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Assessing the Impact of PVC Pipe Diameter on Compressive Strength and Cracking in Hollow Prism Concrete

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Abstract – In order to enhance the utilization of concrete, it is necessary to explore the impact of PVC pipes incorporated into hollow prism concrete, focusing on their effects on compressive strength and cracking. PVC pipes are commonly employed as reinforcements within concrete structures to bolster their stability. This research delves into the consequences of varying pipe diameters and PVC pipes within hollow prism concrete. The experimental process entails utilizing concrete prisms with 100 x 100 x 300 mm³ dimensions, possessing a compressive strength of fc' 25 MPa. Research outcomes reveal that pipe diameter directly influences compressive strength, where larger diameters are associated with reduced compressive strength. Including pipes in the concrete does not yield a substantial discrepancy in compressive strength. Concrete prisms with incorporated pipes exhibit a Columnar-type collapse, indicative of dominant compressive stress, whereas prisms without pipes undergo a Shear-type collapse, signifying a shift in stress distribution. It emphasizes the pivotal role of reinforcements like PVC pipes in upholding the structural integrity of concrete, thereby mitigating potential damage.

Keywords: Hollow Prism Concrete, Compressive Strength, PVC Pipe, Collapse

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1. Introduction

Columns are one of the most important structural elements in building construction. Column strength greatly determines the stability and safety of the building, so careful research is needed in terms of column design [1]. One aspect that affects the strength of the column is the presence of pipes embedded in the column structure. Pipes planted in columns are made with the aim of being an aesthetic form of a building, as well as for rainwater drainage or electrical installations.

(National Standardization Agency, 2013) states that pipelines, together with their hooks, which are installed in columns should not occupy more than 4% of the cross-sectional area [2], [3], [4], [5]. Any type of casing that does not harm the concrete or reinforcement can be placed in the concrete, but the work must be done properly so that the structure is not damaged (National Standardization Agency, 2019) [6], [7], [8]. The thickness of the concrete cover for pipes installed with fittings must be at least 40 mm for concrete exposed to weather and at least 20 mm for concrete not exposed to weather or soil contact (National Standardization Agency, 2019) [9], [10], [11]. However, in practice, it is common to find columns with pipe openings that exceed 4% of the cross-sectional area [12]. The presence of pipe holes in the column can affect the strength of the column structure [13], [14], [15], [16], [17]. Therefore, it is necessary to conduct research to determine the effect of holes on the compressive strength of column structures [18], [19], [20], [21].

This research was conducted with the aim of analyzing the effect of holes with variations in pipe diameter on the compressive strength of concrete columns. By using a reinforced concrete simulation using a rectangular prism model with a size of 10 x 10 x 30 cm3 using a concrete quality of F'c 25 MPa.

This research is expected to contribute to the development of civil engineering science, especially in the design and analysis of column structures. In addition, the results of this study can provide useful information for practitioners in industrial construction, especially in the process of planning and constructing buildings with perforated columns.

2. Purpose

2.1. Identification of Compressive Strength

The objective is to compare the compressive strength of hollow prism concrete models containing embedded PVC pipes with those without embedded PVC pipes, using varying diameters of PVC pipes.

2.2. Analyzing the Influence of PVC Pipes on Compressive Strength

Analyzing the comparative results of compressive

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strength in hollow prism concrete models with embedded PVC pipes, compared to those without embedded PVC pipes, using varying diameters of PVC pipes.

2.3. Analysis of Cracking Types in Hollow Prism Concrete

It is analyzing the types of failure that occur in hollow prism concrete models with embedded PVC pipes compared to those without embedded PVC pipes, using varying diameters of PVC pipes.

3. Research Method

This study employs hollow prism concrete samples, featuring varying diameters of PVC pipes: ½ inch, 1 inch, 1 ¼ inch, and 1 ½ inch. The concrete specimens are treated by covering them with burlap sacks and maintaining moisture by periodically sprinkling water, simulating column maintenance [22]. Compressive strength tests are conducted using a Digital Compression Machine following the concrete fabrication and treatment processes [23]. The tests are performed on the hollow prism concrete specimens with pipes embedded within the concrete and those without pipes, employing different PVC pipe diameters. The data obtained from the compressive strength tests will be recorded and analyzed. Furthermore, visual observations are made on the condition of the pipes and the prism concrete after testing. The test results will be subjected to descriptive analysis, and graphs will be utilized to visualize the relationship between the pipe diameter and the compressive strength of the hollow prism concrete.

For the concrete compressive strength testing, the concrete prism specimens with dimensions of 100 mm x 100 mm and a height of 300 mm are subjected to a load P until failure occurs. However, hollow and solid prism specimens are used for this current research. Due to the applied load P, compressive stress is induced in the concrete equal to P divided by the cross-sectional area of the concrete (A), thus formulated as :

$$fc' = \frac{P}{A}$$

With :

fc' = Compressive Strength (MPa)

P = Force (N)

A = Area (mm^2)

However, in this study, the cross-sectional area (A) is reduced by the area of the pipe or radius, thus formulated:

$$fc' = \frac{P}{A - (\pi r^2)}$$

4. Result and Discussion

From the research results of hollow prism concrete specimens with dimensions of 100 mm x 100 mm x 300 mm, compared to hollow prism concrete specimens without pipes of the same size, variations were introduced by modifying the holes (voids) with diameters of ½ inch, 1 inch, 1 ¼ inch, and 1 ½ inch. In the compressive strength testing of hollow prism concrete specimens with pipes, for the ½ inch hole (void) variation, the average compressive strength values (A1, A2, A3) were 13.364 MPa. For the hollow prism concrete specimens without pipes (A4, A5, A6), with the ½-inch hole (void) variation, the average compressive strength value was 14.664 MPa. The difference in the average compressive strength values between (A1, A2, A3) and (A4, A5, A6) was 1.3 MPa, indicating higher average compressive strength values for (A4, A5, A6).

Testing of prism concrete with varying pipe hole (void) sizes of 1 inch resulted in an average compressive strength value of 11.403 MPa (C1, C2, C3). Testing for variations (C4, C5, C6) with 1-inch pipe holes (voids) yielded an average compressive strength value of 11.331 MPa. The difference in average compressive strength values between (C1, C2, C3) and (C4, C5, C6) was 0.072 MPa, indicating higher average compressive strength values for test specimens (C1, C2, C3).

Testing of prism concrete with varying pipe hole (void) sizes of 1 ¼ inch resulted in an average compressive strength value of 10.710 MPa, showing a decrease of 0.693 MPa compared to the average compressive strength value of (C1, C2, C3). Testing for variations (D4, D5, D6) with 1 ¼ inch pipe holes (voids) yielded an average compressive strength value of 10.621 MPa, indicating a decrease of 0.710 MPa when compared to the average compressive strength value of (C4, C5, C6). The difference in average compressive strength values between (D1, D2, D3) and (D4, D5, D6) was 0.089 MPa, with higher average compressive strength values for test specimens (D1, D2, D3).

Testing of prism concrete with varying pipe hole (void) sizes of 1 ½ inch resulted in an average compressive strength value of 10.869 MPa, representing an increase of 0.159 MPa compared to the average compressive strength value of (D1, D2, D3). Testing for variations (E4, E5, E6) with 1 ½ inch pipe holes (voids) yielded an average compressive strength value of 10.763 MPa, indicating an increase of 0.142 MPa when compared to the average compressive strength value of (D4, D5, D6). Compared to the average compressive strength value of (E1, E2, E3), test specimens (E4, E5, E6) exhibited a lower difference of 0.106 MPa. The results of testing on hollow prism concrete with and without pipes can be seen in Table 1 and Table 2

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Table 1
Compressive Strength of Hollow Prism Concrete with Pipes

Code	Ø Pipe (inch)	Ø Pipe (mm)	*fc'* (MPa)	Average *fc'* (MPa)
A1	1/2"	22	10,208	13,364
A2		22	15,561	
A3		22	14,324	
C1	1"	32	8,710	11,403
C2		32	11,353	
C3		32	14,147	
D1	1 1/4	42	9,564	10,710
D2		42	8,520	
D3		42	14,045	
E1	1 1/2"	48	11,768	10,869
E2		48	10,633	
E3		48	10,206	

Table 2
Compressive Strength of Hollow Prism Concrete without Pipes

Code	Ø Pipe (inch)	Ø Pipe (mm)	*fc'* (MPa)	Average *fc'* (MPa)
A4	1/2"	22	15,613	14,664
A5		22	14,054	
A6		22	14,324	
C4	1"	32	10,135	11,331
C5		32	12,810	
C6		32	11,048	
D4	1 1/4	42	8,740	10,621
D5		42	5,850	
D6		42	17,272	
E4	1 1/2"	48	11,659	10,763
E5		48	11,146	
E6		48	9,486	

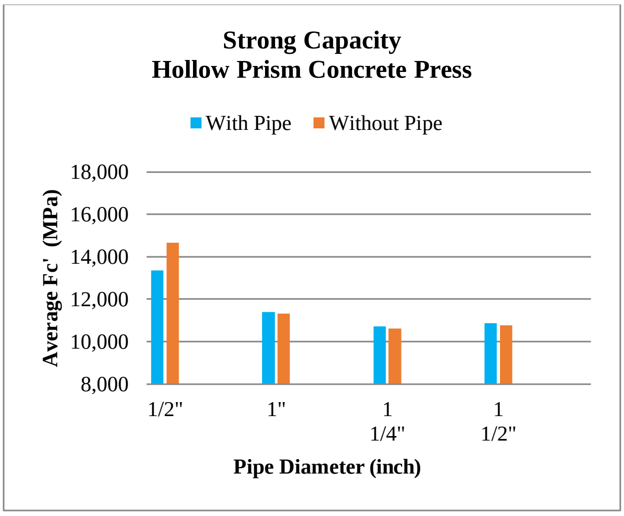

Figure 1. Graph of Comparison of Hollow Prism Concrete Compressive Strength

The graph above illustrates that in hollow prism concrete with pipes, the highest average compressive strength value is obtained with a ½ inch hole (void) variation at 13.364 MPa, and in hollow prism concrete without pipes, the highest average compressive strength value is also obtained with a ½ inch hole (void) variation at 14.664 MPa. When comparing both, the highest average compressive strength value is achieved in hollow prism concrete without pipes with a ½ inch hole (void) variation. According to the author's observations, this phenomenon can be attributed to the acceleration of damage in hollow prism concrete with pipes using the ½-inch hole (void) variation due to the presence of the embedded pipe during the compressive strength testing. On the other hand, the hollow prism concrete without pipes does not experience this acceleration of damage, as no pipes are embedded within. It is substantiated by the author's tests on the compressive force of each pipe with diameters of ½ inch, 1 inch, 1 ¼ inch, and 1 ½ inch. The compressive force values for the pipes are presented in Table 3 and displayed in graphical form in Figure 2.

Table 3
Pipe Compressive Strength Capacity Test Results

Brand	Ø Pipe (inch)	Area (mm^2)	Force (kN)	*fc'* (MPa)
Trilliun Basics	1/2"	96,555	1,300	13,464
	1"	188,400	8,400	44,586
	3/4"	136,778	9,400	68,724
	1 1/4"	286,713	10,200	35,576
	1 1/2"	330,045	14,000	42,418

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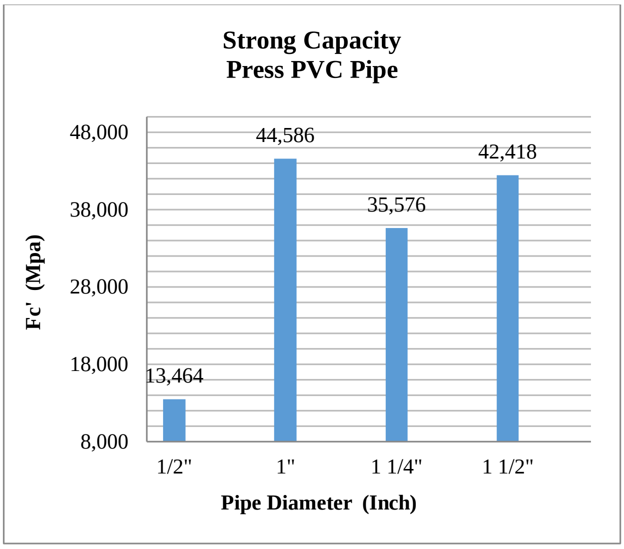

Figure 2. Graph of PVC Pipe Compressive Strength

The following is documentation of PVC pipe testing of ½ inch, 1 inch, 1 ¼ inch and 1 ½ inch diameters:

Figure 3. ½ Inch Diameter PVC Pipe Test Results

Figure 4. 1 Inch Diameter PVC Pipe Test Results

Figure 5. 1 ¼ Inch Diameter PVC Pipe Test Results

Figure 6. Test Results For PVC Pipe Diameter 1 ½ Inch

Based on the data and results of the pipe compressive force testing, in the 1/2 inch pipe diameter variation (Figure 3), the pipe experienced deformation due to the compressive force from the Digital Compression Machine. The pipe underwent deformation or bending, affecting the compressive strength of the hollow prism concrete with pipes in the 1/2-inch hole (void) variation. It led to a lower compressive strength value for the hollow prism concrete with pipes in the 1/2 inch hole (void) variation than that without pipes in the same hole (void).

On the other hand, the hollow prism concrete with pipes also experienced increased compressive force due to the pipes embedded within the concrete. The hollow prism concrete with pipes with a pipe diameter of 1/2 inch received an additional compressive force of 1.300 kN. For a diameter of 1 inch, the additional force was 8.400 kN, for a diameter of 1 ¼ inch, it was 10.200 kN, and for the hollow prism concrete with pipes in the 1 ½ inch hole (void) variation, the additional compressive force was

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14.000 kN. It caused the hollow prism concrete with pipes to have higher average compressive strength values than those without pipes, except for the 1/2-inch hole (void) variation. According to (SNI 1974: 2011, 2011), concrete cracks can be classified into 5 types, as shown in Figure 7 below:

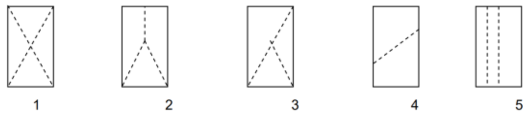

Figure 7. Concrete Crack Pattern (SNI 1974 : 2011, 2011)

Note :

1. Cone
2. Cone and Split
3. Cone and Shear
4. Shear
5. Columnar

Below are the crack patterns that occur in hollow prism concrete after the compressive strength.

Figure 8. Prism Concrete With ½ Inch Hole Variation Pipe
Columnar Crack Type

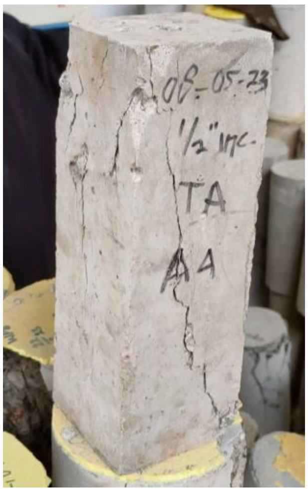

Figure 9. Prism Concrete Without Pipe ½ inch Hole Variation Columnar Crack Type

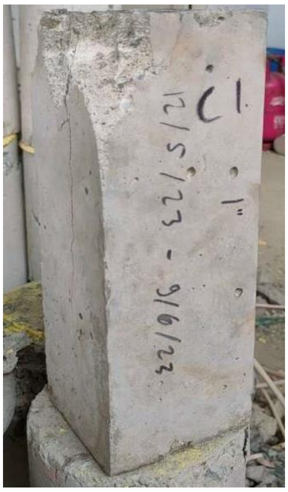

Figure 10. Prism Concrete With 1 inch Hole Variation Pipe Columnar Crack Type

Figure 11. Prism Concrete Without Pipe 1 inch Hole Variation Shear Crack Type

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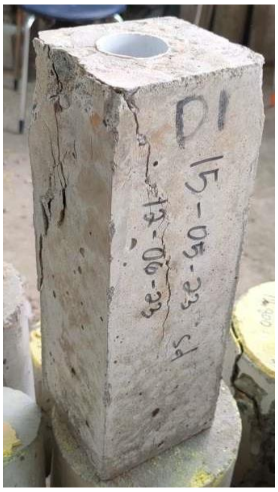

Figure 12. Prism Concrete With 1 ¼ inch Hole Variation Pipe
Columnar Crack Type

Figure 13. Prism Concrete Without Pipe Hole Variation 1 ¼ inch Shear Crack Type

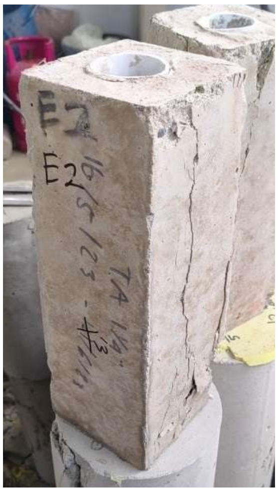

Figure 14. Prism Concrete With 1 ½ inch Hole Variation Pipe
Columnar Crack Type

Figure 15. Prism Concrete Without Pipe 1 ½ inch Hole Variation
Shear Crack Type

Based on the results of the above testing, it can be observed that hollow prism concrete with pipes experienced Columnar type failure. It is indicates conformity with concrete theory, where the dominant stress on concrete is compressive stress.

Meanwhile, in the case of hollow prism concrete without pipes, it experienced a shear-type failure pattern. A different scenario unfolds with hollow prism concrete without pipes, where the stress distribution within the concrete changes, shifting from the dominance of compressive stress to shear stress. This highlights the potential vulnerability of concrete lacking reinforcing structures like PVC pipes. The shear-type failure in hollow prism concrete without pipes also signifies a reduction in the minimal stiffness of pipeless hollow concrete.

The greater compressive strength of the pipes compared to the concrete (2.6 times) helps maintain the compressive failure of the concrete. However, the contribution of pipe compressive strength to the concrete does not significantly enhance the compressive strength of the concrete with pipes.

Furthermore, in testing hollow prism concrete with ½ inch hole (void) variation (A1), the pipes within the concrete lose their adhesive strength after the compressive strength testing. It is evident in Figure 16, where gaps between the concrete and the pipes are visible. It calls for further research on the adhesive strength of the pipes to the concrete.

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Figure 16. Results of Zoom in Concrete Test Object Prism A1

5. Conclusions

Based on the research conducted on concrete prism with pipes, concrete prism without pipes with dimensions of 100 mm x 100 mm x 300 mm, and solid concrete cubes, the following conclusions can be drawn:

5.1. *Influence of pipe diameter*

In the ½-inch hole (void) variation, both the hollow prism concrete with pipes and the hollow prism concrete without pipes yield the highest average compressive strength values compared to the variations with hole (void) sizes of 1-inch, 1 ¼ inch, and 1 ½ inch. This indicates that increasing the hole size (void) in both the hollow prism concrete with and without pipes significantly decreases the average compressive strength values. The larger the hole diameter, the lower the compressive strength values generated.

5.2. *Correlation of compressive strength and pipe diameter*

Based on the results and discussions, pipes embedded within the concrete also influence the compressive strength values by adding compressive force to the concrete. The magnitude of this compressive force varies depending on the pipe diameter. The larger the pipe diameter, the greater the compressive force generated. Overall, hollow prism concrete with embedded pipes yields a higher compressive strength capacity than hollow prism concrete without pipes.

In general, the ratio between the two is not significantly substantial. It suggests that the presence or absence of pipes embedded within the concrete doesn't greatly affect the compressive strength of both test specimens.

5.3. *Crack Pattern*

Based on the above testing results, it can be concluded that hollow prism concrete with pipes generally experiences Columnar type failure, indicating the dominance of compressive stress in the concrete. Conversely, hollow prism concrete without pipes undergoes shear-type failure, signifying a shift in stress distribution from compressive stress to shear stress. This indicates that hollow prism concrete without pipes has a higher potential for damage due to the absence of reinforcing structures like PVC pipes. The shear-type failure in hollow prism concrete without pipes also indicates a reduction in the minimal stiffness of pipeless hollow concrete.

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