FINITE ELEMENT MODELLING OF CRACKED CONCRETE STRUCTURES AFFECTED BY ALKALI-SILICA REACTION

[1]MOHITKUMAR CHAUDHARY, [2]MINA MORTAZAVI, [3]SANJAY NIMBALKAR

[1]Masters Research Candidate, School of Civil and Environmental Engineering,
University of Technology Sydney (UTS), Australia
[2]Lecturer at School of Civil and Environmental Engineering, University of Technology Sydney (UTS), Australia
[3]Senior Lecturer at School of Civil and Environmental Engineering, University of Technology Sydney (UTS), Australia
E-mail: [1]Mohitkumar.s.chaudhary@student.uts.edu.au, [2]Mina.mortazavi@uts.edu.au, [3]Sanjay.Nimbalkar@uts.edu.au

Abstract - Concrete's mechanical characteristics can deteriorate as a result of the alkali-silica reaction (ASR), which can affect serviceability and even reduce the load-bearing capacity of concrete structures. Given the significance of the issue, substantial research, largely through experimental investigations, has been done to better understand how ASR affects the mechanical properties of specimens of plain and reinforced concrete. In this research study, a model has been developed with a new approach of modelling ASR affected concrete beam. The model has utilized a layered approach with varying moduli. The literature on ASR affected concrete, has shown that the crack development occurs that affects the modulus of Elasticity, compressive strength and tensile strength. The flexural capacity of a beam is highly dependent on the Elastic Modulus property of the concrete. Existing literature shows that up to 50% loss in the Modulus is observed in the concrete specimen. The model is, then, compared to a model from an existing research and loss in the properties leading to loss in flexural capacity is discussed.

Keywords - Alkali Silica Reaction, Elastic Modulus, Mechanical Properties, FEM Model.

I. INTRODUCTION

The Alkali-Silica Reaction (ASR) also called the concrete cancer has proven to be a serious problem for concrete structures and its durability. The reaction has various factors contributing to its beginning and growth. All over world, the concrete infrastructure suffering from ASR have to undergo re-construction and maintenance costs. The growth of the reaction occurs with the growth of an expansive gel that causes micro-structural cracks, which can eventually lead to macro-cracks and thus, the degradation of concrete.

Alkali-Silica Reaction can cause far more damage to the structure due to the degradation of, not only concrete but also the mechanical properties of the concrete. Loss of mechanical properties or the strength will cause the rupture of structural integrity of the structure.

II. RESEARCH SIGNIFICANCE

Concrete's strength may be greatly decreased by the Alkali Silica Reaction (ASR), as observed by [17]. According to [9], a decrease in strength would result in the formation of cracks. It would also cause a decrease in the elastic modulus and excessive swelling, which would result in large deformations that would exceed the serviceability limit states. Finally, the expansion of concrete caused by ASR creates stresses that cause damage and a decrease in strength. So, wherever feasible, avoid ASR by using non-reactive aggregates. When using reactive aggregates cannot be avoided, mitigation strategies such adding more cementitious materials and limiting the amount of total alkali in the concrete mix must be used. Structures that are already experiencing ASR, however, need to be evaluated. As a result, precise techniques that are designed for the examination of ASR impacts on structural behavior are required. For rehabilitation objectives, these instruments are necessary to record the observed behavior as well as to foresee the long-term consequences and potential failure mechanisms.

III. REDUCTION OF MECHANICAL PROPERTIES

The concrete specimens subjected to ASR, demonstrated reduced compressive strength, tensile strength and elastic modulus compared to the 28 day relative value [11].

The expansive cracks formed by ASR can cause considerable reduction in elastic modulus and the compressive strength, as also has been mentioned by many researchers after performing experiments.
An illustrative model Fig. 1, prepared by [16], shows the process of crack initiation and propagation for the concrete matrix affected by ASR expansion, at aggregate level and describes how the crack propagation drops the mechanical properties. The highly affected or the early affected property is the elastic modulus. Compared to compressive strength, as can be seen in the figure, the elastic modulus is reduced by 30% at only an expansion of 0.05%. The cracks are formed and propagate between the cement phase and the aggregate, at an expansion level of 0.012%. At this phase, a drop of 10% and 35% is seen in the compressive strength and the elastic modulus, respectively. The size and shape of the cracks continuously rise and at an expansion of 0.2% cracks seep into the aggregate and reduces the elastic

modulus to 50% and compressive strength to 75%. And eventually, as the expansion keeps on growing, cracks network is developed through interconnection and leaves the elastic modulus and compressive strength of 40% and 60%, respectively. At further expansion, the decrease in modulus of elasticity continues while the compressive strength does not drop further.

Institution of Structural Engineers [11], published a report for guidance on Alkali-Silica Reaction affected concrete structures. This report was published in 1992 and contains a thorough guidance about the chemical process of ASR, laboratory testing and results, effects on mechanical properties and the discussion on research needs.

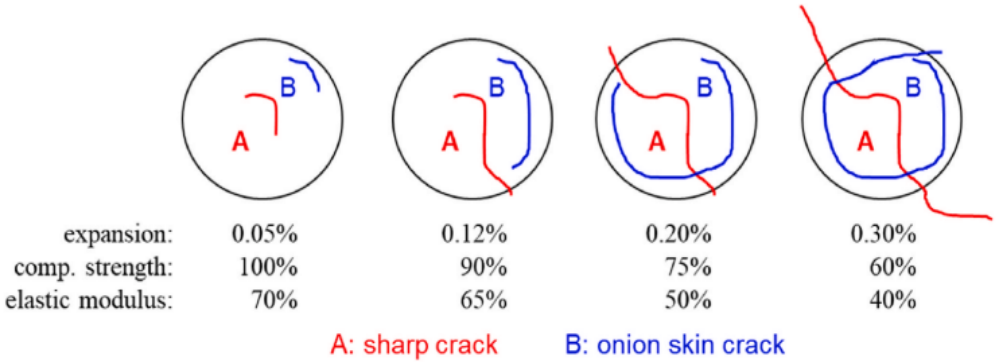


Figure 1 Relationship between ASR expansion crack development and mechanical behavior changes [16].

The lower bound values for various ASR free expansions of those properties of unaffected concrete at 28 days are shown in Table 1 as percentages to the mechanical properties of concrete under unconstrained conditions. Lower bounds to laboratory data from tests on cast cubes, cylinders, prisms, and from tests on cores removed from structures were used to create the tabulated values.

Property	Percentage strength as compared with unaffected concrete for various mounts of free expansion				
	0.5 mm/m	1.0 mm/m	2.5 mm/m	5.0 mm/m	10.0 mm/m
Cube Compression	100	85	80	75	70
Uniaxial Compression	95	80	60	60	*
Tension	85	75	55	40	*
Elastic Modulus	100	70	50	35	30

Table 1 Lower bound residual mechanical properties as percentage of values for unaffected concrete at 28 days [11].

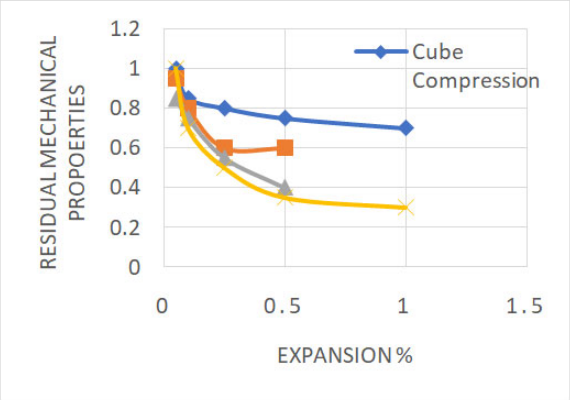


Figure 2 Residual mechanical properties compared to unaffected concrete at 28 days [11].

IV. ADAPTION OF MODEL

The literature gives information on how the mechanical properties of the ASR affected concrete is proportional to the internal and surface cracks. For a ASR affected concrete beam, the section of the beam can have the varying layers of moduli which is due to the presence of micro and macro cracks, present in the core and the surface of the section, respectively. The internal stress conditions affect the boundary conditions and the dimensions of the structure. Due to this reason, for any damaged structure, it is observed that the surface cracks more severe than the internal cracks [7]. The comprehensive field findings [3], suggest that the depths of near-surface layers in existing ASR-affected concrete buildings that had relative humidity levels below the 80% threshold level varied greatly. Tensile stresses are formed in the layers as a result of the non-reactive layers preventing the inner cores from expanding. These tensile strains may increase to a point where they result in surface cracking.

In a study [4], it was observed that the maximum tensile stresses that can be created in the non-reactive layers of model concrete cylinders impacted by ASR are calculated in order to predict the critical free expansions for surface cracking. If the strength and modulus elasticity of the concrete, the dimensions of the cylinder, and the depth of the non-reactive layer are

known, a simple calculation can be used to determine the critical free expansions for surface cracking in ASR-affected unreinforced concretes. This is based on the assumption that expansive pressure is proportional to free expansion and that the non-reactive near-surface layers restrain expansions of inner cores.

Due to the production of expanding products at specific reaction sites or surfaces, ASR has two major structural impacts.

(a) The development of new micro cracks or the escalation of preexisting ones in the concrete matrix, which results in a slower increase in strength than usual and, in certain cases, a genuine decrease in strength over time.
(b) The expansion of the concrete's body, which creates restraint forces both inside the body's internal non-reactive zones and anywhere else it interacts with other materials, such reinforcement or other structural components [5].

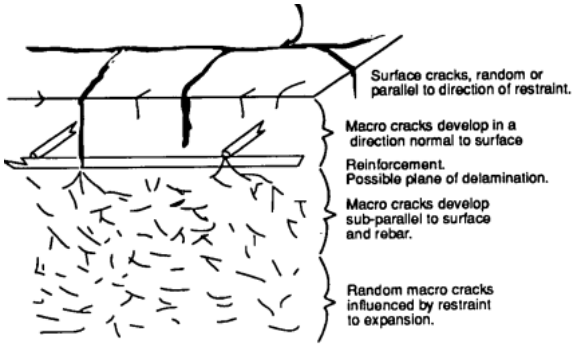


Figure 3 Development of Macro-cracks [5].

The variation in the outermost and the innermost zones of the concrete section, gives rise to formation of macro and micro cracks, respectively. Tensile strain at the surface, which can lead to macro-cracking, is caused by the variable expansion in combination with the higher expansion of the internal concrete [11]. The macro cracks on the concrete surface, are greater than the internal micro cracks, which leads to considerable amount of loss in strength for the outermost concrete fibers compared to the internal. This phenomena can mean that the cross section of the ASR affected beam has varying strength, with the outermost fibers having lesser strength due to the macro crack development. The varying and differential expansion at the center and the surface of the specimen, causes the surface cracks. Cracks typically only penetrate close to the "neutral axis" that separates the expansive and less expansive sections, and not across it [5]. Surface cracking is oriented by the interaction between the core and the surface. The matrix's response to local expansion under a compressive stress field on the heart concrete will be to take advantage of the weakest stress field. This will prevent expansion in the direction of the applied field, and any micro cracking that does occur will likely take place parallel to the applied field and produce expansion that is normal to it. On the other hand, if a tensile field is applied, regular micro cracking will take place in this field.

An anisotropic stiffness decrease is seen in the study [10], for restrained specimens, which is similar to the expansion behaviour. A greater drop in modulus of elasticity is discovered in the free directions (X and Y) than in the direction with sustained loading (Z). One causative variable, namely the expansion in the same direction, accounts for the lowering of the elasticity modulus in a specific direction.

V. DISCUSSION OF FLEXURAL CAPACITY REDUCTION

The model in this research serves as a stepping stone for Engineering design approach. The model has layered moduli which reflects the actual impact of ASR on a concrete element. This information is useful in designing a concrete beam that is affected by ASR. The various moduli from the layered model can help estimate the flexural strength of the beam and thus, the design capacity can be commented upon when the beam acts under various load conditions. The variance in the moduli can reflect that the design approach of an ASR affected beam can be different than the design of a conventional Reinforced concrete beam.

The model used for this research is different than the models used previously in any research and is a new approach. The model is layered in the various moduli with the outermost layer having the lowest modulus reflecting the strength loss due to ASR. The model is layered in 4 layers. The outermost layer having the modulus drop up to 50%. The modulus of layers will increase as it goes towards the core and the innermost layer will have the 100% modulus reflecting the ASR behaviour where the cracks and the strength loss due to sapling of concrete is more on the outside edge than the innermost section of a concrete beam.

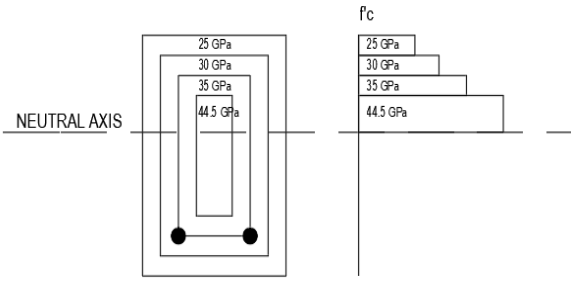


Figure 4. Equilibrium Rectangular Stress Block scenario at ultimate strength conditions

The Fig. 5, shows the initial step in incorporating this research into a beam design. The layered moduli section of the beam can be used for designing the beam similar to the design of conventional RC beam. The calculation of the ultimate strength can be used for commenting on the actual drop in the strength of a beam affected by ASR.

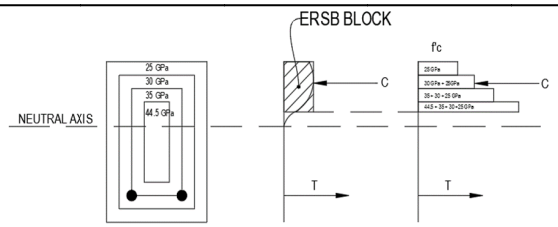


Figure 5. Shows the representation of a layered beam model section at ultimate strength conditions.

For this research, the concrete beam model is used with bottom reinforcement. The length of beam is 1.6m and the cross section has dimensions 200mm width and 300mm height. The research paper used for comparison of this research model has same beam dimensions.

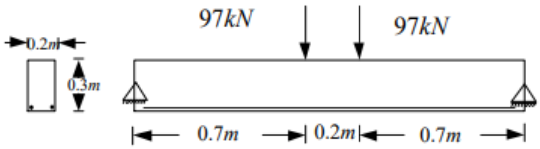


Figure 6. Shows the beam model used for modelling [20].

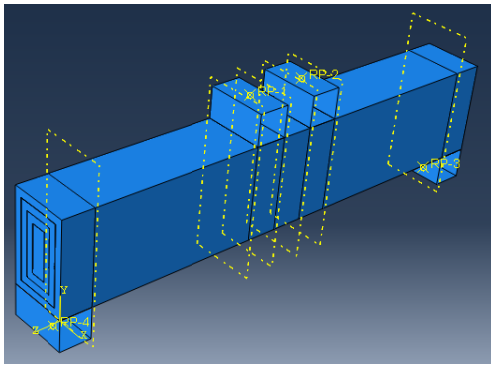


Figure 7. Abaqus Layered beam model with varying moduli.

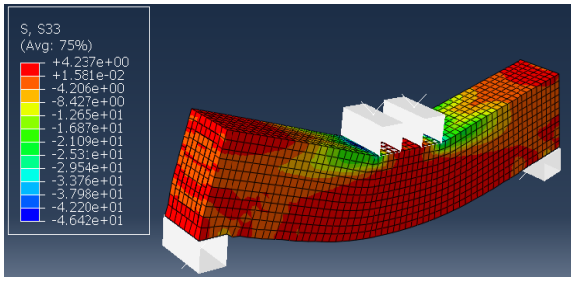


Figure 8. Abaqus Layered beam model with varying moduli.

The concrete is modelled using the concrete damaged plasticity model available in Abaqus by providing stress versus inelastic strain data. Also, data is adopted from [19] as shown in the figure below.

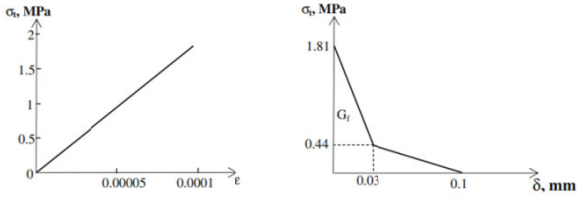


Figure 10. Concrete under uni-axial tension [19].

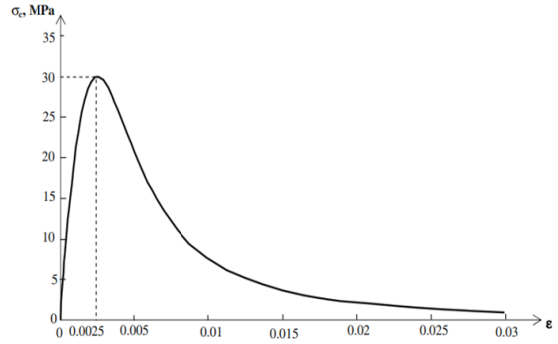


Figure 11. Stress–strain relationship for concrete under uni-axial compression [19].

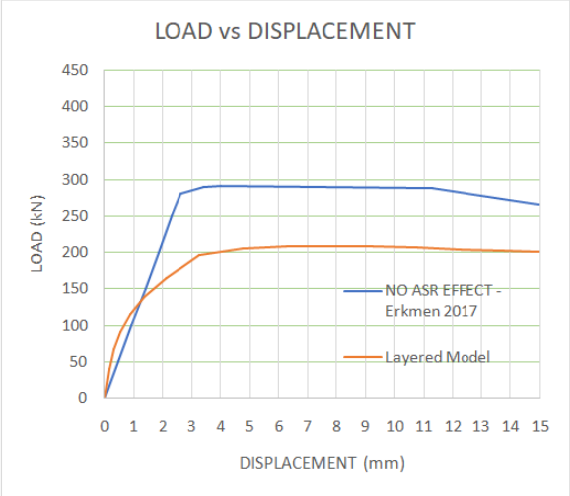


Figure 9. Comparison of Models.

VI. CONCLUSION

The load bearing capacity represents the functionality and the safety provided by the structure. Therefore, the determination of strength reduction due to ASR is very critical. The prevention of ASR is dependent on chemical reactivity and moisture content and various other factors. However, the durability issues for the existing structures is a matter of utmost importance. The macro model will be useful in predicting the reduction in the load bearing capacity of ASR affected concrete. This research will allow to understand the ASR mechanism at macro level. Furthermore, the research in this topic will serve as a stepping-stone for future research works.

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