Short-term strength of anchor screws on modified acrylic adhesives

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Abstract. Theoretical and experimental studies of the stress-strain state with a short pulling force acting on concrete smooth steel rods with acrylic adhesives were carried out by such scientists as L.N. Shutenko, M.S. Zolotov, B.Yu. Pugi, etc. However, it should be noted that when performing these experimental studies ordinary acrylic adhesive was used. The purpose of the experimental studies was to determine the short-term strength of anchor bolted joints on acrylic adhesives using various modifiers and the depths of bolt insertion. As glue in the manufacture of prototypes of anchor bolted joints, a modified acrylic composition was used. If we accept the strength of the ZnO seal as 100\%, then the strength of the ground mica and methacrylic acid seals differ by 0.35 MPa and 3.5\%, respectively. The results of experiments to determine the strength of anchor bolted joints are systematized depending on the diameter of the anchors and the depth of their embedment in concrete. Based on our studies and analysis of experiments by other researchers, it is recommended that anchoring bolted joints to a depth of $l = 8\upsilon$. 

1. Introduction
In connection with the creation of new compositions of acrylic glue modified with additives [1, 2], which increased its adhesive and cohesive properties, it became necessary to determine the strength of adhesion under static short-term loading.

Theoretical and experimental studies of the stress-strain state with a short-term pulling force acting on concrete smooth steel rods with acrylic adhesives were carried out by such scientists as L.N. Shutenko, M.S. Zolotov, B.Yu. Pugi, etc. [1, 2, 4-11]. It should be noted that when performing these experimental studies ordinary acrylic adhesive was used.

As preliminary studies have shown, the use of modified acrylic compositions with higher adhesive and cohesive properties during anchoring works leads to a decrease in the depth of embedment of anchors, and, consequently, to a significant economic effect.

2. Determination of the strength of the connection depending on the modifier
The purpose of the experimental studies was to determine the short-term strength of anchor bolts on acrylic adhesives using various modifiers and bolt depths.

Experimental studies were performed in accordance with recommendations [1-5].

A modified acrylic composition was used as an adhesive in the manufacture of prototype anchor bolts (Table 1) [4-6].
Table 1. Physico-mechanical properties of acrylic adhesive modifiers

| Modifier of ordinary acrylic glue | Tensile strength, MPa | Modulus of elasticity $E$, MPa | Poisson's ratio, $\mu$ |
|----------------------------------|-----------------------|-------------------------------|-----------------|
| ZnO                              | 98.61                 | 0.553 $\cdot 10^4$           |                 |
| Methacrylic acid                 | 97.43                 | 0.521 $\cdot 10^4$           | 0.20            |
| Ground mica                      | 96.34                 | 0.528 $\cdot 10^4$           |                 |

The scheme of the samples testing with short-term impact on the anchorage of the tensile force is shown in Figure 1. The tests were performed on the hydraulic press of the UIM-50. The load application rate was 2.5 to 3.0 MPa per second. Maximum force was determined corresponding to either the adhesive failure of the adhesive compound or the rupture of the anchor bolt connection. The results of the experiments are shown in Table 2.

If you accept the strength of the anchor seal with the application ZnO by 100 %, then the strength of the seals using ground mica and methacrylic acid is different by 0.35 MPa and 3.5 %, respectively.

The use of zinc oxide as a modifier simplifies a little the technological process of preparation of glue and anchor bolt connection device, creates more favourable conditions from the point of view of safety of conducting anchorage works.

Zinc oxide is less deficient and relatively cheaper, that is why it has been accepted in further studies as a modifying additive.

The modified acrylic adhesive has high strength characteristics [4] that can be varied over a wide range by introducing special additives. Changing the adhesive properties, it is possible to choose an economical composition with minimal consumption of acrylic polymer adhesive composition.
Table 2. Strength characteristics of anchor bolts at 20 mm diameter anchors

| Depth of anchor seal \( l \), mm | Tensile strength, MPa | + ground mica | + ZnO | + methacrylic acid |
|----------------------------------|-----------------------|---------------|-------|-------------------|
|                                  | strength | the nature of the destruction | strength | the nature of the destruction | strength | the nature of the destruction |
| \( l=10d_s=200 \)               | -        | -                           | 467.8   | rupture of the anchor | - | - |
| \( l=9d_s=180 \)                | -        | -                           | 341.1   | mixed              | - | - |
| \( l=8d_s=160 \)                | 283.7    | by contact adhesive anchor  | 284.7   | on contact adhesive anchor | 274.8 | by contact adhesive anchor |

3. Determination of the strength of the connection depending on the diameter of the anchor and the depth of embedment

Next, we studied the compounds on the adhesive modified with zinc oxide, in which anchor bolt joints were used, the diameter of which varied from 12 to 56 mm. The thickness of the adhesive layer was assigned from the condition of geometric similarity of the anchor joint. It remained constant for all samples of the same diameter. This made possible to eliminate the influence of the transverse dimensions of the anchor on the stress-strain state of the joint and to establish the relationship between the depth of embedment of the anchor and the tensile strength of the system under the short-term action of the pulling force.

A view of a sample anchor bolted joint prepared for testing is shown in Figure 2.

A study of the strength of anchor bolt joints at embedment depths of 10, 9, and 8 anchor diameters was performed on separate series of samples.

The test scheme for samples of anchor bolted joints is shown in Figure 1.

![Figure 2](image)

**Figure 2.** View of an anchor bolt sample prepared for testing on a modified acrylic adhesive.

The results of experiments to determine the strength of anchor bolted joints are systematized depending on the diameter of the anchors and the depth of their embedment in concrete are presented in table 3. For each of the experimental series, the nature of their destruction was determined, which was determined by the breakdown of the anchor, violation of the adhesive strength at the adhesive-anchor contact or mixed destruction.
Table 3. Strength characteristics of anchor bolted joints during short-term loading

| Anchor diameter, \(d, \) mm | Tensile strength, MPa | Tensile strength, MPa | Tensile strength, MPa |
|-----------------------------|-----------------------|-----------------------|-----------------------|
| \(l = 10d, \) mm | \(108\) | 475.5 anchor break | \(180\) | 349.5 mixed |
| \(l = 9d, \) mm | \(128\) | 471.4 anchor break | \(160\) | 341.1 mixed |
| \(l = 8d, \) mm | \(192\) | 467.8 anchor break | \(240\) | 341.1 mixed |

Figure 3 presents data on the nature of the change in the strength of anchor bolt joints depending on the depth of embedment, based on the results of testing anchors with a diameter of 12 and 56 mm. All other strength curves for anchors with a diameter of 16 to 48 mm are placed in the interval between them.

Smooth curves are constructed according to the results of processing the obtained experimental data with mathematical statistics methods using a computer program. They are described by the regression equation:

\[
\sigma_s = \frac{1}{a + bl} \cdot c, \tag{1}
\]

where \(a, b, c\) are the experimental parameters shown in table 4.
Table 4. The values of the experimental parameters a, b and c of equation (1) describing the graph in Figure 3, as well as correlation indices and mean square errors of the regression equations

| Diameter anchors, mm | Coefficient | r, correlation index | s, standard error of the regression equation |
|----------------------|-------------|----------------------|---------------------------------------------|
| 12                   | 0.0094      | -0.00082             | 0.9985                                      | 9.5115                                      |
| 20                   | 0.0096      | -0.00084             | 0.9984                                      | 8.8154                                      |
| 56                   | 0.0111      | -0.0012              | 0.9995                                      | 5.0897                                      |

Analysis of the results of experiments to determine the short-term strength of anchor bolt joints (Table 3 and Figure 3) showed that the strength depends primarily on the depth of the bolt in concrete.

Based on the analysis of experimental studies, the short-term strength of anchor bolted joints on modified acrylic adhesives was determined. Accepted compositions showed almost the same strength results.

4. Conclusions
The short-term strength of anchor bolted joints on modified ZnO acrylic glue depending on the depth of the bolt was determined. It was found that with a depth of embedment of anchor bolted joints \( l = 10d_t \) the destruction of anchor bolted joints occurs as a result of rupture of bolts; at \( l = 9d_t \) – the destruction of anchor bolted joints occurred either at break of the anchor, or at the contact of the adhesive-anchor, and at \( l \leq 8d_t \) – by contact adhesive anchor.

Based on our studies and analysis of experiments by other researchers, it is recommended that anchoring bolted joints to a depth of \( l = 8d_t \).
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