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Experimental Study on the Increased Cover Specifications in IS 456:2000 and the Resulting Crack Width Implications in RC Slabs for Mild and Moderate Exposure

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Abstract: **IS 456:2000 is the most influential and used code in India which plays a leading role related to concrete and reinforced concrete in many areas such as education, design, production, construction etc. Continuous research focuses on gaps in knowledge and the research findings renovate or alter existing codal provisions or add new provisions to raise the role of concrete industry to a higher level of performance. The general environment to which the concrete will be exposed is classified into five levels of severity, that is mild, moderate, severe, very severe and extreme in increasing degree of severity as per Cl 8.2.2.1 of IS 456:2000. A test programme was initiated to investigate the validity of the specified clause of code relative to durability. Of the five environmental exposure conditions, the first two exposure conditions namely mild and moderate cases are taken for investigation. The code specifies that if the detailing of reinforcement is as per code, the currently stipulated increased covers would not adversely affect the crack width development and ensures the durability of concrete. The reported test results show that mere adoption of detailing of steel reinforcement as specified in the code, ensuring durability, relative to crack growth is not totally valid.**

Keywords: **Crack width, concrete cover, durability, RC slabs.**

I. INTRODUCTION

Code IS 456:2000 is the most influential and extensively used code in India and plays a leading role in many ways related to concrete and reinforced concrete in the areas of education, research, design, production, construction, infrastructure projects, repair and retrofit. Although many would argue that change is counter to human nature, it is sometimes necessary to effect strategic change to make a measurable leap in efficiency and productivity. A test programme was initiated to investigate the influence increased concrete covers in reinforced concrete slabs, stipulated in the IS 456:2000 on the development of induced crack widths when the detailing of steel reinforcement is as per codal specification. The reported results reveal that mere adoption of detailing of steel reinforcement as specified in the code; ensuring durability relative to crack growth is not totally valid. When tensile stress in concrete exceeds its tensile strength crack forms. There are three reasons for limiting the crack widths in structures. These are: 1.Appearance 2.Durability and 3.Liquid tightness. These three requirements are not applicable simultaneously in a particular structure. Cracks greater than 0.3mm allow ingress of moisture and chemical attack to the concrete resulting in corrosion to steel reinforcement. In harmful or severe environments even lesser widths 0.2 and 0.1mm cause damage as per code.

Deterioration of concrete and corrosion of reinforcement have caused innumerable damages and even collapse of structures world over. This intolerable situation propelled research activity and necessitated conduct of conferences, seminars and discussions throughout the world to find ways and means to contain lack of durability. Durability has occupied centre stage in activities of concrete technology for a few decades. Consequently, it is not surprising that most of the important changes and additions in the most recent revision (4th revision) of IS 456:2000 deal with cement materials, construction of concrete structures and durability of concrete. The present code substantially enhanced nominal covers, depending upon the degree of environmental exposure. Similar revisions happened with other countries much earlier. Concrete covers have to be large and crack widths to be small for durability; these conflicting requirements are to be resolved rationally. Both the requirements of crack width and cover are to be coupled to meeting durability requirements.

If concrete is to serve the purpose for which it is designed during its intended lifetime it has to be durable. In the past use of working stress method in the design and steel reinforcement with characteristic yield strength of 250 MPa, developed low tensile stresses in the reinforcements at service loads. It is known in the laboratory investigations, cracking is generally proportional to the tensile stresses in steel. With low tensile stresses in the reinforcements at service loads, the structure exhibited limited low crack widths, and served their needed functions without any distress due to induced cracking; this helped preservation of durability in reinforced concrete structures. Clear cover is the distance measured from the exposure concrete surface to the nearest surface of the reinforcing bar. Code Cl 26.4.1 defines nominal cover as the design depth of concrete cover to all steel reinforcements including links. The cover is required to protect the reinforcing bars from corrosion and fire. Cover also gives the reinforcing bars sufficient embedment to enable them to be stressed without slipping. The cover varies from 20 to 75 mm as per environmental exposure condition.

The surface width of the cracks should not exceed 0.3mm in members where cracking is not harmful and does not have any serious adverse effects upon the preservation of reinforcing steel. In members where cracking in the tensile zone is harmful either because they are exposed to moisture or in contact soil or ground water, an upper limit of 0.2mm is suggested for the maximum width of cracks. For particularly aggressive environment, such as severe, very severe and extreme category in Table 3 of IS 456:2000, the assessed surface width of cracks should not exceed 0.1mm.

II. EXPERIMENTAL INVESTIGATION

A. Details of specimen and materials:

In the experimental programme undertaken, five full scale slabs, two in the mild and three in the moderate were designed to serve in these exposure conditions and tested under simply supported and uniformly distributed load. All the slabs were identical in geometry measuring 600mm in width and 2.8m in total length. The simply supported effective span was 2.5m. The overall depth of the slab varied in accordance with the exposure conditions. Mild exposure slabs were 100mm deep and moderate exposure slabs were 110mm deep. The minimum weight of the slab was 3.75kN, requiring 120kN crane for its transport. The nominal covers of the slabs were in accordance with those specified in Table 16 of the code, 20mm for mild exposure slabs and 30mm for moderate exposure slabs. As per code IS 456:2000 (Table 5), the properties of the concrete, the minimum cement content, maximum water cement ratio and minimum grade of concrete are respectively 300kg/m3 (3kN/m3), 0.55 and M20 for mild exposure case; and these were 300kg/m3 (3kN/m3), 0.50 and M25 for moderate case; these values were followed in the present investigation. For each exposure condition varying percentages of steel reinforcement starting with a minimum value to a possible maximum value were adopted.

The percentage of flexural reinforcement adopted varied from a minimum value, which is more than the minimum specified by the code, 0.12 percent of the total minimum cross sectional area with high strength deformed bars to near maximum permissible value. Spacing requirement of flexural reinforcement in slabs was in compliance with codal specification. As reinforcement detailing satisfied the codal requirements, the slabs should not violate the stipulated crack width requirements of the code. The distribution steel used was mild steel of 6mm dia bars.

The fine aggregate used was river sand conforming to zone-II with a specific gravity of 2.66 and fineness modulus of 2.15. The coarse aggregate was well graded combination of maximum size 20mm and 10mm in the ratio of 3:2; the specific gravity was 2.74. The slabs are designated by 2 letters and a numeral. Mild exposure slabs are MI1 and MI2 and the moderate exposure slabs are MO1, MO2 and MO3.

The laboratory floor was used as bottom plank and brick masonry partitions constituted side vertical forms, the brick masonry was plastered. Cement mortar cover blocks of adequate size and strength at needed spacing were provided to steel reinforcement. The concrete was machine-mixed and poured in slab moulds in two layers; each layer was vibrated with needle immersion vibrator and flat vibrator up to total depth of slab. The top surface of the slab was smoothened with trowel and all the slab specimens were kept under moist curing in the laboratory till the date of testing. For concrete compressive and tensile strength, adequate number of 150mm cubes and 150x300 mm cylinders respectively were cast and cured along with the test slab specimens.

B. Details of testing:

The slabs were tested in the laboratory. The load test set-up was constructed in the laboratory by erecting two pedestals of plan size 250x700mm separated by about 2.5m with a height of 750mm. The slabs were tested simply supported on an effective span of 2.5m. Total length of slabs was 2.8m. Sand bag loading was adapted as live load for testing. Sand bags each weighing 0.4 kN were laid on the top of the slab; in the span six bags were necessary touching each other. The width of the each sand bag was 600mm occupying the whole width of the slab. Each sand bag weighed 0.4 kN, 6bags touching each other occupied full span of 2.5m, weighed 2.4kN. Each layer of sand bags with a weight of 2.4kN was treated as one load stage. The slabs were instrumented for the measurement of deflection at mid-span and crack widths at each load stage. A hand held microscope with a least count of 0.1mm capable of measuring a minimum crack width of 0.05mm by judgement was used. A dial gauge was used under the slab at mid span; the least count of the dial gauge was 0.01mm. At each load stage maximum crack width, deflection and the total super imposed load on the slab were measured and noted. Cracks on both vertical side faces were marked and the maximum crack width was measured at each load stage. The slabs were tested to design ultimate load.

The slabs could not be tested to experimental ultimate load because of the inability to load with sand bags beyond a particular height. The load - crack width graphs and load-deflection curves for mild and moderate exposure case are drawn respectively.

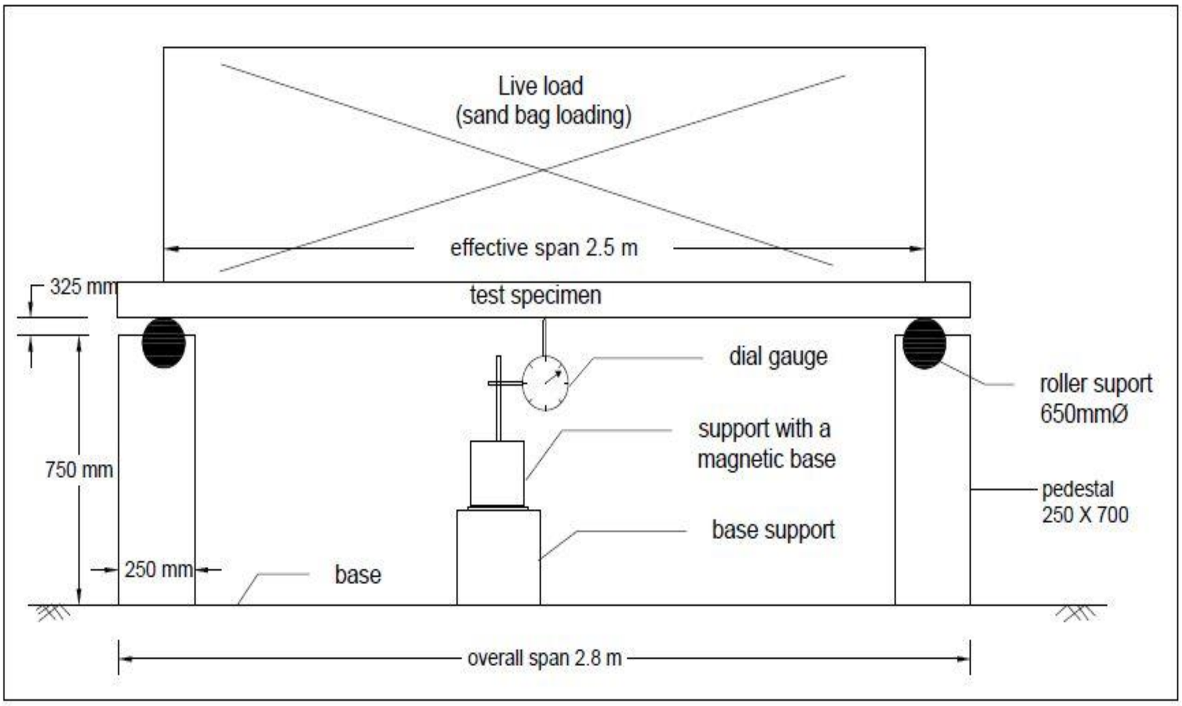

Fig.1 Schematic diagram of test setup

Table 1: Details of experimental programme

Exposure Condition	Slab Label	Slab depth Overall depth (mm)	Slab depth Effective depth (mm)	Nominal Concrete cover (mm)	Flexural reinforcement and spacing (mm)	Width of slab (mm)	Overall length of slab (m)	Effective Span of slab (m)
Mild	MI1	100	76	20	3 Nos of 8Ø - 221 c/c	600	2.8	2.5
	MI2	100	76	20	6 Nos of 8Ø – 106.4 c/c	600	2.8	2.5
Moderate	MO1	110	76	30	3 Nos of 8Ø - 221 c/c	600	2.8	2.5
	MO2	110	76	30	6 Nos of 8Ø – 106.4 c/c	600	2.8	2.5
	MO3	110	76	30	9 Nos of 8Ø – 66.5 c/c	600	2.8	2.5

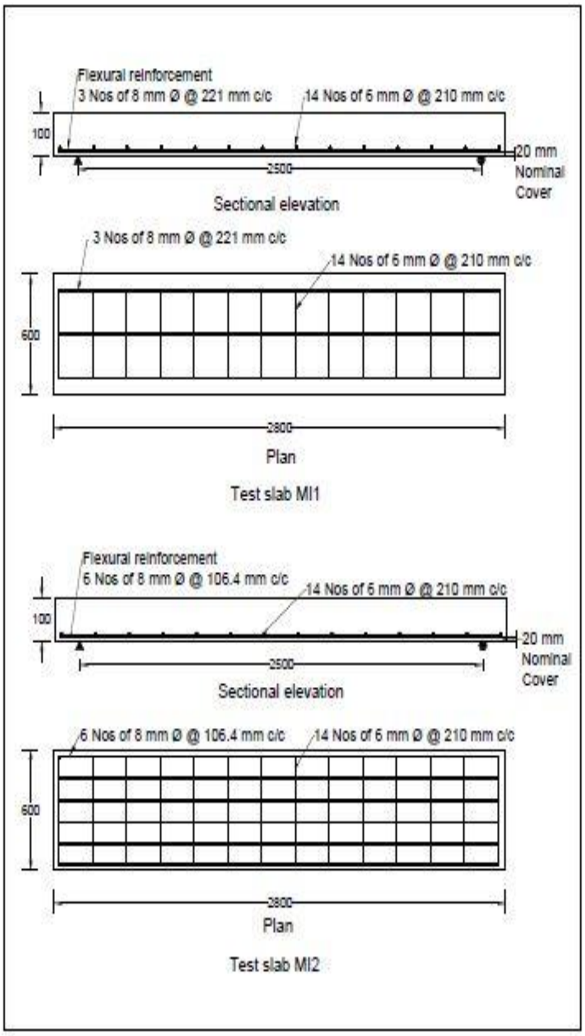

Fig.2 Reinforcement details of test slabs MI1 & MI2

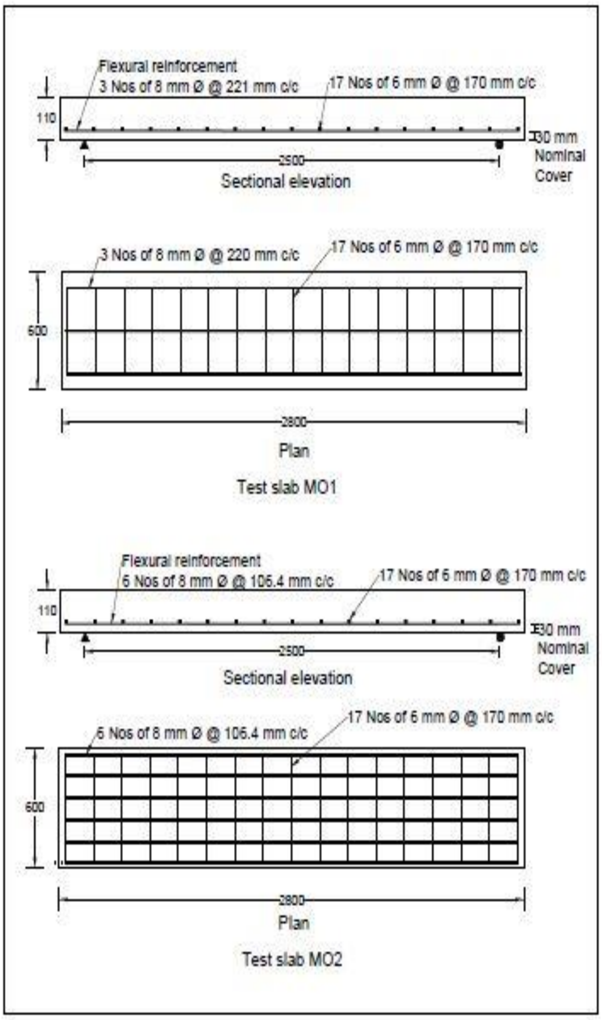

Fig.3 Reinforcement details of test slabs MO1 & MO2

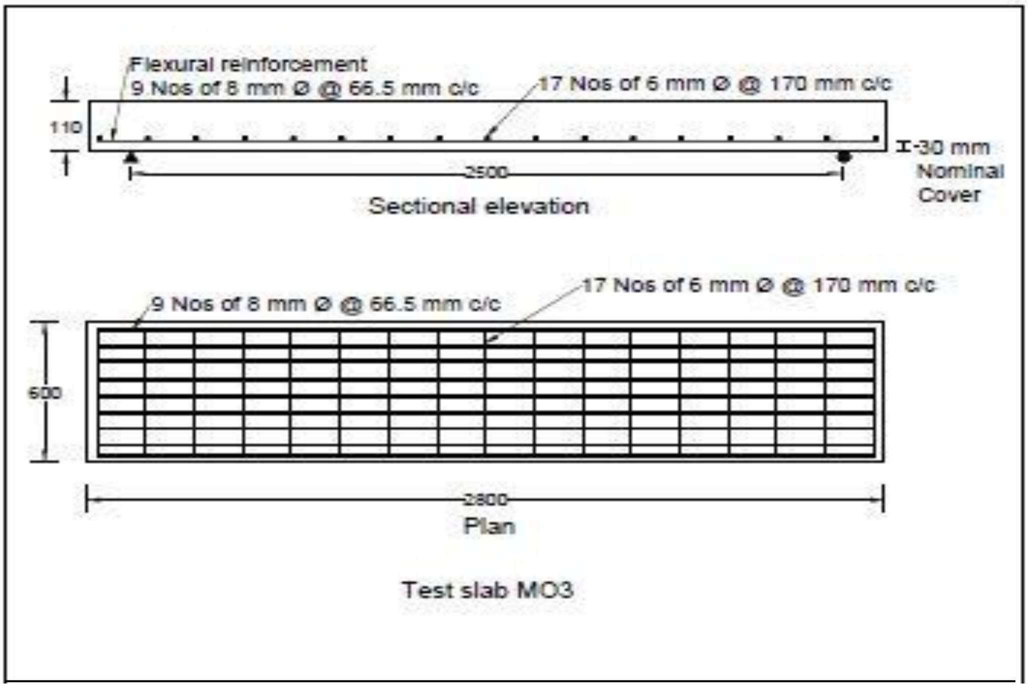

Fig.4 Reinforcement details of test slab MO3

Table 2: Details of loading on test slabs

Slab level	Type of exposure	Compressive strength at the time of slab testing (MPa)	Split tensile strength at the time of slab testing (MPa)	Dead load of slab (kN)	Intensity of dead load (kN/m^2)	Total design load at ultimate (kN)	Total design load at service (kN)	Design live load at ultimate (kN)	Design live load at service (kN)	Intensity of design live load at service (kN/m^2)
MI1	Mild	29.0	2.40	3.75	2.50	14.65	9.77	10.90	7.27	4.84
MI2	Mild	29.0	2.40	3.75	2.50	26.65	17.77	22.90	15.27	10.18
MO1	Moderate	36.2	2.54	4.13	2.75	14.93	9.95	10.80	7.20	4.80
MO2	Moderate	36.2	2.54	4.13	2.75	27.70	18.47	23.57	15.71	10.47
MO3	Moderate	36.2	2.54	4.13	2.75	38.38	25.59	34.25	22.83	15.22

Fig.5 Test load with sand bags for slab MI1

Fig.6 Test load with sand bags for slab MI2

Fig.7 Test load with sand bags for slab MO1

Fig.8 Test load with sand bags for slab MO2

Fig.9 Test load with sand bags for slab MO3

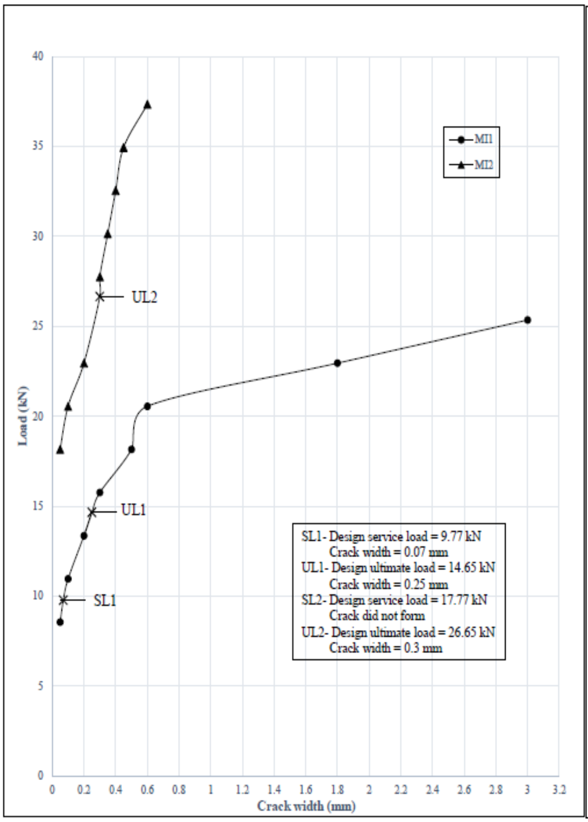

Fig.10 Load - Crack width curves of Mild exposure

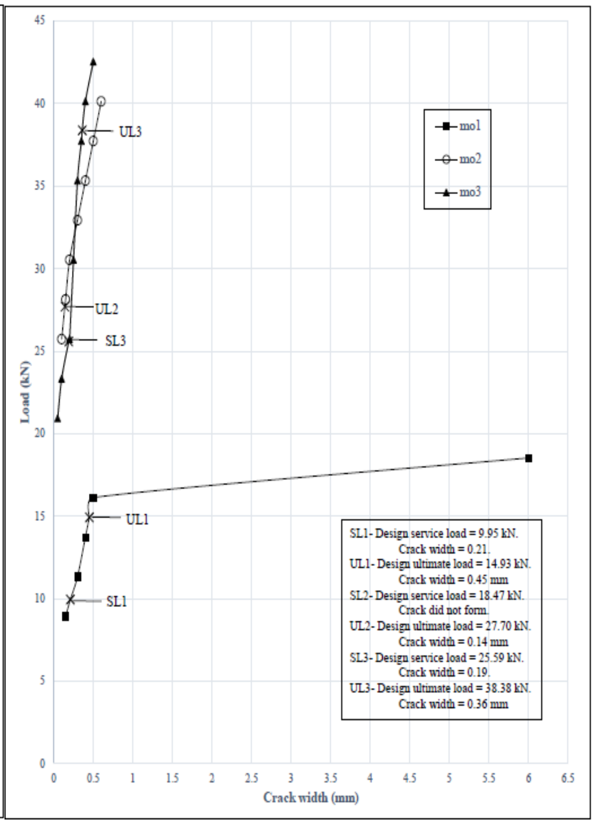

Fig.11 Load - Crack width curves of Moderate exposure

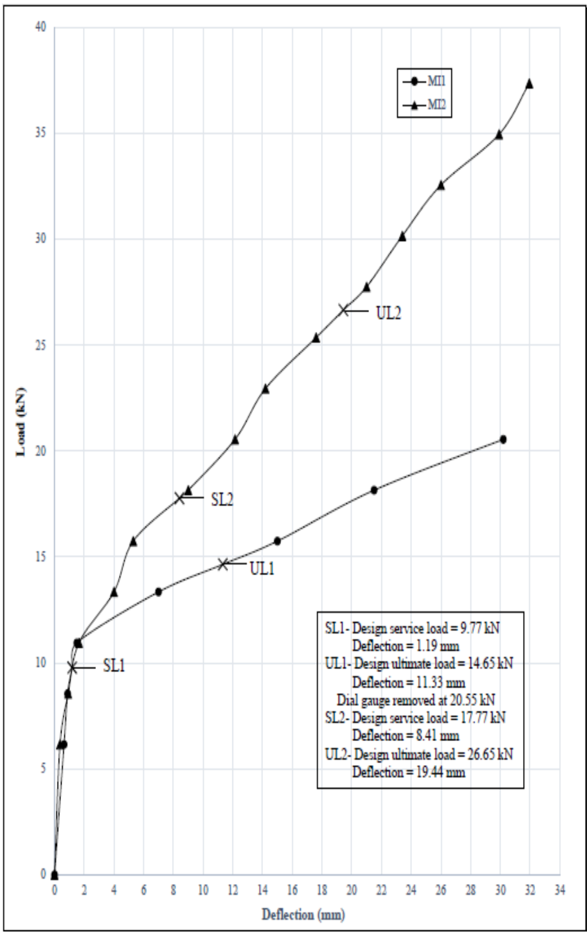

Fig.12 Load - Deflection curves of Mild exposure

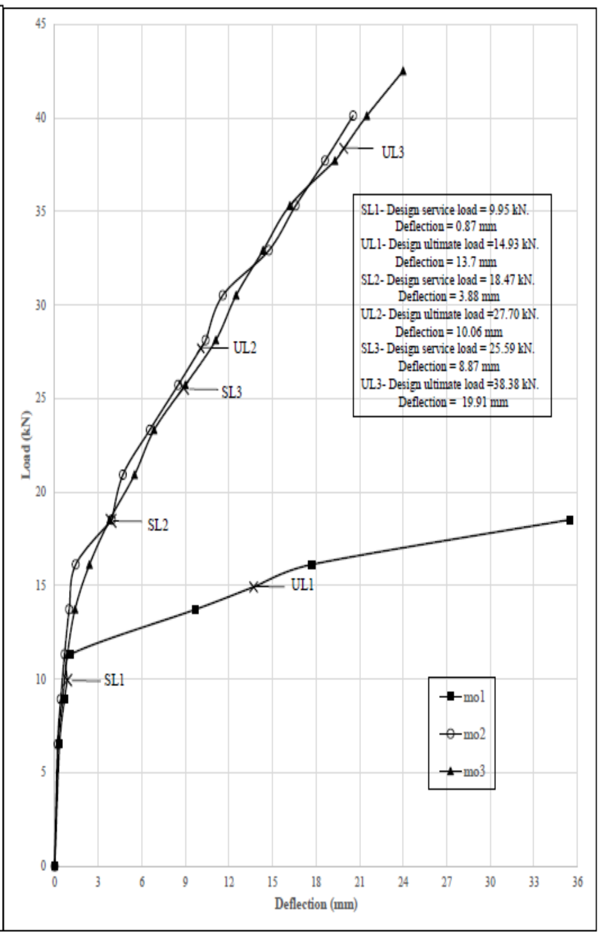

Fig.13 Load - Deflection curves of Moderate exposure

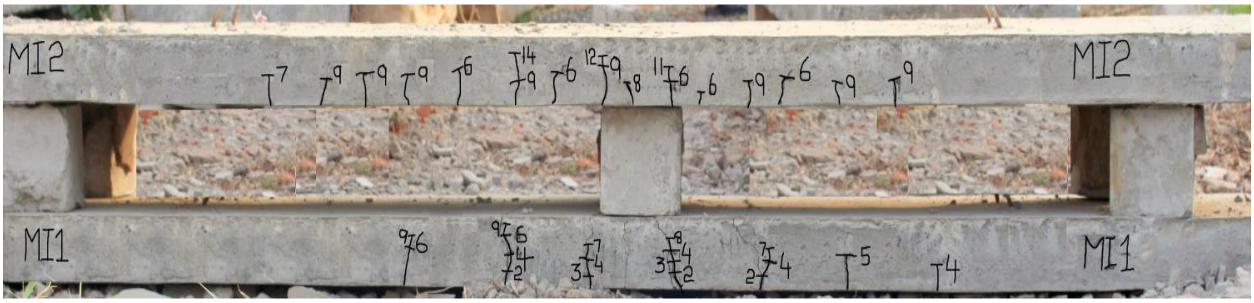

Fig.14 Crack width pattern for Mild slabs

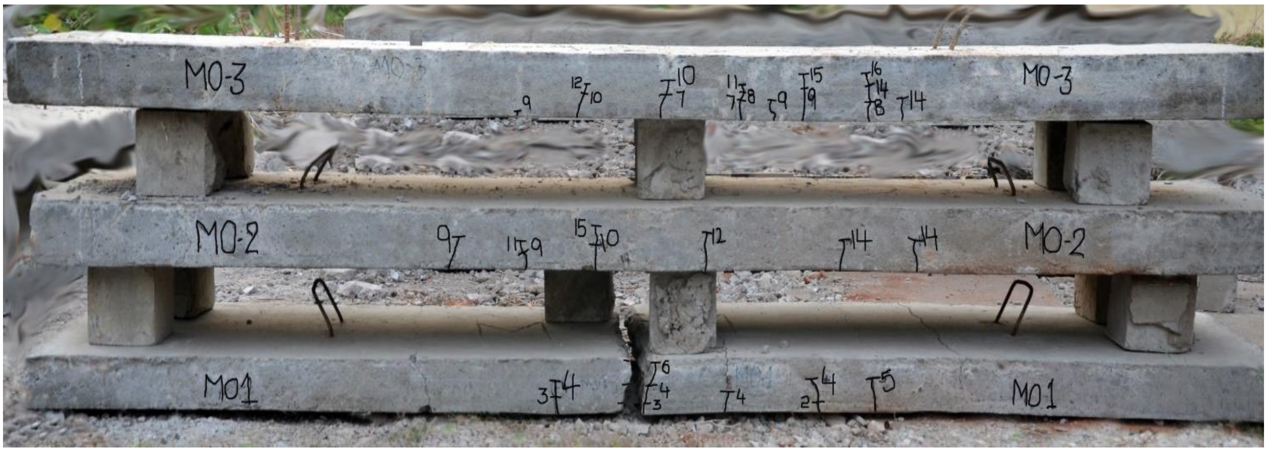

Fig.15 Crack width pattern for Moderate slabs

III. RESULTS & DISCUSSION

Table 3: Test results, loads & crack width

lab label	Load at 0.1mm crack width (kN)	Load at 0.2mm crack width (kN)	Load at 0.3mm crack width (kN)	Load at 0.4mm crack width (kN)	Load at 0.5mm crack width (kN)	Load at 0.6mm crack width (kN)	Design Service stage		Design Ultimate stage	
							Load (kN)	Crack width (mm)	Load (kN)	Crack width (mm)
MI1	10.95	13.35	15.75	16.95	18.15	20.55	9.77	0.07	14.65	0.25
MI2	20.55	22.95	25.35	32.55	35.75	37.35	17.77	No crack formed at service	26.65	0.30
MO1	———	9.73	11.33	13.73	16.13	16.17	9.95	0.21	14.93	0.45
MO2	25.73	30.53	32.93	35.33	37.73	40.13	18.47	No crack formed at service	27.70	0.14
MO3	23.33	25.73	35.33	40.13	42.53	———	25.59	0.19	38.38	0.36

Table 4: Comparison of theoretical and test crack widths at service load

Slab label	American code (mm)	IS code (mm)	Test Crack width (mm)
MI1	0.29	0.13	0.07
MI2	0.24	0.14	no crack
MO1	0.42	0.13	0.21
MO2	0.34	0.18	no crack
MO3	0.30	0.18	0.19

A. Mild exposure slabs:

Slabs, MI1 and MI2 assumed to occur in mild exposure are designed with increasingly varying flexural reinforcement for normally occurring loads in practice. To bear these design service live loads of 7.27kN and 15.27kN, respectively slabs MI1 and MI2 are designed ; the corresponding live load intensity on the slabs are 4.84 and 10.18kN/m2 . These intensities of load are representative of actual situations in practice such as residence, office, library, parking etc. The permissible crack width as per Cl 35.3.2 (IS 456:2000) for slabs situated in mild exposure is 0.3mm. Slab MI1 developed at service load of 9.77kN a crack width of 0.07mm which is less than the permissible 0.3mm. At loads of 10.95, 13.35 and 15.75kN the slab showed up crack widths respectively 0.1, 0.2 and 0.3mm indicating the slab is durable. At 0.3mm, the load resisted was far higher than the service load. Slab MI2 at its service load of 17.77kN, no crack was developed. In the earlier slab, 0.3mm crack width was obtained at 15.75kN and in the present case; the reason for no crack at 17.77kN closer to 15.75kN could be because of closer spacing of 8mm bars. For slab MI2 0.1, 0.2, 0.3mm cracks appeared respectively at loads 20.55, 22.95, 25.35 kN which is 50% more than the service load which indicates slab MI2 is durable.

B. Moderate exposure slabs:

MO1, MO2 and MO3are designed to serve in moderate exposure condition. In the case of moderate members an upper limit of 0.2mm maximum crack width was suggested by the code in Cl. 35.3.2 (IS 456:2000) and this exposure is specified as moderate.

Slab MO1 is similar to MI1with same amount of steel and bar spacing, same effective depth, larger slab thickness and higher concrete strength. Mainly larger cover resulted in a crack of 0.21mm (at service load of 9.95kN) larger than that of MI1; this crack width is more than the permissible crack of 0.2mm, rendering the slab undurable. It collapsed at a load of 20.93kN.

MO2 slab at service load 18.47kN did not show any crack due to more amount of steel and closer spacing of bars than in the slab MO1 might have resulted in no crack. 0.1mm wide crack formed at 25.73kN, slightly more than service load and 0.2, 0.3mm cracks are formed at loads 30.53 and 32.93kN respectively.

MO3 at service load of 25.59kN developed a crack width of 0.19mm which was less than 0.2mm, making it durable. 0.1, 0.2 and 0.3mm wide cracks formed respectively at loads 23.33, 25.73 and 35.33kN.

Crack widths, for the tested slabs, computed by American code overestimated the test values, while IS code underestimated in some cases.

IV. CONCLUSIONS

A. The experimental investigation undertaken has demonstrated that for mild and moderate environmental exposure conditions, the mere adoption of detailing of steel reinforcement, specified in the Cl. 26.3(IS 456:2000) would ensure durability relative to crack growth is not totally valid.

B. In mild exposure, both the slabs were durable. In moderate exposure, MO1 with minimum percentage of steel was only undurable. The other two slabs were durable.

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