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EXPERIMENTAL STUDY ON SEISMIC PERFORMANCE OF EXTERNAL RC BEAM-COLUMN CONNECTIONS MADE USING RCA

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Abstract

Depletion of natural aggregates is a major challenge for sustainability of construction industry. Therefore, recycling and reuse of concrete extracted from demolished reinforced concrete (RC) structure may reduce the usage of natural coarse aggregates (NCA). However, literature review revealed that very few studies had been carried out on seismic performance evaluation of important structural elements like beam-column connections made using recycled coarse aggregates (RCA). In this paper, performance of external RC beam-column connections, made by partially replacing NCA with RCA (25% by weight), has been studied. The beam-column connections have been subjected to low (0.025 Hz: Type-I loading) and high frequency (1 Hz: Type-II loading) cyclic displacement histories. Each of the displacement amplitudes have been increased after completion of three cycles. The various seismic parameters like energy dissipation capacity and stiffness degradation of beam-column connections made using NCA and RCA have been evaluated and compared. The force-displacement hysteresis loops of the beam-column connections made with both NCA and RCA obtained during the experimental investigation were analysed. Comparison of seismic parameters for both categories of specimens established that the beam-column connections made with RCA is suitable in case of low to moderate seismic demand.

Keywords: recycled coarse aggregates, beam-column connection, seismic design, sustainable construction

1. Introduction

The recent trend in the construction industry is to use the alternative construction materials which can substitute the use of NCA in order to reduce environmental impact. On the other hand, the waste generated from the demolition of old structure and construction activity is a matter of concern all over the world. Thus, recycling and reuse of these wastes may reduce exploitation of natural resources and thereby facilitate promotion of sustainable construction.

During past devastating earthquakes, it has been noted that beam-column connections act as one of the weakest links in moment resisting reinforced concrete (RC) framed structures. Behavior of reinforced concrete frame structures during earthquakes throughout the world has highlighted the consequences of poor performance of beam-column connections and it has been observed that exterior connections suffer more in comparison to interior ones. Therefore, extensive of experimental and numerical studies [1-3] have been carried to improve seismic performance of external beam column connections made of NCA.

Depletion of NCA posed a major challenge for sustainability of construction industry. Therefore, recycling and reuse of aggregate extracted from demolished RC structure may reduce the usage of NCA. Disposal of construction and demolition waste materials is also a big problem in view of scarcity of landfills. Re-using of aggregates extracted from construction demolition waste will solve both the problem. Tem et al. [4] carried out studies on removal of cement mortar from the aggregates obtained from construction waste. In the present study, cement mortar of RCA has been removed by abrasion process.

Literature review revealed that very few studies had been carried out on seismic performance evaluation of important structural elements like beam-column connections made using RCA. Corinaldesi and Moriconi [5], Xiao et al. [6], Corinaldesi et al. [7] carried out experimental studies for performance evaluation of structural elements in which RCA partially replaced NCA. In these studies, test models of different structural elements have subjected to slow cyclic loadings. Therefore, there is a need to study efficacy of RCA use in important structural component like external beam column joint subjected cyclic loading of relatively higher frequency.

In this study, an experimental investigation has been carried out on seismic performance evaluation of external beam-column connections subjected to cyclic displacement histories of two different frequencies. Comparison of seismic performance parameters like ultimate load carrying capacity, cumulative energy dissipation, stiffness degradation of the control specimens with those of the specimens made with RCA (partial replacement) has been carried out.

2. Experimental program

The study has been focused on a 2/3rd scale external RC beam-column connection in which 25 % of NCA is replaced by RCA. Four specimens of scaled beam column connections have tested under lateral loads of two different frequencies in this experimental program. These specimens comprised of half the length of column on each side of the joint and half of the beam up to mid-span. Boundaries of the specimens correspond to the points of contraflexure in beam and column. Two specimens made of NCA are designated as NCA specimens while two specimens using NCA is partially replaced by RCA are designated as RCA specimen.

2.1 Description of specimens

Fig. 1 shows the reinforcement detailing of beam-column connections. It was kept same for all four specimens. The cross-section of column was 200 mm x 200 mm, height of column was 2200 mm and the beam cross-section was 240 mm x 200 mm, the length of beam was 1000 mm. The four number of high yield deformed bars (yield strength of 500 MPa) of 12 mm diameter and two 8mm diameter bars was used as main reinforcement in column and beam. Two 12 mm bars and one 8 mm diameter bars each at top and bottom provided for both column and beam cross-section. The lateral ties of 8 mm bars (HYSD) @50 mm c/c spacing provided in the special confining zone (D-region) of column and in the remaining part of the column the 6 mm bars (HYSD) lateral ties was used @100 mm c/c spacing. In the beam 6 mm bars (HYSD) stirrups was used @50 mm c/c spacing near the beam-column connection up to the length of 450 mm and in the remaining part of the beam 6 mm (HYSD) bars stirrups @80 mm c/c spacing was provided. The reinforcement and stirrups has been designed in accordance of IS:456-2000 [8] and IS:13920-1993 [9]. M30 grade of concrete was used in NCA and RCA specimens tested under Type-I loading and M40 grade of concrete was used for both specimens for tested under Type-II loading. Acceptance criteria of the test specimens as per ACI 374.1-05 are not mandatory as the specimens are part of weak beam-strong column moment frame.

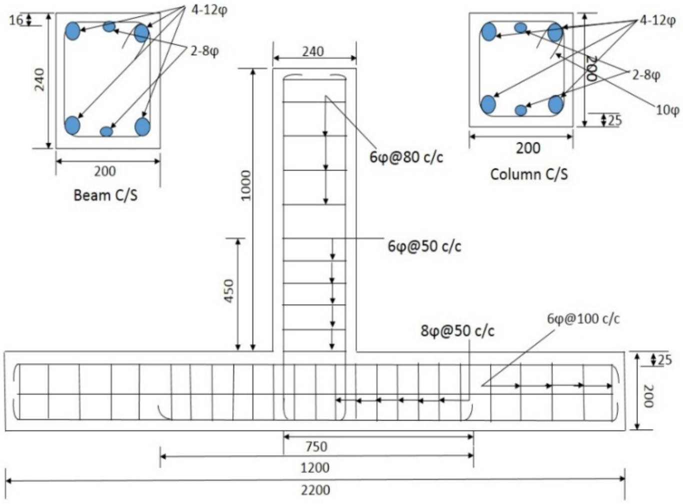


Fig. 1- Reinforcement details for Beam-Column specimens (2/3 scale).

2.3 Test set-up and instrumentation

A MTS servo hydraulic actuator of ±250 kN and ±125 mm stroke length was used for this test program. In-built load cell and LVDT in the actuator are used for measurement of lateral load and displacement respectively. The hydraulic jack with capacity of 500 kN was used to apply the constant axial load. The column of the beam-column joint is placed in horizontal position while the beam has been placed in vertical position in the test set-up. The axial load of 15% of the gross capacity of the column, to represent the gravity load, is applied with help of the hydraulic jack of maximum capacity of 500 kN. The jack was fitted to the A-frame and the roller supports are provided at the both ends of the column. Photograph of the actual test set-up is shown in Fig. 2.

Fig. 2 - Photograph of test set-up

2.4 Details of loading histories

Displacement controlled cyclic loading with the loading frequencies of 0.025 Hz and 1.0 Hz respectively was applied to the specimens. The displacement amplitudes were increased after completion of three cycles for particular amplitude. The slow frequency loading is designated as Type-I loading and high frequency loading is designated as Type-II loading. The typical displacement histories of both the loading types are shown in Fig. 3-4. The first amplitude applied is 3.0 mm followed by displacement of 5.5 mm, 8.0 mm and 10.00 mm then after an increment of 5.0 mm displacement was applied in every cycle up to 60.00 mm.

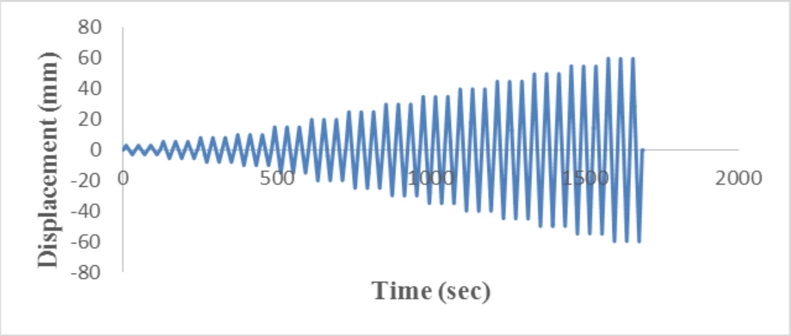


Fig. 3 - Displacement-time history for Type-I loading

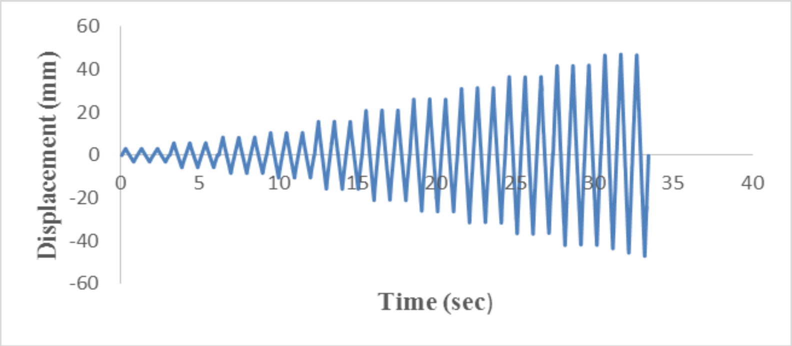


Fig. 4- Displacement-time history for Type-II loading

3. Analysis and Comparison of Test Results

Results of material tests and test results of cyclic load testing are presented in this section. Measured responses of this experimental program are then analyzed critically to evaluate performance of RCA specimen.

3.1 Material testing

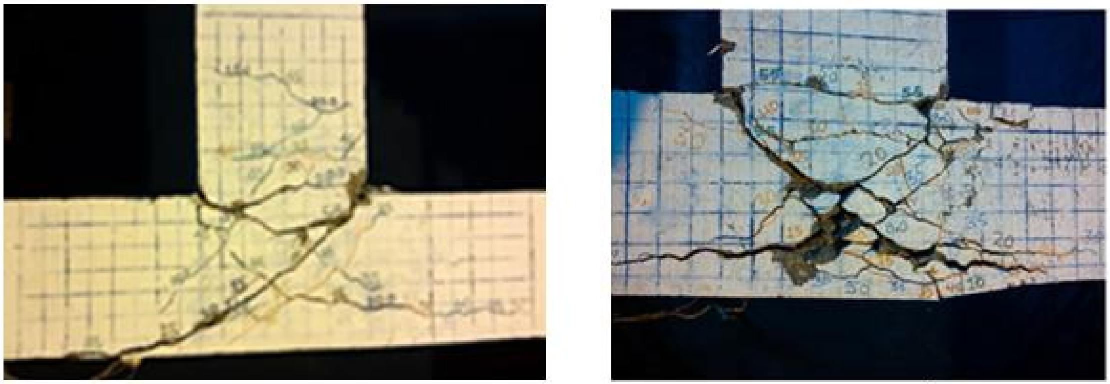
Six concrete cubes were cast for each mix from the same concrete mix, which has been used to cast of RC beam-column connections. The tests performed on these concrete cubes were UPV test, rebound hammer test, air permeability test and compressive strength test. The results were presented in Table 1. It was observed that the rebound number and pulse velocity values decreases when RCA was added in the concrete mix but difference is not very significant. The Air-permeability value increases on partial replacement of NCA by RCA. Compressive strength values are of similar order for both the specimens under both types of loadings.

Table 1: Hardened properties of NCA and RCA concrete

Specimen	Type	Rebound Number (R)	Ultrasonic Pulse Velocity (m/s)	Air-Permeability (m/s)	Compressive strength (MPa)
Specimen 1	NCA	33.1	4170	1.21E-18	34.4
Specimen 2	RCA	27.7	3930	1.23E-18	28.0
Specimen 3	NCA	31.3	4510	1.07E-18	48.4
Specimen 4	RCA	30.7	4340	1.31E-18	48.0

3.2 Behavior of NCA and RCA specimens

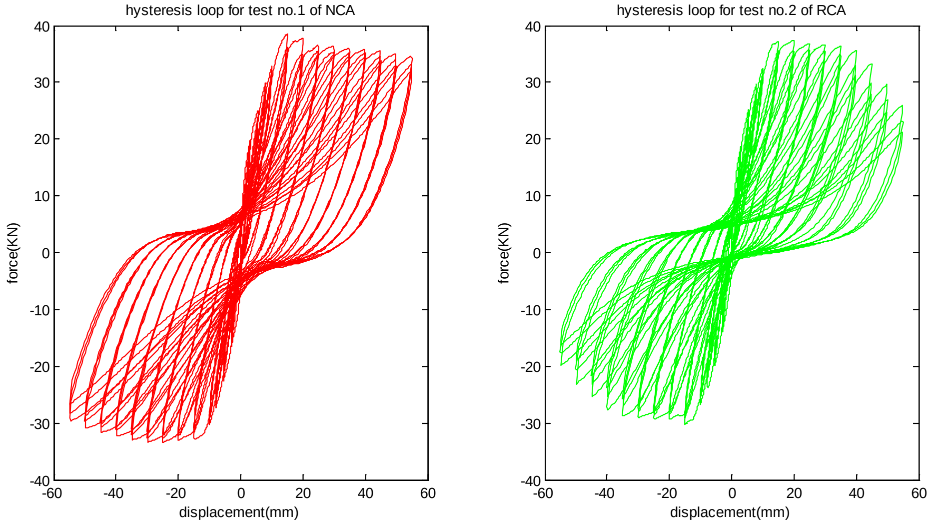
Fig. 5 shows the damaged NCA and RCA specimens at ± 50 mm displacement subjected to type-I loading. First cracks in both the specimen developed at displacement of 5.5 mm. Damage level in RCA specimen at ± 50 mm displacement is higher than that in the NCA specimen which is evident from the Fig. 5. In both cases, damages were distributed over entire joint region. Fig. 6 shows force-displacement hysteresis loops of both types of specimens subjected to type-I loading. Maximum load carrying capacities of both types of specimens are comparable. However, it is observed that that the decrease in loading carrying capacity in RCA specimen was initiated after 30 mm displacement but there was no appreciable loss of loading carrying capacity in NCA specimen until 40 mm displacement. Early disintegration/crushing of concrete in RCA specimen subjected cyclic loading (type-I loading) are responsible for decrease in its load carrying capacity at higher displacement level.



(a) NCA specimen (b) RCA specimen

Fig. 5- NCA and RCA specimens at the end of +/- 50.00 mm for Type-I loading

Fig. 7 shows the damaged NCA and RCA specimens at ± 45 mm displacement subjected to type-II loading. Damage patterns in both the specimens under type-II loading (higher frequency) are significantly different from that under type-I loading (lower frequency). In case of type-II loading, damage is concentrated mainly in beam-column interface in the NCA specimens and joint region witnessed minor cracking. Major damage in RCA specimen is also located in beam-column interface but joint region experienced moderate cracking in this case. Maximum load carrying capacities of both types of specimens are comparable also under type-II loading. Further, rate of decrease in load carrying capacity is very slow in both types of specimens under type-II loading. This behavior may be attributed to lower level of damage of joint region under type-II loading.



(a) NCA specimen

(b) RCA specimen

Fig. 6: Force-displacement hysteresis loop at +/- 50.00 mm for Type-I loading

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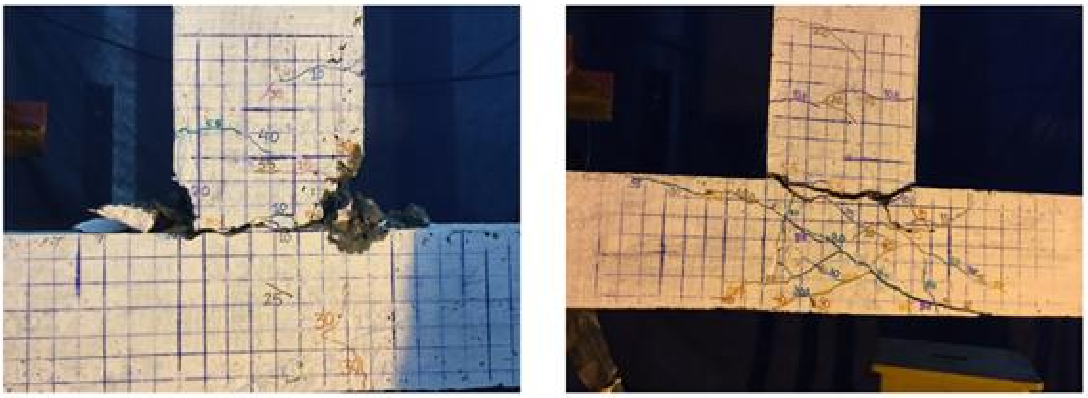


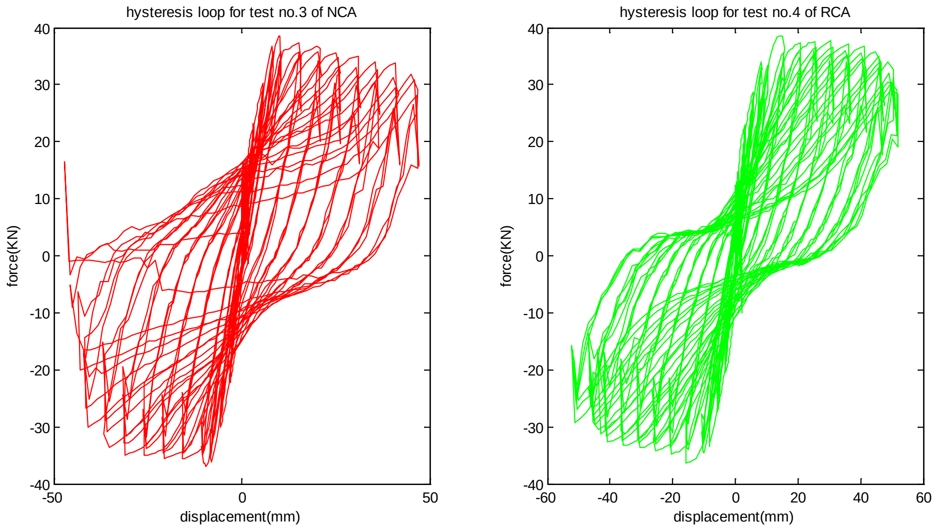
(a) NCA specimen

(b) RCA specimen

Fig. 5- NCA and RCA specimens at the end of +/- 45.00 mm for Type-II loading

3.3 Energy Dissipation

The ability of structural elements to withstand earthquake forces mainly depends on the energy capacity of the structural element. The area under the force-displacement hysteresis loops as shown in Fig. 6 and Fig. 8 is a measure of energy dissipation. The cumulative energy dissipation versus drift angle plots of beam-column connection for NCA and RCA specimens were shown in Fig. 9-10 under both types of loadings. It is observed from Fig. 9-10 that the cumulative energy dissipation values for both NCA and RCA specimens were similar during lower drift levels under both types of loading. However, the difference in the cumulative energy dissipation for both types of specimen increases for both classes of loadings at higher drift levels but the difference is more pronounced for type-I loading.



(a) NCA specimen (b) RCA specimen

Fig. 8- Force displacement hysteresis loops NCA and RCA specimens for Type-II loading

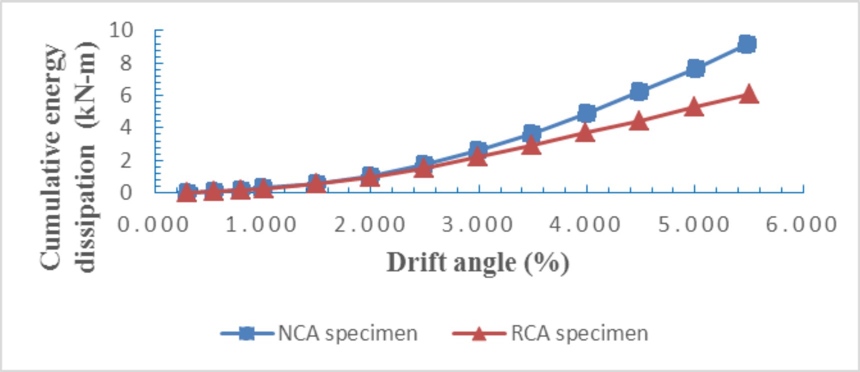


Fig. 9 - Cumulative energy dissipation for Type-I loading

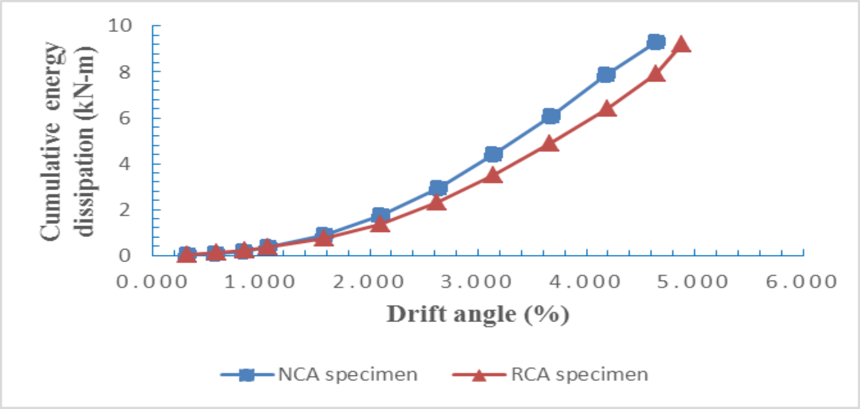


Fig. 10 - Cumulative energy dissipation for Type-II loading

3.4 Stiffness Degradation

Stiffness is defined as the rigidity of the element i.e. the extent to which it resists deformation in response to a applied force. The secant stiffness is the index of the response of the specimen to application of load during a load cycle and it also indicates degradation of rigidity from one cycle to the next one. It was calculated by joining the peak of positive and negative capacity of given cycle. The two points one on positive and the other on negative side of envelope curve are joined by straight line and the slope of this straight provides the stiffness (*K*) of the beam-column connections corresponding to that particular amplitude and it is calculated using Eq. (1).

$$K = \frac{F_D^+ - F_D^-}{D_D^+ - D_D^-} \tag{1}$$

where, F_D^+ and F_D^- are peak loads in push and pull direction respectively
and D_D^+ and D_D^- are peak displacements in push and pull direction respectively

Fig. 11 – 12 show plots of stiffness vs drift angle for NCA and RCA specimens subjected to both types of loadings. It is found that stiffness of RCA specimens at low drift levels is little lesser as compared to that of NCA specimens under both types of loadings. Stiffness degradation patterns beyond 1.5% drift level for both types of specimens subjected both classes of loadings are similar.

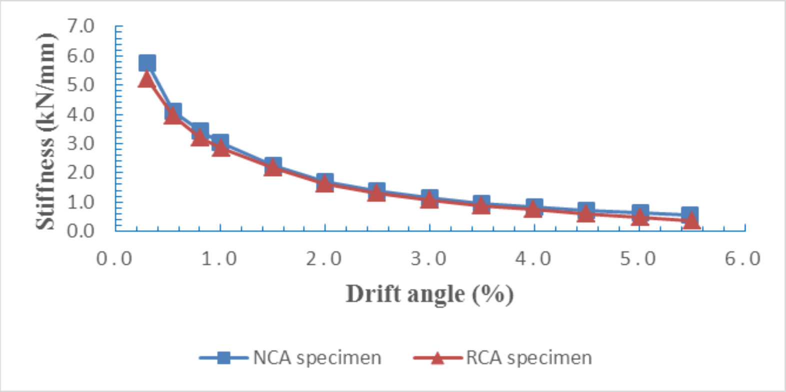


Fig. 11 - Comparison of stiffness under Type-I loading

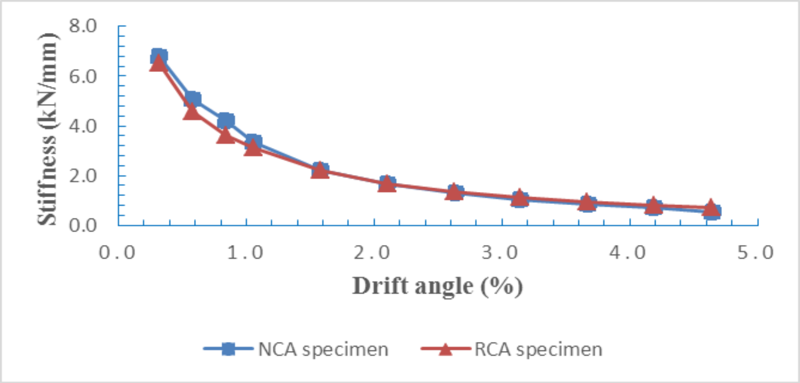


Fig. 12 - Comparison of stiffness under Type-II loading

4. Conclusions

Based on the present study on performance evaluation of NCA and RCA in beam-column connections subjected to cyclic loadings of two different frequencies the following conclusions are drawn:

1. The type of loadings did not affect the maximum load carrying capacity for both NCA and RCA specimens.

2. Level of cumulative energy dissipation in RCA and NCA specimens corresponding to lower drift levels are similar for both low and high frequency loadings. But cumulative energy dissipation is comparatively higher in case of NCA specimen for higher drift level for low frequency loading. For high frequency loading, however, difference in cumulative energy dissipation for both specimens is not very prominent.

3. Stiffness degradation in both types of specimens follows similar trend for both types of loading. For high frequency loading, lower damage was observed for the RCA specimen during last few cycles. This may be due to good ductile property.

4. Comparison of various seismic parameters established suitability of RCA in beam-column connections for buildings having lower drift levels and for buildings situated in zones with low to moderate seismicity.

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