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Experimental Study of Two-way Half Slab Precast Concrete using Rextangular Rigid Connection

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Abstract

A half-slab precast concrete (HSPC) system with precast bottom layers and in-situ cast top layers has been widely applied in various constructions. It generally behaves as a one-way slab due to the absence of positive-flexural reinforcements in the perpendicular direction to the precast component. However, in some cases, the HSPC was also applied in a two-way slab system. Consequently, a particular design and treatment in the connection between precast members was required, so that the bending moment in two orthogonal directions could be accommodated. In the present study, an innovative rectangular rigid connection (RRC) in a two-way HSPC system was investigated through an experimental test. It was found that the RRC-HSPC presented only a 9.13% reduction of the load at the crack, a 16.44% reduction of the ultimate load, and a 6.06% increase of the deflection at the crack when compared to the monolithic one.

Introduction

Half slab precast concrete (HSPC) is a structural slab system that is constructed of two layers of concrete. The bottom layer is the precast half slab and the top layer is the in-situ concrete, as illustrated in Figure 1. The utilization of HSPC in various constructions is beneficial considering a significant reduction of the construction time, compared to the conventional in-situ cast concrete slab [1-4].

In general, the HSPC system is applied in a one-way slab, in which the length-to-width ratio is greater than 2. In such a case, the primary bending moment works in a parallel direction to the precast layer. Consequently, in a one-way slab, no special connection treatment is required in the connection between adjacent precast layers. In practice, a simple connection is generally implemented, as shown in Figure 2, as reported in the literature [5].

On the other hand, when the HSPC is used in the two-way slab, in which the length-to-width ratio is less than 2, the working bending moments are significant in the two orthogonal directions. Consequently, a special treatment should be applied in the connection between adjacent precast slabs in order to resist both bending moments. Otherwise, crack opening is likely to occur along the precast connections.

A sample case was reported in a port construction, as shown in Figure 3, where the HSPC was used in a two-way slab system. However, only a simple connection between adjacent precast slabs is used. As a result, cracks along the precast connection were observed at the bottom side, as presented in Figure 4. Such a case indicates that the simple connection between adjacent precast slabs barely resists the bending moment in a perpendicular direction to the connection. Therefore, the development of a suitable rigid connection between adjacent precast slabs is needed in the case of a two-way slab system.

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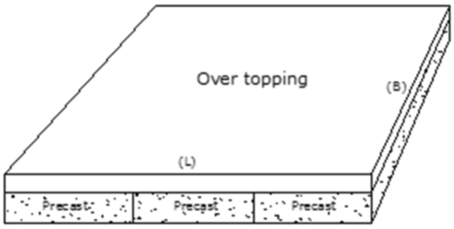

Figure 1. Half Slab Precast Concrete System

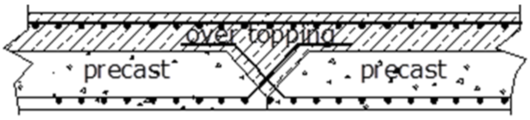

Figure 2. The Common Simple Connection Applied between the Precast Slab Concrete Components

Figure 3. The Implementation of Simple Connection in a Port Construction

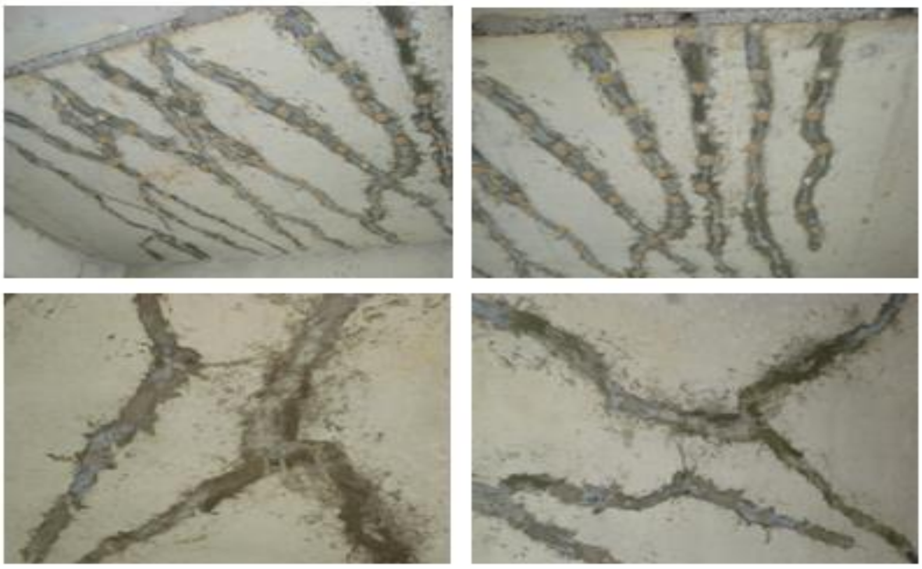

Figure 4. The Crack that Occurs at the Bottom Part of a Two-way Half Slab Precast

Investigations on the connection in HSPC have been conducted by many researchers. Hieber et al. [6] proposed an interlocking connection that can resist the shear load. Kim et al. [7] investigated the performance of prestressed precast concrete slabs using reinforcement connections in longitudinal directions. Kim et al. [8] also investigated the crack width of the HSPC system using looping connections. El-Sayed et al [9] evaluate the web shear design procedures for precast prestressed hollow core slabs. Sun et al [10] investigated the use of Ceramsite lightweight high-titanium heavy slag for slab joint improvement. It was found that the bearing capacity is larger than that of a conventional concrete composite slab.

Yardim et al. [11] proposed a connection in a thin precast panel that behaves as a composite slab with permanent formwork in a residential building. Siswosukartoo et al. [12] proposed an HSPC system for green construction of residential buildings. Santos and Julio [13], investigated the horizontal friction between precast and in-site cast concretes in a HSPC system. The mechanism of stress distribution depended on some parameters, such as cohesive properties, friction coefficient, and dowel action. Lee et al [14] investigated the deflection mechanism of an HSPC system. Vakhsouri et al. [15] studied the slip behavior of reinforcement in the HSPC structures.

Investigation on the HSPC behavior in a two-way slab system is still limited. Tezuka et al. [16] investigated the behavior of two-way long span slabs using half-precast waffle concrete. Moldovan and Mathe [17] investigated a two-way waffle slab with post-tension stressing. Fall et al. [18] researched analytically the behavior of two-way slabs with steel fibers. Kim et al. [19] proposed flexural strengthening of a two-way slab using CFRP. However, the above studies mainly investigated the behavior of two-way slabs when casted as a monolithic slab.

In the previous research [20], a triangular rigid connection (TRC) between precast panels in the HSPC two-way slab system was investigated. In comparison, monolithic two-way slabs were also tested. The specimens were subjected to a point load at the middle span. The results showed that the application of TRC in a two-way HSPC slab decreased the cracking load by 15.18% and increased the deflection at the crack by 18.18%.

In the present study, a rectangular rigid connection (RRC-HSPC) between precast panels was proposed and experimentally investigated. The performance was then compared to TRC-HSPC and monolithic ones reported in the previous research [20].

RRC-HSPC Specification and Loading Protocol

In this experimental study, two-way slab specimens with dimensions of 220x220x20 cm, similar to the specimens in the previous research [20], were constructed using RRC between precast panels. The slab dimension and detail of the slab reinforcement are presented in Figures 5 and 6. The depths of the precast panel and the top cast in-situ concrete were 12 cm and 8 cm, respectively. The overlapping length of the rectangular loop in the precast connection was 13.65 cm. The average strength of the concrete and the specification of the flexural reinforcement were reported in Table 1.

The result obtained from the test on two identical samples in the present study was then compared to the previous experimentations conducted by the authors of this paper [20]. In that study, two types of two-way slabs were constructed with similar total thickness and strength of concrete and identical flexural reinforcement, when compared to the specimen in this study. The first specimen was a monolithic one and the second specimen was a half-precast system using a triangular connection (TRC-HSPC). Thus, in Table 1, the concrete strength and the reinforcement of the specimens previously tested were also reported. Several shear connectors were prepared during the fabrication of the precast panels to avoid a slip between the precast panel and the top concrete.

Table 1. Specification of the Concrete Strength and the Flexural Reinforcement of the Slabs

Specimen	Concrete compressive strength (MPa) at 28 days		Two-way Flexural Reinforcement (mm) fy=384 MPa	
	Half-slab precast	Overtopping	Top	Bottom
Monolithic [20]	40.2 MPa		Ø8-150	Ø10-150
TRC-HSPC [20]	40.2 MPa	37.3 MPa	Ø8-150	Ø10-150
RRC-HSPC	40.2 MPa	37.3 MPa	Ø8-150	Ø10-150

Figure 7 presents the configuration of the testing method. The slab specimens were simply supported on the four sides. The displacement at the middle span was observed using LVDTs in X (lateral), Y (lateral), and Z (vertical) directions. The concentrated load was applied at the middle span through a rigid plate with a dimension of 20x20 cm. The load was applied incrementally in the loading and unloading phase as shown in Figure 8. As shown in Figure 8, three peak load levels were considered that correspond to the predicted loads at elastic, crack, and plastic conditions.

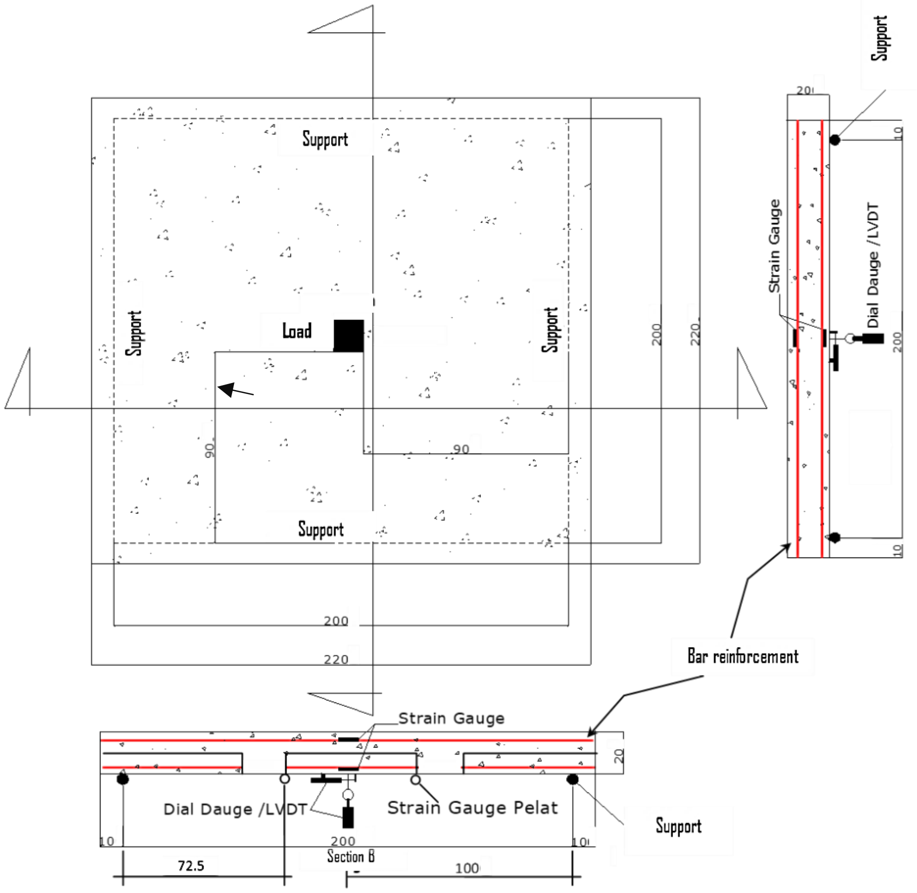

Figure 5. The Slab Dimension under Study and the Position of Applied Concentrated Load

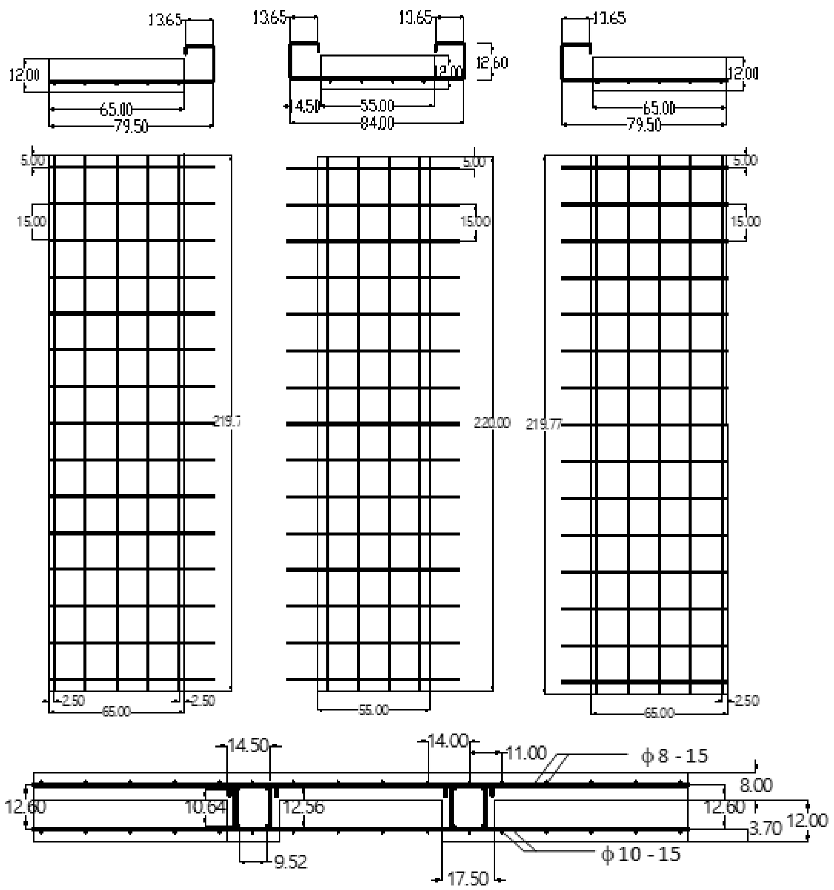

Figure 6. Detail of the Bar Reinforcements of the Precast Panels with Rectangular Rigid Connection (RRC)

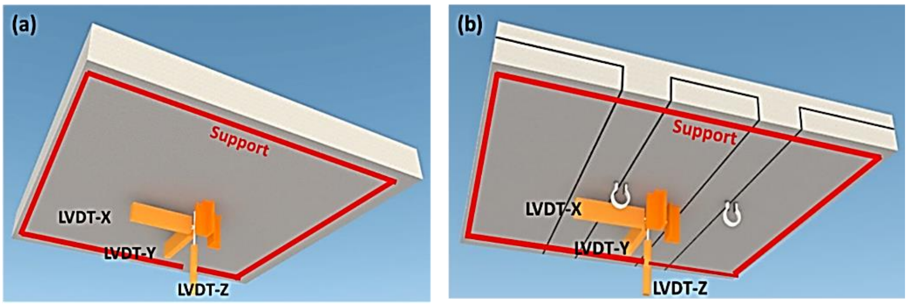

Figure 7. Configuration of the LVDTs and Support on the (a) Monolithic slab 20, and (b) RRC-HCPS Slab

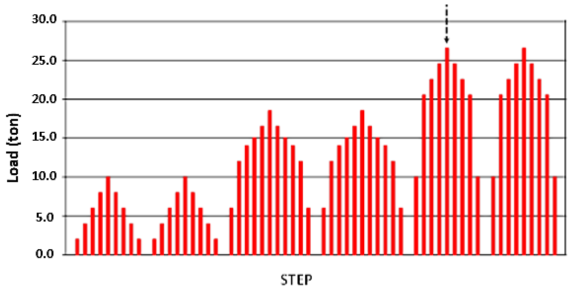

Figure 8. The Applied Cyclic Loading

Results and Discussion

Figure 9 presents the crack propagation during the loading test. For clearer visualization, the corresponding sketches of the crack propagation are presented in Figure 10. The dashed black line indicates the connection line between precast panels and the red crossed box indicates the position of the loading plate. The red cross corresponds to the position of the loading plate.

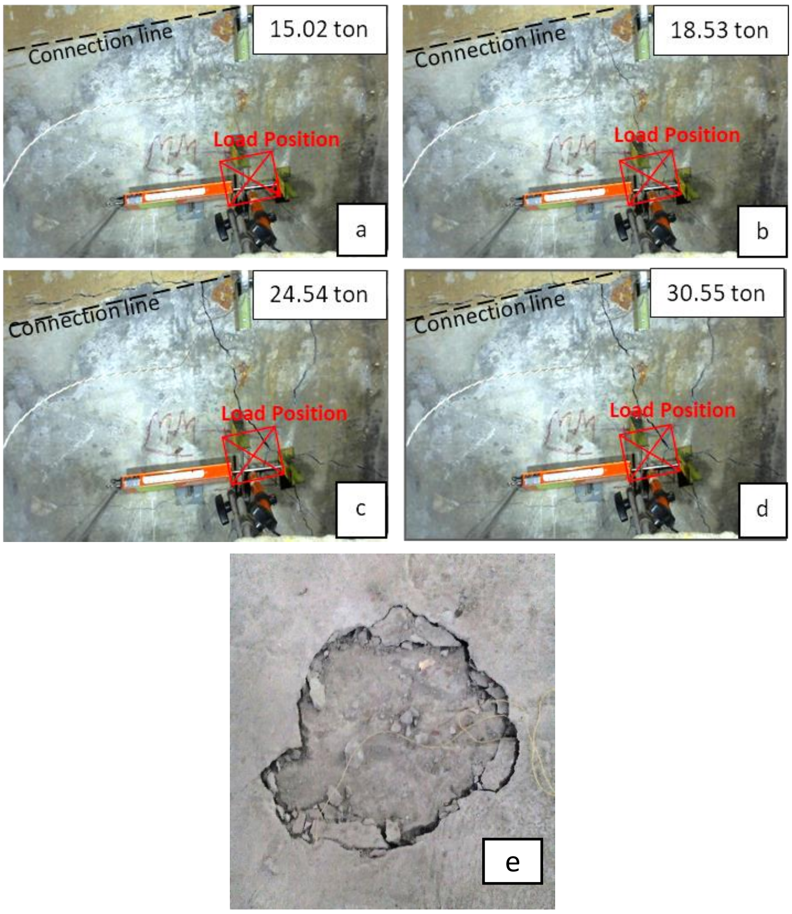

Figure 9. (a-d) Crack Propagation during the Loading Test of the RRC-HSPC Slab, and (e) Punching Shear Failure at the Loading Point

Based on the crack propagation of the RRC-HSPC slab, a transversal initial crack was observed at load 15.02 ton that stopped when reaching the connection line, as shown in Figure 9a. It was then followed by a crack parallel along the connection between precast components at 18.53 tons, as shown in Figure 9b. With the increase of the applied load, the connection between precast components became tighter. At this step, the slab started to behave as a two-way slab, indicated by diagonal crack propagation, as shown in Figure 9c. Figure 9d shows the condition at the ultimate load in which a punching shear failure was observed, indicated by a crushing of the slab surface at the loading point, as shown in 9e. On the other hand, in the monolithic two-way slab system, the cracks spread diagonally starting from the initiation of cracks [20].

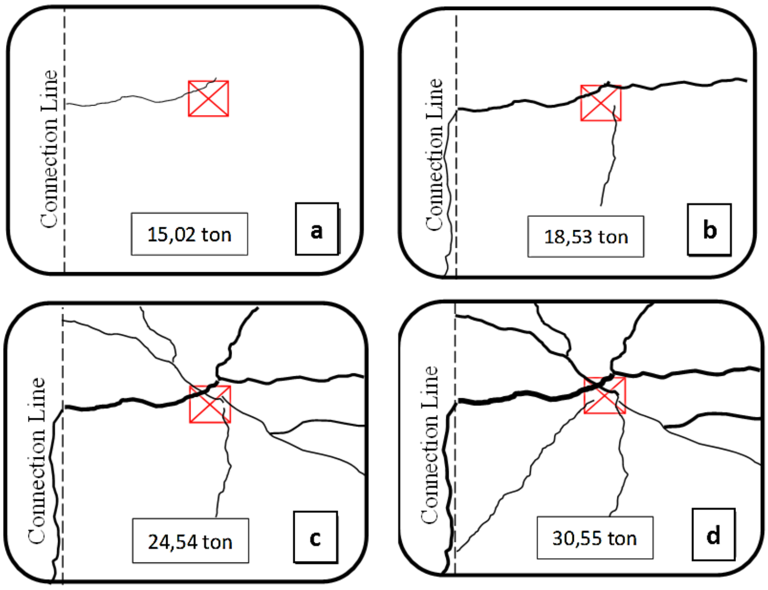

Figure 10. Sketch of the Crack Propagation during the Loading Test of the RRC-HSPC Slab. The Red Cross Corresponds to the Position of the Loading Plate

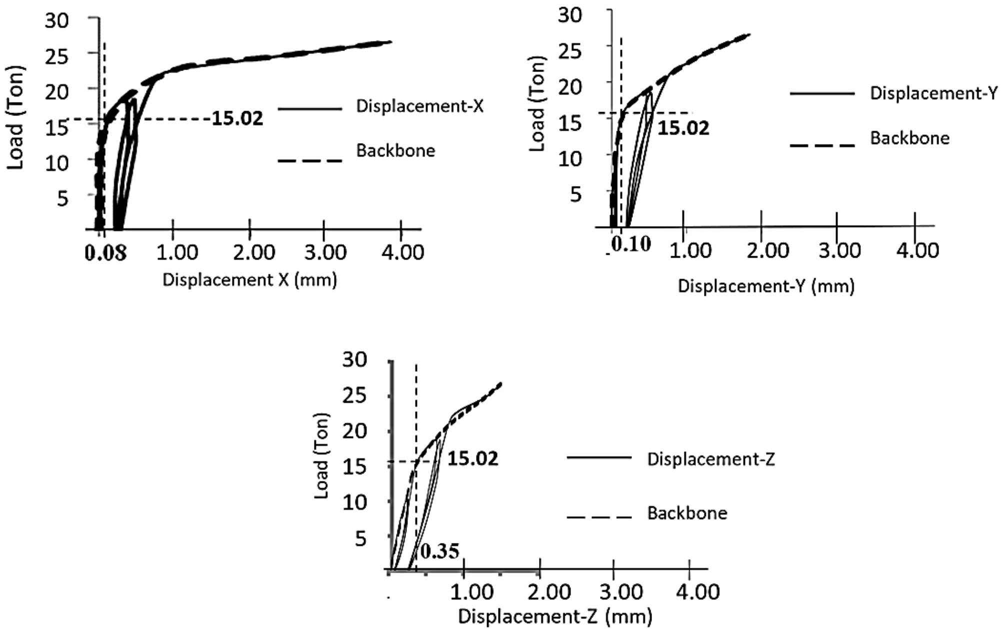

Figure 11. Load-displacement Curves of RRC-HSPC Slab under Cyclic Loading Test

Figure 11 shows the force-displacement curves in X, Y, and Z directions, recorded at the center point of the RRC-HSPC during the test. Based on the vertical displacement curve (Displacement-z), the crack was observed at the load of 15.02 tons and the deflection of 0.35 mm. Meanwhile, in the X and Y directions, the displacements at the crack were observed 0.08 and 0.10 mm, respectively.

It is worth noting that in Figure 11, the displacements in the X and Y directions were not symmetric. At the same level of applied load, the displacement in the X direction was significantly larger compared to the displacement in the Y direction. Such a trend was mainly caused by the dominant opening of the precast connection rather than the crack perpendicular to the connection.

Table 2 summarizes the results of the previous experimentation by the same authors [20]. The values of load correspond to the averaged value from the test on two identical specimens. When compared to the results in the previous experimental study [20] on a two-way monolithic slab, the RRC-HSPC model presented slightly inferior behavior, as shown in Table 2. The load at the crack was 9.13% less and the deflection at the crack was 6.06% larger. However, when compared to the two-way HSPC slab with triangular rigid connection (TRC-HSPC), the RRC-HSPC model presented superior behavior, with a larger cracking load and less vertical deflection at the crack, as shown in Table 2. Meanwhile, the RRC-HSPC presented an ultimate load 16.44% lower than the monolithic one. Almost the same reduction of ultimate load was also observed in the test of TRC-HSPC specimens.

Table 2. Performance of The Three Different Two-way Slab Models at The Crack Condition

Slab model	Load at crack (ton)	Deflection at crack (mm)	Load at failure (ton)	Comparison with the monolithic slab		
				Δ_{load} at crack	$\Delta_{deflection}$ at crack	Δ_{load} at failure
Monolithic [20]	16.53	0.33	36.56	-	-	-
TRC-HSPC [20]	14.02	0.39	30.50	-15.18 %	18.18 %	-16.57 %
RRC-HSPC	15.02	0.35	30.55	-9.13 %	6.06 %	-16.44 %

Conclusions

An experimental study has been conducted to investigate the performance of two-way half-slab precast concrete using a rigid rectangular connection (RRC-HSPC). The slab model was subjected to an incremental concentrated load to observe its behavior in elastic and after crack conditions. Different from the monolithic slab, the crack in RRC-HSPC propagated mainly along the connection line between precast components. After the connection became tighter, the cracks started to spread diagonally, as in the case of the monolithic two-way slab.

It was found that the behavior of the RRC-HSPC model was slightly inferior to the monolithic slab model tested in the previous study, indicated by 15.18% reduction of load at crack, 18.18% increase of deflection at crack, and 16.44% reduction of ultimate load. However, when compared to the two-way HSPC slab using a triangular rigid connection (TRC-HSPC), the RRC-HSPC model presented superior behavior, with a larger cracking load and less deflection at the crack.

In future research, the optimum overlapping length of the connection reinforcement between precast components will be further investigated.

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