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Performance of Hollow Core Concrete Slab reinforced by embedded steel tubes

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Abstract— The aims of this paper are gaining additive knowledge about using steel tubes as reinforcement for hollow-core concrete slabs. For this purpose, this paper presents an investigation of how one-way concrete slabs would behave after embedding steel tubes within the cross section. Five concrete slabs were cast, these specimens differ from one another in the horizontal distance (spacing) between the two steel tubes placed within its cross section, steel tubes positioned in the center of the shorter lane of the specimen (width) which is 400 mm, the steel tubes spaced from each other with 4 different configurations, they were 0, 100, 200 and 300 mm. The ratio of the clear spacing between the two tubes and to the total width of the specimen is indicated (s/b) equal to (0, 0.25, 0.5 and 0.75). In addition to one solid slab cast and tested as a reference for the testing results. All five concrete slabs were loaded up to failure by submitting load at one point at the center of the slab. Only one variable was deemed to be considered and checked on this study which is the (s/b) ratio defined earlier. The results exhibit that, using steel tubes as reinforcement increase the first crack load by 12.75% compared to the reference slab, as well as increasing the ultimate load capacity by 59.02% compared to the reference slab. As for the mid-span deflection, the specimens with steel tubes embedded decreased the deflection values up to 47.37 %.

Keywords— One-way concrete slab, steel tubes, embedded, concrete ultimate capacity, deflection, hollow core concrete slab.

1. Introduction

Using Hollow Core concrete slabs have multiple advantages; some of them are the decrease of weight, which enables designers to go for larger span lengths, as well as possessing a decreased depth ratio, which can save 6 to 10 inches of slab thickness. In addition, of being sound resistance which is very useful in residential buildings as the hollow core slabs have better sound absorption. Different strengthening methods have been developed for reinforced concrete slabs, steel reinforcement bars, grids, plates or fibers are added into the concrete in order to improve the concrete strength against different kinds of stresses [1]. A composite structure consists of two or more materials placed together in a structural element in such way that each material is used to its advantage and results in the best solution for the combination [2]. Some of the methods of strengthening concrete slabs consist of profiled steel decking with in site concrete casting [3]. In addition, for being a permanent formwork such decking will provide enough shear bond with the concrete so that when the concrete has gained strength the two combined materials will act as one better material [4]. While other methods require that, the steel to be fully embedded into the concrete in order to achieve full composite action [5], such as using steel channel sections either to be single channel or double channel sections [5]. Using steel tubes embedded in the slab will result in creating composite hollow core slab but with improved loading capacity, deflection resistance than a regular voided slab.

2. The Experimental Study

2.1 *Materials*

Several materials were used throughout the course of this study, including Ordinary Portland cement, natural sand with 4.75 mm as a max particle size, course aggregate with 8 mm as a max particle size, main steel reinforcement of 4 mm diameter with 420 MPa yielding strength, and steel tubes of 0.75 inches diameter with 1.89 mm thickness and 330 MPa yielding strength. **Table. 1** below shows the mix design used to cast the 5 specimens

Table 1: Mix Design of concrete

Materials	**Kg/m^3**
Cement	350
Sand	754
Gravel	1100
Water	154

The concrete compressive strength (f'_c) was determined by testing control cubes at the age of 28 days, 3 cubes averaging 31 MPa compressive strength. Below **Tables 2** and **Table 3** and **Table 4** shows the testing results of the materials used in the study.

Table 2: Physical Test results of the cement

Physical Properties	Test Results	ASTM C150
Finesses, Specific Surface	290	280
Setting time using Viscat's Instrument	Initial (160)	45
	Final (280)	75

Table 3: Grading of Coarse aggregate

Sieve Size (mm)	% Passing	% Passing of the overall limit of ASTM C33
19	100	100-100
12.5	92	90-100
9.5	55	40-70
4.75	8	0-15
2.36	0	0-5

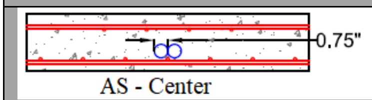
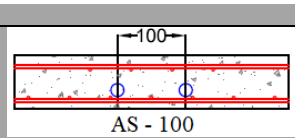
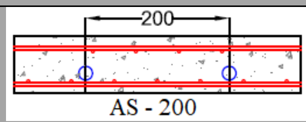
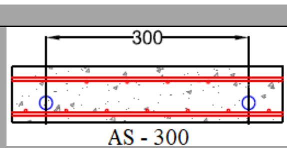
Table 4: Grading of Fine aggregate

Sieve Size (mm)	% Passing	% Passing of the overall limit of ASTM C33
9.5	100	100-100
4.75	98	95-100
2.36	90	80-100
1.18	75	50-85
0.6	40	25-60
0.3	15	5-30
0.15	5	0-10

2.2 *Test Specimen*

A total of 5 specimens were tested in this work, all having the same exterior dimensions which are 1000 x 400 x 80 mm, as well as all of the five slabs are reinforced by 4 mm rebars as per the minimum requirement of ACI 318-14 [6], four specimens contain steel tubes within their sections and the last one of these specimens is fully solid not containing any steel tubes and was tested as a reference slab for comparison of the test results. The four slabs differ from one another by the spacing between the two steel tubes placed in the single slab which earlier was referred to as (s/b) ratio, Table 5 displays the details of the specimens in this study.

Table 5: Specimens designations and cross sectional area

Cross Section	s/b ratio
	0
	0.25
	0.5
	0.75

2.3 *Instrumentation*

A Hydraulic jack with a capacity of 50 tons was used to apply the point load, strain gauges used to measure the strain of the concrete and the steel, dial gauge used to measure the deflection at the center of the specimen and finally a load cell of 0.01 sensitivity was used to measure the applied load.

2.4 *Testing Procedures*

After curing, the specimens were painted with white color in order to make ease spotting the cracks and marking them throughout the test as well as marking the locations of supports were the specimen sits, also marking the point load area in the center and the locations of the strain sensors as showing in Fig.1. the steel frame members above the jack were used to fit the loading mechanism, their weight was measure and accounted for, the initial readings were all recorded at a previously prepared sheet. The increment used was 2 kN, in each increment all the readings were registered and the whole specimen was inspected for cracks which was highlighted in a colored marker and the loading that caused the crack was written next to the highlighting area for each loading stage (increment).

Figure 1: Test Setup, showing tools and supporting frame

3. The Test Results

3.1 *First Cracking Loads and Patterns*

The results of the appearance of first cracks and cracking load capacity of the specimens will be discussed in this section, all five specimens showed similar cracking pattern as the cracks first started as transverse cracks at the mid-span area in the tension zone with an average of 8.5 kN for the four specimens as the first crack appeared in the reference slab at 7.5 kN, from that it can be calculated that the increase in the load capacity is 13%, as load further increased the cracks propagated reaching the side face of the specimen and with load further increases reaching near 90% of its ultimate capacity, the flexural failure occurred in the concrete as the specimens start losing its stiffness and bend rapidly in the deflection, at ultimate load flexural cracks and fractures occurred causing total failure to the concrete. Below Table 6 shows the details of the first cracking loads results.

Table 6: First Cracking loads

Specimen Designation	s/b ratio	First cracking load (kN)	% Increase in first cracking load with respect to S-REF
S-REF	None	7.5	---
AS-Center	0	10	33%
AS-100	0.25	8	6%
AS-200	0.5	8	6%
AS-300	0.75	8	6%

3.2 *Load-Deflection & Ultimate Loads*

In this section the test results of deflection and its relation to the load will be discussed as well as the ultimate load capacity of each tested specimen, the load-deflection behavior can be divided into stages, 1st stage of linear curvature as it can be seen in Fig. 2, this stage ends at the point when load is almost up to 1st cracking load in which the material of the specimen was elastic, and no cracks occurred. When first cracks appeared at the tension face, the pattern of load-deflection curvature starts to change initiating the 2nd stage and changing from linear to nonlinear, this 2nd stage presented an increase rate for the deflection values with respect to applied load, finally as load approaches its ultimate values the rate of increasing deflection becomes rapid until failure occurs. The effect of the steel tubes in these one-way concrete slabs shines in increasing the strength of the slab, as the result compared between the reference slab and other four slabs the deflection was decreased by (42.93%, 55.86%, 40.76% and 49.94%) for specimens (AS-Center, AS-100, AS-200 and AS-300) respectively, which indicates that the specimen of s/b ratio (0.25) was the best to decrease the value of mid-span deflection. Regarding the ultimate load capacity it can be noticed from the test results that using these circular steel tubes had a huge effect on the concrete by increasing the ultimate load capacity of all specimens compared to the reference slab as the percentage increase reaching 77.78% in (AS-300) of s/b ratio 0.75 and was minimum of 44.5% in (AS-100) of s/b ratio 0.25. Table. 4 and Figures Fig.2 presents the load-deflection data as well as the ultimate load data.

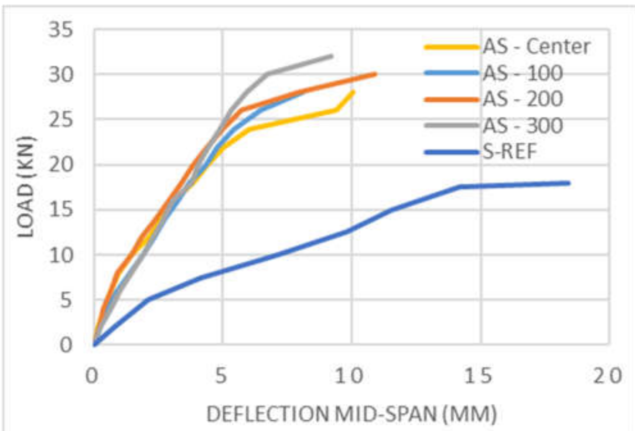


Figure 2: Load-Mid Span Deflection

Table 7: Load-Deflection & Ultimate Load

Specimen Designation	s/b ratio	Ultimate Load Capacity (kN)	Increase in ultimate load capacity %	Mid-Span deflection (mm)	Decrease In Deflection %
S-REF	---	18	---	18.4	--
AS-Center	0	28	55.5	10.5	42.93
AS-100	0.25	26	44.5	8.12	55.86
AS-200	0.5	28.5	58.3	10.9	40.76
AS-300	0.75	32	77.78	9.21	49.94

4. Conclusion

- The use of steel tubes embedded in one-way concrete slabs caused delay in the appearance of first cracks i.e. increased the first cracking load capacity of the specimens, as the increase of the cracking load reached 12.75% compared with the reference slab, while in regards to the s/b ratio it was found that the specimen of s/b (0) was the best to resist cracks as it was the highest reaching 10 kN, which is higher than other specimens by 25% and higher by 33% from the reference slab.
- The use of steel tubes embedded in one-way concrete slabs have a huge effect on increasing the slab ultimate capacity load compared to the reference slab, the minimum increase in the ultimate load capacity reached 44.5% in specimen AS-100 (s/b = 0.25) while the maximum increase reached 77.78% in specimen AS-300 (s/b = 0.75), which indicates the increasing the spacing of the steel tubes have increased the load capacity that these slabs can provide.
- The use of the steel tubes embedded in one-way concrete slabs have a good effect on decreasing the mid-span deflection as results shown that the percentage decrease had an average of 47.37%, as specimen of s/b ratio equal to 0.25 was the most to decrease the deflection by 55.86% while the specimen of s/b ratio of 0.5 was the least to decrease deflection by 40.76%.

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دراسة تأثير استخدام انابيب فولاذية مبطنة على بلاطات خرسانية مجوفة ذات اتجاه واحد

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الخلاصة – يهدف هذا البحث الى الزيادة الحاصلة في اداء البلاطات الخرسانية المجوفة ذات الاتجاه الواحد التي يمكن الحصول عليها بواسطة استخدام انابيب فولاذية كأسياخ تسليح للخرسانة. خلال هذا البحث تم التحقق من تصرف البلاطات الخرسانية المجوفة ذات الاتجاه الواحد في حال تم استخدام انابيب فولاذية دائرية المقطع كتسليح. تم فحص ما مجموعه 5 نماذج, هذه النماذج الخمسة تختلف فيما بينها اختلاف بسيط و هو ان 4 منها تحوي على اثنين من الانابيب الفولاذية موضموعة بمسافات مختلفة, حيث تم وضع الانابيب في وسط البعد القصير (العرض) و الذي اجمالي طوله هو 400 ملم, تم وضع الانابيب بأربع مساحات مختلفة و هي (0) ملم و (100) ملم و (200) ملم و الاخير (300) ملم. تم استخدام المصطلح نسبة (م/ع) والتي تعني المسافة بين انبوبي الفولاذ في المقطع الخرساني مقسومة على العرض الكلي للمقطع الذي هو 400 ملم. بالتالي اصبح لدينا (م/ع = 0) و (0.25) و (0.5) و (0.75) ذلك بالاضافة الى النموذج الخامس الذي لا يحتوي على اي انبوب في داخله و الي تم فحصه كمصدر لمقارنة النماذج. تم فحص جميع النماذج الخمسة لحين وصولها الى الفشل الكلي وذلك بتسليط حمل مركز وسطي على النموذج. و المتغير الوحيد في هذا البحث هو نسبة (م/ع) التي تم تعريفها مسبقا. النتائج اضهرت ان استخدام الانابيب الفولاذية زاد من الحمل المسبب لضهور الشقوق الاولية للنماذج بمقدار 12.75% , وكذلك زيادة قدرة التحمل القصوى للنماذج بمقدار 59.02%. و بالنسبة للهطول في منتصف النموذج, اضهرت النتائج بأن اضافة الانابيب الفولاذية قللت من قيمة الهطول بمقدار 47.37%.

الكلمات الرئيسية – بلاطات خرسانية ذات اتجاه واحد، انابيب فولاذية، مبطنة، هطول، قدرة تحمل قصوى.