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Comparative Study of Tapered Section with Castellated Girder for Industrial Building

Dr. M.K.Maroliya

Associate Professor, Applied Mechanics Department, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat.

***Abstract*— The economical designing concept become very popular nowadays. Like Pre-engineered Buildings (PEB) are used worldwide due to their less usage of material and also for the strength requirement. Tapered sections are majorly used in the PEB. A different type of PEB members is also introduced, they are called castellated beam. In India this type of structures not widely used as the IS codes have no specifications regarding the castellated members. This paper deals with the manual designing of castellated beams using the guidelines given by various codes. The outcome obtains cover the effect of change in parameters of castellated beams. Also, by using the IS code specified steel what significant changes can be achieved is going to be checked.**

Key words: Castellated beams, Vierendeel bending, Tapered section, Angle of hexagon, Parent beam.

INTRODUCTION

Economic designing becoming a basic requirement in modern day construction. In any type of construction work over all cost of the structure and the material usage are the most affecting factors. From centuries, the new idea and innovations comes in the light, thought they came from the different region, but their design ideology remains same. In the construction industries though the load carrying by a structure is main concern, but if there is any way that make the design of structure more durable and economical then this type of design becomes the first choice. To meet the requirement of rapidly growing demands in construction work alternative way is to be in corporate. In structural engineering one of the ways is Pre-Engineered Buildings (PEB). The well-known economical designing of structure is Pre-Engineered Buildings also known as PEB structures are widely constructed around the globe. The main reason to PEB becoming famous is that the quantity Of material used in the structure is very less compare to our old traditional structures and as its first fabricated in the factory and then brought to the site location the construction time also reduces. In a Pre-Engineered Building design, the main concern is to design all the section in such a way that the structure attains its full strength and the material usage also become less. Most commonly used sections in PEB are the Tapered sections. Tapered sections are basically an I-section with varying depth and flange. The main aim is to obtain the requirement strength of the structure. An efficiently designed PEB can be lighter than the conventional steel building.

As mentioned above PEB is a good alternative of the conventional building design. In addition, there are also some new members other than tapered sections which are used nowadays in the PEB. These members are called castellated beams. Normally beam with any shape of opening at certain intervals with higher depth are called castellated beams. In the castellated beam the most commonly used shape is hexagon. The beam with circular openings is termed as cellular beams as shown in the figure.

The castellated beams and cellular beams are made from the root beams by using the mechanical tools. This type of members mainly designs for axial forces. The opening along the length also provides excessive opportunities to supply electric wires, sprinkler pipes etc. Due to the opening the structure became lighter and, it's also giving an esthetical appearance to the structure.

Fig. 1: Cellular beams

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Excessive generation of Vierendeel moment can lead to failure of the beam. The Vierendeel bending failure occurs due to formation of plastic hinges at four locations around the opening in the region of high shear. The Vierendeel bending is the additional parameter which needs to be checked with the other parameters.

In this present work STAAD Pro. Software was used to design the PEB. By using that data manual design of castellated beams was carried out using the AISC guidelines. The main focus of the study is to find the suitability of the castellated beams.

Method of analysis

To get the design loads and data for a PEB model, the IS codes were used and for the manual design of the castellated beams AISC 31 was preferred. IS 800 is used to design the PEB structure, IS 875 code is used to find the wind load. Indian Standards have no specifications about the castellated beams so we preferred the AISC standards. AISC 31 code is used to design the castellated beams as it contains designing details as well as the limitations.

Modelling of structure

Table 1: Details of PEB model

Span	16 m
Length	48 m
Height	11 m
No. of bay	6
Bay spacing	8 m
Location	Delhi
Structure type	Warehouse

Mention above is the geometric data of the structure. The load applied on the structure are shown,

Table 2: Dead load and Live load

D.L	
Main Rafter	4.46 kN/m
Column	2.97 kN/m
L.L	4.46 kN/m

The PEB model was analysed for the wind load using IS 875 (Part-3)-2015. The manual data for the wind load calculation is shown the table below,

Table 3: Wind force for the rafter member

Angle		Wind Force (kN/m)	
		0+Cpi	0-Cpi
0	EF	-2.17	-8.48
	GH	-6.95	-0.64
		90+Cpi	90-Cpi
90	EG	-2.44	-8.75
	FH	-6.95	-0.64

After applying all the necessary loads, the analysis of the structure was carried out in STAAD software and tapered section was selected according the data.

Table 4: Section properties

Tapered section	D_t	D_b	t_w	b	t_f
Main column					
R1	700	350	18	230	18
R2	350	230	18	230	18
R3	230	230	18	230	18
Main Rafter					
R4	280	400	16	240	16
R5	400	600	16	240	16
R6	600	680	16	240	16

Above-mentioned data clearly indicates that the flange width (b) and thickness of web (t_w) and flanges (t_f) remain same throughout the section, the only change taken into account is the depth of the member.

As the value of bending moment is governing factor according to the PEB designing guideline the depth of section become higher in the area the of the higher moments.

Manual design of castellated beam

The codes which used to design the castellated beams are basically EUROCODES and AISC. There are no guidelines in IS standard codes to design castellated beams. As, there is no guide lines for the design process of the castellated beams, we tried to design the section theoretically by using the AISC 31 CODE guidelines given for cellular beams and castellated beams.

An excel sheet was prepared by using the example which is given in the AISC code for castellated beam. For this research the method is same as per AISC guidelines, load is same only the angle was predefined and effect of that change of the angle on other design parameters is theoretically observed.

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The manual calculation of castellated beam was carried out with the same yield strength as per the PEB model designed in the STAAD. For our calculation purpose the parameters which indicated in the IS standard for standard beams are used as parent beam. The aim of this calculation is to check that what significant changes occur for different values of Angle of hexagonal cut(θ) in the castellated beam.

Optimisation of design for castellated beams for different angles

For theoretical calculation purposes, the load act on the castellated beams is same as that for the PEB. This may give a hint for the design of castellated beams from parent beams, which were taken from the IS standard specifications.

In this calculation the value of hexagonal cut(θ) is predefined.

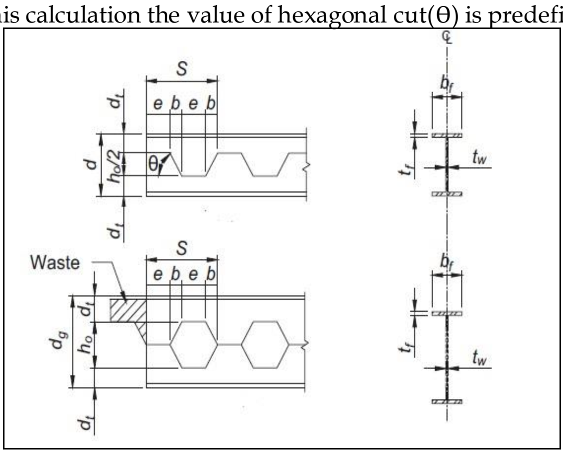

Fig. 2: Parameters of Castellated beam

As shown in the figures the parameters of castellated beams are,

θ = Angle of hexagonal cut
d_t= Depth of Tee section
d = Full nominal depth
h_0= Height of opening of castellated beam
d_g= Depth of expanded beam
b_f = Flange width
t_f = Flange thickness
t_w= Web thickness
e = Length of tee section, also length of solid web section along centre line
b = Horizontal length

Properties and loads assigned to the castellated beams are,

F_y = 345 N/mm²
F_u = 490 N/mm²
e = 76.2 mm (3 inch.)

Loads,

D.L = 4.46 kN/m
L.L = 4.46 kN/m
W.L = 6.3 kN/m

The analysis of castellated beam is carried out using LRFD method mention in the AISC 31 code. The results are taken for deflection under the effect of applied loads. The parent beam is gradually changed until all the requirements are met by the designed beam.

RESULT AND DISCUSSION

PEB building are more durable and efficient than the conventional structural system. A Tapered section is got assembled in such a way that the whole structure acting as the one unit. The Tapered section is a good option for higher load and moments carrying member. The designing of varying depth section mainly depends on the bending moment diagram pattern of the PEB members. In PEB designing longer span with column free area can be achieved. Tie members generally provided to resist only axial load generated by wind.

Castellated beam was analyse using theoretical calculation provided by AISC CODES. LRFD method was taken in the consideration. Castellated beam design was done using IS standard specified steel as root beam. The effect of change in the value of the angle of hexagonal (θ) was also carried out theoretically and the parameters which are affected simultaneously are also taken in the consideration.

Results of castellated beam

Graphical representation of the obtained data are shown below for different values,

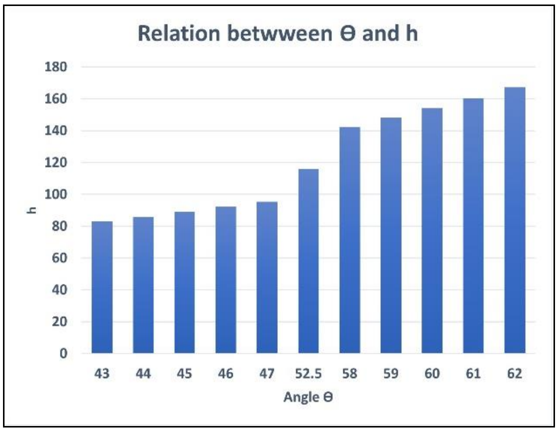

Fig. 3: Relation between hexagonal angle (θ) and half height of castellated opening (h)

- *Change of angle results in change in the value of "h - half height of castellated opening" and "dt - depth of tee".*
- *This change also affects the deflection of the beam.*
- *Change in the values of angle of hexagonal cut(θ) have significant effects on other parameters.*

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- *With the increase of angle (ϴ) values of half height of castellated opening (h) increases simultaneously.*
- *For the values of depth of tee (dt) and deflection (Δ) decreases as the value of hexagonal angle (ϴ) increases.*
- *Above shown graphs indicates that the value of angle increases the deflection value decrease.*
- *The tapered section we are getting using the software have the depth more than 600mm while the manual calculation of castellated beam gives lesser depth.*
- *Castellated beams are lightweight structures compared to the tapered sections.*

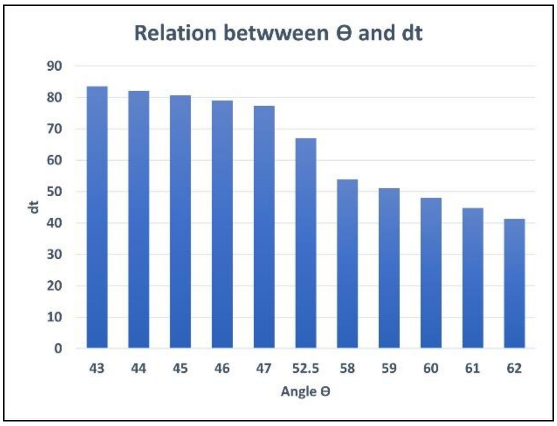

Fig. 4: Relation between hexagonal angle (ϴ) and depth of tee (dt)

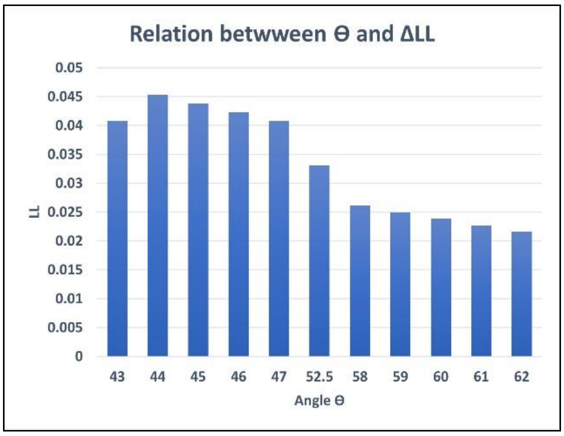

Fig. 5: Relation between hexagonal angle (ϴ) and deflection (Δ) due to live load (LL)

- *For the values of depth of tee (dt) and deflection (Δ) decreases as the value of hexagonal angle (ϴ) increases.*
- *Above shown graphs indicates that the value of angle increases the deflection value decrease.*
- *The tapered section we are getting using the software have the depth more than 600mm while the manual calculation of castellated beam gives lesser depth.*
- *Castellated beams are lightweight structures compared to the tapered sections.*

CONCLUSION

By using the AISC guidelines for theoretical designed of the castellated beams some important points are noted below,

- The angle of hexagonal have (ϴ) affects the overall depth of the structure.
- Size of hexagonal opening also increase simultaneously with hexagonal angle (ϴ).
- Deflection value for all the loads are decreases as the value of hexagonal angle (ϴ) increases.
- If the deflection value exceeds the limitation of given angle then it may lead to failure of the structure.
- Which indicates that the value of hexagonal angle should be taken higher.
- Deflection value is higher for angle 43 and less for angle 62.
- The overall depth of castellated beam for angle 43 is 330mm and for angle 62 the overall depth is 420mm.
- Castellated beam shows grate resistance against higher load, but it cannot be used for higher moment areas for that tapered sections are preferable.
- Tapered section designed using STAAD have 680mm depth for Principal Rafter and for the manually design castellated beam the max depth is 420mm.
- The main cause of failure for castellated beams is Vierendeel bending. As the corner stresses of hexagon exceed certain limits it causes the Vierendeel bending in the member.
- Castellated beam only uses for axial loads.
- Manual data gives a slight hint that may be castellated beams are more suitable and also economical where the bending moments are not the major concern.
- It's difficult to tell that which section is suitable compare to other as this thing require more data
- A trial calculation was done in this thesis works which indicates that the angles are suitable up to the values suggested in AISC 31, if the value of angle exceeds the suggested value its ultimately led to failure of the member.

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- There are other parameters like centre-to-centre distance between two opening which may be affect the load carrying capacity of different angle.
- It is also necessary to provide higher section tapered column member for castellated beams as its not suited for bending.
- it would become easier to design which can be done manually as well as practically.

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Table 5: Change in parameters for different angles

Angle Θ	Ratio h/b	h mm	dt mm	Ix	Iy	Δ_{LL} mm	Δ_{DL} mm	Δ_{TL} mm
43	0.93252	82.901	83.55	1352118	22140962	0.0408	0.0985	0.1392
44	0.96569	85.85	82.075	1282399	22140840	0.0453	0.1095	0.1548
45	1	88.9	80.55	1212972	22140713	0.0438	0.1057	0.1495
46	1.03553	92.059	78.971	1143905	22140581	0.0423	0.1021	0.1443
47	1.07237	95.334	77.333	1075279	22140444	0.0408	0.0985	0.1392
52.5	1.30323	115.86	67.072	710747.3	22139589	0.0331	0.0799	0.1129
58	1.60033	142.27	53.865	390167.3	22138489	0.0261	0.0631	0.0893
59	1.66428	147.95	51.023	340191.7	22138252	0.025	0.0603	0.0852
60	1.73205	153.98	48.01	293749.4	22138001	0.0238	0.0575	0.0813
61	1.80405	160.38	44.81	251306.5	22137734	0.0227	0.0548	0.0548
62	1.88073	167.2	41.402	213352	22137450	0.0216	0.0521	0.0736