Cyclic Performance of Cross Slanted Corrugated Steel Plate Shear Wall with Beam Only Connected Infill Plates

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***Abstract*— Corrugated Steel Plate Shear Walls have gained significance and repute for being effective lateral force withstanding systems. Corrugated plates are characterized by higher out of plane stiffness and buckling stability than flat plates, assuring their enhanced hysteretic actions. In ordinary Steel Plate Shear Walls infill plates are fixed to beams and columns. But, detaching the infill plate from columns and connecting it to the beams only is assumed here as a system for reducing column demands. The current study explores the cyclic performance of Cross Slanted CSPSWs with beam only connected infill plates. The design of a one story single-bay specimen was done and its finite element model was developed by using ABAQUS software. Parametric studies have targeted CSPSWs with different geometric variables, including the orientation of the infill plate.**

Keywords*— *Corrugated steel plate shear wall, Cross slanted infill plate, Out of plane stiffness

I. INTRODUCTION

Steel Plate Shear Walls are frequently employed as lateral force resisting systems in building structures owing to their high stiffness, strength, and ductility. Steel Plate Shear Walls are either stiffened or unstiffened in type. Stiffened Steel Plate Shear Walls enjoy greater initial stiffness, higher shear strength, and bigger ductility than unstiffened ones. Corrugated steel plate shear wall which consists of a steel boundary frame and a corrugated steel wall panel with the corrugation in the horizontal or vertical direction, is a new sort of lateral load resisting system within the family of steel plate shear walls. Compared with the unstiffened special plate shear walls, Corrugated Steel Plate Shear Wall would have greater elastic buckling capacity and more resistance to the gravity loads transferred to the wall panel or avoid them, depending on the corrugation direction. Corrugated plates are characterized by higher out of plane stiffness and buckling stability than flat plates, ensuring their enhanced hysteretic behavior. In ordinary Steel Plate Shear Walls, infill plates are fixed to beams and columns. Detaching the infill plate from columns and connecting to the beams only is assumed here as a way for reducing column demands. The current study explores the cyclic performance of Corrugated SPSWs with beam only connected infill plates. Besides reducing column demands, beam only connected Steel Plate Shear Walls have other advantages. In beam-only-connected SPSWs, panels can be fabricated so that there would be a gap between panel edges and the columns, or several panels are often fabricated with a little panel aspect ratio installed parallel to each other during a span. In both cases, a gap space could also be easily given adjacent to the column without perforating the infill plate. Moreover, connecting the corrugated infill plate, especially a light-gauge one, to the boundary frame members was found challenging and difficult due to its thickness and geometry, that is, a matter that could prolong the construction time. In the case of beam only connected Steel Plate Shear Walls, the infill panel can be attached to the frame beams only, while the attachment between the infill panel and columns is ignored. However, the behavior of Corrugated SPSWs with beam only connected infill plates has not been studied before. This study investigates the feasibility of using corrugated plates as infill plates in beam only connected Steel Plate Shear Walls. We modeled and analyzed a one story single bay specimen using the commercially available software package ABAQUS. A parametric analysis was employed to research the mentioned model by varying its geometry. The parametric study incorporated corrugated plate orientation (horizontal, vertical, and cross slanted) and thickness of the corrugated plate.

II. OBJECTIVES

- Provide an efficient and accurate finite element model to understand the cyclic performance of Cross-Slanted CSPSWs with beam-only connected infill plates in the ABAQUS software.
- Parametric studies have targeted CSPSWs with different geometric variables, including orientation of the corrugated plate and infill plate thickness.

III. SUMMARY OF LITERATURE REVIEW

Corrugated Steel Plate Shear Walls have good seismic performance with higher buckling capacity, lateral stiffness, and out-of-plane stiffness than Steel Plate Shear Walls while offering additional advantages in construction convenience and serviceability. Subsequent experimental and numerical studies of Steel Plate Shear Walls with beam-only-connected infill plates demonstrated that these systems had good initial stiffness and lateral strength and considerable ductility and energy dissipation capacity. As the analysis of vertical corrugated steel plate shear walls shows the least deformations as compared to normal steel plate shear walls and horizontal corrugated steel plate shear walls. Tension forces on columns due to infill plate tension action were eliminated when an infill plate was connected only to the beams; therefore, columns experienced less axial and flexural demand, and early failure of columns might be avoided.

IV. FINITE ELEMENT MODELLING

The model is a half-scale conventional residential building. ABAQUS, the finite element software, was employed to develop the models. Components of the boundary frame include beams, columns, and stiffeners as well as corrugated infill panels. “Tie” constraint command was used to connect the infill plate to the boundary elements. Mesh sizes of 50 mm and 25 mm were selected for the boundary frame and infill plate, respectively. The height and length of the models are measured to be 1.74 m and 2.7 m, respectively, from center to center of elements.

A. SECTIONAL PROPERTIES

As per IS 12778, the sectional properties of the finite element model are tabulated in table 1.

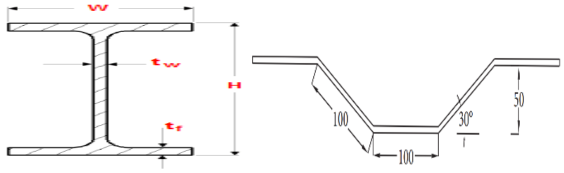

TABLE 1. Sectional Properties of CSPSW Model

Model	Section	H	W	t_w	$t_{f\ (mm)}$
Upper Beam	NPB 220	220	110	5.9	9.2
Lower Beam	WPB 260	260	260	10	17.5
Column	WPB 200	200	200	9	15

B. MATERIAL PROPERTIES

As per IS 456 2000, the material mechanical properties of the finite element model are tabulated in table 2.

TABLE 2. Material properties of CSPSW

Element	Young’s modulus (GPa)	Yield stress (MPa)	Ultimate stress (MPa)	Poisson’s ratio
Plate	200	262	360	0.3
Frame	202	280	390	0.3

C. MODELS OF STEEL PLATE SHEAR WALL

To analyze the performance of beam only connected CSPSWs, a series of parametric researches were performed on specimens. The parametric study includes changing the orientation of the corrugated plate. That is flat, horizontal, vertical, and cross-slanted infill plates are connected with and without beam. These specimen was modeled in ABAQUS software.

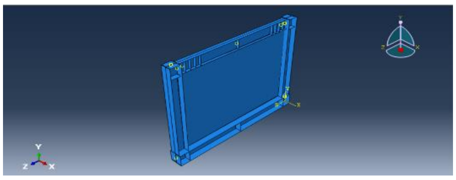

Fig.1.Fully Connected Flat SPSW

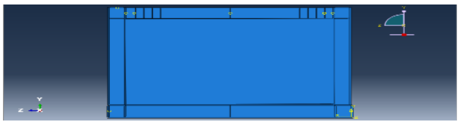

Fig.2.Beam only Connected Flat SPSW

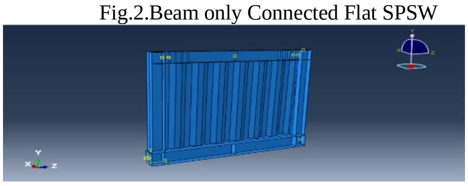

Fig.3.Fully connected vertical CSPSW

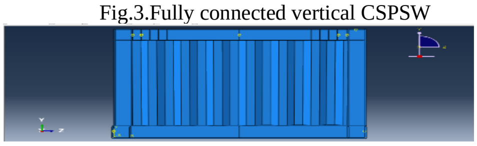

Fig.4.Beam only Connected Vertical CSPSW

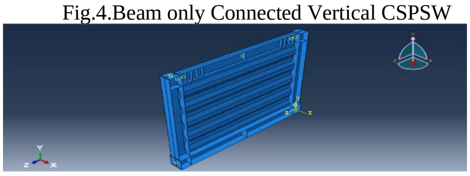

Fig.5.Fully Connected Horizontal CSPSW

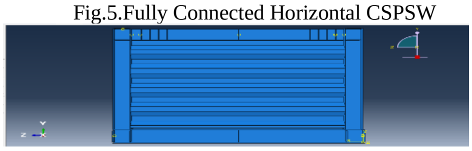

Fig.6.Beam Only Connected Horizontal CSPSW

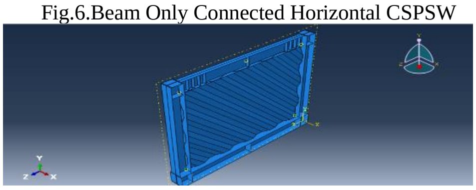

Fig.7.Fully Connected Cross Slanted CSPSW

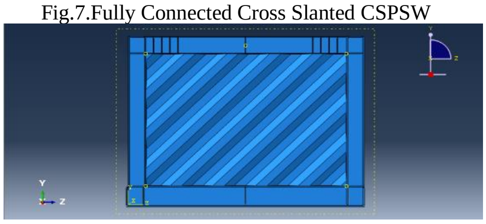

Fig.8.Beam Only Connected Cross Slanted CSPSW

V. VALIDATION

To validate the finite element model, A well-established experimental test was considered for calibration. The flat and horizontal/vertical corrugated Steel Plate Shear Walls tested by Emami et al. [1].Hysteresis curves as well as overall behavior and failure modes under cyclic loading have been compared with those obtained from the experiment. The experimental and numerical result of models tested by Emami et al. [1].is illustrated in the below figures and tabulated in Table. Good agreement between the numerical and test results indicates the validity of the finite element model.

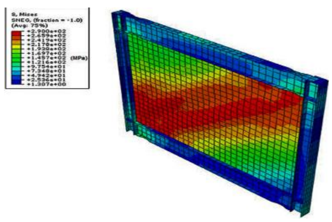

Fig.9.Maximum Inplane Principle Stress Contours in Flat SPSW

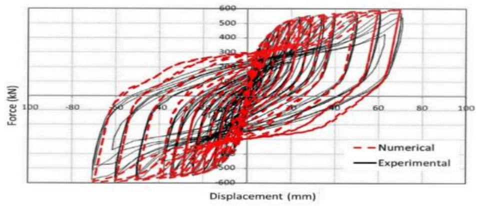

Fig.10.Comparison of experimental and numerical hysteresis curve for Flat SPSWs tested by Emami et al.

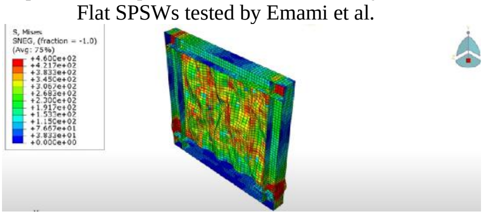

Fig.11. Maximum Inplane Principle Stress Contours in Vertical CSPSW

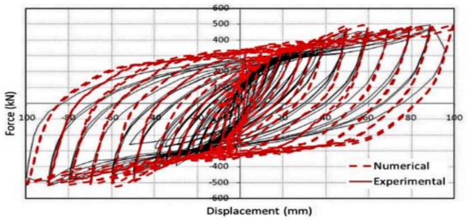

Fig.12. Comparison of experimental and numerical hysteresis curve for Vertical CSPSWs tested by Emami et al.

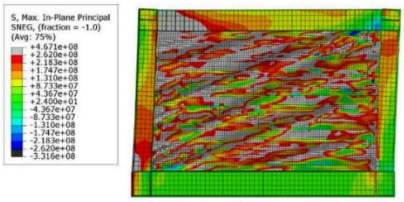

Fig.13. Maximum Inplane Principle Stress Contours in Horizontal CSPSW

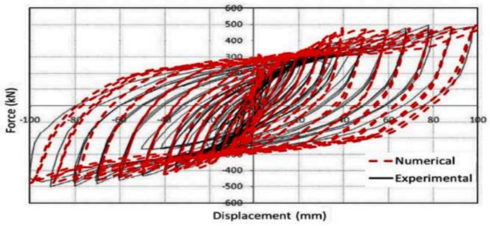

Fig.14. Comparison of experimental and numerical hysteresis curve for Horizontal CSPSWs tested by Emami et al.[1]

TABLE 3. Initial Stiffness Obtained from Experimental and Numerical Results

Initial Stiffness	(MN/m)		
	Experimental	Numerical	Exp/Num
Flat SPSW	108	109.9	0.98
Vertical CSPSW	125	130.4	0.96
Horizontal CSPSW	130	132.2	0.98

TABLE 4.Ultimate Strength Obtained from Experimental and Numerical Results

Ultimate Strength	(kN)		
	Experimental	Numerical	Exp/Num
Flat SPSW	597	598.8	1.0
Vertical CSPSW	498	523.8	0.95
Horizontal CSPSW	502	492.8	1.02

VI. PARAMETRIC STUDY

Here, a cross slanted corrugated steel plate shear wall is proposed, and its lateral force resistance performance is analyzed by the finite element method. The finite element software ABAQUS is used to study its lateral force resistance behavior and the stress mechanism is analyzed. In order to have a better understanding of the advantages of the designed cross slanted corrugated steel plate shear wall, it is compared with the flat SPSW, Vertical CSPSW, and Horizontal CSPSW. The Cross Slanted corrugated infill plates were oriented at 45 degrees.

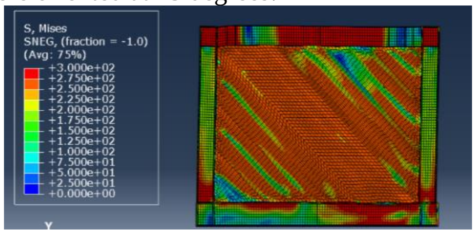

Fig.15. Maximum Inplane Principle Stress Contours in Cross Slanted CSPSW

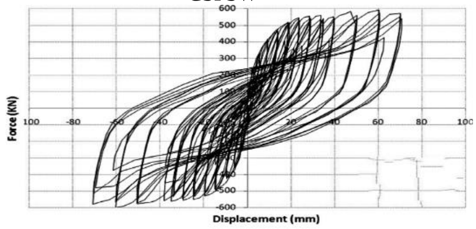

Fig.16. Hysteresis Curve for Cross Slanted CSPSW

The ultimate strength obtained from the hysteresis curve of cross slanted CSPSW was 601.2 kN and the initial stiffness was 135.3. It can be concluded that the initial stiffness and ultimate strength of the cross slanted corrugated steel plate shear wall structure are significantly higher than that of the flat steel plate shear wall and the horizontal and vertical corrugated steel plate shear wall.

The behavior of cross-slanted CSPSWs with beam only connected infill plates has not been studied before. This study investigates the feasibility of using corrugated plates as infill plates in beam only connected Steel Plate Shear Walls.

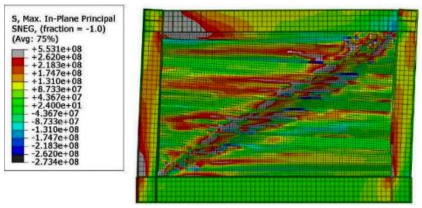

Fig.17. Maximum Inplane Principle Stress Contours in Beam only Connected Horizontal CSPSW

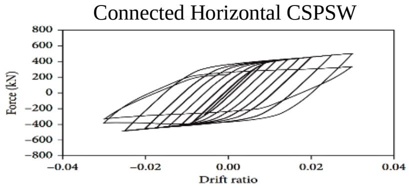

Fig.18. Hysteresis Curve for Beam only Connected Horizontal CSPSW

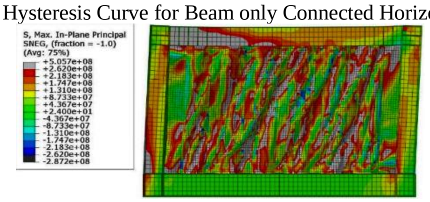

Fig.19. Maximum Inplane Principle Stress Contours in Beam only Connected Vertical CSPSW

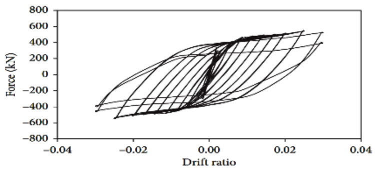

Fig.20. Hysteresis Curve for Beam only Connected Vertical CSPSW

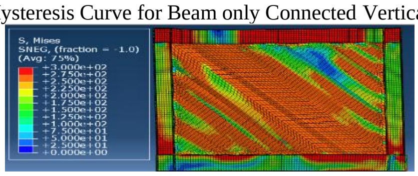

Fig.21. Maximum Inplane Principle Stress Contours in Beam only Connected Cross Slanted CSPSW

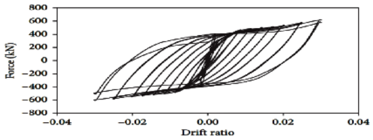

Fig.22. Hysteresis Curve for Beam only Connected Cross Slanted CSPSW

TABLE 5.Initial Stiffness and Ultimate Strength of Beam Only Connected Infill Plates

	Initial Stiffness (MN/m)	Ultimate Strength(kN)
Horizontal CSPSW	98.3	486.9
Vertical CSPSW	128.2	502.8
Cross Slanted CSPSW	123.4	589.7

VII. RESULT AND DISCUSSION

Tension forces on columns due to infill plate tension action were eliminated when an infill plate was connected only to the beams; therefore, columns experienced less axial and flexural demand, and early failure of columns might be avoided. Detaching columns from the infill plate decreased initial stiffness, ultimate strength, and dissipated energy of CSPSWs. In the case of Horizontal CSPSW, detaching columns from the infill plate reduced the initial stiffness from 132.2 to 98.3 MN/m, showing a considerable decrease, and reduced ultimate strength from 492.8 to 486.9 kN respectively. However, in the case of Vertical CSPSW, detaching columns from the infill plate reduced the initial stiffness from 130.4 to 128.2 MN/m and attenuated the ultimate strength from 523.8 to 502.8 kN respectively indicating a lower amount of decrease than that for Horizontal CSPSW. In the case of cross slanted CSPSW detaching columns from the infill, plate reduced the initial stiffness from 135.3 to 123.4 MN/m and attenuated the ultimate strength from 601.2 to 589.7 kN respectively.

VIII.CONCLUSION

The cyclic performance of Cross Slanted Corrugated Steel Plate Shear Walls with beam only connected infill plates was investigated in this study. Several finite element models were developed and analyzed for parametric studies. Infill plate orientation was the main parameter in this performance evaluation. Responses of interest were a force deformation relationship, initial stiffness and ultimate strength.

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