An experimental study on the performance of precast ferrocement panel for composite masonry slab systems

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Abstract
This study investigates the necessary norms of precast slabs connections experimentally in order to adapt and suggest a new connection system for existing composite masonry floor. In order to check the system security, full size precast slab tests performed for both slab-beam-slab (SBS) connection and slab-slab (SS) connection. Slabs, designed with the norms of standards and information from literature, were tested under distributed loads. It has been experimentally proved that the offered SBS connection successfully improved the performance the proposed slab floors.

Keywords: Precast, ferrocement, masonry, composite slab.

Introduction

Precast composite floor slab system has been a leading system in construction industry. While design and construction aspects for precast concrete floors have been carefully considered, aspects of the support of precast concrete floors in building structures have not been fully covered by building codes (Mejia-McMaster & Park, 1994).

Composite brick slab (CBS) system has been practicing method in India for small-scale construction and rural sector for roofing purpose (Kumar, 2005). The system has been developed; it is purposed to use ferrocement as bottom layer of Reinforced Brickwork (RB) slabs with the intention that masonry will resist compression and both reinforcement and mesh reinforcement will resist tension (Kaushik, Gupta, & Rehman, 1987). An additional step for CBS is appeared as semi precast CBS. Brick infill in precast ferrocement inverted channels used as flexural members. This channel section is ending with secondary ribs. Experimental studies showed that full composite action was carried out at the first loading stages. However, towards the ultimate load stage, the ribs of the ferrocement trough started deflecting sideways and bond between the ribs and brick infill was partly broken. Slippages were observed due to the poor surface connection and high horizontal shear. A noteworthy result is that connection between the layers was found to be adequate up to working load and no separation cracks were observed. However, near the ultimate load separation was observed at the secondary ribs that are located at the ends of the specimens. Therefore, intermitted ribs were suggested for better composite action at the ultimate load stage (Paramewaran, 1988).

One of the significant milestones of composite precast slab system is half precast slabs. Alternatively, some of the researchers used ferrocement as precast folded plate (Yardim, 2018). Precast ferrocement structures were appeared as roof element at early stages of its development (Carretero-Ayuso & García-Sanz-Calcedo, 2018). Many different types of section were tried as precast elements and comparison was done between each precast and composite systems ; Lee, Paramasivam, Tam, Ong, & Tan, 1990; Cox et al., 2019; Ataei, Bradford, & Liu, 2016).

However, flexural performance of above motioned slabs was adequate until ultimate load, integrity of the systems is a concern after the service load. Moreover, connectivity of the developed system was not questioned. On the other hand, connection for ferrocement inverted rib slab system; slab to slab and beam to slab connection is tested by small scale model. Cast in situ concrete with two layer of wire mesh provide connection between slab to slab and beam to slab link by means of inverted ribs at the edges. Limited results were presented and suggested connection. Effect on moment connection was leaved uncertain (Omorodion-Ikhimwin, 1984).

Yee (2001) reported that the connections provide structural safety, continuity and monolithic action at beam and slab structure. Moreover, it was declared that added negative moment reinforcement steel not only develops continuity but also act as mechanic for developing high compression force at the end face of the bearing edge of precast slab. Additionally, it is underlined that this aid in developing shears friction that increases the resistance of the joint to vertical shear, and reduces importance of the bearing area required between the precast beams(Yee, 2001).

The majority of experimental studies are on precast structural elements precast beam-column joints without transverse beams and slabs (Bonilla, Bezerra, Larrúa Quevedo, Recarey Morfa, & Mirambell Arrizabalaga, 2015; Saleem, Khurram, Amin, & Khan, 2018; Ma, Jiang, & Wang, 2019). However, seismic performance and mode of failures of precast beam-column and precast beam-slab are directly affected by existance of the transverse beams and slabs (Parastesh, Hajirasouliha, & Ramezani, 2014; Chen, Yan, & Gao, 2012; Choi, Choi, & Choi, 2013; Yuksel et al., 2015; Köken & Köroglu, 2014; Yardim, 2018).

In this study, present connection system of precast half slab system applied on the proposed composite slab system. Capability and validity of proposed connection system was investigated. Ultimate load capacity, deflection characteristics and strength along depth of specimens were examined. Effects such as inadequate bearing length, horizontal load consideration, and dowel action of reinforcement steel were neglected in this study. All test specimens were designed for most common live load for residential buildings in British Standard. The structural designs of composite reinforced concrete principles were used for design and analysis of slabs. Recognized standards, theory and considerations were tried to follow as close as possible, so that the results can also be compared with the analytical procedures given in the respective standard and theory.

Materials and methods

Testing set up

Flexural Tests have been carried out on full size specimens of 6 numbers of 1.3m x 3m x 0.125 m (W x L x D) composite brick slabs. Details of test sample are stated in Table 1. Four out of six flexural test specimen were tested under two-line load (BS1to BS4) and last two specimens were tested under partially distributed load (BS5 and BS6). Mechanical properties of all bricks are same. Two Ferrocement precast panel has been tested under two-line load (PS1 and PS2). Additional four precast layer were cast for slab to slab and slab to beam connection test. One-way specimens, simply supported over a span of about 2800 mm and width of 1300 mm, have been chosen for flexural and connection tests. The brick composite specimen is shown in Figure 1. Sections and details for precast layer of composite brick slab are given in Figure 2. The ferrocement reinforcement used in all slabs consisted of high tensile steel bars and galvanized welded square wire mesh of 0.9 mm diameter and 12 mm openings. The tensile strength of the mesh was found 321 N/mm².

Table 1. Experimental Flexural Test Program for Brick Composite Slab (Source: Self-elaboration)

Group	ID of Specimen	Loading Type	Size			No. of L^{*}. Ribs	No. of T^{**}.Ribs
			L	W	D		
Brick(A)	BS1	Two L. load	3000	1300	125	2	4
	BS2	Two L. load	3000	1300	125	2	4
	BS3	Two L. load	3000	1300	125	2	4
	BS4	Two L. load	3000	1300	125	2	4
Brick(B)	BS5	Dist. load	3000	1300	125	2	4
	BS6	Dist. load	3000	1300	125	2	4
Precast	PBS1	Two L. load	3000	1300	75	3	2
	PBS2	Two L. load	3000	1300	75	4	2

Figure 1. Ferrocement Brick Composite Floor Slab (Source: Self-elaboration).

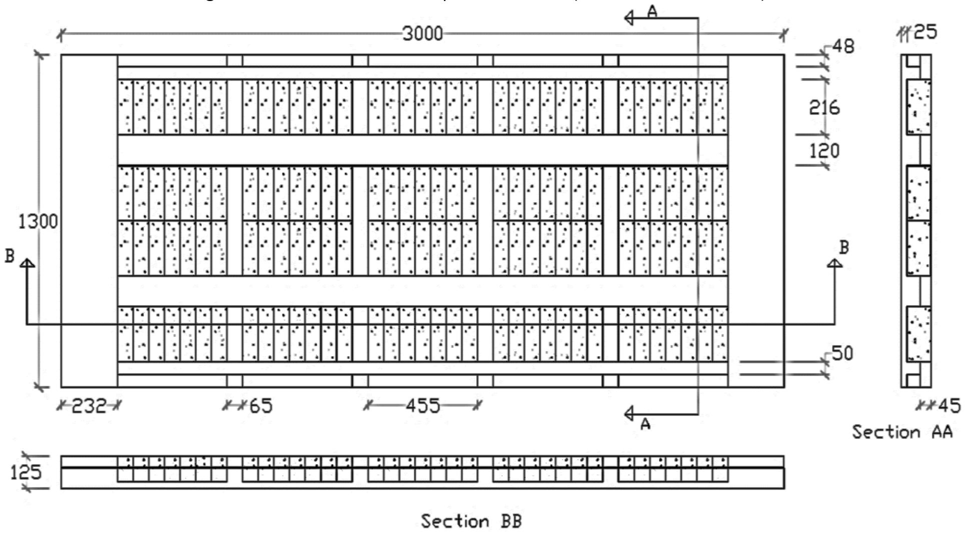
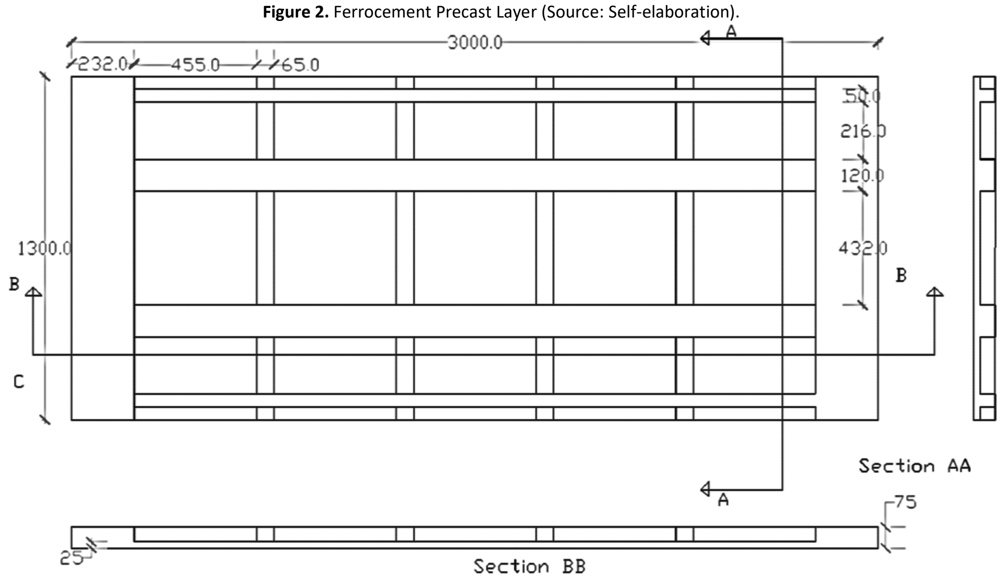
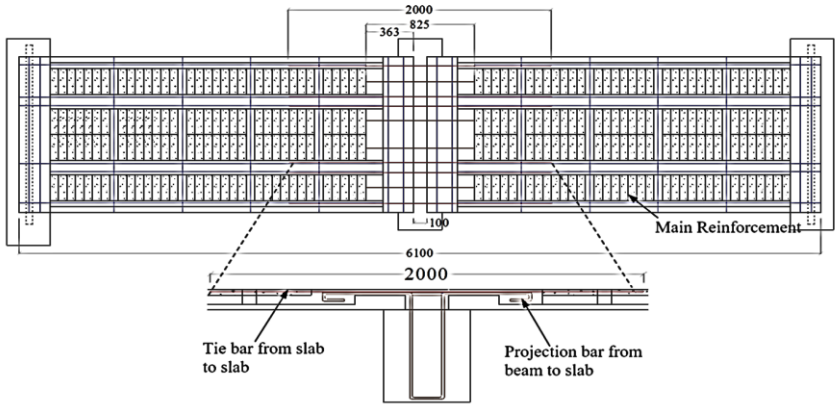


Figure 2. Ferrocement Precast Layer (Source: Self-elaboration).



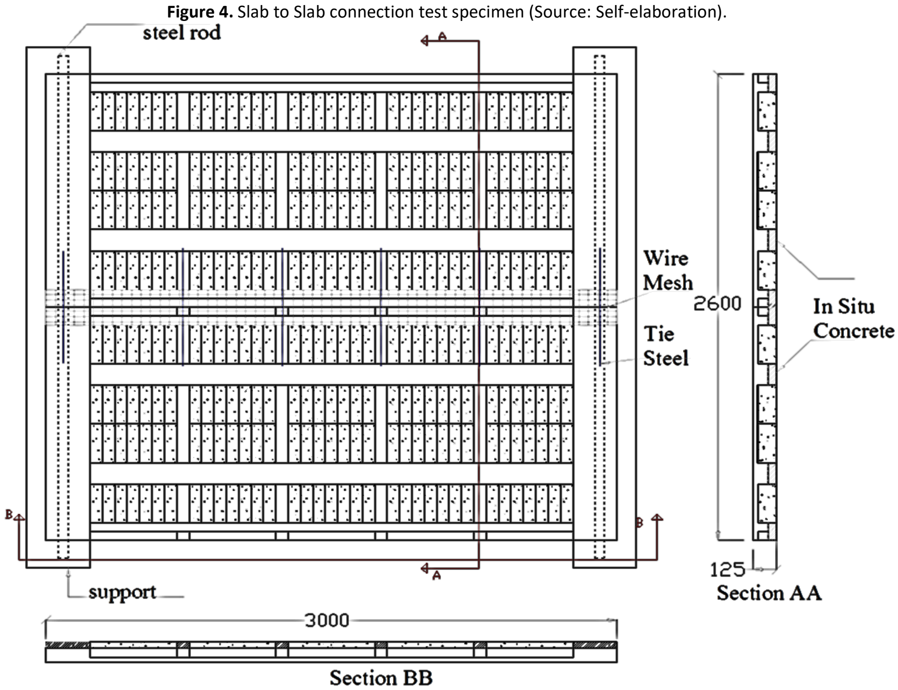
Slab to beam connection performance of developed precast slab was test on moment connection specimen. The connection was created by casting to precast ferrocement panel with a half-precast beam together at the actual size. Size and detail of test specimen is given in Figure 3. Geometrical drawing of the steel tie is given in Figure 3. The tensile strength of the mesh was found 348 N/mm².

Figure 3. Slab– beam-slab connection (Source: Self-elaboration).



Slab to slab connection were created by using two actual size (1300 mm (W) x 3000 mm (L) x 125 mm (D)) precast layer side by side on simply supported condition. Details of the specimen are shown in Figure 4.

Figure 4. Slab to Slab connection test specimen (Source: Self-elaboration).



The constructions of the specimens can be summarized in three stages; preparation of precast layer, placing of masonry blocks and filling of cast-in situ topping. The wire mesh was cut according to the required dimension. Then, the steel bars were tied on top of the mesh with a specified spacing using spacers. Strain gauges were welded in the middle of each steel bar where the highest yielding part is expected to occur. The mortar was poured into the formwork to fill the voids between polystyrene blocks. The specimens were cured for six days. On the seventh day, the specimens were demolded and turned over. The polystyrene blocks were removed leaving empty spaces for bricks. Bricks were then placed in the empty spaces on the ferrocement deck. The side walls of the deck were enclosed with formwork to receive the in-situ concrete topping. Concrete was poured in the voids between formwork and bricks.

3 m span length slabs were used to construct the slab to beam connection test specimen. Concrete beam was cast with the size of 400mm x 500mm x 1600mm (Width x Depth x Length). This beam was located on strong floor and top of it was carefully leveled to avoid any uneven surface dilemma. Other ends of the slabs were formed by 50 mm roller to create simply supported end.

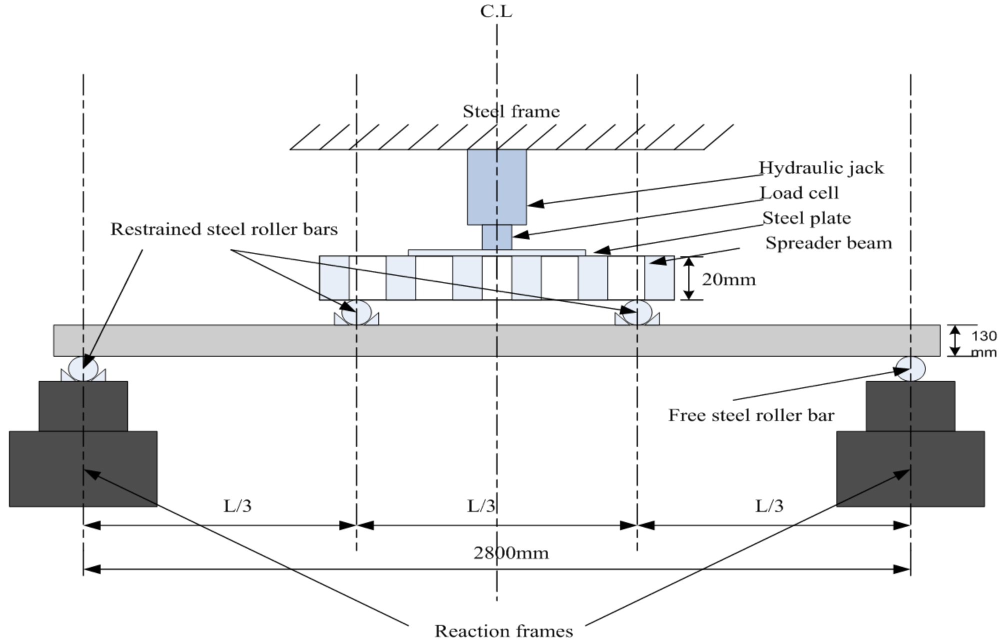
Before steel placement, reinforcement was instrumented with strain gages. Once all steel was instrumented, tied into place and side formwork fixed, the concrete was placed. Specimen left to cure for next 28 days.

Second connection test specimen was carried out for slab to slab connection. Two pre constructed 3 m span length layers were placed on simply supported ends side by side. Simply supported condition is provided by two 50 mm diameter rod with 2.8 m length. After temporary mid support placed, bricks were located in groove.

Side formworks were fixed to receive in situ concrete layer. Instrumented steel ties of the connection were located and two layer of wire mesh laid between the adjacent end ribs. Dial gages were placed to the midspan for all test specimens. Accordingly, electrical strain gauges were installed along the depth on edge of the slab, at the bottom and top surface of the composite slab.

Flexural tests were carried out on a simply supported 2800 mm clear span. To apply two lines loading; load by hydraulic jack, transfer to I beam though a load cell as shown in Figure 5. Same types of test setting were used for flexural test on ferrocement precast panel. The load was applied on the slab slowly with approximately regular increments. Until the formation of first crack, the load increments were small (approximately 2kN) to get more representative recorded reading. Afterwards, the load increment was increased 3kN up to failure.

Figure 5. Test set up for simply supported two-line load test series (Source: Self-elaboration).



Distributed Loads were applied by layers of cement bags weighing 50 kg each. Cement bags are added on top of slab as uniformly disrupted load, bags are placed one by one and symmetrically to avoid uneven loading. Each layer of load consists of 8 cement bags, giving 4 kN for each load increment (Figure 6).

Figure 6. Loading for Slab Beam Slab Connection Test (Source: Self-elaboration).

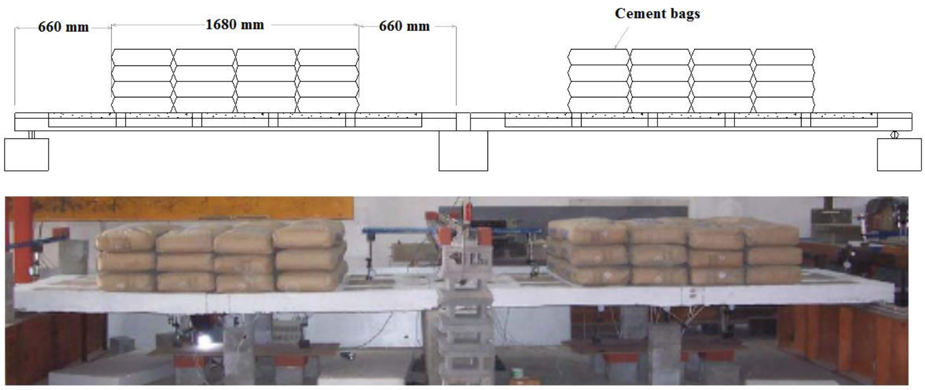
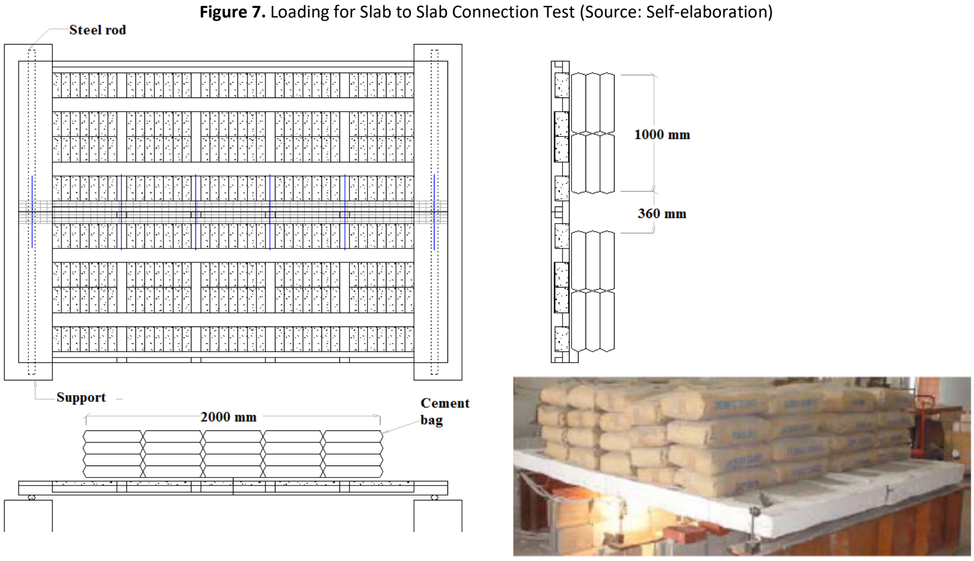


Figure 7. Loading for Slab to Slab Connection Test (Source: Self-elaboration)



Both slab to beam and slab to slab specimens were loaded symmetrically and gradually by 50 kg cement bags (Figure 7). The load was applied on the slab slowly with approximately regular increments. Load increment is 4 kN on slab beam slab specimen and 5 kN on slab to slab specimen. However, it was increased by 2 kN and 2.5 kN for slab beam slab and slab to slab specimen respectively until first crack load. Observed cracks were examined by crack measurement instrument. Testing continued, well beyond the maximum load, until the specimen showed large increase in deflection without appreciable further increase in load. After every load increment the load was held constant for at least five minutes then the data were recorded.

Results and Discussion

The Brick (A) and Brick (B) slabs followed almost same curves at the elastic uncracked zone. With small difference of cracking load curves divert to multiple crack zone. BS1 to BS6 all the specimen shows almost same trend at their multiple crack zones also. Finally all the specimens failed in different ultimate load. The composite slab drew ductile load deflection curves. The first crack was observed at the left side surface. It was started from bottom and went up to about 600 mm in length. The crack width was less than 0.1 mm. Possibly some other cracks occurred at bottom surface of the specimen but because of access difficulties, that small cracks could not be monitored. As the load increases, the length of the crack increases, more cracks appeared at the bottom surface of the specimen as well as at both the side surfaces. After this stage, wire mesh yielding zone started. The widest crack observed before the specimen failed was around 5 mm width, located near the center line of the specimen. Crack patters for all flexural members were examined.

All brick slab specimens shows classical ferrocement slab characteristic. Cracks were located between two-line load set. After carefully inspection it is recorded that none of the slabs showed any sing of horizontal crack. With no exception the specimens show classical reinforced concrete slab flexural failure characteristics. Maximum deflection varies between 31 to 35 mm. Mean loads deflections for BS1 to BS2 are shown in Figure 8. Theoretical and experimental result is stated at Table 2.

Figure 8. Load Deflection Curves for Brick Composite Slabs (Source: Self-elaboration)

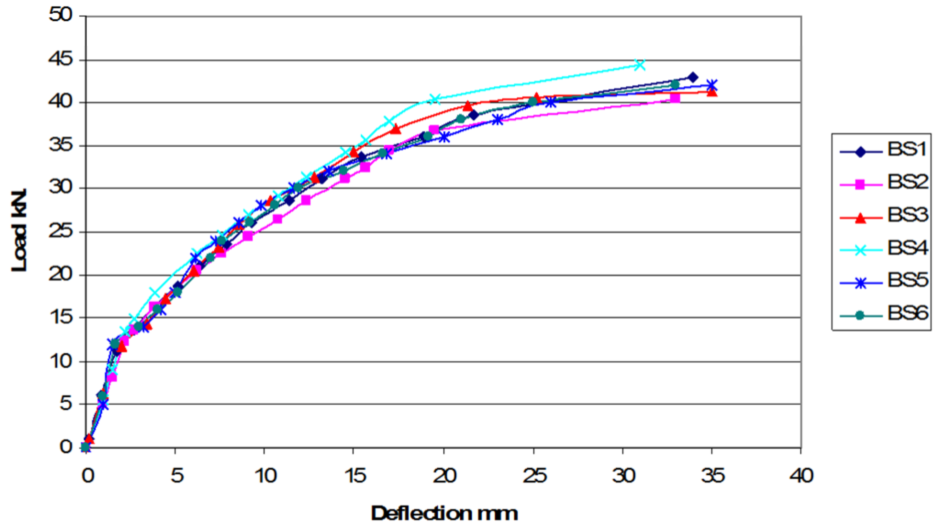


Table 2. Summary of Theoretical and Experimental results (Source: Self-elaboration).

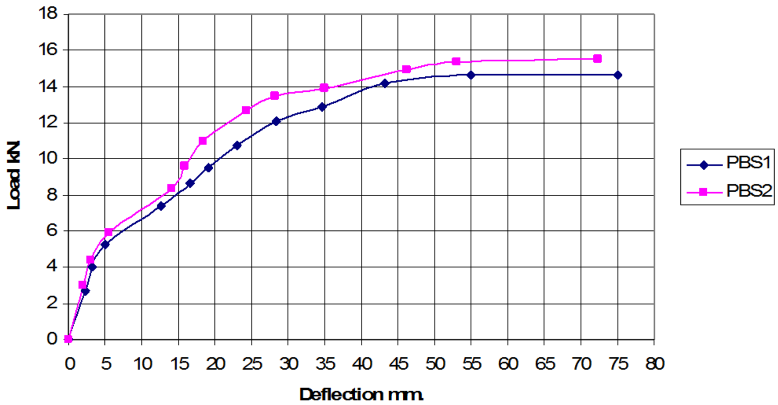
Specimens		First Crack Load (kN)		Ultimate load (P_{ULT}) (kN)		Ultimate Moment, M_U (kNm/m)		$\frac{M_U\ (Expt)}{M_U\ (Theor)}$	Mode of Failure
Brick(A)	BS1	12.0	11.22	38.0	43.0	13.63	15.43	1.13	Flexural
	BS2	12.0	12.24	38.0	40.4	13.63	14.49	1.06	Flexural
	BS3	12.0	11.70	38.0	41.25	13.63	14.79	1.08	Flexural

	BS4	12.0	13.46	38.0	44.44	13.63	15.96	1.17	Flexural
Brick(B)	BS5	12.0	10.0	38.0	42.0	13.63	15.07	1.10	Flexural
	BS6	12.0	10.0	38.0	42.0	13.63	15.07	1.10	Flexural
Precast	PBS1	6.3	5.28	15.8	14.65	5.66	5.25	0.93	Flexural
	PBS2	6.3	5.6	15.8	15.48	5.66	5.55	0.98	Flexural

Careful strain inspection proves that, strain at top surface of the composite slab is equal for both toping concrete and masonry unit. Due to load caring capacity, stronger structure bears more load with same strain of weaker structure. The strain results on top of the structures are similarly with early experimental results (Chakrabarti, Sharma, & Chandra, 1988). It is observed that, structures 'strain response at compression zone are perfectly equal until service load and slight changes observed while getting closer to ultimate load. After ultimate load, system failed by chipping of the longitudinal ribs followed by masonry units. Deformation of compression zone was clearly observed at brick masonry units. Final failures took place by gradually crashing of both concrete and masonry at extreme top fiber.

Load deflection curves for Precast Specimen (PBS1, PBS2) are shown in Figure 9. Curves shows classical ferrocement slab structure trend of load deflection curve under flexural load. First crack was recoded at 5.2 kN with over 4.5 mm (deflection /L = 0.00178) deflection. The structure could carry small amount of (2 kN/m) load with no consideration of safety factor. Crack numbers were increased with increasing of load and large deformation was observed. At the deflection of 55 mm system failed by crashing of ribs.

Figure 9. Load deflection curves for PBS1 and PBS2 Specimens (Source: Self-elaboration).



First crack of the slab beam slab was observed at fixed end of the specimen at slab 2. This crack was recorded at 12 kN loading. As load was increased, several cracks appeared on the top surface of the connection. At the load of 18 kN, first connection crack observed at connection side of slab 1 with first flexural crack at middle of same slab. At the same loading, First crack of the slab 1 was stretch throughout of entire width of the slab. At the early stages of the testing crack's propagation of the connection of both slabs shows symmetry. These expected symmetric actions were continued throughout entire stages of the slab beam slab testing.

The first crack load of slab-to-slab specimen was observed at 15 kN loading step, which is similar with the single flexure test specimen. These cracks were observed at outer side of the both slabs. Symmetric formation of cracks continued after first crack load. Next loading (17 kN), firsts cracks were stretched toward center of bottom of the slabs.

Load deflection curves for slab to slab connection and slab to beam connection specimen are shown in Figure 10 and 11 respectively. This Slab showed same characteristic of deflection at mid span. Classical ferrocement structure with three stages of deflection curves was observed. Behaviour of slab was same as single flexural member however first crack and ultimate load of the connection specimen is slightly higher. Load deflection curves for slab to beam connection is given with a simple supported slab load deflection curves in Figure 11.

Figure 10. Load Deflection Curves at Mid Span of Slab 1 and Slab 2 (Source: Self-elaboration).

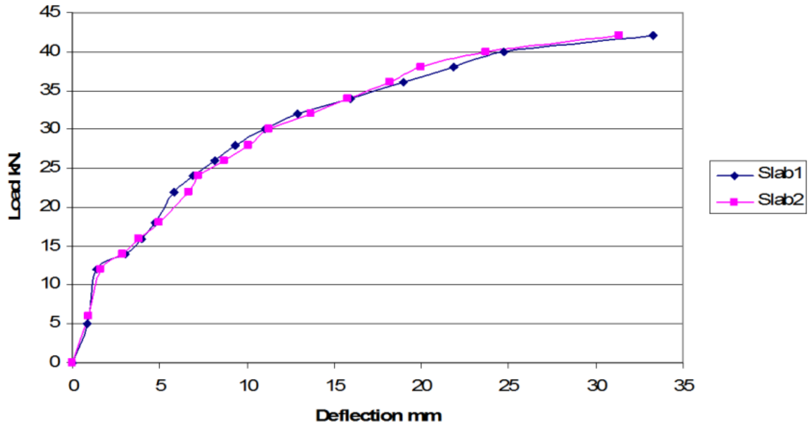
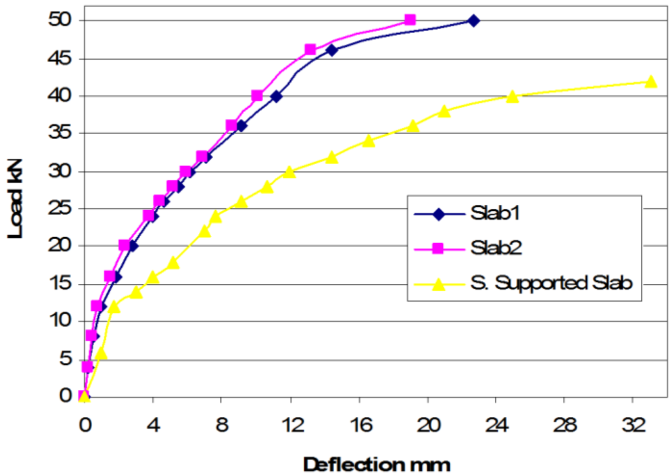


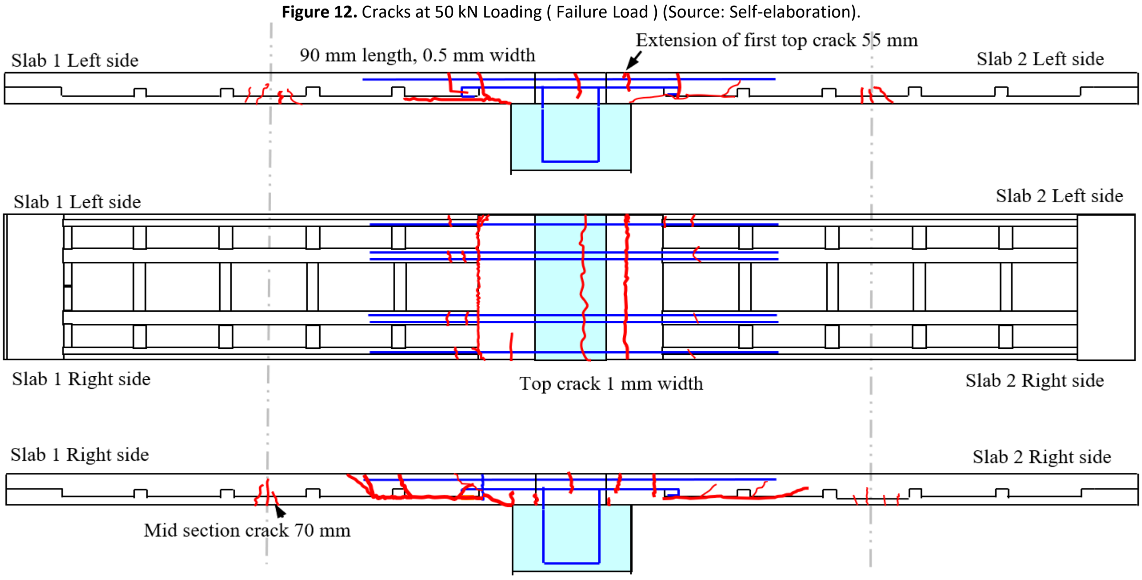
Figure 11. Load mid Span Deflection Curve for Connected Slabs and Simply S. Slab (Source: Self-elaboration)



The mid-section cracks numbers and sizes were increased at 46 kN loading on slab to beam connection specimen. Subsequent loading stages, (50 kN) connection fail took place followed by flexural fail. Both side connections fail gradually, cracks were observed before fail at side of slab and top section of connection as shown in Figure 12. At Ultimate load, horizontal crack started at surface of beam increase its length till end of tie steel.

Failure of specimen start with large cracks at connection, followed by connection tie steel yielding. Ultimate failure is took place by association of both connection and flexural failure.

Figure 12. Cracks at 50 kN Loading (Failure Load) (Source: Self-elaboration).



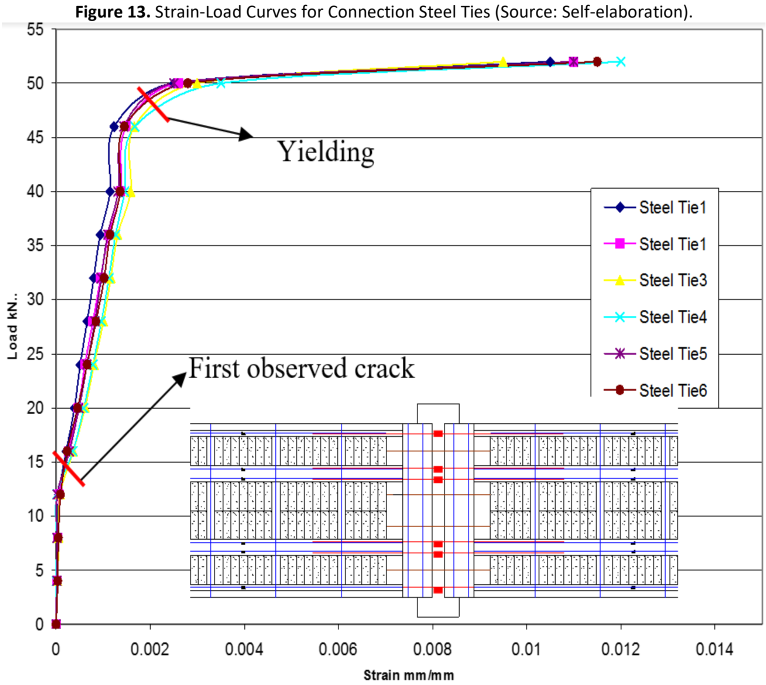
Suggested service load deflection is 0.2 mm for precast unit at support (Mejia-McMaster & Park, 1994). Total displacement on fixed support was recorded as 0.5 mm and 0.2 mm deflection is observed at loading of 32 kN for each slab. At this loading maximum crack width was recorded at connection section was 0.6 mm. Cracks on mid span of slabs were still shows less then 0.4 mm width. Following loadings led to multiple crack for slabs ʼmid section and increase of both crack number and width for connection section. Experimental and theoretical ultimate load and moment capacity for slabs and connection are stated in Table 3.

Table 3. Ultimate Loads and Moments for Slab Beam Slab Connection Test (Source: Self-elaboration).

Slab 1 & Slab 2				Connection	
Ult. Load, P_{ult} kN		Ult. Moment, M_{ult} kNm/m		Ult. Moment, M_{ult} kNm/m	
Theo.	Exp.	Theo.	Exp.	Theo.	Exp.
53	50	16.3	15.4	22.15	22.08

Almost no strain was recorded at steel tie of slab to beam connection test until fist crack load. After the crack, stain of steel recorded as shown in Figure 13. All tie steels were yielded at failure load. Tension strain of composite structure was investigated at top surface of slab, near connection beam. Both side of specimen instrumented by demec points; Two demec points placed on concrete rib, other two placed on concrete and brick as shown in Figure 14. Strain increments were recorded almost equal until first crack load. However, after first crack, strain increments were varied with small difference. These differences become significant near ultimate load. Recorded strain shows that, at tension section of composite slab act as composedly, as shown in Figure 13-14.

Figure 13. Strain-Load Curves for Connection Steel Ties (Source: Self-elaboration).



Testing responses for slab to slab connection were same with individual simply supported slab testing. No significant changes recorded at tie steel placed between two slabs. Cracks were started at sides of both slabs and grown towards connected side. Cracks paths and propagation were quite similar for both as shown in Figure 15. Failure crack were formed throughout mid section of both slab width. There were no cracks or separation recorded at connection section between two slabs. Maximum strain recorded at center tie connection was 0.0005 mm/mm which is 25 % of yielding strain of 0.002 mm/mm. Therefore, minimum tie steel recommended in standard should apply for proposed system.

Figure 14. Strain-Load Curves for Tension Section of Connection (Source: Self-elaboration).

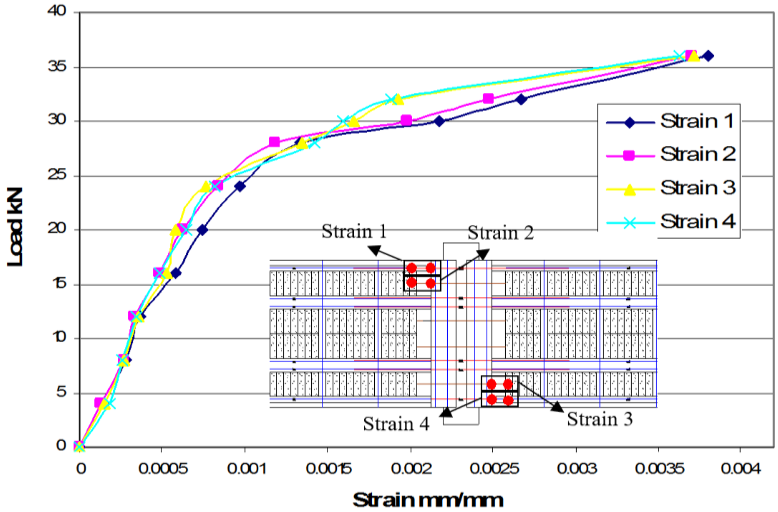


Figure 15. Failure Cracks for Slab to Slab Connection (Source: Self-elaboration).

Conclusions

In this study, experimental test results represented that the proposed test setups can be used successfully to assess the connection characteristics for both beam to slab and slab to slab connection. Design of slabs were suggested and defined by selecting information from literatures and standards. These suggested connections were tested successfully under distributed load. Following statements can be done:

- Full scale test for brick masonry composite slab prove that interlocking mechanism is working perfectly.
- System serves until and after ultimate load as full composite manner.
- Crack patent shows that system is giving enough warning before fail.
- Precast ferrocement panel load capacity is not enough to carry wet concrete topping, masonry and construction load.

Therefore, structure is required temporary supports at construction stages.

No bearing failure was recorded during the test. Failure of the moment resisted connection took place by ultimate yielding of tie steel followed by yielding of the flexural reinforcement of both slabs. The system carries loads well beyond design capacity of the slabs. As a result, the connection type of precast half slab and hollow core slab is adequate to be applied to the proposed system.

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