

Seismic Evaluation of Prefabricated Industrial Building

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Abstract - With the advent of industrialization, most of the heavy commercial and industrial structures are predominantly prefabricated steel structures. Prefabricated structures are preferred due to their low cost and quick construction. Such structures are of great importance as they contain loads of valuable machinery and manpower and are at the same time subjected to heavy loadings within and lateral action of wind and earthquake. The functional requirements of an industry govern the configuration of the structure. As a result, the provided configuration may not be effective in resisting the earthquake forces prevalent to the location under consideration. Therefore, based on the seismicity of a region the industrial structures need to be assessed for their safety during an extreme earthquake. This paper deals with seismic evaluation of an existing industrial structure with different arrangements in bracings for its non-linear capacity with the help of pushover analysis to pick out the most efficient configuration. An attempt is made to recommend different types of configurations for the seismicity of the region. As the behaviour under extreme earthquake event is required to be studied, non-linear static pushover analyses have been adopted. Various response parameters are studied for the selected configurations and compared. Concluding remarks have been made regarding suitability of the considered configurations for a given seismicity and required performance objectives.

Key Words: Seismic Evaluation, Nonlinear Static Analysis, Existing structures, Pushover Analysis, Prefabricated, Industrial, Bracings, Seismic Zone.

1. INTRODUCTION

In India, there is a growing trend of using prefabricated structures in the construction of industrial buildings because traditional RCC buildings take significantly longer to construct and have very little scrap value if the setup needs to be moved, as well as having a high scrap value. Prefabrication is considered cost-effective for a large construction since it reduces transportation costs. If we use ordinary steel constructions, the time frame will be longer, and the cost will be higher, making it uneconomical in the long run. This approach provides many advantages over the traditional steel construction concept. Despite of many advantages of PEB, their seismic resistance has been a matter of concern.

It is therefore important not only to assess the seismic performance of existing PEB, but also provide suitable configurations for seismic demands.

1.1 Seismic Evaluation

The performance characteristics of a structure's components determine its seismic behaviour. The critical components in the structural system are those forming the lateral load path and those necessary for the vertical stability of the structure. With the increase of seismic loading, component inelastic behaviour, damage, and failure may occur. These events by themselves may not cause the failure of the structure; however, redistribution of loads may overstress other components and accelerate the distress and ultimate collapse of the structure. It is also logical that the determination of the seismic resistance of the structure should include the inelastic component behaviour and the components' potential modes of failure [1]. Static pushover analysis or dynamic methods can be used to assess the seismic performance of existing structures. An analytical model is represented in 2-D or 3-D perspective for the application of pushover force virtually in the analysis tool or program. The structure's lateral load-roof displacement response is calculated as the static load pattern is raised in stages until a particular goal displacement level or collapse is attained. The pushover approach evaluates the sequence of component damage or failure, and if the behaviour is adequately reflected, the ultimate load and drift at the collapse of the structure can be calculated. It's a straightforward and promising method for evaluating existing constructions' lateral load resistance.

2. LITERATURE REVIEW

An exhaustive study on pushover analysis was conducted for the performance of structures subjected to earthquakes in various regions and for various codes.

A Ghobarah [1] presented review of the state-of-the-art, concepts, philosophy and approaches for the seismic assessment of existing reinforced concrete structures. He concluded that, the elastic time-history analysis is not appropriate for the determination of the behaviour of the existing RC structures which depend on inelastic displacement and deformation up to collapse. Nonlinear methods are feasible and promising for determining behaviour under inelastic force deformation.

A Kadid, D.Yahiaoui [2] reviewed two 3 storey and two 6 storey frame for different bracings. They concluded that addition of bracings greatly enhances characteristics of the structure. The section size is seen to have a quite influence on deformation and ductility of the buildings.

Kasim A. Kormaz, Musa UZER[3] studied the use of tension strands and its different members for bracings. The effect of the tension strands was studied with the help of linear and non-linear analyses. He observed that the non linear analyses gave more accurate results.

Sevket Murat Senel and Mehmet Palanci [6] made an extensive study on high seismicity located 98 buildings. The authors observed that little change in soil properties deals with sensitive damage to the whole structure and a moderate damage may also lead to monetary losses. Displacement was observed by two method, i.e., Capacity spectrum and displacement approach.

Gennaro Magliulo et al [7] reviewed static and dynamic nonlinear analyses for assessment of existing precast buildings. The author observed that elastic analyses show that high frequency modes are to be considered in order to take into account the effects of the seismic vertical component. The obtained analysis results show that nonlinear dynamic analyses can take into account characteristics of the existing structure.

Vaseem Inamdar et al [10] intended to compare the performance of structure by using ISMB and ISNB (hollow pipes) steel sections as a bracing element on the 15-story complex steel frame

3. SYSTEM DEVELOPMENT

The process of analyzing and designing a new structure differs greatly from that of evaluating the seismic performance of an existing structure. There is an implied goal in the design process that may or may not be the same as the goal for rehabilitation of the existing structure.

3.1 Seismic Evaluation Process

The evaluation process consists of two stages, viz., preliminary evaluation and detailed evaluation.

- **Preliminary Evaluation**

In this stage, site survey is to be done for collection of information regarding the structure. Some calculations are also involved like shear stress and axial stresses in member. Observations for soft storey, short columns, discontinuities, member redundancy, irregularity in mass, mezzanine floor, etc.

- **Detailed Evaluation**

This stage is not required if the structure fulfills the preliminary stage evaluation norms. In this stage, strength of component of the structure is to be calculated knowing the present-day material strength and knowledge factor for deterioration of material strength. For resisting the seismic demand, Linear/Non-linear/static/dynamic analysis is required for modified lateral force resistance. Current capacity of the structure is to be compared with the expected seismic demand.

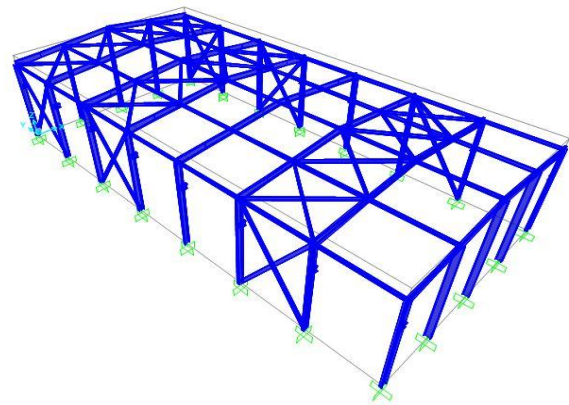


Fig-1: 3D view of example building

The existing structure as shown in fig 1 was analyzed by reproducing the geometry from the obtained drawings. The effects of the existing structure differed dramatically across orthogonal orientations. As a result, it was discovered that bracings in one direction are required.

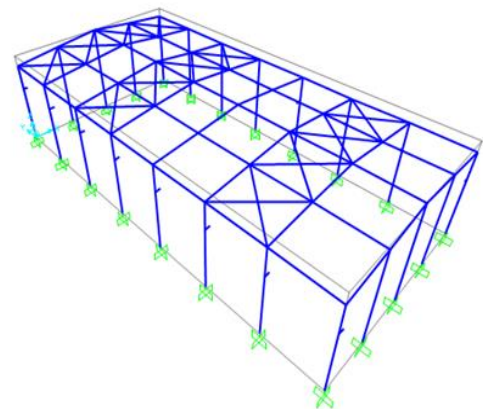
3.2 Structure Specifications

The building considered in this study is of dimensions 22m x 45m with an eave height of 10m. The building is prefabricated located in Seismic Zone II (Aurangabad, Maharashtra). Bay Spacing is 6.5m. The slope of the roof is 1 in 10. The building consists of elements like columns, purlins, rafters, crane beams, sheeting, and bracings. It consists of a crane with a capacity of 10 tons. Steel members have yield strength of 250 MPa, but PEB members have a strength of 345 MPa.

3.3 Models created in SAP2000

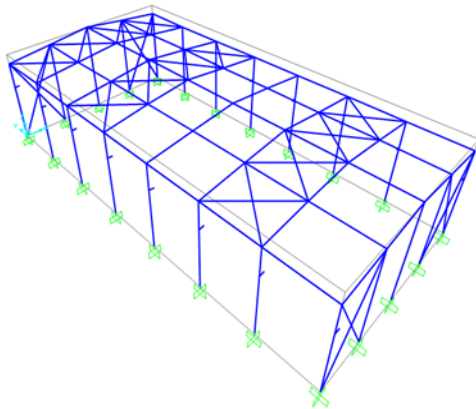
Industrial structural models were developed to examine the change in response to stiffness changes using bracings. The constructed models were analysed in a variety of methods, including

- (a) Model 1: Bare Frame



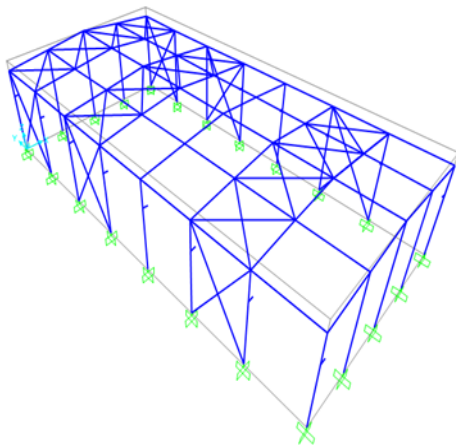
(a)

(b) Model 2: Bare Frame with bracings along the shorter direction



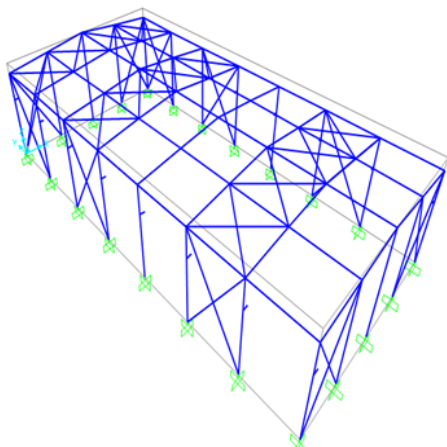
(b)

(c) Model 3: Existing Frame



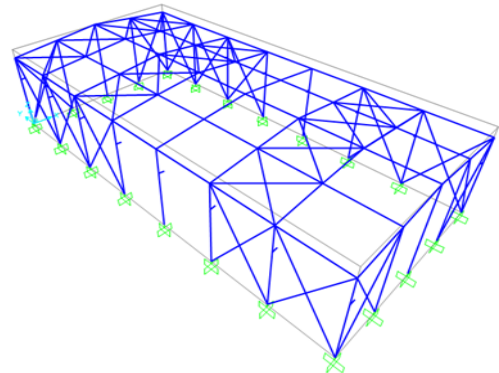
(c)

(d) Model 4: Existing Frame with additional bracings along the shorter direction



(d)

(e) Model 5: Existing frame with additional bracings except for functional openings



(e)

Fig-2: Models used for the analysis

The fig 2 (a), (b), (c), (d) and (e) shows 3D view of the models created for different possibilities of bracings.

Table -1: General Characteristics of the Existing Industrial system

Type of Structural System	Web Dimensions	Flange Dimensions
Columns	500 x 5	240 x 10
Rafters	600 x 5	180 x 6
Rafter End Frame	750~600 x 6	180 x 8
Purlins	300 x 6	150 x 8
Bracings	300 x 5	150 x 5
Crane Beam	500 x 8	240 x 10

3.4 Methodology

1. Selected Existing Industrial Structure.
2. Created geometry from obtained drawings.
3. Analyse its adequacy for seismic zone II condition.
4. Carryout non-linear analysis for different configuration resulting in decrease or increase in lateral stiffness.
5. Assess the adequacy of the different configurations for different seismic zones with the help of capacity spectrum and seismic co-efficient.
6. Redesign existing structure for different seismic zones. (increased member sizes)
7. Carryout non-linear analysis to assess their performance.

4. RESULTS AND DISCUSSION

Displacement

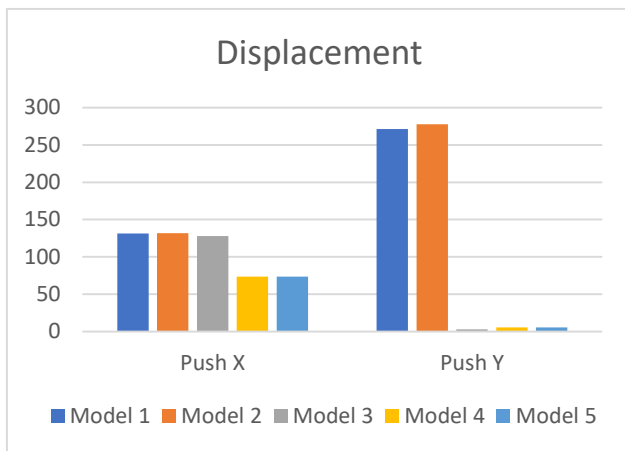


Chart -1: Displacement for different models

In model 03, displacement resulting from push x case is higher than model 4 and model 5, if we observe the difference between model 3 and 4 is bracings along the x-direction. The above results show a higher value in displacement than the codal value since it was not designed for nonlinear behaviour parameters. This clearly is visible in the case of pushy which is having a minimum displacement in all of the above cases.

Time Period

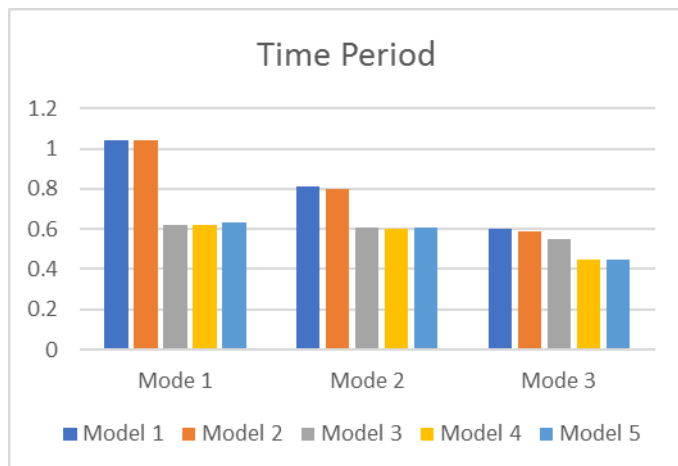


Chart -2: Time period for different models

The time period in chart-2 specified above is for the first three mode shape contribution. The maximum contribution of forces is believed to be attributed to the first mode shape. Model 03 is an existing structure with a time period of 0.62 seconds. The other two versions, denoted by the numbers before and after, are trials to make it stiffer and more flexible. Models 01 and 02 are more flexible because they have a longer time period, whereas models 4 and 5 are less versatile since they have a shorter time period.

Base Shear

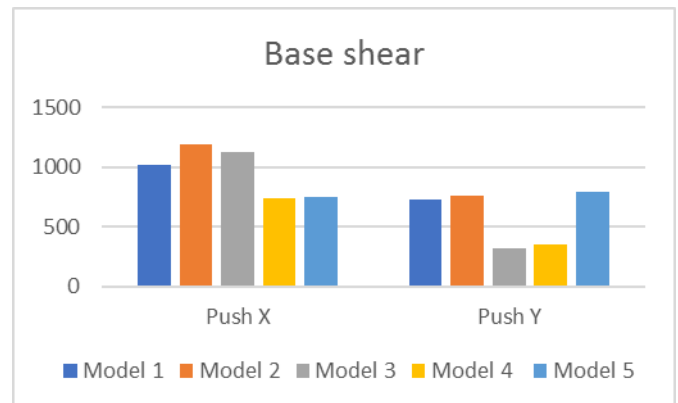


Chart -3: Base Shear for different models

As the stiffness of the model increases, the base shear in the frame parts decreases. Because stiffer structures draw higher forces, as described in previous subheads, this is correct, but because the members are redundant in number, there is load transfer in the connected members. If the overall members are considered, it is possible to demonstrate that rigid constructions have more forces than flexible structures.

Pushover Curve

Since a comparison of five models are to be made and it becomes difficult to represent each pushover curve. Thus, pushover curves of all the five cases in the x and y direction are shown as following:

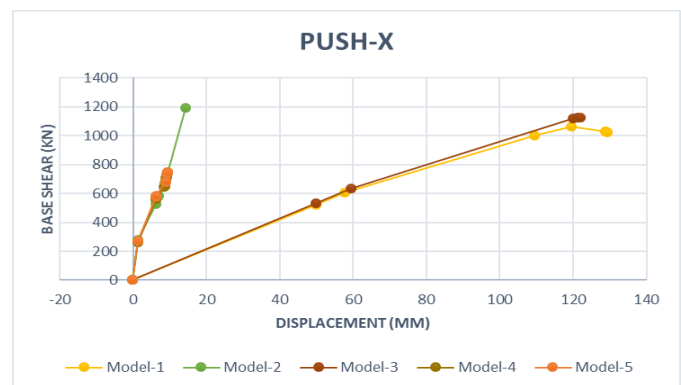


Chart -4: Pushover X curve for created models

Models 2, 4, and 5 have less displacement than the others. Models 4 and 5 are stiffer in comparison, however, model 2 is not stiff in comparison, but it does have bracings to withstand deformation. Models 1 and 3 have larger displacements because they have less stiffness to counter lateral forces in the direction of x-axis.

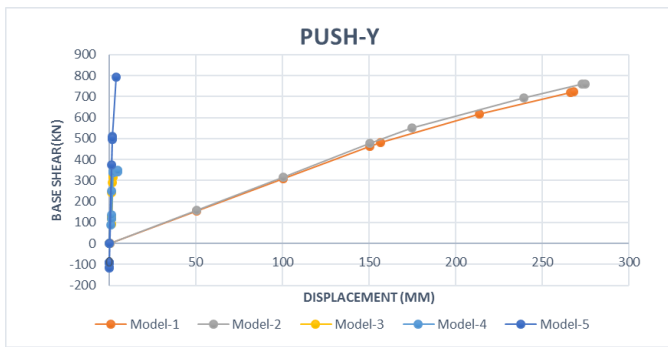


Chart -5: Pushover Y curve for crated models

Models 1 and 2 have identical pushover curves since their displacement values are the same. The maximum forces in all circumstances are roughly 700 KN. Bracings are missing in Models 1 and 2 to withstand force in the direction of y-axis. The maximum force of Model 3 and Model 4 are roughly 300KN. Model 5 has bracings for enhanced stiffness; hence force values are higher and displacement values are lower.

Performance Level

The predicted displacement of the peak inelastic control node during ground shaking is represented by a point on the pushover curve. In other words, the building is predicted to be pushed up to this level by a future earthquake. It is also known as target displacement.

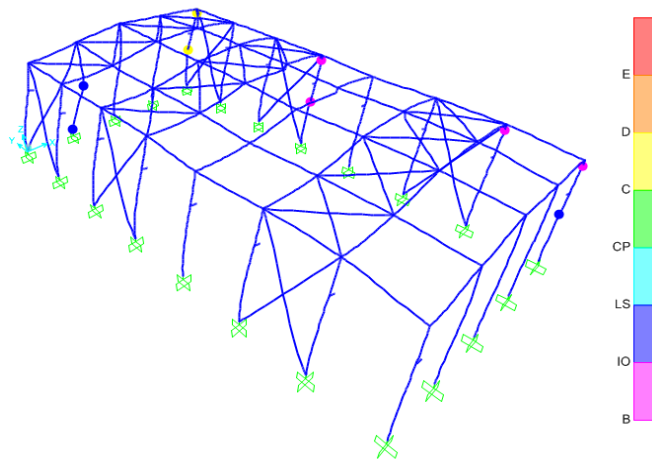


Fig 3: Model 03 showing number of hinge formation in the x-direction.

Fig 3 and Fig 4 shows hinge formation in the structure at the maximum step in both orthogonal direction, x and y for existing structure model named model 3. Similar representation of hinge formation of other models is shown in the table format given below as table 2 and table 3. Fig 3 and fig 4 shows the hinges with the performance level as IO, LS, CP and Collapse with color codes.

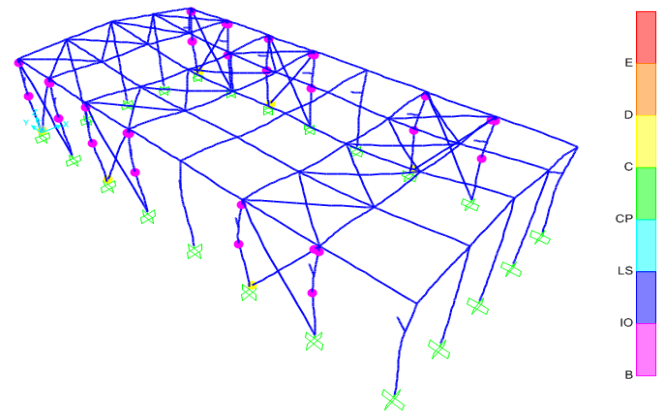


Fig 4: Model 03 showing number of hinge formation in the y-direction.

Table -2: Performance level of all configuration in X direction at maximum step

Sr. No.	Model No.	Dir.	Number of hinges at ultimate condition				
			B to IO	IO to LS	LS to CP	CP to C	C to D
1	1	PushX	5	3	0	0	3
2	2	PushX	6	5	0	0	8
3	3	PushX	4	3	0	0	2
4	4	PushX	15	1	0	0	7
5	5	PushX	9	1	0	0	6

The hinge formed in the examined models as the maximum step of the corresponding case is represented in the table 2 and 3 above. It is possible to detect that the number of hinges is higher in the latter versions due to their stiffness. The table clearly shows that the current geometry attracts fewer hinge failures. Model 3 necessitates rigidity for pushy loading consideration.

Table -3: Performance level of all configuration in Y direction at maximum step

Sr. No.	Model No.	Dir.	Number of hinges at ultimate condition				
			B to IO	IO to LS	LS to CP	CP to C	C to D
1	1	PushY	1	3	0	0	3
2	2	PushY	3	3	0	0	3
3	3	PushY	30	0	0	0	6
4	4	PushY	30	0	0	0	8
5	5	PushY	39	8	0	0	10

Capacity Demand Spectrum for all models

The equivalent damping and natural period rise as the non-linear deformation of the components increases. This ADRS is created automatically by SAP2000 in our current study utilizing FEMA and ATC criteria. The corresponding seismic coefficients C_a and C_v are given by, according to the provisions and commentary of Indian Seismic Code IS 1893 (Part-1).

$$C_a \text{ and } C_v = Z * I$$

As per above formula the seismic coefficient C_a and C_v according to Indian seismic zone II, III, IV and V becomes 0.1, 0.16, 0.24 and 0.36 respectively for an importance factor of 1.

The performance point is the intersection of the capacity and demand curves. The resultant capacity spectrum is displayed for all types of setups using the seismic coefficient computed above.

Table -4: Performance point values for different seismic zones (PushX case)

	Performance Point for PushX(mm)			
	Zone II	Zone III	Zone IV	Zone V
Model 01	12.9	20.722	31.15	46.793
Model 02	1.5	1.877	2.375	4.18

Model 03	13.204	21.211	31.888	47.904
Model 04	0.579	1.003	1.93	1.93
Model 05	0.574	0.996	1.907	4.361

Table -5: Performance point values for different seismic zones (PushY case)

	Performance Point for PushY(mm)			
	Zone II	Zone III	Zone IV	Zone V
Model 01	25.727	40.867	61.054	91.334
Model 02	25.781	40.953	61.182	91.57
Model 03	1.01	1.518	2.291	N.A.
Model 04	1.035	1.576	2.306	N.A.
Model 05	0.6	0.858	1.205	1.852

From the table 4 and 5, it is observed that in each case the capacity curve intersects the demand curve with a larger displacement compared to the lower seismic zone. Thus, the level of safety for structure is more in lower seismic zone. As a result, the margin of safety against collapse for the identical structure designed in a higher-intensity seismic zone will be relatively limited.

Model 03 and Model 04 doesn't withstand the seismic loadings in Y direction and are not recommended in higher seismic zones.

5. CONCLUSIONS

Following successful assessments of various combinations of existing structural models, nonlinear static analysis was done over a variety of different configurations and zones by causing the structure to deform laterally at a monotonic rate.

Following conclusions have been made:

- The hinges formed in the models are seen to be below the IO performance level. Under C to D performance levels, just a few hinges are created. For model 3, the optimal number of hinges are formed.
- The model gains lateral stiffness as the number of bracings increases, but displacement values decrease.
- The majority of the hinges stayed in the IO performance level after nonlinear analysis. Model 5 has a maximum of ten hinges with performance levels ranging from C to D.

- The existing structure (Model 3) can withstand zone 2 seismic loadings but is a little weak in the shorter direction. As a result, it is advised that the structure have nominal additional bracings that are not as heavy as those given in the old building.
- Model 01 and Model 02 are suitable for any seismic zone as the capacity and demand curve intersect at a relatively lower value on nonlinear capacity curve. Margin of safety is higher in both the directions for model 01 and model 02.
- Model 03 and Model 04 are capable to withstand the lateral force for all zones in X direction but fail to withstand the seismic force in zone 05 in Y direction and in zone 04 there is small margin of safety. So, model 03 and model 04 is recommended up to zone 03.
- Model 05 is not recommended for zone V because the performance point increases drastically compared to other cases and is capable to withstand up to seismic zone IV.

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