Advances in Engineering Research, volume 207
Proceedings of the 2nd International Seminar of Science and Applied Technology (ISSAT 2021)

Flexural and Vibration Performance Analysis of Autoclaved Aerated Concrete (AAC) Slab

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ABSTRACT
AAC slab is a component of precast floor slabs commonly used in buildings. As a new product, the performance of AAC must be examined to ensure that its slabs meet the requirements of the applicable standards. Those requirements are reviewed in terms of strength and stiffness. This research was conducted experimentally using 3 test objects of AAC slabs size: 2000x600x125 mm with *two-point load* method, in addition to testing physical and mechanical characteristics of AAC material in the laboratory as input for numerical modeling. AAC samples were taken by core-drilling 30 samples of panels, then 6 samples of cubes were taken by cutting the plates when they came out of the *Autoclave*, and 3 cylindrical samples with a diameter of 150 mm x 300 mm. The samples were then tested in the laboratory to determine the parameters of the mechanical properties such as a stress-strain graph, compressive strength, modulus of elasticity, and maximum strain. Physical properties such as specific gravity and water content were also tested. All samples were taken from the same place. Numerical analysis was carried out using ANSYS R3 2019 to obtain slab vibration parameters. The result showed that AAC has an average maximum principal stress area load of 4.48 kN/m^2, and meets the requirement to be used in the office, school, and residential houses. Furthermore, this study also found a natural frequency can be a standard of comfort building criteria.

Keywords: *Aerated Autoclave Concrete, Slab, Flexural Strength, Vibration.*

1. INTRODUCTION

Aerated Autoclaved Concrete (AAC) is a material consist of cement, silica sand, lime, gypsum, and aluminium. Those materials have a bulk density range from 350 – 850 kg/m^3, which is lighter than normal concrete.

AAC is usually used as a lightweight brick due to its lightweight material. Apart from that, AAC is being developed as precast floor panels. So, the construction of floor slabs no longer requires scaffolding or waiting for the concrete to reach a certain period. Also, the lightweight factor can reduce the dead load. The floor structure is a component that has the largest weight percentage of a building. A simple calculation shows that 40-60% of the dead weight is a floor slab structure[1]. Therefore, AAC slab can be a solution to reduce the weight of the building. Based on SNI 1727:2020, the building is designed to have different living loads based on its function, ranging from private rooms (0.96 kN/m2), classrooms (1.92 kN/m2), offices (2.4 kN /m2), and public spaces (4.79 kN/m2). Besides that, the requirement includes the stiffness that can be seen from the deflection on each building component.

The strength of the structure is largely determined by the mechanical characteristic itself. The physical and mechanical characteristics of AAC for each place can be changed inconstantly because the material from each place is different. For example, Wang Bo et.al [2] tested the compressive strength of AAC with a density of 525 kg/m3. This study obtained a compressive strength ranged from 2.79 to 4.68 MPa. In another place, Abed et. al [3] did a compressive test on AAC as equal to the relative density of compressive strength by 1.80 - 3.00 MPa. Then, Israngkura et al. [4] obtained AAC compressive strength ranged between 1.20 - 1.26. This study also found the influence of AAC on performance if its materials are applied as a slab. ASTM C1693 classifies AAC into three groups of compressive strength, specifically mentioned groups with a minimum compressive strength of 2, 4, and 6 MPa.

The flexural strength test of AAC panels was conducted on Zhang et. al[5] that examined the flexural strength of 9 units of AAC slabs in China. The maximum load ranged from 19 - 31 kN, but the test results cannot be compared with the AAC slab in Indonesia because every place has different characteristics depends on its AAC materials.

1.1. Our Contribution

This study presents the performance of AAC materials and panels, which can be utilize as an illustration for potential users before using the product and comparing it with the applicable standards in Indonesia. The result test of the physical and material properties of the slab can be a reference, either for developing the design or evaluating the product.

1.2 Paper Structure

This paper consists of four parts. The first part describes the research contribution and the paper structure. The second part describes the object of research, research locations, criteria, and standards used as comparisons and their relation to previous research. The third section describes the research method, and a discussion of the data obtained. The last section describes the conclusions based on the results of the vibration and bending test of the AAC slab.

2. BACKGROUND

A building has strength and stiffness requirements for each building's components to meet the requirements of safety and comfort. A good building component must have sufficient ductility—the signs when the component will collapse. There is a precast plate on the market and it is commonly used. Therefore it is necessary to ensure whether it meets the requirements or not.

The building is designed with different dead loads in each room depending on the room's characteristics. The list of loads is listed in SNI 1727:2020 concerning *Beban Minimum* (Minimum Loads) for the building's design and other structures. Table 1 shows the live loads for various room functions.

Table 1. Live loads for various room functions

Utilization	Loading	
	Area load kN/m²	Point load kN
Office	2,4	8,9
Dining Room / Restaurant	4,79	-
Classroom	1,92	4,5
Gymnasium	4,79	-
Recreation area	3,59	-
Prison (Jail)	1,92	-
Laboratory	2,87	4,45

There is also a vibration requirement that is more directed towards user convenience. In this study, the AISC DG11 standard was taken as vibration measurement.

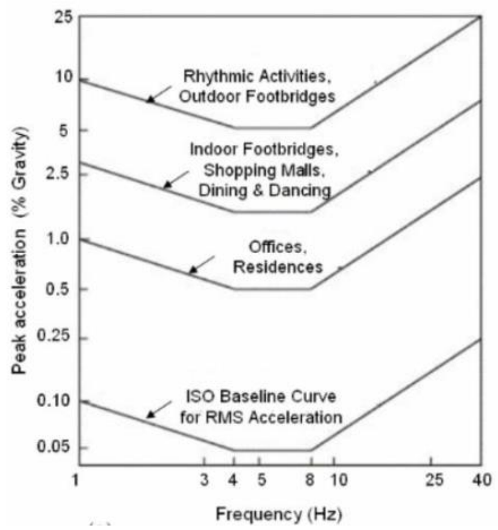

Figure 1 Vibration criteria based on AISC DG11

Moreover, there is a deflection limit for floor slabs. L/360 is for floors that do not support non-structural components and will be damaged by large deflections, L/240 is for roof constructions that hold non-structural components and will not be damaged by large deflections, and L/480 is for slabs that hold non-structural components and will be damaged if large deflection happens.

On the other hand, the characteristic of the slab to the vibration parameters must be considered because this is related to the convenience. Floor slabs can vibrate due to the way of load burden on them; one of them is human activity. So far, it is known that vibrations at a frequency of 4 - 8 Hz are quite disturbing to humans. Moreover, the frequency of the slabs in the same range can occur a high resonance that may cause a vibration response in the floor system. [6-8]

In terms of durability, AAC material is a porous material. As a result, there is an interaction between water vapor, water, and AAC material so that AAC can be porous [9]. Therefore, it is better if the installation of AAC for buildings is protected by a waterproof layer or if it is necessary for closed space.

2.1. Test Object

2.1.1. AAC Floor Slab

The test object is a slab with the size of 2000x600x125 mm with reinforcement and details as follows:

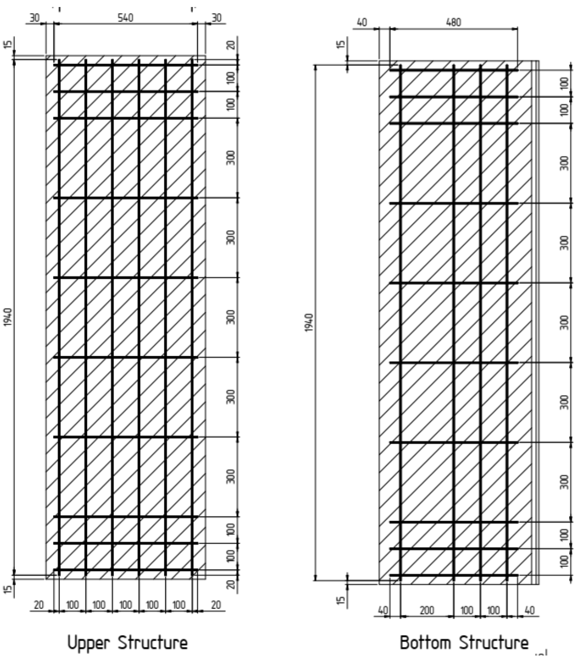

Figure 2 AAC Panel Test Object

The AAC slab taken is the factory product. So, in this case, it is not discussed, neither the AAC manufacturing process nor the foundry process.

2.1.2. Material of AAC

The samples were taken from 3 units cylindrical with 150x300 mm in size for modulus of elasticity testing and 6 cube samples of 100x100 mm in size for testing the compressive strength, density, and moisture content. These samples were tested at the age of more than 28 days at room temperature conditions.

3. RESEARCH METHODS

3.1. Physical and Mechanical Characteristics of AAC

The physical and mechanical characteristics of the components of the AAC slab were obtained from the results of field tests and previous research. They are discussed as follows:

3.1.1. Aerated Autoclaved Concrete (AAC)

The tests were carried out in the laboratory to obtain the physical and mechanical properties of AAC, where the AAC sample was printed on 150x300 mm cylindrical mold, then a pressure test was carried out until the test object collapsed as follows:

Figure 3 AAC Cylinder Sample Test

The AAC sample was pressed until it collapsed and two dial gauge units were placed to see the deformation process. Then, the deformation and load data were processed into stress-strain which is presented in the following curve:

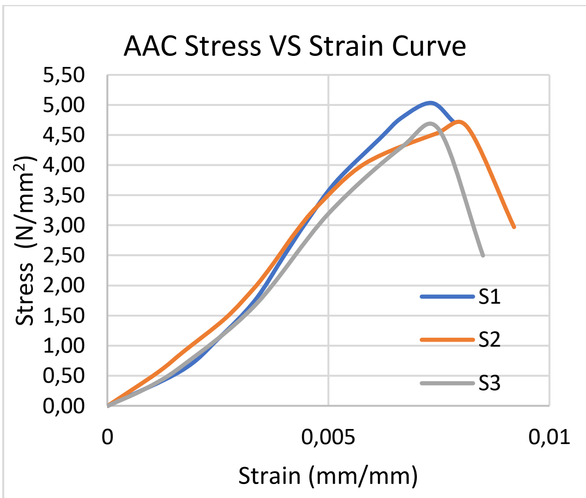

Figure 4 Stress-Strain Curve of AAC

The modulus of elasticity of the AAC sample used the formula according to ASTM C-1693 which AAC modulus of elasticity was calculated at 0.33 of the maximum stress and strain, as the following equation:

$$E_c = \frac{f_b - f_a}{\varepsilon_b - \varepsilon_a} \quad (1)$$

Description:

f_a = Stress on 0.05 f'AAC
f_B = Stress on 0.33 f'AAC
ε_a = Strain occurs on 0.05 f'AAC, and
ε_a = Strain occurs on 0.33 f'AAC.

So, the calculation for the modulus of elasticity for each test is as follows:

Table 2. Test result of Mechanical Properties Parameter

Parameter	Unit	Sample		
		S1	S2	S3
Weight	N/mm³	7857,02	7781,31	7914,05
Max. Stress	N/mm²	5,03	4,58	4,59
Max. Strain	mm/mm	0,0073	0,0074	0,0075
0,05f'	N/mm²	0,25	0,23	0,23
0,33f'	N/mm²	1,66	1,51	1,52
Reg 0,05f'	mm/mm	0,00083	0,00048	0,00068
Reg 0,33f'	mm/mm	0,00323	0,00274	0,00312
Δ stress	N/mm²	1,41	1,28	1,29
Δ strain	mm/mm	0,00240	0,00226	0,00244
Modulus Elasticity	N/mm²	586,98	567,52	526,85

Furthermore, the physical properties of the AAC material were also tested for 6 samples in the form of a cube with a size of 100x100x100 mm. The samples were obtained from the same factory as the cylindrical specimens with the following results :

Table 3. Test result of Physical Properties Parameter

Sample No.	Normal Density	Dry Density	Moisture Content
	N/mm³	N/mm³	%
K1	8063,25	6498,14	24,09
K2	8053,34	6448,62	24,88
K3	7884,54	6263,61	25,88
K4	9005,19	7276,92	23,75
K5	8244,75	6653,83	23,91
K6	8314,79	6833,94	21,67
AVERAGE	8260,98	6662,51	24,03

Material properties for AAC were taken from the average value of the test sample. The result of average physical and mechanical properties is presented as follows:

Table 4. Test Result of average physical and mechanical properties

Parameter	Denomination	Value
Press	N/mm2	4,73
Max. Strain	mm/mm	0,0074
Modulus of Elasticity	N/mm2	560,45
Normal BJ	N/m3	8260,98
Dry BJ	N/m3	6662,51
Water Content	%	24,03

3.2. AAC Slab Flexural Test Result

To determine the performance of the existing panels, a flexural strength test of the AAC panel was carried out to obtain a permit load from the plate. The test used a *two-point load* method based on ASTM C-78 with the result as follows :

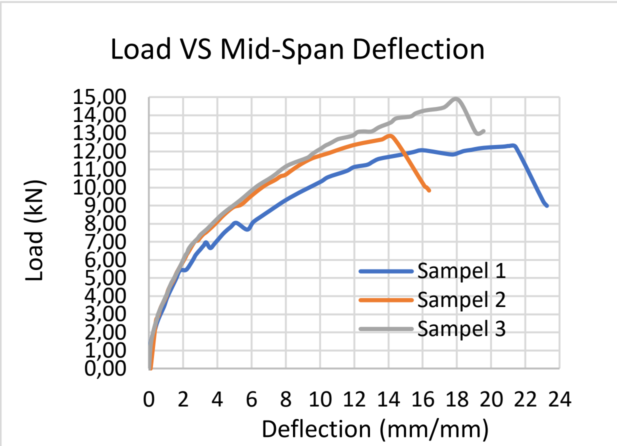

Figure 5 Load VS Deflection Curve

Based on the experimental test, the average principal load is presented as follows:

Table 5. ACC Flexural Test Result

Parameter	De-nomination	Test Object		
		S1	S2	S3
Pmax	kN	12,30	12,77	14,85
Lmax	mm	21,29	14,49	18,29
P_{cr}	kN	5,41	5,33	4,90
L_{cr}	mm	1,89	1,89	1,69
q	kN/m	2,71	2,67	2,45
M_{max}	kN.m	1,35	1,33	1,23
q'	kN/m²	4,51	4,45	4,09
Average Principal Load (kN/m²)		4,48		

Pcr and Lcr are determined visually and graphically when the first structural crack occurs between the two values then the smallest is taken. From these data, the ultimate moment occurs during the crack because the moment represents the nominal moment owned by the slab, the example calculation for the sample is presented as follows:

q = P/L = 5,41kN / 2 m = 2,71 kN/m (2)
Mu = 1/8.q.L^2 = 1/8 * 2,71 kN/m^2 * $(2\ m)^2$ (3)
Mu = 1,35 kN.m (4)
q' = q / b = 1,35 kN/m / 0,6 m = 4,51 kN/m^2 (5)

Based on the calculation, the existing concrete slab is capable of receiving a load of 460 kg/m^2.

To calculate the live load that the slab can take, it is necessary to enter a loading factor that the ultimate load combination is commonly formed from the most influential loading combination through 1.2 DL + 1.6 LL. The compressive strength data needs to be processed to produce a permissible live load, as follows:

1. Slab Weight Assumptions
   W = PxLxTxBJ = 2x0.6x0.125x8,26 (6)
   W = 1,2390 kN
   Qdl = W/b = 1,239 kN / 2 m = 0,619,5 kN/m (7)

   The weight of the slab has been calculated at the time of testing, so the average principal load of 4.35 kN/m^2 is the applicable weight for 0.2 DL and 1.6 LL as of the principal live load is calculated as follows :

2. Calculation of Principal Live Load
   1,6 LL + 0,2 DL = 4,35 kN/m^2 (8)
   LL = ((4,48 kN/m2) – 0,2 DL) / 1,6 (9)
   LL = 2,72 kN/m^2

Based on the calculation, the sample AAC panels meet the requirements for use in several rooms, such as office room, patient room, reading room, prison, one-and-two residences, classrooms, and warehouses.

3.2.1 Slab Stiffness

The deflection of the slab is determined by the deflection at Pcr because the load is only permitted and assumed to work up to the Pcr where the panel experiences the first crack. Therefore the evaluation of the slab to deflection is calculated as follows :

Table 6. AAC Slab Deflection

Sample	Deflection when Pcr	Max. Deflection		
		L/240	L/360	L/480
	mm	mm	mm	mm
P1	1,89	8,33	5,56	4,17
P2	1,89	8,33	5,56	4,17
P3	1,69	8,33	5,56	4,17

Based on Table 6, the AAC slab meets the requirements for applicable deflection. It means that the plate meets the deflection requirements if it carries non-structural components that will be damaged when deflection occurs.

3.2.2 Slab Vibration

The plate vibration analysis was carried by numerical method with ANSYS 2019 R3 application. The geometry of the AAC slab model was made based on the product design of the AAC slab which is conditioned to be on the support beam. This was done for modeling the conditions like in the following figure :

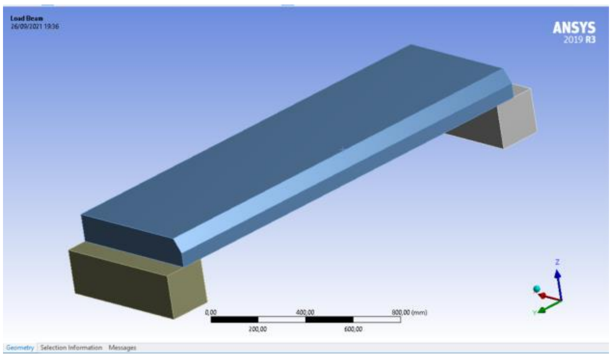

Figure 6 Floor Slab Modelling on ANSYS R3 2019

To get good results for Solid65 material, rectangular meshing was chosen in the model, AAC plates, supports, and load beams, while meshing was not required for reinforcement because these elements were made on nodes in the meshed volume material.

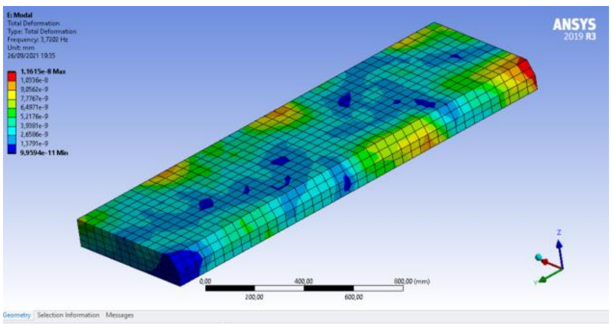

Figure 7 Result of Analysis Modal on ANSYS R3 2019

Vibration analysis used available modal analysis tools. Based on the analysis results, the natural frequency of the slab was 3.72 Hz. Based on the AISC DG11 standard, the slab fell into the range between the office and residential houses category. However, this numerical analysis still requires verification with experimental test data.

4. CONCLUSION

Based on experimental results, the AAC slab had sufficient performance for rooms. However, for rooms that had a higher performance like public spaces, corridors, stairs, lobbies, and armory, AAC panels required reinforcement to improve principal average load, for example with CFRP.[10] The deflection on the plate still met the maximum deflection requirements. Judging from the vibration parameters, the AAC slab had a frequency that can be accepted by humans without being disturbed.

However, the performance of the slab samples tested in this study cannot be used as an absolute reference to represent the entire performance of AAC slab circulating in Indonesia. This is due to the design, material quality, and condition of the AAC slab. The test can be different, and it requires more test samples and varying conditions.

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