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USE OF STEEL ANCHORS IN FRP REHABILITATION SYSTEMS

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ABSTRACT

Seismic rehabilitation using fibre reinforced polymers (FRP) has been recently extensively studied. The use of advanced composites has been applied to structural elements such as beams, columns, beam-column joints and walls. In several rehabilitation schemes there is a need to anchor the FRP sheets using steel or FRP anchors. Anchors may be needed in the confinement of beam-column joints and end column in walls. The objective of this study is to evaluate the performance of steel and FRP anchors. Experimental programs were conducted on the rehabilitation of columns, beam-column joints and structural walls using advanced composites. FRP and steel anchors were used. Steel anchors were instrumented with strain gauges to measure the tension force developed in the anchors. It was concluded that the steel and FRP anchors performed equally well under tension. However, the steel anchors were capable of resisting shear forces while the FRP anchors failed in shear resulting in abrupt failure of the rehabilitation system.

Introduction

The repair and rehabilitation of structural components using fibre reinforced polymers (FRP) has recently received much attention. Rehabilitation systems were developed and tested for beams, columns, beam-column joints and walls. In several situations, it may be necessary to anchor the FRP sheets to develop the forces in the fibres and provide continuation of the tension forces needed for confinement. As an example, when wrapping a circular column with FRP sheets where the fibres are oriented in the lateral direction, the confinement forces are provided by tension in the fibres. However, in the fibre wrapping of a rectangular or square columns, bulging of the fibres on the flat sides may reduce the confinement efficiency of the fibres. A practical solution is to use anchor bolts to reduce the bulging of the FRP sheets on the column sides.

Anchoring FRP sheets is also advantageous is the case where the confining loops need to be closed. Effective confinement of the column at the beam-column joint may be provided by U shaped FRP sheet and anchors to tie the open ends of the fibre sheets as shown in Fig. 1. In the

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case of T sections with no access to the top of flanges, the web confinement can be provided by U shaped FRP sheet anchored near the top of the web as shown in Fig. 2. This technique is effective particularly in areas of the beam subjected to shear and torsion. Anchors were also effectively applied to the confinement of the end columns in a structural wall as illustrated by the cross section shown in Fig. 3. The steel through rods clamp steel plates on both sides of the concrete section using hand-tightened nut. Another technique is to use fibre ties that are anchored into the confined core at one end while the other end is sandwiched between the carbon fibre reinforced polymers (CFRP) wraps as shown in Fig. 4. The tie rods are being compared to the FRP anchors since they are serving similar function of anchoring to FRP to the concrete.

Tests conducted on the FRP rehabilitation of various structural elements using steel rods and FRP anchors proved the efficiency of the system. However, research into the performance of different anchoring systems has not been conducted. The objective of this study is to evaluate the performance and design of steel and FRP anchors.

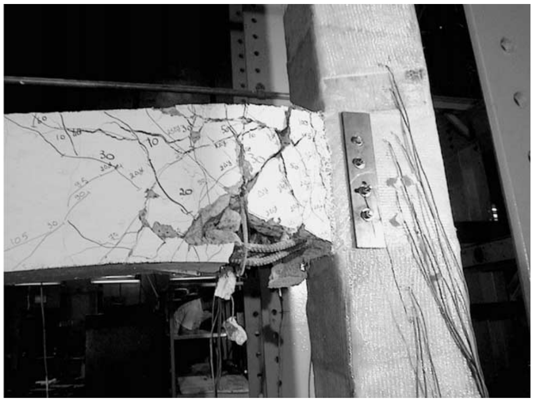


Figure 1 FRP column confinement at the beam-column joint

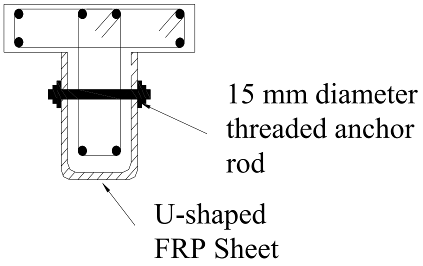


Figure 2 Rehabilitation of beam for shear or torsion without access to flange top

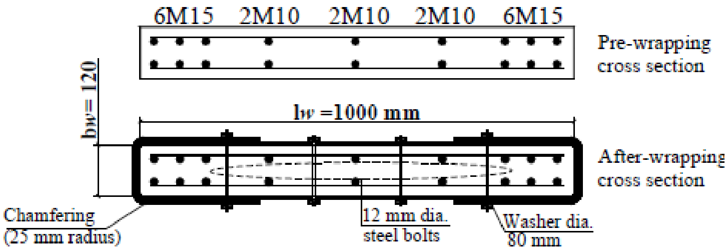


Figure 3 Confinement of end element of a wall using anchored FRP

Figure 4 FRP anchors

Test Program

Two sets of tests are reported in this study. The tests compare the use of steel and CFRP anchors in the rehabilitation of different structural systems. One set of tests is on short columns and the second is on walls.

Short Column Tests

Two short square columns were built of height 914 mm and cross section 305x305 mm. The columns were reinforced with 8-M20 longitudinal bars and M10 transverse bars. The columns were designed to earlier code (ACI 1963). The deficient columns were wrapped with CFRP sheets with the fibres in the horizontal direction for confinement. Because of the potential bulging of the column sides which will reduce the confinement efficiency, anchors were used. In one of the columns C1, 12 mm diameter steel anchors were used along the height as shown in Fig. 5. In the second column C2, 75 mm deep CFRP anchors were used. The axial load, shear and moment were applied to the column end using a hydraulic jack, an actuator and a pantograph arrangement as shown in Fig. 6. More details on the short column tests are available elsewhere (Ghobarah and Galal 2004).

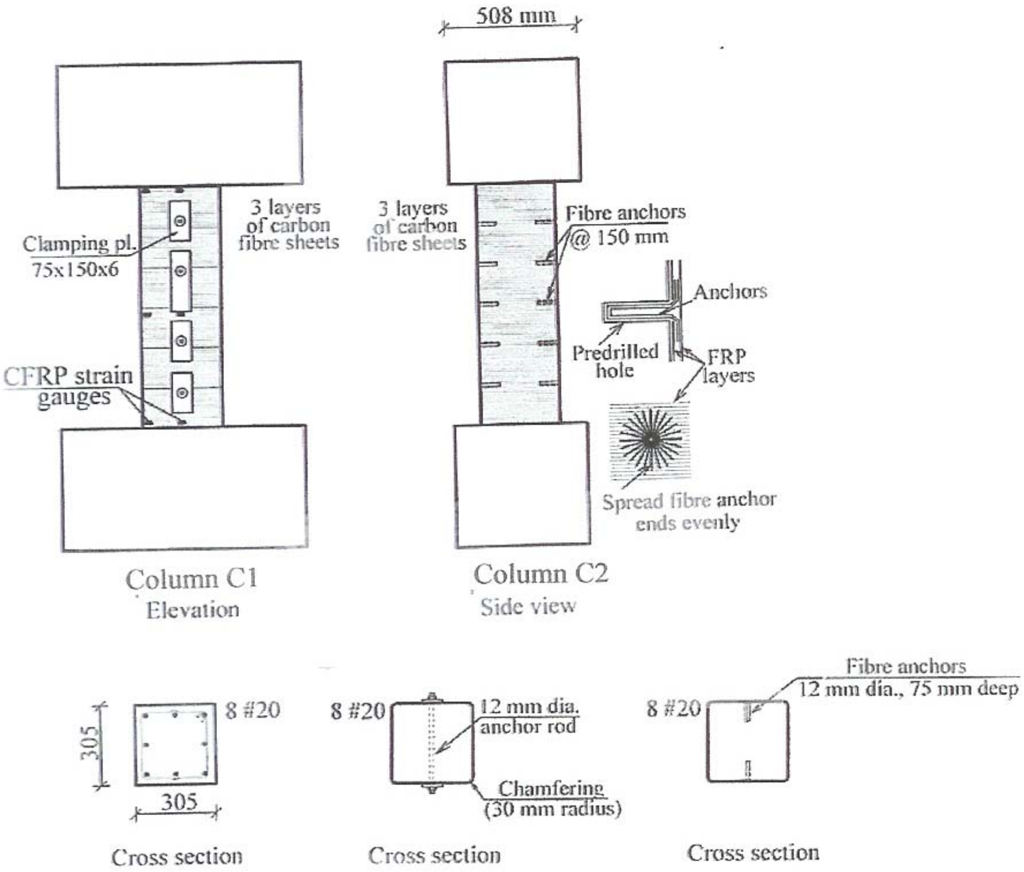


Figure 5 Test columns C1 and C2

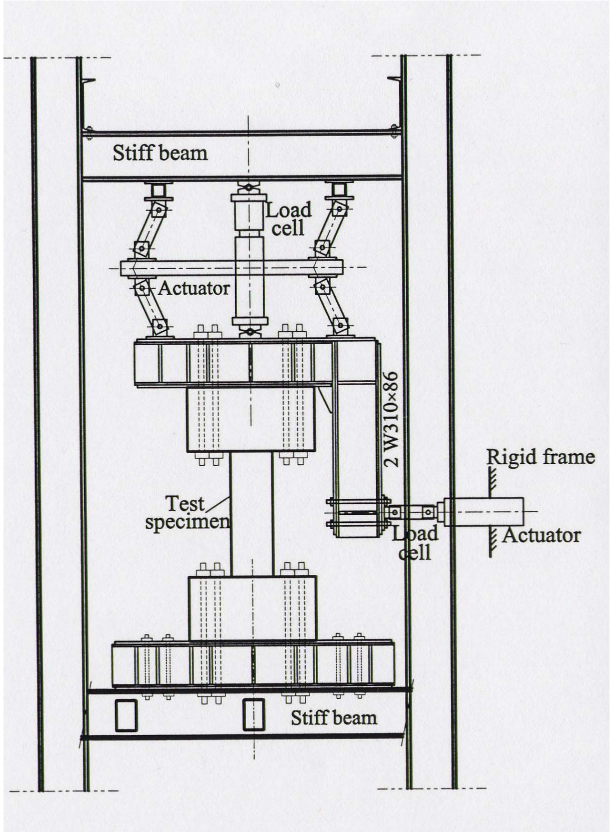
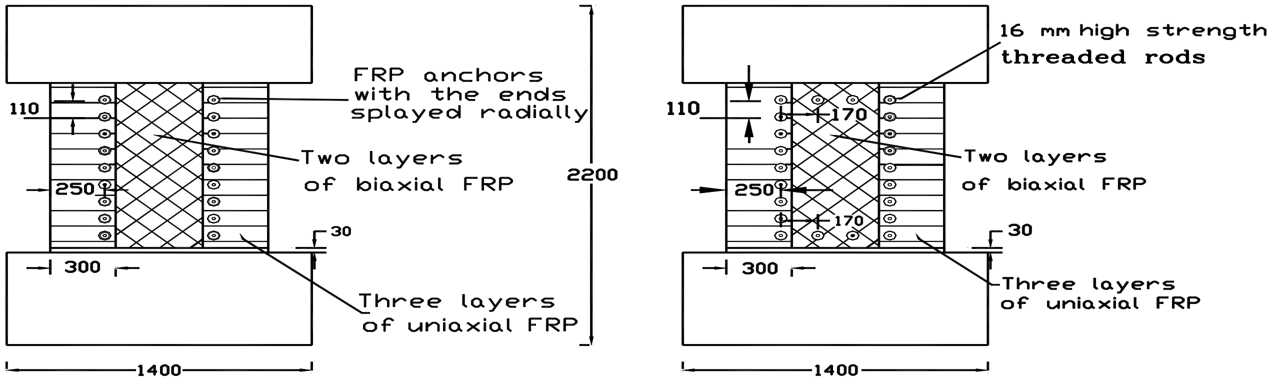


Figure 6 Test setup for columns

Wall Tests

Two test walls were built 1.1 m in height, length of 1.0 m, and thickness of 0.12 m. The two walls had similar dimensions, concrete material and reinforcement. The walls were designed according to the earlier version of ACI (1963). The two walls were rehabilitated using CFRP sheets. The rehabilitation scheme included sheets with ± 45^o fibre orientation for web shear strengthening. The two end column elements were wrapped with a U shaped sheet with the fibers oriented in the horizontal direction for confinement. To complete the confinement loop, the free ends of the U shaped sheets were anchored through a hole in the wall thickness. In one of the test walls W1, carbon fibre anchors were used. In the second wall W2, 16 mm diameter high strength threaded rods were used. The anchors were spaced 110 mm along the wall height. The wall dimensions and reinforcement details are shown in Figs. 3 and 7. The axial load, shear and moment were applied to the walls using the three-actuator setup shown in Fig. 8. Details of the wall tests are available elsewhere (Ghobarah and Khalil 2004 and khalil and Ghobarah 2005).



Wall RW1

Wall RW2

Figure 7 Test walls

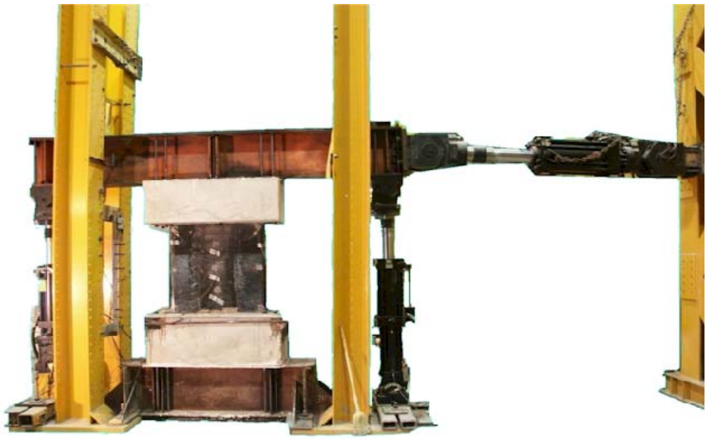


Figure 8 Test setup for walls

Material Properties

The average concrete compressive strength at the time of testing was 38 MPa. The average yield strength for the vertical steel bars was 470 MPa and the average yield strength for the transverse reinforcement was 600 MPa. Two types of CFRP sheets were used: Tyfo BCC Composite and Tyfo SCH-35 Composite. The Tyfo BCC is a bi-directional carbon fabric where the primary fibres are oriented in the $\pm 45^{\circ}$ direction. The Tyfo SCH-35 Composite is a uni-directional carbon fabric where the primary fibres are oriented in the 0° direction. The tensile modulus in the direction of the fibres as was supplied by the manufacturer is 65 GPa for Tyfo BCC and 78 GPa for Tyfo SCH-35 and the ultimate tensile strength is 717 MPa for Tyfo BCC and 991 MPa for Tyfo SCH-35 (Fyfe 2002).

Anchor Design

The maximum force in the anchor was calculated to be slightly below the capacity of the CFRP fibres used for the confinement of the concrete section. The steel anchor yield force determined their maximum spacing between the anchors. In effect, the anchor is designed to yield just before the confining composite fibres failed in tension. The fibre anchors were made of bundled carbon fibres cut out from SCH-35 composite sheets. The number of fibres was selected to be the same as the number of to be anchored for confinement continuity.

Instrumentation

The data acquisition system consisted of an analog to digital board of 72 channels, a microcomputer, and data-acquisition software. Load cells measured the applied loads by the hydraulic jack and actuators. Strain gauges were attached to the horizontal and vertical reinforcement steel bars. Strain gauges were also installed on the steel anchor rods to measure the state of strain during the test. Vertical, horizontal, and diagonal strain gauges were attached to the FRP sheets of the rehabilitated columns and walls. Lateral displacements of the specimens, relative rotation of the two end blocks, and shear deformations were measured using linear variable differential transformers (LVDTs).

Results

The columns were subjected to a constant vertical load. The lateral load on the test columns and walls was applied cyclically. Before the first steel yield, tests were conducted in the load-controlled mode. After yielding, the load was applied in the displacement-controlled mode. The load was increased until failure occurred. The envelope of the lateral load-lateral displacement hystretic loops for the two test columns C1 and C2 are shown in Fig. 9. Column C1 represents the column with steel anchors while column C2 represents the column with CFRP anchors. The cumulative energy dissipated by the two columns is plotted against the displacement ductility factor in Fig. 10. The displacement ductility factor is defined as the displacement at the top of the column divided by the displacement at the first steel yield. The variation of the measured strain in the tie rod near the bottom of the test column C1 is shown in Fig. 11.

The walls were subjected to a constant axial load by manipulating the load applied by the two vertical actuators. The lateral load and moment at the top of the wall were increased cyclically until failure. Before the first steel yield, tests were conducted in the load-controlled mode. After yielding, the load was applied in the displacement-controlled mode. The applied lateral load and the measured lateral drift of the two walls are plotted in Fig. 12. The drift is defined as the lateral displacement at the top of the wall divided by the wall height. Wall W1 represents the wall rehabilitated using CFRP anchors while wall W2 represented the case of the steel anchors as shown in Fig. 7.

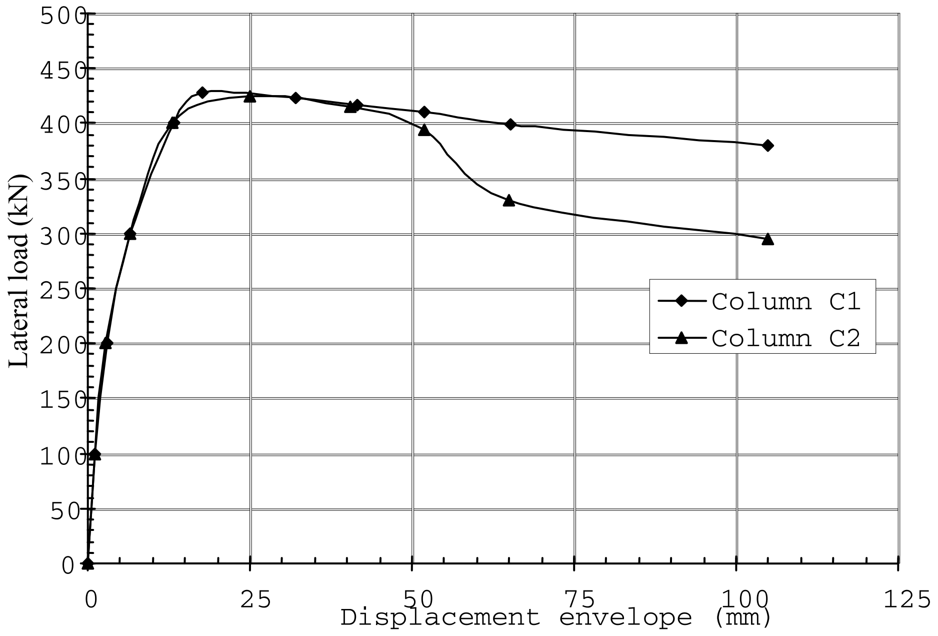


Figure 9 Envelope of load-displacement plot for the test columns

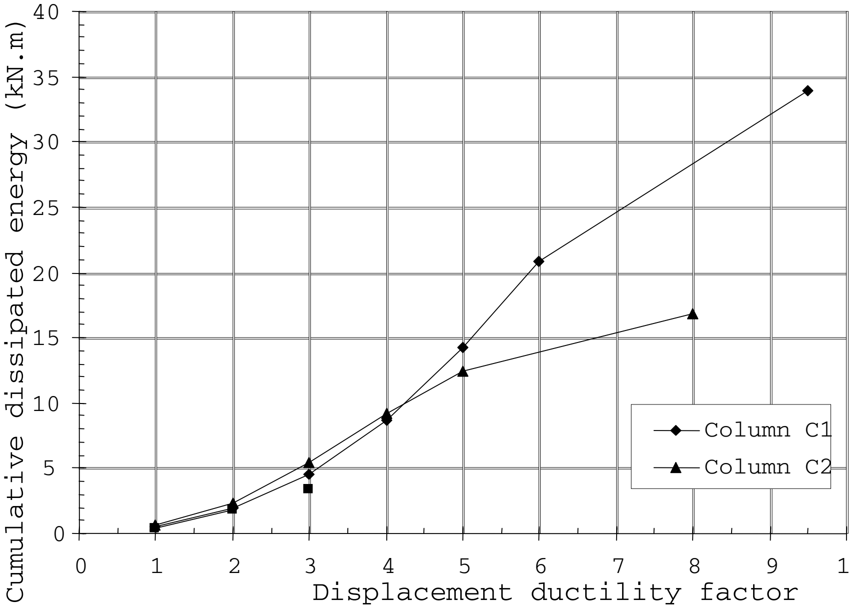


Figure 10 cumulative dissipated energy for the test columns

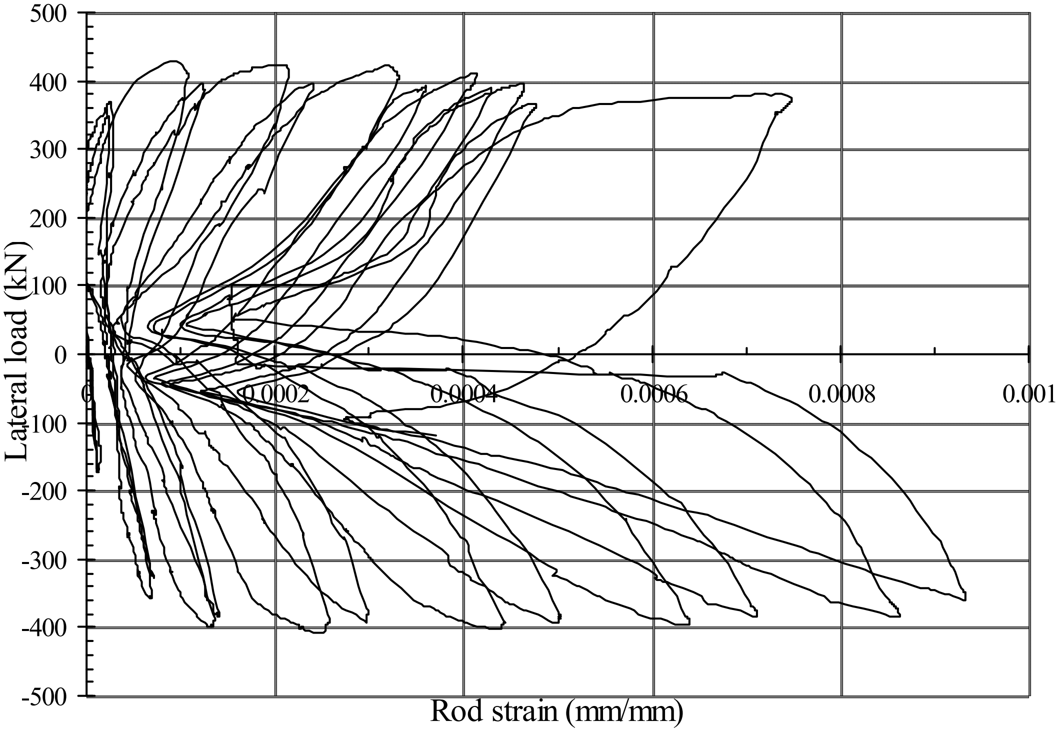


Figure 11 Measured strain in the tie rod near the bottom of the column

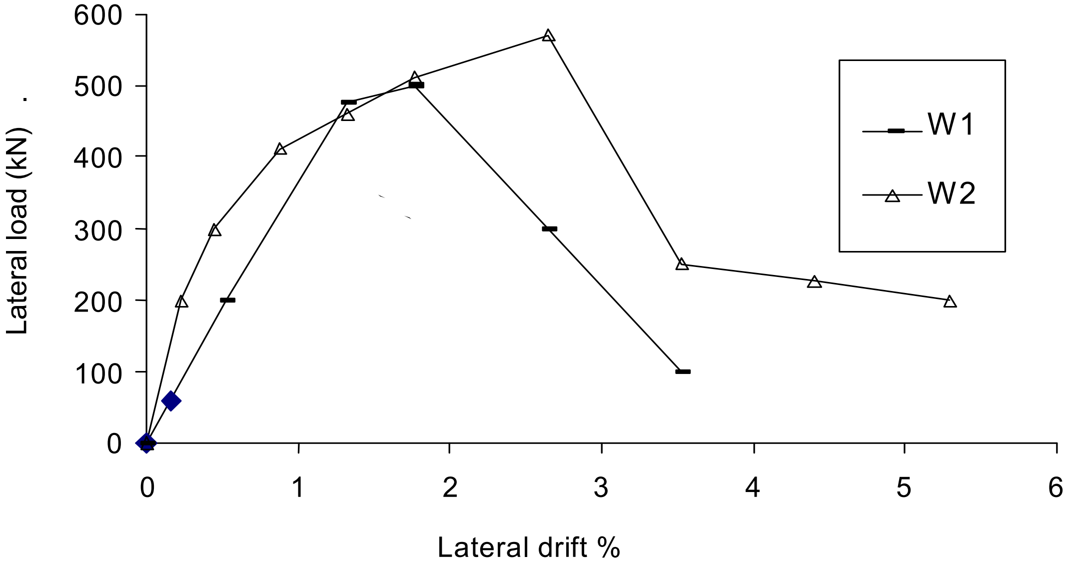


Figure 12 comparison of the envelopes of the two test walls

Discussion

In general from aesthetic point of view, it is difficult to notice that CFRP anchors are used under the fibre wrap. On the other hand, the nuts on the steel anchors are quite noticeable. In addition, they are difficult to cover up. Fig. 9 shows that the two columns C1 with steel anchors, and column C2 with fibre anchors sustained the same maximum lateral load. After the maximum load was reached, the composite anchors could not support the effective confinement of the concrete section particularly near the bottom where the shear is high. However, the steel anchors continued to function by enhancing the effective confinement of the composite sheets until concrete crushing near the bottom of the column caused its failure. The force in the steel rods near the bottom of the column continued to increase as shown by the increasing strain in Fig. 11. The strain in the tie rod remained below yield. Similar behaviour can be seen from the cumulative energy dissipation plot shown in Fig. 10. The capability for high energy dissipation is a measure of the effective confinement of the columns. The figure shows that column C1 outperformed column C2.

In the wall test program, it can be seen that the wall W2 with steel anchors sustained a higher maximum lateral load than did wall W2 with composite anchors. Past the maximum load and up to failure, the performance of Wall 2 showed more ductility than W1. During the test of wall W1 several composite anchors failed in areas of high shear near the top and bottom of the wall. These failures contributed to the loss of concrete confinement in areas of high shear.

Conclusions

The use of anchors in the FRP rehabilitation of various structural elements was found to be an effective technique for tying the free ends of the CFRP sheets and for effective confinement of the concrete section.

Steel anchors installed through the column or FRP anchors in the column improved the confinement function of the composite sheets. The steel anchors were shown to function as intended by the measured high levels of stains that they sustained.

FRP or steel anchors driven through the wall in the web region near the top and the bottom of the wall (at the ends of the FRP sheet) successfully delayed onset of debonding of FRP sheets from the web of the wall thus increasing the ductility of the wall by delaying the shear failure. Anchors were effective in closing the confinement hoop of the U-shaped CFRP sheets by tying the free ends of the sheet. The end column confinements improved the ductility of the walls. The steel anchors outperformed composite anchors as several failed in areas of high shear.

Acknowledgement

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