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EXPERIMENTAL INVESTIGATION OF THE RESPONSE OF PRECAST FOAM CONCRETE UNDER MONOTONIC LOADING

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ABSTRACT: Indonesia is among the nations with a comparatively high risk of earthquakes. Concrete is one of the most commonly utilized building materials. By mixing foam liquid, also known as a foam agent, with the water in the concrete design mix, this research can create foam concrete. The goal of this study is to analyze the link between precast foam concrete panels' load and deflection. This research is conducted as a lab experiment. This investigation is being conducted in a laboratory as an experiment. The volumes of foam that this research used were 15.7, 25.12, and 37.68 liters. The 40 × 70 x 8 cm precast foam concrete panels (PFCP) are utilized. The strength of the PFCP is assessed by load and deflection testing with UTM equipment attached to an LVDT. After 28 days, this research test for deflection and load. According to the study's findings, the volume weight that resulted was 1210.71 kg/m^3. The PFCP test item produced an average load of 64.64, 61.04, and 26.79 kN for each modification in foam volume, resulting in a deflection of 2.65, 4.16, and 4.22 mm. The results of the study demonstrate that PFCP can be utilized in reinforced concrete frame walls in place of bricks, Hebel, briquette, and other filler materials. Additionally, this research can be applied to non-structural materials like fillers or partitions. The panels have the advantage of not absorbing heat, which can save energy for air conditioning systems, and they require less aggregate and cement due to their reduced density.

Keywords: Load, Displacement, Precast panel, Foam concrete

1. INTRODUCTION

Due to the incredibly fast development of the building and infrastructure industries, natural resources are currently becoming increasingly scarce. Cement, the main component of concrete, is a natural material commonly used in infrastructure and construction projects. However, cement releases 6–7% of the world's CO_2 emissions into the atmosphere annually, making it a major contributor to greenhouse gas emissions. As a result, we need to work to lessen the adverse environmental effects, including changing the source of raw materials used to create cement or developing substitute derivative goods [1–4].

Some cement makers have shifted from using OPC's raw materials to Portland composite cement (PCC), which is more energy and environmentally friendly than OPC. PCC manufacture is more economical, which boosts cement production capacity while also reducing negative environmental effects. Concrete is currently the most widely used building material in the world, with an annual output of 2.8 g/tonne in 2009 (WBCSD, World Business Council for Sustainable Development). An essential binding component of concrete is cement. Portland cement types 1, 2, 3, 4, and 5 are made by mining, combining minerals such as clay and limestone in certain ratios, grinding them up, and then heating them to high temperatures in a rotating kiln. Because the mixture is heated using fossil fuels and calcium carbonate (lime) decomposes into calcium oxide, this process consumes a lot of energy and resources and emits a lot of CO_{2s}. Global CO_2 emissions from cement production are estimated to be around 900 kg per ton, which represents 5–8% of all CO_2 emissions from human activities in the atmosphere [5–9].

There has been a significant trend in Indonesia over the past few decades toward the development of alternative additions for the production of environmentally friendly cement mixes, like Portland composite cement, based on factors related to sustainable infrastructure development, waste reduction (such as fly ash), and environmental conservation. First manufactured in compliance with the 2005 rules (SNI 2005), composite Portland cement was subsequently updated with the adoption of SNI 2012 [10–13].

Foam concrete has been developed for cement-based materials. Lightweight concrete with a density of 400–1,850 kg/m^3 and sporadic air holes created by a mixture of foam agents in the mortar is known as foam concrete. This product is a cement derivative. Low cement content, efficient aggregate use, and superior flowability are characteristics of foam concrete [14, 15]. Foamed concrete is being used more and more in building construction around the world. The usage of this material is mainly driven by

environmental concerns and energy savings. Foamed concrete material is composed of two main components and two further additives.

The main ingredient, mortar, is composed of cement, aggregate, and water. The mixture is then supplemented with foam agents. In order to produce lightweight concrete, foamed concrete mixes a brittle or porous cement paste or a cement and fine sand mixture with uniformly distributed micro- or macroscopic air cells [16, 17]. It is an inexpensive, lightweight, environmentally friendly building material that offers thermal insulation and is fire and termite-resistant. Foamed concrete is also widely used in the building sector for non-structural elements like dividers. Its benefits include a lighter density that reduces the requirement for aggregate and cement, resistance to thermal insulation, and energy savings for air conditioners [18–20].

Fig.1 Red brick wall

Fig.2 Lightweight concrete precast panel walls

However, manufactured housing has become more and more popular in recent years due to the need for affordable housing. The manufacturer must carefully study and develop the behaviour of these structures in order to make optimal use of materials. This will ensure that design techniques based on the observed behaviour make it easier to execute and maintain the structural unit. The use of foam concrete precast panels is one possible way to create lightweight, earthquake-resistant walls. A red brick wall and a foam concrete precast panel wall are contrasted in Figs. 1 and 2.

Moss clinging to the red brick masonry surface suggests that in contrast to walls made of PFCP, red brick walls are not weather-resistant. However, lightweight concrete precast panels weigh less than the plaster of red brick. For this reason, precast panels are a very attractive choice, especially for small residential constructions. This study aims to investigate the relationship between load and deflection in PFCP.

2. RESEARCH SIGNIFICANCE

Given the negative effects of conventional cement production on the environment, we support the use of sustainable substitutes like Portland Composite Cement (PCC). This demonstrates Indonesia's focus on eco-friendly cement blends and the increasing use of foam concrete in buildings because of its lightweight and sustainable qualities. The behavior of foam concrete precast panels under load and under bending, however, has not been extensively studied. To ensure that structures are sturdy, particularly in earthquake-prone locations and inexpensive housing projects, this study set out to investigate this link.

3. MATERIAL AND METHOD

3.1 Fine Aggregate

The physical characteristics of the fine aggregate were evaluated by the Eco Materials Laboratory, Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, as indicated in Table 1.

Table 1 Physical properties of fine aggregate

No.	Material Characteristics	Testing result
1	Specific gravity	
	-Dry specific gravity	2.584
	-Saturated surface dry specific gravity	2.608
	-Apparent specific gravity	2.649
2	Water absorption (%)	0.911
3	Sludge content (%)	0.959
4	Fineness modulus	1.256
5	Volume weight (kg/lt)	
	-Loose	1.40
	-Dense	1,48
6	Water content (%)	3,59
7	Organic content	No.1

This research used Pinrang Regency silica sand for the fine aggregate. The Indonesian National Standard (SNI), which addresses specific gravity (dry, apparent and saturated surface dry), water content, mud content, volume weight, water absorption, organic content, and other aspects, is used to test the fine aggregate's properties.

3.2 Portland Composite Cement (PCC)

The physical property evaluation findings for PCC cement are shown in Table 2. According to Table 2's physical properties, PCC cement satisfies the necessary SNI standards for mortar and concrete materials. The chemical characteristics of PCC cement are shown in Table 3 (XRF test results).

Table 2 Portland composite cement characteristic

Material Characteristics	SNI 15-7064-2004 Standard	Testing result
Water content (%)	12 max.	11.5
Fineness	280 min.	382
Development, % (max.)	0.80 max.	-
Compressive strength		
a. 3 days (kg/cm^2)	125 min.	185
b. 7 days (kg/cm^2)	200 min.	263
c. 28 days (kg/cm^2)	250 min.	410
Setting time (Vicat tes)		
a. Initial setting, minutes	45 min.	132.5
b. Final setting, minutes	375 min.	198
Fake tie time	50 min.	-
7 days hydration temperature, kal/gr		65
Normal consistency (%)		25.15
Specific gravity		3.13

Table 3 Chemical characteristics of portland composite cement (XRF test)

Compound	Content (%)
MgO	0.99
SO_3	1.81
SiO_2	18.39
Al_2O_3	5.15
Fe_2O_3	3.14
CaO	61.79
LOI	4.61

The predominant constituents of the cement used as a binder are calcium (CaO) and silica (SiO_2), which account for 61.79% and 18.39% of its chemical composition, respectively [21]. In the meantime, MgO, SO_3, Al_2O_3, Fe_2O_3, and LOI (loss of Ignition) make up 0.99%, 1.81%, 5.15%, 3.14%, and 4.61% of the cement's chemical composition, respectively [22].

3.3 Mix Design Foam Concrete Mixture

The mix design for foam concrete, which contains foam volumes of 15.7, 25.12, and 37.68 litters, is shown in Table 4. Figure 3 illustrates the lightweight concrete casting procedure. It is predicated on the outcomes of the initial combination study, which produced a uniform lightweight concrete mixture without the need for a segregation process.

Table 4 Mix design of foam concrete (1 m^3)

Material	Type	Mixture		
		I	II	III
Water	Soil		232 kg	
Sand	River		1325 kg	
Cement	PCC		662.5 kg	
Admixture (Sikament LN)	Type F		16.6 kg	
Total			2236,1 kg	
LWC Density		1602 kg/m^3	1470 kg/m^3	1318 kg/m^3
Mortar Portion		67.47%	51.13%	44.59%
Foam Portion		32.53%	48.87%	55.41%
Foam Agent/Water Comparison			3 : 10	

Here are the steps to mix foam concrete:

1. The first step is to make a foam solution by dissolving the foam agent in a container of water at a ratio of 3:10.
2. This research used a propeller to stir the mixture for two minutes until foam began to form. Foam is made in a different container outside of the mixer machine.
3. Next, mix the cement and sand in a dry mixer for two minutes, and produce the mortar based on the type of casting.
4. After the admixture has dissolved in the water, add it and stir for another minute.
5. Perform a slump test to ensure the combination has reached the proper slump.
6. When the mortar achieves the design slump, the mixer adds the foamed solution combination.
7. Next, keep churning until a foamy concrete mixture forms, which should take another three minutes.
8. Then, to find the density of the foam concrete while it is still new, weigh a certain amount of the mixture in a measuring cup (1000 ml).
9. Next, pour foam concrete into a cylindrical mould that is 200 mm high and 100 mm wide.

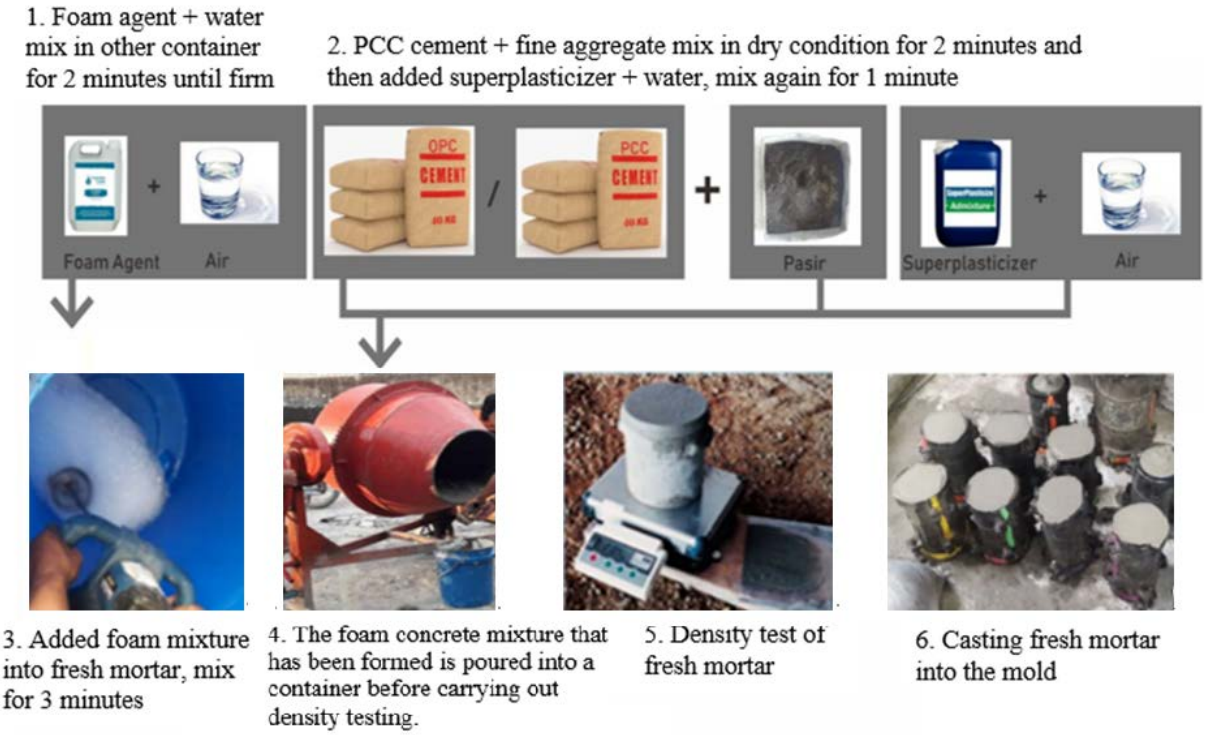

Fig.3 Foam concrete casting process

3.4 Research Design

This experimental study is carried out in the lab. The PFCP are 40 × 70 × 8 cm in size, and foam volumes of 15.7, 25.12, and 37.68 litters are used. We examined the load and deflection of the foam concrete precast panels after they had matured for 28 days. The test uses a UTM instrument to measure the load and LVDT technology to measure the deflection that occurs in PFCP.

This study's objective is to use foam concrete to engineer a lightweight concrete mixture. In order to develop lightweight materials, engineers in this study experimented with several foam uses. To verify the foam concrete's classification as lightweight concrete, we measured its volume weight. Lastly, in order to verify that PFCP is a suitable filler material for reinforced concrete frames, we performed stress and deflection experiments.

3.5 Load Vs Displacement Test

The deflection problem brought on by the operational load is one of the main features of reinforced concrete constructions. The strength and adaptability of reinforced concrete structures for operating loads may be diminished if they flex, thus we must design them with enough stiffness to minimize deflections. An extended span in this situation can result in a notable variation. This is usually accomplished by decreasing the deflection by raising the cross-sectional stiffness (EI).

In terms of mechanics, the relationship between deflection (ω), cross-sectional stiffness (EI), and bending moment (M) is as follows:

$$\frac{d^2\upsilon}{dx^2} = \frac{M}{EI} \quad (1)$$

The deflection value at the mid-span can be found by applying the differential equation. The following deflection results from a basic support supporting a beam with a concentrated load at the centre of the span:

$$\delta = \upsilon_{max} = \frac{PL^3}{48 \times EI} \quad (2)$$

A diagram of the load and deflection tests is shown in Fig.4. To ascertain the extent of the deflection that transpired during the load and deflection tests, we positioned two linear variable displacement transducers (LVDTs) vertically. To determine the magnitude of the resulting load, we linked a data logger to a Universal Testing Machine (UTM) equipment. Each testing instrument is connected to a data logger, which generates computerized data results.

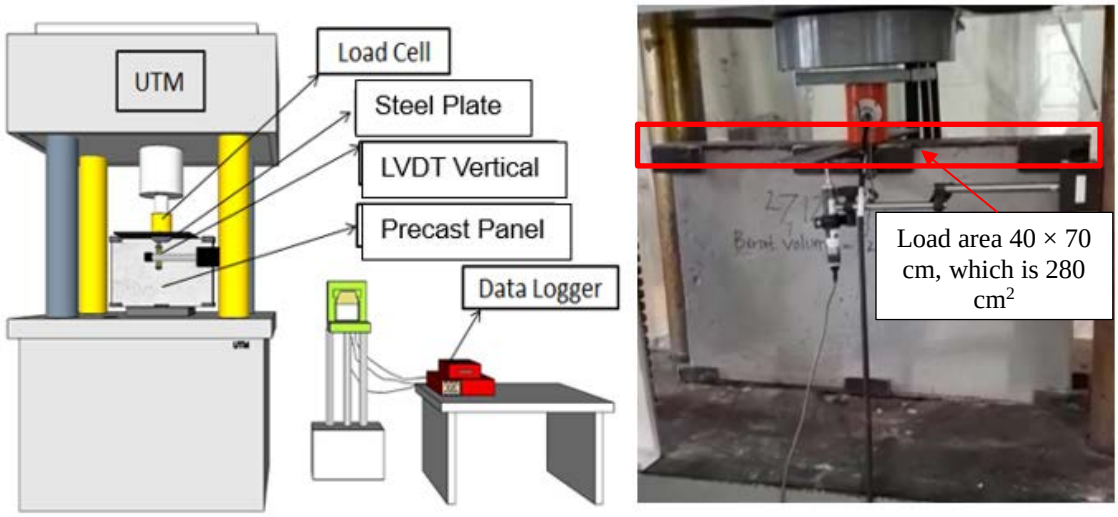

Fig.4 Evaluating precast foam concrete panels for load and deflection

4. RESULT AND DISCUSSION

4.1 Form Concrete Slump Flow

Figure 5 shows the results of measuring the slump flow of foam concrete. The slump flow is 22 ± 2 cm, which is consistent with the expected slump.

Fig.5 Slump flow

4.2 The Compressive Strength of Cylindrical Foam Concrete

The compressive strength values for 10 cm to 20 cm cylindrical foam concrete are shown in Table 5. At 3, 7, and 28 days, we produced compressive strengths of 4.34 MPa, 6.09 MPa, and 7.95 MPa, respectively. The compressive strength value of foam concrete is influenced by its volume weight. According to SNI 03:2847:2013, which specifies that the volume weight of lightweight concrete varies between 1140 and 1840 kg/m3, and the average volume weight of the foam concrete generated is 1210 kg/m3, the results show that all test objects are composed of foam concrete. The volume weight of foam concrete is greatly influenced by the amount of foam used. The foam concrete becomes lighter and loses compressive strength when more foam is added [23].

Table 5 Compressive strength of foam concrete cylinder specimen

Curing duration (Days)	Compressive strength of specimens (MPa)			Average of compressive strength specimens (MPa)
	I	II	III	
3	4.63	4.13	4.27	4.34
7	5.81	6.16	6.30	6.09
28	7.96	8.11	7.77	7.95

SNI 03-0349-1989 states that the created strong foam concrete can be used as concrete bricks for wall installation. As foam concrete ages, we observe a rise in its compressive strength value. Table 5 shows that the average compressive strength required for quality I and quality II concrete bricks is 9.8 MPa and 9.8 MPa, respectively, while the lowest permissible compressive strength for lightweight structural concrete is 6.9 MPa. The minimum compressive strength required for grade III concrete bricks is 3.9 MPa, whereas the minimum required for grade IV concrete bricks is 2.5 MPa. Mixed-I and mixed-II foam concrete are included in the quality II category of concrete. Meanwhile, we designate Mix III as concrete of Quality III [24, 25].

The behaviour of Portland cement, mainly concrete, is consistent with all mixes' evident increase in peak stress with specimen age [26, 27]. The older foam concrete gets, the higher its compressive strength gets. The composite Portland cement's reaction stabilized the bubbles that developed after the foam was mixed into the concrete, resulting in a 28-day procedure that raised the concrete's compressive strength. The compressive strength of foam concrete may vary depending on how much foam is added to the mixture [28–30].

4.3 Load-Displacement of Foam Concrete Panel Precast

Three test objects were used in a 28-day load and displacement test of foam concrete precast panels. The volume weight of precast panels ranges from 1210 to 1217.1 kg/m^3. The load-deflection relationship of precast foam concrete panels with foam volumes of 15.7, 25.12, and 37.68 litters is shown in Fig.6.

The UTM equipment distributes a loading area of 40 × 70 cm through the load cell, yielding a total area of 280 cm^2 and a sample length of 70 cm, as shown by the load-displacement graph in Figure 6.

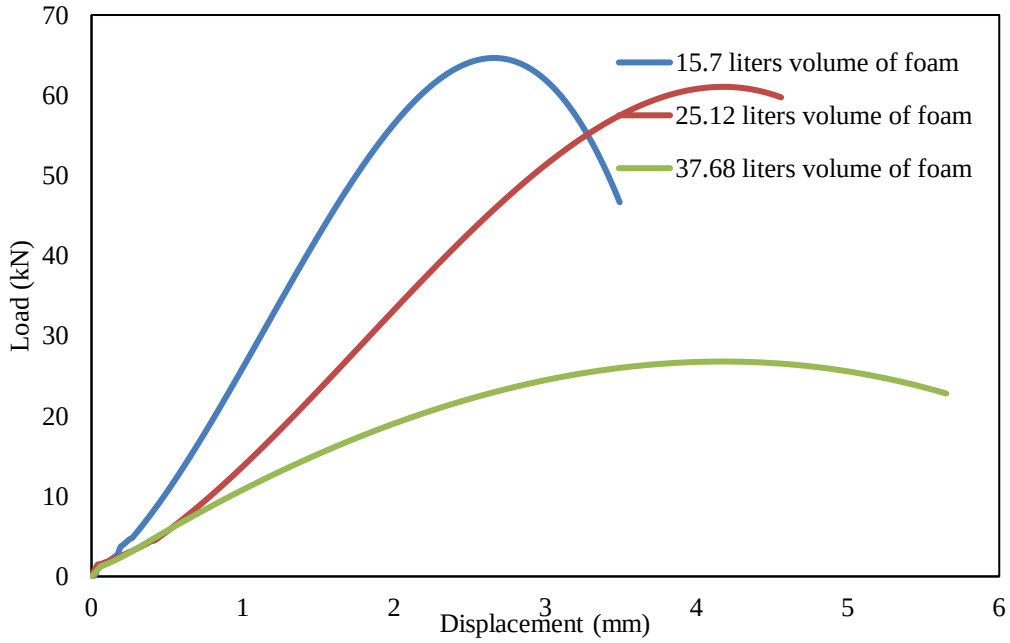

Fig.6 Load-displacement of foam concrete panel precast

The load and deflection produced by precast foam concrete panels in mix I (foam volume 15.7 litters) are 64.64 kN and 2.65 mm, respectively, as shown in Figure 6. Mixture II (foam volume: 25.12 litters) produced 61.04 kN and 4.16 mm of load and deflection, whereas mixture III (foam volume: 37.68 litters) produced 26.79 kN and 4.22 mm of load and deflection. As the specimen ages, the peak load increases in all compositions, which is consistent with the behaviour of Portland cement, mostly concrete. As foam concrete gets older, its load capacity rises. The composite Portland cement reacts with the foam after it has been mixed into the concrete, producing bubbles that stabilize and raise the load value. Over the next 28 days, these bubbles hydrate. Mixture I is the result of combinations II and III, which raise the load value by 58.55% and 5.56%, respectively [31].

The amount of foam added to the mixture can affect the load ratings that foam concrete precast panels can sustain [32]. The results of the tests demonstrated that the maximum load that the foam concrete precast panels could support was significantly impacted by the addition of a foam agent to the foam concrete mixture. The resulting load values unequivocally demonstrate that the more foam used, the lower the load values that foam concrete precast panels can tolerate [33, 34]. The deflection values of foam concrete mixtures I, II, and III vary significantly when gas is added [35]. This feature is frequently used to estimate the zone of gas accumulation.

5. CONCLUSION

1. PCC cement, superplasticizer, and sand combine with mortar to form foam concrete, which has good compaction because to its high binding qualities. Because of the outstanding compatibility of all the elements used, foam concrete can harden during the bonding process, as evidenced by the increase in its compressive strength and split tensile strength from three to twenty-eight days.
2. The greater foam volume used, the lighter and lower the compressive strength of the resulting foam concrete. For class II wall masonry, which calls for a solid concrete brick quality level of 70 kg/cm^2 and a class II hollow concrete brick quality of 50 kg/cm^2, foam concrete with 15.7 litters and 25.15 litters of foam volume can be used as concrete bricks. According to SNI 03-0349-1989, foam concrete with a 37.68-liter capacity can be used as concrete bricks in class III wall pairings with solid concrete brick quality levels of 40 kg/cm2 and class III with hollow concrete brick quality levels of 35 kg/cm^2.

3. According to the findings of the load and deflection tests, the precast foam concrete panels have a resultant load of 61.04 kN and a deflection of 4.16 mm. This illustrates that precast foam concrete panels can be used as divider materials in earthquake-resistant buildings.

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