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# Strength and Deformation of Combined Beams with Side Reinforced Plates

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**Abstract.** The results of experimental studies of combined beams consisting of a stone part, reinforced with side reinforced concrete plates are given. Experimentally shown the viability of the proposed structures. The conditions for ensuring the combined action of a stone beam and a reinforced concrete plate are given. Cases are shown when one-sided plates can be used and when double-sided reinforced concrete plates can be used. A comparison of experimental data with the data calculated by the authors developed methods is given. A good agreement between theoretical and calculated data is shown.

## Introduction

In the works of the authors of this article [1-3], the basic principles of the design and manufacture of stone structures reinforced with side one-sided and two-sided reinforced concrete plates, and their advantages compared to bending stone elements reinforced with reinforcement are shown. In these works, the methods of calculating the joint work of a stone bending element with a side reinforced concrete plate, the method of determining the forces in anchors connecting the stone part with the reinforced concrete are given. The method of calculation is given, including accounting of non-linear properties of materials, which is based on the standard procedure [4, 5], but adapted to the presence of two vertical layers with different properties of materials.

It is known that the criterion for the correctness of any method of calculation, in addition to the correctly chosen prerequisites and the theoretical approach, is its experimental verification.

## Aim of Work

In connection with the foregoing, the purpose of this article is to experimentally test the strength and deformability of bending stone elements reinforced with side reinforced concrete plates, comparing the experimental data with data obtained by the developed calculation methods in order to verify these techniques.

## General Material

The purpose of the experiment was to test the method developed by the authors for calculating strength and stiffness [1-3, 8] by the results of in situ tests of stone beams reinforced with single-sided and double-sided reinforced concrete plates. It was planned to find out the influence of the thickness of the side reinforced concrete plates, the method of their attachment to the stone beam, the effect of reinforcement, the material of the stone beam: clay brick and aerated concrete block. A total of 16 combined beams were manufactured and tested. The sectional diagram of the experimental combined beams is shown in Fig. 1.

Beams of mark B are made of gas concrete blocks with one-sided or double-sided reinforced concrete plates; BK mark beams are made of clay brick with a one-sided reinforcing concrete plate.

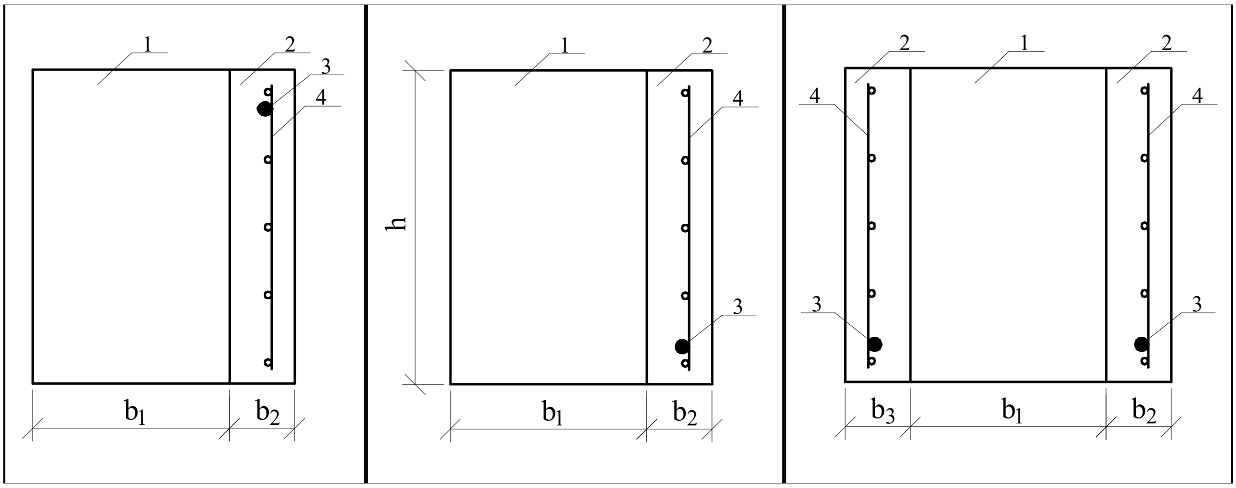

Figure 1. Cross sections of experimental beams

Gas concrete beams with one-sided plates were made of three gas concrete blocks measuring 200x300x600 mm. The height of the beam was 300 mm, the width of its cross section – 200 mm + thickness of the side reinforced concrete plate. The length of the beams is 1800 mm, the estimated span is 1500 mm. The load application is a concentrated force in the middle of the span.

During tests of gas concrete beams reinforced with bilateral side reinforced concrete plates, with loads of 1/9 ÷ 1/7 of failure load, normal cracks appeared on the lateral reinforced concrete plates. A feature of these cracks was the fact that they spread over the entire height of the beam with approximately the same opening.

The fact that normal cracks propagate to the entire section height is explained by the fact that gas concrete blocks located between reinforced concrete plates put pressure on the latter in the horizontal direction across the span. As a result, transverse bending moments appear in the plates and cracks form on their outer surface. However, these cracks do not affect the bearing capacity of the combined beams. Indeed, in all beams with double-sided reinforced concrete plates, such cracks practically did not increase until the last stage of loading.

At loads of 0.4–0.45 from the failure load in gas concrete blocks, normal cracks were formed. Approximately at the same load levels in the lateral reinforced concrete plates force normal cracks formed in the middle of the span. Upon further loading, these cracks opened and subsequently turned into critical ones, along which destruction occurred. Cracks in gas concrete blocks throughout the test had a greater opening compared with cracks in reinforced concrete plates.

Beams with a one-sided reinforced concrete plate had the same diameter and class of bearing reinforcement, but different thickness of the reinforced concrete plate in order to establish the influence of the plate thickness on the stress-strain state of the beam and its bearing capacity. It should be noted that the bearing capacity and displacement of beams with different thicknesses did not differ much from each other.

Unlike beams with double-sided reinforced concrete plates, no cracks appeared on the lateral surfaces of reinforced concrete plates for the entire section height.

The nature of the deformation and cracking in the beams with one-sided plates are similar to the deformation of beams with double-sided plates. The bends in the linear work of beams appeared much earlier (at load levels of 0.3-0.4 from destructive). This is due primarily to the smaller area of the bearing reinforcement in beams with one-sided plates as compared to beams with double-sided plates.

When testing beams mark BK (brick beams, reinforced with one-sided reinforced concrete plates) with a load on the beam about 1/3 of the fracture in the brick part cracks were formed. In the absence of a reinforced concrete plate, the beam would have been destroyed under this load. And from this moment of loading, the “load-deflection” schedule deviated from linear operation.

At a load of about 50% of the failure load, cracks were also formed in the middle of the span of reinforced concrete plates. A further increase in load led to the opening of cracks in the stone part and a small opening of cracks in the reinforced concrete plate. With a load of 60% of the failure, the crack opening width in the brick part reached 0.5–0.6 mm, and the cracks in the reinforced concrete plate remained hairline. A further slight increase in load led to an even greater crack opening in the brick part of the beam.

With a load of 80% of the failure crack in the reinforced concrete plate were opened to a width of 0.3 mm, and the cracks in the brick part were about 1 mm. With a load of 93–95% of the failure, crack opening width in a reinforced concrete plate was already 0.55–0.6 mm, and in a brick part – 1.5 mm. Before the bearing capacity was exhausted, horizontal puncturing cracks appeared in the compressed zone of the reinforced concrete plate.

It should be noted that throughout the loading of the beams, mutual shear of blocks of the brick part separated by a normal crack was not observed. No detachment or cracking between the brick part and the reinforced concrete plate was also noted, which indicates reliable operation of such a structure. The movements of the faces of the brick part and the reinforced concrete plate practically did not differ, which indicates the absence of any noticeable torsion of the combined beam despite the asymmetrical cross-section (a more rigid reinforced concrete plate and a less rigid brick beam).

Experimental displacements were compared with theoretical, obtained by the author's method [1-3, 8]. Figures 2 and 3 show load-deflection graphs for gas concrete (Fig. 2) and brick (Fig. 3) beams reinforced with reinforced concrete plates. In this case, the vertical axis represents the magnitude of the concentrated load in the middle of the span in Newtons; on the horizontal axis – deflection in the middle of the span in millimeters.

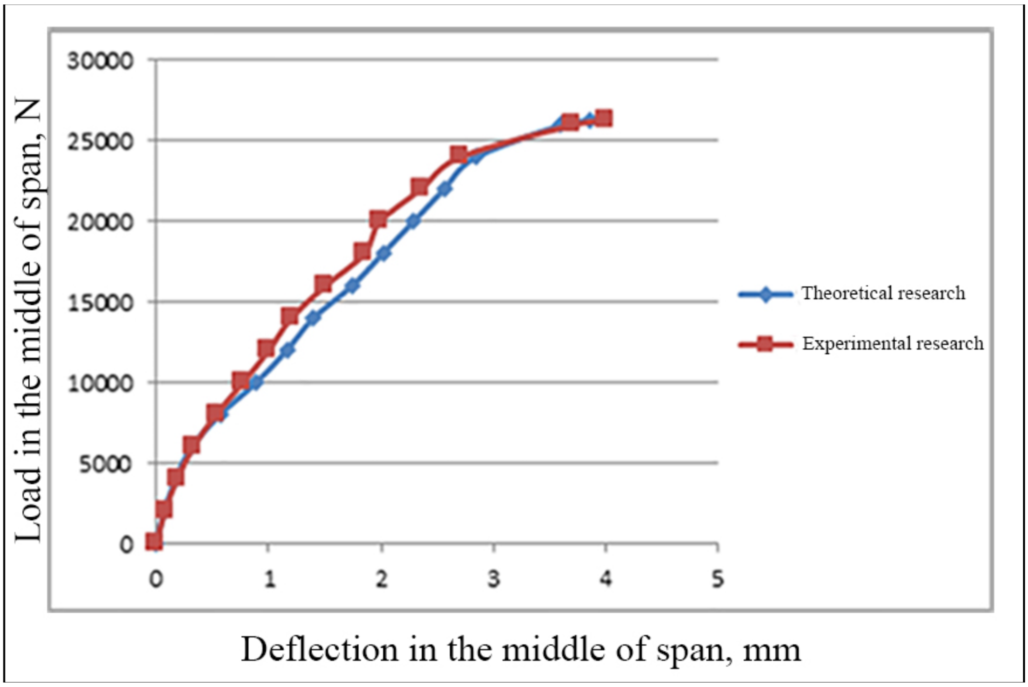


Figure 2. Graph "load-deflection" for B-1-3-N beam

When calculating brick beams reinforced with a reinforced concrete plate, the deformation modulus of the stone part of the combined structure was changed according to the method [7]. In this case, a program for calculating combined beams was used using the deformation model [3].

As can be seen from Figures 2 and 3, the theoretical data are in good agreement with the experimental data.

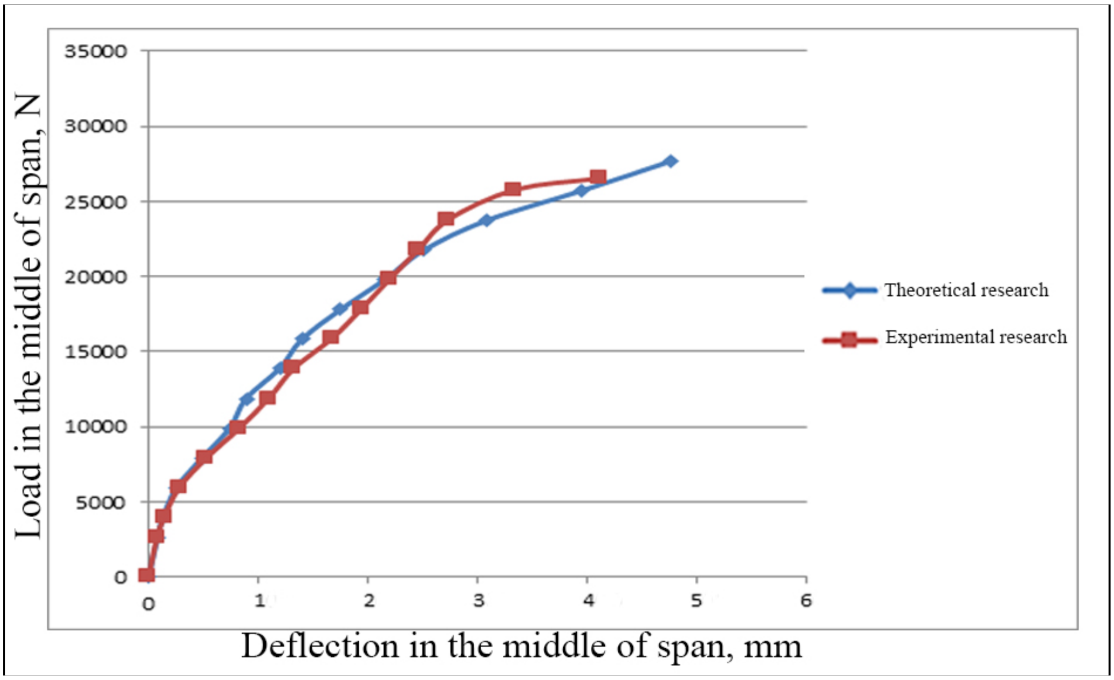


Figure 3. Graph “load-deflection” for BK-4 beam

**Experimental Data Analysis**

Comparison of experimental data of all 16 beams with calculated ones showed a good match. The average value of the error ranges from 2% to 21%. The coefficient of variation is from 3.5 to 12%. These data indicate the reliability of the calculation methods developed by the authors in [1-3, 8].

Experimental studies have shown that combined structures consisting of stone beams (brick, gas concrete), reinforced with single-sided or double-sided reinforced concrete plates, are quite viable. The main bearing part of such a combined structure are reinforced concrete plates. The bearing capacity of the whole structure mainly depends on their reinforcement and in some way on thickness. The stone part of such a combined beam, although it directly plays a minor role, indirectly significantly enhances the structure in general. Due to the presence of stone filling thin reinforced concrete plates do not lose the stability of the flat shape of the bend, and their bearing capacity is fully realized. In addition, the stone part of the combined structure is involved in the work of the compressed zone, which is used in the calculations when the height of the compressed zone is determined using both the strength of concrete in reinforced concrete plates and the strength of the stone part of the combined structure.

When reinforcing gas concrete elements with side reinforced concrete plates, it is mandatory to put anchors connecting the gas concrete blocks to reinforced concrete plates. Experimental studies have shown that in the absence of anchors, reinforced concrete plates almost immediately exfoliate from the gas concrete blocks. Adhesion without the use of adhesives is not enough to ensure the joint work of the combined structure.

The work of the combined structure corresponds to the work of reinforced concrete beams. Cracking, destruction and deformation occurs similarly to reinforced concrete beams, which also gives the right to use the method of calculating reinforced concrete structures for calculating such combined structures with the corresponding amendments adopted in [1-3].

When the load is perceived, the cracks in the stone part of the combined structure have a greater opening width than the cracks in reinforced concrete plates. At maximum loads, these cracks have a opening width of more than 1-1.5 mm. However, this factor cannot be dangerous, since in this case cracks in reinforced concrete plates open up to a small width. Considering that the working reinforcement of the combined construction, as well as the grid intended for fastening the reinforced concrete plate, is in the thickness of the concrete plate, the opening of cracks in the stone part cannot influence the corrosion of the working reinforcement and the grid.

Experimental studies have shown that for fastening one-sided reinforced concrete plates to the stone part, it is enough to use construction screws with a length of 70-100 mm. In case of double-sided plates, such plates can be interconnected with a wire of Ø3-4 mm passed into the holes drilled in the stone part and tied to the grid plate. Pitch and diameter of anchors can be selected by calculation.

Experimental studies have also shown that combined structures can be loaded both with a load applied to reinforced concrete plates and to the stone part, and a load applied only to the stone part. This factor is very important, since when reinforcing existing stone walls, it is not always possible to transfer the load to the reinforcing element. When loading a structure with a load applied only to the stone part, the beam is quite efficient and its work practically does not differ from the work of the beam, the load to which is applied both to the stone part and to reinforced concrete plates. The smaller value of the breaking load in the experiment is explained only by the small diameter and the number of anchors connecting the stone part with the reinforced concrete part. An increase in the diameter and/or pitch of the anchors leads to an increase in the bearing capacity of the structure and the approach of its work to monolithic.

In the presence of one-sided reinforced concrete plates, despite the asymmetry of the section, no noticeable torsion of the beams occurs (in the experiments there was no noticeable difference in the deformations of the opposite faces of the beams), since the ratio of the width of the section and the span of the beams is such that the effect of the asymmetric arrangement of the plates is small. Due to the fact that the stone walls have small spans compared with their height, the use of single-sided plates is fully justified. This experimental factor allows us to conclude that when designing short beams, the asymmetrical arrangement of reinforced concrete plates can be neglected and the calculation of such elements should be carried out as well as the calculation with a symmetrical two-sided arrangement of plates.

The work of brick beams with one-sided reinforced concrete plates also showed the reliability of such structures. The displacement of the banks of a critical normal crack in the brick part was not observed throughout the experiment. Cracks in the brick part formed earlier than cracks in the reinforced concrete plate and throughout the experiment had a greater opening width than the width of the crack opening in the reinforced concrete plate. Torsion of the beams, despite the asymmetrical section in the presence of a stone beam and a one-sided reinforced concrete plate, was not observed, which makes it possible to calculate them as a usual flexible symmetric element. The work of all the beams after the formation of cracks was nonlinear.

**Conclusions**

The experimental studies described in this article led to the following conclusions:

1. Combined flexible concrete elements consisting of a stone part and bilateral or unilateral reinforced concrete plates are quite viable and can be recommended in the practice of construction.
2. The stone part of the combined structure plays the role of an element preventing the loss of stability of the flat shape of the bending of reinforced concrete plates.
3. When reinforcing gas concrete elements with side reinforced concrete plates, the condition of the presence of anchors connecting the stone and reinforced concrete parts is mandatory.
4. The combined structure is equally efficient both when loading only the stone part, and when loading both the stone part and reinforced concrete plates.
5. In the combined elements, in which the ratio of the span to the height of the section and width is small, the use of single-sided reinforced concrete plates is effective as bilateral ones. In the experiments, there was no noticeable difference in the deformations of the opposite faces of the beams, which indicates the absence of any significant torsion.
6. The results of calculations according to the methods proposed in the works of the authors [1-3, 8] are in good agreement with the experimental data. The average value of the error ranges from 2% to 21%. The coefficient of variation is from 3.5 to 12%. A good agreement between the calculated and experimental data indicates the reliability of the proposed calculation methods and the possibility of their application in design practice.

The prospect of research in this direction is the complete calculation algorithms and manufacturing techniques for stone bendable elements reinforced with side reinforced concrete plates development.

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