Experimental research and modeling of chemical anchor systems under static and dynamic loading

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Abstract: In article considered modeling of fastening post bridge barriers to the bridge, bearing system used chemical adhesive anchor systems at static and dynamic loads. In paper shown the possibilities of the analysis of the causes of critical plastic deformations and extreme stresses in the bridge barrier elements at the static and dynamic loads due to crash of the vehicle on bridge barriers. Analysis of the operation of bridge barriers in a collision allowed the optimal parameters to provided and saved lives in case of accidents.

Keywords: adhesive anchor systems, modeling, finite element method, FEM, road barrier, bridge barrier.

One of the places of emergency-dangerous sites considered road bridges, designed to pass all vehicles on the roads. In case of vehicle crash, the bridge barrier obliged to hold the vehicle from departure on pedestrian part of the bridge (in the presence) and/or out of bridge limits. However, the choice of type of the bridge barrier limited in type of bridge’s width and problematical character of ensuring fastening bridge barrier to the bridge bearing system.

The perspective direction of ensured high quality and strong fastening bridge barrier to the bridge bearing system under limited conditions of deepening is using the chemical adhesive anchor system. Adhesive anchor system consisted of metal element and glue structure and relayed loads from steel element to the bridge bearing system through glue structure. Practically special studies on the work of anchor joints for posts of bridge barriers, including testing and modeling, not conducted.

In this paper presented the results of research on the connection of attachment points for the bridge barriers pillars. The bridge barriers pillars used adhesive anchor system of the most common frame size – M24 [1]. The whole research divided into three stages.

At the first stage, bench tests of the adhesive anchor studs carried out in order to determine the maximum breaking strength and determine the mechanical characteristics of the stud material. The tests carried out on a WPM testing machine with a maximum force of 300 kN. The test carried out on 10 samples. The length of the working part of the samples, after installation in the testing machine was 290 mm (Fig. 1). Anchor studs subjected to a uniformly increasing tensile load until the moment of destruction at a constant loading rate of 20 mm / min. Loading rate of 20 mm / min corresponded static loading.
Figure 1. The loading pattern of the sample anchor studs

The results of laboratory bench tests shown in Table 1.

Modulus of elasticity $E$ Table 1. Test results

| Characteristic                              | Value  |
|---------------------------------------------|--------|
| $L_{rab}$ – working length of the sample, mm | 290    |
| $F_0$ – is the initial cross-sectional area of the sample, mm$^2$ | 386    |
| $L$ – is the working length of the sample after testing, mm | 310    |
| $F_{sh}$ – the area of local narrowing (neck), mm$^2$ | 285    |
| $N$ – destructive force, kH | 246 |
| $\delta$ – is the relative elongation at break, % | 6,67 |
| $\psi$ – relative narrowing, % | 5     |
| $\sigma_v$ – temporary resistance limit, MPa | 640    |
| Modulus of elasticity $E$, MPa | 200000 |
| Poisson's ratio | 0,3    |

At the second stage, simulated post static tests of the bridge barrier with adhesive anchor system.
In accordance with the static bench test scheme built a virtual (finite element) test model used the adhesive anchor system.

Figure 2 shown the finite element (FE) models of structural elements used in bench static tests. Post elements made of thin sheet metal, i.e. the thickness of the elements was much smaller than the other geometrical dimensions. This simplification allowed to made the virtual model with shell finite elements [1-4, 11]. The axis of symmetry of the rib according to the results of measurements of the stand during preparation for bench static tests established not symmetrically with respect to the longitudinal axis. The offset (eccentricity) was 3 mm, which taken into account in the FE model. The stud modeled with bim finite elements. The main mechanical and strength characteristics of the post material obtained at the first phase (see Table 2). The adhesive anchor modeled as a bond imposed between a metal element and a bridge bearing system. The bond removed when reached the ultimate stress, allowed the metal element to perform translational motion relative to the bridge bearing system.

Table 2. The main physical and mechanical characteristics of the post

| Physical and mechanical characteristics          | 200000 | 7850 | 349 | 490 | 0.3 | 26 |
|-------------------------------------------------|--------|------|-----|-----|-----|----|
| Modulus of elasticity E, MPa                    |        |      |     |     |     |    |
| Density, kg/m³                                  |        |      |     |     |     |    |
| Yield strength, MPa                             |        |      |     |     |     |    |
| Tensile strength, MPa                           |        |      |     |     |     |    |
| Poisson's ratio                                 |        |      |     |     |     |    |
| δ – is the relative elongation at break, %      |        |      |     |     |     |    |

In accordance with the data in Tables 1 and 2, constructed true deformation diagrams (Figure 3), which used in the simulation.
Figure 2. FE model: a) post; b) studs; c) assembly.
b)

Figure 3. True deformation diagrams: a) - Steel 35; b) - Steel 3

The load element adopted in the form of rigid cylinder. The loading rate in the model was 80 mm/min. The behavior of the FE model post during the virtual bench static tests presented in Figure 4.
Figure 4. Post behavior during virtual static test
Figure 5 shown the behavior of the post during virtual and bench tests under static loading.
As result of the calculation, obtained the values of the resulting efforts, the resulting moments, as well as the stress-strain state (before the destruction) of each of the adhesive anchor stud (Figure 6).

Figure 7 shown a dependence of the force on the post at the place of contact between the post and the load element against the movement of the loading element.
Figure 6. Static test results: a) resulting efforts; b) resulting moments; c) stress-strain state
Figure 7. The dependence of the force on the post at the place of contact between the post and the load element on the movement of the load element

At the third stage, conducted virtual dynamic (impact) tests bridge barrier post using adhesive anchor system and their comparison with bench dynamic tests.

In accordance with the bench dynamic testing scheme, FE models, and the physical and mechanical characteristics of materials that obtained in the first two stages, built a virtual (FE) model of dynamic (shock) tests (Figure 8) [2-11].
The behavior of the structure during the impact and the comparison of bench and virtual tests presented in Figure 9.
Figure 9. Comparison of bench and virtual dynamic tests
The resulting values of the resulting forces, the resulting moments, as well as the stress-strain state (before failure) on each of the anchor stud presented in Figure 10.
Figure 10. Dynamic (impact) test results: a) resulting efforts; b) resulting moments; c) stress-strain state

According to the results of the research, draw the following conclusions:

1) Use of chemical adhesive anchor advisable when installed bridge barrier, since all the components of the anchor system comply with the stated characteristics and ensure reliable operation of the structure under static and dynamic loading. According to the results of studies of the destruction of the adhesive composition did not occur, and the rupture of metal elements occurred when stresses exceeding the calculated values reached due to the design and technological features.

2) Due to inaccuracies in technological processes of post assembly, which detected as a result of measuring post dimensions, and checking their compliance with the drawing (offset of the axis of symmetry of the post’s rib relative to the longitudinal axis by 3 mm), large deformations occurred. It affected the operation of the post, on the magnitude of the energy absorption of the post, as well as on the redistribution of the generalized efforts on the stud anchor.

3) For a given rigid structure, the equivalent stresses on the front anchor studs reach values of 670 MPa, which corresponded to the limit values for the material of the stud.

4) The results of the conducted virtual tests completely repeat the results of full-scale static and dynamic bench tests. That made it possible to consider conducting a virtual experiment in the research, analysis of the design and fine-tuning of elements of building structures of this type as promised. The analysis of the results obtained the virtual experiment made it possible to identify the causes of the appearance of critical plastic deformations and ultimate stresses.

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