Failure Pattern of Prefabricated Foam Concrete as Infill Wall Under In-Plane Lateral Loading

Article *in* Design Engineering (Toronto) · August 2021

4 authors:

Miswar Tumpu
88 PUBLICATIONS 47 CITATIONS
SEE PROFILE

Herman Parung
Universitas Hasanuddin
95 PUBLICATIONS 138 CITATIONS
SEE PROFILE

M.W. Tjaronge
Universitas Hasanuddin
111 PUBLICATIONS 388 CITATIONS
SEE PROFILE

Andi Arwin Amiruddin
Universitas Hasanuddin
53 PUBLICATIONS 108 CITATIONS
SEE PROFILE

Design Engineering

ISSN: 0011-9342 | Year 2021
Issue: 7 | Pages: 7168-7178

Failure Pattern of Prefabricated Foam Concrete as Infill Wall Under In-Plane Lateral Loading

M. Tumpu[1], Herman Parung[2], M. W. Tjaronge[2] and A. Arwin Amiruddin[3]
[1]Doctoral Course Student, Civil Engineering Department, Hasanuddin University
[2]Professor, Civil Engineering Department, Hasanuddin University
[3]Associate Professor, Civil Engineering Department, Hasanuddin University
[1]tumpumiswar@gmail.com*, [2]parungherman@yahoo.co.id, [3]tjaronge@yahoo.co.jp,
[3]a.arwinamiruddin@yahoo.com

Abstract:

Many areas in Indonesia are located directly above earthquake faults, making the areas have a relatively high earthquake vulnerability. The occurrence of many shallow earthquakes is associated with the faults. 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-story, two-story houses in rural and urban residential areas, or mixed-use commercial buildings from two to four floors in urban commercial areas. This research is experimental laboratory research. With two test objects were produced. The first one was a bare RC frame, and the second one was an RC frame infilled with prefabricated foam concrete blocks. This study aimed to determine the rate and pattern of failure of the two specimens as a function of the level of lateral strength. The load given was a cyclic load that represents the earthquake load. The test was carried out using the displacement control method, which refers to the ASTM E2126-11 test standard. The test results showed prefabricated foam concrete blocks could be employed as a filling material of reinforced concrete frame structure instead of bust clay bricks and autoclaved lightweight concrete (ALC) blocks of reinforced concrete frame structure. The bare RC frame experiences flexural cracks that spread and enlarge until spalling occured. In the RC frame infilled with prefabricated foam concrete block, shear crack failure that spreads and enlarges until spalling occurs was observed in the RC frame, and the prefabricated foam concrete was damaged with failure patterns in the form of corner crushing, diagonal compression, sliding shear, and diagonal cracking. RC frame that use prefabricated foam concrete blocks as infill walls had a more excellent in-plane lateral loading capability than bare RC frame at the damage levels of Operational Limit State (OLS), Damage Limit State (DLS) and Life Safety Limit (ULS).

Keywords: Failure pattern, Prefabricated foam concrete, Infill wall, Lateral loading

I. INTRODUCTION

Many regions in Indonesia located nearby the earthquake faults hence almost every year seismic disasters generate in the various areas in Indonesia. In Indonesia, residential houses commonly use masonry infill RC frames for enclosing and interior partitioning walls. Although most of the buildings used masonry infill RC frames, many residential houses and one-to-two-story buildings are constructed without reference to proper construction quality, correct detailing, and right structural design; hence, the constructions were considered as non-engineered buildings. Most of the buildings in Indonesia, including residential houses with one to three stories, school buildings, office buildings, and others, use burnt clay bricks as infill of RC frames. According to the most recent earthquake events in Indonesia such as Palu Earthquake (2019), Mamuju-Majene Earthquake (2021), RC frame buildings with burnt clay bricks as infill walls are considerably vulnerable under seismic loadings, as shown in Fig 1. In this regards, several extensive efforts have been made to reduce burnt clay brick as an infill wall.

Many available experimental researches concluded that the effect of infill wall on RC frame to respond the seismic action and the failure pattern is complicated and depends on the constitutive characteristics of an infill with respect to the RC frame properties [1]. Destructive earthquaqe event investigation conducted by Flavia De. L. et al., (2018) [2] reported that the brittle property of commonly used unreinforced masonry wall produces several seismic deficiencies of RC frames infilled wall. The brittle property and rigidness of the infill wall may create insufficient ductile, lessen the resistance of the seismic loading and provoke detrimental effect causing extensive seismic damage.

Fig 1: RC frame buildings with burnt clay bricks as infill walls are considerably vulnerable under seismic loadings

One of the key parameters to measure the performance of the existing building structures, including residential houses is the failure pattern that occurs in the infill wall and RC frame due to the earthquake. In addition, the analysis results of the experimental study on the failure pattern that occurred on the masonry infilled RC frame specimens were very useful to support seismic design and assessments [5].

In the last few decades, one of the materials that have attracted the attention of experts working in building construction is foam concrete. The materials used to manufacture foam concrete are Portland cement-based mortar combined with a stable foam produced from foam agents and water. The use of foam concrete reduces the need for coarse aggregate in building construction, resulting in reduced mining and coarse aggregate production that supports environmental conservation [6,7,8].

This present experimental research is a section of a vast-scope ongoing research work, which aims to improve the seismic standard and evaluation methods for RC and masonry infilled RC frames of buildings and dwelling houses in Indonesia, particularly RC frame infilled with prefabricated foamed concrete. The present paper aims to correlate the level and failure pattern of the infill wall made with prefabricated foamed concrete and RC frame as a function of the level of lateral load.

II. EXPERIMENTAL PROGRAM

A. Mechanical Properties of Reinforcing Bars

Plain steel bar was used for sloof reinforcement, wherein the longitudinal reinforcement used Ø10 plain steel bar and transverse reinforcement used Ø8 plain steel bar. For column reinforcement, longitudinal reinforcement used D13 deformed steel bar, and transverse reinforcement used Ø8 plain steel bar. From the results of the tensile strength test of reinforcement steel bar as shown in Table 1, the testing result shows that all reinforcement bars met the yield strength requirements as required in SNI 2052:2017 [9].

TABLE I Mechanical properties of reinforcing bars for sloof and column reinforcement

Diameter	Strength		Classification
	fy (MPa)	fu (MPa)	
D13	473.74	643.15	BJTS 520
Ø10	469.76	598.88	BJTP 280
Ø8	377.87	420.96	BJTP 280

B. Mechanical Properties of Concrete for Sloof, Columns, Ring Balk, Foam Concrete and Mortar

Table 2 shows the mechanical properties of concrete for sloof, columns, ring balk, foam concrete and mortar at 28 days. It can be seen that the compressive strength test results for sloof, column, and beam at the age of 28 days are 22.60 MPa and 31.87 MPa, respectively. The resulting compressive strength value has met the design of compressive strength value for sloof, namely K-250 or equivalent to 20.4 MPa and for columns and beams, namely 30 MPa.

Crushed river stone used for sloof and ring balk had sizes of 5-10 mm and 10-20 mm. Because the column has a flat shape, the crushed river stone used was 5-10 mm in size.

TABLE II Mechanical Properties of Concrete for Sloof, Columns and Ring Balk

Materials type	Concrete slump (cm)	Volume weight (kg/m^3)	Compressive strength (f'c) (MPa)
Normal concrete for sloof	12.00	2400.00	22.60
Normal concrete for column and beam	10.00	2400.00	31.87

C. Mechanical Properties of Foam Concrete and Mortar

Table 3 shows the mechanical properties of foam concrete and mortar at the age of 28 days. In foam concrete which is used as a filling material for walls in the form of precast foam concrete panels, the volume weight and compressive strength values at the age of 28 days are 1457.70 kg/m^3 and 7.38 MPa, respectively. While the mortar used as an adhesive between precast foam concrete panels has a compressive strength value of 3.32 MPa.

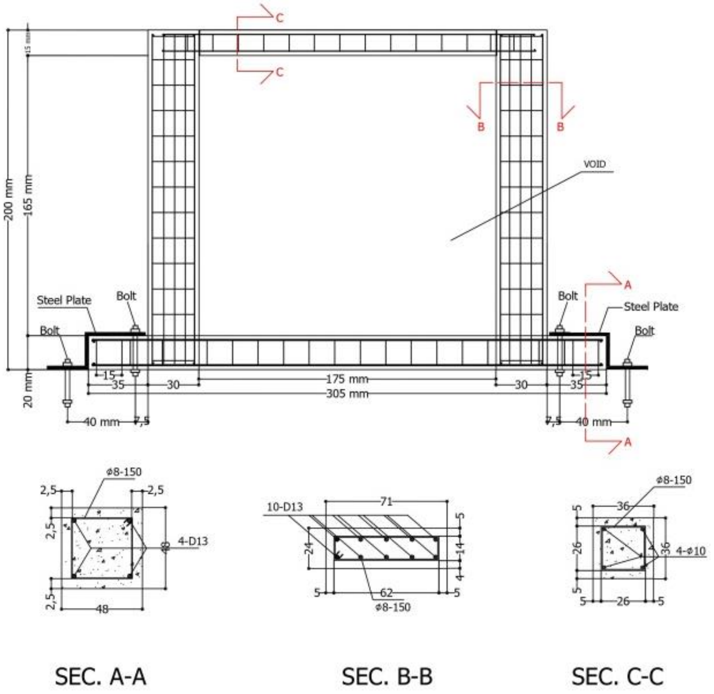
The river sand used to make foam concrete and mortar had a maximum size of 5 mm, specific gravity in surface saturated dry (SSD) conditions of 2.01, water content 6,15%, fineness modulus 2,40, and water absorption 12,18%, respectively.

TABLE III Mechanical properties of foam concrete and mortar

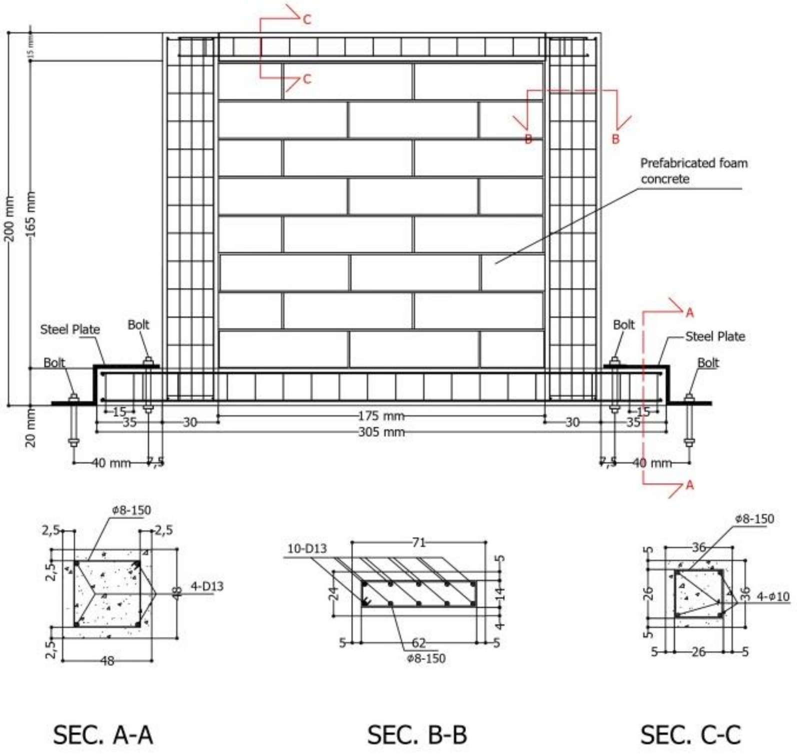
Materials type	Flow (cm)	Volume weight (kg/m^3)	Compressive strength (f'c) (MPa)
Foam concrete for prefabricated blocks	22.00	1457.70	7.38
Mortar	23.00	1800.00	3.32

D. Design of Specimens

Two specimens were prepared in this experimental program. The first specimen was a bare RC frame and the second specimen was RC frame infilled with prefabricated plain foamed concrete blocks. The specimen details are shown in Fig. 3.



(a) Bare RC frame



(b) RC frame infilled with prefabricated foam concrete

Fig 3: Specimens detail

For prefabricated foamed concrete infill RC frames, infill wall was first constructed and prior the infill wall construction, the height for each row of blocks was carefully determined. The prefabricated foamed concrete were built with 80 (width) × 200 (height) × 700 (length) mm solid blocks. The thickness of mortar joint at head, bed and side part was approximately 15 mm.

A prevalent Indonesia RC frame for low-rise buildings and residential houses was used to reflect the standard reinforcement details and materials used as references when preparing the test specimens.

E. In-Plane Test Setup, Instrumentation and Testing Protocol

The equipments used in the in-plane lateral loading test are set up in Fig. 4 and Fig. 5, for the bare RC frame and RC frame infilled with prefabricated foamed concrete blocks, respectively.

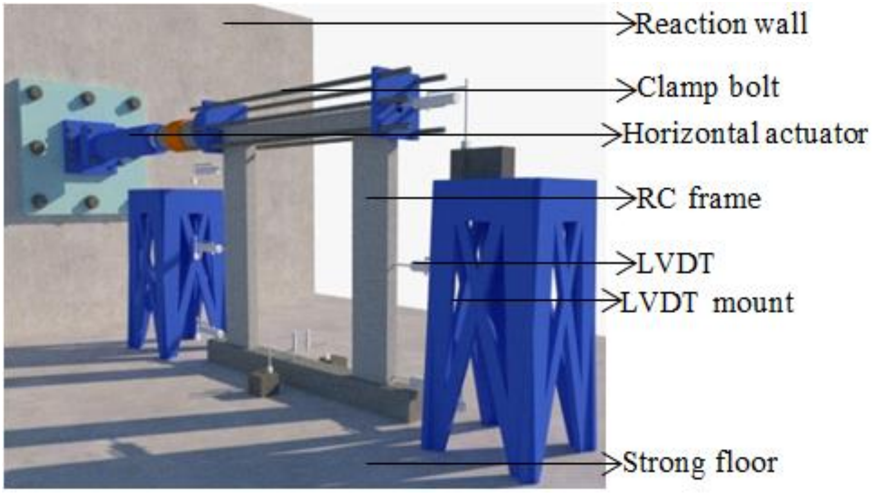


Fig 4: Set up of bare RC frame specimen

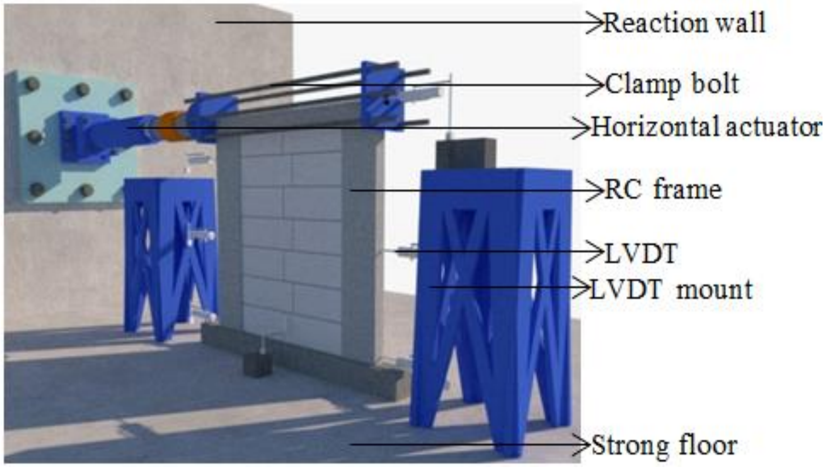


Fig 5: Set up of RC frame infilled with prefabricated foam concrete blocks

The lateral cyclic loading test was performed based on method B ISO 16670 Protocol and ASTM E2126-02a (ASTM 2003). The order of the amplitudes was given in Table 4. In this study, the speed of the actuator used was 0.5 mm/s. The determination of the ultimate displacement (Δm) was based on the SNI 1726-2019 earthquake technical specification (Earthquake Resistance Planning Procedures for Building and Non-Building Structures) [10], which is 2% of the height of the test object. The height of the test object was 200 cm, so the magnitude of 100% Δm was 4 cm.

TABLE IV Test Method B—Amplitudes of the Reversed Cycles (ASTM E2126-02a (ASTM 2003))

Pattern	Step	Minimum number of cycle	Amplitude, % Δ_m	Horizontal displacement (cm)	Drift ratio (%)
1	1	1	1.25	0.00	0.025
	2	1	2.50	0.10	0.05
	3	1	5.00	0.20	0.10
	4	1	7.50	0.30	0.15
	5	1	10.00	0.40	0.20
2	6	3	20.00	0.80	0.40
	7	3	40.00	1.60	0.80
	8	3	60.00	2.40	1.20
	9	3	80.00	3.20	1.60
	10	3	100.00	4.00	2.00
	11	3	Additional increments of 20 (until specimen failure)	4.80	2.40

F. Failure Patterns and Damage State Level

Failure patterns that change with the addition (according to the order) of %Δm of lateral cyclic loading were observed and captured with photos for failure pattern analysis. The results were correlated with lateral cyclic loading level and damage state level.

Damage State Levels

This study adopted three damage state levels that have been proposed by Morandi P. et al., 2018 [5] in analyzing the damage that occurs in masonry-infilled RC frames. This study specifically defined the effects of in-plane lateral loading on RC frames, and prefabricated foam concrete infilled RC frames based on three types of damage state levels which are described as follows:

a. Operational Limit State (OLS)

- ✓ Bare frame is considered damage slightly.
- ✓ The prefabricated foam concrete is considered damage slightly.

All very light dan superficial cracking no need to be repaired.

b. Damage Limit State (DLS)

- ✓ Very limited crushing and spalling occurred on the bare RC frame.
- ✓ Very limited crushing and spalling occurred on the bare RC frame.

c. Life Safety Limit (ULS)

At this damage state level, although the damage is not the life-threatening state but still life safety state, the repairability of RC frame and prefabricated foam concrete block requires unreasonable cost.

III. RESULTS AND DISCUSSION

A. Bare RC Frame

Table 5 describes the damage pattern in detail and its relationship to the bare RC frame's cyclic loading test level and damage state level.

The failure pattern in the bare RC frame was flexural cracks that began to appear at Δm of 2.50% and continued to spread and enlarge to Δm 10.00%, which was OLS damage. Damage state-level DLS was in the form of flexural cracks starting from Δm 20.00% to Δm 80.00%, where there was very limited spalling of the concrete cover in several places. The damaged state-level ULS is in the form of a flexural crack that continued to grow so that spalling occurred, which showed that the bare RC frame had suffered severe damage.

TABLE V Damage pattern in detail and damage state level of bare RC frame

Amplitude, % Δ_m	Lateral force (N)	Failure pattern of bare RC frame	Damage state level
1.25	1,020	Very light flexural cracks (almost no damage)	OLS
2.50	2,280	Flexural cracks propagated and increased in width but can be categorized as slight damage	
5.00	4,780		
7.50	6,220		
10.00	7,620		
20.00	9,740	Flexural cracks propagated and increased in width resulting in the very limited spalling of the concrete	DLS
40.00	16,570		

60.00	21,110	cover in several places. Repairing can be carried out effectively and economically to restore the structural function of the bare frame RC.	
80.00	23,600		
100.00	25,620	Bare RC frames suffered severe damage in spalling and flexural cracks, where repairing and retrofitting were ineffective and not economical.	ULS
120.00	32,680		

B. RC Frame Infilled with Prefabricated Foam Concrete Plain Foamed Concrete Blocks

Table 6 shows the failure pattern in detail and damage state level of RC frame infilled with prefabricated foam concrete blocks. The failure pattern in the RC frame was a shear crack, starting at Δm of 7.5% and continued to spread and enlarge. Failure patterns in prefabricated foam concrete as infilled wall were corner crushing, diagonal compression, sliding shear, and diagonal cracking. The failure patterns was the same as the masonry made of brick [3]. Damage state levels of OLS, DLS, and ULS range from Δm 1.25% to 2.50%, Δm 7.50% to 60.00%, Δm 80.00% to 120.00%, respectively.

TABLE VI Damage pattern in detail and damage state level of RC frame infilled prefabricated foam concrete

Amplitude, % Δ_m	Lateral force (N)	Failure pattern of infilled RC frame	Damage state level
1.25	1,920	No visible damage	OLS
2.50	3,420		
5.00	6,440	Propagated shear cracks appeared on the prefabricated foam concrete but can be categorized as slight damage	
7.50	9,750	Shear cracks begin to appear in the RC frame when Δm is equal to 7.50%. Efficient and economical repairments can be performed to overcome the failures that have occurred at this level state. The five main failure patterns were corner crushing, diagonal compression, sliding shear, diagonal cracking, and frame damage.	DLS
10.00	12,780		
20.00	22,080		
40.00	31,010		
60.00	36,870		
80.00	41,120	The failure patterns in corner destruction, diagonal compression, sliding shear, diagonal crack were widespread	ULS
100.00	41,140		

120.00	49,410	to form severe damage on the infill made of prefabricated foam concrete. Severe damage in the forms of propagated and wider shear cracking and widespread spalling of concrete cover appeared on the RC frame. At this state damage level, prefabricated foam concrete and RC frame were not repairable and retrofittable at an economical cost.	

C. Ratio of Lf_{iRCf} to Lf_{BRC}

Table 7 shows the Ratio of Lf_{iRCf} to Lf_{BRC}. It can be noted that the presence of prefabricated foam concrete blocks as infilled material increased the ability to bear in-plane lateral load. Hence, the ratio of Lf_{iRCf} to Lf_{BRC} at DLS and ULS was 1.56 and 1.51, respectively.

TABLE VII Ratio of Lf_{iRCf} to Lf_{BRC}

Damage state	Lateral force of Bare RC frame (Lf_{BRC})	Lateral force of infilled RC frame (Lf_{iRCf})	Ratio of Lf_{iRCf} to Lf_{BRC}
OLS	7,620 N	6,440 N	6,440/7,620 = 0.85
DLS	23,600 N	36,870 N	36.87/23,600 = 1.56
ULS	32,680 N	49,410 N	49,410/32,680 = 1.51

IV. CONCLUSION

1. Prefabricated foam concrete block can be used as an alternative infilled material for reinforced concrete frame structures instead of bust clay bricks and autoclaved lightweight concrete (ALC) blocks, etc.

2. The failure pattern of the bare RC frame was flexural cracks that spread and enlarge until spalling occurs. In the RC frame infilled with prefabricated foam concrete blocks, the failure pattern that occured in the RC frame was shear cracking until spalling occured, while the damage pattern in the prefabricated foam concrete blocks was corner crushing, diagonal compression, sliding shear, and diagonal cracking.

3. At the damage state-level OLS, DLS, and ULS, the RC frame that used prefabricated foam concrete blocks as infill wall could carry more significant in-plane lateral load than bare RC frames.

ACKNOWLEDGMENT

The bare RC frame and RC frame infilled with prefabricated plain foamed concrete blocks were prepared and conditioned at the Eco Material and Concrete and Structural Earthquake Engineering Laboratory at Civil Engineering Department Hasanuddin University, Indonesia. The authors would like to express their sincere thanks to Dr. Muhammad Akbar Caronge, Mansyur, MT, and Muhammad Hamdar Yusri, ST, for this research through their assistance with providing helps during this study.

REFERENCES

1. Shing, P. B. and Mehrabi, A. B. 2002. Behaviour and analysis of masonry-infilled frames. Prog. Struct. Engng Mater, 2002; 4:320–331 (DOI: 10.1002/pse.122).
2. Flavia De L. et al. 2018. RC infilled building performance against the evidence of the 2016 EEFIT Central Italy post-earthquake reconnaissance mission: empirical fragilities and comparison with the FAST method. Bull Earthquake Eng 16, 2943–2969 (2018). https://doi.org/10.1007/s10518-017-0289-1.
3. Pantò B. and Rossi P. P. 2019. A new macromodel for the assessment of the seismic response of infilled RC frames, Earthquake Engineering and Structural Dynamics, DOI: 10.1002/eqe.3163.
4. Alwashali et al. 2019. Experimental investigation of influences of several parameters on seismic capacity of masonry infilled reinforced concrete frame. Engineering Structures, Volume 189, 15 June 2019, Pages 11-24. https://doi.org/10.1016/j.engstruct.2019.03.020.
5. Morandi P., Hak S., and Magens G. 2018. Performance-based interpretation of in-plane cyclic tests on RC frames with strong masonry infills. Engineering Structures 156 (2018): 503-521.
6. Sunarno Y., Tjaronge M. W. and Irmawaty R. 2020. Preliminary study on early compressive strength of foam concrete using Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC). IOP Conf. Ser.: Earth Environ. Sci. 419.
7. Y.H. Mugahed Amran, N. Farzadnia, A.A. Abang Ali, Properties and applications of foamed concrete; a review, Constr. Build. Mater. 101 (2015) 990–1005.
8. A. Hajimohammadi, T. Ngo, P. Mendis, Enhancing the strength of pre-made foams for foam concrete applications, Cem. Concr. Compos. 87 (2018) 164–171.
9. SNI 2052:2017. Baja Tulangan Beton (in Indonesian).
10. SNI 1726:2019. Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non gedung (in Indonesian).