# Experimental study on deformation behavior of partially restrained steel fiber reinforced high strength SCC two way rectangular slabs.

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**Abstract** – *It is a well-known fact in structural engineering that the actual load carrying capacity of restrained RC slabs is much higher than that calculated using yield line analysis. This load enhancement is attributed to a phenomenon called 'compressive membrane action' (CMA). There have been many researches in the past which include both experimental and analytical studies on how percentage of reinforcement, support conditions, shape of slab, aspect ratio of slab, coefficient of orthotrophy of reinforcement, grade of concrete, type of load affect the load enhancement due to CMA. This paper investigates experimentally the effect of 'steel fiber reinforced high strength sel-compacting concrete' (SFHSSCC) in the deformation behavior of two way rectangular slabs with three edges fixed and one long edge free under simulated uniform loading. SFHSSCC is considered to be a very important material in the field of structural engineering in recent decades. High toughness, high ductility, high residual strengths after first crack and improved workability are the main advantages of using SFHSSCC. In the present study a total of eight slabs (1mx1.5m) 75mm thick were cast and tested under simulated uniform loading using sixteen-point load disperser. Four slabs were of high strength traditionally vibrated concrete (SFHSTVC) and other four were of high strength self-compacting concrete. All four slabs in each group had fixed conventional reinforcement along with steel fiber reinforcement of 0.25%, 0.5%, 0.75% and 1% respectively for first to fourth slabs. The experimental investigation included determining central deflections and crack width at different stages of loading, ultimate load carrying capacity, partial safety factors and comparing them with theoretical results and Indian codal provisions. It is concluded that SFHSSCC slabs behaved almost similar to SFHSTVC slabs and load enhancement due to CMA increased with increase in fiber percentage.*

*Key Words: Compressive membrane action (CMA), SFHSSCC, Johansen's ultimate load, load enhancement, Partial safety factors.*

## 1. INTRODUCTION

Reinforced concrete two way slabs is an efficient, economical structural component in any structural frames used in buildings, bridges, flyovers, etc. The slab behavior is fundamentally based on its edge's fixity which occurs as simple supports, partially restrained supports and fully restrained supports. Modern structural systems are highly complex in configurations and are highly stressed due to heavy loadings and large spans. This results in larger sections for structural members and thus dense reinforcements to resist forces with normal strength concrete which in turn increases the dead weight on the foundation. Therefore the use of high strength self - compacting concrete (HSSCC) elements ($f_{ck}$>50Mpa) for concrete structures has proven very popular in recent years. The three important properties of HSSCC are

1) Filling ability- ability to fill all areas and should reach the nooks and corners into which it is placed.
2) Passing ability- Its ability to pass through congested reinforcement without segregation of the constituents or blocking.
3) Resistance to segregation – Its ability to retain the coarse components of the mix in suspension in order to maintain a homogenous material.

Generally for structural applications, steel fibers should be used in a role supplementary to conventional reinforcement and inclusion of fibers in a conventionally reinforced member is primarily not for strength increase, as this strength increase can be more easily and economically obtained by bar reinforcement. When the fiber reinforcement is in the form of short discrete fibers, they act effectively as rigid inclusions in the concrete matrix. Physically, they have thus the same order of magnitude as aggregate inclusion.

Steel fiber reinforcement therefore can't be regarded as a direct replacement for longitudinal reinforcement in RC members. However due to its inherent properties, the presence of steel fibers in the body of concrete can be expected to improve resistance to cracking, deflection and other serviceability conditions. The uses of Steel fiber reinforced concrete (SFRC) over the past thirty years have been so varied and so widespread, that it is difficult to categorize them. The most common applications are pavements, tunnel linings, pavements and slabs, shotcrete, airport pavements, bridge deck slab repairs and so on.

The advantages of HSC, SCC and SFRC can be effectively utilized in structural applications if all these are used as one unit. That is steel fiber reinforced high strength self-compacting concrete (SFHSSCC). Off late many researchers are showing inclination to study SFHSSCC. Some works on SFHSSCC have been reported, and is becoming a hot topic for researchers, due to its tremendous potential in construction use. Hence this research work is an endeavor in this direction.

In the calculation of the ultimate loads of two-way reinforced concrete slabs, the yield line theory accredited to A.Ingerslev[1] and extended by K.W Johansen[2] has been widely adopted. This theory does not include the effect of forces in the plane of the slab and under-estimates the ultimate loads of slabs when in-plane compressive forces are present because the compression enhances the ultimate moment of resistance of the section. In the common case of a lightly reinforced slab the large shift of the position of the neutral axis which occurs with cracking; causes a tendency for the edges of the slab to move outward as the slab deflects further. If the edges are restrained against outward movement, compressive forces are induced in the plane of the slab which increases the load carrying capacity of slab. This phenomenon is called as 'compressive membrane action' (CMA).

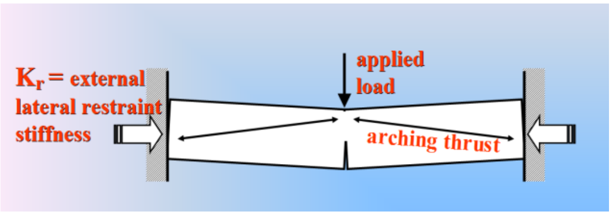


Fig -1: Compressive membrane action

There have been many researches [3][4][5] in the past which include both experimental and analytical studies on how percentage of reinforcement, support conditions, shape of slab, aspect ratio of slab, coefficient of orthotropy of reinforcement, grade of concrete, type of load affect the load enhancement due to CMA. This paper investigates experimentally the effect of 'steel fiber reinforced high strength sel-compacting concrete' (SFHSSCC) in the deformation behavior of two way rectangular slabs with three edges fixed and one long edge free under simulated uniform loading.

## 2. SCOPE OF STUDY

An experimental work was intended, with the below mentioned scope of study for a uniformly distributed simulated loading through a specially fabricated load disperser for this work.

(a) To obtain the mix proportion for $M_{70}$ HSTVC by perumal's method and HSSCC by Nansu's method.
(b) To study the strength and deformation behavior of high strength traditionally vibrated concrete (HSTVC) and high strength self-compacting concrete (HSSCC) rectangular slabs with three sides fixed and one end free.

(c) To study the effect of fibers on central deflections in the slabs.
(d) To study the deflections and crack widths at various stages of loading like initial cracks, loads, working loads and ultimate loads in these slabs. To compare these with the Indian codal provisions and obtain partial safety factors for deflections and maximum crack widths for HSTVC and HSSCC slabs.
(e) To study and compute the load enhancement for different fiber content in the slabs over the crack loads and yield line loads called Johansen's load.

## 3. METHODOLOGY

Total number of eight 1m x 1.5m, 75mm thick, three edges fixed and one long edge free slabs were cast and tested. Four slabs were of HSTVC and four slabs were of HSSCC .The effective short span was 900 mm, while the effective long span was 1400 mm, resulting in an aspect ratio of 1.55. The slabs were extended by 50 mm on all four sides beyond the supports. The steel fiber quantity was varied with the various percentages i.e., 0.25%, 0.5%, 0.75% and 1% for each slab. The conventional reinforcement in longer span and shorter span was kept constant as 0.21% (Spacing of steel was 150 mm in both directions). 5mm dia tor kari steel with yield strength 550N/mm$^2$ and Crimped steel fibers with aspect ratio 33 were used as conventional and fiber reinforcement respectively.

### 3.1 Mix design

Grade of concrete for all slabs was $M_{70}$. Mix design method for HSTVC was obtained from Perumal[6] and for HSSCC from Nansu [7]. After a number of trial mixes, the final mix proportions were arrived for HSTVC and HSSCC which are listed in the following tables.

Table -1: Mix proportions for HSTVC.

| Particulars | Quantity | Unit |
|---|---|---|
| Cement OPC 53 | 450 | Kg/m³ |
| Fine aggregate | 705 | Kg/m³ |
| Coarse aggregate | 1000 | Kg/m³ |
| Silica fume | 50 | Kg/m³ |
| Water | 150 | Kg/m³ |
| Super plasticizer | 12.5 | Kg/m³ |

Table -2: Mix proportions for HSSCC.

| Particulars | Quantity | Unit |
|---|---|---|
| Cement OPC 53 | 400 | Kg/m³ |
| Fine aggregate | 834.4 | Kg/m³ |
| Coarse aggregate | 768.88 | Kg/m³ |
| Fly ash | 142.62 | Kg/m³ |
| Water | 179.35 | Kg/m³ |
| Super plasticizer | 9.22 | Kg/m³ |
| VMA | 0.2% of cementitious material | |

Fig -2: Crimped steel fibers

Fig -3: Mold for casting slabs.

### 3.2 Test setup

Slabs were fastened to a supporting frame using 450mm long 16mm dia anchor bolts to achieve the fixed support condition. The loading arrangement consisted of specially fabricated sixteen-point load disperser to simulate uniformly distributed load along with a hydraulic jack of 500KN capacity. The vertical deflections were measured using strain gauge and crack width with microscope.

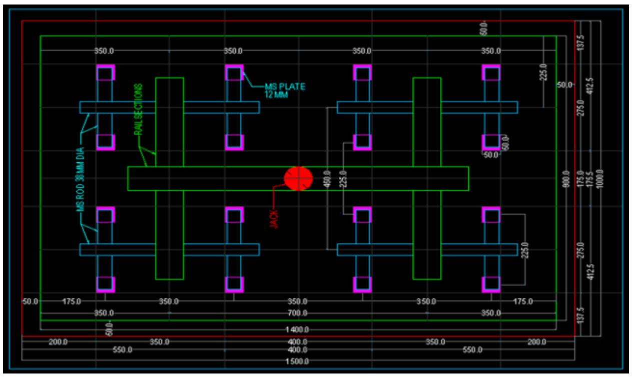

Fig -4: Layout of loading arrangement
Fig -5: Front view of loading arrangement

Fig -6: Top view of loading arrangement

## 4. RESULTS AND DISCUSSIONS

Theoretical ultimate load carrying capacity $P_J$ of all slabs was calculated based on Johansen's yield line theory.

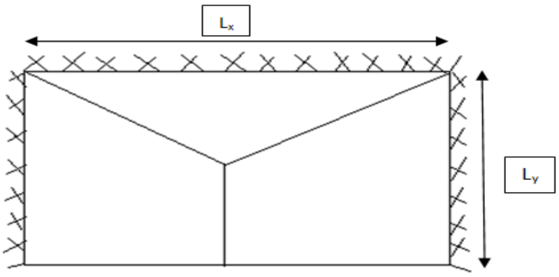


Fig -7: Typical yield line of three fixed & one end free slab

Fig -8: Crack pattern of HSTVC slab with 0.25% fiber @ tension face.

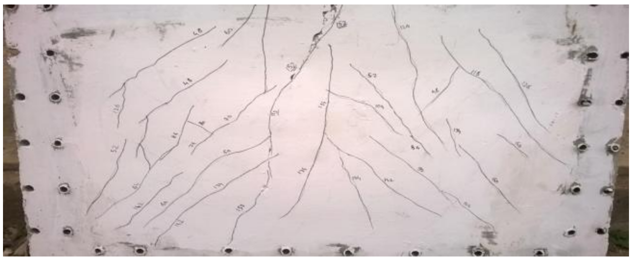

Fig -8: Crack pattern of HSSCC slab with 0.25% fiber @ tension face

Table 3: Deflection at different loads for HSTVC slabs

| %OF FIBERS | Pcr kN | $P_w=\frac{2}{3}P_j$ kN | Pu kN | $\delta_{cr}$ mm | $\delta_w$ mm | $\delta_u$ mm |
|---|---|---|---|---|---|---|
| 0.25 | 76 | 63.27 | 168 | 6.95 | 3.81 | 18.65 |
| 0.50 | 50 | 63.29 | 184 | 2.41 | 4.08 | 21.41 |
| 0.75 | 62 | 63.32 | 196 | 3.03 | 3.13 | 20.15 |
| 1.0 | 48 | 63.35 | 214 | 2.45 | 3.83 | 16.55 |

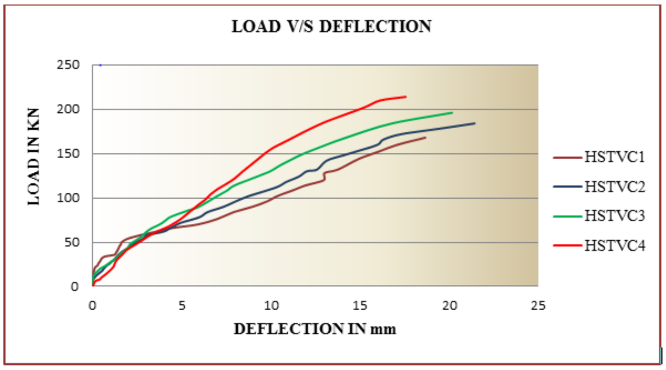


Chart 1: Load v/s deflection for all HSTVC slabs

Table -4: Deflection at different loads for HSSCC slabs

| %OF FIBERS | Pcr kN | $P_w=\frac{2}{3}P_j$ kN | Pu kN | $\delta_{cr}$ mm | $\delta_w$ mm | $\delta_u$ mm |
|---|---|---|---|---|---|---|
| 0.25 | 48 | 63.24 | 152 | 1.15 | 1.92 | 18.41 |
| 0.50 | 56 | 63.27 | 164 | 1.68 | 2..34 | 17.18 |
| 0.75 | 64 | 63.30 | 178 | 3.38 | 3.30 | 21.95 |
| 1.0 | 60 | 63.34 | 186 | 2.48 | 2.63 | 19.49 |

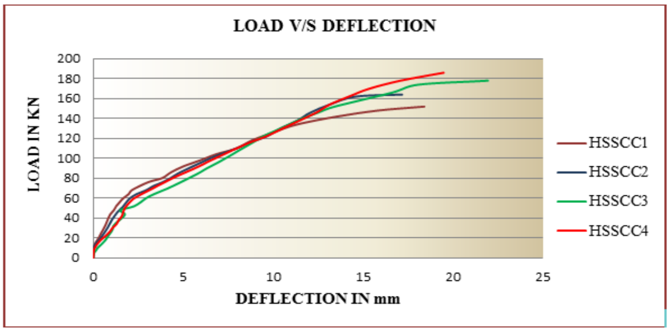


Chart 2: Load v/s deflection for all HSSCC slabs

Table -5: load enhancement for different fiber percentage

| SLAB ID | %OF FIBERS | $P_u$(KN) | $P_j$(KN) | $L_e$= [($P_u$-$P_j$) x100]/$P_j$ (%) |
|---|---|---|---|---|
| HSTVC1 | 0.25 | 168 | 94.91 | 77.01 |
| HSTVC2 | 0.50 | 184 | 94.94 | 93.81 |
| HSTVC3 | 0.75 | 196 | 94.98 | 106.36 |
| HSTVC4 | 1.0 | 214 | 95.03 | 125.19 |
| HSSCC1 | 0.25 | 152 | 94.86 | 60.24 |
| HSSCC2 | 0.50 | 164 | 94.91 | 72.79 |
| HSSCC3 | 0.75 | 178 | 94.96 | 87.44 |
| HSSCC4 | 1.0 | 186 | 95.01 | 95.76 |

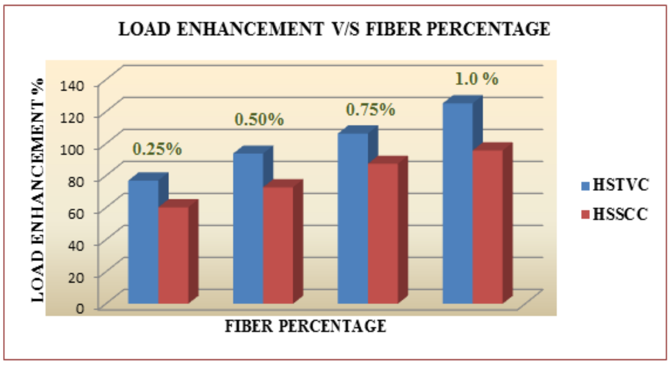


Chart 4: Load enhancement v/s fiber percentage

Table -6: Partial safety factors

| SLAB ID | FIBER % | FOS deflection | FOScrack width |
|---|---|---|---|
| HSTVC1 | 0.25 | 2.65 | 1.96 |
| HSTVC2 | 0.50 | 3.15 | 2.08 |
| HSTVC3 | 0.75 | 3.22 | 2.15 |
| HSTVC4 | 1.0 | 3.95 | 2.68 |
| HSSCC1 | 0.25 | 1.92 | 1.74 |
| HSSCC2 | 0.50 | 2.25 | 2.18 |
| HSSCC3 | 0.75 | 2.86 | 2.40 |
| HSSCC4 | 1.0 | 2.95 | 2.43 |

$$\mathrm{FOS}_{\mathrm{Deflection}} = \frac{P_j}{P_s}$$

$$\mathrm{FOS}_{\mathrm{Crack\,width}} = \frac{\mathrm{P}_{0.3\mathrm{cr}}}{\frac{2}{3}\mathrm{P}_{\mathrm{j}}}$$

Behaviors of SFHSSCC slabs were almost similar to that of SFHSTVC slabs. All slabs behaved linearly up to about 30% of loading and in the later stages of loading the behavior were nonlinear. It was observed in the experiment that after the initiation of first crack, with the increase in applied load the crack propagation was very slow which clearly proved the crack arresting property of steel fibers. Also all the slabs had crack patterns in accordance to the typical yield line pattern of slabs three edges fixed and one long edge free. Failure of all slabs was indicated by widening of cracks and propagation from tension face to compression face. Ultimate load increased with increase in fiber % for both SFHSSCC & SFHTVC slabs.
Partial safety factors with respect to limiting deflection and limiting crack width were well above the values prescribed by Indian codes. The values ranged from 1.96 to 2.68 for SFHSTVC slabs and 1.74 to 2.43 for SFHSSCC slabs.

Load enhancement due to CMA increased with increase in fiber %. However the enhancement values were higher for SFHSTVC which can be observed in table 5.

## 4.1 Notations used

1. $P_{cr}$= Load at first crack
2. $P_u$= Ultimate load at failure
3. $P_{0.3cr}$= Load at 0.3mm crack
4. $P_j$= Johansen's ultimate load
5. $P_s$= Load at deflection of $l_y/750$
6. $P_w$= Service load
7. $\delta_{cr}$, $\delta_w$, $\delta_u$= Deflections at $P_{cr}$, $P_w$ & $P_u$ respectively
8. $L_e$= Load enhancement
9. $L_x$ & $L_y$= effective long and short spans of slab

## 5. CONCLUSIONS

After analyzing the data obtained from all eight slabs, following conclusions were drawn

1. With increase in fiber by 0.25%, the ultimate load increased by around 5% to 10% in all slabs. Thus it can be concluded that fibers increase the flexural strength of slabs.
2. With increase in fiber by 0.25%, Load enhancement increased by around 15% to 20%. Therefore CMA can be effectively utilized with increased percentage of steel fibers. However there is a need for further investigation to find the optimum value of fiber % to utilize CMA.
3. It was observed in the experiment that the crack propagation was very slow from initial crack to limiting crack width i.e., 0.3mm. But after 0.3mm the cracks widened rapidly up to failure. Thus it can be concluded that the fibers played a great role in arresting the cracks thereby increasing the residual strength of slabs.
4. The partial safety factors w.r.t limiting deflections for all slabs were greater than 1.5. However FOS w.r.t limiting crack width were less than 1.5 in experimental investigation done by Bipin[9] on the same kind of slabs . But in the present study, FOS Crack width for all slabs was greater than 1.5 which can be attributed to the presence of steel fibers.
5. The benefits of fiber inclusion were not indicated in ultimate deflection of slabs as the deflections did not decrease with increased fiber content. This needs further analytical investigations.
6. From all the observations it can be finally concluded that SFHSSCC which is an emerging material in the field of civil engineering can be used effectively in heavily loaded slabs and steel fibers do not hinder the CMA.

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