Structural Behavior by Reinforcement Type in the Joint of RC Beams and Columns Mixed with Waste Tire Material

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***Abstract* - One main purpose of this study is to measure the improvement of the ductility through structural tests of the connection between an exterior column and a beam of normal concrete in comparison with a concrete frame constructed with a mix of waste tire material. The actual section size of each column and beam is 30㎝×30㎝ with the reinforced concrete (henceforth RC), which is based on a ¼-scale design with exterior columns and beams. The models are termed NCJ-1, TCJ-1, NCJ-2, NCJ-2, NCJ-3, and TCJ-3 for the six (6) types used here. It is estimated that the main rebar in the beam is not anchored over the boundary of the connection rejoin. Instead, it is anchored only to the boundary. The displacement of a diagonally reinforced connection rejoin with the waste-tire mixture showed a 3.3% increase with a 3% decrease of the resistance capacity. In the model of the connection rejoin with more waste-tire mixture and rebar anchored over the boundary of the connection rejoin.**

Keywords: Connection, Beam-Column Joint, Displacement, Deformation, Energy Absorption, Resistant Capacity.

I. INTRODUCTION

Bending moment and shear loading at the point of connection between a beam and a column can become concentrated and cause much damage to RC structures due to periodical lateral loads when a seismic load occurs. Therefore, the capacity of this type of connection can be decreased by a plastic hinge or by cyclic loads, such as a seismic load, with a decrease in the bonding capacity and a subsequent decrease in the ductility as a mechanism.

It is known that the exterior columns and beams of RC structures are important parts of a frame. Critical damage to a connection between a column and a beam can arise due to a periodical lateral load such as a seismic load, as the stress can become concentrated on the joint, which typically does not have isometric stiffness. Therefore, more stress can be added to the joint where a column and a beam are faced. There is a mechanism through which the ductility of the joint can be decreased as the displacement increases at a beam-to-column connection area.

One main purpose of this study is to measure the improvement of the ductility through structural tests of the connection between an exterior column and a beam of normal concrete in comparison with a concrete frame constructed with a mix of waste tire material.

Therefore, a better design that can absorb more energy is required so that the beams have sufficient ductility such that the bonding does not weaken or a shear fracture does not occur.

It was confirmed that in terms of the unit volume, one (1) percent of the waste tire mixture offers the optimal concrete strength when using this type of waste tire-mixture [1].

This study seeks to determine if an exterior column and a beam of an RC structure have greater ductility against periodical lateral loads such as a seismic load when they contain waste tire chips. This was done through a comparison of normal and waste-tire-mixed concrete using ¼-scale section models.

Main beam re-bar anchorage sites, in this case the joint and areas over the boundary of the joint, are selected as variables, although many other factors can be considered.

There are three (3) measuring points in the lateral, longitudinal, and diagonal directions. Gauges are installed on six (6) concrete parts and eight (8) rebar parts.

LVDTs to check the displacement of each point were attached at distances of 20cm on both the left- and righthand sides from the center of the connection region of each column and beam so that the repetitive effect of the load can be measured for not only the connection rejoined parts but also for the parts over the joint.

II. METHODS

A. Concrete

1) Concrete mixture: Concrete with a concrete design strength Fc of 240kg/cm^2 (24Mpa) commonly used for practical structures in Korea, was specified in the mix design with the waste tire material in this study. A slump value of 15cm, as commonly applied, was adopted here as well for good workability. The maximum diameter of the coarse aggregate was 25mm or less, the fine aggregate amounted to 47.5%, the NaCl amounted to 0.30kg/m^3, and the air volume was 4.5 ± 1.5% in this study. These values are shown in Table.

TABLE I
Mixed Design of Concrete (kg/m^3)

W/C	**C**	**Water**	**Coarse agg**	**Fine agg**
47.8 %	356kg	170kg	956kg	848kg
Admixture		Rubber (1%)	Slump	
1.78kg		23kg	15cm	

2) Variables and types of test models: The actual section size of each column and beam is 30㎝×30㎝ with the reinforced concrete (henceforth RC), which is based on a ¼-scale design with exterior columns and beams. The models are termed NCJ-1, TCJ-1, NCJ-2, NCJ-2, NCJ-3, and TCJ-3 for the six (6) types used here, as shown in Table II.

TABLE II
Compressive Strength of Concrete Material

Test Models		**Compressive Strength(MPa)**	**Reinforcement Type**
Normal Concrete	NCJ-1	24	Main rebar of the beam is anchored to the boundary of the connection rejoin
	NCJ-2	24	Main rebar of the beam is anchored over the boundary of the connection rejoin
	NCJ-3	24	Main rebar of the beam is anchored diagonally in the beam-column joint
Waste tire-Concrete	TCJ-1	24	Same as NCJ-1
	TCJ-2	24	Same as NCJ-2
	TCJ-3	24	Same as NCJ-3

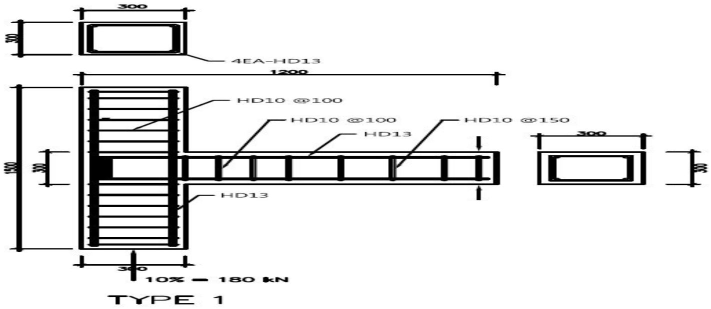
B. Creation of the test pieces and curing

Test pieces were made in accordance with actual site conditions. The form, which is used most commonly in Korea, has been applied here to prevent deformation when the concrete is poured. Concrete was delivered from a commercial batcher plant to maintain a consistent quality and mixing design.

Curing was done using an insulation cover with a suitable water proportion. The curing temperature was 22℃±3 and the curing time was 28 days.

C. Reinforcement

Reinforcement depended on the type, as shown in Fig. 1. [2].



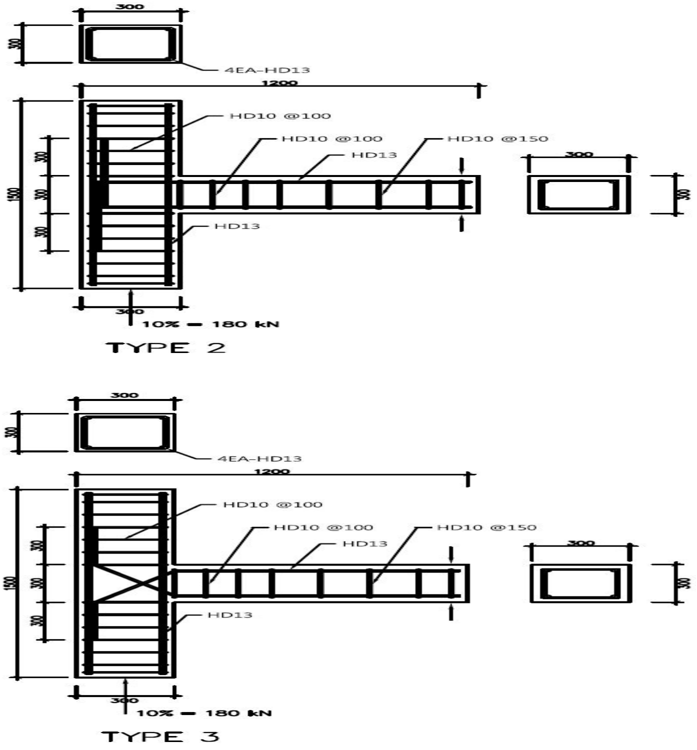


Fig.1. Reinforcement by type

D. Compressive strength and Poisson’s ratio

1) Creation of the test molds: Test molds 100x200mm in size were created and cured in water in the laboratory of the batcher plant in accordance with the KS F 2403 specifications (ASTM C39/39M-12a; Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens). The Poisson’s ratio was measured in accordance with the KS F 2438 specifications. The results of the test were compared to those with 40% under a limited load.

2) Compression test: Compression tests for the molds were done using a 100-ton universal testing machine. Concrete gauges to determine the horizontal and longitudinal strain with which to calculate the Poisson’s ratio of this concrete material were attached to the test molds, as shown in Tables III and IV

TABLE III
Compressive Strength

Kind	Design strength	1	2	3	4	5	Aver.
Normal concrete	24Mpa	32	33	32	32	33	32.40
Waste tire-mixing Concrete	24Mpa	26	26	26	24	22	24.80

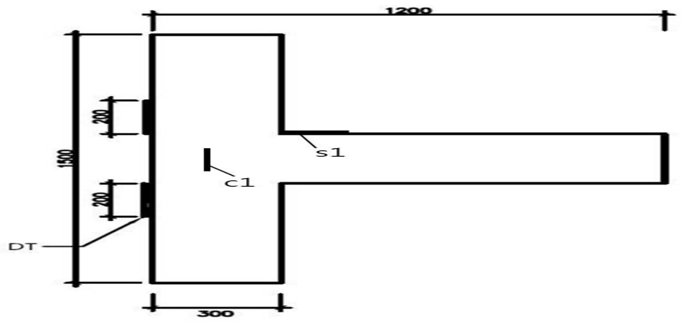


Fig.2. Positions of the LVDT, steel, and concrete gauges

TABLE IV
Poisson's ratio at P $_{max}$

Kind	Design strength	1	2	3	4	5	Aver.
Horizontal	Normal concrete	1999	1197	1249	1894	1100	1,487.80
	Waste tire-mixing Concrete	1091	529	1603	778	530	906.20
longitudinal	Normal concrete	2686	2598	2445	2637	2245	2,522.20
	Waste tire-mixing Concrete	2252	1793	2069	1857	1869	1,968.00
Poisson's ratio Horizontal/ longitudinal	Normal concrete	0.744	0.460	0.510	0.718	0.489	0.58
	Waste tire-mixing Concrete	0.484	0.295	0.774	0.418	0.283	0.45

E. Test setup

1) Set up diagram: The test setup was created as shown in Fig.3, including a reaction frame with sufficient stiffness against longitudinal and horizontal loading. An actuator with a capacity of 50 tons of tensile and compression loading was used to supply an 18-ton longitudinal load in proportion with 10% of the column design strength.

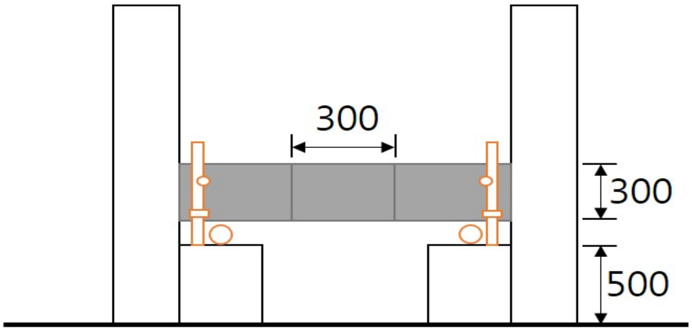


Fig.3 Test set up

F. Test method

Load cells were attached onto both the left and right sides to force a load repeatedly. A continuous longitudinal load was loaded onto the column first. Loading of 57 cycles was done to investigate the cracking shape and transfer path. The test frame was entirely fractured upon the seventh cycle. Additionally, residual deformation and restoration of the frame were investigated under increasing loads of one (1) ton each, as shown in Fig.4.

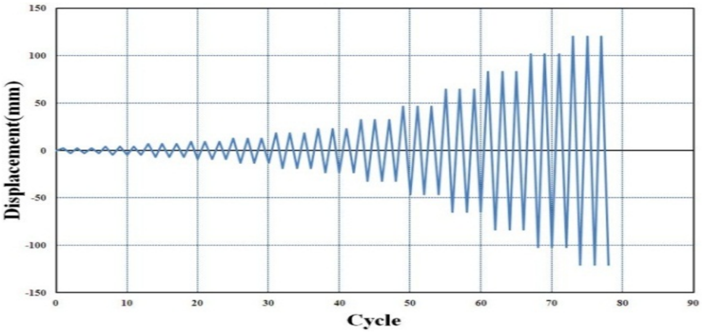


Fig.4. Load history curve

Three cycles for the same displacement were used while increasing the load progressively to the initial cracking with displacement of 2.78mm.

III. RESULTS

A. Characteristics of the load displacement and fracture shape

1) Load-displacement, NCJ-1: In NCJ-1 with normal concrete, the initial cracking occurred at a displacement of 2.78mm under a load of 38kN on the face at which the column and the beam are in contact. This crack increased as more load was placed on it. Additionally, the maximum fracture occurred after forcing the load up to a displacement of 32.45mm. The load-displacement curve is shown in Fig.5. and the final fracture shape is shown in Fig.6.[3]

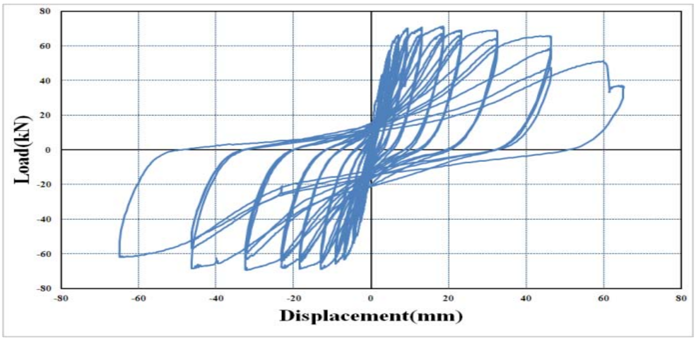


Fig.5. Load – displacement curve, NCJ-1

Fig.6. Fracture shape, NCJ-1

B. Load-displacement and fracture shape, TCJ-1

In TCJ-1 with waste-tire-mixing concrete, the initial crack occurred at a displacement of 2.78mm under loading of 40KN. Loading was done on the face at which the column and the beam are connected. A shear crack occurred on the upper end of the connection rejoin, as well.

Maximum fracturing was noted after forcing in the negative (-) direction. The size of the crack is 23.18mm. The load-displacement curve is shown in Fig.7 and the final fracture shape is shown in Fig.8.

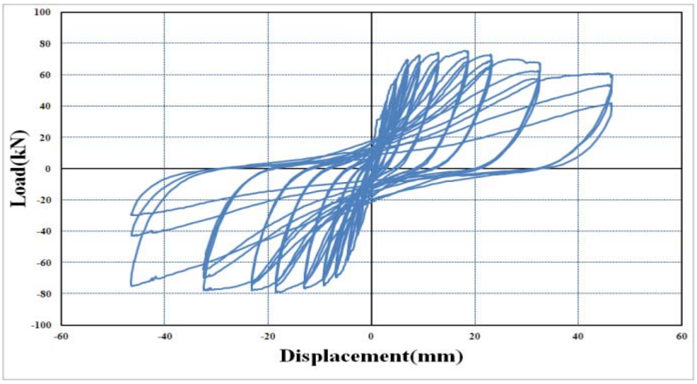


Fig.7. Load – displacement curve, TCJ-1

Fig.8. Fracture shape, TCJ-1

C. Load-displacement and fracture shape, NCJ-2

In NCJ-2, which consists of normal concrete, the initial crack occurred at a displacement of 2.78mm with a load of 43KN. Additional cracking was noted on the face of the column and the connection rejoin as the load was increased.

A fracture on the connection rejoin occurred during the first cycle with a positive load, with 23.18mm strain, while the stress was progressively decreased in NCJ-2. These results are shown in Fig.9 and Fig.10.

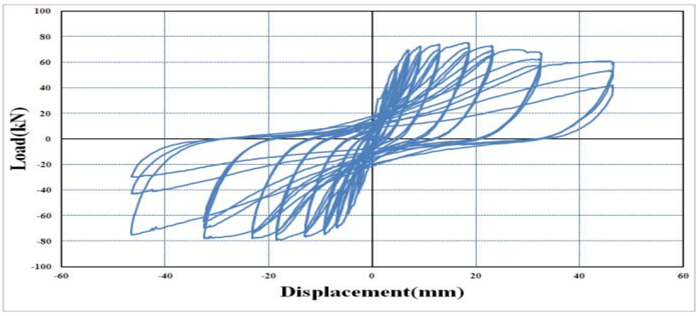


Fig.9. Load – displacement curve, NCJ-2

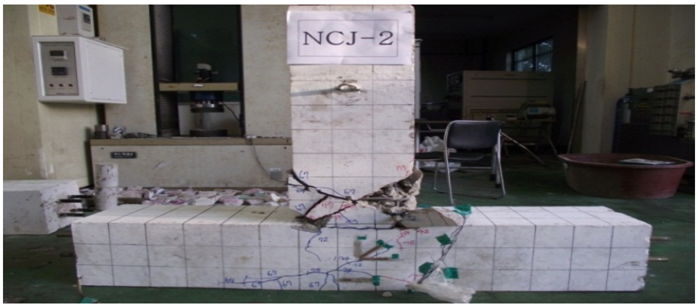


Fig.10. Fracture shape, NCJ-2

D. Load displacement and fracture shape, TCJ-2

The load displacement and fracture of Type-2 are shown in Fig.11. and Fig.12.

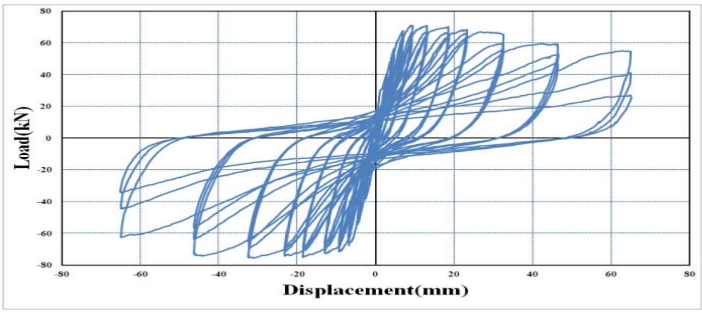


Fig.11. Load – displacement curve, TCJ-2

Fig.12. Fracture shape, TCJ-2

E. Load displacement and fracture shape, NCJ-3 and FCJ-3

The load displacement and fracture conditions of Type-3 are shown in Fig.13, Fig.14, Fig.15, and Fig.16. [3]

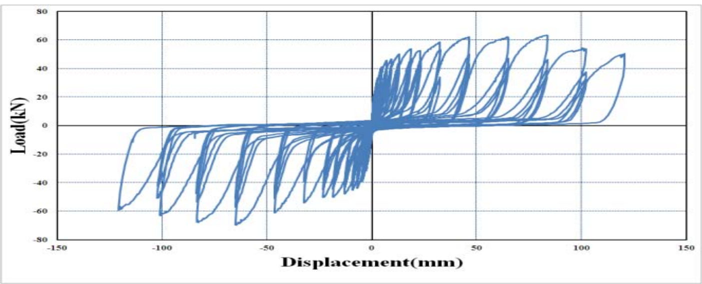


Fig.13. Load displacement curve, NCJ-3

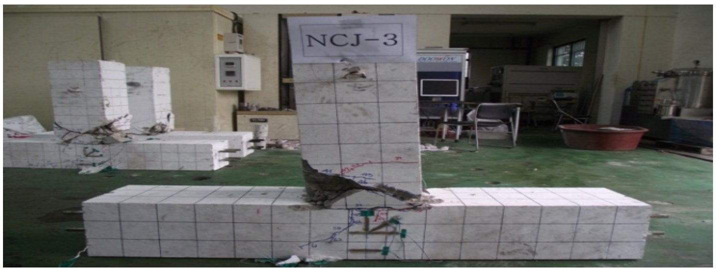


Fig.14. Fracture shape, NCJ-3

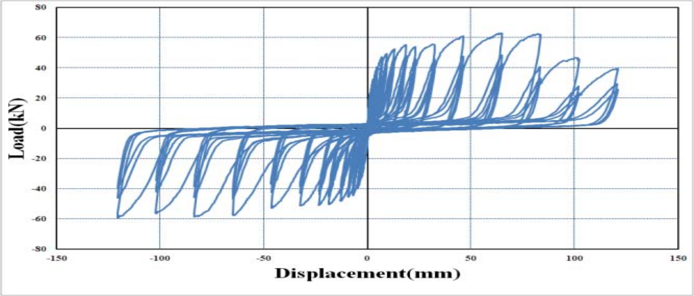


Fig.15. Load displacement curve, TCJ-3

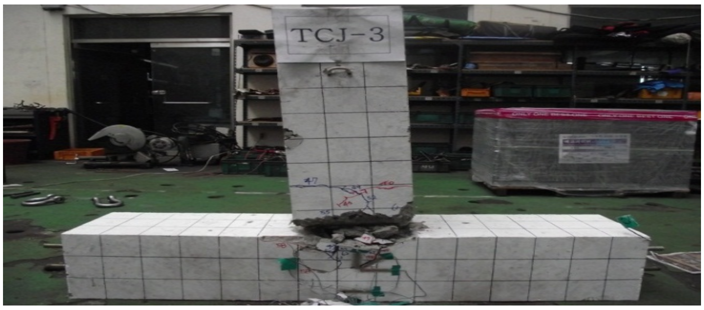


Fig.16. Load displacement curve, TCJ-3

F. Load deformations

The load deformations for Types 1, 2, and 3 with rebar are shown in Fig.17. [3]

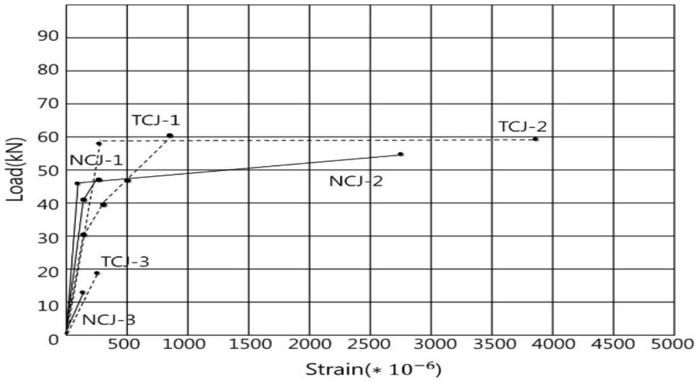


Fig.17. Strain of rebar for Type-1 at the s1 measuring point

It is estimated that the test frame with the mixture of waste tire chips has a stronger reinforcement effect of the main anchor bar and the beam-column joint than the other cases.

It is estimated that more deformation can arise due to more anchorage over the boundary of the joint area, and a greater recovering capacity of the waste-tire mixed concrete can be realized in Type-2.

More deformation was noted with the waste-tire mixture as compared to the normal concrete. It is estimated that the anchorage of the main rebar is over the area of the joint between the column and the beam in Type-3.

Approximately fourfold the deformation, without a conspicuous decrease of the resistance capacity, was noted in TCJ-1 at the c1 concrete strain gauge.

An increase in deformation of approximately 36% and only a 7% decrease of the resistance capacity were noted in TCJ-2. It is estimated that practical applications are feasible using this condition according to the results of the c1 concrete strain gauge.

Approximately twice the deformation and only a 10% decrease of the resistance capacity were realized in TCJ-3 at the c1 concrete stain gauge.

IV. ANALYSIS

In the comparison of NCJ and TCJ, some fracturing and initial cracking were noted on the face of the joint. It is estimated that both the column and the beam are stiff, differing from the “strong column-weak beam” principle.

In the load-displacement graph of NCJ-1, the maximum displacement was 62mm and the load was 70KN in the normal concrete case.

Regarding another aspect of TCJ-1, for the same case but with the waste-tire mixed concrete, the initial crack occurred at a point of 30mm on the beam away from the face of the connection rejoin at which the column and beam are in contact. The concept of “strong column-weak beam” was realized in TCJ-1, although the sections of column and beam are identical, with a plastic hinge on the beam to conform to the “strong column and weak beam” principle. In addition, no particular improvement, such as improved energy absorption, was noted in TCJ-1 with the waste-tire-mix, with maximum stress of only 78KN and maximum displacement of 45mm. This explains why TCJ-1 does not show more displacement in this case. It is estimated that the main rebar in the beam is not anchored over the boundary of the connection rejoin. Instead, it is anchored only to the boundary. Eventually, the connection rejoin itself behaves separately without forming a body consisting of the column and the beam at the joint due to the insufficient anchorage capacity.

In the comparison of NCJ-2 and TCJ-2, in which the main rebar in the beam is anchored over the boundary of the connection rejoin, maximum stress of 79KN and maximum displacement of 45mm were noted in NCJ-2, while these were 77KN and 65mm, respectively, in TCJ-2. It is estimated that the column capacity is slightly weaker than in the other cases, which cannot be desirable given the design principle of “strong column-weak beam.”

Additionally, in NCJ-2 with normal concrete, and in TCJ-2 with the waste-tire mixed concrete, the initial crack was noted on the face of the connection rejoin, i.e., the point of contact with the beam. A fracture in the connection rejoin was noted in TCJ-2 but not in NCJ-2 as it occurred in the column. It was considered that the fracture mechanism improved more in TCJ-2 than in NCJ-2

It was estimated that the energy-absorbing ability is increased by 44%, more than the NCJ-2 case, despite the fact that the maximum stress decreased by only 2.5%.

Moreover, despite the fact that the resistance capacity in this case was 65KN and the maximum stress showed a 7.6% decrease compared to other cases, it was noted that a 51% increase with a displacement of 119mm occurred, showing the feasibility of this type in structures against seismic loads.

In contrast, in the comparison of NCJ-3 with the normal concrete and TCJ-3 with the waste-tire concrete, 23mm more displacement and 63KN less resistance capacity in TCJ-3 were noted, contributing to energy absorption with a 3% decrease of the maximum stress and a 3.3% maximum strain.

V. CONCLUSION

This study assessed the structural behavior of a connection rejoin of an RC column and a beam to be loaded with longitudinal force on the column and cyclic and vertical loading on the beam to determine the applicability and reliability of the materials in this study.

The structural characteristics of two different materials, both normal concrete and waste-tire-mixed concrete, were reviewed in terms of their energy-absorbing ability against cyclic loads.

The following conclusions from the above analysis were drawn:

1) It is concluded that equal capacity of the column and the beam cannot be realized while varying the anchorage method of the connection region, even when the section size of the column and beam are the same, given the principle of a strong column and a weak beam in the structural design.

2) The displacement of a diagonally reinforced connection rejoin with the waste-tire mixture showed a 3.3% increase with a 3% decrease of the resistance capacity. The capacity to resist deformation by the above reinforcement method with the waste-tire mixture showed an increase of more than 50% over the other anchorage types of the connection rejoin, even when the strength was decreased by only 7.6%. The condition of this case can be more effective in a structural design that requires more energy absorption than a normal case.

3) In the model of the connection rejoin with more waste-tire mixture and rebar anchored over the boundary of the connection rejoin, a 44% increase in the displacement was noted compared to when the anchorage was not over the boundary of the joint. The decrease in the strength was only 2.5% in this case, demonstrating its potential as an effective structure that requires a considerable resistance capacity with permissible displacement.

ACKNOWLEDGEMENT

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