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Research Article

FINITE ELEMENT ANALYSIS OF RECYCLED AGGREGATE SLAB UNDER STATIC LOADING USING ABAQUS

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A B S T R A C T

This paper present the ABAQUS program is used to model the behaviour of reinforced concrete (RC) slab subjected to static loading. The Nonlinear finite element model uses the concrete damaged plasticity (CDP) approach. The model used in the present study can help to compare the experimental investigations under considerations as a valuable data for the design aspect. Four test slab specimens of size 600X600X60mm with four different mixes with partial replacement of Natural coarse aggregate with Recycled coarse aggregate (RCA) and Treated recycled coarse aggregate (TRCA) were modeled in ABAQUS 6.14 to study first crack load, ultimate load and load deflection behavior, Hence, the Nonlinear finite element models can simulate the behavior of recycled aggregate slab under static loading condition and with good agreement with that of experimental obtained results.

INTRODUCTION

Every Construction begins with Destruction. The deposition of construction garbage which is increasingly accumulated due to various causes such as demolition of old construction is also an environmental concern. one of the fastest growing industries is construction and it is expected to continue growing exponentially with the increase in urban population. In order to eliminate the problem of waste is by reusing, recycling and reducing the construction materials in activities of construction. The use of recycled coarse aggregates (RCA) in structural concrete reduces the aggregates transportation distances, CO_2 emissions, and landfill space required for the construction waste material by enhancing the protection of the natural environment in a sustainable way.

The Finite Element Analysis (FEA) is the simulation of any given physical phenomenon using the numerical technique called Finite Element Method (FEM). Engineers use FEA software to reduce the number of physical prototypes and experiments and optimize components in their design phase to develop better products, faster while saving on expenses. The use of FEA tools has become widespread due to increased computation power and the ability of FEA software packages to simulate incredibly complicated components, structures and systems under a wide variety of situations and loading conditions.

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Very few analytical investigations have been conducted under static loading for concrete slab that contain combination of untreated and treated recycled coarse aggregates. So, in this study a Finite element analysis is carried out using ABAQUS 6.14.

LITERATURE REVIEW

The present analytical analysis is concentrated on static loading of slab using RCA and treated RCA as partial replacement for NCA concrete. Numerous researches focused their studies on Recycled aggregate concrete and analytical investigation using Finite element method of Reinforced Concrete components.

The Properties of recycled concrete aggregate under different curing conditions (air, water, paint) and increasing the concrete age led to an increase in its ultimate strength. According to the Madan Mohan Reddy [6], investigated the use of construction and demolition waste as a Recycled Concrete Aggregate (RCA) in the production of new concrete. The studies were conducted with an M20 mix with the selected w/c ratio:0.5 and the development of compressive strength of the RAC and NAC at the age of7 & 28 days were assessed. The result shows the compressive strength of RAC is on average 87% of the NCA and the Slump of RAC is low and that can be improved by using Saturated Surface Dry condition of RCA [3,4] Conducted an experimental study on recycled aggregate concrete obtained from the construction demolition waste and used it as a full replacement for natural coarse aggregate with mix ratio 1:2:4 and w/c of 0.5, and carried out compressive strength test at 7,14,21, 28 days. The 28 days compressive strength of 12 batches of recycled aggregate concrete which they have obtained is 29.42 N/mm^2 which were greater than characteristic compressive strength of 25 N/mm^2. The experimental and the theoretical studies about the elasticity modulus and energy capacities. A. M Mahmoud[5] ,worked on the behavior of flat slab with and without punching shear reinforcement on various parameter such as column size, slab thickness and punching shear reinforcement system. A parametric study was performed and experimental results are compared with the FEM model in ANSYS[4] [6] used the ABAQUS program to model the behaviour of reinforced concrete (RC) beams. The size of beam used was 305 X 770 X 6095mm and was modelled in ABAQUS using model proposed by Saenz [13]. The results indicated that the displacement, tensile strain for the main reinforcement, compressive strain for concrete and crack patterns obtained from the finite element model (FEM) are well matched with the experimental results. A 3D model of a concrete cube was prepared using smeared crack model and concrete damage plasticity approach by [7]. A comparative study for cube of size 150mm modelled in ABAQUS using C3D8 element was done using different models and their results were discussed. [8] presented a finite element analysis of eight identical beams of size 150 X 300 X 1960mm for the effect of retrofitting with Carbon fiber reinforced polymer. A nonlinear finite element analysis was carried out using stress strain relationship proposed by Saenz[15]. The analyses results showed good agreement with the experimental data regarding load–displacement response, crack pattern and debonding failure mode when the cohesive bond model was used. The perfect bond model failed to capture the softening behaviour of the beams. There is no significant difference between the elastic isotropic and orthotropic models for the CFRP. [11] Investigated on the vulnerability of the flat slab-column connection subjected to lateral loading. It is checked through the analyses of finite element analysis. The finite element analyses have been conducted with ABAQUS software. Elastoplastic CDP model is used a material modelling for the reinforced concrete. The concrete damage plasticity model and linear elastic plastic model are used in this study. Mesh size adopted here is 10 mm. It is found that thickness of the slab, reinforcement ratio, usage of bent bars, high strength materials are the important factors in punching shear failure in the slab column connection. [13] worked on studying the modeling of 3D cube in the general purpose software ABAQUS using smeared crack model and CDP model approach. A monotonic loading is applied. Experimental results are compared with the numerical analysis results. Both the model is predicting good but CDP model is hugely dependent on the mesh size. As it over predicts the stress value for the particular mesh size and when the mesh size is reduced by certain amount stress value also reaches to the actual desirable value.

Hence an attempt has been made in the present study to validate existing Finite element model with [8] in ABAQUS 6.14 and the same concrete damaged plasticity model is used to compare the experimental results obtained.

Experimental Work

As from the experimental results obtained for reinforced aggregate concrete was prepared by partial replacement of crushed concrete coarse aggregates with natural coarse aggregates. The study also includes treating the recycled concrete aggregates with Nitoflor Lithurin (basically mixture of sodium silicate and lithium silicate solutions) to enhance the surface properties of RCA.

Twelve identical slab of size 600X600X60mm as shown in Figure 1 with four different mixes (i) S 1:100%NCA (conventional concrete of grade M-25) (ii) S-2:50% TRCA+50%NCA (M-25 grade concrete made using 50% treated recycled concrete aggregate and 50% natural coarse aggregate)(iii)S3:50%TRCA+30%NCA+20%RCA,(M-25 grade concrete made using 50% treated recycled concrete aggregate, 30% natural coarse aggregate and 20% recycled concrete aggregate) and(iv) S-4: 80%NCA+20%RCA (M-25 grade concrete made 80% natural coarse aggregate and 20% recycled concrete aggregate) were casted and tested for static loading behaviour at Department of Civil Engineering, UVCE, Bangalore University, Bengaluru, and Karnataka, India.

load-deflection curve for all the four slab is presented in the Figure 2. The results like *as* first crack load, ultimate load and load deflection behavior, ductility index, energy absorption capacity, toughness index, cracking moment and punching shear are determined and also the theoretical and experimental load were compared.

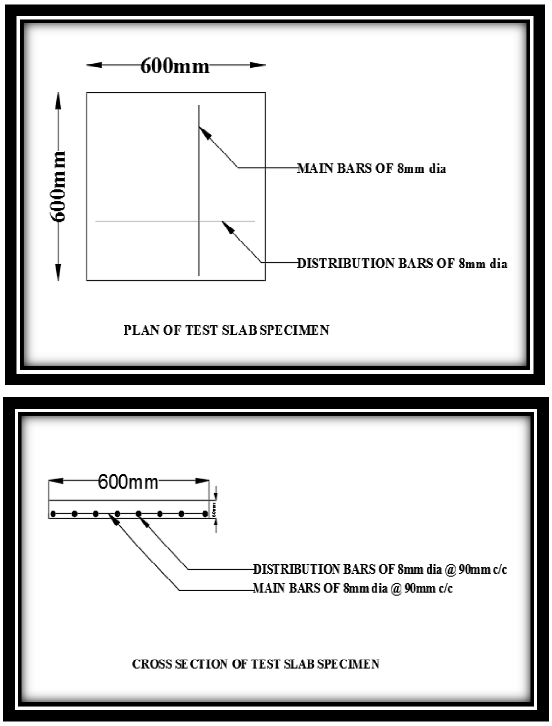

Fig 1 Geometry, reinforcement of the tested slab

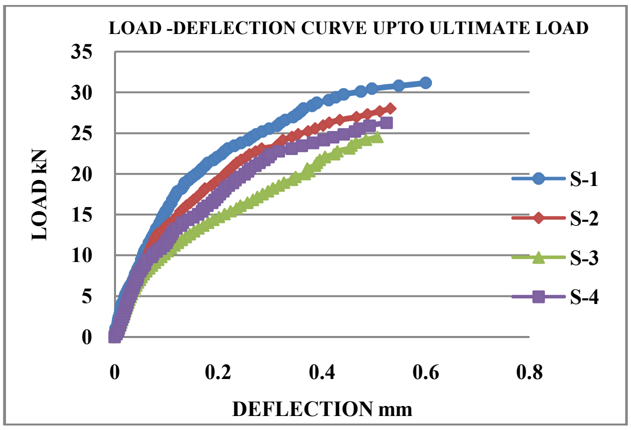

Fig 2 Experimental load-deflection curve of all specimens

Finite Element Analysis

Finite element analysis was performed to model the nonlinear behaviour of the recycled aggregate slab of size 600X600X60mm for four different matrices (i) S-1 (conventional concrete 100% NCA), (ii)S-2 (50% TRCA +50% NCA containing concrete) (iii)S-3 (50% TRCA+30% NCA+20% RCA containing concrete) and (iv) S-4 (80% NCA +20% RCA containing concrete). The FEA package ABAQUS 6.14 was used for the analytical analysis of static load of recycled aggregate slab.

Material Properties and constitutive Models used

Concrete

Concrete is defined as an isotropic material before yielding and cracking model is defined for nonlinear analysis. 3D solid element is used for modelling of concrete as C3D8R which indicates eight nodes in three degrees of freedom in x,y and z directions. The compressive strength obtained from experimental studies f_{ck} is 31.7N/mm^2. The linear properties used in ABAQUS 6.14 for the analytical analysis are shown in Table 1.

Table 1 Linear Properties of Concrete

Parameter	Value
Concrete Density	2500 kg/m^3
Young's Modulus	$5000X\sqrt{f_{ck}}$=28,151.37N/mm^2
Poisson's ratio	0.17

To predict the behaviour of concrete, non-linear analysis using Concrete damage plasticity model because it uses concepts of isotropic damage elasticity in conjunction with isotropic tensile and compressive plasticity to represent the inelastic behaviour of concrete.

The parameters for nonlinear behaviour of concrete used in ABAQUS 6.14 are shown below.

Table 2 Nonlinear properties of concrete

Parameter	Value
Dilation angel (φ)	35°
Plastic potential eccentricity (e)	0.1
Initial biaxial/uniaxial ratio (f_{bo} / f_{co})	1.16
Shape of the loading surface (K_c)	0.66
Viscosity parameters	0

The stress strain relationship for compressive behaviour of concrete is derived from the relationship proposed using stress strain in uni axial compression by Saenz[13]

$$\sigma_c = \frac{E_c \times \epsilon_c}{1 + (R + R_E - 2)\left(\frac{\epsilon_c}{\epsilon_0}\right) - (2R - 1)\left(\frac{\epsilon_c}{\epsilon_0}\right)^2 + R\left(\frac{\epsilon_c}{\epsilon_0}\right)^3}$$

where

$$R = \frac{R_E\,(R_\sigma - 1)}{(R_\epsilon - 1)^2} - \frac{1}{R_\epsilon},\quad R_E = \frac{E_c}{E_o}$$

σ_c = Stress in concrete
ϵ_c = Strain in concrete
E_c = Initial modulus of elasticity
f'_c = maximum compressive strength of concrete.
Strain ratio; $R_\epsilon = \epsilon_f / \epsilon_0 = 4$
Stress ratio; $R_\sigma = f'_c / \sigma_f = 4$
ϵ_f and σ_f are maximum strain and corresponding stress on the uniaxial stress-strain curve
ϵ_0 = Strain corresponding to f'_c in a uniaxial compressive test = 0.0025.
Secant Modulus: $E_0 = f'_c / \epsilon_0$

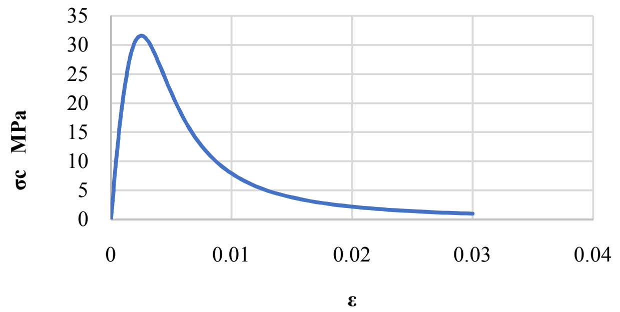

Fig 3 Stress-strain relationship of concrete under uniaxial compression by Saenz[13]

The tensile strength of concrete f_{cr} is calculated as per IS 456:2000[15] The tensile behaviour of concrete is obtained by the stress strain relation under uni axial tension proposed by Massicotte[14] as shown in Figure

$f_{cr} = 0.7 \text{ X } \sqrt{f_{ck}} = 3.94$ N/mm^2

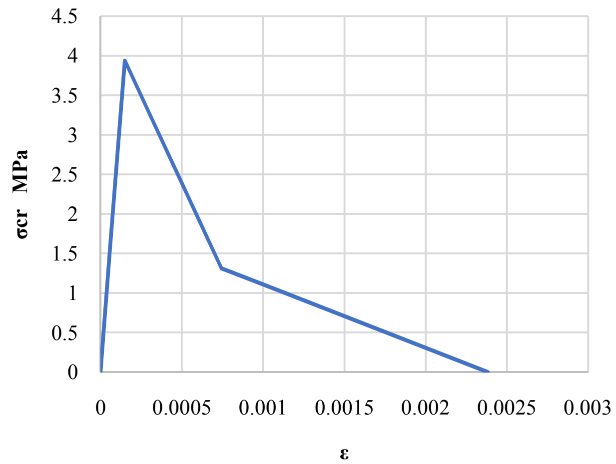

Fig 4 Stress-strain relationship of concrete under uniaxial tension by Massicotte[13]

Steel

Steel reinforcement was modelled as 3D truss element as T3D2 having 2 node displacement and assumed to be elastic perfectly plastic material. The reinforcement steel used in the present investigation is HYSD bars having yield strength f_y = 500 N/mm^2 and elastic modulus E_s = 200 GPa. A poisson's ratio of 0.3 was used for steel reinforcement.

The model is assembled using translation and rotation options in ABAQUS 6.14 according to their geometry as shown in Figure 5.

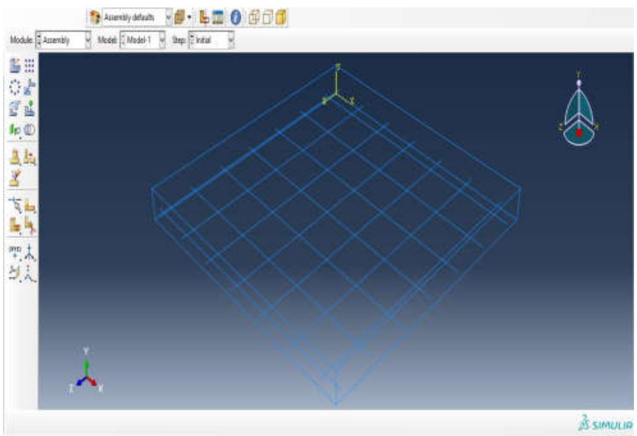

Fig 5 Modelling of slab in ABAQUS 6.14

Numerical Analysis

The interface between steel reinforcement and concrete was considered as perfect bond. The steel reinforcement was embedded into the host region of concrete.

Meshing is important in the FEM analysis which comprise of shape and size of element. The meshing of model was done before loading condition and was discretized into finite elements. For solid element rectangular mesh of size 15mm was used as shown in Figure 6

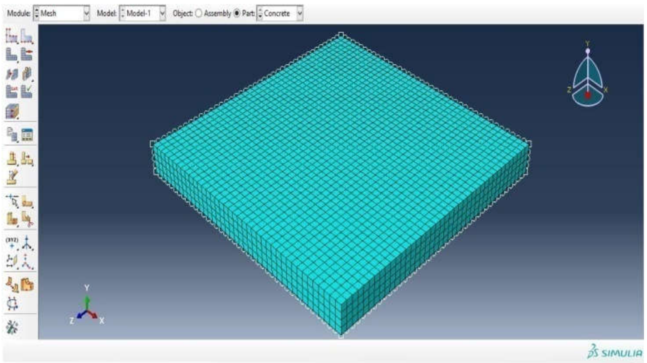

Fig 6 Meshing of slab in ABAQUS 6.14

A point load of 32N/mm^2 is applied at the top of the slab. A fixed boundary condition is applied at the edges of the slab as shown in Figure 7

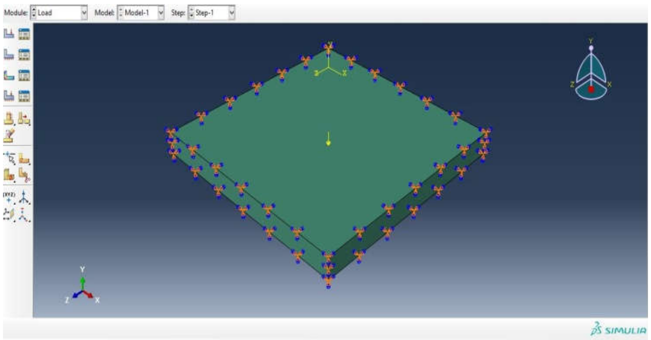

Fig 7 Loading and Boundary Conditions of slab in ABAQUS 6.14

RESULTS

Analytical results of static loading on recycled aggregate concrete slab using ABAQUS 6.14 for specimens (i) S-1 (conventional concrete 100% NCA), (ii)S-2 (50% TRCA +50% NCA containing concrete) (iii)S-3 (50% TRCA+30% NCA+20% RCA containing concrete) and (iv) S-4 (80% NCA +20% RCA containing concrete) are shown below.

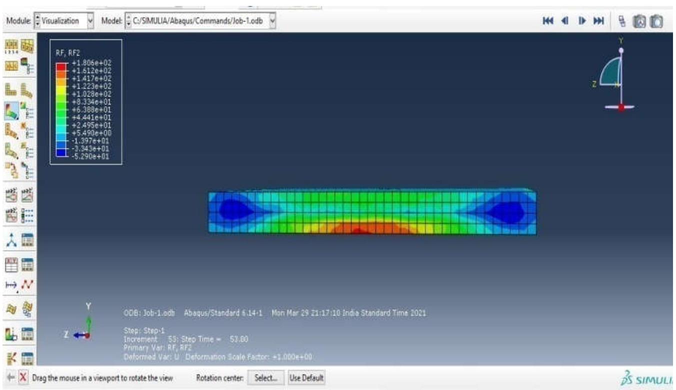

Fig 8 Reaction Force of slab S-1(100% NCA) in ABAQUS 6.14

The analysis is run for the requisite parameters and models and the results are visualized in the ABAQUS 6.14. The obtained output results are, Reaction force shown in Figure 8 and deflection at 0.61mm at mid point of slab shown in Figure 9.

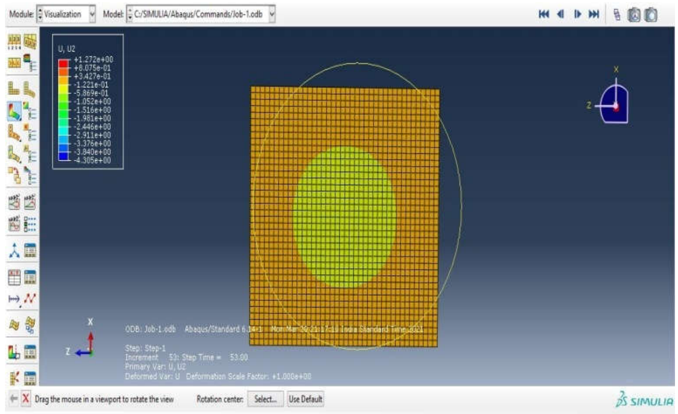

Fig 9 Deflection of slab S-1(100% NCA) in ABAQUS 6.14

From observing load versus s deflection curves from ABAQUS 6.14, the following data is obtained in the present investigation for slab specimens of size 600 X 600 X 60mm subjected to static loading and the following results were investigated.

- Deflection Behavior
- First Crack Load
- Ultimate Load

Deflection Behavior

The Deflection Behavior is obtained from load-deflection curve after static loading analysis carried out in ABAQUS 6.14 are shown for S-1,S-2,S-3and S-4 below.

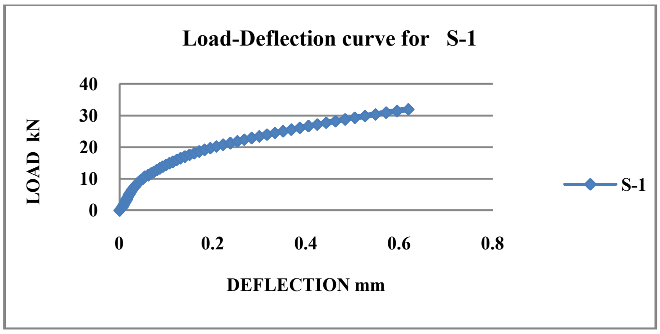

Fig 10 Load-deflection curve for slab S-1(100% NCA) in ABAQUS 6.14

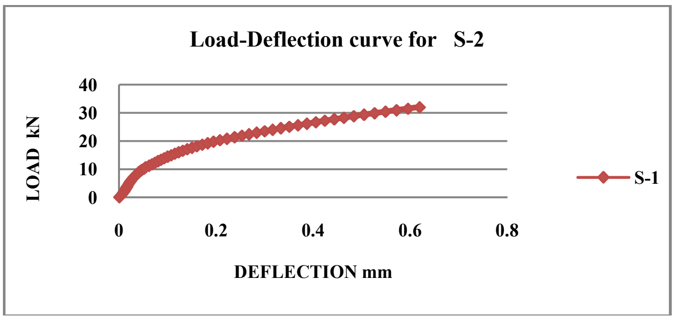

Fig 11 Load-deflection curve for slab S-2 (50%trca+50% NCA) in ABAQUS 6.14

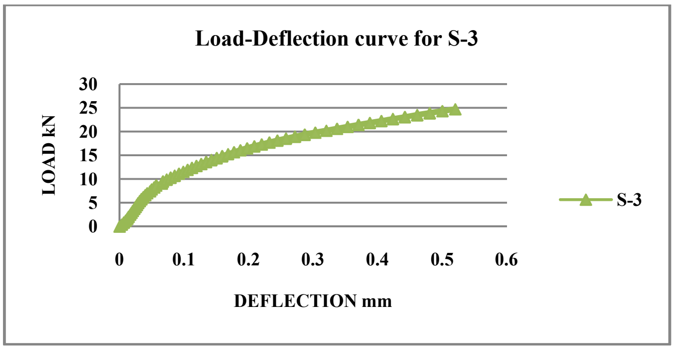

Fig 12 Load-deflection curve for slab S-3(50% TRCA+30% NCA+20% RCA) in ABAQUS 6.14

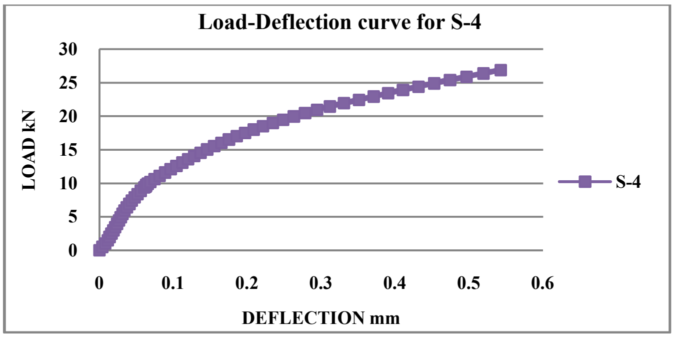

Fig 13 Load-deflection curve for slab S-4(4 (80% NCA +20% RCA containing concrete)) in ABAQUS 6.14.

First crack Load

The first crack load is obtained from load-deflection curve after static loading analysis carried out in ABAQUS 6.14 are shown below

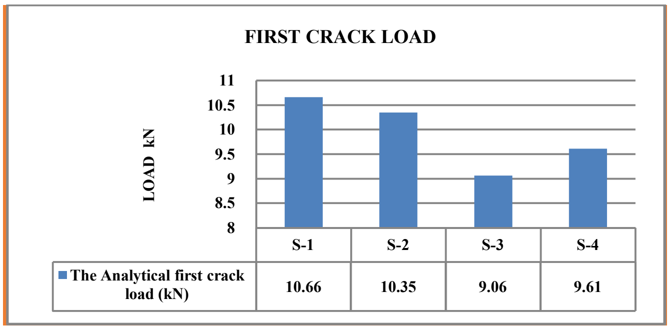

Fig 14 First crack load

Ultimate load

The ultimate or failure load obtained for four different mixes are shown are shown below

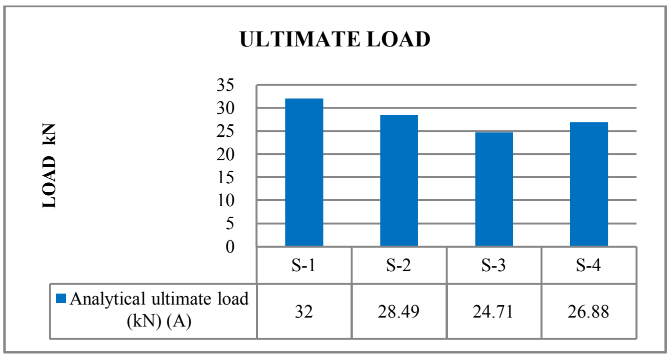

Fig 15 Ultimate-deflection

Comparison of experimental and analytical (ABAQUS 6.14) results

The analytical results obtained from ABAQUS 6.14 are compared with respect to the experimental results are as follows

Comparison of Experimental and Analytical (ABAQUS 6.14) load deflection curve

The analytical and experimental load deflection curve are compared and the ratio of experimental to analytical results (E/A) are shown below.

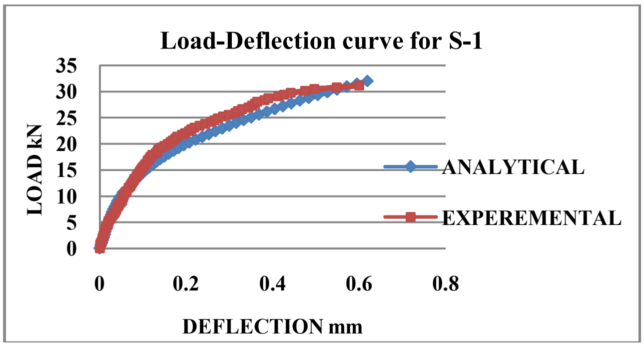

Figure 19 Comparison of Experimental and Analytical values of S-1 load deflection curve (P- δ curve).

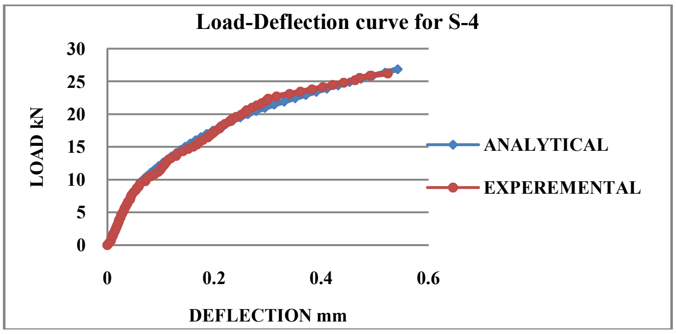

Figure 20 Comparison of Experimental and Analytical values of S-4 load deflection curve (P- δ curve).

The load deflection curves of S-1, S-2, S-3 and S-4 for both experimental and analytical analysis are compared and it can be seen that the load deflection curve has similar trend with that of experimental load deflection curve of the recycled aggregate slab S-1, S-2, -3 and S-4 respectively

Comparison of Experimental and Analytical (ABAQUS 6.14) First crack load

The analytical First crack load and experimental first crack load are compared and the ratio of experimental to analytical results (E/A) are shown below.

Table 3 Comparison of First crack load

Designation	Experimental First Crack Load(Kn)	Analytical First Crack Load(Kn)	(E/A)
S-1	10.15	10.66	0.95
S-2	9.8	10.35	0.94
S-3	8.4	9.06	0.92
S-4	9.45	9.61	0.98

Comparison of experimental and analytical (ABAQUS 6.14) Ultimate load

The analytical Ultimate load and experimental Ultimate load are compared and the ratio of experimental to analytical results (E/A) are shown below.

Table 4 Comparison of Ultimate load

Designation	Experimental Failure Load(kN)	Analytical Failure Load(kN)	E/A
S-1	31.15	32	0.973
S-2	28	28.49	0.982
S-3	24.5	24.71	0.991
S-4	26.25	26.88	0.976

CONCLUSIONS

1. The load –deflection mid point defection behavior under flexure for matrix under consideration viz.,.(i) S-1:100%NCA(conventional concrete of grade M-25) (ii) S-2:50%NCA+50%TRCA (M-25 grade concrete made using 50% natural coarse aggregate and 50 % treated recycled concrete aggregate) (iii) S-3:30 % NCA+50%TRCA+20%RCA (M-25 grade concrete made using 30% natural coarse aggregate, 50% treated recycled concrete aggregate and 20% recycled coarse aggregate) (iv) S-4:80%NCA+20%RCA (M-25 grade concrete made 80% natural coarse aggregate and 20% recycled coarse aggregate) for which load deflection behavior is determined. Load deflection curve shows linear variation up to first crack level and behave in non-linear way with further increase in load.
2. The first crack loads of the four mixes in the present analytical study (i) S-1 (conventional concrete), (ii) S-2 (50% NCA +50% TRCA containing concrete) (iii) S-3 (30% NCA+50% TRCA+20% RCA containing concrete)and (iv) S-4 (80% NCA +20% RCA containing concrete) are 10.66 kN, 10.35 kN, 9.06 kN, 9.61 kN respectively. It is observed that from analytical results, first crack load for other slabs as achieved up to 97.09%, 84.49%, and 90.15% with respect to control slab S-1.It is experimentally evident that for test slab specimen S-2, first crack load has been significantly achieved up to 93.83 % in comparison with S-1(Control Specimen).The percentage change of analytical to experimental first crack load for S-1, S-2, S-3 and S-4 is 4.78%, 5.31%, 7.28% and 1.66% respectively.
3. The analytically obtained values of ultimate Load for S-1 is 32kN where as for S-2, S-3 and S-4 are 28.49kN, 24.71 kN and 26.88 kN respectively. It is observed that from experimental results, ultimate load for other slabs are achieved up to 89.30%,77.21% and 84% with respect to control slab S-1.It is analytically evident that for test slab specimen S-2 ultimate load has been significantly achieved up to 89.30% in comparison with S-1(Control Specimen).The percentage change of analytical to experimental ultimate load for S-1, S-2, S-3 and S-4 is 2.65%, 1.71%, 1.0% and 1.85% respectively.

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