Study of Haunched Beam Frame Subjected to Various Load Conditions

Jayesh V Sadavare[1] and Dr.S.N.Tande[2]

[1]*M.Tech. Student, Civil Engineering Department, Walchand College of Engineering, Sangli*
[2]*Professor and H.O.D. Civil Engineering Department, Walchand College of Engineering, Sangli*

Abstract - *In medium span beams, prismatic beams are widely used. As the length of the span increases, the rise in depth causes certain beams to become uneconomical. In such cases, the best solution is non prismatic beams (haunched beams). This paper shows analysis and design technique for structures having haunched beam members. Commercial structural software for structural study and design has more evolved in this few years. Nowadays, software is more user friendly, in addition to giving engineers with more modelling ways to solve critical, difficult problems and geometries. Worldwide, commercial structural analysis software alike SAP2000 or STAAD-Pro provides engineers for modelling and analysis of haunched beams. In addition, haunched beam and normal beam were analysed in this software to compare displacement, stiffness, stress, etc. factors. Beam with different cross section like rectangular, T beam analysed. Along with software analysis, physical experiments were done as well; using steel, concrete and composite materials then comparison among all results were made.*

Every information on test prototypes, specimens, instrumentation, and test set up and test procedures are determined in the details of the experiments. Results obtained for relation between moment capability and modes of failure are provided. It is noticed that these connections represent the features of a rigid link with proper designing and detailing.

In line with the distribution of the internal stresses, non-prismatic members may be used to form the beam members. With the minimum load and needed materials, one can achieve the necessary strength by using these types of beams and can meet architectural or functional requirements. Non-prismatic beams with fixed, linear, and parabolic height and width variations are widely used for industrial structures, bridges, and high rise buildings.

***Keywords**: Prismatic, STAAD-Pro, SAP, Stiffness, Haunch Beams, strength*

1. INTRODUCTION

Beam that changes its cross section over its length is a haunch beam. The study for lateral forces results in higher values of moments on the end support of the beam (and above part of the columns) in a beam column connection, typically on the top of the column where the rafter is attached to the column, with a moment tolerant connection, and the values goes downs sharply, as you step away from the ends. In medium span beams, prismatic beams are widely used. As the length of the span increases, the rise in depth allows certain beams to become uneconomical. In such cases, the best solution is non-prismatic beams (haunched beams). Results of haunched and prismatic beams are compared with each other and these values were compared with the deflection limits given in the IS 456:2000. Here are the benefits of using haunched beams:

1. Enhanced ability to bridge larger spans with reduced depth.
2. Efficient use of concrete and reinforcement or of steel materials if steel structure.
3. Optimum use of materials thereby weights reduction of the structure for a given vertical and lateral stiffness.

A Kaveh, L Mottaghi & R A Izadifard (2020) designed haunched type of frame, the optimum design of frames with reinforced concrete with Haunched beams is explained also the relationship with prime cost and prime carbon dioxide emitting is investigated.

Valentina Mercuria, Giuseppe Balduzzib, Domenico Aspronec & Ferdinando Auricchiod (2020) , studied characteristics of non prismatic beam gives their simulation like a non trivial work, such as: changes in both cross sectional areal region and second moments of areas and simple estimation of analytical solutions using approximate methods; stress redistributions in normal and non prismatic beam differ considerably

Joon Kyu Lee & Byoung Koo Lee (2019), given research represents the elasticity of haunched rectangular cross-section cantilever beam subjected to charge. The beams under consideration are non-linearly elastic. The impacts on elastic behavior of beam parameters, includes top responses, strains-stresses loaded to the cross-sectional area, have been considered.

J Y Richard Liew & N E Shanmugam (2016), the behaviour of steel-concrete composite haunch ties is discussed. Haunch beams were constructed by contemplating the relation of the beams and columns to a static moment. This paper adopted European code to design. Prediction of ultimate moment established by moment equation which numerically fine not practical oriented.

Dimitris L & Karabalis A M (2015), the author has presented the determination of the flexural stiffness matrix of structures consisting of tapered beams, the author has proposed a basic but effective approximate procedure.

Chenwai & Koji (2015), This thesis examined the effect of loading on strain gauge beams. Completed Haunched and Prismatic Beams experiment. They gave an idea from the observation that the crack pattern often begins away from the linear component.

2. METHODOLOGY

A property of material assigned to models is concrete only. The loading conditions of the beam are LSM and loads are self-weight, floor load, etc. From the software we can compute on theoretical values not the practical one. But these values can compare within each other's. Results can be calculated from software are as follows:

1. Deflection of beams : in vertical and horizontal plane
2. Storey drifts : max sway of structures
3. Mode shapes of structures : when structure is subjected to shear loading
4. Weight of structures
5. Rayleigh's frequency
6. Maximum stress value in cross sections
7. Analysis by Theoretical Method

2. a) Deflection of beams

Any beam can analyses by manual method, but while analyzing Haunched beam with fixed ends, the Macaulay's double integration system is adopted. To analyses this beam deflection and slope where Haunch angle meets the prismatic portion to equated to each other so that constant can found. To apply loading conditions the live load, dead load, floor finish load should be taken into the account.

Macaulay's double integration method to solve beam problem:

In Macaulay's method, the differential equation for the elastic curve of a beam will also be used to evaluate the deflection and slope of the loaded beam, so we must remember the differential equation for a beam's elastic curve here. General differential equation for elastic curve of a beam is,

$$M = EI \frac{d^2y}{dx^2}$$

E = Elastic modulus

I = Moment of Inertia

M = Summation of moment

But in this beam case, the moment of inertia is changing cubically so there should be integration throughout the length till cross section remains constant.

$$\int_0^x \frac{b \times \left[d - \frac{(D-d)x}{l}\right]^3}{12}$$

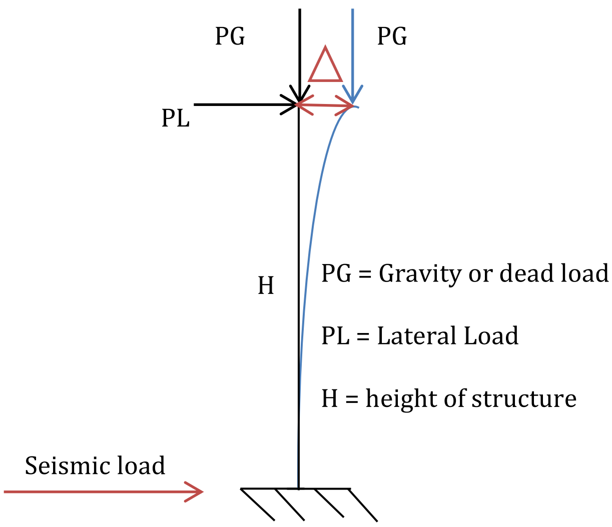
D = depth at support

d = depth at middle portion

x = length of varying cross section

2. b) P-delta Analysis

With use of IS 1893:2016 by calculating base shear the P-Δ analysis is done on prismatic and Haunched beam so comparison is done. The dimensions and other required data to know delta is discussed below.



Moment = PL × H + PG × △

(Pre-dominant) (Extra)

Fig 1. *P-Delta analysis model*

From the following example, the meaning of P - Δ, Non-Linear behaviour can be seen. The building's high floors structure is 20 m for height, with every storey being 5 m high. With dispersed loads on each stage, the columns are completely set at the root. Furthermore, the top floor has vertical loads and self-weight is considered so that gravity or dead loads can simulate. A comparatively slight horizontal force subjected to the side of the system is also present.

3. DESIGN:

haunched beam –

Wall= 0.23 × 1 × 3.2 × 19 = 13.98 kN/m

Floor= $\frac{5\times 5\times 0.15\times 25}{4\times 5} + \frac{3\times 5}{4}$ = 8.43 kN/m

Total W= 22.41 kN/m

10 % self-wt. = 24.65 kN/m

Total Wu= 37 kN/m

Distance of point of contra flexure from midpoint of beam of fixed condition,

$$\frac{l}{2\times\sqrt{3}} = 1.44\text{m}$$

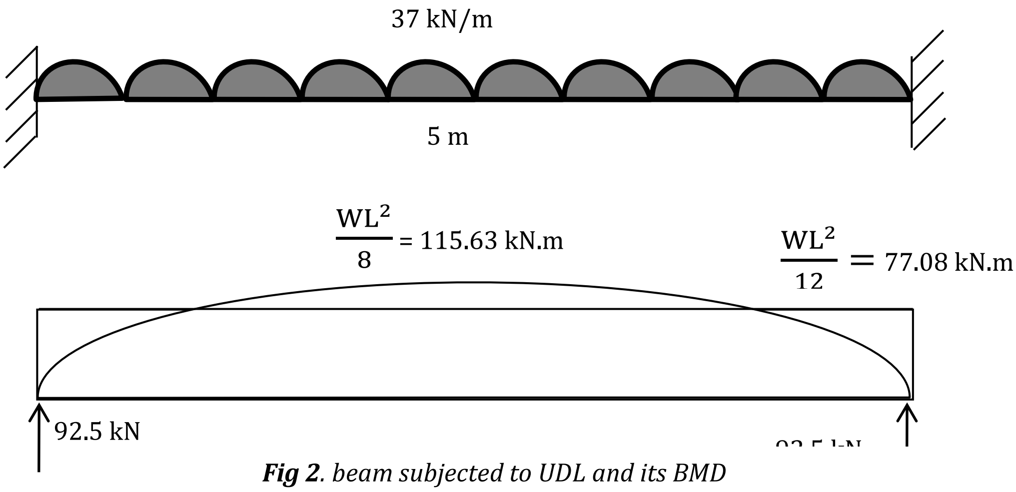


***Fig 2**. beam subjected to UDL and its BMD*

Let, f_{ck} Strength of concrete =25 N/mm^2

f_y Strength of steel = 415 N/mm^2

Normal beam:

$115.63 \times 10^6 = 0.138 \times b \times d^2 \times fck$

d = 381.7 mm So, D= 400 mm

Haunched beam:

$(115.63-77.08) \times 10^6 = 0.138 \times b \times d^2 \times fck$

d = 220.4 mm So, D = 300 mm (middle)

$81.38 \times 10^6 = 0.138 \times b \times d^2 \times fck$

d = 311.6 mm So, D = 350 mm (end)

Finding contra flexure point to give tapered section,

Considering x any section,

$92.5 \times X - 37 \times X^2 \times 0.5 - 77.08 = 0;$

X= 3.94 and 1.05 m

Deflection of Haunched beam –

1-End part 2- middle part

$E_1 = E_2 = 5000 \times 5 = 25000$ N/mm^2

$$I_2 = \frac{230 \text{ X } 300^3}{12} = 517.5 \times 10^6 \text{ mm}^4$$

$$I_1 = \int_0^{1050} \frac{230 \times \left(350 - \frac{50x}{1050}\right)^3}{12} = 690 \times 10^6 \text{ mm}^4$$

After doing integrations and finding constants, we get,

Y = 3.88 mm

Deflection of Prismatic beam –

E = 25000 N/mm^2

$$I = \frac{230 \times 400^3}{12} = 1.22 \times 10^9 \text{ mm}^4$$

$$y = \frac{Wl^4}{384\ EI}$$

Y = 1.96 mm

4. FLEXURAL TEST IN ABAQUS:

Following model gives idea about dimensions it is important to know the energy capacity and behavior of beam.

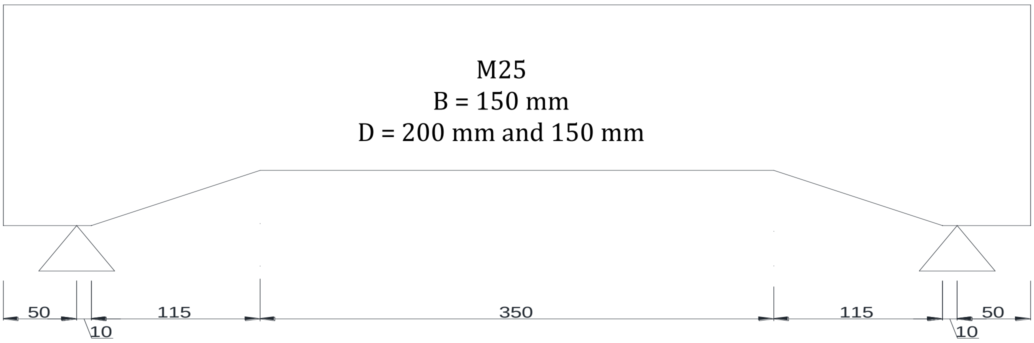
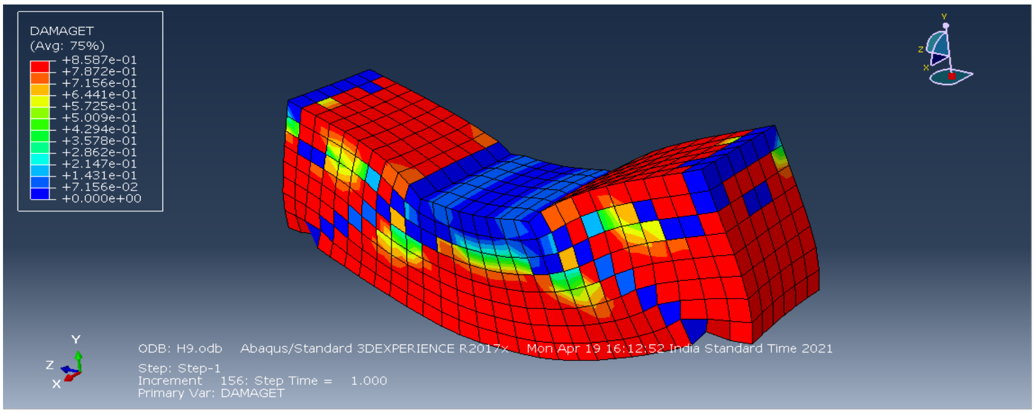
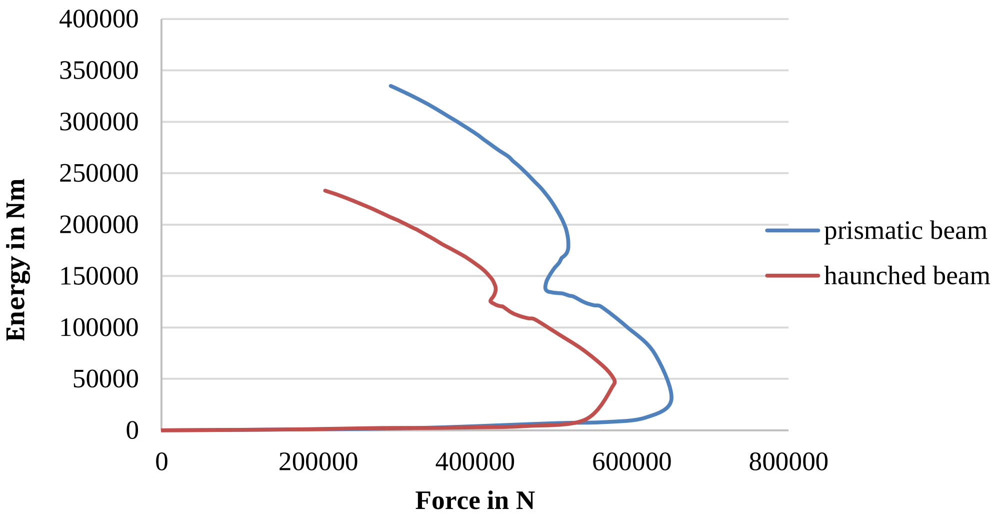


***Fig 3**. Dimensions of model*



***Img. 2.** Analysis in Abaqus*



***Graph 1.** Force vs energy from Abaqus*

5. CALCULATION OF BASE SHEAR:

1. Slab depth: 125 mm thick
2. Wall thickness: 230 mm thick wall
3. M25 concrete

Earthquake parameters considered:

1. Zone: II, III, IV and V
2. Soil type : Hard soil
3. Importance factor: 1

Column properties

Storey	Normal Beam Frame	Haunch Beam Frame
Foundation to 15th	230X750 mm	230X750mm

Beam Properties

Storey	Normal Beam Frame	Haunch Beam Frame
Foundation to 5th	230X600 mm	(230X650-230X600-230X650) mm
5th floor to 10th	230X530 mm	(230X600-230X530-230X600) mm
10th to15th floor	230X450 mm	(230X530-230X450-230X530) mm

	No.	b	d	l	Unit Wt.	Floor no.	Total W KN
Column weight =	25	0.23	0.75	3	25	15	4851.56
Beam weight =	40	0.23	0.6	7.5	25	5	5175
	40	0.23	0.53	7.5	25	5	4571.25
	40	0.23	0.45	7.5	25	5	3881.25
Slab=	16	7.5	0.15	7.5	25	15	50625
Wall=	40	0.23	3	7.5	20	15	62100
						Total W kN =	131204.06

Ta =	1.009075698 sec.	
Sa/g =	1.36/T =	1.34
I =	1	
R =	3	
Z =	0.36	
Ah =	0.080866084	
Vb =	10609.95872 kN	
Hi^2 =	11160	

Table 1. *Base shear calculations*

	Height in m	Q Base shear kN		Cumulative Q kN
H1	45	Q1	1925.19	1925.19
H2	42	Q2	1677.05	3602.25
H3	39	Q3	1446.03	5048.28
H4	36	Q4	1232.12	6280.41
H5	33	Q5	1035.32	7315.73
H6	30	Q6	855.64	8171.37
H7	27	Q7	693.06	8864.44
H8	24	Q8	547.61	9412.06
H9	21	Q9	419.26	9831.32
H10	18	Q10	308.03	10139.35
H11	15	Q11	213.91	10353.26
H12	12	Q12	136.90	10490.16
H13	9	Q13	77.00	10567.17
H14	6	Q14	34.22	10601.40
H15	3	Q15	8.55	10609.95

Table 1. *Base shear calculations in various zones*

Zone	Base shear from Present results in kN	
	Prismatic	**Haunched**
II	2947.11	2987.22
III	4715.54	4779.24
IV	7073.3	71.68.78
V	10609.9	10753

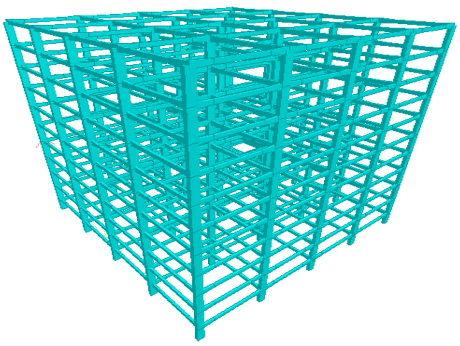
6. LATERAL DEFLECTION OF STRUCTURE:

Model properties are as follows for linear dynamic analysis: this example is taken from "*Effect of Haunched Beams in Moment Resisting RC Frames*[20]*, Jeethu Ponnachan, 2018*" research paper. Author run analysis in SAP2000, presently this model with same conditions analyzed on STAAD.Pro so that it achieves reliability and good accuracy. It is important to see how beams respond to the seismic loading.

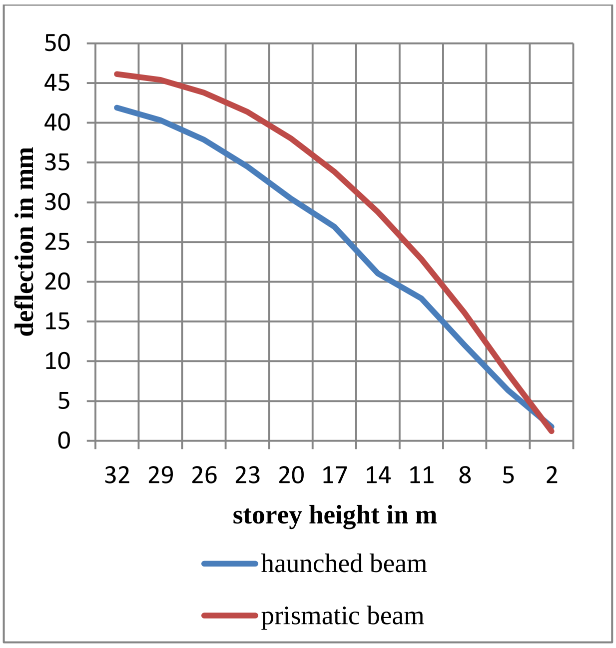
Parameter	**Prismatic**	**Haunched**
Bays	4X4	4X4
Bay length	8m	8m
Storey no.	10	10
Storey ht.	3m	3m
Beam	230X630	230X400, 230X630
Column	380X750	380X750

Table 3. *Deflection of various storeys*

height m	**Haunched beam (mm)**	**Prismatic beam (mm)**
32	41.89	46.115
29	40.33	45.39
26	37.85	43.807
23	34.50	41.39
20	30.48	38.02
17	26.92	33.83
14	21.04	28.77
11	17.91	22.86
8	12.03	16.08
5	6.345	8.46
2	1.768	1.2



Img. 2. *STAAD.Pro model*



Graph 2. *Deflection Vs Storey height*

7. WIND ANALYSIS:

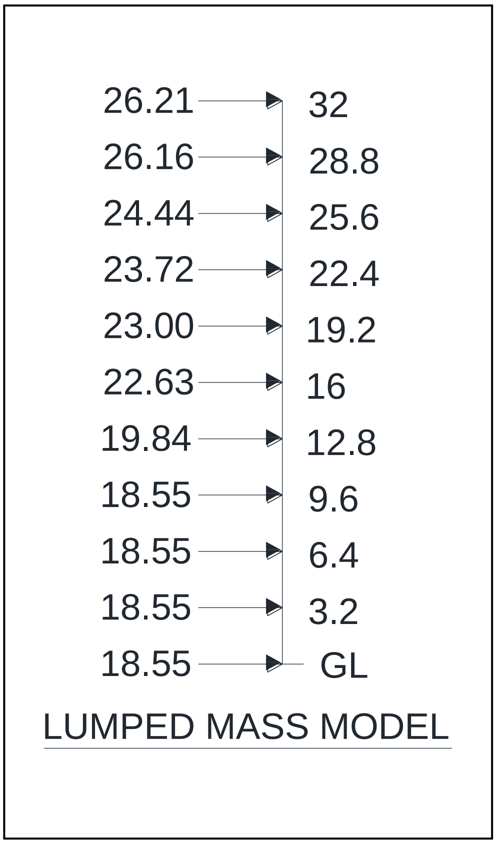
The wind analysis is important as wind force gives extra displacement to structure, to counteract this we can provide extra steel to bear more stress and control displacement.
The analysis completed using IS 875 part 3 1987.
The following example or problem taken from "*Approximations of Lateral Displacements of Reinforced Concrete Frames with Symmetric Haunched Beams in the Elastic Range of Response Using Commercial Software*" by Arturo Tena-Colunga, M.ASCE and Luis Andrés Martínez-Becerril.

Steps:

1. Defining coefficient.
2. Calculating wind pressure.
3. Assigning force at node.
4. Run same model in STAAD.Pro and compare.

By IS 875 PART 3 1987				
Bays =	4 in X , 4 in Y			
Length =	7 m			
Storey count=	10			
Ht=	3.2m			
Location =	Pune			
Design for =	50 yrs			
Category of terrain=	3	(5.3.2.1)		
	Terrain with numerous closely spaced obstructions having the size of building-structures up to 10 m in height with or without a few isolated tall structures.			
Topography =	Upwind slope less than 3 degree			
Column=	0.3X0.23			
PLATE=	0.15 M			
N BEAM=	0.23X0.57			
H BEAM=	0.23X0.47 END @ 1.47M ; 0.23X0.34 MIDDLE 4.06M			
VZ=	VB.K1.K2.K3			
K1=	Risk coe.	(5.3.1)	TABLE 1	
K2=	Terrain, height and structure size FACTOR	(5.3.2)	TABLE 2	
	CATEGORY - 3	(5.3.2.1)		
	CLASS B - Structures and/or their components such as cladding, glazing, roofing, etc, having maximum dimension' (greatest horizontal or vertical dimension) between 20 and 50 m.	(5.3.2.2)		
K3=	Topography	(5.3.3) (5.3.3.1)	The effect of topography will be significant at a site when the upwind slope is greater than about 3 DEGREE, and below that, the value of ks may be taken to be equal to 1.	
VB=	39 M/S		APPENDIX A (5.2)	Wind speed
PZ=	$0.6V_z^2$	5.4	Design Wind Pressure	
Design wind load (F) =	CF.AE.PZ 6.3			
CF=	H/b = 1.14 greater or equal to 1 use figure			
	A/B = 1			
	BY INTERPOLATION FROM GRPAH WE GET,			
	1.25	FORCE COEFFECIENT		
AE eff.area =	7x1	Per unit width		
Force on nodes=	Storey ht * F			

HEIGHT	VB	K1	K2	K3	VZ	PZ (N/MMSQ)	CF	AE	F (N/M)	FORCE AT NODES IN KN
32	39	1	1.046	1	40.79	998.49	1.25	7	8736.79	26.217
28.8	39	1	1.045	1	40.75	996.58	1.25	7	8720.09	26.16
25.6	39	1	1.01	1	39.39	930.94	1.25	7	8145.75	24.43
22.4	39	1	0.995	1	38.80	903.49	1.25	7	7905.59	23.71
19.2	39	1	0.98	1	38.22	876.46	1.25	7	7669.03	23.00
16	39	1	0.972	1	37.90	862.20	1.25	7	7544.33	22.63
12.8	39	1	0.91	1	35.49	755.72	1.25	7	6612.58	19.83
9.6	39	1	0.88	1	34.32	706.71	1.25	7	6183.77	18.55
6.4	39	1	0.88	1	34.32	706.71	1.25	7	6183.77	18.55
3.2	39	1	0.88	1	34.32	706.71	1.25	7	6183.77	18.55
0	39	1	0.88	1	34.32	706.71	1.25	7	6183.77	18.55



Img.3. *Nodes subjected to wind force*

Table 4. *Deflection of frame in STAAD.Pro analysis*

Case	X	Y	Z
Prismatic beam	77.92	110.60	0.025
Haunched beam	87.77	117.15	0.039

RESULTS:

1. In beam deflection, haunched beam shows 3.88 mm and 1.96 mm by prismatic beam.
2. Base shear calculation shows more values for haunched beam frame as it has bigger column than prismatic beam frame.
3. Lateral deflection of haunched beam frame is lesser than prismatic beam frame by 10 % at each story approximately.
4. Delta of haunched beam frame is 1.29 mm and 1.56 mm for prismatic beam frame.
5. Haunched beam frame shows more deflection when it is subjected to wind load than prismatic beam frame by 11%.

CONCLUSION:

1. In beam deflection the haunched beam has good energy redistribution than prismatic beam. So the deflection is more.
2. The energy bearing capacity of haunched beam is higher than prismatic beam approximately 49% more.
3. Due to stiffer nature the lateral deflection shows lesser values of haunched beam than prismatic beam.
4. Failure at toe of haunch occurs and longer length shifts failure to heel at connections is seen by ABAQUS analysis.

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