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Seismic Analysis of an Optimised Energy Dissipating Shear Key

Nizwin K S[1], Anju Mary Ealias[2]
[1]*PG Scholar, SCMS School of Engineering and Technology, Ernakulam, Kerala, India.*
[2]*Assistant Professor, SCMS School of Engineering and Technology, Ernakulam, Kerala, India.*

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Abstract: *Infrastructure such as bridges are significantly vulnerable to earthquakes causing huge damage to the structure. The energy generated during an earthquake needs to be properly dissipated to make a resilient structure against earthquake. Conventional reinforced shear keys and elastomeric pads were found to be less effective and difficult to be replaced. The 2004 earthquake caused the Chengappa bridge across the Austen Strait in the Andaman Islands to displace horizontally and fell off from the bearings. lack of restrainers to arrest excessive displacement of the bridge deck was one among the important cause of damage. As motivated by the need for enhanced earthquake resistant structures, this paper proposes a novel approach to seismic resilience by introducing optimised shear key dampers into the bridges. The hourglass model of dampers is remodelled and a parameter analysis is conducted on geometry, configuration and energy dissipation to develop a novel optimised shear key based on key factors such as ductility, stiffness and ultimate displacements.*

Key Word: *Shear key, damper, optimisation*.

I.INTRODUCTION

Earthquake is caused by the movement of tectonic plates that release huge amounts of energy. These tectonic plates converge or diverge in a collision. The energy generated during an earthquake needs to be properly dissipated from the structure to reduce its damage. Infrastructure such as buildings and bridges are significantly vulnerable to earthquakes. Energy-dissipating shear keys are one of the novel and effective instruments used for dissipating energy. Earthquake causes the loss of hundreds of lives and damage to the infrastructure each year. The shear keys have a critical role for to enhance the performance of the structure by absorbing and dissipating energy reducing the impact on structure. The vibrations during earthquake are absorbed by energy-dissipating shear key which act as a damper; hence improvisations and innovations are essential in the field of designing optimised shear key dampers. They work under the principles of friction, deformation or yielding of materials thus reducing the drifts, peak response of the structure and chances of progressive collapses. Hence the optimised shear key ensures the safety with in the cost benefits. Hence shear key dampers can be modelled based on the parameters considering adequate results on ductility, stiffness, ultimate load carrying capacity and ultimate displacement etc. Shear key damper is modelled, boundary conditions are assigned and various parameters are analysed.

II.MODELLING

A shear key damper is modelled using the ANSYS software for the analysis. The density, Youngs modulus and poisons ratio are inputted as the engineering data. The damper is made of steel with an ultimate strength of 235MPa with good ductile and weldability properties. The boundary conditions are assigned such that the upper part of the plate is subjected to displacement loading. The displacement provided is 90mm after repeated evaluation. The bottom plate is fixed as rigid connection. Loading is applied horizontally as lateral loads in an earthquake scenario. The simulation and analysis are based on finite element method and meshing is done in order to divide the entire damper to smaller elements. The loading and boundary conditions are applied to each element. The meshing size provided is 10mm.The models are analysed and equivalent plastic strain, deformation and energy dissipation output results are evaluated.

III. PARAMETER ANALYSIS

A parametric analysis is conducted in order to study the influence of constituent parameters on the performance of shear key damper. A parameter analysis helps to understand how the parameters influence behaviour of shear key damper under cyclic loading conditions. The performance is analysed based on the ultimate displacement, ultimate loading. ductility, and stiffness results of damper. Thus, a detailed optimisation process enhances the energy dissipation and reduces the cost without compromising performance. The parameters are listed below.

- Number of sets of damper plates
- Thickness of plates
- Spacing configuration between the plates

- Number of elliptical plates
- Energy dissipation

3.1 Number of sets of plates

The arrangement and configuration are an important parameter influencing the overall performance. Damper plates with three, two and single plate are analysed to study the influence of stiffness and ductility.

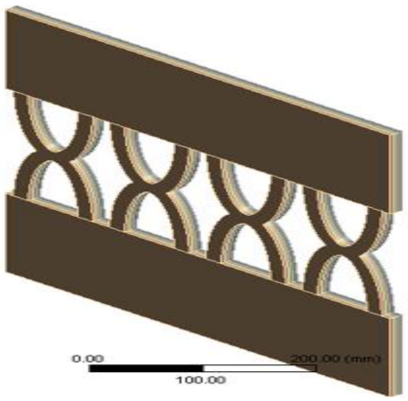

Fig. 1 Three sets of 5mm plates

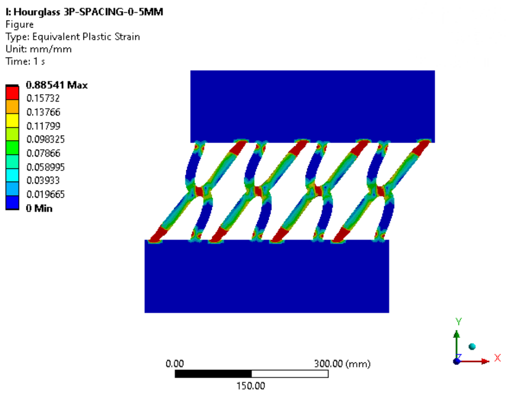

Fig. 2 Equivalent plastic strain

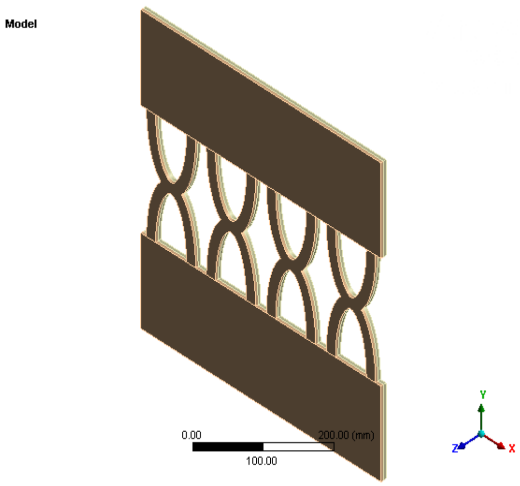

Fig. 3 Two sets of 5mm plates

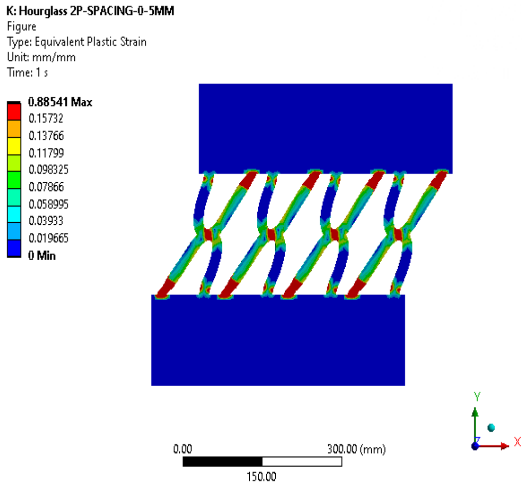

Fig. 4 Equivalent plastic strain

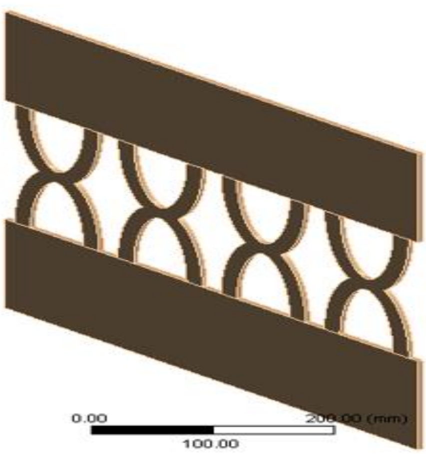

Fig. 5 One set of 5mm plate

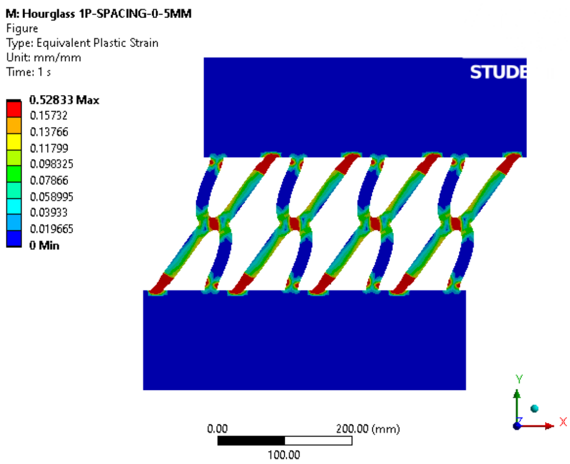

Fig. 6 Equivalent plastic strain

Table 1 Comparison between number of sets of plates

Model (5mm each)	Yield load (kN)	Yield displacement (mm)	Stiffness (kN/mm)	Ultimate load (kN)	Ultimate displacement (mm)	Ductility
3 Set of plates	135.30	5.25	25.77	291.53	68.29	13.01
2 Set of plates	90.15	5.25	17.17	190.53	68.20	12.99
1 Set of plate	36.04	1.84	19.61	95.66	66.53	36.21

The increase in the number of sets of plates in the arrangement can increase the load-carrying capacity and stiffness, however the single set of plate had the higher ductility hence as a sacrificial shear key damper ductile property of shear key is preferred. The ductility of single set of plate was 36.21 while three sets of plate had only 13.01.

3.2 Thickness of plate

The influence of thickness on the stiffness, load carrying capacity and the ductility is analysed below.

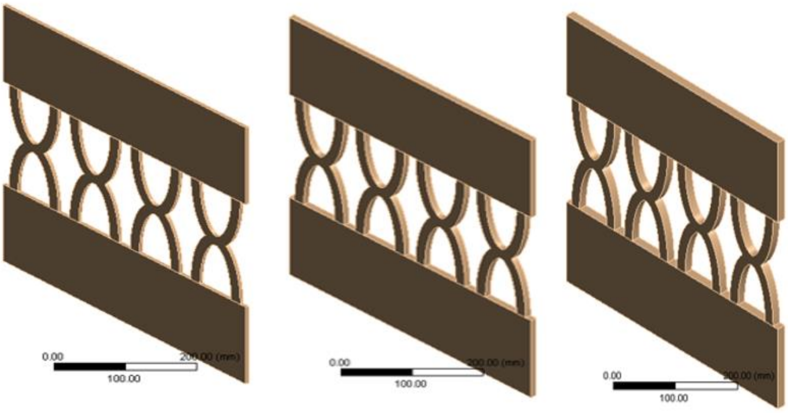

Fig. 7 5,10,15 mm thickness plates

Table 2 Comparison between thickness of plates

Model (mm)	Yield load (kN)	Yield displacement (mm)	Stiffness (kN/mm)	Ultimate load (kN)	Ultimate displacement (mm)	Ductility
Thickness 5	36.04	1.84	19.61	95.66	66.53	36.21
Thickness 10	71.60	1.84	38.95	193.45	68.05	37.02
Thickness 15	106.45	1.84	57.89	292.65	68.34	37.17

With the increase in thickness of the plate the load-carrying capacity and stiffness increase, however, the yield displacement and the ductility remain nearly the same.

3.3 Spacing between plates

Multiple number of plates are needed to be arranged in a bridge to prevent unseating. The spacing provided in between the plates are an important factor while transfering the stress to the adjacent dampers equally. Three sets of plates with spacing 0,5,10,15 mm are modeled given below.

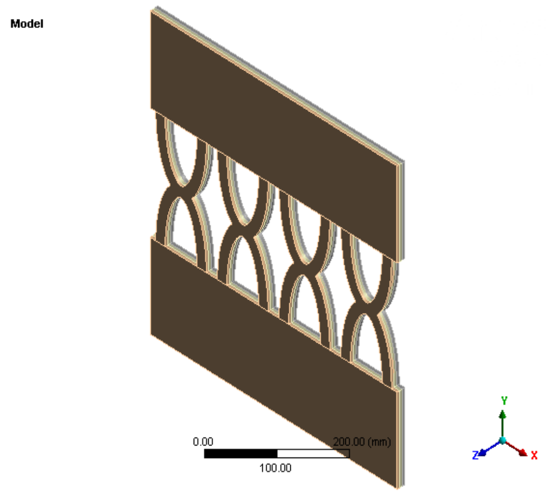

Fig. 8 Spacing 0 mm

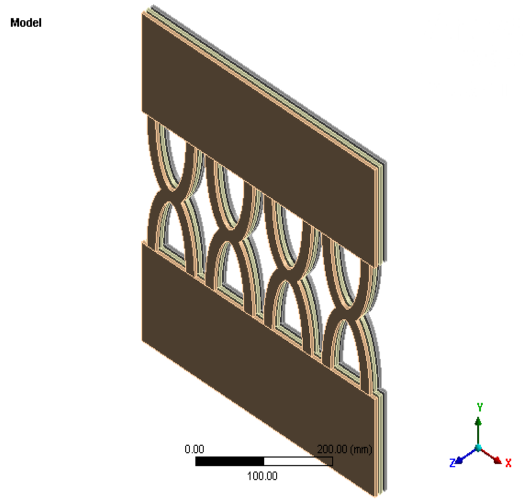

Fig. 9 Spacing 5 mm

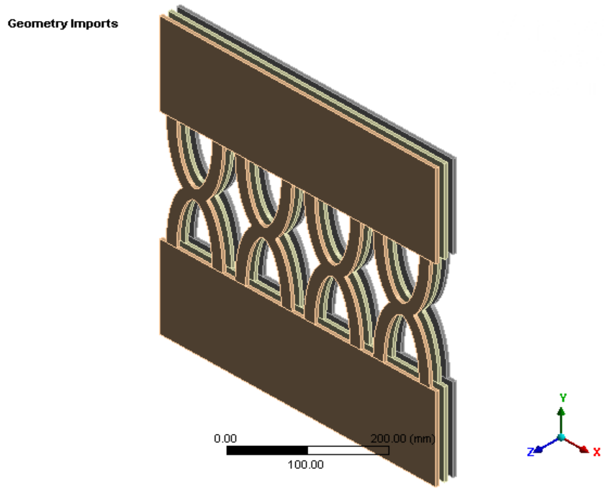

Fig. 10 Spacing 10 mm

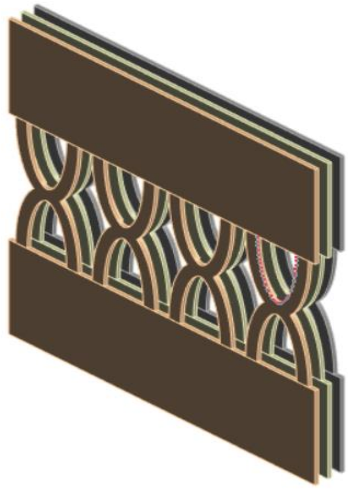

Fig. 11 Spacing 15 mm

Table 3 Comparison between spacing of plates

Model (5mm)	Yield load (kN)	Yield displacement (mm)	Stiffness (kN/mm)	Ultimate load (kN)	Ultimate displacement (mm)	Ductility
Spacing 0	135.3	5.25	25.77	291.53	68.29	13.01
Spacing 5	108.11	1.84	58.83	286.98	66.53	36.21
Spacing10	107.0	2.21	48.51	257.40	76.45	34.66
Spacing 15	106.96	2.21	48.48	257.62	75.72	34.32

The ultimate load, and ductility increases when spacing of the plates is arranged equal to the thickness of the plate that models compared to no spacing plates and also reduces with a further increase in spacing. To provide optimum results in case of stiffness providing adequate spacing is considerable.

3.4 Number of elliptical plates

The hourglass damper plates of different numbers under constant area and depth are analysed.

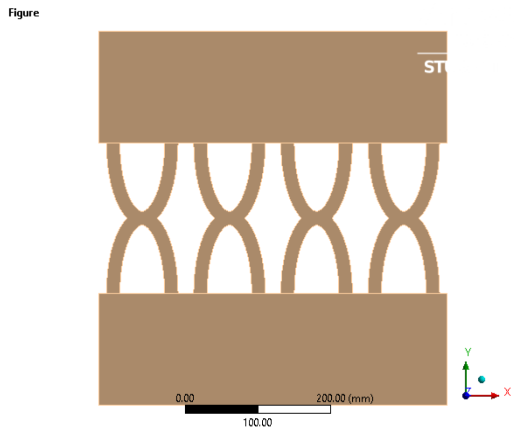

Fig. 12 Four number damper plates

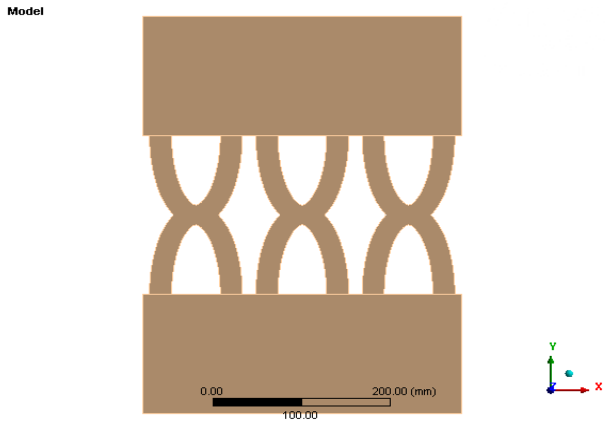

Fig. 13 Three number damper plates

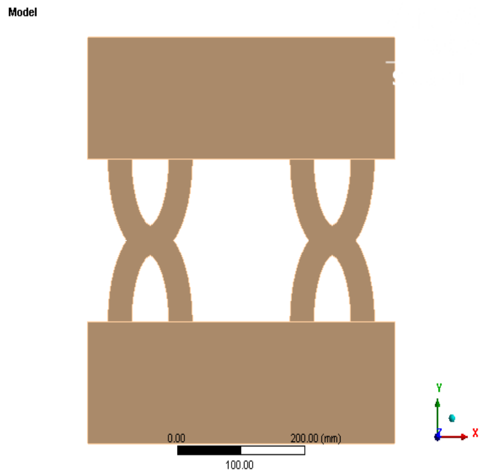

Fig. 14 Two number damper plates

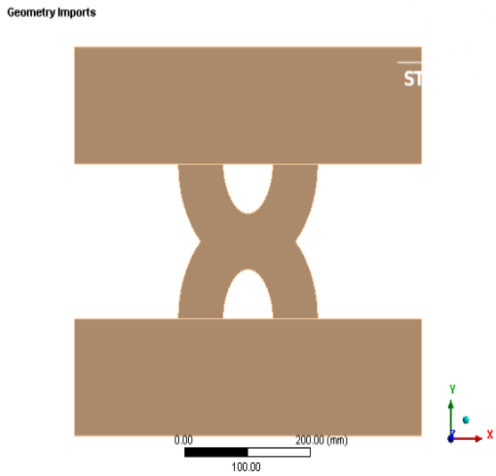

Fig. 15 One number damper plate

Table 4 Comparison between number elliptical plates

No. of elliptical damper	Yield load (kN)	Yield displacement (mm)	Stiffness (kN/mm)	Ultimate load (kN)	Ultimate displacement (mm)	Ductility
4	34.75	2.21	15.75	83.11	74.79	33.91
3	31.24	0.99	31.47	87.58	73.67	74.23
2	39.37	0.77	50.99	101.75	80.65	104.46
1	61.68	0.77	79.88	97.85	48.86	63.28

For a constant area, among 4,3,2,1 numbers of damper plates the 2 number elliptical plates provide maximum load-carrying capacity of 101.75kN and ductility of 104.46.

3.5 Energy dissipation

Energy dissipation using damper plates during earthquakes is critical for minimizing damage to structures and preventing fatalities by lowering the impact of seismic forces. It improves the resilience of buildings and infrastructure, assuring their stability and functionality in the face of seismic activity. Hence energy dissipation is an important factor for the performance of a damper. The hysteresis loop represents the relation between the earthquake motion input force and the dampers deformation response during an earthquake. The total area of enclosure of the hysteresis curve represents the dissipated energy from the shear key damper.The energy generated from earthquake needs to be dissipated to reduce the induced vibrations on the structure hence the mitigation of earthquake-induced structural damage depends on this dissipation. The size of hysteresis curve and form provide information on how well the damper dissipates seismic energy. A larger loop area is usually indicative of greater the ability for energy absorption.

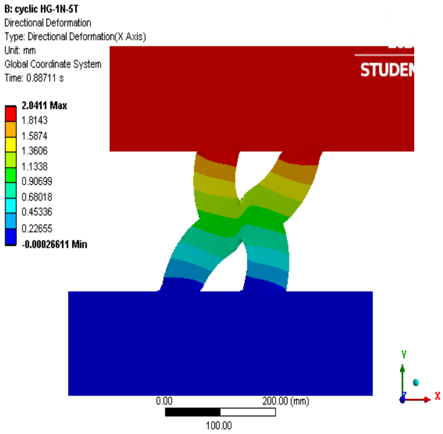

Fig.16 Deformation of a single damper

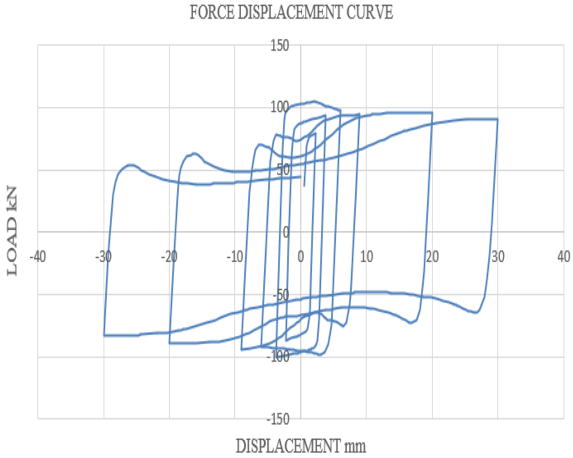

Fig.17 Hysteresis loop of a single damper

Origin is a robust data analysis and graphing programme. It is especially used to evaluate experimental data, such as hysteresis loop data from seismic tests. Origin makes it possible for users to produce intricate hysteresis loop plots and illustrations, which makes it easier to comprehend how dampers dissipate energy during earthquake events. By using Origin's advanced statistical and mathematical functions, users can assess the region that the hysteresis loop defines quantitatively. This allows for accurate measurements of energy dissipation and helps optimise damper design for improved earthquake resistance.

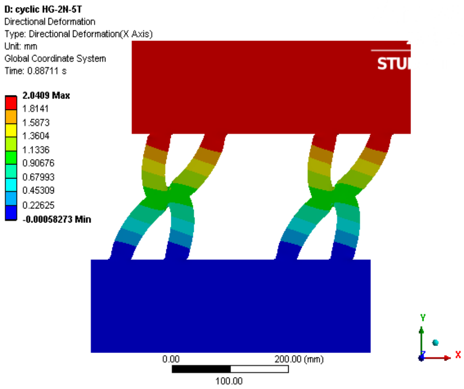

Fig.18 Deformation of two damper plates

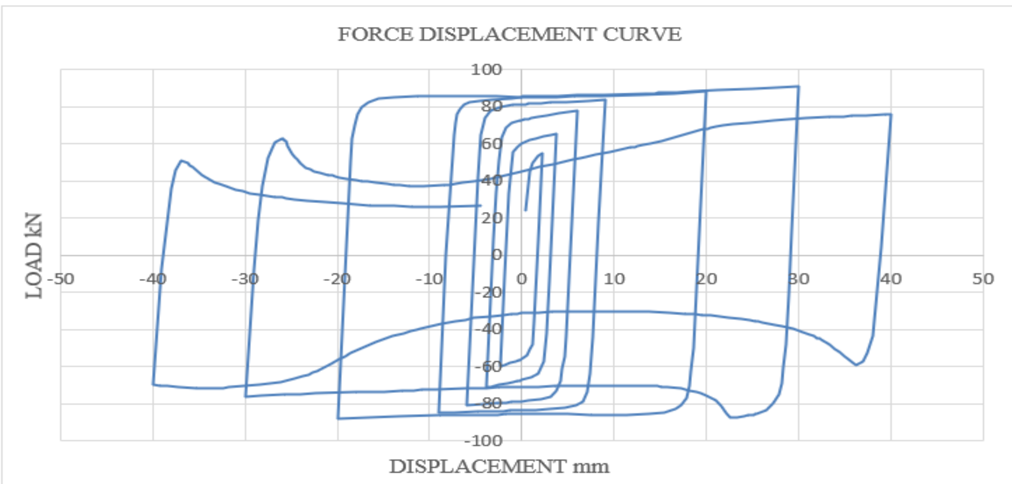

Fig.19 Hysteresis loop of 2 damper plates

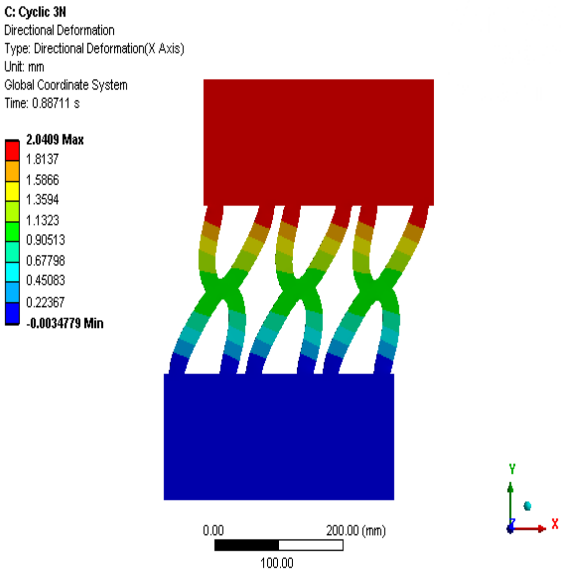

Fig.20 Deformation of three damper plates

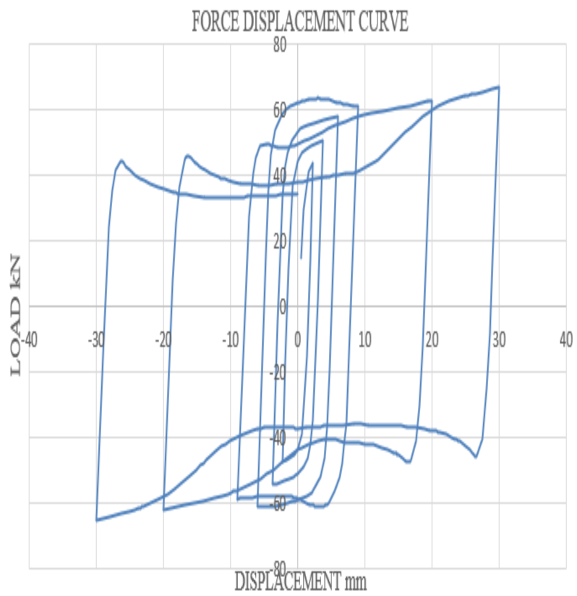

Fig.21 Hysteresis loop of 3 damper plates

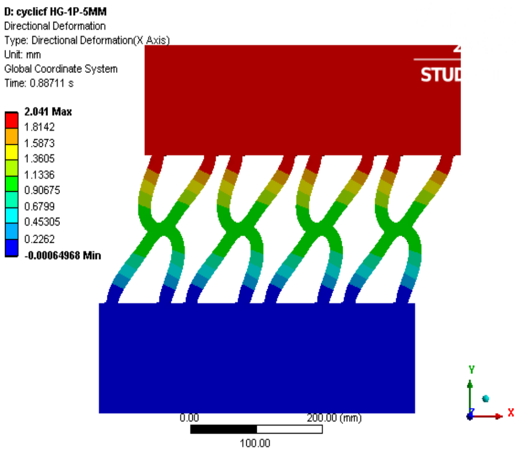

Fig.22 Deformation of four damper plates

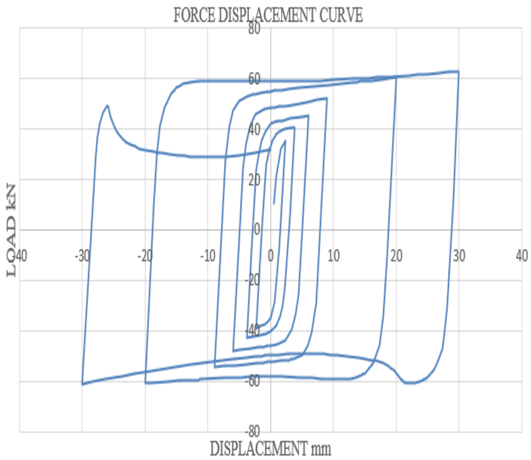

Fig.23 Hysteresis loop of four damper plates

Table 5 Comparison between number of plates and energy dissipation

Number of hourglass dampers	Energy dissipated (kJ)
1	18.73×10^6
2	27.395×10^6
3	12.482×10^6
4	13.201×10^6

The maximum load carrying capacity and the energy dissipation is for the 2 number of hourglass dampers of thickness 5mm. The two numbered damper had an energy dissipation of 27.395×10^6Kj.

IV. FINITE ELEMENTS ANALYSIS

The optimized shear key is designed with two number of elliptical damper plates with a single set of thickness 5mm. The ductility and stiffness are given more priority since they hold an inevitable role during energy dissipation and yielding. It allows for significant rate of deformation till failure and acts as a sacrificial element. The two numbers damper was found to be having highest energy dissipation characteristics from the hysteresis loop and also higher ductility, ultimate displacement and ultimate load carrying capacity. Hence ensures stability under loads for buildings, bridges and industrial facilities.

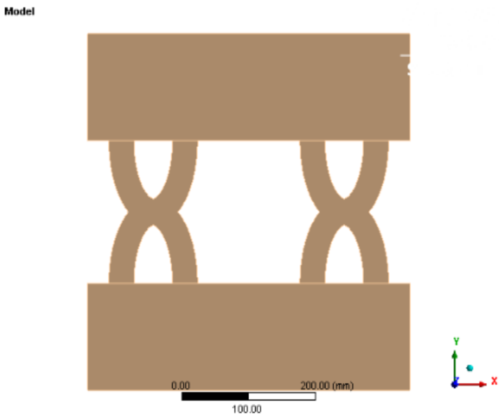

Fig.24 Optimised shear key

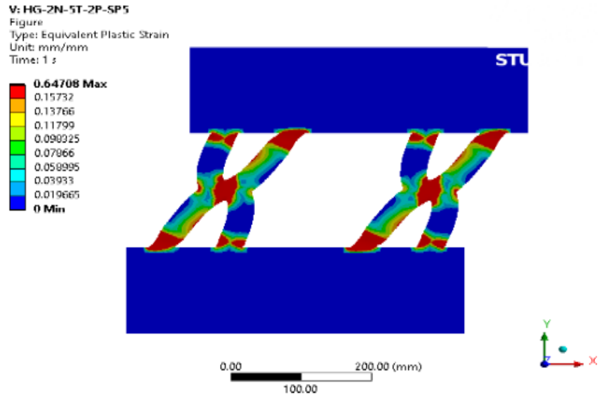

Fig.25 Equivalent plastic strain

V.CONCLUSION

The increase in the number of sets of plates in the arrangement can increase the load-carrying capacity and stiffness, whereas ductility is reduced. The stiffness, load carrying capacity, and ductility increase when the spacing of the plates is arranged equal to the thickness of the plate that models compared to no spacing plates and also reduces with a further increase in spacing. With the increase in thickness of the plate the load-carrying capacity and stiffness increase, however, the yield displacement and the ductility remain nearly the same. Even though 3 sets of plates with 5 mm thickness at 5mm spacing have slightly higher stiffness, the ultimate load and ductility are higher for 1 plate of 15 mm thickness, thereby reducing the cost of wastage and workmanship. For a constant area, 2 number elliptical plates provide maximum load-carrying capacity and ductility. Maximum energy dissipation is found to be in two number dampers compared to other models. An optimised shear key was developed with two number of hourglass plates in a single set with maximum energy dissipation, ductility and ultimate displacement. In conclusion, the incorporation of shear key dampers in designs is crucial for enhancing seismic performance, mitigating potential damage, and ensuring the safety and resilience in buildings and bridges.

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