Experimental Studies of Strength Inclined Sections Bent Elements from Autoclaved Aerated Concrete

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Abstract. The tasks of the experimental study included determining the design characteristics of autoclave aerated concrete (AAC) beams with a density of 600 kg/cm³, strength 4 MPa, namely, the width of the crack opening of the bending elements, checking the updated methodology for the effect of shear span to depth ratio \([a/h]\), obtaining new data on the work of bending elements when the load approaches maximum, as well as in the stage of the beyond state, the distribution of deflections along the length of the elements, the distribution relative to the strain of the compression zone, tension zone and deformation of the joint zone of the transverse force and the bending moment and obtained experimental data on the bearing capacity and deformability of the beams for various values of span shear. The measured test data provide a basis for evaluating the accuracy of existing strength-design equations to predict the capacity of such specimens. The study in this paper can provide a reliable experimental basis for further analysis and engineering application of AAC beams in the future.

1. Introduction

At present, it is necessary to find concrete and practical solutions to the problems of thermal insulation of reinforced concrete structures and buildings. This is one of the most important problems faced by relatively cold countries such as Russia, European Union countries, China and others. In addition to countries with relatively hot climates, such as South Africa and the Arabian Gulf. In turn, thermal insulation requires additional costs, which are sometimes high, plus the energy costs used for heating or cooling. In this regard, several studies have been carried out to obtaining building materials, which, in turn, are good thermal insulation, without the need to build additional walls in buildings for the purpose of thermal insulation [1, 2, 3, 4, 5]. One of the most important materials currently is autoclave aerated concrete. In Russia, in recent decades, the silicate industry has experienced a new rise in production due to the modernization of old and commissioning of new autoclaved aerated concrete production plants. According to the National Association of Autoclaved Aerated Concrete Manufacturers. Over 12 years, its output increased by 6.5 times, and the share of wall materials produced in Russia increased from 6 to 30%. In 2012 alone, aerated concrete production increased by more than 20%, exceeding the volume of 7 million m³. According to official statistics, in 2013, cellular concrete became the main wall material in Russia. Its production volumes slightly exceeded the production of ceramic wall materials [1].
2. Experimental program
investigated by loading until fracture of 4 groups, each group consists of three samples, beams (12 pcs) with dimensions of 1200x100x250 mm. in the first group the effect of shear span to depth ratio \([a/h] = 0.8\), in the second group the ratio \([a/h] = 1\), in the third group the ratio \([a/h] = 1.2\) and the fourth group of the ratio \([a/h] = 1.6\). Table 1. All autoclaved aerated concrete beams were obtained from the AERO BELU factory which complies with the Russian Standard Specification. (Fig. 1). The samples’ dry density was 600 kg/m3 namely B06 and the strength was kept above 3.5MPa namely A3.5 [3].

Table 1. Information of AAC beams.

| Sample№ | Dimension [mm] | the effect of shear span to depth ratio \([a/h]\) | longitudinal reinforcement | shear reinforcement | The type of Beams |
|---------|----------------|---------------------------------|--------------------------|-------------------|------------------|
| group Ba-1 | 1200x100x250 | 200/250, \((a/h)= 0.8\) | Ø8 A240 | Ø6 A240 | B06 , A3.5 |
| group Ba-2 | 1200x100x250 | 250/250, \((a/h)= 1\) | Ø8 A240 | Ø6 A240 | B06 , A3.5 |
| group Ba-3 | 1200x100x250 | 300/250, \((a/h)= 1.2\) | Ø8 A240 | Ø6 A240 | B06 , A3.5 |
| group Ba-4 | 1200x100x250 | 400/250, \((a/h)= 1.6\) | Ø8 A240 | Ø6 A240 | B06 , A3.5 |

2.1. Test setup
Beams were tested as single-span articulated [7, 8, 9, 10]. A load in the form of two concentrated forces with equal shear spans was transmitted (Fig. 2). During beam tests, loading was carried out in steps equal to 10% of the expected ultimate load. The stages preceding the formation of cracks and immediately before the fracture were taken equal to 5% of the estimated breaking load. This made it possible to more accurately determine the moment of crack formation, deformation, and deflection before reaching the maximum load and made it possible to more reliably determine the possible nonlinearity immediately before crack formation and when passing through the maximum load, and thereby to obtain a larger number of points on the diagrams of the stress-strain state of the cross sections. During the tests, the force transmitted to the beam, the longitudinal deformations of concrete and reinforcement, and the deflections of the beam were controlled. In addition, at each stage of loading up to a load level equal to 0.8 of the destructive load, also measuring the crack width value with a crack meter device CK-102. The opening widths of normal and inclined cracks were measured. Longitudinal deformation concrete of a compression, tension zone also deformation of a joint zone of transverse force and bending moment were measured with dial gauges with a division value of 0.001 mm with a measurement base of 200 mm. To duplicate the readings of mechanical devices when measuring longitudinal strains of a compression, tension zone also deformation of a joint zone of transverse force and bending moment also used strain gauges with a measurement base of 50 mm. Deflections of the beams to the maximum load were measured using dial gauges (division value 0.01 mm) mounted on a
specially made frame that “belonged” to the beam. This allowed us to obtain the values of the deflections without the influence of sediments (i.e., the displacement of the beam supports in space).

![Figure 2. Beam installation with loading device.](image-url)

2.2. Results and discussion

In the first stages of loading, concrete deformations developed almost linearly in proportion to the increase in load values [8,9,10]. This linear proportionality was observed almost until the formation of cracks. During the formation of cracks, an unstable pattern of the distribution of deformations was observed, which later regained stability. After the formation of cracks, the graphs of concrete deformations acquired a nonlinearity that increased as one approached the maximum load-bearing capacity. At this time, there was an active opening of cracks, an increase in their height, accompanied by a violation of the adhesion of concrete and reinforcement in certain areas, chart 2. Shown Relationship load - compressive strain zone, chart 3. Shows the relationship between load and deformation of the tension zone and the chart 4. Shows the relationship between the load and the deformation of the joint zone of the transverse force and the bending moment, for 4 groups of beams from autoclaved aerated concrete Ba-1, Ba-2, Ba-3 and Ba-4, respectively, the effect of shear span to depth ratio \( \frac{a}{h} \) = 0.8, 1, 1.2 and 1.6, respectively.

The study found that with a two-point loading system, diagonal cracks are usually the first cracks that are observed in a clean beam span. (On an oblique section). With an increase in the load, the number of cracks in this zone increased, the cracks propagated. The type of destruction for most beams, is shear failure. This indicates poor adhesion between lightweight concrete and reinforcing steel. There are many factors that influence the adhesion between lightweight concrete and reinforcing steel, where the compressive strength plays an important role in the adhesion when the adhesion is increased by increasing the compressive strength.it can also be explained by the fact that for beams with a lower percentage of reinforcement, the disengagement of reinforcement with concrete is faster.

The nature of the development of deflections before the formation of cracks in the experimental samples is similar to the nature of the development of curvatures (there is a linear proportionality between the development of deflections and an increase in load). When cracking occurs on the “moment – deflection” curves, a kink appears, then plastic deformations of materials begin to develop, which give
nonlinearity to the process of increasing deflections. Chart 1. Shown relative load - deflection. Table 2 shows the results of 4 groups’ beams from autoclaved aerated concrete, figure 3. Shows the characteristics of the beams destruction. The number of cracks in the first group \([a / h] = 0.8\) reached 3 cracks, and in the fourth group \([a / h] = 1.6\) the number of cracks reached 10. From the above we can say the number of cracks increases with increasing the effect of shear span to depth ratio \([a / h]\). The distances between the cracks also decrease with increasing the effect of shear span to depth ratio \([a / h]\).

Figure 3. Shows the character destruction of beams.
Table 2. The result of 4 groups Ba-1, Ba-2, Ba-3 and Ba-4 respectively.

| Type                  | Ba-1 group [a / h]= 0.8 | Ba-2 group [a / h]= 1 | Ba-3 group [a / h]= 1.2 | Ba-4 group [a / h]= 1.6 |
|-----------------------|------------------------|-----------------------|-------------------------|-------------------------|
|                       | The average values of the three samples | The average values of the three samples | The average values of the three samples | The average values of the three samples |
| Ultimate load [kg]    | 3500                   | 2800                   | 2350                    | 2133                    |
| Max Moment [kg.m]     | 350                    | 350                    | 352.5                   | 426.6                   |
| Crack width[mm]       | 2.17                   | 1.5                    | 1.5633                  | 7                       |
| Load [kg] at first crack | 2100               | 2000                   | 1666                    | 1150                    |
Max Strain in comp. zone | 0.012 | 0.017112 | 0.0215 | 0.02454
---|---|---|---|---
Max Strain in ten. zone | 0.024 | 0.0265 | 0.02991 | 0.0325
Ultimate deformation of the joint zone of transverse force and bending moment | 0.01651 | 0.009119 | 0.00783 | 0.00885
Mid span deflection [mm] at ultimate load | 6.5 | 7.2 | 8.7 | 9.5
Failure mode | shear failure | shear failure | bending-shear failure | bending-shear failure

3. Summary
Experimental results presented in the paper and qualitative conclusions can be used as the basis for the author's method of the autoclaved aerated concrete beams structural analysis in order to optimally design the structures of this type.

From the load-strain curve it can be seen that the AAC beam has a high plastic deformability and good ductility compared with the traditional reinforced concrete beam. The cracking load as a percentage of the maximum load ranged from 40% to 50% and is, on average, approximately 45% of the failure load.

It is observed in the article that under two-points loading system, diagonal cracks are usually the first cracks to be observed in the beam’s clear span. The principal mode of failure in the beams having adequate reinforcement is diagonal tension cracking. The shear failure is a common type for all beams, this indicates a weak the bond strength between lightweight concrete and reinforcing steel. Future research is needed to increase the bond strength between the steel reinforcement and autoclave aerated concrete. Therefore it became necessary to conduct a study in the future that includes rigidity the inclined sections cellular and heavy reinforced concrete construction.

4. References
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