Some factors influencing the long term strength of concrete

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INTRODUCTION

Concrete is frequently subjected in practice to relatively low stresses from an early age before the loads gradually increase to their more permanent values. This is often a natural consequence of the construction sequence. The effect of graduated loading over extended periods is not normally considered, however, either for crushing tests or for conventional creep tests in which a single increment in load is applied fairly rapidly.

Even before concrete is loaded externally cracks may be present due to shrinkage or other effects [1]. Glucklich [2] postulated that loading causes these cracks to grow and new cracks to form. The stress level which produces continuous crack growth is termed the point of discontinuity and ultimate failure is considered inevitable [3]. This stress level coincides with the "strength under sustained load" considered by Rusch [4]. Failure will never occur if this discontinuity stress is not reached.

Washa and Fluck [5] loaded specimens to 25% of their 28 day strength and then removed the load after 10 1/2 years. The specimens, together with corresponding companion specimens which had been left under the same ambient conditions, were then tested to determine both the ultimate strength and modulus of elasticity. The strength of the long term specimens varied between 0.95 and 1.05 of the strength of the unloaded specimens. Similar tests were performed by Freudenthal and Roll [6] using stresses between 17 and 83% of the 28 day strength of the concrete. Increases in strength for the loaded specimens were up to 30% but considerable variations were found for specimens of different sizes.

Coutinho [7] recently showed that a long term load will improve the ultimate compressive strength of concrete by as much as 20% for a specimen initially loaded at an age of 7 days, and 10% for a specimen loaded at 6 months. He ascribed the increase in strength to a "forced" hydration of the cement due to the water in the concrete being under pressure. His results confirmed that no failure would occur during long term loading if the discontinuity stress was not reached.
If creep increases the ultimate strength of concrete, then factors which increase creep would be expected to increase strength also. The present investigation therefore considered the effects of variation in cement content, aggregate size and specimen age.

**TESTING TECHNIQUE**

Creep tests frequently utilise spring systems because of their low cost. However, for the present work hydraulic machines have the following advantages.

1. Load increments may be applied very conveniently.
2. Large load increments may be applied rapidly to cause failure of the specimen.
3. There is no loss in load due to the shortening of the specimen, providing that the hydraulic pressure is kept constant.
4. The use of standard load indicating equipment ensures an accuracy which is difficult to achieve with inexpensive spring systems.

Initially a Mohr and Federhaff universal testing machine which incorporated a load holding device was used but it was capable of testing only one specimen at a time. A testing rig was therefore developed whereby a number of specimens could be loaded simultaneously, as shown in figure 1.

![General view of test rig](image)

The series of hydraulic jacks were connected to an Avery Console (i.e. pump) which incorporated a load holding device. A spherical seat was positioned above each jack which effectively provided a small compression testing machine to grade A specification [8]. The maximum load per jack was 30 000 lbf. (136.5 kN). The specimens used were 2" (50.8 mm) square, giving a maximum stress of 7 500 p.s.i. (51.7 MN/m²). Strains were measured on a 4" (101.6 mm) gauge length using a demountable mechanical gauge.

**EXPERIMENTAL PROGRAMME**

Details of the aggregates are given in Table I. All aggregates were soaked for 24 hours prior to mixing. The 2" square by 4½" long specimens were cast with their major axes in a horizontal plane. Moisture losses during the long term tests were minimised by painting the specimens with three coats of Febcure "Super" curing compound. The mix proportions for the concretes and mortars are given in Table II. The concrete mixes, CI-3, contained the optimum coarse aggregate content [9].

![Stress/time diagram for specimens loaded at 3 days](image)

Figure 2 shows the load/time curve for the long term test of a concrete tested at an age of three days. Notice that the long-term load must not approach the point of discontinuity if it is to increase, rather than decrease, the subsequent short-term strength. The load time diagrams were therefore made the same for both the short-term and long-term tests above the load required to cause discontinuity. Figure 2 shows that the long term load was taken up to a maximum of approximately 50% of the 28 day strength before the short-term load was applied at the standard rate of 1 000 p.s.i. per minute.

Unloaded companion specimens were stored by the testing rig during a long-term test so that they were subjected to the same temperature and humidity conditions throughout.