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A Study on Crack Propagation and Crack Branching In Lightly Reinforced Concrete Beams Using Digital Image Correlation- A Review

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ABSTRACT – It is a recent advancement in the construction technology,since it is light in weight, therefore bringing economy in the construction. Steel is replaced by the glass fibre helps in avoiding structural deterioration and corrosion in reinforced concrete structures.
Keeping in mind about the global environmental conditions, many alternatives are searched to increase the strength, durability, shrinkage characteristics and serviceability of concrete.
Hence, here glass fibre is added and tests have been performed with varying percentage of 1%, 2% and 3% of cement by adding as an admixture.

KEYWORDS: Glass fibre, Light weight, Economic, Eco friendly, Compressive strength.

I. INTRODUCTION

Concrete is a quasi-brittle material that has a relatively weak tensile strength when compared with its compressive strength. It is therefore susceptible to cracking. The cracking process in concrete is complex because the crack itself is a partially damaged zone with some capability for stress-transfer in the fracture process zone (FPZ). The FPZ acts as a transition zone between the discontinuous open crack and the continuous intact material beyond the crack. Although there is some debate about what constitutes a FPZ, and the size of the FPZ, there is a general agreement that it exists in concrete [1]. A realistic description of the FPZ is essential in order to understand damage mechanisms and to predict and optimize the behaviour of concrete structures.

In reinforced concrete, the fracture process is further complicated by the presence of the reinforcement that affects the crack development and propagation. The cracking process is associated with diverse phenomena such as the formation of cracks, crack propagation, the existence of micro-cracks, interactions between the reinforcement and concrete, and the concrete microstructure e.g. cement and aggregate [2]. In addition, numerous factors can influence the cracking process and reinforcement crack bridging including the concrete compressive strength, thetype, the properties and the ratio of the longitudinal reinforcement, the bond between the reinforcement and the concrete, and the geometrical properties and the size of the beam. These factors can be inter-related and inter-dependant. Furthermore, the cracking process in reinforced concrete (RC) may involve several macro-cracks propagating at the same time leading to different failure modes. Internal reinforcement bridges a crack and improves the fracture toughness by providing a stitching action that prevents the crack faces from opening and controls the crack growth by increasing the energy demand for crack advancement [3]. The fracture energy is closely related to the FPZ size and this implies that the existence of a FPZ may be the intrinsic cause for size effects. In concrete the FPZ covers a narrow crack band and only the region along the crack path is affected by cracking [4]. However, in reinforced concrete the nature of the FPZ remains unclear. Most theoretical studies incorporate the reinforcement according to the principle of superposition by considering concrete fracture and adding the effect of the reinforcement as a closing force [5]. Although the fracture properties of reinforced concrete at the structural scale havebeen studied, there is a need for further detailed investigations to better understand the nature of the fracture process.

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Understanding cracking in reinforced concrete is important for the strength assessment and renovation of existing structures. Relatively few fracture-oriented experimental studies have been conducted on concrete with internal steel reinforcement. Knowledge of concrete fracture processes can help identify suitable analytical approaches that capture the details of the crack process. This study presents an experimental investigation of RC beams subjected to three point bending. A particular focus is the localised zone around the crack and the crack branching phenomena. Crack branching is a toughening mechanism in quasi-brittle materials and can be a source of size effects. Yet it has received little or no attention when studying the fracture of RC beams. In reinforced concrete, the confinement provided by the reinforcement to the crack path increases the possibility of crack branching. The crack branching that takes places during the failure process makes the failure behaviour more ductile. The aim of this project is to experimentally determine the relationship between size, reinforcement ratio and ductility through investigation of crack branching in RC beams. Although more experiments are required to generalize the results, this project acts as a foundation to describe the flexural behaviour of lightly reinforced concrete beams and for further investigations of RC fracture processes.

II. BACKGROUND AND SCOPE

Over the past decades various studies were conducted to investigate concrete cracking and models were developed to simulate the cracking process in reinforced concrete beams. These models can broadly be classified as either plasticity-based models which are justified in the case of ductile behaviour e.g. beams with sufficient internal steel, or fracture mechanics-based models which do not treat fracture as a point phenomenon but use fracture mechanics principles to explain crack propagation. The cracking process in concrete is complicated because it is associated with the development of minor cracks and micro cracks as well as macro-cracks. Cracking is also connected with other phenomena such as strain localization and bridging. In a traditional strength criterion analysis, the behaviour is described using continuum variables of stress and strain. However, during fracture propagation the behaviour depends on what is happening in the fracture process zone (FPZ) ahead of the crack tip, which is a partially damaged zone with some residual ability to transfer stress. This zone is analytically challenging for model developers and structural engineers because it is a transition zone between the discontinuous open crack and the continuous intact material beyond the crack. So it cannot be modelled using the continuum variables. Since fracture mechanics provides rules and principles for crack propagation in materials, it can also provide a tool for studying the cracking process in concrete. Interest in the application of fracture mechanics to concrete has been due to the realisation that strength criteria were not adequate to explain concrete cracking . Although fracture mechanics provides a rational approach for studying cracking and has been applied to concrete fracture for over forty years, it has typically not been widely adopted within design code equations and lacks a certain acceptance from the structural concrete community. One of the reasons is that fracture mechanics approaches are often modeled using finite element tools and this makes it difficult for inclusion in the development of guidelines. Furthermore, fracture mechanics has its own parameters and terms and civil engineers are less familiar with them. This means that conventional empirical stress-based approaches have been preferred for structural applications. In spite of the resistance of the structural concrete community to the application of fracture mechanics, fracture mechanics is important in order to better understand the behaviour of structures that are very sensitive to fracture such as structures in tension. Another example is where the tensile softening behaviour is important such as in lightly reinforced concrete beams. Reinforced concrete beams with low ratios of longitudinal reinforcement will be the subject of the current study. Although the fracture properties of reinforced concrete at the structural scale have been studied, there is a need for further detailed investigations of cracks in reinforced concrete to better understand the nature of the fracture process and improve existing models. Improving existing models does not necessary mean making them more complex. However, it does involve enhancing our understanding of the behaviour in a way that is translated to new applications without missing the important features. The recent advances in image processing techniques as well as in high-resolution digital cameras can provide advanced tools to measure fracture properties and provide insight into the cracking process. Such real observations can lead to the development of new models or the improvement of existing models.

III. OBJECTIVES

This project aims to carry out an in-depth investigation of the crack propagation RCC beams. This will be achieved through experimental work which is required to observe the true cracking behaviour in RC beams. More specifically, the objectives of this project are:

- To study the effect of reinforcement on the crack propagation in concrete beams.
- To observe the effect of beam depths on relative depth of crack branching.
- To study the effect of both beam depth and reinforcement on the ductility of RCC beams through investigation of crack branching.
- To see the relation between the relative depth of crack branching and ductility.

IV. LITERATURE REVIEW

- **Skarzynski** and **Tejchman** [9] tested small RC beams with a height of 80 mm and length 320 mm(effective length 240 mm) with a reinforcement ratio of 1.5%. It was found that the localised zones are always created prior to the attainment of the peak load and the lengths of the fracture zones in RC beams (0.8 of the beam height) are higher than those in unreinforced concrete beams (0.6 of the beam height).
- **Alam et al.** [10] used Acoustic Emission (AE) to study microcracking in RC beams. It was found that as the beam size increases, the fracture process changes from tensile-microcracking-macrocracking to shear-compression macrocracking. Digital image correlation has also been used to study the cracking in reinforced concrete beams failing in shear and it was found that the observed size effect was in agreement with Bazant's size effect [11].

- **Annette Beedholm , Jakob Fiskera, Lars German** [12] proposed an approach for predicting crack systems, and more importantly crack widths in beams from the experimental observations of the crack pattern in flexural members investigated by Sherwood. The approach assumes the initial existence of flexural cracks the spacing between which is estimated by a simple empirical relation proposed by Reineck. For a certain configuration of the depth, cover, reinforcement ratio etc. secondary cracks are allowed to develop in between the flexural cracks. The theoretical results show that the spacing between the flexural cracks shows a linear proportionality to the effective depth of the member with only a minor variation with respect to the reinforcement ratio, neglectable for beams with an effective depth smaller than about 800mm. This is supported by the experimental observations. On the contrary, the secondary cracks indicate no apparent dependency of the variation in effective depth. When comparing the results of the estimated crack widths to the measurements that approach it is seen to precisely reproduce the observed size effect in

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terms of the

- relative increase. With respect to the absolute values of the estimated crack widths a fairly goodagreement is also seen.

- **N.A.B. Yehia** [13] has done experimental testing of 9 notched reinforced concrete specimens underfour point bending. The beams comprise three beam sizes and three tension reinforcing steel ratios. All beams have constant span/depth ratio of 4, initial notch/depth ratio of 0.3. Two strengthening fiber laminates were used: Glass fiber for the two lower tension reinforcing steel ratios and Carbon fiber for the higher tension reinforcing steel ratio. The strengthening laminates were designed to enhance beam moment capacity by 15% to 150% depending on the beam size and reinforcement ratio. To simulate real life strengthening situations, beams were first loaded until the notch propagated to 0.5 the beam depth. The strengthening fiber laminate was then introduced to the tension side of the beam while the load was kept applied to the other side of the beam. The fracture moment for a given crack depth was calculated through an analytical algorithm which employs Linear Elastic Fracture Mechanics. The approach takes into consideration the previous loading history of the beam prior to introducing the strengthening laminate. Test measurements of crack extension and applied load were used to compare the fracture moment recorded experimentally to that one calculated analytically. The application of the solution algorithm to different specimen sizes _ cross-section dimensions, reinforcement ratio, and strengthening fiber laminate showed that the solution algorithm is able to effectively predict the behavior of larger beam size and/or reinforcement better than that of smaller beam size and/or reinforcement. A sensitivity analysis wasconducted to explore this point.

- **C. Barris et al.** [14] have studied the cracking behavior of GFRP RC elements based on the results of an experimental program involving 15 beams. The paper studies the influence of the reinforcing material, concrete cover, stirrup spacing and bond between the concrete and the reinforcement. For this purpose, two different types of GFRP and steel bars were used. The cracking behaviour (crack width and spacing) in the pure bending zone was analysed up to the service load. Crack width was consistently acquired by using a Digital Image Correlation (DIC) technique. The 2D full-field displacements of the pure flexural zone were registered using 4 digital cameras and commercial software that enables the evolution of the specimen cracks to be analysed. Finally, bond coefficients have been adjusted to different formulations in terms of crack spacing and crack width.

- **Wei Dong , Xiangming Zhou, Gediminas Kastiukas** [15] employed the digital image correlation (DIC) technique is employed to investigate the fracture process at rock-concrete interfaces under three-point bending (TPB), and four-point shearing (FPS) of rock-concrete composite beams with various pre-crack positions. According to the displacement fields obtained from experiment, the crack width, and propagation length during the fracture process can be derived, providing information on the evolution of the fracture process zone (FPZ) at the interface. The resultsindicated that under TPB, the fracture of the rock-concrete interface is mode I dominated fracture although slight sliding displacement was also observed. Under FPS, the mode II component may increase in the case of a small notched crack length-to-depth ratio, resulting in the crack kinking into the rock. It was also observed that the FPZ length at the peak load is far longer for a specimen under FPS than under TPB.

- **Subramaniam et al.** [16] tested steel fiber reinforced concrete beams with fiber volume fractions equal to 0.5% and 0.75% with a shear span to depth ratio equal to 1.8. The cracking in the beams is evaluated using the full-field surface displacements obtained from the digital image correlation (DIC) technique. Analysis of images shows that a full depth shear crack is established before the peak load. The displacements measured from across the shear crack indicate a continuous increase in the crack opening displacement associated with increasing slip between the two crack faces. From crack opening and sliding measurements across the shear crack, the dilatant behavior is identical in beams with and without steel fiber reinforcement. Failure in control beams is brittle and results in a large opening of the shear crack. In the SFRC beams with 0.5% volume fraction, there is a continuous decrease in the residual load carrying capacity after the peak load which is associated with an increase in the crack opening displacement. In SFRC beams with 0.75% fiber volume fraction, the increased resistance to crack opening provided by the fibers results in a significantly smaller crack opening and a large increase in the peak load. The crack opening due to dilatancy is arrested, resulting in shear failure by the formation of a secondary shear crack or by flexural

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failure. The crack opening displacement across the shear crack at the peak load in the load response of the control and the SFRC beams are nominally identical. Failure in shear occurs when the crack opening control provided by the flexural reinforcement and steel fibers is inadequate to sustain the aggregate interlock.

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