CONSTITUTIVE MODEL FOR CONCRETE IN PLANE STRAIN CONDITION AND IT'S APPLICATION TO THE ANALYSIS OF A GRAVITY DAM[1]

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The non-linear behaviour of a gravity dam is usually analysed, within the plane strain condition, by assuming that the stress-strain relationships in the directions of principal stresses (i.e. σ_1-ε_1 and σ_2-ε_2) follow the non-linear uniaxial constitutive relation (σ_u-ε_u). However, it is now well-established that the non-linear biaxial constitutive relations for concrete differ significantly from the non-linear behaviour of concrete under uniaxial loading conditions (Kupfer et al. 1969, Kupfer 1973, Tasuji 1976, etc.). It is therefore, desirable to employ a non-linear biaxial constitutive relationship for concrete, when analyzing various structural characteristics of a gravity dam. However, it is a point of concern that the previously reported non-linear biaxial constitutive relationships for concrete deal, almost entirely, with the plane stress condition, and that there is currently a lack of theoretical and experimental data dealing with the plane strain condition. Development of a non-linear biaxial constitutive relationship for concrete subjected to the plane strain condition is, therefore, desirable for analyzing the stress conditions within the body of a gravity dam (amongst other plane strain problems).

Key words: gravity dam, non-linear operation, plane deformation, principal stress, failure criteria, crack.

The present work reports the stress-strain relationships for plain concrete, which are based on a non-linear biaxial anisotropic (orthotropic) constitutive model, catering for *plane strain conditions* (Raoof et al., 2000). The presently reported constitutive relationship is based on an extension of the previously developed non-linear biaxial anisotropic (orthotropic) constitutive model for concrete, which related to the *plane stress conditions* (Raoof et al., 1999). The extension from *plane stress* to *plane strain conditions* is based on the modification of a failure criterion for plain concrete subjected to a three-dimensional state of stresses. To this end, the four-parameter failure criteria developed by Ottosen or Hsieh (Chen, 1982) has been used. Detailed derivations are given elsewhere (Raoof et al., 1999, 2000), and will not be repeated here, due to space limitations. Instead, in what follows, some representative results will be briefly discussed, with these highlighting the practical implications of using the presently reported plane strain model (in preference to the previously available plane stress models) for analyzing the biaxial state of stresses within the body of gravity dams.

As a starting point, results were produced for the Compression-Compression mode of biaxial stresses with $\alpha=\sigma_3/\sigma_1=0.05$ (Fig. 1). From Fig. 1, it is found that the compressive strength of concrete is increased considerably even for the case of a small value for α. Indeed, the compressive strength of concrete is found to be about twice of that corresponding to uniaxial compression and plane stress conditions. With the values of α increased up to, firstly, α=0.10 and, then, up to α=0.15, significant increases in the associate values of the concrete compressive strength were found. The assumed value of α was not, however, increased any further, as the appropriate values of α in Compression-Compression mode of biaxial stresses, within the body

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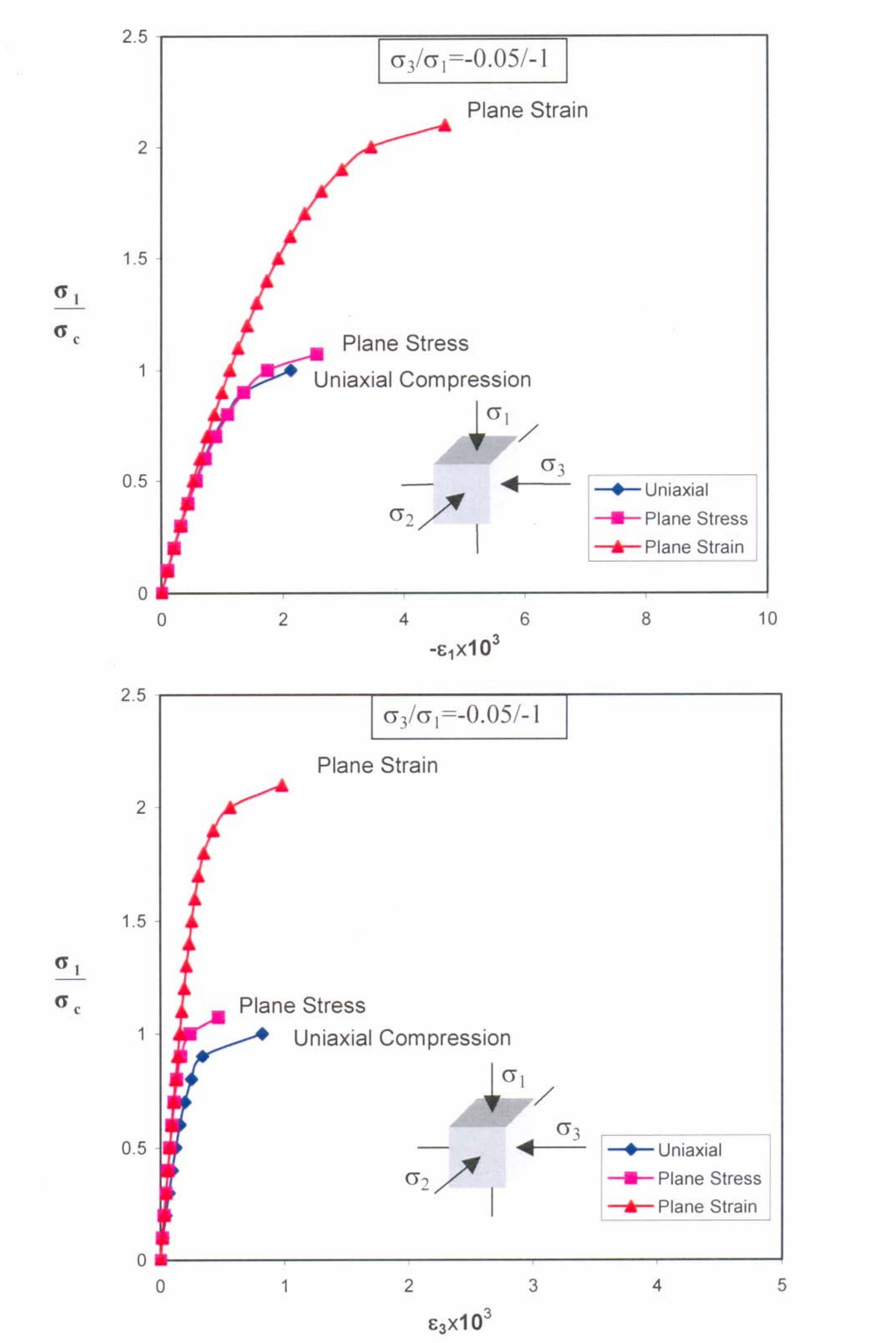


Figure 1 Comparison of Uniaxial Compression Test, Plane Stress and Plane Strain Conditions of concrete for Compression-Compression state with α=0.05.

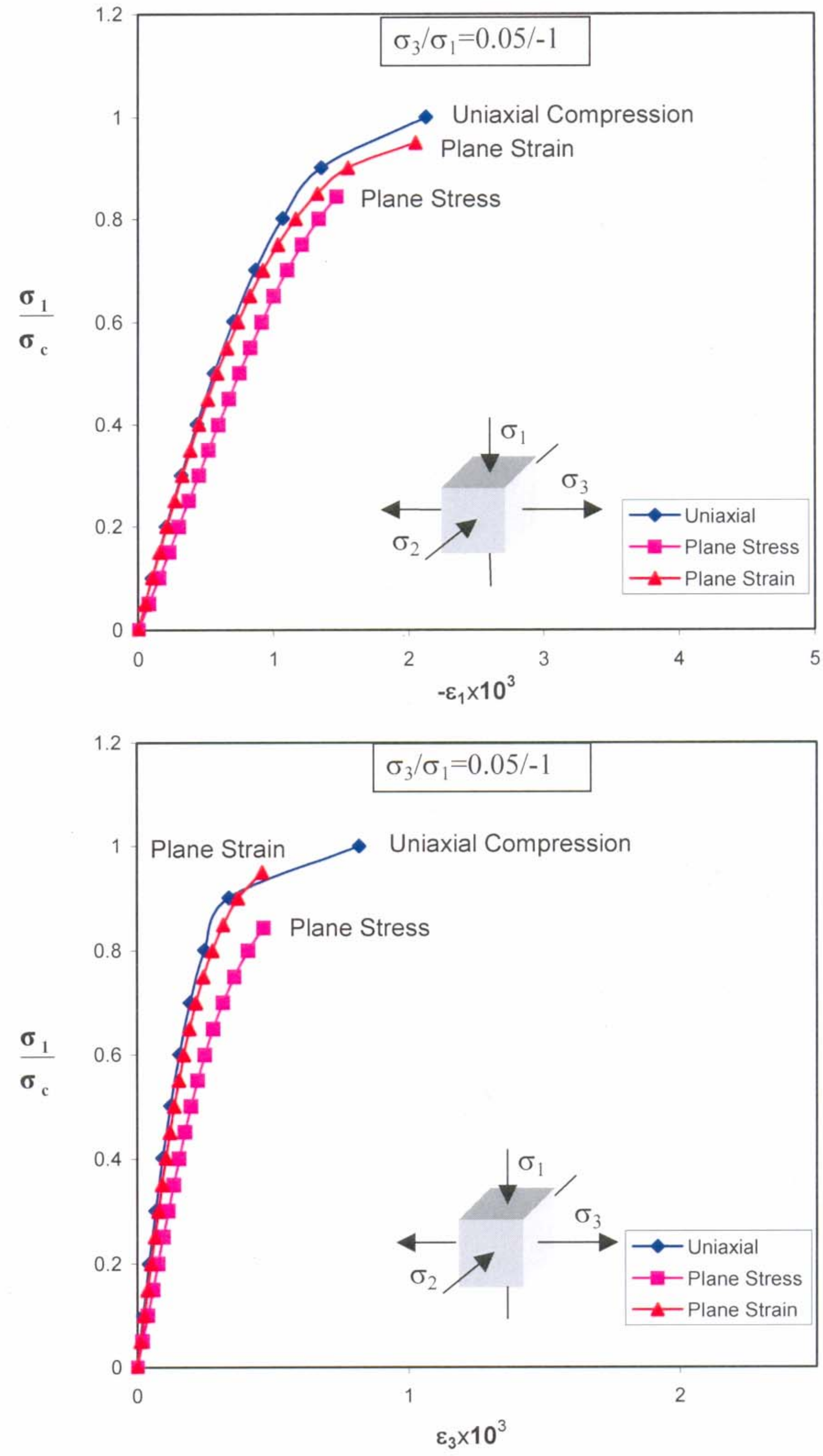


Figure 2 Comparison of Uniaxial Compression Test, Plane Stress and Plane Strain Conditions of concrete for Tension-Compression state with α=-0.05.

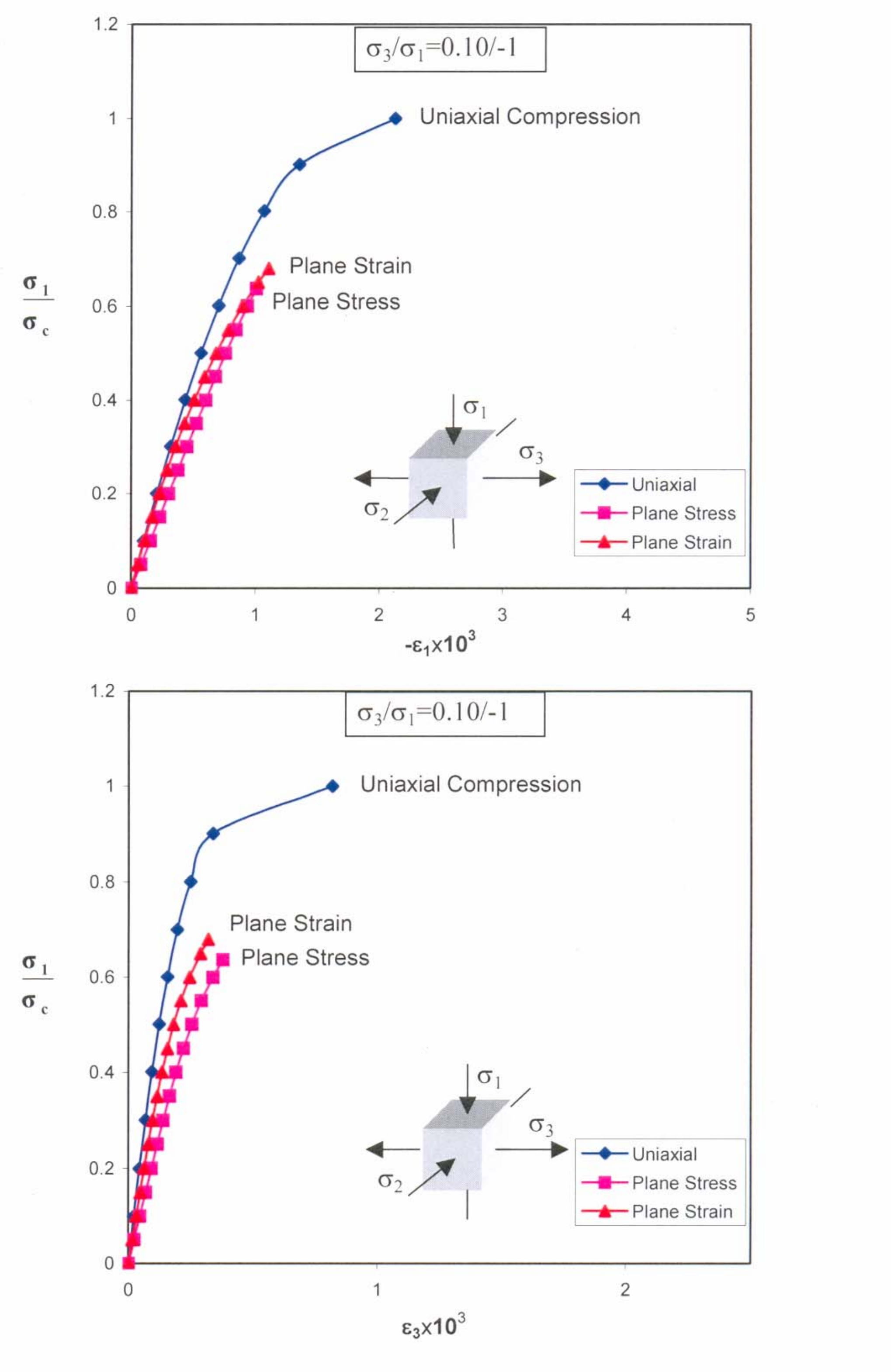
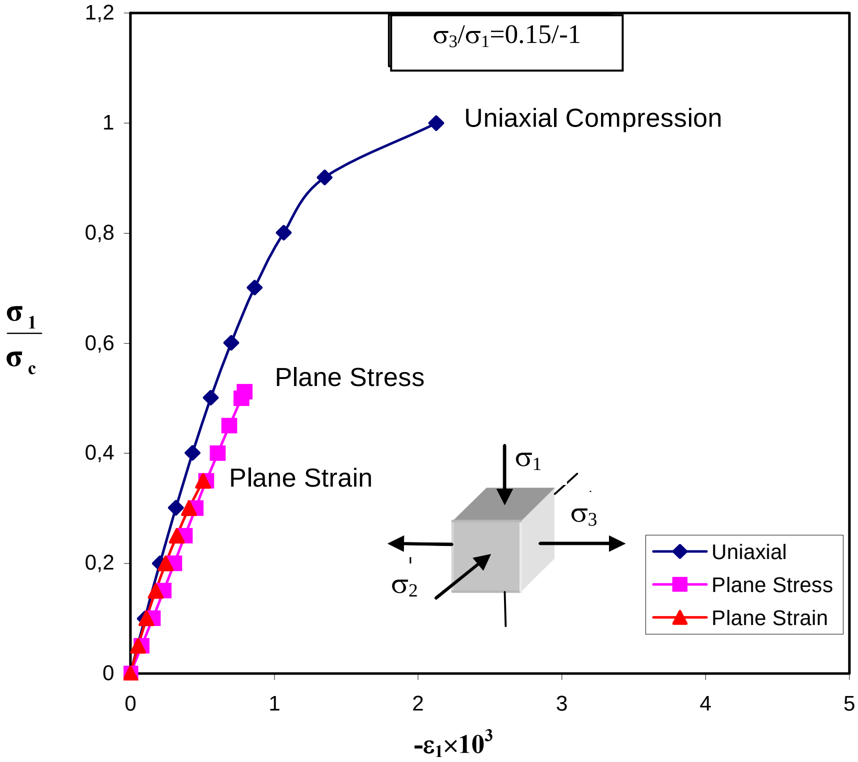


Figure 3 Comparison of Uniaxial Compression Test, Plane Stress and Plane Strain Conditions of concrete for Tension-Compression state with α=-0.10.



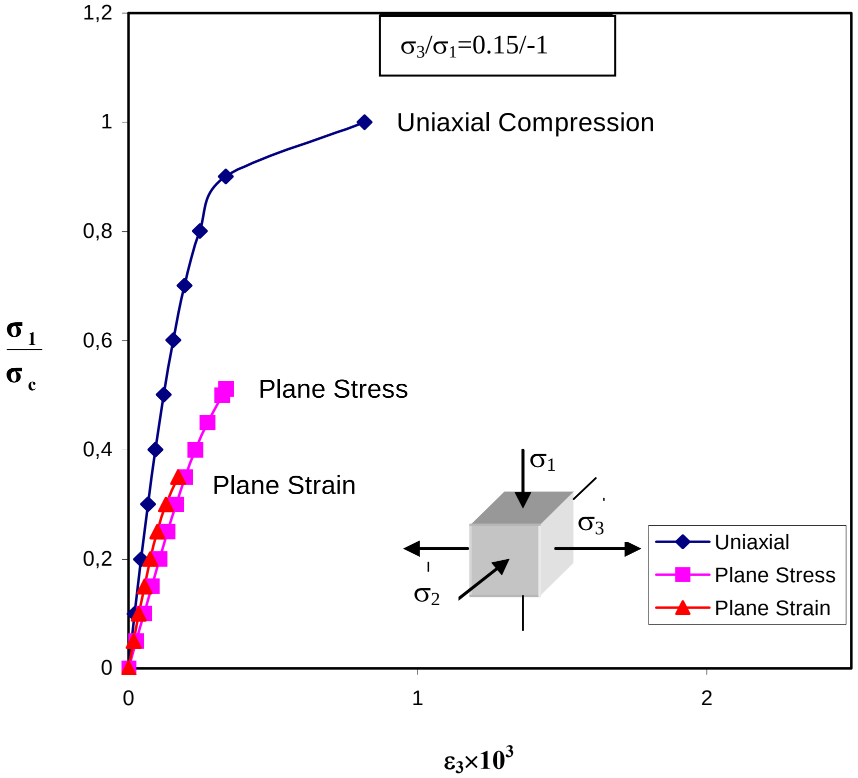


Figure 4 Comparison of Uniaxial Compression Test, Plane Stress and Plane Strain Conditions of concrete for Tension-Compression state with α=-0.15

of a gravity dam, generally lie within the range of 0 to 0.2 (i.e. $0.00 \leq \alpha \leq 0.20$) and, even, over this range, a very substantial reserve in terms of the concrete compressive strength in the body of a gravity dam (under the plane strain conditions) was found.

Of more practical importance, however, is the behaviour of concrete in the Tension-Compression mode of biaxial stresses. In this context, results in Fig. 2 (with $\alpha=-0.05$), show that the value of concrete compressive strength, under the plane strain condition, is more than that associated with the plane stress condition, although lower than the corresponding uniaxial compressive strength. Further work indicated that the value of concrete compressive strength under the plane strain conditions decreases with increasing values of α: with $\alpha=-0.10$, results in Fig. 3 suggest that the value of concrete compressive strength under plane strain condition is equal to that under the plane stress condition and when $\alpha=-0.15$, the results in Fig. 4 show that the value of concrete compressive strength under the plane strain condition becomes less than that corresponding to the plane stress condition.. It then, follows that the plane strain condition is more critical (i.e. it worsens the behaviour of concrete) at the region of Tension-Compression mode of biaxial stresses encountered near the upstream face of a gravity dam: this is of course the region where the most dangerous stresses can occur, with these causing crack occurrence and propagation within the body of a gravity dam. Obviously, in the course of analyzing the state of stresses in a gravity dam in the plane strain condition, it is necessary to reliably investigate the possibility of crack occurrence and propagation within the body of the structure.

R E F E R E N C E S

Chen, W. F. (1982), Plasticity in Reinforced Concrete. *McGraw-Hill, New York.*

Kupfer, H. B., Hilsdorf, H. K., and Rusch, H. (1969), 'Behaviour of Concrete Under Biaxial Stresses', *ACI Journal, Vol. 66, No. 8, Aug., 656-666.*

Kupfer, H. B. (1973), 'Das Verhalten des Betons unter mehrachsiger kurzzeitbelastung unter besonderer Berucksichtigung der zweiachsigen beanspruchung', *Deutcher Ausschuss fur Stahlbeton, Berlin, No.229.*

Kupfer, H. B., and Gerstle, K. H. (1973), 'Behaviour of Concrete Under Biaxial Stresses', *J. Engng. Mech. Div., ASCE, Vol. 99, No. EM4, Aug., 853-866.*

Raoof, M., Mazza', G., Motsonelidze, A., Abuladze, V. (1999), "Periodic Report No.1 for INTAS, Brussels, Belgium", *Loughborough-Milan-Tbilisi, pp. 94.*

Raoof, M., Mazza', G., Motsonelidze, A., Abuladze, V. (2000), "Periodic Report No.2 for INTAS, Brussels, Belgium", *Loughborough-Milan-Tbilisi, pp. 159.*

Tasuji, M. E. (1976), 'The Behaviour of Plain Concrete Subject to Biaxial Stress', *Ithacha, N. Y., Cornell University, Department of Structural Engineering, Research Report No. 360, pp. 171.*

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