IJE TRANSACTIONS A: Basics Vol. 35 No. 10, (October 2022) 1959-1966

International Journal of Engineering

Journal Homepage: www.ije.ir

Analytical and Experimental Investigation of Recycled Aggregate Concrete Beams Subjected to Pure Torsion

N. Masne*, S. Suryawanshi

Department of Civil Engineering, S. V. National Institute of Technology, Surat, India

PAPER INFO

Paper history:
Received 29 May 2022
Received in revised form 25 June 2022
Accepted 27 June 2022

Keywords:
Atena-3D
Natural Aggregates Concrete
Nonlinear Analysis
Pure Torsion
Recycled Concrete Aggregates
Replacement Ratio

ABSTRACT

This study presents the ATENA-3D simulation of natural aggregate concrete (NAC) and recycled aggregate concrete (RAC) beams subjected to pure torsion and the beam was validated by the experimental results with corresponding outputs. All the test specimens were 150 mm wide, 250 mm, deep and 1800 mm long. The natural coarse aggregate (NCA) were replaced by coarse recycled concrete aggregate (RCA) at three replacement ratios of 0 %, 50 %, and 100 % to prepare concrete. All the beam specimens were simulated and tested to assess the parameters like torque, twist, crack pattern, stiffness, and toughness in pure torsion. The comparison of ATENA-3D and experimental results showed that torque resistance capacity, stiffness, and toughness of beams decreased as the % of RCA increased in the concrete. A similar torque-twist curve pattern was observed in simulation and experimental studies. All the specimens failed due to torsional cracking. The torsional capacity of the beams in ATENA-3D software was higher by 9.80 %, 10.67 %, and 12.80 % than the experimental results. The results reveal that varying the quantity of RCA in RAC does not compromise the pure torsional behavior of the beam in both methods. Also, it can be concluded that the use of RCA in RAC is acceptable for structural concrete beams in pure torsion.

doi: *10.5829/ije.2022.35.10a.14*

1. INTRODUCTION

Crushing of concrete to generate the coarse aggregate for the manufacturing of fresh concrete is a typical method for producing environment friendly concrete for new infrastructure. This conserves natural resources and eliminates the need for waste concrete dumps. The total availability of RCA in India is about 1.8 million tonnes per year[1]. As a new structural material RAC will help practicing as well as a research engineers to predict not only its bearing capacity but also its deformation capability during the course of loading. Under the uniaxial compression, the behavior of normal-strength RAC develops a stress-strain relationship for the same and there is an empirical expression for RAC [1]. The toughness and ductility index of the RAC decreases as the percentage of RCA increases in the concrete. In addition to this, the test results indicated the RCA content has a remarkable influence on the compressive strength of the concrete [2]. The comparison between experimental and numerical results confirmed that the criterion of failure and mechanical behavior of standard concrete will be applicable to RAC and concluded that the performance dependent failure criterion was suitable for concretes with RCA [3]. The RAC made from the tested cubes and precast concrete columns performed satisfactorily and did not vary considerably from the control concrete performance [4]. The mechanical behavior of wall beams made of RAC showed better structural integrity than conventional brick wall beams [5]. According to Sarsam et al. [6], the torsional behavior of RAC beams was found satisfactory when compared to NAC beams and concluded that the use of RAC in structural beams is practically possible in pure torsion. The experimental seismic torsional behavior of the NAC and RAC beams was found satisfactory [7]. The numerical (Abaqus) and experimental analysis of NAC and RAC beams confirm that both the types of the concrete beam were perform well in seismic torsion [8]. With the increased usage of finite element analysis (FEA)

*Corresponding Author Institutional Email: *nsmasne@gmail.com* (N. Masne)

[1] https://cpcb.nic.in/openpdffile.php?id=TGF0ZXN0RmlsZS8xNTlfMTQ5NTQ0NjM5N19tZWRpYXBob3RvMTkyLnBkZg

Please cite this article as: N. Masne, S. Suryawanshi, Analytical and Experimental Investigation of Recycled Aggregate Concrete Beams Subjected to Pure Torsion, ***International Journal of Engineering, Transactions A: Basics***, Vol. 35, No. 10, (2022), 1959-1966

to address complicated issues ANSYS, ABAQUS, ATENA-3D, and some other FEA software were utilized to analyze the structural concrete elements under a variety of loading reported in the literature [9-13]. The ATENA-3D FEM software was also used to investigate the flexural capacity of a slab, and the results were found consistent with experimental data [14]. Except for the investigation by Sarsam et al. [6], there is a shortage of information in the literature on a pure torsional test of RAC beams in analytical and experimental works. The primary purpose of this comparative study was to examine the effect of RCA in RAC beams on the pure torsional behavior under static loading conditions. This objective was accomplished in two stages. The first stage was a structural laboratory test of NAC and RAC beams, where the deflection and load carrying capacity of all beams were measured and translated into torque-twist curves for further investigation. In the second stage, the experimental results were compared with ATENA-3D software results under pure torsion, for which the model for RAC behavior is used from the literature [1].

2. ATENA-3D ANALYSIS- FINITE ELEMENT MODELLING

ATENA-3D is a FEM-based software used to simulate and analyse reinforced concrete structural elements. All processes to generate model geometry, assign material specifications, simulate loading and support conditions, and monitor structural member reaction under applied force are given in detail. The basic idea of FEM modeling is to divide the mathematical model into non-overlapping geometric components. All of the elements' responses are given in the form of a fixed number of degrees of freedom that are described by an unknown function or a collection of nodes. The mathematical model's answer is then a discrete model, formed by linking or assembling all the pieces. As part of the finite element approach, reinforced concrete may either be modelled as a composite (i.e., the concrete and embedded steel) or as a discrete material model (i.e., the concrete and the reinforcing steel). The finite element approach is particularly suited for superimposing material models for composite material components. In ATENA-3D, numerous constitutive models that account for these effects are established. ATENA-3D's graphical user interface (GUI) provides an efficient and potent environment for solving a wide variety of anchoring problems. ATENA-3D enables computer-based simulations of structural tests. This is the current trend in the area of research and development. Material models of this type can be utilized for virtually all forms of reinforced concrete structural components, and they are particularly useful in the design of structures.

3. MATERIAL MODELS

ATENA-3D's material models can be used with different materials. It also allows to use user defined material models which are very helpful to model the material that is not available in its library.

3. 1. Concrete

There are several material models in ATENA-3D's library that depict concrete behavior, but the software allows users to define their own material models. The stress-strain relationship of the structural member's concrete is calculated by testing a specimen under compression. This measured data or any other stress-strain relationship from the literature can be entered into "3D NonlinearCementitious 2 User" to model concrete behavior. Figure 1 shows the user-defined material definition window and the resulting stress-strain curve.

In this study, the 3D FEM simulation software ATENA-3D was utilized to model the experimental results. In order to replicate the behavior of concrete, a smeared crack model, i.e. total strain crack, was chosen since it gives a variable stress-strain relationship for both compression and tension. As illustrated in Figure 1, and Equation (1) the Suryawanshi et al. [2] model was chosen to represent the nonlinear behavior of the concrete in compression for both NAC and RAC.

$$\bar{\sigma} = a(\bar{\varepsilon}) + b(\bar{\varepsilon})^2 + c(\bar{\varepsilon})^3 + d(\bar{\varepsilon})^4 \quad (1)$$

where, $\bar{\sigma}$ (The normalized stress) is the ratio of the stress level under consideration to the peak stress (σ/f_c') and $\bar{\varepsilon}$ (The normalized strain) is the ratio of the strain corresponding to σ and the strain at peak stress$(\varepsilon/\varepsilon_0)$.

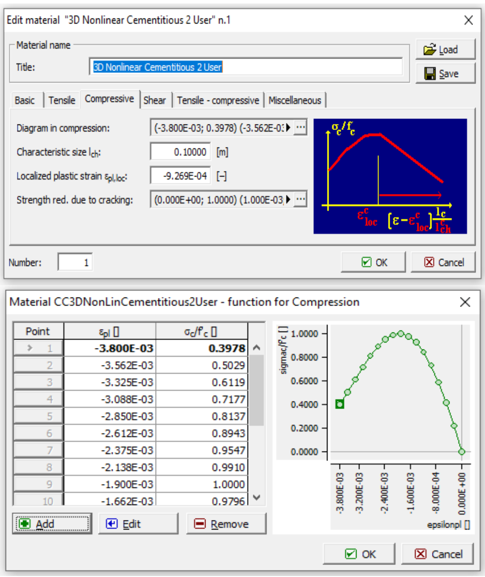


Figure 1. Material model used for concrete

Coefficient a represents the ratio of the initial tangent modulus and the secant modulus corresponding to peak stress (E_{itm}/E_p) and is defined in terms of the RCA replacement level. R is percentage replacement of NCA by RCA.

3. 2. Steel Reinforcement ATENA-3D software allows users to give input actual stress-strain curves of steel reinforcement to mimic its behavior. This provision obviously gives more accurate results compared to that because of the use of an idealized stress-strain relationship for steel. Figure 2 shows the experimental stress-strain curve used as input data for ATENA-3D.

As a result, Figure 3 depicts a comparable stress-strain relationship obtained using ATENA-3D software. It should be noted that additional qualities, such as elastic modulus, are eventually taken care of by ATENA-3D itself on the basis of input data in the form of a stress-strain relationship or empirically determined values.

3. 3. Loading and Supporting Steel Plates 3D Elastic Isotropic material model properties were applied for simulation as shown in Figure 4. This 3D Elastic Isotropic Material model is suggested for the support and loading steel plates because, it is commonly required to avoid any unrealistic stress concentration in nonlinear analysis. As this may cause early cracking or failure in the supporting and loading steel plates. If the support conditions are applied at single nodes, this may create strong stress concentrations affecting the analysis results [10]. The same properties of steel plates were also reported in literature [10, 14].

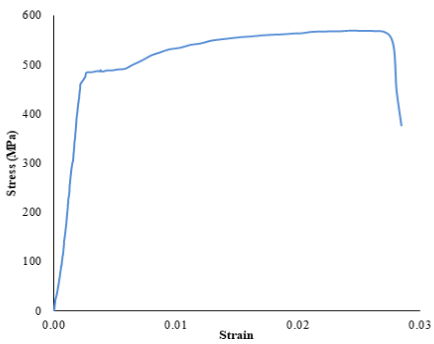


Figure 2. Measured stress-strain relationship for steel rebar, 12 mm diameter

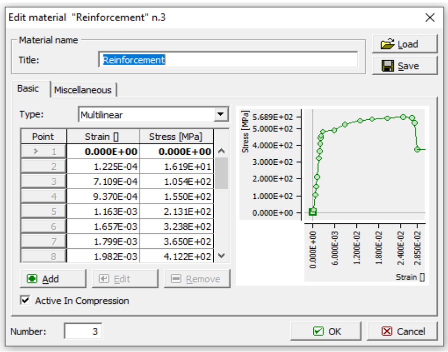


Figure 3. Experimental stress-strain relationship for steel reinforcement

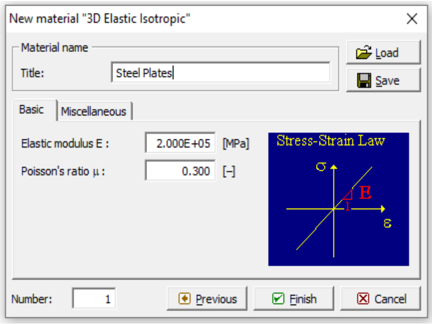


Figure 4. Material properties used for steel plates

3. 4. Geometry Definition Figure 5 shows the geometry of the concrete beam and it was generated with the reinforcement (both longitudinal and transverse) modeled as bar (truss) elements in ATENA-3D software. Thermo-Mechanically Treated deformed steel reinforcement bars were used in the experiments and the same bars were modeled in ATENA-3D. The 2 bars of 10 mm diameter for the top and 3 bars of 12 mm diameter at bottom and 8 mm diameter bar for stirrups at 100 mm spacing were used for all the beam. The 3 bars of 12 diameters were used in the top and bottom of lever arms with 8 mm diameter stirrups with 50 mm spacing, as shown in Figure 6. Steel plates of small thickness were used for loading the beam to simulate the small contact (theoretically line contact) of the loading rollers. At support also steel plates were used as the channel caps were used upon the supporting rollers.

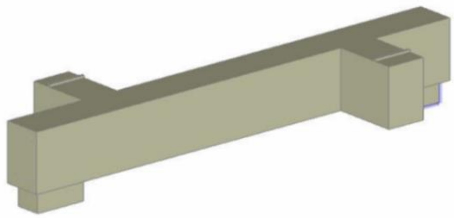


Figure 5. Geometry of the beam specimen in ATENA-3D

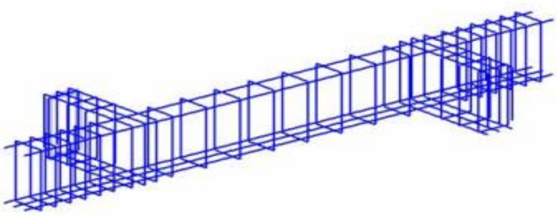


Figure 6. Reinforcement created in ATENA-3D

3. 5. Finite Element Mesh and Element Type Isoperimetric formulations with linear and/or quadratic interpolation functions are used for the majority of ATENA-3D components. The isoperimetric formulation of one-dimensional, two-dimensional, and three-dimensional elements is considered to be one of the "classic" formulations of elements. This is very important, particularly in nonlinear analysis. In ATENA-3D software, 3D solid brick hexahedron and tetrahedron elements can be used to construct FE mesh. The element type (i.e. shape function) is linear or quadrilateral depending on the needed accuracy. Figure 7 depicts the use of tetrahedral elements of 50 mm size in this study.

3. 6. Boundary Conditions, Loading and Monitoring Points The load was applied to the beam models as "prescribed deformation" located in the middle of the loading plate's upper surface. The vertical (i.e., z-direction) movement of the support plate was restrained by line support positioned along the middle line of the plate's bottom surface. As the rollers were free to rotate about the longitudinal axis (i.e. x-direction) only end nodes of the line support were restrained against translation. The monitoring point to record the load was positioned in the center of the top surface of the load plates, where the specified deformation was applied, as depicted in Figure 8. The point of the deflection observers was at the same point where the deflection was considered. After creating the geometry and necessary inputs analysis of the model is done in the processing (run) mode.

4. EXPERIMENTAL INVESTIGATION

4. 1. Materials Grade 53 ordinary portland cement following the requirements of IS: 12269-2013 [15], was used during the experiment. Locally available white river sand complying with zone II of standard IS 383: 1970 (reaffirmed in 2016) [16], was used as fine aggregate (FA) (fineness modulus = 2.85). NCA of nominal maximum size 20 mm conforming to the definite coarse aggregate grading limits of IS 383:1970 (reaffirmed 2016) [16], were used. The RCA was acquired by treating laboratory-tested concrete samples using a mechanical breaker and jaw crusher. RCA was manually blended within the coarse aggregate grading limitations established in IS 383-1970. (Reaffirmed 2016) [16]. There were two size fractions of coarse aggregate: 4.75–10 mm and 10–20 mm used in the experimental work for concrete. The 0 %, 50 %, and 100 % replacement of RCA consider as R0, R50, and R100 concrete for beams. Thermo-Mechanically Treated deformed steel reinforcement bars used in the experiment and simulation were discussed in section 3.4. According to IS 10262 [17], the absolute volume method was used to design all three types of M30 grade NAC and RAC mixture, and IS 456 [18] was followed for the casting of concrete. According to the IS 456 [18], potable tap water was used for the purpose of mixing and curing the concrete. A commercially available polycarboxylic ether-based High-Range Water Reducing admixture (HRWRA), conforming to IS 9103:1999 (1999b) [19], was used to achieve the desired workability of the concrete in this experimental work. Plastic-coated plywood forms were used for torsion beams. 150 mm diameter and 300 mm in length cylinders were used to cast the concrete cylinder for compression and tensile tests. All the beam specimens were covered with gunny bags in the lab on a level surface for 28 days curing. All the cylinders were immersed in a water tank for curing until tested.

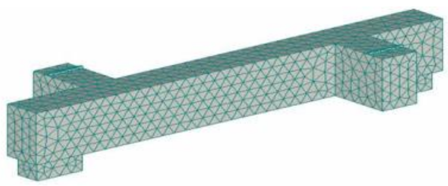


Figure 7. FE mesh of tetrahedral elements

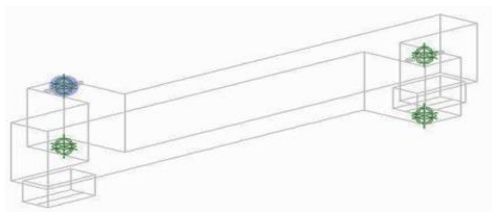


Figure 8. Position of monitoring points to record load and deflection

4. 2. Test Setup and Instrumentation The test setup was designed to test the beam in pure torsion. Figure 9 shows the experimental test setup for testing beams in pure torsion. The tested beams were progressively loaded into the center of the steel spreader beam with a small load increment till failure by a 1000 kN capacity of hydraulic jack. Two lever arms of 250 mm in length,150 mm wide, and 250 mm in depth were provided at 1000 mm distance on the opposite sides of the beam to apply the load at the top and to measure the deflection at the bottom. The beams were supported by rollers and the load was applied through a spreader steel beam resting on loading rollers. Vertical deformations in the reinforced concrete beam were recorded by dual linear variable displacement transducers (LVDTs) located below the lever arms of the torsion span. The data from LVDT and the load sensor were attached to the data acquisition system (DAS). The recorded data were a crack pattern, ultimate torque, and angle of twist for all beams. The ropes were used to tie the hydraulic jack, load cell, and spreader beam for safety purposes which was not affecting the reading, at any stage of testing.

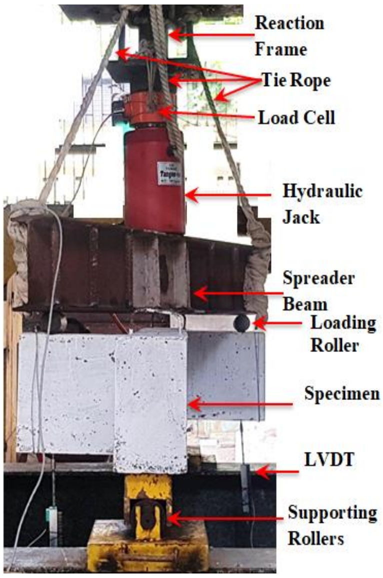


Figure 9. Experimental test set-up for testing beams in pure torsion

5. RESULTS AND DISCUSSION

In ATENA-3D software, a simulation of the NAC and RAC beam was performed using a modified version of the Newton–Raphson method. This modified method maintains equilibrium in the tolerance for displacement iteration and keeps the load increase constant, allowing for accurate loading values. This method creates a set of nonlinear equations using incremental step-by-step analysis, where the stiff matrix of the first equation is used to save time [14]. For optimal results, a mixture of the full and modified Newton–Raphson techniques has been used in practice. Finally, the behavior of modeled beams was studied, including torque-twist behavior, crack patterns and these models results were compared with experimental work in pure torsion.

5. 1. Effect of RCA on Compressive and Tensile Strength of RAC The mean of the three-cylinder test data was used to calculate the compressive and tensile strengths of all three types of concrete. With an increases the percentage of RCA in concrete, compressive and tensile strength decreases, and a similar trend was reported in the literature [6]. Figure 10 compares NCA and RCA concrete compressive and tensile strengths. The results were as expected, i.e., reducing compressive and tensile strength decreased ultimate torque, and confirmed the findings in this work. When the compressive strength of all simulated beams was reduced, the torque resistance capacity significantly changed.

5. 2. Cracking Behavior of NAC and RAC Beams in Pure Torsion The propagation of cracks and

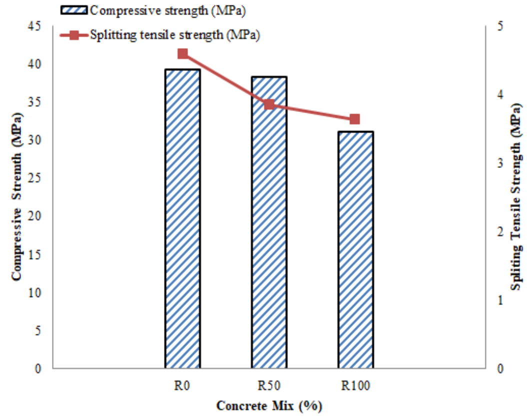
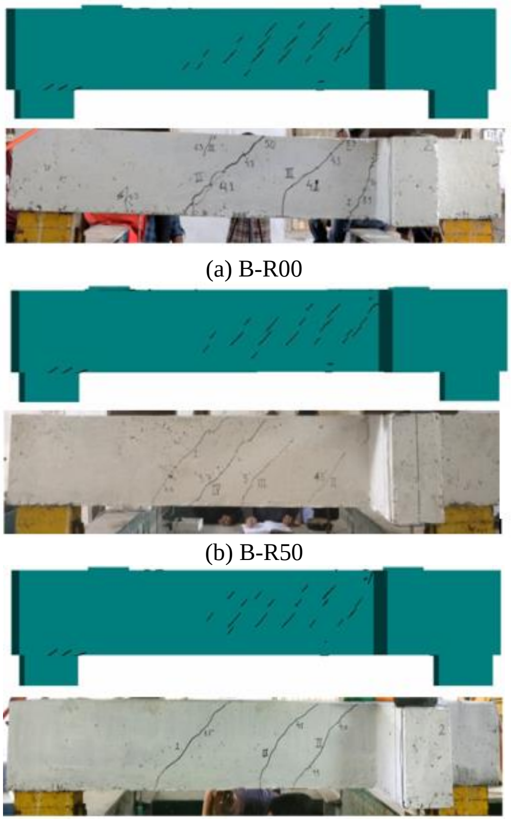


Figure 10. Effect of RCA replacement on compressive strength and tensile strength of concrete

failure patterns were observed as part of this study. At the start of the simulation and experimental test, when the load increased linearly, no cracks were observed in the both methods. The behavior of the beam was generally elastic until it cracked, and torsion mostly resisted by concrete. The cracking patterns generated in ATENA-3D analysis and experientially obtained cracking patterns are existing in Figure 11. It was seen that in all the beams with different percentage of replacement of RCA, the cracking pattern more or less similar, the same failure pattern reported in the literature [8]. The first crack has been generated practically at constant load in the range of 34 to 36 KN in all beam specimens. The first diagonal torsional crack was initiated from the center of longer side of all beams in both method. All the propagated cracks were inclined at an angle of 45° to the longitudinal axis of beam [8]. Number of cracks observed in NAC beams less than the number of cracks in 50 % and 100 % RCA in RAC beams when test was finished. The failure became in the beam with the widening of one of these cracks in both test. However, the peak load was decreased with an increase in the percentage of RCA in concrete. This shows that RAC and NAC beams were behave similarly in ATENA-3D and experiment.

5. 3. Effect on Torsional Strength and Angle of Twist of NAC and RAC Beams Each beam specimen was tested in a load frame in order to measure the torsional capacity and angle of twist and to study the effect of RCA on the RAC beam in pure torsion. The continuous monitoring of each load increment and the corresponding deflection was carried out. The load-deflection data was transformed into torque-twist data and the test results have been compiled for further analysis. The torque resisting capacity and the angle of twist of the tested NAC and RAC beams are reported in Table 1, based on ATENA-3D and experimental data.

The torsional capacity of the beams in ATENA-3D software was higher by 9.80 %, 10.67 %, and 12.80 %,



(a) B-R00

(b) B-R50

(c) B-R100

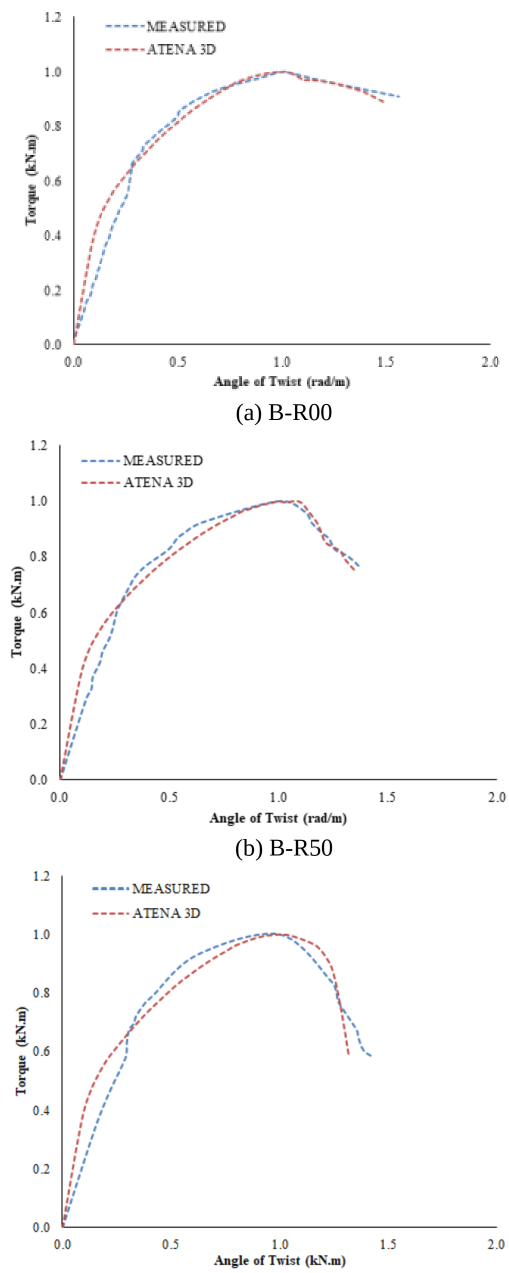
Figure 11. Comparison of measured and ATENA-3D simulated crack patterns at peak load

respectively than the experimental value for 0%, 50%, and 100% replacement of RCA in RAC beams. It should be noted that the torsional capacity of the beam was higher in ATENA-3D than the experimental value. This is because of idealized support conditions. Moreover, the roller supports which were actually used in the experiment could not be modeled in ATENA-3D due to its limitations regarding establishing the line contacts [10].

5. 4. Effect on Torque-Twist Curve of NAC and RAC Beams For all the tested beams, the relationship between torque and angle of twist was as usual, with almost linear behavior followed by nonlinear behavior until failure, as illustrated in Figure 12. It has been observed that the torque-twist curves obtained from the software analysis and experiments were almost similar for NAC and RAC beams, parallel tendency described in the prior works [9]. The experimental and numerical recorded peak value of torsional moment was 9.20 kN.m and 10.20 kN.m for the beam specimen with 0% replacement of RCA, 8.95 kN.m, and 10.02 kN.m for 50% replacement of RCA, and 7.50 kN.m and 8.60 kN.m for 100% replacement of RCA, respectively. The

TABLE 1. Comparison of torque-twist of NAC and RAC beams

Method/Beam ID		B-R00	B-R50	B-R100
Measured	Torque (kN.m)	9.20	8.95	7.50
	Twist (rad/m)	0.044	0.045	0.048
ATENA-3D	Torque (kN.m)	10.20	10.02	8.60
	Twist (rad/m)	0.023	0.023	0.024



(a) B-R00

(b) B-R50

(c) B-R100

Figure 12. Torque-Twist curve for all beam specimens (in normalized form)

measured corresponding angle of twist was 0.044 rad/m and 0.023 rad/m, 0.045 rad/m and 0.023 rad/m and 0.048 rad/m and 0.024 rad/m, respectively. The following salient observations can be placed on record in light of this study. The torque-twist behavior of beams B-R00 and B-R50 were identical until cracking and had an approximately similar trend up to the maximum torque. Then, the B-R50 beam curve turns as the curve of B-R100. The area under the torque-twist curve drops as the level of RCA replacement rises. An addition of RCA in concrete leads to a decrease in slopes of torque-twist curves after the peak, indicating the brittleness nature of the RAC than NAC.

5. 5. Effect on Torsional Stiffness and Toughness of NAC and RAC Beams The torsional stiffness of all the beams was evaluated at ultimate states for analytical and experimental methods, which shown as the % of RCA increases in the concrete the stiffness of RAC beams decreases [7] as shown in Table 2. Because of decreasing the stiffness of beams, the angle of twist increases after the ultimate state in pure torsion for the entire specimen. The analytical stiffness higher than the measured stiffness was observed for all the beams. The toughness is the property of the strength and ductility of beams. It was appropriately considered from the entire area in the torque-twist curve. The toughness was reduced as the % of RCA increased [2] in concrete as depicted in Table 2 for both methods. The experimental torsional toughness was found lower than the analytical values for all the beams.

5. 6. Comparison of Torsional Moment Using Standards In order to assess whether current code provisions on the design of pure torsional members made of NAC are applicable to the RAC members in their present form or not, widely accepted codes such as IS: 456 [18] based on Skew Bending Theory [18, 20] and ACI: 318 [21] which is based on Space Truss Analogy [21-23] and have been considered for comparison. The experimentally measured and ATENA-3D obtained values of ultimate torsional moments were compared with international standards. The outcome of this limited exercise is presented in Figure 12. It has been seen that the entire method gives safe values with varying degrees of accuracy. FEA can be used to predict the behavior of reinforced NAC and RAC beams. Finally, the results reveal that varying the quantity of RCA in the RAC beam does not compromise pure torsional behavior in both methods.

TABLE 2. Torsional stiffness and toughness for measured and analytical method

Method/Beam ID		B-R00	B-R50	B-R100
Stiffness	Measured (kNm^2)	209.09	198.89	156.25
	ATENA-3D (kNm^2)	443.47	435.65	358.33
Toughness	Measured (kNm/m)	1.263	1.039	1.038
	ATENA -3D (kNm/m)	1.303	1.053	1.048

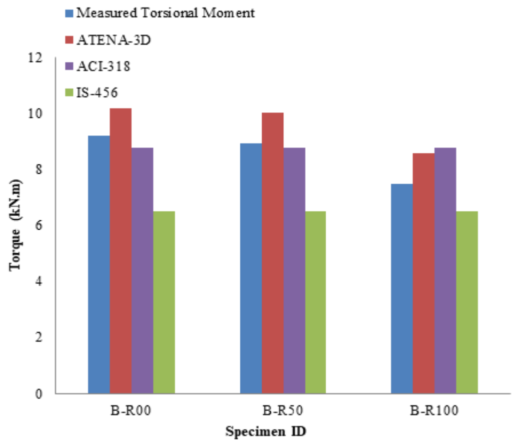


Figure 12. Comparison of torsional moment with different methods

6. CONCLUSION

In this comparative work, the effect of RCA on the pure torsional behavior of RAC beams was numerically investigated and compared with the outcomes of experimental work.

- As the percentage of RCA increased in concrete, the compressive and tensile strength decreased.
- The experientially obtained cracking patterns and cracking patterns generated in ATENA-3D analysis have been compared. It was seen that in all beams with different percentage of replacement of RCA, the cracking patterns were more or less comparable.
- The torsional capacity of the beams in ATENA-3D software was higher by 9.80 %, 10.67 %, and 12.80 %, respectively than the experimental value for 0 %, 50 %, and 100 % replacement of RCA in RAC beams. Both the studies have confirmed that the torsional capacity of the RAC beam was marginally less than the NAC beams.
- The comparison of experimentally obtained torque-twist curves and ATENA-3D analysis torque-twist curves was found similar, however, not identical in nature.
- The stiffness and toughness were reduced as the percentage of RCA increased in RAC in both methods.
- After comparing the torsional moment of the beam with international standards, all beams were given safe values with varying degrees of accuracy.

- The ATENA-3D simulation program can be used to predict the behavior of NAC and RAC beams in pure torsion with due care.
- When comparing these two approaches, the usage of RCA in RAC is suitable for structural concrete beams in pure torsion.

7. REFERENCES

1. Suryawanshi, S., Singh, B. and Bhargava, P., "Equation for stress–strain relationship of recycled aggregate concrete in axial compression", ***Magazine of Concrete Research***, Vol. 70, No. 4, (2018), 163-171. https://doi.org/10.1680/jmacr.16.00108
2. Suryawanshi, S., Singh, B. and Bhargava, P., Characterization of recycled aggregate concrete, in Advances in structural engineering. 2015, Springer.1813-1822.
3. Folino, P. and Xargay, H., "Recycled aggregate concrete–mechanical behavior under uniaxial and triaxial compression", ***Construction and Building Materials***, Vol. 56, No., (2014), 21-31. doi. https://doi.org/10.1016/j.conbuildmat.2014.01.073
4. Malešev, M., Radonjanin, V. and Marinković, S., "Recycled concrete as aggregate for structural concrete production", ***Sustainability***, Vol. 2, No. 5, (2010), 1204-1225.
5. Zhang, M., Fu, X.J., Wu, Y. and Sun, H., "Test study on the mechanical behavior of recycled aggregate concrete wall-beam", in Applied Mechanics and Materials, Trans Tech Publ. Vol. 351, No. Issue, (2013), 260-263.
6. Sarsam, K.F., Salih, N. and Hussein, M., "Assessment of reinforced recycling aggregate concrete beams under torsional moment", ***International Journal of Engineering & Technology***, Vol. 7, No. 4.20, (2018), 623-628. doi: 10.14419/ijet.v7i4.20.27403.
7. Wang, X., Liu, B. and Zhang, C., "Seismic behavior of recycled aggregate concrete beams under cyclic torsion", ***Construction and Building Materials***, Vol. 129, (2016), 193-203. doi. http://dx.doi.org/10.1016/j.conbuildmat.2016.10.101
8. Fu, J.L., Liu, B.K., Ma, J.W. and Zhou, H., "Experimental study on seismic behavior of recycled aggregate concrete torsion beams with abaqus", in Advanced Materials Research, Trans Tech Publ. Vol. 1079, (2015), 220-225.
9. Cervenka, V. and Cervenka, J., "Atena program documentation– part 2-2: User's manual for atena3d", ***Prague, República Theca***, (2003).
10. Červenka, J., Procházková, Z. and Sajdlova, T., "Atena program documentation, part 4-2, tutorial for program atena 3d", ***Cervenka Consulting, Prag***, (2013).
11. Phani Prasanthi, P., Sivaji Babu, K. and Eswar Kumar, A., "Waviness effect of fiber on buckling behavior of sisal/carbon nanotube reinforced composites using experimental finite element method", ***International Journal of Engineering***, ***Transactions C: Aspects,*** Vol. 34, No. 12, (2021), 2617-2623. https://doi.org/10.5829/ije.2021.34.12C.06
12. Shadmand, M., Hedayatnasab, A. and Kohnehpooshi, O., "Strengthening of rc beams using steel plate-fiber concrete composite jackets (finite element simulation and experimental investigation)", ***International Journal of Engineering***, ***Transactions A: Basics***, Vol. 35, No. 1, (2022), 73-92. https://doi.org/10.5829/ije.2022.35.01a.07
13. Beiram, A. and Al-Mutairee, H., "Effect of using waste rubber as partial replacement of coarse aggregate on torsional strength of square reinforced concrete beam", ***International Journal of Engineering***, ***Transactions B: Applications***, Vol. 35, No. 2, (2022), 397-405. https://doi.org/10.5829/ije.2022.35.02b.16
14. Kaur, S., Kaur, P., Kaur, I. and Gupta, S., "Nonlinear analysis of two-layered shcc and reinforced concrete composite slabs", ***Innovative Infrastructure Solutions***, Vol. 7, No. 1, (2022), 1-11. https://doi.org/10.1007/s41062-021-00654-2
15. "Bis is12269-13, ordinary portland cement, 53 grade-specification, bureau of indian standards", (2013).
16. "Bis is383-1970 [reaffirmed 2016], specification for coarse and fine aggregates from natural sources for concrete, bureau of indian standards, " (2016).
17. "Bis is10262-09, concrete mix proportioning-guidelines, bureau of indian standards, " (2009).
18. "Bis (bureau of indian standards) is 456: 2007 'indian standard plain and reinforced concrete code of practice', bureau of indian standards, new delhi ", (2007).
19. "Bis is9103-99, concrete admixtures specification, bureau of indian standards," (1999).
20. Subramanian, N., "Design of reinforced concrete structures.1st ed. , Oxford University Press:, (2013), 306-333.
21. Wight, J., Barth, F., Becker, R., Bondy, K., Breen, J., Cagley, J., Collins, M., Corley, W., Dolan, C. and Fiorato, A., "Aci committee 318," building code requirements for structural concrete (aci 318-05) and commentary (aci 318r-05)", ***Am. Concr. Institute, Farmingt. Hills, MI***, (2003), 430.
22. Wight, J.K. and MacGregor, J.G., "Reinforced concrete, Pearson Education UK, (2016).
23. Pillai., S., U. and Menon, D., "Reinforced concrete structures., Tata mcgraw-hill, (2009).

Persian Abstract

چکیده

این مطالعه شبیه‌سازی ATENA-3D از بتن سنگدانه طبیعی (NAC) و تیرهای بتن سنگدانه بازیافتی (RAC) را ارائه می‌دهد که در معرض پیچش خالص قرار گرفته‌اند و تیر با نتایج تجربی با خروجی‌های مربوطه تأیید شد. تمام نمونه های آزمایشی دارای عرض ۱۵۰ میلی متر، عمق ۲۵۰ میلی متر و طول ۱۸۰۰ میلی متر بودند. سنگدانه درشت طبیعی (NCA)با سنگدانه بتن بازیافتی درشت (RCA)در سه نسبت جایگزینی ۰٪، ۵۰٪ و ۱۰۰٪ برای آماده سازی بتن جایگزین گردید. تمام نمونه‌های تیر برای ارزیابی پارامترهایی مانند گشتاور، پیچش، الگوی ترک، سختی و چقرمگی در پیچش خالص، شبیه‌سازی و آزمایش شدند. مقایسه ATENA-3D و نتایج تجربی نشان داد که ظرفیت مقاومت گشتاور، سختی و چقرمگی تیرها با افزایش درصد RCA در بتن کاهش می‌یابد. الگوی منحنی گشتاور–پیچش مشابهی در شبیه‌سازی و مطالعات تجربی مشاهده شد. تمام نمونه ها به دلیل ترک خوردگی پیچشی شکست خوردند. ظرفیت پیچشی تیرها در نرم افزار ATENA-3D به میزان ۹/۸۰ درصد، ۱۰/۶۷ درصد و ۱۲/۸۰ درصد بیشتر از نتایج تجربی بود. نتایج نشان می‌دهد که تغییر مقدار RCA در RAC رفتار پیچشی خالص تیر را در هر دو روش به خطر نمی‌اندازد. همچنین می توان نتیجه گرفت که استفاده از RCA در RAC برای تیرهای بتنی سازه ای در پیچش خالص قابل قبول است.