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Effect of Various Arrangements of Dampers on the Structure Fixed and Isolated at Base

Kiran M[1], Dr. B. K. Narendra[2]

[1]M.Tech student,[2]Professor & Principal, Department of Civil Engineering

B.G.S Institute of Technology B.G Nagar, Mandya, Karnataka State, India 571448

Abstract - In the proposed work, the effectiveness of providing the dampers with various type of arrangement for the structure subjected to real time earthquake ground motion is investigated. A space frame structure with six degrees of freedom is used to study the effectiveness of providing various types of arrangement. Three types of earthquakes are considered for the study. The variation of the structure with dampers is differentiated to the variation of the structure without dampers so as to study the effectiveness of providing various types of arrangement. The response of the structure obtained by providing various types of arrangement is be compared so as to propose the most effective arrangement of providing the damper to resist the structure subjected to earthquakes. In addition the effectiveness of providing dampers with various types of arrangement for a friction pendulum system (FPS) base isolated structure will also be studied. A computer program developed for the analysis of fixed base and base isolated structure will be modified so as to provide various types of dampers.

Keywords: base isolated, FPS, dampers, space frame.

I.INTRODUCTION

One of the most terrifying and harsh occurrences of environment is a huge earthquake and aftereffects it is very aggressive. An earthquake is occurred due to the rapid release of strain that has gathered over a long time which causes the immediate movement in the inner core of earth. The forces of plate tectonics have formed the earth as the large plates that from the Earth's surface move gently above, below, and earlier each other for billions of years. The movement is steady for sometimes. The plates are sealed each other, not capable to discharge the accumulating strain energy at other times. The plates break easily, when the accumulated energy produces strong enough. Now a days a different technique to resist the structures subjected to earthquakes have been proposed .They fall in to the two major groups. In one of the approach, the structures are prevented from earthquake forces by isolating them at the ground. This is known as base isolation technique. The second approach is to improve the earthquake resistance of buildings on the basis of dissipation of energy and damping. Thus, a large number of energy dissipation devices have been generated and they are fitted in real structures.

II. SYSTEMMODEL

The finite element method is a powerful tool which fulfils the requirement of a true theoretical solution such as equilibrium, compatibility, material constitutive behaviour and boundary condition is used in the analysis. Available computer program developed is used to study the response of the space frame structure resting on sliding bearing with friction pendulum system subjected to ground acceleration. The program considered all six degrees of freedom at each node.

The effectiveness of providing the dampers with various type of arrangement for the fixed base and isolated structure is investigated for the real earthquake excitation. A four storey space frame structure resting on friction pendulum bearing as shown in figure 3.1 is considered for the study. The geometrical and material property of the structure are as follows; mass of structure is 42.5×10^3 kg/m^4, each column has a size of *0.6mx0.6m* and beam of size *0.3mx0.6m*, internal damping of structure is 5%, friction coefficient of sliding surface is 0.02, Elastic modulus of concrete is 2.2×10^7 kN/m^2 .The damping coefficient of damper value is varied from a small value of 50 kN-sec/m to 1000 kN-sec/m. The system is subjected to three real earthquake excitations namely; Chi-Chi (1999), El-Centro (1940), Northridge (1994) and response of structure is studied.Various arrangements of damping device considered for the study are shown in Fig. 2.1 to 2.4.

1) Type 1: Single diagonal damper arrangement.
2) Type 2: Inverted V damper arrangement.
3) Type 3: Double diagonal damper arrangement.
4) Type 4: Inverted V with outer diagonal damper arrangement.

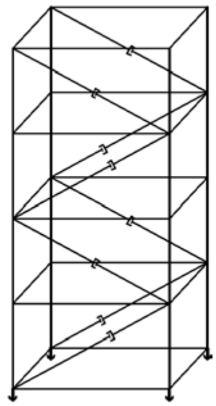

Fig. 2.1 Type 1

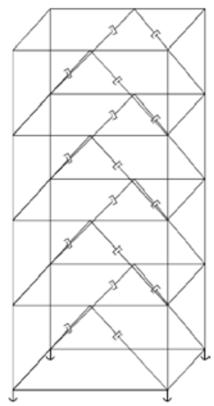

Fig.2.2 Type 2

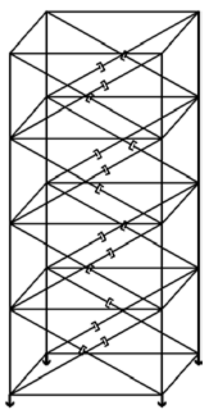

Fig.2.3 Type 3

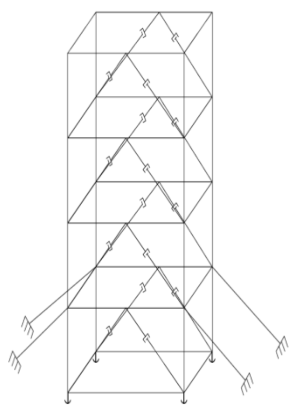

Fig. 2.4 Type 4

III. PREVIOUS WORK

There have been an ample number of studies on usage of isolated and fixed structural systems in the past and present. A few literatures on isolated and fixed structural systems and isolated and fixed structural systems with dampers from the past are as follows.

Gucraud et al (1985): explained an isolation device on the basis of sliding elastomer bearing pads. The friction plates and reinforced neoprene pads are interfered as double draft for the foundation system of structure. The accelerations and horizontal seismic forces subjected to structure can limited by the Ground and primary structure which are bonded by pads.

Lin Su et al (1991): Suggested a sliding resilient base isolation device which is characterised by friction for the structure of a non-uniform shear beam. The above paper attempts to study the displacement and acceleration of effective response spectra for the structure isolated at base for various earthquake are estimated .The above paper concluded that sliding resilient friction base isolation device is more active in decreasing peak deflection and acceleration of structural responses without creating extremely huge displacements at base.

Maria Qing Feng et al (1994): Based on analytical and experimental studies proposed a system of adjustable sliding base isolation bearings which was tested on a shake table using a structural model equipped with this system. Control algorithms developed specifically to control the frictional force that has a nonlinear characteristic and to study the effectiveness of the system.

Makris and Constantinou (1991):The proposed research is validated by the dynamic test and very good agreement between expected and experimental is obtained. This journal presented the Numerical algorithms for the solution of the constitutive relationship of the frequency and time domain. And also presented the some test results of a single degree of freedom viscous damping system. Those results are useful for the design of vibration isolation systems. In addition, a viscous equivalent oscillator whose response is defined essentially the same as the insulating viscous damper.

Constantinou (1992):conducted and documented analytical and experimental study of structural seismic response with additional fluid viscous dampers. In the work they have discussed about different energy dissipating devices such as friction dampers, visco-elastic dampers, viscous walls and FVD. In the report they have verified mechanical properties of FVD through an experiment. They have also studied the responses of a structure without and with dampers. They developed mathematical models of different structures and these models were later validated by performing earthquake simulator testing on experimental models of the same.

Ying Zhou (2012): The applied design technique for reinforced concrete buildings is planned with viscous dampers is the main objective of this work. Recommended design procedure is categorized into two phases. In the very first phase, settings of the viscous dampers and the mechanical constraints were identified. The other phase, the connecting damping structure, decreasing the changes and extra damping coefficient is examined. The above paper concludes that the proposed design method to reach the crucial necessity of development and design which leads to innovations on viscous fluid dampers.

IV. PROPOSED METHODOLOGY

The structure is divided into number of elements consisting of beams and columns. The beams and columns are modelled using two nodded frame elements with six degrees of freedom at each node i.e., three translations along x, y, zaxes and three rotations about these axes. For each element, the stiffness matrix, k_s, consistent mass matrix, m_s, and transformation matrix, t_s, are obtained. The mass matrix and the stiffness matrix of each element from local direction are transformed to global direction as proposed by Paz (2001). The mass matrix and the stiffness matrix of each element are assembled by direct stiffness method to get the overall mass matrix, M, and overall stiffness matrix, K, for the entire structure. Knowing the overall mass matrix, M, and overall stiffness matrix, K, the frequencies for the superstructure (fixed base structure) is obtained using simultaneous iteration method. The damping matrix for superstructure is obtained using Rayleigh's equation, $C = \alpha M + \beta K$, where α and β are the constants. These constants can be determined easily if the damping ratio for each mode is known. The overall dynamic equation of equilibrium for the entire structure can be expressed in matrix notations as

$$M\ddot{u} + Cu + Ku = f(t) \qquad (4.1)$$

Where M, C and K are the overall mass, damping, and stiffness matrices of size 6n × 6n,

The nodal load vector due to earthquake is obtained using the equation

$$f(t) = -M\,I\,\ddot{u}g(t) \qquad (4.2)$$

Where M is the overall mass matrix, I is the influence vector, üg(t) is the ground acceleration. The resulting equation of dynamic equilibrium is solved using Newmark's method to obtain the displacements and acceleration at the nodes as explained in Chopra (1995). Owing to its unconditional stability, the constant average acceleration scheme (with $\beta = 1/4$ and $\gamma = 1/2$) is adopted.

Modelling of Isolation Bearing:

In order to develop the basic mathematical model of the isolator sliding surfaces, consider the motion of a rigid block of mass *m* sliding on smooth curved surface of defined geometry, y=f(x). The restoring force offered by the curved sliding surface can be defined as lateral force required to cause a horizontal displacement *x*. Assuming a point contact the various forces acting on the sliding surface when the block is displaced from its original position at the origin of coordinate axes are shown in figure 4.3. If f_R be the restoring force acting in the horizontal direction then,

$f_R\cos\theta - W\sin\theta = 0$ (components of f_R and W along r-direction)

$$f_R - W\frac{\sin\theta}{\cos\theta} = 0$$

$f_R = m\,g\tan\theta$ (where W= mg)

$$f_R = m\,g\frac{dy}{dx} \qquad (4.3)$$

Assuming the restoring force is mathematically represented by an equivalent nonlinear massless horizontal spring, the spring force can be expressed as the product of the equivalent spring stiffness and the deformation, x

$$\text{i.e., } f_R = k_b\,x \qquad (4.4)$$

Where k_b is the instantaneous spring stiffness and *x* is sliding displacement of the mass. If the mass is modelled as a single degree-of-freedom oscillator, the spring force (restoring force) can be

$$f_R = m\,\omega_b^2\,x \quad \{\text{because } \omega_b = \sqrt{\frac{k_b}{m}}\}$$

$$\text{Or, } f_R = k_b\,x \quad \{\text{because } k_b = \frac{m\,g}{R}\} \qquad (4.5)$$

Here k_b is stiffness of isolator and ω_b is the instantaneous isolator frequency and depends solely on the geometry of sliding surface. In the friction pendulum system, which has a spherical sliding surface, this is almost constant and is approximately equal to $\sqrt{g/R}$, where *R* is the radius of curvature of the sliding surface.

The structure resting on FPS passes through two types of phases namely, non-sliding phase and sliding phase. In stick phase (non-sliding phase) the structure does not move with respect to the sliding surface. The total motion can be considered as a series of non-sliding and sliding phase in succession. In non-sliding phase the structure behave as a conventional fixed-base structure. During this phase frictional resistance is greater than the mobilized frictional force. When mobilized frictional force overcomes the frictional resistance; the system enters the second phase and starts sliding. In the proposed analysis, the sliding and non-sliding phases are modelled using a fictitious spring of stiffness k_s.

Non-Sliding Phase:

In non-sliding phase the structure behave as a conventional fixed base structure. During this phase frictional resistance, F_S is greater than the mobilized frictional force, F_X. At the beginning, before the structure starts sliding, the displacement of the structure at the base is equal to the displacement of foundation. Hence, the relative displacement between the base of the structure and the foundation remains constant and is equal to zero. The relative acceleration and relative velocity of the base is also equal to zero when the structure enters the sliding phase, it slides relatively to the ground. When it again enters the non-sliding phase after sliding to some distance say, *u* the relative acceleration and relative velocity again becomes Zero, and the relative displacement remains constant and is equal to *u*, during this phase. Hence, when he structure is in non-sliding phase, the relative acceleration ($\ddot{u}_b$) and relative velocity (u_b) is equal to zero and relative displacement (u) at the base is constant during this phase. The stiffness of the spring, k_s, at the base of each column is considered as very large ($k_s = 1x10^{15} kN/m$). The dynamic equation of motion for the non-sliding phase is the same as given in equation 4.1

Sliding Phase:

When the mobilized frictional force F_x, is equal to or more than the frictional resistance, F_s, the system enters the second phase and starts sliding. The mobilized frictional force F*x*, and remains constant during this phase. The stiffness of the fictitious spring, k_s, is considered to zero ($k_{s=}$ 0), so as to allow the sliding of the super structure at the interface. The dynamic equations of motion for the structure during this phase is,

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F(t)\}-\{F_{xmax}\} \quad (4.6)$$

Where, [*K*] is the stiffness matrix of the structure including stiffness of the fictitious spring k_s (k_s being equal to zero), and stiffness of isolator, $k_b\{F_{xmax}\}$ is the vector with zeros at all locations except those corresponding to the horizontal degree-of-freedom at the base of the structure. At these degrees-of-freedom, the vector $\{F_{xmax}\}$ will have values equal to F_s.

Criteria for Change Phase:

The system is in non-sliding phase if the mobilized frictional force at the interface of sliding bearing is less than the frictional resistance (ie. $|F_x| < F_s$). However the system starts sliding as soon as the mobilized frictional force attains the frictional resistance (ie. $|F_x| \geq F_s$). During sliding phase, whenever the sliding velocity at the base becomes zero, the phase of the motion is checked to determine whether the system remains in the sliding phase or sticks to the foundation, i.e. when the sliding velocity of the base mass is equal to zero and $|F_x| < F_s$, the system enters to non-sliding phase otherwise even if the sliding velocity is equal to zero and $|F_x| \geq F_s$, the system remains in sliding phase only. .

Determination of Member forces:

The displacement obtained at each node is assigned for each member. The forces in each member are then obtained by multiplying element stiffness matrix with the nodal displacement vector.

V. SIMULATION

Effect of providing damper of various type of arrangement for structure fixed at base.
In this case structure is fixed at base and hence moves along with ground during earthquake. The response considered for the structure is base shear since the displacement at base is zero.

Effect onTime History Response:

The time history response of fixed base structure subjected to three earthquakes with various arrangements of damping device and the corresponding response for the fixed base structure without damping device are compared in order to study the effectiveness of providing various types of arrangement of damper on fixed base structure. The time history responses of base shear for fixed base structure withdamping coefficient of 500 kN-sec/m and without dampers are shown in table 1.

Table 1 Peak Base Shear Response of Fixed Base Structure With and Without Damper

Earthquakes	**Various damper arrangements**	**Base shear (kN)**	
		Without damper	**With damper**
Chi Chi	Type 1	233.81	159.26
	Type 2	233.81	135.23
	Type 3	233.81	138.43
	Type 4	233.81	120.37
El Centro	Type 1	266.1	177.63
	Type 2	266.1	131.92
	Type 3	266.1	137.92
	Type 4	266.1	105.82
Northridge	Type 1	486.75	291.02
	Type 2	486.75	224.57
	Type 3	486.75	234.47
	Type 4	486.75	193.28

Following observations can be drawn from figure 5.1

1) This shows that the base shear response of the structure is lesser for the structure with all four types of dampers arrangement compared to the corresponding response of the structure without dampers for all three earthquakes. The above discussion shows that all the damping devices are

beneficial for the fixed structure subjected to earthquake ground motion.

2) However, type 4 arrangement of damper is more effective compared to the other types of damping arrangements for all the three types of earthquakes.

Effect of Damping Coefficient of Damper for Various Type of Damper Arrangement:

The effect of damping coefficient of various types of damper arrangement on base shear response of fixed base structure is studied. Figure 5.1 shows the variation of base shear response with damping coefficient of damper for the fixed base structure subjected to different earthquakes.

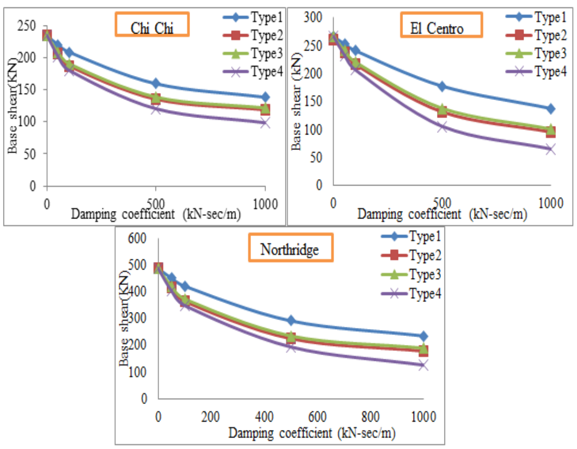

Fig. 5.1

Variation of base shear for different arrangement of dampers with varying damping coefficient of damper for different earthquake

Following observations can be drawn from figure 5.1

1) As the damping coefficient increases there is a gradual reduction in base shear response for fixed base structure for all arrangement of damper for all the three earthquakes.
2) Type 4 arrangement of damper shows a significant reduction in base shear of fixed base structure for all values of damping coefficient for all type of earthquake ground motion.
3) Thus the type 4 arrangement of damper is the most effective arrangement for all values of damping coefficient.

Effect of Storey Shear Response:

The storey shear response of fixed base structure subjected to three earthquakes with various arrangements of damping device and the corresponding response of the fixed base structure without damping device is compared in figure 5.2

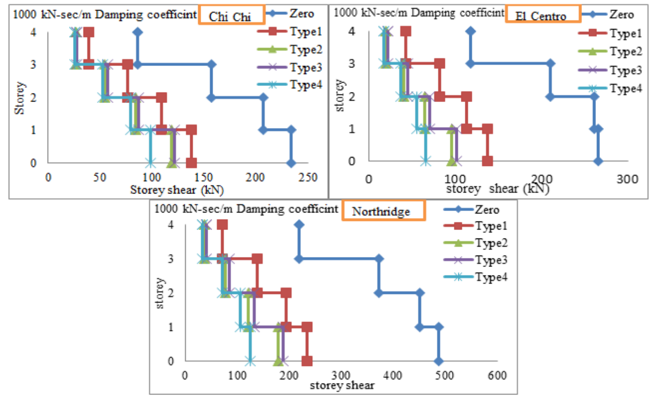

Fig.5.2Variation of storey shear for different arrangement of dampers for with and without damper for different earthquake

Following observations can be drawn from figure 5.2

1) The shear at all the storeys for the structure is lesser for the structure with all four types of dampers arrangement compared to the corresponding shear for the structure without dampers for all three earthquakes. This shows that all the damping devices are effective to reduce the shear at all the storeys for the fixed structure subjected to earthquake ground motion.
2) Among the four type of damping arrangement type 4 arrangement of damping device is more effective compared to the other types of damping arrangements to reduce the shear at different storeys.

Effect of Providing Damper of Various Type of Arrangement for Structure Isolated with FPS:

The friction pendulum system (FPS) is consists of a spherical sliding surface of radius 1m. The isolated structure has the displacement at base and it should be minimum for practical application.

Effect on Time History Response:

The response of isolated structure subjected to three earthquakes is studied with various arrangements of damping device. The time history response quantities of interest are the sliding displacement and base shear of structure. The response of the isolated structure with damping coefficient of 500 kN-sec/m and without damping device is compared in table 5.2 for various arrangement of damper subjected to three earthquakes.

Table 2 Peak Base Shear and Sliding Displacement Response Of Fixed Base Structure With And Without Damper

Earthquakes	Various damper arrangements	Base shear (kN)		Sliding Displacement (mm)	
		Without damper	With damper	Without damper	With damper
Chi Chi	Type 1	124.96	123.36	346.73	345.47
	Type 2	124.96	122.32	346.73	345.65
	Type 3	124.96	123.51	346.73	346.9
	Type 4	124.96	29.73	346.73	58.76
El Centro	Type 1	37.95	37.11	92.07	89.86
	Type 2	37.95	36.59	92.07	89.33
	Type 3	37.95	37.08	92.07	89.97
	Type 4	37.95	17.76	92.07	20.03
Northridge	Type 1	65.55	66.29	175.58	175.38
	Type 2	65.55	65.24	175.58	175.31
	Type 3	65.55	65.94	175.58	176.06
	Type 4	65.55	43.48	175.58	38.78

Following observations can be drawn from figure 5.2

1) This observation shows that type 1, type 2 and type 3 arrangement of damper has no much effect on both the sliding displacement and base shear response of the isolated structure whereas the type 4 arrangement of damper reduces both the sliding displacement and base shear significantly. Thus it shows that only the type 4 arrangement for an effect on sliding displacement and base shear of the isolated structure.
2) In the case of fixed base structure all type of damper arrangement will have the effect whereas in this case only the type 4 arrangement of damper will have effect and other types will not have much effect.

Effect of Damping Coefficient of Damper for various Type of Damper Arrangement:

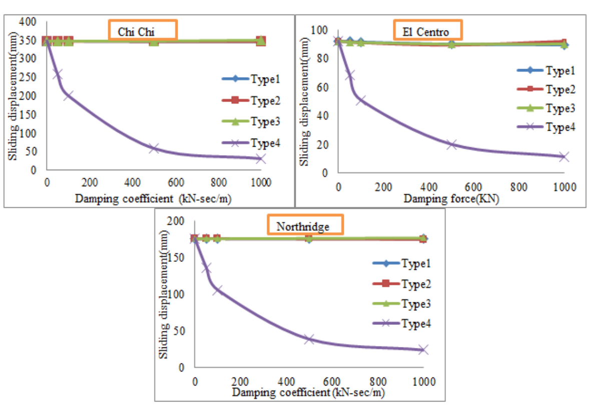

Fig.5.3 Variation of displacement for different arrangement of dampers with varying damping coefficient of damper for different earthquake

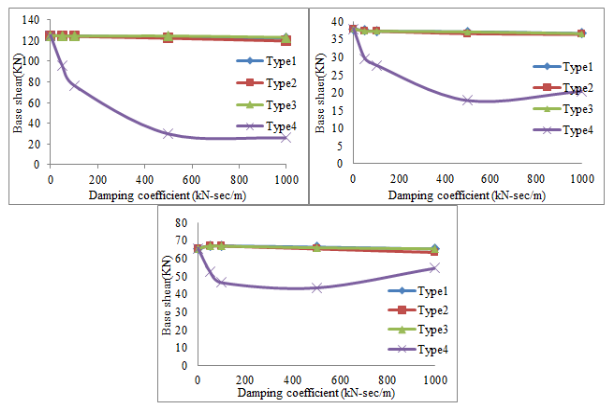

Fig 5.4 Variation of base shear for different arrangement of dampers with varying damping coefficient of damper for Northridge earthquake

The effect of damping coefficient of various types of damper arrangement on the sliding displacement and base shear response of isolated structure is also studied. Figure 5.3-5.4 shows the variation of the response with damping coefficient for the isolated structure subjected to different earthquake ground motions.

From figures 5.3-5.4, it can be observe that

1) The type 1, type 2, and type3 arrangement of damper has no much effect on sliding displacement and base shear of the structure for all values of damping coefficient of damper for all earthquakes considered for the study.
2) However, the type 4 arrangement of damper shows considerable effect on response of the isolated structure. In this case as observed from figure, the sliding displacement decreases with increases in damping coefficient of damper. Base shear decreases initially with increases in damping coefficient of

damper, reaches a minimum value and then increases with increase in damping coefficient.

3) This shows that there exists on optimum damping coefficient at which the base shear is minimum. However, this optimum damping coefficient is same for different earthquakes. It is equal to 500kN-Sec/m for El Centro and Northridge earthquake. Thus, the type 4 arrangement of damper will have the maximum effect on base shear at optimum damping coefficient. If the damping coefficient is larger than optimum value, it may show detrimental effect.

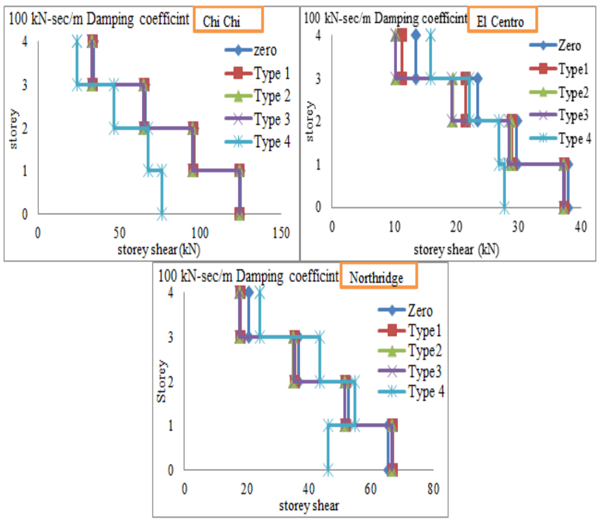

Fig. 5.5 Variation of storey shear for different arrangement of dampers for with and without damper for El Centro earthquake

Effect of Storey Shear Response:

The storey shear response of isolated structure subjected to three earthquakes with various arrangements of damping device is compared with that of the isolated structure without damper are shown in figures 5.5.

From figure 5.5, it can be observed that

1) The shear response of isolated structure with type 1 type 2 and type 3 arrangement of damper has no much effect for Chi Chi and Northridge earthquake whereas the shear at all the storey with type 4 arrangement of damper is reduces compare to shear of structure without damper for Chi Chi earthquake.

2) The storey shear response of isolated structure with type 1, type 2 and type 3 arrangement of damper marginally reduces compare to the structure without damper for El Centro earthquake at all the storeys whereas the storey shear for type 4 arrangement of damper is effective only up to second floor of the structure, whereas it has no much effect on storey three and four.

3) The shear at all the storeys for the structure is not much for the structure with all four types of dampers arrangement compared to the corresponding shear for the structure without dampers for Northridge earthquakes.

VI. CONCLUSION

The effect of various arrangements of dampers for the four storey structure fixed at the base and isolated at the base subjected to three earthquake ground accelerations is studied. Based on the analysis results, the following conclusions are drawn:

1) All the four types of damper arrangements are effective to reduce the base shear of the structure fixed at the base. However among all the four types of damper arrangement, the inverted V with outer diagonal arrangement (fourth type) is has a maximum effect to reduce the response of structure at the base.

2) The three types of damper arrangement i.e. Single diagonal (Type 1), inverted V (Type 2) and double diagonal (Type 3) has no much effect on the structure isolated with FPS, whereas the inverted V with outer diagonal arrangement (Type 4) arrangement of damper shows the effect on both sliding displacement and base shear of structure. It reduces the sliding displacement and base shear of the isolate structure significantly.

3) As damping coefficient increases there is a gradual reduction in base shear response for all arrangement of damper for the fixed base structure. However the type 4 of damper arrangement shows significant effect for all values of damping coefficient.

4) Single diagonal (Type 1), inverted V (Type 2) and double diagonal (Type 3) arrangements of dampers has no much effect on sliding displacement and base shear of the structure isolated with FPS at all values of damping coefficient. However the inverted V with outer diagonal arrangement (Type4) arrangement of damper shows isolated structure for all values of damping coefficient.

5) The sliding displacement decreases with increasing damping coefficient of damper. The base shear response reduces as damping coefficient increases shows a minimum value and then starts increasing with further increases of damping coefficient. Thus there exists an optimum damping coefficient at which the base shear is minimum.

6) However, the damping coefficient which gives minimum base shear is different for different earthquakes. Hence, the damper planned for one type of

earthquake may not be effective for other type of earthquake.

7) The analysis shows that the performance of damping device is effective in reducing the sliding displacement up to 90.95% and base shear up to 79.35% for structure isolated with FPS.
8) The analysis shows that the performance of damping device is effective in reducing the base shear up to 75.40% for structure fixed at base.
9) Thus, all the four type of damper arrangement shows the beneficial effect for the structure fixed at the base where as for structure isolated with FPS, the only inverted V with outer diagonal arrangement of damper (Type 4) will show the beneficial effect. The other arrangement will not show much effect on response of the structure

VII. FUTURE SCOPE OF WORK

- The present work, study the response of space frame structure of fixed base and isolated with FPS. This study can be extended to structure isolated with rubber bearing.
- Different type of dampers like friction damper, viscoelastic damper, metallic damper, etc., are also available, these dampers can be also employed in the analysis.
  - The study of damper effect on fixed base and isolated structure is confined only on area building, it can be extended to various structures like bridges, water tank and the significance of damper effect on the structure response can be studied.

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