Behavior of Concrete Columns Using High-Performance Concrete Mixed with Steel Fibers in Prefabricated Steel Tubes as Reinforcement

Piyaphol Srihabutra [1], Sittisak Ansanan [2], Peng Ying [3] and Raungrut Cheerarot [4,*]

[1, 2, 4] Department of Civil Engineering, Mahasarakham University, Khamriang, Kantarawichai, Mahasarakham 44150, Thailand

[3] Department of Civil Engineering, Putian University, Putian Fujian 351100, China

*Corresponding Email : raungrut.c@msu.ac.th

Abstract. *This study investigated the behavior of reinforced concrete columns using high-performance concrete (HPC) filled in prefabricated steel tubes to serve as reinforcement. The experimental setup involved HPC with a compressive strength of 1,515 kg/cm², filled into steel tubes with diameters of ¾, 1, and 1¼ inches, replacing the reinforcement in concrete columns sized 150x150x600 mm. The concrete used for casting the sample columns had a compressive strength of 257 kg/cm². The columns were tested for axial and eccentric loading at displacements of 20, 40, and 60 mm to determine the maximum compressive strength, bending moment, interaction diagrams, and failure patterns of the steel-reinforced concrete columns. The experimental results showed that the axial compressive strength of columns using HPC in steel tubes as reinforcement was higher than that of the control concrete columns. The compressive strength at various eccentricities showed a slight increase compared to the control columns. The comparison between experimental compressive strengths and bending moments with calculated values indicated a consistent trend. Furthermore, the failure patterns of the concrete columns revealed both compression and tension failures.*

Keywords:

high-performance concrete, prefabricated steel tubes, steel fibers, reinforced concrete columns

1. Introduction

Reinforced concrete (RC) structures have been widely used and continuously developed for centuries to enhance their limits and performance, adapting to evolving construction designs and technologies. In recent decades, concrete has been improved by incorporating various materials, including pozzolanic substances and fibers [1]. The integration of glass fibers in reinforced concrete has emerged as an alternative for corrosion-resistant structures [2]. Additionally, high-performance concrete (HPC) has gained popularity in construction due to its strength, durability, and resistance to external deterioration [3].

Extensive and ongoing research, such as that conducted by Abbas et al. [4], has explored the use of steel fibers in high-performance concrete in various proportions. Yu et al. [5] investigated the mixture design and properties assessment of fiber-reinforced high-performance concrete, while Yoo et al. [6] examined the effects of fiber quantity on the mechanical properties and fracture behavior of fiber-reinforced cementitious composites. Steel fibers have become a favored additive in high-performance concrete, significantly enhancing its properties based on multiple studies [7-9]. These enhancements include increased compressive and tensile strength, reduced cracking, and improved flexural strength [10].

Concrete columns, a critical component of building structures, have seen significant advancements in their quality and performance over recent years. Research efforts like those by AlAjarmeh et al. [11] utilized GFRP bars and helical wraps in hollow concrete columns to study their compressive behavior. Additionally, exploring alternative materials to steel reinforcement in concrete columns has become a focus. For instance, Ahmed et al. [12] investigated the behavior of concrete-filled fiber-reinforced polymer (FRP) tube (CFFT) columns reinforced with FRP bars of carbon and glass under axial compression. Hosinieh et al. [13] studied the axial load-bearing performance of ultra-high-performance fiber-reinforced concrete (UHPFRC) columns, and Elchalakani and Ma [14] examined the use of glass fiber-reinforced polymer (GFRP) bars as reinforcement in columns under axial and eccentric loads. The popularity of glass and carbon fiber-reinforced polymers as a replacement for steel reinforcement has been growing [15-16]. Furthermore, the design of reinforced concrete columns has evolved, with Li et al. [17] exploring the numerical behavior of high-strength concrete-filled steel tubular columns under eccentric compression, and Wei et al. [18] investigating the behavior of ultra-high-performance concrete (UHPC) columns reinforced with circular steel tubes under axial compression. Patel et al. [19] experimented with short columns filled with concrete in circular stainless steel tubes for axial load-bearing, and Fanggi and Ozbakkaloglu [20] studied short fiber-

reinforced polymer (FRP) columns combined with short steel columns filled with concrete for axial load-bearing, offering another alternative to steel-reinforced concrete columns. These studies indicate an ongoing exploration of using different tubes filled with concrete as reinforcement in concrete columns to reduce the use of steel reinforcement. Hence, this research employed high-performance concrete mixed with steel fibers in prefabricated steel tubes as reinforcement to study the behavior of concrete columns under axial and eccentric loads.

2. Materials and Methods

2.1 Materials Used in the Research and Concrete Mixture

The normal concrete mixture consists of Portland cement type I, river sand with a fineness modulus (FM) of 2.76, coarse aggregate with a maximum size of ¾ inch, and clean water. The mix is designed for a compressive strength of 240 kg/cm² at 28 days and a slump value of 10 ± 2 cm. The mixture for high-performance concrete (HPC) with steel fibers includes Portland cement type I, micro silica (940U), river sand, superplasticizer, water-reducing, and set-retarding admixture (Type F), Hook end steel fibers according to UNI EN 10016 with a diameter of 0.50 mm and a length of 30 mm, and clean water. This mixture is designed for a compressive strength of 1,500 kg/cm² at 28 days and a flow table spread of 55 cm. The quantities of materials and mix proportions are shown in Table 1. For the

reinforcement of the concrete columns, DB12 (SD 40) steel was used, along with prefabricated steel tubes for encasing the high-performance concrete mixed with steel fibers, with diameters of ¾, 1, and 1¼ inches and a thickness of 1.20 mm. RB6 (SR 24) was used for stirrups.

From the compressive strength tests, the standard concrete exhibited a compressive strength of 257 kg/cm² and a slump of 11.50 cm. The high-performance concrete mixed with steel fibers showed a compressive strength of 1,515 kg/cm² and a slump flow of 58.50 cm.

2.2 Concrete Column Testing

High-performance concrete mixed with steel fibers was filled into prefabricated steel tubes of diameters ¾, 1, and 1¼ inches to prepare the high-performance concrete. Subsequently, concrete columns of dimensions 150x150x600 mm were cast, reinforced with 4DB12 steel bars and RB6 stirrups at 0.15 m intervals, serving as control concrete columns and columns reinforced with prefabricated steel tubes filled with high-performance concrete across all three sizes. The preparation for filling the high-performance concrete into the prefabricated steel tubes is illustrated in Figures 1(a) and 1(b). After 24 hours, the specimens were cured using plastic until they reached 28 days of age.

Subsequently, the specimens were tested for compressive strength using a universal testing machine (UTM), applying axial force and eccentricities of 20, 40, and 60 mm, as illustrated in Figure 2.

Table 1 Mix Proportions for Normal and High-Performance Concrete

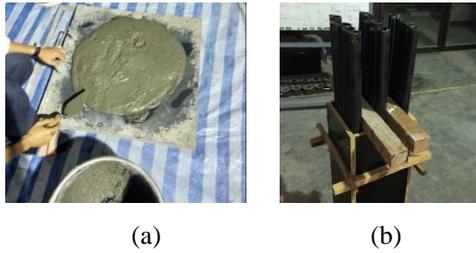| List	Normal Concrete (kg/m³)	High-Performance Concrete (kg/m³)
Portland Cement Type I	285	862
Micro Silica (Silica Fume) Type 940 U	-	100
Sand with graded size distribution according to ASTM C 136, FM 2.76	840	1168
Coarse Aggregate with a maximum size of ¾ inch according to ASTM C 33-85	1120	-
Water	205	215
Superplasticizer and Water-Reducing and Set-Retarding Admixture Type F according to ASTM C 494	-	33.33
Hook End Steel Fibers according to UNI EN 10016 with a diameter of 0.50 mm and a length of 30 mm	-	45.33

Fig. 1 Filling of High-Performance Concrete into Prefabricated Steel Tubes.

Fig. 2 Testing of Concrete Columns.

2.3 Theory of Design for Reinforced Concrete Columns

Normal concrete columns, when subjected to axial loads, exhibit behavior as shown in Figure 3(a) and are described by Equation (1). When the conventional reinforcement is replaced with prefabricated steel tubes filled with high-performance concrete, the behavior of the concrete columns changes, as depicted in Figure 3(b) and described by Equation (2).
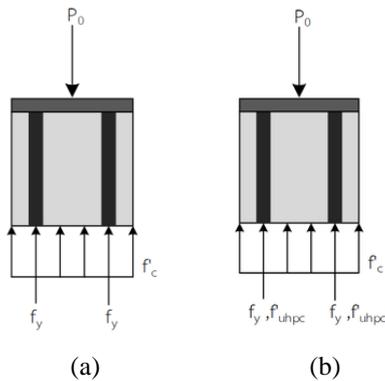
Fig. 3 Behavior and Force Components in the Axial Direction of Standard Concrete Columns and Concrete Columns Reinforced with Prefabricated Steel Tubes Filled with High-Performance Concrete.

$$P_n = 0.85f'_c (A_g - A_{st}) + f_y A_{st} \qquad (1)$$

$$P_n = 0.85f'_c (A_g - A_{pipe}) + f_y A_{pipe} + f'_{uhpc} A_{uhpc} \qquad (2)$$

Where P_n represents the nominal strength in axial compression of the concrete column cross-section, f'_c is the compressive strength of concrete, f'_{uhpc} is the compressive strength of high-performance concrete, A_g is the total

cross-sectional area, A_{st} is the cross-sectional area of the reinforcement, A_{pipe} is the cross-sectional area of the steel tube, and A_{uhpc} is the cross-sectional area of the high-performance concrete filled in the steel tube, f_y denotes the yield strength of the reinforcement.

When forces are applied at different eccentricities, the behavior of standard concrete columns is as depicted in Figure 4 and described by Equation (3). Meanwhile, the conventional reinforcement is replaced with prefabricated steel tubes filled with high-performance concrete. The behavior of the concrete columns is shown in Figure 5 and described by Equation (4).

$$P_n = 0.85f'_c\, ab + A'_s\, f'_s - A_s f_s \qquad (3)$$

$$P_n = 0.85f'_c\, (ab - (A_{pipe} + A_{uhpc})) + A'_s\, f'_s + A'_{uhpc}\, f'_{uhpc} - A_s f_s \qquad (4)$$
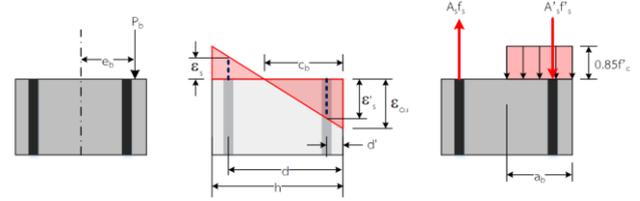

Fig. 4 Behavior and Force Components with Eccentricity from the Axis.
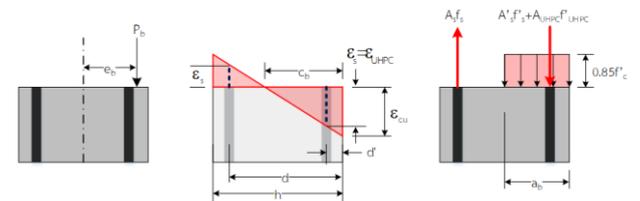

Fig. 5 Behavior and Force Components with Eccentricity from the Axis of Concrete Columns Reinforced with Prefabricated Steel Tubes Filled with High-Performance Concrete.

3. Results and Discussions

3.1 Axial Load-Bearing Capacity and Eccentric Loading

From the experimental results presented in Table 2, it was found that the axial compressive strength of the control concrete columns (CC) (e=0) was 51,086 kg. When conventional reinforcement was replaced with prefabricated steel tubes filled with high-performance concrete, the axial compressive strength of the concrete columns was found to be 52,977, 61,264, and 74,794 kg for steel tube sizes of ¾, 1, and 1¼ inches, respectively, which are higher than that of the control concrete columns (CC). This is due to the fact that the cross-sectional area of the reinforcement in the control concrete columns is less than the cross-sectional area of the steel tubes filled with high-performance concrete, resulting in the strength of the

reinforcement in the control concrete columns ($f_y A_{st}$) being less than the strength generated by the steel tubes and high-performance concrete ($f_y A_{pipe} + f'_{uhpc} A_{uhpc}$), as demonstrated in Equations (1) and (2) and Figure 3. These equations calculate the nominal compressive strength of the control concrete columns and the columns reinforced with prefabricated steel tubes filled with high-performance concrete, respectively.

It is evident that due to the cross-sectional area and the compressive strength of the high-performance concrete, substituting these values into Equation (2) results in a calculated axial load-bearing capacity that is higher. This finding is consistent with the experimental results presented in Table 2.

When the eccentricity from the axis is increased, it was observed that the axial compressive strength of the control concrete columns (CC) decreases with the increase in eccentricity, with values of 42,131, 31,038, and 22,976 kg at eccentricities of 20, 40, and 60 mm (e=20, 40, 60 mm) respectively. When replaced with prefabricated steel tubes filled with high-performance concrete, according to the calculation formula for axial compressive strength of concrete columns as Equation (3), it becomes Equation (4). The behavior and force components that occur are depicted in Figure 5.

The concrete columns reinforced with prefabricated steel tubes filled with high-performance concrete of ¾ inch diameter (PUHPC3/4) showed a decrease in compressive strength as the eccentricity from the axis increased, with values of 47,274, 33,213, and 19,029 kg at eccentricities of 20, 40, and 60 mm (e=20, 40, 60 mm), respectively. For diameters of 1 inch and 1¼ inches (PUHPC1 and PUHPC1(1/4)), the values were 48,826, 35,987, and 25,236 kg for PUHPC1, and 49,150, 38,328, and 27,177 kg for PUHPC1(1/4) at eccentricities of 20, 40, and 60 mm (e=20, 40, 60 mm), respectively. These findings are consistent with Equation (4), as shown in Table 2 and Figure 6.
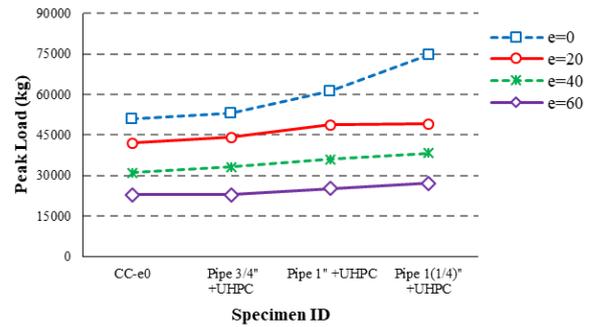

Fig. 6 Axial and Eccentric Load-Bearing Capacity of Concrete Columns.

Table 2 Test Results of Reinforced Concrete Columns at Various Eccentricities

Specimen ID	Longitudinal	Eccentricity (mm)	e/h	Peak load Calculate (kg)	Peak load Experiment (kg)	Moment Calculate (kg-m)	Moment Experiment (kg-m)
CC-e0	4-DB12	0	0	65,095	51,086	0.00	0.00
CC-e20	4-DB12	20	0.13	45,133	42,131	904	842
CC-e40	4-DB12	40	0.27	30,221	31,037	1,209	1,241
CC-e60	4-DB12	60	0.40	21,019	22,976	1,261	1,378
PUHPC3/4-e0	4-Pipe 3/4"+UHPC	0	0	78,539	52,977	0.00	0.00
PUHPC3/4-e20	4-Pipe 3/4"+UHPC	20	0.13	45,735	47,273	888	945
PUHPC3/4-e40	4-Pipe 3/4"+UHPC	40	0.27	28,374	33,212	1,112	1,328
PUHPC3/4-e60	4-Pipe 3/4"+UHPC	60	0.40	17,275	23,029	1,031	1,141
PUHPC1-e0	4-Pipe 1"+UHPC	0	0	93,705	61,263	0.00	0.00
PUHPC1-e20	4-Pipe 1"+UHPC	20	0.13	48,118	48,826	924	776
PUHPC1-e40	4-Pipe 1"+UHPC	40	0.27	27,334	35,987	1,069	1,279
PUHPC1-e60	4-Pipe 1"+UHPC	60	0.40	17,374	25,236	1,037	1,154
PUHPC1(1/4)-e0	4-Pipe 1(1/4)"+UHPC	0	0	117,639	74,793	0.00	0.00
PUHPC1(1/4)-e20	4-Pipe 1(1/4)"+UHPC	20	0.13	48,678	49,149	924	982
PUHPC1(1/4)-e40	4-Pipe 1(1/4)"+UHPC	40	0.27	25,390	38,328	994	1,253
PUHPC1(1/4)-e60	4-Pipe 1(1/4)"+UHPC	60	0.40	16,457	27,176	974	1,270

Replacing conventional reinforcement with prefabricated steel tubes filled with high-performance concrete results in an increased compressive strength of concrete columns compared to control concrete columns under axial loads. This is due to the higher compressive strength of high-performance concrete (f'_{uhpc}), which slightly increases when subjected to eccentric loads. When comparing the compressive strength of concrete columns calculated from Equations (2) and (4), it is found that the values and trends are consistent, as depicted in Figure 7.
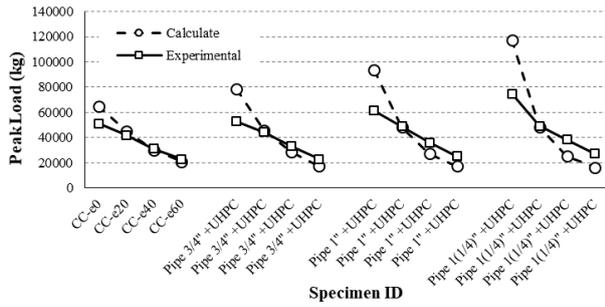
Fig. 7 Maximum Compressive Strength at Different Eccentricities of Concrete Columns.

3.2 Bending Moment in Reinforced Concrete Columns

When a compressive force is applied at eccentricities of 20, 40, and 60 mm (e=20, 40, 60 mm) from the axis, and from the equation ($M_n=P_ne$), a bending moment is generated. In Table 2, the bending moment of control concrete columns (CC) at an eccentricity of 20 mm (e=20) is 843 kg-m, at (e=40) it is 1,242 kg-m, and at (e=60) it is 1,379 kg-m. Concrete columns reinforced with prefabricated steel tubes filled with high-performance concrete show a bending moment trend in the same direction as the load-bearing capacity of the concrete columns, with values exceeding those of the control concrete columns (CC), as depicted in Figure 8.
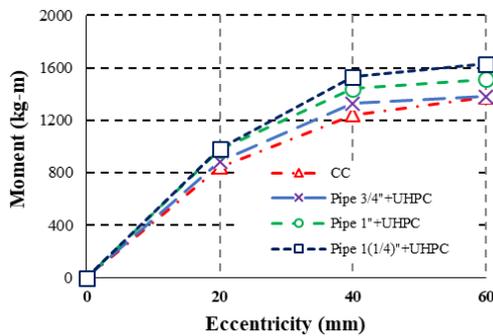

Fig. 8 Bending Moments of Reinforced Concrete Columns with Various Sizes of Prefabricated Steel Tubes.

3.3 Interaction Diagram and Failure Patterns of Reinforced Concrete Columns

The equilibrium eccentricity (e_b) indicates the condition of column failure. When e<e_b leads to a situation where compression failure occurs, while for values of e>e_b indicating tension failure. The calculation of e_b is according to Equation (5).

$$e_b = \frac{M_{nb}}{P_{nb}} \qquad (5)$$

Where P_b represents the sum of vertical forces generated by the concrete and reinforcement, which is calculated as Equation (6), and M_b is the equilibrium moment about the centroid of the column cross-section, calculated as Equation (7).

$$P_{nb} = C_c + C_s - T \qquad (6)$$

$$M_{nb} = C_c\left(\frac{h}{2}-\frac{a}{2}\right) + C_s\left(\frac{h}{2}-d'\right) - T\left(d-\frac{h}{2}\right) \qquad (7)$$

It was found that the equilibrium condition for column failure occurs at e_b=89.0 mm. When the eccentricity is increased to 20, 40, and 60 mm, the failure condition falls within the range of compression-controlled failures (e_b>e20-e60), as shown in Figures 9 and 10.
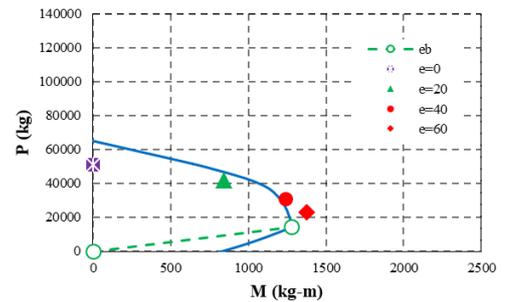

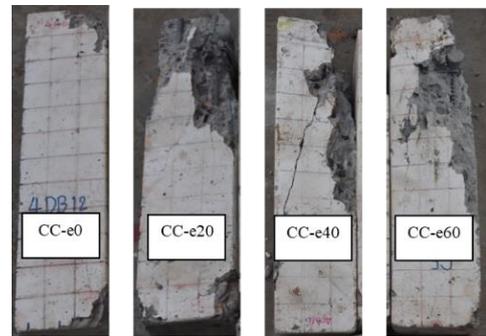**Fig. 9** Interaction Diagram of Control Reinforced Concrete Columns (CC).

Fig. 10 Failure Patterns of Control Reinforced Concrete Columns (CC).

When considering the interaction diagram (P_n-M_n) for concrete columns reinforced with prefabricated steel tubes filled with high-performance concrete, the values P_{nb} and M_{nb} must consider the combined forces generated by the prefabricated steel tubes and the high-performance concrete, as demonstrated in Equations (8) and (9), respectively.

$$P_{nb} = C_c + (C_s + C_{uhpc}) - T \qquad (8)$$

$$M_{nb} = C_c\left(\frac{h}{2} - \frac{a}{2}\right) + (C_s + C_{uhpc})\left(\frac{h}{2} - d'\right) - T\left(d - \frac{h}{2}\right) \quad (9)$$

For the concrete columns reinforced with prefabricated steel tubes filled with high-performance concrete of ¾ inch diameter (PUHPC3/4), it was found that the equilibrium condition for column failure is at e_b = 54.8 mm. At eccentricities of 20 and 40 mm, the failure condition falls within the range of compression-controlled failures (e_b>e20, e40), similar to control reinforced concrete columns. However, at an eccentricity of 60 mm, the failure occurs due to tension-controlled failures (e_b<e60), as shown in Figures 11 and 12.

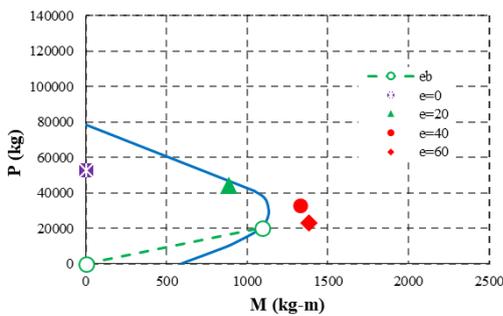**Fig. 11** Interaction Diagram of Concrete Columns Reinforced with Prefabricated Steel Tubes Filled with UHPC of ¾ Inch Diameter (PUHPC3/4).
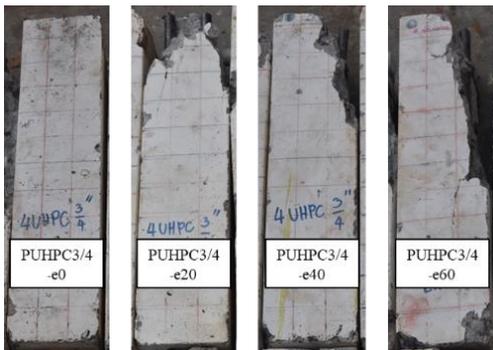

Fig. 12 Failure of Concrete Columns Reinforced with Prefabricated Steel Tubes Filled with UHPC of ¾ Inch Diameter (PUHPC3/4).

The interaction diagram (P_n-M_n) for concrete columns reinforced with steel tubes filled with high-performance concrete of 1-inch diameter (PUHPC1) shows that the equilibrium condition for column failure is at e_b= 58.5 mm. At eccentricities of 20 and 40 mm, the failure condition falls within the range of compression-controlled failures (e_b>e20, e40), indicating that the column fails predominantly due to compression. However, at an

eccentricity of 60 mm, the column exhibits tension-controlled failures (e_b<e60), indicating that the failure is predominantly due to tension, as shown in Figures 13 and 14.
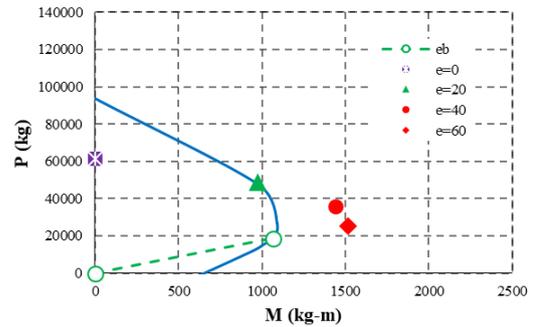

Fig. 13 Interaction Diagram of Concrete Columns Reinforced with Prefabricated Steel Tubes Filled with UHPC of 1 Inch Diameter (PUHPC1).
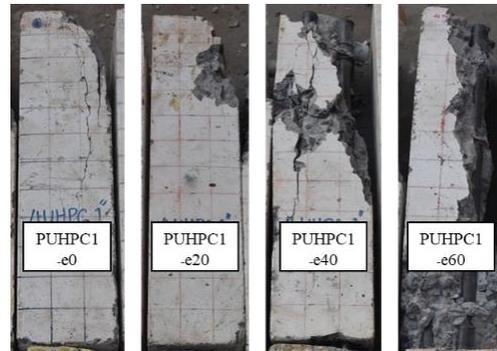

Fig. 14 Failure of Concrete Columns Reinforced with Prefabricated Steel Tubes Filled with UHPC of 1 Inch Diameter (PUHPC1).

The interaction diagram (P_n-M_n) for reinforced concrete columns with prefabricated steel tubes filled with high-performance concrete of 1¼ inches diameter (PUHPC1(1/4)) shows that the equilibrium condition for column failure is at e_b = 69.7 mm. When the eccentricity is increased to 20, 40, and 60 mm, the failure condition falls within the range of compression-controlled failures (e_b>e20-e60), indicating that the column fails predominantly due to compression across all tested eccentricities, as shown in Figures 15 and 16.
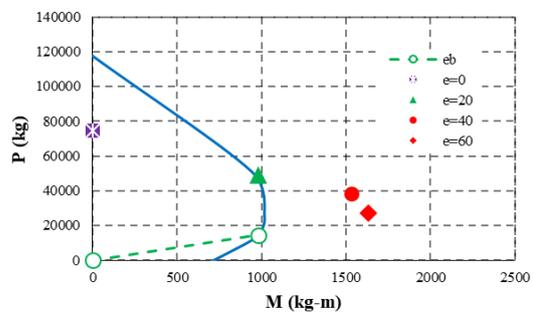

Fig. 15 Interaction Diagram of Concrete Columns Reinforced with Prefabricated Steel Tubes Filled with UHPC of 1¼ Inch Diameter (PUHPC1(1/4).
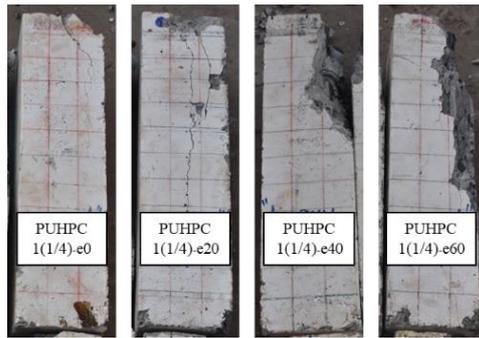
Fig. 16 Failure of Concrete Columns Reinforced with Prefabricated Steel Tubes Filled with UHPC of 1¼ Inch Diameter (PUHPC1(1/4)).

4. Conclusions

The experimental study on the behavior of reinforced concrete columns using high-performance concrete in prefabricated steel tubes as reinforcement can be summarized as follows:

1. The compressive strength of concrete columns from the experimental results shows a trend consistent with the calculated results.

2. The axial compressive strength of control concrete columns (CC-e0) was found to be 51,086 kg. As the eccentricity from the axis increased, the compressive strength decreased, with values of 42,131, 31,038, and 22,976 kg at eccentricities of 20, 40, and 60 mm (e=20, 40, 60) respectively. Replacing conventional reinforcement with prefabricated steel tubes filled with high-performance concrete showed an increase in compressive strength over the control concrete columns, with the PUHPC1(1/4)-e0 showing the highest axial compressive capacity at (e=0), amounting to 74,794 kg, and decreasing as the eccentricity increased.

3. The bending moment trends in the same direction as the load-bearing capacity of the concrete columns. Concrete columns reinforced with prefabricated steel tubes filled with high-performance concrete exhibited higher bending moments than control concrete columns (CC).

4. From the interaction diagram (P_n-M_n) for control reinforced concrete columns (CC), it was observed that the failure condition falls within the range of compression-controlled failures. When conventional reinforcement is replaced with prefabricated steel tubes filled with high-performance concrete of various sizes (PUHPC3/4, PUHPC1, and PUHPC1(1/4)), at eccentricities of 20 and 40 mm, the failure condition remains within the range of compression-controlled failures. At an eccentricity of 60 mm, the failure condition transitions to tension-controlled failures.

References

[1] V. Sata, "The Use of local pozzolan in fiber reinforced concrete," *Engineering and Applied Science Research*, vol. 37, no. 1, pp. 29-37, 2010.

[2] K. Chaimoon, "Concrete Reinforced with FRP Bars: Alternative for Noncorrosive Structures," *Engineering and Applied Science Research*, vol. 37, no. 3, pp. 237-245, 2010.

[3] B. A. Graybeal, "Behavior of ultra-high performance Concrete connections between precast bridge deck elements." *CBC*, 2010

[4] S. Abbas, A. M. Soliman, and M. L. Nehdi, "Exploring mechanical and durability properties of ultra-high performance concrete incorporating various steel fiber lengths and dosages," *Construction and Building Materials*, vol. 75, pp. 429-441, 2015.

[5] R. Yu, P. Spiesz, and H. Brouwers, "Mix design and properties assessment of ultra-high performance fibre reinforced concrete (UHPFRC)," *Cement and concrete research*, vol. 56, pp. 29-39, 2014.

[6] D.-Y. Yoo, J.-H. Lee, and Y.-S. Yoon, "Effect of fiber content on mechanical and fracture properties of ultra high performance fiber reinforced cementitious composites," *Composite structures*, vol. 106, pp. 742-753, 2013.

[7] R. Yu, P. Spiesz, and H. Brouwers, "Development of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC): Towards an efficient utilization of binders and fibres*," Construction and building materials*, vol. 79, pp. 273-282, 2015.

[8] D.-Y. Yoo, G. Zi, S.-T. Kang et al., "Biaxial flexural behavior of ultra-high-performance fiber-reinforced concrete with different fiber lengths and placement methods," *Cement and Concrete Composites*, vol. 63, pp. 51-66, 2015.

[9] M. Aldahdooh, N. M. Bunnori, and M. M. Johari, "Evaluation of ultra-high-performance-fiber reinforced concrete binder content using the response surface method," *Materials & Design* (1980-2015), vol. 52, pp. 957-965, 2013.

[10] A. Amin, S. J. Foster, and W. Kaufmann, "Instantaneous deflection calculation for steel fibre reinforced concrete one way members," *Engineering Structures*, vol. 131, pp. 438-445, 2017.

[11] O. AlAjarmeh, A. Manalo, B. Benmokrane et al., "Compressive behavior of axially loaded circular hollow concrete columns reinforced with GFRP bars and spirals," *Construction and Building Materials*, vol. 194, pp. 12-23, 2019.

[12] A. A. Ahmed, M. Hassan, H. Mohamed et al., "Axial behavior of circular CFFT long columns internally reinforced with steel or carbon and glass FRP longitudinal bars," *Engineering Structures*, vol. 155, pp. 267-278, 2018.

[13] M. M. Hosinieh, H. Aoude, W. D. Cook et al., "Behavior of ultra-high performance fiber reinforced concrete columns under pure axial loading," *Engineering Structures*, vol. 99, pp. 388-401, 2015.

[14] M. Elchalakani, and G. Ma, "Tests of glass fibre reinforced polymer rectangular concrete columns subjected to concentric and eccentric axial loading," *Engineering Structures*, vol. 151, pp. 93-104, 2017.

[15] H. A. Hasan, M. N. Sheikh, and M. N. Hadi, "Performance evaluation of high strength concrete and steel fibre high strength concrete columns reinforced with GFRP bars and helices," *Construction and Building Materials*, vol. 134, pp. 297-310, 2017.

[16] Q. S. Khan, M. N. Sheikh, and M. N. Hadi, "Concrete Filled Carbon FRP Tube (CFRP-CFFT) columns with and without CFRP reinforcing bars: Axial-flexural interactions," *Composites Part B: Engineering*, vol. 133, pp. 42-52, 2018.

[17] G. Li, B. Chen, Z. Yang et al., "Experimental and numerical behaviour of eccentrically loaded high strength concrete filled high strength square steel tube stub columns," *Thin-Walled Structures*, vol. 127, pp. 483-499, 2018.

[18] J. Wei, Z. Xie, W. Zhang et al., "Experimental study on circular steel tube-confined reinforced UHPC columns under axial loading," *Engineering Structures*, vol. 230, pp. 111599, 2021.

[19] V. I. Patel, M. Hassanein, H.-T. Thai et al., "Behaviour of axially loaded circular concrete-filled bimetallic stainless-carbon steel tubular short columns," *Engineering Structures*, vol. 147, pp. 583-597, 2017.

[20] B. A. L. Fanggi, and T. Ozbakkaloglu, "Square FRP–HSC–steel composite columns: Behavior under axial compression," *Engineering Structures*, vol. 92, pp. 156-171, 2015.