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EFFECT OF SEMI RIGID CONNECTION ON PRE ENGINEERED BUILDING STRUCTURES

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ABSTRACT

A Pre-engineered steel building (PEB) has become one of the most efficient & simplified building type in the steel construction industry use of tapered members for columns and rafter is one of the basic property of PEB. Use of web tapered member increase the efficiency of PEB. The connection between the tapered member is the crucial factor which decide the efficiency of structure tapered with decide of research, semi-rigid beam to column connections have been widely accepted. It is very interesting to study the effect of semi-rigid connections of the tapered member like PEB during the pushover analysis of structure. The different level of rigidity of joints may changes the behavior of capacity & demand curve of pushover analysis. The variation of results may alter the different values of damage indices, Response reduction factor and even vulnerability assessment factor.

So here in the present study, the attempt is being make to study the effect of different levels of rigidity factor of a joint for PEB structure, the aim of the present work is to investigate the different value of Response reduction factor for varying the rigidity levels of a joint of PEB. The pushover analysis (non-linear static analysis) is going to perform for the structure, the performance point is likely to be study for all developed models. The response reduction factor values are mostly given by IS 1893: 2016 Part-I for generalized structure without mentioning the types of connections. So here the attempt is being made to calculate their value by Newmark Hall method as per existing literatures. Lastly the comparison of R Factors is done for all the developed models.

From the entire study it is observed that the more value of rigidity of a joint provide more value of response reduction factor. The performance point of capacity & demand curve as per ACT 40 shows much erratic for lesser values of rigidity factors of PEB connections.

Keywords: *PEB structure, Response reduction factor, Nonlinear static analysis, Semi-rigid connections.*

2. INTRODUCTION

Steel is naturally ductile and versatile material; it is the material of choice for construction. The steel industry is expanding very fast in almost every country. A number of technologies, systems, and products are developed in the construction industry, the PEB concept is one of them. The main concept in the PEB is geometry of frame matches the shape of bending moment diagram. As a result, slender tapered frame elements are used. To achieve this configuration, built-up tapered I sections are used. This leads to the optimization of the material usage thereby reducing the weight of the structure. Use of PEB structure has been limited to Northern America and Mid East till 1990's after which outspread to Asia and Africa regions.

The PEB construction concept has now gained widespread acceptance and commercial success. International contractors and designers who earlier only stipulated conventional steel construction, now begun to specify the approach towards PEB. No other building technique match PEB when it comes to speed and value form excavation to occupancy. Pre-engineered building has many advantages which made the PEB industry's explosive growth in recent years. The advantages include: Reduction of construction time, Lower cost, Flexibility of expansion, large clear spans, Quality control, Low maintenance, seismic reliability, architectural versatility, environment friendly.

PEB becomes more popular now a day because these buildings are most economical, short erection time period, low cost, light weight, etc. PEB are engineered at factory and assemble at site. PEB consists of primary elements and secondary elements, I-shaped members such as taper rafter, taper columns, etc. comes under primary elements, cold form members like “Z”, “C”- purlins, bracings, etc. comes under secondary elements, as can be depicted in Figure 1.

The large part of the Indian economy is contributed by the construction industry. The researcher makes an effort not only to make a structure economical but also to make it eco- friendly. As compared to other construction materials steel is a very expensive material. With the help of paints making steel rustproof. In recent, PEB is modern technology is introduced in steel structure. In steel structure design the Pre-engineering building system a modern technology that provides economical, Sustainable and eco-friendly structures. Whereas before the introduction of the PEB system in steel structure construction conventional steel building system is used this is to provide time-consuming, costly design. The pre-engineering building is costly due to more consumption of steel because of using a uniform cross-section of the hot- rolled section throughout the member length. However, based on the loading effect built-up section used in PEB and only bolted connections are provided at the construction site.

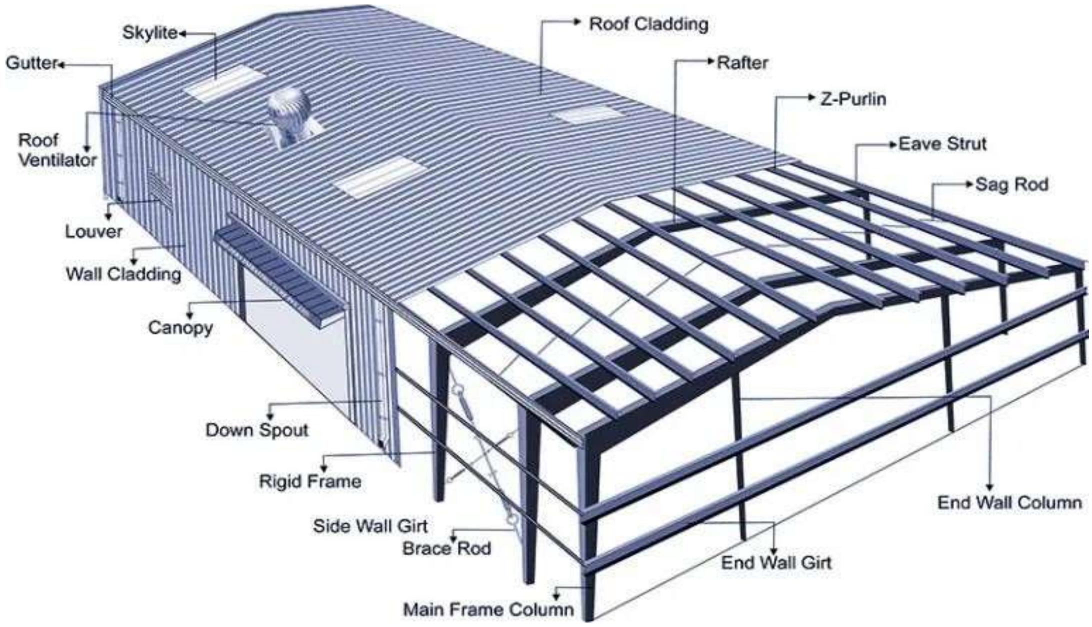


Fig 1: Pre-engineered building components

Although PEB systems are extensively used in industrial and many other non residential constructions worldwide, it is relatively a new concept in India. These concepts were introduced to the Indian markets lately in the late 1990's with the opening up of the economy and a number of multi nationals setting up their projects. India has an installed steel capacity of 35 to 40 million tones & apparent steel consumption is around 27 to 30 million tones.

One of the emerging fields in seismic design of structures is the Performance Based Design. The subject is still in the realm of research and academics, and is only slowly emerging out into the practitioner's arena. Seismic design is slowly transforming from a stage where a linear elastic analysis for a structure was sufficient for both its elastic and ductile design, to a stage where especially dedicated non-linear procedure is to be done, which finally influences the seismic design as a whole.

The need for a simple method to predict the non-linear behavior of a structure under seismic loads saw light in what is now popularly known as the Pushover Analysis (PA). It can help demonstrate how progressive failure in buildings really occurs, and identify the mode of final failure. Putting simply, PA is a non-linear analysis procedure to estimate the strength capacity of a structure beyond its elastic limit (meaning Limit State) up to its ultimate strength in the post-elastic range. In the process, the method also predicts potential weak areas in the structure, by keeping track of the sequence of damages of each and every member in the structure (by use of what are called 'hinges' they hold).

Hinges are points on a structure where one expects cracking and yielding to occur in relatively higher intensity so that they show high flexural (or shear) displacement, as it approaches its ultimate strength under cyclic loading. These are locations where one expects to see cross diagonal cracks in an actual building structure after a seismic mayhem, and they are found to be at the either ends of beams and columns, the 'cross' of the cracks being at a small distance from the joint – that is where one is expected to insert the hinges in the beams and columns of the corresponding computer analysis model. Hinges are of various types namely, flexural hinges, shear hinges and axial hinges.

Basically a hinge represents localized force-displacement relation of a member through its elastic and inelastic phases under seismic loads. For example, a flexural hinge represents the moment- rotation relation of a beam of which a typical one is as represented in Fig.2. AB represents the linear elastic range from unloaded state A to its effective yield B, followed by an inelastic but linear response of reduced (ductile) stiffness from B to C. CD shows a sudden reduction in load resistance, followed by a reduced resistance from D to E, and finally a total loss of resistance from E to F.

Hinges are inserted in the structural members of a framed structure typically as shown in Fig.3. These hinges have non-linear states defined as 'Immediate Occupancy' (IO), 'Life Safety' (LS) and 'Collapse Prevention' (CP) within its ductile range. This is usually done by dividing B-C into four parts and denoting IO, LS and CP, which are states of each individual hinges (in spite of the fact that the structure as a whole too have these states defined by drift limits). There are different criteria for dividing the segment BC. For instance, one such specification is at 10%, 60%, and 90% of the segment BC for IO, LS and CP respectively.

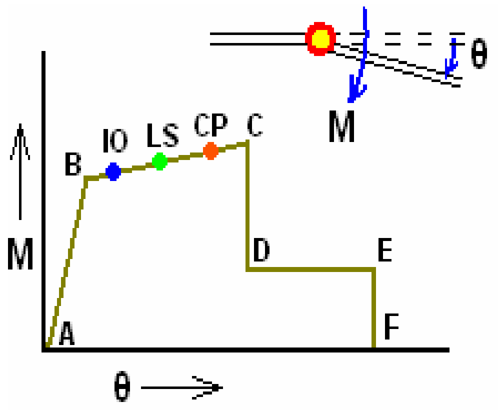


Fig.2: A Typical Flexural Hinge Property, showing IO, (Immediate Occupancy), LS (Life Safety) and CP, (Collapse Prevention)

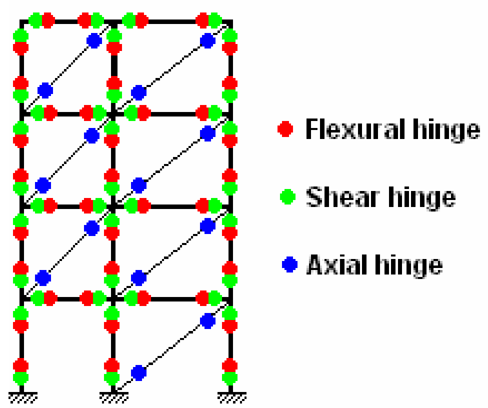


Fig.3: Typical Locations of Hinges in a structural model.

The study of PEB has attracted many researchers in recent years, like Hussain et al. (2017) had performed the analysis of a frame against the seismic forces. They have carried out comparison between ordinary moment resisting frame and special moment resisting frame. They have found that when there is increase in seismic load the steel required for ordinary moment resisting frame is much higher than special moment resting frame. They also stated that drift is more in ordinary moment frame as compared to special moment resisting frame. They found that steel can be saved by 7% for main frame and 60% to 30% for bracings by use of special moment resting frame.

Venkata Ramana and Ingle (2017) have focuses on estimating the actual value of R factor of RC framed buildings designed and detailed following the Indian standards and comparing these values with the value suggested in the Indian code. The main focus of this study was to evaluate component wise computation of R factor and effect of number of storeys on this factor using Pushover analysis. Performance level considered in this study is corresponding to global performance level (at 2% storey drift) and local performance level (life safety level) whichever occurs first. From this study, it was found that Indian seismic code giving conservative

R value for regular RC framed buildings as per considered performance level. Also found that overstrength factor is decreasing and ductility factor is increasing as the number of storeys increases.

Saleem et al. (2018) had carried out design of PEB for members' i.e. hot rolled sections and cold-formed sections. Minimum weight design of CSB was carried out to achieve the design of the PEB. They state that Minimum Weight is directly proportional to Minimum Cost. These two structures were compared not only economically but also for structural safety. They found that using cold-formed steel for secondary framing instead of hot rolled has decreased the weight by 60%, also by use of built-up sections in place of hot rolled sections for primary framing decreased the cost by 30%.The deflections and sway shown by hot rolled sections when used for primary and secondary framing is less when compared to others. They also stated that, rather built-up sections shows higher sway but is within the limits as specified in MBMA 2005.

Pradeep Kumar et al. (2019) have studied various codes, They have compared various structural parameters between PEB and CSB by using various codes viz IS800:2007,IS 800:1984, MBMA-96 and AISC-89. They have found that there is increase in section weight when designed by IS 800:1984 as compared to IS800:2007. The deflections stated in Indian standard are higher than MBMA. When the design was compared between IS 800:2007 and AISC/MBMA the weight was greater.

Gokul et al. (2021) have compared CSB and PSB. They have obtained the results by analyzing and designing of an Industrial shed. They have found that the total steel take off of the PEB is about 60% as that of CSB. The author have observed that the weight of the frame is dependent on the bay spacing; with increase up to certain limit there is decrease in weight while after that limit it increases. They also found that displacement is more in CSB as compared to PEB whereas axial force is more in PEB as compared to CSB.

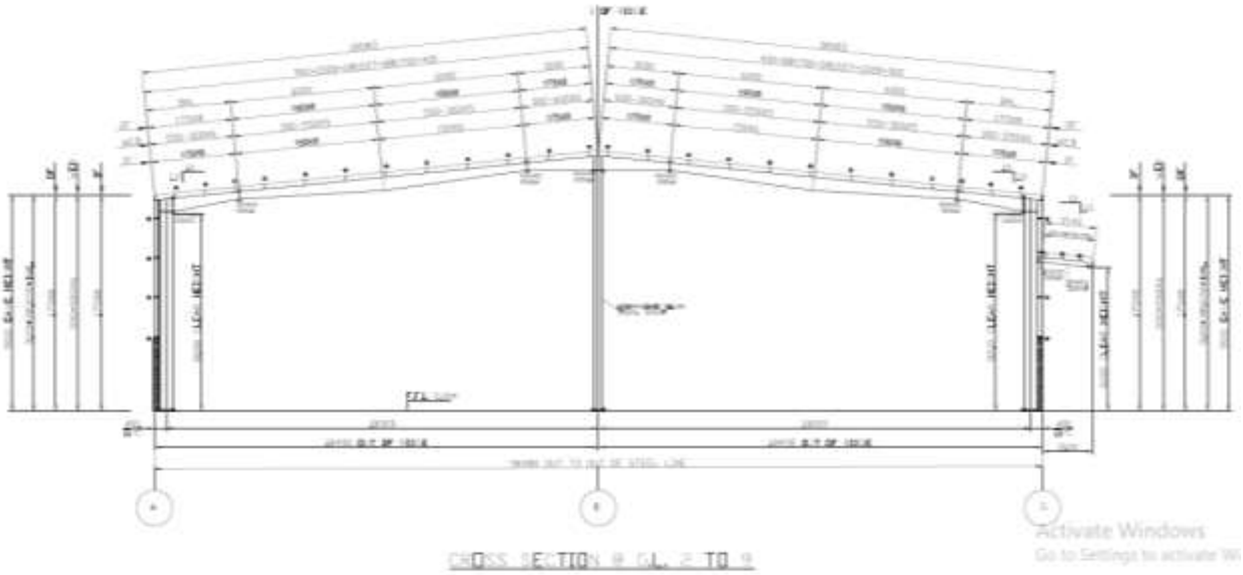
Subramanian et al. (2023) has made a brief description on the selection of framing system. Also they have made a description on the type of materials used for roof and wall. They have stated the types of structure and the types of framing system that can be used. They stated that braced frames may be more economical than unbraced frame in situations where the labour cost is low. They have described about one of the roofing systems through fastened lapped-seam roofing. They stated that rather this roofing system is more economical it is susceptible to leakage and hence standing-seam metal roofs consisting of metal panel running vertically on the roof deck are used in present day constructions.

The uncertainty over the response reduction factor is still the challenges face by the structural engineer in design offices. Many papers were found on the evaluation of response reduction factor for fixed base structural system with rigid connections of the members. But very few studies are available on semi-rigid connection and PEB building response reduction factor. In most of the literatures the authors have used two approaches for determining the response reduction factor namely, Newmark Hall Technique and Miranda Technique.

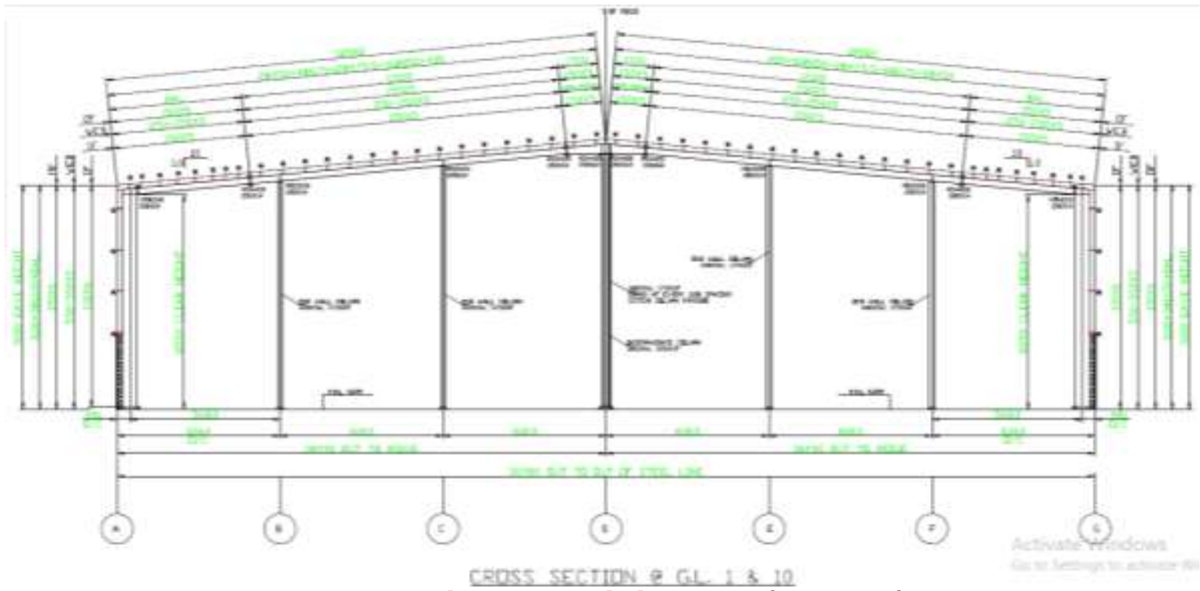
So, here in the present paper, the main intention is to study the effect of semi rigid connection of industrial building pre-engineered building components considering different values of semi-rigid connections at beam-column and beam to beam joint connectivity, prepare the model in SAP 2000NL software and perform the pushover analysis and thereby calculate the response reduction factor as per Newmark Hall Technique.

3. METHODOLOGY AND PROBLEM STATEMENT

The detailed elevation and plan of PEB industrial structure is shown in Figure 4 and 5 respectively. These drawings also consists the structural member sizes for tapered section. The exterior frame structural dimensions are different than the interior frame as can be seen through this figures sectional elevation.



a) Sectional elevation of interior frames.



b) Sectional elevation of exterior frames.

Fig 4: Elevation of structures

As per the AutoCAD drawing, the model is prepared in SAP 2000NL (as can be seen in Fig 6) and perform the nonlinear static analysis of structure by assigning the hinge properties to all the structural elements. The hinge properties are assign as per the ATC 40 guidelines. Using SAP2000, the non-linear static pushover analysis has been carried out on the three-dimensional frames. All the beams and columns have been modelled using the two noded frame element and shear walls are modelled using shell area element available in SAP2000. The axial load effects are neglected in the case of beams, by using the rigid diaphragm effect. In case of columns, the effect of axial loads on plastic hinges are considered using P-M-M interaction diagram for each different RC section. No shear hinge formation is considered in these analysis, as various design and detailing provisions specified in IS 13920 eliminate the possibility of such a failure. Pushover curve are generally used to present the output of non-linear static analysis. Pushover Curve is nothing but a plot of base shear versus roof displacement plot.

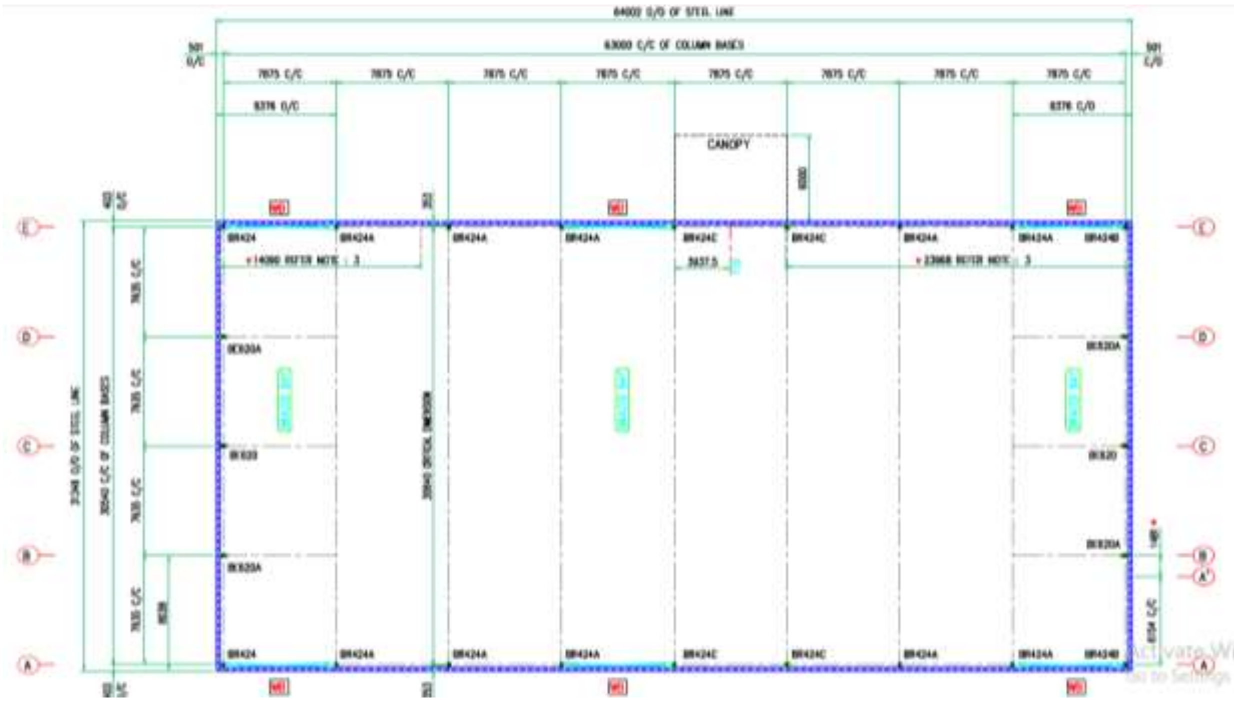


Fig 5: Plan of structure.

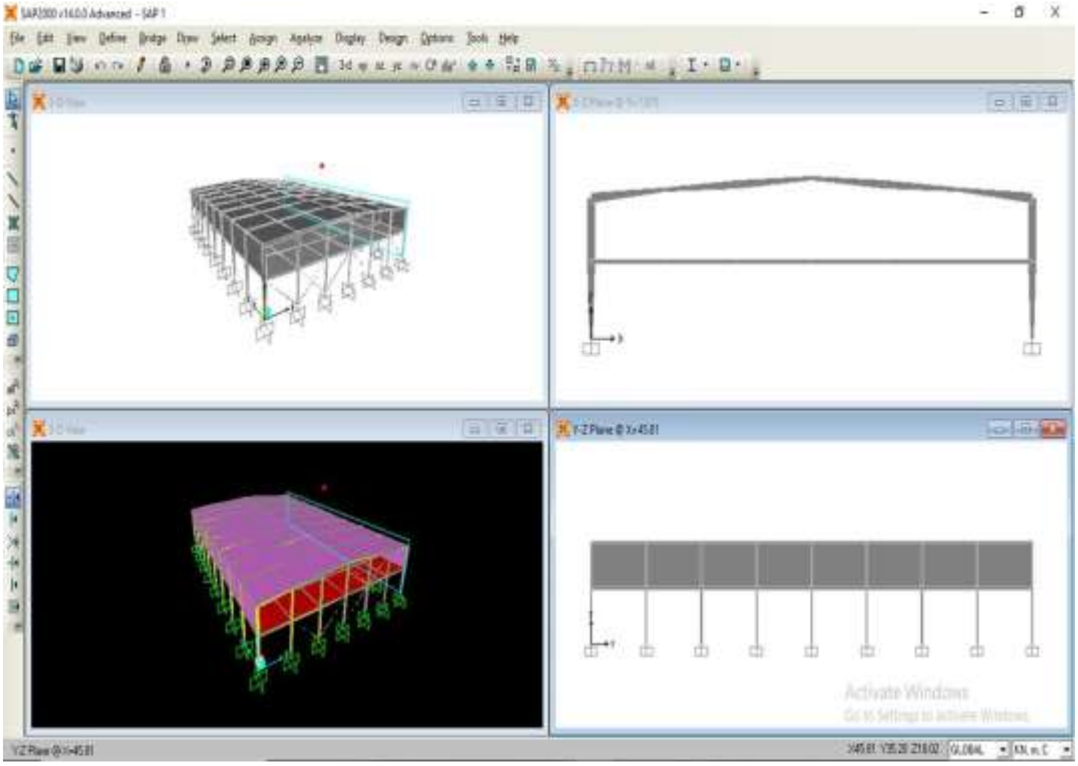


Fig 6: PEB model in SAP 2000NL.

In this study R factor is calculated considering performance limit of the structure. Performance limit consists of provision of drift and lateral displacement whichever will come first. The maximum/ultimate base shear is defined as the base shear capacity of the RC structure just before the onset of lateral stiffness degradation. As per the performance analysis given in FEMA 356 building performance is considered between Life safety and collapse prevention range.

The structural performance level of a building shall be selected from four discrete structural performance level and two intermediate structural performance ranges. This study selected performance level between life safety structural performance (S-3) and collapse prevention structural performance level (S-5). Discrete performance level Limit safety structural performance range (S-4) comes between S-3 and S-5 range.

The response reduction factor, R, represents the ratio of the maximum lateral force if structure remains elastic (Ve), to the lateral force (Vd), which it has been designed to withstand. Response reduction R factors are essential seismic design tools, which are typically used to describe the level of inelasticity expected in lateral structural systems during an earthquake. Commonly, the response reduction factor is expressed as a function of various parameters of the structural system, such as strength, ductility, damping and redundancy.

$$R = R_s \times R_\mu \times R_\varepsilon \times R_r$$

Where R_s is the strength factor, R_r is the redundancy factor, R_μ is the ductility factor and R_ξ is the damping factor.

Redundancy factor: Redundancy factor R_r can be estimated as ratio of ultimate load (V_u) to first significant yield load (V_y); estimation of this factor requires detailed non-linear analyses.

$$R_r = V_u/V_y$$

Ductility factor (R_μ) is calculated as relative displacement (ultimate displacement) to the yield displacement.

$$M = (\Delta_m)/(\Delta_y)$$

Where Δm and Δy are the maximum drift capacity and yield displacement respectively. For the calculation of ductility reduction factor the researcher Newmark and Hall formulae is used.

As per Newmark and Hall formula, $R_\mu = \sqrt{2\mu - 1}$ For, $\frac{T_1}{4} \leq T \leq T_1$

Where, μ is displacement ductility ratio is defined as maximum absolute relative displacement to its yield displacement.

The over strength factor is a measure of the additional strength a structure has beyond its design strength. The additional strength exhibited by structures is due to various reasons, including sequential yielding of critical points, factor of safety considered for the materials, load combinations considered for design, member size ductile detailing etc. In the present study redundancy factor is taken as 1 considering economical design.

Strength factor is calculated as maximum base shear force at yield level (V_y) divide by design seismic base shear force (V_d).

$$\text{Strength Factor } (R_S) = \frac{\text{Yield shear } (V_y)}{\text{Design base shear } (V_d)}$$

Damping factor R_ξ is used for structures which are provided with additional energy dissipating (viscous damping) devices. The damping factor is assumed as 1 for buildings without such devices. In this study, the damping factor is assumed to be 1.

Figure 7 presented the detailed methodology flowchart for present study.

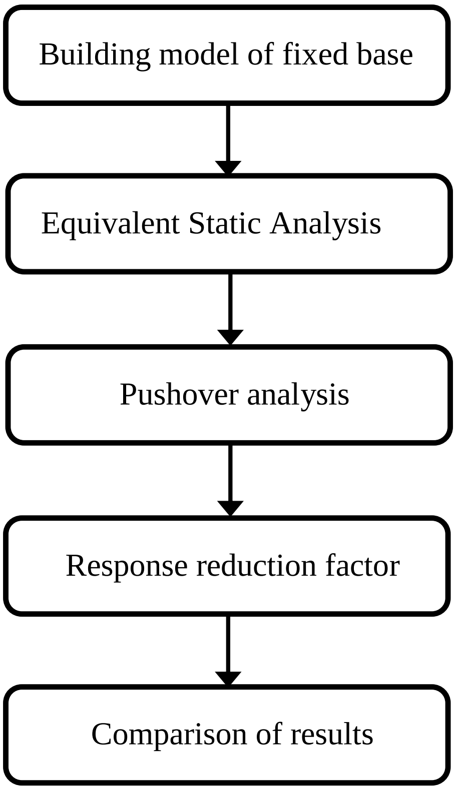


Fig 7: Methodology flowchart

4. RESULTS AND DISCUSSION

The nonlinear static analysis results are measured in terms of base shear and roof displacements for all the developed models. Total four models are prepared based on the joint rigidity factors, namely 0.2 rigidity

(0.2R), 0.4 rigidity (0.4R), 0.6 rigidity (0.6R) and 1 rigidity. The pushover curves are plotted along X and Y direction of building plan.

It is found that the total weight of the structure including live load is 3585 kN, Total horizontal base shear as per equivalent static method of seismic analysis as per IS 1893:2016 is 97 kN. The first fundamental frequency is 0.68 rad/sec along Y direction (in which total 60% mass gets excited). After performing pushover analysis, yield force and yield displacement along X-direction is obtained as 242 kN and 0.113m respectively. Similarly, yield force and yield displacement along Y-direction is obtained as 445 kN and 0.206m respectively. The sample basis pushover hinge formation for complete rigid factor is represented in Figure 8 and 9 along X and Y direction respectively.

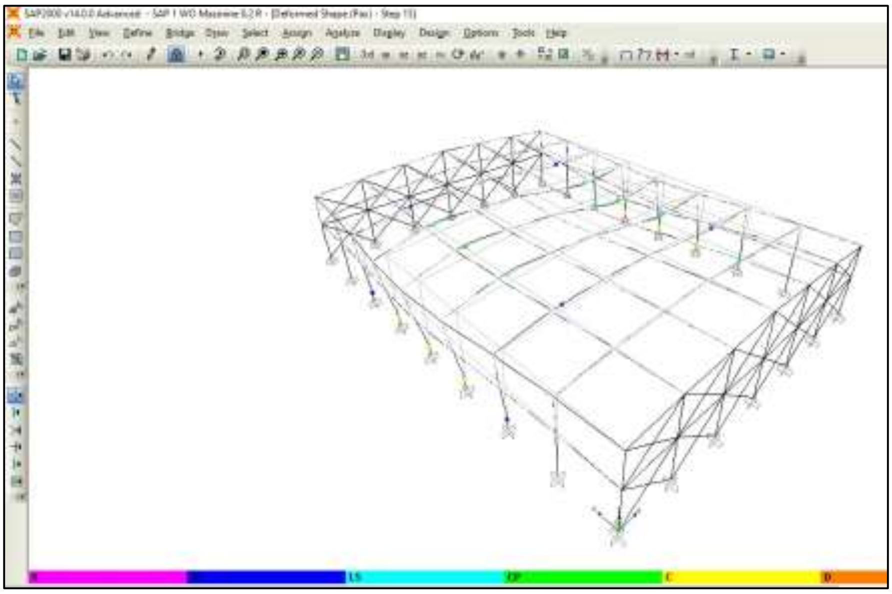


Fig 8: Push-over hinged formation along X-direction.

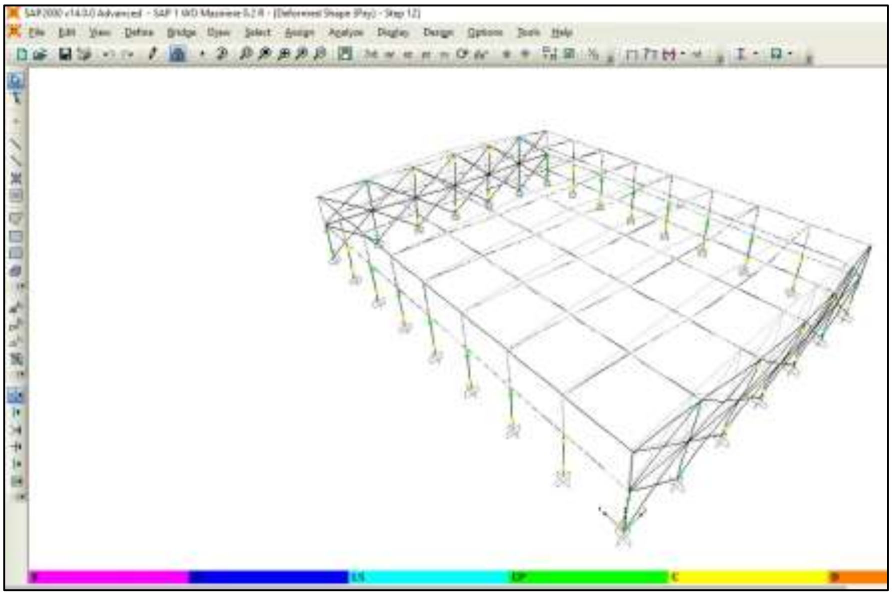


Fig 9: Push-over hinged formation along Y-direction

The pushover curves are plotted in Figure 10 for all the four types of semi rigid connections along X and Y directions.

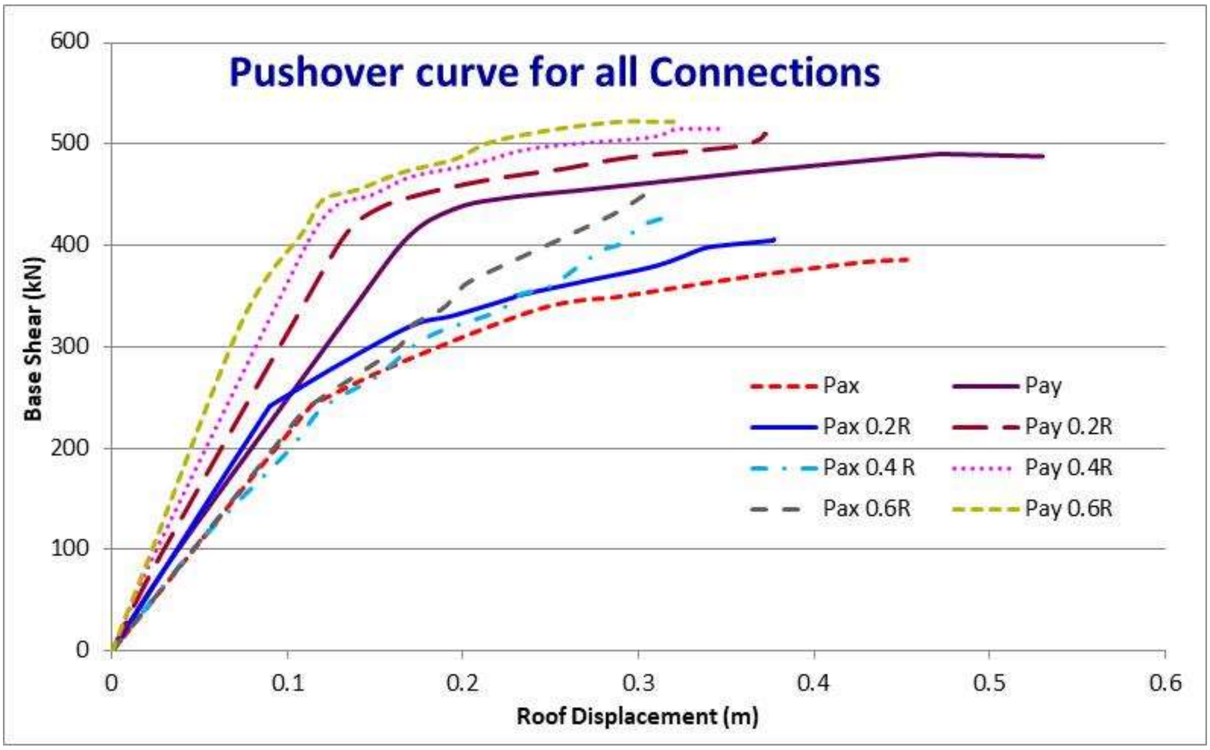


Fig. 10: Pushover curves for all types of connections along X and Y directions.

All models shows significant level of ductility, along X-direction the ultimate displacement for 100% rigidity connection is 0.45 m, however along Y-direction for same type of rigidity the ultimate displacement is obtained as 0.53 m. From the figure it is clear that as the rigidity zone factor is reduces for the connections the roof displacement decreases and base shear increases, the ductility loses and the model are became brittle more susceptible to damages.

The response reduction factor is calculated for all the models as per Newmark Hall technique, and tabulated in Table 1.

Table 1: Response reduction factor for all models.

Model configuration	Response Reduction Factor	
	Along X direction	Along Y direction
100 % rigidity model	5.64	5.157
20% rigidity model	4.42	4.152
40% rigidity model	4.25	3.878
60% rigidity model	3.74	3.292

From the table 1, it is observed that the as the rigidity factor increases for the joints the structure became more redundant and response reduction factor is also increases that means the base shear force requirement is reduces for the structure. The response reduction factor is very well matches with the IS 1893 requirements, for special structures the R factor should be nearer to 5 and for ordinary structure R factor is nearly equal to 3.

5. CONCLUSION

The PEB Structure is modelled and analyzed in SAP 2000NL Software for different cases of Semi- Rigid connections. From numerical study, the following conclusions are drawn:

- In all cases of Semi-Rigid connections, the Pushover curves are different along X-direction and Y-direction. Due to flexibility of joints the structure behavior became brittle having less displacement but high base shear force.
- The Response Reduction Factor R values are closely matched with the IS 1893:2016 values.
- The more value of rigidity of a joint provides more value of response reduction factor.
- The performance point of capacity & demand curve as per ACT 40 shows much erratic for lesser values of rigidity factors of PEB connections.

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