Analysis of PEB with single and multiple gables

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Abstract—**Pre-Engineered buildings are a modern way of construction of traditional steel buildings that results in reduction of weight and cost of the structure. A large number of studies have been conducted to find out the benefits of a PEB (Pre-Engineered building) over CSB (Conventional steel building). In the present study, an attempt is made to study the performance of PEB structures with varying spans and configurations. The response of the structures is compared in terms of displacements, maximum bending moments, support reactions and weights of the structures. The effects of varying height of the structure are also studied.**

Keywords—PEB, steel structures, sustainability, minimum weight, multi-gable frame

I. INTRODUCTION

In today's world of dwindling natural resources, researchers are constantly seeking to develop new and more sustainable construction techniques. Pre-Engineered building is one such new technique that aims at achieving minimum weight of construction. Pre-engineered buildings, or PEBs, are an excellent solution when huge column free spaces are required, as they can span considerably longer distances than conventional buildings. The components are pre-designed and are fabricated in a factory according to the specifications before being assembled on-site. This means that construction is faster and less complicated than in traditional steel structures where fabrication is done on-site.

II. LITERATURE SURVEY

Z. Darshana (2012) analyzed and designed a PEB according to Indian standards (IS 800: 2007, IS 875: 1987, IS 1893: 2016 and American standards (MBMA-96, AISC-89) and made a comparison between the results obtained by both standards. The study concluded that MBMA and AISC consider lesser live loads and higher deflection is allowed as compared to IS code. Thus, MBMA and AISC gave a more economical design as compared to IS code [1].

Md. U. Saleem and H. J. Qureshi (2018) investigated the performance of PEB steel frames and developed a comparison with conventional steel buildings in terms of frame weights, lateral displacements (sway), and vertical displacements. With the analysis and design of several steel frames on Staad Pro software, an overall reduction of 30-40% in steel weight was observed in the main frames spanning between 30m to 50m. Because of the building's smaller weight and lighter roofing, seismic forces had no major influence on the frame weights. When compared to traditional hot-rolled steel frames, the PEB steel frames had lower lateral and vertical displacements [2].

V. V. Sai, P. Poluraju and B. V. Rao (2021) compared the structural performance of multiple bay systems in distinct wind and seismic zones, namely Hyderabad and Vijayawada. Staad.Pro software was used for analysis and design. Bending moment (BM) and shear force (SF) magnitudes were used to evaluate the PEB's structural performance. According to the study, the weight of the construction in Vijayawada was 11.04% greater than the weight of the structure in Hyderabad. The wind speed and seismic zone factors were found to have an effect on the structural weight and section sizes of the structure [3].

V.P. Raut and P. S. Patil (2021) carried out research to compare the displacement and weight of pre-engineered warehouse structures with regard to modifications in foundation strata and varying spans and base fixity. It was observed that the weight of structure was higher when pinned base was assigned as compared to fixed base. Tonnage was also shown to be greater in soft soils, followed by medium soil and hard soil [4].

H. Sneha, W. Pranoti and H. Abhay (2021) performed analysis of a truss for multiple factors such as terrain categories, structure class, topography, height and structure size, and estimated wind loads in accordance with Indian Standard Code specifications. A typical frame of an industrial warehouse was designed by using both the concepts and analyzing the designed frames using the structural analysis and design software Staad.Pro for the purpose of the study. The research presented a comparative result of study to encourage optimum design of steel industrial shed structure. This research covers the planning of an industrial warehouse [5].

S. K. Sah, M. Z. Kangda, S. Sathe and N. Mate (2022) explored the study and design of PEB structures, as well as many elements of PEB such as characteristics, configuration, and performance in comparison to conventional steel buildings. A design method for PEB structure is presented as well as section ratio constraints and the specification for design is PEB is presented. The study concluded that PEB building is a superior and more cost-effective technology when long, clear span, and quick construction are required. It was also discovered that increasing the distance between the bays up to a certain limit reduced the weight of the building, but extra separation increased the weight [6].

J. Disha and K. Gaurav (2023) investigated the structural behavior of PEBs with various spans. Various parameters like Bending moments, axial forces, support reactions, rotations, deflections are compared for the different spans. In addition, research was conducted to propose the use of tubular steel sectional connections for the beam-rafter junction in the designed PEBs. It was found from the study that these proposed connections are a viable option for PEBs up to a moderate span, lowering steel weight in the structure [7].

Researchers like G. S Kiran, A. K. Rao, and R. P. Kumar (2014), S. Kalesha, B.S.S. R. Reddy, and D. C. K. Jagarapu (2020), C. Kavitha, S. Suryaprakash, N. Lavanya, and S. Durgadevi (2021), L. Sharma, N. Taak, and P. K. Mishra (2021), etc. have also worked on behavior of PEB structures that led to findings indicating better performance of PEB structures as compared to Conventional steel buildings in terms of reduction in cost of structure, ease of construction, better performance in seismic loads etc. [8],[9],[10],[11].

In the present study, the behavior of PEB's as regards variation of bending moment, axial forces, support reactions, horizontal and vertical reactions and weight of the structure designed is compared for single span and multiple span gables.

III. METHODOLOGY

A. *Modelliing of PEB structure*

Fig. 1 shows the section of the main frame for the models of PEB. In the current research study, all of the necessary information, such as building layout, span lengths, bay spacings, and roof slopes, are chosen based on a review of the literature and are kept within the same range. A single span PEB with widths of 25m, 50m, and 75m was used for the purpose of the study. Multiple gable PEBs having span of 25m x 2 and 25m x 3 are also analyzed. It is understood that multi-gable buildings offer the advantage of lowering the height of the building ridge (peak) for very wide structures. Hence, multi-gable spans with two and three spans are analyzed, and the difference between a single gable PEB and a multi-gable PEB spanning the same distance is studied. A FEM-based program is used for modelling and analysis.

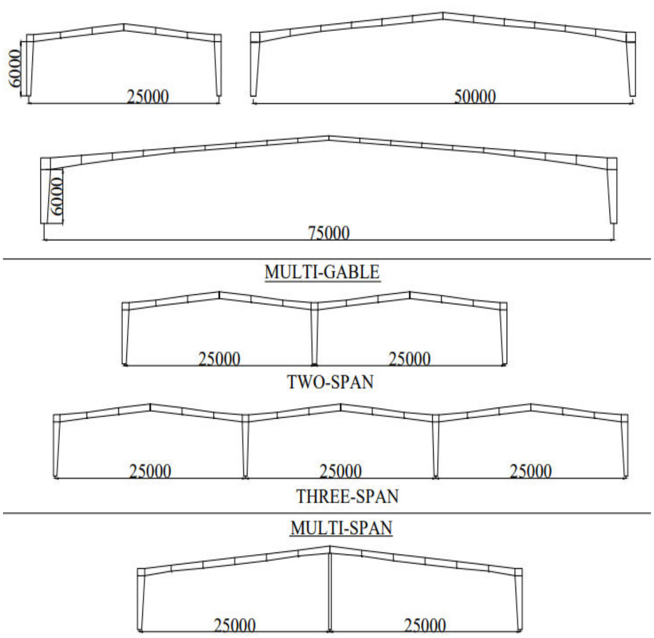

Fig. 1. Different types of main frame of PEB

The performance of PEB structures is investigated by varying the spans and configurations. The response of the structures is compared in terms of displacements, maximum bending moments, support reactions and weights of the structures. The effects of varying height of the structure is also studied.

B. *Materials and methods*

- Support condition is given as pinned for the whole structure.
- Lateral stability to the structure is provided by the provision of horizontal and vertical bracings. The end bays and the central bay are braced. For 50m and 75m single span, additional horizontal bracings are provided to prevent excessive horizontal deflection.

Fig.2 shows the plan of a single span PEB structure.

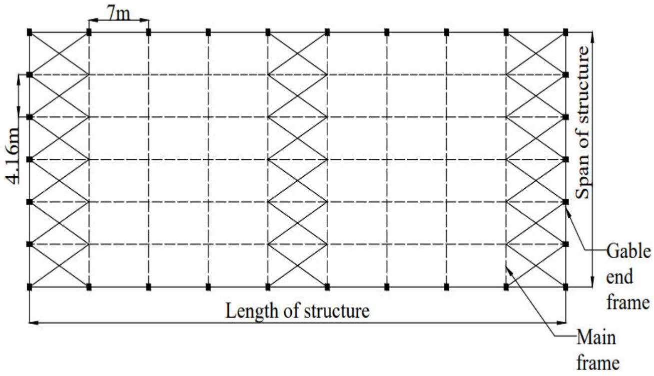

Fig. 2. Plan of PEB structure.

The specifications for the design of the PEB considered are presented in Table I.

TABLE I. DETAILS OF PEB

Description	Data
Location	Goa
Length	63m
Width	25m, 25x2m, 25x3m,50m and 75m.
Clear height at eaves	6m, 8m and 10m
Roof slope	1 in 10
Bay spacing	7m
Gable end wall column spacing	4.16m
Purlin spacing	1.5m
Bracing	X-bracing

C. *Loading*

The dead load (DL), live load (LL), seismic load (EL) and wind load calculations are done as per the IS code and the parameters used for the load calculations are as presented below. Table II shows the parameters for wind load calculations.

Dead load for 0.47mm thick galvalume sheeting and supporting purlin = 0.15 kN/m^2.

Collateral load due to lighting, solar panels = 25 kN/m^2.

Live load = 0.75 kN/m^2.

TABLE II. PARAMETERS FOR WIND LOAD CALCULATIONS

Description	Data
Design code	IS 875 (Part 3): 2015
Basic wind speed, V_b	39 m/s
Terrain category	Category 2
Risk coefficient, k_1	1
Terrain height factor, k_2	1.05
Topography, k_3	1
Importance factor for cyclonic region, k_4	1.15
Enclosed condition	Partially enclosed

Table III shows the parameters for seismic load calculations.

TABLE III. PARAMETERS FOR SEISMIC LOAD CALCULATIONS

Description	Data
Design code	IS 1893 (Part 1): 2016
Seismic zone	III
Soil type	II (Medium soil)
Importance factor	1
Response reduction factor	3.0 (OMRF)

The load combinations are considered for strength design as well as serviceability design as per IS 800:2007. The load combinations that are considered are listed in Table IV.

TABLE IV. LOAD COMBINATIONS

Strength Design	Serviceability Design
1.5DL +1.5CL + 1.5LL	1DL+1CL+1LL
1.2DL +1.2CL + 1.2LL + 1.2WL/EL	1DL+1WL/EL
1.5DL +1.5CL + 1.5WL/EL	1DL+0.8LL+0.8WL
0.9DL + 1.5WL/EL	1DL+0.8LL+0.8EL

IV. RESULTS AND DISCUSSION

A. Optimisation

Member dimensions for the tapered I sections for the main frame are provided by trial-and-error method. After analysis, the steel design check of the members is done. The members that fail are revised. The major axis and minor axis moment for design action is evaluated in relation to major axis and minor axis moment in design strength (Design Action ≤ Design Strength) in steel design. If the design action (critical load) exceeds the design strength, the section will break, and the ratio will be greater than one. If the section fails for combined forces, the section's depth must be raised so that it is capable of being resisting the loads. To achieve smooth tapering, a minimum depth at the support and a maximum depth at the top portion are determined using the bending moment diagram. The sections are optimised as much as possible to achieve a minimum weight of the structure. A greater depth of web and flange and a greater thickness of flange is provided where the major axis moment is large. As the height of the columns increases, the thickness of web is increased to prevent the columns from failing in axial loads. The flange thickness provided range between 16mm to 40mm for rafters and 20mm to 40mm for columns. The web thickness provided ranges from 8mm to 25mm for rafters and 12mm to 30mm for columns.

B. Weight of the stucture

Table V shows the steel takeoff of each of the PEB structures. The quantity of steel increased by almost 4.5 times in 50m single span as compared to 25m single span. The increase in steel quantity from 50m span to 75 m span was observed to be around 1.5 times.

TABLE V. STEEL-TAKEOFF OF PEB STRUCTURES

Span (m)	Height at eaves (m)	Weight in tonnes			
		Column	Beam	Brace weight	Total
25	6	23.89	64.63	1.88	90.4
	8	32.66	64.63	2.85	100.14
	10	43.53	64.57	3.33	111.43
25X2	6	36.02	134.85	3.77	174.64
	8	48.79	136.63	4.35	189.77
	10	70.96	138.91	7.83	217.7
25X3	6	47.42	209.1	5.03	261.55
	8	69.64	208.41	9.09	287.14
	10	101.7	208.46	9.59	319.75
50 (centre support)	6	33.57	135.95	4.79	174.31
	8	44.5	135.95	5.51	185.96
	10	65.69	136	6.38	208.07
50m single span	6	64.13	332.72	3.62	400.47
	8	100.98	332.72	4.17	437.87
	10	142.13	346.95	4.79	493.87
75m single span	6	108.88	598.86	4.45	712.19
	8	148.72	623.19	5.14	777.05

Fig. 3 shows the variation of quantity of steel to the height of the structure. There is a steady rise in the graph as the height at eaves increases. From the graph it is observed that the least amount of steel is used in 25m single span structure and greatest amount of steel is used in 75m single span structure. Also, the amount of steel needed for 25m x 2 span structure is very close to the amount of steel needed for 50m centrally supported PEB, indicating that either of the two may be preferred according to the requirements of the project.

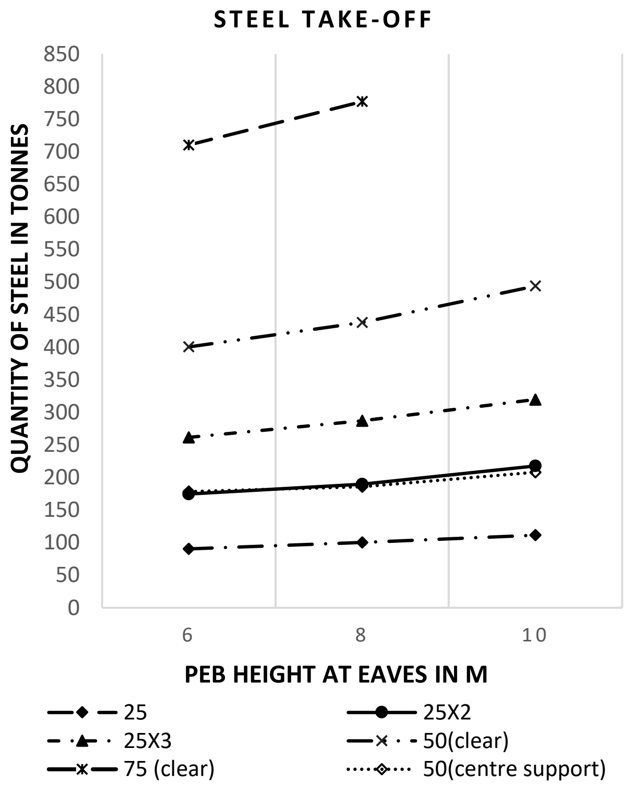

Fig. 3. Steel take off of various spans

C. Horizontal and Vertical displacements

Table VI shows the values of horizontal displacement in X-direction and vertical displacement in Z-direction. Displacements are determined for serviceability load combinations.

TABLE VI. HORIZONTAL AND VERTICAL DEFLECTIONS

Span (m)	Height at eaves (m)	Displacement (mm)	
		Horizontal (x-direction)	Vertical (z-direction)
25	6	16.15	43.25
	8	38.17	48.77
	10	76.84	53.6
25X2	6	8.40	34.13
	8	18.28	35.06
	10	33.95	34.09
25X3	6	10.52	34.85
	8	15.47	38.78
	10	29.96	41.34
50m (centre support)	6	22.82	49.80
	8	38.73	48.13
	10	70.84	46.54
50m single span	6	17.79	170.4
	8	22.89	195.98
	10	35.13	220.87
75m single span	6	50.32	385.31
	8	59.78	469.82

The maximum limits considered for horizontal and vertical displacement are H/150 and V/180 respectively. It is observed that the displacement is maximum for single span of 25m as compared to the multi-span 25x2 and 25x3m. The section for 25m single span PEB which is safe from BM and shear considerations, fails in horizontal deflection at 10m eaves height and 75m single span PEB fails in vertical deflection at 8m eaves height and hence, requires support at the center to qualify for deflection criteria. Fig. 4 shows the variation of horizontal displacement of the structures.

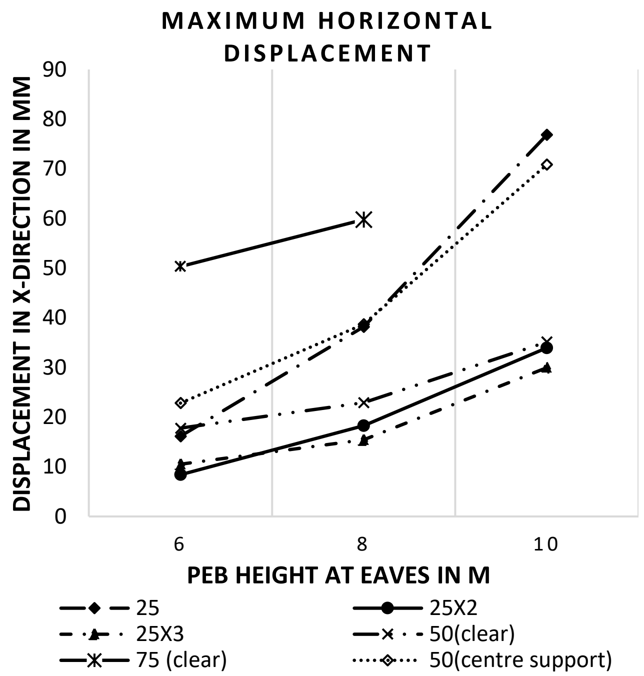

Fig. 4. Maximum horizontal displacement

Fig. 5 shows the variation of vertical displacement of the structures.

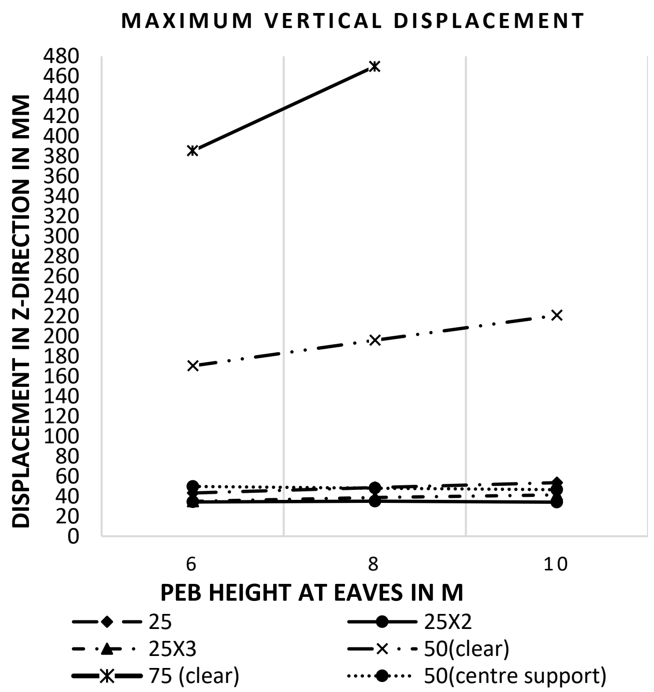

Fig. 5. Maximum vertical displacement

D. Maximum Bending moments

The Bending moments developed in the outer columns of the structures are compared. It is observed that the bending moment in major axis has a gradual increase in case of single spans as the eaves height increases but a different trend was observed in the case of multi-gable structures. The bending moment decreased even though the height at eaves increased. Fig. 6 shows the values for maximum bending moment in columns for different spans at different heights of eaves.

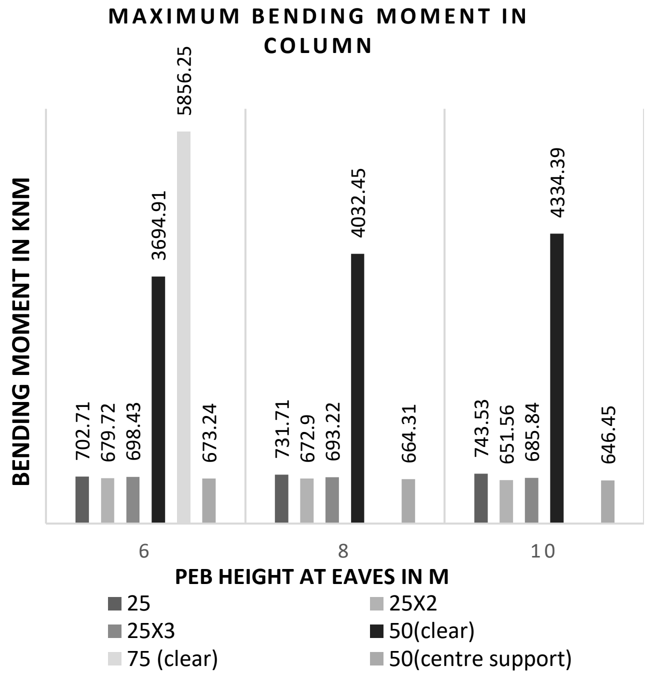

Fig. 6. Maximum Bending moment in column

E. Maximum axial forces

Fig. 7 shows the trend of axial forces developed in end columns of different spans.

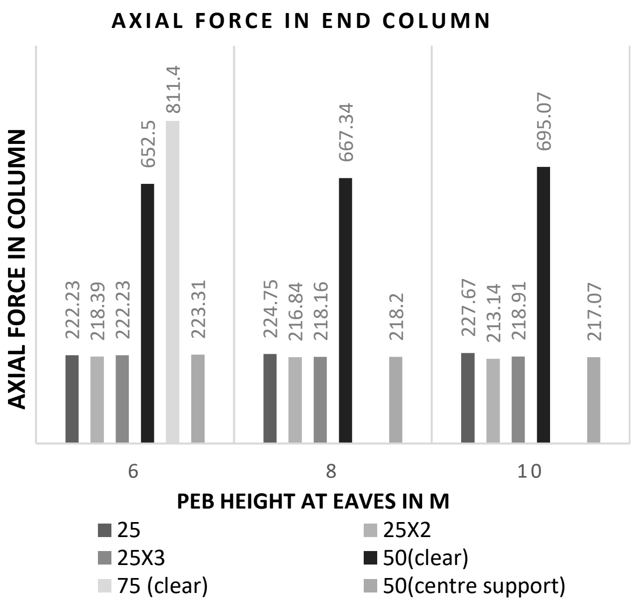

Fig. 7. Maximum Axial force in column

The axial forces developed in columns roughly remain to be in the same range in 25m, 25x2m, 25x3m and 50m centrally supported span. Maximum axial force is observed in 75m span. Central columns in multi-gable spans developed higher axial forces than the end wall columns.

F. Support reactions

Fig. 8 shows the trend of support reactions developed in end columns of different spans. Support reactions are found to be maximum at the braced bays. The wind columns developed higher support reactions in Y direction as they mainly resist wind loads. A higher value of support reaction is also observed in central columns in multi-gable and multi-span structures by two times.

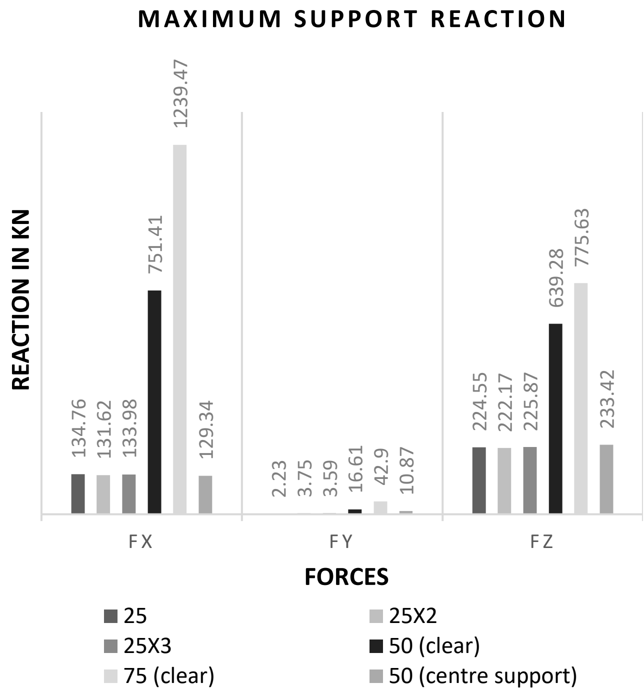

Fig. 8. Maximum support reaction

V. CONCLUSION

From the parametric studies conducted, it is concluded that:

- For PEB of 25m span, 25m x 2 and 25m x3 spans gives least weight of the members required, lowest values of bending moments, axial forces, support reactions at columns and horizontal and vertical deflections, as compared to single span of 50m and 75m.
- As height at gable increases, the weight of steel required for same span also increases to the tune of 8-12 %.
- For large spans, central deflection is larger, however, adopting support at mid span, results in reduction central deflection, moments, axial forces etc. by about 70-80%.
- Horizontal displacement reduces by about 50% when multiple spans are chosen instead of single large span as observed in the case of 25m x 2 span and 50m centrally supported span, hence multiple spans give better lateral stability to the structure.

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