Incorporation of LITS in Finite-Element models

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INTRODUCTION

Load induced thermal strain (LITS) is an integral part of the behaviour of concrete in fire. The existence of LITS has been well documented and modelled by different researchers. It is vital that this strain development is correctly represented in structural models, as the locked in strains due to LITS constituents are significant. Current methods of modelling LITS involve incorporating the strains into constitutive curves. This approach allows the total strains developed due to LITS to be simply included in a finite element analysis. More thorough representation is needed to accurately represent the plastic components in loading directions, and the total strains in non-loading directions. This poster presents a technique to allow the evolution of LITS in accordance with the rules developed in several academic material models.

What is LITS

LITS is defined as the difference in strain between the free thermal expansion (ε_{th}) of concrete, and the thermal expansion when the same concrete is heated under a level of pre-stress. Figure 1 shows the difference between a typical unstressed sample and a pre-stressed sample. It can be observed that under higher levels of pre-stress the material shrinks.

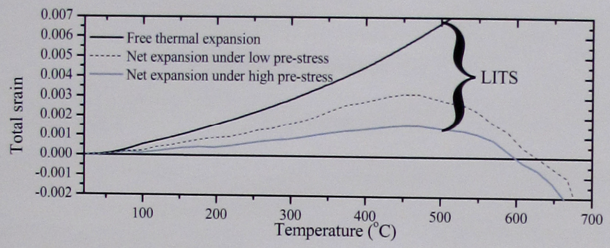


Fig. 1 Difference between strains when concrete is heated with different levels of applied stress.

Simple Inclusion in the finite-element method

Consider a small cube of concrete, subject to a displacement controlled loading in principle direction 2, but free to move in the transverse directions with a Drucker-Prager yield surface and a perfectly plastic material behaviour. The associative isotropic flow rule (used here for simplicity) dictates that once the yield surface is reached, plastic strain must occur in a direction orthogonal to the yield surface in stress space. This means that plastic strains are induced in directions other than the one in which the load is applied.

Figure 2 illustrates the difference between the total strain in the loading and in the non-loading directions. Where an elastic modulus that is distinct from the gradient of the constitutive curve is used, the lateral strains are much greater than when the "apparent" modulus is used.

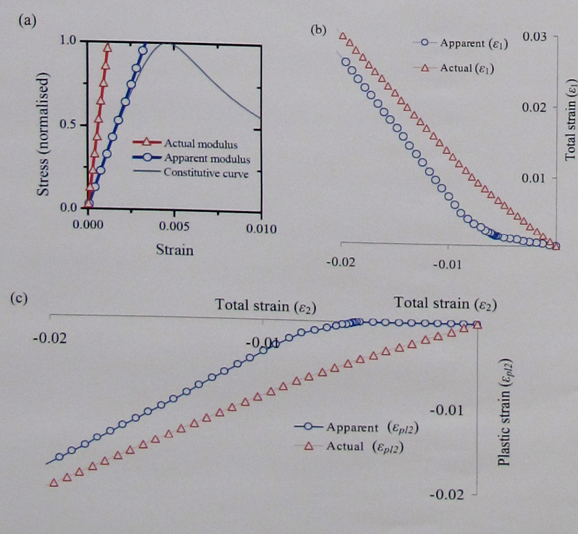
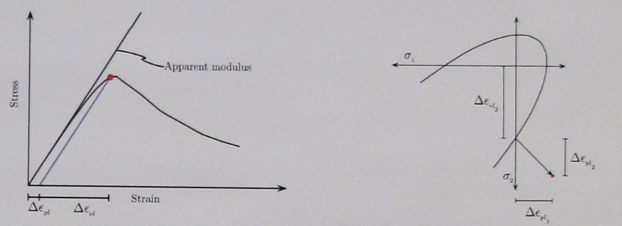


Fig. 2 The same constitutive curve with different elastic moduli gives different lateral deformations and direct plastic strains.

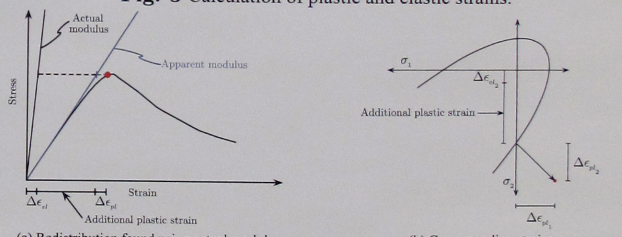
Embedded modulus

To allow the modelling of LITS to be more representative, a new method for the inclusion of LITS in the constitutive model while avoiding the transverse strain issue outlined above is proposed. The Drucker-Prager yield criterion and plasticity equations are solved in a two step method: first, the elastic strains and corresponding plastic strains are calculated using the apparent modulus and the normal solution methods (Figure 3); secondly, the elastic (ε_{elI}) and plastic (ε_{plI}) strains are recalculated using the actual modulus (Fig. 4). As such, the actual modulus is *embedded* within the solution procedure.



(a) Hardening with apparent modulus (b) Corresponding strains

Fig. 3 Calculation of plastic and elastic strains.



(a) Redistribution found using actual modulus (b) Corresponding strains

Fig. 4 Redistribution of strains due to the difference between actual modulus and apparent modulus.

Conclusions

The total lateral strains experienced by the "embedded" material are the same as those experienced by the "apparent" material. Equally, the total plastic strain experienced in the loading direction is the same as those experienced by the "actual" material. Thus, a fully plastic, transient strain constituent has been included in the model without affecting the deformations in the non-loading directions. This allows the plastic LITS effect to be successfully modelled uni-axially and in proportion to the applied stress in the way stated in the governing LITS equations (Figure 5).

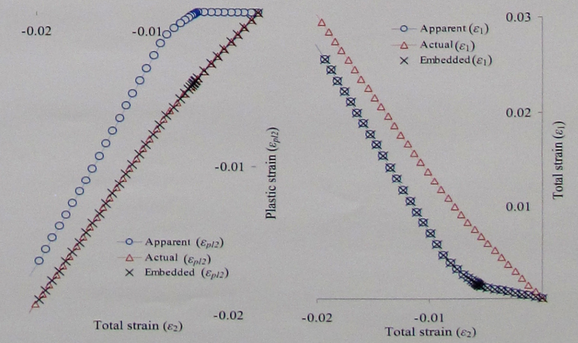


Fig. 5 Comparison of two stage approach with results from original models.