SEISMIC STRENGTHENING OF SMALLSCALE PLAIN CONCRETE COLUMNSWITH NEW HYBRID STEEL-FRP JACKETS

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ABSTRACT

In present study, a novel hybrid retrofitting device including inner steel strips and outer peripheral FRP wraps proposed and investigated experimentally for strengthening of concrete cylinders specimens. A total of 4concrete cylinderswhich had an inner diameter of 84.1 mm and a height of 345.0 mmillustrating slenderness ratio of 4, were prepared. For comparison purpose, one specimen was strengthened using only CFRP confinement with four layers, whereas the other was reinforced using proposed hybrid steel-FRP. Four steel strips (two percent of concrete specimen volume) attached using two part SIKA resin epoxy binder while one, two and three layer CFRP confined aforementioned steel. The retrofitting design philosophy of proposed scheme explained briefly based on some common codes. Axial compression tests were conducted using the universal structural testing machine with maximum capacity of 2000 KN. Particle image velociemetery (PIV) method was used for calculating the stress-strain curves of specimens accomplished using a digital image correlation code, GeoPIV.Due to the lower cost, potential of obtaining the whole displacement field on common structural tests and applicability for data recording of explosive testssuch as FRP collapse at high level loading conditions, PIV method can be widely used as asuitablealternative to conventional measurement techniques. The PIV dataverified toward the strain gauges data. The role of some parameters was examined by comparing axial load-versus-axial (peak force, drift ratios and energy dissipation). The results demonstrate that steel-FRP hybrid confinement method is a viable solution toward enhancing the flexural strength and ductility of plain concrete columns under seismic loads.

INTRODUCTION

Over the world, earthquakes have exposed the vulnerability of existing structures. The columns and piers are the most important members of each common structure (Dionysios et al., 2009).Some olden structures such as railroad and road bridges have the piers build using masonry and plain concrete materials. However the thick concrete section can enhance the shear strength of the pier, but these concrete gravity piers which have built without consideration of an earthquake-resistant design, have the problem of inadequacy at flexural strength and the possibility of the pier overturning due to lateral loading such as braking force or earthquake shakes (choi et al.,2011) . Many researches were conducted about the retrofitting of reinforced concrete columns, but the investigations are rare in the case ofplain concrete piers.

There are many solutions for strengthening of these columns. Externally bonded fiber-reinforced polymers (FRP), as a promising rehabilitation system has been examined in literatures. It is proved that although FRP system improved the ductility and energy absorption capacity of the RC columns, but no significant improvement in strength. Steel jacketing, as a conventional strengthening technique, enhanced the flexural strength, shear capacity, stiffness, ductility and axial load carrying capacity, but it is not suitable for corroded RC columns knowing this truth which the steel jacket may be damaged by marine environments and de-icing salts (Li et al., 2009).Hybrid structures are those in which two (or more) dissimilar materials could structurally complement each other. The hybrid structural system consisting of FRP composites and traditional materials such as concrete and/or steelcombinedtogether optimally(Hollaway,2010).Meanwhile, combining two kinds of materials can enhancethe seismic performance of plain concrete columns. The application history of hybrid systems about retrofitting of columns is less than one decade. In 2007, Li was proposed a new type of hybrid confining device, a tubular steel lattice that is externally protected by a thin fiber reinforced polymer (FRP) skin(Li,2007). Li et al. (2009) investigated the effectiveness of simultaneous application of carbon fiber-reinforced polymer (CFRP) sheets and steel jacket to upgrade corrosion-damaged reinforced concrete (RC) columns. Choi et al. (2011) applied the composite of Fiber Reinforced Polymer (FRP) and steel plates (FSP) which attached longitudinally on the surface of the pier for solving the cracking problem of railroad bridge pier.NooriShiraziet. al (2012) was proposed a novel hybrid retrofitting scheme for retrofitting of plain concrete cylinders and verified adequacy. It is noticeable that this scheme is also suitable for strengthening of RC structural members which haven't required reinforcement because of old design code philosophy or mass reducing of longitudinal and transverse reinforcement under severe corrosion conditions. For these, the objectives of this study are (1) investigating about effectiveness of hybrid strengthening technique in comparison to FRP retrofitted technique; (2) to study the effects of the CFRP layers on the mechanical behavior; (3) application of PIV analysis for extraction displacement and strain.

About the hybrid Steel-FRP systems

In current study, combined application of inner steel stripsand outer FRP layers confinement was illustrated.As it was introduced before (NooriShirazi et al., 2012).the steel strips will be attached on the surface of column along the height using two-part adhesive. Then the remained gap between strips and column surface fills using low strength concrete (or grout). After about 48 hours, the CFRP layersattaches using the binders. In Fig 1, a schematic view of proposed hybrid scheme was illustrated.Some assumptions

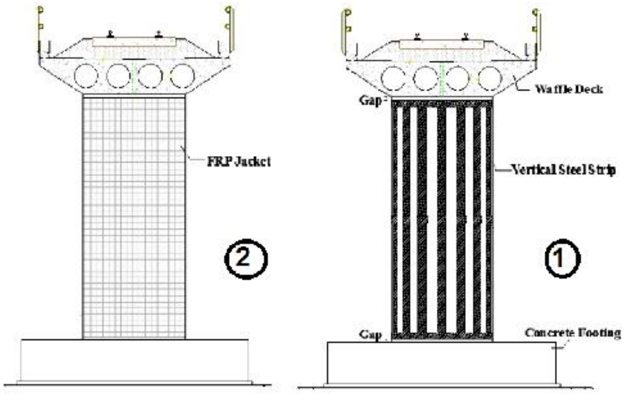

Figure 1.an illustrating of hybrid Steel-FRP retrofitting scheme

were made. Steel strips have similar mechanical behavior as longitudinal steel reinforcement and will be applicable forflexural strength enhancingonly; however the lateral stiffness of column increases somewhat resultant to drastic earthquake effects onto the influenced structure.FRP wraps implements lateral pressure onto concrete core which refines the ductility and compressive strength. It also restricts the lateral buckling of steel profiles along the height. The steel strips and FRP wraps attaches using two-part resin epoxy binders with wet lay-up procedure.

design philosophy

The design philosophy of the aforementioned retrofitting scheme is based on flexural, shear and ductility demands of the propose column. These design recommendations are based on limit-states design principles.

Shear strengthening

FRP systems have indicated to increase the shear strength of existing concrete beams and columns by full or partially wrapping the members (Malvar et al. 1995; Chajes et al. 1995; Norris et al. 1997; Kachlakev and McCurry2000). Increasing the shear strength can also result in flexural failures, which are relatively more ductile in nature as compared to shear failures.The step by step calculation procedure of shear strengthening was illustrated below:
Compute the design material properties. Calculate the effective strain level in the FRP shear reinforcement. Determine the required area of FRP reinforcement. Determine the number of plies, strip width and its spacing. For more information, please refer to reference (ACI 440.2R,2002).

Flexural strengthening

This is simple. The target column will be evaluated about flexural strength demand. This work carries out using the existent longitudinal steel reinforcement and comparing to calculated dimensions of column under analysis of full structure model. Using moment-curvature analysis and modeling of aforementioned column in finite element software such as ANSYS, required flexural strength of column will be calculate.Having the known axial force data and required flexural strength of the column, design of the steel strips become similar to design of column flexural steel reinforcement. The number, thickness and other dimensions of strips will be calculate and select using obtained area. For more information, please refer to reference (389 ISSue of IRAN)

Particle Image Velocimetry (PIV) for structural analyses

Particle Image Velocimetry (PIV)is a non-destructive and non-contacting method for measuring surface deformation of an object subjected to forces by comparing images taken under different loading conditions. An image of the targeted area is divided into small subareas. Then,a subsequent image analyzed by comparing the small subareas and following their new positions. Therefore it is possible to measure the full field deformation of an area (McCormick and Lord, 2012). Over the last decade there has been rapid development in image processing techniques as well as in high resolution digital cameras. Due to the lower cost, potential of obtaining whole displacement field on common structural tests and applicability for some tests which explosion occurs at the end (such as explosive collapse of FRP wrapped members under uniform pressure), PIV method could be widely used as an alternative to conventional measurement techniques such as mechanical strain gauges, electrical strain gauge and LVDT in structural engineering.GeoPIVis a software package which involves PIV (particle image velocimetry)technique for measuring strain and displacementwith high degree of accuracy using relatively inexpensive digital cameras and produced by White et al., 2003 [11]. At present study, we used PIV method for calculating axial and radial displacement at middle height of cylindrical specimens having verified the accuracy of PIV method in comparison to strain gauge data at two specimens.

experimental program

Comprehensive experimental tests were conducted in the structure laboratory of Sahand University of technology. Unfortunately at writing time of paper, 1/10 of total specimens were tested and results were applied. Four cylindrical concrete specimenswere manufactured.The test parameters of the wrapped columns are given in Table 1.

Table 1.Test parameters of wrapped column

Specimen	No. of CFRP layers	Steel strip wide,thickness,length (mm)	Steel strip volume percentage	$f_C^{'}(28days)$,
4LF	4	-	-	22.20 Mpa
S1-1F-4S	1	10-3-343	2%	22.20 Mpa
S1-2F-4S	2	10-3-343	3%	22.20 Mpa
S1-3F-4S	3	10 -3 -343	4%	22.20 Mpa

The specimens had a total height of 345 mm.All specimens have circular cross section with 86 mm diameter (slenderness ratio of 4).The concrete of specimens had the specified strength of 22.20 Mpa in 28 days of curing. Except for 4LF specimen, the other had longitudinal steel reinforcement which had a form ofthin strips with aforementioned dimensions illustrated at Table 1. One parameter was studied including the CFRP degree of confinement. One benchmark specimens (4LF) was considered for comparing purpose. For all strengthenedspecimens, wrapping of the FRP was applied with bond between the FRP and the concrete. The CFRP was applied along the full height of concrete and its anchorage reinforcement is provided by means of extra FRP lengthat thetwo ends. These wet lay-up FRP types are glued, impregnated, and cured in place. For the CFRP system (C240 unidirectional sheet/Multipox T epoxy) was used, with a width of 340 mm and a nominal (equivalent dry fiber) thickness of 0.11 mm. The ST37 standard steel was used for construction of longitudinal strips.

Test procedure and data extraction

The test specimens were cast in the laboratory, and concrete quality control of the specimens was observed. The specimens were tested using a compression testing machine with a capacity of 2000 kN under displacement control condition at loading rate of 1 mm/min.One of the main objects of the study was application of PIV method for recording axial displacement of the specimens. For this, the required data of two specimenS1-1F-4S and S1-2F-4S was recorded using both the strain gauge with accuracy of 0.01 mm and PIV analysisprocedure, but only the PIV procedure was used to monitor the axial displacement of remained cylindrical specimens. Thesetup configuration of the PIV measurements is schematically shown in Fig. 2.

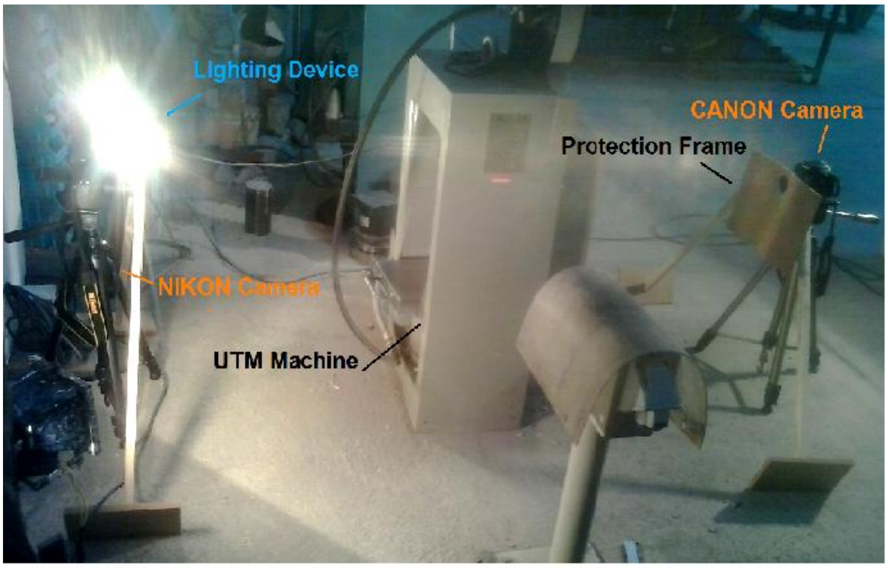

Figure 2. A schematic view of loading setup

As can be seen, two camera records the images of specimens every 4 second. The DSLR NIKON D5200 which has high resolution 24.1 megapixcel and the CANON KISS which has a quality of 18 mega pixel. Both cameras have the capability of full HD film recording. The UTM machine and both cameras have an equal start time by using trigger control. The CANON camera takes full HD film which involves the picture of strain gauge and the full height of specimen. For reducing the error of environmental light variation onto the accuracy of results, three projectors were located at three different angle of UTM machine.All testswill be continuing until the collapse of specimens. For GeoPIV software, some main recommendation is required. For running of program, two input file such as launch file and mesh file is required. Launch file has some important parameters, but mesh file created at process of analysis. At present study, the leapfrog was used 20 megapixel. The mesh size and the axis space of two adjacent meshes was used 20 megapixel. The searchzonepixels and subpixelmeth parameters were 20 and 1 respectively.

EXPERIMENTAL TEST RESULTS

The test results of the specimens were mentioned in terms ofaxial displacement-time data at middle height of specimens.

verification of GeoPIV analysis

Many researchers had proved previouslythe accuracy and precision of GeoPIV software. At present study, we verifiedaccuracy of the PIV procedureby comparing data of strain gauge result and GeoPIV analysis data. For getting object, we considered two specimens before. At Fig. 3, the comparative axial force-axial displacement at the lower surface of S1-2F-4S cylinder (has maximum displacement because topfixed end surface of UTM machine) was presented. As can be seen, high compatibility is considerable. The error is about 1% which is excellent for a structural test data. The curve form of the GeoPIV analysis is not smooth, because this procedure is able to indicate even small vibrations of UTM machine along duration of test, whereas the other commonmechanical and electrical gauges were unable to it. The curve has three parts, first part with lower slope is pertained to plain concrete behavior. After crushing of concrete, the second part of curve begins. At this stage, longitudinal steel strips with contribution of CFRP enhance axial deformation of concrete. At end of this stage, strips will be buckled. End of final part occurs when the CFRP reached to its unltimatestrain. This explanation is at ideal state and convenient construction conditions. However, if the edges of strips become sharp, the CFRP will be tearing without experiencing ultimate strength. The comparative axial displacement-time of two measuring procedure at Fig. 4 was indicated that the GeoPIV software analysis can predict the actual behavior of retrofitted columns. This proposition is true about theS1-2F-4S specimen; however the error percentage was 6% which is convenient. The results wereillustrated at Figure 5. As shown, GeoPIV procedure can predict actual behavior of cylindrical specimens.The damage of two specimens was illustrated in Fig. 6. That is obvious that the collapse of two specimens occurred at one fourth end of specimens. However, first concrete crushed because of limit specified strength, but the combination of CFRP wraps and steel strips confined the concrete until the CFRP reached to its ultimate strain limit. The steel strips had similar behavior aslongitudinal reinforcement and had buckled under exerted uniform pressure.

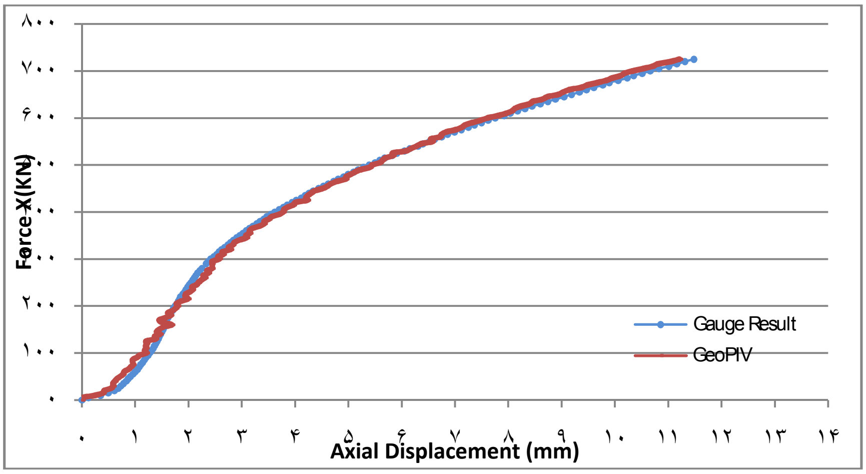

Figure 3. Comparative curves of GeoPIV analysis and strain gauge result

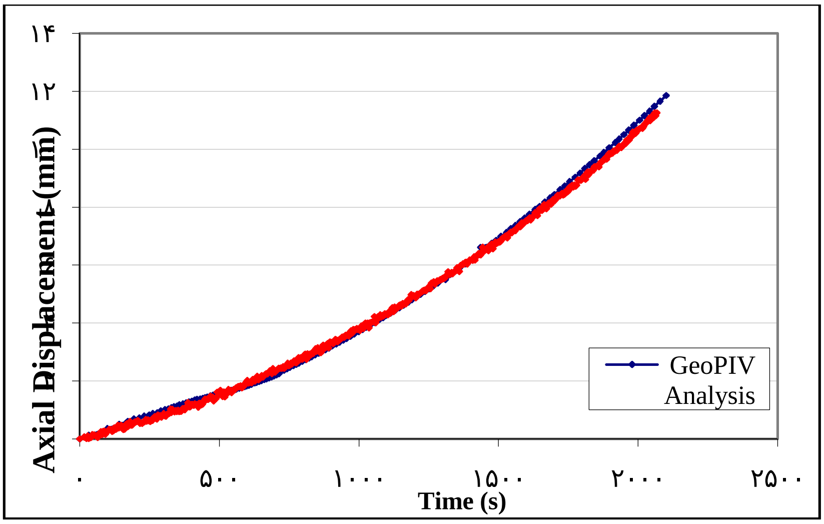

Figure 4. Comparative curves of GeoPIV analysis and strain gauge result

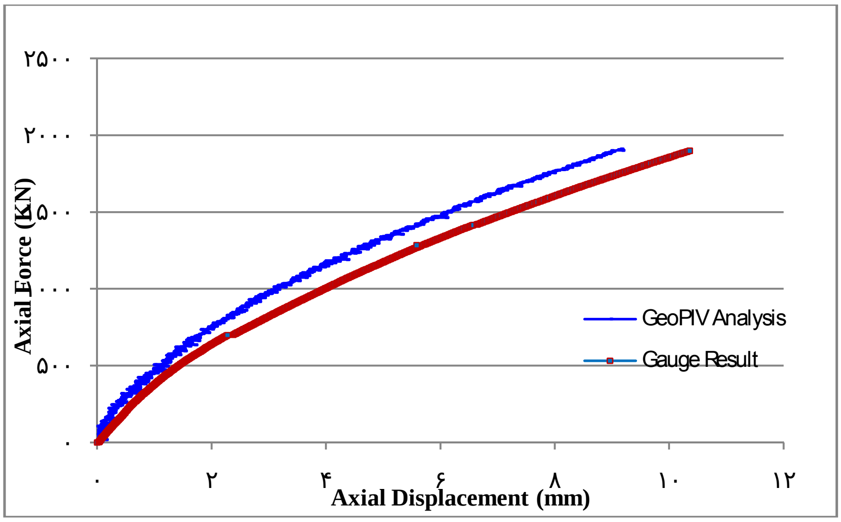

Figure 5. Comparative curves of GeoPIV analysis and strain gauge result

Based on the results, we will use PIV analysis for indentifying the total behavior of other specimens.

Discussion about axial behavior of specimens

Knowing the verified PIV analysis to estimate results, we will use image processing method for recording axial displacement at middle height of other specimens. First, we search about the influence number of CFRP layers on the behavior of hybrid retrofitted specimen by comparing the results of S1-3F-4S specimens to two verified specimens. For identifying improvement at mechanical behavior of hybrid retrofitted specimens, one specimen strengthened by four layer same CFRP layers and the results was compared.

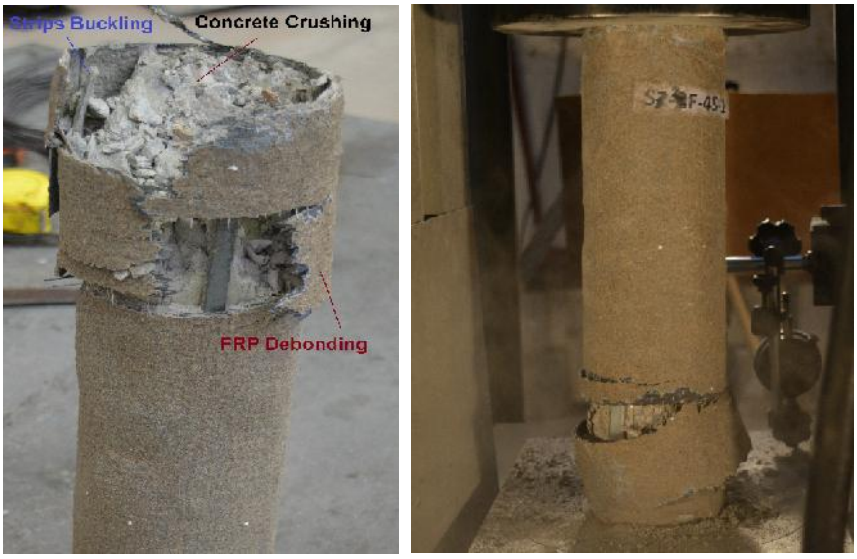

Figure 6. Collapse of S1-1F-4S and S1-1F-6S specimens respectively from left to right

Comparative axial displacement- time (time duration of test) of S1-3F-4S and 4LF specimens was illustrated at Fig. 7. Maximum axial displacement of SL-3F-4S specimen was about 11.75 mm, whereas this case is 9.07 mm for 4LF specimen. This indicates 29.5% improvement at axial deformation. At equal time for example 600 second of test beginning, 4LF specimen experienced 6.21 mm displacement but the displacement of another specimen was 4.11 mm. This proves that retrofitted specimen using hybrid confinement has harden behavior than to CFRP only retrofitted specimen and more time needed for receiving same displacement. Hybrid retrofitting increase elastic stiffness of retrofitted column, but the ductility and energy dissipation of retrofitted specimen will be increase. The collapse of two specimens at the end of test was shown at Figures 8(a) and 8(c).

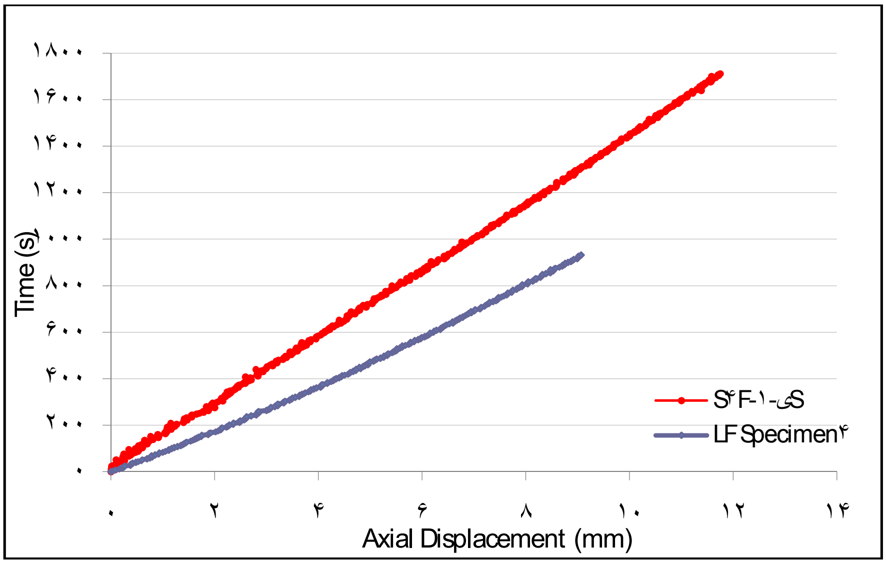

Figure 7.Comparative axial displacement-time of 4LF and S1-3F-4S specimens

At Fig. 8(b), animated position of target point at arbitrary mesh from beginning to end of loading was obvious.However, the deducted data of test because of time limitation was little, based on this research some recommendations was proposed. However the complete results will be explained at next papers.

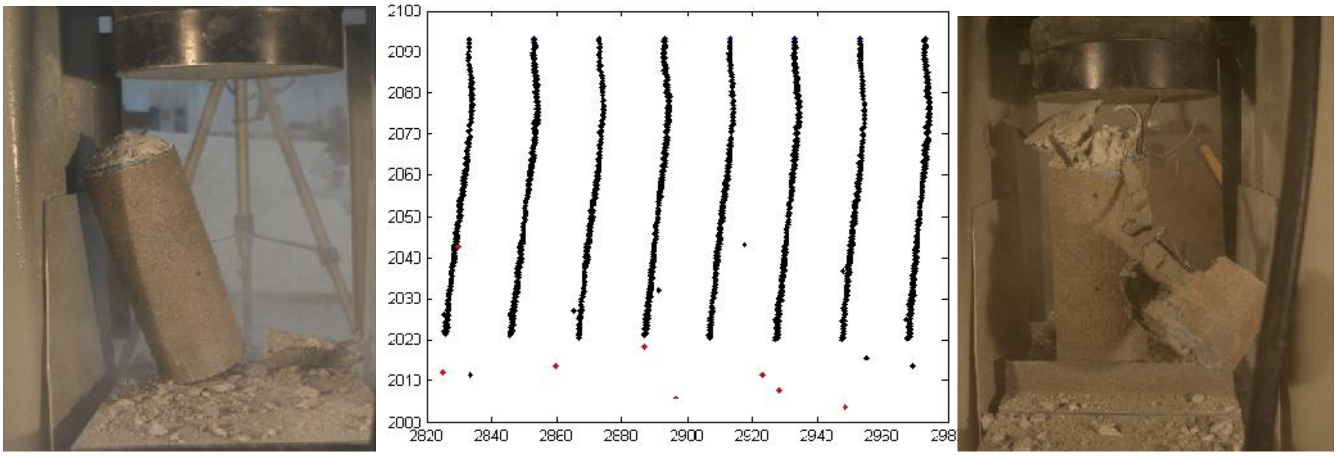

Figure 8.(a) 4LF specimen after damage (b) line animate of mesh axis at duration of test (c) S1-3F-4S specimen after collapse

Conclusions

Based on the results and previous obtained results, as the strength of concrete increases, the ductility will be increases as well as energy dissipation. Increasing the percentage of steel profiles will enhance drift ratio, energy dissipation and also stiffness of retrofitted columns. The CFRP confinement effect is directly related to the applied layers which the compressive concrete strength, energy dissipation and shear strength of concrete will be enhanced. It was also found that the plain concrete columns strengthened with proposed scheme behaved better than those strengthened only with the single CFRP material in case of energy dissipation and axial deformation in addition to flexural strength. The results demonstrate that steel-FRP hybrid confinement is a viable solution toward enhancing the flexural strength and ductility of plain concrete columns under seismic loads.

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