Experimental Study on Shear Behavior of Reinforced Autoclaved Aerated Concrete Slab

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Abstract. Process two-points concentrate force load shearing trial for 6 ALC plates (Autoclaved aerated concrete reinforced plate), the article introduced the trial specimen structure, trial device and load scheme. This trial obtained the influence of the shear capacity of ALC plate like failure mode, load-deflection curve, stress (varying) distribution, steel types and shear span ratio. The research shown that: ①The reinforced ALC plate easily form the strong bending and weak shearing members, happen shear pressure failure when designed shear span ratio $\lambda=2.5$, happen diagonal-tension failure, when designed shear span ratio $\lambda>5$; ②If the oblique crack position close to the anchoring gusset or pass through anchoring section then maybe weaken the anchoring force and reduce the shearing strength of plate. Because of its brittle nature, anchorage failure must be avoid. Sufficient anchorage can theoretically be provided either by bond or by cross bars welded to the longitudinal reinforcement. ③For the calculation method of the shear bearing capacity of ALC without shear reinforcement with high strength longitudinal steel reinforcement, the technical code for the application of autoclaved aerated concrete in building in China is no longer applicable, EU standards calculated result are all less than the measured values, the method of international RILEM materials association is more suitable and the calculated value more close to the measured value.

Keywords: Autoclaved aerated concrete slab; Static loading; Shear capacity; Shear performance.

1. Introduction

Autoclaved aerated concrete reinforced plate (abbreviation ALC plate) has the advantages at light weight, better heat preservation and heat insulation performance, strong fire-resistant, better durable and industry produce and so on, widely applied in wall plates and floor plates. For a long time, ALC plate with the use of H235 or cold drawn low carbon steel bar, high strength steel bar like HRB400 and CRB600H instead of it with the upgrade and development of building steels. Hu Jianjun[1] processed bending trial for the ALC plate with longitudinal steel bar strength exceeding 600MPa, finally, the trial specimen happened bend-shearing failure which controlled by the main oblique crack in the bending- shear section. Li Youqing et al.[2] believed that the ALC plate was prone to brittle failure, and its ultimate bearing capacity was mainly determined by the shear strength of the plate under the action of concentrated. Qu Xiushu et al.[3] carried out bending test on ALC plate with high-strength longitudinal reinforcement by means of uniformly distributed weight loading method, and the failure form of the specimen was still bending shear failure. As for the phenomenon of shear failure in the practical application of ALC plate with high strength reinforcement, there is no targeted shear trial study on the reinforced ALC plate at home and abroad, so it is worth exploring how to
design the shear capacity of ALC plate reasonably. Based on the above problems, this article processed
the shear performance trial of ALC plate with high strength longitudinal reinforcement, and the shear
strength value obtained from the trial was compared with the calculated value of the formula in the
existing Chinese standards [4], RILEM material association [5] and EU standards [6]. The conclusion is
used as reference for the shear design of ALC reinforced plate.

2. Test Overview

2.1. Specimens Design and Production

The geometric dimensions (length × width × thickness) of the test specimens are:
3000mm×600mm×150mm and 1500mm×600mm×150mm, As shown in Figure1.
The compressive strength of aerated concrete is 3.75MPa and the density grade is 578.6 kg/m³. The
specimen is only equipped with the lower tensile longitudinal reinforcement, the parameters are shown
in Table 1. The steel material properties are shown in Table 2

| Plates NO | PL (1-2) | PL (1-3) | RS (2-1) | RL (2-2) | RL (2-3) |
|----------|----------|----------|----------|----------|----------|
| Length[mm]| 1500     | 3000     | 3000     | 1500     | 3000     | 3000     |
| Steel types | HPB300 | HPB300 | HPB300 | HRB400 | HRB400 | HRB400 |
| Number of longitudinal bars | 6A8 | 6A8 | 6A8 | 6C8 | 6C8 | 6C8 |
| Reinforcement ratio [%] | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 |
| End transverse reinforcement | 3A6 | 3A6 | 3A6 | 3A6 | 3A6 | 3A6 |
| Shear span(a) | 300 | 700 | 900 | 300 | 700 | 900 |
| Shear span ratio (λ) | 2.5 | 5.83 | 7.5 | 2.5 | 5.83 | 7.5 |

"P" and "R" represent the type of reinforcement for plates HPB300 and HRB400, respectively, and "L"
represents the plate size of 3000mm×600mm×150mm. "S" stands for plate size of 1500mm×600mm×150mm.
The shear span (a) is the minimum distance between the point of concentrated load on the plate and the edge of
the support. The shear span ratio (λ) is equal to the shear span(a) divided by the effective height of the
section(h₀).

| Steel types | d [mm] | fy [MPa] | fu [MPa] | Es [10⁵MPa] |
|-------------|--------|----------|----------|-------------|
| HRB400      | 8      | 480.7    | 581.6    | 2.07        |
| HPB300      | 8      | 380.6    | 439.8    | 2.10        |

“d” represents the diameter of the steel bar; “fy” represents the yield strength of reinforcement; “fu” represents
the ultimate strength; “Es” represents the elastic modulus of reinforcement.

Figure 1. Reinforcement drawing of plates.

Table 1. Reinforcement parameters of ALC plate.

Table 2. Properties of steel material.
3. Loading and Testing Plan

3.1. Test Set-up and Test Plan

According to the force in the actual engineering application of the ALC roof panel [7], the concentrated force quarter point loading and trisection point loading was adopted in the trial to measure the shear performance of the slab. Both ends of the specimen were restrained by fixed hinge support and rolling hinge support respectively. The trial uses jack to load. The longitudinal bar strain gauge is pasted into the hole at the bottom of aerated concrete slab, which is used to measure the strain change of each part during the trial. During the test, the development characteristics of the cracks were observed and the positions and corresponding loads were marked on the plates. The loading device and the arrangement of measuring points are shown in Figure 2.

![Figure 2. Trial device and displacement measuring points.](image)

Strain and deformation measuring points are arranged as follows:

1. Tensile longitudinal bar strain: paste resistance strain gauge L1~L6, paste 2 reinforcing bars on each side, take the average value when drawing; named: L-L; L-C; L-R.
2. Mid-span and support displacement: measuring points W1~W4, using a dial scale of 50mm and precision of 0.01mm, W2 and W3 to measure the bending deflection in the plate span, and W1 and W4 to measure the settlement displacement at both ends of the support.

4. Test Results and Data Analysis

4.1. Induction of Experimental Phenomena

As shown in Figure 3, the failure modes of trial specimens are divided into three categories: (1) shear compression failure; (2) bond failure; (3) diagonal-tension failure. The following sections describe different failure modes of ALC plate.

![Figure 3. The failure modes of ALC plate.](image)

(a)Shear compression failure  (b) Bond failure  (c) Diagonal tension failure

The specimen PS(1-1) had a shear compression failure similar to that of ordinary reinforced concrete slab. When the specimen was loaded to 13kN, no cracks appeared, the displacement meter reading and strain gauge reading increase linearly with the step by step increase of load. At this point, the specimen is in the elastic stage. When the specimen was loaded to 13.3kN, normal section cracks appeared in the pure bending section. At 14.6kN, the first oblique crack appeared in the shear span section. With the increase of load, the normal section cracks and oblique cracks develop continuously. At 24kN, the oblique crack changes from the development to the roof to the horizontal extension. At 26kN, the oblique crack extends horizontally to the edge of the loading point, and the member is damaged due to the crushing of aerated concrete in the compression area.

The bond failure occurred in specimen RS(2-1), and the experimental phenomenon is as follows: When loaded to 7.5kN, normal section cracks appear in the pure bending section. At 7.5-10kN, the...
normal section crack develops continuously in the pure bending section. At 10.5kN, a main oblique crack suddenly appeared in the bending shear section on the right side of the specimen, extending from the support to the loading point. The whole right panel is cut off; the crack penetrates the plate surface and a transverse fracture is formed on the side of the specimen.

The specimens PL(1-2), PL(1-3), RL(2-2) and RL(2-3) all suffered from diagonal-tension failure. Taking the specimen RL(2-3) as an example, the experimental phenomena are as follows: When loaded to 2.6kN, the pure bending section cracked and two cracks appeared. When 2.6-11.5kN, new vertical cracks appear in the pure bending section and extend upward. At 5.8-8.5kN, most of the fractures in the pure bending section extend to 1/2h, while a few extend to 2/3h. (H is the plate thickness). When the load reaches 7.5kN, oblique cracks appear in the shear span. At 8.5-10.5kN, the oblique crack extends rapidly towards the loading point. When loaded to 10.5kN, a large amount of autoclaved aerated concrete at the bottom of the specimen falls off. The longitudinal tensile steel bar was exposed and the specimen was damaged by diagonal-tension failure.

4.2. Shear Theory Analysis

Table 3 presents the value of the shear capacity of the specimens calculated by relevant domestic and foreign norms, and compares it with the test value, and the following conclusions are drawn:

In terms of expression form, the current formula of Chinese standard only takes into account the strength of autoclaved aerated concrete and the effective section height of plate, which is easy to calculate. However, from the calculation results, for the specimens equipped with HPB300 steel bar and shear pressure failure, the calculation results are relatively small and have a large safety reserve. The calculated results of specimens with diagonal-tension are too large to be safe. For the specimens with HRB400, the calculated results are all less than the measured values.

The European standards formula takes into account the ratio of reinforcement and the compressive strength of aerated concrete, and introduces the material component coefficient. The calculated results of the shear bearing capacity are all less than the measured values and are inclined to safety.

The formula of RILEM materials association also takes into account factors such as shear span ratio, reinforcement ratio and compressive strength of aerated concrete. For the specimens with high strength longitudinal bars and diagonal tension failure, the calculated result is closer to the measured value of shear capacity.

Table 3. Calculation of shear capacity of ALC plate.

| NO. | $V^{c1}_u$ [kN] | $V^{c2}_u$ [kN] | $\omega_1$ | $V^{c1}_u$ [kN] | $V^{c2}_u$ [kN] | $\omega_2$ | $V^{c3}_u$ [kN] | $\omega_3$ |
|-----|----------------|----------------|----------|----------------|----------------|----------|----------------|----------|
| PS (1-1) | 26.05 | 9.11 | 0.35 | 20.04 | 0.77 | 7.75 | 0.30 |
| PL (1-2) | 8.35 | 9.11 | 1.09 | 11.81 | 1.41 | 7.75 | 0.93 |
| PL (1-3) | 8.10 | 9.11 | 1.13 | 10.43 | 1.29 | 7.75 | 0.96 |
| RS (2-1) | 10.00 | 9.23 | 0.92 | 20.04 | 2.00 | 7.85 | 0.78 |
| RL (2-2) | 12.10 | 8.66 | 0.72 | 11.81 | 0.98 | 7.40 | 0.61 |
| RL (2-3) | 10.50 | 9.11 | 0.87 | 10.43 | 0.99 | 7.75 | 0.74 |

Where: $V^{c1}_u$—Actual value of anti-shear carrying capacity; $V^{c2}_u$—Anti-shear carrying capacity obtained according to the current standard of China; $V^{c3}_u$—Anti-shear carrying capacity based on the international RILEM formula; $V^{c4}_u$—Anti-shear carrying capacity obtained according to the European specification formula; $\omega_1$, $\omega_2$, $\omega_3$—Represents the ratio of calculated value to measured values.

5. Summary

(1) The shear failure pattern of ALC plate is similar to that of ordinary reinforced concrete. Shear pressure failure occurs when the shear span ratio ($\lambda$) is 2.5. The specimen is similar to a tie rod arch. Aerated concrete forms arch ring to bear the pressure, the tensile steel bar such as a tie bar bear tension. When the shear span ratio ($\lambda$) is greater than 5, the diagonal-tension failure occurs, and the load when the oblique crack appears is basically close to the failure load of the specimen, and the shear bearing capacity of the section is generally very low.

(2) The trial appearance shown that: The influence of bearing length on shear strength increases with
the decrease of shear span ratio. When the length of bearing is more than a certain value, the shear strength does not increase. The shearing strength not continue increasing after the pedestal extension length exceed a certain value. In the case of large shear span, the position of oblique crack is far from the anchorage bar, and the end anchorage bar has little influence on the shear bearing capacity.

(3) As the ALC plate with high strength longitudinal reinforcement is mainly shear failure, the material strength is not fully utilized. The calculation method of shear design in the current Chinese standards is no longer applicable, and the calculation result of the EU standards is too small. The calculated value of the shear strength of the ALC without shear reinforcement with high strength longitudinal steel reinforcement, is the closest to the test value in the RILEM formula. In practical engineering application, it is suggested to use the RILEM formula to design the shear capacity of ALC plate with high strength.

References
[1] HU Jianjun. Analysis of Flexural Performance of Autoclaved Aerated Concrete Slab and Experimental Study on Joints. Tongji University, 2006.
[2] LI Youqing. the Study and Development of Reinforcement Calculating and Management Application Software of YTONG Slab. Tongji University, 2007.
[3] QU Xiushu CHEN Zhihua SUN Guojun. Experimental and Numerical Analysis Study on the Structural Performance of Autoclaved Aerated Concrete (AAC) Wall Slab. Journal of Building Materials, 2012, 15(2): 268-273.
[4] JGJ/T17-2008. Technical Specification for Application of Autoclaved Aerated Concrete.
[5] RILEM Technic Committees78. MCA and 51-ALC Autoclaved Aerated Concrete Properties, Testing and Design, 1993.
[6] EN B. 12602-2008 Prefabricated reinforced components of autoclaved aerated concrete. British Standards Institution. London, UK, 2008.
[7] GB/T 11969-2008. Test methods of autoclaved aerated concrete.