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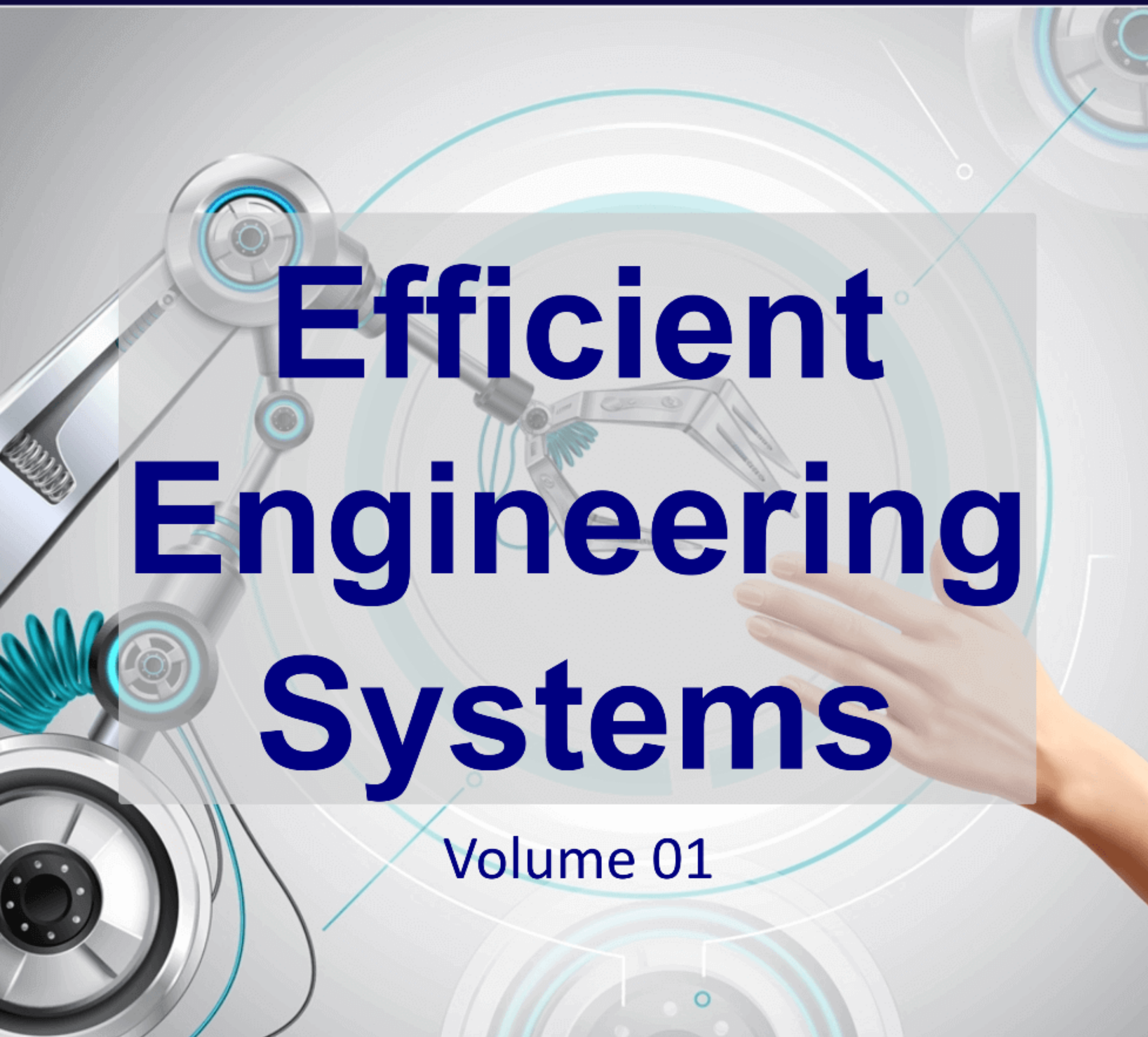

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Analysis of Strengthened Industrial Structure under Seismic Loading

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ABSTRACT

Industrial structures are used in power, petrochemical, agriculture and manufacturing sectors. The function of industrial structures is to encounter the extreme variations in loads that are likely to occur during manufacturing and finishing process of any industry such as temperature variation, variation in internal pressure and exposure to highly toxic and corrosive materials. Hence, it is important to have detailed information regarding the industrial processes and their effects, as this may guide to compute the loads in order to design a stable industrial structure. In the present work an existing industrial building subjected to different loading and having two strengthening methods: provision of secondary beams normal to the primary beams and providing knee bracings. The analysis has been performed using STAAD Pro V8i.Time history analysis is carried out for machine loading. For earthquake loading, both linear static and linear dynamic methods are used. The results indicate that the fundamental time period reduces with strengthening techniques and overall stiffness of the structure increases. The resonance frequency can be eliminated. Further, the provision of secondary beams normal to the primary beams gives better results.

Keywords: Bracings, Dynamic Loads, Industrial Structures, STAAD PRO, Steel Structures

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1. INTRODUCTION

Industrial structures are different from general buildings as depicted through their forms and functions. They are well suited for power, petrochemical, agriculture and other manufacturing sectors. These structures encounter the extreme variations in loads, that is likely to occur during various processes in any industry. The loads include those due to temperature variation, variation in internal pressure and exposure to highly toxic and corrosive materials in addition to external loads. Because of the dynamic nature of the loads, the design of industrial structure is complex and challenging. Therefore, it is important to have detailed information regarding the various specific industrial processes and their effects, as this may become guide in planning and structural framing operations as well as in computing the loads for the stable design. Further, it is important that the plan shall be flexible as the service conditions diverge usually in these structures and provision shall be available for future extension without altering the present manufacturing layout [1].

The flooring systems commonly used in any industrial structure are composite steel deck concrete floor and steel chequered plate floor. Chequered plate is rolled steel plate with non-slippery patterns. The thickness of the plate varies from 3mm to 12mm (approximately weighing 287 to 990 N/m^2). The patterns project approximately 1.5 mm above the plain plate. Fig.1 shows the typical chequered plate. Composite deck slab consists of reinforced concrete slab on top of steel sheeting and are connected by shear connectors. The deck slab is supported by secondary beams at the bottom forming the composite slab as illustrated in Fig. 2.

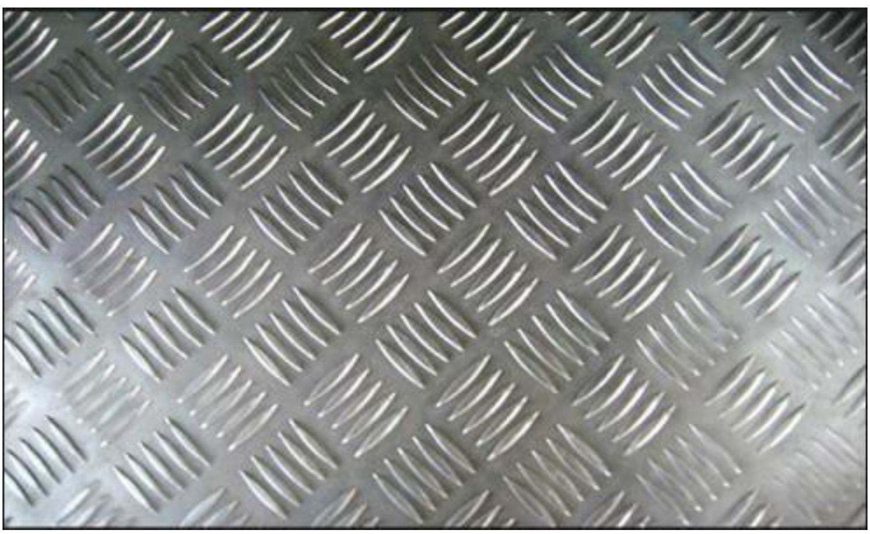


Fig. 1. Chequered plate

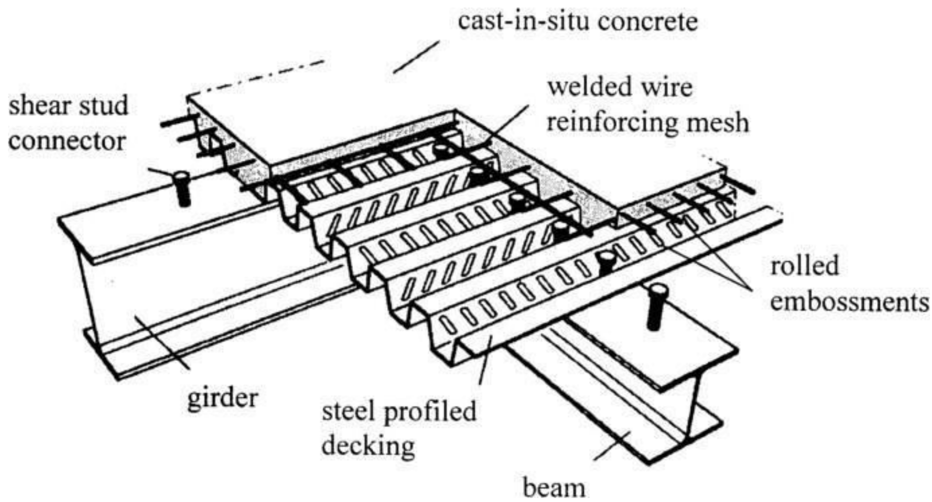


Fig. 2. Composite Deck Slab

In addition, an efficient bracing system provided in both transverse and longitudinal direction facilitate in preventing the deformations of the industrial structure caused due to the actions of wind, seismic loads and machine loads [2]. Iervolino *et al.* [3] presented natural procedure for seismic vulnerability assessment of industrial construction considering the large range of structural type. They related fragility curves with parameters in the design domain of structural design using regression method. Subramanian [4] has detailed several methods of analysis that accurately determine the forces and moments in various elements of steel structures along with behavior of the structure when bracings are provided in longitudinal and transverse direction.

Richard et al. [5] studied the seismic behavior of a heavy industrial building with highly irregular geometry, mass and stiffness distribution using STAAD Pro software. The building considered was braced with low ductility concentrically braced steel frames. They concluded that response spectrum analysis provides appropriate prediction of the seismic response of the industrial building. They further analysed seismic response of regular mill type crane supporting steel structures and irregular heavy industrial building using elastic time-history dynamic analyses and validated through equivalent static force procedure and the response spectrum analysis method [6].

Liberatore *et al.* [7] compared the damages observed at Emilia Region of Northern Italy during May 2012 earthquake with that of L'Aquila (central Italy), earthquake of 2009. The area affected by earthquake was higly densed with industrial buildings. They considered seven main types of damage related to: column base, short column failure, column top, shed beam, roof element, cladding/infill panel, and steel stand. The results of the analyses highlight the directionality of damage, the relevance of the vertical component of earthquake excitation, along with the significant inelastic rotation induced in the columns.

Hong Hao [8] presented the predictions of structural response under dynamic loads with different loading rates. He discussed the basic concepts of structural dynamics, differences in influence by low-rate dynamic and high-rate blast loadings the structures. The single-degree-of-freedom analysis is proved to ve more accurate in structural response analysis to blast loadings. Ramesh and Vinothkumar [9] used SAP to numerically analyze an industrial structure subjected to wind, earthquake and blast load. They reported that the provision of shear walls reduce the stress under dynamic loading. In addition to columns, the structure shall be modified with shear walls. Adin *et al.* [10] adopted X-bracing, eccentric bracing, diagonal bracing alongwith dampers in their analysis to find the most suitable lateral supporting system for an industrial building subjected to seismic loading. They found that the x bracing and damper with mass ratio 2% are suitable to improve the performance of the building under earthquake load and wind load.

Muhsina et al. [11] used STAAD Pro software to find out the ideal property of the machine foundation that can be placed at each story of an industrial building to safely resist the loads transmitted by machines. They employed response spectrum method for seismic analysis to analyze nuclear power plant (G+2) building. The machines were placed on different floor levels and the response of the machinery on each floor were obtained. Floor response spectrum is generated to study the overall response of the industrial building. Michael Angelides [12] presented the design consideration for industrial structures such as chimneys, bunkers, silos, cooling towers and ducts. He used Americal (ACI), German ((CICIND) and Belgium (CEN) code of practices for the study. Fabrizio [13] evaluated the intensity of non-structural damage in single-storeyed industrial steel buildings using different levels of cladding panels. Ravali and Poluraju [14] employed SAP 2000 and ETABS to carry out response spectrum analysis of 3D pre-engineered industrial structures. They used X-bracings and dampers as the lateral supporting system. They reported that X-bracings are more suitable than dampers as they are effective in reducing the seismic effect as well as economical, while dampers require regular maintenance.

Brunet et al. [15] performed nonlinear response history analyses to examine and compare the seismic response using seismic provisions of Canadian standards.

The suggested the modifications to mobilize higher brace inelastic response, mitigate storey drift concentrations, along with ensuring that the columns can safely resist the seismic induced axial and flexural demands.

The present study attempts to obtain the response of an existing industrial building substantiated with different strengthening methods that are used to withstand heavy loads. The analysis has been performed using STAAD Pro V8i.Time history analysis is carried out for machine loading. For earthquake loading, both linear static and linear dynamic methods are used.

2. STRUCTURAL MODELLING

The G+3 storey steel building is considered in the present analysis. The building consists of composite steel deck floor system on which different machine setups are resting. The column spacing is 5 m in both the directions. The plan, elevation and three dimensional views are shown in the Figs. 3 to 5. Table 1 furnishes details of the building.

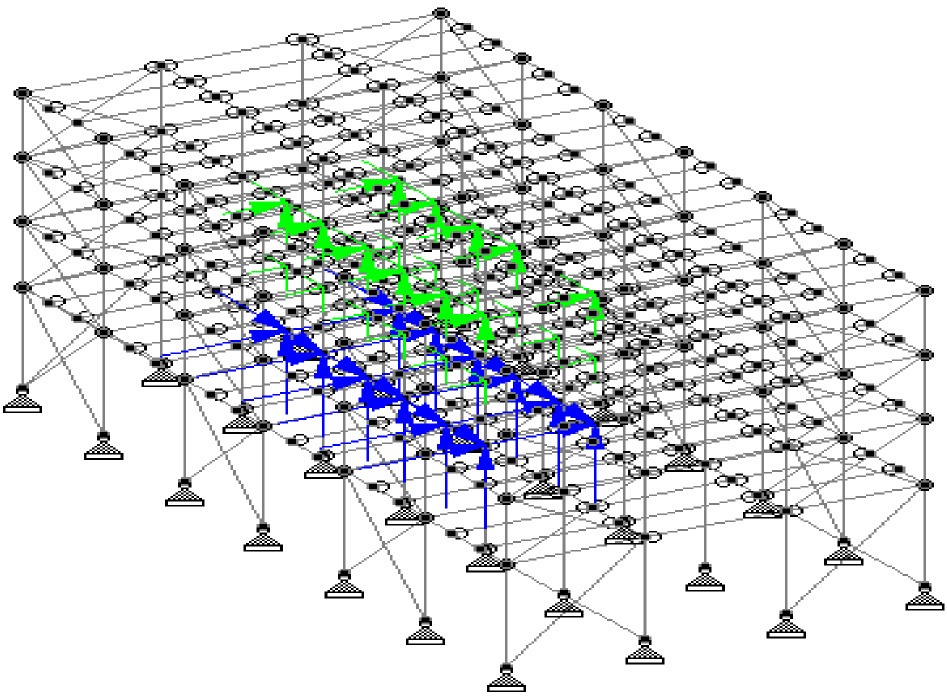


Fig. 3. Machine Loading Points

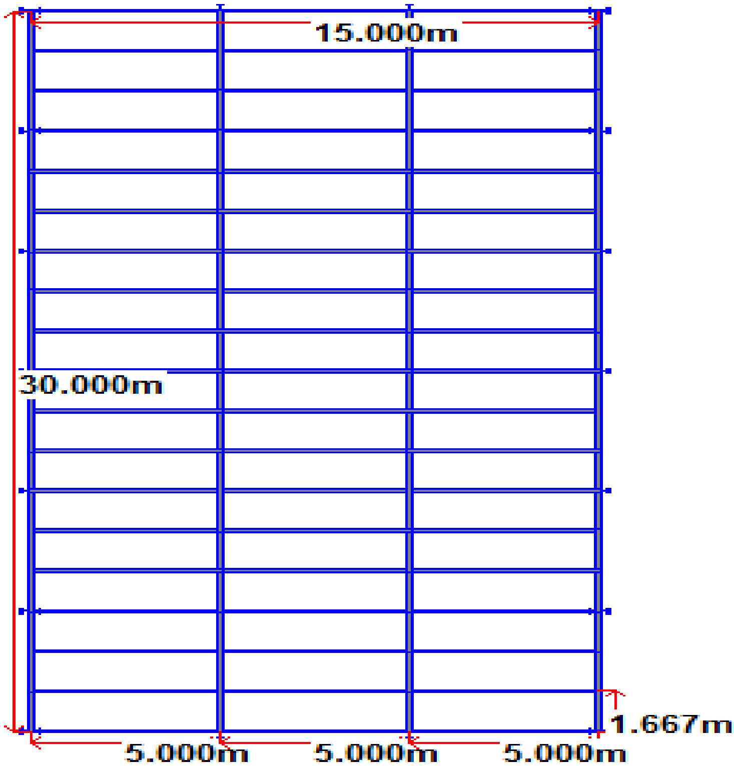


Fig. 4. Plan of the building

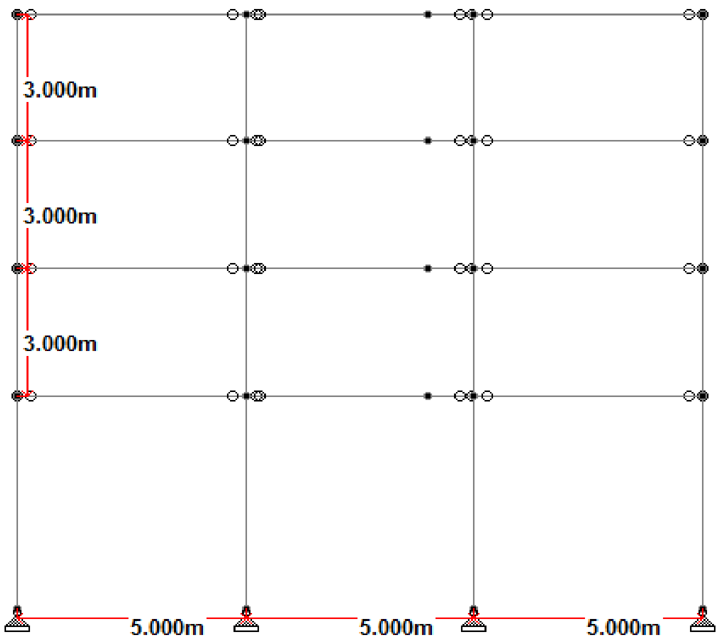


Fig. 5. Elevation of the Building

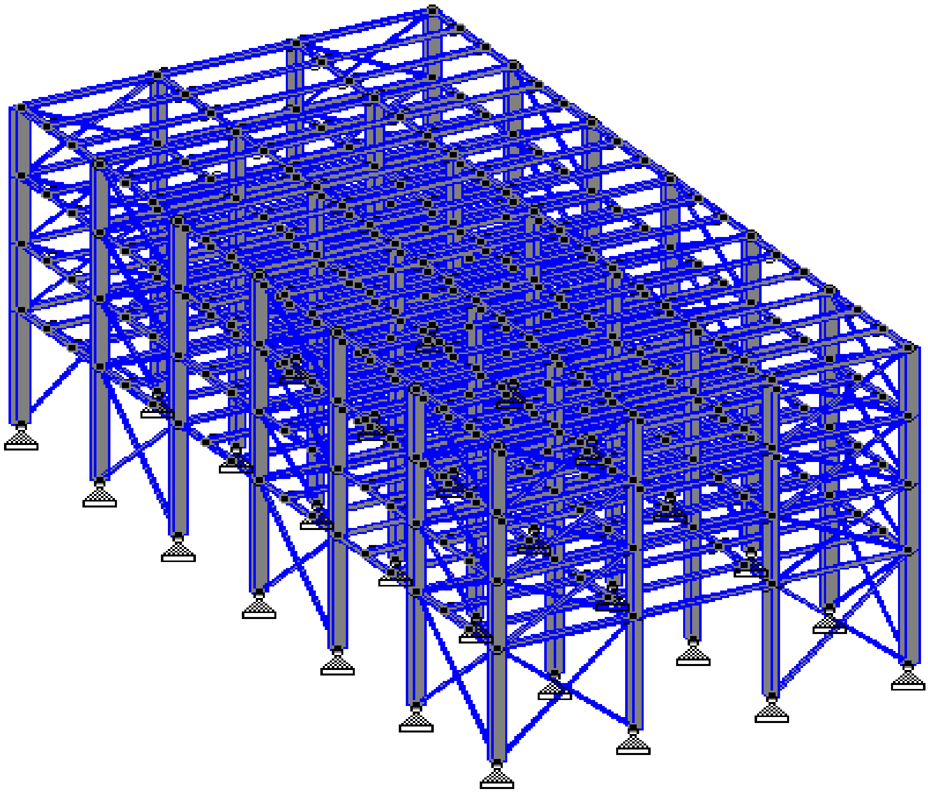


Fig. 6. Model 1 for Industrial Structure under Seismic Loading

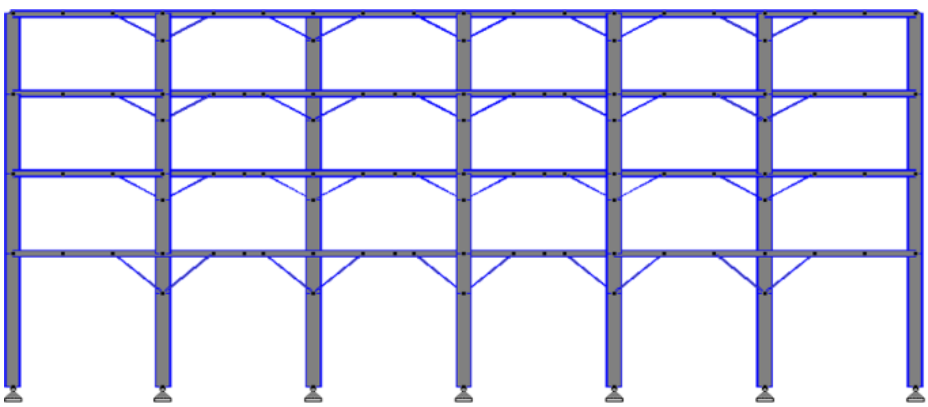


Fig. 7. Model 2 for Industrial Structure under Seismic Loading

Table 1. Building Data

Particulars	Details
Type of structure	Steel
No. of floors	G+3
Floor Height	3 m
Plan dimension	15m x 30m
Column	ISMB 500
Beam	ISMB 250
Bracings	ISA 75x75x6
Type of flooring system	Composite steel deck
Thickness of profiled steel sheeting	10 mm
Profile height	75 mm
Thickness of concrete slab	100 mm
Spacing of secondary beams	1.6 m

2.1. Machine Data

Table 2 gives the details of the machines considered for the present study.

Table 2. Loading details of Machine Type-1 (Forces at points of support in kgf)

Static		Dynamic		
	In operating condition		During start & end	
Vertical	Vertical	Horizontal	Vertical	Horizontal
F1 = 3500	F1=± 135	F1=± 112	F1= ± 3825	F1= ± 220
F2 = 3500	F2=± 135	F2=± 112	F2= ± 3825	F2= ± 220
Frequency = 29.84 Hz No of load cycles = 30				
Maximum allowable displacement = 0.08 mm				

2.2. Developed Model

The analysis is performed on an existing industrial building on which heavy machine setups are planned to be placed at different stories such as Ist, IInd and IIIrd floor. The machines that are going to be used in the industry are Rotating machines. On all floor levels three machines are operating with different loads and frequency. To resist these heavy loads, different types of strengthening methods are employed. To study the response of the building when different strengthening methods are used, 2 models were analysed and their behavior is observed. Model 1is with the secondary beams normal to the primary beams having the section of ISMC 100 while Model 2 is with provision of knee bracing of section ISA 50 × 50 × 6.

3. ANALYSIS AND RESULTS

The industrial structure taken up for the present work is subjected to varying combinations of static and dynamic loads. The results analyzed using STAAD Pro v8i are used to compare the response the structure when different strengthening techniques that are employed. The results obtained are presented in the following sub-sections.

3.1. Results of Model 1 – Provision of Secondary Beams Normal to Primary Beams

In this study, secondary beams having section of ISMC 100 are provided perpendicular to the primary beams to control the displacement and avoid the failure of certain columns and beams. The exterior columns are provided with bracings. Results for this model are as follows:

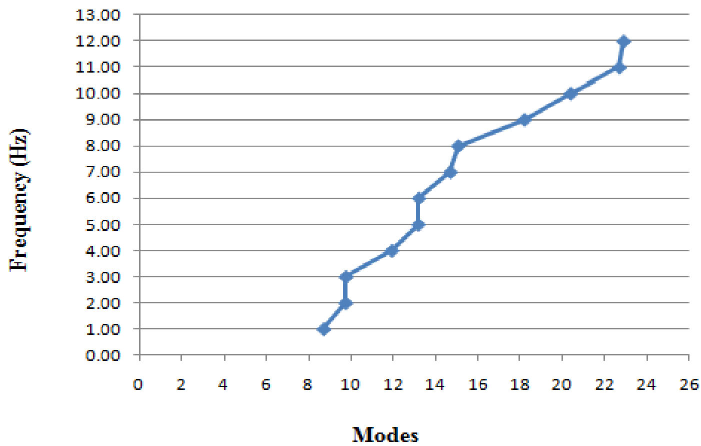


Fig. 8. Variation of frequency with modes

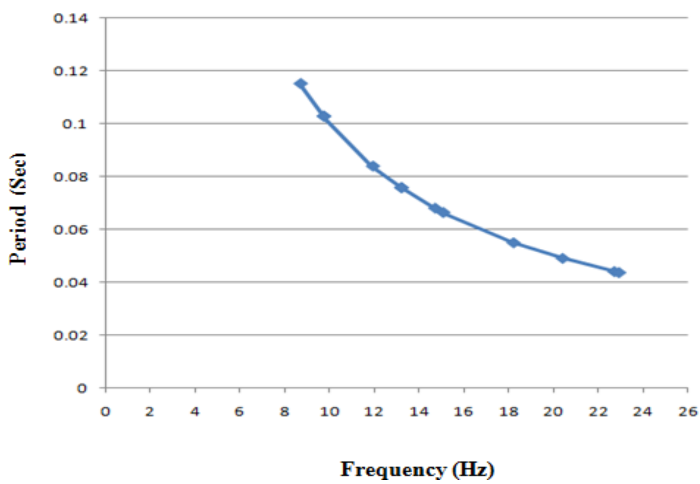
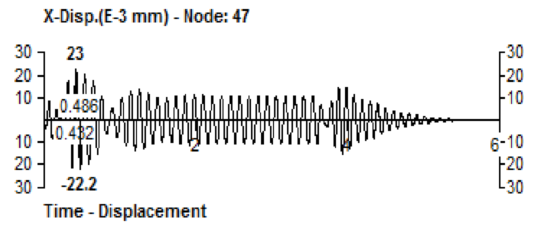


Fig. 9. Variation of frequency with Period

Figure 8 presents the increase trend in frequency with an increase in modes. However, the frequency-period variation is given in Figure 9. Further, Figures presented in Table 3 illustrate the displacements in x-, y-, and z-direction of stories I to III. The maximum value of storey displacement in z-direction occurs in floor III and is 3.376 mm. This maximum value is for the load case EQX (Earthquake in x-direction). The maximum values for joint displacements are 0.052 mm, 0.12 mm and 0.15 mm (in Z – direction) for first, second and third floor respectively. The permissible joint displacements are 0.008 mm, 0.2 mm and 0.2 mm for first, second and third floor respectively. The joint displacements are within the permissible limits. For third storey the value is 0.646 mm (in Z- direction). But the permissible limit is 0.2 mm. These results indicate that the building is resisting the applied loads efficiently and the displacements are within the limits.

Table 3. Displacements due to Model 1

<table>
<tr><th>Floor</th><th>Direction</th><th>Displacement plot</th></tr>
<tr><td rowspan="3">I</td><td>X-direction</td><td>
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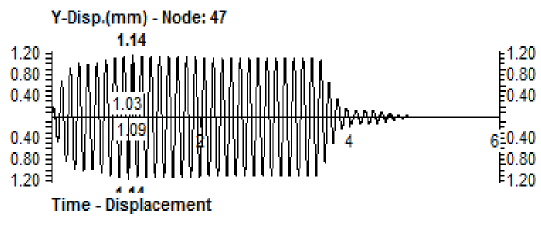
<tr><td>Y-direction</td><td>
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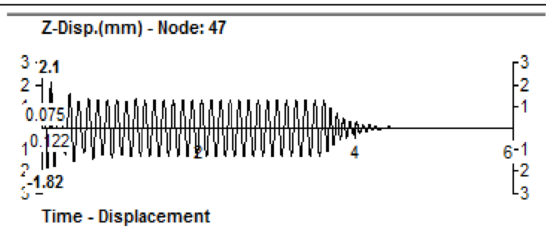
<tr><td>Z-direction</td><td>
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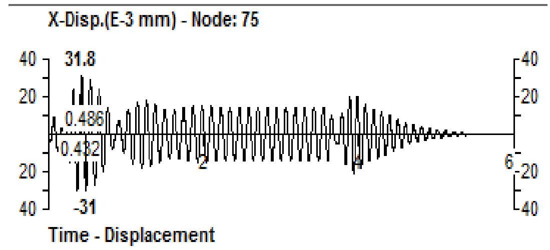
<tr><td rowspan="3">II</td><td>X-direction</td><td>
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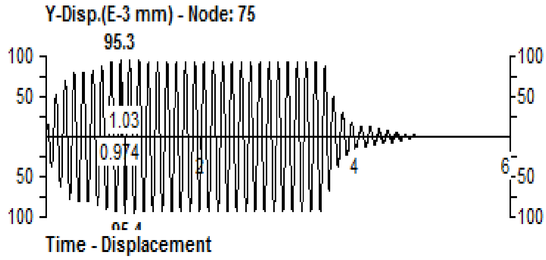
<tr><td>Y-direction</td><td>
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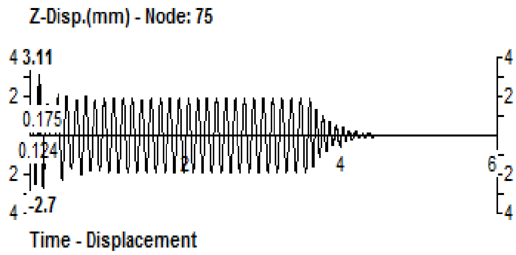
<tr><td>Z-direction</td><td>
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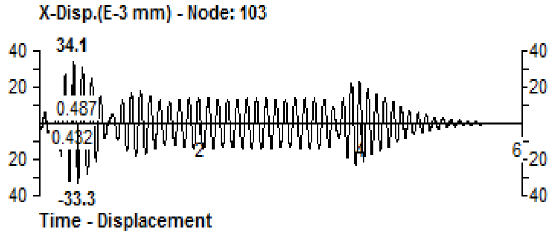
<tr><td rowspan="3">III</td><td>X-direction</td><td>
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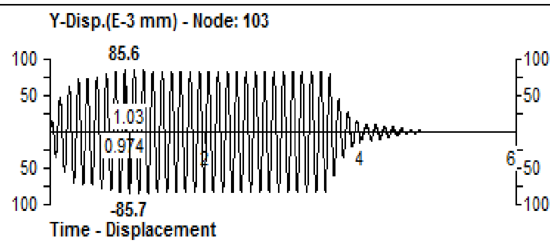
<tr><td>Y-direction</td><td>
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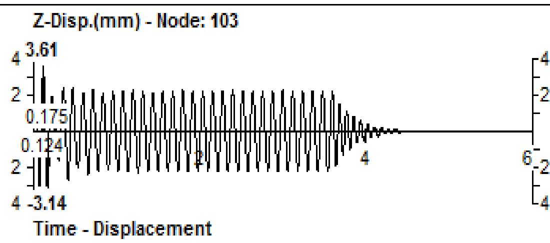
<tr><td>Z-direction</td><td>
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3.2. Results of Model 2 – Provision of Knee Bracing

In this model, knee bracings of section ISA 50x50x6 are used and the exterior columns are provided with bracings. Results for this model are as given below:

Figure 10 presents the increase trend in frequency with an increase in modes. However, the frequency-period variation is given in Figure 11. Further, Figures listed in Table 4 illustrate the displacements in x-, y-, and z-direction of stories I to III. The maximum value of story displacement is 3.67 mm. This maximum value is for the load case EQX. The maximum values for joint displacements are 0.092 mm, 0.218 mm and 0.295 mm (in Z – direction) for first, second and third floor respectively. The permissible joint displacements are 0.008 mm, 0.2 mm and 0.2 mm for first, second and third floor respectively. The joint displacements are slightly exceeding the permissible limits. From the analysis results, we can say that the building is resisting the applied loads efficiently and the displacements are also within the limits.

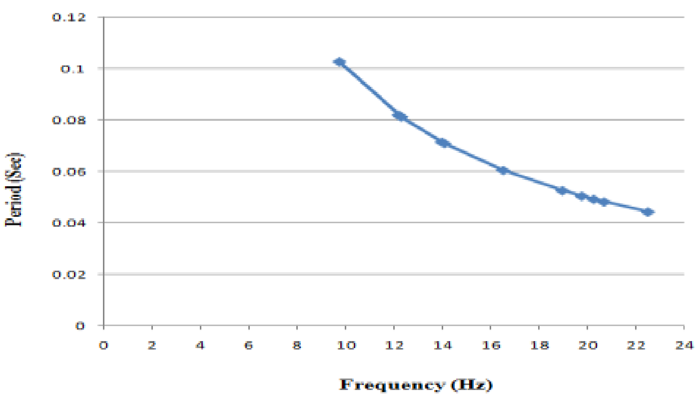


Fig. 10. Variation of frequency with modes

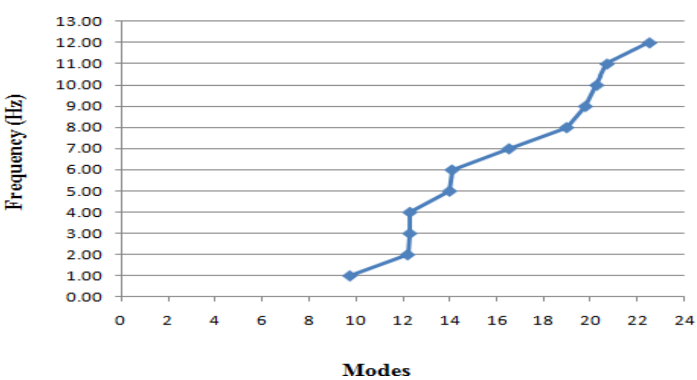
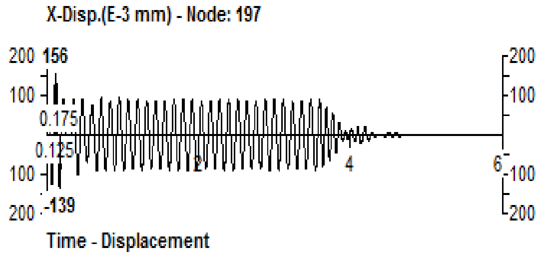
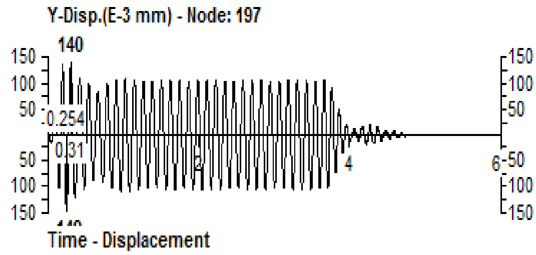
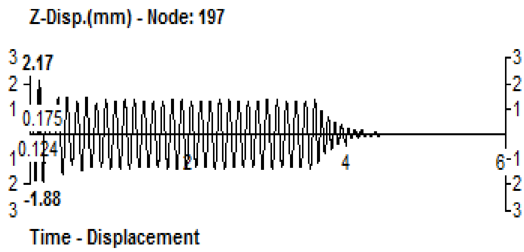
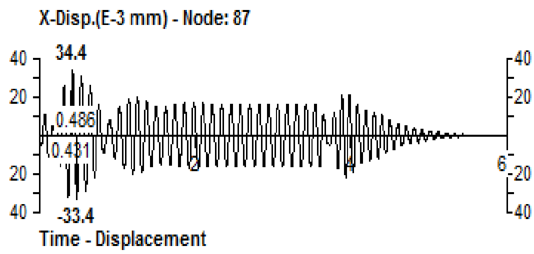
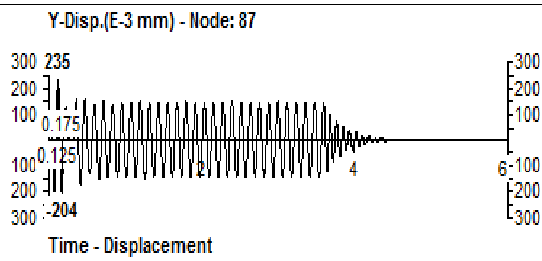
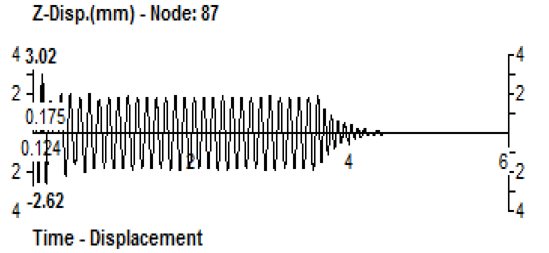
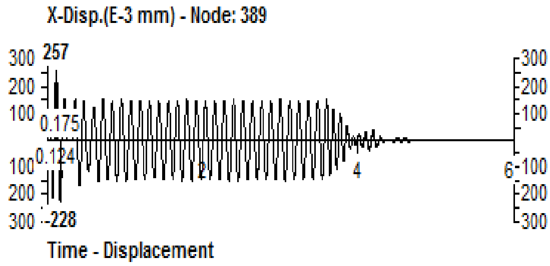
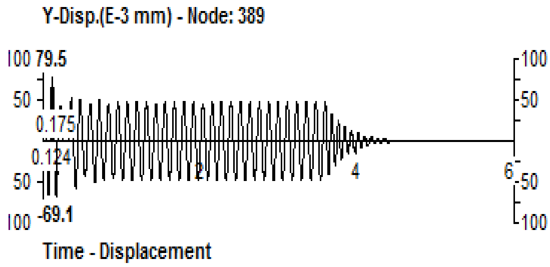
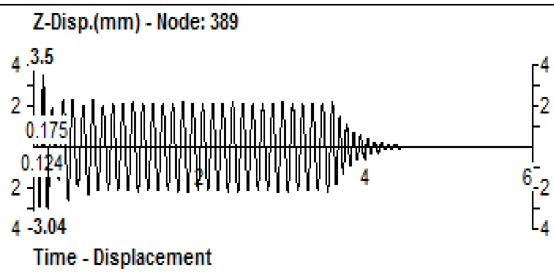


Fig. 11. Variation of frequency with Period

Table 4. Displacements due to Model 2

Floor	Direction	Displacement plot
I	X-direction	
	Y-direction	
	Z-direction	
II	X-direction	
	Y-direction	

	Z-direction	
III	X-direction	
	Y-direction	
	Z-direction	

4. CONCLUSION

In the present work, the study is done on an existing industrial structure with machines under dynamic loads. To resist the applied loads efficiently different strengthening methods are adopted and their behavior is studied. The results of the present study lead to the following conclusions:

1. Base shear and axial force which are the values of response parameters increases with strengthening methods.
2. The fundamental time period reduces with the adoption of strengthening techniques and the value is least by providing bracings to the exterior

columns and strengthening of existing columns by adding T section to the web of the column.

3. The overall stiffness of the building increases by providing strengthening methods and thus the natural period decreases.
4. Accept in case of bracings provided to the exterior columns the joint displacement values are reduced to permissible limits than the allowable joint displacement.
5. The occurrence of resonance is avoided as the natural frequency of the structure is away from the operating frequency of the machines by at least 20%.
6. Both the models with strengthening methods are resisting the applied loads such as gravity loads, machine loads and seismic loads effectively. The displacements obtained are also within the allowable limits (slightly higher for model-2). Model-1 is the most suitable strengthening option.

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