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Design & Analysis of Varying Cross Sectional Cantilever Beam with Trapezoidal Web for Jib Cranes

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ABSTRACT

The study includes an investigation of the bending, shear capacity and lateral-torsional buckling behavior of regular I section cantilever beam of jib crane subjected to self-weight and an eccentric point load at the free end. Different shapes of cantilevers are proposed in this study with different cross section and web shapes. Finite element analysis and experimental study are carried out on both types to calculate and validate results. An optimization technique is to be use to optimize the solution from proposed different designs. The thickness of the flange is constant for all specimens with length 5 m and tested for 500 Kg load lifting capacity. Structural analysis is done to examine the influence of the section dimension due to eccentric point load at the free end on cantilever. Using the study it is observed that not only the web thickness, but also the other geometrical parameter of web (like infill length of corrugated web, width of web & corrugation angle) and sectional cross section & taper angle of cantilever beam influences the resistance to bending, lateral torsional buckling and shear capacity.

Keywords- **Bending, shear capacity, lateral torsional buckling, sectional cross section, taper angle, and web shape.**

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I. INTRODUCTION

Today's industry demands versatile, efficient and cost effective equipment while at the same time providing more flexibility along with significant savings through increased productivity, there are several equipment used in industry for material handling, a jib crane is one of them (refer fig 1). A jib crane is a type of crane making use of a mounted arm to lift and move the material. The arm mounted either perpendicular to or at an acute angle upwards from a pillar or wall, may rotate along its central axis via a limited arc or possibly a full circle. A jib crane is usually used in industrial settings, like warehouses, docks and industrial manufacturing setup, to load and unload material [1].

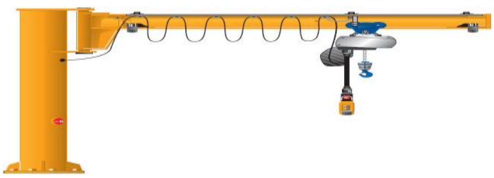


Fig 1 Pillar Type Jib Crane

Beams are essential components of steel construction. A satisfactory design should ensure that the beam is stable and has enough strength and stiffness against the applied loads. For steel beams having an I-shaped cross section, global buckling and local buckling are typical modes of instability. Global instability is in the form of lateral torsional buckling of the beam as a whole, while local instability could be in the form of web or flange buckling [3]. However, at a certain level of the applied load, the beam may buckle laterally, while the cross sections of the beam rotate simultaneously about the beam's axis. This phenomenon is called lateral-torsional buckling [4].

The use of variable cross section beam has been increasing in the steel construction industry. This is because of their ability to increase stability of structure, and sometimes to satisfy architectural and functional requirements in many engineering structures [5]. Tapered beams are widely used in modern technology, mainly due to their structural efficiency. At present, the web-tapered thin-walled I-beam is one of the most popular tapered beams used in practice [6].

In study and investigations, it is observed that the jib crane requires breakdown maintenance most of the times in a year due to the reasons given below (refer fig 2)

a) Lateral shift of cantilever I-type beam with respect to axis of mounting and because of that movement of trolley is restricted.
b) Bending at free end stuck the trolley at tip position
c) Bending caused damage to the bearing.

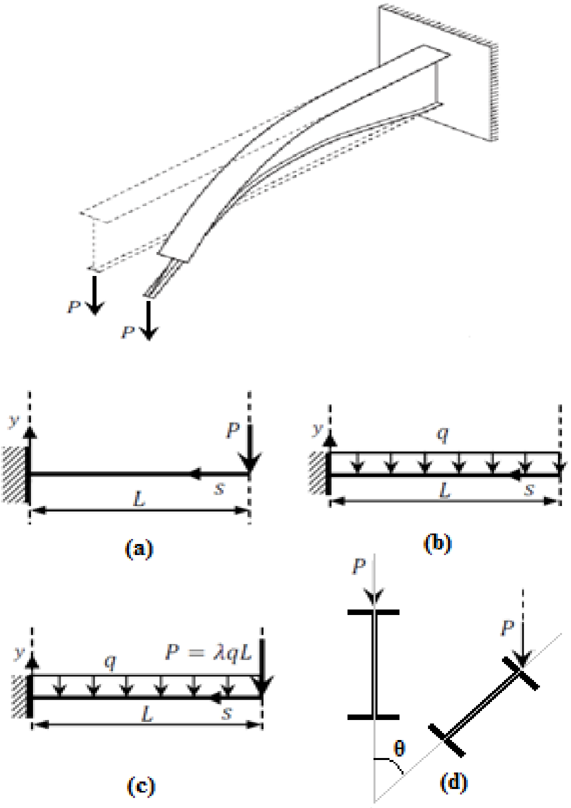


Fig 2 Bending & Lateral Torsional Buckling of I-section cantilever beam due to direct and or eccentric loading

I. PROPOSED DESIGN

A new cantilever beam has to be developed in order to study and analysis the bending and buckling behavior of cantilever beam with using different cross sections and with trapezoidal web section to find resistance capacity of cantilever beam. Several solutions have been proposed in order to combat with bending and buckling problem.

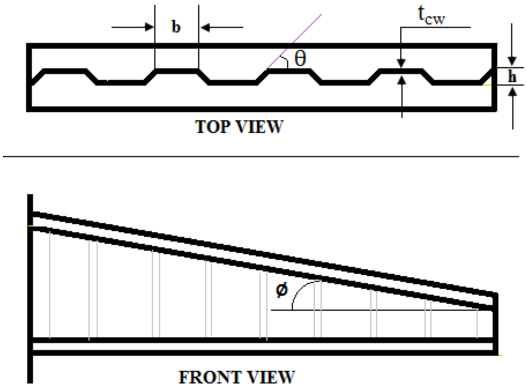


Fig 3 Proposes varying cross section cantilever beam with trapezoidal web

II. METHODOLOGY

A literature study performed in order to understand the mechanism behind bending & lateral-torsional buckling. Failure analysis of regular I beam for direct & eccentric loading. Study & analysis of various parameters of trapezoidal web and taper beam for the evaluation of deflection by CAE software. Experimental setup will be developed for validation of results obtained by FEA. The optical fiber is used to carry out test for measuring the deflection of cantilever beam of varying cross section with trapezoidal web section.

Parameter selection

a) For trapezoidal web
    i. Web thickness (t_w) – 5.7, 6.7 mm
    ii. Corrugation angle (θ) – 30^0, 45^0, 60^0, 75^0
    iii. Infill corrugation plate length (b) – 300, 350 mm
    iv. Corrugation web width (h) – 20, 30 mm

b) For Taper Beam
    i. Taper angle (Ø)
    ii. Cross section of cantilever

III. ANALYSIS OF TRAPEZOIDAL WEB PROFILE

A trapezoid web steel section is built up by welding flanges and a web of trapezoidal corrugated profile (refer fig 4). The main purpose in particular is to increase the out-of-plane stiffness and shear buckling strength without the use of vertical stiffeners. It allows the use of thin plate webs without the need of stiffeners, thus considerably reducing the cost of fabrication. Since there is no standard design method for the new section, this research has been carried out to develop a complete design guide based on analytical and experimental study.

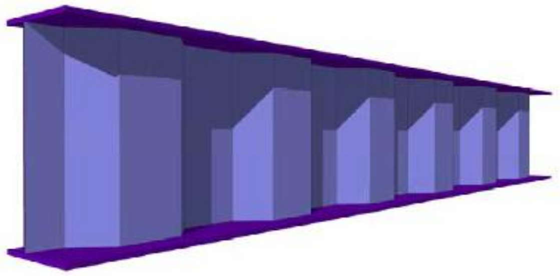


Fig 4 Trapezoidal web profile

A. FEA of flat and trapezoidal web section

Finite element study was carried out on the trapezoidal and straight web section using CAE software. In this study, all models were assumed to buckle under perfect conditions, where there is no initial imperfectness. Loading conditions are also same for all models, two types of loads are considered, one is point load at free end and self weight of beam. To ensure the load is applied through the web, the nodes for the support will be constrained in its x, y, and z translation at the support. The assumptions used in linear buckling analysis are that the linear stiffness matrix does not change prior to buckling and that the stress stiffness matrix is simply a multiple of its initial value.

B. . Modeling

CATIA is used to create the models and are defined in terms of geometric features that must be subdivided into finite elements for solution. This process of sub division is called meshing. Mesh datasets contain information about element types, element discretisation and mesh type. The I-beam models were assigned ungraded mild steel for its material property with Young's modulus, E= 2.1×10^5 N/mm^2, shear modulus, G = 79×10^3 N/mm^2 and Poisson ratio of 0.3. The convergence of the mesh was established by independently increasing the mesh density in each part of the model beam section.

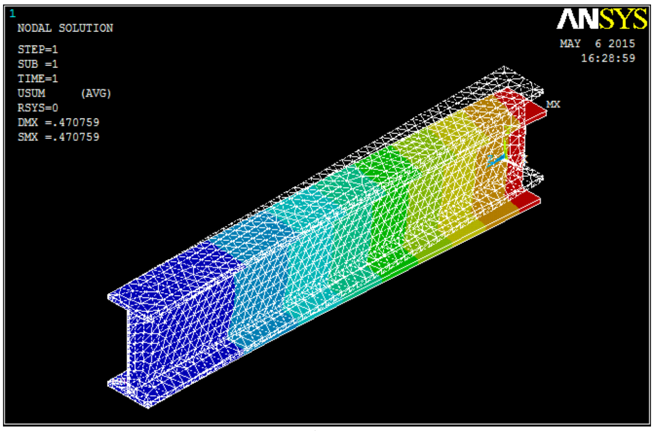


Fig 5 FEA of a straight beam

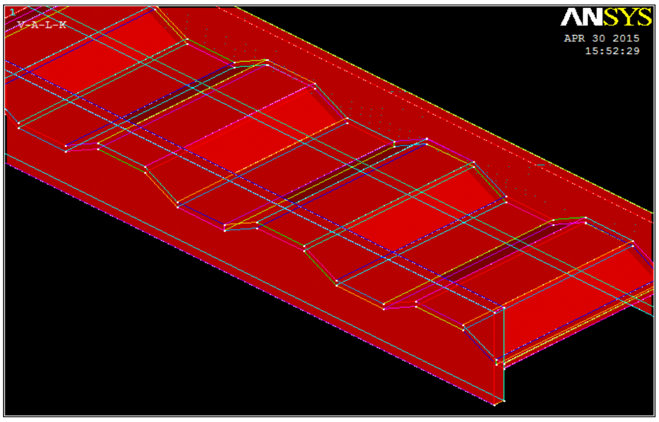


Fig 6 Modelling of trapezoidal web section beam

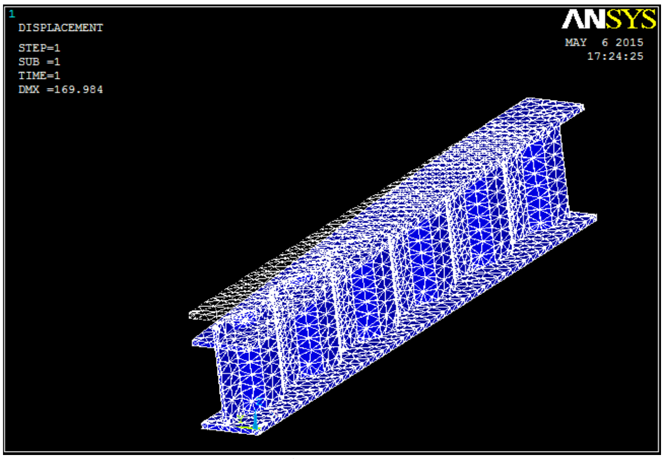


Fig 7 FEA of Trapezoidal Web Beam

C. FEA Results

Table I

FEA results of LTB in Z-axis (mm) for beams with trapezoid & straight web for eccentric loading (e = 100 mm).

Span (mm)	CP length (mm)	WC width (mm)	Web Thk (mm)	Lateral Torsional Buckling in Z-axis (mm)				
				Trapezoidal Beam				FW
				TW 30^0	TW 45^0	TW 60^0	TW 75^0	
3000	300	30	5.7	0.97	0.57	0.99	0.61	7.44
			6.7	0.84	0.41	0.81	0.51	7.11
	350		5.7	1.27	0.98	1.54	1.04	7.44
			6.7	1.08	0.82	1.25	0.89	7.11
5000	300	20	5.7	5.11	4.44	5.01	4.67	32.34
			6.7	4.46	3.79	4.67	4.1	30.79
		30	5.7	3.99	2.87	4.21	3.01	32.34
			6.7	3.24	2.57	3.67	2.78	30.79
	350	30	5.7	4.87	4.11	5.73	4.49	32.34
			6.7	4.24	3.47	4.31	4.1	30.79

Table II

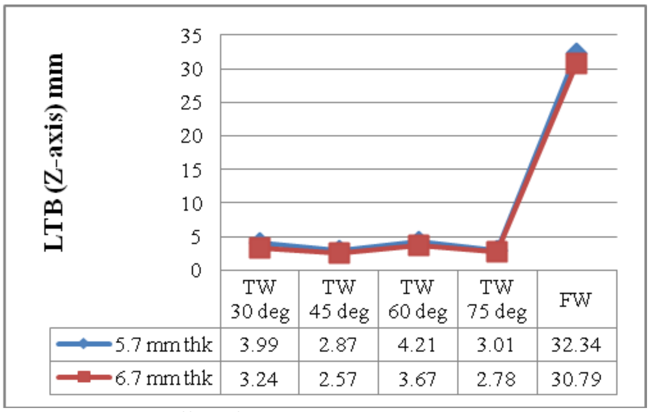
FEA results of Bending in X-axis (mm) for beams with trapezoid & straight web for eccentric loading (e = 100 mm).

Span (mm)	CP length (mm)	WC width (mm)	Web Thk (mm)	Bending in X-axis (mm)				
				Trapezoidal Beam				FW
				TW 30^0	TW 45^0	TW 60^0	TW 75^0	
3000	300	30	5.7	1.77	1.12	1.99	1.51	14.76
			6.7	1.54	0.89	1.71	1.18	13.03
	350		5.7	2.41	1.98	2.2	2.11	14.76
			6.7	2.08	1.61	1.89	1.42	13.03
5000	300	20	5.7	15.72	8.28	13.26	9.32	68.66
			6.7	14.01	7.99	12.54	8.83	66.34
		30	5.7	12.18	7.95	11.74	8.19	68.66
			6.7	10.91	7.02	10.84	7.91	66.34
	350	30	5.7	17.47	9.35	15.91	14.41	68.66
			6.7	15.73	9.34	14.22	13.71	66.34

D. Results and Discussion

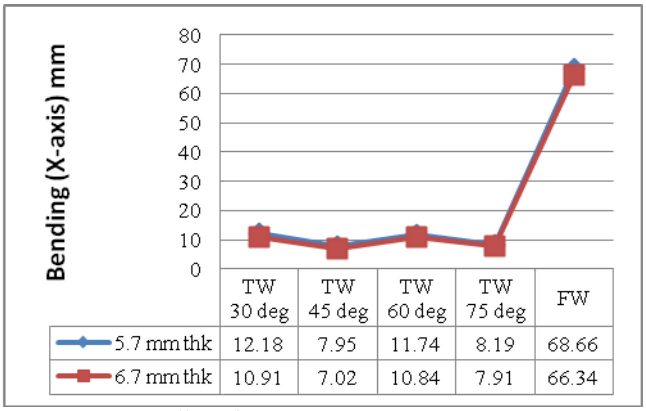
The effect of some geometric properties on the performance of cantilever beam loaded with point load at free ends such as effect of web thickness (t_w), corrugation angle (θ), length of Infill Corrugated Plates (b), and width of corrugated web (h), and web openings were investigated and the other geometric parameters such as B = 100 mm, D = 200 mm and t_f = 10 mm are keep constant. In the following paragraphs, the results of these parameters are presented in detail.

A. Corrugated Web Plate Thickness (t_w)



	TW 30 deg	TW 45 deg	TW 60 deg	TW 75 deg	FW
5.7 mm thk	3.99	2.87	4.21	3.01	32.34
6.7 mm thk	3.24	2.57	3.67	2.78	30.79

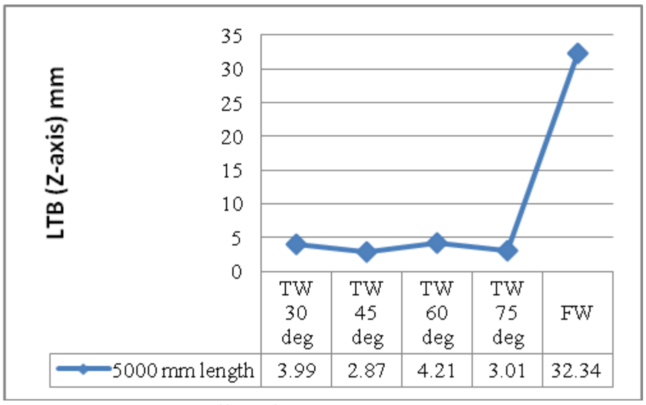
Fig 8 Effect of corrugated web thickness on LTB



	TW 30 deg	TW 45 deg	TW 60 deg	TW 75 deg	FW
5.7 mm thk	12.18	7.95	11.74	8.19	68.66
6.7 mm thk	10.91	7.02	10.84	7.91	66.34

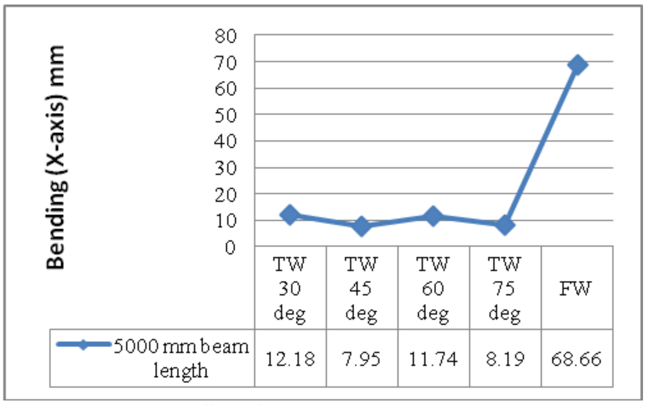
Fig 9 Effect of corrugated web thickness on LTB

B. Corrugated web angle (θ)



	TW 30 deg	TW 45 deg	TW 60 deg	TW 75 deg	FW
5000 mm length	3.99	2.87	4.21	3.01	32.34

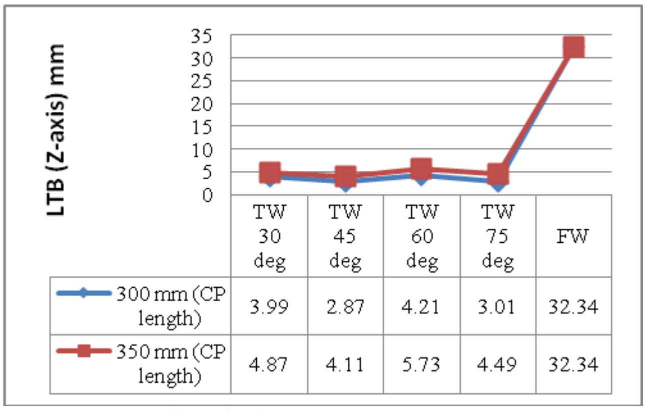
Fig 10 Effect of corrugation angle on LTB



	TW 30 deg	TW 45 deg	TW 60 deg	TW 75 deg	FW
5000 mm beam length	12.18	7.95	11.74	8.19	68.66

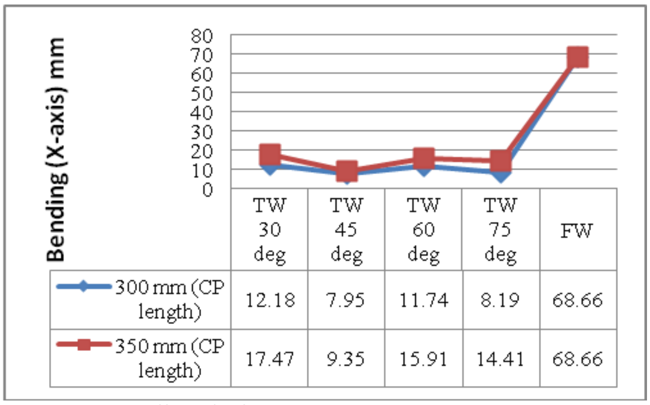
Fig 11 Effect of corrugation angle on Bending

C. Length of Infill Corrugated Plates (b)



	TW 30 deg	TW 45 deg	TW 60 deg	TW 75 deg	FW
300 mm (CP length)	3.99	2.87	4.21	3.01	32.34
350 mm (CP length)	4.87	4.11	5.73	4.49	32.34

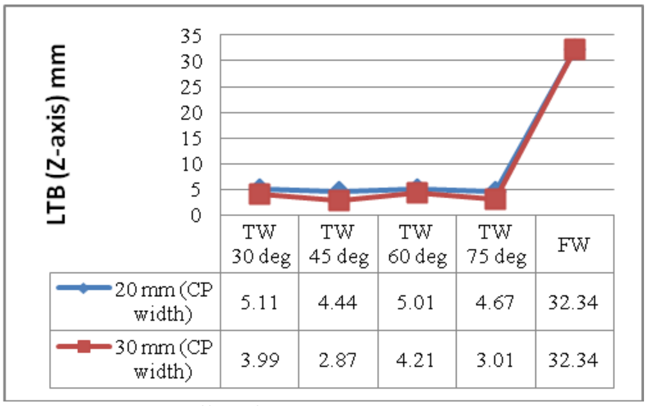
Fig 12 Effect of infill corrugated plate length on LTB



	TW 30 deg	TW 45 deg	TW 60 deg	TW 75 deg	FW
300 mm (CP length)	12.18	7.95	11.74	8.19	68.66
350 mm (CP length)	17.47	9.35	15.91	14.41	68.66

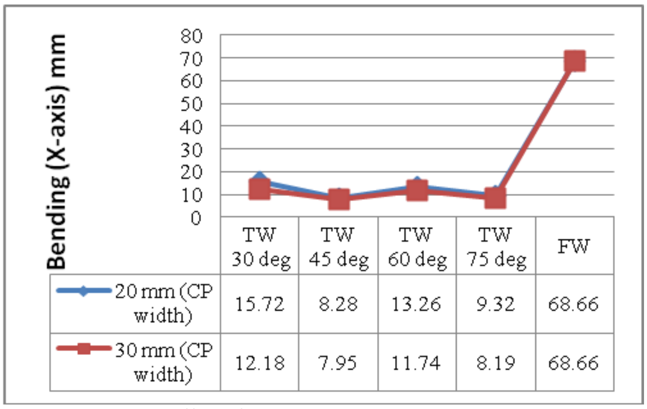
Fig 13 Effect of infill corrugated plate length on Bending

D. Width of corrugated web (h)



	TW 30 deg	TW 45 deg	TW 60 deg	TW 75 deg	FW
20 mm (CP width)	5.11	4.44	5.01	4.67	32.34
30 mm (CP width)	3.99	2.87	4.21	3.01	32.34

Fig 14 Effect of corrugated web width on LTB



	TW 30 deg	TW 45 deg	TW 60 deg	TW 75 deg	FW
20 mm (CP width)	15.72	8.28	13.26	9.32	68.66
30 mm (CP width)	12.18	7.95	11.74	8.19	68.66

Fig 15 Effect of corrugated web width on Bending

E. Advantages of Trapezoidal Web over Straight Web

A finite element analysis is done on the behavior of trapezoidal web steel section and compared the same with regular steel section when applied a load at free end, and the following points are concluded:

1. Trapezoidal web steel section has higher resistance to bending and lateral torsional buckling compared to that of section with flat web section cantilever beam.
2. Trapezoidal web thicknesses, web angle, length of infill corrugated plate, width of corrugated web influences the resistance to bending and lateral torsional buckling resistance of a cantilever beam,
    a. Higher trapezoidal web thickness gives the higher resistance.
    b. With trapezoidal web angle 45^0 and 75^0 will get higher resistance to bending and lateral torsional buckling.
    c. Increasing size of length of infill corrugated plate reduces the resistance to bending and lateral torsional buckling.
    d. Increasing size of width of corrugated web increases the resistance to bending and lateral torsional buckling.

IV. ANALYSIS OF TAPER BEAM

It would be beneficial for designers to determine the location and magnitude of the maximum compressive stress of tapered cantilevers.

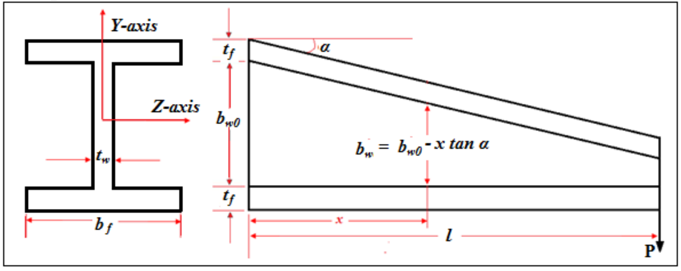


Fig 16 Taper angle calculation

Consider a web tapered I-section cantilever subject to a udl and a concentrated load at its free end. Let *x* be the longitudinal axis of the beam, *y* and *z* be the cross-sectional axes parallel to the web and flange, respectively. Due to the tapering of the web, the section properties of the beam are a function of the coordinate *x* and can be expressed as follows:

$$y = t_f + b_{w0} - \frac{1}{2} x \tan(\alpha)$$

$$I_z = \frac{1}{6} b_f * (t_f)^3 + 2 b_f * t_f \left(\frac{1}{2} t_f + \frac{1}{2} b_{w0} - \frac{1}{2} x \tan(\alpha) \right)^2 + \frac{1}{12} t_w (b_{w0} - x \tan(\alpha))^3$$

where, *y* is the distance from the top of the section to the neutral axis, I_z is the second moment of the cross-sectional area about the z-axes, b_f is the flange width, t_f is the flange thickness, b_{w0} is the web depth at the support ($x = 0$), t_w is the web thickness and α is the tapering angle. For a beam subject to a uniformly distributed load and a concentrated load at its free end M_z can be expressed as follows:

$$M = P(L - x) + \frac{q2(L - x)^2}{2} + \frac{q1(L - x)^2}{6}$$

where, *P*, *q2 and q1* are the concentrated and UDL and UVL, respectively, *x* is the distance from the fixed support and *l* is the cantilever length, as shown in Figure 6. The compressive stress, *σ* of the beam then can be determined as follows:

$$\sigma = \frac{M * y}{I_z}$$

Differentiating Eq. (4) with respect *x* and equating it to zero yields a value for the location of the maximum stress.

$$\frac{d\sigma}{dx} = \frac{y * \frac{dM}{dx}}{I_z} - \frac{M * y * \frac{dI_z}{dx}}{(I_z)^2} + \frac{M * \frac{dy}{dx}}{I_z}$$

$$\frac{dM}{dx} = -p - q2(L - x) - \frac{1}{3} q1(L - x)$$

$$\frac{dy}{dx} = -\frac{1}{2} \tan(a)$$

$$\frac{dI_z}{dx} = -2 b_f t_f \left(\frac{1}{2} t_f + \frac{1}{2} b_{w0} - \frac{1}{2} x \tan(a) \right) \tan(a) - \frac{1}{4} t_w (b_{w0} - x \tan(a))^2 \tan(a)$$

By using the above mathematical model, find out,

- The Location of the Theoretical Maximum Bending Stress
- The Magnitude of the Theoretical Maximum Bending Stress

V. PROPOSED EXPERIMENTAL SETUP

A plastic optical fiber is attached to a (cantilever) beam to monitor its deflection. The change in the light intensity of the optical fiber is monitored using a light-dependent resistor (LDR) and a basic voltage divider circuit. The output of the LDR is continuously measured by the ADC-16 and this simple system is able to provide real-time beam deflection monitoring with a PC. The experiment highlights the deflection of a structure with potential use of an optical fiber as a sensor for monitoring, in real time.

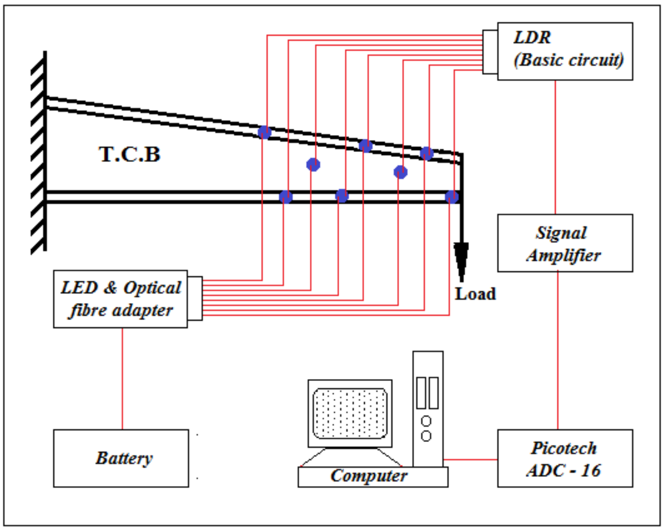


Fig 17 Proposed experimental setup

VII . CONCLUSIONS

In this paper a new design approach of beam shape is proposed to tackle the problems of deflection, lateral torsional buckling of cantilever beam due to direct and eccentric loading. Study and analysis show that how the trapezoidal web & tapered cantilever beam is more capable of resisting the lateral torsional buckling and bending for a given load, if compared to regular I section cantilever beam. From analysis it is observed that not only the web thickness, but also the other geometrical parameter of web (like infill length of corrugated web, width of web & corrugation angle) and sectional cross section and taper of cantilever beam influences the resistance to bending, lateral torsional buckling.

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