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Engineering

# NONLINEAR FINITE ELEMENT ANALYSIS OF LIGHTWEIGHT AGGREGATE REINFORCED CONCRETE SLABS

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**ABSTRACT** This paper presents a nonlinear finite element analysis of lightweight aggregate reinforced concrete slab. In this study, the slabs were modelled using ANSYS V.15 nonlinear finite element software. The concrete is modelled using 'SOLID65'-eight-node brick element, which is capable of brittle materials and the tension reinforcement has been modelled discretely using 'LINK180'-3D spar element. A total 6 slabs were analysed, out of which 3 were lightweight aggregate RC slabs and other 3 were normal weight aggregate RC slabs and grade of concrete used was M30 for all the slabs. The slab had an overall dimension of 1500x1000x70 mm. The main and distribution steel was of 8 mm diameter. The spacing of the main reinforcement of three slabs was 150,175,200 mm respectively. The slabs were studied for ultimate load, load-deflection behaviour for each case and compared with the available experimental values. The above study indicates that finite element modelling is properly able to simulate the behaviour and strength of lightweight aggregate RC slab and normal weight aggregate RC slabs under flexure. The comparison study showed that the FEA predicts a variation in deflection studies, the ratio of FE model deflection to experimental deflection being and also the ultimate load predicted by FE model is lesser than experimental by a variation of %.

**KEYWORDS :** Lightweight concrete, finite element analysis, ANSYS, Load-deflection, Slabs, Meshing

## INTRODUCTION

Reinforced concrete is used in construction industries in huge quantity during the construction of structures. Usually the plain concrete possess high compressive strength but its tensile strength is very low. To increase the tensile strength of concrete, reinforcement is provided to it. Beams, columns, foundation, slabs etc are the common RC structure found in normal buildings. The proper design and detailing of the elements will influence the performance of the structures.

Slab is a very important structural member in buildings. The flooring systems of most of the structures like office, commercial and residential buildings, bridges, sports stadiums and other facilities are called slabs. Generally, the main functions of slabs are to carry gravity forces, such as loads from human weight, goods and furniture, vehicles and so on. In modern structure design, to resist external lateral actions such as wind, earthquake and lateral earth load, slabs are designed as floor diaphragms.

As the span of building increases, deflection of slab becomes more important. Finally, the slab thickness is increased leading to increase in column and base size. Thus, materials like concrete and steel will be consumed more. To overcome these disadvantages due to increasing self-weight of slabs, lightweight aggregate concrete slabs were suggested. This slab system consists of lightweight aggregates which will optimize the size of vertical members like walls and columns by reducing the weight of slabs.

### Experimental Study:

In the experimental study, totally 6 slabs were modelled wherein, 3 slabs were Lightweight Aggregate RC Slab(LWAC) two way simply supported and other 3 slabs were Normal weight Aggregate RC Slab (NWAC) two way simply supported of overall dimension 1500mmx1000mmx70mm and tested them under 16 point bending load. The percentage of main reinforcement was kept varying.

### Nonlinear Finite Element Analysis:

In the finite element analysis totally 6 slabs were modelled wherein, 3 slabs were Lightweight Aggregate Reinforced Concrete Slab (LWAC) two way simply supported and other 3 slabs were Normal weight aggregate RC Slab (NWAC) two was simply supported and remaining 3 slabs were normal weight aggregate.

The SOLID65 element requires non-linear isotropic and multi-linear isotropic material properties for the correct modelling of the concrete material. Von Mises failure criterion was used for multi-linear isotropic material along with the model of William and Warnke (1975)[4] to define the concrete failure. Poisson's ratio (ν) and modulus of elasticity of the concrete ($E_x$) are the linear inputs required.

British Standard Eurocode 2 (BS EC2,2014)[6] was used for the compressive uniaxial stress-strain relationship for the calculation of multi-linear isotropic stress-strain curve of concrete.

As per the experimental setup the boundary conditions considered was that the slab was fixed at all the ends. So, to simulate the same, in Finite Element the nodes at the ends of the column are restrained in all directions. A total of 300 kN which is the working load, is applied transversely at selected 16 points to get an actual behaviour of uniformly distributed load. The load of 300 kN is divided into its component and applied onto each node. The load on the slab is applied at nodes at a distance 175mm from the left end of the support edge. The support conditions and loads can be seen in figure 1 and figure 2 respectively.

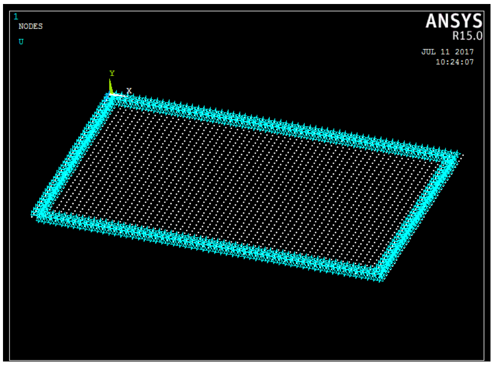



**Figure 1: Boundary Conditions**

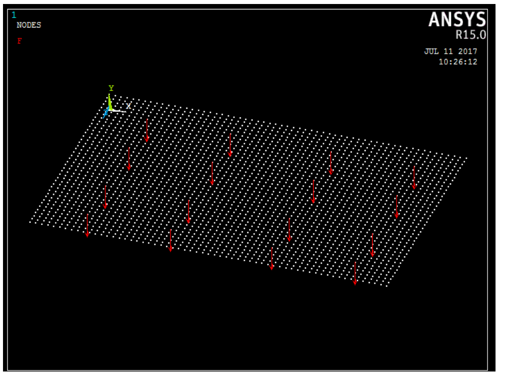
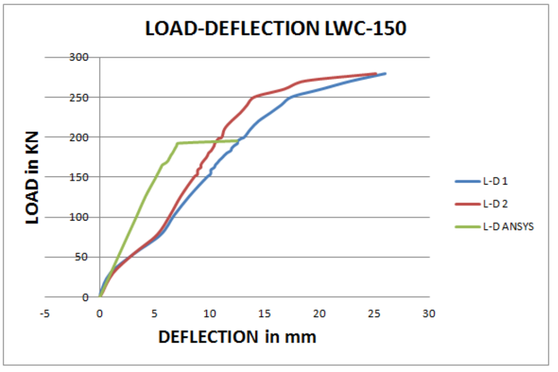



**Figure 2: Applied Loads on the Slabs**

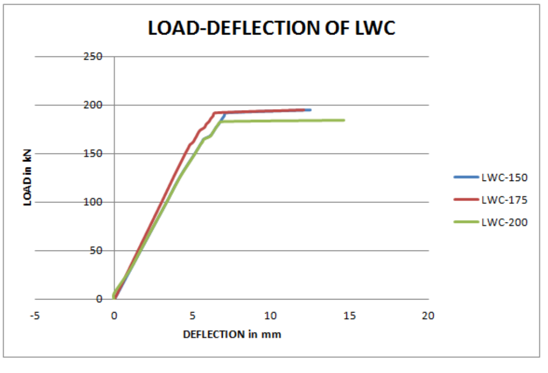
**Results and Comparisons:**

The load-deflection curve of both experimental and the ANSYS is given below




**Graph-1: Load-deflection behaviour for LWC-150**

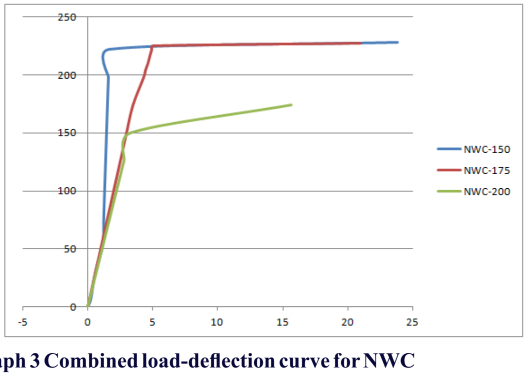
The slab was reinforced with 8mm diameter bars spaced 150mm center to center in the longer direction and with 8mm diameter bars spaced 120mm center to center in the other direction. A total load of 196.5kN was applied in 131 steps. The first crack appeared at a load of 6kN, as the load was increased the deformation also increased and there was a failure of beam at an ultimate load of 196.5kN with a deflection of 12.48mm. Graph 5.10 shows the load-deflection behavior of ANSYS and Experimental, it was seen that almost upto yield point the deflection of ANSYS and experimental were very similar and beyond yield the deflection began to vary. It was seen that the load carried in the experimental setup was 51.7% more than the load carried in ANSYS. This could be due to the fact that in ANSYS the member cannot be loaded when stress in steel reaches 415N/mm$^2$. But experimentally there was no means to arrive at the stress of steel, hence loading was continued until complete failure of the joint.




**Graph-2: Combined load-deflection curve for LWC**

A graph was plotted for combined load-deflection curve for LWC, it was seen that LWC-200 had larger deflection compared to other LWC and LWC-175 has larger load carrying capacity and less deflection compared to other LWC slabs.

The graph 3 shows the combined load-deflection curve for NWC. As it is seen in graph 3, NWC-200 had larger deflection compared to other NWC and NWC-150 has larger load carrying capacity and less deflection compared to other NWC slabs.




**Graph 3 Combined load-deflection curve for NWC**

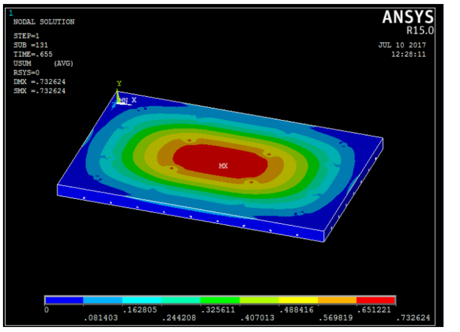



**Figure 3: Ultimate deflection for LWC-150**

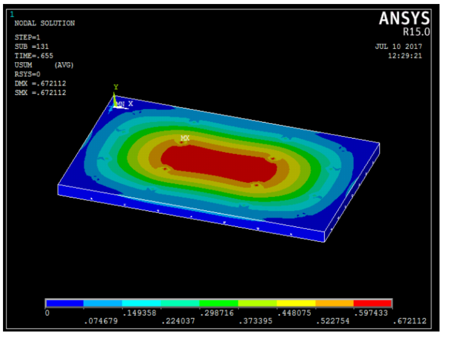



**Figure 4: Ultimate deflection for LWC-175**

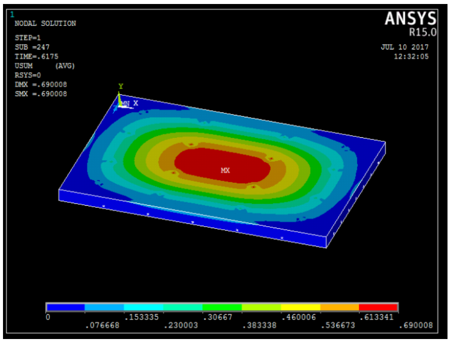



**Figure 5: Ultimate deflection for LWC-200**

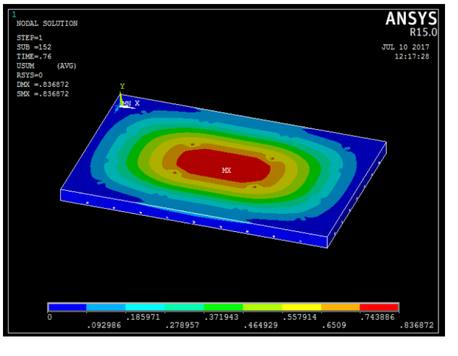



**Figure 6: Ultimate deflection for NWC-150**

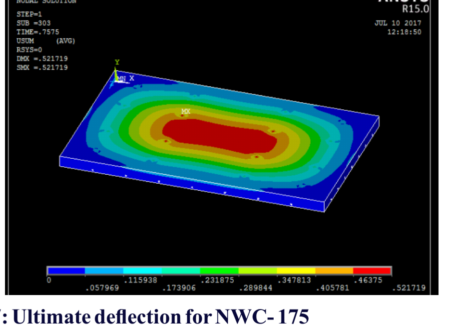



**Figure 7: Ultimate deflection for NWC- 175**

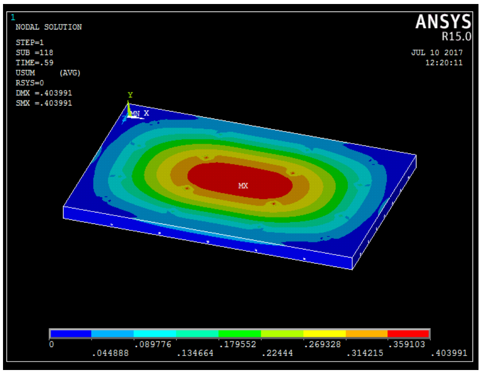



**Figure 8: Ultimate deflection for NWC-200**

**Comparison of Ultimate load with Johansen's loading:**

The following table gives the ultimate load obtained in FEM analysis and Johansen's Ultimate loading. After the analysis of the data, it was seen that ultimate load of the FEM method and Johansen's formula had not much variance. The analytical ultimate loads were relatively lower compared to experimental and also Johansen's Load. This can be due to the fact that in ANSYS, recording of the first crack can be done easily but in experiments microscope is needed and crack should be visible to record accurately.

**TABLE 1: FEM AND JOHANSSEN'S ULTIMATE LOADING**

| SLAB ID | $P_U$ (kN/mm$^2$) | $P_j$ (kN/mm$^2$) |
|---|---|---|
| LWC-150 | 145.55 | 155.404 |
| LWC-175 | 145.55 | 153.596 |
| LWC-200 | 131.11 | 143.03 |
| NWC-150 | 185.77 | 197.52 |
| NWC-175 | 168.518 | 180.003 |
| NWC-200 | 131.11 | 143.03 |

**Summary and Conclusions:**

The analytical investigation on the normal weight aggregate slabs and lightweight aggregate slabs was carried to study the load-deflection parameter and compare the results with the experimental results and Johansen's load.

- Finite element models were created of normal weight aggregate RC slab and lightweight aggregate RC slab using ANSYS 15.0 and compared the results of this model with experimental results
- The structural behaviour of lightweight aggregate RC slab was compared with normal weight RC slab using finite element analysis.
- Load-deflection curve was developed of lightweight aggregate RC slab and normal weight aggregate slab and compared the same with the curve developed from experimental results.
- 6 specimens were modelled and the reinforcement was varied wherein 3 specimen are lightweight aggregate RC slab and remaining are normal weight aggregate RC slab and analysed using ANSYS.
- The effect of reinforcement variation was studied with respect to the load-deflection behaviour.

Based on the results of the analytical investigation, the following conclusions are drawn:

The load carried by the experimental setup was more than the load carried in ANSYS. This could be due to the fact that in ANSYS the member cannot be loaded when stress in steel reaches 415N/mm$^2$. But in case of experimental analysis there was no means to arrive at the stress of steel. Hence, loading was continued until complete failure of the joint.

The combined load-deflection behaviour of lightweight aggregate RC slab shows that for LWC-200 has larger deflection compared to other LWC slabs and LWC-175 has larger load carrying capacity and less deflection compared to other LWC slabs. It means that for higher reinforcement the deflection is more and as the reinforcement decreases the load carrying capacity increases.

The combined load-deflection behaviour of normal weight aggregate RC slab shows that for smaller loads NWC-200 has larger deflection compared to other NWC slabs whereas at higher loads NWC-150 has larger load carrying capacity and less deflection compared to other NWC slabs. It means that for lower reinforcement the load carrying capacity increases and deflects less.

The stress- strain values were applied using the British Standard Eurocode 2 (BS EC2,2014) for both concrete material properties. It gave a satisfactory result and thus can be used for the analysis in ANSYS in future.

The increment of load in the analysis played a major role in the convergence of the solution. As the analysis time and storage space was main importance, the displacement convergence method proved to be efficient.

For most of the slabs formation of cracks before the ultimate load was well corresponded with the observed failure modes of the experimental slabs in flexure.

Thus to put it in a nut shell, it can be concluded that the 3D ANSYS model can be used to analyse the nonlinear behaviour of lightweight aggregate RC slab and normal weight aggregate slab. It also showed satisfactory results when compared with the observations and statistics of the experimental tests.

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