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Numerical Study on M40 Grade of Self Compacting Concrete

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Abstract—* Development of self-compacting concrete (SCC) is a very desirable achievement in the reinforced concrete (RC) structures for overcoming issues associated with many problems such as congestions of steel reinforcement. This non-vibrating concrete is not affected by the skill of workers, and the shape and amount of reinforcing bar arrangement of a structure. Due to the high fluidity and resisting power of reinforcing of SCC, it can be pumped longer distances. In this study, the finite element (FE) modeling of three SCC beams in shear while taking into account, the flexural tensile strength of concrete is computed and the results are compared with the available experimental tested reinforced SCC beams. The stirrups are located at 75 mm apart from the end of beams up to the loading point. The electrical strain gauges (ESGs) have been embedded on the stirrups and their strain readings are taken for every step of load increment. For modeling longitudinal steel reinforcing bars and concrete, the 3-D elements with 2-node and 8-node, are used respectively. The comparison of results obtained by two methods is indicated that a good satisfactory agreement is achieved.

I. INTRODUCTION

1.1 GENERAL

Self-compacting concrete (SCC) is an innovative and highly flowable type of concrete that is designed to have excellent workability and cohesiveness without the need for mechanical vibration during placement. It is characterized by its ability to fill and flow through intricate and congested reinforcement, resulting in improved consolidation and compaction without any significant segregation or bleeding.

SCC was developed in the late 1980s to address the challenges faced in traditional concrete construction, such as labor-intensive placement techniques and limitations in achieving adequate compaction in heavily reinforced structural elements. By eliminating the need for vibration, SCC not only enhances construction efficiency but also improves the durability and overall quality of concrete structures.

The key properties that distinguish SCC from conventional concrete include:

1. High Flowability: SCC exhibits exceptional flowability due to its high paste volume and optimized particle size distribution. It can flow effortlessly into complex formwork and around reinforcement without the need for compaction.
2. High Cohesiveness: Despite its high flowability, SCC maintains excellent cohesiveness, ensuring that the concrete remains intact and does not segregate during placement and subsequent hardening.
3. Improved Homogeneity: The self-leveling and self-compacting nature of SCC promote uniform distribution of cementitious materials and aggregates throughout the concrete matrix, resulting in a more homogenous mixture.

Self-compacting concrete (SCC) is a highly flowable, non-segregating concrete that can fill even the most congested reinforcement without the need for vibration. The flexural behavior of SCC plays a critical role in determining the structural performance of reinforced concrete elements. Numerical analysis using advanced software like ANSYS provides a valuable tool to understand and predict the flexural response of SCC structures. This report aims to present a numerical analysis of the flexural behavior of self-compacting concrete using ANSYS.

1.2 OBJECTIVE OF STUDY

The objective of studying the flexural behavior of self-compacting concrete (SCC) is to gain a comprehensive understanding of its structural performance and behavior under bending loads. The specific objectives may include.

1. Model Development: Create an accurate numerical model of the SCC specimen, considering its geometry, material properties, and reinforcement details. This involves defining the appropriate constitutive models and input parameters for the concrete and reinforcement.
2. Validate Material Models: Validate the chosen material models within ANSYS by comparing the numerical results with experimental data. This ensures that the material behavior of SCC is accurately represented in the analysis
3. Assess Flexural Strength: Determine the flexural strength of SCC beams or slabs using ANSYS simulations. Analyze the load-deflection response to identify the ultimate flexural capacity and investigate the failure modes of the structure.
4. Study Stress Distribution: Analyze the stress distribution within the SCC specimen under bending loads. Evaluate the distribution of compressive and tensile stresses along the cross-section to assess the load-carrying capacity and identify potential areas of concern.
5. Investigate Crack Formation and Propagation: Simulate the crack formation and propagation in SCC under flexural loading. Analyze the crack patterns, including their initiation, development, and width, to evaluate the crack resistance and assess the impact on the structural integrity.

By achieving these objectives, the numerical analysis of the flexural behavior of SCC in ANSYS contributes to a better understanding of its structural response, helps optimize the design of SCC structures, and provides valuable insights for engineers involved in the construction of concrete elements subjected to bending loads.

II. LITERATURE REVIEW

Bertil Persson (2001), carried out an experimental and numerical study on mechanical properties, such as strength, elastic modulus, creep and shrinkage of self-compacting concrete and the corresponding properties of normal compacting concrete. The study included eight mix proportions of sealed or air-cured specimens with water binder ratio (w/b) varying between 0.24 and 0.80. Fifty percent of the mixes were SCC and rests were NCC. The age at loading of the concretes in the creep studies varied between 2 and 90 days. Strength and relative humidity were also found. The results indicated that elastic modulus, creep and shrinkage of SCC did not differ significantly from the corresponding properties of NCC.

Nan Su et al (2001), proposed a new mix design method for self-compacting concrete. First, the amount of aggregates required was determined, and the paste of binders was then filled into the voids of aggregates to ensure that the concrete thus obtained has flow ability, self-compacting ability and other desired SCC properties. The amount of aggregates, binders and mixing water, as well as type and dosage of super plasticizer to be used are the major factors influencing the properties of SCC. Slump flow, V-funnel, L-flow, U-box and compressive strength tests were carried out to examine the performance of SCC, and the results indicated that the proposed method could be used to produce successfully SCC of high quality. Compared to the method developed by the Japanese Ready-Mixed Concrete Association (JRMCA), this method is simpler, easier for implementation and less timeconsuming, requires a smaller amount of binders and saves cost.

Bouzoubaa and Lachemi (2001) carried out an experimental investigation to evaluate the performance of SCC made with high volumes of fly ash. Nine SCC mixtures and one control concrete were made during the study. The content of the cementations materials was maintained constant (400 kg/m3), while the water/cementations material ratios ranged from 0.35 to 0.45. The self-compacting mixtures had a cement replacement of 40%, 50%, and 60% by Class F fly ash. Tests were carried out on all mixtures to obtain the properties of fresh concrete in terms of viscosity and stability. The mechanical properties of hardened concrete such as compressive strength and drying shrinkage were also determined. The SCC mixes developed 28-day compressive strength ranging from 26 to 48 MPa. They reported that economical SCC mixes could be successfully developed by incorporating high volumes of Class F fly ash.

Sri Ravindra rajah (2003) et al made an attempt to increase the stability of fresh concrete (cohesiveness) using increased amount of fine materials in the mixes. They reported about the development of self-compacting concrete with reduced segregation potential. The systematic experimental approach showed that partial replacement of coarse and fine aggregate with finer materials could produce self-compacting concrete with low segregation potential as assessed by the V-Funnel test. The results of bleeding test and strength development with age were highlighted by them. The results showed that fly ash could be used successfully in producing selfcompacting high-strength concrete with reduced segregation potential. It was also reported that fly ash in self-compacting concrete helps in improving the strength beyond 28 days. Self-Compacting Concrete.

Hajime Okamura and Masahiro Ouchi (2003) addressed the two major issues faced by the international community in using SCC, namely the absence of a proper mix design method and jovial testing method. They proposed a mix design method for SCC based on paste and mortar studies for super plasticizer compatibility followed by trail mixes. However, it was emphasized that the need to test the final product for passing ability, filling ability, and flow ability and segregation resistance was more relevant.

Paratibha Aggarwal (2008) et al presented a procedure for the design of self-compacting concrete mixes based on an experimental investigation. At the water/powder ratio of 1.180 to 1.215, slump flow test, V-funnel test and L-box test results were found to be satisfactory, i.e. passing ability; filling ability and segregation resistance are well within the limits. SCC was developed without using VMA in this study. Further, compressive strength at the ages of 7, 28, and 90 days was also determined. By using the OPC 43 grade, normal strength of 25 MPa to 33 MPa at 28-days was obtained, keeping the cement content around 350 kg/m3 to 414 kg/m3.

III. METHODOLOGY FOR ANALYSIS OF SELF-COMPACTING CONCRETE

3. METHODOLOGY

1. Material Modeling
2. Geometry and Meshing
3. Boundary Conditions
4. Analysis Setup
5. Post-processing
6. Validation and Sensitivity Analysis

3.1 Material Modeling

a. Concrete Material: Select an appropriate constitutive model to represent the behavior of self-compacting concrete (SCC) in ANSYS. This can be a nonlinear elastic-plastic model, such as Drucker-Prager or Mohr-Coulomb, that captures the stress-strain response under various loading conditions.

b. Material Parameters: Determine the material properties of SCC through laboratory testing, including compressive strength, tensile strength, elastic modulus, Poisson's ratio, and any other relevant properties required by the chosen constitutive model.

3.2 Geometry and Meshing:

a. Geometry Creation: Create a three-dimensional (3D) model of the SCC specimen, such as a beam or slab, in ANSYS based on the actual dimensions and reinforcement details. b. Mesh Generation: Generate a suitable mesh for the SCC model. Pay attention to mesh refinement in critical regions such as the tension and compression zones, where accurate stress and strain calculations are crucial. Use appropriate element types for modeling the concrete and reinforcement.

3.3 Boundary Conditions:

a. Support Conditions: Apply the appropriate support conditions to simulate the real-world behavior of the SCC structure. This may include fixed or simply supported boundary conditions.

b. Loading Conditions: Define the loading conditions based on the specific flexural test or structural analysis being performed. This can include point loads, distributed loads, or uniform loads, depending on the study objectives.

3.4 Analysis Setup

a. Solution Strategy: Select the appropriate analysis type in ANSYS, such as a nonlinear static analysis, to capture the behavior of SCC under bending loads. Nonlinear analysis is typically necessary to accurately capture the concrete's nonlinear response and crack formation.

b. Load Step and Convergence Criteria: Define the load steps to gradually apply the bending load to the SCC specimen. Use suitable convergence criteria, such as force or displacement convergence, to ensure the accuracy and stability of the analysis results.

3.5 Post-processing

a. Results Extraction: Extract and analyze the relevant results, including deflections, stresses, strains, crack patterns, and failure modes from the ANSYS analysis. Visualize these results using ANSYS post-processing tools.

b. Interpretation: Interpret the results to understand the flexural behavior of SCC. Analyze the load-deflection curves, crack patterns, stress distributions, and other parameters of interest to draw conclusions about the structural performance of SCC.

3.6 Validation and Sensitivity Analysis

a. Validation: Validate the numerical results by comparing them with experimental data or analytical solutions if available. Ensure that the numerical model accurately predicts the behavior of SCC under bending loads.

b. Sensitivity Analysis: Perform sensitivity analyses to explore the effects of varying input parameters, such as concrete strength, reinforcement detailing, and loading conditions, on the flexural behavior of SCC. Evaluate how changes in these parameters influence the structural response.

3.7 Optimization and Design Recommendations

Based on the analysis results, optimize the SCC mixture proportions, reinforcement detailing, or structural design to enhance the flexural behavior and meet the desired performance criteria. Provide design recommendations for SCC structures subjected to bending loads.

IV. NUMERICAL ANALYSIS OF SELF-COMPACTING CONCRETE

4.1 FINITE ELEMENT MODELING

As an initial step, a FE analysis requires meshing of the model. In the other words, an important step in FE modeling is the selection of the mesh density. A convergence of results for steel reinforcement and concrete is obtained when an adequate number of elements are used in the model; this is practically achieved when an increase in the mesh density has a negligible effect on results. The ANSYS software [15] has been performed for nonlinear analyses and then, the steps of FE modeling are presented.

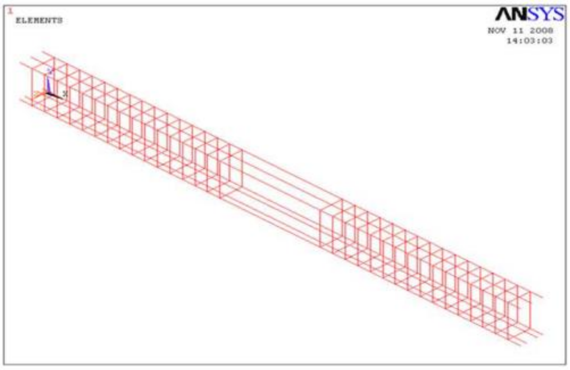

Figure 1. The FE model of steel

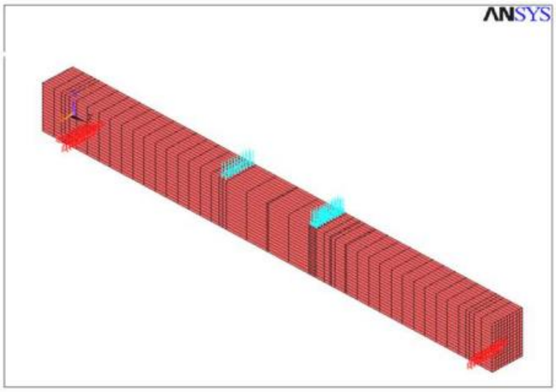

Figure 2. The FE model of concrete

Define pinned supports: If you want to simulate pinned supports, such as immovable boundaries or points of displacement, use the "pinned Support" or "Free Displacement" boundary condition. Specify the relevant degrees of freedom (e.g., translation or rotation) that are constrained.

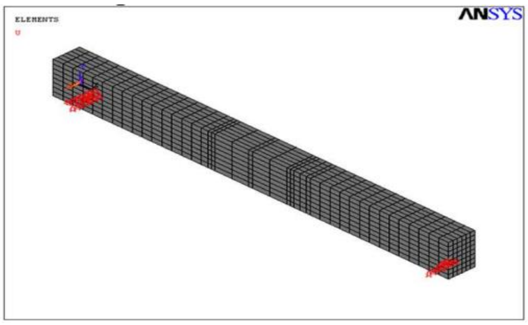

Figure 3. Boundary conditions of FE model

Apply forces or pressures: If you want to apply forces or pressure loads to your model, use the "Force" or "Pressure" boundary condition. Specify the magnitude, direction, and distribution of the applied load on the selected model entities.

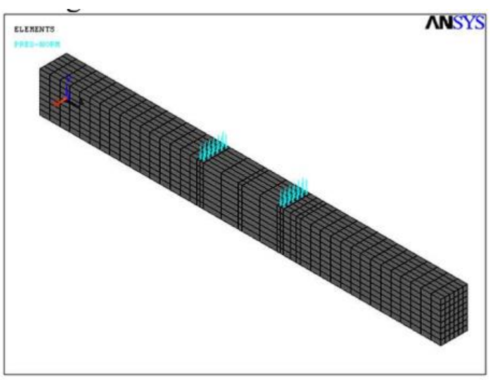

Figure 4. External loading of FE model

V. NUMERICAL ANALYSIS RESULTS

The results of FE analysis with proposed and ACI values of r f is indicated that a very good agreement is available with that of the experimental result. Meanwhile, the results of Load-shear strain curves.

5.1 The load-shear strain by fe analysis and experimental results for different f_r values at flexural cracking of beams.

Table 1. Results for different f_r values at flexural cracking of beams

Beam No.	f_r (MPa)	Numerical analysis results	
		p_{cr} (kN)	ε_{scr}
1	4.1	18.5	0.0083
2	4	12	0.0029
3	4.2	17	o.0038

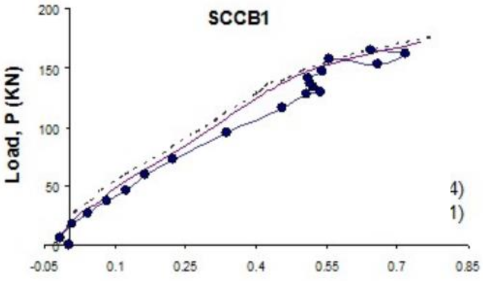

Figure 5. SCCB1 Load VS shear strain

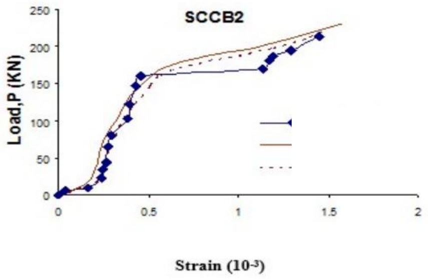

Figure 6. SCCB2 Load VS shear strain

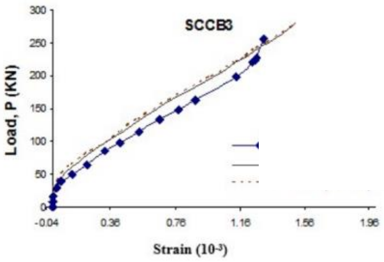

Figure 7. SCCB3 Load VS shear strain

5.2 Shear stress calculation and width of flexural-shear cracks

FE modeling shear stress values are performed and the curves. load-stirrup stress of FE modeling results for different f_r values at the failure of beam.

Table 1. Results for different f_r values at flexural cracking of beams

Beam No.	f_r (MPa)	Numerical analysis Results ϑs (MPa)
1	4.1	150
2	4	320
3	4.2	300

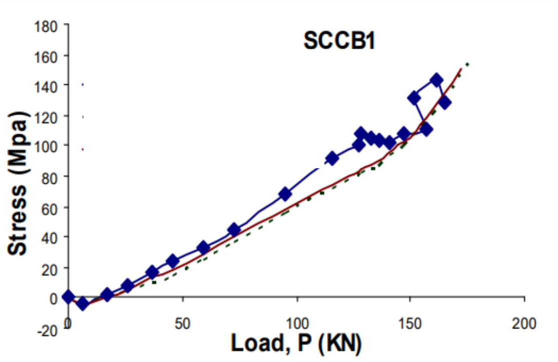

Figure 8. SCCB1 Load VS shear stress

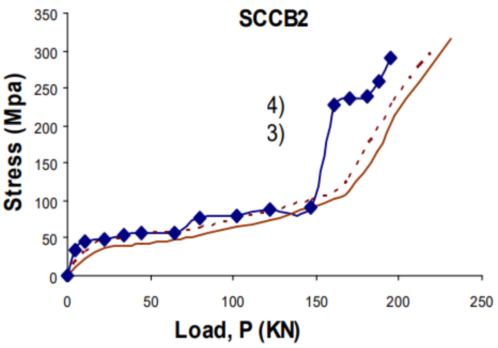

Figure 9. SCCB2 Load VS shear stress

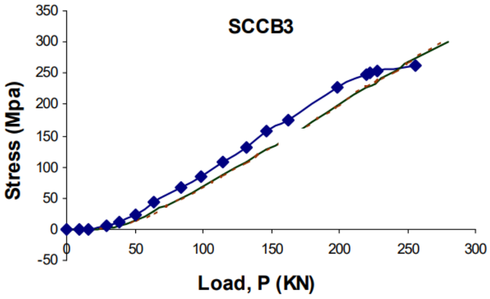

Figure 10. SCCB3 Load VS shear stress

CONCLUSION

The current study presents results of the FE analysis work of three reinforced SCC beams in shear taking into account, the flexural tensile strength f_r of concrete. The load-stirrup strain and load-stirrup stress curves for different values of f_r obtained by the FE model and the ACI and the proposed values were compared and it was almost concluded that, the obtained curves are coinciding with each other up to the load causes the occurrence of flexural-shear cracks.

FE analysis results of stirrup-strain at flexural cracking ε_{cr} are very low and this is an indication of the superiority of this type of concrete shear force before crack. At the occurrence of flexural-shear cracks, very narrow cracks are opened (i.e., their width was ranging from 0.05, 0.04 and 0.02 mm for SCCB1 to SCCB3).

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