Twin Steel Helix Fiber Reinforced Concrete

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Abstract: As on date the most widely used construction material is still Reinforced cement concrete. As concrete is strong in compression and week in tension, steel is placed in concrete where ever tension is anticipated. The process is proven to be cumbersome, time consuming and expensive. Fiber reinforced concrete has emerged as a consequence which offers improved tensile strength in addition to increased compressive strength. Twin steel helix fiber with more frictional resistance are added in concrete matrix to improve tensile strength of concrete. In this paper experimental results of compressive strength and tensile of different grade of concrete with different dosages of twin steel helix fibers are presented.

Index Terms: Twin steel helix Fiber reinforced concrete (TSHFRC), Tensile strength.

I. INTRODUCTION

It's a well-known fact that even as on this date too, reinforced cement concrete is still the most widely used construction material all over the world. It is well known that concrete is strong in compression and weak in tension and as a reason steel is used at all locations where tensile stress develops in all structural elements. However, availability of a construction material which can resist both compression and tension and can be produced with equal ease as conventional concrete is most desirable. Such a construction material shall also be economically viable, easy for production, handling and placing and yet durable like conventional RCC. Twin steel helix fiber reinforced concrete (TSHFRC) as a construction material is the right choice meeting all the above requirements. TSHFRC consists of two tiny steel wires of 0.25mm diameter twisted together and cut into pieces of 20mm length added to cement concrete during mixing, replacing the rebar to some extent or in full to achieve higher crack resistance and structural strength throughout the concrete mass in all directions. The shape of cross section and the number of twists of steel and cement concrete. The steel wire, with its twisted profile is a far superior reinforcement and is a better improvement over fibers of any time. When concrete is stressed or bent, the fibers with smooth profile will slide-out with minimal possible friction. But the same fibers provided with deformation like a hooked end or corrugation adds friction and increases pullout force.

A. TSHFRC-OTHER TYPES FRC

Ferro-cement is a composite material consisting of steel wool and cement mortar. It consists of closely spaced wire fabric which are impregnated with rice cement mortar mix. The steel wool is generally obtained from lathe machining job works, mechanical workshops, are usually 0.5-1.0mm wide with varying lengths. The structural orientation of the steel wool can be arbitrary. The steel wool is mixed with cement mortar of cement sand ratio 1:2 with water cement ratio 0.4-0.45 the thickness of Ferro-cement elements usually varies from 20mm-30mm. this material is found suitable in making special types structural elements like shelves which have strength through forms, and structures like roofs, silos, water tanks and pipe lines. The development of Ferro-cement depends on suitable casting techniques for required shape. Development of proper fabrication techniques for Ferro-cement is still not a widely explored. Areas and gaps need to be filled. Fiber reinforced concrete is a composite material consisting of cement mortar or concrete, discontinuous, discrete, uniformly dispersed fibers and steel reinforcement. It has been recognized long since that the additional of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its static and dynamic properties. Unlike the Ferro-cement n fiber reinforced concretes, in which fibers s are used in addition to rebar, in TSH fiber reinforced concrete usage of rebars drastically reduced or avoided all together. The TSH fibers are twisted fibers made from electrogalvanized steel. The twist changes the failure mechanism from simple pulling out to torsion mode resulting in a more efficient use of steel fiber.

B. ADVANTEGES OF TSH FIBER CONCRETE

1. Unlike rebar or mesh, helix increases the pre-crack modulus of rupture.

2. Adds post crack tensile strength.

3. Does not permit micro cracks to develop.

4. Works in all three dimensions and throughout the entire section of concrete.

5. Excellent shear protection.

These are three reasons engineering prefer to use helix

1. First crack prevention.

2. Post crack strength increase and

3. Overall cost reduction.

C. OBJECTIVES OF THE PRESENT STUDY

1. To establish a stress strain relation of TSH fiber reinforced concrete in both compression and tension, that can well establish the overall stress strain behavior.

2. To develop moment carrying capacities of rectangular sections using both TSH fiber reinforced concrete and conventional reinforced concrete.

3. To develop equivalent rectangular stress block parameters for TSH fiber reinforced concrete in order to extend the concepts of stress block analysis to design structural member.

II. LITERATURE REVIEW

Antoine E, Naaman (2003) described in this paper the usage and application of new generation of steel fibers for use in cement, ceramic and polymeric matrices [1].

Flavio de Andrade silval et al (2009) performed an experimental investigation to understand the sisal fiber pull out behavior from a cement matrix [2].

Dong-joo kim et al (2009) Provided the performance of an innovative slip hardening twisted steel fiber in the compression with other fibers including straight steel smooth fiber, high strength steel hooked fiber, SPECTRA (High molecular weight polyethylene) fiber and PVA fiber [3].

Gustavo J Parra-Montesinos (2005) investigated recent applications of tensile strain-hardening, high performance fiber reinforced cement composites (HPFRCCs) in earth-quake resistant structures is presented. [4]

Min-yuan cheng et al (2010) investigated effectiveness of steel fiber reinforced cement for increasing punching shear strength and ductility in slab subjected to monotonically increased concentrated loads are presented [5]

The discovery of Vikant S. vairagade et al (2013) is based on the laboratory experiment; cube and cylindrical specimens have been designed with metallic and non-metallic groups of fibers. In metallic fibers, steel fibers of hook end with 50, 60 aspect ratio and crimped round (copper coated) of 52.85 aspect ratio containing 0%and 0.5% volume fraction were used without adding admixtures [6]

III. EXPERIMENTAL INVESTIGATION

In the present study the TSH fiber reinforced concrete elements of grades corresponding to M20, M25 and M30 with different percentages of helix mesh reinforcement are taken-up. The concrete mix design has been carried out using IS code method as per 10262-2009. The cement that is used in the concrete mix confirm to OPC 53grade of make ultra tech. the coarse aggregate size varies from 10mm to down below, belongs to the quarry Deshmukh located in Nalgonda district. The fine aggregate used is Rob sand belonging to the quarry Deshmukh located in Nalgonda district. Potable water is used for concrete making. Making use of above material, the mix design of concrete conforming to grades M20, M25 and M30 have been designed under controlled conditions in the laboratory environment using IS code method as per provisions of BS code 8110 no of cylinders of size 150mm diameter and 300mm long were prepared to carry out compression tests. The cylinders are prepared with percentages of helix fiber mesh varying from 0%, 0.15%, 0.30% and 0.45%. They are cured for 28days, before testing is carried out. Similarly, concrete prisms 500mm long with 100mm*100mm sectional dimensions are also prepared conforming to grades M20, M25 and M30 with helix fiber mesh varying from 0%, 0.15%, 0.3% and 0.45%. The concrete prisms are used for bending tests.

A. COMPRESSION TEST

After having designed the concrete mix as described above, the concrete cylinders with 150mm diameter 300mm long have been casted. The compression test has been performed on the concrete cylinders to evaluate the compressive strength of fiber reinforced concrete. During the process of performing tests the relation between the stress and strain is also plotted. Concrete cubes were also prepared of sizes 150*150*150mm and were tested to evaluate for compressive strength after 28 days curing the test was performed as per IS516-1959.

B. TENSION TEST

The tension test to evaluate the tensile strength of concrete and the stress strain variation in the concrete is performed using two methods.

1. Split tensile test

2. Uni-Axial direct tensile test

1. SPLIT TENSION TEST:

Split tensile strength on cylinders was carried out according to the procedure given in IS 516-1956. Immediately after the removal of cylindrical specimens from the water tank are kept on the test surface. The surfaces, which are to be in contact with the packing strips. The bearing surfaces of the testing machine were wiped

clean. The cylinder was placed horizontally in the centering with packing skip (wooden strip)/ or loading pieces carefully poisoned along the top and bottom of the plane of loading of the specimen. The wooden pieces were placed on top of the cylinder and bottom of the cylinder, so that the specimen is located centrally. The load was applied without shock and increased continuously at a normal rate with the rage 1.2N/mm2/min to 2.4N/mm2/min until failure of the specimen.

The maximum load applied was recorded at failure and the appearance of concrete and unused features in the type of failure was observed. The test result is presented in the table form, and then the splitting tensile strength of the specimen was calculated by using the following formula,

$$F_{ct}=2P/\pi*L*d$$

Where, P= Maximum load in newton applied to the specimen, L= length of the specimen in mm, D= cross sectional dimension of the specimen in mm

2. UNI-AXIAL DIRECT TENSION TEST (DOG BONE SHAPED SPECIMEN)

The uni-axial direct tensile test method is the method by which it can identify the key properties of FRC; such as strain hardening or strain softening, the elastic modulus, and stress verses strain relationships under tension. These are the constitution properties of FRC that are useful for the modeling and design of FRC structural member [Naaman, et al 2007]. However, currently there is no standard method for this test available in the U.S.

Some uni-axial tensile tests were carried out at UT-Arlington [Chao et al 2011]. The specimen was specifically designed so that a pin-pin loading condition is created at the ends. Both the ends have double dog bone geometry and are strengthened by the steel mesh to ensure that cracking would only occur in the central portion of the specimen, with in the gauge length. The double dog bone shape is used to provide a better transition to avoid stress concentration which resulted from the reduction of cross section. The central portion has a square cross section with a dimension of 4*4 inches. This dimension was selected to ensure more uniformly distributed fibers while maintaining a suitable weight for laboratory handling. The strains were measured by a pair of linear variable differential transformers (LVDTs) with a gauge length of approximately 6 inches. Tests were carried out by a closed-loop, servo-controlled machine with a loading rate of approximately 0.0002 inches/min.

Having performed the compression test and tension test on the concrete the information pertaining to its

1. Permissible compressive strength,

2. Permissible tensile strength,

3. The stress strain curve in compression and

4. The stress strain curve in tension.

IV. DESIGN METHODOLOGY USING TSHFRC

A. FLEXURAL ELEMENTS:

The method of development is as described under:

Let the sectional dimensions of the member be B and D, where B is the width and D is the depth of the section. As the member is subjected to bending moment the member bends causing maximum bending strains on the extreme fibers of the beam section. On one extreme edge it is tensile and on the other it is compressive, assuming zero value strain at a particular locationwithin the depth of the section. This location is referred as neutral layer. The strain along the depth of the section varies uniformly. The location where the strain is zero, the magnitude of the stress is obviously zero. In the zone of the tensile strain, the corresponding tensile stresses can be mapped, obtained from the relevant stress strain curve. Similarly, in the compressive strain zone the corresponding compressive stresses can be mapped, obtained from the stress-strain curve.

To begin our calculations, an arbitrary depth of neutral axis (corresponding to zero strain) is assumed. Depending on the nature of moment, compressive/ tensile strains develop on either sides of the neutral layer. Across the depth of the section, corresponding the strains, the respective compressive/tensile stresses are plotted, as explained above, obtained from the relevant stress-strain diagrams. The total force on the section on either side of the neutral layer is determined. The force on one side is compressive while on the other side is tensile. If our initial assumption for neutral axis depth id exact, the magnitude of the total forces on either side shall be the same, which is quite unlikely. Using an iterative procedure, the neutral axis depth is kept on altered until the total compressive force is equal to the total tensile force. This is the true depth of neutral axis. The locations of the center of gravities of the total compressive and total tensile from the neutral layer are worked-out. The sum of the distances, gives the lever arm for the section. The product of the lesser of the compressive/tensile forces with the lever arm gives the moment of resistance of the section.

B. COLUMN ELEMENTS

The axial loads with Bi-axial moment carrying capacity of the section

Here, the columns are assumed to be short rectangular columns (buckling effects ignored). A trial section for the column (B*D) is assumed. Say, for example the results pertaining to axial force (P) and the biaxial moments (M_{zz} and M_{yy}) for the member are obtained from the structural analysis.

Let A, Z_{zz} and Z_{yy} are the area of cross section, modulus of section about the stronger axis and modulus of the section about the weaker axis respectively. The maximum and minimum compressive stresses develop in the section are given by $\sigma_{max}=P/A+M_{zz}/Z_{zz}+M_{yy}/Z_{yy}$ and $\sigma_{min}=P/A-M_{zz}/Z_{zz}-M_{yy}/Z_{yy}$ respectively. The value of stress obtained for |max shall not be more than the maximum permissible compressive stress of the concrete for that grade and fibers ratio. Similarly, if the minimum happens to be tensile, it shall not be more than that of the maximum permissible tensile stress of concrete for that grade and fibers ratio.

V. UTILITY OF PRESENT STUDY

The cost of the building structure (abstract estimate) with stabilized structural configuration is worked out using principles of estimation. The abstract estimate for the same structure as designed by staad pro package using limit state method is also worked out. The percentage difference between the abstract estimates of two different methods are worked out to emphasis the need of the present study. Three such building structures have been analyzed and the design using to methods to draw generalized conclusions. However, we are presently in the process of optimization program using genetic algorithm to propose safe economical column and beam sections for a proposal building frame. Once the output of the member forces available frame staad pro package.

VI. SPECIMEN CALCULATIONS

In all the three buildings whose plans were enclosed at the end of the thesis were designed using RCC limit state method and TSHFRC concrete to substantiate the utility of the present study. In the present chapter, the specimen calculations pertaining to one building only had been presented.

The calculations enlisted below are with respective building plan figure 7.3. The structural configuration for the building plan figure 7.3 has been modeled using staad pro package. The sizes of the column are taken as per the architectural drawing the beams have been oriented in such a way that they all come under walls. Extra beams are also being provided to ensure that all slabs are either transfer load in one-way mechanism or two-way mechanism. The width of the beams was 230mm and depths of the beams vary as per the span of the beams (approximately $1/10^{th}$ of the span of the beam). M20 grade concrete was used to model the both beams and columns of the structure. The slab thickness was assumed to be 100mm on which a floor finishing load of 1.5KN/m^2 was assumed. The imposed load on all slabs taken as 2KN/m^2. The staad model developed as above is analyzed for load combinations due to dead load and imposed load only. The structural design of beams and columns as obtained from staad pro has been recorded. The member in forces for all beams and columns has been recorded. The cost of steel is separately calculated for

beams members and column members. Having obtained the member forces in all beams and columns using staad pro package as described above. The most optimal sectional dimensions for all beams and columns using TSHFRC is worked out. By optimal it implies the cost of concrete inclusive of the steel fiber content shall be lowest. Having proposed the optimal section for all buildings elements the analysis using staad pro is re-run. The sectional properties of the members are revised to suit.

VII. RESULTS AND DISCUSSIONS

The present work includes: Performing experiments to determine in the laboratory to determine,

1. Stress-strain characteristics in compression.

2. Stress-strain characteristics in tension for fiber reinforced concrete made using helix fiber as the reinforcing material. It has already been reported that the concrete conforming to M20, M25 and M30 has been designed as per IS code method. The percentage of mesh has been varied from 0.15%, 0.3% and 0.45% of the area of cross section of the concrete element. Discard number of cubes of 150*150*150mm and cylinders of 150mm diameter and 300mm long. This apart, special tensile brisket was also prepared. The revised member end forces obtained from staad pro. The process is repeated until a situation of stability is arrived. A stable configuration is one in which the analysis is due to re-run of staad pro don't alter the member forces. For a stable state of structural configuration, the total cost of TSHFRC.

TABLE I.
MATERIAL REQUIRED FOR 1 CUBIC METER OF CONCRETE

Grade	Cement	Fine aggregate	Coarse aggregate	water
	Kg/m^3	Kg	Kg	Kg/m^3
M20	380	1019	868	190
M25	400	996	848	200
M30	445	966	823	200

TABLE II.
DETAILS OF MIX DESIGN

Sample ID	Details of mix design
CC-1	Cement concrete using normal river sand
CC-2	Cement concrete using robo sand
TSHFRC-1	Cement concrete with robo sand & 0.15% of TSHFRC
TSHFRC-2	Cement concrete with robo sand & 0.3% of TSHFRC
TSHFRC-3	Cement concrete with robo sand & 0.45% of TSHFRC

TABLE III.
RESULTS OF M20 GRADE CONCRETE

M20				
Designation	Average compressive strength (mpa)		Average split tensile strength (mpa)	
	First crack	Ultimate strength	First crack	Ultimate strength
CC-1	25.60	30.60	2.30	2.35
CC-2	27.50	29.40	2.30	2.45
TSHFRC-1	27.50	32.50	2.85	4.30
TSHFRC-2	27.80	35.65	2.60	6.50
TSHFRC-3	28.50	37.0	2.90	7.17

TABLE IV.
RESULTS OF M25 GRADE CONCRETE

M25				
Designation	Average compressive strength (mpa)		Average split tensile strength (mpa)	
	First crack	Ultimate strength	First crack	Ultimate strength
CC-1	29.00	30.60	2.60	2.85
CC-2	29.50	32.75	2.58	2.73
TSHFRC-1	28.50	37.50	2.88	6.25
TSHFRC-2	28.00	38.35	3.10	7.00
TSHFRC-3	29.35	38.00	3.06	7.15

TABLE V.
RESULTS OF M30 GRADE CONCRETE

M30				
Designation	Average compressive strength (mpa)		Average split tensile strength (mpa)	
	First crack	Ultimate strength	First crack	Ultimate strength
CC-1	31.34	35.7	2.8	3.25
CC-2	32.50	34.5	2.88	3.28
TSHFRC-1	32.15	40.12	3.25	6.50
TSHFRC-2	33.70	40.50	3.64	7.35
TSHFRC-3	32.64	41.50	3.45	7.23

7.1 STRESS STRAIN GRAPHS

Figure 7.1(a). Tension curve of M20 grade with 0.15% TSHFRC

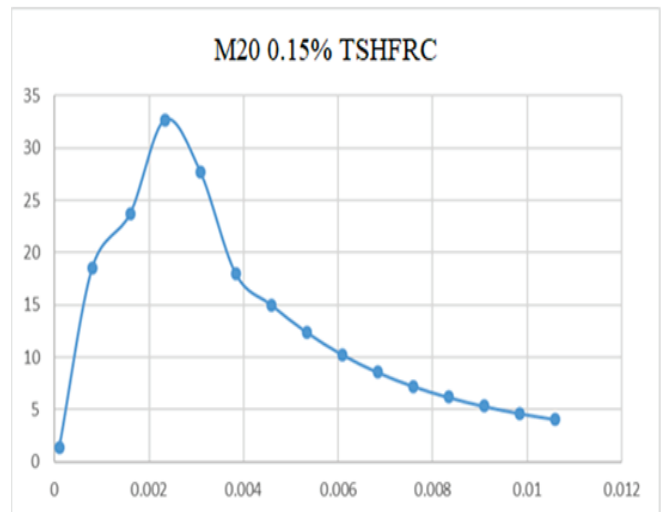**Figure 7.1 (b) Compression curve of M20 grade with 0.15% TSHFRC**

7.2 STRESS STRAIN DIAGRAM
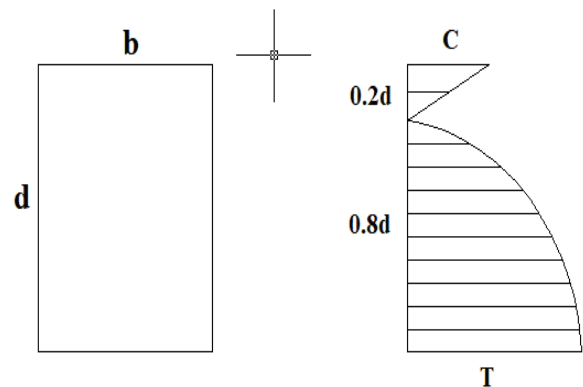
Figure 7.2. Stress Strain diagram
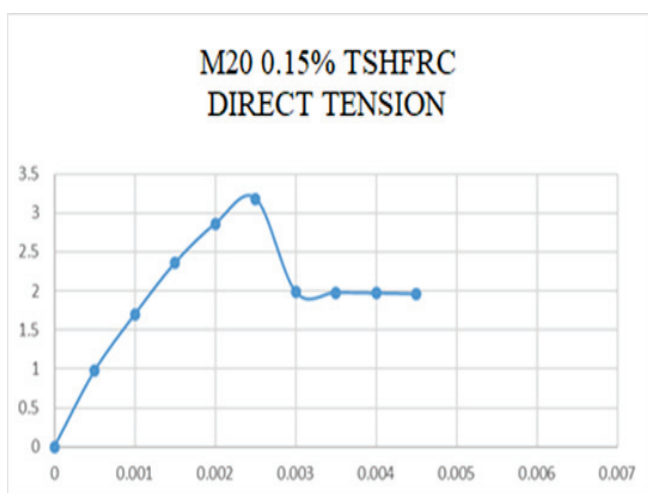
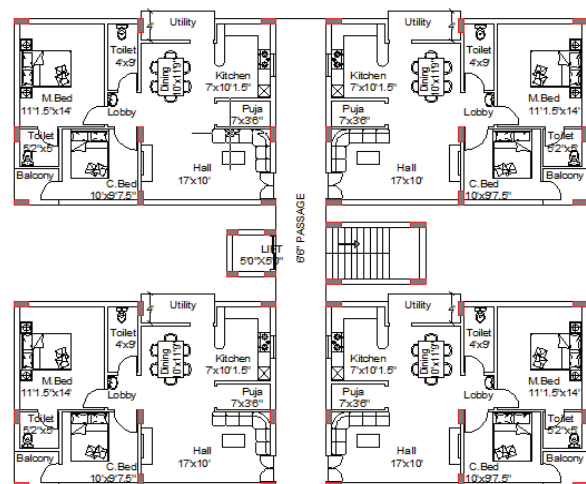## 7.3 BUILDING PLANS AND STAAD MODEL

Figure 7.3(a). Building plan
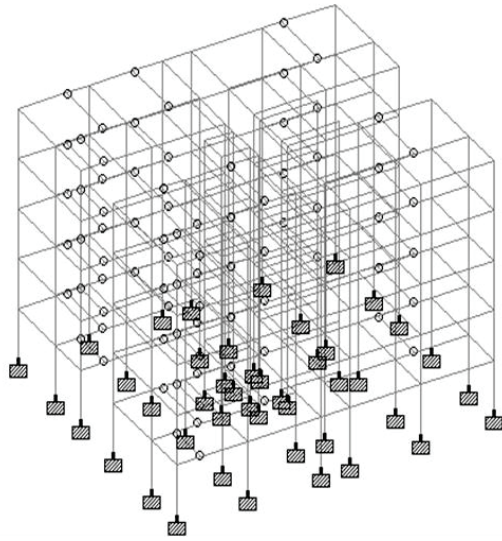
Figure 7.3(b). Staad model

TABLE VI
0.15% FIBERS M20 GRADE

From graph	S.No	From graph	Avg tension	Y1 (d)	Avg*Y1
Et=0.0025	0	0	0	0	0
σt=3.25	1	0.5	0.25	0.7	0.19d
Ec=0.0025 *(0.2/0.8d) =0.000625d	2	1	0.75	0.68	0.51d
From graph σc=15N/mm2	3	1.45	1.225	0.6	0.735d
C=b(1/2*0.2d*15 =1.5bd	4	1.8	1.625	0.52	0.845d
Yc=h/3,h=0.2 =0.06666666667	5	2.2	2	0.44	0.88d
	6	2.45	2.325	0.3	0.837d
	7	2.75	2.6	0.2	0.728d
	8	3	2.875	0.2	0.575
	9	3.2	3.1	0.1	0.372
	10	3.25	3.225	0.04	0.129
			T= 19.97*0.08 d		Total=5.801*0.08
			=1.598bd		=0.46bd
Yt=total/t					
0.287859825					
Lever arm=d-(0.290d+0.0667 d)					
0.6433d					
Mu=t*lever arm					
1.02799bd²					
Mu=c*lever arm					
0.96495bd²					

TABLE VII (A)
BEAM CALCULATIONS

1	2	3	4	5	6	7	8	9
9	200	400	3350	35.07	45.9	59.5	0.7	2.7
118	200	500	1620	62.36	71.7	56.9	0.5	2.7
10	200	500	3050	62.32	71.7	69	0.6	2.7
133	200	500	2040	58.52	71.7	36.6	0.3	2.7
566	200	300	2010	23.53	25.8	13.1	0.2	2.7

1-Beam number from staad

2-Breadth in mm

3-Depth in mm

4-Length in mm

5-Moment obtained from staad

6-Moment capacity of TSH fibers

7-Flexural shear

8-Shear stress

9-Permissible tensile shear stress

TABLE VII (B)
BEAM COST CALCULATIONS

10	11	12	13	14	15	16	17	18
9	0.3	M20	Safe	0.26	6.31	938	1262	2200
118	0.3	M20	Safe	0.16	3.81	567	763	1330
10	0.3	M20	Safe	0.30	7.18	1067	1436	2504
133	0.3	M20	Safe	0.20	4.80	714	960	1674
566	0.3	M20	Safe	0.12	2.84	422	568	990

10-Beam number from staad

11-Dosage of TSH fibers

12-Grade of concrete

13-Remarks

14-Volume of concrete in cubic meters

15-Quantity of TSH fibers in kgs

16-Cost of concrete in Rs

17-Cost of TSH fibers in Rs

18-Total cost in Rs

TABLE VIII (A)
COLUMN CALCULATIONS

1	2	3	4	5	6	7	8	9
11	200	400	3050	8000	722	17	2.85	$10*10^9$
14	200	400	3050	8000	609	34	6.27	$10*10^9$
17	200	400	3050	8000	447	40	7.39	$10*10^9$
20	200	400	3050	8000	282	40	7.49	$10*10^9$
23	200	400	3050	8000	115	47	8.27	$10*10^9$

1-Column number from staad

2-Breadth in mm

3-Depth in mm

4-Height in mm

5-Area in mm

6-Axial load Pu in KN

7-Moment in z-direction KN/m^2

8- Moment in y-direction KN/m^2

9-Moment of inertia in z- direction

TABLE VIII (B)
COLUMN COST CALCULATIONS

10	11	12	13	14	15	16
11	266666666.7	13.28	15	M20	0.15	Safe
14	266666666.7	16.47	18	M20	0.3	Safe
17	266666666.7	15.9	17	M20	0.45	Safe
20	266666666.7	13.8	15	M20	0.15	Safe
23	266666666.7	13.42	15	M20	0.15	Safe

10-Column number from staad

11- Moment of inertia in y- direction

12-Stress=$(P/A+M_{zz}/I_{zz}*D/2+M_{yy}/I_{yy}*B/2)$

13-Permissible maximum compressive stress

14-Grade of concrete

15-Doasage of TSH fibers

16-Remarks

TABLE VIII. (C)
CONTINUATION OF COLUMN COST CALCULATIONS

17	18	19	20	21	22
11	0.244	2.8731	854	574.62	1428.62
14	0.244	5.7462	854	1149.24	2003.24
17	0.244	8.6193	854	1723.86	2577.86
20	0.244	2.8731	854	574.62	1428.62
23	0.244	2.8731	854	574.62	1428.62

17-Column numbers from staad.

18-Volume of concrete in cubic meters

19-Quantity of TSH fibers in Kgs

20-Cost of concrete in Rs

21-Cost of TSH fibers in Rs

22-Total cost in Rs

TABLE IX
COST COMPARISON

RCC building				Helix fiber reinforced concrete building			
Building-1				Building-1			
(Rs)	beam	Column	T	(Rs)	beam	column	T
Steel	223160	122220	345380	Steel	132310	38300	170610
Concrete	80500	43050	123550	Concrete	110654	45639	156293
total	468930			Total	326903		
Building-2				Building-2			
(Rs)	beam	Column	T	(Rs)	beam	column	T
Steel	334530	141750	476280	Steel	225900	38212	264112
Concrete	144550	43400	187950	Concrete	166822	51807	218629
total	664230			Total	482741		
Building-3				Building-3			
(Rs)	beam	Column	T	(Rs)	beam	column	T
Steel	966840	59290	1026130	Steel	462713	255658	718371
Concrete	445200	29050	474250	Concrete	357853	173301	531154
total	1500380			Total	1249525		

VIII. CONCLUSIONS

1. The inclusion of TSH fibers have considerably increased the compressive strength of concrete for all grades of concrete M20, M25 and M30 as can be seen from table no III to V

2. Similarly, the inclusion of TSH fibers have also substantially increased the tensile strength of concrete as can be seen from table no III to V

3. Even though not quantified, the addition TSH fibers have substantially increased the ductility of all grades of concrete.

4. The utility of the present study is amply demonstrated with the help of case studies on three number of RCC buildings. The results obtained are used for drawing following conclusions.

- The quantity of concrete consumed in making columns has increased by 5.6%, when TSH fiber concrete is used.

- The quantity of concrete consumed in making beams has also increased by 27.25%, when TSH fiber concrete is used.

- But the total amount of steel consumed in columns is reduced by 68.6%, when TSH fiber concrete is used.

- Similarly, the total amount of steel consumed in beams is reduced by 40.71%, when TSH fiber concrete is used.

- The overall cost of building is reduced by 30%, when TSH fiber concrete is used.

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