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FRC – A New Sustainable Option for Construction to Mitigate Earthquakes

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***Abstract*—**Ten simply supported grossly underreinforced tapered concrete beams of full size were tested upto complete collapse under flexural effect .Out of 10 beams, 5 beams were nonfibrous and the remaining beams contained fibres. The beams had a variation in the tapered angle as 2°, 4°, 6°, 8° and 10°. The concrete mix, conventional steel and the type of fibre used were held constant. Flat corrugated steel fibres were utilized as secondary reinforcement. The strength and stability parameters were measured. It is established that the fibrous tapered beams can be used economically in earthquake prone areas.

***Keywords*—**Earthquake, Grossly underreinforced sections, Fibre reinforced concrete, Tapered beams.

I. Introduction

CONCRETE is probably the most widely used man made construction material around the world. The use of different types of fibres in varying shapes and sizes along with the ingredients of concrete was investigated to produce a composite material called 'fibre reinforced concrete' (FRC) or 'fibrous concrete'. The progress and economics of construction technology depends on the intelligent use of materials and on the continuous improvement of available materials.

Fibres arrest cracks and increase the tensile strength of concrete as was proved by Romauldi and Batson [1]. The ductility of fibrous beams is also increased as shown by Swamy and Mangat [2], Sasturkar[3] and Kaushik and Sasturkar[4]. Liang and Galvez [5] proved that the peak-load capacity and fracture toughness, as indicator of ductility, were enhanced.

Crack resistance and fracture toughness of fibrous beams is enhanced as shown by Johnston and Gray [6] and Balaguru, P.N. Narahari R and Patel M, [7]. Ramakrishnan and Lokvik [8] concluded that the flexural fatigue values are increased in fibrous beams. Similar deflection patterns for fully and partially fibrous beam sections were observed as indicated by Nagaraj and Dwarakanath [9]. Reduction of dead weight of a beam by decrease in its dimensions and without too much concession in its load carrying capacity was studied by Fatih, A.Tefaruk and Kamuran [10].

Sufficient work has been carried out on rectangular reinforced concrete (RC) beams containing fibres.

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No much work has been reported in the literature on tapered beams containing steel fibrous concrete. Hence it is decided to test conventional RC tapered beams which are reinforced with steel fibres.

II. Experimental Programme

Roof beams used in most of the destroyed residential dwellings in earthquake prone areas were made out of wood. RC can be one of the effective materials for resisting earthquake. Hence the wooden beams are now to be replaced in Toto by RC beams containing fibres. When concrete beams are used as supporting systems the dead load of beams is too high which can be reduced by tapered beams. The thickness of such sections is selected mainly according to the conditions for distributing the reinforcement and to facilitate the placing of concrete.The tapered beams are used for single storeyed dwellings in villages for overlaying the pitched roof materials specially in earthquake prone areas. The beam supports the purlins, roof cladding, solar and roof panels. They can be used for construction of cattle sheds. In the case of occurance of an earthquake, the human life and cattles can be saved due to the lesser weight of tapered beams and roofing material when compared to nontapered beams with RC slabs. Hence this study is undertaken.

The pitched roof may consist of simple lightweight fibre panels as roofing material. Since there is no live load acting on roof, these beams are designed as grossly underreinforced beam sections containing the bare minimum amount of conventional steel reinforcement. This reinforcement is just sufficient to differentiate a RC beam from a plain concrete (PC) beam which does not contain any steel skeleton.

The experimental investigation consisted of casting and testing ten grossly underreinforced tapered beams of full size having overall span of 2000 mm and a thickness of 150 mm. The effective span was kept as 1900 mm. These beams were divided in two sets. The first set of 5 beams were nonfibrous (NF) sections whereas the remaining 5 beams contained steel fibres (F) as additional reinforcement. The second set of 5 beams contained fibres upto *two-third* the depth of the beam from the bottom. All the two sets of the beams had the variation in the tapered angle as 2°, 4°, 6°, 8° and 10°.The numerical following the letters F or NF denotes the tapered angle. The depth at midspan is kept constant equal to 285 mm and is varied at the ends for each set of beams to obtain the desired tapered angle.

The steel fibres were supplied by M/s Stewols & Co., Nagpur, India. A constant volume fraction of fibres equal to 1.15 % was used throughout the investigation .The fibres used were 'Shaktiman flat corrugated steel fibres' having a rectangular cross section of 2 mm width and 0.6 mm thick. They were 25 mm in length. These fibres were extremely ductile and possess a tensile strength upto 550 MPa. The fibres were spread uniformly in the entire cross section of the beam. The cage reinforcement consisted of two bars of 8 mm diameter as main steel and two legged 8 mm diameter stirrups at 195 mm c/c as shear steel. It has been proved in the literature by Thandavamoorthy [11]-[12] that the newly developed 'Thermo-Mechanically Treated' (TMT) bars have greater ductility performance than the mild steel or deformed bars. Hence TMT bars are used as conventional steel skeleton in the present investigation.

ACC-Suraksha Cement, locally available river sand and crushed Basalt stone aggregate of size 12 mm and down was used to get M20 grade of concrete mix having the proportion of ingredients as 1:1.50:2.34 with a water-cement ratio of 0.50. The concrete mix had an adequate workability for both plain and fibrous concrete.

The beams were cured for a period of twenty eight days. They were dried for a period of 24 hours. All the beams were white washed on both faces to mark the propagation of cracks at each successive increment of load. They were then tested upto collapse under flexural loading conditions by applying a single point load at the centre of the beam as suggested by Ramesh, Jayasimha Pattar, Narasimha Rao and Santhosh[13]. The beams were tested on a 1000 kN capacity loading frame. Baty dial gauges were used to record the deflections at the centre of the beam.

III. Results And Discussions

On the basis of investigations carried out in the present study, the various structural properties are listed in Table I and Table II. The notations used in Table I and Table II are shown in the nomenclature.

The structural behaviour of fibrous and nonfibrous beams was studied. The characteristics like cracking load, ultimate load, load-deflection behaviour and cracking patterns were studied rigorously as indicated in Table III and Table IV. Even though a few of these structural characteristics are showing a negative configuration and are sounding unhealthy, these beams have shown best affirmative performance which helps specially for the beams to be used in pitched roof construction in earthquake prone area to save the human life.

Fig.1 shows the loading techniques employed in the present investigation along with the beam test setup.

A. Comparison of Fibrous and Nonfibrous Beams

Two companion beams having same tapered angle are compared to each other and the behaviour of fibrous beams is studied with respect to a nonfibrous beam section. The various structural characteristics of fibrous beams are tabulated in Table III and Table IV.

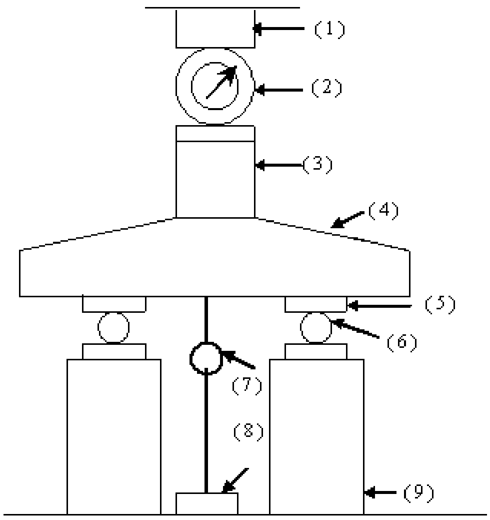

Fig. 1 Beam test setup

(1)To loading frame (2) Proving ring (3) Hydraulic jack (4) Tapered beam (5) Bearing plate (6) Roller support (7) Deflectometer (8) Magnetic base (9) Floor supports

TABLE I
LOAD – DEFLECTION CHARACTERISTICS OF BEAMS

S.No.	T	P_1 kN	P_2 kN	Δ_1 mm	Δ_2 mm
1	NF2	20	36	0.43	10.60
2	F2	22	33	0.81	16.59
3	NF4	22	30	0.74	3.81
4	F4	24	38	1.00	16.2
5	NF6	18	36	0.82	15.50
6	F6	20	36	0.61	16.38
7	NF8	20	30	1.66	7.85
8	F8	17	32	0.66	6.13
9	NF10	17	29	0.69	3.37
10	F10	20	36	0.86	18.82

1. Loads

It was seen that there was an increase in initial cracking load of 10%, 9%, 11% and 18% for the beams with tapered angles of 2˚, 4˚, 6˚ and 10˚, respectively. A reduction of 15% was observed for the beam having tapered angle of 8˚. It was observed that the ultimate load-carrying capacity of

TABLE II
CRACKING CHARACTERISTICS OF BEAMS

S.No	T	N	H mm	S_1 mm	S_2 mm
1	NF2	5	250	225	198
2	F2	4	275	240	215
3	NF4	3	250	230	198
4	F4	8	280	390	160
5	NF6	9	278	200	139
6	F6	8	275	230	91
7	NF8	6	250	220	191
8	F8	7	280	250	145
9	NF10	10	265	200	122
10	F10	8	260	210	142

fibrous beams depicted varities of phenomenon. There was an increase of 27 %, 7 % and 24% for beams with tapered angles of 4˚, 8˚ and 10˚, respectively, whereas there was a decrease of 8% for tapered angle of 2˚. The ultimate load remained constant for 6˚ tapered beam.

2. Deflections

It was seen that the deflections at serviceability increased by 88%, 35% and 25% in beams with tapered angles of 2˚, 4˚ and 10˚, respectively, whereas a reduction of 26% and 60% was noticed in beams with 6˚ and 8˚ tapered angle, respectively. It was observed that the deflection at ultimate load showed an increase of 57%, 325% and 6% in the beams of tapered angle 2˚, 4˚ and 6˚, respectively. A dramatic increase of 458% at ultimate load was depicted in the beam having tapered angle of 10˚ whereas the beam having a tapered angle of 8˚ showed a reduction of 22%.

TABLE III
COMPARISON OF LOAD – DEFLECTION CHARACTERISTICS OF NONFIBROUS AND FIBROUS BEAMS
(% increase +ve, % decrease –ve)

S.No	T	P_1 %	P_2 %	Δ_1 %	Δ_2 %
1	F2	+10	-8	+88	+57
2	F4	+9	+27	+35	+325
3	F6	+11	0	-26	+6
4	F8	-15	+7	-60	-22
5	F10	+18	+24	+25	+458

3. Cracking Characteristics

It was observed that the cracks in the middle zone were more in number than the end zones in all the fibrous and nonfibrous beams. It was observed that the maximum height of flexural crack increased by 10%, 12% and 12% in the beams having tapered angles of 2˚, 4˚ and 8˚, respectively, whereas a marginal decrease of 1% and 2% was noticed in the beams with tapered angle of 6˚ and 10˚, respectively. A reduction in the average crack spacing by 19%, 35 % and 25% was observed in the beams of tapered angle 4˚, 6˚ and 8˚, respectively. However, there was an increase in the average crack spacing by 9% and 16 % for the beams having tapered angle 2˚ and 10˚, respectively.

The test results shown in Table I to Table IV are represented alternatively in Fig. 2 to Fig. 10.

The maximum crack spacing increased reasonably by 70%, 15% and 14% for beams having tapered angles of 4˚, 6˚ and 8˚, respectively whereas a marginal increase of 7 % and 5% was seen in the beams of tapered angle 2˚ and 10˚. The total number of cracks showed an increase of 17% in the beam having tapered angle of 8˚, whereas a decrease of 20%, 11% and 20% was observed in the beams with tapered angle 2˚, 6˚ and 10˚, respectively. A dramatic increase of 167% in the total number of cracks was observed in tapered angle beam of 4˚.

Fig. 11 and Fig. 12 show the cracking patterns of typical beams.

To summarize, the fibrous beams recorded an optimum increase of 18%, 27% and 88% in the initial cracking load, ultimate load and deflection at serviceability, respectively. A

TABLE IV
COMPARISON OF CRACKING CHARACTERISTICS OF NONFIBROUS AND FIBROUS BEAMS
(% increase +ve, % decrease –ve)

S.No.	T	N %	H %	S_1 %	S_2 %
1	F2	-20	+10	+7	+9
2	F4	+167	+12	+70	-19
3	F6	-11	-1	+15	-35
4	F8	+17	+12	+14	-24
5	F10	-20	-2	+5	+16

dramatic increase of 458% was noticed in the deflection at ultimate stage over the corresponding nonfibrous companion beam. An optimum increase of 167% was observed in the total number of cracks. There was an optimum reduction of 35% in the average crack spacing. There was marginal reduction in the maximum height of flexural crack.

In general, it was observed that all the beams with and without fibres failed in flexural mode only. Most of the cracks were developed in the middle one-third zone of the beam. The structural characteristic property of developing reasonably large number of cracks in the fibrous sets of beams confirmed the law of fracture mechanics.

Further, all the deflection values obtained at initial cracking load were within the permissible limit of serviceability as per I S 456-2000[14]. As per this I S Code, the permissible value is effective span/250 or 1900/250 or 7.60 mm in the present investigation. The same limit of serviceability holds good for both fibrous and nonfibrous beam specimens tested under flexural effect. The cracking characteristics and the deflection at ultimate stage was studied on FRC nontapered beams by the authors Jenq and Shah [15] wherein similar conclusions were drawn as were depicted in the present investigation on tapered beams.

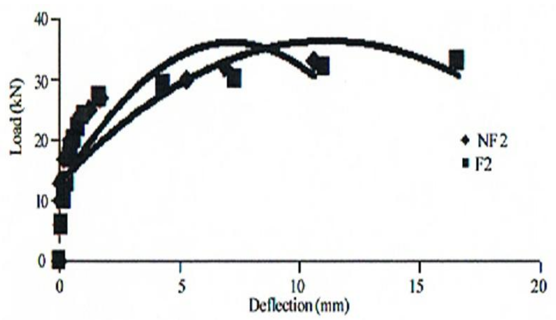

Fig. 2 Load- deflection curves for NF2 and F2

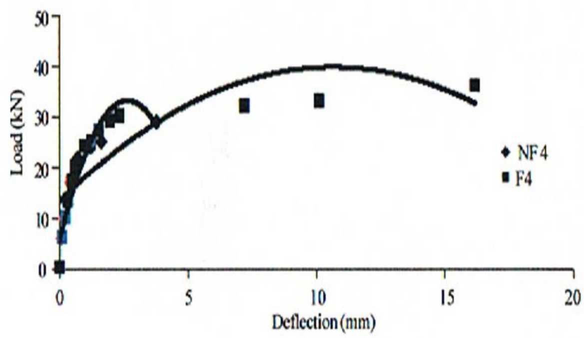

Fig. 3 Load- deflection curves for NF4 and F4

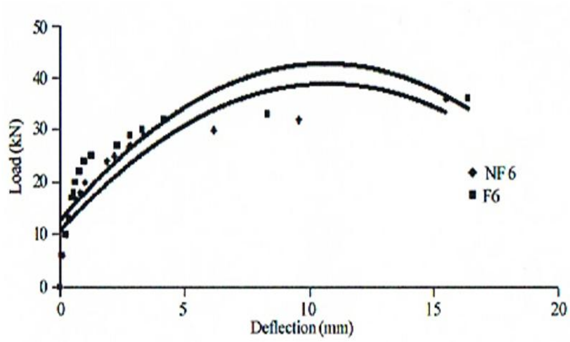

Fig. 4 Load- deflection curves for NF6 and F6

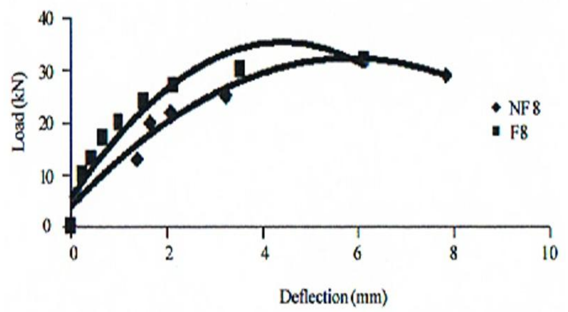

Fig. 5 Load- deflection curves for NF8 and F8

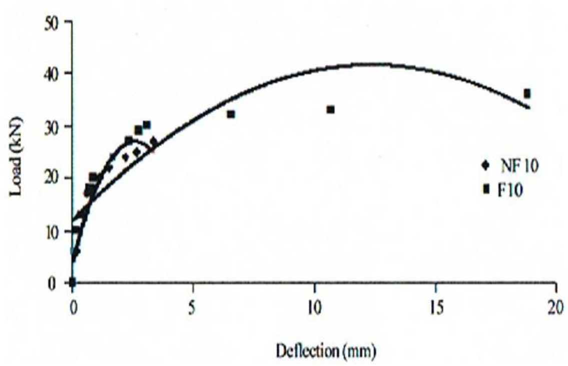

Fig. 6 Load- deflection curves for NF10 and F10

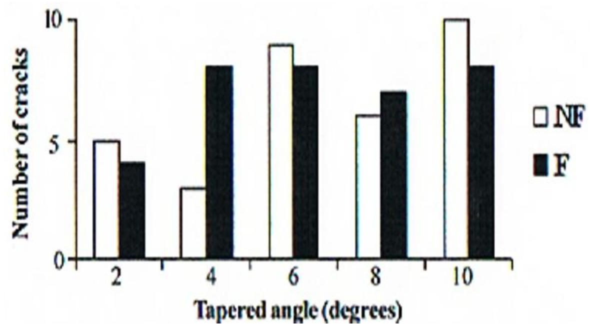

Fig. 7 Cracking characteristics for number of cracks

The beams deflect more and more even though the pumping of oil through hydraulic jack is continued. Also there is no further increase in the ultimate load carrying capacity. This happens due to the pullout property of fibres and the beam does not collapse suddenly and there is no catastrophic failure harming the inmates of the house. The inmates of the house get ample amount of time and warning to come out of their dwellings comfortably saving their life

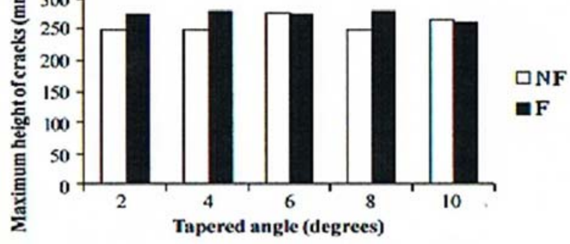

Fig. 8 Cracking characteristics for maximum height of crack

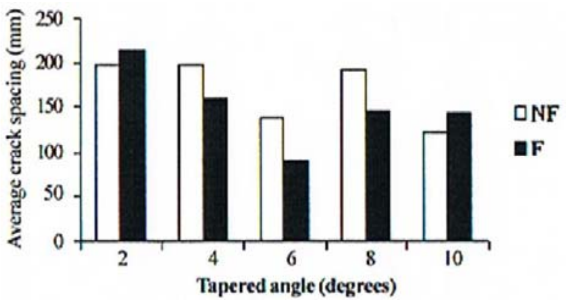

Fig. 9 Cracking characteristics for average crack spacing

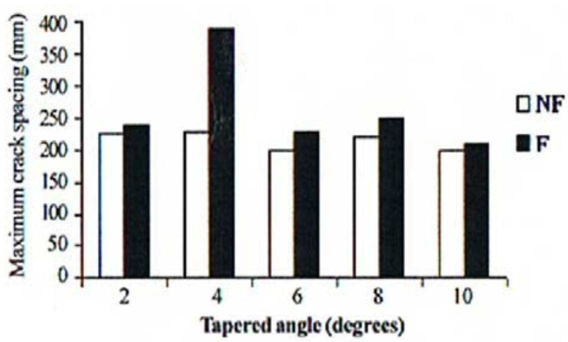

Fig. 10 Cracking characteristics for maximum crack spacing

and property indicating the high quality performance of fibrous tapered beams. Thus it is concluded that the fibrous tapered beams can be used economically in earthquake prone areas looking at its ultimate load–carrying capacity and ultimate deflection performance characteristics even though they are costlier by one and a half times than nonfibrous beams.

A similar performance of FRC was observed by the author Sasturkar [16]-[17]-[18]-[19]-[20] by using variety of fibres and hence led to its use in roof beams in earthquake prone areas. The affirmative and rich performance of FRC as is evident from the investigations and discussions in the present paper highlights the sustainable option for the new construction in seismic zone. This new type of construction can be rigorously implemented practically in seismic areas provided the different types of fibres are made commercially available.

IV. Economics

It would, however, be unrealistic to compare the cost of fibre reinforced concrete with that of conventionally reinforced concrete on the cost of materials alone.

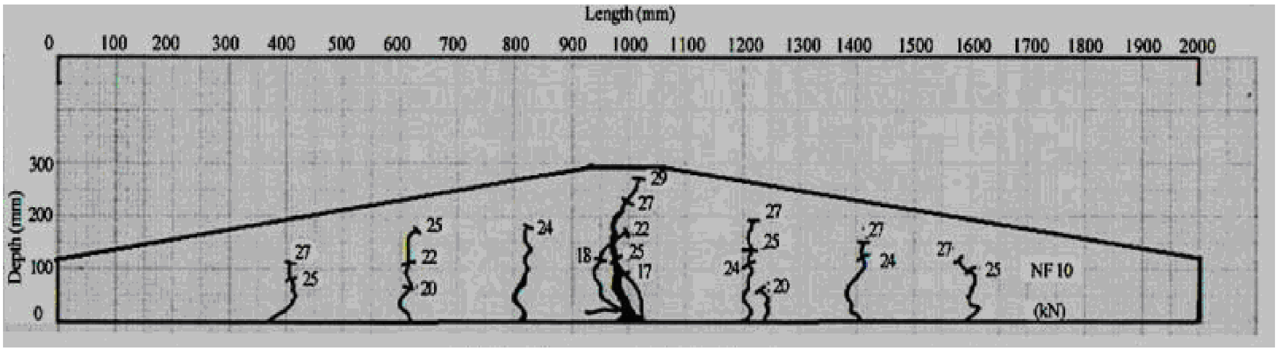

Fig. 11 Cracking patterns of a typical nonfibrous beam

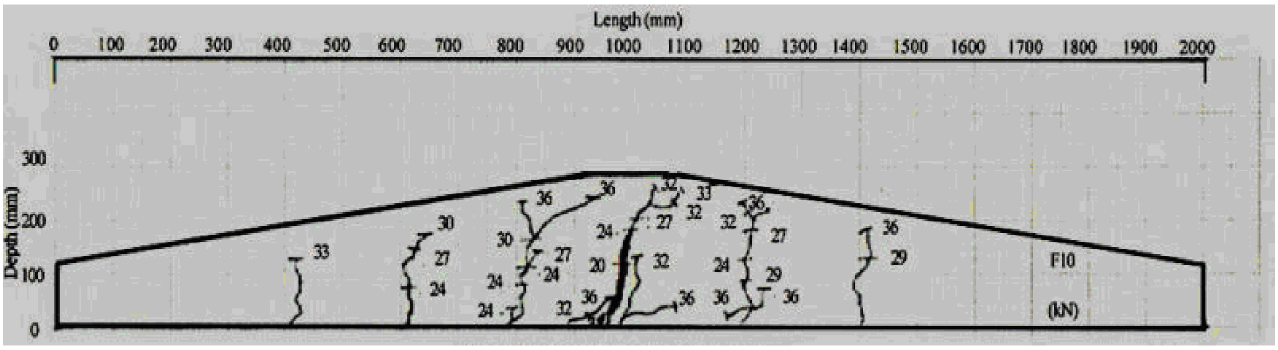

Fig. 12 Cracking patterns of a typical fibrous beam

Economics must be also related to performance and serviceability, which are prime functions of designs. The additional cost of the new composite material should therefore be considered in relation to the various advantages that can be achieved.

The rates of various materials are as follows. These rates are based on 2010- costs.

Cement per m^3 : U$ 98
Fine aggregate per m^3 : U$ 12
Coarse aggregate per m^3 : U$ 7
TMT bars of 8 mmϕ per kg. : U$ 1.2
Shaktiman steel fibres per kg : U$ 1.6

It is clear that the fibrous specimens cost about one and a half times more than nonfibrous one. From the results obtained in this investigation as discussed above, it proves that fibrous concrete is an economical composite material.

V. Conclusion

This study of fibrous concrete tapered beams containing conventional steel leads to the following conclusion.

The fibrous tapered beams of tapered angles 4° and 10° can be used economically in practice looking at its performance and serviceability characteristics even though they are costlier by one and a half times than nonfibrous beams.

Nomenclature

The following symbols were used in this investigation.

H - Maximum height of flexural crack
N - Number of cracks
P_1 - Initial cracking load
P_2 - Ultimate cracking load
S_1 - Maximum crack spacing
S_2 - Average crack spacing
T - Type of beam
Δ_1 - Deflection at serviceability
Δ_2 - Ultimate deflection

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