Deflection Control in RCC Beams by Using Mild Steel Strips (An Experimental Investigation)

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ABSTRACT

It is well recognized that in modern practice, structural failures are all too common in terms Serviceability and are relatively rare in terms of Safety. Adoption of limit state of design and higher grades of concrete and steel in modern RCC structures has led to overall thinner member sections and high stress levels at service loads. These in turn have resulted in larger deflections, crack- widths, vibrations etc. In particular, it is the Serviceability Limit state of 'Durability' that calls for particular attention, because 'Deflection' is a very important criteria need to be taken into account. Due to architectural constrain generally depth of beams are restricted, that leads to more deflection in a beam. An attempt has been made through this project to check the feasibility and efficiency of Mild Steel sheets used as a composite material with traditional RCC beams to modify its serviceability criteria. MS Sheets are used due to their economy, durability and are also easily available in large variety of cross-sections (gauges). MS sheets also have the property of being cast to any shape without much need of significant formwork. The composite construction has an edge over the conventional reinforced concrete material because of its ease of construction, thinner sections as compared to RCC, efficient bonding with concrete due to its large surface area & high tensile strength (per unit weight) which makes it a favourable material for prefabrication also. The ill effect of corrosion is reduced here as the MS Strips are embedded into the concrete material, thus less prone to exposure and also has no aesthetic issues. Extra care can be taken by providing coating also. The main aim of this project is to increase the stiffness of beam in order to control the deflection. Mild steel sheets and strips of varying thickness (gauges) were embedded into traditional RCC beam vertically alongside faces in longitudinal direction. This increases both moment of inertia as well as modulus of elasticity of beam, thus increasing its stiffness and controlling deflection. The test results are compared and it has been observed that deflection is controlled by about 30% and strength is increased by about 25% in MS-strip composite beams as compared to controlbeam.

Keywords: composite beam, limit state of design, MS-sheets, Deflection, Stiffness, Moment of inertia, flexural member etc…

INTRODUCTION

An important and economic combination of construction materials is that of steel and concrete. The concept of composite construction has been adopted in this project to control deflection and to check failure due to serviceability. In this section we are providing the background details of this method and what are our prime objectives. Serviceability limit state of design is to be adopted, which is the guiding factor to check deflection, cracking, vibration, durability,etc.

Beams have been used since dim antiquity to support loads over empty space, as roof beams supported by thick columns, or as bridges thrown across water, for example. The Egyptians invented the colonnaded building that was the inspiration for the classic Greek temple. Even with the scarcity of timber in Egypt, wooden beams supported the roofs. Early bridges were beams supported at each end by the stream banks, or on piles, on which a deck was constructed for traffic. In either case, the trunk of a tree was the usual beam, trimmed and either left round or squared. Our word "beam" is, in fact, cognate with German *Baum* or Dutch *boom*. A tree makes a very satifactory beam, indeed, and practically all beams were originally timber beams. Stone beams, as in door lintels, could be used only for very short spans and light loads, because of the brittleness of stone. Brittle materials do not make good beams.

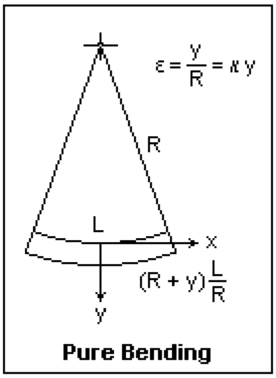
Through the millennia, beams were designed by empirical methods, applicable only to specific cases and incapable of generalization. Galileo studied beams, and although he did not get it quite right, he showed how the subject should be approached. The theory of beams was only perfected in the late 17th century with the rise of the science of elasticity, and was shown to be a subject of great complexity for which a full and accurate solution was very difficult. This remains true even with modern computational methods, such as the method of finite elements, which produces only numbers (not designs) but very little insight, and depends on parameters that are not well known and models that may contain errors. These methods have great value, but are not a comprehensive solution.

The theory of beams shows remarkably well the power of the approximate methods called "strength of materials methods." These methods depend on the use of statics, superposition and simplifying assumptions that turn out to be very close to the truth. They give approximate, not exact, results that are usually more than adequate for engineering work. Calculus and a little differential equations are all the mathematics required for this approach, not the partial differential equations or tensor analysis that are typical tools in elasticity.

Strength of materials methods can be used for beams of arbitrary cross sections, for beams whose shape varies along the length, for loads applied in any direction at any point, distributed or concentrated. Many of these applications are discussed in the first reference, which shows the versatility of the method. The results obtained are fully adequate for engineering design. On the other hand, an accurate and rigorous quantitative solution in these varied cases would be extremely difficult and usually impossible.

Pure Bending

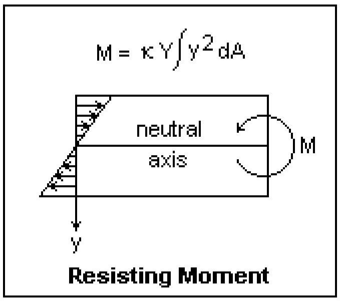
A beam is in pure uniform bending when the shear stress in the beam is zero, and the bending moment is constant. It is not very easy to achieve this state in practice. Opposite couples of moment M applied to the ends of a uniform beam creates pure bending, and there must be no transverse loads. If the ends of a beam are joined by a cord in tension, as in an archery bow, the beam is in pure bending with a superimposed axial compression. In the strength of materials picture, we would consider this as the superposition of uniform bending and uniform compression, which would be treated separately. Let us assume here that a beam under consideration has a cross section symmetrical with respect to a plane that is normal to the bending moment. Deflections will be in this plane, and we will establish x and y axes such that the x-axis is along the beam, and y is either upwards or downwards. Usually, y is taken positive downwards, and then the positive z-axis is into the plane, and a positive moment is clockwise.



Pure Bending

In strength of materials, we assume that the curve assumed by a beam in pure uniform bending is circular. Transverse planes remain plane, and intersect at an axis parallel to the z-axis and a distance R above the reference line defining the axis of the beam. This reference line can be defined rather arbitrarily, so we shall take it as the line through the centroid of the cross section, which will turn out to be significant. R is the radius of curvature of the stressed beam, and its *curvature* is κ = 1/R. An axial distance L before bending at a position y changes in length by ΔL = (L/R)y, so the longitudinal strain is ΔL/L = y/R = κy. This simple assumption proves to be very close to the fact in most cases. It is an important conclusion that the plane of the cross-section will not warp, but remain plane. Because lateral strains are related to longitudinal stresses, the cross-section will change slightly in shape, however.

The longitudinal stress σ will be proportional to the strain. Since the beam is not constrained laterally, σ = Yε = κYy, and Y is the Young's Modulus, with the same dimensions as the stress. Statics requires that the net force on a cross section of the beam be zero (in a free-body diagram of, say, the portion of the beam to the right of the cross-section there are no other longitudinal forces). This means that $\kappa Y \int y\,dA = 0$, or $\int y\,dA = 0$. This is precisely the condition that y = 0 locate the centroid of the cross-sectional area. The axis y = 0 is, then, called the *neutral axis* because the longitudinal stresses there are zero.



Resisting Moment

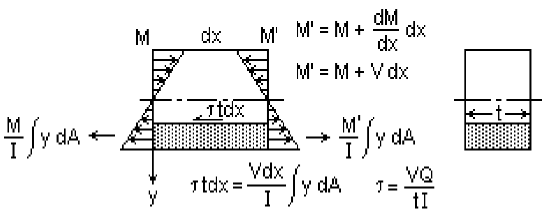
Since the normal forces are opposite for y > 0 and Y < 0, they most certainly will exert a moment $\kappa Y \int y^2 dA$ in the z-direction, and this must equal the applied bending moment M for equilibrium. A free-body diagram of the portion of the beam to the right of the plane considered is shown in the figure. The integral is called the *moment of inertia of area*, and is represented by I. Then, we have $\kappa YI = M$, or $\kappa = M/YI$. We have now found the curvature of the beam in terms of the applied bending moment, which is a rather exciting result, and one which Galileo would have admired.

Shear

Under more general loading conditions, a transverse force will act on the cut surface of the free body we considered above. The *shear* is negative of the sum of the forces on the beam to the left of the section. Just as we considered a bending moment only in one plane for simplicity, the shear forces will be considered to act vertically only. This vertical force is distributed over the section, and its average value is V/A, where V is the shear, positive downward (in the direction of increasing y). The distribution is, however, by no means uniform, so we need to know how the shear stress is distributed.

Shear stress has the peculiarity that it is in opposite directions on two parallel bounding surfaces (so that the net force will be zero), and even more importantly, there must be shear stresses of equal amounts at right angles (so that the net moment will be zero). Instead of finding the vertical shear stress at some height y, it will be easier to find the horizontal shear stress at that height. Once we have done so, it will be equal to the vertical shear stress.

To find the shear stress, we consider the shaded portion of the beam shown in the diagram as a free body. On the lower surface, the stress is zero. On the end faces, the stresses in the x-direction are due to the bending moment, and are proportional to the bending moment M and the distance from the neutral axis y. In fact, $\sigma = My/I$. If V > 0, then M' is greater than M by Vdx, and the total force on the right-hand face will be larger than the total force on the left-hand face. The difference must be balanced by the shear stresses over the upper face, which give a total force of τtdx, where dx is the length of the element, and t is its width. We assume that the shear stress τ is constant across the width of the element, which it is if the sides are parallel where the stress is being found. The result of this summation of forces is that $\tau = VQ/It$, where Q is the first moment of the shaded area with respect to the neutral axis. This is easily found if the shaded area is a rectangle, since then it is just the area of the rectangle times the distance from its centroid to the neutral axis. Everything needed for the derivation is found in the diagram, which will repay close study. Even when we must make different assumptions, the calculation of shear stresses is based on the same principles.



Shear in a Parallel-Sided Beam

EXPERIMENTRAL INVESTIGATION DESIGNPHILOSOPHY

Over the years various design philosophies have been evolved in different parts of the world, with regard to reinforced concrete design. A design philosophy is built up on a few fundamental premises and is reflective of a way of thinking Limit state of design is to be used which is the most widely used method in the world. It aims for a comprehensive and rational solution to design problem, by considering safety at ultimate loads and serviceability at working loads. Ultimate limit state also known as limit state of collapse deals with strength, overturning, sliding, buckling, fatigue fracture etc and serviceability limit state deals with discomfort to occupancy and malfunction, caused by excessive deflection, crack-width, vibration, leakage and also loss of durability.

Serviceability limit state is to be satisfied in the design, because it causes many problems such as;

- Aesthetic/ Psychological discomfort.
- Crack width formation.
- Pending in roof or slab.
- Reduces structural integrity
- Excessive vibration

Types of Deflection

a) **Short-term Deflection:** (Due to applied service load): If the applied bending moment is less than cracking moment, than the full un cracked section provides the rigidity and the moment of inertia for the gross section (Ig) . But when applied moment is greater than cracking moment, different size tension cracks occur and the position of neutral axis varies. The position of a beam where the applied moment is less than cracking moment (M_{cr}), is assumed to be un cracked and moment of inertia can be assumed I_g. When applied moment is greater than M_{cr}, tensile cracks that develop in the beam will ineffectively cause the beam cross section to reduce and moment of inertia is assumed to be equal to I_{cr}.

The IS code has given the moment of inertia that is used for deflection calculation .This moment of inertia is called as Effective Moment of Inertia(Ieff)

$$I_{eff} = I_{cr}/\{I.2-(M_{cr}/M)n\}$$

$n = z(1-k)b_w/db$

b_w= breadth of web.

b = breadth of compression face.

Stiffness trend:

$$EI_T > EI_{gr} > EI_{eff} > EI_{cr}$$

a) Long-term Deflection: (Due to sustained load) Long term load further increases the deflections because of shrinkage and creep that is the function of age of concrete, percentage of compression steel, temperature etc. Both creep and shrinkage depend on the amount of concrete. Therefore introduction of MS-sheet helps in minimizing the effect of creep and shrinkage.

To overcome the above drawback of deflection and to increase the Ieff and reduce the effect of creep and shrinkage, MS-sheets are introduced. Test results are analyzed to check the effect of MS-strips on the beam.

Design of a beam

Limit state of design was adopted for the design of control beam. The internal resisting forces were calculated at some assumed load and the theoretical behavior of control beam was studied.

Assumptions

a) Plane section normal to beam axis remain plane after bending.

b) Maximum compressive strain in concrete shall be taken as0.0035

c) Tensile strength of concrete isignored.

d) The strain in tension reinforcement at the ultimate limit state shall not be less than(0.87fy/Es)+0.002

Design Results

a) Effective span =1.75m

b) Cross section = (100×150) mm , d_{eff}=130mm

c) Characteristic strength of concrete = 20 MPa (nominal mix)

d) Assumed load =20KN

e) Applied moment(2-point load) =5.87KNm

f) Mu (limiting) =4.69KN

g) Re-bars (Fe-415) : 2-10ϕ diameter bars at bottom & 2- 8ϕ diameter bar attop.

h) Shear stirrups: 6ϕ bars at a spacing of100mm.

Arrangement of Steel in Beams

8ϕ and 10ϕ bars were used for tensile and compression reinforcement respectively. 6ϕ stirrups were used for shear reinforcement. MS strips were embedded in concrete material vertically in cross-section along axial direction, to increase the stiffness of beam

Specimen:

A beam of nominal mix M-20 (1:1.5:3) with dimensions 100mm × 150mm and effective span of 1.75m reinforced with steel bars and MS-sheets.

Control Beam:

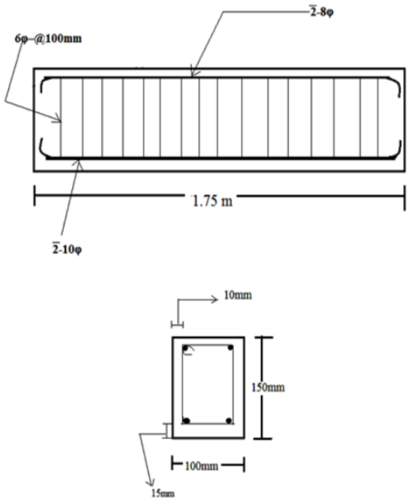


Fig-1: Normal RCC beam

Beam with MS-Strips provided in Full Depth Axially:

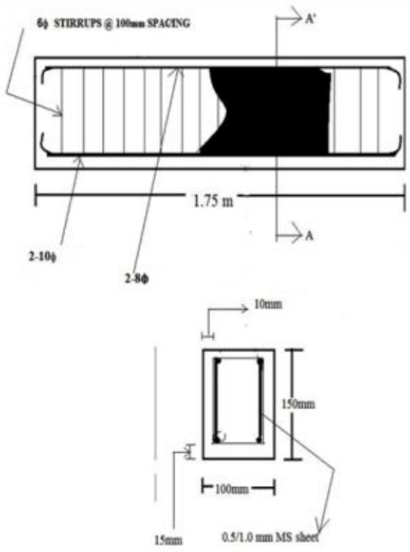
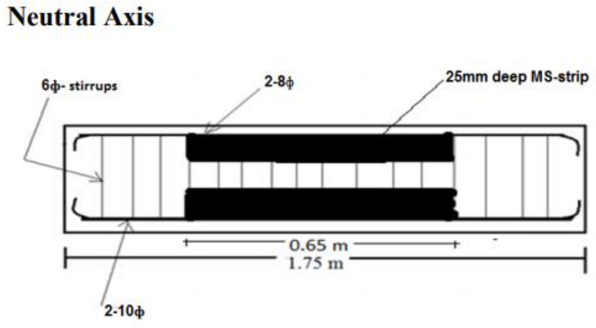


Fig-2: Composite RCC beam with MS-strips on full face

Beam with MS-Strips above and below Neutral Axis:



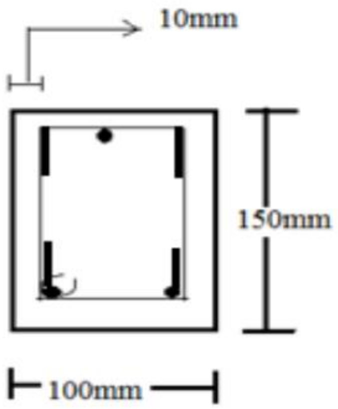


Fig -3: Composite RCC beam with MS-strips in central part above & below NA (L/3)

An experimental program was undertaken to verify the proposed design procedure and to calibrate future analytical studies. The twelve (3 of each type) full-scale beam specimens were instrumented for deflection and load measurements. The beams were tested under loading frame and concrete cubes were tested under UTM. This section gives an overview of the experimental program including details of the instrumentation and data acquisition.


b)

Fig -4: MS strips embedded in beam

Loading Test Frame and Data Acquisition:

The most important part of instrumentation is the loading frame made of structural steel columns and I-sections. The capacity of loading-frame is 500 KN. Specimens were set up with loading at one-third positions of a beam. A picture of the loading frame is shown in Fig -5. The vertical load is provided with the help of a hydraulic jack and the pumping unit, where as the load is to be measured with the help of proving ring attached to the pumping assembly and loading frame. 50 KN proving ring with a least count of 0.84 KN was used to calculate the load and the deflection caused was measured with the help of dial gauge kept below the beam at Central position, with a least count of 0.0254mm. The vertical load is measured in KN and the deflection is measured in mm from the dial gauge. The load is applied in regular intervals at a uniform rate; and deflection is calculated accordingly. This continues till the ultimate load is achieved and failure of the test specimen occurs.


a)

Fig-5: Beam testing

Testing Arrangement:

The testing of beam is to be done as per --- ASTM-D6272 All the twelve beams were tested under simply supported end conditions. Four point bending test was adopted for testing, because it ensures pure flexure behavior at the central part of the beam. Out of these twelve beams three are control beams, which are tested after 28 days of curing to find out the ultimate load carrying capacity and the maximum deflection at failure. Subsequently the remaining nine beams, three of each type are tested in the same manner of control beam and the test results of each specimen were compared.

RESULTS AND DISCUSSIONS

In this section brief introduction about the material used in the project and their engineering properties are even, as obtained from the test results. From test results of beams, load-vs-deflection curves for all types of beams are drawn. The final results of all the beams are composed and thoroughly studied. Different parameters like deflection stiffness, strength etc was taken under consideration to check the feasibility of the project. The crack pattern in beams was also studied and appropriate conclusions were drawn keeping in view the serviceability criteria.

Materials and their properties

The materials used in this project were cement, fine aggregates, coarse aggregates, steel bars, mild steel sheets and binding wires. The various engineering properties of all the materials are obtained from testing of materials.

Cement

Cement acts as binding material in concrete, which binds coarse aggregates and fine aggregates. The property of cement affects the strength of concrete. The cement used was 43-Grade (IS 8112). The standard consistency of cement used was 30.34% with a fineness of 3%.

Coarse and Fine Aggregates

sand is usually used as fine aggregate after it is cleaned and rendered free from silt clay and other impurities. The testing of sand is necessary in order to check its engineering properties. 1kg of sand was taken and sieve analysis was done to obtain zone of sand (zone-II), which gives us an indication about its compatibility. Coarse aggregate from about 75% of concrete of nominal mix M20. Gravel and crushed rock are normally used as coarse aggregate, the maximum size of coarse aggregate to be used in RCC work depends on thickness of member and space available around reinforcing bar. As the size of specimens is small so the aggregate size taken is about 8-10mm.

Steel Bars and MS Sheets

Concrete is reinforced with steel primary to make up for concretes incapability for tensile resistance. Steel imparts ductility to a material that is otherwise brittle. The steel used in this project was Fe-415 and Fe-250 of nominal diameter of 6mm, 8mm and 10mm.

MS sheet is used as a composite material in order to increase the stiffness of beam.

Table-1 physical properties of MS-Sheet

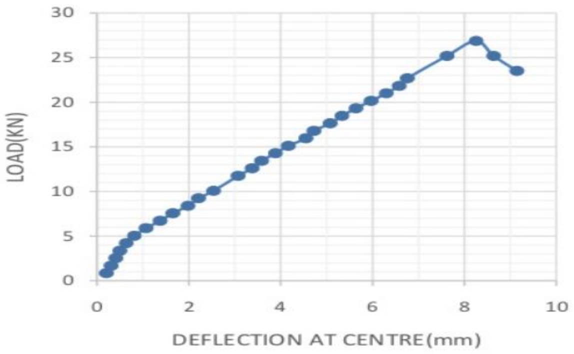
s.no	Propertis of MS-Sheet	0.5 mm thick	1mm thick
1	Gauge	25	19
2	density	7850kg/m^3	7850kg/m^3
3	Modulus of elasticity	2*10^{5}MPa	2*10^{5}MPa
4	Poison ratio	0.3	0.3
5	Ultimate strength	410MPa	410MPa
6	Yield strength	250MPa	250MPa

Observation of Results

In this section load-vs-deflection curve of all beams are plotted. The curves of all beams are compared and thoroughly studied, and various conclusions are drawn.

Normal Beam (CB)

Reading of proving ring (div)	Applied load on beam (KN)	Reading of Center dial gauge (div)	Deflection at center (mm)
1	0.84	8	0.2032
3	2.52	16	0.4064
5	4.2	25	0.635
7	5.88	42	1.0668
9	7.56	65	1.651
11	9.24	87	2.2098
12	10.08	100	2.54
15	12.6	133	3.3782
17	14.28	153	3.8862
19	15.96	179	4.5466
21	17.64	200	5.08
23	19.32	222	5.6388
24	20.16	235	5.969
25	21	248	6.2992
26	21.84	259	6.5786
27	22.68	266	6.7564
30	25.2	300	7.62
32	26.88	325	8.255
30	25.2	340	8.636
28	23.52	360	9.144



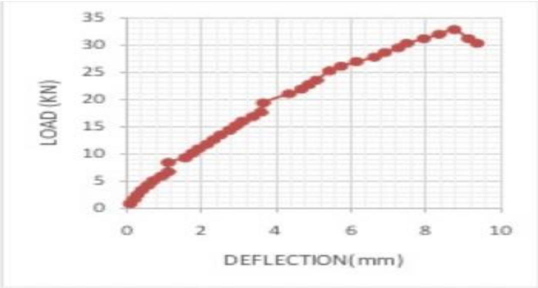
Graph-1 load vs deflection curve of CB

Fig-6 crack pattern in CB (a) Initial crack near center (b) Crack propagation

Beam with 0.5mm MS Strip on Full Face (T-1)

b)

a)



Graph -2: load vs deflection curve of beam T-1

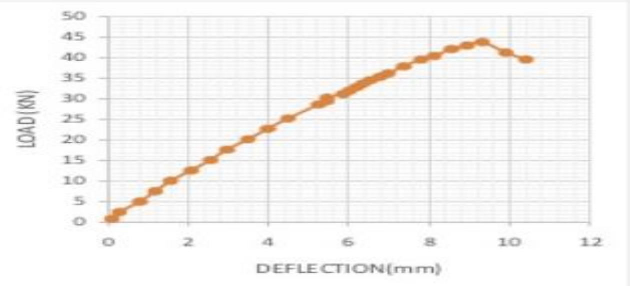
Table-3 Experimental observation of T-1

Reading of proving ring (div)	Applied load on beam (KN)	Reading of Center dial gauge (div)	Deflection at center (mm)
1	0.84	4	0.1016
2	1.68	8	0.2032
3	2.52	12	0.3048
4	3.36	16.5	0.4191
5	4.2	22.5	0.5715
6	5.04	28	0.7112
8	6.72	44	1.1176
10	8.4	44	1.1176
12	10.08	69	1.7526
13	10.92	76	1.9304
15	12.6	92	2.3368
17	14.25	108	2.7432
18	15.12	115	2.921
20	16.8	133	3.3782
21	17.64	141.5	3.5941
23	19.32	144	3.6576
26	21.84	184	4.6736
27	22.68	192	4.8768
30	25.2	214	5.4356
32	26.88	242	6.1468
33	27.72	261	6.6294
34	28.56	272	6.9088
35	29.4	286	7.2644
36	30.24	295	7.493
37	31.08	313	7.9502
38	31.92	329	8.3566
39	32.76	345	8.763
37	31.08	360	9.144
36	30.24	375	9.375

Table-4 Experimental observations of beam T-2

Reading of proving ring (div)	Applied load on beam (KN)	Reading of Center dial gauge (div)	Deflection at center (mm)
1	0.84	4.5	0.1143
.3	2.52	12	0.3048
6	5.04	32	0.8128
9	7.56	47	1.1938
12	10.08	62	1.5748
15	12.6	82	2.0828

18	15.12	101	2.5654
21	17.64	117	2.9718
24	20.16	138	3.5052
27	22.68	157	3.9878
30	25.2	177	4.4958
34	28.56	207	5.2578
35	29.4	215	5.461
36	30.24	215	5.461
38	31.92	237	6.0198
39	32.76	244	6.1976
41	34.44	257	6.5278
43	36.12	275	6.985
45	37.8	290	7.366
47	39.48	307	7.7978
48	40.32	320	8.128
50	42	337	8.5598
51	42.84	352	8.9408
52	43.68	367	9.3218
49	41.16	390	9.906
47	39.48	410	10.414

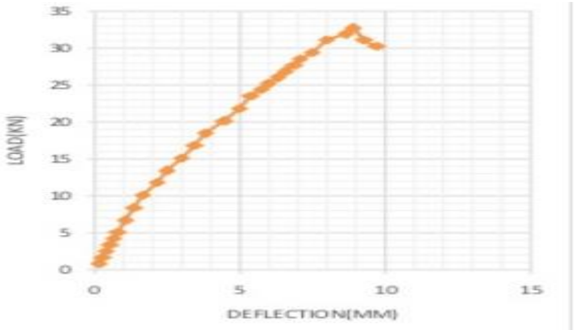


Graph -3: load vs deflection curve of beam T-2

Fig -8: crack pattern and propagation in beam T-2

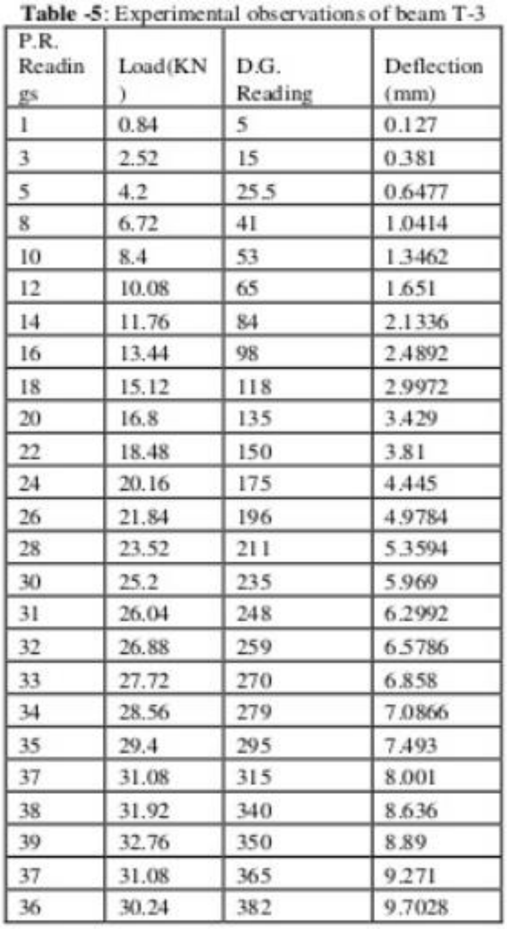
Beam with 1mm MS Strips above and below Neutral Axis (central Part)-T3

Fig -9: crack pattern in T-3 beam



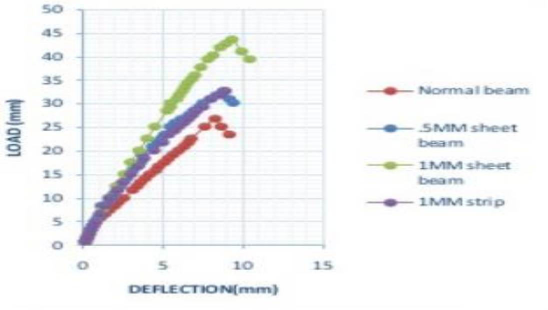
Graph -4: load vs deflection curve of T-3 beam

Table -5: Experimental observations of beam T-3



P.R. Readings	Load(KN)	D.G. Reading	Deflection (mm)
1	0.84	5	0.127
3	2.52	15	0.381
5	4.2	25.5	0.6477
8	6.72	41	1.0414
10	8.4	53	1.3462
12	10.08	65	1.651
14	11.76	84	2.1336
16	13.44	98	2.4892
18	15.12	118	2.9972
20	16.8	135	3.429
22	18.48	150	3.81
24	20.16	175	4.445
26	21.84	196	4.9784
28	23.52	211	5.3594
30	25.2	235	5.969
31	26.04	248	6.2992
32	26.88	259	6.5786
33	27.72	270	6.858
34	28.56	279	7.0866
35	29.4	295	7.493
37	31.08	315	8.001
38	31.92	340	8.636
39	32.76	350	8.89
37	31.08	365	9.271
36	30.24	382	9.7028

Comparision of Results



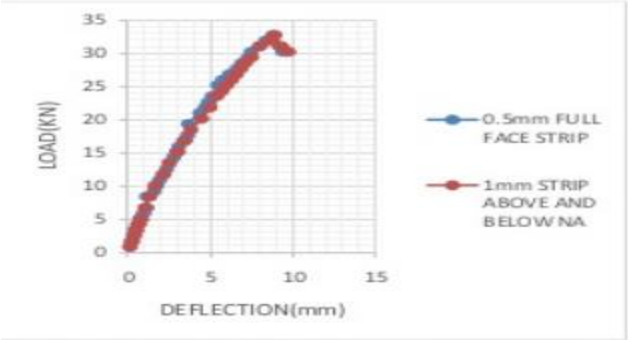
Graph -5: load vs deflection curve of all beams

Table-6: comparision of results of all beams

s.no	Type of Beam	Load (KN)	Deflection at center (mm)	Remarks
1	CB	26.88	8.255	-
2	T-1	26.88 32.76	6.53 8.76	Load carrying capacity Increases and sufficient control in deflection
3	T-2	26.88 43.68	4.98 9.32	Load carrying capacity Increases higher than that of beam T-1 and remarkable control in deflection.
4	T-3	26.88 32.76	6.578 8.89	Almost same behavior as that of beam T-1

From the initial portion of graph, the behavior of all beams is same which indicates that initial load is carried by concrete. After this, graph of composite beams shows increase in slope than normal beam indicating that composite beam carries more load and shows less deflection, therefore it can be concluded that the stiffness of composite bema has increased. Moreover, the beam with 1mm strip has maximum slope as compared to other beams increasing thickness of MS strips. Also the graph of T-1 and T-3 shows almost same behavior which shows the effect of depth of sheet in deflection control.

Comparison between Beam T-1 and T-3



Graph -6: load vs deflection curve of T-1 & T-3

From the above graph the following conclusion are obtained:

Deflection Control

S.no	Load (KN)	Deflection in beam T-1 (mm)	Deflection in beam T-3 (mm)	Remarks

1	27	6.15	6.85	Load at initial crack of both T-1 & T-2.

From the above data it is clear that the deflection at a particular load is slightly more in beam T-3 as compared to T-1. The stiffness is 4.39 KN/mm and 3.94 KM/mm for T-1 and T-3 respectively. This indicates the depth of strip affects the stiffness more.

Load Carrying Capacity

S.no	**Beam**	**Max. deflection (mm)**	**Load(KN)**
1	T-1	8.763	32.76
2	T-3	8.89	32.76

From the above data it is clear that the load carrying capacity of both T-1 and T-3 is same. This indicates that the strip is more effective and economical at central position.

CONCLUSIONS

By comparing the test results of control beam and test beams we conclude:

1. **DEFLECTION CONTROL**
   - By using 0.5mm thick MS-strip (full-face) deflection is controlled by 28% as compared to normal beam.
   - By using 1mm thick MS-strip (full-face) deflection is controlled by 42% as compared to normal beam.
   - By using 1mm thick MS-strip (above and below neutral axis) deflection is controlled by 22% as compared to normal beam.
2. **STRENGTH**
   - Strength is increased by 22% as compared to control beam by using 0.5mm thick MS-strip.
   - Strength is increased by 62% as compared to control beam by using 1mm thick MS-strip.
   - Strength is increased by 22% as compared to control beam by using 1mm thick MS-strip (above and below NA)
3. **STIFFNESS**
   - Stiffness is increased by 38% by introducing 0.5mm thick MS-strip along full face.
   - Stiffness is increased by 72% by introducing 1mm thick MS-strip along full face.
   - Stiffness is increased by 29.5% by introducing 0.5mm thick MS-strip above and below NA
4. Introducing of MS-sheet increases the ductility of beam.
5. MS-sheet also acts as shear reinforcement.
6. Weight of a composite structure is quite low as compared to normal R.C.C structure thus economical.
7. The maximum shear force and maximum bending moment are less in composite to normal R.C.C beam.
8. The introduction of strip at central position is more effective and economical.