Seismic Performance Evaluation of Industrial Steel Structures Through Dynamic Analysis

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Abstract- *The study concludes that incorporating bracing systems and dampers significantly enhances the seismic performance of industrial steel structures by effectively reducing lateral displacement, vibration, and storey drift. Among the configurations analyzed, models with X-bracing combined with dampers having a mass ratio of 1.5% demonstrated superior performance under both earthquake and wind loading conditions. A comparative assessment between conventional steel frames, braced systems, and damper-integrated structures highlights the effectiveness of these lateral load-resisting strategies.*

This research involves a detailed parametric study based on nonlinear dynamic analysis of three-dimensional industrial steel structures using SAP2000 software. Various bracing configurations, particularly X-bracing systems, along with different damper mass ratios, are considered to evaluate their influence on structural response under seismic excitation.

Industrial steel structures often possess large member sizes, resulting in higher dead loads, which in turn increase their susceptibility to seismic effects. Despite the growing adoption of braced systems, comprehensive analytical studies addressing their effectiveness in controlling seismic response remain limited in India.

The primary objective of this work is to identify and propose efficient and practical lateral load-resisting systems (LLRSS) suitable for industrial buildings. These systems aim to improve structural safety and can be applied to both new constructions and existing structures.

Since buildings are subjected to lateral loads from earthquakes and wind in addition to gravity loads, inadequate design against such forces may lead to excessive stresses, structural sway, and potential collapse, posing risks to life and property. Therefore, it is essential to adopt appropriate structural technologies that ensure stability and resilience under lateral loading conditions.

Keywords: bracings, dampers,baseshear,SAP2000 software.

I. INTRODUCTION

Earthquakes are natural phenomena, which cause the ground to shake. The earth's interior is hot and in a molten state. As the lava comes to the surface, itcools and new land is formed. The lands so formed have to continuously keep drifting to allow new material to surface. According to the theory of plate tectonics, the entire surface of the earth can be considered to be like several plates, constantly on the move. These plates brush against each other orcollide at their boundaries giving rise to earthquakes. Therefore regions close to the plate boundary are highly seismic and regions further from the boundaries exhibit less seismicity. Earthquakes may also be caused by other actions such as underground explosions. The study of why and where earthquakes occur comes under geology. The main aim of all kinds of structural system in a building is to transfer the gravity load effectively and thus assure safety of the structure. Apart from these vertical loads, structure is also subjected to lateral loads which can develop high stress which will cause, sway of the structure. Buildings are usually subjected to different types of loads i.e. Lateral load due to wind and earthquake and vertical loads due to gravity (Dead + Live load on the structure).So the structure should be such that it should be strong enough which can resist all types of loads. When structures are subjected to lateral loads especially tall structures, these structures show large displacement and to reduce this displacement and drift moment resisting frames along with different types of lateral load resisting structural forms are available. Among them braces and shear walls is the most common lateral load resisting systems. In areas subjected to earthquakes, reinforced concrete structures having tall heights cannot bear large displacements. To resist the drifts and large displacements in buildings which may damage the buildings and cause loss of life, can be reduced to a large extent by using bracing systems. The present work focuses on finding the suitable bracing configuration that will adequately reduce the response of the structure to seismic excitation.

BRACING SYSTEM

Braced frame system in the structure consists of truss members as bracing elements. These bracings are commonly used in structures, subjected to lateral loads. They resist lateral forces mainly with the brace members in compression or tension. This makes the bracing system highly efficient in resisting the lateral loads. Also, another reason for the braced frame system to be efficient is, it makes the structure laterally stiff. With least addition of the material to the frame and it forms economical structure for any heights.

TYPESOFBRACINGS

Based on the types of braces employed in this study, bracing systems are classified depending on whether the braces are connected at column beam joint or away from column beam joint. Braces are grouped into various categories as follows

Based on the material used in braces:-

a) **RCC brace:** These are the braces which are made up of reinforced cement concrete. The Cross section of concrete brace is similar to RCC beam or column section. These types of braces are strong in compression but are rarely used because of their construction difficulties and also another disadvantage is, these braces cannot be replaced once damaged due to seismic loads and hence it becomes uneconomical.
b) **Steelbrace:** in Steel braces different types of steel sections can be used such as channel sections, angle sections, I sections etc or tubular section. These braces usually resist large tension force and fail in buckling. The main advantage of steel braces is it can be replaced after the damage hence making it economical.

Based on the way braces are connected to the frame:-

a) **Concentric:** In a concentrically braced frame bracing members are connected to beam or column junction. Different types of concentric braces can be further classified depending on their configuration. Examples for concentric braces are Vtype, Xtype, K type etc.
b) **Eccentric:** In an eccentrically braced frame bracing members are connected to separate points on the beam or column. The segment or link present between be am members help in absorbing energy from seismic activity through plastic deformation. Eccentric Bracings improve the lateral stiffness and increase the energy dissipation capacity. In eccentric connection of the braces to beams, the lateral stiffness of the frame depends upon the flexural stiffness.

Based on the bracesc on figuration:-

a) **V brace:** Bracing where a pair of braces joins at a single point on the beam span. Inverted V brace is that form of chevron bracing that terminates at point on beam from below.
b) **X brace:** Bracing where two diagonal braces crosses near mid-length of the bracing members.
c) **K brace:** Bracing where a pair of braces connected on one side of a column joins at a single point on another leg of column.

DAMPERS

Steel special moment resisting frames (SMRFs) are one of the preferred options for seismic design in regions of high seismicity. The1994 Northridge and 1995 Kobe earthquakes demonstrated that the standard assumptions and construction detail (complete penetration welding of beam flanges to column flanges and bolted/welded shear tab) exhibited sudden and brittle failure. To address this issue, extensive testing and evaluations were conducted and pre-qualified connections have been developed. Reduced beam section(RBS); see Figure 1, is a connection that is qualified for any size member. By reducing the beam flexural capacity, nonlinearity is concentrated in the reduced region and away from the potentially vulnerable beam-to-column connection. The combination of viscous damping devices (VDDs), and steel SMRFs presents an attractive design option. The result is a highly damped, low-frequency building that limits seismic demand on structural and nonstructural components.

VDDs are an ideal option due to their high damping because they are velocity dependent, and hence, do not significantly increase demand on foundations or columns. VDDs were originally developed for the defense and aerospace industries. They are activated by the transfer of incompressible silicone fluids between chambers at opposite ends of the unit through orifices, During seismic events, the devices become active and the seismic input energy is converted to heat and is thus dissipated. In the past several years, the authors applied the design methodology discussed here for a number of steel SMRF buildings

TYPESOFDAMPERS

Dampers are classified based on their performance of friction, metal (flowing), viscous, visco elastic; shape memory alloys (SMA) and mass dampers. Among the advantages of using dampers we can infer to high energy absorbance, easy to install and replace them as well as coordination to other structure members. (journal,2006)**.**

Friction Dampers

In this type of damper, seismic energy is spent in overcoming friction in the contact surfaces. Among other features of these dampers can be classified as avoiding fatigue in served loads (due to the non-active dampers under load) and their performance independent to loading velocity and ambient temperature. These dampers are installed in parallel to bracing (journal, 2006)**.**

PVD Damper

It is another type of friction damper and due to ease to installation is one of the most widely used dampers in structures (Warn, 2004). PVD damper can be used to create necessary damping for flexible structures, such as bending steel frame or to provide effective damping to relative stiffness of structures (Naeim, 1995). PVD damper is designed to installation where displacement can generate necessary damping such as installation of metal skeleton brace or concrete moment frame.

- PVD damper acts ef fectively on low displacements. For example, one 1MN PVD damper can acts effectively for 0.5 mm to 5 mm displacement.
- PVD damper requires no maintenance and does not have any lubrication or winder components.
- PVD damper behavior is like the behavior of a metal damper.

Pall Friction Damper

Another type of friction damper is Pall friction damper. This damper includes a bracing and some steel plate with friction screws. And they should be installed in the middle of bracing. Steel sheets are connected to each other by high strength bolts and they have a slip by a certain force, to each other.

Lead Injection Damper(LED)

This damper is made of a two-chamber cylinder, piston and lead inside piston. And by piston moving during earthquake, lead moves from larger chamber to smaller chamber. And with plastic deformation, the kinetic energy is wasted as heat. The longitudinal section of lead damper injection is shown (Saiidi et al., 1999).

This type of dampers is connected to the structure in three ways:

- damper installation in the floor or foundation (in the method of seismic isolation)
- connecting dampers in stern pericardial braces
- Damper installation in diagonal braces.

PRINCIPLESOFDAMPING

Damping on a general basis means to stop the vibrations. In structural engineering, damping can be defined as the inherent property of the structure to oppose movement. The higher the damping of the structure, the quicker it will return to its original position from displacement. Damping, β also changes the period of response of the un damped structure T, to damped period Td.

$$Td=T/(1-\beta 2)^{0.5}$$

Where,$\beta=Wd/(4\pi Ws)$
Wd=cyclic energy dissipated.
Ws= is the strain energy.

NEED FOR PRESENTSTUDY

At present, the bracing system, and dampers systems are considered as important element in lateral load resisting system. There have been numerous researches done on this field of study to determine the optimum bracing systems and dampers under seismic loading. But the current research involves scale of loading and structural behavior unlike previous researches. The dampers and bracings are incorporated into a high steel building on both its north and south faces as well as on the truss and the bracing are subjected to dynamic analysis as well as wind analysis. The method of non linear dynamic analysis method to analyze the truss and the building. The scope of this project is also the detail of loading and behavior to obtain a better idea of the bracing system and damper system.

OBJECTIVE OF THE STUDY:

- To study the seismic performance of steel turbine building using IS 1893(Part1)-2002.
- To develop the structure with x typeof bracing system.
- To analyze the structure under static and dynamic loading.
- To compare the response of the structure under dynamic loading with dampers and bracing system.

SCOPE OF THE STUDY:

The present study on bracing systems is limited to high rise multi-storied buildings.

- Usage of fully steel super structure and concrete foundation to develop the structural behavior to act on the bracing systems.
- Various loading cases including equipment loads and other important conditions used for the static as well as dynamic analysis.
- Nodal displacement at the same node for all the models considered for comparison which determines the response of the bracings.

II. LITERATUREREVIEW

Alireza Heysami et al., (2014) The investigates types of dampers and their performance during earthquake. Also, they have investigated the tall buildings in the world and satisfactory level of damper performance has been studied. And the results show that no only dampers have an acceptable seismic behavior against lateral forces such as wind and earthquake forces. In seismic structures upgrading, one of the lateral force reduction caused by the earthquake is use of dampers. During an earthquake, high energy is applied to the structure. This energy is applied in two types of kinetic and potential (strain) to structure and it is absorbed or amortized. If structure is free of damping, its vibration will be continuously, but due to the material damping, vibration is reduced. Damping increasing reduces structural response (acceleration and displacement) damping effect at low frequency (close to zero) have no effect on spectrum amount a(acceleration and displacement) damping effect at low frequency (close to zero) have no nd at high frequency, it has low effect on response acceleration. Dampers are classified based on their performance of friction, metal (flowing), viscous, viscoelastic; shape memory alloys (SMA) and mass dampers. Among the advantages of using dampers we can infer to high energy absorbance, easy to install and replace them as well as coordination to other structure members.

III. METHODOLOGY

CONSTRUCTION OF STEEL STRUCTURE

Model Type

Model 1- Frame with X-braced dampers Model2–FramewithoutX-bracedbracings

Structural Members

Beam details	I section (Meters)
Out side height (t3)	0.3
Top flange (t2)	0.12
Top flange thickness (tf)	0.03
Web thickness (tw)	0.03
Bottom flange width (t2b)	0.12
Bottom flange thickness (tfb)	0.03

Steel frame	Meters
Depth t3	0.1
Width	0.3

Material properties

Grade of Steel	Fe500
Young's modulus of steel	20000 Mpa
Poisons ratio	0.3
Density of steel	76.98 Kn/m^3
Bearing capacity of soil	200 Kn/m^2

Details of Building

Utility of Building	Industrial building
No of Bays	11X11 bays
Bay width along X-direction	3 mts
Bay width along Y-direction	3 mts
Wind speed (m/s)	44 m/s (Hyderabad)
Terrain category	2 (Hyderabad)
Wind coefficient	0.8 (wind wards- varies)
Seismic Zone	5 (high)
Soil type	Medium(Type 2)
Response reduction factor	5
Importance factor	1.0
Damping of Structures	5%
Bracings	X type Bracings

SpecificationofDamperUsed

Damper	X-braced friction damper(Non Linear)
Type	Pall friction damper
Position	Outside the column
Thickness	200 mm
Damping co-efficient	0.5
Stiffness	200

MODELING

Studied the architectural Planed Aligned the structural elements to suit from the structural engineering point of view .Modeled the structure using SAP 2000 with three different types of bracing systems

MODELSINSAP2000

Industrial steel structure by Bracings

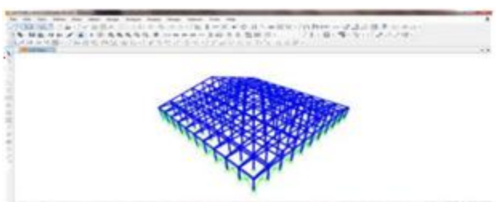


Figure: Industrial steel structure by Bracings Industrial steel structure by using Dampers

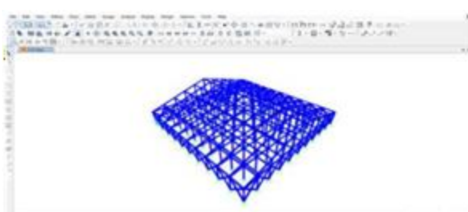


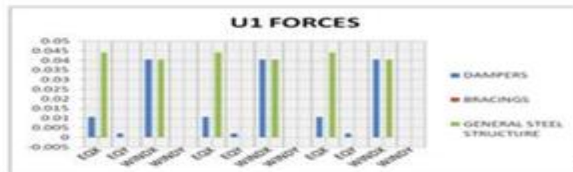
Figure: **Industrial steel structure by using Dampers**

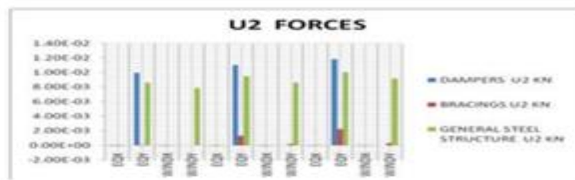
IV. RESULTS AND ANALYSIS

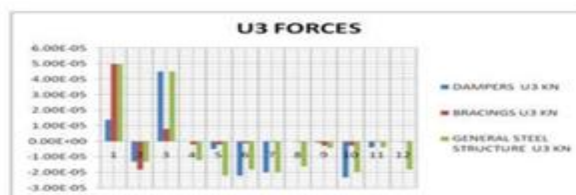
COMPARASION OF DAMPERS & BRACINGS AND GENERAL STEEL STRUCTURES

JOINT DISPLACEMENTS UNIVERSAL FORCES

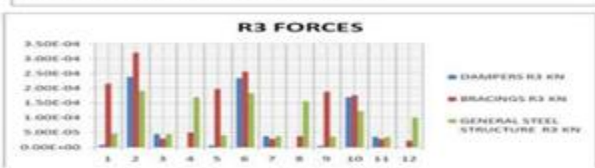
			U1 KN			U2 KN			U3 KN		
Joint text	Output case	Case type text	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURE	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURE	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURE
12	EQX	LinStatic	0.010592	0.000202	0.044168	-7.90E-05	-7.30E-05	-2.60E-05	1.40E-05	5.00E-05	5.00E-05
12	EQY	LinStatic	0.002089	-4.40E-05	-7.20E-05	0.009979	8.70E-05	0.008629	-1.30E-05	-1.80E-05	-1.30E-05
12	WINDX	LinStatic	0.040507	3.30E-05	0.040507	-2.40E-05	-1.40E-05	-2.40E-05	4.50E-05	8.20E-06	4.50E-05
12	WINDY	LinStatic	0	-3.64E-06	-6.10E-05	0	1.40E-05	0.007898	0	-1.98E-06	-1.20E-05
13	EQX	LinStatic	0.010575	0.000154	0.044111	-7.30E-05	5.57E-06	4.66E-06	-4.86E-06	-1.87E-06	-2.20E-05
13	EQY	LinStatic	0.002098	-3.40E-05	-6.30E-05	0.011037	0.001346	0.009477	-2.20E-05	-1.08E-06	-1.80E-05
13	WINDX	LinStatic	0.040456	2.50E-05	0.040456	4.31E-06	-2.20E-05	4.31E-06	-2.00E-05	-2.24E-07	-2.00E-05
13	WINDY	LinStatic	0	-3.17E-06	-5.30E-05	0	0.000204	0.008639	0	-2.73E-07	-1.60E-05
14	EQX	LinStatic	0.010563	0.000124	0.044073	-7.40E-05	-1.20E-05	5.74E-06	-7.66E-07	-2.61E-06	-4.10E-06
14	EQY	LinStatic	0.002113	-2.40E-05	-5.00E-05	0.011865	0.002263	0.010098	-2.30E-05	-2.68E-06	-2.00E-05
14	WINDX	LinStatic	0.040423	2.00E-05	0.040423	5.30E-06	-3.90E-05	5.30E-06	-3.70E-06	-2.67E-07	-3.70E-06
14	WINDY	LinStatic	0	-2.20E-06	-4.20E-05	0	0.000321	0.009153	0	-4.03E-07	-1.80E-05





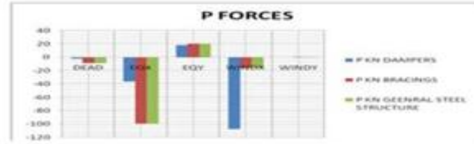


			R1 KN			R2 KN			R3 KN		
Joint text	Output case	Case type text	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURE	DAMPERS	BRACINGS	GENERAL STEEL BRACINGS	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURE
12	EQX	LinStatic	4.50E-05	9.50E-05	2.30E-05	0.00106	5.40E-05	0.004301	7.33E-06	0.000216	4.70E-05
12	EQY	LinStatic	-0.00301	-0.000104	-0.002607	0.000215	1.50E-05	-2.58E-06	0.000238	0.000321	0.000152
12	WINDX	LinStatic	2.20E-05	2.80E-05	2.20E-05	0.003935	8.67E-06	0.003935	4.40E-05	2.80E-05	4.40E-05
12	WINDY	LinStatic	0	-1.60E-05	-0.002378	0	2.00E-05	-2.03E-06	0	5.00E-05	0.000169
13	EQX	LinStatic	4.10E-05	6.10E-05	5.44E-06	0.000463	5.50E-05	0.001845	5.88E-06	0.000198	4.00E-05
13	EQY	LinStatic	-0.00295	-0.000467	-0.00253	8.20E-05	-3.03E-06	-9.10E-06	0.000235	0.000256	0.000183
13	WINDX	LinStatic	4.97E-06	3.40E-05	4.97E-06	0.001684	8.76E-06	0.001684	3.70E-05	2.70E-05	3.70E-05
13	WINDY	LinStatic	0	-6.70E-05	-0.002292	0	6.85E-06	-7.48E-06	0	3.70E-05	0.000156
14	EQX	LinStatic	3.90E-05	1.60E-05	-3.97E-06	0.000602	3.70E-05	0.002434	5.04E-06	0.000188	3.60E-05
14	EQY	LinStatic	-0.00348	-0.000767	-0.002931	0.000115	3.90E-06	-6.41E-06	0.000169	0.000176	0.000123
14	WINDX	LinStatic	-3.76E-06	2.90E-05	-3.76E-06	0.002226	5.92E-06	0.002226	3.40E-05	2.70E-05	3.40E-05
14	WINDY	LinStatic	0	-0.000101	-0.002631	0	9.35E-06	-5.29E-06	0	2.10E-05	9.90E-05



ELEMENTFORCES

			P KN			V2 KN			V3 KN		
station	output case	case type text	DAMPERS	BRACINGS	GEENRAL STEEL STRUCTURE	DAMPERS	BRACINGS	GEENRAL STEEL STRUCTURE	DAMPERS	BRACINGS	GEENRAL STEEL STRUCTURE
2.5	DEAD	LinStatic	-2.111	-8.533	-8.533	7.107	5.357	7.107	0.001115	0.948	0.001115
2.5	EQX	LinStatic	-35.924	-99.004	-99.004	5.144	0.253	20.764	0.286	10.774	1.998
2.5	EQY	LinStatic	18.128	20.81	20.81	0.992	0.079	-0.051	-4.629	-7.805	-3.375
2.5	WINDX	LinStatic	-107.117	-15.547	-15.547	18.985	0.04	18.985	1.877	1.826	1.877
2.5	WINDY	LinStatic	0	0.956	0.956	0	0.096	-0.043	0	-1.18	-2.73



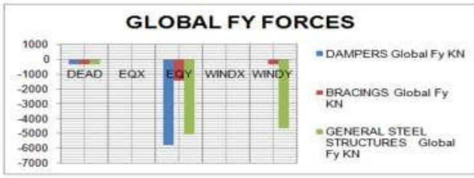
Frame text	station	output case	case type text	DAMPERS	BRACINGS	GEENRAL STEEL STRUCTURE
				M2 KN-m	M2 KN-m	M2 KN-m
1	2.5	DEAD	LinStatic	0.1368	-0.6443	0.1368
1	2.5	EQX	LinStatic	-0.2641	-10.4981	-1.8882
1	2.5	EQY	LinStatic	6.6833	8.8004	5.5256
1	2.5	WINDX	LinStatic	-1.7746	-1.8113	-1.7746
1	2.5	WINDY	LinStatic	0	1.3766	4.9312

Frame text	station	output case	case type text	DAMPERS	BRACINGS	GEENRAL STEEL STRUCTURE
				M3 KN-m	M3 KN-m	M3 KN-m
1	2.5	DEAD	LinStatic	-2.0759	-0.9598	-2.0759
1	2.5	EQX	LinStatic	-4.1241	-0.2553	-16.5682
1	2.5	EQY	LinStatic	-0.7648	-0.0481	0.0625
1	2.5	WINDX	LinStatic	-15.1414	-0.0404	-15.1414
1	2.5	WINDY	LinStatic	0	-0.0732	0.0523

BASEREACTIONS

Out put text	Case type text	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURES
		Global Fx KN	Global Fx KN	Global Fx KN
DEAD	LinStatic	-341	-341	-341
EQX	LinStatic	-1196.204	-1478.722	-5066.372
EQY	LinStatic	-341	3.71E-13	-1.44E-13
WINDX	LinStatic	-4694.097	-341	-4694.097
WINDY	LinStatic	0	3.73E-13	-1.76E-13

Out put text	Case type text	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURES
		Global Fy KN	Global Fy KN	Global Fy KN
DEAD	LinStatic	-341	-341	-341
EQX	LinStatic	4.12E-12	4.05E-12	-6.80E-13
EQY	LinStatic	-5791.996	-1478.722	-5066.372
WINDX	LinStatic	-5.66E-13	4.08E-12	-5.66E-13
WINDY	LinStatic	0	-341	-4694.097



Out put text	Case type text	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURES
		Global Fz	Global Fz	Global Fz
DEAD	LinStatic	9058.222	9500.703	9058.222
EQX	LinStatic	8.40E-12	3.23E-12	6.77E-11
EQY	LinStatic	6.18E-13	1.24E-14	2.81E-13
WINDX	LinStatic	1.12E-11	-7.55E-14	1.12E-11
WINDY	LinStatic	0	2.09E-14	-3.23E-13

Out put text	Case type text	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURES
		Global Mx	Global Mx	Global Mx
DEAD	LinStatic	- 135059.331	-141696.539	-135059.331
EQX	LinStatic	-341	-341	-1.50E-09
EQY	LinStatic	27907.5714	8247.8238	23693.1041
WINDX	LinStatic	-3.27E-10	-341	-3.27E-10
WINDY	LinStatic	0	1155	21355.5122

Out put text	Case type text	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURES
		Global My	Global My	Global My
DEAD	LinStatic	- 137369.331	-144006.539	-137369.331
EQX	LinStatic	-6524.322	-8247.8238	-23693.1041
EQY	LinStatic	-1155	-341	-1.48E-12
WINDX	LinStatic	- 21355.5122	-1155	-21355.5122
WINDY	LinStatic	0	-341	3.52E-12

Out put text	Case type text	DAMPERS	BRACINGS	GENERAL STEEL STRUCTURES
		Global Mz	Global Mz	Global Mz
DEAD	LinStatic	-10571	-10571	-10571
EQX	LinStatic	- 17943.0652	-22180.8364	-75995.5829
EQY	LinStatic	- 91994.9474	-22180.8364	-75995.5829
WINDX	LinStatic	- 70411.4598	-5115	-70411.4598
WINDY	LinStatic	0	-5115	-70411.4598

V. CONCLUSIONS

The thesis attempts to study the effect of bracings and dampers under earthquake and wind loads for industrial steel structures. This study has been mainly carried out to determine the change in various dynamic parameters due to consideration different bracings, dampers with different mass ratio and height by breadth ratios. On the basis of results obtained, some of the important conclusions are presented here. Modals with bracings are more effective in reducing structural parameters than dampers. Modals with damper are most effective in reducing systematic parameters than bracings. The usefulness of dampers is observed when the mass ratio of damper is 2%. In bracings x bracing is found out to be more economical.

The assembled joint masses has constant values for both Bracings and Dampers the maximum value is observed for Bracing system than Dampers. Joint reaction values are maximum for force F3 in case of Bracings and is maximum for moment M1 in case of Dampers universal force U2 in case of Bracings and is maximum for moment M1 in case of Dampers.

- Base reactions is maximum for dead load of structure in all cases
- The value of time decreases and the value of frequency increases in all the cases.
- the element forces for universal forces (U1, U2, U3) and reactions (R1, R2,R3) has less values for the Bracings system than other cases
- Base reactions are also has less values for Bracings than the Dampers.
- Effective stress ratio decreases with the increase in stiffness of building. From the study it has

been found that Dampers are more economical than bracing.

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