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 vs strain curve for cement paste and concrete is strain-rate dependent \( (1, 2, 3, 4, 5) \). At slower strain-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 strain-rate. When using this method to estimate the stress vs 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 occurring 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 vs strain curve is lower. The total
strain occurring 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/mm²) 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 vs 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