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Ingress and Corrosion in Cracked Reinforced Concrete

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Objectives

The objectives of this PhD project are to:

- Develop models to estimate the ingress of aggressive substances into cracked reinforced concrete and
- Improve the understanding of the effect cracks have on the corrosion of reinforcing steel.

Motivation


Figure 1: Corrosion-Induced Damage

Corrosion has been estimated to cost 3-4% of the GDP in industrialized countries. In the U.S. the direct cost of corrosion of the aging highway bridge infrastructure has been estimated between \$6.4 billion and \$10.2 billion annually, with indirect cost estimates over 10 times the direct cost.

Cracks develop in concrete through physical and chemical processes, which may occur at varying stages of the lifetime of a structure, and result in varying crack characteristics. Cracks provide easy access of aggressive substances from the environment. Therefore, corrosion of the reinforcement may initiate rapidly.


Figure 2: Cracking in Bridge Deck

Life-cycle modeling is becoming a common tool for civil engineers. Current models for reinforced concrete structures have focused on the deterioration of uncracked concrete. However, this rarely represents the actual condition of a reinforced concrete structure. A key improvement in life-cycle modeling is the inclusion of the effect of cracking on the transport, corrosion, and deterioration in reinforced concrete.

Approach

The overall approach of this three year research project consists of:

- Comparison of cracking in laboratory and in-situ concrete (see detailed description)
- Quantification of ingress in cracked reinforced concrete
- Establishment of a link between crack characteristics and relevant transport mechanism(s)
- Development of a finite element model to estimate ingress of aggressive substances in cracked reinforced concrete, and
- Investigation of the corrosion behavior of reinforcing steel in cracked reinforced concrete structures.

Collaboration

This PhD project is a continuation of the collaboration between Purdue University School of Civil Engineering and BYG•DTU, which was initiated through the Knud Højgaard Foundation.

Comparison of Cracking in Laboratory and In-situ Concrete

Scope

The cracking behavior of reinforced concrete laboratory specimen under three point bending was investigated using a photogrammetry technique. Results from this investigation will be compared to more traditional crack width measurement techniques and to in-situ cracks. If flexural loading simulates in-situ load, an investigation into the ingress and corrosion will commence on similar laboratory specimen.

Methodology

3-D Photogrammetry

Using commercial 3-D digital photogrammetry equipment (Aramis) the cracking behavior of reinforced concrete laboratory specimen has been investigated. One face of the concrete was removed to expose the reinforcement, such that the effect of reinforcement could be monitored.

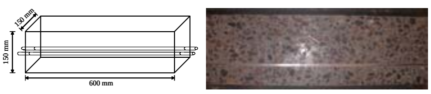

Figure 3: Reinforced Concrete Laboratory Specimen (a) Geometry and (b) Exposed Steel

A stochastic spatter pattern was applied to the concrete surface using white and black spray paint to provide adequate contrast. The reinforcement was painted white to dull the shiny metal. The aggregates remained clearly visible after application of the paint. The specimens were then placed under flexural loading and images were captured by the Aramis system with CCD digital cameras (Figure 4).

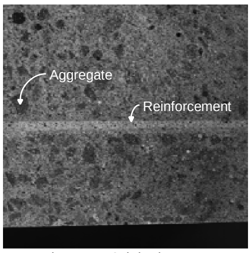

Figure 4: Original Image

A mesh mask was applied by the provided software to the original image. Each grid in the mesh was associated with particular grayscales on the image, and therefore may be matched to all subsequent images taken during the test. Figure 5 shows the initial, undeformed mesh next to an image taken from the same location after load has been applied. The deformation of the individual mesh grids is readily apparent.

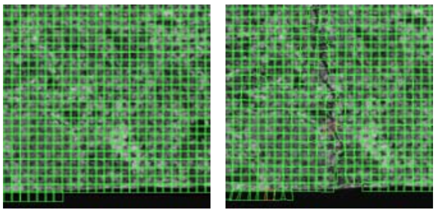

Figure 5: Meshed Images (a) Before and (b) After Loading (Zoomed)

The strain of the individual mesh grids was calculated incrementally through the test period, yielding information on the specimen deformation.

Experimental Results

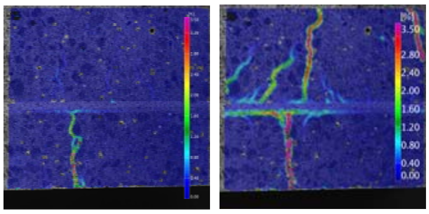

Figure 6: Mesh Strain Overlay on Reinforced Concrete Laboratory Specimen under (a) Estimated Cracking Load (14kN) and (b) 35 kN

Figure 6 shows a representation of the strain in the mesh grid. After testing was completed, points were specified on the imaged surface to collect point-point displacement measurements as shown in Figure 7 and 8.

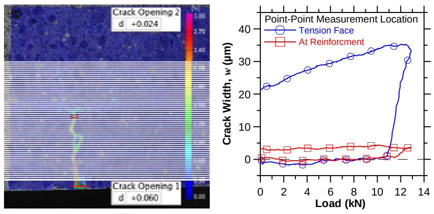

Figure 7: (a) Virtual Displacement Gages and (b) Cracking Response

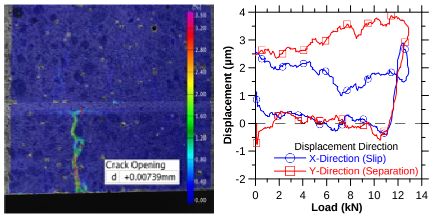

Figure 8: (a) Virtual Displacement Gages and (b) Mechanical Response at Concrete/Steel Interface

The effect of the increasing crack width (at the tension face) on the response at the concrete/steel interface is shown in Figure 9. The increase in the displacement at the interface appears to coincide with the opening of the crack at the tension face.

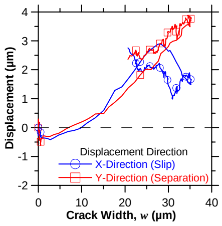

Figure 9: Slip versus Crack Mouth Opening Response

Preliminary Conclusions

The preliminary conclusions of this comparison between laboratory and in-situ cracking are:

- The Aramis photogrammetry equipment is effective at detecting cracking in concrete and at the steel/concrete interface
- Aramis provides qualitative and quantitative information on concrete cracking
- Crack widths have been measured at various locations, illustrating V-shape cracking
- Slip and separation at the steel/concrete interface occured with minimal crack openings induced by flexural load.

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