USE of Composite Materials in Seismic Retrofitting of RC Shear Wall

Sanjivan Mahadik, S. R. Bhagat

Abstract— A majority of the structures throughout the world are constructed of reinforced concrete. Reinforced concrete has good compressive strength but it shows brittle failure at joints or connections when subjected to bending moment due to seismic load. Some seismic load resisting system is essential to minimize the effect of seismic load to avoid failure of structures. The most common lateral load resistance systems found in many reinforced concrete structures is shear walls. Shear walls have been widely accepted as effective alternatives to moment resistant frames in seismic design of concrete structures. The main purpose of providing shear walls is to resist wind and earthquake forces in addition to gravity force. Many existing buildings which have been constructed without proper provisions of seismic resisting aid but these structures have RC walls around the stair blocks and elevator or along the structure perimeter. These elements are often reinforced to resist the vertical loads only, without considering the seismic actions. In few cases, the elements may be reinforced to resist horizontal wind loads but this provided reinforcement may be insufficient and effective against the design seismic actions recommended by the latest standards. In order to transform the existing RC walls into seismic resistant shear walls, different retrofit materials and techniques are traditionally proposed. Several composite materials have been tried by researchers to improve the behaviour of concrete used in different structural members and shear walls to improve their strength either for retrofitting or repair. Transformation of the existing RC walls into anti-seismic shear walls is often preferred due to simplicity and having no drawbacks. Structural members including shear wall requires retrofitting or repair due to change in codal provisions or changes in structure due to functional requirement or due to any other reason. Several composites available in market can be easily utilized for the purpose with different technique. This paper covers review of these methods and technique used in retrofitting RC shear wall.

Keywords: composite materials, seismic retrofitting, base isolation, strength, stiffness, ductility.

I. INTRODUCTION

The most common lateral load resistance systems found in many reinforced concrete structures is shear walls. Shear walls are generally introduced to safeguard the building elements from seismic forces. For most of the tall buildings centrally located elevator shafts or escape shafts acts as a shear wall. Due to changes in usage or standards the existing shear walls may provide adequate seismic resistance capacity. The code recommendations are changing frequently and accordingly it becomes essential to make the changes in structures to satisfy the current code requirement. Several composite materials and techniques have been tried by researchers to improve the seismic resistance of building by retrofitting of shear wall. The provisions made to resist seismic forces by shear wall have been reviewed in this paper. The major focus of review is related to strength, stiffness, ductility and energy dissipation. Behavior of in-strength and stiffness was studied by using composite steel plate shear wall [1], and similar study was carried by using externally bonded FRP sheets [2], [15], [16] and [18]. Steel encased profiles can also be tried for strengthening of RC shear walls [7]. Use of carbon fiber has been made [8] and high performance jacket was also used for strengthening [4]. Use of high-performance fiber-reinforced cement composites (HPFRCCs) and FRCC were tried by [9] and [10]. Use of FRP with RC wall and CFRP was studied by [12],[13]and [28] respectively. Use of shape memory alloy (SMA), and brittle matrix composite (BMC) and engineered cementitious composites (ECC) was studied by [22] and [27] respectively. Ductility behavior was studied by [1, 4, 6, 7, 9, 12, 14, 29] with different composite materials. Energy dissipation of composite shear wall was studied by [1, 4, 6, 7, 18].

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II. STRENGTH AND STIFFNESS

Shear walls are constructed to resist flexural and shear stresses due to seismic load. Several researchers had worked to investigate behaviour of shear wall using composite section, some of which are discussed in this section. Experimental investigation of composite shear wall under shear loading was carried out on composite steel plate shear wall (CSPSW) and is proved to be one of the efficient method for improving the seismic behavior of shear wall [1]. Based on the observations, it was concluded that, with increase in number of bolts in steel shear wall, CSPSW buckling load increases. Use of RC panels at both sides of steel plate improves the strength. Use of high strength concrete reduces damage to the RC panels significantly in comparison with the normal concrete. If center-to-center bolt spacing decreases, steel plate capacity will increase. Load carrying capacity or strength and stiffness of wall can be improved by adding concrete walls on one or both sides. Similar attempt with shear walls after being composited using externally bonded steel plates and FRP sheets and then comparing their analysis results with the results of RC shear walls in order to indicate the effectiveness of using composite elements has been done by [2]. The results of an analytical and parametric study on the effectiveness of using externally bonded steel plates on RC shear walls as a retrofit technique so as to improve their seismic behavior have been investigated.

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The impression of using externally bonded steel plates as an alternative to the boundary element of RC wall was presented. The results show that a ductile behavior close to the behavior of the RC wall with boundary elements could be achieved from the model with a suitable thickness of steel jacket that leads to the theory that steel jacketing could be an alternative for the boundary elements of RC shear walls. Theoretical study and the experimental tests on composite steel-concrete shear walls with steel encased profiles (CSRCW), performed at Politehnica University of Timişoara, Romania. The study consists in numerical analysis and tests on 1:3 scale experimental steel-concrete composite elements. The experimental elements differ by the arrangement of the steel shapes embedded in the cross section of the wall and by the cross section type of the steel encased element [7]. This type of combination showed good improvement in strength stiffness and energy dissipation. The properties of steel shear walls reinforced with carbon fiber polymers (CFRP) are studied by [8]. In the study nonlinear behavior of steel shear walls (SSW) and composite steel shear wall reinforced with carbon fibers (CSSW) was investigated. Experimental and numerical studies were carried out to evaluate the effects of fiber content/angle and panel width on the properties of these walls. Results showed that wider panel widths enhance the behavior of both the SSW and CSSW. Higher fiber contents increase energy absorption, stiffness, over-strength and capacity. Application of FRP and CFRP to shear wall was studied along edges and in the region of plastic hinge area. Analysis results show that the application of externally bonded carbon fiber sheets is an effective seismic strengthening procedure for RC shear walls. The carbon fiber sheets can be used to increase the pre-cracked stiffness, the cracking load up to 35% increase, the yield load and the ultimate flexural capacity increased up to 18% of RC walls [2]. The wrapped CFRP sheets around the plastic hinge range of the RC wall provides not only enough shear strength which results in a ductile flexure failure mode with the concept of strong shear and weak flexure, but also the confinement of concrete in the plastic hinge leads to an increase in the ductility of the RC wall. Seismic retrofitting of existing shear walls by means of high performance RC jacket is a new technique for the strengthening of existing RC shear walls based on the application of very thin high performance RC jackets is presented by [4]. The results show the efficiency of the proposed solution in significantly increasing the structure resistance and deformation capacity. By applying a very thin high strength jacket, RC walls of existing buildings can be transformed into shear walls, characterized by a large stiffness and strength, as well as a pronounced deformation capacity and ductility. The strengthening of existing RC walls by means of thin high performance jackets, made of high performance fiber concrete reinforced with high strength steel meshes improves performance of shear wall [9]. Relaxation of confinement reinforcement requirements in structural walls through the use of fiber reinforced cement composites is possible [10]. Fiber reinforced cement composites (FRCCs) in critical regions of slender structural walls was experimentally evaluated with the goal of eliminating the need for special confinement reinforcement in wall boundary regions while maintaining adequate displacement capacity. The use of an FRCC material with 2.0% volume fraction of steel hooked fibers allows the total elimination of boundary confinement reinforcement without any noticeable adverse effect in wall performance. Use of FRCC in RC shear wall helps in reducing the confinement reinforcement required, also achieves required strength and stiffness if added in required percentage. Cyclic tests on FRP retrofitted RC shear wall panels shows good performance. Experimental program that aimed to investigate the seismic performance of reinforced concrete (RC) shear walls retrofitted using carbon fiber-reinforced polymer (FRP) composites was carried. The FRP rehabilitated wall panel performs efficiently showing an improved flexural behavior compared to the control wall [12]. Experiments on seismic retrofit and repair of reinforced concrete shear walls are studied [13].The retrofit involved the use of carbon fibred-reinforced polymer (CFRP) wrap for improving the lap splice. The retrofit and repair techniques improved the displacement ductility, and prevented premature failure of the lap splices. The retrofitted walls are able to develop their nominal flexural capacities, and achieved a ductility value of 2. The repair technique consisted of a SFRSCC jacket over the lap splice region, increases the nominal flexural capacity of the wall at its base. The walls developed significant yielding in the flexural bars and achieved higher displacement ductility's and flexural moment capacities. It is found that, SFRC can be successfully used in to improve performance of shear wall. Application of externally bonded carbon fiber sheets is an effective seismic strengthening and repair procedure for reinforced concrete shear walls [15]. The carbon fiber repair system can be used to recover the initial elastic stiffness and to increase the yield load and ultimate flexural capacity of seismically damaged walls. In strengthening applications, the carbon fiber sheets can be used to increase the pre-cracked stiffness, the secant stiffness at yield and the cracking load, the yield load and the ultimate flexural capacity of undamaged walls. FRP strengthening of shear walls with openings was found efficient [16] with remarkable improvement in ultimate lateral load capacity. Evaluation of a shear wall reinforced with glass FRP bars subjected to lateral cyclic loading was done [18].Shear walls totally reinforced with glass FRP bars which can be comparable to steel reinforced shear wall. Improvements of concrete shear wall structures by smart materials have found numerous applications in many areas in civil engineering [22]. One class of these materials is shape memory alloy (SMA) which exhibits several unique characteristics such as super elasticity and shape memory effect. Due to these characteristics, research efforts have been extended to use SMA in controlling civil structures. Application of brittle matrix composite (BMC) is found beneficial for seismic retrofit of reinforced concrete structures. BMC called engineered cementitious compound ECC panel exhibits extensive tensile micro cracking distributed over large volume. As result of the material tensile hardening behavior tensile and shear stress concentration near the construction joints was diffused, which leads to significant delay in formation of large localized cracks. In fact panel fails due to compression crushing near the joint before any localized tensile crack occurred. On contrary if brittle material was used, localized cracks formed at very early loading stage. Propagation of these cracks along the joints and diagonally towards the center of panel leads to failure at load and displacement level much lower than ECC was used.

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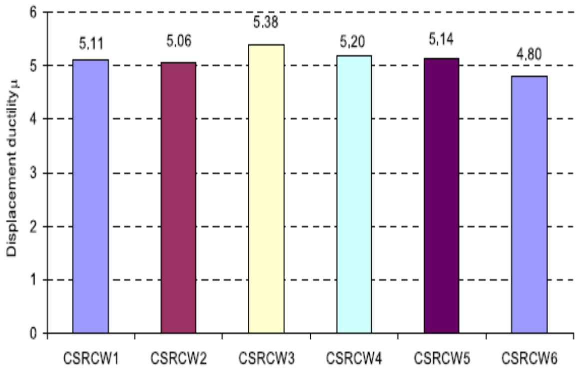
The ECC panel fails to average shear stress and average shear strain greater than regular wall. ECC panel is beneficial in delaying localized tensile cracks [27]. Theoretical and experimental studies related to the seismic retrofits of the reinforced concrete frames containing partition walls using carbon fiber reinforced polymer materials is found effective retrofitting measure [28]. Carbon fiber reinforced polymer with sufficient end anchorages is an effective retrofitting m

III.DUCTILITY

Ductility is defined as the ratio of maximum deflection to deflection at yield point. Experimental investigation of steel composite shear wall under shear loading shows that, using RC panels at both sides improves the main properties of specimens like energy dissipation and strength, while decreasing its ductility [1]. If center-to-center bolt spacing decreases, steel plate capacity will increase, while system ductility will decrease. The ductility decreased by providing RC panels at both sides of the shear wall. CFRP wrap around shear wall improves mode of failure from brittle to ductile [2]. Use of very high performance jacket improves ductility [4]. Ductility also increases by providing shear wall with concrete filled tube columns and concealed truss [6]. In theoretical and experimental study of composite shear wall with steel encased profile was made by [7] and the value of the ductility



coefficient μ for each tested specimen is represented in Fig. 6. It was investigated that all composite steel-concrete reinforced concrete shear wall with encased profile CSRCW have a higher ductility than the common reinforced wall CSRCW (6).

Figure 6 Comparative ductility coefficients [7]. (Specimen 1-5 with steel incased profile and 6 of ordinary SW 6)

Cyclic test on FRP reinforced wall panel made by [12] shows that shear wall retrofitted with FRP has increased flexural capacity along with decrease in displacement ductility. Experiment on seismic retrofit and repair of reinforced concrete shear wall was conducted to investigate behavior of shear wall retrofitted with carbon fiber reinforced polymer (CFRP) warp and steel fiber reinforced with self-consolidating concrete SFRSCC jacket[13]. The technique of using SFRSCC achieves higher displacement ductility than original RC wall. Study of retrofitting of shear wall with different methods was made with comparing different parameter of walls retrofitted with carbon fiber sheets CFS, Steel Plate, Engineered Cementitious Composites ECC, Micro Defect Free MDF. Investigation shows that ductility of shear wall with CFS & ECC is higher than other materials [4].

Experimental study on seismic behavior of mid-rise RC shear wall with concealed truss [29] shows yield displacement of the mid-rise shear wall with concealed steel frame, with concealed steel bar truss, and with concealed steel truss are smaller than that of the ordinary mid-rise shear wall, which indicates that the steel bar truss and the steel truss slowdown the development of the cracking, increase the late strength of the structure, and decrease the relevant displacement. The ductility coefficient of the mid-rise shear wall with concealed steel frame, with concealed steel bar truss, and with concealed steel truss are larger than that of the ordinary mid-rise shear wall.

High-performance fiber-reinforced cement composites, an alternative for seismic design of structures [9] are studied comparing behavior of HFRCC with regular materials in tension and compression. Figure 7 shows a qualitative comparison between typical tensile stress-strain curves corresponding to high-performance and regular FRCCs. As can be seen, HPFRCCs exhibit substantially larger strain capacity and toughness compared with traditional FRCCs, which makes them ideal for use in members, subjected to large inelastic deformation demands.

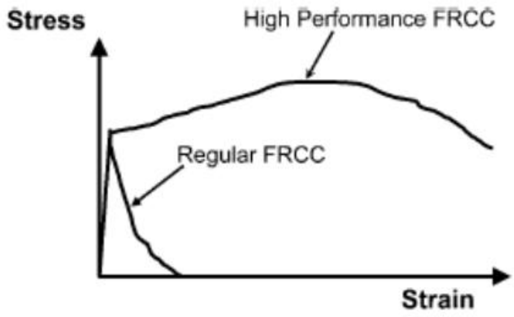


Figure 7 Tensile stress-strain response of regular and high performance FRCCs [9].

IV. ENERGYDISSIPATION

Energy dissipation of shear wall is obtained from area bounded by hysteretic loop of the cycle. As per investigation made by [1] energy dissipation of composite shear wall is 25% higher than that of the plain steel shear wall [1]. Providing RC panel on both sides improves the energy dissipation. Evolution of shear wall reinforced with Glass FRP bars subjected to lateral cyclic loading [18] shows improvement in energy dissipation.

Use of concrete in filled steel tube column and concealed steel truss was studied by [6]. Energy dissipation for this type of composite wall is significantly higher than traditional shear wall. While doing theoretical and experimental study of composite steel-concrete shear wall with steel encased profiles [7] it is investigated that all type of steel encased profiles composite shear wall have more energy dissipation than usual reinforced wall provided with same reinforcement areas. The dissipated energy (E) in each cycle was evaluated from the horizontal load (P) versus lateral displacement (Δ) hysteretic curves, as the area bounded by hysteretic loop of that cycle. A comparison between the total dissipated energy (E-total) within each test performed is presented in Fig. 8.

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It was concluded that all tested composite steel reinforced concrete walls dissipated more energy than the usual reinforced concrete wall, provided with the same reinforcement area in the sectional extremities CSRCW6.

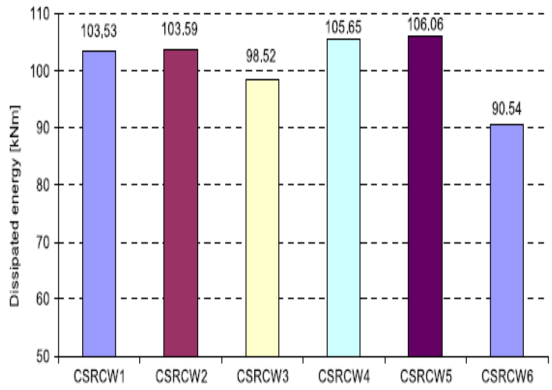

Figure 8 Comparative energy dissipation [7] (Specimen 1-5 with steel incased profile and 6 of ordinary SW 6)

Steel shear wall reinforced with carbon fiber polymer [8] shows with higher panel width values increase energy absorption of both the SSW and the CSSW specimens (Fig. 9). An increase in b/d ratios made the walls more capable in the energy absorption values (Fig. 10). Also, higher fiber contents improve energy absorption of SSW specimen. Results obtained from Fig.10 show that the CFRP increases the energy absorption values of the SSW from 1.84 to 2.45 times. The CFRP is more effective on thinner SSWs. It can be concluded that these values make the CSSW a more effective system under seismic loads.

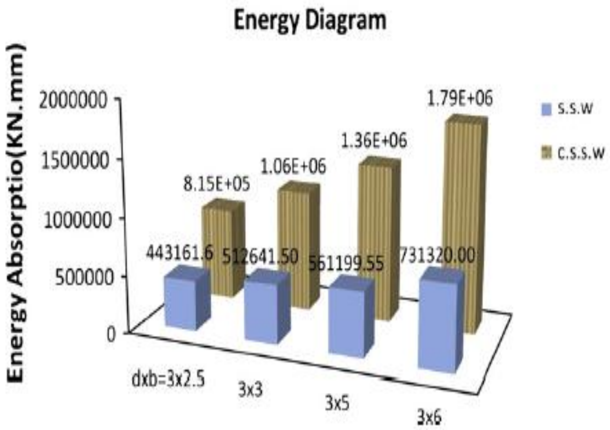

Figure 9 Energy absorption diagram [8].

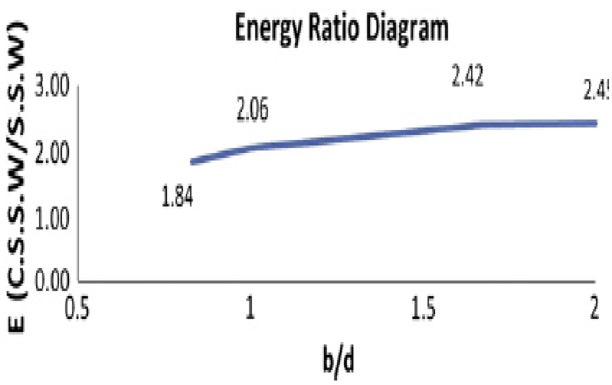

Figure 10 Energy dissipation ratio diagram [8]

Retrofitting of shear wall with different materials and methods [14] were studied. Solid wall shows higher value of energy dissipation than retrofitted. Having opening area of 23% energy dissipation area decreased by 50% approximately.

V. CONCLUSION

Core walls constructed around lift shafts and stairways of existing buildings can be retrofitted by using different composite materials and techniques. A variety of composite materials are available in market which can be added to concrete to improve its performance.Several techniques are currently available to retrofit and strengthen buildings with sufficient stiffness, strength and/or ductility. RC structures can successfully been strengthened or retrofitted with advanced composite materials and by using different techniques. FRP composites are readily used for strengthening applications mainly due to the relative ease of installation compared to conventional materials and methods. Strengthening with FRP composites have done mostly due to only possible solution available. The use of a very thin high performance jacket allows doubling the structure ultimate resistance. The technique allows to largely increasing the structure deformation capacity and ductility, which are the main goal of every seismic strengthening design. The retrofitted walls with FRP are able to develop their nominal flexural capacities, and achieve a required ductility. Different advanced composite materials like SFRC, GFRC, BMC, CFRC etc. may be successfully used for seismic retrofitting of RC wall. Different encased profiles may be successfully introduced in RC shear wall to improve its performance under seismic loads. Thus it can be conclude that it is essential and also possible to retrofit the buildings which are seismically unsafe by using different advanced materials and retrofitting techniques applying on existing core walls which are not designed to resist seismic forces.

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