International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 05 | May 2020 www.irjet.net p-ISSN: 2395-0072

Seismic Performance of Hybrid Coupling Beam with Triple Slit Damper

Moyalan Hima Thomas[1], Seethu Sunny[2]

[1]PG Student, Dept. of Civil Engineering, MGM College of Engineering & Technology, Kerala, India
[2]Assistant Professor, Dept. of Civil Engineering, MGM College of Engineering & Technology, Kerala, India

---

Abstract - *Major earthquakes in the recent times have demonstrated that our built environment and infrastructure need to be more resilient to earthquakes. To ensure minimal disruption to everyday life and business in urban society, prompt post-earthquake recovery of buildings is necessary. In high seismic zones, coupled wall systems are often used in high-rise buildings to provide lateral resistance to earthquake loading. The post-earthquake repair or replacement of RC coupling beams are costly and time-consuming once damaged. Therefore, as an alternative to traditional RC coupling beams, various types of hybrid coupling beams have been proposed recently. In this paper, a novel type of hybrid coupled wall (HCW) system, which consists of reinforced concrete (RC) wall piers and hybrid coupling beams with triple slit metallic damper, has been proposed for enhancing the seismic resilience of high-rise buildings. This project presents the assessment of the seismic performance of two multistoried frames with HCW and conventional coupled wall (CCW) system located in a highly seismic area using ANSYS.*

***Key Words*: Hybrid Coupled Wall (HCW), Seismic Design, Seismic Performance, Composite Walls, Structural Fuse**

1. INTRODUCTION

Recent major earthquakes have shown that our built environment and infrastructure, particularly in the urban areas need to be more resilient to earthquakes. In seismically active regions, the most used system to resist lateral loads in medium to high-rise buildings are the coupled shear wall systems. They are widely used because of their dual seismic defense mechanism, i.e., the coupling beams and the shear walls. In other words, coupled core wall system consists of two shear walls connected intermittently by beams along the height. The connecting beam is called the coupling beam. The coupling beams exhibit superior energy dissipating characteristics and are expected to behave in a ductile manner. Coupling beams are designed to endure inelastic deformations under design-level earthquakes. Even though the coupling beams are intended to dissipate most of the input seismic energy, in many cases, significant damage is concentrated in the wall pier. Repair of such damages is found to be costly in terms of both money and time leading to long-lasting loss of occupancy and slow recovery of the community. To ensure minimal disruption to everyday life and business in the urban society, prompt post-earthquake recovery of buildings is a necessity. One solution to achieve this is to use easily replaceable components or devices in the energy dissipation regions of the structure.

In this paper, analysis two 11 story shear wall frames are conducted: one with the hybrid coupled wall system (HCW) and the other with conventional coupled wall (CCW) system to study their seismic performance using time history analysis. The HCW system consists of reinforced concrete (RC) shear walls connected with hybrid coupling beams. The hybrid coupling beam is configured with the triple slit metallic damper in the midspan region of the beam and a RC beam at each end of the metallic damper. On the other hand, the CCW system consists of RC shear walls connected with traditional RC coupling beams. The finite element model for the analytical study was created using the ANSYS Workbench software.

1.1 Scope and Objectives of the Study

Hybrid coupling beam installed with a triple slit damper is selected for this study. The work is limited to modelling and analysis of multistoried frame with HCW and CCW system using the software ANSYS. Analysis performed were restricted to modal analysis and time history analysis.

.

The main objectives of the study are follows:

- To develop and investigate the performance of a multi-storeyed frame with Hybrid Coupled Wall (HCW) system.
- To develop and investigate the performance of a multi-storeyed frame with Conventional Coupled Wall (CCW)system.
- To compare the analyses results of the HCW and CCW systems.

2. FINITE ELEMENT MODELLING

2.1 General

The parameters for modelling of the coupled wall system are adopted from the Journal paper titled “Seismic performance evaluation of coupled wall system with novel replaceable steel truss coupling beams” by Yong Li, et.al (2018), from Advances in Structural Engineering which is shown in fig. 1.

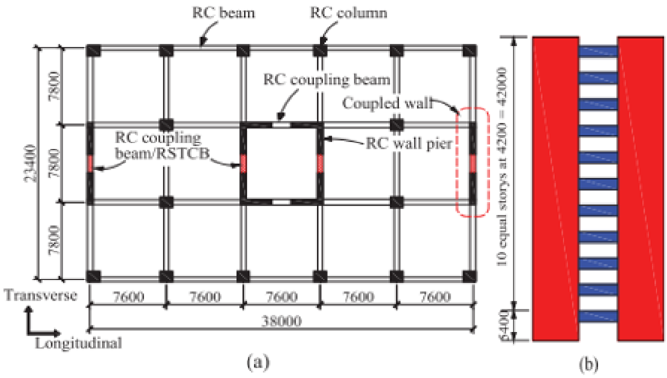


Fig -1 11-storey of prototype structure geometry (units: mm): (a) typical floor plan and (b) elevation of coupled wall [5]

2.2 Material Properties

The materials used in the modelling of the structure are concrete and steel. The material properties and the location where they are used are shown in table 1.

Table -1: Material property

Materials	Concrete	Steel
Location	Shear Wall and Coupling Beam	Metallic Damper
Young's Modulus (MPa)	3.87x10^4	2.03x10^5
Poisson's Ratio	0.15	0,3
Compressive/ Tensile strength (MPa)	60	235
Density (kg/m3)	2500	7850

2.3 Multistoried Frame with Hybrid Coupled Wall System

A two-dimensional multi-storeyed frame is constructed as per the dimensions shown in fig. 1 for the finite element analysis. The frame is modelled as 2-D structural solid elements (PLANE182) in ANSYS which is shown in fig 2.

To evaluate the seismic performance of the structure, dynamic analysis is performed. The two common types of dynamic analysis involved are modal analysis and transient dynamic analysis. Modal analysis is the process of determining the inherent dynamic characteristics of a system in forms of natural frequencies, damping factors, and mode shapes, and using them to formulate a mathematical model for its dynamic behavior. Transient dynamic analysis, also known as time-history analysis, aims at finding dynamic responses of a structure under arbitrary time-dependent loads. For performing the time-history analysis, the frequency of the EL Centro earthquake is applied.

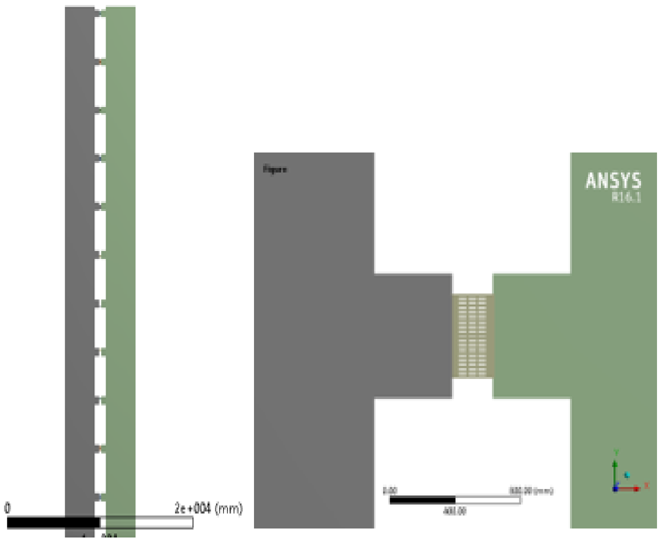


Fig -2: Model of the multi-storeyed frame with HCW system

From the modal analysis performed initially, the natural frequency which gives the displacement in the X direction of the model is obtained at mode 6. The corresponding natural frequency in this mode is 2.0232 Hz. The total deformation and mode shape at mode 6 is shown in fig. 3.

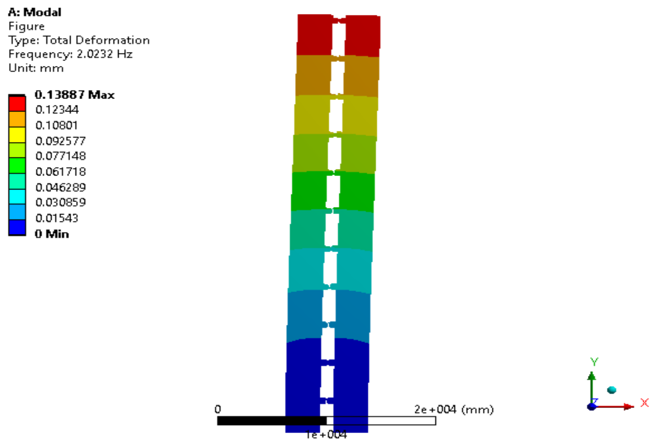


Fig -3: Total deformation and mode shape at Mode 6

After completion of the modal analysis, the transient dynamic analysis is performed. The fig. 4 shows the total storey displacement of the multi-storeyed frame with the hybrid coupled wall system. For better understanding, the magnified images of the deformation is shown in figure 5. It can be seen from this figure that the deformations of the coupling beams are concentrated at the metallic damper (yield section) whereas the coupling beam (non-yield section) remain vertical to the wall piers. From fig. 6 it can be observed that the maximum storey drift of the structure is 26.2 mm at 5secs.

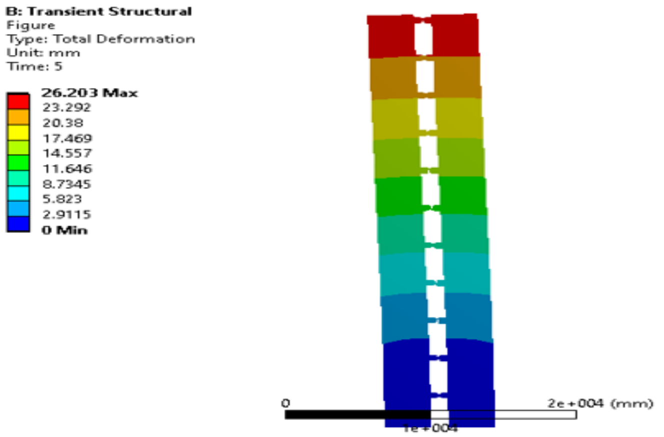


Fig -4: Total Deformation of the multi-storeyed frame with HCW

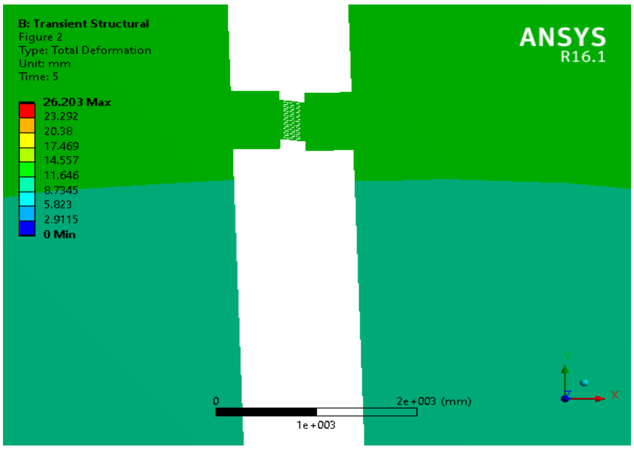


Fig -5: Enlarged view of the deformation of HCW system

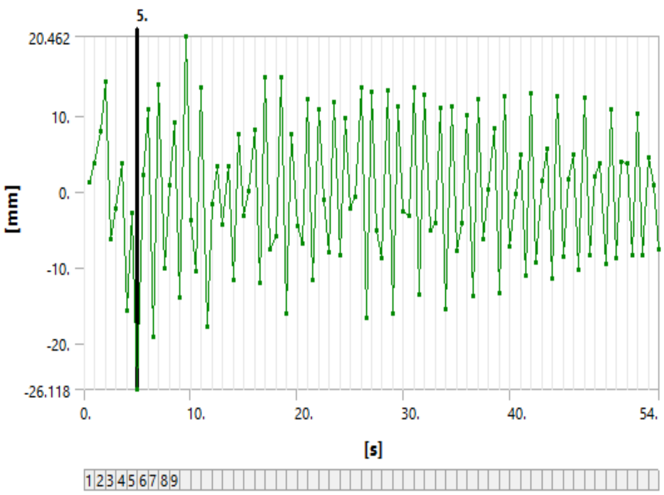


Fig- 6: Deformation versus time for HCW system

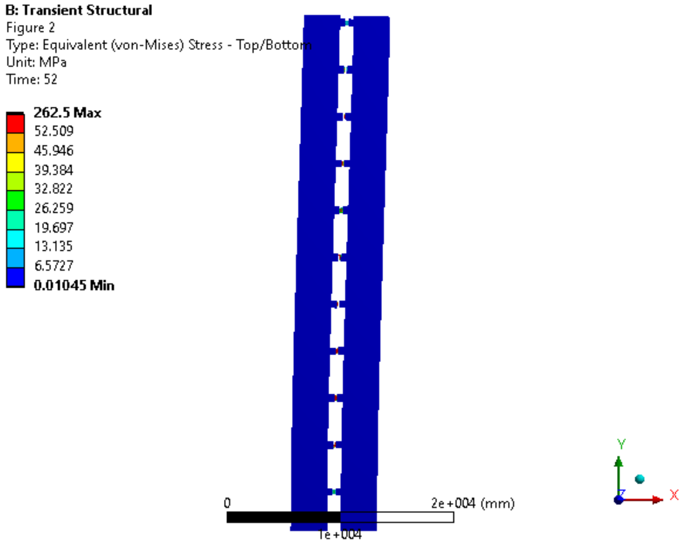


Fig- 7: Equivalent stress diagram of multi-storey with HCW system

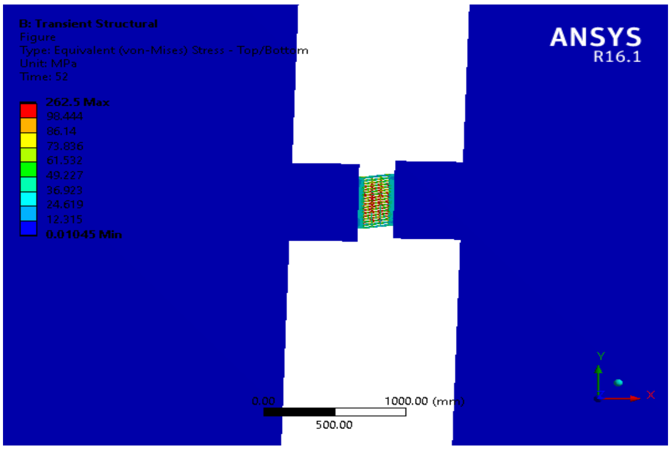


Fig- 8: Enlarged view of the equivalent stress diagram in the HCW system

It can be well observed from figures 7 and 8 that the stresses and deformations are concentrated in the metallic damper area and that they do not extend to the coupling beam or wall pier areas.

The fig. 9 shows the base shear v/s time graph obtained from ANSYS. It can be observed from this graph that the maximum base shear value of the structure is 399.36kN and occurs at the 5th second. It can also be seen that the base shear value reduces gradually after the 5th second.

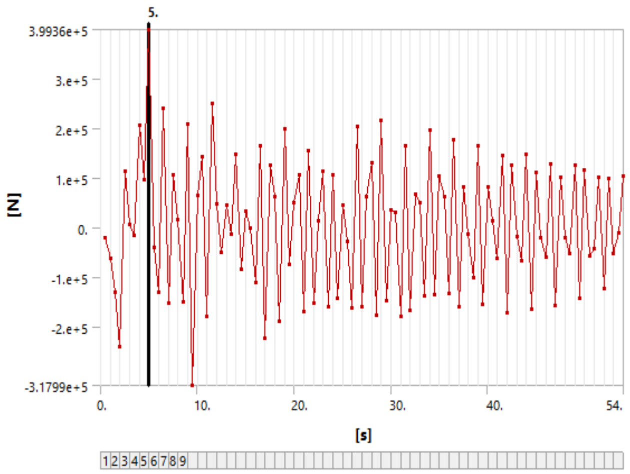


Fig- 9: Base shear v/s time graph for multi-storeyed frame with HCW system

2.4 Multistoried Frame with Conventional Coupled Wall System

The multi-storeyed frame with CCW system for the finite element analysis is modeled as 2-D structural solid elements (PLANE182), same as that for the frame with HCW system. The Fig. 10 shows the finite element model of the multi-storeyed frame with CCW system developed in ANSYS.

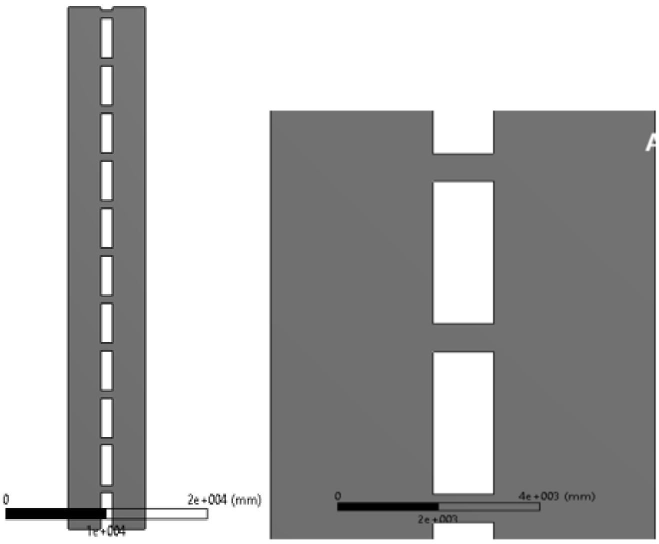


Fig- 10: Model of the multi-storeyed frame with CCW system

After the completion of modelling, modal analysis is performed first for which 20 modes are defined. The natural frequency which gives the displacement in the X direction of the model is obtained at mode 5. The corresponding natural frequency in this mode is 2.2612Hz. The total deformation and mode shape at mode 5 is shown in fig 11.

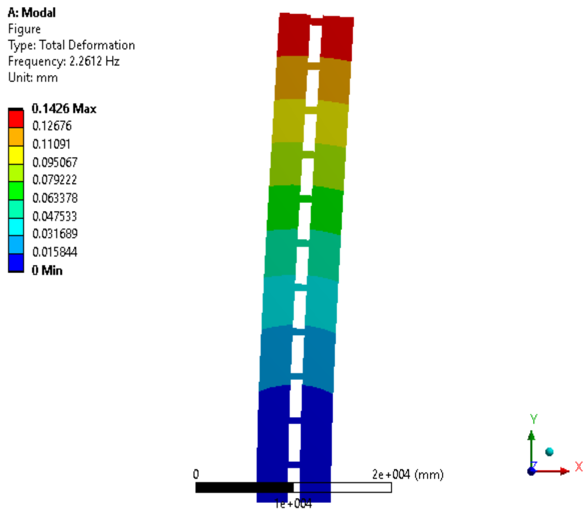


Fig- 11: Total deformation and mode shape at Mode 5

After completion of the modal analysis, the transient dynamic analysis is performed same as that done in the case of multi-storeyed frame with HCW system. Fig. 12 shows the total storey displacement of the multi-storeyed frame with the conventional coupled wall system. For better understanding the magnified images of the deformation is shown in figure 13. It can be seen from this figure that the coupling beams suffer bending type deformation. From fig. 14 it can be observed that the maximum storey drift of the structure is 31.374 mm at 24.5secs.

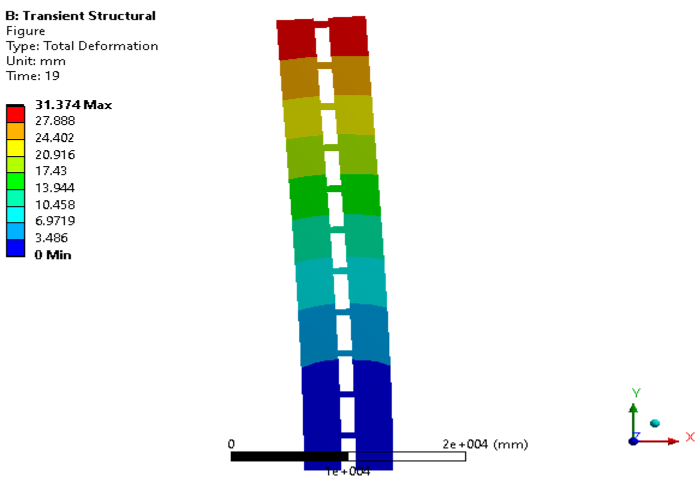


Fig- 12: Total Deformation of the multi-storeyed frame with CCW

Fig. 15 shows the equivalent stress concentrations in the multi-storeyed frames with CCW system. Fig. 16 shows the magnified view of the same for better understanding. The figures show that the tensile parts of the wall piers and the coupling beams are suffering severe damages due to stress concentrations.

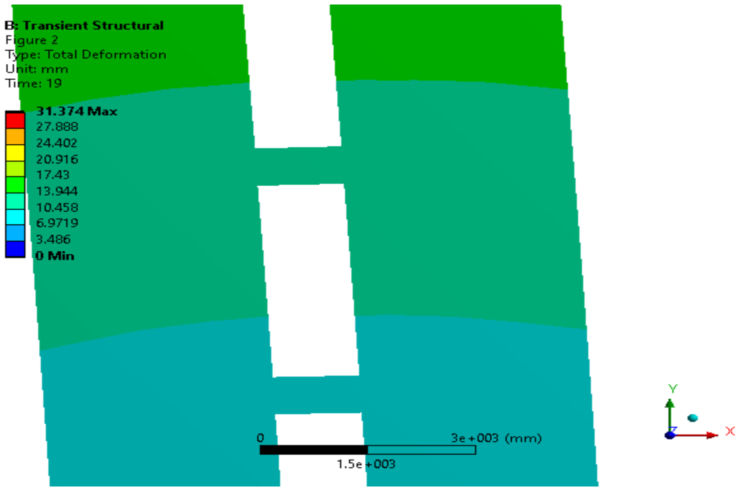


Fig- 13: Enlarged view of the deformation in the CCW system

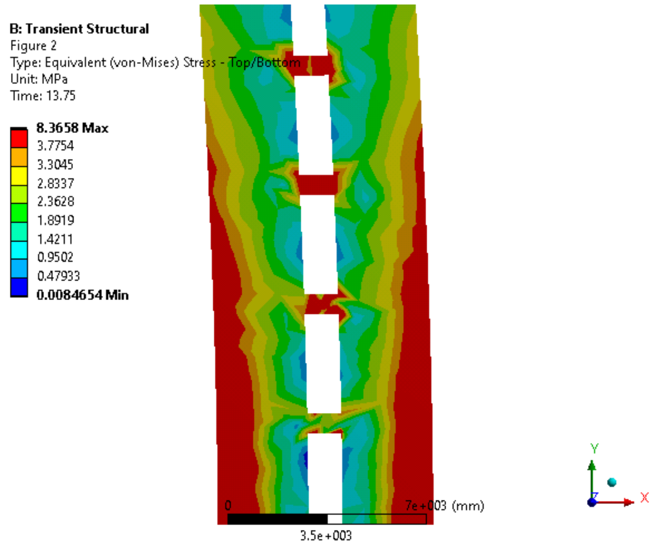


Fig- 15: Equivalent stress diagram of multi-storey with CCW system

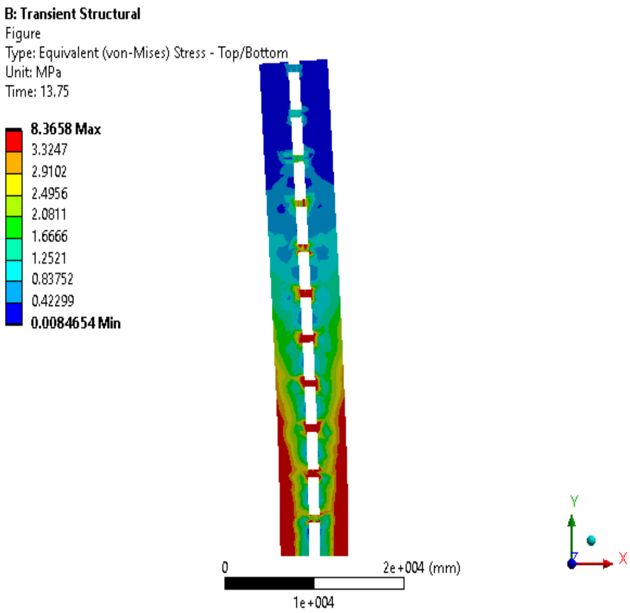


Fig- 14: Deformation versus time for CCW system

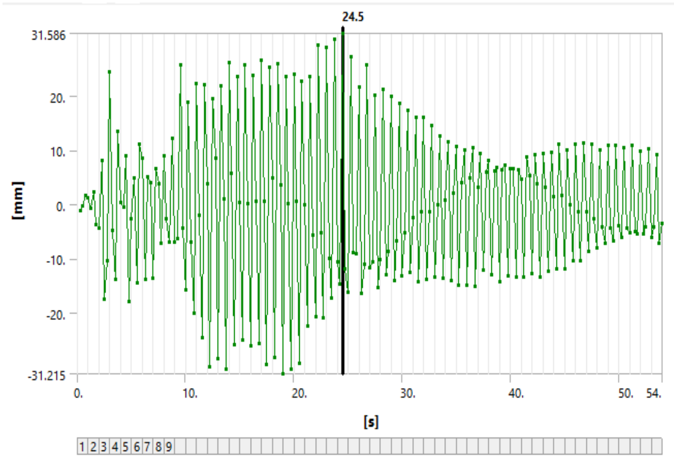


Fig- 16: Enlarged view of the equivalent stress diagram in the CCW system

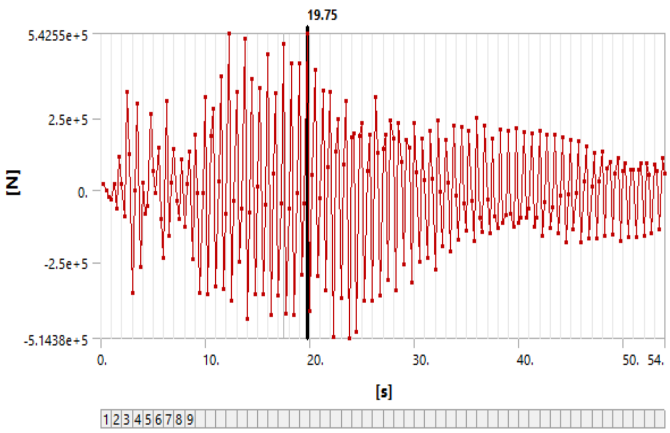


Fig- 17: Base shear v/s time graph for multi-storeyed frame with CCW system

The fig.17 shows the base shear v/s time graph obtained from ANSYS. It can be observed from this graph that the maximum base shear value of the structure is 542.55kN and occurs at 19.75 second.

3. RESULT AND DISCUSSIONS

3.1 Time Period

From the modal analysis, the natural frequency (f) which gives the displacement in the X direction of both the models are obtained. From the frequencies the time period (T) of each of the models is computed. The frequencies and corresponding time periods are given below in table 2. The time period of the frame with HCW system is slightly higher than that of the frame with CCW system. Since the masses of the two frames are almost similar, it can be said that the frame with HCW systems is a little more flexible than the CCW systems.

Multistoried Frame Model	Mode	Frequency obtained from ANSYS (f) (Hz)	Time Period (T) T=1/f (sec)
HCW system	6	2.0232	0.494
CCW system	5	2.2612	0.4422

Table- 2: Frequency and time period of HCW and CCW systems

3.2 Base Shear

The maximum base shear value of the HCW system is 399.36 kN at 5secs and it can be observed that the base shear reduces thereafter. The maximum base shear value of CCW system is seen to be 542.55 kN at 19.75 secs. Thus, an increase of about 35.85% in the base shear values of the CCW system is seen as compared to the HCW system. Chart 1 shows the comparison of the base shear values of the two systems in graphical form.

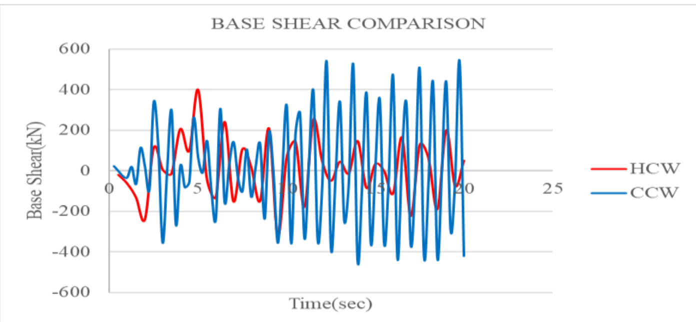


Chart- 1: Comparison graph of base shear for multistoried frame with HCW and CCW system

3.3 Story Displacement

A comparative study of the story displacements for the two models is also conducted. The maximum displacement for the multistoried frame with HCW system is 26.203mm and that with CCW system is 31.374mm. It shows that the displacement along the height of the structure has reduced by 19.73% in the HCW system as compared to the CCW system. Chart 2 shows the graphical representation of the same.

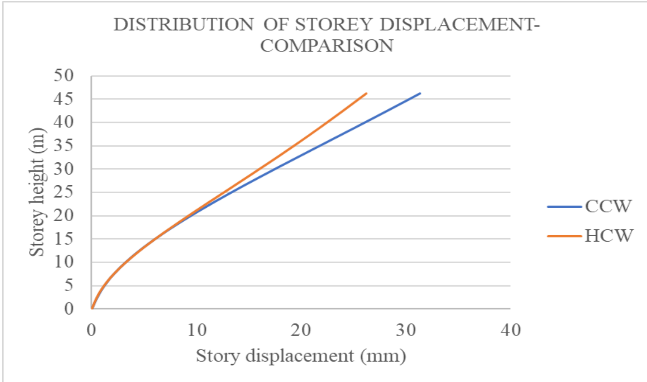
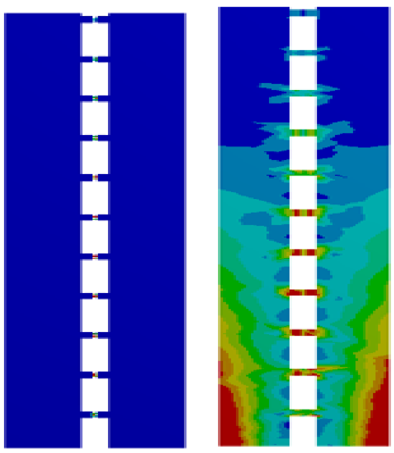


Chart- 2: Comparison graph of distribution of story displacement for multistoried frame with HCW and CCW system

3.4 Damage Analysis

The damage distribution contours under earthquake are shown in fig. 18 for the HCW and CCW structures. Both the wall and the coupling beam in the CCW system experience much greater damage than those in the HCW system. The damage in the HCW system is concentrated in the midspan damper and very less amount of damage is extended to the coupling beams.



(a) (b)

Fig- :18 Damage Distribution under ground motion: (a) HCW system, (b) CCW system

4. CONCLUSIONS

In this paper, the seismic performance of two coupled wall systems: Hybrid Coupled Wall (HCW) system and Conventional Coupled Wall (CCW) system were evaluated under maximum considered earthquake (MCE). The HCW system consists of RC shear walls and hybrid coupling beams with the triple slit metallic damper at the mid span and RC beam segments at both ends of the damper and the CCW system consists of RC shear walls and coupling beams. An 11-storey prototype structure was modelled in ANSYS and dynamic analysis was conducted for this purpose. Based on the analysis results, the following conclusions are drawn:

1. Compared with the structure with conventional RC coupling beams, the structure with the hybrid coupling beams reduced the base shear force by about 35.85%. The deformation mode was changed in the latter case, and most of the energy was consumed by the metallic damper, rather than the wall components as in the case of the CCW system.
2. The story displacement along the height of the structure was reduced by 19.73% in the HCW system as compared to the CCW system. Thus, the use of triple slit metallic damper leads to good overall seismic responses with reduced story displacements.
3. From the stress and damage contours it can be concluded that, large amounts of energy can be dissipated and most of the damage can be concentrated in the metallic dampers which can be easily replaced after earthquake. Thus, by installing replaceable triple slit metallic dampers the behaviour and post-earthquake recovery of the coupled wall system can be improved significantly.
4. Thus, with the use of this replaceable damper, the repair time and cost post-earthquake can be reduced significantly, thereby enhancing the seismic performance of the HCW building.

ACKNOWLEDGEMENT

I wish to thank the Principal and Head of Civil Engineering Department of MGM College of Engineering and Technology, affiliated by Kerala Technological University for their support. This paper is based on the work carried out by me (Moyalan Hima Thomas), as part of my PG course, under the guidance of Ms. Seethu Sunny (Assistant Professor, MGM College of Engineering and Technology, Kerala). I express my gratitude for her valuable guidance.

REFERENCES

[1] Tao Wang, Qingxue Shanga , Xiaoting Wangb , Jichao Lia and Zi'ang Kong (2018), "Experimental validation of RC shear wall structures with hybrid coupling beams", Journal of Soil Dynamics and Earthquake Engineering,111, 14-30.

[2] Constantin Christopoulos and Michael Montgomery (2013), "Viscoelastic coupling dampers (VCDs) for enhanced wind and seismic performance of high-rise buildings", Earthquake Engineering and Structural Dynamics, 42, 2217-2233.

[3] Xiaodong Ji, Dan Liua and Carlos Molina Hutt (2018), "Seismic performance evaluation of a high-rise building with novel hybrid coupled walls", Journal of Engineering Structures, 169, 216-225.

[4]Bahram M. Shahrooz, Patrick J. Fortney and Kent A. Harries, (2018), "Steel Coupling Beams with a Replaceable Fuse", Journal of Structural Engineering, 144, 1- 11.

[5] Yong Li, Ye Liu and Shaoping Meng (2018), "Seismic performance evaluation of coupled wall system with novel replaceable steel truss coupling beams", Advances in Structural Engineering, 10, 1-13.

[6] Xilin Lu, Cong Chen, Huanjun Jiang and Shanshan Wang (2018), "Shaking table tests and numerical analyses of an RC coupled wall structure with replaceable coupling beams", Article in Earthquake engineering and Structural Dynamics, 47, 1882- 1904.

[7] Cong Chen, Renjie Xiao , Xilin Lu and Yun Chen(2017), "Study on Shear wall structures with combined form of replaceable devices". Advances in Structural Engineering, 21, 1327-1348.

[8] Xiaodong Ji, Yandong Wang ; Qifeng Ma and Taichiro Okazaki (2016), "Cyclic Behaviour of Replaceable Steel Coupling Beams", Journal of Structural Engineering, 733, 1-11.

[9] Min-Yuan Cheng, Rijalul Fikri and Cheng-Cheng Chen (2015), "Experimental study of reinforced concrete and hybrid coupled shear wall system", Journal of Engineering Structures, 82, 14- 225.

[10] Patrick J. Fortney, Bahram M. Shahrooz and Gian A. Rassati (2007), "Large-Scale Testing of a Replaceable "Fuse" Steel Coupling Beam", Journal of Structural Engineering, 133, 1801- 1807.

[11] Guoqiang Li, Feifei Sun, Mengde Pang, Wenyang Liu, and Haijiang Wang (2016), "Structural Shear Wall Systems with Metal Energy Dissipation Mechanism", International Journal of High-Rise Building, 5, 195- 203.

[12] Francesco Sarti, Alessando Palermo and Stefano Pampanin (2016), "Fuse-Type External Replaceable Dissipaters: Experimental Program and Numerical Modelling", Journal of Structural Engineering, 142, 1- 12.

[13] Abdelatee A. Eljadei and Kent A. Harries (2014), "Design of coupled wall structures as evolving structural systems", Journal of Engineering Structures, 73, 100- 113.