LATERAL RESISTANCE AND SEISMIC BEHAVIOUR OF STEEL PLATE CONCRETE COMPOSITE SHEAR WALL.

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Abstract— The paper presents Lateral resistance and seismic behaviour of the steel plate concrete composite shear wall. Numerical analysis on composite shear wall was carried out through ANSYS WORKBENCH 16.1 software. The traditional RC shear wall tends to develop tension cracks in the tension zones and crush in the localized compression areas during large cyclic excursions. Cracks and crushing failures result in splitting and spalling failure of the wall with serious deterioration of stiffness and reduction in strength. Thus some improved technology in construction required to meet the needs, Composite shear Wall comprises of two faceplates, concrete, shear studs and tie rods as connectors. Lateral resistance on composite shear wall with various Aspect ratio and shear stud shapes were studied. For the strengthening of composite shear wall, stiffeners were introduced in wall and nonlinear cyclic analysis on composite shear wall with different stiffener arrangement such as diagonal, radial, vertical, circular was carried out. The wall with Aspect ratio 1 shows good lateral resistance. There is no significant variation in the performance of walls with different shear stud shape. Steel plate concrete composite shear wall with diagonally arranged stiffener shows good seismic performance as compared to other shear walls.

Index Terms— Aspect ratio, Non linear cyclic analysis, RC shear wall, shear stud, steel plate concrete composite shear wall (SPCCSW), steel face plates, stiffeners, Tie rods, ultra-light weight cement composite.

1 INTRODUCTION

Shear wall is a structural system composed of shear panels to counter the effects of lateral load acting on a structure. The first generation of shear walls is reinforced concrete walls, have been widely used in high-rise buildings due to their high lateral stiffness and strength, but they are susceptible to brittle failure caused by the compressive failure of concrete when subjected to strong earthquakes and traditional RC shear wall tends to develop tension cracks in the tension zones and crush in the localized compression areas during large cyclic excursions. Thus the second generations of walls were developed that are steel plate shear walls (SPSW). In this type of shear walls, the resistant core is of steel sheets instead of reinforced concrete, these walls having sufficient stiffness, have high ductility, but disadvantage of SPSW is the buckling of the infill steel plate in compression field which triggers significant reductions in lateral stiffness, shear capacity, and energy absorption of the system. From studies it's found that composite construction can overcome all the drawbacks that seen in the conventional methods of construction and it can give much better seismic performance thus The third generations of shear walls called composite steel plate shear walls (CSPSWs). A composite shear wall generally comprises two steel faceplates, infill concrete and connectors. The connectors, which join the steel faceplates and the faceplates to the infill concrete, are typically shear studs, tie rods and/or structural shapes. Shear studs and tie rods are typically welded to the steel faceplates.

Compared to the traditional reinforced concrete (RC) wall, the composite wall has higher bearing and deformation capacities. So the wall thickness can be reduced and more usable floor areas can be obtained when using the composite walls in the super high-rise buildings.

Several studies were done on the seismic behaviour of steel plate concrete composite shear wall (SPCCSW) from 1970 to 2019. In all the studies its found that performance of SPCCSW is good as compare to steel plate as well as RC shear wall,because of its ductility and energy dissipation characteristics.

Nam H. Nguyen et al.performed numerical study of steel plate concrete (SC) composite walls using ABAQUS. Predictions are compared to data from reversed cyclic, inelastic tests of four large-scale SC wall piers with an aspect ratio of 1.0,wall consist of steel faceplates, infill concrete, shear studs and tierods as connectors. Results concludes, the damage progression of all walls was similar, cracking and crushing of infill concrete occurs at the toes of the walls. Loss of stiffness and strength was observed in all walls at lateral displacements greater than that corresponding to peak load.

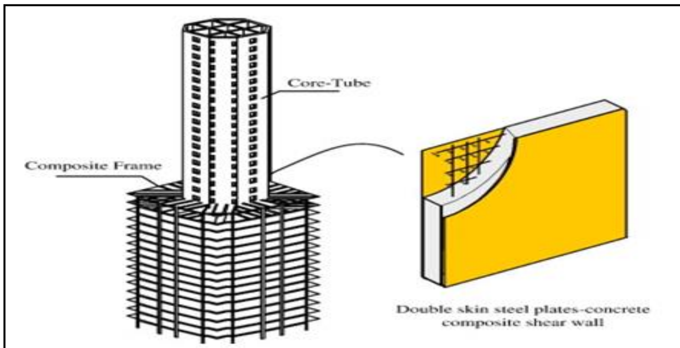

Fig. 1. Composite shear wall

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Siamak Epackachi et al; researched on the topic Seismic analysis and design of steel-plate concrete composite shear wall piers. They done finite element analysis of 98 SC wall piers by taking design variables as wall aspect ratio, reinforcement ratio, slenderness ratio, axial load, yield strength of the steel faceplates. Uniaxial compressive strength of concrete on in-plane response were studied, through the software LS-DYNA. It's found that Lateral load capacity and stiffness are affected significantly by aspect ratio. Although faceplate slenderness ratio had the smallest effect on strength and initial stiffness, Aspect ratio has a substantial impact on global response.

Wei Wang et al. they investigated on the topic Experimental Study on Seismic Behavior of Steel Plate RC Composite Shear Wall. Steel plate encased in the middle of a reinforced concrete shear wall. Aspect ratio, thickness of the wall and the steel plate were taken as design variables. Found that the thickness of the wall is the most important parameter to increase deformability, ductility and energy dissipation capacity, followed by detailing and thickness of the steel plate. Compared with lateral ties, the structural detailing of shear studs on steel plates is more effective.

Soheil Kordbegli et al. conducted Numerical Study on the Seismic Behavior of Composite Steel Plate Shear Walls with Openings. Numerical studies were carried out to evaluate the effect of elastic stiffness, effective or secant stiffness, failure load, absorbed energy, and ductility ratio on the performance of these walls. The results of analysis of finite element models in the wall with openings modeled in ABAQUS software. Analysis showed that the use of openings in the center of these walls was favorable due to the reducing negative effects of the studied parameters on the wall performance, and their use in the corners of the composite shear walls is not suggested.

This paper presents a finite element models of steel plate concrete composite shear wall. The models are used to investigate the lateral and seismic behaviour of the steel plate concrete composite shear walls. The models with different aspect ratio and shear stud shapes subjected to push over analysis to understand the laeral resistance capacity and seismic behaviour of SPCCSW, with different types of stiffeners were studied to understand the behaviour of shearwall under cyclic excursion.The modelling was done in ANSYS WORKBENCH 16.1.

2. Numerical study

ANSYS Workbench 16.1 was used for the finite element modeling and analysis. Figure 2 prsents the ansys model and cross csection view of SPCCSW. Higher order 3-D 20-node solid element SOLID186 was used for infill concrete. The steel faceplates are modelled by using SOLID65. The studs and tie rods on the steel faceplates are represented by beam elements. The steel plates and concrete and concrete, steel plate and connectors were provided with proper bonding using two elements CONTA174 AND TARGE170. Frictional contact is used for the interaction between the steelfaceplates and the infill concrete. A coefficient of friction of 0.4 between steel and concrete was assumed. The lateral resistance of the specimes with different aspect ratio and shape of shear stud were analysed by push over analysis and seismic performance with different stiffeners were dine by cyclic testing.

2.1 Material details

Steel plate, SPCCSW uses two steel faceplates of thickness 5mm and grade of steel as Fe 250. Shear stud, helps to achieve composite action between steel and concrete. For the study 8mm diameter, Fe345 steel with a spacing of 102mm were used. Tie rod it also a connection member that connects the two faceplate and maintains bonding between steel and concrete, here 8mm diameter, Fe 345 steel with a spacing 305mm tie rod were used. Ultra-light weight cement composite, Consisting of OPC, water, cenosphere, Admixtures, Steel Fibre. It's a type of novel composites characterized by combinations of low densities typically less than 1500 kg/m3, high compressive strengths more than 60 MPa.

TABLE 1

MATERIAL PROPERTIES

component	Diameter/ thickness (mm)	Modulus of elasticity(MPa)	Density (kg/m^3)	Yield strength (MPa)
Steel plate	5	2x10^5	7860	250
concrete	300	10790	1250	2.3
Shear stud	8	2x10^5	7860	345
Tie rod	8	2x10^5	7860	345

Displacement based loading of 20mm applied as lateral load and base of the wall maintained as fixed support. Non-linear push over analysis on the model with different aspect ratio were studied. There are 4 aspect ratio of 0.75, 1, 1.25, and 1.5, as taken for to find the lateral resistance of the shear wall. And the failure modes were studied.

TABLE 2
ASPECT RATIO: DIMENSIONS AND RESULTS

Aspect ratio	Height (mm)	Breadth (mm)	Total wall Thickness (mm)	Thickness of steel plates (mm)	Deformation (mm)	Maximum Load (kN)
0.75	1125	1500	310	5	23.754	2290.6
1	1500	1500	310	5	11.221	1931.08
1.25	1875	1500	310	5	19.496	1657.76
1.5	2250	1500	310	5	20.85	2031.6

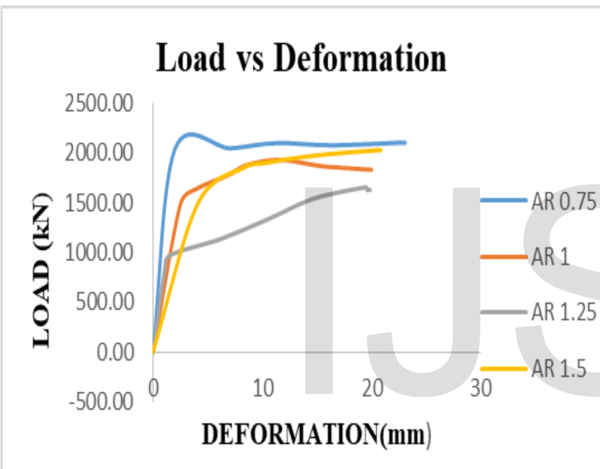

Fig. 2 load deformation graph for different Aspect ratio

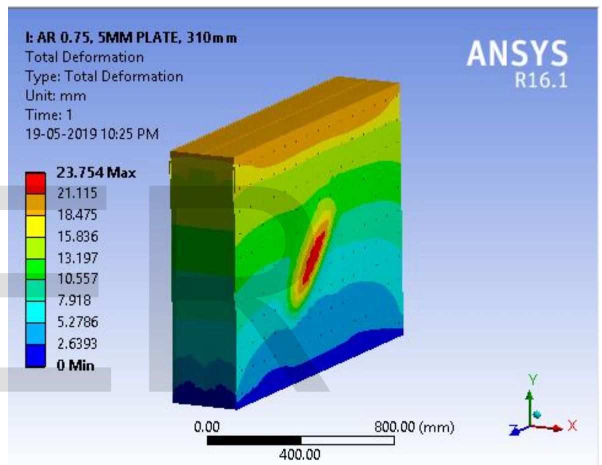

Fig. 3 Deformation of wall AR 0.75

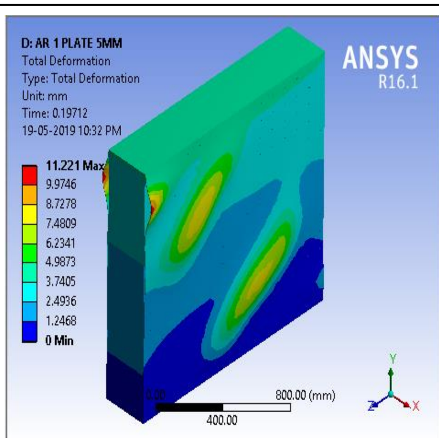

Fig 4 deformation of wall AR 1

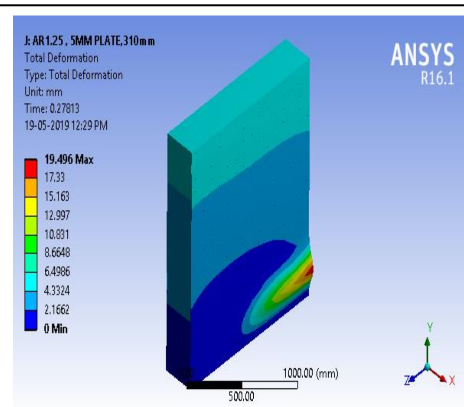

Fig 5 deformation of wall AR 1.25

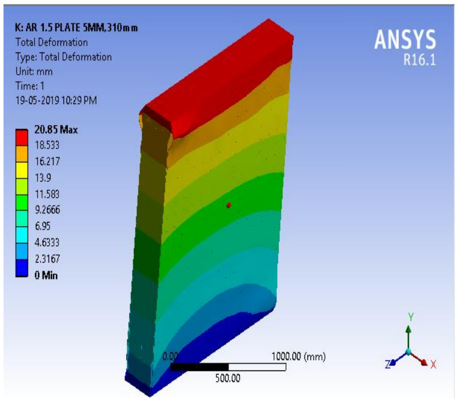

Fig 6 Deformation of wall AR1.5

2.3 Effect of Shear Stud Shape

SPCCSW of dimension 1500x1500x310mm were chosen to find the effect of shear stud shape in the behaviour of wall. Steel face plate thickness of 5mm were used .Weight of the shear stud was maintained constant, such that the shear stud with same cross sectional area and different shapes taken for the study. Shapes used are circular, L-shape, rectangular and square, two additional circular section shear stud with grade of steel Fe415 and Fe550 were also used.

TABLE 3
SHEAR STUD SHAPES AND RESULTS

Stud shape	Stud size/ property	Max load(kN)	Deflection (mm)
Circular (CSW1)	Grade 345	1931.3	11.21
L-shape	10x2.5mm vertical 10x2.5mm horizontal	1932.84	10.76
Rectangular	10x5mm	1905.88	11.322
Square	7x7mm	1904.4	11.297
circular	Grade 550	1941.82	12.474
circular	Grade 415	1937	11.751

All the specimen shows approximately same failure pattern without significant variations in the deformation. It understood that as the grade of steel increases the strength of the structure also increased. Thus for the further study shear stud of grade Fe 550 were used.

2.4 seismic analysis

From the push over analysis on composite shear wall it's found that shearstud numbers and size have significant role in the lateral resistance of the wall. To reduce the shear stud numbers and thus to reduce the complexity in construction diameter of the studs are checked with 8mm and 16mm with spacing increased to 305mm. From the analysis result stud diameter was fixed as 16mm with stud spacing 305mm. To improve the seismic performance of composite shearwall and to reduce the buckling chance of steel plate stiffeners added to the structure in various arrangement. Shear stud of grade 550 steel and 16mm diameter with 305mm spacing were used for nonlinear cyclic analysis. Stiffeners of minimum size of 25mm width and 2mm thick were used. 6 number of cycles of load given to the models.

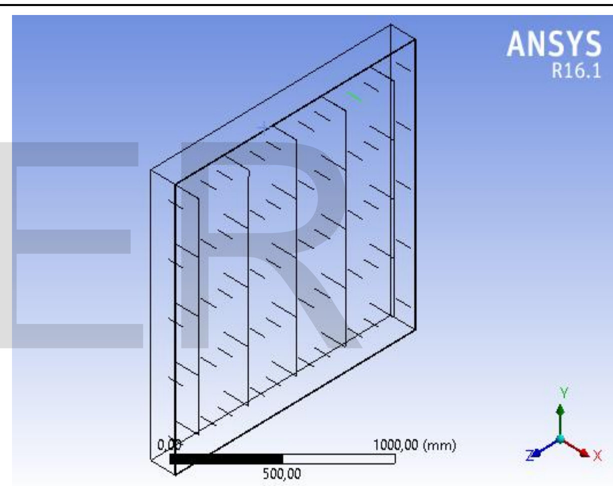

Fig. 7 SPCCSW With vertically arranged stiffeners

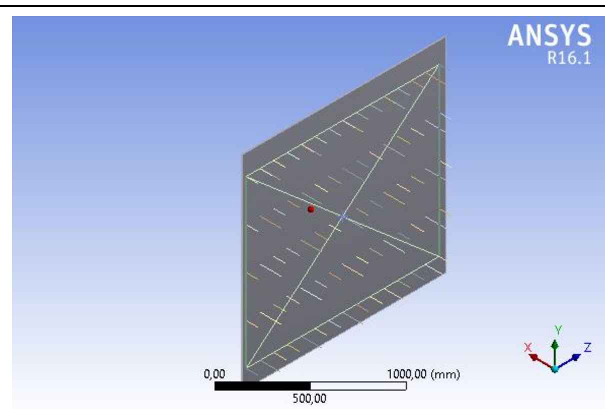

Fig 8 SPCCSW with diagonally arranged stiffeners

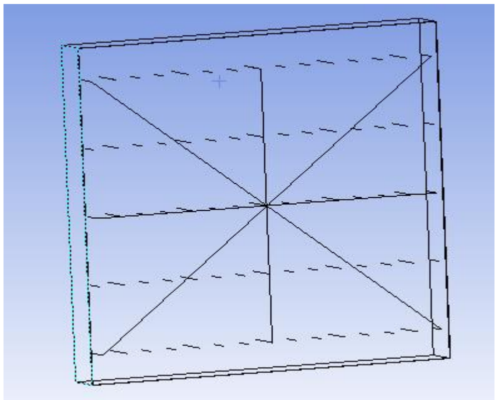

Fig 9 SPCCSW with radially arranged stiffeners

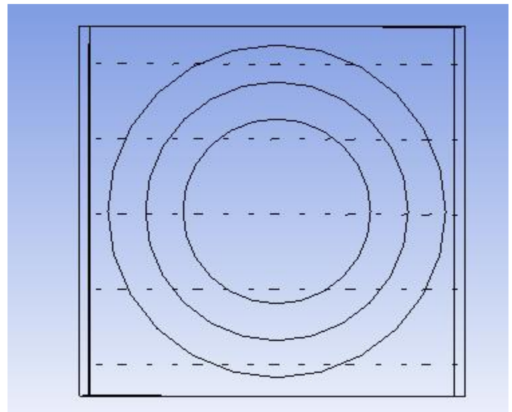

Fig 10 SPCCSW with circular arrangement stiffeners

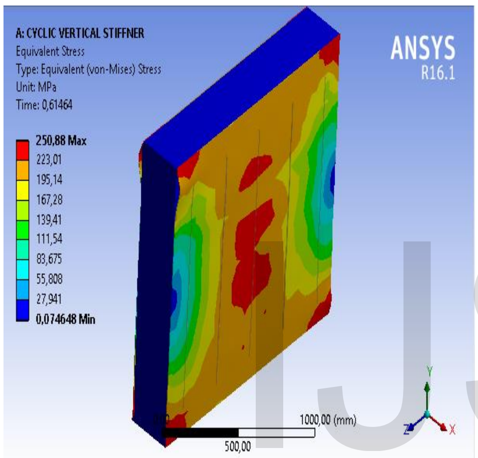

Fig 11 Equivalent stress: Vertically arranged stiffeners

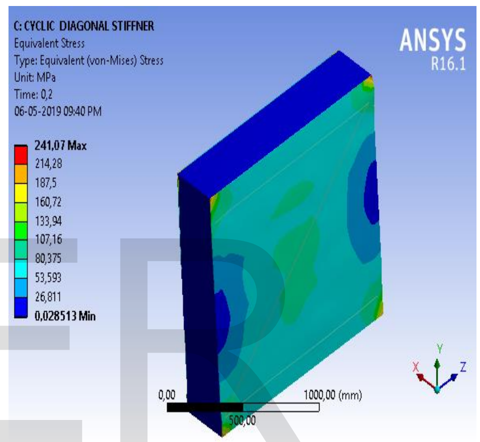

Fig 12 Equivlent stress: Diagonally arranged stiffeners

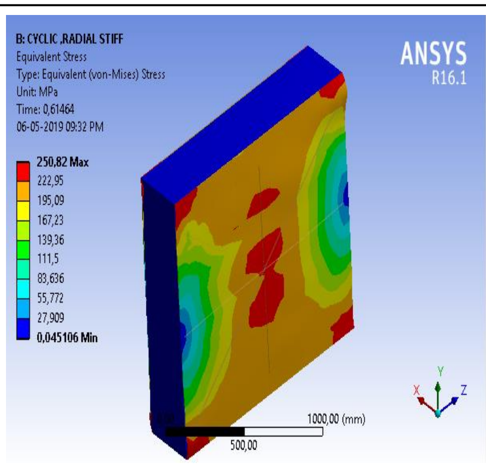

Fig 13 Equivent stress: Radially arranged stiffeners

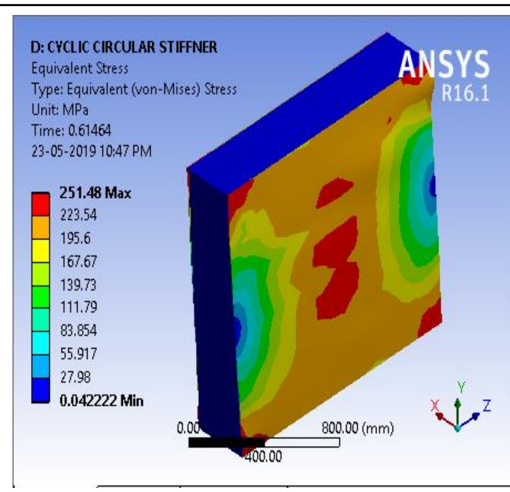

Fig 14 Equivent stress: Circular arrangement stiffeners

TABLE 4

SEISMIC ANALYSIS RESULT OF DIFFERENT STIFFENER ARRANGEMENTS

Stiffener type	Maximum load(kN)	Deflection(mm)
Diagonal	2071	30
Radial	2045	18.388
Vertical	2047.2	19.364
circular	2042.8	20.782

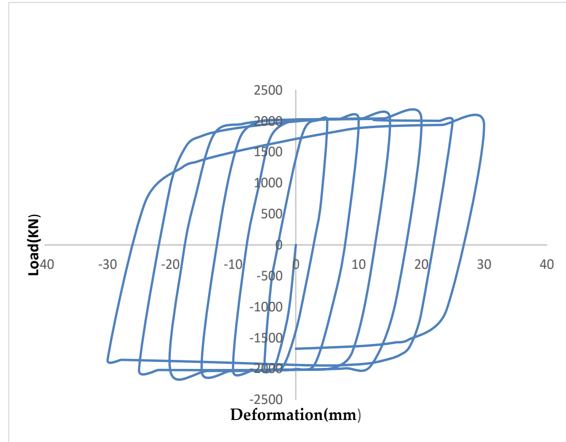

Fig 15 .Vertically arranged stiffeners

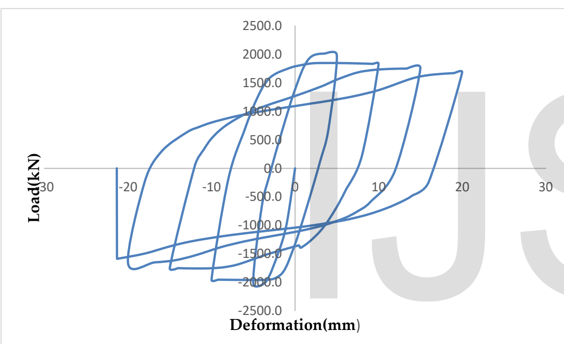

Fig 16. Radially arranged stiffeners

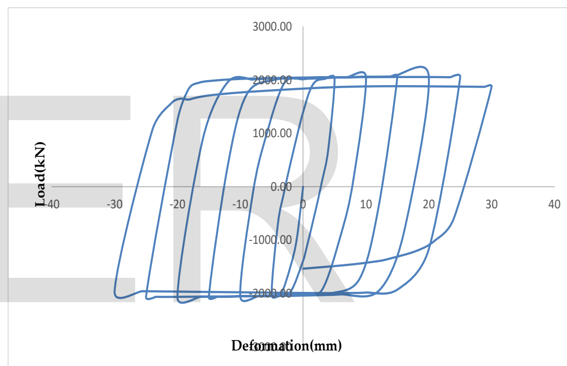

Fig 17. Diagonally arranged stiffeners

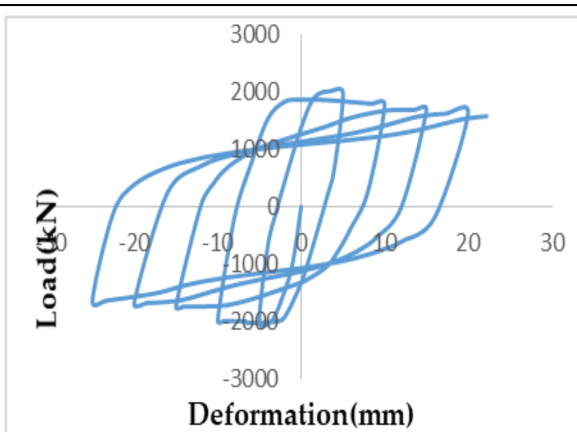

Fig 18. Circular arrangement stiffeners

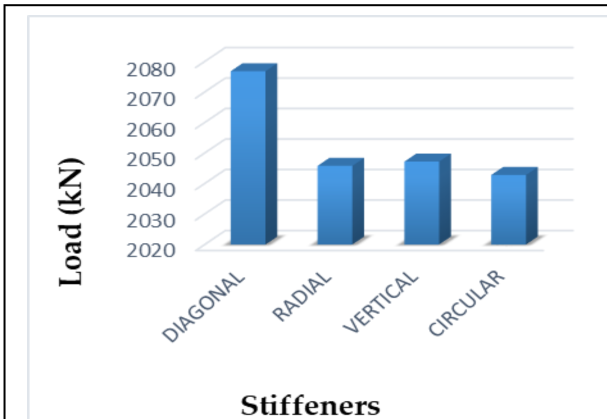

Fig 19. Load Comparison of stiffeners arrangement

3 NUMERICAL ANALYSIS RESULTS

3.1 Aspect ratio

All the walls shows significant amount of deformation while the structure is loaded. The wall with aspect ratio 0.75 shows higher deformation of 23.754mm with maximum load of 2103.6 kN. By studying failure behaviour all walls it seems that wall with aspect ratio 1 have better lateral resistance as compare to other types of walls. For the wall with AR 0.75 and AR 1.5 Shows better load carrying capacity but for 8.93% and 5.21% increase in load carrying capacity shows 111.69% and 85.81% increase in deformation. That is for the small incremental load acting on the structure leads to large deformation to the structure. Thus wall with AR 1 proves to be good as compare to other walls. It seen that as height of the wall increases the deformation is maximum at the top of the wall and wall loses its bonding between steel and concrete infill and shear off. From the lower to higher aspect ratio the first models fails by showing bulging of steel plate at the top vertical face if wall but about AR1.5 the failure is spread to toe of the wall, it's because of loss of stiffness of wall the bonding between elements get loosed and leads to crushing of concrete.

3.2 Effect of shear stud shape

All the specimen shows approximately same failure pattern without significant variations in the deformation. From all the specimens circular section with steel of grade 550 proved to be better in lateral resistance. Load carrying capacity of all the specimens are comparable. It understood that as the grade of steel increases the strength of the structure also increased. Thus for the further study shear stud of grade FE550 were used.

3.3 Damage to SPCCSW walls

In the study of aspect ratio the four types of walls fails by shear failure. The composite action between the steel plate concrete and connectors make the wall better to withstand the load until peak load reached. All the wall shows approximately same pattern of failure. Using different shear stud shape shows same faiure of shearwall without significant variation in the failure deformation. At end of maximum laod reached all the wall showsbuckilng of steel face plate at the middile edge of the walls, and crushning of concrete at the toe of the wall

3.4 cyclic behaviour of walls with different stiffeners

The model tested with push over analysis shows buckling of steel plates at the concrete and steel face plate edged. The inclusion of stiffeners reduced the buckling chance of steel faceplates and seismic behaviour improved. Diagonal stiffener found to be the good stiffener arrangement and good hysteresis loop. Total six number of cycles were applied to the different stiffener arrangement. From that vertical and diagonal stiffeners shows good seismic performance as compare to radial arranged stiifeners and circular arrangement stiffener. By comparing diagonally arranged stiffener and vertically arranged stiffeners diagonal stiffners occupies large area in hysteresis loop and maximum number of cycles thus diagonally arranged stiffeners are better as compared to other three models.

4. CONCLUSIONS

Numerical study on lateral resistance and seismic behaviour of steel plate concrete composite shear wall was studied using finite element software ANSYS WORKBENCH 16.1.lateral resistance of wall with different aspect ratio and different shear stud shape were studied.seismic performance of steel plate concrete composite shear wall with different shear stud arrangement also studied. The main conclusions are listed as follows:

1. Aspect ratio have a key influence on the performance of shear wall. From the studied aspect ratio range of SPCCSW, the wall with AR1 shows good lateral resistance behaviour as compared to other types of wall
2. As the shear stud shape change, contribute only small variations in the maximum load withstanding capability of the wall. The best shape is found to be circular to resist the lateral load. And also found that higher the grade of connecters higher the performance.
3. Higher the diameter of the studs can reduce the complexity in construction and getting good strength to withstand the load.
4. As the inclusion of stiffeners reduced the buckling chance of steel faceplate and seismic behaviour improved. Diagonal stiffener found to be the good stiffener arrangement and good hysteresis loop. As compare to other types of stiffeners taken for the study.
5. By studying the seismic performance of different types of shear walls it's found that maximum load bearing capacity and lower deformation occurs on SCC shear wall with diagonal stiffeners.

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