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A Structural Approach to the Analysis and Design of Steel Beam in Pre-Cast Slim Floor Structure

S.Anjana
Assistant Professor,
Department of Civil Engineering,
Sri Ramakrishna Institute of Technology,
Coimbatore 10.

M.Shanmuga Raja,
Structural Engineer,
Alamiah Building Company KSCC,
Kuwait.

G.Baskar Singh,
Assistant Professor,
Civil Engineering Department,
S.Veerasamy Chettiar College of Engineering and Technology,
Puliyangudi, Tirunelveli.

ABSTRACT

Welded steel beams with trapezoidal box cross-sections and specially punched webs were developed to be preferably applied together with hollow core pre-stressed concrete slabs as composite beams in slim floors. Heights of standard produced steel beam copy the range of produced HC-units heights. Utilization of these slim composite beams enables to achieve an effective solution also in combination with filigree or in-situ cast concrete decks. The aim of the present investigation is to analyze the behavior of load carrying capacity for slim floor composite beam supported on precast column. This study describes a full-scale test on a typical model beam of 6m span for its flexural behavior with hinged supports and three points loading. The observed strength parameters are compared with predicted failure loads according to international code provisions with the help of Finite Element Analysis programme Delta beam FEM.

Keywords

Slim Floor, Steel Beam, Static Load and Load Carrying Capacity.

1. INTRODUCTION

Worldwide, many prestressed composite beams are used in commercial and domestic buildings for the precast structure. Precast beam offers an economic and versatile solution in any type of building construction. So that precast structure introduces slim floor structure. Slim floor is a generic term used to describe a form of construction where the supporting beams are contained within the depth of the hollow core concrete slab. This is achieved by supporting the slab of the bottom flange of the beam. The key feature of slim floor construction is that the steel beams are embedded within the slab depth, resulting in an overall structural depth of between 275 to 400 mm.

Typically the floor plate consists of either a composite slab using deep decking, or precast concrete hollow core units, which span between the beams. As opposed to traditional composite construction, which is more efficient for longer spans, slim floor construction offers opportunities for steel in span ranges between 5 to 10 m.

2. OBJECTIVE

Slim floor steel beam has been introduced as a new structural beam system in past 5 years, in the past researchers have investigated the various structure and various material that are commonly used in steel sections.

Nadaskya P. (2012) has studied about design parameters for larger spans of Welded steel trapezoidal beam and slightly over designed size of HC-units in combination with reinforced top concrete membrane utilization gives enough high 1st natural frequency of floor in range 4 to 5Hz and response factors R lower than 1.0.

Ehab Ellobody (2012) has completed nonlinear 3-D finite element models have been developed to investigate the structural behaviour of unprotected simply supported composite carbon steel and composite stainless steel beam constructions under fire conditions. The study has shown that composite slim floor stainless steel beam construction offers a considerable increase in the fire resistance and better structural fire behaviour compared with traditional composite slim floor carbon steel construction.

Silvana De Nardin A, Ana L.H.C. El Debs (2011) reports the results of full-scale tests in beam-to-column connections for composite slim floor systems, including tests on Bare Steel connection and composite connection. Tests results previously obtained on partially encased composite beams were used to define the position of the headed studs in the slim floor system.

In practice, slim floor steel beams are manufactured with standard available sections. This paper describes a section which has four plates connected with Mig weld and specially punched with web hole for composite action, Main objective of this project is to study the flexural behaviour of slim floor built-up steel sections using mild steel members.

3. SPECIMEN MODEL

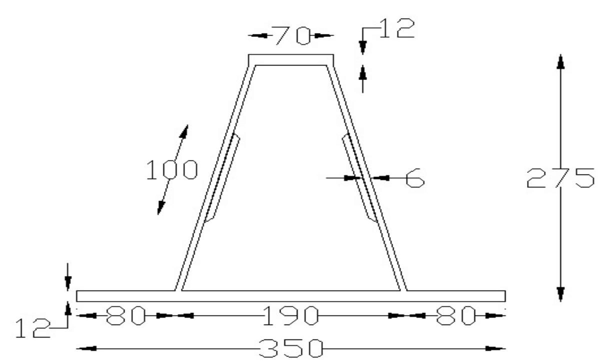

Figure 1. Cross sectional view of the steel beam

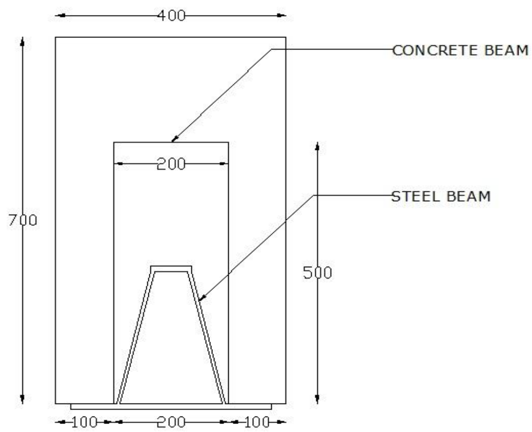

Figure 2. Cross sectional view of the steel beam with concrete beam for loading purpose

4. MANUFACTURE METHOD

4.1 Material

Plates	Flame cutting and mechanical cutting
Rebars	Mechanical cutting
Welding	with MAG machine or manually
Welding class	C (SFS-EN 25817)

4.2 Manufacturing Tolerances

Length L	= 2400mm =	± 5 mm
Width B	= 350mm =	± 5 mm
Height h	= 270mm =	± 3 mm
Lateral flexure f_p		≤ L / 650
Flexure f_n		± L / 650
Size and location of holes		± 5 mm
Location of couplings		± 5 mm
Location of supp. parts (c-profile, cambers, formwork sheet)		± 5 mm

4.3 Painting

The lower surface of the beam primed to SA2,5 40 µm. Other painting and surface treatment are agreed upon separately with the customer. For example, when the beams are exposed to weather at the sites, it is recommendable to consider a thicker paint coating.

Figure 3. manufacturing of steel beam

5. EXPERIMENTAL INVESTICATION

5.1 Tension Test on Steel Sheet

IS 1663-1960 part 1 recommends the method of conducting tensile test on steel sheet strip which is less than 3mm and not less than 0.5mmthick.

5.2 Stress Strain Curves:

The following figure shows the stress vs strain curve for 1.2 mm MSP. Yield stress=250 MPa.

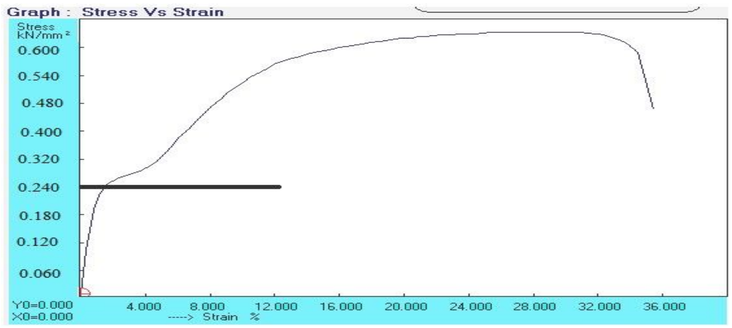

Figure 4. Stress vs. strain curve for 1.2 mm mild steel plate

Stress vs Strain curve for 12mm diameter bar is shown in the figure. Yield stress =415 MPa

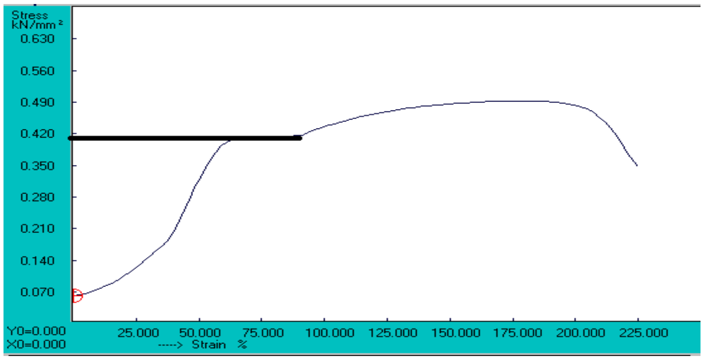

Figure 5. Stress vs. strain curve for 12 mm diameter bar

5.3 Physical Properties of Material

Table 1. Physical properties of material

Thickness of top and bottom plate	12 mm
Thickness of web portion	6 mm
Young's modulus	$2x10^5$ N/mm^2
Poisson's ratio	0.3
Density	78E-9

5.4 Experimental Setup (Three point load)

Three point loading is applied at L/3 and L/2 distance from either end of the specimen and it is loaded gradually up to maximum load, the deflections and strain values are to be recorded using deflectometer and proving ring. The Load is gradually applied by means of a hydraulic jack which is operated manually. The Specimen is supported on two supports. Three point loading is applied on the top through two rollers and a channel section kept over the top. Three deflectometers are used, one at L/3 distance and other at L/2 distance. Strain gauges are used at bottom plate and web portion. In bottom and web plate 12 and 8 nos of strain gauges are located to measure the change in measurement in strain. Specimens are placed on the loading frame and rollers provided at either ends for simply supported end condition. Proving ring is fitted to measure the loading. The Hydraulic Jack is kept on top and Proving Ring (of maximum capacity of 30 KN) is kept on top of Jack.

Properties:

Hydraulic Jack : capacity = 100 TONNE

Proving Ring : capacity = 50kN

Least count of Deflectometer : 0.01 mm

Least count of Strain Gauge : 0.002 mm

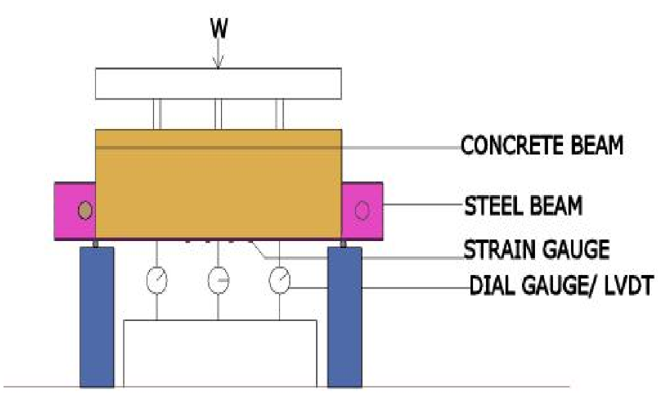

Figure 6. Testing Arrangement of Beam

Concrete beam is casting for applying uniformly distributed load on steel beam. Steel beam and concrete beam is casted. Testing of steel beam is to be completed as soon as possible.

Arrangement of Deflectometer

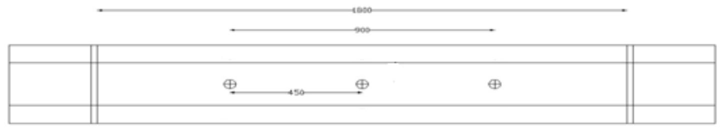

Figure 7. Location of LVDT in steel beam

Table 2. Test Result for flexural Bending upto 300KN

D27-350	Buckling Load (KN)	Ultimate Load (KN)	Deflection		FAILURE
			L/2	L/3	
Trial 1	300	>300	4.32	4.18	Does Not Occur
Trial 2	300	>300	4.29	4.15	Does Not Occur
Trial 3	300	>300	4.27	4.14	Does Not Occur

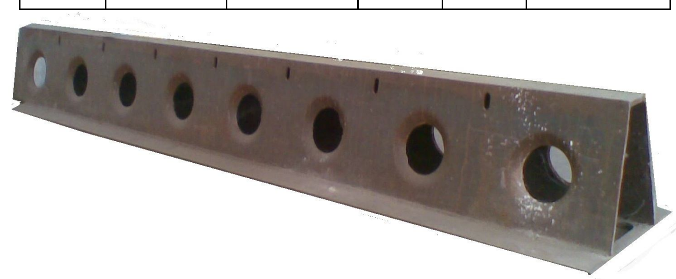

Figure 8. Full Scale D27-350 Steel Beam

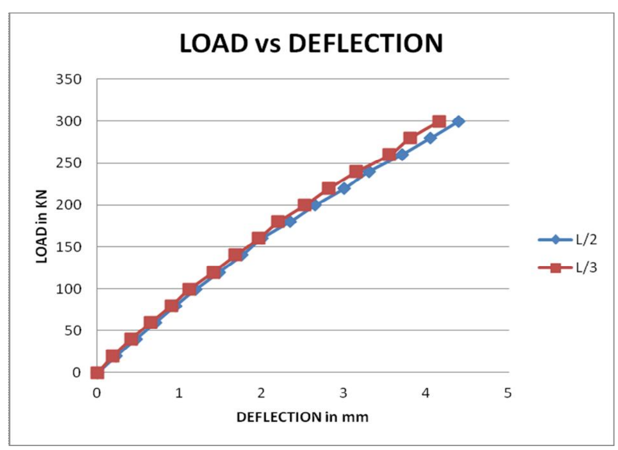

Figure 9. Load Vs Deflection Graph for D27-350

6. NUMERICAL INVESTICATION

6.1 Delta Beam Calculation Program

Delta Beam calculation program is designed for analysing and optimizing steel beams used in buildings. The analysis of structure is based on linear elastic theory for both composite structures and steel structures, as appropriate.

The calculation of forces, moments and deformations of the beam structure is base on FEM (Finite Element Method). The post analysis of FEM results is based on selected standard. The program generates a Finite Element Model based on the 3D model defined by the user. The 2 node beam element with 7 degrees of freedom in each node is used to model the beams for FEM analysis.

The post analysis of the FEM results (forces, moments and deformations) is based on selected standard sizes.

6.2 SPECIMEN DETAILS

Size	B	b1	b2	d2	h	Ø
D20-200	200	97.5	100	10	200	80
D20-300	300	97.5	180	10	200	80
D20-400	400	130	278	10	200	80
D26-300	300	97.5	148	10	265	150
D26-400	400	130	245	12	265	150
D27-350	350	80	190	12	275	100
D32-300	300	97.5	110	14	320	150
D32-400	400	130	210	14	320	150
D37-400	400	130	180	18	370	150
D37-500	500	130	278	18	370	150
D40-400	400	130	180	20	400	150
D40-500	500	130	278	20	400	150
D50-500	500	130	230	20	500	150
D50-600	600	130	330	20	500	150

The allowable load-bearing capacity [kN/m] is presented for single-span beams according to the type of the beam. The beam D20-200 is analysis in Delta Beam FEM software and shear force, bending moment and deflection is shown in below.

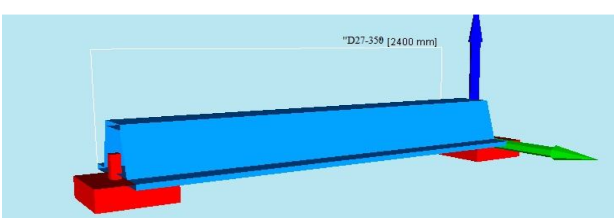

Figure 10. Full Scale Steel Beam Model

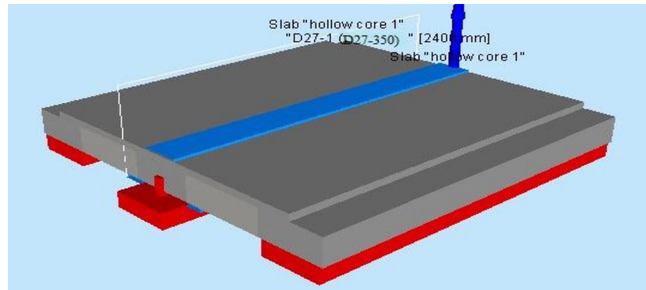

Figure 11. Full Scale Steel Beam Model with Slab on Both Side

Table 3. Load Characteristics

Name	Type	Location	Load	Loading Case
Slab 1 load	line load	0-2400	6.4	primary slab and joint concrete
Structural topping 1 Load	line load	0-2400	3.6	Structural topping
Slab 2	line load	0-2400	6.4	primary slab and joint concrete
Structural topping 2 Load	line load	0-2400	3.6	Structural topping
DB1(D27-350) Load	line load	0-2400	1	Beam and rebar
Joint Concrete load	line load	0-2400	0.9	primary slab and joint concrete

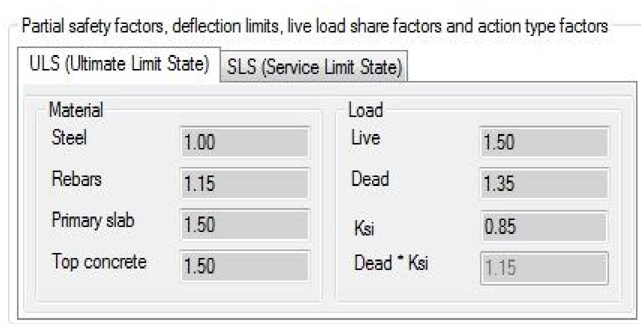

Figure 12. Partially Safety Factor

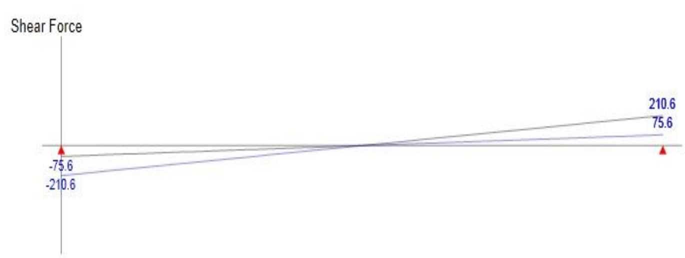

Figure 13. Shear force diagram

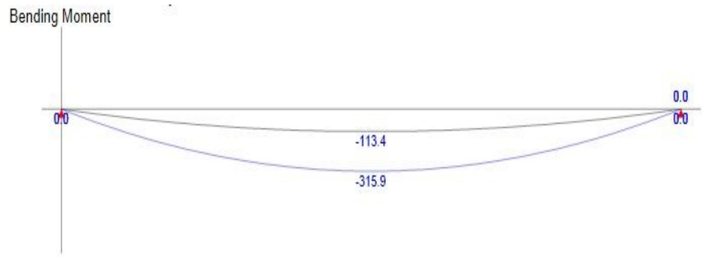

Figure 14. Bending Moment diagram

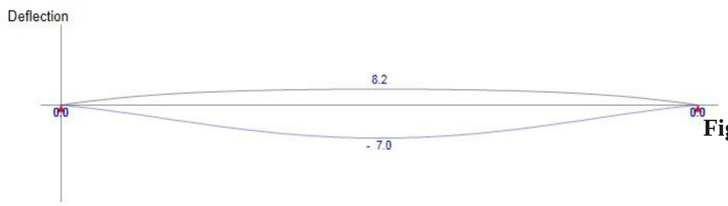

Figure 15. Deflection diagram

The allowable load-bearing capacity [kN/m] is presented for single-span beams according to the type of the beam.

The following defaults have been used when calculating the curves:

1. steel beam S355J2G3
2. concrete MC35/45
3. 30 % of allowable load is static
4. temporary surface loading during construction 0,5 kN/ m^2
5. flexure caused by static load is eliminated by precambering
6. surface casting 50 mm (not structural)
7. hollow-core slabs are the same height as the beam

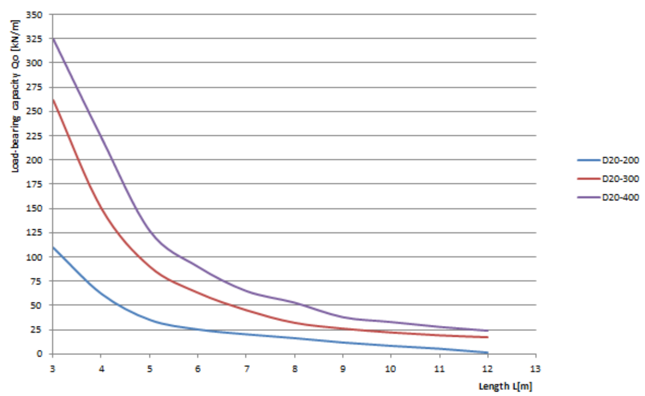

Figure 16. Characteristics Load Bearing Capacity of D20-200-300-400 Steel Beam

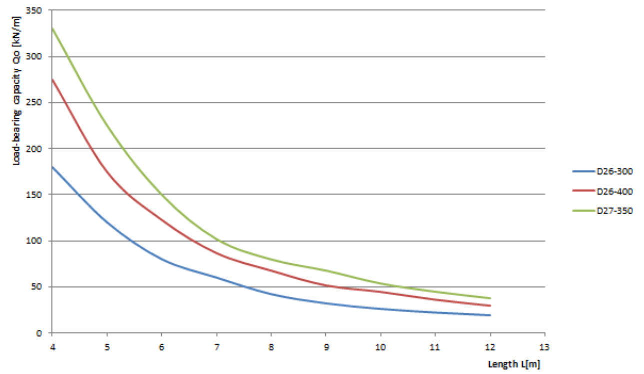

Figure 17. Characteristics Load Bearing Capacity of D26-200-400 and D27-350 Steel Beam

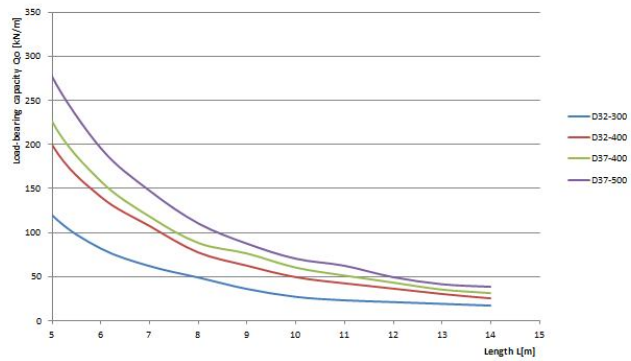

Figure 18. Characteristics Load Bearing Capacity of D32-300-400 Steel Beam

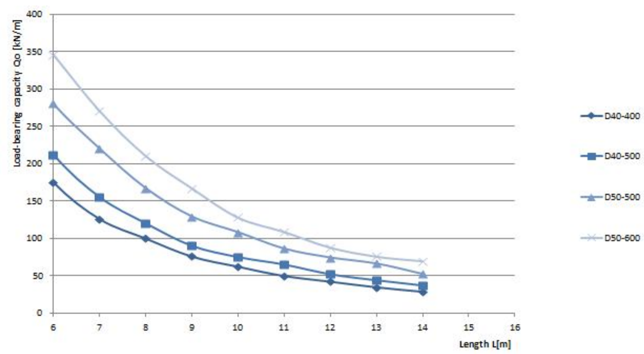

Figure 19. Characteristics Load Bearing Capacity of D40-400-500 and D50-500-600 Steel Beam

Table 4. DELTA BEAM Finite Element Results

Sl.No	Model Name	Length (m)	Ultimate Load (KN/m)	Deflection of DELTA BEAM (mm)
1	D20-200	3m	110	4.9
2	D20-300	3m	260	8.26
3	D20-400	3m	325	5.48
4	D26-300	4m	180	10.55
5	D26-400	4m	275	11.96
6	D27-350	4m	330	13.1
7	D32-300	5m	120	12.94
8	D32-400	5m	200	15.51
9	D37-400	5m	225	13.48
10	D37-500	5m	275	13.8
11	D40-400	6m	175	18.91
12	D40-500	6m	210	18.58
13	D50-500	6m	280	15.85
14	D50-600	6m	345	17.39

THEORITICAL INVESTIGATION

Table 5. Theoretical results

Specimen Name	Length (mm)	Load (KN/m)	Area (mm^2)	Moment of Inertia (mm^4)	y Bottom (mm)	section Modulus (mm^3)	Allowable Deflection (mm)	Actual Deflection (mm)
D20-200	3000	110	5985.59	8194970	83.2821	984001.444	12.5	7.07
D20-300	3000	260	7604.32	1.22E+08	92.2089	1322631.02	12.5	11.24
D20-400	3000	325	9773.41	2.36E+08	96.1431	2458886.95	12.5	7.24
D26-300	4000	180	8023.65	2.06E+08	116.023	1774613.91	16.6	14.57
D26-400	4000	275	10182.2	2.88E+08	122.0692	2357333.66	16.6	15.92
D27-350	4000	330	8136.86	3.36E+08	83.1418	4037996.32	16.6	16.38
D32-300	5000	120	8264.17	2.77E+08	131.6236	2106174.78	20.8	17.61
D32-400	5000	200	10454.7	4E+08	141.0661	2836461.68	20.8	20.33
D37-400	5000	225	10720.4	5.14E+08	157.2661	3269487.65	20.8	17.80
D37-500	5000	275	12499.3	6.75E+08	169.8814	3975311.32	20.8	16.56
D40-400	6000	175	11068.3	6.2E+08	170.8873	3625648.81	25	23.83
D40-500	6000	210	12847.3	8.08E+08	184.0241	4390216.73	25	21.93
D50-500	6000	280	13505.3	1.22E+09	220.0927	5548262.01	25	19.34
D50-600	6000	345	15305.3	1.52E+09	233.5281	6513792.41	25	19.13

Table 6. Comparison of Experimental results, Theoretical results and Numerical results

Specimen Name	Length in mm	Load KN	Deflection in mm			Ratio of Deflection [Experimental/Theoretical]	Ratio of Deflection [experimental/ Delta beam]
			Experimental Result	Delta Beam result	Theoretical result		
D27-350	2400	300	4.46	3.98	4.12	1.08	1.12

Table 7. Comparison of Numerical results &Theoretical results

Sl.no	Specimen Name	Length in mm	Load KN/m	Theoretical result in mm		Delta Beam Deflection result in mm	Ratio of Deflection [Theoretical/Delta beam]
				Actual deflection	Allowable deflection		
1	D20-200	3000	110	12.5	7.07	4.9	1.44
2	D20-300	3000	260	12.5	11.24	8.26	1.36
3	D20-400	3000	325	12.5	7.24	5.48	1.32
4	D26-300	4000	180	16.6	14.57	10.55	1.38
5	D26-400	4000	275	16.6	15.92	11.96	1.33
6	D27-350	4000	330	16.6	16.38	13.1	1.25
7	D32-300	5000	120	20.8	17.61	12.94	1.36
8	D32-400	5000	200	20.8	20.33	15.51	1.31
9	D37-400	5000	225	20.8	17.80	13.48	1.32
10	D37-500	5000	275	20.8	16.56	13.8	1.2
11	D40-400	6000	175	25	23.83	18.91	1.26
12	D40-500	6000	210	25	21.93	18.58	1.18
13	D50-500	6000	280	25	19.34	15.85	1.22
14	D50-600	6000	345	25	19.13	17.39	1.1

7. CONCLUSION

Design of Welded steel beams with trapezoidal box cross-sections and specially punched webs are required for the consideration of Flexure and Local Buckling.

The Numerical analysis and Experimental testing of specimen has been done and its results are compared.

A series of experimental tests on Welded steel beams with trapezoidal box cross-sections and specially punched webs section have been performed. The experiments were carried out between hinged ends. Load carrying capacity of steel beam should be compared.

Both DELTA BEAM 1.0 and Experimental results agree well.

The load Vs deflection curve shows the behaviour of the section.

Failure is initiated by flexural & local buckling torsion failure doesn't occur in this type of steel section.

Carrying capacity for local buckling is increased due to increase in effective area.

By verifying the theoretical results with experimental results, it should have minor difference and it is torsion less intermediate steel beam. So it is perfectly suitable in precast structure.

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