NUMERICAL INVESTIGATIONS ON RECYCLED AGGREGATE RC BEAMS

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Abstract

One of the major challenges in our present society is the protection of environment. Some of the important elements in this respect are reduction in the consumption of energy and natural raw materials. The use of recycled aggregates from construction and demolition waste has been receiving increased attention in recent sustainable construction environment. However the question that needs to be addressed is whether one can consistently produce good quality concrete using recycled aggregates (RA). Strength, stiffness and durability characteristics of structural components built using recycled aggregates are required to be studied carefully. Towards this, a static nonlinear finite element analysis is carried out to understand the behavior of reinforced concrete beam made with Recycled aggregate to the extent of 50% replacement of total aggregate volume. Flexural load is applied on the beams. The capacity in terms of strength and stiffness are discussed. Equivalent stress strain graph is derived using moment curvature relationship. Equivalent model is validated by comparing with experimental results available in literature. Response from numerical investigation indicates that Recycled aggregate can be used as structural members.

***Keywords:** - Recycled aggregates, Construction and demolition waste, Reinforced concrete, Moment curvature, Equivalent Stress strain relationship, nonlinear analysis*

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1. INTRODUCTION

Continuous exploitation of non renewable resources and treating millions of tones of construction and demolition waste are the current challenges that must be addressed by the construction industry. In developing countries like India, there is a large amount of construction and demolition waste generation due to two main factors called Urbanization and Modernization. In India 25% of total solid waste generated is from construction Industry. It is also estimated that nearly 750 million cubic meters of coarse aggregate required for future Infrastructure development. Use of demolished concrete has been limited to nonstructural purpose, road construction and mainly used as landfill. The recycling of demolition waste as aggregates is a best alternative that can reduce the need of disposal and can be used for construction and maintenance, where there is a shortage of raw aggregates [1]. Therefore, recent studies indicate that use of recycled coarse aggregate obtained from building demolition waste helps to transform traditional concrete into sustainable material. This paper presents the details of the nonlinear static analysis of the beam made with partial replacement of recycled aggregate carried out using ANSYS software by representing the material characteristics with suitable equivalent stress- strain curve for different mix proportions. The response in terms of strength and stiffness is compared to understand the behavior of beam made using normal aggregate recycled aggregate concrete. Recent research of Chakradhara et al., [2] examines the behavior of reinforced concrete members containing different percentage of recycled aggregates under impact load. Their results do not show any major difference in resistance with 25% RCA and normal concrete. They found the reduction in impact resistance with increase in percentage of recycled coarse aggregate.Theoretical models were produced to predict the flexural failure of reinforced concrete beams under blast loads by G.Carto & F.Stochino., [3]. Two approaches were discussed for the study of Reinforced Concrete beams. In first approach, the beam is modeled and its elastic-plastic behavior is expressed through non linear Bending moment & Curvature relationship. Simplified Approach for Finite Element Analysis of Laced Reinforced Concrete Beams was discussed by N.Anandavalli et al., [4] they proposed a new approach for finite element modeling by considering RC as a homogeneous material whose stress-strain characteristics are derived based on the Moment- Curvature relationship of the structural component. The proposed approach can be extended to ordinary RC by modifying the ultimate stress strain values. Au et al., [6] have clearly explained the two dimensional nonlinear finite element procedures which are based on secant modulus approach, for the analysis of reinforced concrete beams under cyclic loading.

2. METHODOLOGY

2.1 Moment-Curvature Relationship

The flexural behavior of a reinforced concrete cross-section (a non-linear material) can best be studied by using its moment-curvature relationship.The relationship between the moment and curvature of reinforced sections is a very important parameter for nonlinear analysis of RC framed structure. A clear view of the strength, stiffness, ductility, and energy dissipation capacity can be obtained from this relationship. The moment-curvature relationship for the beam element is generated using well-established procedure using the idealized stress-strain characteristics of concrete and steel, as given in IS 456:2000 (7) and shown in Fig. 1, respectively. The moments and corresponding curvatures are calculated for the following stages

1. When the strain in concrete in the extreme tension fibre reaches the cracking strain (*Mcr* and F*cr*);
2. When the strain in steel reaches the strain corresponding to the stress of *fy* (*Mfy* and F*fy*);
3. When the strain in concrete in the extreme compressive fibre reaches a value of 0.0035 (*Mc* and F*c*); and

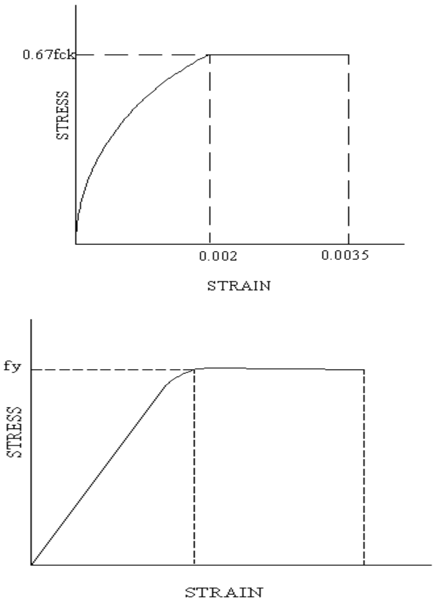

Fig-1: Stress–strain curve for concrete and steel reinforcement [7]

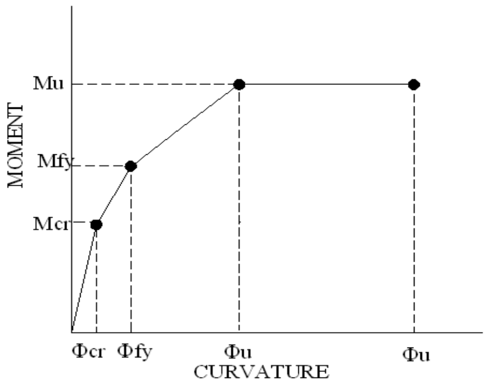

Fig -2: Moment Curvature relation [4]

The cracking moment *Mcr & Φcr* for the beam element is given by

$$M_{cr} = (f_{cr} * I_t)/ (D/2) \quad (1)$$

$$\Phi_{cr} = M_{cr} / (E_c * I_t) \quad (2)$$

Where f_{cr} is modulus of rupture; I_t is transformed moment of inertia; D is the overall depth; E_c is modulus of elasticity of concrete.

2.2 Derivation of Equivalent Stress Strain Relation

The multi-linear moment-curvature relationship, as shown in Fig-2, can easily be obtained from sectional properties. Conventionally, steel and concrete are modelled as separate entities and different material models are used directly. In this study, the single material model using an equivalent stress-strain relationship for RC beams is proposed. The equivalent stress-strain relationship for a RC element is derived from the moment-curvature relationship. Stress-strain characteristics are considered to be multi-linear. The equivalent stress and strain at the first stage corresponding to concrete cracking is obtained by

$$\sigma_{cr} = 6\, M_{cr} / bD^2 \quad (3)$$

$$\varepsilon_{cr} = \Phi_{cr} (D/2 \quad (4)$$

For any stage i, $\sigma_i = 6\, M_i / bD^2$ (5)

$$\varepsilon_i = \Phi_i (D/2) \quad (6)$$

2.3 Finite Element Modeling

A problem is taken from the experimental work reported in literature. The experimental work is carried out on reinforced concrete beam under simply supported conditions [6]. From the available literature, the geometric and material properties are taken. The beam considered in this investigation is 200 x 300mm in cross section with an overall length of 3000 mm. The beam is reinforced with 3 numbers of 16 mm diameter rods in longitudinal direction on both tension and compression faces. Geometry is modeled using equivalent property approach. Beam model is created using 2D line element. Plastic Beam 23 is a uniaxial element with tension, compression and bending capabilities. It is a two dimensional element, which has three degrees of freedom per node. As per finite element concept, the model is discretized into very fine elements of size 10mm. Line meshing is used. This type of mesh divides the full model into uniform size elements. This composite structure is modeled by equivalent property approach in which concrete and steel acts together as a single equivalent model. In this case, the bond slip effect is neglected. The element connectivity was ensured before solving. The boundary conditions are given after meshing. Simply supported condition is adopted. Then nonlinear solution options are given. The analysis is performed using Newton–Raphson solution procedure. Frontal solver is used.

3. VALIDATION

The boundary condition of the beam is assumed as simply supported in this validation. Table 1 and Table 2 shows the material properties obtained from the experiments. Chart -1 shows moment curvature relation and Chart -2 shows the equivalent stress strain curve of the reinforced concrete beam [6]. After the model is created, a nonlinear finite element analysis is carried out. From the analysis, the behavior of specimen is obtained. Load–displacement response of reinforced concrete beam is shown in Chart -3.

Results are found to be in approximate comparison with that of experimental results, thus validating the numerical model.

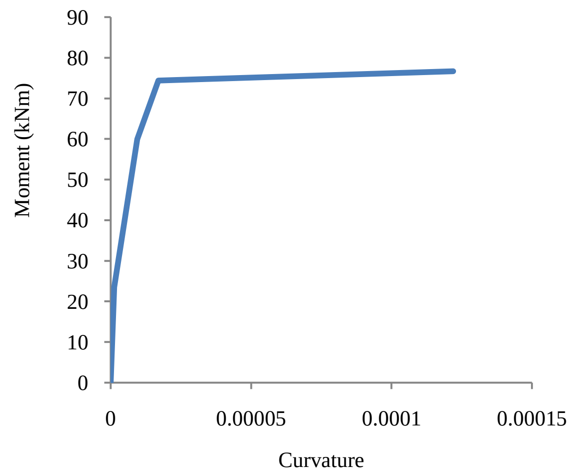

Chart -1: Moment–curvature (M52 grade)

Table -1: Parameters taken for the validation study (literature)

Parameters	**Dimensio**	**units**
Breadth of beam	200	mm
Depth of beam	300	mm
Span	3000	mm
Diameter of the bar	16	mm
Cover	25	mm
Yield strength of steel	488	N/mm^2
Compressive strength of concrete	52	N/mm^2
Young's modulus of concrete	27000	N/mm^2
No. of rods at bottom & top	3	
Young's modulus of steel	200000	N/mm^2
Young's modulus of concrete	27000	N/mm^2
Load carrying capacity	68.44	KN/m
Spacing of stirrup c/c	150	mm

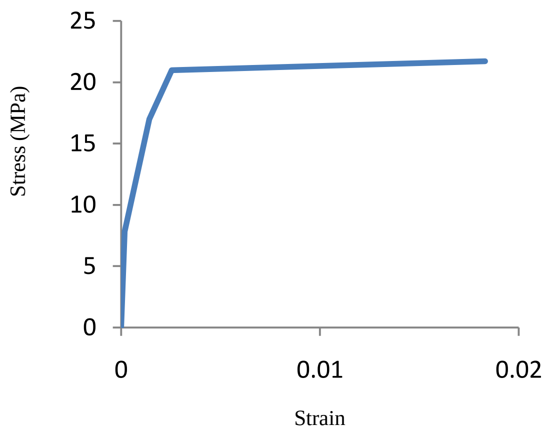

Chart -2: Stress–strain curve (M52 grade)

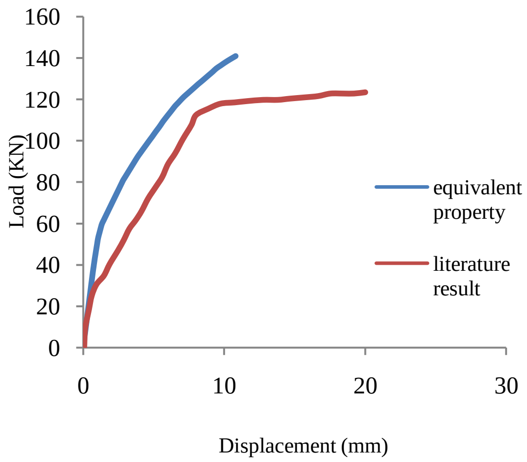

Chart -3: Load versus displacement response of RCBeam[6]

4. NUMERICAL STUDY

Two cases of beams are taken. Case 1 represents 0% replacement of coarse aggregate with recycled aggregate whereas Case 2 indicates 50% replacement of coarse aggregates with recycled aggregate.

Table -2: Material properties of recycled aggregate concrete RMB-0

Parameters	**Dimension**	**units**
Breadth of beam	250	mm
Depth of beam	400	mm
Span	5000	mm
Diameter of the bar	16	mm
Cover	25	mm
Yield strength of steel	415	N/mm^2
Compressive strength of concrete	45	N/mm^2
Density of Concrete	25	KN/m^3
No. of rods at bottom	3	
No. of rods at top	2	
Young's modulus of steel	200000	N/mm^2
Young's modulus of concrete	29000	N/mm^2
Load carrying capacity of beam	50	KN/m
Spacing of stirrup c/c	150	mm

Table -3: Material properties of recycled aggregate concrete RMB-50

Parameters	**Dimension**	**units**
Breadth of beam	250	mm
Depth of beam	400	mm
Span	5000	mm
Diameter of the bar	16	mm
Cover	25	mm
Yield strength of steel	415	N/mm^2
Compressive strength of concrete	44.25	N/mm^2
Density of Concrete	25	KN/m^3

No. of rods at bottom	3	
No. of rods at top	2	
Young's modulus of steel	200000	N/mm^2
Young's modulus of concrete	28000	N/mm^2

Numerical simulation is carried out. After calibrating the results with the experiments, the virtual tests using ANSYS was done for 50% replacement of recycled aggregate. The geometry of the specimens is 250x400mm. The beam is reinforced with 3, 16 mm diameter rods in tension face and 2, 16 mm diameter rods in compression face. Chart -4 shows the moment curvature relation where as Chart -5 shows the equivalent stress strain property for recycled aggregate concrete with 0% and 50% replacement [5]. The material properties of the recycled aggregate concrete are listed in Table 3 & Table 4.

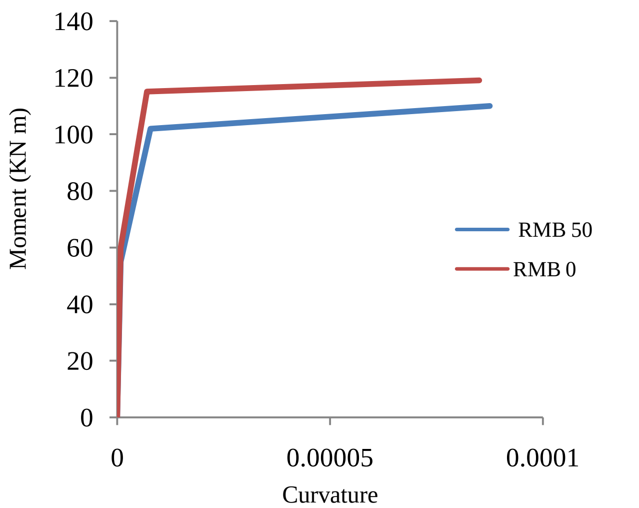

Chart -4: M-Φ curve

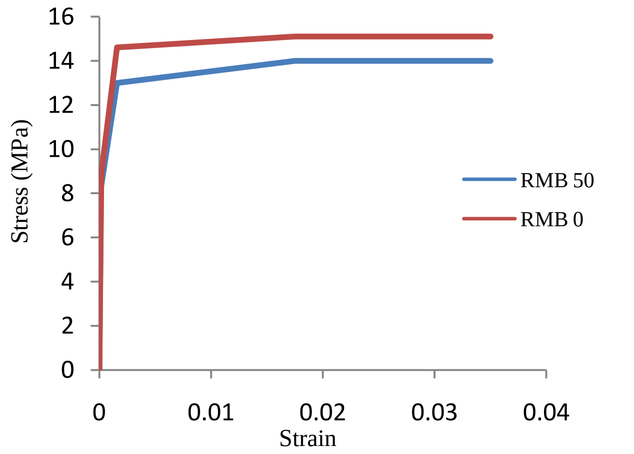

Chart -5: Stress–strain curve

5. RESULTS AND DISCUSSIONS

The behavior of reinforced concrete beams that contains recycled aggregate is investigated in this paper in terms of deflection, stress and ductility.

The following results may be drawn from the validation and numerical studies

i) The model is created using ANSYS and validated using experimental results. Maximum variation between the experimental and predicted loads was around 15%. This variation is probably due to effects of bond slip between the concrete and steel rod which is neglected in numerical model.

ii) It is also because of the equivalent property approach used whereas solid element approach is used for the same problem in literature. The displacement at peak load varies by about 15% between 0% and 50 % replacement of recycled aggregate. It is observed that displacement is higher in RMB-50.

iii) The results from the investigation suggest that reinforced concrete beams built with recycled aggregate can be used as a load- bearing structural elements. Further investigations are required to ensure the maximum percentage of replacement.

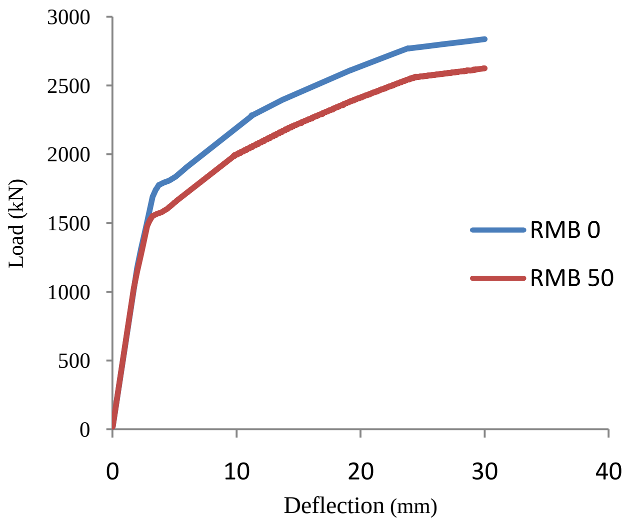

Chart -6: Load versus displacement M35 RMB (0 & 50)

6. CONCLUSION

In this paper, numerical investigations on RC beams with recycled aggregates are carried out to understand the behavior of recycled aggregate concrete beams. A nonlinear finite element analysis is performed and the behavior of beams is studied for normal recycled aggregate concrete and recycled aggregate concrete with 50 % replacement. Responses from analysis on RAC beams indicate that recycled aggregate can be used in structural elements, while the allowable percentage of replacement of recycled aggregate needs further investigation.

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