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Control of Displacement of Irregular Buildings Provided with Dampers

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ABSTRACT- The application of tuned mass damper techniques with the purpose of mitigating the impacts of seismic affecting high-rise structures. The top story or stories of a building are isolated in the planned layout so that they may function as the 'tuned' mass. From the theoretical perspective of time-delay-displacement (TMD) systems, this method eliminates the addition of unnecessary duplicate mass.

This parametric analysis of a trade-off compares the effectiveness of dispersing stiffness using resettable devices and rubber bearings. The effectiveness of these redesigned structural control systems is investigated by spectral analysis of a simplified 2-degree-of-freedom model, and the general validity of the best generated parameters is shown. The spectrum analysis concludes with a first pass at the design that is optimum and consistent with current design practices.

When it comes to retrofitting, redeveloping, or upgrading a structure, the building systems offer a great deal of potential for applications of structural control. Consistent response reductions are obtained over a wide variety of structure natural frequencies when using this technique. Without the usual restricted emphasis of prior research, the overall performance of the structure is investigated using a variety of performance criteria.

Conventional structural reaction indicators such as performance and storey/structure hysteretic energy and wreckage requirement developed from statistical analysis are utilized to evaluate the integrity of the structure. This study provides a framework for creating building systems, with an emphasis on their flexible structural configuration and the resulting performance. Therefore, construction systems have a lot of promise, particularly for retrofitting in areas where a paucity of land prevents sprawling cities from growing horizontally. Finally, the method given provides a glimpse into how rethinking conventional methods with cutting-edge technology might yield substantial improvements.

KEYWORDS- Viscous damper (VD), Viscoelastic damper (VED), and Tuned mass damper (TMD), Pendulum Tuned Mass Damper (PTMD)

I. INTRODUCTION

A. *General*

Passive supplemental energy dissipating devices or base isolation devices are effective solutions that can improve structural performance. There are various energy dissipation devices, such as the metallic dampers, friction dampers, viscoelastic dampers and the fluid viscous dampers. A comprehensive review of the special characteristics of these devices, along with the research issues relevant to their behaviour under dynamic loading is available in published literature. Amongst these energy absorbing devices, fluid viscous dampers sometimes have applications in vibration control of various structural and mechanical systems. In this study we have used viscous damper to control the displacement in the building.

A common form of vertical discontinuity increases from reduction of the lateral dimension of the building along its height. This building category is labelled as `stepped' building in this paper. This building form is becoming increasingly popular in modern multi-story building construction mainly because of its functional and aesthetic architecture. In particular, such a stepped form provides for adequate daylight and ventilation for the lower stories in an urban locality with closely spaced tall buildings. This type of building provides for compliance with building bye-law restrictions related to `floor area ratio' (practice in India).

Stepped buildings are characterized by staggered abrupt reductions in floor area along the height of the building, with successive drops in mass, strength and stiffness (not necessarily at the same rate). changes in stiffness and mass height-wise give the dynamic feature of these buildings distinct from the regular building.

B. *Viscous damper*

A very large number of mechanical systems are in use, and there are several potential equipment and mechanical systems whose performance can be greatly enhanced by using the right type configuration of these dampers. These dampers are found to be efficient in both, base isolation and as energy dissipation devices for structural control.

Fluid viscous dampers are good for increasing the performance of the building because they minimize the deformation demand and the force demand. A main feature of fluid viscous damper is that they are capable of providing a very high energy dissolution density (i.e., the energy dissolution is very large in comparison to the size of the damper). These dampers have been found to be effective for both minimum-duration loads as well as longer-duration loads (earthquake forces or wind loads)

C. *Viscoelastic damper*

Encapsulated viscoelastic materials (VEM) provide the advantage of minimize vibrations over a long range of frequencies compared with TMDs. However, viscoelastic damping works optimally only Resotec product in composite floor for a specific mode of vibration. However, use of viscoelastic materials is a cheap method of increasing the damping if comprise during construction. An instance of viscoelastic damping can be observed in the Resotec system, as depicted in Figure 1. This system consists of a thin layer of viscoelastic material with high damping properties, encompassing a specific total thickness of about 3 mm. Resotec is sandwiched between the top flange of the floor steel beams and concrete slab for a proportion of the beam near each end where the shear stresses are the greatest. It is delineated that the damping of a fitted-out floor is typically twice by the amalgamation of Resotec. However, this product needs to be incorporated within the floor during construction and is not advisable as a remedy measure.

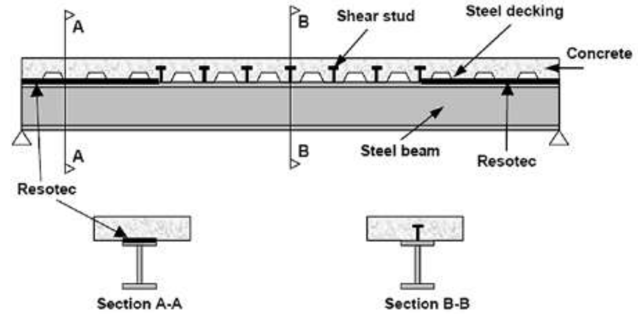


Figure 1: Resotech product in composite floor

D. *Tuned mass damper*

The principle of a TMD was initially utilized when Den Hartog in 1947 reintroduced the dynamic absorber invented by Frahm in 1909. Generally, a TMD consists of a mass, spring, and dashpot and is tuned to the natural frequency of the primary system. When the foremost system begins to oscillate it excites the TMD into motion and hence the TMD dissipate energy from the adjacent vibrating floor. The TMD inertia forces produced by this motion are anti-phase to the excitation force. The first use of a TMD for floor vibration was invented by Lenzen who used small TMDs with a all the mass of about 2% of the floor mass.

The TMDs were made of steel hung by springs and dashpots from the floor beams. Lenzen reported floors with annoying vibration characteristics became satisfactory by tuning the TMDs to a natural frequency of about 1.0 Hz less than that of the floor and using a damping ratio of 7.5%. An example of a latest TMD is a Pendulum Tuned Mass Damper. Experiments were carried out to test the performance of the PTMD and it is resulting that the damper reduced the floor vibration in the range of 50%–70%. Floor vibrations due to walking excitation typically produce very small floor displacements which are generally less than 0.1 mm. A TMD would typically have a maximum displacement around ten times larger than the floor (i.e., in the order of 1 mm). In reality, it is difficult to produce a practical viscous damper that provides a reasonable level of damping given this very small displacement

E. *Project definition*

In order to minimize the maximum seismic response of structures like buildings, bridges and other civil structures, a variety of passive energy reducing devices have been implemented on them for over forty years. Various experimental and analytical experiments about structures with supplemental damping have been presented in the past.

So, this topic has been chosen for finding the performance of the vertical geometrically irregular structure provided with dampers analytically under earthquake excitation for further contribution in this area.

F. *Organization of thesis*

In this thesis, Chapter I contains introduction about the topic and the work of the thesis. Chapter II discusses literature review of the various journal paper related to this topic and identifies areas where further research is required. Chapter III gives the methodology of this research work and the step-by-step process of the work. Chapter IV consists of the validation of the software which has been used in this work for analysis of the problem. Chapter V contains the analysis of buildings with and without damper. Chapter VI concludes the thesis stating the finding of study carried out.

II. LITERATURE REVIEW

A. *General*

Passive supplemental energy dissipating devices or base isolation devices are effective solutions that can improve structural performance. There are various energy dissipation devices, such as the metallic dampers, friction dampers, viscoelastic dampers and the fluid viscous dampers. A broad review of the special characteristics of these devices, along with the research provided relevant to their behaviour under dynamic loading is given in published literature. In the middle of these energy absorbing devices, fluid viscous dampers frequently have applications in vibration control of various structural and mechanical systems. A very huge number of mechanical systems are in use, and there are many potential equipment and mechanical systems whose output can be greatly enhanced by using the right type/configuration of these dampers. These dampers are found to be efficient in both, base isolation and as energy dissipation devices for structural control.

B. *George D. Hatzigeorgiou, Nikos G. Pnevmatikos [1]*

George D. Hatzigeorgiou, Nikos G. Pnevmatikos have studied the inelastic response behavior of buildings with supplemental viscous dampers under close by source pulse like ground motions. we know that design of dampers in need of the effectual evaluation of high seismic velocities or maximum damping forces. In order to avoid complicated methods, such as the dynamic inelastic analysis, it has been proposed that a simple and effective evaluating method for these maximum values using the inelastic velocity ratio. The evaluation of maximum inelastic velocity or damping force allows from their corresponding elastic counterparts through this ratio which is a modification factor.

In this paper, an extensive parametric study was carried out by the authors, to examine the influence of characteristics of structure (period of vibration, post-elastic stiffness, force reduction factor), of supplemental damping (equivalent viscous damping ratio) and of ground motion (type of earthquake) on the maximum seismic velocities and damping forces.

C. Jae-Do Kang, Hiroshi Tagawa [2]

Jae-Do Kang, Hiroshi Tagawa presented a new vibration control system based on a seesaw mechanism with fluid viscous dampers. The suggest vibration control system contain 3 parts: seesaw, brace, and fluid viscous dampers (FVDs). The advantages of the proposed system are only tensile force appears in bracing members. Consequently, the brace buckling problem is negligible. This benefit is useful for steel rods for bracing members. Long steel rods are applicable for bracing between the seesaw members and the moment frame connections over several stories by introducing pre-tension in rods.

In this work the relation between the frame displacement and the damper deformation is derived. Based on this relation analysis models of simplified type of seesaw energy dissipation system are developed. Eventually, with and without dampers seismic response analyses are conducted for three-story and six-story steel moment frames. A diagonal-brace-FVD system and a chevron-brace-FVD system are analyzed for comparison in addition to the proposed system. For the six-story frame parameter analyses of rod stiffness and damping coefficient are conducted. The displacement is discussed for the maximum story drift angle and response of the top floor. Result shows a high capability of seesaw energy dissipation system for improving the structural response.

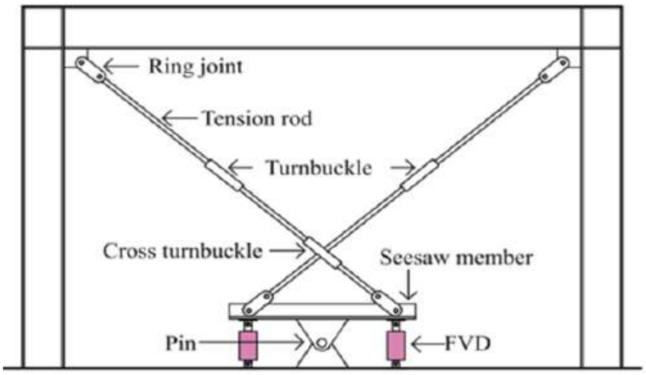


Figure 2: Proposed vibration control system

A damper-housing filled with fluid is contained in Fluid viscous dampers (FVDs) include a piston head with orifices, which is mostly a compound of silicone or a similar type of oil. Energy is dissipated in the damper as the piston rod moves through the fluid and forces the fluid to flow through the orifices in the piston head.

Vibration control system with long rods and seesaw mechanism was proposed by Kang and Tagawa. Fig.2 portrays the proposed vibration control system comprising a Brace, Seesaw, and FVDs. A couple of FVDs are installed in the seesaw member, which is pin-supported. The brace members comprise two tension rods, turnbuckles, and a cross-turnbuckle. The seesaw member from the edge intersected by tension rods. By introducing pre-tension in rods, only tensile force appears in bracing members. Accordingly, the brace buckling problem is negligible, and steel rods are applicable as bracing between the seesaw member and the moment frame connections over some stories.

The FVDs dissipate energy via movement of the piston through a highly viscous fluid when the frame deforms under a lateral load. The tensile axial force is generated immediately in the opposite rod when the lateral load direction reverses. The seesaw mechanism characteristics is the base of this behavior.

D. Dilip I. Narkhede, Ravi Sinha [3]

Results presented by this paper is from experimental study to distinguish fluid viscous dampers. To evaluate the relative performance of structures with fluid viscous dampers the mathematical formulation and a numerical study has been done and those viscus dampers are subjected to short-duration shock (impulse) loading. The response has been investigated of influence of damper nonlinearity (α) and the supplemental damping ratio (ξsd). The supplemental damping ratio is found by equivalent linearization using the concept of equal energy dissipation of nonlinear fluid viscous dampers when subjected to shock excitation. For preliminary decisions some design charts also used on parameters of nonlinear dampers to be used in design are also presented by this paper.

E. A.V. Bhaskararao, R.S. Jangid [4]

A.V. Bhaskararao, R.S. Jangid presented analytical seismic responses of two adjacent structures. Modeling of a single-degree-of-freedom (SDOF) structure, connected with a friction damper is presented in this paper. They also derived Closed-form expressions during non-slip and slip modes and are presented in the form of recurrence formulae. However, for damper connected multi-degree-of-freedom (MDOF) structures the derivation of analytical equations for seismic responses is quite cumbersome as it involves some dampers vibrating in sliding phase and the rest in non-sliding phase at any instant of time.

Two numerical models of friction dampers are proposed for MDOF structures to overcome this difficulty considering an example of SDOF structures and validated with the results obtained from the analytical model. The dynamic behavior of the two connected SDOF structures found that the proposed two numerical models are predicting. Further, displacement, acceleration and shear forces of connected adjacent structures the effectiveness of dampers in terms of the reduction of structural responses is investigated.

To investigate the optimum slip force of the damper a parametric study is also conducted. In addition, rather than providing dampers at all floor levels the optimal placement of dampers, is also studied to minimize the cost of dampers. To connect adjacent structures of different fundamental frequencies using friction dampers can effectively reduce earthquake induced responses of one structure if the slip force of the dampers is appropriately selected is also shown by results. Further, Earthquake response of the combined system can be reduced significantly by providing lesser dampers at appropriate locations rather than connecting two adjacent structures at all floors.

The authors have also found that connecting the adjacent structures with passive energy dissipation devices has attracted the attention of many researchers due to its ability in mitigating the dynamic responses and also to reduce the probability of pounding. Additional space is not needed to install of such devices and effectively utilized the free space available between two adjacent structures for placing the control devices. To reduce the mutual pounding of structures which occurred in past major seismic events buildings interconnected by non-linear hysteretic damping devices such types of arrangement are also helpful.

F. Saidi, E.F. Gad, J.L. Wilson, N. Haritos [5]

The use of light material composite systems and long span floor systems are included in the recent changes in the construction of building floors. Although many advantages can get from these changes, due to human activities such floor systems can suffer from excessive vibration. Due to the reduction in inherent damping associated with modern fit outs this problem is exacerbated in office buildings.

Excessive floor vibrations are often realized after the completion of construction or following structural modifications and normally arise due to inadequate knowledge of the damping values in the design process. Thus, to reduce floor accelerations rectification measures are normally required. To reduce floor vibrations a new innovative passive viscoelastic damper. To achieve various damping values this damper can be easily tuned to the fundamental frequency of the floor and can be designed. The analytical development of the damper presented on a prototype to demonstrate its effectiveness with experimental results is discusses in this paper.

G. Carlos A. Martínez, Oscar Curadelli, María E. Compagnoni [6]

Nowadays, it is known that the seismic performance of buildings can be improved, through the use of energy dissipation devices. However, the locations and sizes of these devices need to be properly defined, for efficiency and structural safety.

In this work, the focus was on a procedure to optimally define the damping coefficients of added linear viscous dampers to meet an expected level of performance on buildings under seismic excitation is proposed. The performance criterion is expressed in terms of a maximum inter story drift, which is one of the most important limitations provided by the seismic design codes. The effectiveness of the damper distribution obtained by means of different objective functions is also assessed for a given level of performance.

Knowing that the main contribution to the total uncertainty with the aim of achieving robust results is due to the excitation, through a stationary stochastic process is the most appropriate approach to model the excitation is defined by the seismic design code and characterized by a power spectral density compatible with the response spectrum. Accordingly, the structural response is obtained in the frequency domain. The proposed procedure is verified, on planar and three-dimensional steel buildings with coupled lateral and torsional vibrations through the numerical example.

H. Kyung-Won Min, Ji-Young Seong, Jinkoo Kim [7]

For determining the required damping force of a friction damper this study proposed a simple design procedure by installing friction damper in a single-story structure. By approximating a nonlinear Coulomb damping force with an equivalent viscous damping force, the analysis model was transformed into an equivalent mass-spring-dashpot system.

For the dynamic magnification factor (DMF) for a steady-state response the derivation of closed form solution is using the energy balance equation is evaluated. Using the DMF at the natural frequency the equivalent viscous damping ratio was defined. The transfer function between input harmonic excitation and output structural response was obtained from the DMF, and with and without friction dampers the response reduction factor of the root mean square (RMS) of displacements was analytically determined.

Mean response reduction factors matched well with the target values it was concluded, based on the dynamic analysis results.

I. Pradip Sarka, A. Meher Prasad, Devdas Menon [8]

This paper proposes a new method of quantifying irregularity in the building frames, accounting for dynamic characteristics (mass and stiffness). A basis for assessing the degree of irregularities in a stepped building frame is provided by the proposed `regularity index'. Empirical formula for estimating fundamental period for regular frames specified by modification of the code also proposes in this paper, to estimate the fundamental time period of the stepped building frame. A function of the regularity index is the proposed equation for fundamental time periods. For various types of stepped irregular frames, it has been validated.

J. Concluding Remarks of Literature Survey

In this literature review it is found out that examining the maximum velocities and the maximum damping forces for nonlinear structures generally present lower values for these parameters in comparison with the counterparts of the elastic systems.

It is observed that the effective viscous damping ratio, the period of vibration and the forced reduction factors strongly affect the inelastic velocity ratio. Furthermore, this ratio also affected by the type of seismic fault mechanism also. Fluid viscous dampers (FVDs), Brace, seesaw these three parts are comprised by the proposed seesaw energy dissipation system (SEDS). By introducing pre-tension in rods, the friction dampers were found to be very effective in reducing the earthquake responses of the adjacent connected structures. From the above literature study it was found that buildings with vertical geometric irregularity increase the displacement of the building. The performance of vertical geometrically irregular buildings provided with dampers would be evaluated in this thesis work.

K. Objectives of the Project work

- To estimate the effect of vertical geometric irregularity of the building on the top story displacement of the frame without passive dampers.
- To find out the number of dampers required to passively control the top story displacement of the vertical geometrically irregular frames.
- To study the reduction in displacement by providing dampers in 0%, 15%, 30%, 45%, 60% and 75% vertical geometrically irregular buildings.

L. Scope of the Project

During this project work analysis of the G+12 buildings with vertical geometric irregularity of 0%, 15%, 30%, 45%, 60% and 75% provided with dampers has been studied. For analysis purpose the software sap 2000-17 has been used.

III. METHODOLOGY

For studying the Pseudo Static analysis of the vertical geometrically irregular buildings provided with dampers a G+12 building was selected. The plan of the model has plotted dimensions 21 m x 26 m in X-direction and Y-direction respectively. The buildings are modeled as fixed base buildings with 0%, 15%, 30%, 45%, 60% and 75% of vertical geometric irregularity. The vertical geometric irregularity of the building is calculated from the IS1893-2002. For the analysis of the fixed base buildings response spectrum method as per IS1893-2002 was used in the software.

A. Design code perspective on stepped building

The stepped building form is recognized by several design codes, such as IS 1893-2002 [3] and ASCE 7:2005 [4], as a typical form of vertical geometric irregularity that merits special design consideration. As per IS 1893-2002, when the lateral dimension of the maximum offset (A) at the roof level exceeds 25% of the lateral dimension of the building at the base (L) such building forms are to be treated as vertically irregular, as shown in Fig.3 (a). As per ASCE 7:2005, when the horizontal dimension of the building in any story (Li) is more than 130% of that in an adjacent story (LiC1) this building will be considered as vertically irregular as shown in Fig.3(b). Evidently, the codes consider the ratio of geometric lateral dimension of one story of a building to the other story as a parameter to define vertical geometric irregularity. This does not account for the offsets in the other floors. Also, the definitions of vertical geometric irregularity in design codes do not account for gradual variation in vertical geometric irregularity. Moreover, they treat all kinds of geometrically irregular buildings as one category.

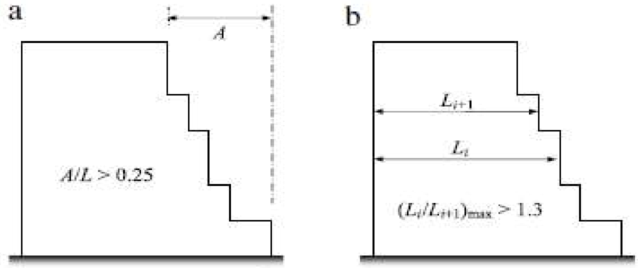


Figure 3: Vertical geometric irregularity according to (a) IS 1893:2002 and (b) ASCE 7:2005

Modeling of the selected structures is done in soft computing tool sap 2000-17. Pseudo static analysis was performed on the model. Response spectrum method was used to estimate the pseudo static loads on the frame.

B. Response spectrum method

The Response Spectrum is a method of estimation of maximum responses (acceleration, velocity and displacement) of a family of SDOF systems subjected to a prescribed ground motion. A set of possible forces and deformations a real structure would experience under earthquake loads given to the structural designer by the RSM utilizes the response spectra.

One Response Spectrum method and other Seismic Coefficient are two methods, In IS:1893 is described to carry out the analysis for earthquake forces. One Table (in Clause 4.2.1) is also provided to decide upon the method to be used, depending upon building height and zone. Building with irregular shape and/or irregular distribution of mass and stiffness in vertical and/or horizontal plane, it is clearly mentioned at the bottom of this table, shall be analyzed as per Response Spectrum Method. For all practical reasons, no building is uniform in all the respects (i.e., shape, mass/stiffness distribution in horizontal and vertical plane). This means that for no building, the Seismic Co-efficient method shall be resorted.

Response spectrum method is tedious and time-consuming process, analysts' resort to computer applications most of time. Now while, modeling the structure, in most of available software's, usually, one models the space frame, neglecting the in-fill wall stiffness. These results in flexible frames, and due to which, in most of cases, the program gives a higher time period and results into lower base shear. Today the seismic coefficient method should not be applied to anything other than mass concrete with the availability of powerful computers and software. In such a case the infill walls and slabs should be modeled. a reduction coefficient would not be applicable. These can be modeled as plates, if software has plate modeling capability. Alternatively, a pair of diagonal members connecting the four corners of the slab or wall (in each bay) could be used to mimic the shear behavior.

The truss members must consist solely of diagonal elements designed to bear axial loads. The elastic properties can be derived from first principles, by matching forces and deformations in a plate and the equivalent diagonals.

C. Seismic Base Shear

The seismic base shear V_B in a given direction shall be determined in accordance with the following equation:

$$V_B = A_h W \text{ -----------------------3.1}$$

Where:

A_h is the Seismic response coefficient

W represents the cumulative dead load and relevant segments of other loads.

D. Calculation of Seismic Response Coefficient

The seismic response coefficient A_h can be determined in compliance with the following equation:

$$\mathrm{Ah} = \frac{\mathrm{Sa}}{\mathrm{g}} \times \frac{\mathrm{ZI}}{\mathrm{R}} ---------3.2$$

Where:

Z is Zone factor

Sa/g is the Average response acceleration coefficient

R is the response reduction factor

I is the importance factor depending upon the functional use of structure

E. Period Determination

The fundamental period of the building, T, in the direction under consideration shall be established using the structural properties and deformational characteristics of the resisting elements in a properly validated analysis or, as another option, it is allowed to be considered as the estimated fundamental period, T, determined based on the specifications of sec. The fundamental period, T, shall not exceed the product of the coefficient for upper limit on calculated period from and the approximate fundamental period T.

$T = 0.075\ (h)^{3/4}$ for R.C.C. frame building

$T = 0.085\ (h)^{3/4}$ for building made of Steel frame

Where

h is the building height in meters

After analysis of the vertical geometrically irregular buildings having 0%, 15%, 30%, 45%, 60% and 75% of vertical geometric irregularity with and without dampers, the top floor displacement in x-direction have been studied in every structure. The effect of the vertical geometric irregularity on the displacement has been found out.

F. Concluding remarks

In this chapter a brief discussion about the methodology of the selected problem and the procedure of the work is covered. The software tool sap 2000-17 which is being used in this work is defined and it will be validated in the next chapter. Calculation of the % of vertical geometric irregularity is also discussed. Pseudo static analysis method which is used in this work is explained.

G. Steps to be followed in this study

- G+12 story Model has been chosen.
- Modeling of the buildings with 0%, 15%, 30%, 45%, 60% and 75% of vertical geometric irregularity have been done.
- Pseudo Static analysis has been done using sap 2000-17 with response spectrum method.
- Displacement parameters of the buildings without dampers were studied.
- Properties of the damper such as coefficient of damping was calculated by new method which is explained briefly in chapter 5
- Dampers were provided to all the models and the decrease in displacement after providing dampers was noted for each case.
- Number of dampers required to control the different vertical geometrically irregular buildings have been found.

IV. VALIDATION

A. Introduction

In this chapter validation of the soft computing tool sap 2000-17 is done by comparing the results obtained by the chosen software tool with those presented in the journal paper **"Dynamic Analysis of Reinforced Concrete Building with Plan Irregularities"[8]** International Journal of Emerging Technology and Advanced Engineering Volume 3, Issue 9, September 2013 published by Mohammed Yousuf, P.M. Shimpale [9].

B. Problem definition

Validation problem was taken from the above mentioned paper in which parameters for regular and irregular buildings have been studied.

A G+5 building was modeled as fixed base building and analyzed with soft computing tool SAP 2000-17. Pseudo static responses of the building were studied. The model is symmetric in plan as well as elevation. The CQC method was employed to get dynamic responses for 5% damping. Figure shows the plan of the model it has plotted dimensions 21 m x 26 m in X-direction and Y-direction respectively.

For the analysis of fixed base building response spectrum method as per I.S. 1893: 2002 was used. Fig 4. Represents response spectra for 5% damping rocky soil. X-axis shows period "T" in seconds and Y-axis shows spectral acceleration.

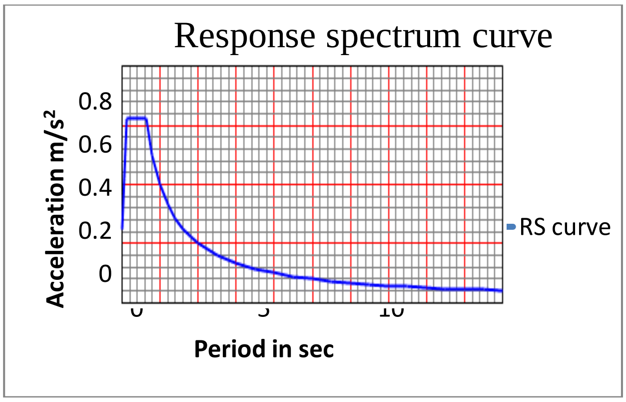


Figure 4: Figure of response spectrum I.S. 1893: 2002

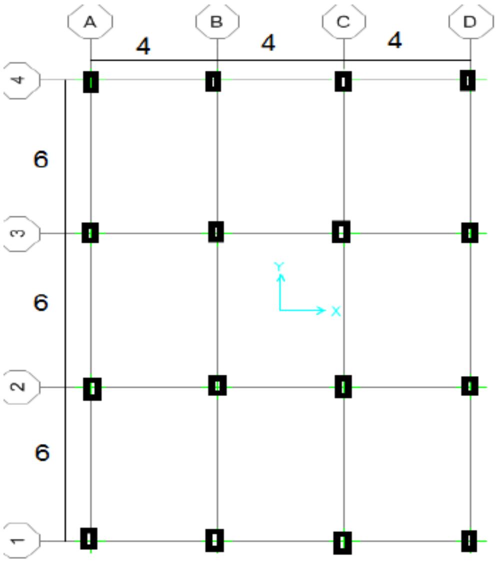


Figure 5: Plan of G+5 story building

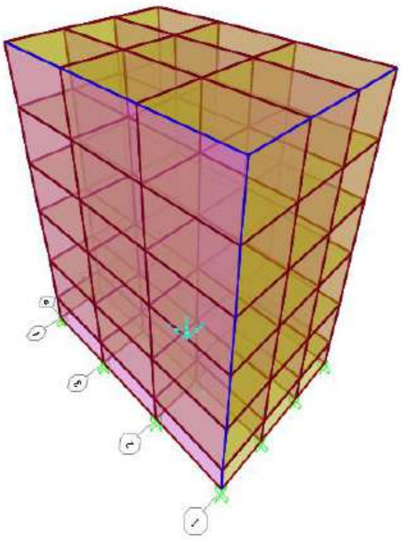


Figure 6: 3D view of G+5 story building

Figure 5 shows plan of the G+5 story building with position of the columns and 3D views of the G+5 story building shown in Figure 6.

C. *Assumed preliminary data of an RCC frame*

- Type of structure: Six storied rigid jointed R.C.C building.
- Seismic zone IV (Table No.2 I.S 1893(part 1):2002)
- Number of stories: Six (G+5)
- Floor height: 3.5 m (Bottom story 2 m)
- Imposed load: 5 KN/m^2
- Materials: Concrete (M25), Reinforcement (Fe 415)
- Size of columns: 230x500 mm (story 1-3), 230 x 350 mm (story 4-5)
- Size of beams: 230 x 600 mm
- Depth of slab 150 mm

D. *Comparison of the displacement results*

The building was analyzed with the assumed data as above and the results of the inter story drift was compared which were coming nearly equal to the calculated value of the paper. Displacement comparison of each floor of the frame in x-direction was tabulated in Table 1.

E. *Displacement at each floor in X-direction*

Table 1: Displacement comparison of each floor of the frame in x-direction

Sr. No	Story No	Displacement in X-direction (mm) SAP 2000-17	Displacement in X-direction (mm) in Paper
01	06	27	27
02	05	22.9	23
03	04	18	18.2
04	03	12.7	12.7
05	02	6.8	6.6
06	01	2.2	2.2

F. *Inter story drift is calculated by formula*

$\Delta u_i = u_i - u_{i-1} - \Theta_{i-1} h_i$ ---------------------4.1

Where,

u_i is the i^{th} story displacement
u_{i-1} is the $(i-1)^{th}$ story displacement
Θ_{i-1} is the angle of $(i-1)^{th}$ story displacement
h_i is the Height of i^{th} story

G. *Comparison of inter story drift at each story*

The comparison of the inter story drift of G+5 story building is tabulated in Table 2.

Table 2: Inter story drift comparison

No. of Story	Inter story drift (mm)	
	SAP 2000-17	Inter story Drift calculated in paper
1	0.00012	0.000125
2	0.00021	0.00020
3	0.00023	0.00023
4	0.00026	0.00026
5	0.00022	0.00021
6	0.00007	0.00008

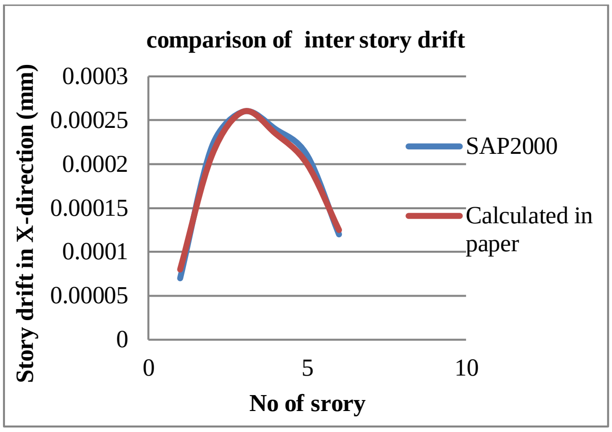


Figure 7: Figure of inter story drift comparison at each story

Figure 7 shows the comparison of inter story drift of G+5 story building in which the values calculated by the software sap 2000-17 nearly superimposed with values calculated in the paper of Mohammed Yousef, P.M. Shim pale [9].

H. *Concluding remarks*

From the above results we have seen that the displacement calculated by Yousuf and Shimple [9] in their study is matching with the results of the sap 2000-17 software. The inter story results are also matching so from above results we can conclude that our soft computing tool sap 2000-17 is validated for our study.

V. ANALYSIS OF BUILDINGS WITH AND WITHOUT DAMPER

A. *Definition of the problem*

A G+12 building was selected and modeled as fixed base buildings with 0%, 15%, 30%, 45%, 60% and 75% of vertical geometric irregularity. The plan of the model has plotted dimensions 21m x 26 m in X-direction and Y-direction respectively. Model was analyzed with soft computing tool Sap 2000-17. Pseudo Static responses of the building were studied. The CQC method was employed to get equivalent static for 5% damping. Fig 8 shows the plan of the model. For the analysis of fixed base building response spectrum method as per IS1893-2002 was used. Firstly, the building with 0% vertical geometric irregularity was analyzed with and without damper then the buildings with 15%, 30%, 45%, 60% and 75% of vertical geometric irregularity were analyzed with and without dampers.

B. *Response spectra parameters used for analysis in Sap 2000-17*

• Soil strata-	Medium soil
• Importance factor-	1.5
• Response reduction factor-	5
• Code-	IS1893-2002

C. *Properties of structure studied*

Assumed Preliminary data considered for 12 stories RCC frame is as follows

- Type of structure: Twelve storied rigid jointed RCC building
- Number of stories Twelve (G+12)
- Floor height 3.2 m
- Imposed load 2 KN/m^2
- Materials Concrete (M45), Reinforcement (Fe 415)
- Size of Columns 650 mm x 650 mm (story 1-7), 450 mm x 450 mm (story 8-12)
- Size of Beams 400 mm x 800 mm (outside beams), 400 mm x 600 mm (internal beams)
- Depth of slab 180 mm
- Response Spectra As per IS1893-2002

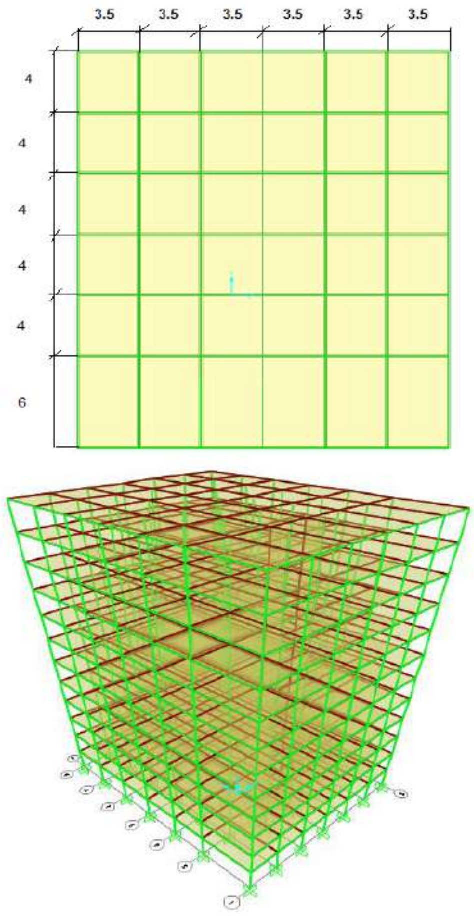


Figure 8: Plan and 3 D model of G+12 RCC frame with 0% vertical geometric irregularity

Plan and 3D model of G+12 RCC frame with 0% vertical geometric irregularity shown in Fig 8. The vertical geometric irregularity considered was of 15%, 30%, 45%, 60% and 75%. Plan of all the buildings are same. Buildings with 15%, 30%, 45%, 60% and 75% vertical geometric irregularity are shown in Fig 9, Fig 10, Fig 11, Fig 12 and Fig 13.

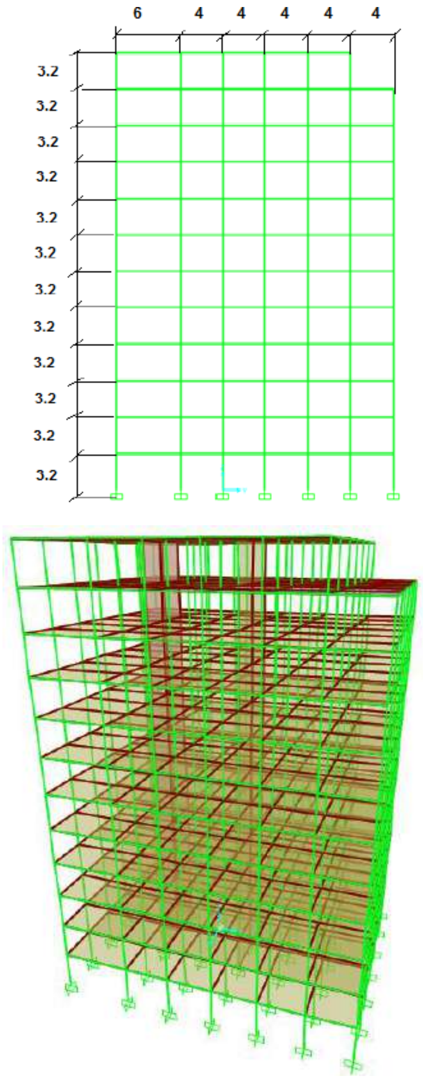
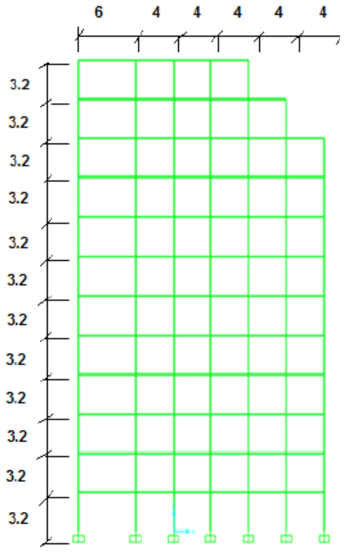


Figure 9: Building with 15% vertical geometric irregularity



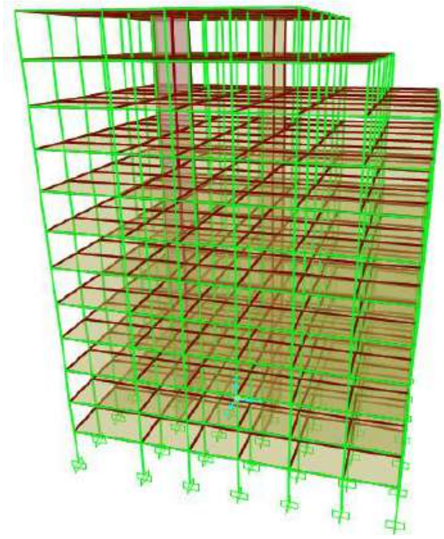
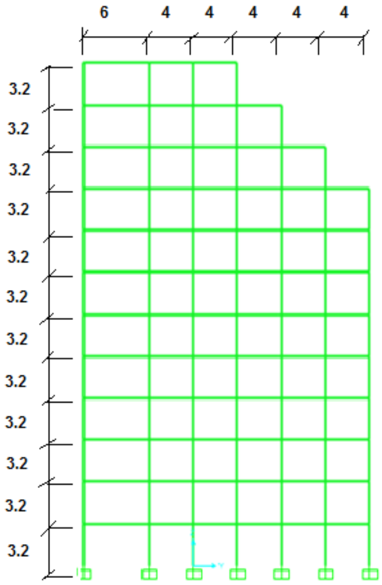


Figure 10: Building with 30% vertical geometric irregularity



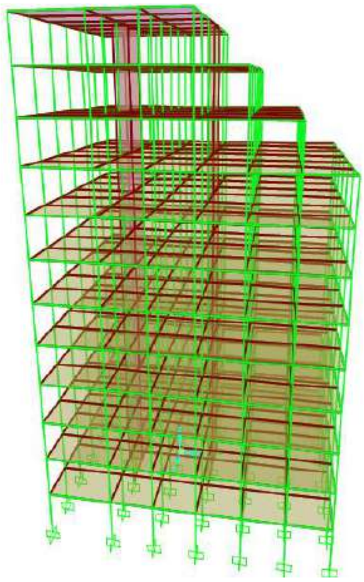
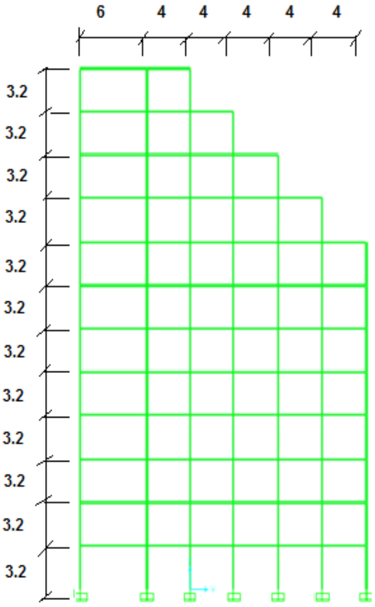


Figure 11: Building with 45% vertical geometric irregularity



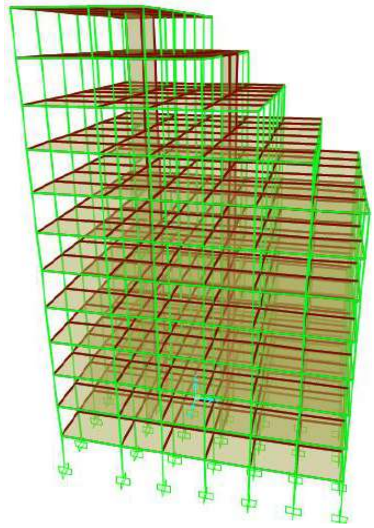
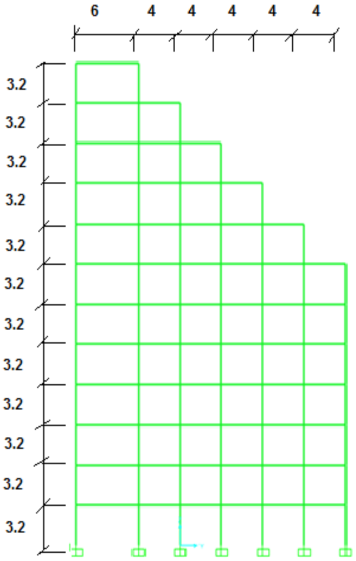


Figure 12: Building with 60% vertical geometric irregularity



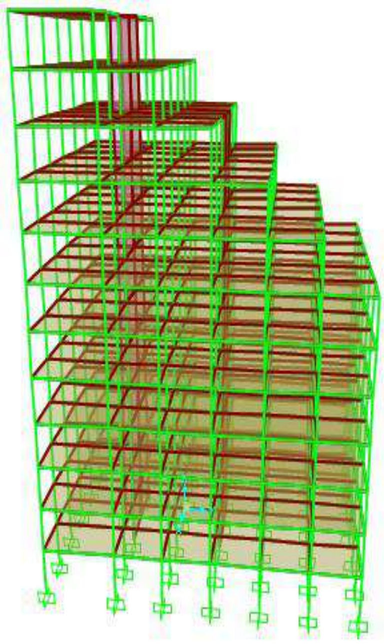


Figure 13: Building with 75% vertical geometric irregularity

Firstly, the Pseudo Static analysis of the building with 0% vertical geometric irregularity was carried out with response spectrum method as per IS1893-2002. The parametric study of the displacement of the frame without damper was calculated. Then trials were taken with varying numbers of viscous dampers provided at each location and a few sets of locations were investigated. The details of all these trials are discussed in the following.

D. Calculation of coefficient of damping

To find out the coefficient of damping first of all steel double angle of (100 mm x 80 mm x 8 mm) bracings were provided at all bays in each direction and the axial force in the respective bracings was calculated. The angle size (100 mm x 80 mm x 8 mm) was selected by trails of different sizes till the building design was found to be satisfactory against earthquake loads. Fig 20(a). shows the bracings provided at front face of x-axis of the building to find out maximum axial force in the bracings.

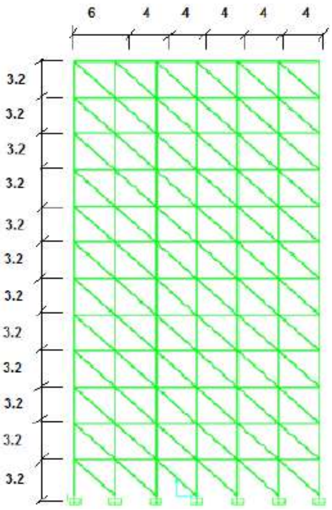
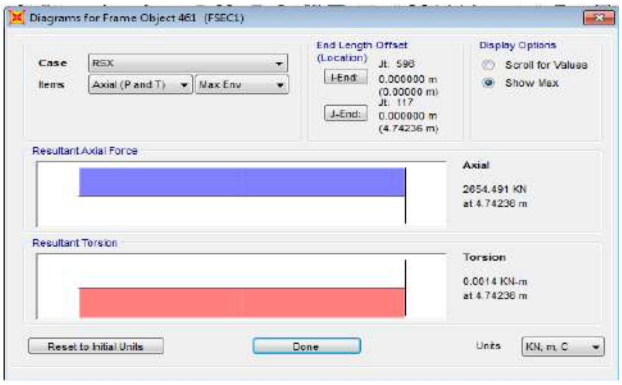


Figure 14: Bracings at various location to find out maximum axial force



Case: RSX

Items: Axial (P and T) | Max Env

Jt. 596

I-End: 0.000000 m (0.00000 m)

Jt. 117

J-End: 0.000000 m (4.74236 m)

Axial

2654.491 KN at 4.74236 m

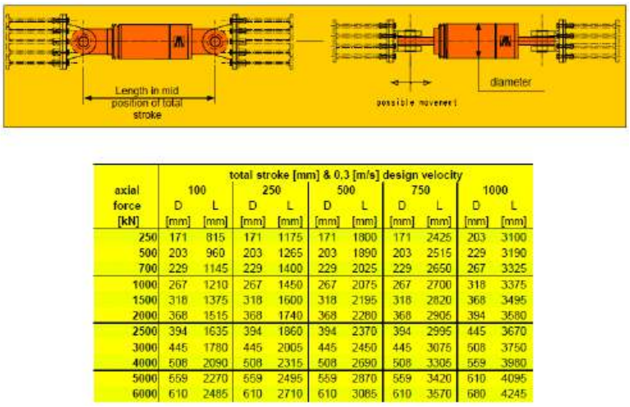
Torsion

0.0014 KN-m at 4.74236 m

Units: KN, m, C

Figure 15: Maximum axial force in bracing

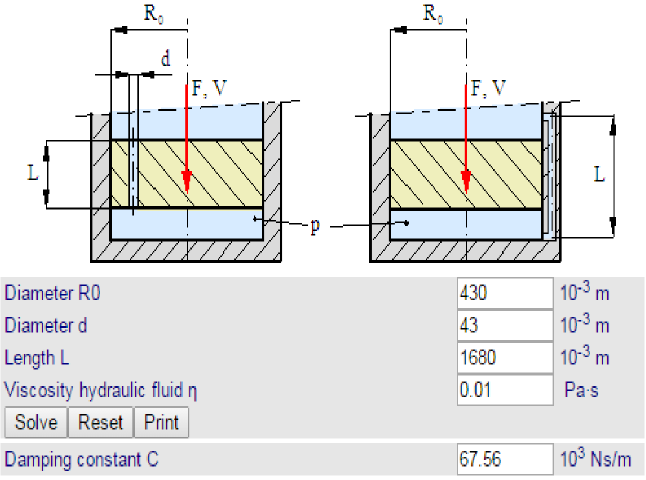
Fig. 21 shows the maximum axial force that was calculated by Sap 2000-17 in the bracing. Maximum displacement of the top story has been found out as 231.1mm. The length and the diameter of the viscous dampers have to be calculated by interpolation from the given figure 16 of the viscous damper supplier MAURER shown in Fig 21.



axial force [kN]	total stroke [mm] & 0,3 [m/s] design velocity									
	100		250		500		750		1000	
	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]	D [mm]	L [mm]
250	171	815	171	1175	171	1800	171	2425	203	3100
500	203	960	203	1265	203	1890	203	2515	229	3190
700	229	1145	229	1400	229	2025	229	2650	267	3325
1000	267	1210	267	1450	267	2075	267	2700	318	3375
1500	318	1375	318	1600	318	2195	318	2820	368	3495
2000	368	1515	368	1740	368	2280	368	2905	394	3580
2500	394	1635	394	1860	394	2370	394	2995	445	3670
3000	445	1780	445	2005	445	2450	445	3075	508	3750
4000	508	2090	508	2315	508	2690	508	3305	559	3980
5000	559	2270	559	2495	559	2870	559	3420	610	4095
6000	610	2485	610	2710	610	3085	610	3570	680	4245

Figure 16: Table for diameter and length of the viscous damper

By putting these parameters in the calculator available on internet>url:http://www.tribologyabc.com/calculators/damper.htm the value of coefficient of damping was calculated for the damper. The calculated value of the coefficient of damping is shown in Fig. 22(a).



Diameter R0	430	10^{-3} m
Diameter d	43	10^{-3} m
Length L	1680	10^{-3} m
Viscosity hydraulic fluid η	0.01	Pa·s
Damping constant C	67.56	10^{3} Ns/m

Figure 17: Coefficient of damping calculator

Maximum axial force = 2654.6 KN
Diameter of the damper = 430 mm
Length of the damper = 1680 mm
Coefficient of damping = 67.56 x10^3 Ns/m
Coefficient of damping is taken as 70 Ns/m

E. Optimization of numbers and positions of the damper in the building

Dampers are provided at different locations in different numbers and the corresponding displacement was noted down. The trial at which building shows maximum decrease in displacement was selected to demonstrate the optimum positions and numbers of the dampers. Shows the displacement in the building without damper. Building provided with dampers in vertical direction at front face of x-axis is shown in Fig 14.

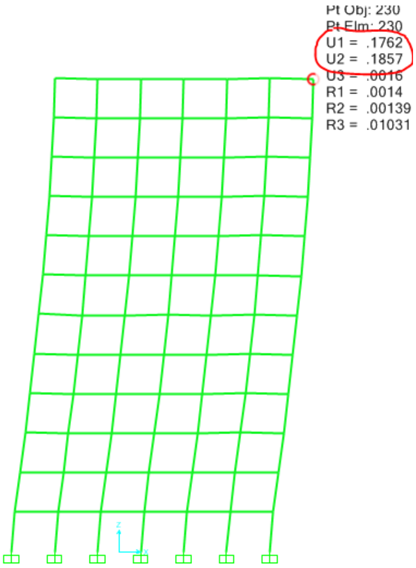


Figure 18(a): Building without dampers

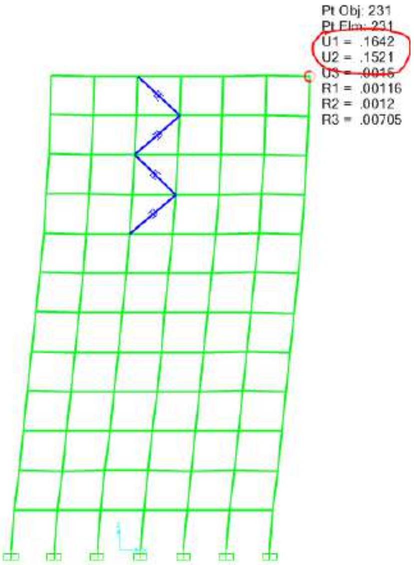


Figure 18(b): Building with 4 dampers in vertical at front face of X-direction

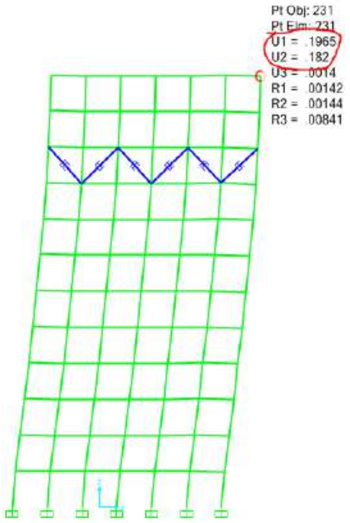


Figure: 19: (a). 6 numbers of dampers in horizontal direction

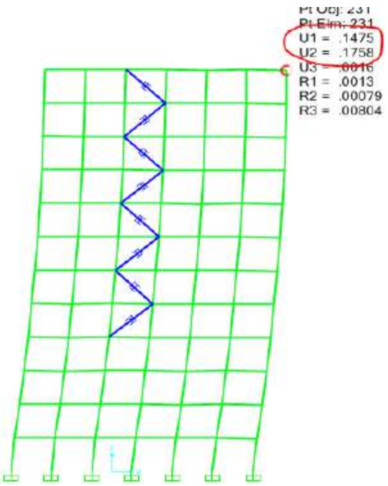


Figure 19(b): 8 numbers of dampers in vertical direction

Fig. 15 shows the displacement of the building with 6 numbers of dampers in horizontal direction in zigzag position and Fig16. 8 numbers of dampers in vertical direction at front face of x-axis.

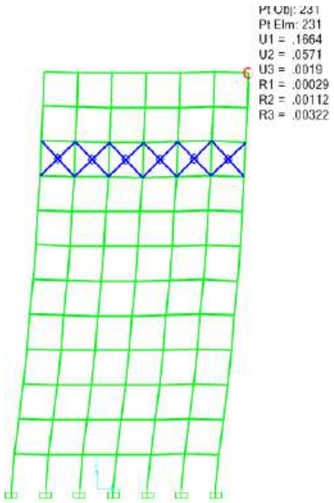


Figure 20(a): 12 numbers of dampers in H-direction

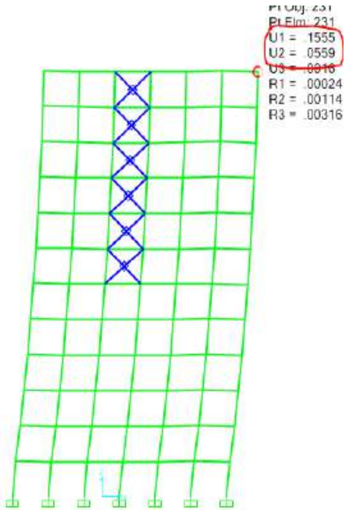
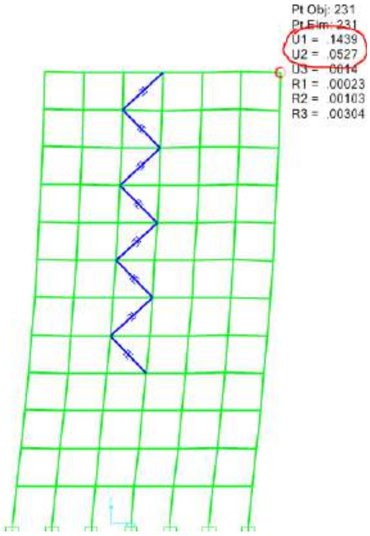


Figure 20(b): 12 numbers of dampers in vertical direction

Figure 16 shows the displacement of the building with 12 numbers of dampers in H-direction in cross position and Fig 17. shows 12 numbers of dampers in vertical direction.



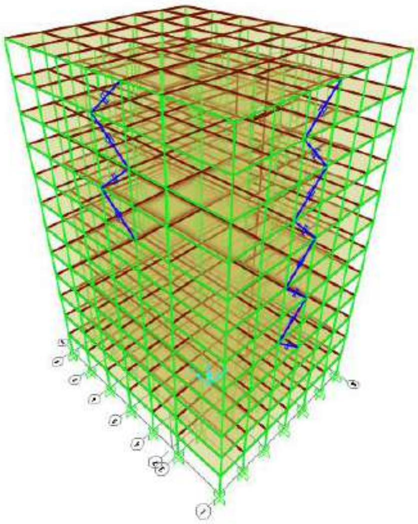


Figure 21: Provided 12 numbers of dampers 8 at front face of X-axis 4 at each side of face Y-axis

Figure 18(a) shows the displacement of the building with 12 numbers of dampers 8 at front face of x-axis 4 at the face of y-axis.

Table 3: Optimization of numbers and position of dampers

Sr. no	No of dampers	Location of dampers	Displacement (mm)
1	4	Vertical zigzag at front face of x- axis	164.2
2	6	Horizontal zigzag at front face of x- axis	196.5
3	8	Vertical zigzag at front face of x- axis	147.5
4	12	Horizontal cross at front face of x-axis	166.4
5	12	Vertical cross at front face of x-axis	155.5
6	12	Zigzag 8 at front face of x-axis 4 along Y-axis	143.9
7	14	Zigzag 8 at front face of x-axis 6 along Y-axis	125.1

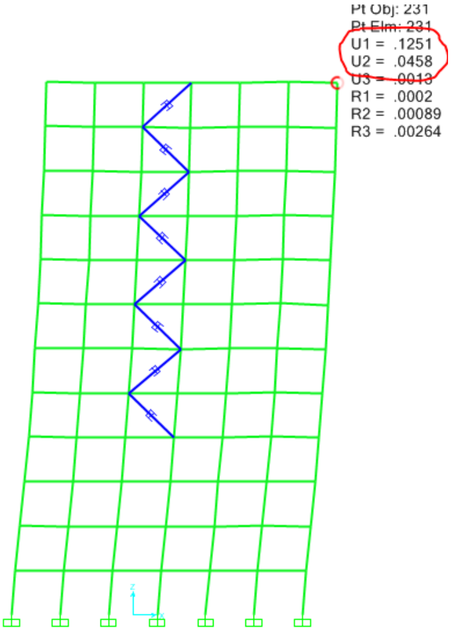


Figure 22(a): 14 numbers of dampers in zigzag vertical direction

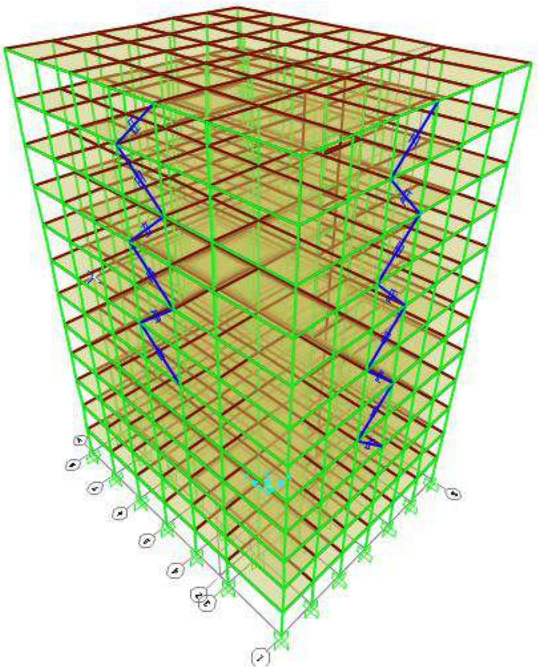


Figure 22(b): 14 numbers of dampers at different locations

Fig. 19(a) shows the displacement of the building with 14 numbers of dampers in H-direction and Fig 19(b). shows the displacement of the building with 14 numbers of dampers at different locations.
The numbers and positions of the dampers were fixed by taking trials. The 7 trails that have been done are shown in Table 3. These positions of the dampers give better results in comparison to other positions. Providing 10 dampers in zigzag shape decrease the displacement up to 25% while in other position it only decreases the displacement up to 5%-10%.

F. *Results and Discussion*

In this project the Earthquake analysis results for Response spectrum curve of IS1893-2002 were represented in terms of joint displacement and percentage of decrease in displacement in the building. Purpose was to check the effect of the damper on the behaviour of the building.

G. *Response spectrum analysis results for (IS1893-2002)*

- *Top story displacement comparison*

Table 4: Top story displacement comparison

% of vertical geometric irregularity	0	15	30	45	60	75
Displacement in (mm)	176.2	188.6	198.2	216.5	226.9	248.7
% increase in displacement	0	6.8	12.5	22.7	28.4	42.6

In the above Table 4, we can observe the increase in the displacement due to providing the vertical geometric irregularity to the building is significant. The graphical representation of the increase in displacement is given below.

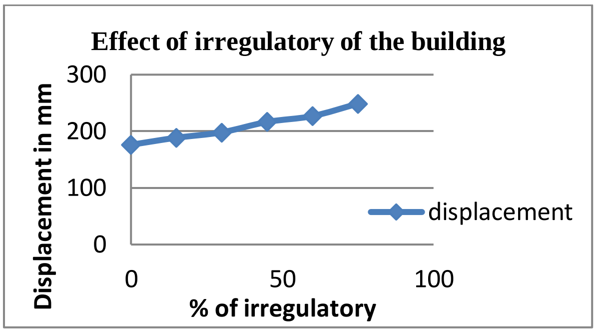


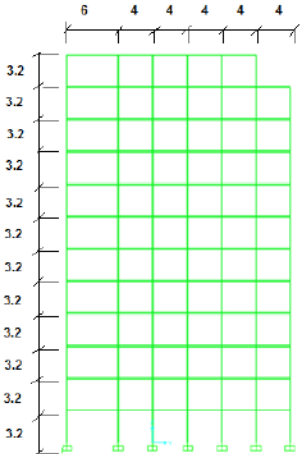
Figure 23: Effect of vertical geometric irregularity of building on top floor displacement

The above Fig 23. clearly shows that the building with 0% vertical geometric irregularity is having much lesser displacement in comparison to the building with vertical geometric irregularity.

H. *Effect of dampers on displacement of the building*

Dampers were provided to the building to enhance the performance of the building. In this study dampers were provided in all the 6 models to decrease the displacement at the top floor of the vertical geometric irregular building. The numbers and position of the dampers were selected by trail method same as explained in the previous chapter.

- *Building with 15% vertical geometric irregularity*



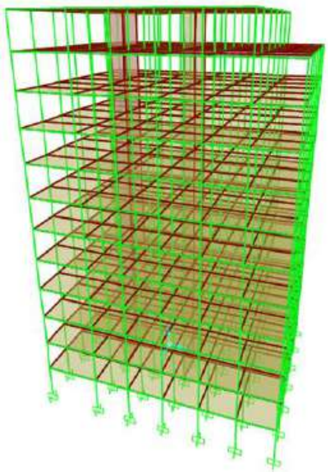
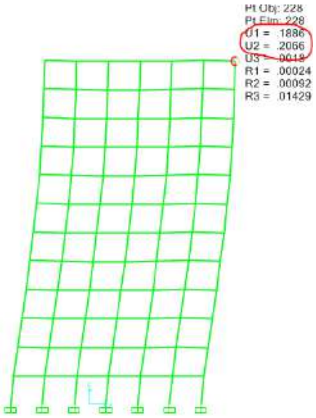


Figure 24: 3D model of 15% irregular building

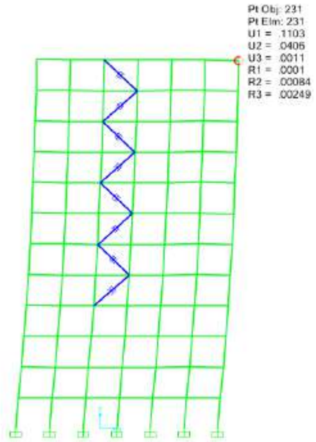
Building with 15% vertical geometric irregularity was analyzed in sap 2000-17 Fig 24. Show the 3D model of 15% vertical geometric irregular building. Pseudo static responses of the building were studied. The CQC method was employed to get Pseudo static analysis for 5% damping. Figure shows the side view and 3D view of the model it has plotted dimensions 21m x 26 m in X-direction and Y-direction respectively. For the analysis of fixed base building response spectrum method as per IS1893-2002 was used. Comparison between the displacement at the top story of the building without damper and with damper is shown in Fig 25(a) and Fig 25(b).

- *Comparison of displacement at top story*



```
Pt Obj: 228
Pt Elm: 228
U1 =  .1886
U2 =  .2066
U3 =  .0018
R1 =  .00024
R2 =  .00092
R3 =  .01429
```

Figure 25(a): Building without damper



```
Pt Obj: 231
Pt Elm: 231
U1 =  .1103
U2 =  .0406
U3 =  .0011
R1 =  .0001
R2 =  .00084
R3 =  .00249
```

Figure 25(b): Building with damper

The numbers and positions of the dampers were fixed by taking trials. The 7 trails that have been done are shown in Table 5. These positions of the dampers give better results in comparison to other positions. Providing 14 dampers in zigzag 8 at front face of x-axis 6 along Y-axis decrease the displacement up to 40% while in other position it only decreases the displacement up to 20%-30%. Different trails are shown in the table 5.

Table 5: Trails for damper optimization

Sr. no	No of dampers	Location of dampers	Displacement (mm)
1	7	Vertical zigzag at front face of X- axis	169.0
2	8	Horizontal zigzag at front face of X- axis	164.3
3	9	Vertical zigzag at front face of X- axis	158.8
4	10	Horizontal cross at front face of X-axis	153.9
5	11	Vertical cross at front face of X-axis	139.2
6	12	Zigzag 8 at front face of X-axis 4 along Y-axis	123.4
7	14	Zigzag 8 at front face of X-axis 6 along Y-axis	110.6

- *Building with 30% vertical geometric irregularity*

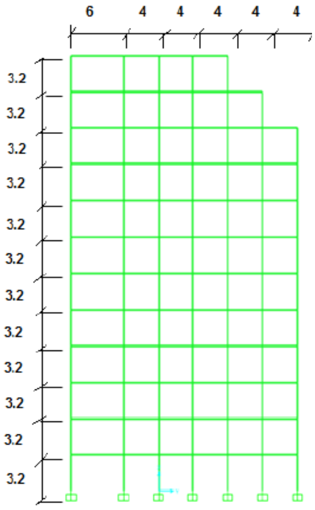


Figure 26(a): Elevation of 30% irregular building

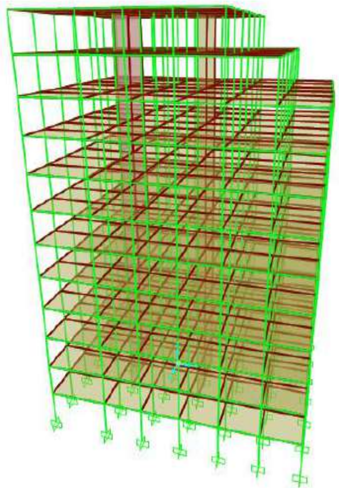


Figure 26(b): 3D model of 30% irregular building

Building with 30% vertical geometric irregularity was analysed in sap 2000-17 Fig. 26 shows the 3D model of 30% vertical geometric irregular building. Pseudo static responses of the building were studied. The CQC method was employed to get Pseudo static responses for 5% damping. Figure shows the side view and 3D view of the model it has plotted dimensions 21m x 26 m in X-direction and Y-direction respectively. For the analysis of fixed base building response spectrum method as per IS1893-2002 was used. Comparison between the displacement at the top story of the building without damper and with damper is shown in Fig 27(a) and Fig 27(b).

- *Comparison of displacement at top story*

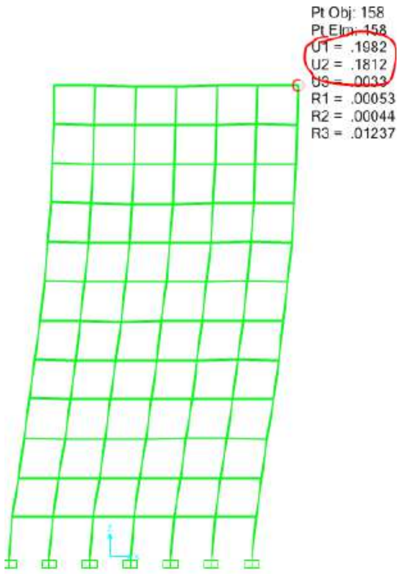


Figure 27(a): Building without damper

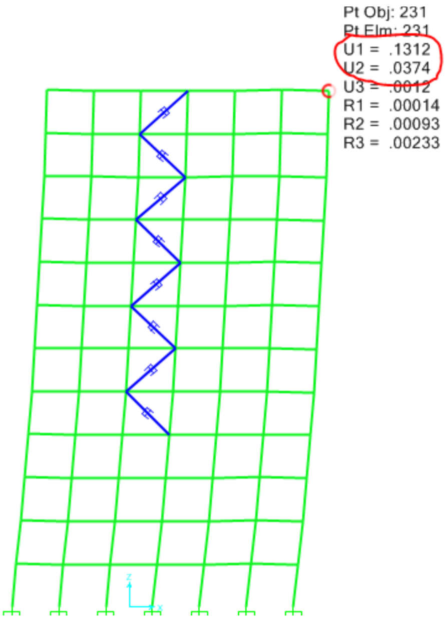


Figure 27(b): Building with damper

The numbers and positions of the dampers were fixed by taking trials. The 5 trails that have been done are shown in Table 6. These positions of the dampers give better results in comparison to other positions. Providing 14 dampers in zigzag 8 at front face of x-axis 6 along Y-axis decrease the displacement up to 40% while in other position it only decreases the displacement up to 20%-30%. Different trails are shown in the table 6.

Table 6: Trails for damper optimization

Sr. no	No of dampers	Location of dampers	Displacement (mm)
1	8	Zigzag vertical at front face of X- axis	191.8
2	10	Zigzag vertical at front face of X- axis	181.5
3	11	Zigzag 8 at front face of X-axis 3 along Y-axis	160.7
4	13	Zigzag 8 at front face of X-axis 5 along Y-axis	141.3
5	15	Zigzag 8 at front face of X-axis 7 along Y-axis	131.2

- *Building with 45% vertical geometric irregularity*

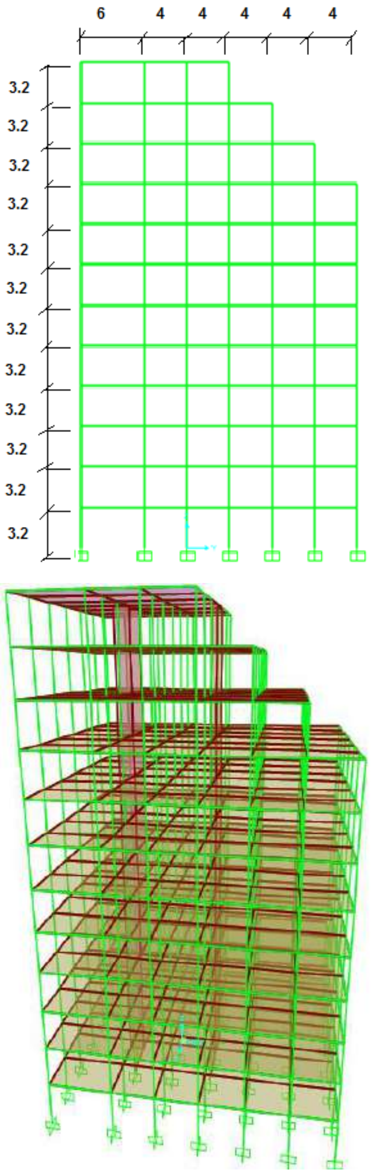


Figure 28: Building with 45% vertical geometric irregularity

Building with 45% vertical geometric irregularity was analysed in sap 2000-17 Fig. 28. shows the 3D model of 45% vertical geometric irregular building. Pseudo static of the building were studied. The CQC method was employed to get Pseudo static responses for 5% damping. Figure shows the side view and 3D view of the model it has plotted dimensions 21m x 26 m in X-direction and Y-direction respectively. For the analysis of fixed base building response spectrum method as per IS1893-2002 was used. Comparison between the displacement at the top story of the building without damper and with damper is shown in Fig. 29(a) and Fig. 29(b).

- *Comparison of displacement at top story*

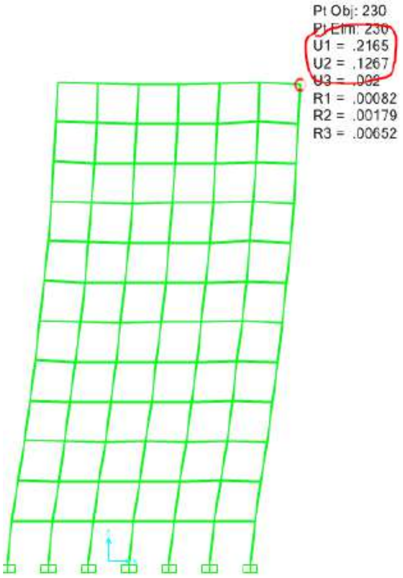


Figure 29(a): Building without damper

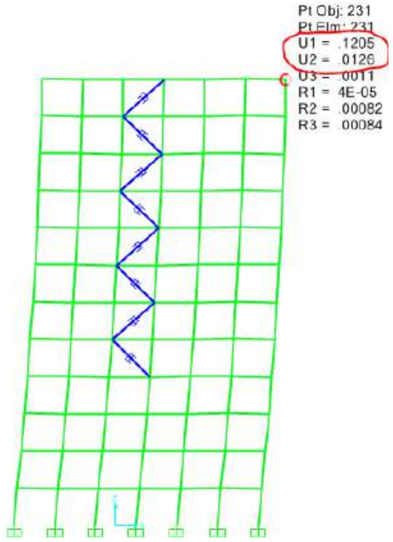


Figure 29(b): Building with damper

The numbers and positions of the dampers were fixed by taking trials. The 5 trails that have been done are shown in Table 7. These positions of the dampers give better results in comparison to other positions. Providing 16 dampers in zigzag 8 at front face of x-axis 8 along Y-axis decrease the displacement up to 45% while in other position it only decreases the displacement up to 20%-30%. Different trails are shown in the table 7.

Table 7: Trails for damper optimization

Sr. no	No of dampers	Location of dampers	Displacement (mm)
1	8	Zigzag vertical at front face of x- axis	204.7
2	10	Zigzag vertical at front face of x- axis	196.9
3	12	Zigzag 8 at front face of x-axis 4 along Y-axis	209.2
4	14	Zigzag 8 at front face of x-axis 6 along Y-axis	127.8
5	16	Zigzag 8 at front face of x-axis 8 along Y-axis	120.5

- *Building with 60% vertical geometric irregularity*

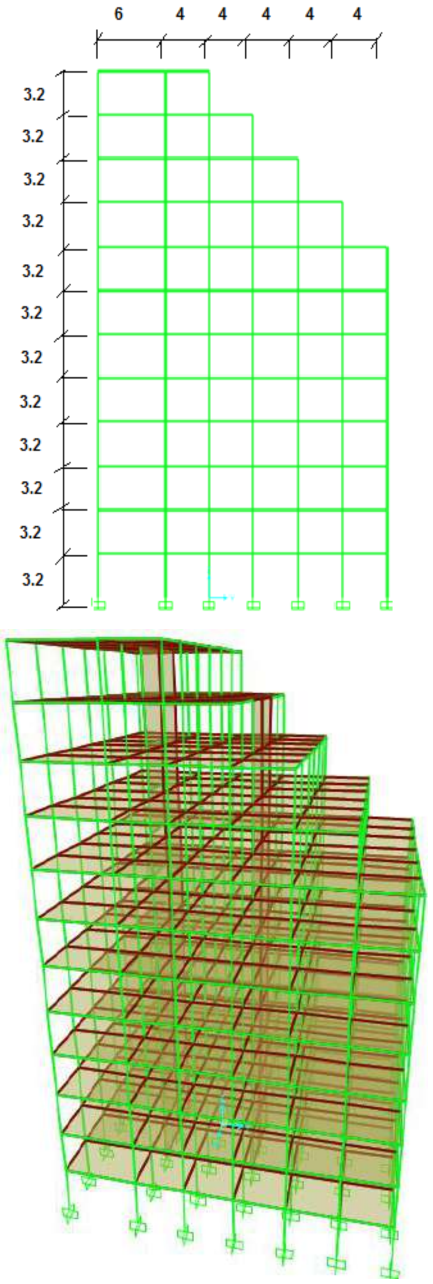


Figure 30: Building with 60% vertical geometric irregularity

Building with 60% vertical geometric irregularity was analysed in sap 2000-17 Fig. 30. Show the 3D model of

60% vertical geometric irregular building. Pseudo static responses of the building were studied. The CQC method was employed to get Pseudo static responses for 5% damping. Fig. shows the side view and 3D view of the model it has plotted dimensions 21m x 26 m in X-direction and Y-direction respectively. For the analysis of fixed base building response spectrum method as per IS1893-2002 was used. Comparison between the displacement at the top story of the building without damper and with damper is shown in Fig. 31(a) and Fig 31(b).

- *Comparison of displacement at top story*

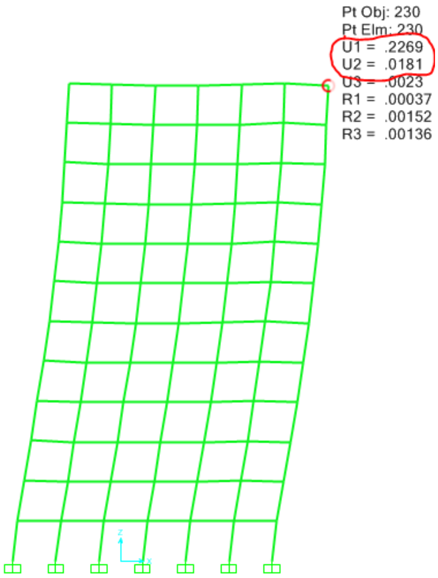


Figure 31(a): Building without damper

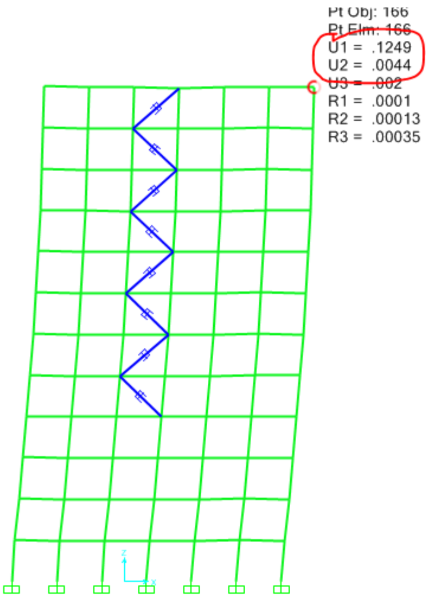


Figure 31(b): Building with damper

The numbers and positions of the dampers were fixed by taking trials. The 6 trails that have been done are shown in Table 8. These positions of the dampers give better results in comparison to other positions. Providing 16 dampers in zigzag 8 at front face of x-axis 8 along Y-axis decrease the displacement up to 45% while in other position it only decreases the displacement up to 20%-30%. Different trails are shown in the table 8.

Table 8: Trails for damper optimization

Sr. no	No of dampers	Location of dampers	Displacement (mm)
1	8	Zigzag vertical at front face of x- axis	212.6
2	10	Zigzag vertical at front face of x- axis	202.3
3	12	Zigzag 8 at front face of x-axis 4 along Y-axis	187.4
4	13	Zigzag 8 at front face of x-axis 5 along Y-axis	173.9
5	14	Zigzag 8 at front face of x-axis 6 along Y-axis	148.9
6	16	Zigzag 8 at front face of x-axis 8 along Y-axis	124.9

- *Building with 75% vertical geometric irregularity*

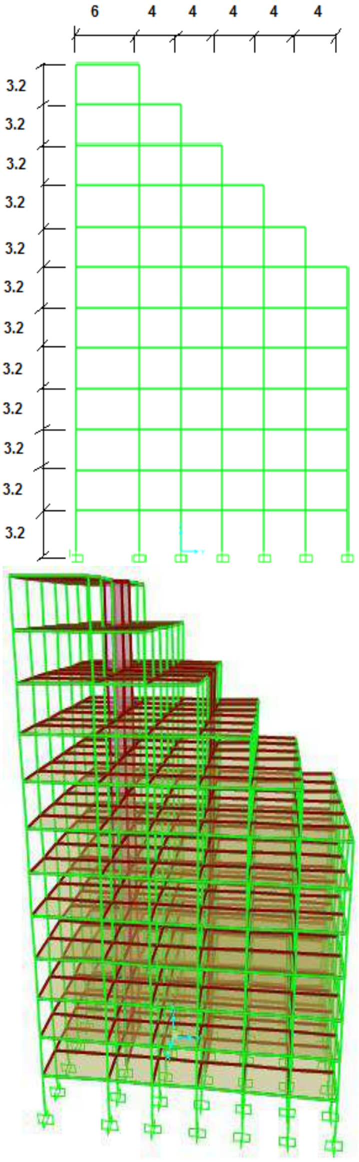


Figure 32: Building with 75% vertical geometric irregularity

Building with 75% vertical geometric irregularity analysed in sap 2000-17 Fig. 32. shows the 3D model of 75% vertical geometric irregular building. Pseudo static responses of the building were studied. The CQC method was employed to get Pseudo static responses for 5% damping. Figure shows the side view and 3D view of the model it has plotted dimensions 21m x 26 m in X-direction and Y-direction respectively. For the analysis of fixed base building response spectrum method as per IS1893-2002 was used. Comparison between the displacement at the top story of the building without damper and with damper is shown in Fig. 33(a) and Fig. 33(b).

- *Comparison of displacement at top story*

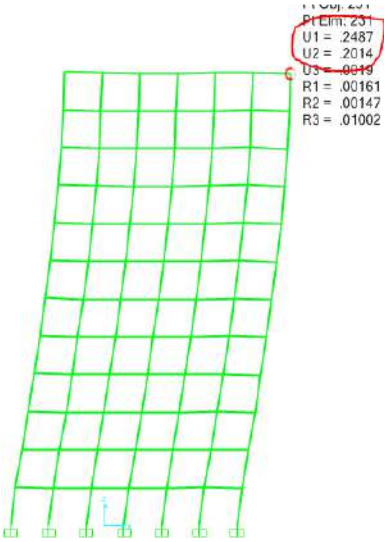


Figure 33(a): Building without damper

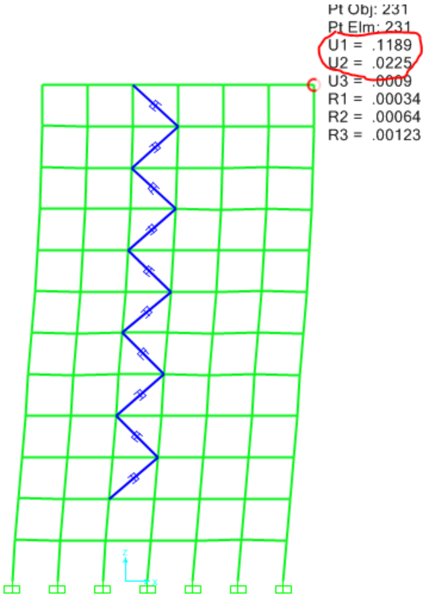


Figure 33(b): Building with damper

The numbers and positions of the dampers were fixed by taking trials. The 6 trails that have been done are shown in Table 9. These positions of the dampers give better results in comparison to other positions. Providing 18 dampers in zigzag 10 at front face of x-axis 8 along Y-axis decrease the displacement up to 50% while in other position it only decreases the displacement up to 20%-30%. Different trails are shown in the table 9.

Table 9: Trails for damper optimization

Sr. no	No of dampers	Location of dampers	Displacement (mm)
1	8	Zigzag 8 at front face of X-axis	231.2
2	10	Zigzag 10 at front face of X-axis	201.5
3	12	Zigzag 8 at front face of X-axis 4 along Y-axis	179.4
4	14	Zigzag 8 at front face of X-axis 6 along Y-axis	158.7
5	16	Zigzag 8 at front face of X-axis 8 along Y-axis	142.9
6	18	Zigzag 10 at front face of X-axis 8 along Y-axis	118.9

I. *Results*

The buildings analysed above with 0%, 15%, 30%, 45%, 60% and 75% of vertical geometric irregularity provided with dampers shows significant decrease in displacement Table 10. Shows effect of damper on displacement in X direction of the building**.** Due to vertical geometric irregularity, there was increase in displacement and also no of dampers required were more. Fig 34. shows the comparison between displacements of the buildings without damper and with damper.

Table 10: Effect of damper on displacement in X direction of the building

Sr no	% of vertical geometric irregularity	No of dampers required	Displacement without damper (mm)	Displacement after providing damper (mm)
1	0	10	176.2	125.1
2	15	12	188.6	110.6
3	30	13	198.2	131.2
4	45	14	216.5	120.5
5	60	15	226.9	124.9
6	75	17	248.7	118.9

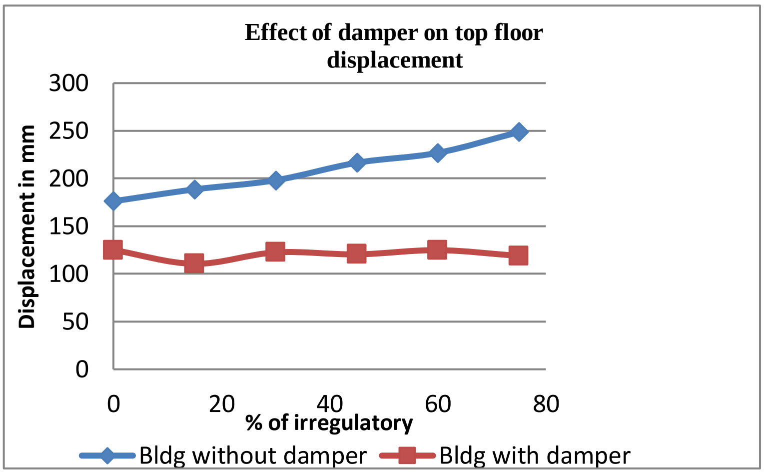


Figure 34: Effect of damper on displacement of the building

J. *Discussion*

- *Top floor displacement*

The analysis result shows that due to providing the damper to the building at proper location there will be 35%-50% decrease in displacement in every frame. To provide proper no of damper 8-10 trails have been taken and at which displacement shows minimum value was selected.

- *Effect on displacement due to vertical geometric irregularity of the building*

By providing vertical geometric irregularity to the building there was increase in displacement about 15%-60%. Vertical geometric irregularity below 25% doesn't affect much on the displacement of the building to have minimum displacement the vertical geometric irregularity should be less and the damper should be provided at proper location.

VI. CONCLUSION AND FUTURE SCOPE

A. *Introductory Remarks*

This chapter gives the conclusion of this thesis. It also discusses about the effect of vertical geometric irregularity to the buildings.

B. *Conclusions*

In this project G+12 buildings with and without dampers have been analysed for various % of vertical geometric irregularity. The conclusions from this thesis are enumerated in the following:

- The building provided with viscous dampers shows 35%-50% decrease in the maximum displacement as compared to a regular building.
- Numbers and position of the dampers affect the decrease in maximum displacement.
- Minimum number of dampers can be found out by trail method as demonstrated.
- Increase in displacement due to vertical geometric irregularity of the building is about 6%-43% of the maximum displacement of the regular building.
- For 0% vertical geometric irregularity providing 10 dampers in zigzag shape decrease the maximum displacement up to 25%.
- For 15% vertical geometric irregularity providing 14 dampers in zigzag 8 at front face of x-axis 6 along y-axis decrease the maximum displacement up to 40%.
- For 30% vertical geometric irregularity providing 14 dampers in zigzag 8 at front face of x-axis 6 along y-axis decrease the maximum displacement up to 40%.
- For 45% vertical geometric irregularity providing 16 dampers in zigzag 8 at front face of x-axis 8 along y-axis decrease the maximum displacement up to 45%.
- For 60% vertical geometric irregularity providing 16 dampers in zigzag 8 at front face of x-axis 8 along y-axis decrease the maximum displacement up to 45%.
- For 75% vertical geometric providing 18 dampers in zigzag 10 at front face of x-axis 8 along y-axis decrease the displacement up to 50%.
- The number of dampers required for various % of vertical geometric irregularity of the buildings was different.
- Lesser the vertical geometric irregularity in a building, lesser will be the number of dampers required for the building.

C. *Future Scope*

A study of geometrically irregular buildings in plan can be studied in future. The same models can be checked for possible reduction in maximum displacements by providing different types of dampers. Analysis of the models with and without provision of dampers can be taken up for study under earthquake acceleration time histories.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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