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An Improved Design and Evaluation of Cost Effective Metallic Pipe Damper for Seismic Retrofitting

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Abstract: The energy dissipation capacity of a building is poor when it is not provided with any kind of seismic protection methods, especially when it is situated in seismic active zones. Dampers can be provided to overcome this. Passive controlled metallic damper is one of the most commonly used dampers for seismic resistance in buildings. This type of damper helps to dissipate seismic loads acting on the building by making the structure to behave as elastic in nature where as it act as plastic in nature. In this type of dampers a newly formed metallic damper called dual pipe damper (DPD) is used for seismic resistance. DPD is a cost effective and economical damper which is easy to install in both newly formed structure and old building without any seismic resisting elements. In this paper, the improvement in dual pipe damper is analysed through nonlinear pushover analysis and the energy dissipation capacity of improved pipe damper is also determined. The finite element analysis of DPD as well as improved metallic pipe damper is done using ANSYS workbench 16.1 software. The main parameters consider in this paper is to find the improved metallic pipe damper by increasing the number of metallic pipes and also changing the arrangement of bracing in these dampers. As a result of this FE analysis metallic pipe damper with better energy dissipation capacity is obtained.

Keywords: Dual pipe damper (DPD), Improved metallic pipe damper, Three pipe damper, Four pipe damper, ANSYS workbench 16.1 software, Nonlinear pushover analysis

I. INTRODUCTION

High rise buildings which are constructed for the purpose of residential and commercial are mostly done using steel frame structure. Steel framed structures are easy to construct and time saving. Even though there are many things which we have to consider while constructing a steel structure like live load, dead load, soil property, foundation of building, zone of construction, material property etc., the building which is in a seismic active zone experience lateral earthquake force in addition to primary gravity load. The intensity of earthquake and property of structure determines the performance of the building. In steel framed structure the stiffness is more important than the strength of the structure. This property of the building is improved using the installation of dampers and bracings. Dampers are a dissipating device which helps to resist displacement of buildings during earthquakes. It helps to reduce the buckling of columns and beams in a structure which in turn leads to the increase of structural stiffness. Dampers are mainly classified into three types based on its performance at the time of an earthquake. Active, semi active and passive earthquake energy dissipation dampers are used in retrofitting, out of which the passive control system is the most economical and shows effective mechanism. This system doesn’t need any external power source and hardware or software control devices compared to active and semi active systems. The main objective of this device is to absorb the seismic input energy as much as possible, thus reducing force and displacement demand and also reducing the damage to gravity load carrying members.

The dampers with passive control system are most commonly used due to its installation procedures as well as its adaptability to a building structure as required. The energy dissipation of a dual pipe damper depends upon the plastic deformation of steel material in its flexural form. This damper is easy to install in both RCC structure and steel structure, for both in newly constructed and for seismic retrofitting of existing buildings.

The objective of the current study is to find the improvement in the property of DPD. DPDs with different diameter, thickness and breadth of the pipe were modeled and analysed using ANSYS workbench 16.1 software. As a result of FE analysis the best model is taken based on its ultimate load carrying capacity and the result is taken for further analysis to increasing the number of pipes and changing the distance between the bracing joints. Load displacement for this nonlinear pushover analysis is taken according to FEMA 461 [19], where the displacement is provided to find the ultimate load carrying capacity of the metallic pipe damper.

II. PREVIOUS RESEARCH

Dual pipe damper is a passive earthquake metallic damper, introduced by Shervin Maleki and Saeed Mahjoubi [10]. They conducted cyclic quasi static tests and analytical studies on four samples of DPD to find the energy dissipation capacity. As a result of this study, excellent ductility, energy absorption and stable hysteresis loops were observed. Due to this property, the damper absorbs a significant amount of seismic energy that hits the building and makes the structure safer at the time of earthquake. In this study only four models were used for comparing and to find the best model among those. The arrangement of dual pipe damper in single framed structure is shown in Fig. 1 which is taken from the reference journal [10], here the dual pipe damper is supported or connected to steel bracing for making a connection between the structural members and damper. The quasi-static test is conducted with the help of FEMA 461, which provides the amplitude of different seismic load. In this study they used displacement load of 48 cycles that can provide the ultimate load carrying capacity of four models. However, there is a deficiency in the number of analysis model to prove the correct energy dissipation capacity of the dual pipe damper. Studies based on DPD are low, which makes it an area of study to check the improvement in energy dissipation capacity.

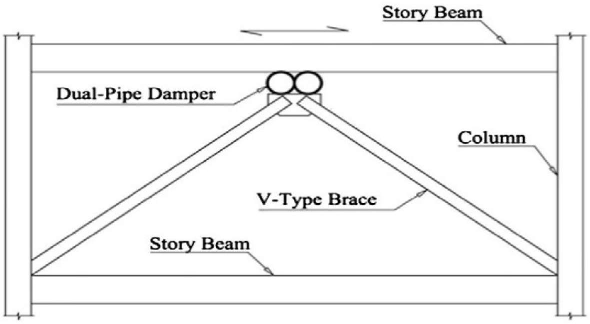

Fig. 1 Dual Pipe Damper in Single Frame

III.OBJECTIVE

The objectives which is considered for the finite element analysis are,

A. To investigate the nonlinear lateral resisting capacity of dual pipe damper
B. To determine the nonlinear investigation of pipe damper with increase in number of metallic pipe in damper
C. To determine the nonlinear investigation of pipe damper with various bracing configurations

IV.MODELING AND ANALYSIS OF METALLIC PIPE DAMPER

Finite element analysis on different models of dual pipe damper is performed, to find the model with better ultimate load carrying capacity. The dual pipe damper with different diameter, thickness and breadth are modeled and analysed using ANSYS workbench 16.1 software. After getting the DPD with better ultimate load, it is taken for further analysis to make improved DPD. For further analysis DPD is installed in single frame with the help of bracings, which provides a connection between damper and structural frame. The bracing which used for connection is of hollow steel section with standard size of HSS5X5X1/4, which has a dimension of 127 mm length along four sides and thickness is about 6.35 mm. The dimensions of I sections which are used for beam and column analysis in single frame for metallic pipe damper installation is shown in Table I.

TABLE I
DIMENSIONS OF I SECTION

Type	Model	Total Depth (mm)	Flang Width (mm)	Flang Thickness (mm)	Web Thickness (mm)
Beam	W24x104	611.12	323.85	19.05	12.70
Column	W14x109	363.73	370.97	21.84	13.33

The dimensions of beam and column are taken as per ASTM, and are used for analysing the dual pipe damper in single frame. Using ANSYS workbench software the improvement in dual pipe damper is modeled and analysed, for that three cases are considered for analysing.

A. Case 1 Nonlinear Lateral Resisting Capacity of DPD

In this case, the dual pipe damper is modeled and analysed to find the nonlinear lateral resistance capacity. For that the steel pipe which is used in the damper is studied by replacing it with other pipes of different diameter, thickness and breadth. This replacement process provides a detailed review about the damper and the stiffness it carries. The damper which shows better ultimate load and ductility is taken as the best sample of DPD. Various types of dual pipe damper based on its specification are shown in Table II. The stiffness capacity of damper is calculated with the help of single frame which consist of two columns and a beam as shown in Fig. 2. The finite element analysis of model which was analysed is also compared with a single frame without bracing and damper and also with a steel frame modeled only with bracing.

TABLE III
DIFFERENT MODELS OF DPD

Models	Diameter (mm)	Thickness (mm)	Breadth (mm)
M1	200	25	50
M2	200	25	75
M3	200	25	100
M4	200	20	50
M5	200	15	50
M6	250	25	50
M7	250	25	75
M8	250	25	100
M9	250	20	50
M10	250	15	50
M11	280	25	50
M12	280	25	75
M13	280	25	100
M14	280	20	50
M15	280	15	50

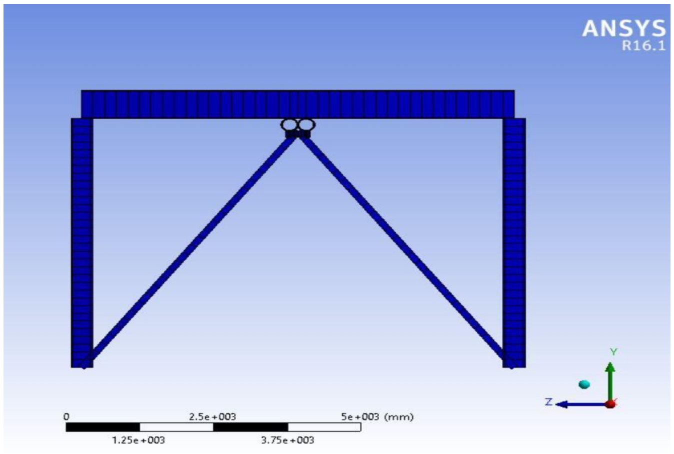

Fig. 2 Arrangement of DPD in Single Frame

B. Case 2 Nonlinear Investigation of Pipe Damper with Increase in Number of Metallic Pipe in Damper

In this case, the improvement of dual pipe damper is done by increasing the number of steel pipes. The dual pipe damper which shows better energy dissipation capacity from the above case is used for this analysis. Based on the change in diameter, thickness and length, DPD is modeled in to 15 types from this damper which shows better ultimate load carrying capacity is taken for the improvement. The improvement in metallic pipe damper can be done by increasing the number of steel pipes used in the damper, from two pipe dampers to three pipe dampers and also calculate the ultimate load of four pipe dampers as shown in Fig. 3 and Fig. 4.

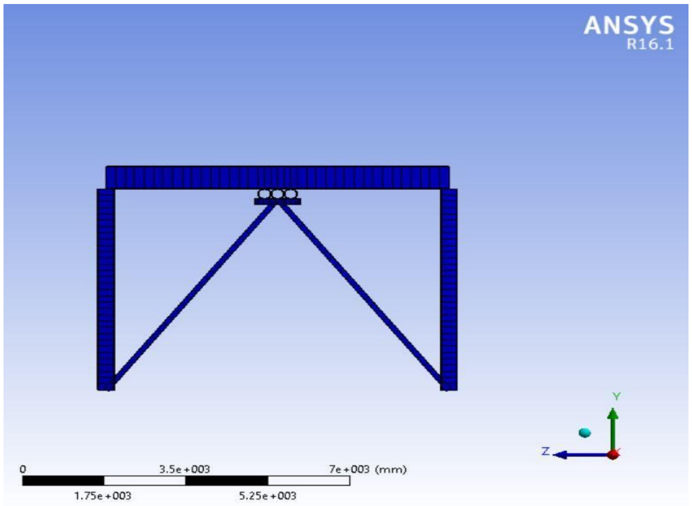

Fig. 3 Metallic Pipe Damper with Three Pipes

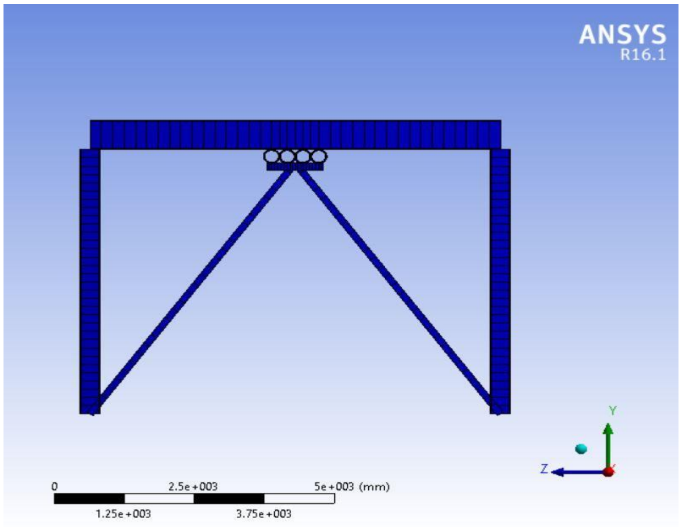

Fig. 4 Metallic Pipe Damper with Four Pipes

C. Case 3 Nonlinear Investigation of Pipe Damper with Various Bracing Configurations

In this case, the metallic pipe damper which shows better energy dissipation capacity from the above case is used for this analysis. Dampers are installed in the frame with the help of bracing, where the most effective bracing for metallic pipe dampers is inverted V bracing. This bracing helps to make a connection between column, beam and damper, thus the arrangement of bracing has a great effect on the ultimate load of damper.

Test based on the conversion of inverted V bracing to eccentric inverted V bracing is done to calculate the improvement it can make in a framed structure. For conducting this analysis the arrangement of bracing in metallic pipe damper which selected from above case is changed. The arrangement of inverted V bracing can be changed in three types such as bracing joining at centre, bracing joining at a distance and bracing joining at end. These three models of arrangement of pipe damper provide the ultimate load carrying capacity of that damper under pushover analysis. By comparing the values of analysis the improvement in metallic pipe damper is obtained.

V. RESULT AND DISCUSSION

Influence of passive controlled metallic pipe damper in a building is analysed using nonlinear pushover analysis. For that the dampers are installed in single frame to find its energy dissipation capacity. As a result of this analysis in ANSYS software the ultimate load carrying capacity of DPD and improved pipe damper is obtained. To study these three objectives are considered such as the nonlinear lateral resisting capacity of dual pipe damper, nonlinear investigation of pipe damper with increase in number of metallic pipe in damper and the nonlinear investigation of pipe damper with various bracing configurations.

A. Case 1 Result of Nonlinear Lateral Resisting Capacity of DPD

The result after finite element analysis of different models of dual pipe damper under cyclic load is calculated. From this the ultimate load, ductility and deformation of each model is obtained and shown in Table III. The energy dissipation capacity of pipe dampers with different diameter, thickness and length is considered for this study and for this analysis 15 models of dual pipe damper are designed and analysed. To check the energy dissipation capacity of the damper under cyclic load a displacement history value given in FEMA 461 is considered. The results of each model are compared with each other to find the DPD with better ultimate load. In this analysis, the model M11 shows a greater ultimate load of 756.37 KN compared to the result of 14 other models.

TABLE IIIII
DIFFERENT MODELS OF DPD WITH ANALYSIS RESULT

Models	Ultimate Load (KN)	Ultimate Displacement (mm)	Yield Displacement (mm)	Ductility
M1	509.28	33.36	4.0279	8.28
M2	515.71	22.25	4.029	5.52
M3	668.07	26.97	4.0291	6.69
M4	249.53	13.23	4.026	3.28
M5	128.85	6.385	4.1064	1.55
M6	689.02	58.47	4.0271	14.52
M7	619.72	40.19	4.029	9.97
M8	667.04	36.08	4.0297	8.95
M9	295.19	22.34	4.0249	5.55
M10	204.57	17.76	4.1735	4.25
M11	756.37	68.67	4.0265	17.05
M12	648.15	46.59	4.0287	11.56
M13	604.69	34.45	4.0298	8.55
M14	279.02	22.26	4.0705	5.47
M15	240.6	23.52	4.203	5.59

The model M11 is designed with a steel pipe diameter, thickness and length about 280 mm, 25 mm and 50 mm. Increase in the value of ultimate load indicates that the model M11 has the capacity to dissipate energy more effectively compared to other dual pipe dampers and the total deformation of M11 damper is shown in Fig. 5. The result of the M11 model is also compared with bare framed structure and structural frame with bracing.

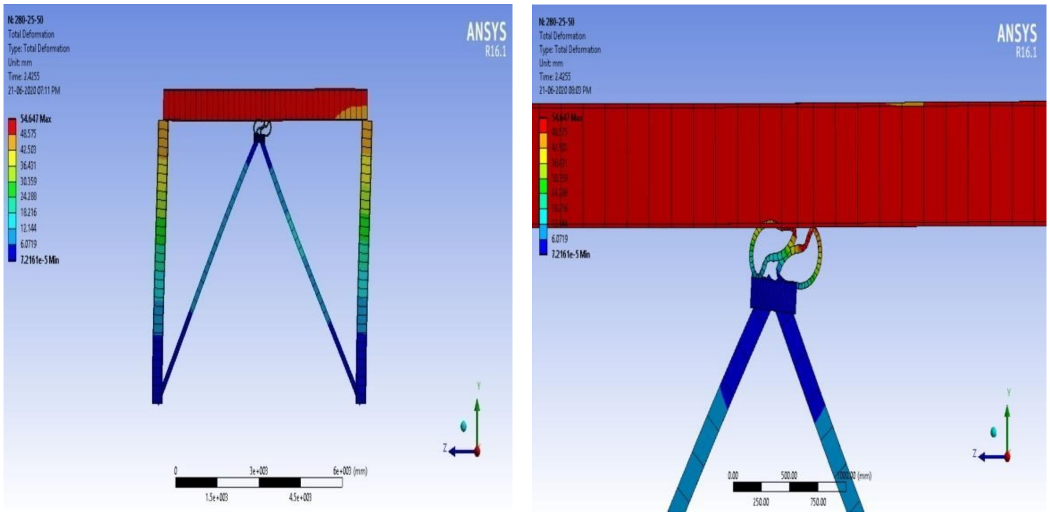

Fig. 5 Total Deformation in M11 Model

The comparison of model M11 is done with the help of load deformation curve. In this, models of three DPD with different diameter but same length and thickness are used and it is also compared with bare frame and frame with bracing as shown in Fig. 6. The ultimate load obtained after finite element analysis in model M11 is about 756.37 KN, which is compared with bare frame and frame with bracing having ultimate load of 710.13 KN and 1219.5 KN. The ductility of DPD is also an important factor we have to consider to find the energy dissipation capacity of DPD. As a result of this analysis it is found that the ductility of M11 model is better compare to other models as well as bare frame and frame with bracing. M11 model shows a ductility of 17.05 where the bare frame and frame with bracing shows the ductility of 11.8 and 6.8 which is low, thus the model M11 is considered as best among these and taken for further analysis.

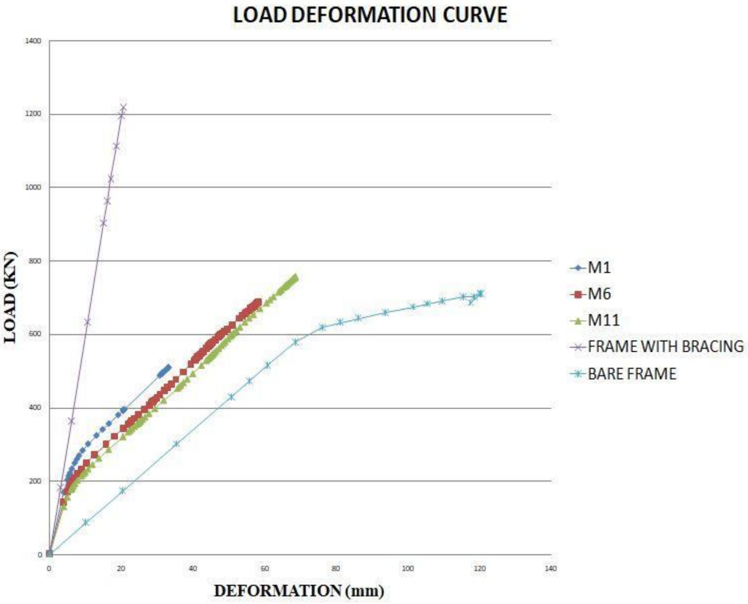

Fig. 6 Load Deformation Curve

B. Case 2 Result of Nonlinear Investigation of Pipe Damper with Increase in Number of Metallic Pipe in Damper

In this case the result obtained after the FE analysis shows that the damper with four steel pipes has better energy dissipating capacity compared with three steel pipes. The model which was used for this analysis is M11, in this the dimensions of the steel pipe is about 280 mm in diameter, 25 mm thickness and 50 mm in length. Based on the analysis done in the above case this model shows better ultimate load carrying capacity, so this model is taken for further study in this case. For analysing this damper a single framed structure is used as shown in Fig. 3 and Fig. 4.

The energy dissipation capacity of three pipe and four pipe dampers is analysed, as a result the ultimate load carrying capacity of these models are obtained. Three pipe dampers show an ultimate load of 446.16 KN where the four pipe damper shows about 538.55 KN, which came to a conclusion that four pipe damper is more efficient compared to three pipe dampers. The total deformation obtained in 3 pipe dampers and 4 pipe dampers are shown in Fig. 7 and Fig. 8, where the deformation in each model is analysed under cyclic load.

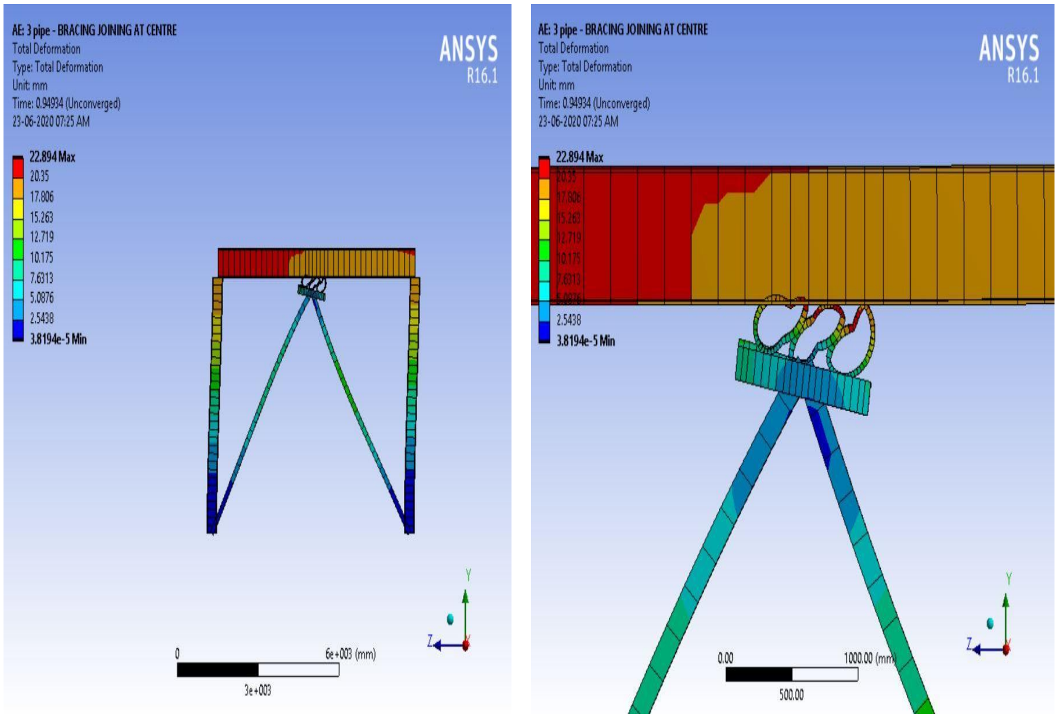

Fig. 7 Total Deformation in 3 Pipe Damper

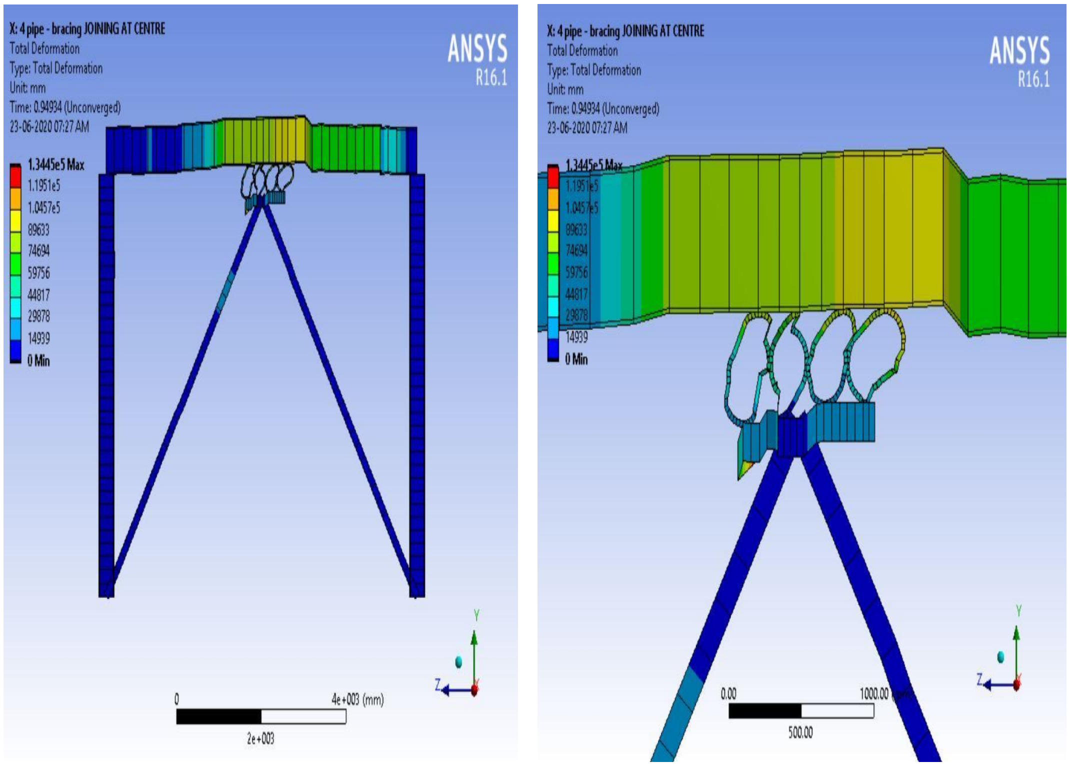

Fig. 8 Total Deformation in 4 Pipe Damper

C. Case 3 Result of Nonlinear Investigation of Pipe Damper with Various Bracing Configurations

In this analysis the model which is obtained from the previous case is used as the damper to study. The model with four steel pipes in damper is taken because it shows better ultimate load of 538.55 KN which is better than three pipe damper. After selecting the model with four steel pipe dampers the arrangement of bracing is changed to find the best model with better dissipation capacity as shown in Fig. 9, Fig. 10 and Fig. 11. For this process three models are analysed such as bracing joining at centre, bracing joining at a distance and bracing joining at end. These models are compared with each other using ANSYS software and the ultimate load of each model are obtained as shown in Table IV. In the analysis result, the model with bracing joining at a distance from each other as shown in Fig. 10 gives better load carrying capacity.

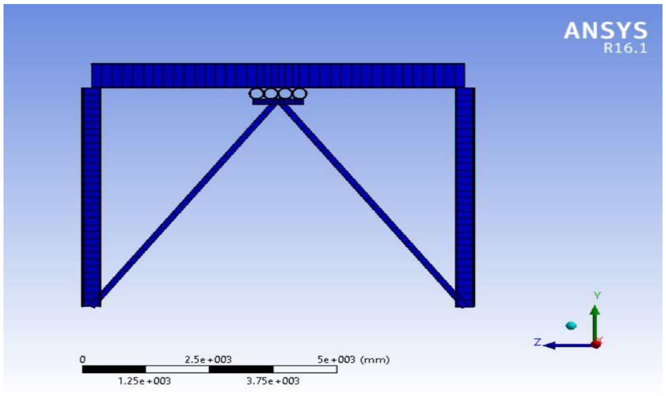

Fig. 9 Bracing Joining at Centre

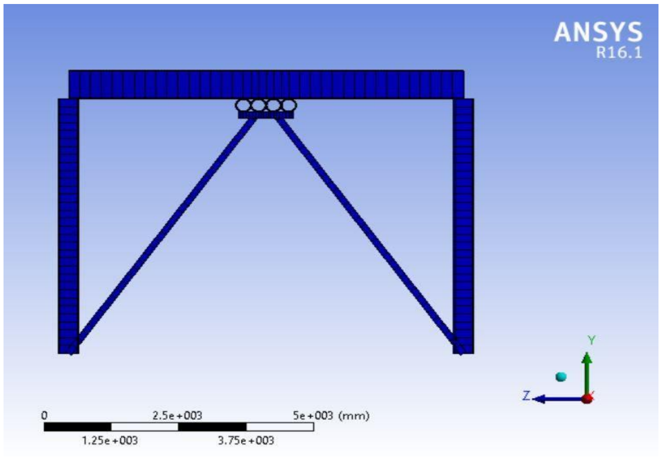

Fig. 10 Bracing Joining at a Distance

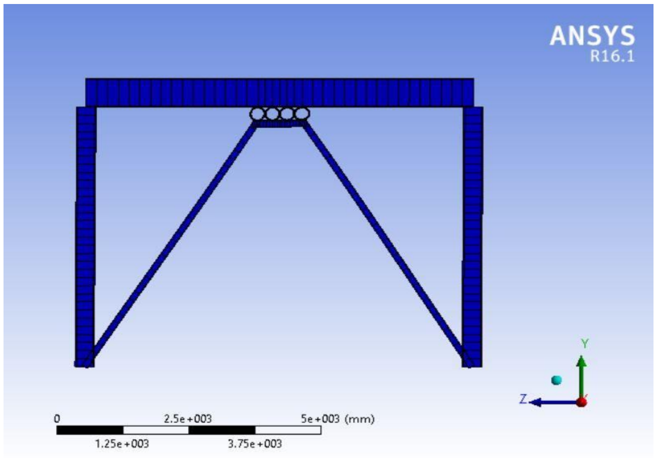

Fig. 11 Bracing Joining at End

TABLE IVV

MODELS OF 4 PIPE DAMPERS WITH ANALYSIS RESULT

4 Pipe Damper	Ultimate Load (KN)
Bracing joining at centre	538.55
Bracing joining at a distance	948.09
Bracing joining at end	921.67

The load displacement curve of four pipe dampers based on the models shown in Table IV is given in Fig. 12. As a result of this analysis in a frame with 4 pipe dampers, the model with bracing joining at a distance shows better ultimate load. This property of the braced damper helps to dissipate seismic energy throughout the building.

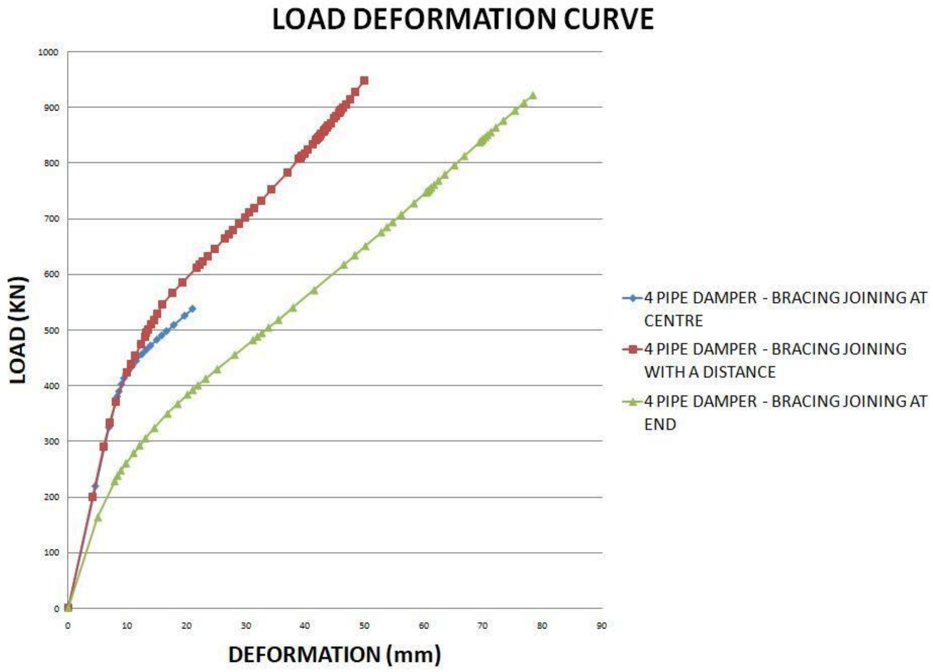

Fig. 12 Load Deformation Curve of 4 Pipe Dampers

VI. CONCLUSION

The study of metallic pipe damper is done to find its ultimate load carrying capacity. For this, a nonlinear pushover analysis of DPD as well as of other improved metallic pipe dampers which are introduced in this study, are done. The main conclusion obtained from the initial analysis is that model M11 have better ultimate load carrying capacity of 756.37 KN when compare to other models. The model M11 is designed with a metallic pipe of diameter 280 mm, 25 mm thickness and 50 mm breadth. The result of nonlinear investigation of pipe damper with an increase in number of metallic pipe shows that the ultimate load capacity of four pipe damper is 538.55 KN and that of three pipe damper is 446.16 KN. Hence it can be inferred that four pipe dampers have better performance than here pipe dampers. Further, four pipe damper is used for investigating the energy dissipation capacity of dampers when bracing configuration is changed. The result shows that ultimate load capacity obtained after pushover analysis of bracing joining at a distance apart is about 948.09 KN, whereas in other models with bracings joining at centre and bracing joining at ends have an ultimate load carrying capacity value of 538.55 KN and 921.67 KN. So, it can be concluded that the metallic pipe damper of four pipes with bracing joining at a distance apart shows better energy dissipation capacity when compared to other models.

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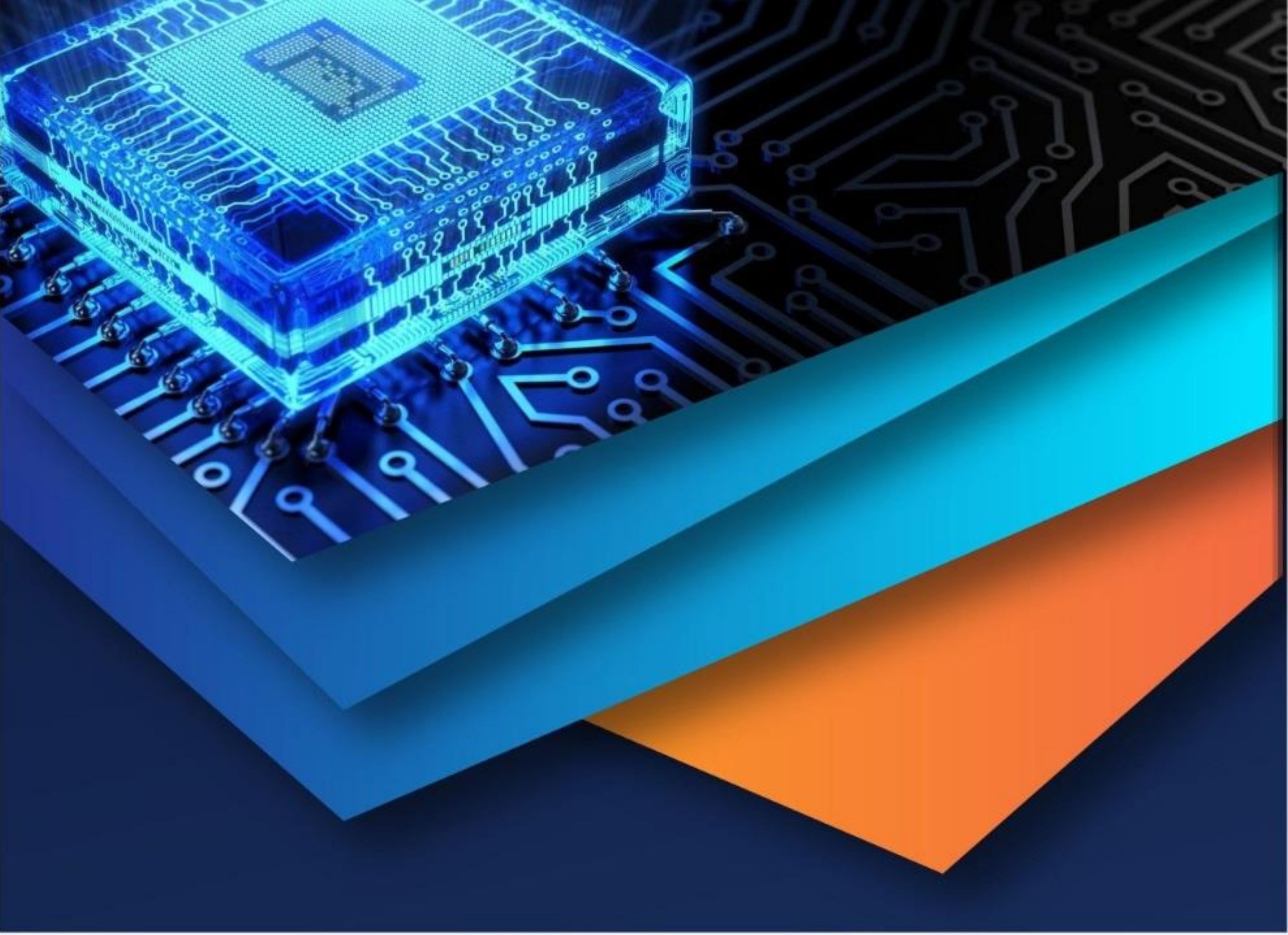

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