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SEISMIC ANALYSIS OF SOIL INTEGRATED RC BUILDING RESTING ON SLOPE EMPLOYING FLUID VISCOUS DAMPERS

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Abstract -*The real estate development in hilly areas has been accelerated due to economic growth and rapid urbanization. But the scarcity of plain ground in hilly regions compels the engineers to construct the buildings on sloping ground. The buildings on sloping ground become highly irregular and asymmetric due to variation in stiffness and mass distribution at each floor. While conducting seismic analysis of such buildings, it is important to consider the effect of soil-structure interaction so as to get accurate response of the structure. It is recommended that buildings on sloping ground should have some kind of lateral load resisting system to minimize the seismic response. In this study, a multi-storey building situated on sloping ground while considering the soil-structure interaction is analyzed by response spectrum method (RSM). Then the fluid viscous dampers (FVD) are employed to control and minimise the seismic responses of the building. The modeling and the response spectrum analysis is carried out using IS: 1893-2016 in ETABS v18.1 software. The conclusions are drawn on the basis of improvement in values of maximum storey displacement, base shear, storey drift due to the incorporation of fluid viscous dampers in the building.*

Key Words: **Sloping ground, Soil-Structure Interaction, Response Spectrum Analysis, Fluid Viscous Dampers, Torsional Irregularity.**

1. INTRODUCTION

In most of the aged cities there is lack of land for new constructions due to which high rise buildings are being built in hilly regions. The behaviour of buildings in hilly regions during earthquake is decided by the distribution of mass and stiffness in both the vertical and the horizontal direction, both of which vary in case of buildings situated in hilly areas. The irregularity and asymmetry in the shape of the building is due to step-back frame and step-back & set-back frame configuration. These types of constructions in the high seismicity areas are exposed to higher shears and torsions as compared to conventional buildings situated on plain grounds. Hence, design such buildings should be done with great attention. It is very important to take the appropriate design constants and other data for designing the building properly. And here soil-structure interaction becomes too important to be ignored, because without considering it, the values of base shear is over estimated and the seismic response of the building is under estimated. Also in the design of such building, employment of some kind of lateral load resisting system is recommended. Structural control is usually classified by its method, or the type of device used to control the seismic response of the structure. There are three types of structural control systems; passive energy dissipation system, active system and semi-active energy dissipation system. Among which, passive devices are frequently used type of control system because they require no external power and such devices are inherently stable. Passive devices have a range of materials and devices for enhancing damping and strength of the building such as fluid viscous dampers (FVD), friction dampers and bracings which have been developed since the 1990's. This paper focuses on the soil-structure interaction to obtain the accurate responses and the use of fluid viscous dampers to reduce those seismic responses.

2. LITERATURE REVIEW

B. G. Birajdar *et.al.* [1] checked the suitability of a building configuration on sloping ground and concluded that the Step back Set back buildings are more suitable on sloping ground. S. Arjun *et.al.*[2] investigated the behaviour of G+3 storied sloped frame building having step-back set-back configuration for sin curve ground motion with different slope angles and observed that short column is more vulnerable during the earthquake. Joshua Daniel [3] compared the dynamic behavior of regular buildings with buildings on slope with same seismic weight concluded that hill buildings have significantly less energy dissipation capacity and more stiffness than the buildings on flat ground different dynamic characteristics than buildings on flat ground. K. Divya *et.al.* [4] studied the seismic behaviour of the G+5 building orientated with respect to the propagation of seismic wave up to 90° and concluded the all the response value increased along the slope with increment of the slope value. Dr. R.B. Khadiranaikar *et.al.* [5] observed that the step-back buildings could prove more vulnerable to seismic loading.
Rahul Ghosh *et.al.* [6] investigated the effect of slope angle variation for the buildings resting on sloping ground. George Gazetas *et.al.* [7] wanted the practicing engineer to make use of results obtained with state-of-the-art formulations, when studying the dynamic response of the building foundations. A. D. Pandey *et.al.* [8] found out that the response reduction factor decreases with increasing

time period. A. R. Chougule *et.al.* [9] studied the effect of soil-structure interaction on multi-storeyed buildings with various foundation types and compared the influence of soil structure interaction with the results obtained when the structure is assumed to have fixed supports. Q. Bhavikatti *et.al.* [10] performed seismic analysis for a building resting on sloping ground with sloping angles 16, 20 and 24 degrees under the effect of soil structure interaction and observed that the soil structure interaction effect leads to effective reduction of base shear. R. M. Jenifer, *et.al.*[11] investigated the effect of Soil-structure interaction on tall buildings with various foundation types and recommended to consider the effect of soil stiffness on foundation while designing building frames for seismic loads.

M. Gabriella Castellano *et.al.*[12] presented studies of application of fluid viscous dampers in monumental buildings to improve their seismic behaviour and gave the structure satisfactory seismic behaviour without any major change to the existing structural design. Dhiraj Ahiwale, *et.al.*[13] analyzed a G+30 steel frame step back building resting on a 25 degree slope incorporated with viscous dampers of various capacities using time history analysis and concluded that the response of step-back building for base shear, top storey displacement and storey drift increases when capacity of FVD increases. Liya Mathew *et.al.* [14] attempted to find the optimum damper parameters for reinforced concrete buildings and concluded that placing dampers throughout the height of the building reduced the seismic response of the building significantly. Ying Zhou *et.al.* [15] proposed a practical design method for reinforced concrete (RC) structures with viscous dampers and concluded that the proposed design method satisfied the requirement of design and recommended the further development of fluid viscous dampers (FVD). M. Arefi [16] wanted to study the optimal damping ratio of the viscous fluid dampers (VFD) in braced frames and concluded that a damping ratio of 10 to 30 gave desired impact.

Samuel Infanti *et.al.*[17] explained the technology of application of tuned mass dampers and fluid viscous dampers to tall structures and proved that viscous dampers can be effectively used in different configurations to minimise the seismic responses of tall buildings to wind and earthquake loads. Sachin Dangi, *et.al.*[18] studied the behaviour of G+6 storey framed structure with shear wall on sloping ground for different slope angles and observed significant reduction in lateral displacements and member forces when shear wall was provided in all cases of slopes. P. R.Vaidya [19] carried out response spectrum analysis of 4 building models with different configuration of shear wall position and concluded that as short columns are the most critical member for building on sloping ground, shear walls must be placed near them to have a good control over shear forces and bending moment in the column. MD Mujeeb, *et.al.* [20] investigated the seismic behaviour of a G+10 storey building connected with and without fluid viscous dampers in seismic zone IV and concluded that, dynamic response of the building was minimum for dampers placed on all four corners.

In most of the aged cities there is lack of land for new constructions due to which high rise buildings are being built in hilly regions. The response of buildings during earthquake depends upon the distribution of mass and stiffness in both the vertical and the horizontal direction, both of which vary in case of buildings situated in hilly areas. The irregularity and asymmetry in the shape of the

3. BUILDING MODEL DETAILS

The structural model considered in this study is a 5-storeyed building of step-back configuration situated on a 27 degree slope. The model has 5 bays along both X and Y direction with each bay being 5m in length and 5m wide. The typical height of the floor is 3.5m. Further details are tabulated and presented in Table-1. The modelling is done in the ETABS v18.1.1 software. A step-back configuration of the building model is selected as it most the vulnerable configuration when exposed to seismic excitation. For response spectrum analysis, the seismic parameters considered are presented in Table-2.

Table -1: Details and dimensions of building model

Sr. No.	Parameters	Values
1	Type of structure	SMRF RC frame
2	Grade of concrete	M30
3	Grade of steel	Fe415
4	Floor height	3.5 m
5	Beam size	300mm x 550mm
6	Column size	300mm x 600mm
7	Slab thickness	150mm
8	Live load on floor	2 kN/m^2
9	Live load on Roof	1.5 kN/m^2
10	Dead load on floor	3 kN/m^2
11	Size of Footing	1m x 1m
12	Wall load	9.11 kN/m^2
13	Parapet Wall Load	6.62 kN/m^2

Table -2: Seismic Parameters (IS Code 1893:2016)

Sr. No.	Parameters	Values
1	Seismic Zone	V (Z=0.36)
2	Importance Factor	1.2
3	Damping	5%
4	Site Class	Type II (Medium)
5	Response Reduction	5

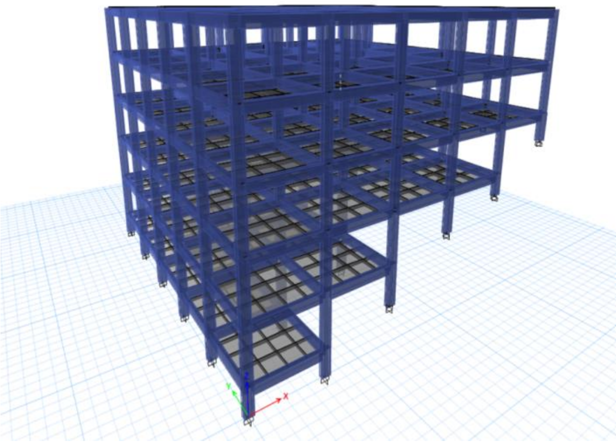

Fig -1: Model of the Step-back Building (FXB).

4. SYSTEM DEVELOPMENT

Analysis of the building frames has been done in ETABS18.1.1, structural analysis software used for static and dynamic analysis. Response Spectrum analysis is performed on three design formats:

1) Fixed Base Building – FXB (Acronym) – Building with fixed supports [Fig-1].
2) Flexible Base Building – FLB – Building with soil-structure interaction [Fig-3].
3) Flexible Base Building with Dampers – FLB750 – Building with soil structure interaction employing fluid viscous dampers of 750 kN capacity [Fig-4].

For the analysis, Response Spectrum Method is used to obtain the behaviour of the building. The fixed base building (FXB) is modelled as building with fixed supports and analysed [Fig-1]. Then for the flexible base building (FLB), the soil-structure interaction is simulated by assigning a total 6 nos. of equivalent springs at the footing of each column for 6 degrees of freedom [Fig-2]. Spring stiffnesses are calculated from formulas [Table 3] given by Wolf (1985) [21]. The soil properties [Table-4] are taken from Chougule and Dyanaval (2013) [9]. And then fluid viscous dampers of 750kN capacity are employed to the flexible base building (FLB750) to get the final results. The soil is taken as soil type (II) – Medium and spring stiffnesses are calculated accordingly. The fluid viscous dampers are modelled as link property in ETABS and their properties [Table-6] are taken from Taylor's Damping Devices [25] for 750 kN capacity dampers.

Table -3: Spring Constants [24]

Spring Constants	**Equivalent Radius (R_o)**
$K_x = K_y = \dfrac{32(1-\vartheta)GR_o}{(7-8\vartheta)}$	$R_o = \dfrac{A_f}{\sqrt{\pi}}$
$K_z = \dfrac{4GR_o}{(1-\vartheta)}$	$R_o = \dfrac{A_f}{\sqrt{\pi}}$
$K_{Rx} = \dfrac{8GR_o{}^3}{3(1-\vartheta)}$	$R_o = \sqrt[4]{\dfrac{4I_{yf}}{\pi}}$
$K_{Ry} = \dfrac{8GR_o{}^3}{3(1-\vartheta)}$	$R_o = \sqrt[4]{\dfrac{4I_{xf}}{\pi}}$
$K_{Rz} = \dfrac{16GR_o{}^3}{3}$	$R_o = \sqrt[4]{\dfrac{2(I_{xf}+I_{yf})}{\pi}}$

G is shear modulus of selected soil, ϑ is the Poisson's ratio of soil and R_o is the equivalent radius; A_f is the area of the footing and I_{xf} and I_{yf} are moments of inertia of the column footing about X and Y axis, respectively. The values of shear modulus (G) and Poisson's ratio (ϑ) for the medium type soil is taken from Chougule and Dyanaval (2013) [9]. The elastic properties of foundation soil for hard and medium soil are tabulated in Table-4 and the numerical values of spring constants for isolated footing for medium type of foundation soil are summarized in Table-5.

Table -4: Soil Properties [9].

Type of Soil	**SBC of soil (kN/m²)**	**Young's Modulus (kN/m²)**	**Poisson Ratio**	**Shear Modulus (G)**
Medium (II)	160	50000	0.45	17241.37
Hard (I)	250	200000	0.45	68965.51

The properties of medium soil are substituted into formulas in table 3 for footing size of 1m x 1m and spring stiffnesses are calculated. The spring stiffnesses are tabulated in Table-5.

Table -5: Spring stiffnesses calculated for medium soil

Soil Type	**Medium**	**Hard**
K_x	50353.607	201414.51
K_y	50353.607	201414.51
K_z	70744.737	282979.07
K_{Rx}	15540.37	62161.519
K_{Ry}	15540.37	62161.519
K_{Rz}	17094.41	68377.67

The springs having stiffnesses for medium soil from table 5 are placed at the footing of each column to simulate the soil-structure interaction effect [Fig-3]. Then the fluid viscous dampers are added to the model at every bay at the corner of the building as indicated in figure 4. Properties for fluid viscous dampers are taken from Taylor' Fluid Viscous Dampers [25] to control the seismic deformations of the building. The properties of the Taylor's fluid viscous dampers are tabulated in table 6 [25].

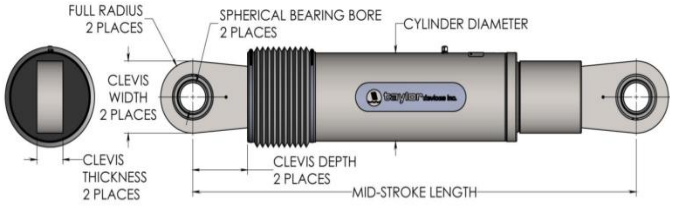

Fig -2: Taylor's Fluid Viscous Dampers [25].

Table -6: Properties of Fluid Viscous Dampers [25].

Force (kN)	**Taylor Device Model No.**	**Spherical Bearing Bore Dia. (mm)**	**Bearing thick-ness (mm)**	**Clevis Depth (mm)**	**Weigh t (kg)**
250	17120	38.10	33	114	41
500	17130	50.80	44	150	82
750	17140	57.15	50	184	136
1000	17150	69.85	61	210	193

The springs are attached at each column base of the flexible base building model as shown in figure 3 to simulate soil-structure interaction. And figure 4 shows the flexible base building with attached fluid viscous dampers of capacity 750 kN.

After successful modeling of all three formats of the building, namely FXB, FLB and FLB750; seismic analysis is conducted using the Response Spectrum Method in the ETABS v18.1.1 software.

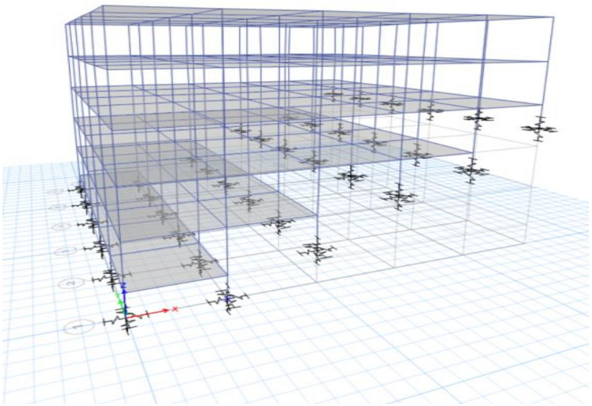

Fig -3: Flexible Base Building (FLB)

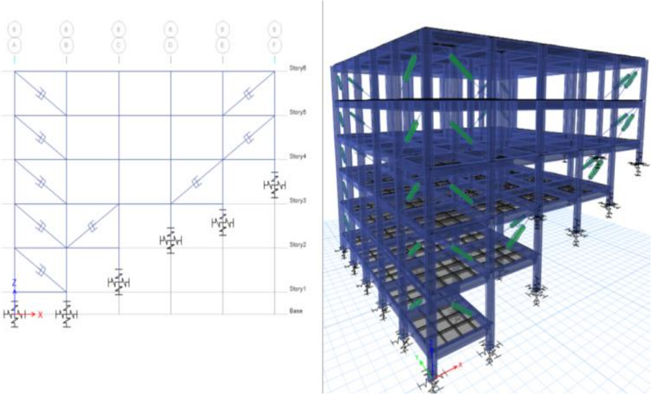

Fig -4: Flexible Base Building with 750 kN FVD (FLB750)

5. RESULTS AND DISCUSSION

Three models namely, FXB, FLB and FLB750 are analyzed by response spectrum method and the results are compared in terms of maximum storey displacement, maximum storey shear, base shear and torsional irregularity.

5.1 Maximum Storey Displacement

The maximum storey displacement are obtained and compared amongst the building models. From the Chart-1 and Chart-2, it can seen that when soil-structure interaction is considered the maximum storey displacement increases in both X and Y direction. This shows that if soil-structure interaction is not considered the building response to seismic excitation is underestimated. The maximum storey displacement is more in Y-direction as compared to X-direction, which suggests the building is stiffer in X-direction. And after employing the fluid viscous dampers, the storey displacement decreases.

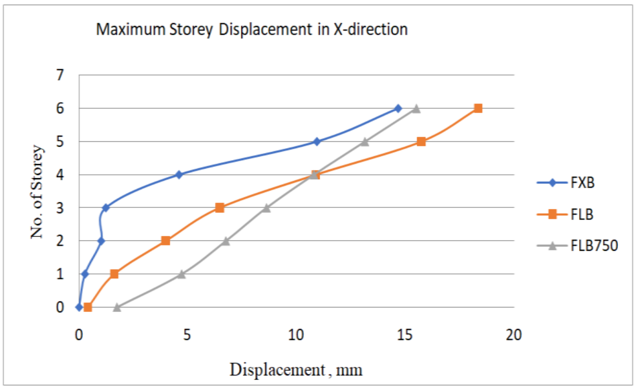

Chart-1: Maximum Storey Displacement in X-direction.

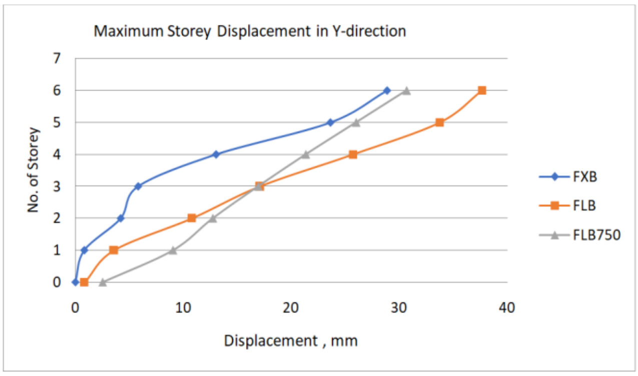

Chart-2: Maximum Storey Displacement in Y-direction.

5.2 Maximum Storey Drift

The maximum storey drifts are obtained and compared amongst the building models. Maximum storey drift should not exceed 0.004 [21]. From the charts Chart-2 and Chart-3, it can seen that when soil-structure interaction is considered the maximum storey drift increases. This shows that if soil –structure interaction is not considered the building response to seismic excitation is underestimated. And after employing the fluid viscous dampers, the storey drift decreases.

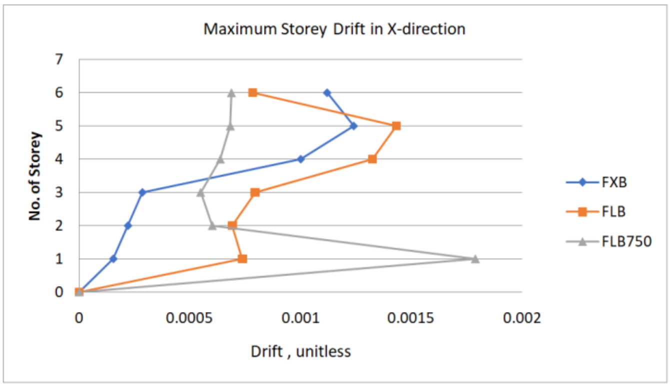

Chart-3: Maximum Storey Drift in X-direction.

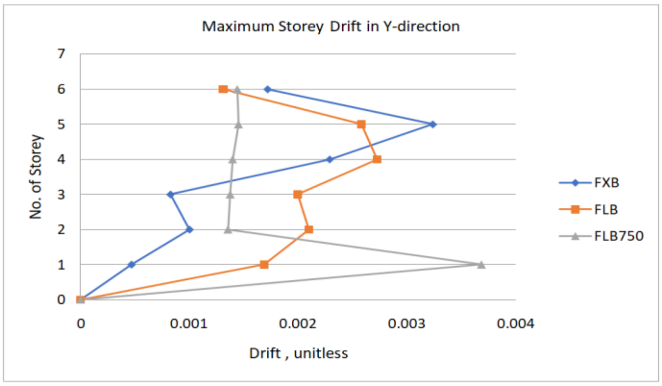

Chart-4: Maximum Storey Drift in Y-direction.

5.3 Base Shear

From the values of base shear in the Chart-5 given below, it is inferred that there is significant reduction of 32% in base shear when soil structure interaction is considered. There is an increase of 37% in the value of base shear when the fluid viscous damper of 750 kN is employed. Though the value of base shear is reduced while considering soil-structure interaction (SSI), its distribution is uneven and it suggests development of torsional moment due to static and accidental eccentricity. Also the increase in base shear is expected when viscous dampers are employed as they increase the stiffness of the building.

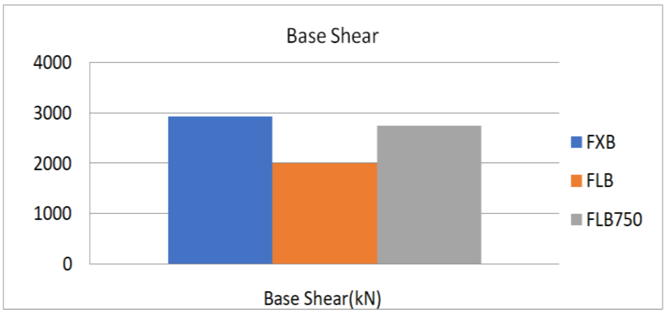

Chart-5: Maximum Base Shear

5.4 Torsional Irregularity

Torsional irregularity is to be considered when floor diaphragms are rigid in their own plan in relation to the vertical structural elements that resist the lateral forces. Torsional irregularity is said to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure [21]. From the Chart-6, it is seen that the fixed base building (FXB) is inherently irregular due to its geometry. But after considering soil-structure interaction, the irregularity becomes even greater. After employing the fluid viscous dampers, the irregularity decreases and fall within the limit and makes the building model stable. It can be observed that the FLB750 (Building with soil structure interaction with FVD) has the diaphragm maximum drift to average drift is well below 1.2 as specified by IS 1893:2016 [21].

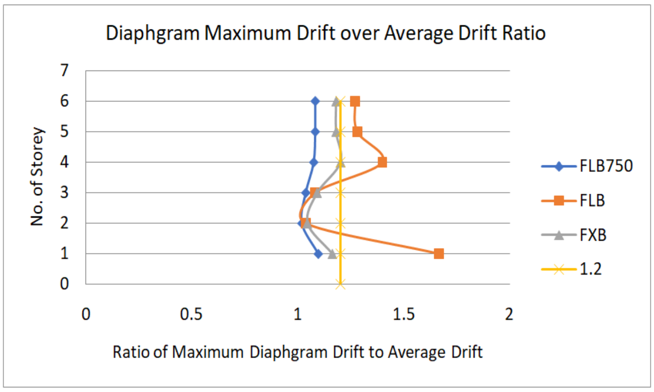

Chart-6: Ratio of Maximum Drift to Average Drift of Diaphragms.

6. CONCLUSIONS

The seismic assessment of building situated on slope considering soil-structure interaction is presented in this paper. Also the effect of fluid viscous dampers on seismic responses of the building is shown. The models were developed and analyzed. From the results presented in previous section, following conclusions are drawn:

1. The structure without soil structure interaction overestimates forces (base shear) and underestimates the responses (max. storey displacement, max. storey drift and torsional irregularity).

2. When the soil structure interaction is considered for a building, the base shear is reduced by 32%, and after the application of fluid viscous dampers to the structure with flexible base, there is 37% increase in the base shear but it is far less than the base shear of fixed base building so soil structure interaction must be considered while designing, as it will result in selecting a more economical section.

3. Though the base shear is reduced by considering soil structure interaction, the distribution of shear force in the building frame is uneven, which suggests development of torsional moment due to static and accidental eccentricity.

4. Torsional irregularity is present in the fixed base building, but when soil structure interaction is considered the irregularity increases beyond the 1.2 ratio. This shows that soil structure interaction is important in design of buildings. When fluid viscous dampers are used, the ratio of diaphragm maximum drift to average drift fall below 1.2 and the torsional irregularity is taken care of.

5. This shows that fluid dampers can efficiently reduce the seismic responses of the building and soil structure interaction should be considered while designing buildings on slope. Fluid viscous dampers of lager capacity can be used to further reduce the seismic responses of the building.

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