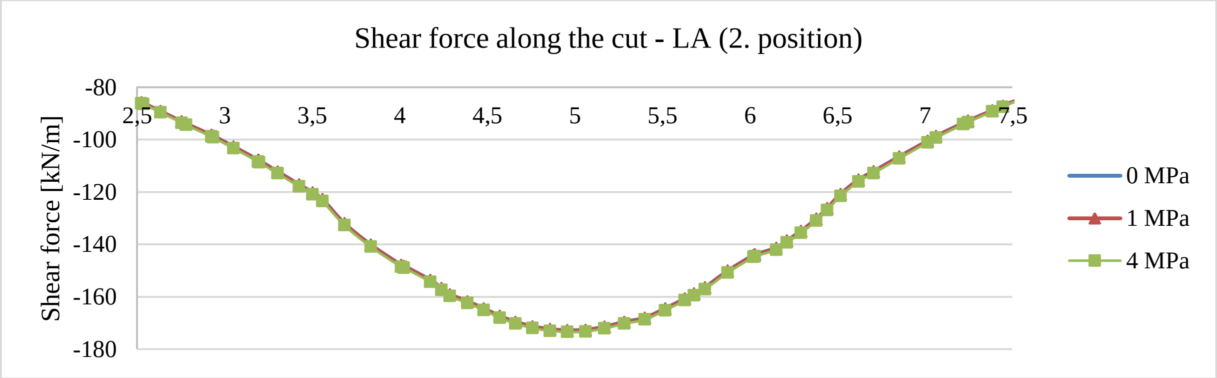

Fig. 6: Shear force along the control section (linear analysis, 2. position).

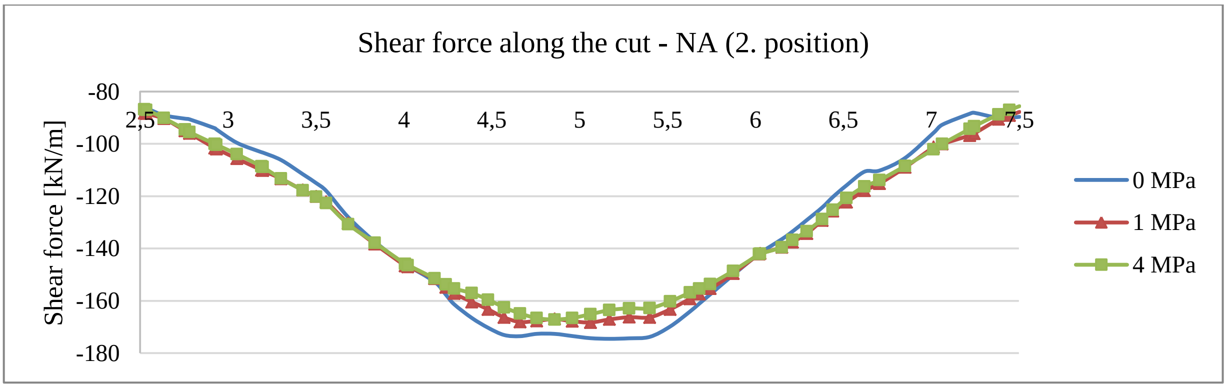

Fig. 7: Shear force along the control section (non-linear analysis, 2. position).

5. Conclusions

The differences between LA and NA are rather small, within 4 % for all positions of concentrated load, with LA resulting in slightly higher values of shear force.

The longitudinal compressive stress in real cantilever slab which leads to limitation of the cracks can in turn have a positive influence on the shear force distribution and consequently on the shear resistance in the critical section. This case also shows, that the differences between the LA and NA are not really significant and are on the safe side when using the LA.

These results show that the linear analysis, which is simpler and less time consuming, offers acceptable and safe results, compared to non-linear analysis. On the other hand, if more accurate results are necessary, the non-linear analysis with compressive stresses can show certain reserves in the verification of shear resistance of the structure.

Acknowledgement

This work was supported by the Scientific Grant Agency of the Ministry of Education, science, research and sport of the Slovak Republic and the Slovak Academy of Sciences no. 1/0810/16.

Refrences

Lantsoght, E. and van der Veen, C. (2010) Experimental study of reinforced concrete bridge decks under concentrated loads near to supports, 13th International Conference and Exhibition - Structural Faults and Repair.

Lantsoght, E., van der Veen, C. and Walraven, J. (2012) Shear capacity of slabs and slab strips loaded close to the support, ACI SP-287, Recent Development in Reinforced Concrete Slab Analysis, Design and Serviceability, 01/2012.

Rombach, G.A. and Latte, S. (2008) Shear resistance of bridge decks without shear reinforcement, Tailor Made Concrete Structures, pp. 519-525, 2008.