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FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE SLAB WITH OPENING

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***Abstract*—** An experimental work was conducted to determine the structural performance of one-way reinforced concrete (RC) slabs with rectangular opening. 5 types of RC slabs which consist of 2 panels for each type were tested by four points bending tests. These include one control slab (S1) without opening and the other four (S2, S3, S4 and S5) with rectangular opening at the centre. S3 slabs were provided with additional rectangular bars surrounding the opening. S4 slabs were provided with additional diagonal bars located at the edges of the opening, and S5 slabs were provided with additional rectangular and diagonal bars surrounding the opening. However, S2 slabs were not provided with any additional bar at the opening. The test results indicate that RC slab with opening gave a reduction of 36% in capacity compared to RC slab without opening. Among the RC slabs with opening, S5 achieved the highest capacity but the effect of additional diagonal bar was not significant. Pure bending cracks were found at the bottom slabs between the two concentrated loads.

***Keywords*:** RC slab, opening, flexural behaviour.

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I. INTRODUCTION

Suspended reinforced concrete (RC) solid slab has been widely used for the multi-storey building. Small openings are required in the slab to accommodate the mechanical and electrical services such as heating, plumbing and ventilating risers. Meanwhile, substantial size openings are required by lift, stairways and elevator shafts. The structural effect for small openings is often not considered due to the ability of the structure to redistributed stresses. However, for large openings, the static system may be altered when it involves a significant amount of concrete and reinforcement bar that need to be removed. This may lead to decrease in ability of the structure to withstand the imposed loads and the structure needs [1].

II. STRUCTURAL DESIGN OF REINFORCED CONCRETE SLAB WITH OPENINGS

The design of RC slab with opening is not clearly stated in BS 8110 [2]. The American Concrete Institute, ACI 318 provides more guidelines for opening size in different location for flat slabs. Figure 1 illustrates the suggested opening sizes and location on a flat slab. The flat slab is divided into column and middle strips in two perpendicular directions. The opening with any size is permitted in the area where middle strip intersects. For the opening in the area interesting column strip, the allowable opening size is 1/8 the width of column strip in either span**.** For opening involved in the area intersecting one column and one middle strip, the maximum opening size is where only 1/4 of the slab reinforcement in either strip may be interrupted. In order to apply the ACI 318 guidelines, the total number of reinforcement for slab without opening on both directions must be maintained. Hence, the reinforcement interrupted on the opening must be replaced on each side of the openings [3]. Both ACI 318 and BS 8110 share the same idea where all the opening must not be encroach on the column head or drop especially at the edge of column where the shear in the slab is the highest.

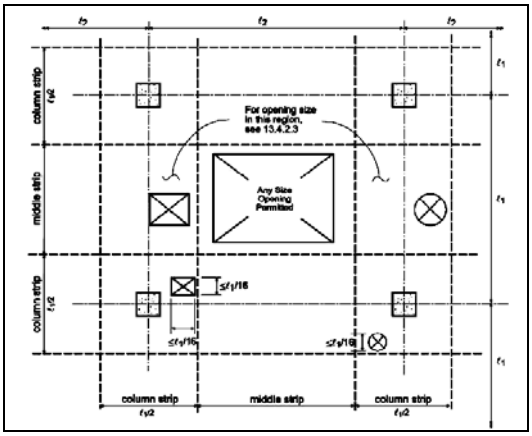

Figure 1: Suggested opening size and location in flat slabs

III. Experimental Program

Concrete

DOE method was adopted as the guidance for designing the concrete mixes to have a target 28 days characteristic strength of 25 N/mm^2. The mixture proportion of cement: sand: aggregate ratio is 1:1.9:2.9 with the water cement ratio of 0.56.

Reinforce Concrete (RC) Slab

Five types of RC slabs which consist of 2 panels for each type were prepared and used in this research. The dimension of the slabs is 300 mm width x 75 mm thick x 1100 mm length. The control slab, S1 (without opening) was provided with 3 and 8 nos of 10 mm high yield steel reinforcement in the longitudinal and transverse directions respectively. A 150 mm x 300 mm rectangular opening was located at the centre of slab S2, S3, S4 and S5. Figure 2 shows the dimension of the control and opening slabs.

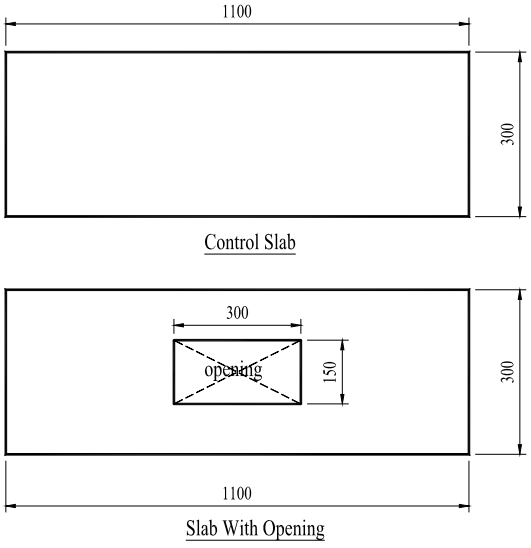

Figure 2: Dimension of RC Slabs

S3 slabs were provided with additional rectangular bars surrounding the opening. S4 slabs were provided with additional diagonal bars located at the edges of the opening, and S5 slabs were provided with additional rectangular and diagonal bars surrounding the opening. However, S2 slabs were not provided with any additional bar at the opening. The detailing of the opening slabs is shown in Figure 3.

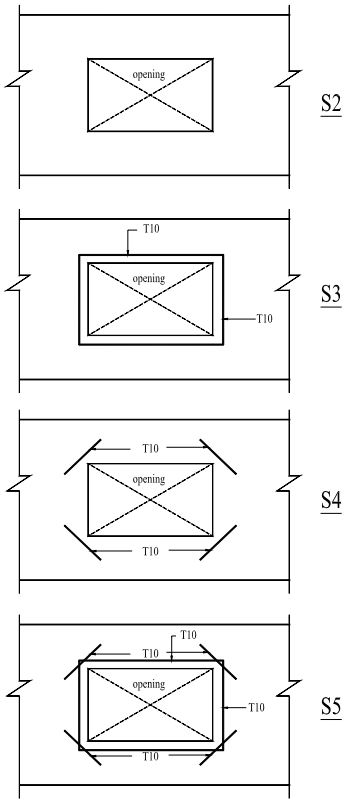

Figure 3: Detailing of the opening slabs

IV. Test Setup And Procedure

All RC slabs were tested by using the 50 tons universal testing machine subjected to four-points bending test system under simple supported condition. Figure 4 shows the test setup and Figure 5 shows the schematic diagram of the four-points bending test.

Figure 4: Four-points bending test setup

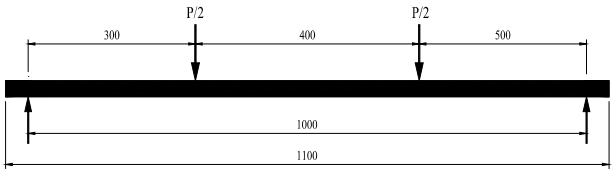

Figure 5: Schematic of four-points bending test

V. Result and Discussion

Flexural Strength of RC Slabs

Flexural strength test data for each panel slab are averaged and summarized in Table 1. The plot (load versus displacement) for each panel is shown in Figure 6. As expected the control RC slab achieved the highest flexural strength compared to the RC slabs with opening. The control slab yielded between 26.3% and 36.6% higher flexural strength than the RC slabs with opening. Among the opening slabs, S5 gained the highest flexural strength. S5 achieved 16.2%, 7.4% and 12.3% higher flexural strength compared to S2, S3 and S4 respectively. From the test results, additional rectangular bars surrounding the opening is the most effective detailing.

Table1: Flexural strength of RC slabs

Panel		First Crack (kN)	Max. Load (kN)	Max Dis. (mm)
S1	Sample 1	18.50	26.00	15.61
	Sample 2	17.00	20.71	18.01
	Average	17.75	23.36	16.81
S2	Sample 1	11.50	14.45	15.69
	Sample 2	10.41	15.16	17.00
	Average	10.96	14.81	16.35
S3	Sample 1	14.00	16.31	13.00
	Sample 2	13.65	15.72	15.88
	Average	13.83	16.02	14.44
S4	Sample 1	11.96	14.75	16.66
	Sample 2	12.44	15.88	15.85
	Average	12.20	15.32	16.19
S5	Sample 1	14.10	16.59	17.31
	Sample 2	14.25	17.82	16.64
	Average	14.18	17.21	16.98

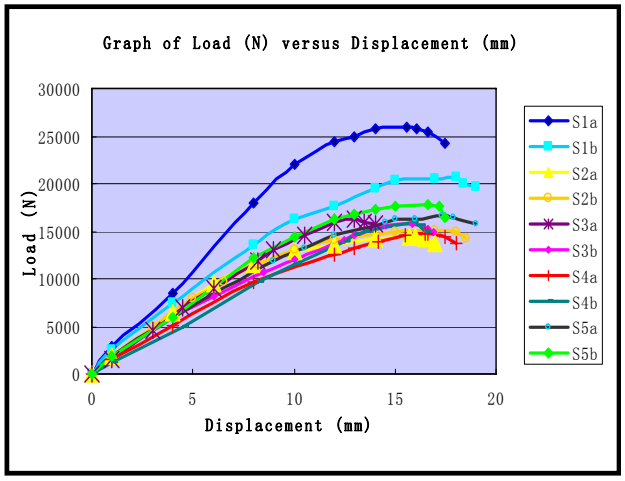

Figure 6: Graph load versus displacement under 4-points bending test

Mode of Failure

In general, all slabs failed under pure bending. First Cracks were found at the bottom surface parallel to the two concentrated line loads for S1. When loads were increased, more vertical cracks developed between the two line loads before it reached the ultimate capacity. S2, S3 and S4 had similar cracking pattern. First crack was found developed from the bottom surface edges under the two line loads and then extended diagonally to the corners of the opening before more and more vertical cracks developed between the two line loads when the loads were increased. The cracking patterns for panel S5 varied from others. The cracks were found started from the bottom surface edges of the line load and then extended diagonally to the corner of the opening when it reached the ultimate capacity. The cracking pattern of the RC slabs is shown in Figure 7.

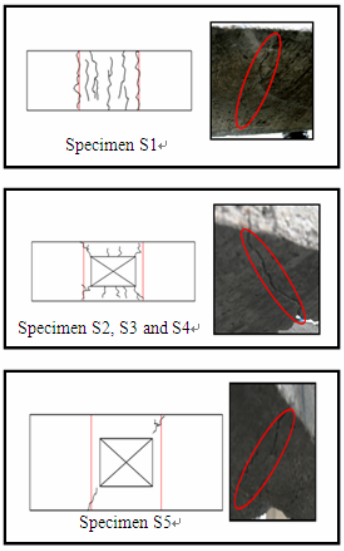

Figure 7: Cracking pattern

VI. Conclusion

Based on the experiment results, the following conclusions may be drawn,

1. The reduction of 15% area due to the rectangular opening located at the centre of the RC slabs reduces 36.6% of flexural strength.

2. The provision of additional reinforcements surrounding the opening increases the flexural capacity of the RC slab.

3. Additional rectangular bar surrounding the opening in RC slabs is the most effective detailing to increase the flexural capacity.

4. The cracking pattern found in the opening slabs show a high concentration stress occurred at the corner of the opening when vertical load is applied.

5. Further research is needed to study the structural behaviour of RC slabs with different shape of opening and location.

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