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Research Article

STEEL FIBRE HIGH STRENGTH & ORDINARY CONCRETE SLABS UNDER PARTIALLY FIXED BOUNDARY CONDITIONS - AN EXPERIMENTAL STUDY

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ABSTRACT

In this study, one of the fairly known practical plate problems was investigated experimentally, a square plate laterally loaded with single concentrated load at mid-span under all edges fixed. Clamping was made continuously along the edges with a small quantity of rotation. This type of clamping could be called as partially fixed. High-strength and ordinary concrete slabs containing steel wire fibers (volumetrically 0.5% and 1.0%) were constructed and tested. Load-deflection relationships were investigated. One of the objectives of this study was to investigate the effects of support rotations. Rotations of supports at corresponding load values were also measured. Ordinary concrete slabs support rotation values were recorded relatively close compared to high strength specimens. Mechanical properties of high-strength concrete and steel fibers were examined. Fracture patterns of plates were presented. Collapse occurred because of adherence loss in all slab specimens.
Keywords: Steel fiber concrete, slab, high strength concrete.

1. INTRODUCTION

Plates are structural members with smooth surfaces. The thickness is quite small as compared to the other two dimensions (length and width). They provide living spaces in buildings. Plates are defined pursuant to mid-plane separating the plate into two halves along the thickness of the plate and they bear loads perpendicular to that surface. The loads acting on a point are called as concentrated loads or point loads. Following the loading, internal forces are generated within the plate as presented in Fig. 1.

Plate equation is written as;

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} \equiv \Delta\Delta w = \frac{p}{D} \tag{1}$$

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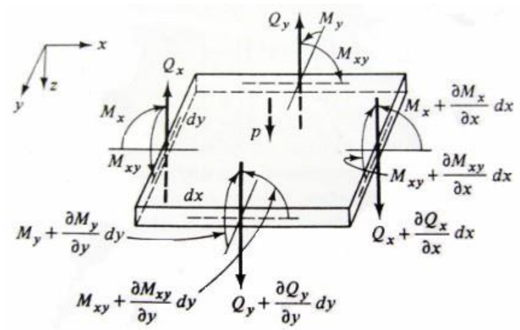

Figure 1. Internal forces generated within a plate [1,2]

This equation is a biquadratic partial differential equation and the equation is solved based on boundary conditions and loads. Type of support designates the boundary conditions. Support types and boundary conditions for plates are provided in Table 1. The symbol "ψ " used in partially fixed support expresses the angle of rotation. It is assumed for partially fixed supports that there is no vertical displacement, but a fair amount of elastic rotation. Partially fixed edges produces extra deflection capability and additional load bearing capacity. Boundary conditions affect slab load bearing behaviour. The publications [3,4,5,6,7] are considered with boundary conditions in slabs are investigated.

Table 1. Support types and boundary conditions [1,2]

Support types	Boundary conditions
Simple support	$(w)_{x=a} = 0;\ (M_x)_{x=a} = \left(\frac{\partial^2 w}{\partial x^2} + \nu \frac{\partial^2 w}{\partial y^2}\right)_{x=a} = 0$
Fixed support	$(w)_{x=a} = 0;\ \left(\frac{\partial w}{\partial x}\right)_{x=a} = 0$
Partially fixed support	$(w)_{x=a} = 0;\ \left(\frac{\partial w}{\partial x}\right)_{x=a} = (p^{\psi})^{-1} D\left(\frac{\partial^2 w}{\partial x^2} + \nu \frac{\partial^2 w}{\partial y^2}\right)_{x=a}$

1.1. Steel-Fibre Concrete

Steel-fibred concrete has quite wide range use including tunnels, structural members subjected to cyclic loads like dynamic loads, quarries, drilling operations, prefabricated structural members, slope stabilizations, repair and reinforcements, hopper walls, airport landing strips, shell structures, breakwaters constructed along the coasts and several other places and operations. Implementations are made with or without reinforcement.

Steel fibers are among the commonly used additives in concrete. Various utilization ratios were indicated in literatures ranging between 0.33 – 5.0% [8,9,10,11]. Steel fiber reinforcement may yield positive outcomes in structural members subjected to torsional forces. Number of cracks increases, but crack widths decrease with the use of steel fibers. Such a case have brought into mind that steel fibers could be used to control cracks in reinforced concrete structural members. Steel fibers may increase elasticity of structural members subjected to torsional forces [12,13]. fibers may yield positive outcomes also in composite slab systems. Steel fibers are used in slabs at different lengths and load bearing capacity increases with increasing fiber lengths. Crack resistance increases and deflections decrease with the use of steel fibers. The publications

[14,15,16] also investigated. The width of shrinkage cracks also decrease, compressive and tensile strengths increase, toughness, rigidity and elasticity are improved with the use of steel fibers. Steel fibers used in concrete additives should not be lumped and be evenly distributed within the concrete mixture [8,17].

1.2. Objective of the study

The primary objective of the present study is to investigate the behavior of two slabs with different dimensions (660x660x40 mm and 1080x1080x40 mm), produced with high-strength and ordinary concrete supplemented with 0.5 and 1% steel fiber (in volume) under partially fixed support conditions.

2. EXPERIMENTS

2.1. Experimental set up

In this study, one of the fairly known practical plate problems was investigated, a square plate laterally loaded with a single concentrated load at mid-span under all edges clamped. Clamping was made continuously along the edges. Experimental set up was prepared by using U140 (h=140 mm) steel profiles. Profiles were perforated at 400 mm spacing along their axis of symmetry to attach the profiles on to steel rods. Plates were placed between two U140 profiles along the plate edges and then attached. Attachments were made only along the axis of symmetry of the profiles. Therefore, a small quantity of rotation was allowed along the clamping and thus the plates with this type of side clamping were called as partially fixed (Fig. 2 and 3).

Figure 2. Loading piston and load-cell

Figure 3. Test set up

2.1.1. Deflection measurements

Load-Deflection relationships were measured. One of them was at the mid-span, the others were on the symmetry axes and far from the boundaries by one-fourth of the length of plate. Deflection measurements were made at 5 points in 660x660mm free-span plates and 9 points in 1060x1060 mm free-span plates. (Fig. 4 and 5).

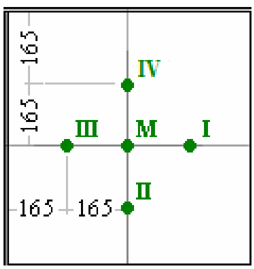

Figure 4. Deflection measurement points for 660x660 mm free-span slabs

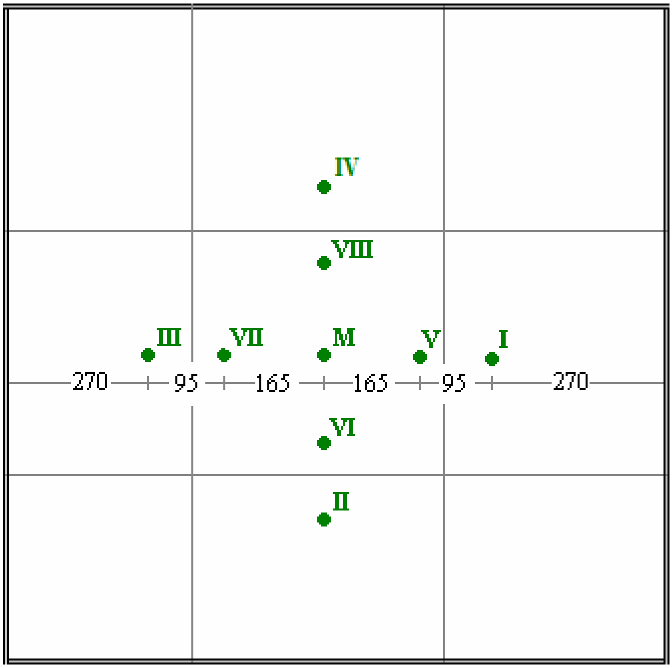

Figure 5. Deflection measurement points for 1060x1060 mm free-span slabs

2.1.2. Mechanical properties of steel fibers

Dimensions and mechanical properties of the steel fibers used in this study are provided in Table 2 and their images are presented in Fig. 6.

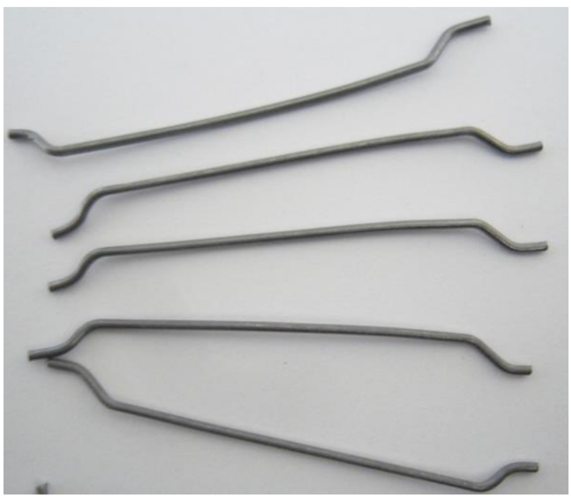

Figure 6. Steel fibers

Table 2. Mechanical properties of steel fibers

Fiber type	Length (mm)	Diameter (mm)	Length/Diameter	Unit Weight (g/cm^3)	Tensile Strength (MPa)
RC 80/60	60	0,75	80	7,85	1100

2.1.3. Aggregate, Concrete and Cement

Limestone was used as the aggregate in this study. Physical properties of the aggregate are provided in Table 3 and concrete mixture ratios are provided in Table 4.

Table 3. Physical properties of aggregate

Aggregate Size	Loose Unit Weight (kg/m^3)	Specific Gravity (kg/m^3)		Water Absorption (%)
		Dry	Saturated	
Coarse (>4mm)	1435	2712	2692	0,49
Fine (<4mm)	1486	2668	2685	0,55

Table 4. Properties of Concrete Mix

Fiber Concrete	Cement Type	Cement dosage (kg/m^3)	Water to Cement Ratio	Aggregate (kg/m^3)	Silica fume (kg/m^3)	Admixture %	Water absorption %	Fiber Ratio to total volume %
High Strength	Cem I 42,5 R	500	0,30	1737	50	2	1,52	0,50 1,00
Ordinary	Cem III 32,5R	350	0,50	1737	-	2	1,52	0,50 1,00

Concrete compressive strengths were measured for each mixture and stress-strain curves were generated. A strain-gage used in strain measurements in uniaxial compression tests of universal testing device.

2.1.4. Support rotation measurements

Support rotations were measured on all edges of partially fixed support. Since the supports were bolted tightly from the top and bottom, it was assumed that there were no vertical displacements, but a slight rotation around the supports. Therefore, support rotations were determined with the aid of an displacement transducer placed 25 mm from the side of the profile. The measurement process is presented in Fig. 7.

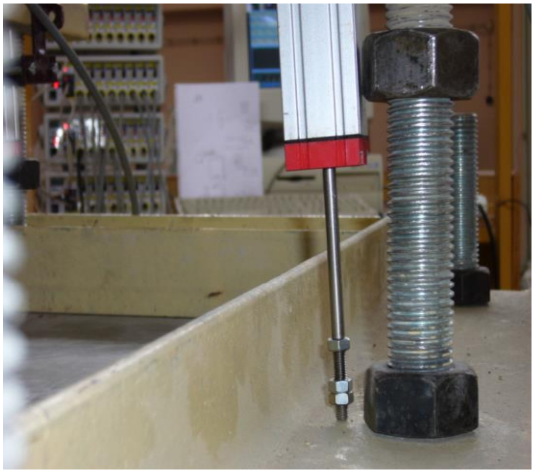

Figure 7. Support rotation measurements

2.2. Test plan

Sizes of slab samples were given in Table 5. All slabs were tested under all edges partially fixed boundary conditions.

Table 5. Properties of slab samples

Fibre (vol.%)	Concrete	Name	Size(mm)
0,50	High strength steel fiber concrete	AL4	900x900x40
		ALB4	1300x1300x40
1,0		AL4I	900x900x40
		ALB4I	1300x1300x40
0,50	Ordinary steel fiber concrete	AGL4	900x900x40
		AGLB4	1300x1300x40
1,0		AGL4I	900x900x40
		AGLB4I	1300x1300x40

3. TEST RESULTS

Compressive strengths of steel-fibred concretes are provided in Table 6 and stress-strain curves of concrete specimens supplemented with 0.5 and 1% steel fiber are presented in Fig. 8 and 9 for high strength concrete. Fig. 10 and 11 are for ordinary concrete including 0.5 and 1% steel fiber.

Table 6. Compressive strengths of experimental slabs

Material	Slab	f_{cm} (MPa)	Std. deviation	f_{ck} (MPa)
High strength steel fiber concrete	AL4	78,4	6,4	70,2
	ALB4	80,4	6,3	72,3
	AL4I	83,3	6,1	76,5
	ALB4I	82,2	6,0	74,5
Ordinary steel fiber concrete	AGL4	42,8	5,1	36,3
	AGLB4	41,9	4,9	35,7
	AGL4I	46,7	4,5	40,9
	AGLB4I	43,2	5,2	36,5

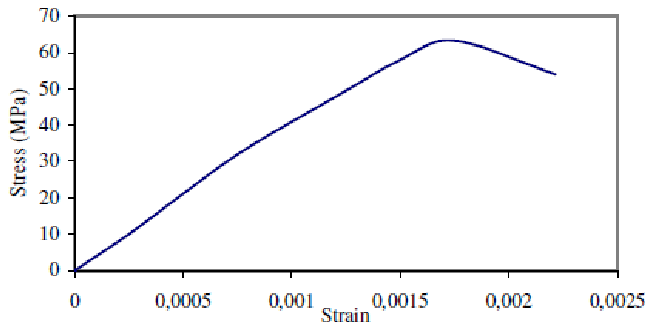

Figure 9. Stress-strain curve for high-strength (1.0% fiber) concrete

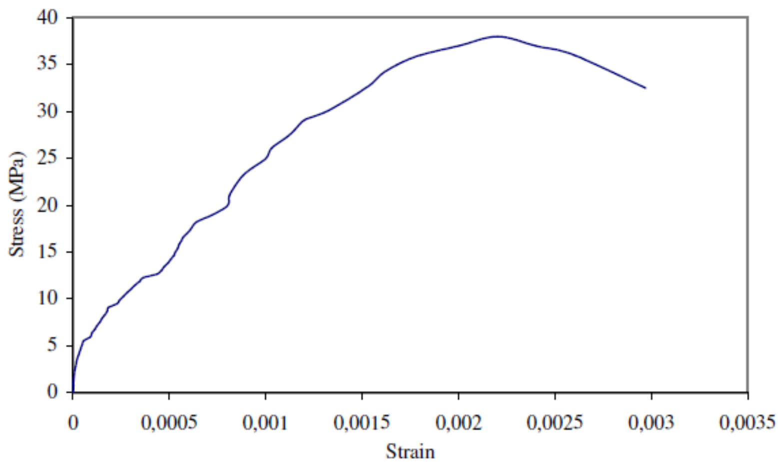

Figure 10. Stress-strain curve for ordinary (0.50% fiber) concrete

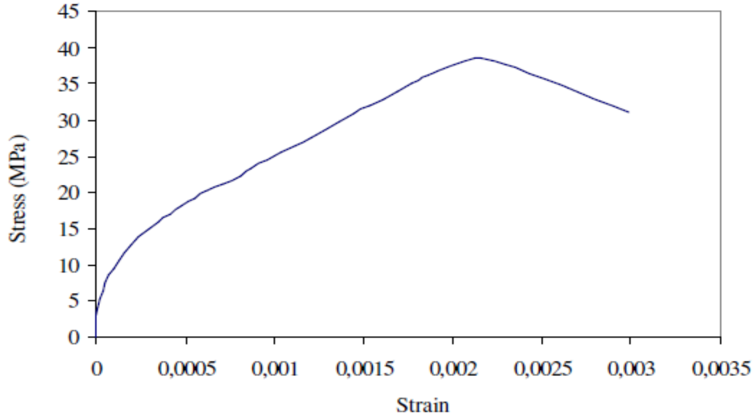

Figure 11. Stress-strain curve for ordinary (1.0% fiber) concrete

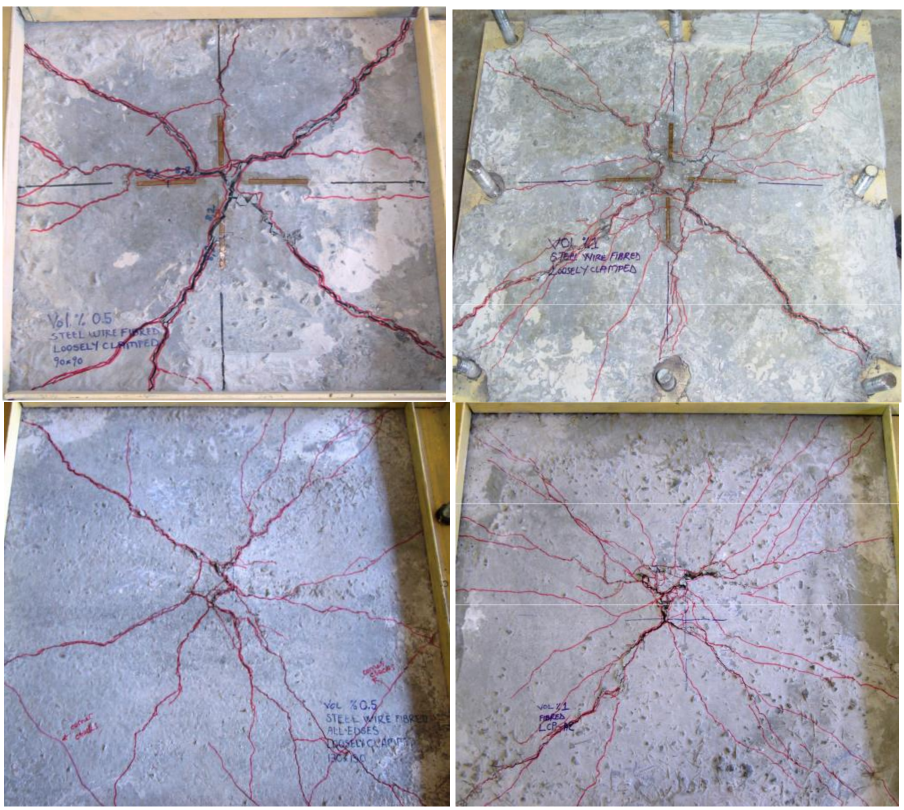

Figure 12. Fracture mechanisms of the high strength fiber concrete test slabs[18]

Fracture mechanisms of the experimental slabs are presented in Fig. 12 for high strength and Fig. 13 for ordinary fiber concrete, respectively. Loading was performed with a concentrated load at mid-span. Experiments were terminated when the cracks reached to the edges. Cracks were marked to make them clear

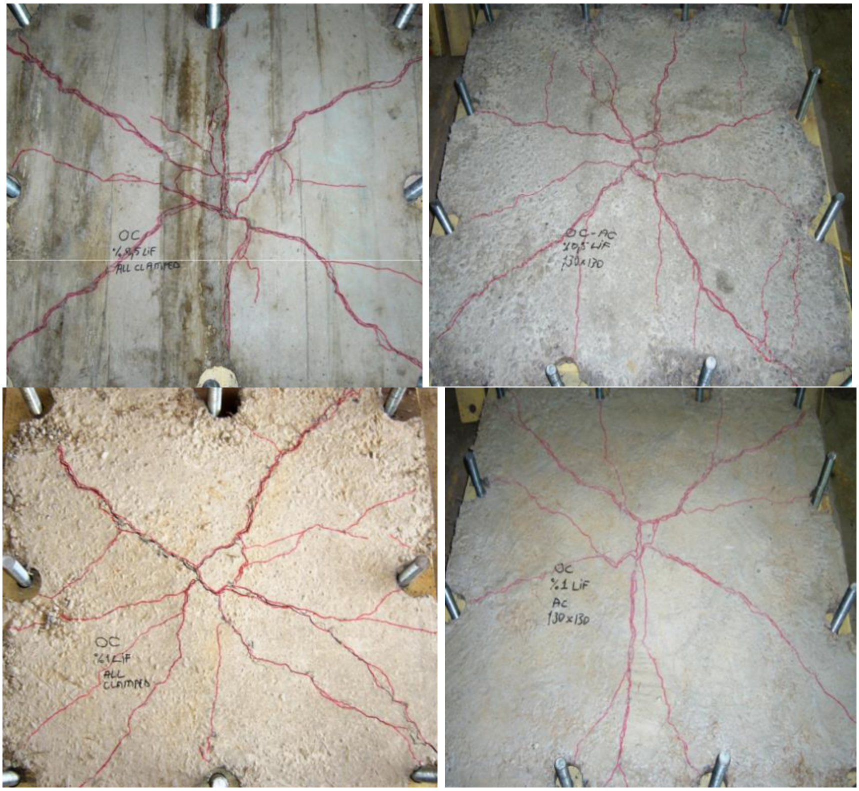

Figure 13. Fracture mechanisms of the ordinary fiber concrete test slabs[18]

Load -deflection curves of the test slabs are presented in Fig. 14 to 17 for high strength, Fig. 18 to 21 for steel fiber ordinary concrete slabs, respectively.

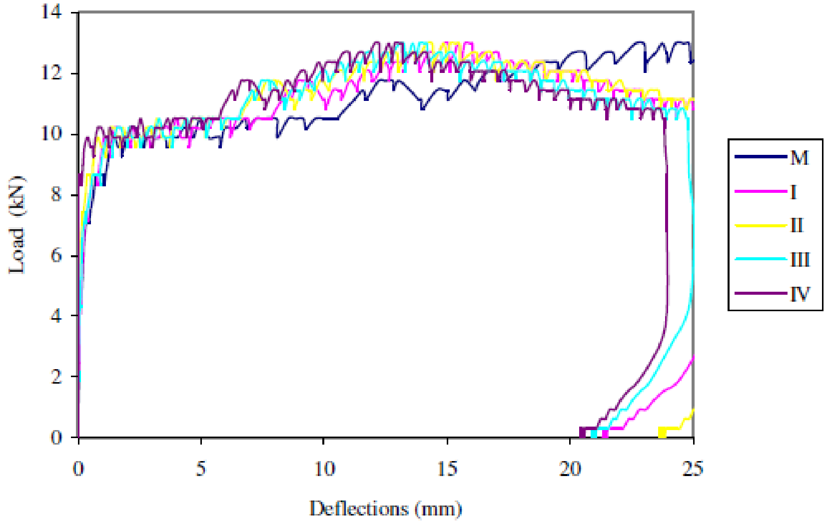

Figure 14. Load-deflection behavior of AL4

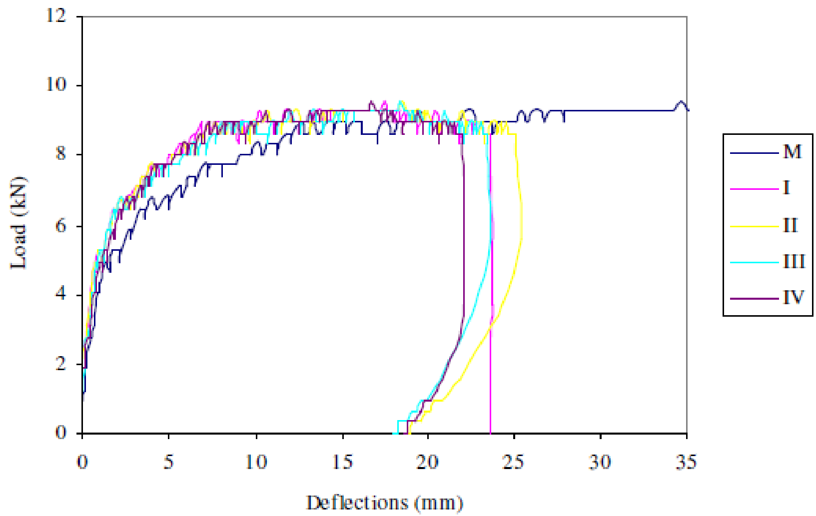

Figure 15. Load-deflection behavior of ALB4

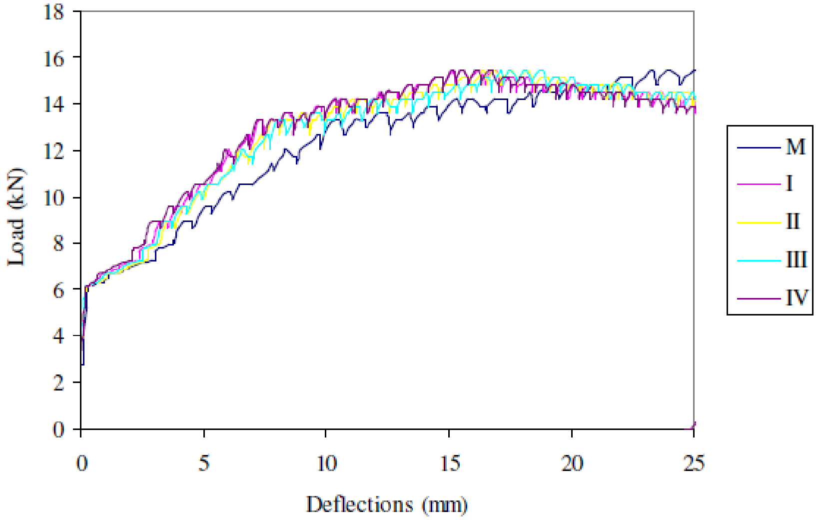

Figure 16. Load-deflection behavior of AL4I

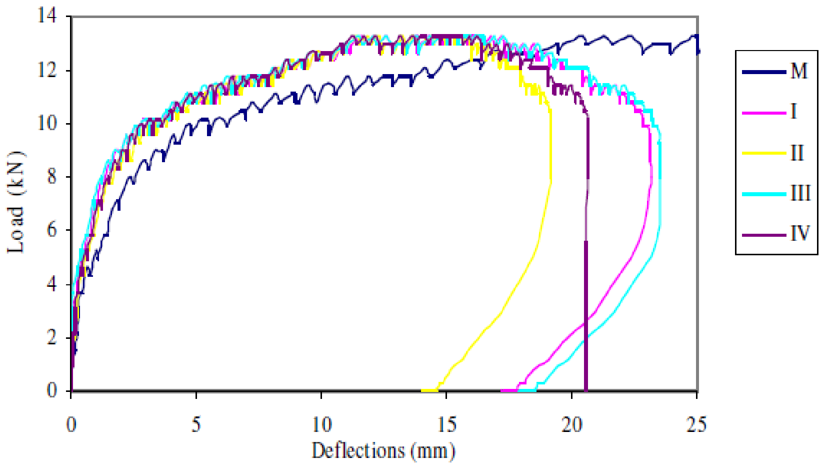

Figure 17. Load-deflection behavior of ALB4I

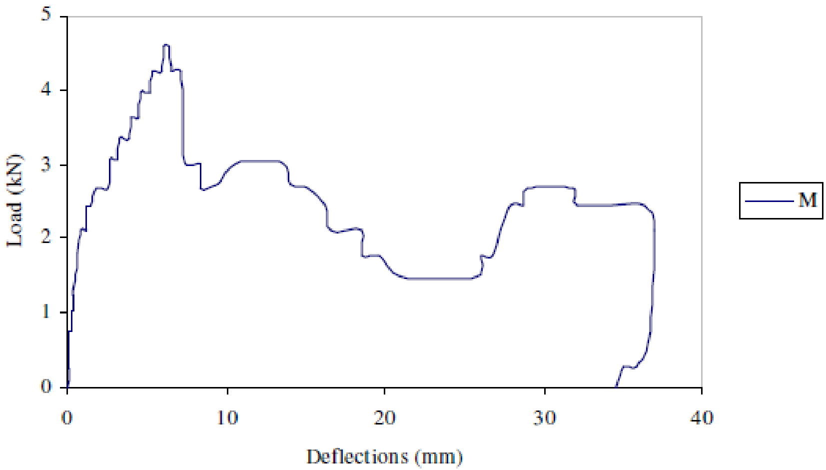

Figure 18. Load-deflection behavior of AGL4

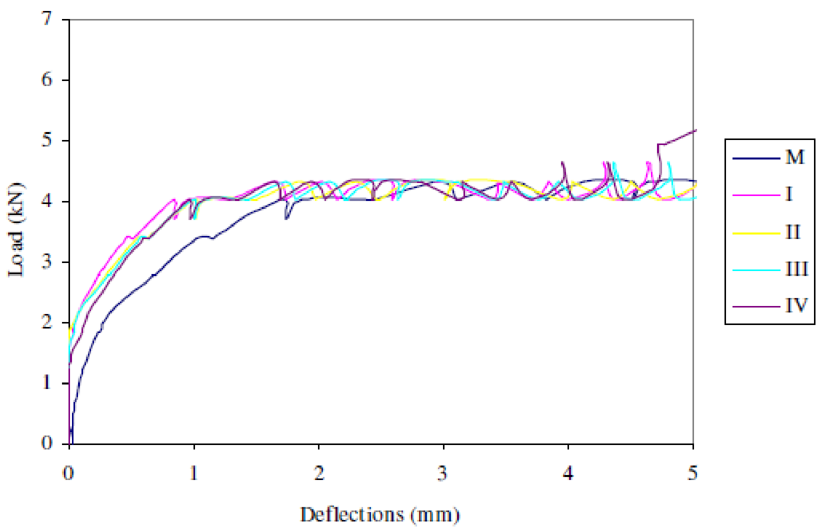

Figure 19. Load-deflection behavior of AGLB4

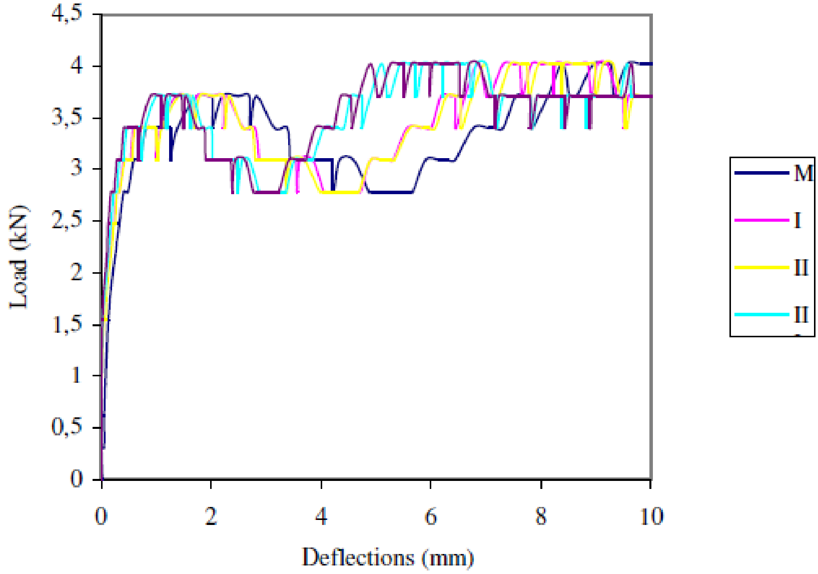

Figure 20. Load-deflection behavior of AGL4I

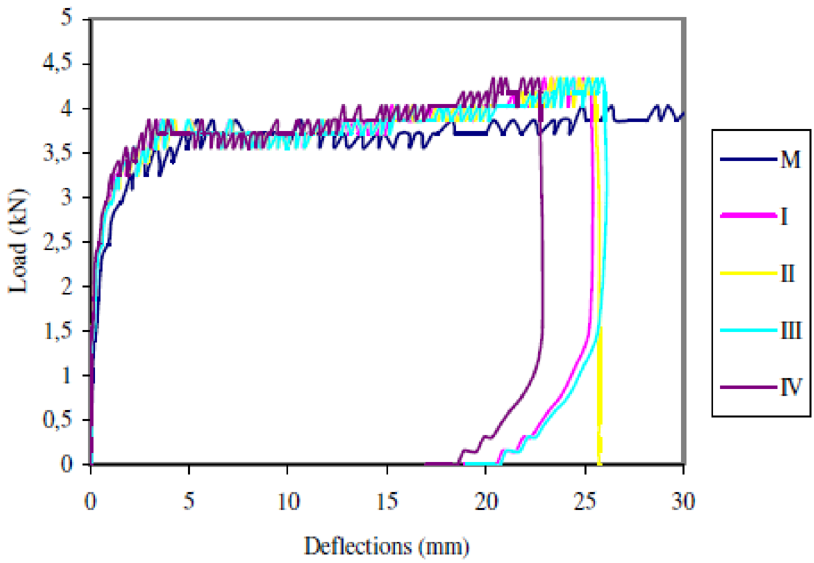

Figure 21. Load-deflection behavior of AGLB4I

Maximum values of the test results are provided in Table 7. As can be inferred from the table, slab rigidity increased with increasing fiber content for high strength test specimens, thus the rotations at the edges also increased. Such a case can clearly be seen when the same-size but different fiber-ratio slabs of AL4 - AL4I and ALB4 - ALB4I were compared. Ordinary concrete specimens maximum failure load value recorded as 4,59 kN for AGL4 (0,5% fibred) specimen.

Table 7. Test results and maximum values

Material	Slab	f_{ck} (MPa)	f_{ctk} (MPa)	Failure Load (kN)	$M_r = f_{ctk} \frac{l h_f^2}{6}$ (kNm/m)	Maximum support rotations (radians)
High strength concrete	AL4	70,2	3,08	12,98	0,821	0,024
	ALB4	72,3	3,12	9,58	0,832	0,011
	AL4I	76,5	3,20	15,45	0,853	0,031
	ALB4I	74,5	3,16	13,29	0,843	0,016
Ordinary concrete	AGL4	36,3	2,11	4,59	0,562	0,007
	AGLB4	35,7	2,09	4,01	0,557	0,006
	AGL4I	40,9	2,23	4,02	0,594	0,006
	AGLB4I	36,5	2,11	3,71	0,562	0,005

Mr represents the first cracking moment. After the first crack, there was no significant change in ultimate load capacity. Collapse occurred because of adherence loss. It is impossible to build undeformable fully rigid support by using the present technology. It was assumed in this study that clamped edges did not have any vertical displacements, but had slight rotations around the supports. One of the objectives of this study was to investigate the effects of support rotations. Support rotations varied between 0.024 – 0.031 radians in 660x660 free-span slabs and between 0.011 – 0.016 in 1060x1060 mm free-span slabs. Ordinary concrete slabs support rotation values were relatively close compared to high strength specimens.

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