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EFFECT OF OVERLAY ON PUNCHING SHEAR CAPACITY OF SLABS

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ABSTRACT: The increase in loading condition on an existing structure such as change of a building from residential to commercial form makes it essential to strengthen the reinforced concrete slabs so that the slabs can sustain the increased loads without any excessive distress to the structural elements. Concrete overlay is expected to be an effective means of strengthening the existing slabs. Overlay causes an increase in thickness as well as in the stiffness of the slab. The deflection of the slab is expected to be restricted after the application of an overlay. In the present study the effect of overlay was studied considering its effect on the punching shear capacity of slabs; experimental limitations prevented studying the effect of uniformly distributed live load. It is understandable that the effect of overlay should be applicable to the flexural behaviour of the slab also. In this study the actual punching shear strength was compared with the code (ACI, BS, CAN and CEP-FIP) predicted values. A total of six simply supported square slabs with a length of 2250 mm on each side were cast and tested in a preliminary effort to ascertain the influence of overlay on the punching shear capacity of slabs. These slabs were grouped into two series. In one series the effect of overlay was studied. In the second series, the effect of dowel bars was studied. Here three slabs of 60 mm, 60 mm and 90 mm depth with equal reinforcement in each of the slabs were considered. The significant positive effect of overlay on the punching shear failure load was noticed. Dowel bars also influenced the effect of overlay positively.

KEYWORDS: Reinforced concrete, slab, overlay, punching shear, dowel bar, reinforcement ratio, testing.

INTRODUCTION

The present study was carried out to propose the concrete overlay as a means of modification, more specifically of the strengthening of the existing buildings to sustain the increased loads rather than the demolition of the structural elements. In the context of Bangladesh, the overlay may be used as a powerful technique of rectification of erroneous structural design. The effectiveness of the overlays may depend on the bond between the slab and the overlay, among many other factors. With this view dowel bars were used on slabs before applying overlay.

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The basic objective of the present experimental program was to investigate the structural response of concrete overlay on reinforced concrete slabs. To emphasize the basic objective, investigations on punching shear capacity, probable crack pattern and deflection of slabs were carried out in the study. The actual punching shear strength of slabs was compared with the predictions of ACI 318 (1995), BS 8110 (1985), CAN-A23.3-M84 (1984) and CEB-FIP (1978). The effect of steel ratio and the effect of dowel bars on the ultimate capacity of slabs were also examined.

A review of literature reveals that punching shear is not a newly identified phenomenon and present design codes indiscriminately use equations, based on punching test conducted on simply supported slabs. All the major codes ignore the effect of quantity of steel on the punching shear strength. Seraj and Mostafa (1997) presented a relationship between non-dimensional punching shear strength of footing to the thickness of footing, keeping all other parameters constant. Although the actual amount of steel in all the specimens was the same, the percentage of steel actually decreased with an increasing footing thickness. Similar to the presently adopted code they suggested that the thickness had a linear contribution to the punching shear strength of footing. Seraj and Mostafa (1997) showed that the non-dimensional punching shear strength increased with corresponding increase in the steel ratio. The usefulness of this finding in case of slabs has been tested in this study.

EXPERIMENTAL PROGRAM

(a) Specimens

In the present study a total of six simply supported square slabs with a length of 2250 mm on each side were cast and tested in a preliminary effort to ascertain the influence of overlay on the punching shear capacity of slabs. These slabs were grouped into two series. The design details of slabs tested are shown in Figure 1 and Table 1. In one series the effect of overlay was studied. In this case three slabs of 60 mm, 60 mm and 80 mm thickness were considered with equal amount of reinforcement in each slab. The second slab of this series was furnished with 20-mm overlay once the original concrete gained appropriate strength. To ensure bond between slab and overlay, dowel bars were used. In the second series, the effect of dowel bars was studied. Here three slabs of 60 mm, 60 mm and 90 mm thickness but with equal amount of reinforcement were cast. In the first slab of this series 30 mm overlay was applied after proper grouting and chipping and without any dowel bar, while in the second slab 30 mm overlay was provided using dowel bars. The monolithic slab was cast to assess the performance of overlay with or without dowel bars.

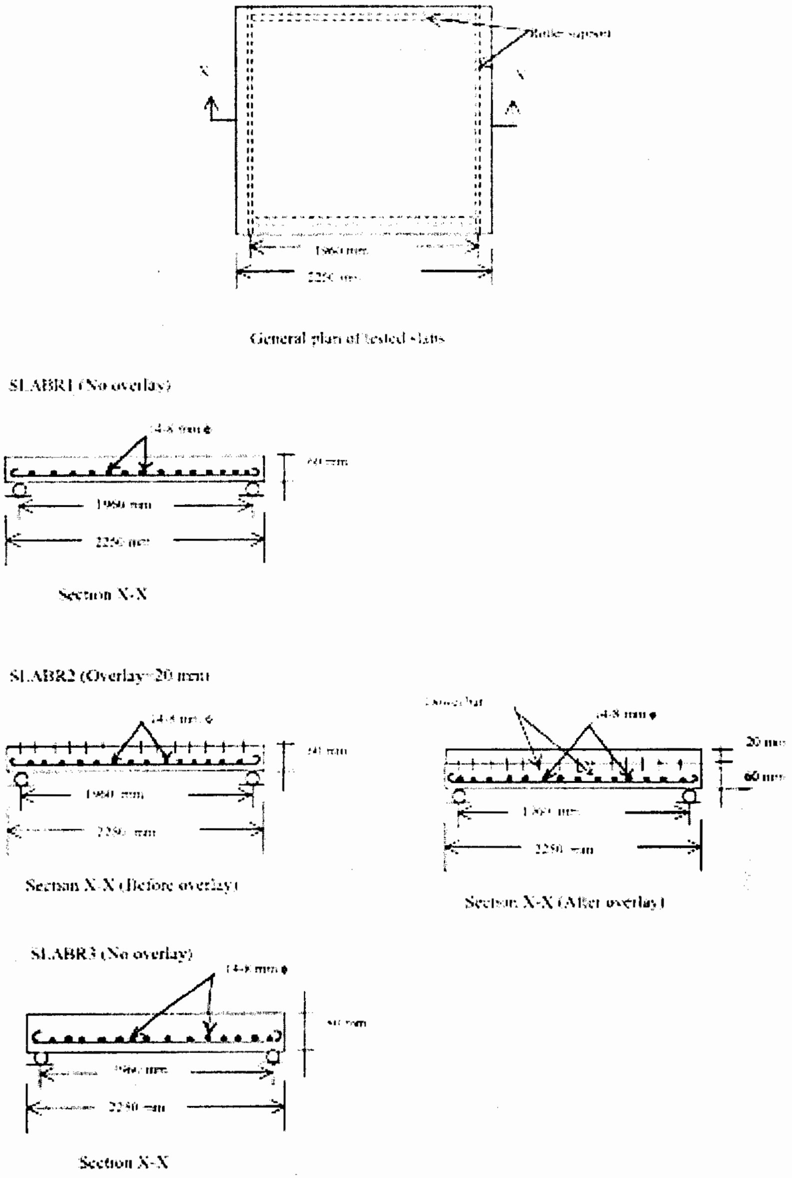


Fig. 1. Design details of slabs

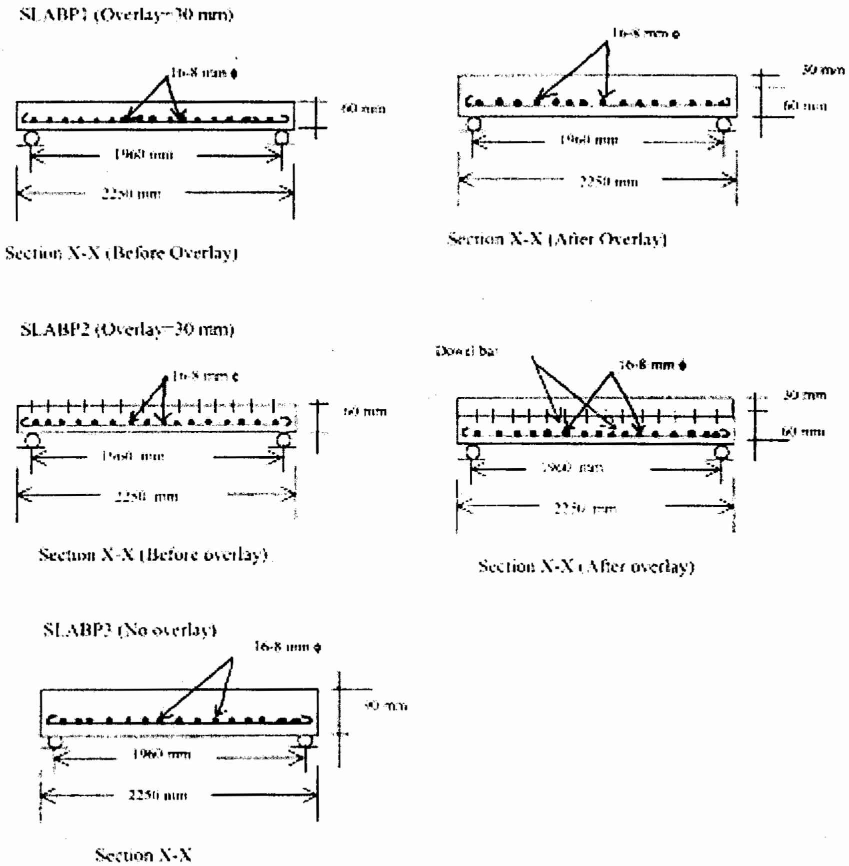


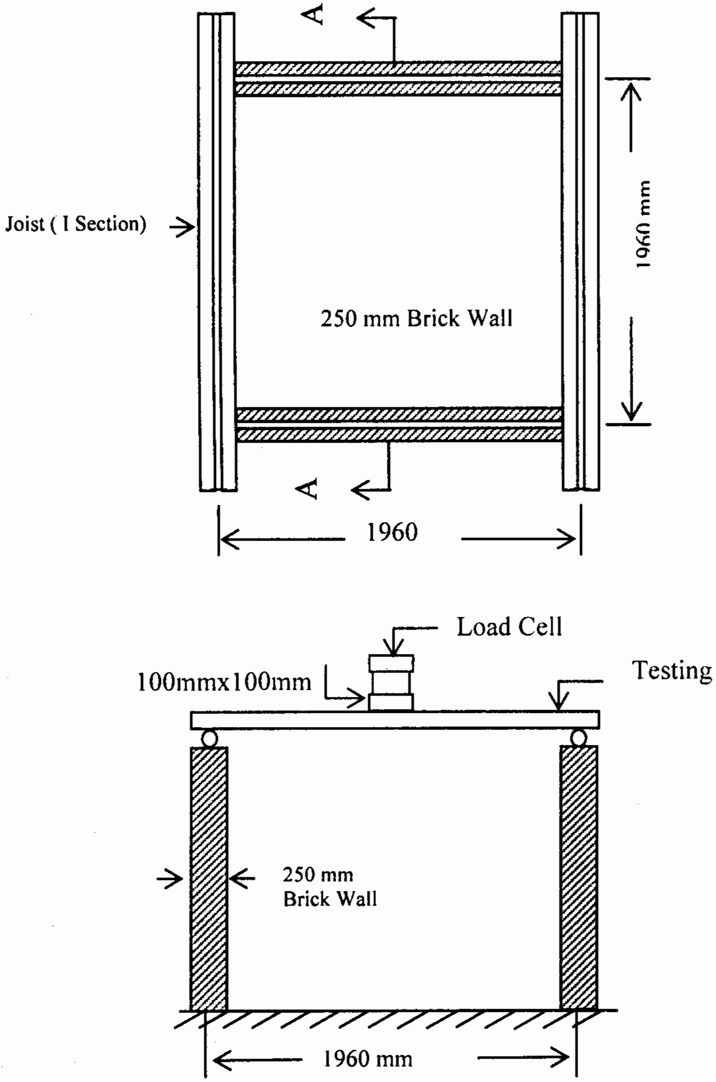
Fig. 1. Design details of slabs (continued)

(b) Materials Used in the Experiment

The cement used in the construction of the specimens and cylinder was ordinary Portland cement Type 1. In the test program 1 inch (25 mm) downgraded brick aggregates with F.M=8.33 were used in overlay concrete. In actual slabs, brick aggregates with F.M=8.68 were used as coarse ingredients. Sylhet sand with F.M=2.48 was used as fine aggregates. Superplasticizer was used as admixture for obtaining higher workability without using excess of water. In the experiment 0.5 litre superplasticizer was used with every 110 lb. (50 kg) cement. Water/ cement ratio of 0.4 was used for the mix of original slab and that of 0.35 was used in overlay mix. A mix per volume of 1:1.5:3 was used. The concrete strength for SLABR1, SLABR2, SLABR3 was 22.5, 21 and 21 MPa, and that for SLABP1, SLABP2, SLABP3 was 21, 22.5 and 20 MPa. Deformed bars having a nominal bar diameter of 8 mm were used in the slabs in both the directions. The average yield strength, ultimate strength and elongation for reinforcing bar were 347.0 MPa, 469.0 MPa and 22.0%, respectively. In this study 10 mm dia deformed 50 grade steel was used as dowel bars in the two slabs before applying overlay to prevent the movement of overlay and slab at the interface against one another. A total of 196 dowel bars of were used at 150 mm centre to centre distance in each of SLABR2 and SLABP2. The length of each of the dowel bars was 30 mm and 40 mm, respectively, in SLABR2 and SLABP2 with 20 mm. All the dowels were inserted a distance of 20 mm into the original slabs.

(c) Testing Arrangement

A testing rig shown in Figure 2 was specially arranged for testing the model slabs. On the two sides of the testing rig, 250 mm brick walls were constructed and another two sides were provided with two I sections as supports for the specimens. Continuous roller support were provided along the edge of the slabs. The center-to-center spacing of the roller supports was 1960 mm. The specimen was placed on roller supports on four sides. A deflectometer was used to record the deflection of slab at a distance of 100 mm away from the geometric center. Load was applied by a stiff screw jack with a capacity of 50 ton through a 100 mm square and 20 mm thick steel plate simulating a concentrated load. Increment of load was kept constant in all the slabs. A load of 0.5 Ton was applied in 30 seconds. During the test after each increment, load was kept constant for at least 1 minute for stabilizing the whole system and monitoring the behaviour of the test slabs.



Section A-A

Fig. 2. Plan and section of testing rig

RESULTS AND DISCUSSION

(a) Ultimate Load Capacity

A summary of the test results for all the specimens is presented in Table 2. All the slabs failed in a punching shear mode. Punching failure and crack pattern of SLABR2 & SLABP2 are shown in Figures 3 and 4, respectively. In Table 2, non-dimensional punching shear strength ($P'u/b_odf'c$) of the specimen is also given. This was calculated by dividing the corresponding maximum punching load ($P'u$) by the product of the compressive strength of concrete ($f'c$) and critical surface focused at half the effective depth (d) away from the perimeter of the load; b_o corresponds to perimeter of critical section of slab. The $P'u$ values reported in Table 2 were obtained from the load monitored during test.

(b) Comparison with Different Design Code

A comparison of the maximum punching load during testing and the punching shear strength predicted by different Codes has been made and shown in Tables 3, 4 and 5. During the calculation of Code predicted punching strength of the specimens, partial safety factors, reduction factors, etc. have been put equal to 1.0.

(c) Load Deflection Characteristics of Slabs

The change in central deflection of slabs with the increase of the load has been studied. Figures 5 and 6 show the load-deflection characteristics of all the slabs tested. As the concentrated load increases, the tangent stiffness begins to decrease upto the failure load. In the load-deflection curve of each slab the experimental failure load and the ultimate load according to different Codes are also identified. From the load deflection curve it is obvious that the failure load is greater than the code predicted values in case of slabs with overlay. But the monolithic slab (SLABR3 and SLABP3) of thickness equal to that of the slab furnished with overlay is not capable of obtaining the code predicted punching capacity because of its low steel ratio.

(d) Effect of Overlay

The ultimate punching capacity of SLABR2 with overlay is increased by about 33% than that of SLABR1 without overlay (Figure 7). Along with this increase in capacity, there is a decrease in deflection of SLABR2 with the increase in load, as compared to the deflection of SLABR1. So there is a significant effect of overlay on punching shear capacity as well as deformation characteristics of slab. Again, from the load-deflection curves of SLABR2 and SLABR3 as shown in Figure 7, the failure load is approximately 8% less in SLABR2 than that in SLABR3, a monolithic slab.

Table 1. Details of the slabs tested

	size (mm×mm)	Layout	overlay (mm)	overlay with/ without dowel	before overlay slab with		after overlay slab with	
					thickness (mm)	steel ratio (%)	thickness (mm)	steel ratio (%)
SLABR1	2250×2250	14-8 mm ϕ both	0	-	60	0.62	60	0.62
SLABR2	2250×2250	14-8 mm ϕ both	20	with dowel	60	0.62	80	0.45
SLABR3	2250×2250	14-8 mm ϕ both	0	-	80	0.45	80	0.45
SLABP1	2250×2250	16-8 mm ϕ both	30	without dowel	60	0.71	90	0.45
SLABP2	2250×2250	16-8 mm ϕ both	30	with dowel	60	0.71	90	0.45
SLABP3	2250×2250	16-8 mm ϕ both	0	-	90	0.45	90	0.45

Table 2. Test results

Slab No.	Design d mm	Actual d mm	Design b_o mm	Actual b_o mm	$P'u$ kN	$P'u/(b_o d f'c)$
SLABR1	50	44	600	576	42.42	0.074
SLABR2	70	69	680	676	56.56	0.058
SLABR3	70	65	680	660	61.28	0.068
SLABP1	80	79	720	716	61.28	0.052
SLABP2	80	85	720	740	75.42	0.053
SLABP3	80	69	720	676	66.00	0.070

Table 3. Different code prediction (using steel ratio and thickness without overlay)

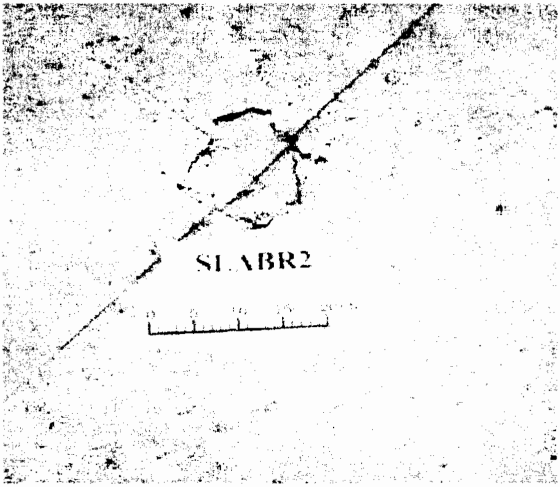
Slab No.	d mm	b_o mm	steel ratio (%)	f'c MPa	ACI kN	BS kN	CAN kN	CEB-FIP kN
SLABR1	50	600	0.62	22.5	46.96	58.91	56.92	44.78
SLABR2	50	600	0.62	21.0	45.37	57.57	55.00	42.54
SLABR3	70	680	0.45	21.0	71.98	82.58	87.25	66.56
SLABP1	50	600	0.71	21.0	45.37	60.24	55.00	42.62
SLABP2	50	600	0.71	22.5	46.96	61.64	56.92	44.63
SLABP3	80	720	0.45	20.2	85.32	98.74	103.42	77.97

Table 4. Different code prediction (using steel ratio and thickness with overlay)

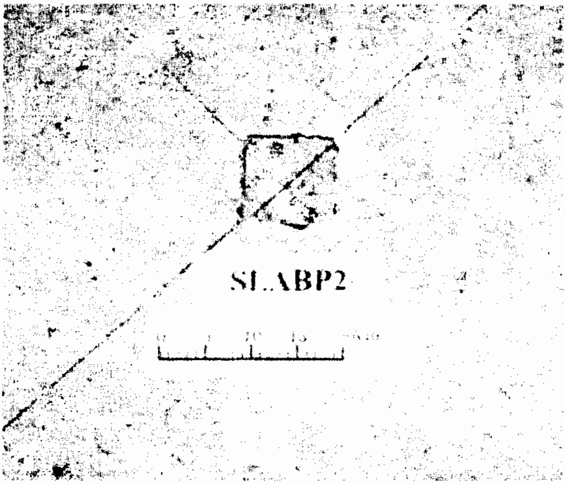
Slab No.	d mm	b_o mm	Steel ratio %	f'c MPa	ACI kN	BS kN	CAN kN	CEB-FIP kN
SLABR2	70	680	0.45	21.0	71.98	82.58	87.25	66.67
SLABP1	80	720	0.45	21.0	87.10	100.10	105.58	80.17
SLABP2	80	720	0.45	22.5	90.16	102.44	109.29	83.92

Table 5. Comparison of experimental results with different codes

Slab No.	Experimental non-dimensional strength	Non-dimensional strength (using steel ratio and thickness without overlay)				Non-dimensional strength (using steel ratio and thickness with overlay)			
		ACI	BS	CAN	CEB-FIP	ACI	BS	CAN	CEB-FIP
SLABR1	0.074	0.070	0.087	0.084	0.066	-	-	-	-
SLABR2	0.058	0.072	0.091	0.087	0.068	0.072	0.083	0.087	0.067
SLABR3	0.068	0.072	0.083	0.087	0.067	-	-	-	-
SLABP1	0.052	0.072	0.096	0.087	0.068	0.072	0.083	0.087	0.066
SLABP1	0.053	0.069	0.091	0.084	0.066	0.070	0.079	0.084	0.065
SLABP3	0.070	0.074	0.085	0.089	0.067	-	-	-	-

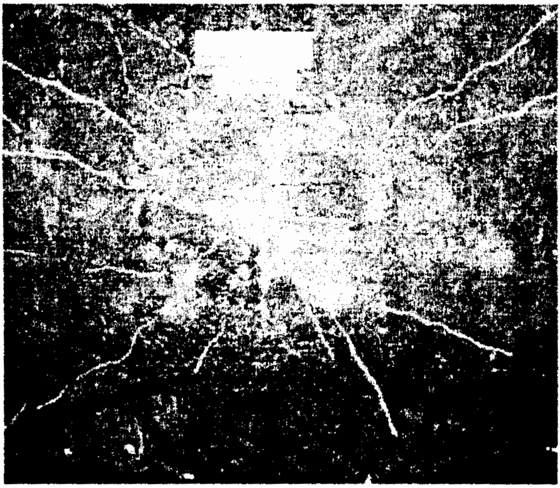


(a) SLABR2 (Top surface)

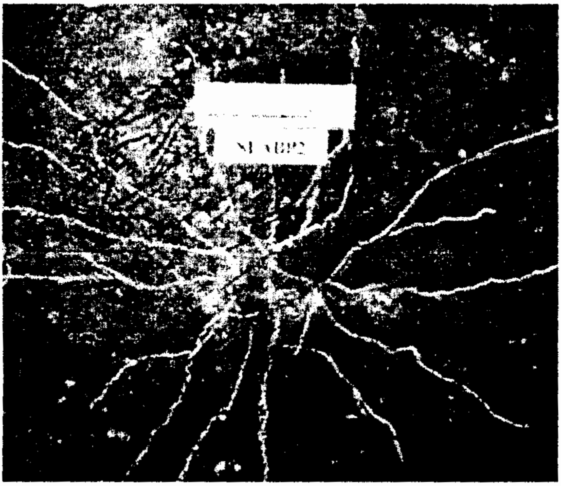


(b) SLABP2 (Top surface)

Fig. 3. Punching failure of (a) SLABR2 and (b) SLABP2



(a) SLABR2 (Bottom surface)



(b) SLABP2 (Bottom surface)

Fig. 4. Crack pattern of (a) SLABR2 and (b) SLABP2

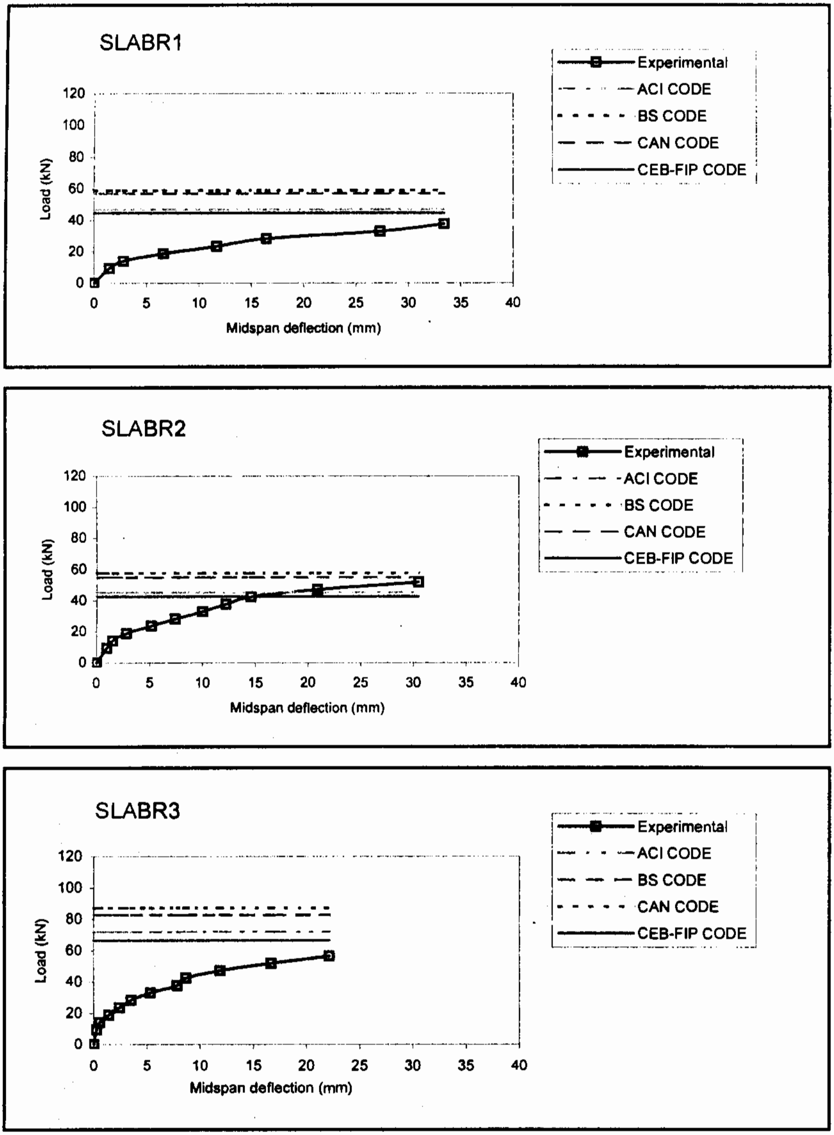


Fig. 5. Load-deflection curves for SLABR1, SLABR2 and SLABR3, and comparison of failure loads with code predictions

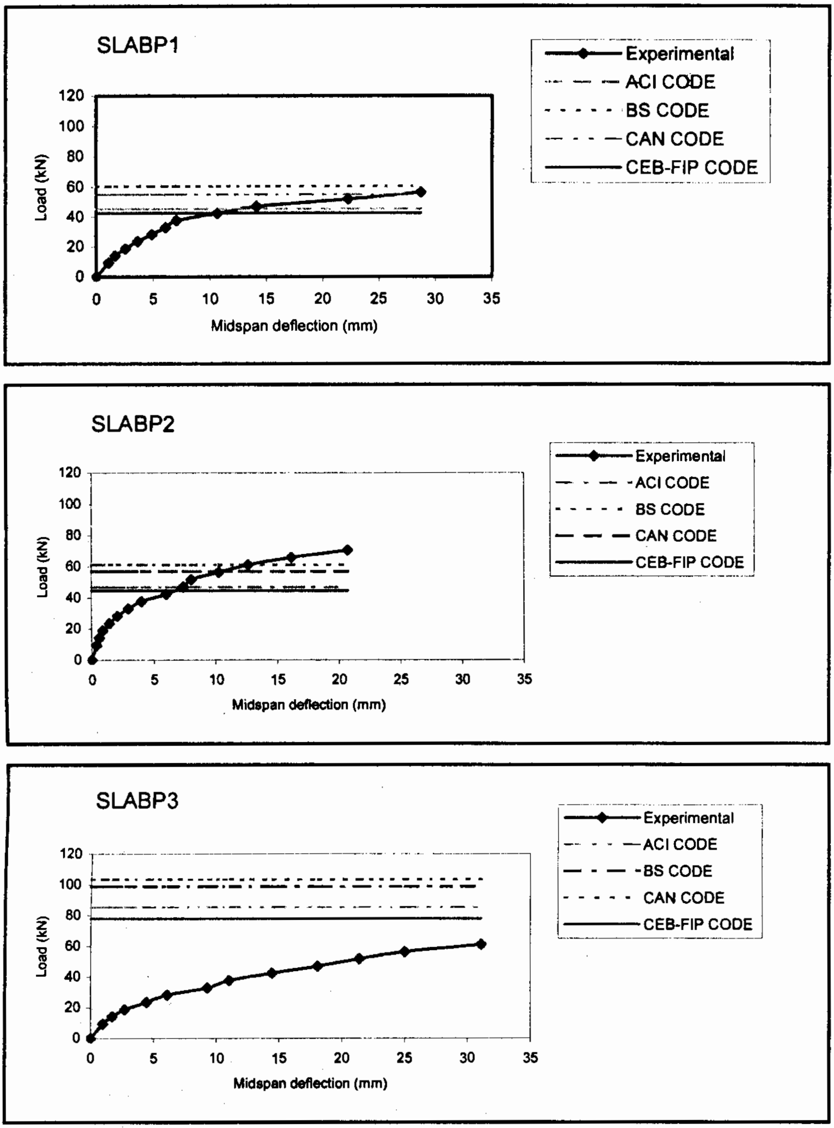


Fig. 6. Load-deflection curves for SLABP1, SLABP2 and SLABP3, and comparison of failure loads with code predictions

Deflection is also less in SLABR2 when compared with SLABR3. According to ACI code an increase in effective depth of about 40% (in case of SLABR2), the punching capacity should be increased about 58%, since the code provides a linear relationship between the punching capacity and the effective depth. In the experiment, due to overlay approximately 33% increase in punching shear capacity was observed in SLABR2. This variation of result with code is due to the fact that ACI code does not consider the steel ratio effect in the punching capacity formula. But the overlay on the slab causes an increase in the slab thickness and thus the steel ratio of the existing slab is decreased.

(e) Effect of Dowel Bars on Overlay

From the load-deflection characteristics of SLABP1 and SLABP2, as shown in Figure 8, it appears that the failure load is increased by about 23% in SLABP2 (overlay with dowel) in comparison to SLABP1 (overlay without dowel). Moreover deflection is also smaller in slab with dowel bars than that in slab without dowel bars. The capacity of SLABP2 is also greater than SLABP3 (monolithic slab) as shown in Figure 8. Better deflection characteristics are also observed in SLABP2 than in SLABP3. But the slab with overlay and no dowel bar contributes less in increasing the punching shear capacity in comparison to the monolithic slab as shown in Figure 8.

(f) Effect of Reinforcement Ratio on Punching Capacity

At the same steel ratio the monolithically cast slab obtained larger non-dimensional strength than that of slab with overlay. In both SLABR2 and SLABR3 the nondimensional strength is less than the SLABR1 as their steel ratios are small as compared to SLABR1. This reduction in strength is approximately 21.5% in SLABR2 and 8% in SLABR3. So the steel ratio influences the punching capacity of slab significantly. But the present codes of practices do not consider this effect in punching capacity.

(g) Cracking Pattern

As shown in Figure 4, a series of cracks radiating from the central loaded area developed on the underside of the tested slabs. In all the specimens the radial crack lines were fine and small in numbers. No significant crack was observed along the lines parallel to the reinforcement. In monolithic slab the reinforcements were bent below the punching area. In slab with dowel bars no reinforcement was bent and cracks were more localized than other types of slabs tested.

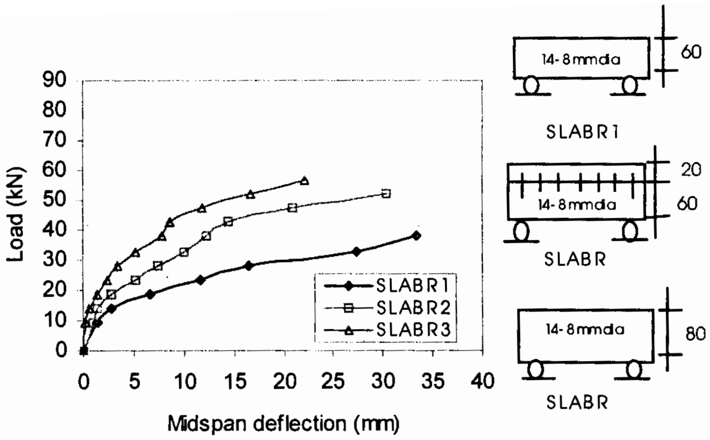


Fig. 7. Effect of overlay on load-deflection behaviour of SLABR1, SLABR2 and SLABR3

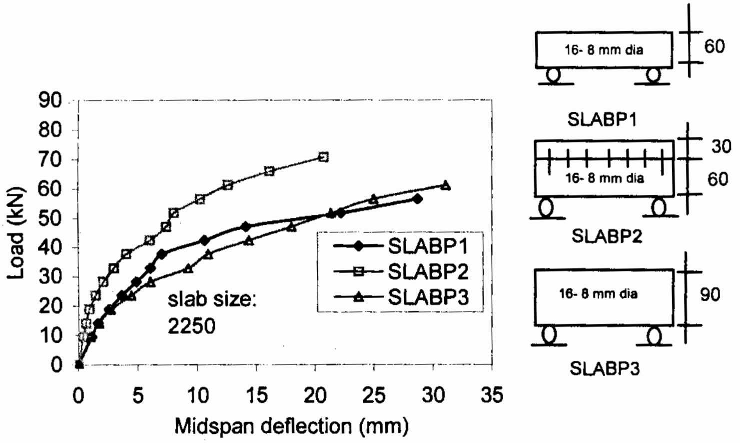


Fig. 8. Effect of overlay on load-deflection curves for SLABP1, SLABP2, SLABP3

CONCLUSIONS AND RECOMMENDATIONS

The test results provided important experimental information on the slabs with overlay subjected to concentrated loading. All the slabs failed in a punching shear mode when subjected to punching load at the slab centre. The results obtained in the test program show some non-uniform results as an effect of overlay due to perhaps some undesirable experimental oversights and small size of the specimens tested. But the positive effect of overlay on the existing slab is obvious from the test results. Overlay causes an increase in the punching shear capacity of existing slabs. In the case of slab with larger steel ratio and relatively high overlay thickness the capacity is greater than that of the monolithic slab. The thickness of the monolithic slab is same as the total thickness of the slab having overlay. But the slab with lower steel ratio and overlay thickness fails to achieve more capacity than that of the monolithic slab. In slab with overlay and dowel bars, the punching shear capacity is more than the slab with overlay and no dowel bar. Thus dowel bars influence the overlay action on existing slabs. Punching shear strength, observed from the punching test conducted on slabs with overlay, is found to be higher than the predictions of present code provisions. But the punching capacity of the monolithic slab is smaller than the code predicted value because of the decrease in steel ratio. Further studies may be carried out on the behaviour of concrete overlay on punching shear capacity of slabs, by varying the size of the slabs, concrete strengths, slab thickness, reinforcement ratio, etc., in order to validate further the findings of the present limited experimental study.

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