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Bearing capacity of pasted anchors in the masonry walls of natural limestone

Несущая способность вклеиваемых анкеров в кладке стен из природного известняка

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Key words: natural limestone; pasted steel anchor; anchor mixture; physical experiment; calculation; Civil Engineering; Construction Industry; Buildings

Ключевые слова: природный известняк; клеевой стальной анкер; анкерный состав; физический эксперимент; расчет; гражданское строительство; строительная индустрия; здания

Abstract. The joint work of pasted steel anchors and wall masonry elements from natural limestone is discussed in the article. The aim of the scientific work is the development of a technique for calculating the load-bearing capacity of anchors in masonry walls from natural limestone and the development of nomograms for the rapid evaluation of the bearing capacity of anchors. The state of the problem of the work of pasted anchors in various materials was studied. It is established that the known methods for calculating the strength of pasted steel anchors do not take into account the joint work of the natural limestone and pasted steel anchor. Previous studies have focused on the study of anchor joints in concrete, and the work of the pasted joint in the masonry walls of natural limestone has not been investigated. In the present work, for the experimental study of the work of pasted steel anchors in the masonry of walls made of natural limestone, the following materials were accepted: natural limestone, periodic profile reinforcement and anchor mixture. General methods of experimental and theoretical research: analysis, synthesis, deduction, induction, analogy. To solve the set tasks, in the experimental part, the strength of the adhesive joint for pulling in stone elements after the strength of the anchor mixture was established, when fitting the fixture ø 12 mm A 500C into it. Experimental samples, tested to determine the strength of the adhesive joint, were destroyed by breaking the stone. This fact confirms the higher strength of the adhesive bond than the stone element. The results of the physical experiment performed by the authors for determining the parameters of the joint work of the pasted steel anchor and the stone elements from natural limestone are presented in article. It has been experimentally established that 0.4 mm is the criterion for the limiting displacement of anchors, in which splitting of stones from the effect of transverse tensile stresses caused by pulling out pasted steel anchors is not allowed. The estimated evaluation of the joint work of pasted steel anchors and wall masonry elements from natural limestone was proposed.

Аннотация. В статье рассматривается совместная работа стальных анкеров и элементов кладки стен из природного известняка. Целью научной работы является разработка методики расчета несущей способности анкеров в каменной кладке стен из природного известняка и разработка номограмм для оперативной оценки несущей способности анкеров. Изучено состояние вопроса о работе клеевых стальных анкеров в различных материалах. Установлено, что известные методики расчета прочности стальных анкеров не учитывают совместную работу природного камня известняка и стального анкера. Предыдущие исследования направлены на изучение анкерных соединений в бетоне, а работа клеевого соединения в каменной кладке стен из природного известняка не исследована. В настоящей работе, для экспериментального исследования работы клеевых стальных анкеров в каменной кладке стен из природного известняка, приняты следующие материалы: камень известняк, арматура периодического профиля и анкерная смесь. Общие методы экспериментальных и теоретических исследований: анализ, синтез, дедукция, индукция, аналогия. Для решения поставленных задач, в экспериментальной части исследованы прочность клеевого

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соединения на выдергивание в каменных элементах после набора прочности анкерного состава, при установке в него арматуры ø 12 мм А 500С. Опытные образцы, испытанные для определения прочности клеевого соединения разрушились путем раскола камня. Это обстоятельство подтверждает более высокую прочность клеевого соединения, чем каменного элемента. В статье представлены результаты физического эксперимента выполненного авторами для определения параметров совместной работы стального анкера и камней природного известняка. Опытным путем установлено, что 0,4 мм – это тот критерий предельного смещения анкеров, при котором не допускается раскол камней от воздействия поперечных напряжений растяжения, возникших при выдергивании стальных анкеров. Предложена расчетная оценка совместной работы стальных анкеров и элементов кладки стен из природного известняка.

1. Introduction

The object of research of scientific work is a technical solution for the reliable fastening of modern hinged facades to buildings with walls of natural limestone.

Research subject: glued joint of a steel anchor in a stone element of natural limestone.

In accordance with the Decree of the Government of the Russian Federation No. 1636 of December 27, 1997 [1] only such anchors are allowed to be used on responsible construction sites whose suitability for use in construction is confirmed by the relevant technical certificate of the Ministry of Construction of the Russian Federation. Anchors that do not have a technical certificate are not allowed for use in critical construction sites [2].

The work of steel anchors fixed in a concrete base, which perceive the tensile and shearing forces from static loads, including their joint action, has been fairly well studied [3–18]. Leading world manufacturers of anchor fasteners Hilti, Fisher, Spit, etc. [19–21], offer methods for calculating and predicting the long-term bearing capacity of anchors fixed in a concrete base. In the recommendations for the design and installation of anchor fastenings of hinged facade systems developed by V.N. Vorobyov [2], the versions of the fastenings of front systems are described quite fully, however, the types of anchorage considered do not contain information on the operation of the glued steel anchor in the walls of natural limestone. Tests of anchor bolts on modified acrylic adhesives in determining the strength of their laying in concrete for short-term, long-term and dynamic loads, conducted by G.A. Molodchenko, V.A. Sklyarov, L.N. Shutenko, M.S. Zolotov and others [22–29] have shown the possibility of using them for fixing building structures and equipment under the action of various combinations of loads on them. In this case, the application of the above-mentioned known techniques for calculating and constructing anchor fasteners on an adhesive basis in elements of masonry of walls made of natural limestone is incorrect. To ensure the reliability of anchorages, it is necessary to account for the joint work of the glue shell of the anchor and the base of natural stone material [30–35].

At present, a large number of works have been devoted to the investigation of the thermal protection properties of hinged ventilated facades [36–38], while the methods for determining the bearing capacity of fastenings of facade systems have not been studied enough and need improvement.

The relevance of the research is that at present there are no methods that take into account the conditions for the joint work of the glue shell of the anchor and the natural limestone stone.

The aim of the scientific work is the development of a technique for calculating the load-bearing capacity of anchors in masonry walls from natural limestone and the development of nomograms for the rapid evaluation of the bearing capacity of anchors.

Objectives:

1. To carry out an experimental study of the joint work of the glue joint of steel anchor and natural limestone stones.

2. Develop proposals for the calculation of steel anchors in the masonry walls of natural limestone.

2. Materials and Methods

The method of full-scale tests and rules for determining the capacity of anchors in relation to longitudinal axial pulling loads with reference to the actual building base are set out in SRT 44416204-010-2010 "Anchor fasteners. The method of determining the bearing capacity by the results of full-scale tests" [39].

The essence of this method is that the tests of the anchorage on the pulling force applied to the anchor along its axis determine the resistance to fastening of the load and the deformation corresponding to the limiting states characteristic for it, and then the load-bearing capacity of the anchors is calculated by processing the test results.

Installation of anchorages in hinged façade systems should be carried out on the basis of a project developed in accordance with the requirements of STO NOSTROY [40] and taking into account the recommendations of the anchor manufacturer. The anchor mark must be indicated in the design documentation [40].

Previous studies have been directed to the study of anchor joints in concrete, the work of the glue joint in the masonry walls of natural limestone was not considered. In the present work, for the experimental study of the joint work of glue steel anchors in the masonry of walls made of natural limestone, the following materials were accepted: a nomulite limestone stone, a periodic profile armature and an anchor mixture.

A natural physical experiment was carried out. The strength of the glued joint is determined when installing anchors in the base of natural limestone stones. General methods of experimental and theoretical research: analysis, synthesis, deduction, induction, analogy.

Based on the analysis and processing of the results obtained, the following strength characteristics are determined:

The physical and mechanical properties of the natural limestone stone used in the manufacture of prototypes are determined by testing a stone element 120x108 mm; h = 156 mm; the volume weight is 1750 kg/m^2. The test was carried out in accordance with Russian State Standard GOST 8.136-74 [41] on the hydraulic press P-125.

Based on the analysis and processing of the results obtained, the strength characteristics of the stone of natural limestone are determined (Table 1).

Table 1. Physical and mechanical properties of natural limestone stone.

Geometric characteristics: ***axbxh, m***	**Weight** ***m, kN***	**Volumetric weight:** $\rho, kg/m^3$	**Destructive load:** ***F, kN***	**Ultimate Compressive Strength:** σ_{cm}, MPa	**Stone mark**
1	2	3	4	5	6
0.12x0.10x0.15	0.035	1750	88.26	6.8	M 50

The physical and mechanical properties of the A 500C armature used in the manufacture of prototypes are determined by testing the rods with a length of 350 mm. The test was carried out in accordance with Russian State Standard GOST 1497-84 [42] on an explosive device MP-500.

Based on the analysis and processing of the results obtained, the following strength and deformation characteristics of the reinforcement are determined: the physical yield strength $\boldsymbol{\sigma_y}$, the time resistance $\boldsymbol{\sigma_u}$, the elastic modulus E_s, the limiting relative deformations ε_{ux} corresponding to class A 500C.

A mortar mixture for anchoring and fixing various building elements in the Ceresit CX 5 masonry has been applied.

According to the manufacturer's data, compressive strength is:

- after 6 hours more than 12.0 MPa;
- after 1 day more than 22.5 MPa;
- after 28 days more than 22.5 MPa.

Flexural strength is:

- after 6 hours more than 2.2 MPa;
- after 1 day more than 2.6 MPa;
- after 28 days more than 8.0 MPa.

Testing of the samples was carried out after the strength of the solution mixture was collected after 28 days.

To solve the set tasks, in the experimental part, glued joints of A-500C armature are investigated when pulled from a stone base. Destruction determined the bearing capacity and deformation of glue joints of steel anchors in stone elements from natural limestone. The depth of the anchoring of the reinforcing bar, to obtain objective results, was taken differently on the basis of technological considerations for attaching hinged ventilated facade systems to the walls of multi-storey buildings.

The scope of the experiment was planned, allowing to obtain the number of experimental data necessary for statistical analysis and processing of the results ensuring the solution of the problems posed in this study.

The test facility is a R-20 rupture machine, into which a prototype is installed in an inventory metal cage. MIG-1 clock indicators are used to measure the deformation of the anchor shear relative to the outer surface of the stone base perpendicular to it.

To assign the load during testing of the adhesive joint, a numerical model was constructed in the PC "LIRA" and the forces acting in the anchor rods during the fastening of hinged ventilated facades to the walls of multi-storey buildings of stones and blocks of saw limestone were determined.

The tests were carried out in accordance with the requirements of Russian State Standard GOST 1497-84 [42].

The load was applied in steps of 0.1 from the expected destructive value to track the dynamics of failure and deformation of the adhesive bond in the test sample.

In prototypes tested after 28 days, the growth of deformations also depended on the anchoring depth. The displacement of the anchor passed along the contact zone "rock stone – anchor".

3. Results and Discussion

The destruction of anchorages can be as follows [2]:

- failure to connect the anchor to the base (in cases where the size or the anchor mark does not correspond to the pulling load, with insufficient anchoring depth, if the anchor installation technology is violated);
- failure of the base material (with insufficient strength of the base material, non-observance of the minimum axial distances);
- cleavage of the base in angular zones (with insufficient edge distances, high proppant force, high shear load);
- destruction of the steel anchor (the rarest case of failure).

The maximum permissible deformations in the test specimen occurred at a load from 24.52 kN to 30.4 kN.

Experimental samples tested to determine the strength of the adhesive bond were destroyed by slipping the glue joint through the contact zone "glue shell – the surface of the stone" and was followed by a subsequent split of fragments of stones. This circumstance confirms the need to take into account the joint work of anchoring elements in the contact area of materials.

It is established that the exhaustion of the bearing capacity of the adhesive joint should be considered when the anchor is displaced relative to the surface of the stone reaching a value of 0.4 mm.

With further load application, the anchor was pulled out of the previously drilled hole instantly, and followed by a split stone (Figures 1, 2).

Figure 1. Type of prototype when the anchor displacement is relative to the upper surface of the stone 0.4 mm

Figure 2. When the anchor was displaced more than 0.4 mm, it was pulled out, followed by a subsequent split of the stones

Splitting of stones occurred at loads exceeding by 15–20 % the load of depletion of the bearing capacity of the adhesive joint (according to the limiting displacement of the anchor 0.4 mm).

Thus, under the action of tensile forces in an anchor glued to a stone wall masonry element from natural limestone, a "glue shell – stone surface" breakdown occurs on the contact.

To develop proposals for calculating the strength of steel anchors in the masonry walls of natural limestone, criteria for limiting the displacement of anchors (0.4 mm) should be adopted, in which the joint work of materials is not allowed.

In connection with the natural variability of the structure of natural limestone stones formed as a deposit product, it is expedient to operate with the factors of joint work of the anchoring elements, proceeding from the assumptions only of the elastic stage of work [3–18]. It should be emphasized that taking into account the inelastic work of the elements can lead to an unreasonable and very dangerous overestimation of the design strength characteristics of anchor joints in natural limestone.

Based on the results of the experiment, the ultimate bonding tension of the glue shell of the steel anchor with the surface of the stone hole of natural limestone is determined by the strength corresponding to the M50 grade.

$$\tau_{cl(0.95)} = \frac{P}{\pi \cdot d_h \cdot h_{ef}} \quad (1)$$

where: d_h – is diameter of the hole previously drilled in stone, mm;

h_{ef} – is depth of anchoring of the anchor (effective anchoring depth), mm;

P – is destructive load, kN.

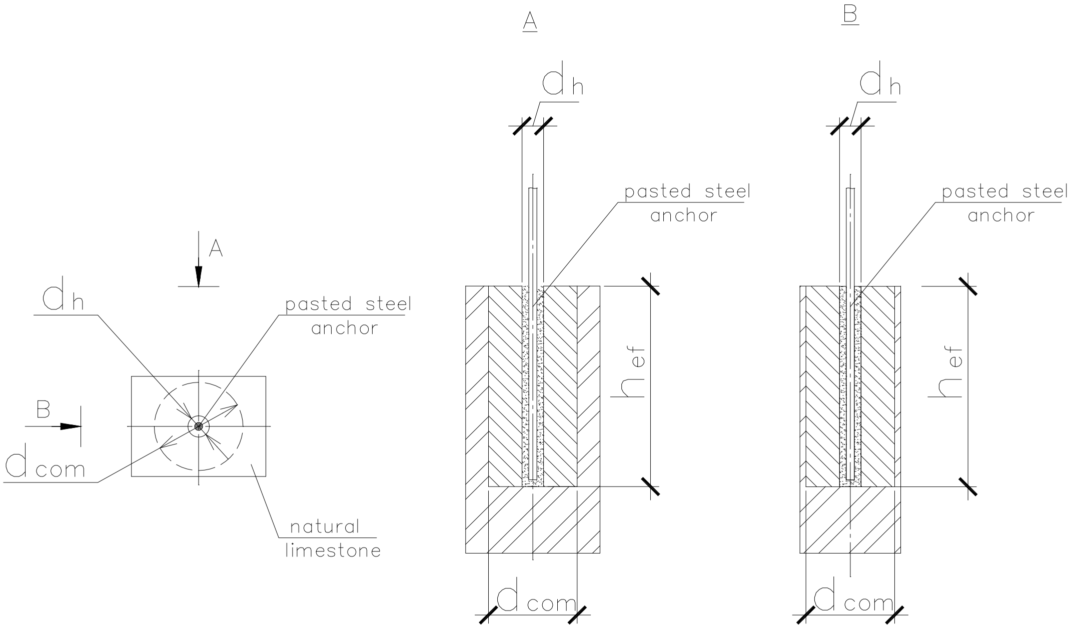

Figure 3. Scheme of a prototype of a natural limestone stone with an adhesive steel anchor

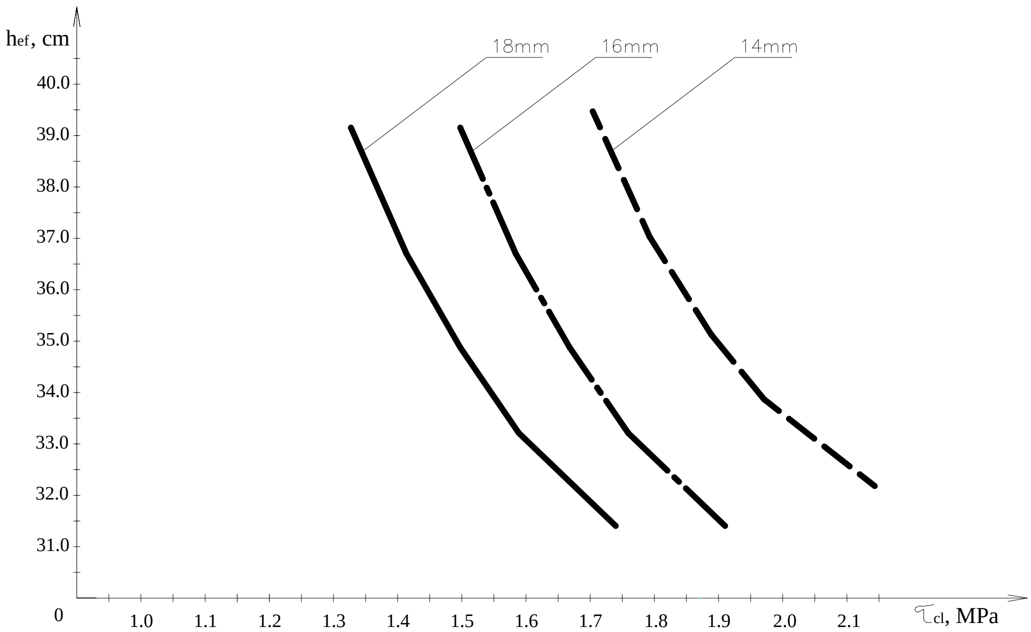

Figure 4. Experimental dependence of the ultimate bonding tension of the glue shell with the surface of the hole in the stone of natural limestone with the strength corresponding to the M50 grade

From the foregoing, when taking into account only the elastic stage of the work, it follows that calculation of the depth of anchoring of the anchor in the stones of saw limestone is determined by the formula:

$$h_{ef} = \frac{P}{\tau_{cl(0,95)} \cdot \pi \cdot d_h} \tag{2}$$

The area of the stone element, subject to compression from pulling the anchor, is determined by the diameter of the conventional stone shell, which is involved in the adhesive work of the anchor in joint work:

$$A_{com} = \frac{\pi}{4}(d_{com}^2 - d_h^2) \tag{3}$$

where d_{com} – is diameter of the conventional stone shell, involved in the glue shell of the anchor in the joint work.

Maximum allowable compression area for M50 stones is:

$$A_{ult.com.} = \frac{P}{M} \tag{4}$$

where P – is breaking load (tensile force in the anchor), kN;

M – is grade of stone, MPa.

$$\frac{\pi}{4}(d_{com}^2 - d_h^2) = \frac{P}{M} \tag{5}$$

From the equality 5, we determine the diameter of the conventional stone shell, which is involved in the adhesive work of the anchor in joint work:

$$d_{com} = \sqrt{0.025 \cdot P + d_h^2} \tag{6}$$

The minimum permissible distance between the holes or to the outer edge of the stone (Figure 5) is determined as follows:

$$B_{min} = d_{com} + 2d_h \tag{7}$$

The recommended distance between the holes or to the outer edge of the stone (Figure 5) is determined by the formula:

$$B_{opt} = 2(d_{com} + d_h) \tag{8}$$

The design load-bearing capacity of the anchor for pulling in the saw limestone of the M50 strength grade will be:

$$P_f = 1.75 * h_{ef} * \cdot \pi \cdot d_h \tag{9}$$

where 1.75 MPa – is a cautious value with a guaranteed probability of 0.95 of the maximum permissible adhesion stress of the anchor glue shell with the surface of the hole in the stone of the limestone of the numulite with strength corresponding to M50 [43].

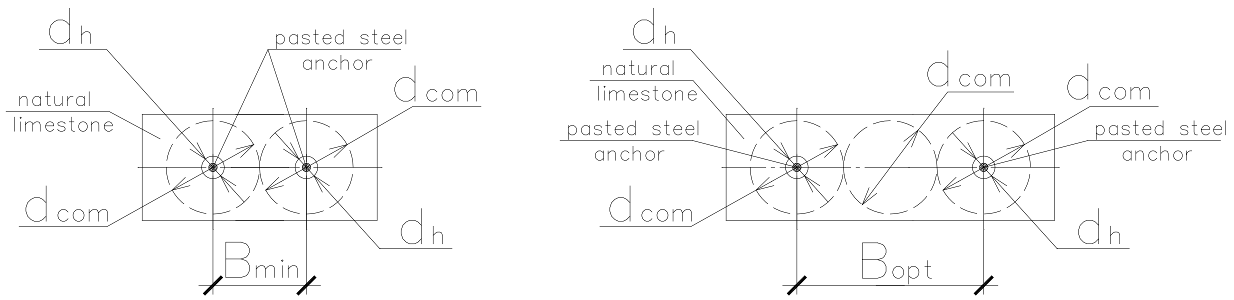

Figure 5. Calculation scheme

To quickly assess the bearing capacity of anchors of different diameters, it is convenient to use nomograms (Figure 6), developed by the authors on the basis of the conducted experiments and statistical processing of the results obtained.

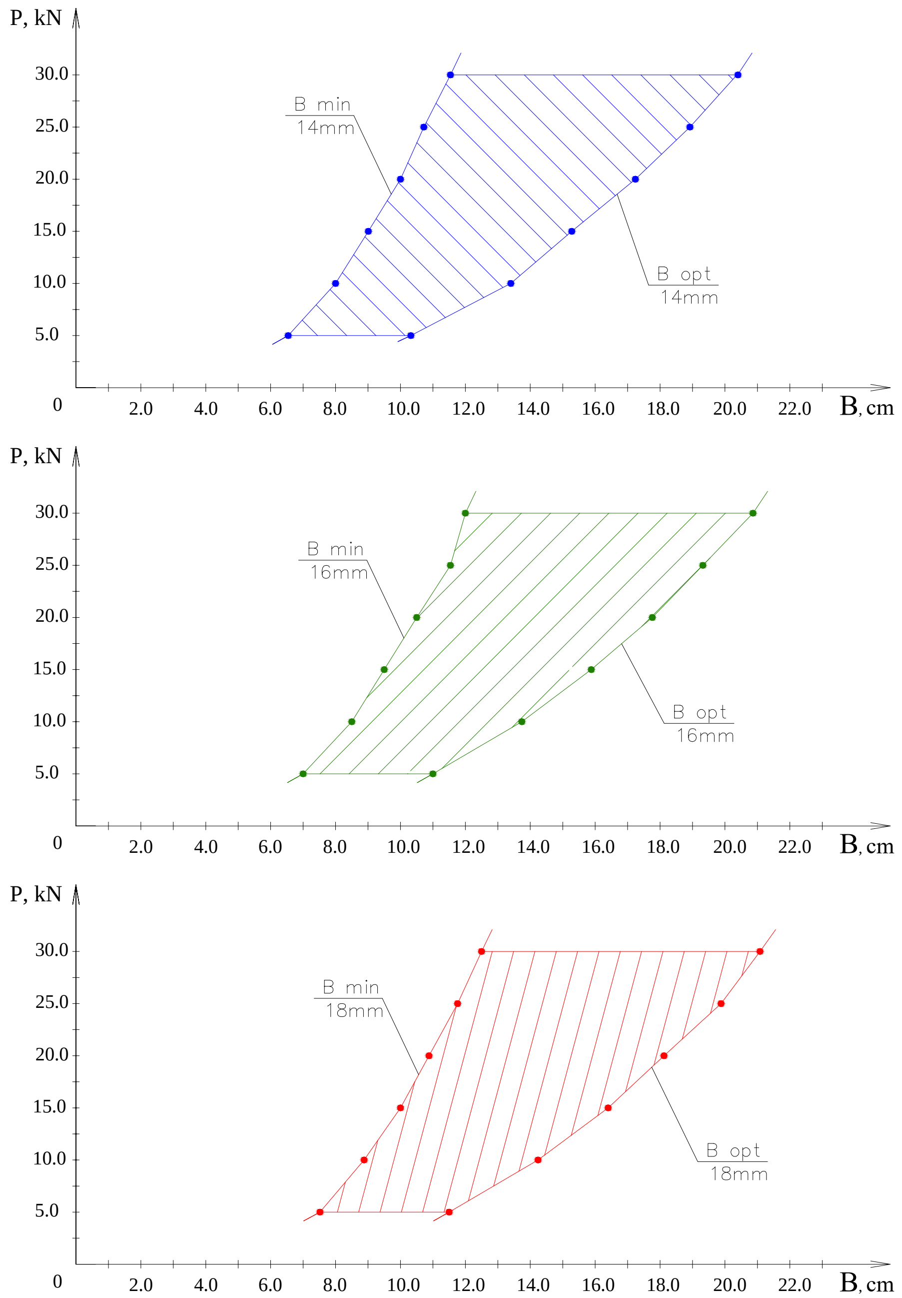

Figure 6. Recommended spacing between the holes (diameter 14 mm, 16 mm, 18 mm) or to the outer edge of the stone (for glue steel anchors) in natural limestone stone with strength corresponding to the M50 grade

4. Conclusions

1. An experimental study of the strength of glue joints of steel anchors and natural limestone stones was carried out. It has been experimentally established that 0.4 mm is the criterion for the limiting displacement of anchors, in which the joint work of the glue joint is preserved in the contact zone "glue shell – stone surface". The obtained research results are relevant for calculating and constructing anchor fastenings of hinged ventilated facades on the walls of buildings made of stones and blocks of saw limestone.

2. In connection with the natural variability of the structure of natural limestone stones formed as a deposit product, taking into account the inelastic work of the elements can lead to an unreasonable and very dangerous overestimation of the design strength characteristics of anchor joints in natural limestone.

3. Proposals for the calculation of steel anchors in masonry walls made of natural limestone have been developed.

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4. When calculating and constructing anchors in natural stones of a different structure or age, it is necessary to perform control tests that specify the actual parameters of the joint operation of the elements in the contact zone "glue shell – stone surface".

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