SEISMIC BEHAVIOUR OF ULTRA HIGH PERFORMANCE CONCRETE SHEAR WALL WITH WELDED WIRE MESH

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Abstract

Shear walls are the vertical elements of the horizontal force resisting system, which are the best choice in earthquake-prone areas. The present study deals with the comparison of the performance of Ultra High-Performance Concrete (UHPC) shear walls with welded wire mesh to that of the UHPC shear walls with conventional reinforcement under seismic type loading. The performance of UHPC shear wall with welded wire mesh and of normal strength concrete shear walls are also compared. The parameters studied are load displacement hysteresis behaviour, first crack load, ultimate load, crack pattern, energy dissipation capacity, stiffness degradation and envelope curve. From the test results, it was observed that UHPC shear walls have greater strength characteristics than normal concrete specimens. Deformation capacity at the ultimate stage of UHPC specimen was found to be higher than that of normal concrete specimen. Specimens reinforced with welded wire mesh exhibit greater hysteresis characteristics. UHPC shear wall specimens with welded wire mesh and UHPC specimens with conventional reinforcement have less stiffness degradation than normal concrete specimens.

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Keywords: Ductility; Energy dissipation; Shear wall; Stiffness degradation; Ultimate load.

1. Introduction

Earthquakes are one of those natural calamities which are vulnerable to both human life and infrastructure. A shear wall is designed to resist the lateral forces that cause the bulk of the damage in earthquakes. Ultra-High-Performance Concrete (UHPC) is one of the latest advances in concrete technology as it overcomes the shortcomings of conventional concrete such as low strength to weight ratio, high permeability, low tensile strength, low ductility, and volume instability. The low permeability allows UHPC to withstand most distress normally associated with Normal Strength Concrete (NSC) and High-Performance Concrete (HPC) such as freeze-thaw deterioration, corrosion of embedded steel, and chemical ingress. The performance of the shear wall under seismic type loading can be improved by proper detailing to make them capable of undergoing large inelastic deformation and dissipating seismic energy. The present study examines the possibility of providing welded wire mesh as an alternative reinforcement for the shear walls in the seismic prone regions. The welded wire meshes consist of a series of parallel longitudinal wires with required spacing.

2. Related Research

2.1 Studies related to behaviour of Shear wall

Investigations of shear walls have been conducted by researchers worldwide by considering various parameters. Tasnimi (2000) evaluated the reduction in the strength, stiffness and energy dissipation of shear wall due to the formation of horizontal crack resulting from the sliding of vertical reinforcement. Dazio et al., (2008) studied the non-linear cyclic behaviour of Hybrid Fibre Concrete structural walls having fibres instead of shear and confinement reinforcement. Dazio et al., (2009) conducted a plastic hinge analysis of RC wall to investigate the effect of different vertical reinforcement contents on the hysteretic behaviour of the slender RC walls. The study proposes that the mechanical properties of the web reinforcement should receive the same attention as the boundary reinforcement for a ductile behaviour of the walls. Quiroz et al., (2013) studied the cyclic behaviour of thin normal concrete shear walls reinforced with electro welded wire mesh and calibrated the three parameter Park hysteresis model. Mohamed et al., (2014) conducted a numerical simulation of mid-rise concrete shear walls reinforced with glass fibre reinforced polymer (GFRP) bars subjected to lateral displacement reversals. Zhao et al., (2019) studied the improved seismic behaviour of shear walls reinforced with carbon fibre reinforced polymer (CFRP) bars as longitudinal reinforcement. Gu et al. (2019) found out the enhanced seismic behaviour of self-centering hybrid RC shear walls over the conventional precast RC shear walls.

2.2 Studies related to Ultra High-Performance Concrete

Ultra-High-Performance Concrete (UHPC) is a fibre-reinforced, super plasticized, silica fume-cement mixture with a very low water-cement ratio (w/c) characterized by the presence of very fine quartz sand (0.15-0.40 mm) instead of ordinary aggregate. Ma et al., (2004) conducted comparative investigations on Ultra-High-Performance Concrete with and without coarse aggregates. Wille et al., (2011) proposed a simpler way to produce Ultra High-Performance Concrete with compressive strength exceeding 150 MPa. Popa et al., (2013) studied the enhancement in compressive strength of Ultra High -Performance Concrete by the addition of steel fibres. Hoang and Fehling (2017) studied the effect of steel fibre content and aspect ratio on the uniaxial tensile and compressive behaviour of ultra-high-performance concrete. Pourbaba et al., (2018) conducted a detailed parametric study on the shear behaviour of UHPC beam specimens. From the literature review, it is observed that studies were conducted to determine the fresh and hardened properties of UHPC. Also, it is noticed that the research in the area of UHPC shear wall with welded wire mesh is scanty.

2.3 Research objectives

In the present study, an experimental investigation is carried out to analyse the behaviour of UHPC shear wall with welded wire mesh under seismic type loading and to compare the behaviour of UHPC shear wall with conventional reinforcement. The study is also extended to compare the performance of UHPC shear wall with welded wire mesh with conventional concrete wall specimens.

3. Experimental Programme

The experiment was conducted to study the effect of welded wire mesh as reinforcement for shear wall. Four numbers of shear wall specimens of dimensions 750 mm x 750 mm x 75 mm with a foundation block of dimension 1350 mm x 450 mm x 100 mm (to provide fixity at the bottom) were cast. The first specimen was made with a normal concrete mix of M40 having conventional reinforcement cage and was designated as 'NC'. The second shear wall specimen was prepared with ultra-high-performance concrete with conventional reinforcement cage and was designated as 'UC'. The third specimen was prepared with M40 grade concrete with welded wire mesh as reinforcement cage and was designated as 'NM'. The fourth specimen was cast with UHPC and welded wire mesh as reinforcement cage and was designated as 'UM'. The specimens were tested under reverse cyclic lateral loading.

3.1 Material Properties and Mix Proportions

The cement used was OPC 53 grade with standard consistency 31% and 28-day compressive strength of 54.5 N/mm^2. The manufactured sand with specific gravity 2.43 and fineness modulus 2.7 was used as fine aggregate. The aggregate of maximum nominal size 12 mm with specific gravity 2.76 and fineness modulus of 6.28 was used as coarse aggregate. Silica fume of specific gravity 2.2 was also added to attain high strength to UHPC. In order to keep the water binder ratio low, the super plasticiser with a total solid content of 40% and specific gravity of 1.11 was also used. The steel fibres complying with the ASTM A820, Type 1 low carbon drawn wire were used as fibres. Two types of fibres – crimped steel fibre of 0.45 mm diameter and 30 mm length and hook end steel fibres of 0.75 mm diameter and 50 mm length having aspect ratio 60 were used. The mix proportion of M40 grade concrete used in the study was arrived as per IS 10262:2019. The mix proportion obtained was 1:1.34:2.6 with water cement ratio 0.38 and super plasticizer dosage was 0.5% by weight of cement. In order to obtain a mix proportion for UHPC, the guidelines given by Aitcin (2004) which is a modified version of ACI 211.1 was used. The mix proportion for UHPC obtained was 1:1.68:2.13 with water cement ratio 0.29. 10% of cement was replaced by silica fume and superplasticizer dosage was 1%. One percentage volume fraction of steel fibres (0.5% hook end fibre and 0.5% crimped fibres) were used.

3.2 Reinforcement details of specimens

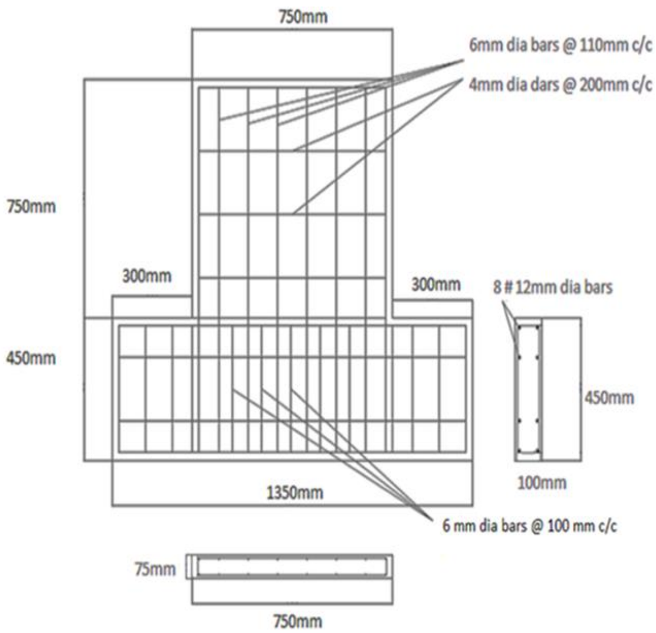

Fig. 1– Dimensions and Reinforcement details of Shear wall specimens NC and UC

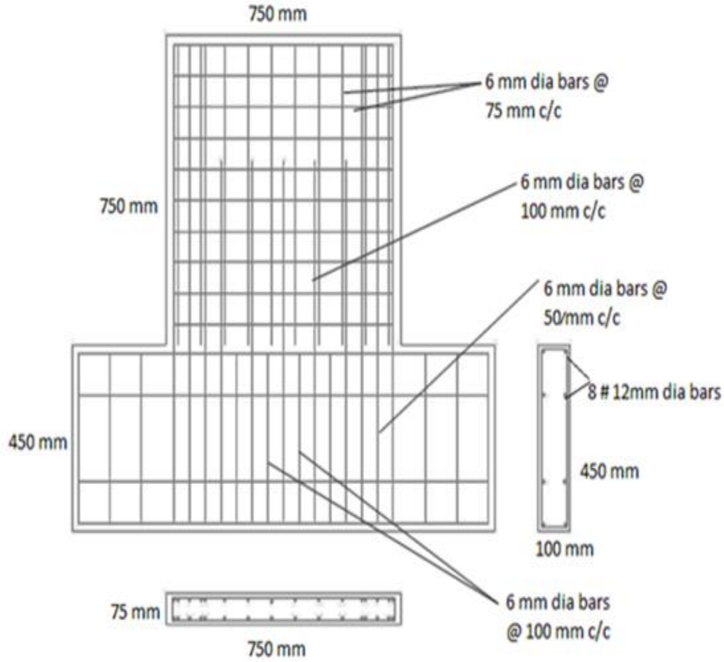

Fig. 2– Dimensions and Reinforcement details of Shear wall specimens NM and UM

The shear wall specimens were reinforced with minimum reinforcement as specified in IS 13920:2016. The horizontal and vertical reinforcement provided were 0.25% of the gross area of concrete. Mild steel bars of diameter 6 mm and 4 mm and welded wire mesh of diameter 6 mm were used. A minimum cover of 25 mm was provided on all faces of the wall panels. The reinforcement was provided in two layers. Fig. 1 and Fig. 2 show the details of the dimensions and reinforcement of specimens.

3.3 Experimental investigation of shear wall specimens

The test set up in the laboratory is as shown in Fig.3. Two screw jacks of 60 t capacity were used for lateral loading which were fixed on both sides of the test frame. It can provide a maximum displacement of ±300 mm and a load of ±597.84 kN. The walls were subjected to lateral reversed cyclic loading at the upper end of specimens until failure. One cycle of loading consisted of both forward and reverse cycles and after each cycle, the amplitude of displacement-controlled loading was increased until failure as shown in Fig. 4.

Fig. 3 – Test Setup

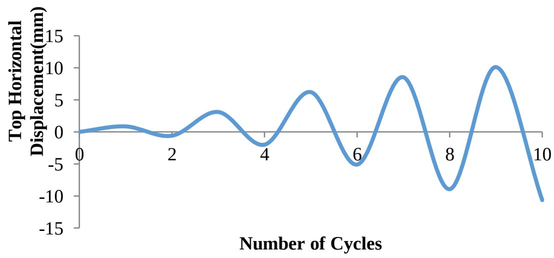

Fig. 4 –Displacement history of specimens

4. Discussion of test results

4.1 Load - displacement hysteresis behaviour

Fig. 5 to Fig. 8 show the load-displacement hysteresis curve of each specimen. The curves are linear up to the formation of the first crack. After cracking, the slope of the curve decreases whereas the displacement increases.

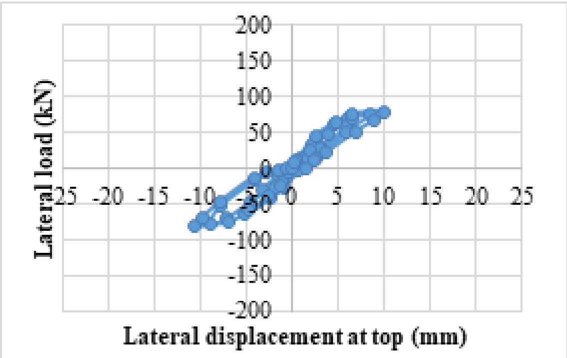

Fig. 5 –Load-Displacement curve of specimen NC

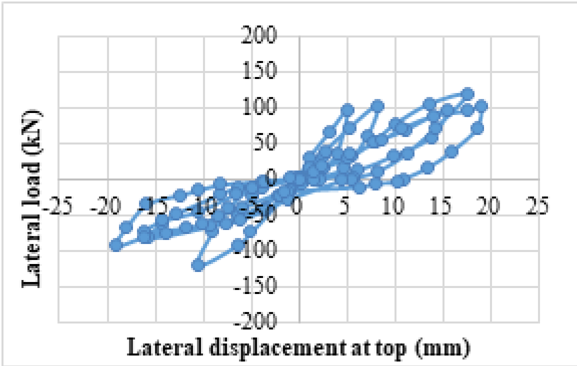

Fig. 6 –Load-Displacement curve of specimen UC

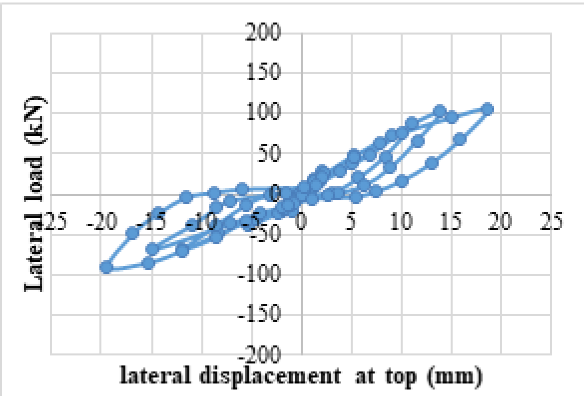

Fig. 7 –Load-Displacement curve of specimen NM

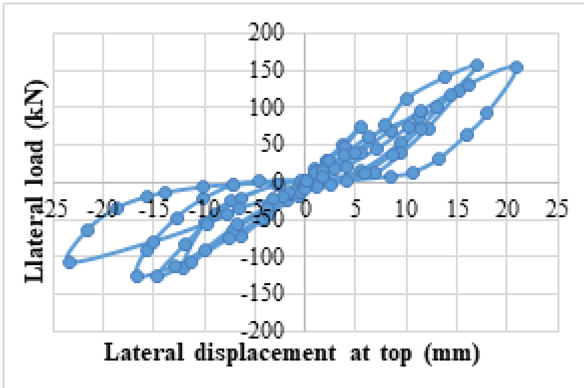

Fig. 8 –Load-Displacement curve of specimen UM

The UHPC specimens have less deflection than normal concrete (NC) specimens for the same level of loading in the initial cycles. The area of the hysteresis curve is more for UHPC specimens than NC specimens. The specimens reinforced with welded wire mesh have more hysteresis loop area than conventionally reinforced specimens. The area of hysteretic curves of UM and UC are more than that of NM and NC.

4.2 First crack load and ultimate load

Table 1 shows the first crack load and ultimate load for each specimen with corresponding deflection and the loading cycle at which the crack was formed.

Table 1 – First crack load and ultimate load of specimens

Specimen	First crack stage			Ultimate stage		
	Cycle	**Load (kN)**	**Displacement (mm)**	**Cycle**	**Load (kN)**	**Displacement (mm)**
NC	3	63	4.55	5	81	10.65
UC	3	71	5.7	7	101	19.08
NM	4	87	11.11	6	91	19.42
UM	4	88	11.23	7	155	20.96

From Table 1, it can be observed that the ultimate loads of UHPC specimens are higher than that of NC specimens. Also, specimens reinforced with welded wire mesh have a higher first crack and ultimate load. The deformation capacity at the ultimate stage of UC specimen is 79 % higher than that of NC specimen and the deformation capacity of UM specimen is 7.93 % higher than that of NM specimen.

4.3 Crack pattern

The specimens show almost similar crack patterns under loading. The UHPC specimens show a dense pattern of cracks with smaller crack widths than NC shear walls. For all specimens, the cracks initiated at the bottom of the walls. On further loading, diagonal cracks were formed in the walls which were widened as the load increased. The crack patterns are shown in Fig.9 to Fig.10.

Fig. 9 –Crack Pattern for specimen NC and NM

Fig. 10 –Crack Pattern for Specimen UC and UM

4.4 Energy dissipation capacity

The cumulative energy dissipation of each specimen at each cycle is given in Table 2.

Table 2 – Cumulative Energy Dissipation Capacity of each Specimen

Cycle	**Energy Dissipation Capacity (kNmm)**			
	NC	**UC**	**NM**	**UM**
1	0.7	0.3	1.2	0.4
2	14.1	9.0	4.8	4.3
3	191.4	276.8	25.6	33.9
4	478.4	941.5	374.2	616.6
5	1033.3	1721.7	1036.6	1466.3
6	-	2895.5	2705.0	2990.1
7	-	4517.8	-	4827.9

Energy dissipation capacity of both UHPC specimens, UC and UM are higher than normal concrete specimens, NC and NM. The cumulative energy dissipation capacity of specimen UC is 77.13 % higher than NC and that of specimen UM is 43.97 % higher than NM. The energy dissipation capacity of UM is 78.59 % higher than NC which proves that it can be used effectively in high seismic prone areas.

4.5 Stiffness degradation

The stiffness of wall specimens, when subjected to cyclic lateral load, decreases with the increasing loading cycle due to flexural cracking of concrete and flexural yielding of reinforcement. Table 3 shows the stiffness values of each specimen at each cycle and Fig.11 shows the comparison of variation of stiffness of each specimen at successive cycles of load reversal. The stiffness in a particular cycle was calculated from the slope of the line joining peak values in each cycle.

Table 3 – Stiffness at each cycle

Cycle	Stiffness of specimen at each cycle			
	NC	UC	NM	UM
1	13.10	15.09	14.41	16.41
2	11.57	12.61	12.50	13.25
3	11.42	12.54	8.25	12.54
4	8.76	11.81	6.80	8.74
5	7.76	5.73	5.94	8.41
6		5.65	5.15	8.25
7		5.07		5.95

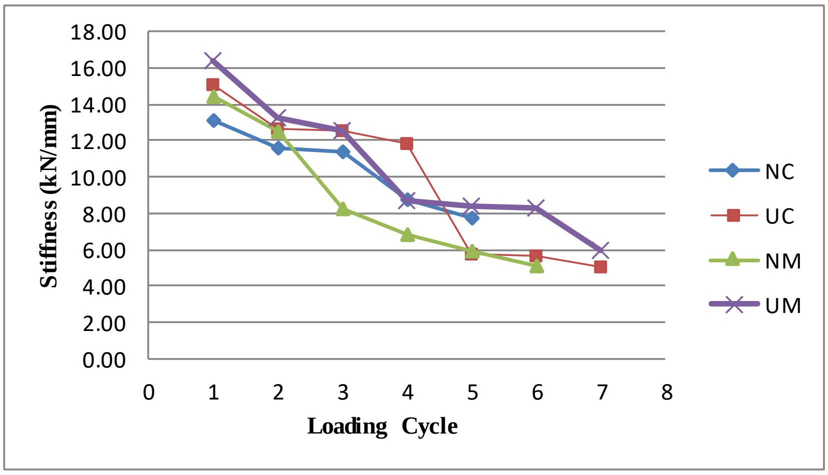

Fig. 11 –Stiffness Degradation of Specimens

The specimen, UM has greater initial stiffness than the other specimens. The initial stiffness of UC and UM shear walls are higher than NC and NM by 15.19 % and 13.85 % respectively.

4.6 Envelope curves

Based on load-displacement hysteresis curves, envelope curves are drawn and shown in Fig. 12 to Fig. 15. The post yield deformability of shear wall specimen UM is higher than the other specimens. In the case of specimen NC, the post yield behaviour is least compared to other specimens.

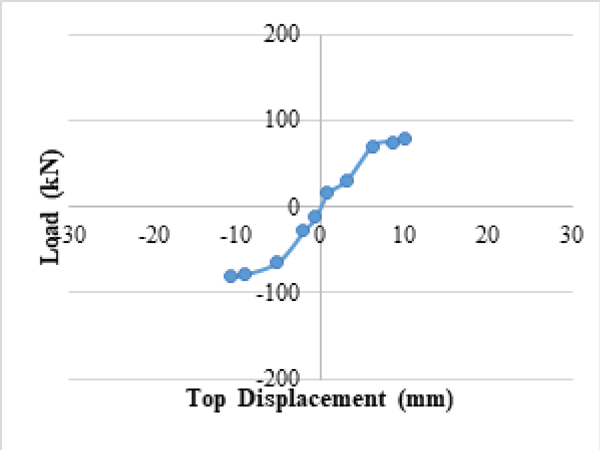

Fig. 12 –Envelope Curve of NC

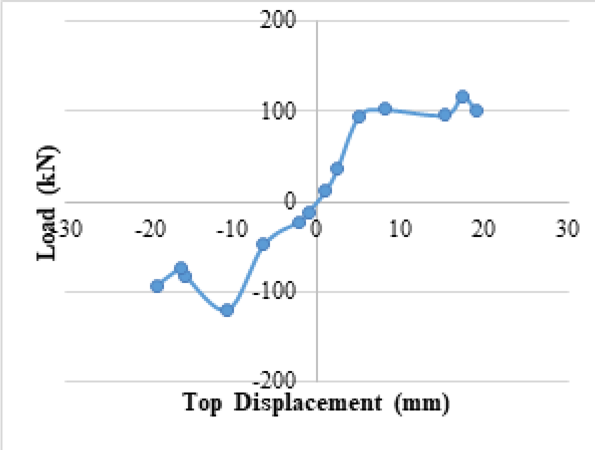

Fig. 13 –Envelope Curve of UC

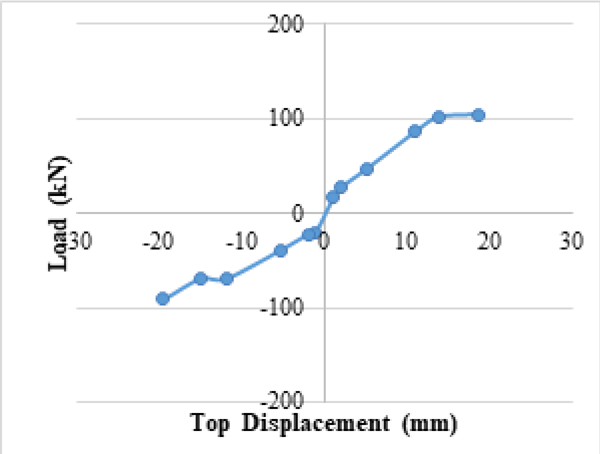

Fig. 14 –Envelope Curve of NM

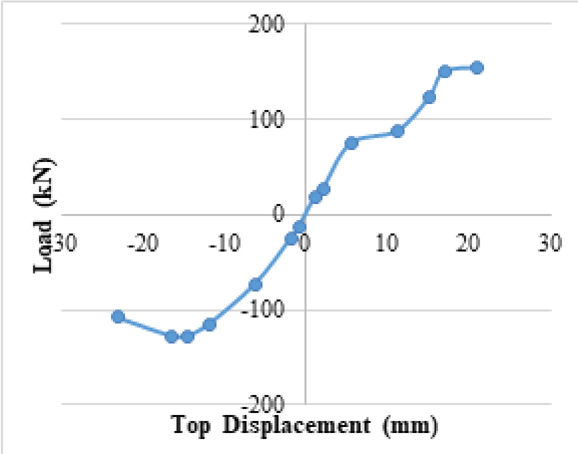

Fig. 15 –Envelope Curve of UM

5. Conclusion

From the comparative studies of Normal Concrete (NC) and Ultra-High-Performance Concrete (UHPC) shear walls, the following conclusions are arrived. The ultimate load capacity of UC is 1.24 times greater than NC and that of UM is 1.7 times greater than NM. UHPC shear walls showed greater strength characteristics than NC specimens. Deformation capacity at the ultimate stage of UC specimen is 79 % higher than that of NC specimen and the capacity of UM specimen is 7.93 % higher than that of NM specimen. Specimens reinforced with welded wire mesh showed greater hysteresis characteristics. The cumulative energy dissipation capacity of specimen UC is 77.13 % higher than NC and the energy dissipation capacity of specimen UM is 43.97 % higher than NM. The initial stiffness of UC and UM shear walls are higher than NC and NM by 15.19 % and 13.85 % respectively. UC and UM exhibit less stiffness degradation than NC and NM. For both NC and NM shear mode of failure was observed whereas for UC and UM, the mode of failure was flexure. Among the four specimens, UM showed superior strength at failure and overall good performance characteristics.

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