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ORIGINAL RESEARCH

FLEXURAL AND SHEAR BEHAVIOUR OF REINFORCED CONCRETE SLAB WITH PVC PIPE AS A CAVITY FORMING IN TWO-WAY SYSTEM

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Abstract

Piping modifications Polyvinyl Chloride as forming a hollow cavity in the concrete slab is one alternative to reduce the self-weight of structure. The placement of PVC pipe that has been modified on the concrete tensile area is expected not to reduce the bending strength of the plate. In the study, the analysis was compared to reinforced concrete slab massive (PB-1) with a hollow reinforced concrete slab PVC (PB-2) with the same thickness and compared well with hollow reinforced concrete slab PVC (PB-3) with an equal volume of the concrete slab massive reinforced (PB-1). All test objects have the same dimensions, including the number and spacing of reinforcement. The analysis method of the moment coefficient obtained flexural strength of PB-1 amounted to 328.175 kN, plate PB-2 amounted to 329.624 kN, and the plate of PB-3 amounted to 387.184 kN. While the results of the analysis using the Navier method deflections values obtained for the plate PB-1, PB-2, and PB-3 are 0.0948 mm, 0.33952 mm, and 0.04267 mm, respectively. Shear forces values for plate PB-1, PB-2 and PB-3 is 965.908 kN, 231.818 kN and 281.429 kN respectively.

KEYWORDS:

Cavity Forming, Flexural and Shear Strength, PVC Hollow Slab, Reinforced Concrete Slab

1 | INTRODUCTION

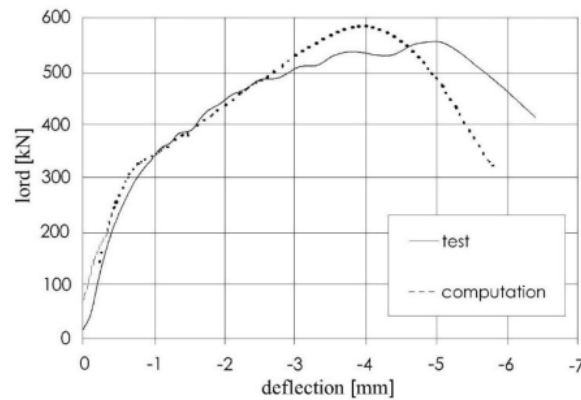
To improve the efficiency of the reinforced concrete slab structure, emerging alternative technologies such as reinforced concrete hollow sphere slab. This technology aims to reduce the self-weight of structure and can save the concrete material. The reinforced concrete slab has been patented hollow ball called Bubble Deck plate with a minimum thickness of 23 cm, and it's generally used for the flat plate with semi-precast system^[1]. Aldejohann and Schenellenbach-Held^[2] mention, in general, the Bubble Deck has the same bending behavior as a solid concrete slab^[3]. Comparisons between the two can be seen in Table^[1]. The main

TABLE 1 Comparison of bubble deck with plates reinforced concrete solid.

% Solid Deck	Same Strength	Same Bending Stiffness	Same Concrete Volume
Strength	100	105	150
Bending Stiffness	87	100	300
Volume of Concrete	66	69	100

TABLE 2 The load capacity plate experiment.

Specimen	Dimension (mm)	Concrete Volume (%)	Initial Crack Load (kN)	Initial Crack Load (%)	Maximum Load (kN)	Maximum Load (%)
PL-1	2200x1100x120	100	21.29	100	43.29	100
PL-2	2200x1100x120	83	11.29	53	46.29	107
PL-3	2200x1100x143	100	15.29	72	68.29	158

**FIGURE 1** The load deflection.

difference between the Bubble Deck with a solid plate is resistance to shear, where the distance between the ball2 determines shear strength analysis in DIN 1045-1 hollow plate (1).

Soeharno (2) was testing their resilient experimentally against reinforced concrete slab hollow ball with a thickness of 12 cm, with a one-way system and the cast in-situ system. Plate bending capacity is obtained as shown in Table 2 (3).

Schnellenbach-Held and Pfeffer (4) modeled the Bubble-Deck failure mechanisms due to the shear forces in the column area with punching test. The study was conducted through experimental and numerical. They were testing numerically using the finite element software non-linear DIANA. Reinforcement modeled appendage embedded assuming perfect bond between concrete and reinforcing steel material. Experimental and numerical comparison can be seen in Figure 1.

An objective analysis of this study was to determine and compare flexural strength, shear strength, and deflection due to uneven loading on a reinforced concrete slab solid. The expected benefits of this analysis are the presence of cavities on a reinforced concrete slab to be obtained by saving the use of concrete and plates lighter, or the same volume of the concrete slab would have a greater effective height.

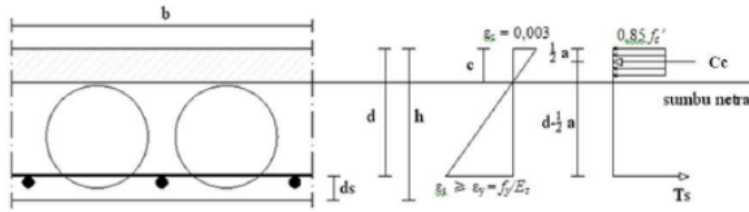


FIGURE 2 Stress and strain diagram of sectional hollow plate.

2 | RELATED WORKS

The distribution of stress and strain in the reinforced concrete slab in a balanced state, the compressive force on concrete (C_c) would be balanced by the tensile strength of steel reinforcement (T_s). The distribution of stress and strain in the plate cross-section hollow balls can be seen in Figure 2. The condition of the steel reinforcement has undergone melting ($f_c = f_y$) that applies Eq. 1

$$C_c = T_s \quad (1)$$

In the steel (E_s) strain = 2.105 Mpa and the compressive strength of concrete $f'_c \leq 30$ Mpa, then the nominal moment sectional calculated using Eq. 2 as follows.

$$M_a = T_s(d - \frac{1}{2} a) = C_c(d - \frac{1}{2} a) = 0.85 f'_c b a(d - \frac{1}{2} a) \quad (2)$$

Methods of Navier can analyze the analysis of two-way plate flexural strength. In the method of moment coefficient sought short spa direction torque value (M_{lx}) and the moment the direction of long span (M_{ly}) at the plate in both directions at the moment coefficient method according to Eq. 3

$$M_{lx} = 0.001 C_x w L_x^2 \quad (3)$$

Navier method using multiple sine Fourier series. Navier method for joint support plate with all four sides and pattern load is uniformly distributed load p_0 is as follows.

Deflection equations for uniform loading pattern are:

$$\Delta h = \frac{16 p_0}{m^6 D} \sum_{m=1}^i \sum_{n=1}^j \frac{\sin \frac{m \pi x}{a} \sin \frac{n \pi y}{b}}{m n \left[\frac{m^2}{a^2} + \frac{n^2}{b^2} \right]^2} \quad (4)$$

Moment equation is the short span direction is:

$$M_x = \frac{16 p_0}{m^4} \sum_{m=1}^i \sum_{n=1}^j \frac{\frac{m^2}{a^2} + \frac{n^2}{b^2}}{m n \left[\frac{m^2}{a^2} + \frac{n^2}{b^2} \right]^2} \sin \frac{m \pi x}{a} \sin \frac{n \pi y}{b} \quad (5)$$

Navier ductility factor for hollow plate is :

$$D = \frac{E h^3}{12(1 - \nu^2)} \times \frac{I_{berongga}}{I_{solid}} \quad (6)$$

TABLE 3 The detail of specimen.

#	Dimension ($p \times l \times t$) (mm)	Diameter of PVC (mm)	Distance Between PVC (mm)	Reinforcement x direction (mm)	Distance y direction (mm)	#Test Object
1.	2700x1800x140			100	100	1
2.	2700x1800x140	76	24	100	100	1
3.	2700x1800x159	76	24	100	100	1

TABLE 4 The comparison volume of the plate.

Specimen	Plate Dimension (mm)	\varnothing Hollow (mm)	Distance Between Hollow (mm)	Dead Load per 1 m^2	ρ (%)	d (mm)	Concrete Volume
PB-1	2700x1800x140	-	-	315.663	0.403	112.4	100.00%
PB-2	2700x1800x140	76	24	273.540	0.403	112.4	86.33%
PB-3	2700x1800x159	76	24	315.663	0.345	131.4	100.00%

Expenses cracks that occur in reinforced concrete structures can be classified into two main categories, namely cracks caused due to external loads such as flexural cracks and shear cracks. Calculation of two-way capabilities of the pre-stressed plate in resisting the shear force is taken from the small value of the following equations as follows.

$$V_c = 0.17 \left(1 + \frac{2}{\beta}\right) \lambda \sqrt{f_c} b_o d \quad (7)$$

$$V_c = 0.083 \left(\frac{\alpha_{sd}}{b_o} + 2\right) \lambda \sqrt{f_c} b_o d \quad (8)$$

$$V_c = 0.33 \lambda \sqrt{f_c'} b_o d \quad (9)$$

3 | MATERIAL AND METHOD

3.1 | Material

The variable plate to be analyzed is three pieces of plates. The first is a solid plate with dimensions of length 2700 mm, width 1800 mm, and 140 mm symbolized by PB-1. The second plate is a hollow reinforced concrete slab with PVC as forming cavities with dimensions of length 2700 mm, width 1800 mm, and thickness is 140 mm, symbolized by PB-2, and the last hollow reinforced concrete slab with PVC as forming cavities with dimensions of length is 2700 mm, width 1800 mm and 159 mm thickness premises symbolized by PB-3. Each cavity PVC used 760 mm diameter, and all plates use steel reinforcement diameter of 8 mm with 100 mm spacing between the rebar. Details of the test specimen in this study can be seen in Table 3.

Details design of a solid plate with dimensions of length 2700 mm, width 1800 mm, and thickness is 140 mm can be seen in Figure 3. The second plate is a hollow reinforced concrete slab with PVC as forming cavities with a thickness of 140 mm can be seen in Figure 4 and the last hollow reinforced concrete slab with PVC as forming cavities with a thickness of 159 mm in Figure 5.

The analysis was conducted consisting of several stages depicted in the flowchart of Figure 6.

The initial stage of this first analysis is a preparatory study which includes the formulation of the issues to be analyzed. Then the next stage is to determine and design the dimensions, including the quality of materials to be used for analysis. In this analysis, it is assumed specimen with a riveted joint support along all four sides. Simulation testing is a test plate with simulated bidirectional distributed load 7. Analysis to calculate the flexural strength of the plate using the Navier deflection and calculating the shear strength using SNI 03-2847-2019 8.

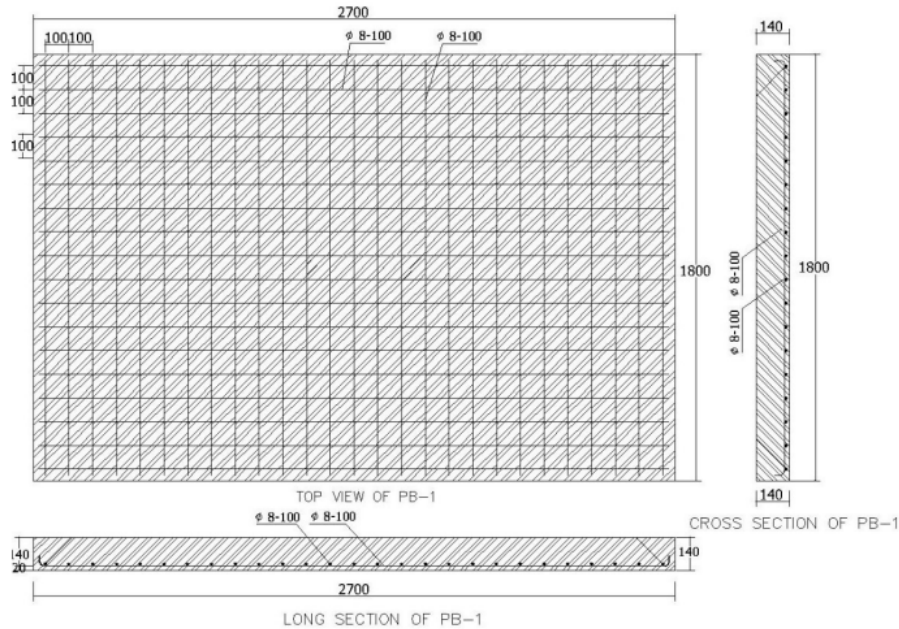


FIGURE 3 The design of solid plate (PB-1).

TABLE 5 The flexural strength analysis.

Plate	A_s (mm^2)	d (mm)	M_n (kNm)	ρ (kN)	Percentage (To PB-1)
PB-1	453416	112.39	17.076	328.175	100.000
PB-2	453.416	112.39	17.076	329.624	100.465
PB-3	453.416	131.39	20.048	387.184	117.999

4 | RESULTS AND DISCUSSION

The analysis of self-weight calculation plates per square meter is obtained as in Table 4.

4.1 | Flexural Strenght Plate

Flexural strength analysis conducted for the flexural strength of each test specimen consisted of a solid reinforced concrete slab as a comparison of two hollow reinforced concrete slab PVC. Using analysis of plate bending strength in both directions to get the maximum load moment coefficients obtained using the method of maximum bending load values as in Table 5.

The maximum load capacity on a massive plate (PB-1) amounted to 328.175 kN. In comparison, the maximum capacity of the hollow reinforced concrete slab 14 cm (PB-2) amounted to 329.624 kN, and a maximum load capacity of hollow reinforced concrete slab PVC thickness Of 15.9 (PB-3) amounted to 387.184 kN, a result compare of the analysis on each plate can be seen in Figure 7.

4.2 | Deflection of Plate

Deflection in the middle plate was analyzed using the Navier method wherein the plate in linear elastic condition so that deflection was calculated before the first crack load. The result of the analysis using the Navier method is shown in Table 6.

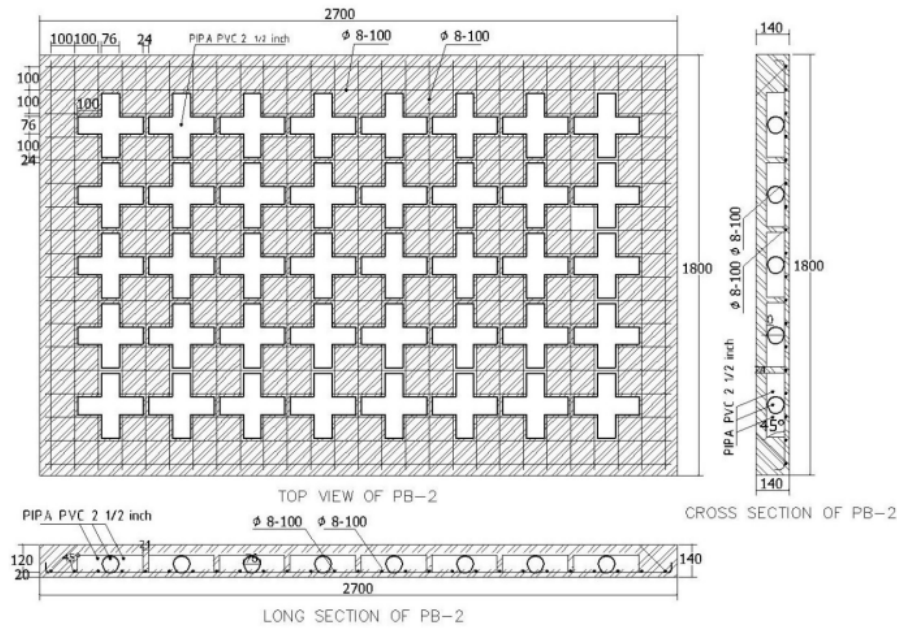


FIGURE 4 The design of hollow reinforced concrete slab (PB-2).

TABLE 6 The deflections with navier method.

Plate	Center of Gravity y (mm)	Inertia Moement (mm^4)	Crack Moment (kNm)	Deflection (mm)
PB-1	68.838	319700750.460	17.356	0.09480
PB-2	68.743	311450000.000	16.931	0.33952
PB-3	78.001	51152646.925	24.507	0.04267

Deflection when the first crack in the reinforcement concrete massive slab (PB-1) greater than deflection hollow reinforced concrete slab (PB-3), but deflection hollow reinforced concrete slab (PB-2) greater than deflection in reinforcement concrete massive slab (PB-1). Results of the calculation shown in Figure 8

4.3 | Shear Force Plate

The main difference between a hollow reinforced concrete slab with a massive plate is the resistance of shear force. The diminishing volume of concrete would reduce the shear of forces. Hence a hollow reinforced concrete slab is in a critical shear area with a minimum cross-section or on a cross-section that has a maximum cavity. Shear forces analysis of hollow reinforced concrete slab in DIN 1045-1 based on the area between the ball, while the area above and below the ball is not included, illustrated in Figure 9

Force shear plates can be analyzed if known around the loading area of the load area. By explaining the critical areas of the hollow core slab above, it approaches to determine the shear region in areas along the middle of the ball, on the edge of the plate line of the ball. Comparison of the result of force shear between reinforcement concrete massive (PB-1), hollow reinforced concrete slab (PB-2), and hollow reinforced concrete slab (PB-3) can be seen in Table 7. The comparative shear force between PB-1, PB-2, and PB-3 is shown in Figure 10

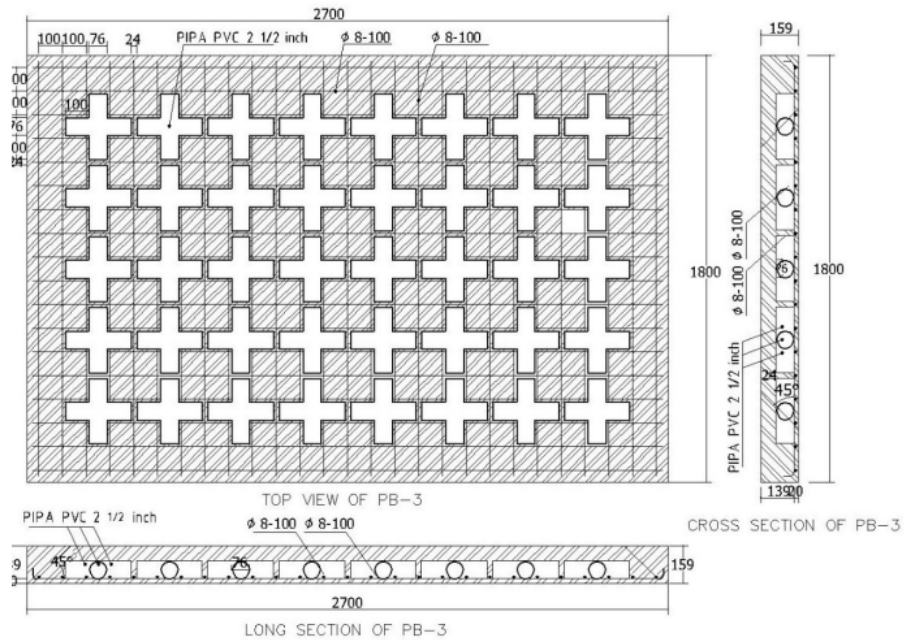


FIGURE 5 The design of hollow reinforced concrete slab (PB-3).

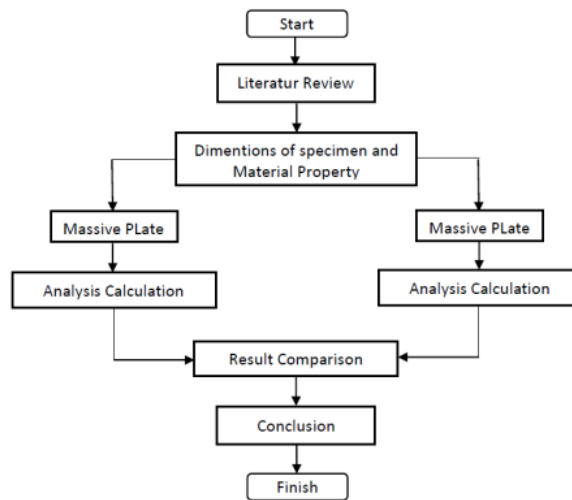


FIGURE 6 Research flowchart.

5 | CONCLUSION

Based on the analysis that has been done, we came up with three conclusions. First, the maximum load capacity on a massive reinforced concrete slab of 328.175 kN, while the maximum capacity load in a hollow reinforced concrete slab is 14 cm and 15.9 cm thick, respectively 329.624 387.184 kN. This suggests that the reduced volume of concrete on a hollow reinforced concrete slab of 14 cm has little effect on the strong bending. While on hollow reinforced concrete slab 15.9 cm, increasing effective

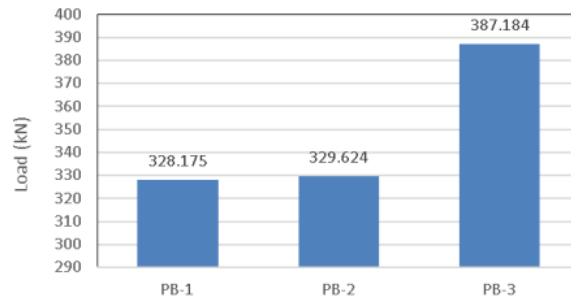


FIGURE 7 The flexural loag.

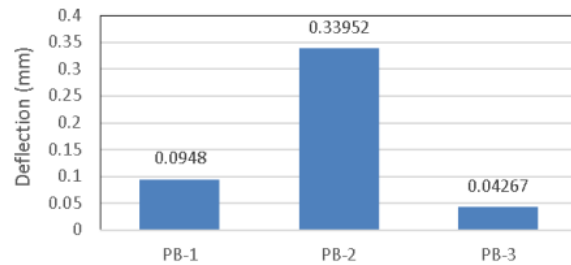


FIGURE 8 The deflection using navier method.

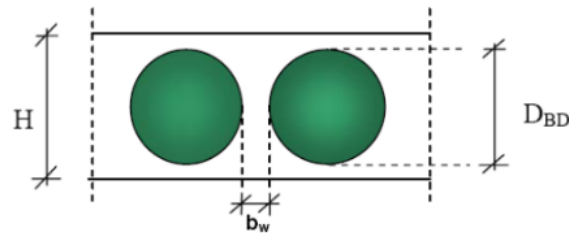


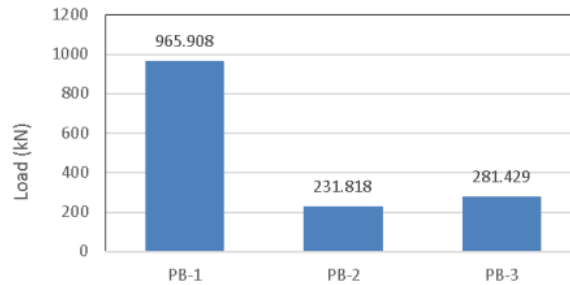
FIGURE 9 The shear cross section in hollow core slab.

high impact plates increases the maximum capacity load. Second, the deflection whenever the initial crack in the middle span amid massive reinforced concrete slab of 0.0948 mm was lower than the deflection of the hollow reinforced concrete slab 14 cm of 0.33952, but higher than hollow reinforced concrete slab 15.9 cm of 0.04267 mm. Third, massive reinforced concrete slab capable of holding a larger shear strength of 965.908 kN compared to hollow reinforced concrete slab 14 cm of 231.818 kN and hollow reinforced concrete slab 15.9 cm of 281.429 kN. This shows that the hollow reinforced concrete slab prone to cracking shear.

Given the result, there are two research directions that can be pursued. First, researchers need to analyze variation of concrete volume cavity. Thus, researchers need to obtain hollow concrete slab with self-weight optimum again the planned load. Second, researchers need to study the influence of the strength of PVC pipe on the power structure of the plate.

TABLE 7 The shear forces analysis.

Plate	Effective Plate Thickness (mm)	Long Analysis (mm)	Wide Analysis (mm)	Shear Foces (kN)	Percentage (%)
PB-1	112.39	2487.61	1237.61	965.908	100
PB-2	112.39	2487.61	1237.61	231.818	24.002
PB-3	131.39	2487.61	1237.61	281.429	29.139

**FIGURE 10** The shear forces of the plate.

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