Proceedings of the 2nd Croatian Conference on Earthquake Engineering - 2CroCEE
Zagreb, Croatia - March 22 to 24, 2023

DOI: https://doi.org/10.5592/CO/2CroCEE.2023.119

SEISMIC PERFORMANCE OF RUBBERIZED CONCRETE IN STRUCTURAL APPLICATIONS

Tanja Kalman Šipoš (1), Kristina Jeleč (2), Ivana Miličević(3),

(1) Associate professor, Faculty of Civil Engineering and Architecture Osijek, Croatia, tkalman@gfos.hr
(2) Research assistant, Faculty of Civil Engineering and Architecture Osijek, Croatia, kstrukar@gfos.hr
(3) Associate professor, Faculty of Civil Engineering and Architecture Osijek, Croatia, ivana.milicevic@gfos.hr

Abstract

Rubberized concrete is a promising material for the structural elements, created by replacing sand with rubber particles in order to significantly reduce environmental impacts from large tyre waste with improved behaviour under earthquake loads.

Experimental studies on nine columns and three frames were carried out in order to determine the capacity of different structural elements in regard to conventional concrete. The specimens were subjected to a cyclic loading following loading protocol used for the seismic performance assessment of structural and non-structural components, as it allows all damage states to be quantified to develop the corresponding fragility models. The results indicated that rubberized concrete columns and frames made of rubberized concrete can delay and reduce the amount of damage occurring under seismic loading. This is attributed to the higher deformability of rubberized concrete compared to conventional.

With these contributions, an increased use of rubberized concrete in global construction can promise a reduction of the significant environmental impacts caused both from waste tyres and the exploitation of natural resources with promotion of environmentally friendly alternative to conventional concrete in structural applications in earthquake prone areas.

Keywords: rubberized concrete, seismic performance, cyclic testing, structural applications

1. Introduction

Tire waste is a significant global concern for a number of reasons, including its propensity to spontaneously combust, the non-biodegradable nature, and the difficulties associated with landfilling it. The construction industry was identified as having a possible application for waste tyres. Since concrete is the material that is utilised the most in this sector, one of the research directions that has been taken recently is the use of recycled tyre waste to produce rubberized concrete [1]. This may be done as a partial substitute for natural aggregate and/or cement.

Concrete has a low ductility and a high brittleness, both of which lead this material to fracture without major deformations. The behaviour of concrete structures can be particularly unreliable under certain stresses, most notably seismic loads, because of these properties. On construction sites, this fact, however, does not make concrete any less appealing due to the many other advantages it offers. Reviewing previous studies [2] on rubberized concrete, which included both normal and self-consolidating concrete, showed that the addition of recycled rubber particles caused decreased density, increased hardness and ductility, improved dynamic properties, and resistance to crack propagation [3–8]. This has been observed after the recycled rubber particles were mixed into the normal and self-consolidating concrete. According to the advantages of rubberized concrete, it is possible to reach the conclusion that recycled rubber particle have a great potential in the production of light-aggregate concrete in structural elements. This is the case despite the fact that a decrease in compressive strength and the modulus of elasticity was also observed [9–12]. Especially those that are likely to be exposed to the effects of earthquakes, and the objective is to lower the probability of spalling on the concrete surface as well as the concrete cover [13, 14].

In order to ensure that a structure can resist a certain amount of ground shaking, it is highly necessary to know how reinforced concrete structures react to earthquakes. Regarding the seismic behaviour of reinforced rubberized concrete columns, there have only been a few experimental investigations conducted. Youssf et al. [13], [15], Hassanli et al. [16], [17], Li and Li [18] and Elghazouli et al. [19] investigated the behaviour of rubberized concrete columns when subjected to cyclic activity. Their findings suggested that by partially replacing the mineral aggregate with recycled rubber particles, the hysteretic damping ratio and energy dissipation were enhanced. This was the case even though the total amount of mineral aggregate remained the same. Additionally, it was discovered that both the flexural and compressive toughness of the material had greatly improved, as had its hysteretic curve and its ductility. First shake-table tests on two large size cantilever reinforced concrete columns were carried out by Moustafa et al. [14]. Columns were tested by going through a series of ground motions that were calibrated to a certain design spectrum. It was shown that the capacity for lateral drift and the amount of energy lost in a column made of rubberized concrete were both enhanced. Because of the greater energy dissipation, the fracture of the rebar was delayed. Higher values were observed for both hysteresis and viscous damping. Study [2] provided a collection that is more extensive and goes into further depth regarding these experimental results.

This study's major objective was to present general results from an experimental evaluation of reinforced concrete columns and frames made using partially replaced aggregate and recycled rubber particles with a cyclic loading used to evaluate their seismic response.

2. Experimental program

A total of three different self-compacting concrete mixes were used to cast a total of nine column specimens and three frames. The target compressive strength for all specimens was 30 MPa; however, the first mixture was made from conventional self-compacting concrete (SCC-0CR), while the other mixtures, 10% and 15% (with 5% of silica fume) of the fine aggregate volume was replaced by rubber particles (RP).

2.1 Material properties

The production of concrete mixes required a number of different components, including Portland cement 42.5 R, which was manufactured in accordance with HRN EN 197-1:2005, mineral and recycled aggregates, dolomite powder, water, and admixtures as it is presented in Table 1. The mineral aggregates comprised fine aggregates (FA) with a particle size range of 0–2 mm and 2–4 mm, as well as coarse aggregates (CA), which included gravel with a particle size range of 4–8 mm and 8–16 mm. In place of a 10% volume ratio of fine mineral aggregate, recycled aggregate crumb rubber (CR) with particles ranging in size from 0.5 to 4 millimetres and with a density of 1050 kilogrammes per cubic metre was utilised as a replacement in concrete mixtures. In addition, dolomite powder was included in the mixture of concrete in order to cover any pores that were present.

Table 1 – Concrete mixture proportions

Mixture ID	**w/b**	**Cement 42.5R [kg/m^3]**	**VMA [kg/m^3]**	**DP [kg/m^3]**	**CR 0-4mm [kg/m^3]**	**FA 0-2mm [kg/m^3]**	**FA 2-4mm [kg/m^3]**	**CA 4-8mm [kg/m^3]**	**CA 8-16mm [kg/m^3]**
SCC-0CR-0SLF	0,4	450	1,35	80	0	324,45	614,00	362,18	452,72
SCC-10CR-0SLF	0,4	450	1,13	80	66	324,45	438,42	362,05	452,56
SCC-15CR-5SLF	0,4	427,5	1,07	80	98,75	323,51	349,84	361,13	451,41

Table 2 contains the results of tests conducted to determine compressive strength, modulus of elasticity, and flexural strength. These data include mean values (μ), as well as the coefficient of variation (CoV). It is clear from this that the addition of up to 15% rubber particles can result in a reduction of compressive strength and modulus of elasticity of up to 29.34% and 27.2%, respectively, when compared to the original value (RP). When it comes to compressive strength, it can be observed that the difference between SCRC mixes M2 and M3 is extremely modest. The reason for this is most likely due to the addition of silica fume to the M3 mixture, which enhances compressive strength. The modulus of elasticity, on the other hand, does not seem to have changed noticeably as a result of this improvement. The results concerning flexural strength revealed a beneficial affect by adding RP and raising it up to 7.47%, which is in contrast to the fact that the addition of RP had a detrimental effect on the qualities of the prior concrete.

Table 2 - Hardened concrete's properties

Mixture ID	**Compressive Strength f_{ck}** [MPa]			**Modulus of Elasticity E_c** [MPa]			**Flexural Strength f_{ct}** [MPa]		
	μ		**CoV**	μ		**CoV**	μ		**CoV**
SCC-0CR-0SLF (REF)	43.70	REF	0.058	38576.62	REF	0.077	4.95	REF	0.065
SCC-10CR-0SLF (R10)	31.25	-28.5%	0.092	35256.04	-8.61%	0.036	5.15	+4.04%	0.020
SCC-15CR-5SLF (R15)	30.88	-29.3%	0.067	28061.61	-27.26%	0.120	5.32	+7.47%	0.045

It was selected to use ribbed reinforcement B500B for the longitudinal column reinforcement, with a diameter of 12 millimetres, and 8 millimetres for the transverse column reinforcement. Reinforcing steel has a nominal yield strength of 500 MPa, and its elongation under ultimate strength is equivalent to 15%. The fym value represents the nominal yield strength. It is anticipated that the ultimate strength will be 600 MPa, and the ultimate elongation will be 20%.

2.2 Specimen's geometry

When measured from the end that is fixed to the location where the transverse force is applied, the length of the column is equal to two hundred centimetres. The square cross-section of the column measures 30 centimetres by 30 centimetres, giving the column a slenderness of 23, which is the consequence of this measurement. The element has a critical length of 35 centimetres when measured from the end of the column that is fixed, which suggests that the formation of the plastic hinge is most likely to occur at that location. The longitudinal reinforcement of the column is comprised of eight bars, each of which has a diameter of twelve millimetres. These bars take up exactly one percent of the column's gross cross-section.

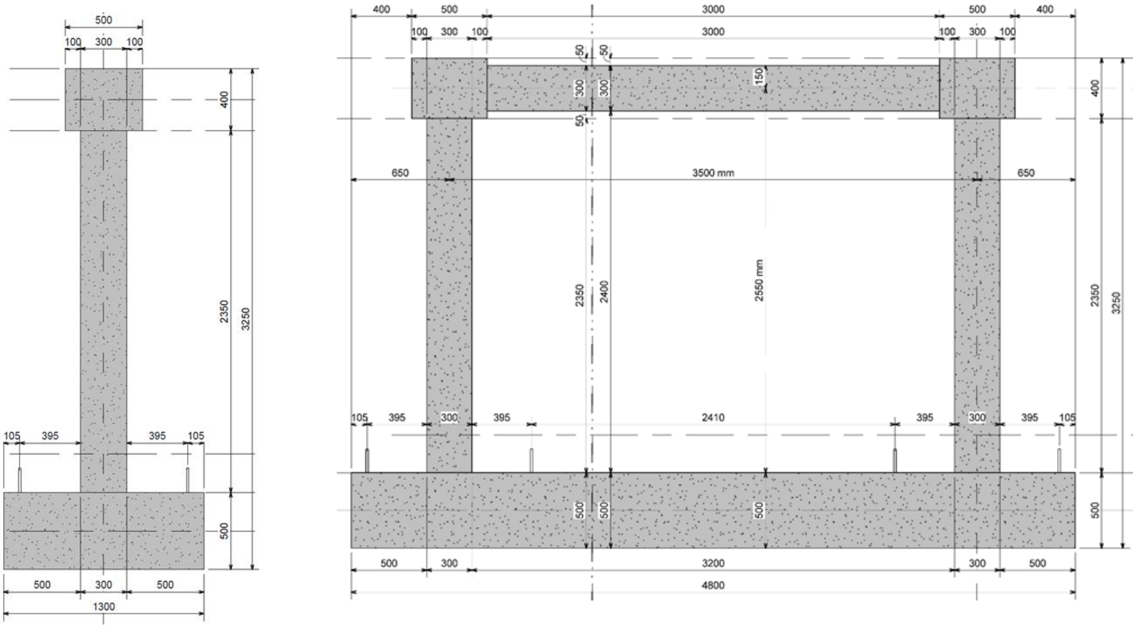

Figure 1. a) Column specimen geometry; b) Frame specimen geometry

The transverse reinforcement, on the other hand, is made up of square and diamond hoops with a diameter of eight millimetres at a distance of seventy-five millimetres inside the critical zone and one hundred fifty millimetres beyond the critical zone.

The axial dimensions of the frames are 3.5 metres by 2.55 metres; the cross-sections of the columns are 30 centimetres by 30 centimetres; and the cross-sections of the beams are 20 centimetres by 30 centimetres. All of these measurements are in centimetres. When you include the foundation beam in the measurement, the entire width and height of the frame comes out to 4.8 metres on each side and 3.25 metres in height. Because the column-beam nodes are wider than the columns, they offer an upper surface that is 40 centimetres by 50 centimetres in size for the application of vertical forces. The total weight of a single frame was 5 tonnes.

2.3 Testing protocol

All specimens went through a cyclic loading method (Fig. 2). This was done in accordance with the loading approach that was recommended by FEMA 461. (2007). Because it enables the quantification of all damage states, this procedure is frequently used for the seismic performance evaluation of structural and non-structural components and equipment. This is necessary for the development of the related fragility models, and it is one of the reasons why it is frequently used. The loading procedure involves a large number of repetitions of cycles, each of which has an amplitude that steadily increases by 1.4 times at each stage. At each amplitude level, two cycles of loading are carried out in order to load the system. The process needs to be carried out a minimum of six times before there is any evidence that an injury has occurred. As a consequence of this, a total of fourteen distinct amplitude levels were selected, and the procedure resulted in a final lateral displacement of 6%, which is equivalent to 120 millimetres. The load application rate is initially set at 0.05 mm/s for the first few cycles of the test, and then it gradually increases to 0.5 mm/s for the final few cycles. This brings the overall amount of time for the testing procedure per specimen up to ninety minutes.

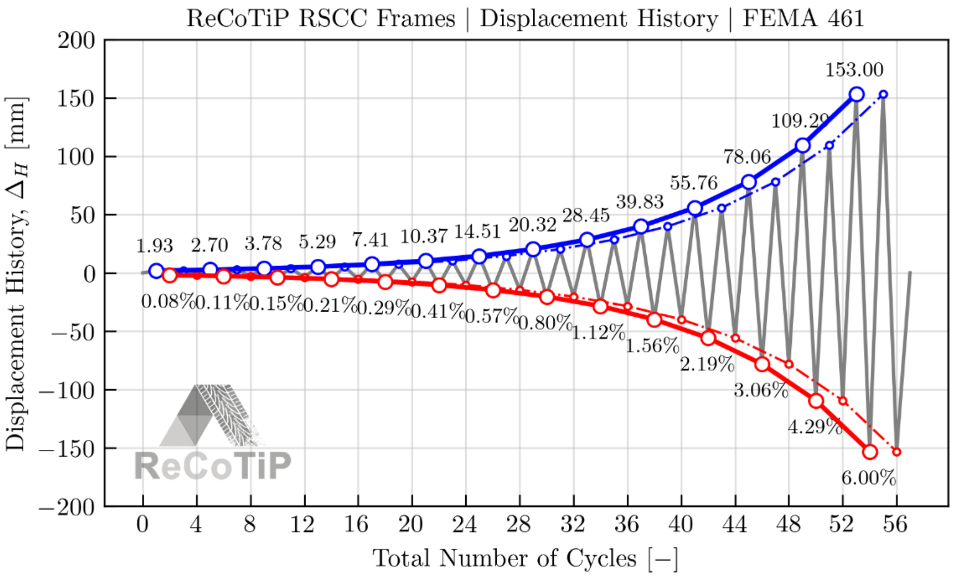

Figure 2. Loading protocol for columns and frames

Instead of being tested in the vertical orientation that was initially planned, the columns were tested in the horizontal orientation at Laboratory in Faculty of Civil Engineering and Architecture Osijek. The availability of a Shimadzu device for universal compressive-tensile testing in the vertical direction is the impetus for this move. The apparatus for compressive-tensile testing that has the potential for accurate computer control permits uncompromising control of the application of force and control of displacement to the test sample, which for this type of testing must be positioned horizontally. As a result, the test specimens are fastened into place with the column foundation beam positioned on the vertical reactive wall and the column body arranged in a horizontal orientation as it is presented in Fig. 3.

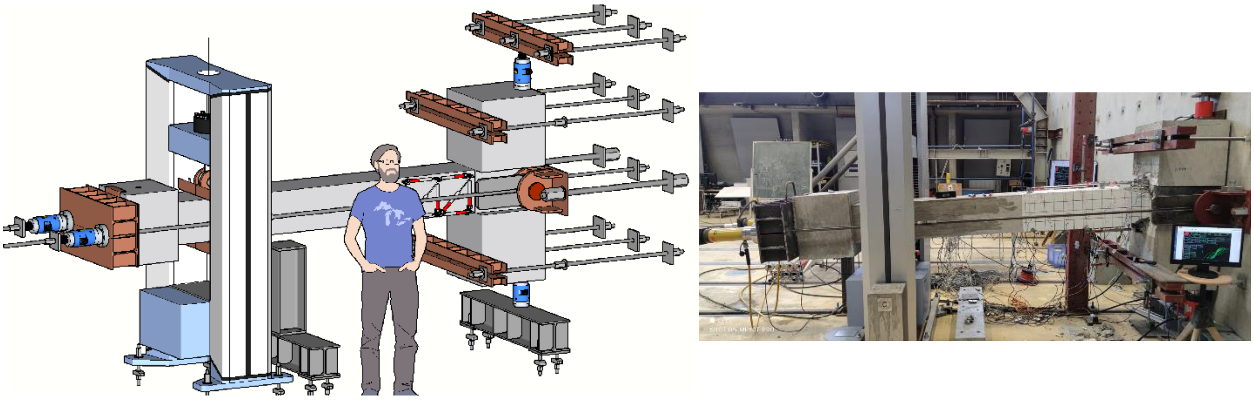

Figure 3. a) Scheme for column testing; b) Testing of columns

Figure 4. a) Scheme for frame testing; b) testing of frames

The testing setup was prepared in Laboratory in ZAG Ljubljana for cycle tests on reinforced concrete frames consisted of a rigid testing floor with a modular system of steel structural parts and a 6 x 7 m huge reaction wall, both of which have a load-carrying capability of 1000 kN/m2 and were spaced apart by a distance of 7 metres. The specimen was fastened to the testing floor using a structure of steel beams and rods that were positioned at both the beginning and the end of the foundation block for the frame. The vertical load of 300 kN on each concrete column was applied by a system consisting of two vertical rods M42, a short beam, and a hydraulic servo-controlled actuator with a capacity of 600 kN. There was a distance of 3.6 metres between the centre lines of the two vertical systems.

Horizontal load (compression and tension) was delivered by a hydraulic servo-controlled actuator with a capacity of 1000 kN and a stroke extension of +/-500 mm, which was part of the horizontal loading system. Yoke is used to make the connection between a specimen and an actuator, which is positioned on the reaction wall. Yoke was constructed using two steel plates and two M42 rods as the component parts. The displacement serves as the controller for the hydraulic actuator.

The system of supports that prevents the specimen from rotating around the vertical axis consisted of two steel frames with four steel modular consoles that block the concrete frame's ability to spin around the vertical axis.

3. Results

By comparing columns in terms of global capacity (Fig. 5) REF specimens reached a maximum shear force of 56 kN at a drift of 3,1% before it reached an ultimate drift of 6% with the force of 48kN.

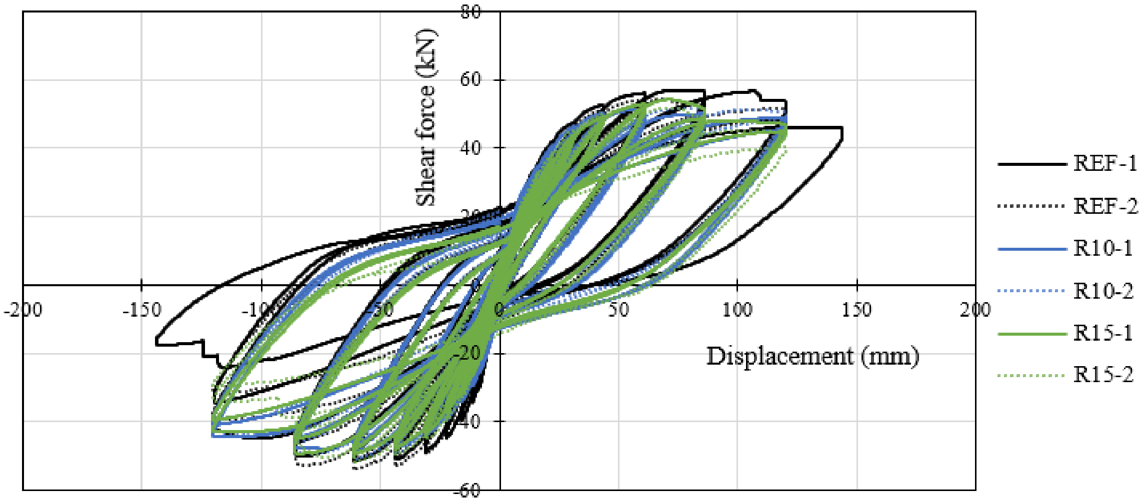

Figure 5. Global hysteresis for columns

Figure 6. Crack propagation in columns: a) REF column; b) R10-1 column; c) R15-2 column

The R10 and R15 column specimens, attained a maximum force of 51 kN at a drift of 3% with the same ultimate force. As a result, the use of the rubber in the concrete may decrease the maximum force while maintaining the ultimate. The REF specimen had an average fc of 43,7 MPa in comparison to fc of 31,25 MPa for the R10 specimen, indicating that the rubberized column would have higher deformability.

Concrete cover spalling in columns began at a drift of 2,2% in the bottom-most 200 mm of the column above the footing and progressed to 250 mm height above the footing at the end of the test (6% drift). According to the Figure 6 it is visible that plastic hinge area is much smaller and crack are much more cracks are much narrower compared to columns made of conventional concrete.

The results of the frame’s tests (Fig. 7) reveal that all three frames have a fairly similar global behaviour. Frame REF, which is made of traditional concrete without additions of rubber aggregates, had the highest load capacity, but the difference between the two is insignificant in comparison to the difference in the compressive strength of the material. When compared to frame REF, frames R10 and R15 (with silica fume), had a load capacity that was only 3% lower than frame REF. What is distinctive about frame REF is that the reinforcement cracked, although in the other frames, there was no such behaviour. In spite of the material's reduced compressive strength, it is feasible to deduce, based on the hysteresis curves, that concretes containing rubber can fully take up the entire load just as well as conventional concretes can.

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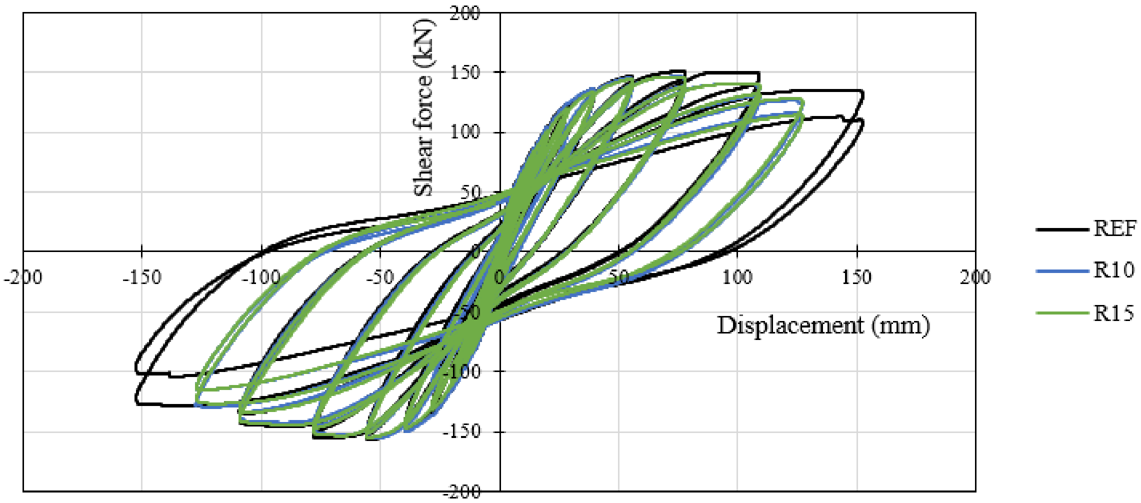

Figure 7. Global hysteresis for frames

Figure 8. Crack propagation and damage in frames

When the frames were inspected after tests have been finished (Fig. 8), the discrepancies become considerably more apparent. That was done by characterising the damage in terms of the location and size of the plastic joints, as well as the position and width of any cracks that have been formed. When compared to frame REF, frames R10 and R15 had less damage (a smaller region of the plastic joint), less falling off of the protective layer, and in the end, there was no breakdown of the reinforcement in the case of the frames with the rubber particles.

Therefore, it is necessary to conclude that there are no restrictions on the use of rubber aggregates as a replacement for one part of the total volume of aggregates (up to 20%) in load-bearing structures at any level. This includes the control of bending, load-bearing capacity, stiffness, while undergoing cyclic loading, and behaviour that corresponds to the action of an earthquake.

In regions that are prone to seismic loads, constructions made of concrete with the addition of rubber can be fully utilised for load-bearing elements and all parts of load-bearing structures. This is especially true in regions where there is a greater risk of damage to structures on a local level from earthquakes, as compared to the case with conventional concrete.

4. Conclusions

The objective of this study is to determine whether or not the incorporation of crumb rubber concrete into reinforced concrete structures, which serves as a material that has the potential to increase the structure's ability to disperse energy, would be beneficial. During the course of the testing procedure,

DOI: *https://doi.org/10.5592/CO/2CroCEE.2023.119*

each of the three frames and each of the six reinforced concrete columns were put through axial compression in addition to being subjected to reversed cyclic loads.

In spite of the fact that the compressive strength of rubberized elements was 28% lower than that of conventional concrete components, the system as a whole was able to withstand a lateral load that was approximately 92% of what traditional concrete elements were capable of managing. This was the case even though the rubberized elements had the ability to withstand a load. This demonstrated that rubber can be used in concrete columns despite having a lower axial compressive strength without having a detrimental impact on the final lateral strength or deformability of the columns. This was demonstrated by the fact that there was no change in either of these characteristics as a result of using rubber. This came to light as a consequence of the investigation that was outlined up top. In addition, the use of rubberized concrete might delay the commencement of the damage caused by an earthquake, which in turn can help to serve to decrease the degree of the damage. The concrete cover spalling was delayed due to the increased flexibility of rubberized concrete in comparison to conventional concrete, and the amount of concrete cracking that occurred was reduced to a minimum. Both of these benefits can be attributed to the fact that rubberized concrete is more elastic than conventional concrete. Because of this, the column cross-section was able to keep its integrity for a greater portion of the test than would have been conceivable in the event that it had not been subjected to this modification. Rubberized concrete is an alternative better for the environment than regular concrete and has the potential to be used in structural sections that are susceptible to the impacts of seismic loading.

Acknowledgements

This paper was supported by Croatian Science Foundation under the project UIP-2017-05-7113 Development of Reinforced Concrete Elements and Systems with Waste Tire Powder—ReCoTiP.

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