SEISMIC PERFORMANCE OF SHEAR WALL WITH DEBONDED REINFORCEMENT

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ABSTRACT. Shear walls are vertical elements of the horizontal force resisting system. When shear walls are designed and constructed properly, they will have the strength and stiffness to resist the horizontal forces. Shear wall has been the best choice in earthquake-prone areas. The performance of shear wall can be improved by strengthening the plastic hinge region of the wall. The present study deals with the comparison of the performance of shear wall with debonded reinforcement at the plastic hinge region with the counterpart conventional shear wall specimen. The debonding of reinforcement from concrete is made by providing steel collars of 75 mm length at the plastic hinge region. The parameters studied are load displacement hysteresis behaviour, first crack load, ultimate load, energy dissipation, displacement ductility and crack pattern. From the study it is observed that the shear wall with debonded reinforcement has improved behaviour than the counterpart wall with conventional reinforcement when subjected to seismic type loading.

Keywords: Ductility, Energy dissipation, Shear wall, Stiffness, Ultimate load.

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INTRODUCTION

Shear walls are vertical elements of the horizontal force resisting system. These walls start at foundation level and continuous throughout the building height and are subjected to bending moments, shear forces and external loads. When shear walls are designed and constructed properly, they will have the strength and stiffness to resist the horizontal forces. To form an effective structure, equal length shear walls shall be placed symmetrically on all four exterior walls of the building. Shear walls are most efficient when they are aligned vertically and are supported on foundation walls or footings. Due to lateral forces, shear walls undergo inelastic deformations usually at the base of the wall which is very advantageous than experiencing only elastic deformation during strong earthquake, as the latter case is uneconomical to the structures. When compared to a beam, shear wall is relatively thin and deep and is subjected to axial loads and it must be designed as an axially loaded beam which is capable of forming reversible plastic hinges, usually at the base, with sufficient rotation capacity.

Investigations of shear walls have been conducted by researchers worldwide by considering various parameters. Carrillo et al., (2015) conducted an experimental study by applying quasi-static cyclic tests to provide information on the effect of lightweight concrete on seismic performance of thin lightly-reinforced shear walls. It is observed that the performances of lightweight concrete walls were better in comparison to walls made of normal weight concrete. Dasgupta et al., (2003) conducted a review study on seismic shear design of RC structural walls. They proposed improvements in IS 13920:1993 provisions on seismic design of RC structural walls. As reported by Mondal et al., (2014), the nonlinear analyses of strut & tie modelling is possible to design squat walls, because there is an orderly behaviour of walls even at large diagonal angle of wall and therefore of the strut angles. Tran and Wallace (2012) conducted experimental studies to provide insight into the nonlinear cyclic response of moderate aspect ratio cantilever structural walls. Jasim et al., (2011) conducted experimental investigation on the structural behavior of concrete wall panels subjected to axial eccentric distributed loading. The authors found that the panels with low aspect ratio tend to fail by crushing, while panels with high aspect ratio tend to fail by buckling. Muthu and Manoj (2017) conducted review study on various experimental and analytical investigations on shear wall with openings.

Debonded Reinforcement

Plastic hinges are the most critical region of the shear walls. Buckling of longitudinal reinforcement was observed when it is subjected to lateral cyclic loading and is predominant in plastic hinge region. Previous studies indicate that the buckling of longitudinal reinforcements of column can be reduced by providing casings and thus improve the load carrying capacity of column at plastic hinge region of columns. Mitra and Bindhu (2015) studied the performance of the RC column specimens with debonding steel casing to reinforcement. The author found that the seismic performance of RC columns can be enhanced significantly by providing debonding casing for reinforcement over the potential plastic hinge zone. Ruangrassamee and Sawaroj (2012) studied the performance of columns with Rebar-Restraining Collars (RRC). The authors found that RRCs have an increase in buckling behaviour and flexural rigidity.

RESEARCH OBJECTIVES AND SIGNIFICANCE

Only limited studies have been conducted to study the performance of shear wall designed as per Indian Standards IS 13920:2016. Also limited research have been conducted to enhance the seismic performance of shear wall by introducing debonded reinforcement. The performance of shear walls with debonded reinforcement is analyzed by testing specimens with steel collars of 75 mm at the critical region, subjected to lateral cyclic loading. The influence of debonding of reinforcement on behaviour of shear wall is studied by comparing the performance of this specimen under cyclic lateral loading with the specimen designed as per IS 13920:2016.

MATERIALS AND METHODS

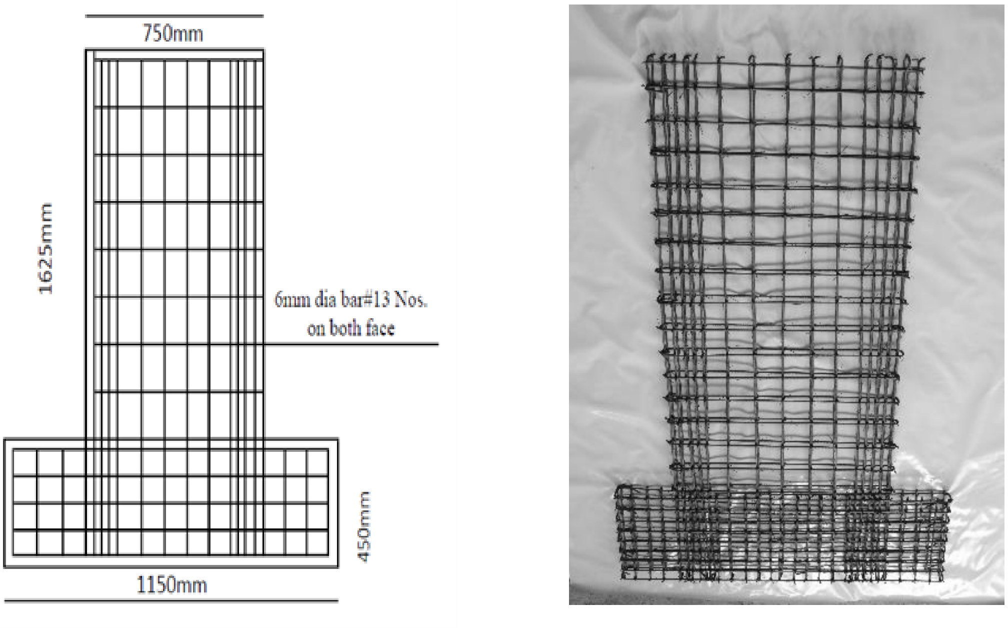
Concrete grade selected for the present study is M35 and the mix design was carried out as per guidelines of IS 10262: 2009. Cement used is Ordinary Portland Cement (OPC) 53 grade conformed to IS 12269:201. Commercially available M sand passing through 4.75 mm IS sieve is used as fine aggregate. Specific gravity and fineness modulus of M sand are 2.56 and 6.3 respectively. Coarse aggregate used is 12mm graded size. Specific gravity and fineness modulus are 2.76 and 6.27 respectively. The properties of coarse and fine aggregates conformed to the IS 383 part III: 1970.The mix proportion arrived was 1:1.64:2.63 and the water-cement ratio was kept as 0.45. The 28-daycompressive strength obtained is 45.62 N/mm^2.Shear walls of dimensions 1625mm x 750mm x 75mm with a foundation bottom beam of dimension 1150mm x 450mm x 100mm were cast from the arrived mix. Mild steel rings of 8mm diameter with 75mm length were used for debonding the reinforcement at the plastic hinge region of non-conventional shear wall specimen (Specimen S2).

Reinforcement Details of Conventional Specimen

The conventional specimen is designated as S1. Reinforcement of shear wall specimens were designed as specified in IS 13920:2016. High yield strength deformed bars of diameter 6mm are used as reinforcement for specimens both in vertical and horizontal direction. The vertical and horizontal reinforcement ratios for both the specimens are 1.3% and 0.8% of gross area respectively. Horizontal reinforcements were provided at 100mm c/c distance. In order to provide confinement at the edges, additional two bars of 6mm diameter were provided at a spacing of 50mm. Minimum cover of 12mm were provided on all faces of the wall panels. The reinforcement bars were provided as two layers. The vertical reinforcement bars were extended to the full depth of foundation. Reinforcement details and photograph of reinforcement cage are shown in Figure 1.

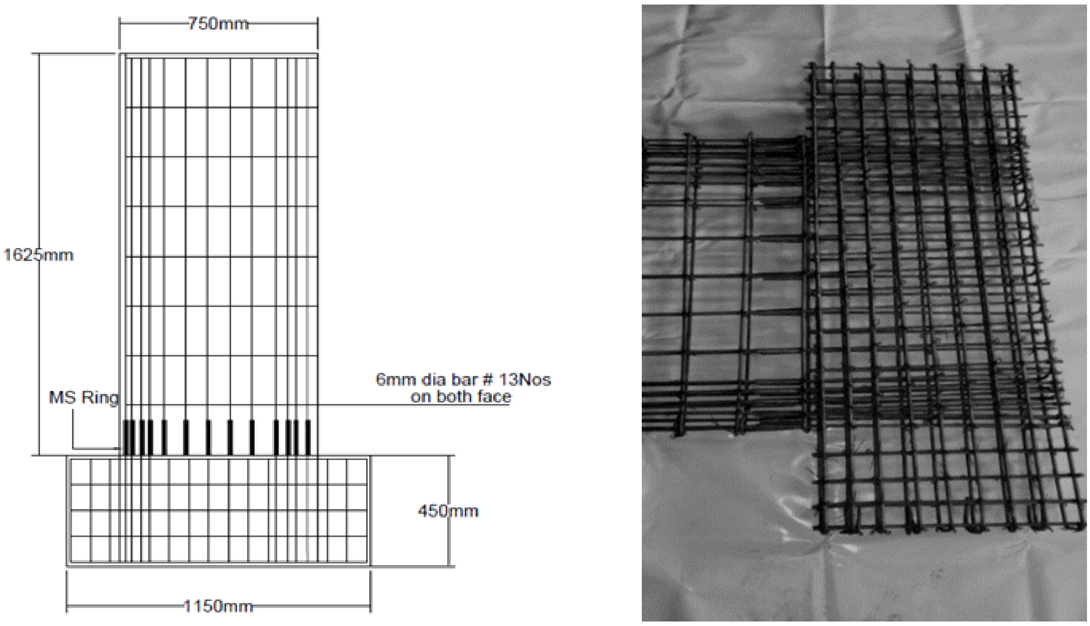
Reinforcement Details of Specimens with Debonded Reinforcement

For debonding the reinforcement of shear wall, 8mm diameter MS tubes of length 75mm were used. The vertical and horizontal reinforcement ratios used in the study for the debonded specimens are also 1.3% and 0.8 % of gross area respectively which is same as provided in conventional specimens with same spacing. MS tubes were provided in all the vertical reinforcement of shear wall at the plastic hinge region, just above the foundation level. Debonded reinforcement details of non-conventional specimen and its photograph of reinforcement cage are shown in Figure 2. The reinforcement details of specimens are tabulated in table 1. Designation of the specimen with debonded reinforcement is S2.



(a) Reinforcement details (b) Photograph of reinforcement cage

Figure 1 Reinforcement details of conventional specimen



(a) Reinforcement details (b) Photograph of reinforcement cage

Figure 2 Reinforcement details of 75mm deboned reinforcement

Table 1 Reinforcement details of shear wall specimens

SL. NO.	DESIGN-TION	DEBONDED LENGTH	MIX	HORIZONTAL REINFORCEMENT		VERTICAL REINFORCEMENT	
				Diameter (mm)	Spacing (mm)	Diameter (mm)	Spacing (mm)
1	S1	Conventional	M35	6	100	6	100
2	S2	75 mm	M35	6	100	6	100

Casting of Specimens

The reinforcement cage was placed on the mould with suitable cover blocks. The concrete was then spread on the mould and proper compactions were given in order to uniformly spread the mix in the mould. The specimens were cast in four layers. For each layer proper compaction were given using needle vibrator. After 24 hours, the specimens were removed from the moulds and 28 days of curing was elapsed.

EXPERIMENTAL INVESTIGATION OF SHEAR WALL SPECIMENS

The test set up in the laboratory is shown in Figure 3. The load was applied using two numbers of screw jack of 60 t capacities for applying lateral load. Load corresponding to each displacement history is measured using load cells of 60 t capacity. Displacement at upper end of the specimen is measured using LVDT having a least count of 0.1mm. Figure 4 shows the cyclic loading history.

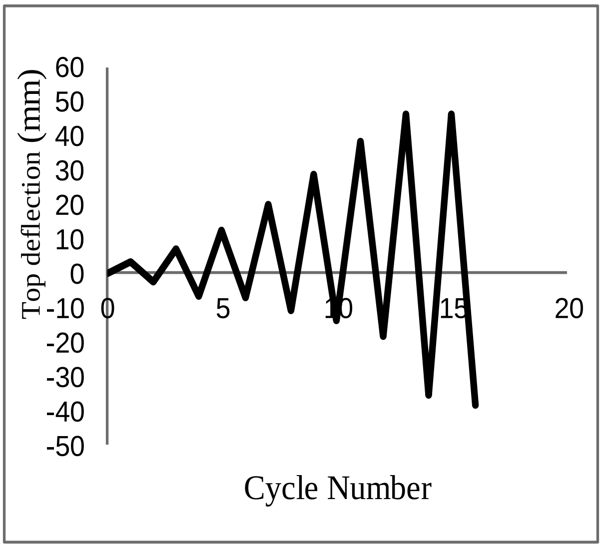


Figure 3 Test set up in the laboratory

Figure 4 Cyclic loading history

TEST RESULTS

Test results are presented in the form of load displacement hysteresis behaviour, first crack and ultimate load, envelope curves, displacement ductility, energy dissipation capacity and crack patterns.

Load-Displacement Hysteresis Behaviour

The load displacement hysteresis behaviour of conventional reinforcement specimen (S1) and specimen with debonded reinforcement (S2) are shown in Figure 5(a) and Figure 5(b) respectively. The hysteresis loop of specimens subjected to lateral reversed cyclic loading are linear up to the formation of first crack. The hysteretic loops between first crack and yield points are very narrow. After yielding, the curves start to incline towards the displacement axis. The loop area and energy dissipation capacity are increased, during corresponding cycles of post yield. The conventional specimen (S1) withstood only seven cycles of loading. While specimen with debonded reinforcement (S2) has improved behaviour and underwent eight cycles of loading.

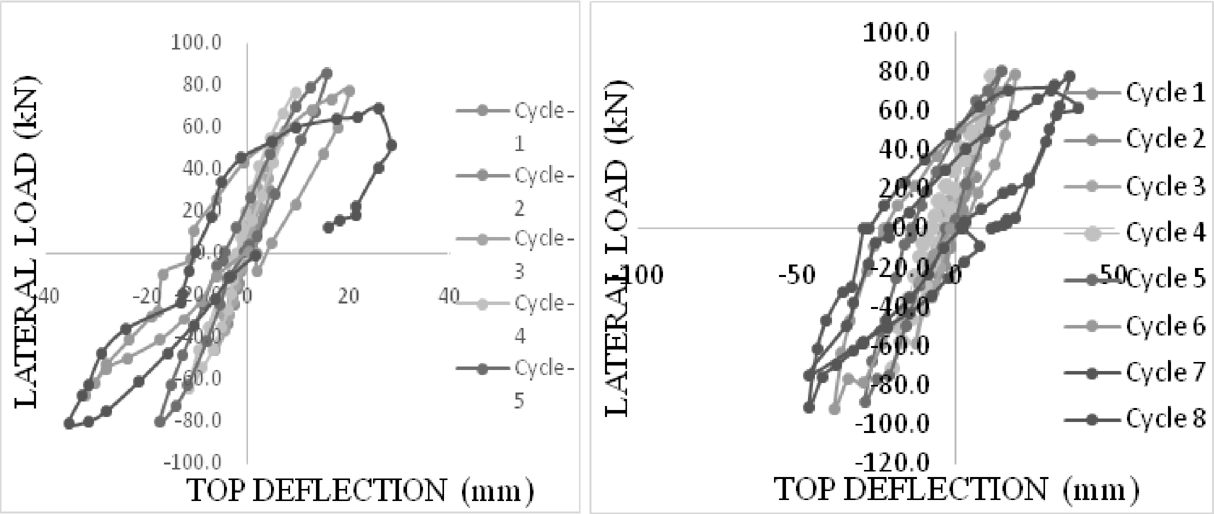


Figure 5 Load Displacement Hysteresis curve of (a) Conventional Specimens (b) Specimen with debonded reinforcement (S2)

First Crack Load and Ultimate Load

The first crack load, the ultimate load of each specimen and their corresponding deflections and number of cycles covered at each stage are tabulated in Table 2.

From the table 2, it can be observed that the ultimate load carrying capacity of specimens with debonded reinforcement is higher than that of conventional specimen by 8.1 %. Specimen with debonded reinforcement has attained higher first crack load than that of conventional specimen.

Table 2 First Crack load and Ultimate Load for each Specimen

SPECIMEN	FIRST CRACK LOAD (kN)			ULTIMATE LOAD (kN)		
	Cycle	Load (kN)	Displacement (mm)	Cycle	Load (kN)	Displacement (mm)
S1	3	46.1	6.4	5	85.3	15.6
S2	3	56.9	7.5	6	92.2	38.3

Envelope Curves

Based on the Load-Displacement hysteresis curves, envelope curves of specimens S1 and S2 are drawn and shown in Figure 6 and Figure 7.

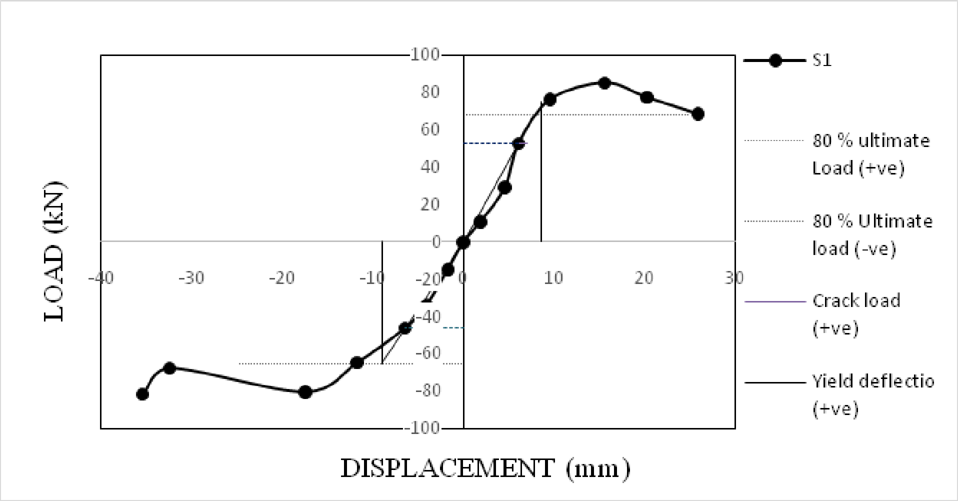


Figure 6 Envelopment curve of specimen S1

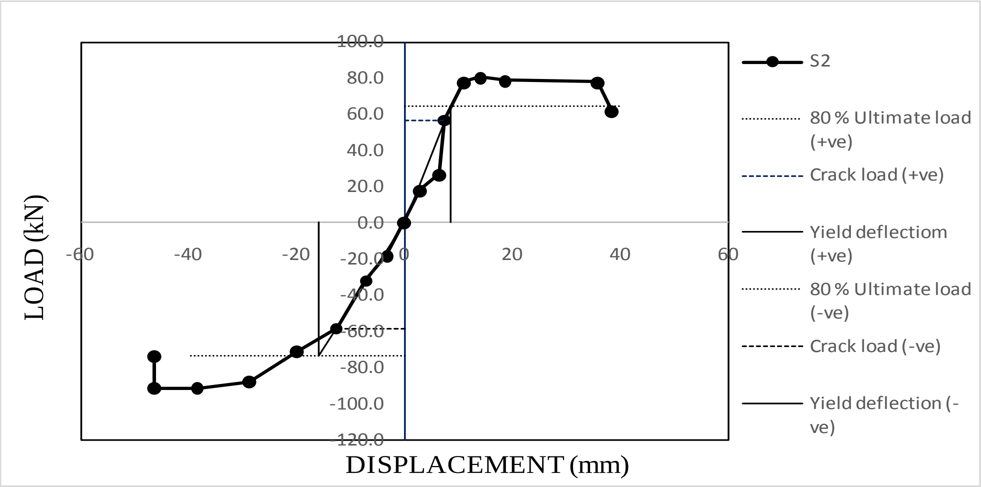


Figure 7 Envelopment curve of specimen S2

From the envelope curves, it can be seen that the post yield deformability of conventional shear wall specimen (S1) is lower than the specimen with debonded reinforcement (S2).

Displacement Ductility

The displacement ductility is defined as the ratio of ultimate and yield displacement for each specimen, determined from the load displacement envelope curves (Shannag et al.,2002).

Table 4 Yield Displacement and Ductility Factor

SPECIMEN NO.	DEFLECTION AT YIELD LOAD (MM)			MAXIMUM DEFLECTION (MM)			DUCTILITY FACTOR
	Positive	Negative	Average	Positive	Negative	Average	
S1	8.63	9.02	8.83	25.80	35.30	30.55	3.45
S2	8.47	15.77	12.12	38.40	46.40	42.40	3.74

Ductility factor of specimens with debonded reinforcement of 75 mm (S2) is higher than that of conventional specimen by 8.29%.

Energy Dissipation Capacity

In seismic design, the inelastic ductile behaviour is associated with energy dissipation upon load reversal. Hence energy dissipation capacity is an essential parameter in seismic structures. Comparison of cumulative energy dissipation capacity of each specimen is shown in Figure 8.

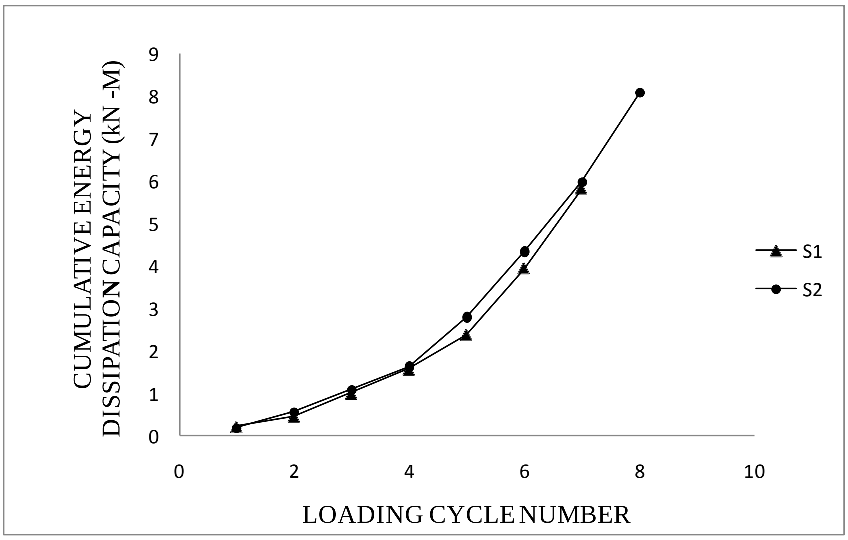


Figure 8 Comparison of Cumulative Energy Dissipation Capacity (kN-m)

Energy dissipation capacity of the specimen with debonded reinforcement (S2) is greater than that of the conventional specimen (S1). The cumulative energy dissipation capacity of specimen S2 is 38.72% higher than the conventional specimen.

Crack Pattern

Both the specimens exhibited almost similar crack pattern under loading. The conventional specimen showed a high dense pattern of cracks than specimen with debonded reinforcement. For the conventional and non-conventional specimens, the cracks initiated at bottom of the walls. On further loading, diagonal cracks were formed in the walls which were widened as the load is increased. On further loading, the cracks at the wall foundation inter face join together and widened. During the progress of reversal loading diagonal cracks from both sides of wall intersects with progressive widening. The specimens failed due to the formation of major cracks at the interface of wall foundation and wall (at base of the wall). The crack patterns of conventional specimen (S1) and the specimen with proposed collar (S2) are shown in Figure 10 and Figure 11 respectively.

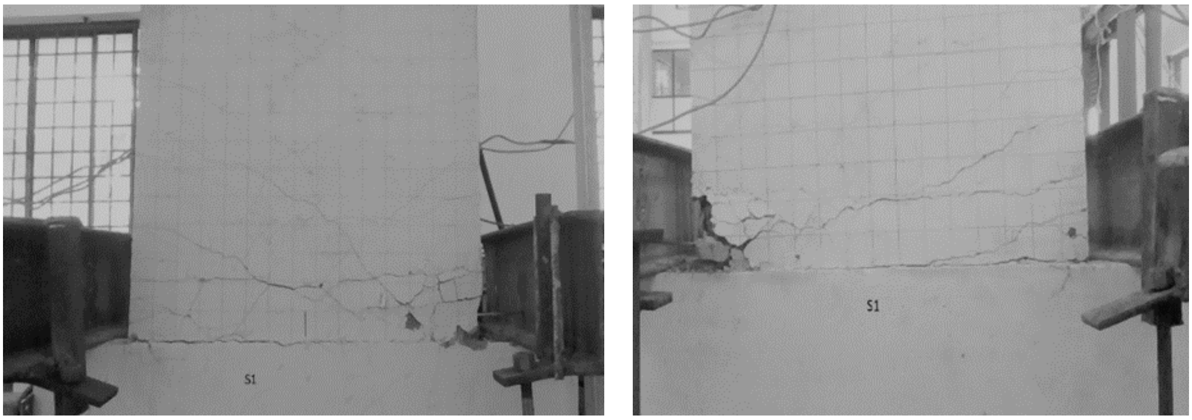


Figure 10 Crack pattern of conventional reinforcement specimen (S1)

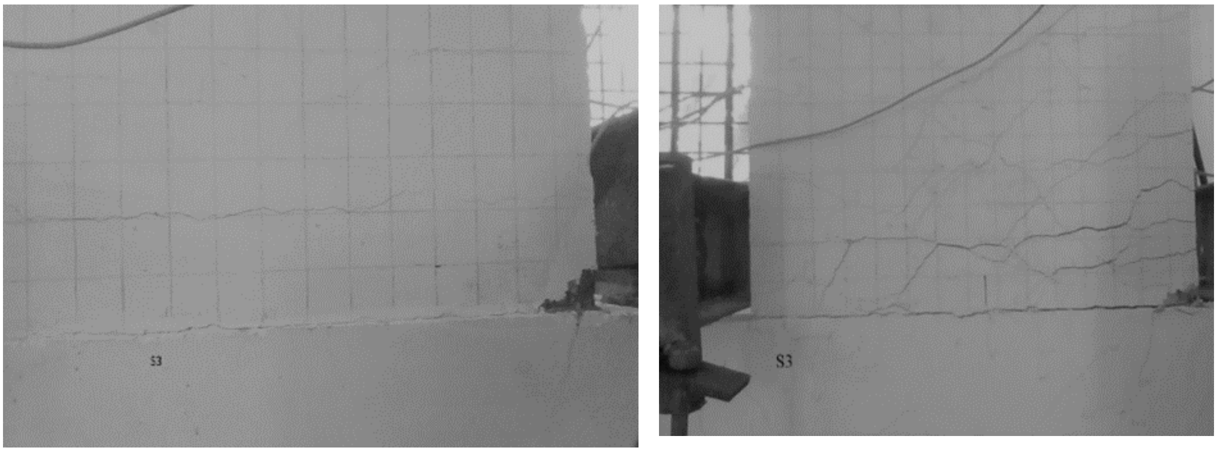


Figure 11 Crack pattern of debonded reinforcement specimen (S2)

CONCLUDING REMARKS

The experimental study deal with the comparison of behaviour of conventional slender shear wall specimen and slender shear wall specimen with debonded reinforcement subjected to lateral loading. On the basis of the experimental results, the ultimate load carrying capacity of the specimen with 75 mm debonded reinforcement is higher than that of the conventional specimen by 8.1%. Test results show that the specimen with debonded reinforcement has greater first crack load and ultimate load than that of conventional specimen. The cumulative energy dissipation capacity of specimen S2 is higher than conventional specimen. The energy dissipation capacity of specimen S2 is increased by 38.72 %. Also, the ductility factor is higher for the specimen with proposed additional collar for reinforcement. The ductility factor of specimen S2 is increased by 8.29 %. The failure modes of specimens were flexure. These outcomes lead to the conclusion that the shear wall with debonded reinforcement can be recommended for construction of buildings in earthquake prone areas.

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