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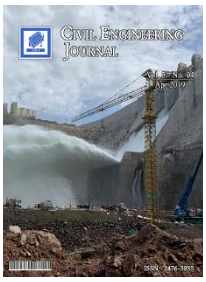

Comparative Study on Two Storey Car Showroom Using Pre-engineered Building (PEB) Concept Based on British Standards and Euro Code

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Abstract

Majority of steel structures are used for low-rise single storey buildings mainly for industrial purpose. Steel structures are preferred for industrial buildings due to its higher strength to weight ratio as compare to RCC structures and steel structures also gives more free internal space by allowing long clear span between columns. Pre-engineered building (PEB) is a modern age concept of utilizing structural steel and optimizing the design by ensuring the economical integrity of the structure. The structural members are designed and fabricated in the factory under controlled environment to produce optimum sections by varying the thickness of the sections along the length of the member as per the bending moment requirement. The aim of the research paper is to analyses and design a PEB car showroom of two storey (G+1) using STAAD Pro in accordance to British standards (BS 5950-1:2000) and Euro codes (EC3 EN-1993-1) with wind and seismic analysis. In order to achieve the above aim of the project, two models of the car showroom were created namely British Standard (BS) model and Euro code (EC) model using STAAD Pro. The member property for BS model is assigned with tapered frame sections while the EC model is assigned with universal standard section frames. The load cases were assigned to the models for analysis include dead load, live load, wind load and seismic load. Wind load and seismic load being the critical dynamic loads that will be analyzed for the stability of the structure against lateral forces. The results from the analysis and design of the two models were within the allowable limits for ultimate and serviceability limit state since the internal stresses in all the members satisfies the unity check ratio requirements for both design codes. The dynamic analysis results suggest that EC model has higher resistance to seismic loading as compare to BS model since the maximum displacement with time in X-direction for EC model is 8.83 mm and for BS model is 10.5 mm. The total weight of the structure for BS model is 1125.431 kN and for EC model is 1214.315 kN, which makes EC model 7.9% heavier than BS model. Moreover, the total weight of all the portal frames for BS model is 457.26 kN and for EC model is 574.725 kN, which makes tapered frame sections to utilize and reduce the amount of steel by 25.7%. Therefore, BS model proved to be an economical model when compared to Euro code.

Keywords: Pre-engineered Buildings (PEB); STAAD Pro; Industrial Structures; Dynamic Loading; Tapered Sections.

1. Introduction

1.1. Pre-engineered Building Design

Steel has been used as a construction material for a very long time. The famous Eiffel tower is one among the oldest steel structure made in 1889 and it has been a symbolic landmark for Paris and it has stood for over 129 years. Despite the fact, steel buildings are not known for high rise structures but instead majority of steel structures are low rise with

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single storey mainly used for industrial purposes. Pre-engineered building (PEB) is a modern concept of utilizing steel structures and optimizing the design by ensuring the economical integrity of the structure [1]. Oman is a well-developed country and its economy mainly depended on exporting petroleum products, but as the country is facing economic crisis due to depletion of crude oil reserve, the country tends to divert its economical vision toward boosting the business sector. This only means that more industries and factories are required to manufacture local products and to export them in order to stabilize the economy of the country. This encourages construction of Pre-engineered building in the country for both small and large scale industries.

Pre-engineered building concept is getting famous rapidly not only in Oman but all around the world due to the increasing demand of Industrial oriented building that requires long clear span with column free space which can provide easy access and mobility within the building. In addition to that, the PEB concept gives economical structural sections by reducing excess steel usage and optimizing the required steel as per the bending moment requirement which has a major advantage over the traditional steel structures where unnecessary wastage of steel is done resulting in increase of material cost and making the construction uneconomical. Pre-engineered building (PEB) offers a lot of advantages over conventional steel building (CSB) construction. In the Some of the main advantages that are offered by PEB, which are reduction in time, reduced cost of construction, light weight foundation, easy, future expansion flexibility, ability for long span column free space, single source responsibility, higher resistance to earthquake. The materials used in conventional steel building consume more cost, so to overcome this “PEB structures” are needed to reduce the cost of the project. In order to reduce the self-weight of conventional steel buildings PEB can be used. Generally PEB can reduce up to 35% of self-weight when compared to conventional steel buildings.

Steel structures are preferred for industrial buildings due to higher strength to weight ratio than RCC structures. Pre-engineered building (PEB) is steel structure in which the structural members and components are fully designed and fabricated in the factory and transported to the site in knock down condition. Normally it requires 6 to 8 weeks for the fabrication process and delivery of all the structural components to the site. The PEB concept utilizes the amount of steel required and produces the most optimum sections based on the bending moment requirement. Hence, the section depth varies throughout the length following the bending moment diagram [2]. In order to achieve the above member configuration, thin steel plates are tapered and combined to give the I-section desired. Since all the design and fabrication is done at the factory under controlled environment, the components are of high quality and precision. PEB design concept offer greater advantage over conventional steel structures (CSB) with roof truss configuration for low rise single storey structures. PEB also fulfils the need and demand of long span column free area by eliminating or minimizing interior columns and walls which is the utmost requirement of almost all industrial buildings. Moreover PEB is much economical in terms of cost and time of construction, which is a major advantage over CSB concept. The advancement in technology has introduced computerized software that makes analysis and designing of PEB structures very simple and easy.

STAAD Pro is an advanced structural analysis and design software which is the most popular software used all over the world for analysing and designing of different types of structures. It supports almost all the designing codes, and can design concrete, steel and timber structures. It provides user friendly interface and visualization of 3D structural model of the building. It is one of the easiest software available for modeling, analyzing and designing of different types of structures. PEB is significantly advantageous over Conventional Steel Building (CSB) structure since it offers less cost and time of construction, it has the ability to span long distance giving column free span, easy flexibility for future expansion, low maintenance cost, single source responsibility and also has higher resistance to moisture, fire, adverse weather condition and earthquake which makes it more durable and safe.

The results obtained the authors concluded that the 3D PEB model weights 43.77 tons and the CSB model weights 74.08 tons i.e. PEB weights 35% lesser than CSB as per IS 800-2007 [3]. The only disadvantage of PEB structure is that they have poor thermal and fire resistance and vulnerable towards corrosion [4]. PEB structures can be easily designed by using advanced softwares like STAAD Pro by following simple procedures and by using different country building codes. It was also concluded that PEB are more advantageous over CSB in terms of cost effectiveness, quality control, simplicity in erection and speed of construction [5].

The deflection of the two structures was studied under dynamic loading from the results obtained and it was concluded by the author that the PEB model with bracing provides more stability against seismic loading and the deflection of the structure is less when compared to the PEB structure without bracing, therefore PEB offers higher earthquake resistance when braced. PEB frame were more stable under wind loading as compared to CSB frame. Moreover, the weight of PEB frame was 27% lesser as compared to the weight of CSB frame [6]. PEB structure over conventional steel structures in details by considering the cost, time and material requirements [7]. The design aspects of Indian standard are higher as compared to the American standards and mentioned the main criteria as listed below which has caused the weight of the structure to be more when designed using IS 800-2007 as compared to MBMA/AISC design code [8]. The deflection of the PEB frames are more as compared to the conventional structure making the structure more flexible and withstand seismic loading [9].

The existence of pre-cast concrete industry are numerous, successfully executed construction project, its uses not disputed and it's the proof that the manufacturing and production technology is practical and cost effective. The growing requirements of architectural design at building construction raise progress of stable and constant development of the industries as this is a new technology [10].The adoptability of PEB in the place of Conventional Steel Building (CSB) design concept resulted in many advantages, including economy and easier fabrication [11]. Presently, large column free area is the utmost requirement for any type of industry and with the advent of computer software's it is now easily possible. With the improvement in technology, computer software's have contributed immensely to the enhancement of quality of life through new researches [12]. "Pre-engineered steel buildings" are those that are totally invented within the industrial plant once planning, shipped to site} in CKD (completely knocked down) condition; and all parts are assembled and erected at a site with nut-bolts, thereby reducing the time of completion. Pre–engineered means that, typically speaking, is any a part of a structure that's factory-made first off to its arrival on the building site [13]. Cold formed steel section over hot rolled section as purlin is almost lighter than 32 % [14]. PEB structures are lighter structures. As PEB is 30 % lighter than CSB structures [15]. PEB steel frames are not only the most economical solution due to lesser weight of construction but also have shown better performance compared to CSB frames [16].

3. Experimental Investigations

3.1. Detailed Methodology

Carry out intense research on PEB structures and understand the design concepts by carrying out sufficient literature reviewing. Collect Journals, and other research related materials that can aid in literature review. Prepare the model on STAAD Pro and carry out the analysis and design of the PEB structure by applying dead load, live load, wind load and seismic load conditions in accordance to both British Standard (BS 5950-1:2000) [17] and Eurocodes (EC3 EN-1993-1) [18] and interpret and compare the output results.

3.2. Proposed Plan and Cross-Sectional Elevation Drawings of the PEB Car Showroom

The first step of the project was to prepare a simple plan and cross sectional elevation of the PEB car showroom before modeling the structure in the STAAD Pro. A simple plan was created in AutoCAD as shown in Figure 1. From the plan it can be seen that the spacing between the fames (bay spacing) is 5.0 m and the columns are located at a distance of 7.5 m to support the mezzanine floor above it and in the front open area the columns are spaced by 15.0 m. The mezzanine floor has an extension at the centre. The side view elevation of the PEB car showroom and shows the spacing of 5.0 m between the frames. The elevation view also shows the eave height of 8.0 m and the mezzanine floor level at 4.0 m (Figure 2).

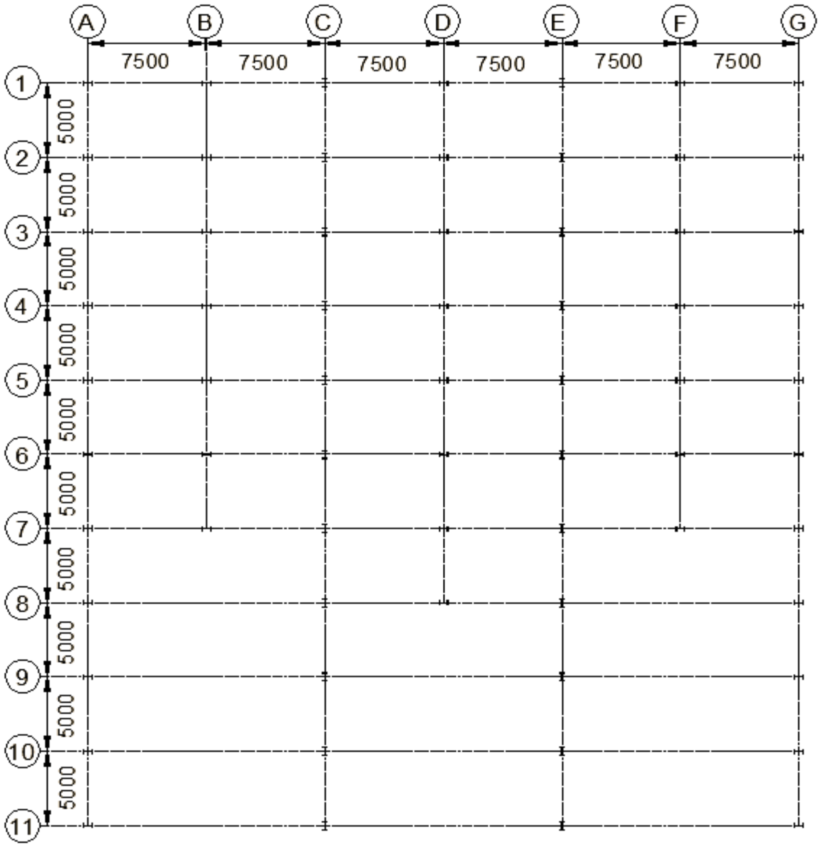

Figure 1. Plan of the proposed PEB car showroom structure

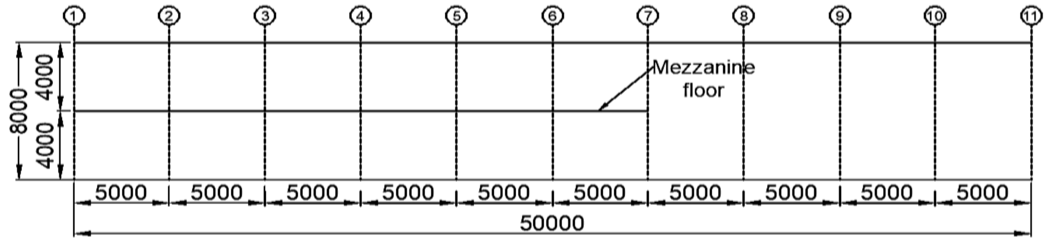

Figure 2. Side view elevation of the car showroom structure

3.3. Actual Model of the PEB Car Showroom

The actual model of the PEB structure of the car showroom was created in STAAD Pro software. Since the aim of the project is to analysis and design the PEB car showroom using both British Standards and Euro code and to compare between the two codes to obtain the most economical design. It is decided to prepare same model of the PEB structure for both cases in order to get the most economical design in terms of material required for each model as per the building code requirements. The car showroom is modeled to have 2 storeys such that it has a ground floor and a mezzanine floor at 4.0 m above the ground level. The specifications of the model frame spacing = 5 m, number of bays = 10, total length = 50 m, width of frame = 45 m, eave height = 8 m was created on the STAAD Pro software.

3.4. Member Properties for British Standard Model

Different member properties were assigned to the PEB car showroom model as per British standard design. These properties are such as tapered portal frame members, standard universal beam and column sections for mezzanine floor, purlin members and bracing members. Tapered portal frame members: Tapered members are customized members that are created and defined by user specifications in STAAD Pro.

The tapered sections are provided by utilizing the amount of steel required as per the bending moment requirements. The tapered members are created in such a way that the depth of the member gradually varies along the length of the member. Tapered section reduces the steel material used as well as the weight of the structure. In this model, the tapered sections were assigned to the rafter beam members and the column members of the portal frames as shown in the Figure 3.

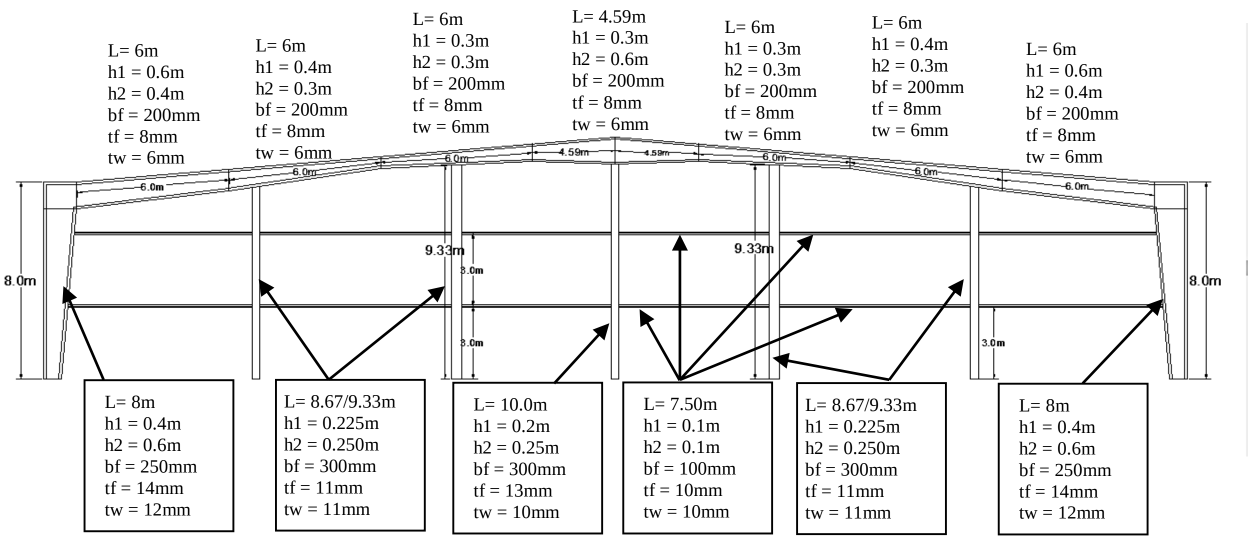

Figure 3. Tapered sections for the front gable frame

3.4.1. Standard Universal Sections for Mezzanine Floor

The standard section of beams and columns were used for supporting the mezzanine floor in the structure. The beams are arranged in secondary and main beam arrangement to transfer the floor loads to the columns and eventually to the foundation. In STAAD Pro the British standard sections are available in the inbuilt section database. The spacing between the main beams is 5.0 m and the spacing between the secondary beams is 1.5 m. The length of secondary beams is 5.0 m and the length of the main beams is 7.5 m. The standard section size of the beam and column used are shown in the Figure 4.

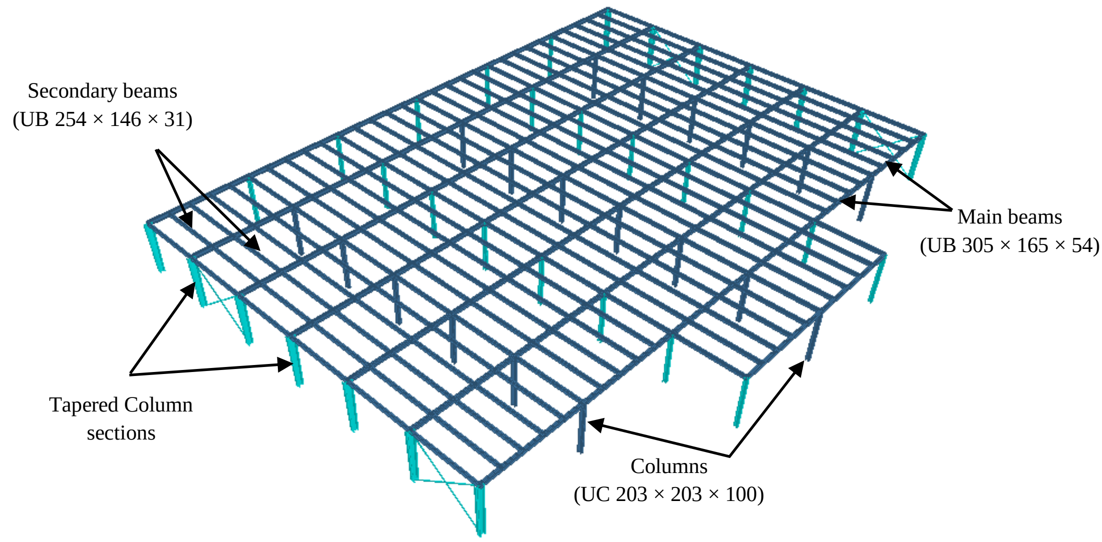

Figure 4. Isomeric 3D rendered view of the mezzanine floor

3.4.2. Bracing and Purlin Members

The bracing and purlins members are provided in order to increase the resistance of the structure against wind load. The purlins are arranged at a spacing of 1.5 m over the entire span of the rafter as shown in Figure 3.18. For purlin members, a British cold formed Z - section (200ZLML625×20) was selected from the inbuilt section database in STAAD Pro. The section 200ZLML625×20 has an overall depth of 200 mm, width of 62.5 mm, thickness of 2 mm and lip of 20 mm. For the bracing members, tie rods of 35 mm diameter were used for column bracing and roof bracing members. But since there is no built-in property for tie rod in STAAD Pro, hence specified the bracing members as a solid pipe of 35 mm diameter. The bracing members are assigned to act as tension members only. The arrangement of the column bracing and roof bracing is shown in Figure 5.

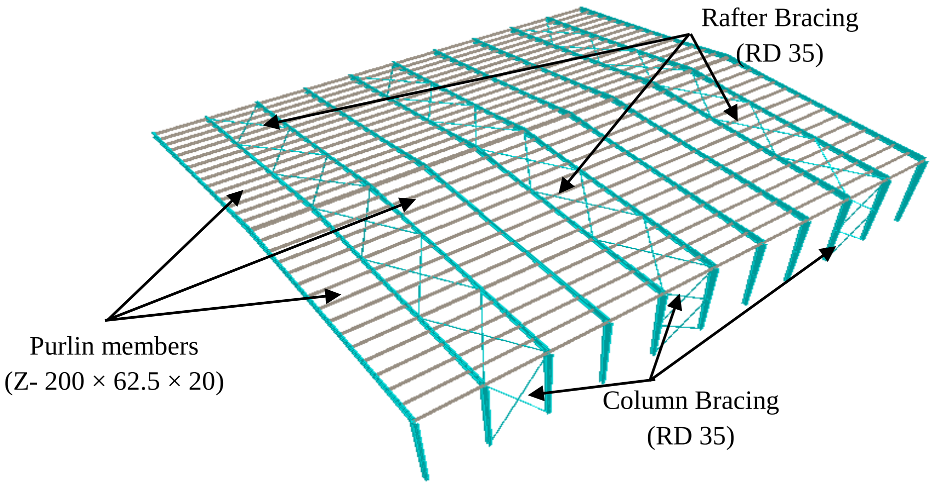

Figure 5. Arrangement of the bracing & purlin members in the structure

3.5. Member Properties for Euro Code Model

The member properties assigned to the Euro code model are very similar to the member properties that were assigned in British Standard model except for the tapered sections for the portal frames. In STAAD pro, the design of a steel structure with customized tapered section properties is not supported and hence the design of the PEB car showroom using Euro code (EN 1993-1-3:2005) could not be implemented. Hence, the portal frame was assigned with universal standard sections instead of using tapered sections for the PEB portal frames. Therefore, the member properties assigned to the Euro code model consist of standard universal beam and column sections for the portal frames and the mezzanine floor, purlin members and bracing members. The purlin and bracing member properties are the same as British Standard model except for the bracing members 25 mm diameter tie rods are used instead of 35 mm diameter.

3.5.1. Standard Universal Sections for the Portal Frame

Euro code does not support customized tapered section design in STAAD Pro, and therefore we have adopted standard sections that are available in the inbuilt section database in STAAD Pro. In Euro code model, the rafter beams member properties are assigned uniformly throughout the length of the rafter by considering the average standard section size from the British standard model of the tapered sections. This was the only possible way by which the design of the PEB car showroom could be implemented as per EN-1993-1-3:2005 in STAAD Pro. In Euro code model, all the portal frames were assigned with same member properties as shown in Figure 6, except for the gable frame different member section size were used as shown in Figure 7.

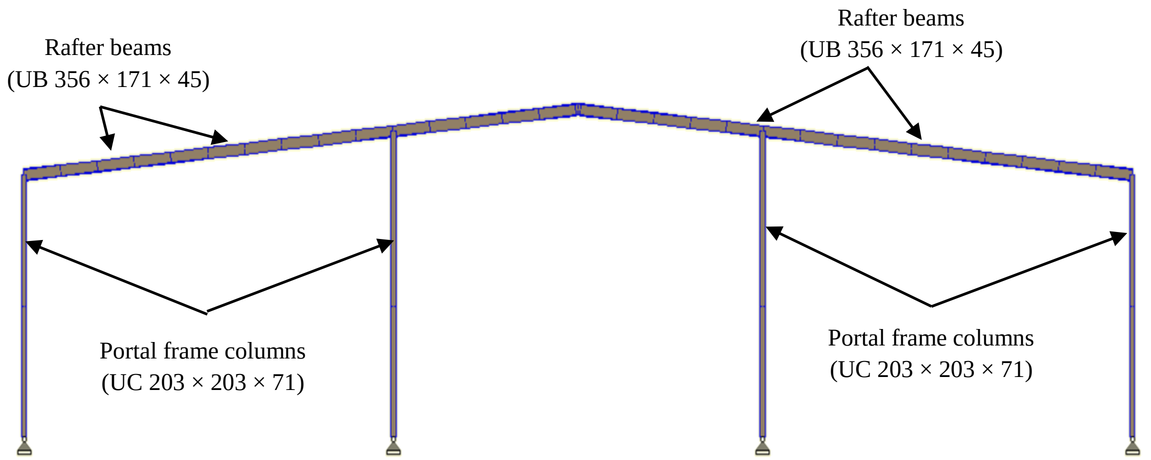

Figure 6. Typical portal frame showing the member properties for Euro code model

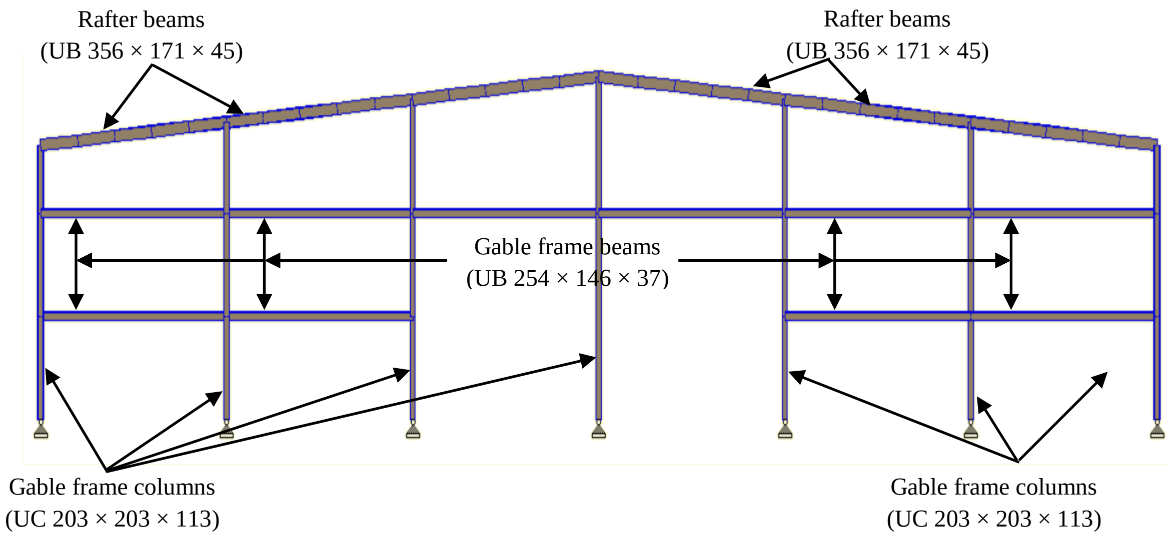

Figure 7. Member properties for the gable frame in Euro code model

3.6. Load Cases Consideration for Analysis

The most important thing to consider after assigning the property of the members correctly to the PEB structure is to assign the load cases appropriately. Load cases are very important and require special attention since all the analysis and design result depends on the loading condition. In this project I will be considering dead load, live load, wind load and seismic load. The load cases are considered based on BS EN 1991-1: 2002 [19].

3.6.1. Dead Load

The dead loads that are applied on the structure include the self-weight of all the structural members, the dead load on the interior and exterior rafters due to the purlins and the galvanized steel roofing sheets placed above it and the dead load on the mezzanine floor due to the concrete deck slab and floor finishes. The self-weight is assigned by a factor of -1 in STAAD Pro.

3.6.2. Imposed Load

The live load is applied to the structure at the roof level and the mezzanine floor level in the structure. At the roof level, the live load on the rafter is mainly due to serviceability access and maintenance consideration only and the live load on the mezzanine floor is mainly due to the vehicular loading (European-Union, 2002) [19].

Imposed load on the rafters: At the roof level, the live load is applied over the rafters in accordance to Euro code (EN-1991-1-1:2002, Table 6.10 [19]). It is stated that, for roofs (of category H) with no accessibility except for nominal maintenance, repair and serviceability access, the imposed load on the roof can be selected within the range of 0.0 kN/m^2 to 1.0 kN/m^2. Therefore, in our case the minimum variable load on the roof for only service accessibility is taken as 0.6 kN/m^2.

Imposed load on the Mezzanine floor: Since this is a car showroom the main variable load will be due to the vehicles. According to Euro code (EN-1991-1-1:2000, Table 6.8 [19]) the vehicle having weight of ≤ 30 kN (Category F), the imposed load due to vehicle may be selected within the range of 1.5 to 2.5 kN/m^2. Therefore, in that regard the imposed load of 2.5 kN/m^2 was applied as floor load on the mezzanine floor

3.6.3. Wind Load

The wind load that would be considered for both codes will have a basic wind speed of 35 m/s under extreme weather conditions. The wind load is calculated in accordance to Euro code (BS EN 1991-1-4:2005) [19, 20].

Total length of the building, b = 50 m, Spacing between the frames, s = 5 m, Width of the portal frames, d = 45 m
Apex height (max) of the structure, h = 10 m, Eave height of the structure, h' = 8 m
Slope of the rafter, α = 5°
Basic wind velocity, (V_b); (EN 1991-1-4, § 4.2, Eq 4.1 [19, 20])
Directional factor, $C_{dir} = 1.0$
Seasonal factor, $C_{season} = 1.0$
Fundamental value of the basic wind velocity, $v_{b,0} = 35\ m/s$
Basic wind Velocity, $v_b = C_{dir} . C_{season} . v_{b,0}$

$v_b = 1.0 \times 1.0 \times 35 = 35\ m/s$

Where by:
C_{dir} = is the directional factor and its recommended value is taken as 1.0
C_{season} = is the seasonal factors and its recommended value is taken as 1.0
$v_{b,0}$ = is the fundamental value of the basic wind velocity and is taken as 35 m/s
Basic velocity pressure, (q_b); (EN 1991-1-4, § 4.5, Eq 4.10 [19, 20])
Density of air, $\rho_{air} = 1.25\ kg/m^3$
Basic velocity pressure, $q_b = \frac{1}{2} \times \rho_{air} \times {v_b}^2$

$q_b = \frac{1}{2} \times 1.25 \times 35^2 = 765.63\ N/m^2$

Peak velocity pressure, q_p (z);
The peak wind pressure is given by the formula; (EN 1991-1-4, § 4.5, Eq 4.8 [19, 20])

$q_{p(z)} = \left[1 + 7l_{v(z)}\right] . ½ . \rho_{air} . v_{m(z)^2}$

$q_{p(z)} = 1778.5\ N/m^2 = 1.78\ kN/m^2$

External Wind pressure coefficients

In this calculation only internal portal frame is considered for the calculating the wind load on the PEB structure. For obtaining the wind load on the exterior frames, it can be taken half of the load that is acting on the interior portal frame.

The external wind pressure acting on the external surfaces can be calculated using;

$w_e = q_p.(z_e).c_{pe}$ (EN 1991-1-4, § 5.2, Eq 5.1 [19, 20])

The wind load calculation are shown in Figure 8 and Table 1. Assigning the wind load to STAAD model as shown in Figure 9.

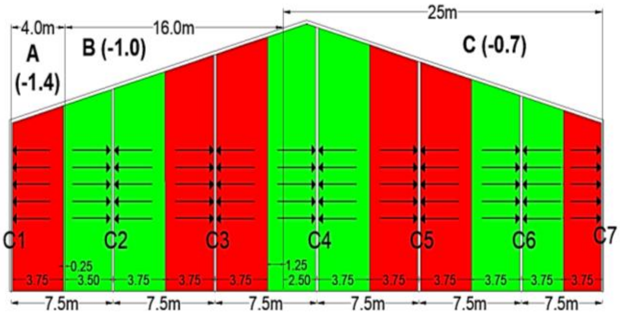

Figure 8. Wind load distribution on the columns of the end frames

Table 1. Wind load calculation on the columns of the end frame

Column	Zone	Coefficient $c_{p,net}$	Width (m) s	Wind load (kN/m) $= q_{p(z)} \sum (c_{pnet} \times s)$
C1	A	-1.4	3.75	-9.35
C2	A + B	-1.4	0.25	-13.53
		-1.0	7.25	
C3	B	-1.0	7.50	-13.35
C4	B + C	-1.0	1.25	-10.00
		-0.7	6.25	
C5	C	-0.7	7.50	-9.35
C6	C	-0.7	7.50	-9.35
C7	C	-0.7	3.75	-4.67

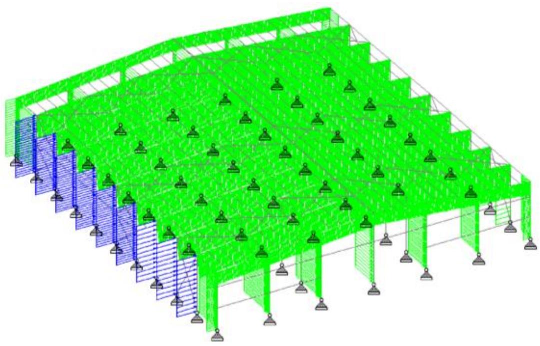

Figure 9. Wind load assigned to the structure

3.7. Seismic Load

Seismic load is also assigned to the structure to study the behavior of the PEB structure under dynamic loading condition. The seismic load is applied to the structure by considering the time history analysis method by using the El-Centro earthquake data of time verses acceleration. The El-Centro data of time against the acceleration were fed in STAAD Pro by selecting the input file of those data while creating the seismic load parameter on the STAAD Pro. The El-Centro data provided a running time of 57 seconds for the seismic load acceleration. The time interval was set to 0.02 second in order to obtain the breakdown results of the deflection at every 0.02 second interval over the complete running time of 57 seconds. The damping parameter was taken as 0.05 and 10 cut-off mode shapes were selected. The seismic load was applied in lateral X-direction (Figure 10).

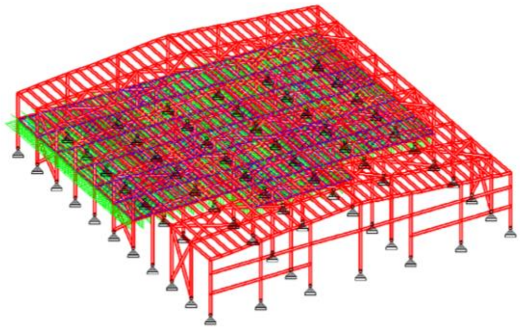

Figure 10. Seismic load assigned to the structure

3.8. Load Combinations

After assigning the above four load cases to the structure, different load combinations were created in order to apply the safety factor for the structure. Below are the load combination in accordance to British standard and Euro code.

Load combination as per British Standard:

- 1.4 DL + 1.6 IL
- 1.4 DL ± 1.4 WL
- 1.2 DL + 1.2 IL ± 1.2 WL
- 1.4 DL ± 1.4 EQ
- 1.2 DL + 1.2 IL ± 1.2 EQ

Load combination as per Euro code:

- 1.35 DL + 1.5 IL
- 1.0 DL ± 1.5 WL
- DL + 0.3 IL + EQ
- DL + EQ

Based on BS steel take off is presented in Table 2.

Table 2. Quantity of steel take off as calculated by STAAD Pro for BS5950

Section member	Property name	Weight (kN) ($\times 10^2$ kg)	% by weight
PEB Portal frames	Tapered	457.260	40.63
Main beams	UB 305×165×54	174.411	15.50
Secondary beams	UB 254×146×31	300.399	26.69
Columns	UC 203×203×100	74.146	6.59
Bracings (35mm tie rod)	RD 35	34.406	3.06
Z-Purlin section	200ZLML625×20	84.809	7.53
		1125.431	**100%**

Based on EC steel take off is presented in Table 3.

Table 3. Quantity of steel take off as calculated by STAAD Pro for Eurocode

Section member	Property name	Weight (kN) ($\times 10^2$ kg)	% by weight
Portal frames rafter beams	UB 356×171×45	218.746	18.01
Portal frame columns	UC 203×203×113	69.061	5.69
	UC 230×203×71	259.724	21.39
Gable frame beams	UB 254×146×37	27.194	2.24
Mezzanine Main beams	UB 356×171×57	184.044	15.15
Mezzanine Secondary beams	UB 254×146×31	300.399	24.74
Mezzanine Columns	UC 230×203×71	52.778	4.35
Bracings (25 mm tie rod)	RD 25	17.560	1.45
Z-Purlin section	200ZLML625×20	84.809	6.98
		1214.315	**100%**

The total weight of the portal frames alone in the structure is equal to:

Total weight of the portal frames $= 218.746 + 69.061 + 259.724 + 27.194 = 574.725\ kN$

Percentage by weight of the portal frame $= \frac{574.725}{1214.315} \times 100 = 47.33\%$

3.9. Comparison between the Output Design Results Obtained from British Standard and Euro code

In this section the main differences and similarities were outlined between the designed output results of the two structures. All the output results were carefully studied and interpreted for both design codes. In order to determine the most cost effective method of designing the PEB car showroom using British standard and Euro code we have to compare the design results of the two models and identify the structure that would be durable and economical in terms of material used. These comparisons are outlined and discussed below.

- British standard model (BS 5950:2000) of the car showroom structure was designed having tapered portal frame sections while the Euro code model (EN 1993-1-1: 2005) of the car showroom structure was designed with universal standard beam & column sections for the portal frames of the structure.
- The design parameters that were assigned to the structure based on British standard and Euro code are shown in Table 2. The grade and yield strength of the steel were applied as S275 and 275 N/mm^2 respectively for both design codes. But the ultimate tensile strength for Euro code was selected as 500 N/mm^2 and for British code as 460 N/mm^2.

- The bracing members for British model were changed from RD 25 to RD 35 in order to resist failure due to seismic loading while for Euro code model the bracing members with RD 25 properties were sufficient to withstand the seismic load and hence they were not changed.
- The dynamic results for the maximum variation in displacement, velocity and acceleration against time of all the rafter nodes taken as an average are presented in Table 4.

Table 4. Results obtained from dynamic analysis of both structures

Parameter	BS 5950:2000	EN 1993-1-1:2005
Displacement Vs time	10.5 mm	8.83 mm
Velocity Vs time	56.7 mm/sec	46.9 mm/sec
Acceleration Vs time	0.518 mm/sec ^{2}	0.472 mm/sec ^{2}

- From the Table 4, it is clearly seen that all the parameter results for Euro code is lower than those for British Standard. This is mainly due to the load combinations created for the codes. But in both cases the results are within the allowable limit.
- The total weight of the structure designed based on British code is 1125.431 kN and the total weight of the structure designed based on Euro code is 1214.315 kN The weight of Euro code model is 7.9% higher than the British standard model.
- The total weight of all the tapered portal frames in British standard model is 457.260 kN and the total weight of all the standard section portal frames in Euro code is 574.725 kN. The amount of steel used for standard sections for all the portal frames in Euro code model is 25.7% more than the amount of steel that was used for all tapered frame sections in British standard model.
- Therefore this implies that, using tapered section have utilized almost 25.7% of steel which eventually reduces the cost of material and cost of construction.

4. Conclusions

Based on the results of analysis and design using the two design codes the following conclusions are drawn.

- The peak wind pressure was calculated as 1.78 kN/m^2 by using a basic wind speed of 35 m/s based on BS EN 1991-1-4:2005 and seismic analysis was done by time history method using El - Centro data (time vs. acceleration).
- As per BS 5950:2000 code analysis, tapered section design was successfully carried out and EN 1993-1-1:2005 code analysis tapered section was not supported by STAAD Pro V8i software.
- The dynamic analysis results obtained for Euro code (EC) are lower than British standard (BS). For instance, the maximum displacement with time in X-direction for Euro code is 8.83 mm and for British standard is 10.5 mm.
- For resisting the seismic loading condition, 25 mm tie rod bracing member were sufficient for Euro code design but for British code 25 mm tie rod failed due to seismic loading and hence they were replaced by 35 mm tie rod bracing members.
- The total weight of the structure for BS model and EC model is 1125.431 kN and 1214.315 kN respectively. This makes EC model 7.9% heavier than BS model.
- The tapered frames contributes to 40.63% of the total weight in BS model
- The average standard section frames contributes to 47.23% of the total weight in EC model.
- The total weight of all the portal frames for BS model and EC model is 457.26 kN and 574.725 kN respectively. This makes tapered frame sections to utilize and reduce the amount of steel by 25.7%.
- All the member results such as deflection, bending moment, shear force and stresses are within the allowable limits for ultimate and serviceability limit state since the internal stresses in all the members satisfies as per unity check ratio requirements for both design codes.
- The foundation of the structure was designed based on the BS model since it has proved to be an economical model as compared to EC model in term of the weight of the materials used.

5. Conflict of Interest

The authors declare no conflict of interest.

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