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The Derivation of a Four-Strain Optimized Mohr's Circle for Use in Experimental Reinforced Concrete Research

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Abstract : One of the best ways of improving our understanding of reinforced concrete is through large-scale experimental testing. The gathered information is critical in making inferences about structural mechanics and deriving the mathematical models that are the basis for finite element analysis programs and design codes. An effective way of measuring the strains across a region of a specimen is by using a system of surface mounted Linear Variable Differential Transformers (LVDTs). While a single LVDT can only measure the linear strain in one direction, by combining several measurements at known angles a Mohr's circle of strain can be derived for the whole region under investigation. This paper presents a method that can be used by researchers, which improves the accuracy and removes experimental bias in the calculation of the Mohr's circle, using four rather than three independent strain measurements. Obtaining high quality strain data is essential, since knowing the angular deviation (shear strain) and the angle of principal strain in the region are important properties in characterizing the governing structural mechanics. For example, the Modified Compression Field Theory (MCFT) developed at the University of Toronto, is a rotating crack model that requires knowing the direction of the principal stress and strain, and then calculates the average secant stiffness in this direction. But since LVDTs can only measure average strains across a plane (i.e., between discrete points), localized cracking and spalling that typically occur in reinforced concrete, can lead to unrealistic results. To build in redundancy and improve the quality of the data gathered, the typical experimental setup for a large-scale shell specimen has four independent directions (X, Y, H, and V) that are instrumented. The question now becomes, which three should be used? The most common approach is to simply discard one of the measurements. The problem is that this can produce drastically different answers, depending on the three strain values that are chosen. To overcome this experimental bias, and to avoid simply discarding valuable data, a more rigorous approach would be to somehow make use of all four measurements. This paper presents the derivation of a method to draw what is effectively a Mohr's circle of 'best-fit', which optimizes the circle by using all four independent strain values. The four-strain optimized Mohr's circle approach has been utilized to process data from recent large-scale shell tests at the University of Toronto (Ruggiero, Proestos, and Bruun), where analysis of the test data has shown that the traditional three-strain method can lead to widely different results. This paper presents the derivation of the method and shows its application in the context of two reinforced concrete shells tested in pure torsion. In general, the constitutive models and relationships that characterize reinforced concrete are only as good as the experimental data that is gathered – ensuring that a rigorous and unbiased approach exists for calculating the Mohr's circle of strain during an experiment, is of utmost importance to the structural research community.

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