Energy Dissipating Processes in the Compression of Cement Paste and Concrete

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INTRODUCTION

Two of the processes which contribute to the energy dissipation when cement paste or concrete is continuously loaded until the ultimate stress is reached are time-dependent effects (creep) and damage (micro-cracking). This paper briefly discusses methods which have been used to indicate the role of time-dependent behaviour in quasi-static loading and then describes a new technique for detecting the occurrence of damage in cyclically loaded specimens tested in uniaxial compression.

TIME-DEPENDENT BEHAVIOUR IN QUASI-STATIC LOADING

It has been clearly established that the stress v strain curve for cement paste and concrete is straining-rate dependent [1,2,3,4,5]. At slower straining-rates the stress corresponding to a given strain is lower than that at faster rates. This effect may be attributed to creep and a method has been suggested[6] for estimating the creep occurring when cement paste or concrete is loaded at a constant straining-rate. When using this method to estimate the stress v strain curves for 14 day-old cement paste specimens, Fig.1, the strains at the higher stresses were greater in practice than those calculated assuming elastic and creep behaviour only. This discrepancy was attributed to structural damage in the specimens caused by the loading.

The slower the straining-rate used in a test the greater will be the contribution of creep. However, if the straining-rate is speeded up it is suggested that a stage will be reached where the contribution of creep to the total strain is negligible. Cole and Spooner(6) showed that there was an increase in the logarithmic decrement of cement paste specimens when the period of vibration was reduced below approximately 0.4 secs and they attributed this increase to time-dependent effects, Fig.2. Therefore, if straining-rates are fast enough - the test completed in 0.4 secs for example - then the effect of creep will be very small.

THE ONSET OF DAMAGE IN QUASI-STATIC LOADING

Jones(7) and other workers since have used various non-destructive techniques to show that damage occurs in concrete before the ultimate stress is reached in compressive loading. However, there has been some discussion as to the proportion of the ultimate stress which can be reached before damage occurs.

In view of the uncertainties and complexities associated with the various indirect methods of detecting damage a simpler, more direct approach was sought and this new method, together with some experimental examples, is now described.

When cement paste or concrete is loaded for the first time, damage occurs when the local stresses exceed the local strength of the material. The onset of damage immediately results in proportionately greater strains occuring since the average stresses on the undamaged material have been increased. On unloading, the damage which has occurred results in an irrecoverable shortening of the specimen. On reloading the specimen to the same maximum

stress as before no more damage occurs (unless the maximum stress reached is a high proportion of the ultimate stress 85-90%) but the initial slope of the stress v strain curve is lower. The total strain occuring in both the first and second loadings is the same at the common maximum stress. These effects are illustrated in Fig.3 for three consecutive loading-unloading cycles (to 15, 18 and 20 N/mm^2) on a concrete specimen. The slopes at low stress of the successive loading curves gradually reduce and the stress-strain curve on reloading to the maximum stress reached in the previous cycle is more linear. However, when the stress on reloading exceeds the maximum of the previous cycle, the stress v strain relationship becomes more curved again indicating that further damage is occurring.

Thus, using loading-unloading cycles the occurrence of damage can be followed throughout the whole stress-strain relationship of a specimen up to and even beyond the ultimate stress and this is illustrated in Fig.4 for a cement paste specimen and a concrete specimen containing flint gravel aggregate. It is significant that the concrete specimen shows a continuous reduction in modulus with increase in the previously applied strain but that the cement paste specimen exhibits an abrupt transition from a constant to a lower value. This indicates that permanent damage is occurring at very low strains in the concrete but not until much later in the cement paste.

CONCLUSIONS

When cement paste and concrete are loaded continuously until the ultimate stress is reached both creep and cracking can contribute significantly to the measured deformations. The contribution of