Research of technologies for restoration of the concrete protective layer of reinforced concrete constructions during the reconstruction of the buildings and structures

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Abstract: The use of reinforced concrete in modern construction is conditioned by its mechanical and physical properties. However, over time, under the influence of all sorts of factors, structures collapse and require repair work to restore quality indicators and geometric configuration. Typically, the destruction of the structure begins with the upper layers of concrete and extends in deep. Therefore, this article presents the results of experimental studies on the restoration of the surface of concrete specimens and determines the dependence of the adhesive strength of recovered concrete with the repair mix depending of the method of preparation of the base structure. Experimental studies were planned and carried out in five series, in which was changed the way the base was prepared: applying two-component glue "Erorip" (TM "MAPEI") to the base; application of two-component "Edmoc" glue (Composite LLC); with wetting the concrete surface and restoring it with a modified concrete mixture; application of "Consolid 1" and "Consolid 2" compositions ("Composite" LLC) with an interval of 24 hours; moistening the surface of the samples with water (control samples). In addition, the strength of adhesion of recovered concrete with the repair mix depending of the spatial position of the repair site was determined. For this purpose, the repair mixture was put into the formwork on the upper, lateral or lower surface of the samples. After 28 days after laying the repair mixture, the average values of adhesion strength of the recovered layers with the base were determined. It was found that in the process of restoration of the upper surface of the samples all the methods of preparation of the base gave a good adhesion of layers of concrete, during the restoration of the lateral surface the best results were obtained in series No. 1 and No. 3, while the restoration of the lower surface is effective in case preparation of the basis as for the series No 3. The results of the obtained experimental research indicates a further need to investigate the method of restoring the lateral and lower surfaces of concrete and reinforced concrete structures.

1. Introduction

Reinforced concrete constructions are the most common ones in buildings and structures. Reinforced concrete constructions have gained such popularity due to the ability to give them any kind and shape. Under the influence of all kinds of factors, including climatic, mechanical, non-observance of clear technological regulations for the execution of works, etc., and also due to errors at the stage of design, concrete constructions collapse, lose their durability and do not meet the requirements of regulatory documents, and therefore do not fully comply its functional purpose. During the reconstruction of...
buildings and structures, they usually perform a complex of construction-assembly works aimed at restoring or changing the geometric dimensions of constructions and restoring their operational properties in the case of damage. The destruction of constructions, as a rule, begins with the protective layer of concrete and extends in deep, resulting in corrosion of the reinforcement and subsequent destruction of the reinforced concrete construction [8, 11].

2. Analysis of recent research and publications
In the process of restoring the protective layer of reinforced concrete constructions, an important indicator is the strength of adhesion of the repair mortar to the existing construction. Analyzing the scientific and technical literature, it was found that the adhesion strength depends on the method of preparation of the concrete surface [3, 4, 11] and the spatial position of the repair area relative to the horizon line [4].

In most cases, the repair of cracks on reinforced concrete constructions is carried out prior to the restoration of the protective layer of concrete. Such works can be carried out according to the investigated technology [5, 6]. According to research data, it is advisable to use the developed surface impregnation technology for gluing cracks with widths from 0.05 to 0.4 mm, classical injection technology at openings from 0 to 0.5 mm, 0.5 to 2.0 mm – combined technology. When using impregnation technology, a film of polymer composition is formed on the surface of the construction, which can subsequently serve as an adhesive layer to restore the protective layer of the construction.

Typically, the restoration of the surface of reinforced concrete constructions is performed by putting a concrete repair mixture into the formwork. This method is also used to ruggedize reinforced concrete constructions, by increasing their cross-section [9, 10, 12].

3. Setting objectives
Research of technology of restoration of a protective concrete layer of reinforced concrete constructions, based on establishing of durability of adhesion of the restored concrete with the recovering mix depending on a position of a surface of a construction and a method of its preparation.

4. Presentment of the main material
Prior to the beginning of the experimental studies, a methodology was developed that involved the restoration of concrete specimens on three types of surfaces, which were determined by the different spatial position of the repair site (top, side, and bottom) in different ways of preparing the base. In this case, it was assumed that the concrete mixture was putted in formwork structures installed at a certain distance from the existing construction.

For the experimental studies there were used samples made of B30 concrete with the geometric dimensions: 270 x 120 x 120 mm. The surface of the specimens to be renewed was cleaned with an angle grinder, followed with dedusting by compressed air.

After completion of the preparatory work, the series of concrete samples was renewed. The work was performed at a temperature of 20 ± 2 °C and a relative humidity of 50 ± 5%.

The concrete mix used to restore the structures had the following component composition (based on 1 m³ of concrete mix): cement (PC II / A-W-500) – 395 kg; river sand (1.5 mm) – 870 kg; crushed stone (2-5 mm) – 1075 kg; water – 170 kg; plasticizer – 7.5 kg.

According to the methodology of experimental studies the restoration of samples was assumed in five series, with different ways preparation of the basis.

The first series of preparation of the basis consisted of applying by brush to the cleaned dry surface of two-component glue "Erorip" produced by TM "MAPEI", to which after 40 min was placed a repair mixture 2 cm thick.

The second series is similar to the first one, using as a adhesive layer two-component glue "Edmock" manufactured by "Composite" LLC, to which a concrete mixture 2 cm thick was placed after 40 min.
The third series of preparation of the basis consisted of moistening the prepared surface with water and arranging the samples in the formwork, followed by the placement of the concrete-modified mixture. The repair concrete mix had the following component composition (based on 1 m³ of concrete mix): cement (PC II / A-W-500) – 450 kg; river sand (1.5 mm) – 750 kg; screening granite (2-5 mm) – 250 kg; crushed stone (5-10 mm) – 800 kg; water – 200 kg; Dynamon SR 3 (1.3%) – 5.9 kg; Mapecure SRA (1%) – 4.5 kg. Modifying additives used in the mixture, manufactured by TM "MAPEI".

In the fourth series, one layer of the "Consolid 1" composition manufactured by "Composite" LLC, prepared according to the manufacturer's recipe, was applied to the cleaned dry concrete surface. After 24 h, another layer of "Consolid 2" composition was applied to the surface. Next, the samples were placed in the formwork structure and after 2 h in the space between the formwork and the prepared surface was placed a concrete mixture 2 cm thick.

The fifth series of preparation of the base – the control one. The surfaces of the specimens, after cleaning and dedusting, were moistened within formwork with water and placed the concrete mix.

For restoration of the upper surface of the specimens, the formwork structure was installed on the lateral faces on four sides 'Figure 1a' and the surfaces of the specimens was prepared for the subsequent placement of a concrete mixture 2 cm thick. During the laying, the mixture was pinned and then compacted, by impacting on the formwork structure by the low-speed vibrating machine. The compaction time was 10-15 s. After 24 h, the specimens were removal from the formwork and their renewed surface moistened twice a day with water for 5 days.

![Figure 1](image)

**Figure 1.** Layout of the specimen relative to the formwork during recovery: *a* – of the upper surface; *b* – of the lateral surface, where: 1 – concrete specimen; 2 – repair mixture; 3 – formwork

For restoration of the lateral surface of concrete specimens, the formwork structure was installed in such a way that a space of 2 cm was formed on one of the lateral faces between the prepared specimen and the formwork 'Figure 1b'. The concrete mixture, while filling the formwork, was pinned, compacted for 10–15 s, by impacting by low-speed vibrating machine to the lateral surface of the formwork structure. After 48 h, the specimens were removed from the formwork and their renewed surfaces moistened twice a day with water for 5 days.

To restore the lower surfaces of concrete specimens was used technology [7, 9] 'Figure 2'.

The formwork design consisted of a bottom and four side faces. In this case, two faces was made of transparent plexiglass and served to control the filling of the formwork with a concrete mixture, and the others were made of plastic. In one of the plastic faces, a hole with a diameter of 35 mm was formed in the middle, into which a metal funnel was glued 'Figure 3'. To prevent leakage of repair mortar from formwork, its joints were sealed with hot-melt glue. At the bottom of the formwork, metal supports 2 cm high were placed in the corners to simulate the blank space between the concrete specimen and the formwork. The bodies of the samples had grooves at the place of installation of the funnel for free passage of the mortar into the formwork.
Previous studies have found that it is impossible to fill the formwork cavity qualitatively while restoring the lower surface of the specimens with the proposed concrete mix, which is due to its rigidity. That is why in order to increase the mobility of the repair mortar, it was decided to increase the amount of water in the composition by 1.5 times. The prepared repair mortar was fed into the funnel by small portions and carried out with a permanent pinning. The flow of the mixture was controlled through the transparent plexiglass. After complete filling of the formwork with the mortar, it was compacted with a vibrating machine at low speed revolutions for 10–15 s. During the vibration, the mortar remaining in the funnel was filling the formwork additionally. After that the funnel was removed and the hole was closed with a stopper. The recovered samples were removed from the formwork after 2 days. Subsequently, the samples were moistened with water twice a day for five days.

After 28 days after the restoration of the surfaces of the samples the adherence strength of the restored layers with the base was determined. For this purpose, the restored surface was cleaned and dedusted. Metallic plates with catch members were glued to this surface with epoxy glue.

Determination of adhesive strength was made using a special device "Figure 4" by a known method [1].
**Figure 4.** The device for determining the adhesion strength of the layers of the construction

The results of the experimental tests are given in table 1.

| № series of the study | Adhesion strength of the protective layer and base of the recovered samples | Kind of destruction | Kind of destruction | Kind of destruction |
|------------------------|---------------------------------------------------------------------------|---------------------|---------------------|---------------------|
|                        | From above                                                                 | Laterally           | From the bottom     |                     |
|                        | MPa                                                                       | MPa                 | MPa                 |                     |
| 1                      | 1,42                                                                      | 1,15                | 0,37                | Adhesive type (in the junction of layers) |
| 2                      | 0,82                                                                      | 0,7                 | 0,57                | Adhesive type (in the junction of layers) |
| 3                      | 0,98                                                                      | 1,1                 | 0,82                | Adhesive - cohesive type |
| 4                      | 0,91                                                                      | 0,76                | 0                   | It came off during the sawing |
| 5                      | 0,7                                                                       | 0,4                 | 0                   | It came off during the sawing |

According to the results of the study given in table 1, a diagram of adhesion strength of recovered concrete and repair mortar was constructed "Figure 5".
Figure 5. Diagram of adhesion strength of reclaimed concrete to the base, depending on the method of surface preparation and the spatial position of the repair site: a – from above; b – laterally; c – from the bottom.

After analysis of the results of the research, it was found that during the restoration of the upper surfaces of the samples, the best adhesion strength between the layers was observed in the series of studies No. 1 and 3 with the cohesive type of destruction; that is, tears were formed in the layer of a new concrete ‘Figure 6a’. In the series of studies No. 2, 4 and 5, tears were formed at the junction of two layers – it is the adhesive type of destruction ‘Figure 6b’.

Figure 6. Type of destruction of specimens: a – cohesive destruction; b – adhesive destruction

In the case of the restoration of the lateral surfaces of specimens series 1 and 3, the destruction occurred in the body of recovered concrete. There were the destructions of the specimens on the border of layers in other series of studies.

No bonding of the layers was observed at all on the samples of series 4 and 5, which were recovered from below. During the preparation of the specimens for adhesion tests, the recovered layer was separated. In research series № 3, the highest adhesive strength was observed. In series 2 and 3, the destructions occurred at the junction of two layers.

5. Conclusions
As a result of experimental studies, it is established that the highest adhesion strength of concrete layers is observed when using the glue "Erorip" and in a series of studies on the restoration by the modified concrete mixture.

The adhesive strength of concrete layers when using two-component "Edmock" glue is in the range of 0.57–0.82 MPa. In all cases, the destruction occurred at the junction of "old" and "new" concrete.

The results obtained in a series of studies No. 4 (surface preparation with "Consolid" 1 and "Consolid" 2 compositions) revealed that in the case of the restoration of the upper surfaces of the
specimens, the average adhesion strength was 0.91 MPa, of the laterals – 0.76 MPa, lower – no grip. In all cases, the destruction occurred at the junction of the layers.

A series of studies of control samples (the method of surface preparation was to moisten the surface of the base) was able to establish that in the process of restoration of the upper surfaces of the samples, the average value of adhesion was 0.7 MPa, in laterals – 0.4 MPa, the lower – no grip. In this case, the destruction in all tests occurred at the junction of the layers.

The lowest adhesion strength in all series of specimens was observed during the restoration of the lower surfaces of concrete specimens. This can be explained by the fact that in the process of compaction of the mortar on the upper surface of the last that adjacent to the concrete sample, cement milk is formed, which prevents the connection of two layers of concrete.

6. References
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