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EXPERIMENTAL PERFORMANCE EVALUATION OF RC COLUMNS WITH TRC PERMANENT FORM

S. Kim(1), S. Park(2), K. Y. Moon(3), S. J. Kim(4), C. Chang(5) , J. M. Yang(6) , and O. Kwon(7)

(1) Postdoctoral Researcher, Department of Architectural Engineering, Keimyung University, kimsiyun1989@gmail.com
(2) Graduate Student, Department of Architectural Engineering, Keimyung University, tkdehftm88@gmail.com
(3) Graduate Student, Department of Architectural Engineering, Keimyung University, mky9404@gmail.com
(4) Associate Professor, Department of Architectural Engineering, Keimyung University, sjkim4@kmu.ac.kr
(5) Professor, Department of Civil Engineering, Keimyung University, Daegu, Korea, changclint@gmail.com
(6) Assistant Professor, Department of Civil Engineering, Keimyung University, Daegu, Korea, jm.yang@kmu.ac.kr
(7) Associate Professor, Department of Civil & Mineral Engineering, University of Toronto, os.kwon@utoronto.ca

Abstract

The paper presents the experimental evaluation of the seismic performance of RC columns confined by a newly proposed Textile Reinforced Concrete (TRC) permanent form. The TRC is made with a continuous textile fabric incorporated into a cementitious matrix, and thus it has outstanding properties of high tensile strength, ductile behavior, and low layer thickness. Considering the advantages of this composite material, the permanent form is developed to improve the seismic performance of RC columns and reduce the construction cost. To experimentally evaluate the performance of RC columns confined by TRC form, a total of six specimens are constructed and tested. The first specimen is non-seismically designed, while the second one is code-conforming column. The rest of specimens are constructed by applying the TRC form with Carbon, Basalt, and Aramid fibers. The observations and interpretation of experimental results are discussed and compared with the case of the conventional RC columns. It is concluded that the TRC permanent form could significantly improve the seismic performance of RC columns.

Keywords: Textile Reinforced Concrete; RC Column; Permanent Form; Seismic Performance

1. Introduction

A moderate earthquake of moment magnitude, M_w 5.4 hit the southeastern Korea, particularly Pohang city on 15 November 2017. Due to the relatively very shallow depth (7 km) and the Pohang basin which consists of nonmarine to deep marine sedimentary strata, the Pohang earthquake was the most damaging event in South Korea since the first seismograph was installed in 1905. 31,114 buildings were damaged to various degrees and the most structural damage was caused by the poor construction practice of housings and non-seismic design of reinforced concrete (RC) structures. Particularly, many piloti-type low-rise RC buildings were severely damaged due to plan irregularity, insufficient seismic details and poor construction practice. As shown in Fig. 1, the failure of many RC columns in the seismically designed buildings was observed due to the poor construction. The designed cross section was not properly secured due to an excessive concrete cover of 100mm thickness and an inclusion of drainage pipes in the column member. The spacing of the shear reinforcement far exceeded the design standard of 152mm to 260mm. The poor anchorage of tie, which did not to comply with hook detail standards were also observed.

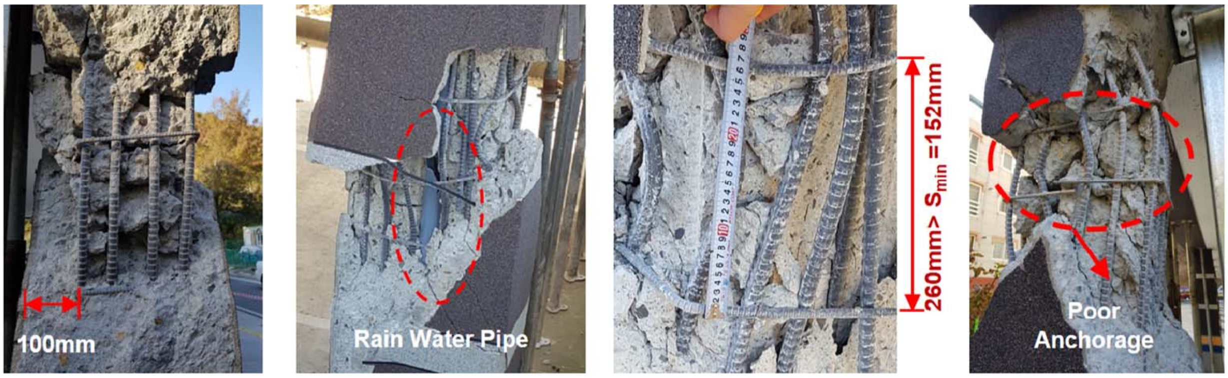


Fig. 1 – Failure of RC column due to Pohang earthquake

As confirmed in the earthquake damages in Pohang, seismic performance of small piloti structures in Korea has not been fully guaranteed due to mainly the poor working environments. Most of these small low-rise piloti structures are constructed by small-to-medium sized construction companies with insufficient construction management capacity or employing low-skilled workers. Thus, the variation of the construction quality and structural performance of the small low-rise piloti structural in Korea could be considerably large and these buildings are vulnerable to the earthquake.

In some researches, permanent formwork systems have been developed to improve seismic performance and reduce construction period. These forms are precast products with uniform quality and can shorten the time for construction because the formwork removal process is omitted. Recently, FRP-based permanent formwork to improve the seismic performance of RC buildings was developed and tested. Ozbakkaloglu and Saatcioglu (2007) [1] investigates the use of FRP stay-in-place (SIP) formwork as concrete confinement reinforcement for high-strength columns with square cross section. The experimental results indicate that the deformation capacity of high-strength concrete columns can be significantly improved by using FRP form. Elnabelsy and Saatcioglu (2017) [2] developes the FRP SIP formwork, which provides easy form assembly, protection of steel reinforcement and concrete against corrosion and chemical attacks, while also improving the strength and ductility of structural elements. This research shows that inelastic deformability of columns with developed CFRP permanent formwork significanlty increases. However, the FRP-based permanent formwork is expensive due to the large amount of the required fibers, and is vulnerable to the external environment such as high corrosion susceptibility, poor durability and low fire resistance.

Recently, there has been a growing interest in the use of textile reinforced concrete (TRC) or textitle reinforced mortar (TRM) as a material for constructing new structural members and strengthening or repairing old structures[3, 4, 5, 6, 7, 8]. TRC is a composite material consisting of a cement-based matrix with typically small maximum aggregate grain sizes and high-performance, continuous multifilament yarns made of alkali-resistant glass, carbon, polymer or other materials. By using TRC the tensile strength, ductility, and corrosion resistance of concrete can be increased [9, 10, 11, 12, 13, 14]. Thus, in this paper, a new TRC permanent form is developed to improve the structural performance of RC columns and expedite the construction process. The performance of RC columns confined by the developed TRC form system is experimentally evaluted through the cyclic static tests

2. Experimental program

2.1. TRC permanent form

The Textile Reinforced Concrete (TRC) consists of textile fabric and the concrete matrix as shown in Fig. 2. The TRC has high tensile strength due to the characteristics of textile fibers, and also has excellent advantages with respect to high durability, corrosion free, formability, and light weight.

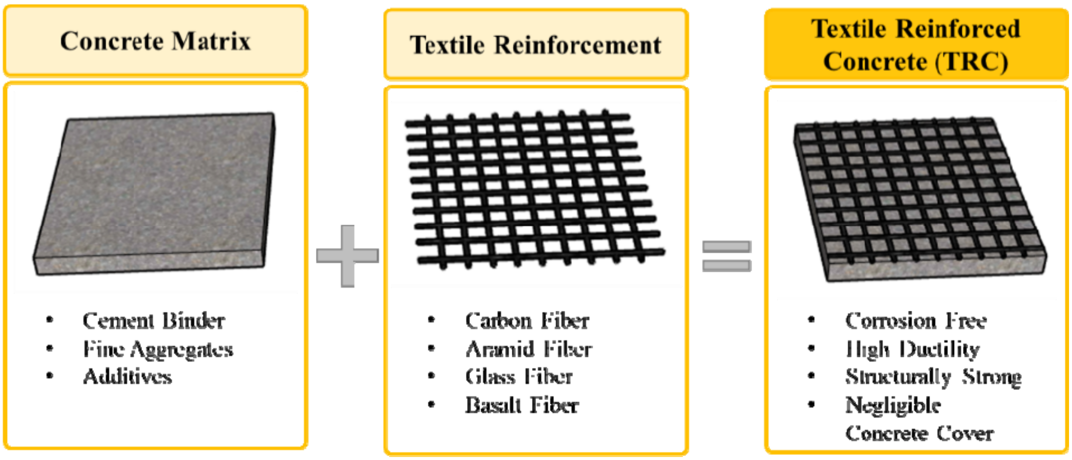


Fig. 2 – The concept of TRC

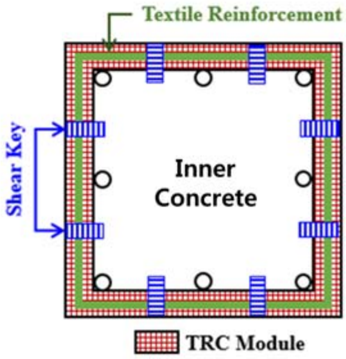


Fig. 3. Flexural test of TRC panel

Fig. 4. Concept of TRC permanent form system

Fig. 3 shows the flexural test of TRC panel with aramid fibers. A progressive failure was observed for the TRC panel, which showed high flexural strength and toughness. By utilizing these advantages of the

TRC panel, it is possible to provide the formwork function for construction of RC structure and also to improve the seismic performance of the structural member. Fig. 4 describes the concept of the developed TRC permanent form system. This study focuses on the development of stay-in-place formwork for rectangular columns which is most frequently used in small residential facilities.

2.2. Test specimen and set-up

In order to assess the seismic performance of RC columns confined by TRC permanent form, a total of six specimens were constructed and tested. The first and second specimens were RC columns without TRC permanent form. These have non-seismic (NC) and seismic (SC) details as reference specimens for evaluating the performance of the developed TRC permanent form. The rest of specimens were strengthened by using TRC permanent form. As shown in Table 1, experimental parameters were stirrup, type of yarn, shape of fiber, and number of layer. In particular, the permanent form of ANC specimen was constructed using strip-shaped aramid fabric commonly used in FRP wrapping method. The mechanical properties of the fabric are shown in Table 2. The textile fabrics of carbon and basalt were composed of a bi-directional grid shape. The mechanical properties of these fabrics were investigated in each direction, while those of aramid fibers were tested in one direction because of strip-shaped.

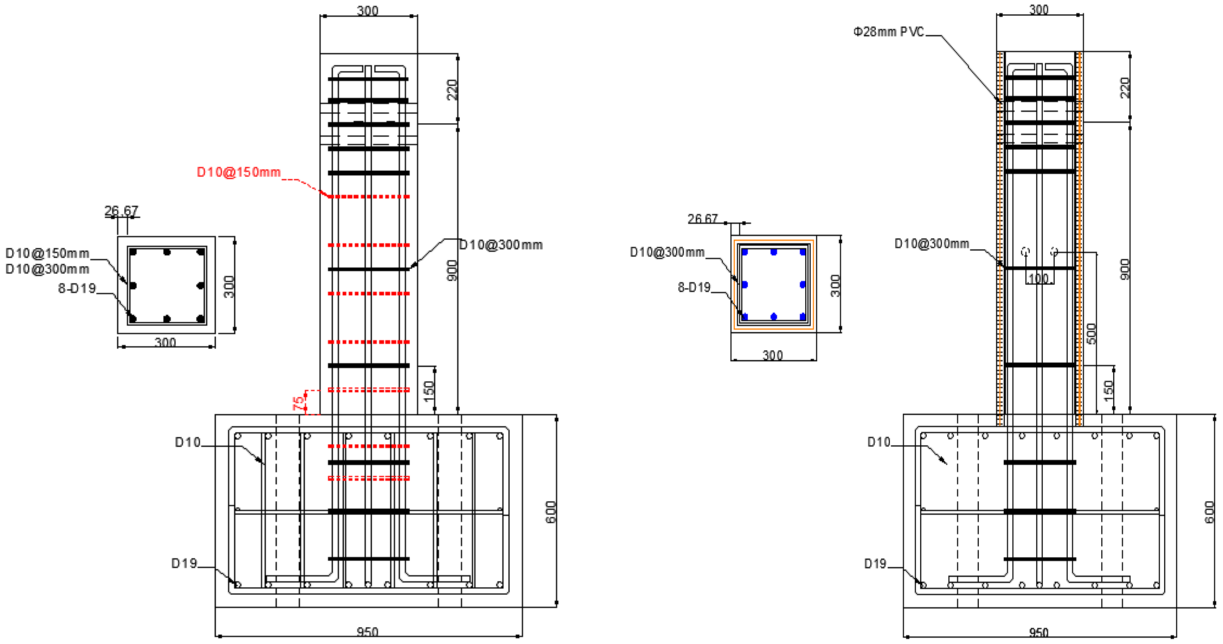
Table 1 – Details of test specimens

Specimen	**Stirrup (mm)**	**Type of yarn**	**Shape of fiber**	**Number of layer**
NC	300	-	-	-
SC	150	-	-	-
C1NC	300	Carbon	Grid type	1
C2NC				2
B2NC		Basalt		2
ANC		Aramid	Strip type	1

Table 2 – Properties of the fabric

Type of fabric	**Tensile strength (MPa)**		**Elastic Modulus (GPa)**		**Elongation (%)**		**Density (g/cm^2)**
	Warp	**Weft**	**Warp**	**Weft**	**Warp**	**Weft**	
Carbon (Grid)	2,551	2,847	230	218	1.17	1.24	1.80
Basalt (Grid)	135	125	73	83	1.86	1.50	2.75
Aramid (Strip)	790		17		15~30		1.38

The 2/3 scale model of the prototype RC column was constructed and tested as shown in Fig. 5. The cross-section is 300x300mm with 8-D13 longitudinal rebars and D10 stirrups. the effective height of the specimen is 900mm. SC specimen was designed to have seismic details with a stirrup spacing of 150mm, while the others specimens had non-seismic details with a stirrup spacing of 300mm. The concrete compressive strength obtained from 28-day cylinder test was 22.22MPa. The initial axial load for all specimens was 10% of the column capacity (0.1fcAg, 243kN). Also, TRC permanent form was constructed in order to replace concrete cover compared to conventional RC columns.



(a) Specimens without TRC permanent form (b) Specimens with TRC permanent form

Fig. 5 – Details of test specimens

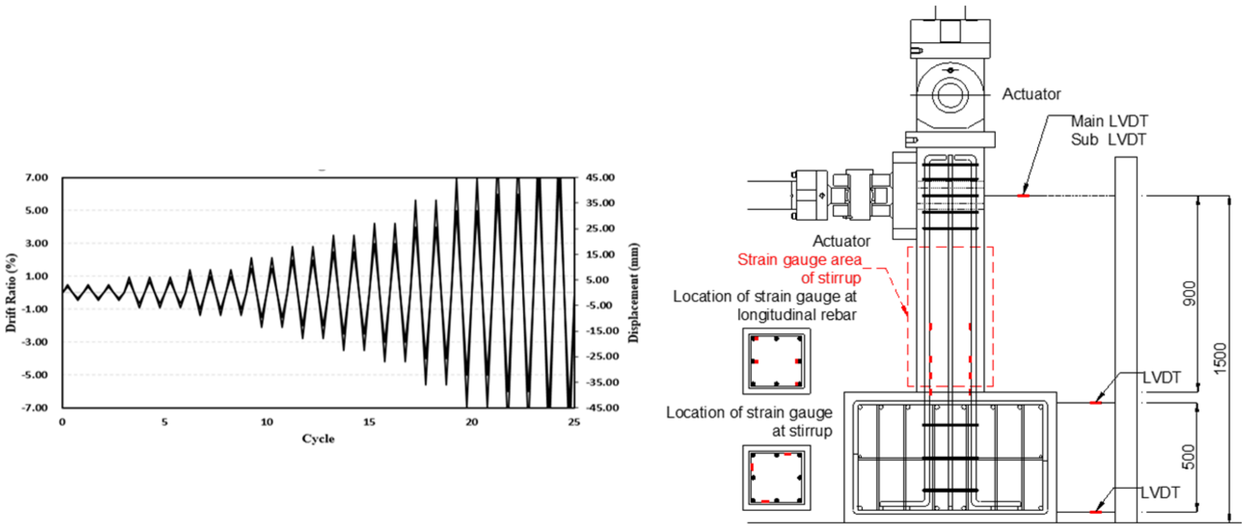


Fig. 6 – Loading protocol and test setup

Fig. 6 shows the applied lateral displacement history for the cyclic tests and overview of test setup for the test specimens. The imposed displacement history included three cycles at each displacement level up to a drift ratio of 1% and two cycles at each displacement level after 1%. The imposed displacement pattern of two or three cycles provides an indication of the strength degradation characteristics. The magnitude of the subsequent displacement level after 1% was determined with an increment of 0.5% and was determined considering the damage status of the tested specimen.

3. Experimental results and observations

3.1. General observations

Fig. 7 shows the cracking patterns of all specimens at failure. Flexural cracks at the bottom of all specimens were observed at the early stage and those cracks were developed to shear diagonal cracks in the middle of specimens at the failure. The crack width of conventional RC column specimens is much wider than those of specimens with TRC permanent form as shown in Fig. 7. The maximum drift ratio of the SC specimen with seismic details reached 3%, while the C2NC specimen strengthened by TRC permanent form with carbon fiber experienced the failure at the drift ratio of maximum 6% due to the effect of textile fabric.


(a) NC (b) SC (c) C1NC (d) C2NC (e) ANC

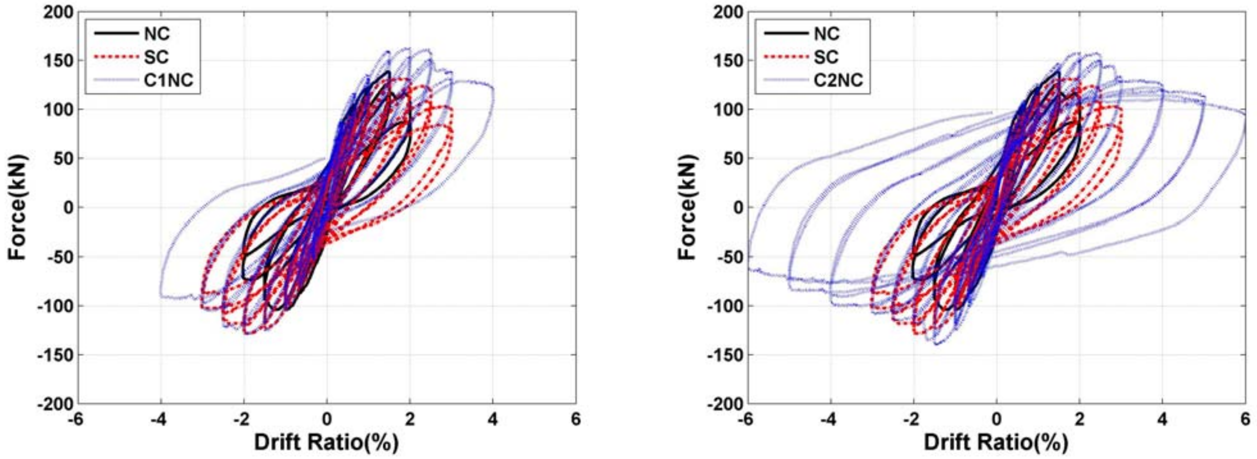
Fig. 7 – Crack pattern

3.2. Force – drift relationship

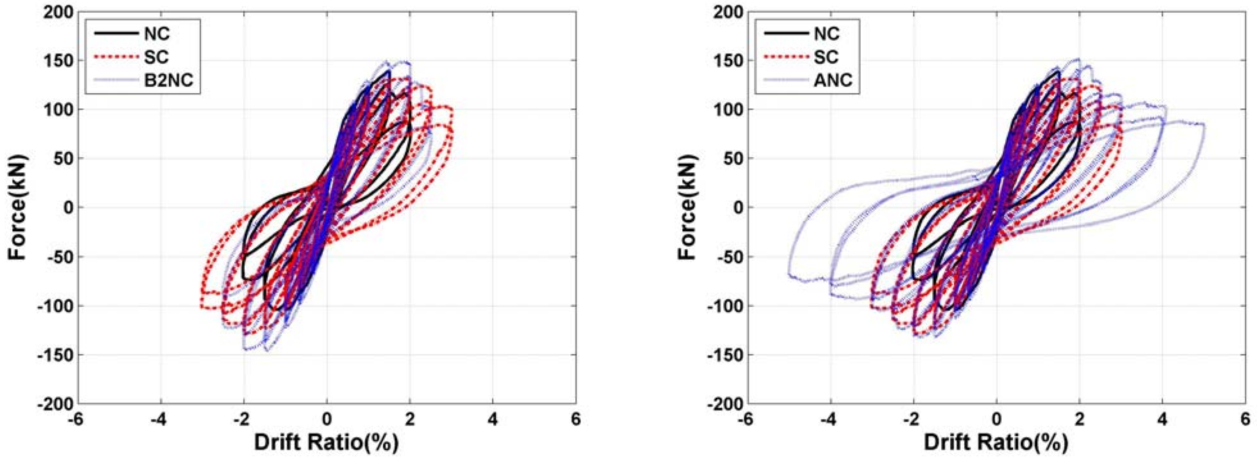
The relationship between the lateral force and drift ratio for all specimens compared to NC and SC specimens is shown in Fig. 8 and the measured test results are detailed in Table 3. In order to evaluate the effect of lateral force on the specimens with TRC permanent form, the average of the measured maximum lateral force in both directions was compared with the case of non-strengthened specimens. The stiffness and lateral force of specimens with TRC permanent form are increased compared to the conventional column specimens, NC and SC. The shear demands of C2NC and B2NC specimen strengthened by TRC permanent form with wrapping of two-layer increased up to 22.04% and 21.29%, respectively, compared to NC specimen. Also, the shear demand of C1NC and C2NC specimens were compared and evaluated to analyze the effect on the number of layers of textile fabrics embedded in TRC permanent form. Although the fiber area of C2NC specimen has more than twice those of C1NC specimen, the shear demand of C2NC specimen increased by only 2.24% compared to those of C1NC specimen. The shear demand of ANC specimen strengthened by TRC permanent with the strip-type fiber increased up to 16.29% compared with NC specimen, but lower than those of the specimens with grid-type textile fabric.

Table 3 – Measured force and displacement

Reference Name	Push direction		Pull direction		Average Max. Force (kN)	Effect of lateral force (%)
	Force (kN)	Displacement (mm)	Force (kN)	Displacement (mm)		
NC	138.89	13.45	104.59	8.87	121.74	-
SC	131.64	14.99	128.58	17.61	130.11	6.88
C1NC	162.55	17.77	128.08	17.39	145.32	19.37
C2NC	157.69	17.89	139.45	13.26	148.57	22.04
B2NC	149.09	12.98	146.23	13.27	147.66	21.29
ANC	151.20	17.90	131.94	13.42	141.57	16.29



(a) C1NC (b) C2NC



(c) B2NC (d) ANC

Fig. 8 – Relationship between the lateral force and drift ratio

3.3. Ductility and energy dissipation

The calculated ductility ratios and cumulative energy dissipations for all specimens are detailed in Table 4. To determine the ductility ratio of each specimen, the displacement corresponding to the first yielding in the longitudinal bar was assumed to be the yield displacement and the ultimate displacement is assumed to be the deformation corresponding to the post-peak displacement when the load-carrying capacity has undergone a reduction of 20%. The ductility ratios of all specimens strengthened by TRC permanent form increased compared with that of the NC specimen. Compared to ductility ratios of conventional column specimens, NC and SC, those of the specimens strengthened with carbon TRC permanent form increased up to 192.79% and 43.01%, respectively, as layers of carbon fiber increased. On the other hand, the ductility ratio of ANC and B2NC specimen increased significantly compared to NC specimen, but were lower or similar to SC specimen.

Table 4 – Ductility and cumulative energy dissipation

Specimen	**Ductility Ratio**		**Cumulative energy dissipation**	
	μ	**Comparison with NC (%)**	**Dissipated energy (kN-m)**	**Comparison with NC (%)**
NC	1.89	-	9.84	-
SC	3.86	104.63	21.59	119.41
C1NC	4.19	122.06	26.11	165.35
C2NC	5.52	192.79	72.43	636.08
B2NC	3.13	65.76	14.93	51.73
ANC	3.80	101.38	37.08	276.83

The energy dissipation was calculated by taking the area enclosed by the corresponding load-displacement hysteretic curve. Results from calculation of cumulative dissipated energy of all specimens are presented in Table 4. The effect of TRC permanent form on the cumulative energy dissipation of RC specimen showed a similar tendency to that of ductility. The cumulative energy dissipation of all specimens except B2NC specimen increased up to 636.08% (C2NC specimen) compared to NC and SC specimens. This is because specimens subjected to the effect of TRC permanent form were damaged at higher drift ratio than the non-strengthened specimens. In particular, the ANC specimen has lower ductility ratio but high cumulative energy dissipation compared to the specimen C1NC. This is because the ANC specimen had load-carrying capacity at drift ratio of 4%, where the C1NC specimen was failed. However, the cumulative energy dissipation of the B2NC specimen was lower than that of the SC specimen. This is because B2NC specimen experienced a significant reduction after maximum lateral force and thus was collapsed at a lower drift ratio than SC specimen.

4. Conclusion

This paper presents the experimental investigation of the seismic performance of RC columns with TRC permanent form. The experimental results are compared with the case of non-strengthened specimen of the impact on general observation, hysteresis loops, ductility, and cumulative energy dissipation. The maximum drift ratio of the specimen was improved up to 6% and failure mode was changed when utilizing the newly developed TRC permanent form. The shear demand of all specimens with TRC permanent form increased compared with the non-strengthened specimens. In particular, the shear demand of specimen with TRC permanent form including carbon textile fabrics increased up to 22.04% and 14.19% compared with those of NC and SC specimens, respectively. The ductility ratio of specimen strengthened with carbon textile fabrics increased up to 192.79% and 43.01% compared with that of NC and SC specimens, respectively. The effect of the TRC permanent form on cumulative energy dissipation of RC columns appeared to be superior. In case of the C2NC specimen, the energy dissipation increased up to 636.08% and 235.48%, respectively compared with the conventional specimens. Taking into account the observations from the study described above, it is concluded that the newly developed TRC permanent form system can significantly improve the seismic performance of RC columns.

5. Acknowledgements

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