

Influence of masonry adhesion on mechanical performance of arches-walls

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Abstract. The combine behavior of masonry arches and walls, which exert an unloading effect on the bearing arches, was analyzed. The finite-element model of the Wallen-Delamot arch was designed for the effect of the load of the overlying masonry. The load action was taken into account both from a combined finite element model with a rigid connection of the arch and overlying masonry, and from the gravitational load transferred to the arch. The dependences of the maximum acting stresses in the arch on the modulus of elasticity of the overlying masonry are constructed, reflecting the behavior of the damaged masonry, which lost rigidity properties. It is shown that when the modulus of elasticity decreases, significant changes occur in the stress-strain state of the entire structure. The obtained results demonstrate that when the arch is loaded with a gravitational load and there are no restrictions on the overlying laying of vertical and horizontal displacements, the stressed state of the arch differs significantly from its state when modeling the entire structure.

1 Introduction

Stone arches have more than a thousand-year history and are important constructive elements of historical buildings. Their problem is still relevant in assessing the technical condition, repairs, reconstruction and modernization of historic buildings. Starting from the simplest forms, determined empirically, the greatest architectural and constructive perfection stone arches received in the 19th century due to the development of methods of construction mechanics [1, 2]. Optimum was the outline of the arches, coinciding with the pressure line. The most damaged parts of the walls of stone buildings of the old building are the zones of arch bridges above window and door openings. Often observed defects are cracks, degradation and stratification of the masonry, and even the dumps of its individual fragments, which can be caused by operational wear, overload, dynamic impacts, man-caused and other factors [3]. Especially unfavorable is the degradation of mortar joints, which in buildings of old buildings were usually carried out on weak calcareous or calc-clay solutions. As a result of the failure of adhesion between mortar seams and stones, the strength of the masonry is reduced by stretching and shearing, as well as its deformation characteristics. Restoration of the working capacity of damaged areas is usually carried out

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by reinforcement, and also by assembling separate areas from the extracted fragments of the masonry [4]. At the same time, reserves of their bearing capacity are not taken into account, due to the joint work of the arches with the masonry sites located above them. It was experimentally established in [5] that the layers of masonry located above the arches participate in the redistribution of the load from their own mass and the weight of the overlaps, thereby unloading the arches. The effect of their joint work increases with the increase in the curvature and arrows of the ascending arches, as well as the thickness of the layers of masonry above them.

Calculation of masonry arches to date is carried out using rod models, and the criterion for the exhaustion of their bearing capacity is the loss of stability [6-9]. At the same time, the load on the arches from the overlaps and the abovementioned sections of the masonry is considered in the form of gravitational masses. In fact, these sections of the masonry work in conjunction with the arches, exerting an unloading influence [10]. In Fig. 1 shows the diagrams of the contact compressive stress σ_y above the window bridges from the concentrated load P , which simulates the reference pressure of the rafter beam located in the clutch above the bridge [5]. It is established that the distribution of these stresses depends significantly on the curvature of the arched bridges and the deformation of the masonry sections located above them. Areas with cracks or with degraded mortar seams are less able to redistribute loads from overlaps to bridges. There are a number of developed computational models for such systems, taking into account different loading cases and the mechanism of joint work of arches-walls [11-14].

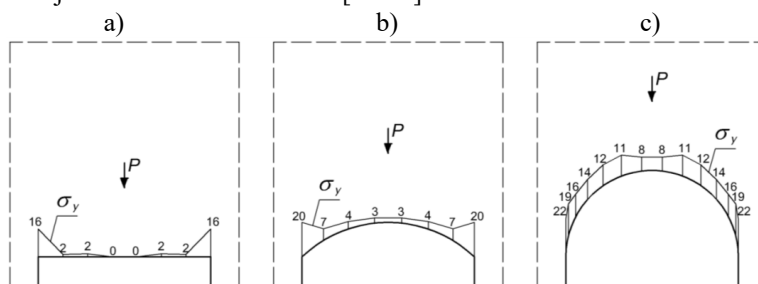


Fig 1. The distribution of the compressive contact stresses σ_y on the upper face of rectilinear (a) and curved (b, c) stone bridges from the action of the concentrated load P

Redistribution of loads significantly relieves the arches and changes the mechanism of their destruction [4]. When loading a self-working arch, its destruction occurs as a result of the loss of static equilibrium caused by the formation of hinges [15, 16]. The latter are due to the release of the pressure curve beyond the core of the cross section, as a result of which the stresses prevail. When working together with layers of masonry located above them, the compressive stresses prevail in them. Accounting for this circumstance in practical engineering calculations with the use of rod models is difficult to implement [20-22]. The most reliable data on the joint work of arches with masonry walls can be obtained experimentally, but this method is labor-intensive. A more exact solution of the problem of the stress state of a structure can be obtained with the help of planar or spatial finite-element computational models.

2 Materials and methods

Below are the results of numerical studies performed by the authors on the example of the Wallen-Delamot stone arch of the New Holland complex in St. Petersburg, erected in the 1770s. (Fig. 2). Semicircular arch, made of limestone (Podustka stone) and decorated with

triglyphs and an elegant garland, is depicted on small columns standing on the banks of the channel. The height of the arch is 23 m, the width of the passage is slightly more than 8 m. As the calculated finite element model, an "arch-wall" consisting of a directly arch and an upstream masonry was adopted. The case of rigid coupling of the arch and the above-mentioned masonry and the case of loading the arch with gravitational load of the masonry were taken into account. Calculations were performed in the Abaqus system from the action of only the own weight of the structure.

The purpose of numerical studies was to determine the dependence of the maximum stresses in the arch on the modulus of elasticity of the overlying masonry, which varied from the initial (for the period of the arch construction) to the minimum value. Reduction of the modulus of elasticity of the overlying masonry may be due to its degradation in the course of long-term operation, for example, as a result of thawing of ceramic stones, destruction of lime-sand mortar seams [17-19]. The elastic characteristics of the arch laying remained unchanged.



Fig 2. View of the Wallen-Delamot arch from the embankment of the Moika River in St. Petersburg

3 Results and discussion

Figure 3 shows the trajectories of the main compressive stresses in the arch-wall, and in Figure 4 the maximum stresses in the arch with the initial modulus of wall masonry elasticity. From their analysis it follows that in all sections of the arch only compressive stresses act, which favorably affects its bearing capacity.

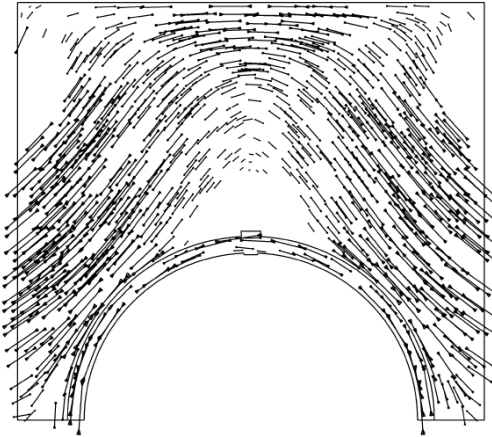


Fig 3. The trajectories of compressive stresses in the arch-wall with the initial modulus of elasticity of the wall masonry

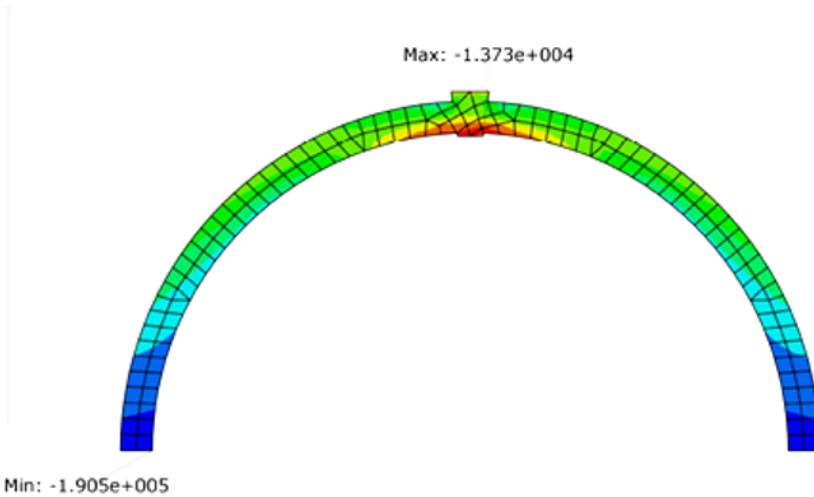


Fig 4. The maximum stresses in the arch with the initial modulus of wall masonry

Dependences of the maximum compressive and tensile stresses in the arch from the modulus of elasticity of the overlying masonry are shown in Figure 5. The maximum tensile stresses in all cases were concentrated in the castle area of the arch, and the maximum compressive stresses in its pricked sections. With a minimum modulus of elasticity of the wall masonry, which is 1% of the initial, the masonry actually loses its stiffness properties and begins to work as a passive ballast.

It is noticeable that with a decrease in the modulus of elasticity of the masonry the walls of the stress are re-distributed due to the compression of the middle third of the arch. The tensile stresses are first reduced to 10% of the initial modulus of elasticity, and then the stresses begin to grow exponentially. With a further decrease in the modulus of elasticity up to 1% of the initial stress, the stretching zones on the outside of the arch are redistributed and appear due to its compression from transverse deformations of the overlying masonry.

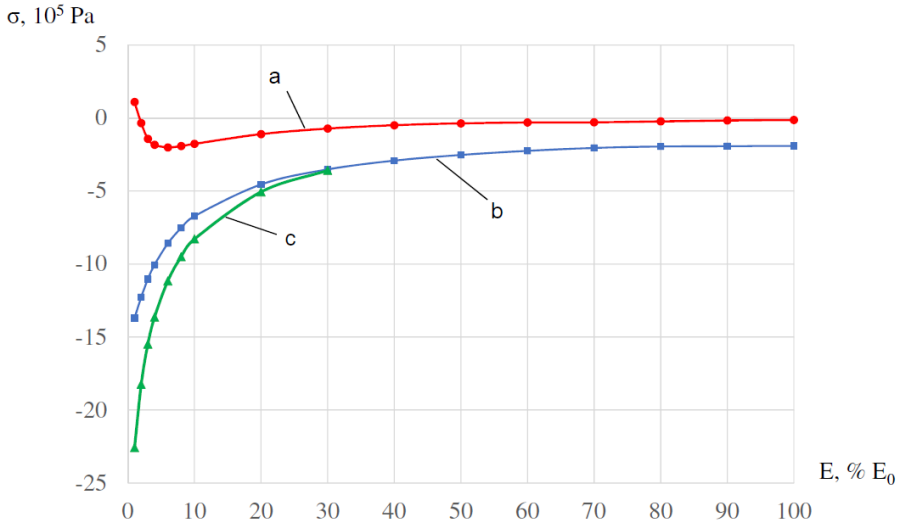


Fig 5. Graphs of maximum stresses in the arch, depending on the modulus of elasticity of the wall masonry:
 a) the voltage in the lower zone of the lock; b) stresses in the arch support zone c) stresses in the upper zone of the key

Figure 6 shows the isopole of stresses in the arch as a self-working structure, loaded with the weight of the overlying wall as a gravitational load. From their comparison with the data of Fig. 5 it follows that the absence of restrictions on the vertical and horizontal movements of the arch by the laying of clay leads to a significant change in its stress state.

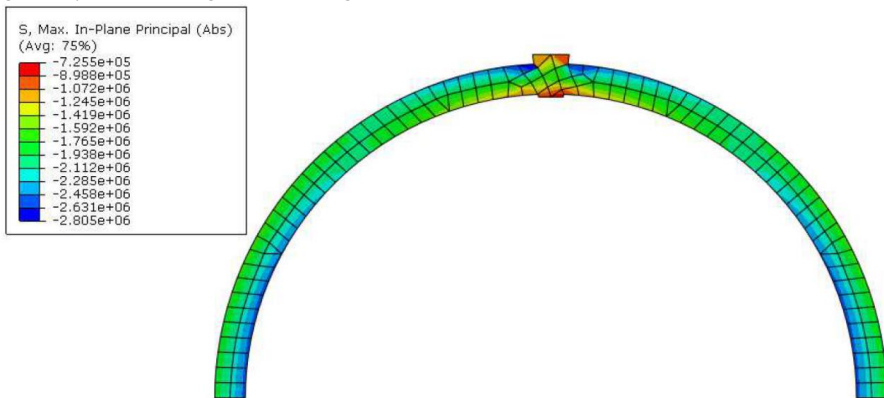


Fig 6. The maximum stresses acting in the arch from the own weight of the overlying wall as a gravitational load

4 Conclusions

As a result of numerical calculations of the Wallen-Delamot stone arch, it was determined that when the threshold value of the elasticity modulus of the overlying masonry reached 5-10% of the original, the acting stresses in the arch begin to grow exponentially. However, when the modulus of elasticity varies from 100% to 10% of the initial value, the stressed state of the arch does not change significantly, it becomes more stable due to an additional compression of the middle thirds. Thus, in case of damage to the "arch-wall", the carrier arch will remain stable.

When the arch is loaded with a gravitational load and there are no restrictions on vertical and horizontal movements caused by overlying masonry, it causes a significant change in the stress state.

This demonstrates that the traditional method of calculating arches does not sufficiently take into account the joint work of the arches and needs to be improved.

Further research is planned to devote to transferring the obtained dependence on the case of spatial vaulted structures when they work together with arch walls and other similar structural elements. Also, the question of correlating the degree of structural damage with the change in its modulus of elasticity remains open.

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