Hollow Concrete Slab with Lightweight Steel Hollow to Mitigate Earthquake Disaster

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ABSTRACT

Using lightweight building materials is one option to mitigate the structure of buildings and other civil buildings against earthquake disasters. This method aims to minimize the weight of the building as the magnitude of the earthquake that hits the building is directly proportional to the building's weight itself. The floor plate of the building is made of reinforced concrete with a weight of 240 kg/m^2. Therefore, this study used 30x30 mm lightweight steel hollow as a hole-forming and as a substitute for shrinkage and temperature reinforcement. This plate was assembled to flexural reinforcement with a diameter of Ø6 -100, the compressive strength of concrete (fc= 25 MPa), thus forming a one-way slab measuring 880x440x90 mm. After the slab had been cured for 28 days, the flexural strength was tested with an Automatic Tension & Compression Testing Machine having a capacity of 3000 kN. As a comparison, the test items were created of two samples with different hollow placements of 3, 4, 5, 6 hollow and solid plates. The major goal of this study is to determine the modulus of rupture (MOR), modulus of elasticity (MOE), and weight reduction owing to the use of lightweight steel hollows as hole-forming and replacement for shrinkage and temperature reinforcement in hollow concrete slabs. The results showed that using 5 and 6 lightweight steel hollows can reduce concrete weight by 10% to 14% while maintaining the maximum modulus of rupture and modulus of elasticity. However, when compared to solid plates, the modulus of rupture and modulus of elasticity were reduced by 60 to 65 percent.

Keywords: *Earthquake Mitigation, Hollow Concrete Slab, Lightweight Steel Hollow*

1. INTRODUCTION

An ideal of building structure design should be qualified for support static and dynamic forces and have sufficient flexibility in absorbing the forces that will work. If the designed building structure is too rigid, cracks and breaks could occur in the building elements even before an earthquake occurs. However, if it is too flexible, then the self-weight of the heavy building elements will knock each other down.

Indonesia is a country prone to earthquakes. Nowadays, traditional houses made of wooden structures with lightweight building materials and resistance to earthquakes are hard to find. Indonesian people seem to prefer high-rise buildings with very rigid structures and using heavy building materials. Therefore, the buildings could collapse altogether. Furthermore, there are some other cases, such as most of the main structural components of the building are damaged, the building looks tilted, or most of the walls and floors of the building are cracked and broken when an earthquake occurs. Hence the selection of materials buildings has an essential role in planning a withstand earthquake shocks building.

Reinforced concrete slabs are constructed of aggregate, cement, and water, and have extremely stiff qualities and are very heavy. Its function is to be the horizontal/diaphragm stiffeners and increase the stiffness of the portal beam. The loads working on the slab are live loads and dead loads (self-weight of the slab), which will cause bending moments. The floor slab is supported by beams and columns. The load working on the slab is transmitted to the column, carried by the foundation, and channeled to the ground as support.

Even though we have a planned structural system that meets the requirements of earthquake-resistant buildings and the subgrade can withstand earthquake loads, the magnitude of the earthquake that hits the building is directly proportional to the building weight. Therefore, it is better to consider using lightweight materials to mitigate earthquake hazards which are currently difficult to predict.

In general, a structural system has some working forces such as tensile, compressive, bending, axial, and torsion. The bending moment occurs due to the transverse load acting on the longitudinal axis of the slab. When the bending occurs, the fibers in the slab element experience tension, and on the other side, the element is stressed. In reinforced concrete structures, the reinforcing steel resists the tensile forces. At the same time, the concrete, shrinkage, and temperature reinforcement resist the compressive forces. So it is expected that they will cooperate to resist the working forces.

When the hole placement point is near the neutral line, the modulus of rupture (MOR) and modulus of elasticity (MOE) increase when compared to the beam without holes, according to [1. Using PVC pipes with varied hole positions, 40, 60, 80, and 100 mm from the top fiber of the beam cross-section, the study intends to assess the effect of hole positioning on the flexural strength of beams measuring 100x150 mm. As a result, we may deduce that the reduction in the compression area has no effect on the concrete's ability to bear the compressive force in this scenario.

The Indonesian National Standard [2], classifies the tensile stress of lightweight steel into lightweight steel with high tensile stress (G550) and lightweight steel with low tensile stress (G300, G250). Lightweight steel has a high level of ductility and is malleable, whereas conventional steel has lower ductility and is easily hardened by heat treatment

The goal of research [3] is to evaluate the flexural strength of a hollow slab with four circular holes in a slab measuring 800x400x100 mm to that of a solid slab, utilizing both regular weight and lightweight aggregate. it was found that if using normal weight aggregate there will be a decrease in flexural strength by 5.49%, whereas if using lightweight aggregate there will be a decrease in flexural strength of 4.91%.

These hollow concrete slabs have been produced by several foreign countries as well as by Indonesia itself, including those produced by Concrete Elementindo Perkasa using wire mesh reinforcement 5 mm and 7 mm, with varying thicknesses of 120 mm; 150 mm; 200 mm, and 250 mm with a width of 1200 mm, the compressive strength of concrete fc = 40 MPa, can reduce 28%-49% by weight of the weight of conventional concrete slabs (Figure 1.a). This precast hollow concrete slab is very economical and practical because it can be directly installed and easy to work with without having to use scaffolding which requires a long time in the assembly process. This precast hollow concrete slab also has problems including having to use heavy equipment in the transportation process because it still has a fairly heavyweight and has not been circulated in the market on a small scale.

From the explained introduction, this study is conducted to obtain a new lightweight and economical material of a hollow concrete slab that could mitigate earthquake disasters. The main idea is to use the lightweight galvalume hollow steel as a substitute for shrinkage and temperature reinforcement as well as forming holes in hollow concrete slabs (Figure 1.b). Hollows concrete slab with shrinkage and temperature reinforcement is tested for its flexural strength before calculating the Modulus of rupture (MOR) and Modulus of elasticity (MOE). Furthermore, the researchers calculate the effect of the weight of the hollow slab with variations of 3, 4, 5, and 6 hollows compared to conventional slabs.

a. Hollow core slab

b. the lightweight hollow steel

Figure 1 Hollow concrete slab and reinforcement details

2. METHODOLOGY

The physical properties of concrete-forming materials such as coarse aggregate, fine aggregate, and cement were tested as part of this study. The sand comes from the Musi River, the coarse aggregate (crushed stone) from Bojonegoro, and the Portland cement type I Baturaja originates from Bojonegoro. Sieve Analysis of Fine and Coarse Aggregates [4], Relative Density (Specific Gravity) and Absorption of Coarse Aggregate [5], Relative Density (Specific Gravity) and Absorption of Fine Aggregate [6], Materials Finer than 75 m (No. 200) Sieve in Mineral Aggregates by Washing [7], Bulk Density ("Unit Weight") and Voids in Aggregate [8, Organic Impurities [13]. The results of the physical properties test used to make a concrete mix design based on [14], the composition of the mixture used to make a cube specimen measuring 150 x 150 mm. A compression strength test[15] is carried out after curing for 28 days. Specimen and design parameters for slab Table 1 with various holes and reinforcement details can be seen in Figure 3.

Table 1. Specimen Design Parameters

Label specimen	hollow	Figure	Number of specimens
PU	0	3.b	2
P3H	3	3.c	2
P4H	4	3.d	2
P5H	5	3.e	2
P6H	6	3.f	2

The slab test is based on a simple beam test with center-point loading using the formula [16] so that the modulus of rupture (MOR) and modulus of elasticity can be calculated:

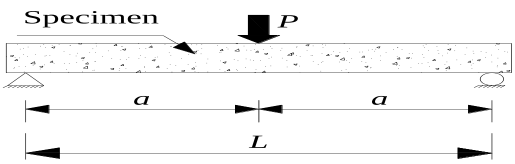


Figure 2 Test Setup Center Point Loading

$$MOE = \frac{\sigma}{\varepsilon} \quad (1)$$

$$MOR = \frac{3P.L}{2.b.h^2} \quad (2)$$

$$\sigma = \frac{P}{A}\ ;\ \ \varepsilon = \frac{\Delta L}{L_o} = \frac{L_1 - L_o}{L_o} \quad (3)$$

where:

MOR= Modulus of rupture (MPa)
MOE= Modulus of elasticity (MPa)
σ = Stress (MPa)
A = cross sectional area (mm2)
ΔL = is change of the length (mm)
ε = Strain (%)
L = Span length (mm)
P = Maksimum load (N)
b = Average width (mm)
h = Average depth (mm)
Lo = length after elongation (mm)
L1 = original length (mm)

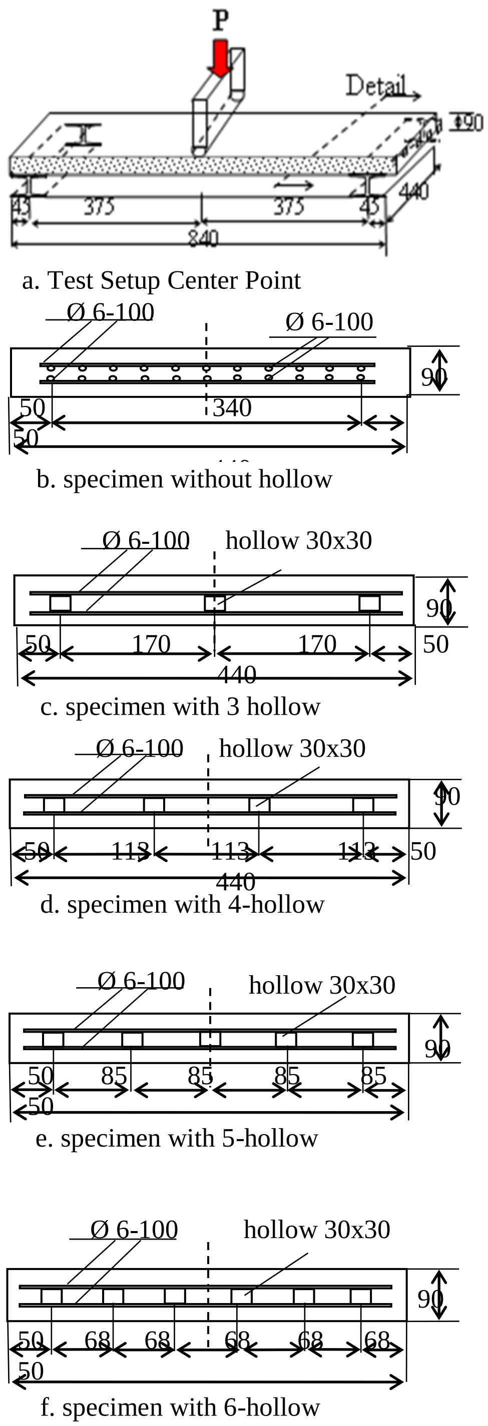


Figure 3 Cross section of steel-reinforced concrete slab

3. RESULT AND DISCUSSION

Table 2 shows the results of testing the physical properties of crushed stone, sand, and cement. The crushed stone has the largest grain size of 9.5 mm with a fine modulus of 4.56, while sand is included in zone 2 (Figure 4), which is graded sand rather rough/rather rough with a fine modulus. 2.7.

Table 2. Result testing of physical properties of crushed stone, sand and cement

Testing	Result Testing			Unit
	Sand	crushed stone	cement	
Sieve Analysis	Zone 2	max 9,5	-	
Specifik gravity bulk	2.46	2.62	2.99	
Specifik gravity (SSD)	2.51	2.66	-	
Absorption	2.04	1.95	-	%
Material finer than 75 µ mm	0.95	0.85	-	%
Unit weight	1299	1413	-	kg/ m^3
Aggregate crushing	-	10.95	-	%
Aggregate abrasion	-	20.15	-	%
Fine modulus	2.7	4.56	-	%
Soundness test	-	1.02	-	%
Organic Impurities	non	-	-	-

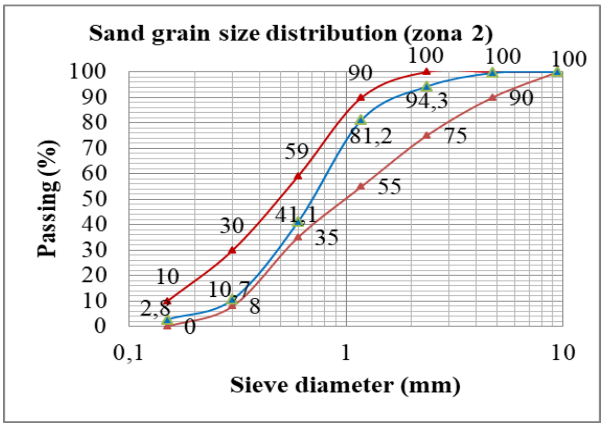


Figure 4 Sand grain size distribution

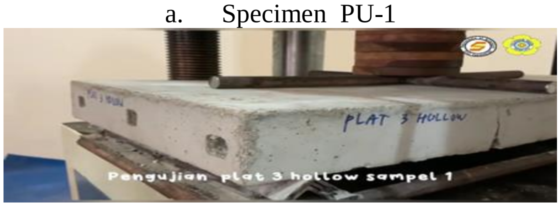
The concrete slab is built of concrete with a sand; crushed stone ratio of 1:1.7:1.4 and a water-cement/fas factor of 0.51. The compressive strength test of five concrete cube samples yielded an average value of fc = 25.24 MPa. The strain-stress ratio is used to measure the resistance of a beam when it undergoes elastic deformation when a force is applied to it. The modulus of elasticity (MOE) is a value used to measure the resistance of a beam when it undergoes elastic deformation when a force is applied to it. The test results of concrete slabs with variations of lightweight steel hollow can be seen in Table 3, where the highest was obtained on plates with 5 hollows and 6 hollows (P5H and P6H) with an average value of 28.51 MPa and 30.52 MPa. MOR is the value of the peak flexural strength acting on the beam before it collapses, it can be seen that the load and the modulus of failure increase with the addition of lightweight steel hollow which is used as a substitute for shrinkage and temperature reinforcement in the slab. On plates, with 5 hollows and 6 hollows (P5H and P6H) it can reduce weight by 10-14%.

Table 3. Result of the Load, Deflection, Modulus of Rupture and Modulus of Elasticity for Slab

Specimen	Weigth (kg)	Yield Load[1] (N)	Peak Load (N)	Deflection at Peak (mm)	MOE[2] (MPa)	MOR (MPa)
PU-1	76.34	19,856	40,092	20.9	80.22	6.27
PU-2	77.05	18,542	43,911	15.2	74.11	5.85
P3H-1	71.51	5,668	5,453	12.5	13.10	1.79
P3H-2	71.91	5,645	9,691	3.75	25.93	1.78
P4H-1	68.78	6,602	10,534	44.8	22.23	2.08
P4H-2	69.01	6,696	9,363	37.5	31.03	2.11
P5H-1	68.07	8,900	15,543	44.5	28.10	2.81
P5H-2	68.02	6,728	11,987	39.9	28.92	2.12
P6H-1	66.25	7,449	13,687	40.1	30.10	2.35
P6H-2	66.35	6,590	11,809	37.5	30.94	2.08

[1]determined using 1.0% offset method
[2]determined using 0.2% offset method

a. Specimen PU-1



b. Specimen P3H-1

c. Specimen P4H-1

d. Specimen P5H-2

e. Specimen P6H-1

Figure 5 State at end of test Specimen

4. CONCLUSION

The following conclusions can be drawn from the study's findings:

1. Lightweight hollow steel can be used as a substitute for shrinkage and temperature reinforcement in the plate, but the distance of reinforcement must be considered because if it is greater than the distance of the shrinkage reinforcement and the maximum temperature it can reduce the modulus of rupture and the Modulus of Elasticity of the plate.

2. Lightweight hollow steel can reduce beam weight and cooperate with concrete in resisting bending moments.

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