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SEISMIC RESPONSE OF RC STRUCTURES USING DIFFERENT TYPES OF DAMPERS

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ABSTRACT

In present analysis, high rise RC frame building of G+ 12 storeys of 39m height is analyzed with and without dampers for different zones and for different dampers. During analysis the Bending Moments, Shear forces, Displacement, and Time periods were found and were compared for various cases. Buildings are modeled and analyzed using standard package ETABS 2016.

I. INTRODUCTION

Earthquake is a disturbance that causes shaking of earth surface due to the movement at underground along fault plane or from volcanic activity. Even though the earthquake lasts for a small duration of time, it causes significant loss of life and damage to property every year. In order to reduce the effect, buildings/structures like public life-line buildings, residential buildings, historical buildings, industrial buildings should be designed to seismic force.

The aim of analysis of earthquake resistant building is that the buildings should be able to resist minor earthquakes without any damage. There are many ways to achieve this. One of it is by providing dampers. Damper is a mechanical system which dissipate earthquake energy into specialized devices which deforms or yield during earthquakes. They enhance energy dissipation in a structure to which they are installed so that the structure has to resist lesser amount of earthquake forces. When the seismic energy is transmitted through them, dampers absorb a part of it and thus damp the motion of building.

The building under consideration in this study is a G+12 storey RCC special moment resistant frame. The schematics of building plan and elevation are shown in figure. The plan is in rectangular shape and measures 16x32 m^2. The total height of the building is 39 m. All storey heights are 3m. Building is modeled without infill walls. The base is fixed to restrain in all 6 DOFs. To control the seismic response and increase the stiffness, dampers like fluid viscous dampers, viscoelastic dampers, pall friction dampers are provided. Dampers are provided at corners throughout the building. ETABS 2016 has been used to carry out this study.

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II. MODELING OF BUILDING

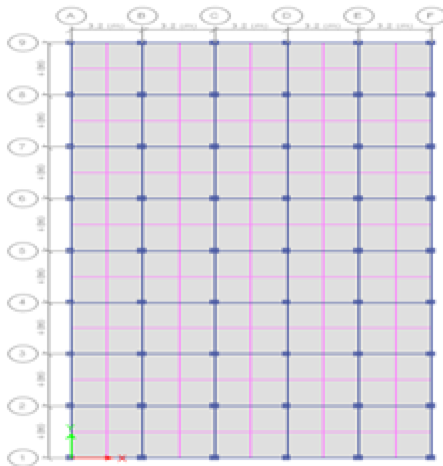

Fig 1: Plan of building

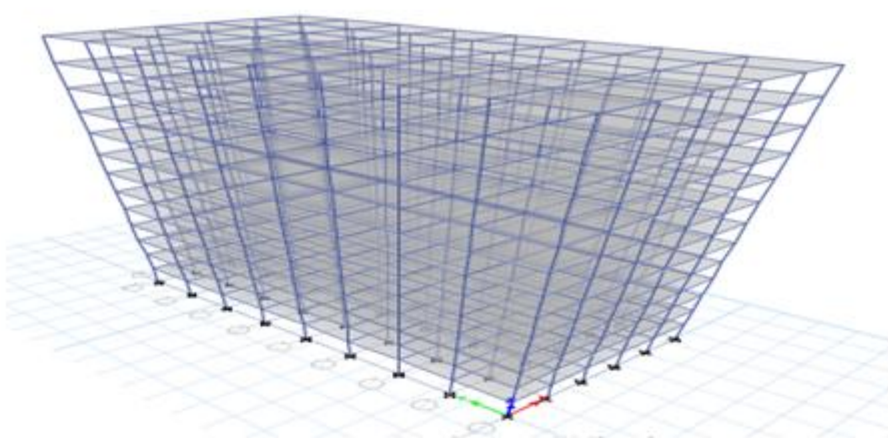

Fig 2: 3D view of building without dampers

2.1 Geometric details:

- ✓ Plan dimension = 16m x 32m
- ✓ Each storey height = 3m
- ✓ Number of storeys = G+12
- ✓ Total height of building = 39m

2.2 Material properties:

- ✓ Grade of concrete = M20 for slabs and M25 for beams and columns
- ✓ Grade of steel = Fe500

2.3 Section properties:

- ✓ Column = 400mm x 400mm
- ✓ Beam = 250mm x 400mm
- ✓ Slab thickness = 125mm (two way slab)

2.4 LOADS:

While applying the loads to the structure we consider only the external loads which are actually acting on the members neglecting its self-weight because ETABS 2016 automatically takes the members self-weight. Additional dead load is given as 3.2 KN/m^2 and live load is given as 4 KN/m^2. The Seismic loads EQ-x and EQ-y are given in Load patterns directly using Code IS1893:2002.

2.5 Seismic properties:

- ✓ Zone factor = 0.36(zone 5), 0.24(zone4), 0.16(zone 3)
- ✓ Response reduction factor(R) = 5
- ✓ Importance factor(I) = 1
- ✓ Soil type = II
- ✓ Damping ratio = 0.05

2.6 Seismic load combinations:

Seismic load combinations are taken as per IS 1893 (Part 1) : 2002 (in cl.6.3)

2.7 Damping properties:

The dampers have been installed at corners only in the exterior throughout the height of the building. The damper is modeled only along one longitudinal direction and restrained in other two transverse directions, in its local coordinate system. Non-linearity is considered along the active direction U1. Rotation has been restrained. Following values have been used to model the damper.

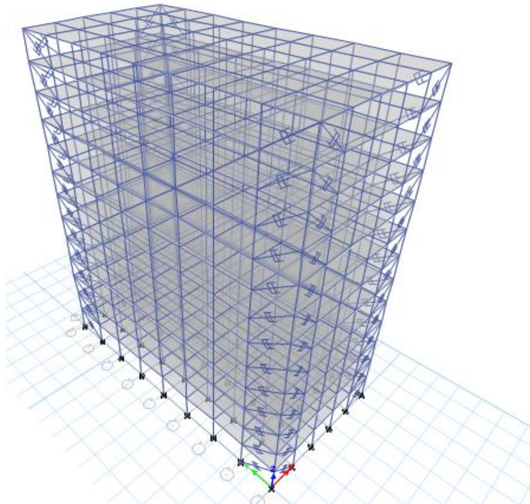

Fig 3 : 3D view of building with viscous dampers friction dampers

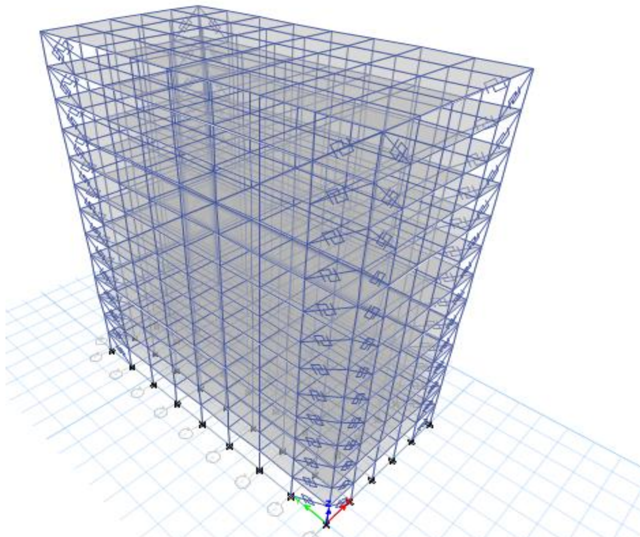

Fig 4 :3D view of building with Pall

- **Fluid viscous damper properties:**

In the course, the damping force should follow the formula:

$F = C v^{\alpha}$

F: damping force   v: velocity of piston relative to cylinder

C: damping coefficient   α: damping exponent varies from 0.1 to 1.

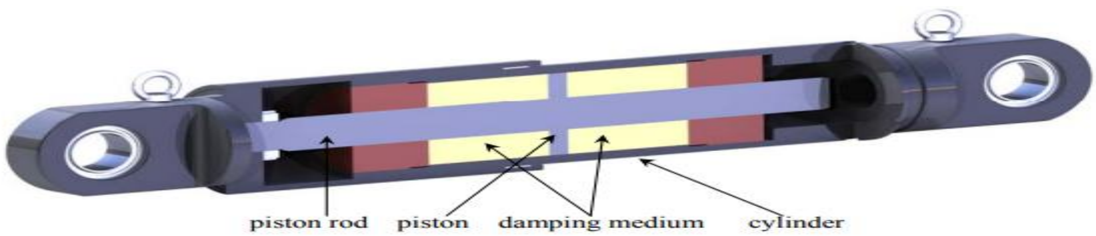

Fig 5- Fluid viscous damper

The product which has been taken into account for development of FVD model in this study is 67DP1892101-type-A damper manufactured by Taylor Devices Inc., USA . It is modeled as a link element with link type damper-exponential.

- ✓ Mass = 1700 Kg.
- ✓ Weight = 0.173 KN
- ✓ Effective Stiffness = 20,000 KN/m
- ✓ Effective Damping = 10,000 KN-s/m
- ✓ Type of damper = Exponential
- ✓ Velocity exponent = 0.2

- **Visco elastic damper properties:**

MATHEMATICAL MODEL OF VISCOELASTIC DAMPER

When a VEM is under a sinusoidal shear stress τ(t) with a frequency ω ,the shear strain γ(t) will lag behind the stress by a phase angle δ as :

$\tau(t) = \tau_0 \sin(\omega t)$ and $\gamma(t) = \sin(\omega t - \delta)$ (1)

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where τ_0 and γ_0 are the stress and strain amplitudes respectively . if the strain is plotted against stress, one will obtain elliptical hysteresis loop.

Visco elastic material is often characterised by storage , G' ,and loss , G",shear moduli to represent the elastic and viscous properties respectively (Lai,1995).the ratio of loss to storage modulus is the loss factor ,η,or so called tangent delta (tanδ) which is used along with G' to describe the material:

$\eta = G''/G' = \tan \delta$ (2)

G' and G" are related to the stress and strain amplitudes

$G' = \tau_0/\gamma_0 \cos \delta$ and $G'' = \tau_0/\gamma_0 \sin \delta$ (3)

From eqn . 1 and 3 , the stress - strain relationship becomes

$\tau(t) = G' \gamma(t) \pm G'' (\gamma_0^2 - \gamma^2(t))^{1/2}$ (4)

Which is an ellipse.

It is convenient to use complex variables to describe the VEM as

$G^* = G' + jG''$ and $|G^*| = \tau_0/\gamma_0 = (G'^2 + G''^2)^{1/2}$ (5)

Where $j = \sqrt{-1}$

In structural and building applications, a viscoelastic damper typically consists of VEM slabs sandwiched between relatively rigid steel plates.The damper configuration is very simple and its operation is straightforward.
The viscoelastic damper can be characterized by storage, K', and loss, K", stiffness and are related to G' and G" as

$K' = G'A/h$, $K'' = G''A/h$ and $\eta = K''/K'$ (6)

Where A is the total shear area and h is the thickness of the VEM slab. An important advantage of the viscoelastic damper that the damper is linearly scaleable as shown in eqn .6. the property of a large damper can be linearly predicted by testing a much smaller damper as long as the testing strain, temperature and frequency are kept the same. K" can be further related to the viscous damping constant as

$C = K''/\omega = \eta K'/\omega$

Where ω is the damper operating frequency.
In this study acrylic-based Visco Elastic Material (VEM) designated as 3M brand ISD 110 (K.C.Chang, Y.Y.Lin) is used whose properties are given in table below.

Damper name	3M ISD 110
Type of damper	Exponential
Effective stiffness	17839.01
Effective damping	19808.12

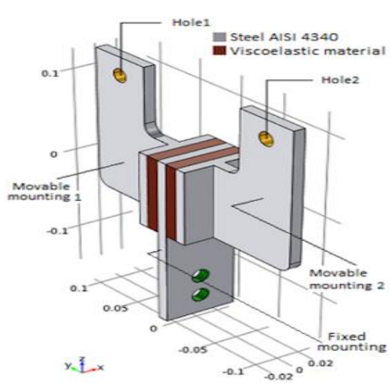

Fig 6 - Visco elastic damper

- **<u>Pall friction damper properties</u>:**

<u>Mathematical model of friction dampers</u>:

Cyclic force-deformation response of Friction Dampers is characterized by rectangular hysteresis loop. The behavior is represented in practice by rigid-perfectly-plastic models. The threshold force at which device starts to deform continuously is called slip-load. The value of this parameter, denoted as P_S, provides a complete definition of idealized model of device. The above description is sufficient to display behavior of friction damper where the elements used to support and connect device to main structural members is considered as rigid. The flexibility of bracings can be introduced in analysis. This is accomplished by considering SR ratio between stiffness k_{bd} of device-brace assembly and structural stiffness k_s. The relationship is given as

$$SR = k_{bd}/k_s \;;\; k_{bd} = 1/(1/k_d + 1/k_b)$$

For a friction element, stiffness k_d of device is considered as infinitely large, i.e., $k_d \approx \infty$ and stiffness k_{bd} of friction assemblage becomes the same as stiffness k_b of supporting bracing. That is,

$$k_{bd} = k_b \;;\; SR = k_b/k_s$$

The slip-load is then related to deformation Δy experienced by device-brace assembly as

$$P_s = k_{bd}\,\Delta y = k_b\,\Delta y$$

For design purposes, this equation is expressed in terms of stiffness parameter SR as

$$P_s = SR\;k_s\,\Delta y$$

This is the basic expression that relates mechanical parameters of friction element. From the equation, it is observed that behavior of friction element is governed by slip load Ps, stiffness ratio SR, and displacement of bracing Δy at which device starts to slip.

<u>Modelling and property definitions of pall friction dampers:</u>

Tension-compression diagonal brace with Pall FD has been modeled as per suggestions available on manufactures website (Pall Dynamics, Canada). Following values have been used to model the damper.

Link type	Mass	Weight	Effective stiffness	Yield strength =slip load	Post yield stiffness ratio	Yielding exponent
-	(kg)	(KN)	(KN/m)	(KN)	-	-
Plastic (wen)	429.32	4.2116	23772.853	700	0.0001	10

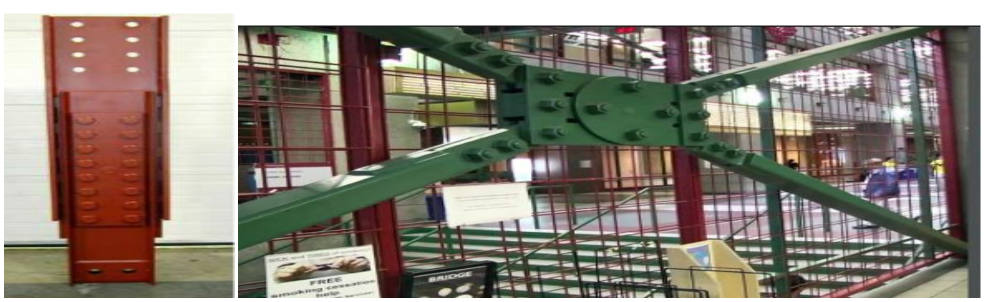

Fig 7- Pall Friction Dampers, Diagonal and X – bracing

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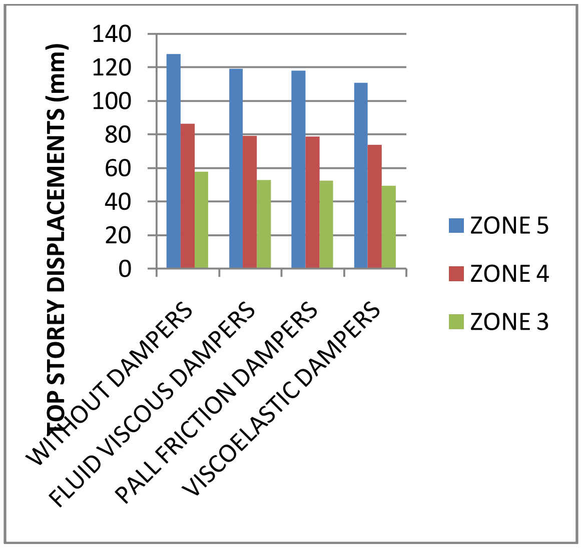
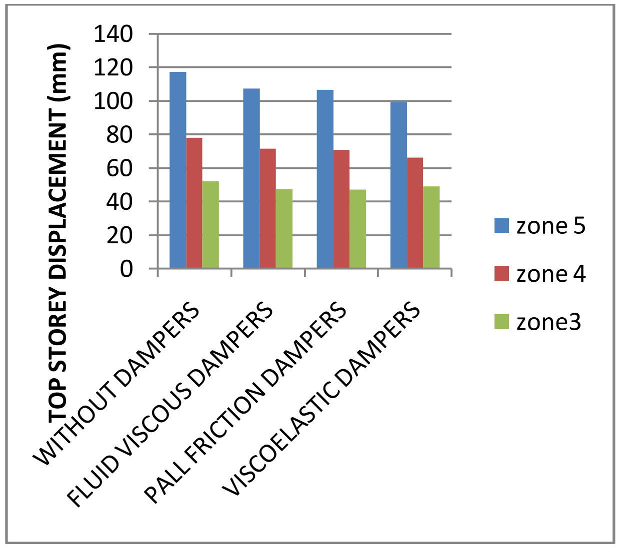
III. RESULTS

3.1 Comparision of top storey displacements with and without dampers:

In X Direction:

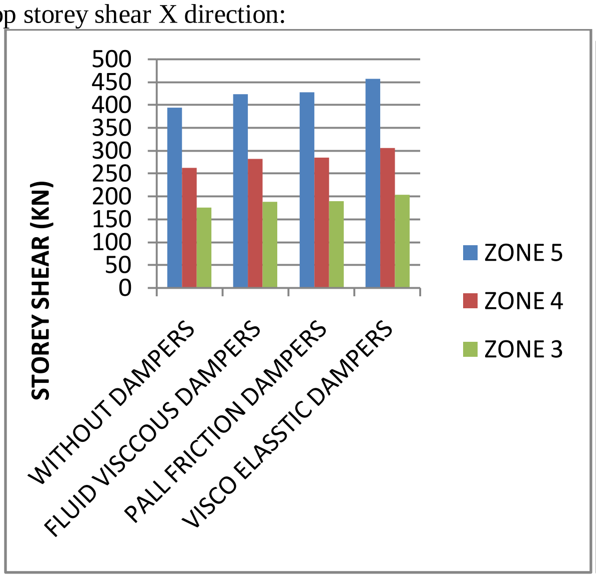


In Y Direction:

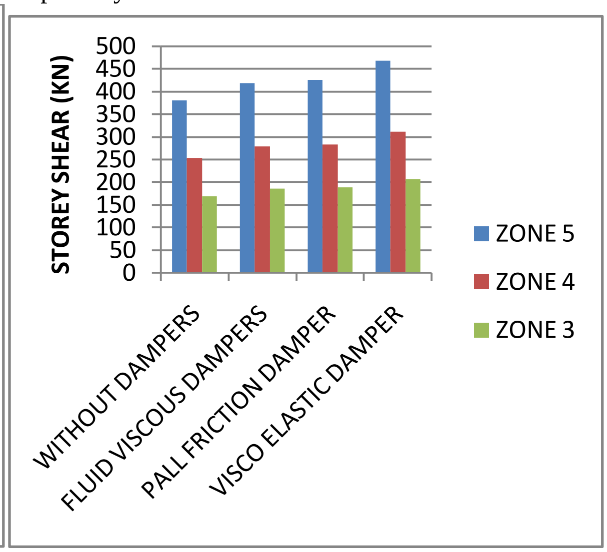


3.2 Storey shear:

Top storey shear X direction:



Top storey shear Y direction:



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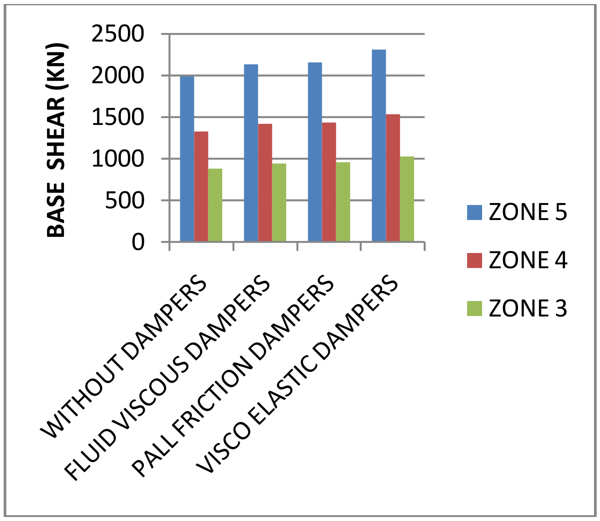
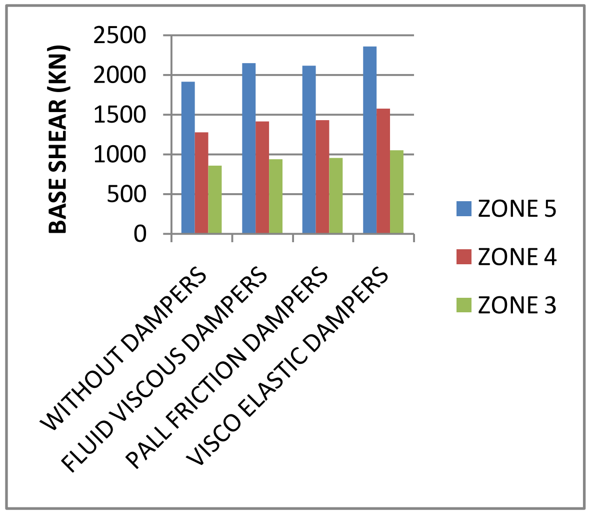
3.3 Base shear:

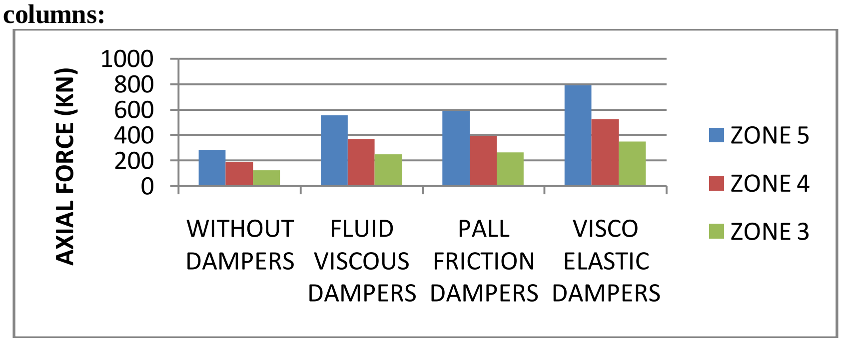
BASE SHEAR IN X DIRECTION :



BASE SHEAR IN Y DIRECTION:



3.4 Axial force in columns:



Axial force in columns are more when provided with dampers than without dampers.

3.5 Maximum bending moments and shear forces of beams:

MAX BENDING MOMENT AND SHEAR FORCE OF BEAMS IN ZONE 5				
FORCES	**WITHOUT DAMPERS**	**FLUID VISCOUS DAMPERS**	**PALL FRICTION DAMPERS**	**VISCOELASTIC DAMPERS**
B.M M MZ (KNm)	59.8191	61.84	59.93	59.98
SHEAR FORCE FY (KN)	95.945	112.441	96.0407	96.8054

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MAX BENDING MOMENT AND SHEAR FORCE OF BEAMS IN ZONE 4				
FORCES	WITHOUT DAMPERS	FLUID VISCOUS DAMPERS	PALL FRICTION DAMPERS	VISCOELASTIC DAMPERS
B.M M MZ (KNm)	42.0778	48.7716	42.1504	42.18
SHEAR FORCE FY (KN)	95.463	112.441	96.0407	96.8054

MAX BENDING MOMENT AND SHEAR FORCE OF BEAMS IN ZONE 3				
FORCES	WITHOUT DAMPERS	FLUID VISCOUS DAMPERS	PALL FRICTION DAMPERS	VISCOELASTIC DAMPERS
B.M M MZ (KNm)	42.0778	48.7716	42.1504	42.18
SHEAR FORCE FY (KN)	95.945	112.441	96.0407	96.8054

3.6 Maximum bending moments and shear forces of columns :

MAX BENDING MOMENT AND SHEAR FORCE OF COLUMNS IN ZONE 5				
FORCES	WITHOUT DAMPERS	FLUID VISCOUS DAMPERS	PALL FRICTION DAMPERS	VISCO ELASTIC DAMPERS
B.M.M MY (KNm)	89.68	94.32	90.65	90.66
B.M M MZ (KNm)	103.389	96.53	95.604	85.4245
SHEAR FORCE FY (KN)	52.196	55.346	56.973	55.919
SHEAR FORCE FZ (KN)	47.824	56.23	48.166	48.7554

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MAX BENDING MOMENT AND SHEAR FORCE OF COLUMNS IN ZONE 4				
FORCES	WITHOUT DAMPERS	FLUID VISCOUS DAMPERS	PALL FRICTION DAMPERS	VISCOELASTIC DAMPERS
B.M.M MY (KNm)	65.477	76.97	65.935	66.725
B.M M MZ (KNm)	68.9318	64.38	63.75	56.973
SHEAR FORCE FY (KN)	39.94	47.08	40.36	41.5294
SHEAR FORCE FZ (KN)	47.824	56.23	48.166	48.7554

MAX BENDING MOMENT AND SHEAR FORCE OF COLUMNS IN ZONE 3				
FORCES	WITHOUT DAMPERS	FLUID VISCOUS DAMPERS	PALL FRICTION DAMPERS	VISCOELASTIC DAMPERS
B.M.M MY (KNm)	65.477	76.97	65.935	66.725
B.M M MZ (KNm)	54.0716	52.75	54.05	51.20
SHEAR FORCE FY (KN)	39.94	47.08	40.36	41.5294
SHEAR FORCE FZ (KN)	47.824	56.23	48.166	48.7554

3.7 Modal periods and frequencies:

Without dampers

Case	Mode	Period	Frequency	Circular Frequency	Eigenvalue
		sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	3.332	0.3	1.8857	3.5559
Modal	2	3.212	0.311	1.956	3.8258
Modal	3	2.927	0.342	2.1469	4.6094
Modal	4	1.087	0.92	5.7782	33.3871
Modal	5	1.048	0.954	5.9954	35.9445
Modal	6	0.956	1.046	6.5741	43.2187

Modal	7	0.626	1.597	10.0321	100.6426
Modal	8	0.602	1.662	10.442	109.0353
Modal	9	0.551	1.816	11.4094	130.1736
Modal	10	0.426	2.35	14.7631	217.9503
Modal	11	0.411	2.435	15.3019	234.1481
Modal	12	0.375	2.664	16.7378	280.1538

Friction dampers

Case	Mode	Period	Frequency	Circular Frequency	Eigenvalue
		sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	2.988	0.335	2.1027	4.4214
Modal	2	2.974	0.336	2.1125	4.4629
Modal	3	2.396	0.417	2.6222	6.8761
Modal	4	0.972	1.029	6.4631	41.7721
Modal	5	0.965	1.036	6.5108	42.3903
Modal	6	0.783	1.277	8.0246	64.394
Modal	7	0.556	1.800	11.3087	127.8856
Modal	8	0.549	1.821	11.4408	130.8909
Modal	9	0.447	2.237	14.0539	197.5111
Modal	10	0.382	2.621	16.4694	271.2399
Modal	11	0.377	2.651	16.6566	277.4417
Modal	12	0.31	3.228	20.2792	411.2464

Fluid viscous dampers

Case	Mode	Period	Frequency	Circular Frequency	Eigenvalue
		sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	3.022	0.331	2.0793	4.3235
Modal	2	2.996	0.334	2.0970	4.3975
Modal	3	2.440	0.410	2.5746	6.6286
Modal	4	0.984	1.016	6.3843	40.7595
Modal	5	0.973	1.027	6.4545	41.6600
Modal	6	0.798	1.253	7.8738	61.9963
Modal	7	0.564	1.774	11.1470	124.2563
Modal	8	0.555	1.801	11.3190	128.1194
Modal	9	0.457	2.189	13.7532	189.1496
Modal	10	0.387	2.586	16.2495	264.0456
Modal	11	0.381	2.624	16.4877	271.8451
Modal	12	0.316	3.163	19.8721	394.9003

Viscoelastic dampers

Case	Mode	Period	Frequency	Circular Frequency	Eigenvalue
		sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	2.768	0.361	2.2700	5.1528
Modal	2	2.707	0.369	2.3208	5.3861
Modal	3	2.022	0.495	3.1080	9.6596
Modal	4	0.884	1.132	7.1099	50.5507
Modal	5	0.867	1.153	7.2431	52.4632
Modal	6	0.651	1.535	9.6446	93.0190
Modal	7	0.492	2.031	12.7622	162.8744
Modal	8	0.484	2.065	12.9770	168.4032
Modal	9	0.361	2.768	17.3909	302.4432
Modal	10	0.338	2.959	18.5903	345.6009
Modal	11	0.333	3.001	18.8535	355.4534
Modal	12	0.253	3.949	24.8125	615.6588

The fundamental period of vibration was observed to be low when dampers are placed compared to fundamental period without dampers.

IV. CONCLUSION

- The effectiveness of dampers is evident in form of reduced storey responses and stress demands on structural elements and indicates the nature of the dampers are displacement based.
- Maximum displacement of bare frame model without damper is 127mm in X direction and 117.2mm in Y direction.
- By providing dampers, in X direction there is reduction in displacement of 6.34% by providing fluid viscous dampers, 7.05% by providing pall friction dampers, 12.7% by providing viscoelastic dampers.
- In Y direction ,there is reduction in displacement of 8.47% by providing fluid viscous dampers, 9.21% by providing pall friction dampers, 15.14% by providing viscoelastic dampers.
- Base shear,storey shear and axial force reveals that by use of dampers there is an overall increase in the value of these parameters which implies the ineffectiveness of dampers in reducing the value of these parameters.
- The increase forces in case of building with dampers has lower damaging effects on the structural members as these forces are considerably shared by the damper brace system.
- Even though the dampers have significantly reduced the responses, the damping demand of structure can be further reduced by optimum selection and installation of dampers at various critical locations.

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