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INFLUENCE OF PREFABRICATED FOAM CONCRETE AS INFILL WALL ON THE STRENGTH DUE TO CYCLIC LOADING

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ABSTRACT: Many areas of Indonesia are located near earthquake faults, resulting in the recurrence of earthquake phenomena in various regions of Indonesia. This research is an experimental study on the behavior of prefabricated foam concrete as wall infill material under lateral cyclic loading. This study analyzed the relationship between load and displacement in prefabricated foam concrete as an infill wall. The test object consisted of 2 wall models: reinforced concrete frames (DB 1) and prefabricated foam concrete infill wall (DB 2). Lateral cyclic loading with displacement control method is carried out to evaluate the structural behavior of the wall regarding ASTM E2126-02a. The test results showed that the strength value of the DB 2 specimen resulted in a 29.61% increase of strength than the DB 1 specimen. Furthermore, the relative stiffness degradation on both specimens is not too significant in both the loaded and unloaded state, so there may be no pinching effect. It's more likely to lead to a more stable condition with higher energy dissipation capability without decreasing the strength of the specimen when compared to the DB 1 specimen. Therefore, foam concrete precast panel can be utilized as an alternative infill material for walls on a reinforced concrete frame structure to be replaced with clay bricks, hebel, batako, etc

Keywords: Prefabricated foam concrete, Infill wall, Strength, Cyclic loading

1. INTRODUCTION

Many areas in Indonesia are located directly above earthquake faults, causing the area to be relatively prone to earthquakes. The occurrence of shallow earthquakes is often associated with errors, as stated in [1]. In Indonesia, masonry infill walls are used as exterior walls and interior partitions in a typical residential house. There are several types of residential houses in Indonesia, such as one to two-story residences in rural and urban residential areas or two to four-story mixed-use commercial buildings in urban commercial areas.

Many areas with residential houses have experienced severe earthquakes in the past. Although one-to-two-story residential houses are built from reinforced concrete frames filled with clay bricks, most are designed without appropriate seismic requirements and can be categorized as non-engineered buildings. Reinforced concrete frames with non-seismic designs in residential houses are easily damaged due to moderate to high magnitude earthquakes that cause considerable loss in life and the economy. In recent decades, the seismic vulnerability of non-engineered buildings has received great attention [2-4].

In the last few decades, the sustainability of construction has been the main parameter in technology development, including in the construction industry. In this regard, innovation based on sustainability in cement production is one of the most widely used materials in construction. Producing a cement mixture that allows the use of its by-products (fly ash), which contains silica in large quantities, could support the reduction of CO_2 gas emissions and also reduce the extraction of natural substances and fuel consumption [5]. Fly ash is a by-product that contains large amounts of silica (SiO_2) and is used in cement production. In Indonesia, one of the national cement factories' mixed cement is Composite Portland Cement, which contains fly ash from coal combustion in power plants. Composite Portland Cement is made based on SNI 7064:2014 [6]. Many studies have shown that Composite Portland Cement can produce concrete with good performance (Tjaronge MW et al., 2014; Erniati et al., 2015; Caronge MA et al., 2017, 2020; Marewangeng et al., 2020 [7-11].

The use of foam material in high-rise building structures and residential houses is part of sustainable innovation based on environmentally friendly materials. The use of foam concrete material as a wall can reduce the load borne by structural elements to reduce the dimensions of beams, columns, and foundations which have implications for reducing the use of concrete materials. Fuel consumption can be reduced by the use of precast element structures with those made of foam concrete. Foam concrete consists of a Portland Cement-based paste, filler or fine aggregate, water, and foam without using coarse aggregate. The foam content produces many small pores in its hardened state so that its weight is lighter than conventional concrete. In contrast, the foam concrete slurry has an excellent consistency to flow freely with its weight in fresh conditions, which can easily fill the mold [12, 13]. Preliminary research on the use of Composite Portland Cement in the manufacturing of foam concrete has been reported by several studies. It shows that hardened foam concrete made of Composite Portland Cement has the same initial compressive strength as foam concrete made from OPC (Ordinary Portland Cement) [14-17].

On the other hand, the demand for low-cost housing in recent years has led to the increasing popularity of artificial housing complexes. The manufacturer's desire to use materials efficiently requires that the behavior of these structures be fully researched and developed. This way, the design procedures will be based on the observed behavior and will ensure the structural unit's ease of execution and maintenance. One of the innovations that can be utilized is a wall-on reinforced concrete frame with foam concrete precast panels as the infill material to produce concrete foam walls that are resistant to earthquake load.

One of the solutions that can be used to improve the performance of high-rise buildings and residential buildings in overcoming horizontal displacement is to install a wall that uses foam concrete precast panels as infill material for reinforced concrete frames. Wall that uses foam concrete precast panels as infill materials can be installed in a vertical position on a certain side of a building, increasing the rigidity of the structure and absorbing large shear forces as the height of the structure increases. The function of the wall in a building structure is also essential to support the structure's floor and ensure it does not collapse when lateral forces occur due to earthquakes. In addition, when walls are placed in strategically suitable locations, they can be used economically to provide the required horizontal load resistance.

Therefore, this study presents an effort to reduce seismic vulnerability in one to two-story residential houses. The effect of foam concrete precast panels as infill material needs to be taken into account as an important parameter along with the characteristics of the reinforced concrete frame, which is used as a portal to evaluate the seismic performance of one to two-story residential houses proportionally. This study aimed to analyze the relationship between load and displacement in prefabricated foam concrete as an infill wall.

2. MATERIALS AND RESEARCH METHOD

The characteristics of the material in this study consisted of the characteristics of the prefabricated foam concrete, the characteristics of the slot, column, and ring balk constituent materials, the characteristics of the foam concrete.

2.1 Characteristics of Prefabricated Foam Concrete

The characteristics of foam concrete precast panels begin with the design of a foam concrete mix, shown in Table 1. Based on the results of the foam concrete mix design, the characteristics of foam concrete are obtained. These characteristics consist of volume weight, compressive strength, and indirect tensile strength, shown in Table 2.

Table 2 shows the mechanical properties of foam concrete used to produce prefabricated foam concrete, whereas the compressive strength of foam concrete was 7.38 MPa, and the indirect tensile strength of foam concrete was 0.74 MPa. Therefore, the result of the density test on foam concrete was 1383 kg/m^3.

Table 1. Material composition for 1 m^3 of foam concrete mix

Material	Mix design for 1 m^3
Water	118.45 kg
Sand	676.92 kg
Cement	307.27 kg
Total	**1102.65 kg**
LWC Density	1375 kg/m^3
Mortar Portion	45%
Foam Portion	55%
Foam Agent: Water	3: 10

Table 2. Characteristics of foam concrete

Density (kg/m^3)	Compressive Strength (C)	Indirect Tensile Strength (fct)
1383	7.38 MPa	0.74 MPa

2.2 Properties of Sloof

Sloof is made from normal concrete with compressive strength f'c = 20.4 MPa (the designed slump was 12 ± 2 cm), and the material composition of the normal concrete is as shown in Table 3.

Table 3. The material composition of normal concrete for sloof (1 m^3)

Material	Weight
Cement	420.00 kg
Fine aggregate	950.00 kg
Coarse aggregate (1-2 cm)	780.00 kg
Water	175.00 liter
Admixture (Retarder)	1.47 liter

For the reinforcement of sloof, a plain bar (BjTP) is used. For the longitudinal reinforcing, a plain Ø10 bar was used, whereas, for the transversal reinforcing, a plain Ø8 was used. Based on the result of the reinforcement bar tensile strength testing as shown in Table 4, it is shown that the material has complied with the minimum yield strength requirement as stated in SNI 2052:2017.

Table 4. Tensile strength test result for sloof reinforcement

Diameter	Strength	
	fy (MPa)	fu (MPa)
Ø10	469.763	598.879
Ø8	377.868	420.964

The compressive strength test result for the concrete used on the slot is shown in Figure 1. It can be seen on the graph that the compressive strength of the concrete at 3, 7, and 28 days consecutively were 9.68 MPa, 16.59 MPa, and 22.60 MPa, respectively. Thus, the resulting concrete compressive strength has met the criteria for the designed compressive strength of K-250 or equal to f'c = 20.4 MPa.

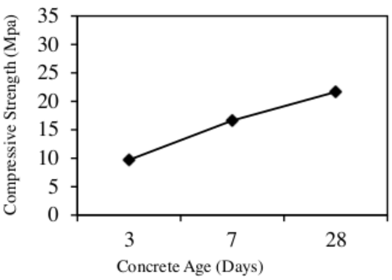

Fig. 1 Compressive strength of concrete for slot

2.3 Properties of Column and Ring Balk

Table 5 shows the mix design composition used for the column and ring balk, and it was designed with the compressive strength of f'c = 30 MPa (designed slump was 10 ± 2 cm).

Table 5. The material composition of normal concrete for column and ring balk (1 m^3)

Material	Weight
Cement	440.00 kg
Fine aggregate	728.00 kg
Coarse aggregate (0.5-1 cm)	537.00 kg
Coarse aggregate (1-2 cm)	470.00 kg
Water	190.00 liter
Admixture (Sika Plastiment Vz)	1.31 liter

For the reinforcement of the column, deformed bar (BjTD) and plain bar (BjTP) were used. In addition, a deformed D13 bar is used for the longitudinal reinforcing, whereas, for the transversal reinforcing, a plain bar Ø8 was used. Based on the result of the reinforcement bar tensile strength testing as shown in Table 6, it is shown that the material has complied with the minimum yield strength requirement as stated in SNI 2052:2017.

Table 6. Tensile strength test result for column and ring balk reinforcement

Diameter	Strength		Classification
	fy (MPa)	fu (MPa)	
D13	473.744	643.150	BJTS 520
Ø8	377.868	420.964	BJTP 280

The compressive strength test result for the concrete used on the column and ring balk is shown in Figure 2. The increase in compressive strength values obtained from both elements were 144.59% and 149.90%. Therefore, the resulting concrete compressive strength at 28 days has met the criteria for the designed compressive strength for column and ring balk, which is f'c = 30 MPa.

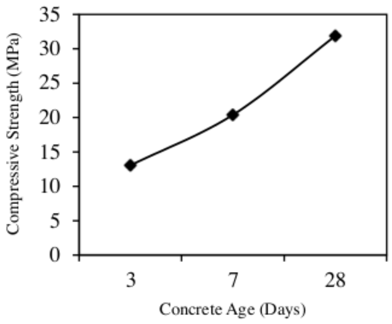

Fig. 2 Compressive strength of concrete for column and ring balk

2.4 Research Specimen and Testing Set-Up

In this study, the test specimens consisted of 2 walls, a wall with prefabricated foam concrete as infill material, and reinforced concrete frames. Specimen DB 1 is a reinforced concrete frame and specimen DB 2 is a wall with prefabricated foam concrete as infill material. Figures 3 and 4 show the detail of each specimen DB 1 and DB 2, respectively. In this study, 8 LVDTs were used as a measure of the magnitude of the displacement which was installed horizontally in the direction of the given load. The cyclic lateral loading is provided by the actuator with an acceleration of 0.5 mm/s. Figures 5 and 6 show the configuration of LVDT and testing setup in the laboratory, respectively.

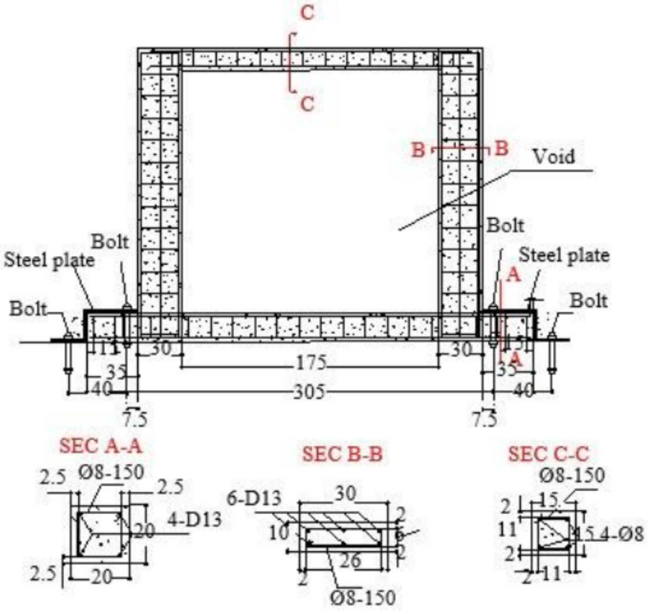

Fig. 3 Specimen DB 1

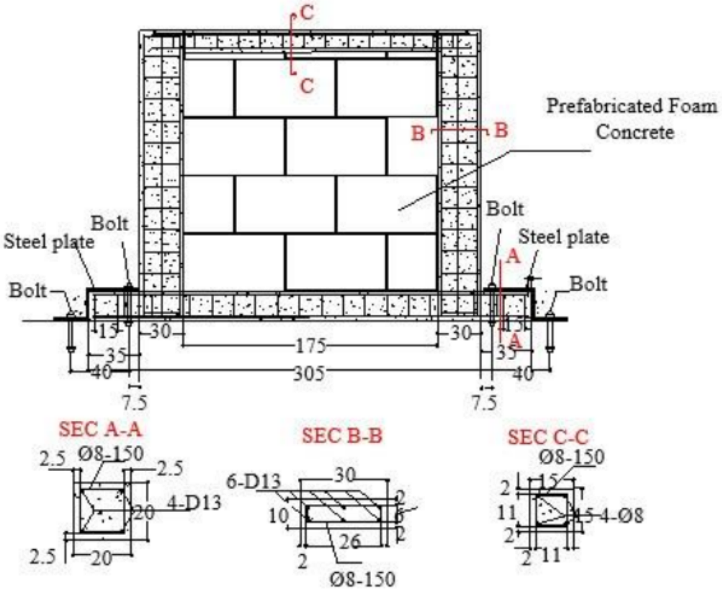

Fig. 4 Specimen DB 2

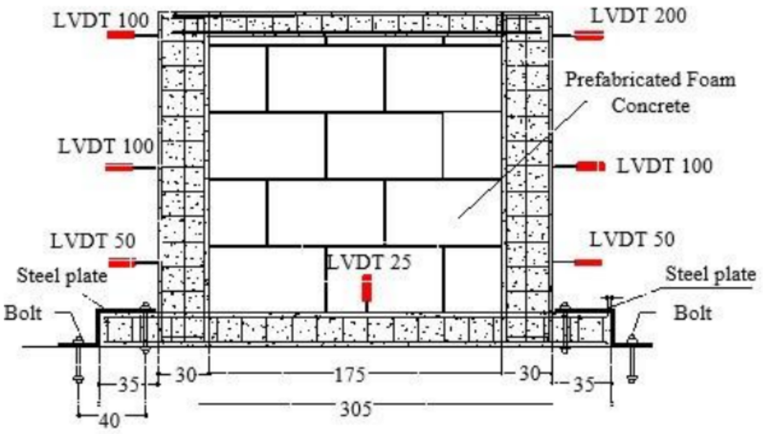

Fig. 5 LVDT Configuration

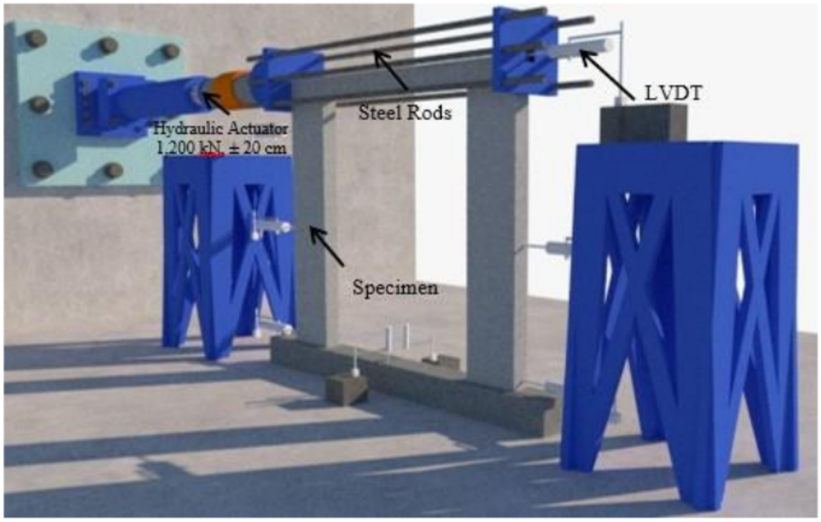

Fig. 6 Testing setup

2.5 Testing Steps of The Specimens

The testing standard for cyclic loading of the specimen refers to ASTM E2126-02a (ASTM 2003). Displacement controlled cyclic lateral loading follows Test Method B (ISO 16670 Protocol). The loading schedule is illustrated in Figure 7. The first displacement pattern consists of five single fully reversed cycles at displacements of 1.25%, 2.5%, 5%, 7.5%, and 10% of the ultimate displacement Δm. The second displacement pattern consists of phases, each containing three fully reversed cycles of equal amplitude, at displacements of 20%, 40%, 60%, 80%, 100%, and 120% of the ultimate displacement Δm. %Δm is the displacement corresponding to the failure limit state in the monotonic test in ASTM E2126-02a (ASTM 2003). This study was not carried out so Δm was determined based on the horizontal deformation of 0.02H in the design rules of the SNI earthquake building (SNI 1726-2019, Indonesia requirement). So the deformation in question is the permissible deformation. Associated with m is the ASTM code against the cyclic test. So %Δm in this study is 40 mm.

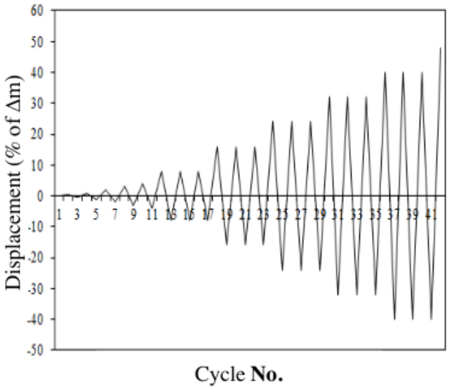

Fig. 7 Cyclic Displacement Schedule as stated in ASTM E2126-02a

3. RESULTS AND DISCUSSION

3.1 Load and Displacement Relationship of Specimen DB 1

The relationship between load and displacement for specimen DB 1 (reinforced concrete frame), which is used as a control specimen in this study to determine the effect of infill material that is the prefabricated foam concrete, due to cyclic loading, can be illustrated in the form of a hysteresis loops curve as shown in Figure 8.

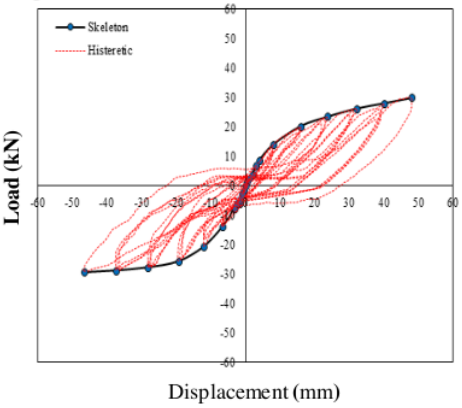

Fig. 8 Load and Displacement Relationship of Specimen DB 1

In addition, based on the hysteresis loops in Figure 8, at the beginning of the compressive loading, the specimen shows a linear elastic behavior up to 6.93 kN load at amplitude (%Δm) of 7.5%. Meanwhile, the specimen shows linear elastic behavior up to 6.05 kN load under tensile loading at deviation ratio of 7.5%. Thus, with the increase in cyclic loading, there is a gradual change in behavior of the specimen, from a linear gradient that turns into a non-linear gradient, which shows an inelastic behavior when it reaches the post-yield zone. This change causes a change in the lateral stiffness of the specimen.

3.2 Load and Displacement Relationship of Specimen DB 2

The relationship between load and displacement for specimen DB 2 can be illustrated in the form of a hysteresis loops curve, as shown in Figure 9.

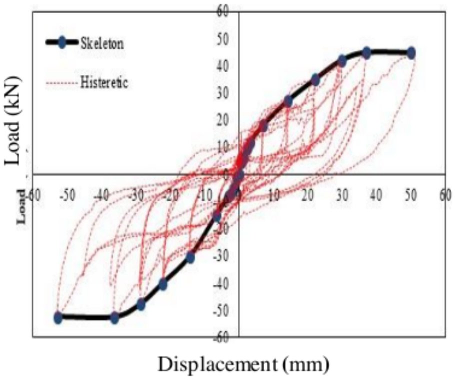

Fig. 9 Load and Displacement Relationship of Specimen DB 2

Under compressive loading, the DB2 specimen curve experienced a significant increase in load up to the amplitude (%Δm) of 40.0%. After that point, the curve experienced an insignificant increase and remained constant until the amplitude (%Δm) of 100.0%. Under tensile loading, the DB2 specimen curve experienced a significant increase in load up to the amplitude (%Δm) of 40.0%. After that point, the curve experienced an insignificant increase and remained constant until the amplitude (%Δm) of 100,0%.

3.3 Load and Displacement Relationship for All Specimens

The comparison graph on the relationship of load and displacement for all specimens is illustrated in Figure 10. It is shown that, until the end of the test, specimen DB 2 has a higher strength than specimen DB 1, and the structure has not collapsed yet. In addition, the strength value of specimens DB 1 and DB 2 were 29.84 kN and 44.88 kN in the compressive loading direction. whereas the value for the tensile loading direction was 29.30 kN and 52.30 kN for specimen DB 1 and specimen DB 2.

Under these conditions, the specimen experienced a decrease in strength until the end of the test at amplitude (%Δm) 120.0%, and the shape of the hysteresis loops curve obtained from the testing is not big. Furthermore, the decrease in relative stiffness that occurs is not too significant for both loaded and unloaded conditions, so there may be no pinching effect. It's more likely to lead to a more stable condition with higher energy dissipation capability without decreasing the strength of the specimen in comparison to DB 1 specimen.

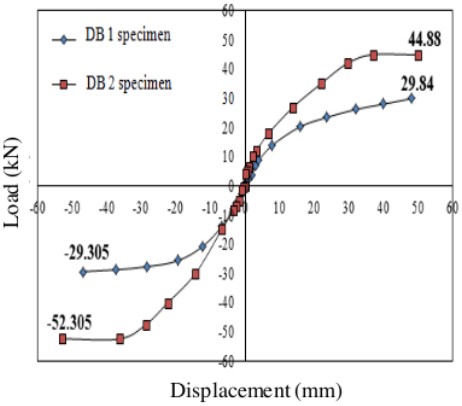

Fig. 10 Comparison of the relationship of load and displacement for all specimens

This showed that the test object that has prefabricated foam concrete as infill wall has a greater strength value so that the use of prefabricated foam concrete as an infill wall influences increased the lateral force. With the increase in lateral cyclic loading due to loading, there is a gradual change in behavior of the specimen from linear to non-linear gradient which shows an inelastic behavior when it reaches the post-yield zone, so this change causes a change in lateral stiffness of the specimen.

4. CONCLUSION

1. The effect of prefabricated foam concrete as an infill wall is to increase the strength of the reinforced concrete frame wall by 50.40% in the compressive loading direction and 78.50% in the tensile loading direction.
2. Foam concrete precast panels can be utilized as an alternative infill material for a wall on a reinforced concrete frame structure to replace clay bricks, hebel, batako, etc.
3. In most building construction, the wall is not part of the structural element but serves as a stiffener and separator between building spaces. However, the result of this study indicates that the use of foam concrete precast panels as infill material shows an excellent structural response in receiving seismic or earthquake loads.
4. The relationship of the wall interaction using prefabricated foam concrete as an infill wall with the reinforced concrete frame had a great influence on the responses of the structure experiencing earthquake forces.

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