On the strength of chemical anchors

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Abstract. The work presents the strut attachment unit study of the bridge barrier road rack to the reinforced concrete slab (strength class of concrete B35) using adhesive (chemical) compositions and anchor-studs under the dynamic load. Bench static tests results and virtual experiment results based on study of digital models presented. The required depth of anchor-stud deepening determined.

1. Introduction

Reducing the number of road accidents, and therefore improving road safety, is a priority for any country. One of the most difficult road sections for safety is road bridging. This is primarily due to the fact that in an accident, the bridge barrier obliged to keep the vehicle from leaving the pedestrian part and/or beyond the bridge. However, the selection of the road barrier limited by the width of the road bridge and the difficulty of installing the road barrier to the load-bearing system of the bridge. One of the modern methods of securing the safety system to the bridge bearing system under limited deepening conditions is the use of chemical anchor consisting of a metal element and an adhesive composition. The purpose of this study is to determine the reasons for breaking of anchor studs [1] during full-scale bench impact tests [2].

As a result of bench impact tests, which carried out at the stand of FSUE "NAMI" the post using BIT-NORD adhesive composition and anchor pins for attaching the strut to the foundation [2], the front anchor pins torn out during loading (figure 1).

Figure 1. Removal front anchor pins as a result of bench impact tests.
Bench impact tests carried out in accordance with the terms of reference and Standard R 52721. Bench impact test diagram shown in figure 2.

![Bench impact test diagram](image)

**Figure 2.** Bench impact test.

2. **Materials and equipment**

To identify the causes of chemical anchors breaking out of the support surface, the study divided into two stages. At the first stage, the ultimate force determined by conducting bench static tests for breaking out of anchor pins (figure 3), which attached to a reinforced concrete slab, with geometric dimensions of 1200x1400x350 and strength class of concrete B35, using adhesive compositions. Bench tests carried out for two installation depth of studs: 170 mm (stud-170) and 210 mm (stud-210) on two types of adhesive compositions BIT-NORD and BIT-200 [1].

![Bench static tests](image)

**Figure 3.** Bench static tests for removal of anchor pins: (a) circuit of the accessory, (b) device for the experiment.
As a result of bench tests of stud-170 and stud-210 on adhesive compositions BIT-NORD and BIT-200, the values of the maximum load in the connection between the stud and the reinforced concrete slab obtained, depending on the depth of sealing, and two main types of destruction also recorded:

1) destruction of the body of the anchor pin (figure 4 (a));
2) destruction of the adhesive joint (figure 4 (b)).

The results of bench tests to determine the ultimate force of the BIT-NORD and BIT-200 adhesive compositions shown in table 1.

![Image of destruction of the anchor pin body and destruction of the adhesive joint.](image)

**Figure 4.** Types of destruction: (a) destruction of the body of the anchor pin, (b) destruction of adhesive joint.

**Table 1.** Bench test results.

| adhesive compositions | installation depth | stud     | maximum force | destruction |
|-----------------------|--------------------|----------|---------------|-------------|
| BIT-NORD              | 170 mm             | Stud-170 | 15.5 t (152 kN) |             |
| BIT-NORD              | 170 mm             | Stud-170 | 15 t (147 kN) |             |
| BIT-NORD              | 210 mm             | Stud-170 | 18.5 t (181 kN) |             |
| BIT-200               | 170 mm             | Stud-210 | 18.5 t (181 kN) |             |
| BIT-200               | 170 mm             | Stud-210 | 17.5 t (172 kN) |             |
| BIT-200               | 210 mm             | Stud-210 | 17.8 t (175 kN) |             |
Analyzing the results (table 1), it concluded that with an installation depth of 170 mm and the use of BIT-NORD adhesive composition, the anchor stud-210 breaks out of the reinforced concrete slab (destruction of the adhesive connection between the stud and the reinforced concrete slab) without breaking the anchor stud. When the installation depth increased to 210 mm, the adhesive joint between the stud and the reinforced concrete slab using the BIT-NORD composition was not destroyed, while the body of the anchor-stud was destroyed stud-210 with a force corresponding to the fracturing force determined by previously performed laboratory bench static tests [3].

When using adhesive composition BIT-200 for attachment of anchor stud-170 and stud-210 with installation depth of 170 mm and 210 mm, respectively, in both cases the body of anchor stud destroyed with forces corresponding to those determined earlier during laboratory bench static tests [3]. At the same time, the loss of the load-bearing capacity of the adhesive connection of the anchor-stud with the reinforced concrete slab did not occur.

3. Modeling
At the second stage, the behavior of chemical anchors during dynamic loading was simulated. Virtual tests conducted on the basis of the finite element method (FEM) using the LS-Dyna multi-purpose software complex [4]. According to the design diagram (see figure 2), the digital test model shown in figure 5 constructed.

![Virtual dynamic test model.](image)

Virtual bench dynamic (impact) tests carried out for anchor stud-170 on the adhesive (chemical) composition of BIT-NORD on the reinforced concrete base of the bridge post. Figures 6 and 7 show the developed digital models of the core elements used in virtual impact tests. The post is a thin-walled profile, so its modeling carried out by shell finite elements. Stud-170 modeled with three-dimensional finite elements [5].

![Digital models of the main elements: (a) post, (b) anchor stud-170.](image)
Figure 7. Digital models of the main parts: (a) loading element (striker), (b) reinforced concrete slab.

The main mechanical characteristics of the post material according to the quality certificate given in table 2. The true stress-strain curve of the post material used in the virtual bench impact test model is shown in figure 8. In the digital model, an elastoplastic model of the material MAT_024_PIECEWISE_LINEAR_PLASTICITY used with the specification of the full stress-strain curve and the constants of the effect of strain rates according to the Cooper-Symonds model [6]. For loading element and concrete slab used rigid material MAT_020_RIGID.

Table 2. Main mechanical characteristics of the post material

| Property                        | Value         |
|---------------------------------|---------------|
| Yield strength, MPa             | 351           |
| Tensile strength, MPa           | 473           |
| Relative deformation at failure, % | 31           |
| Elastic modulus, MPa            | 200000        |
| Poisson ratio                   | 0.31          |

Figure 8. Stress-strain curve of the post material used in digital model.

The main mechanical characteristics of the material of anchor stud-170, obtained in previous studies [5], shown in table 3. The true stress-strain curve of the anchor-stud material used in the virtual model of bench shock tests shown in figure 9.
Table 3. Main mechanical characteristics of the anchor stud material

|                           |       |
|---------------------------|-------|
| Yield strength, MPa       | 479   |
| Tensile strength, MPa     | 713   |
| Relative deformation at failure, % | 7     |

Figure 9. Stress-strain curve of the post material used in digital model.

4. Results
The loading element and reinforced concrete slab in the virtual model of bench shock tests presented as absolutely rigid [7-9]. The connection between the reinforced concrete slab and the anchor studs carried out by means of an indestructible adhesive contact [10, 11]. During dynamic loading (figure 10), the impact energy was 29.43 kJ. The values of the resulting forces in contact between the anchor studs and the reinforced concrete slab shown in figure 11.

Figure 10. Stress-strain state: (a) post, (b) stud.
5. Conclusions
Based on the results of virtual impact tests, it concluded (Figure 11) that the maximum force that occurs in contact between the anchor stud and the reinforced concrete slab is 174 kN, which exceeds the amount of force required to pull out the anchor stud-170 with an installation depth of 170 mm using the BIT-NORD adhesive composition (Table 1). This fact explains the reason for breaking out the anchor stud during bench impact tests and the destruction of the adhesive joint. It is worth noting that the obtained maximum force that occurs in contact between the anchor pin and the reinforced concrete slab, according to the results of virtual impact tests, does not exceed the amount of force required to pull out the anchor stud-210 with a depth of 210 mm and using BIT-NORD adhesive composition (Table 1) conducting virtual experiments based on the use of digital twins [12] is a modern tool for solving research, development and engineering problems with a significant reduction in both time and material costs.

Acknowledgment
Authors are grateful for their scientific advisor, Ph.D., prof. I.V. Demiyanushko for guidance, comments and advice in carrying out this research work.

Financial support
The work carried out with funding under the Development - Digital Technologies Program with the support of the Fund for the Promotion of the Development of Small Forms of Enterprises in the Scientific and Technical Sphere (Innovation Assistance Fund) (№ 47GRCTC10-D5/56182).

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