Towards prediction of compressive strength and modulus of elasticity of high-strength concrete

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1. Introduction

Compressive strength of concrete (f_c) is perhaps the most important overall measure of the quality of concrete, although other characteristics may also be critical. Modulus of elasticity (E_c) is particularly important from a design point of view in reinforced and prestressed concrete, since it can control the concrete behaviour as much as compressive strength. To avoid the time-consuming direct determination of f_c and E_c, it has been attractive to empirically predict both of them. The current empirical equations in codes, standards and recommended practice for estimating compressive strength and modulus of elasticity are based on tests of normal-strength concrete without supplementary cementitious materials. The validity of these relations for high-strength concretes with supplementary cementitious materials should be investigated. An experimental program was carried out at Okayama University to investigate in detail the relationship between f_c and E_c and their development with time, for high-strength concrete.

2. Experimental program

Six series of concrete mixtures were prepared to cover a wide range of variables. Variables included fine and coarse aggregate types, water content, silica fume percentage, water/cementitious ratio, and mixing time. River, Sea and crushed sands were used as fine aggregates (series I), while crushed basalt and clay slate were used as coarse aggregates (series II). Water content level had the values of 120, 140 and 160 kg/m^3 (series III). Silica fume was used as 0, 5, 10 and 15% of the total cementitious materials content (series IV). Water/cementitious materials values were 0.33, 0.25 and 0.20 (series V). Concrete batches were mixed for 2.5, 5.0 and 8.0 minutes (series VI). Ordinary portland cement was used as main cementitious material throughout this study. Whereas, silica fume was the only supplementary cementitious material. Immediately after casting, the casting surface of the specimens was covered with a plastic sheet for 24 hours. Specimens were then removed form moulds and cured under water, at 20C, until testing. Concrete compressive strength and modulus of elasticity were measured on 100 x 200-mm cylinders at 3, 7, 14, 28, 56 and 91 days after casting. At each testing age, three specimens were tested in compression using a very stiff 200-ton capacity hydraulic testing machine. Before testing, end preparation of all specimens was done by grinding to maintain uniform end conditions. An axial extensometer with 100-mm gauge length was used to obtain the strain values of concrete cylinders. The 28-day compressive strength values of the tested concretes fall in a band between 70 and 110 MPa.

3. Results and Discussion

The compressive strength and modulus of elasticity values, experimentally measured at different ages, were compared with the predicted values according to ACI [1,2] and CEB MC90 [3] expressions and presented in Fig. (1) and Fig. (2), respectively. From Fig. (1) it is clear that ACI expression tends to underestimate both compressive strength and modulus of elasticity of high-strength concrete. CEB MC90 expression seems to be reliable and satisfactory for compressive strength, while it tends to overestimate the modulus of elasticity. From the previously mentioned comparison, it can be generally, concluded that within 20 percent precision, compressive strength and modulus of elasticity can be predicted from ACI and CEB MC90 expressions, but in some cases, these values can be greatly wrong. As a result of this study, the following equation is proposed for estimating the compressive strength of high-strength concrete at any age $f_c(t)$, MPa, as a function of 28-day compressive strength $f_c(28)$, MPa, and water/cementitious materials ratio (w/c)

$$f_c(t) = \frac{a\,t}{b+t} f_c(28) \qquad (1)$$

where a=1.1109 – 0.0971 (w/c), b= 1.48 $(a)^{2.95}$, ant t= age of concrete in days

The following proposed equation gives the best-fit line for the relationship between the measured modulus of elasticity $E_c(t)$, GPa, and the compressive strength $f_c(t)$, MPa, of high-strength concrete used in this study

$$E_c(t) = 13.189\left(f_c(t)\right)^{0.27} \qquad (2)$$

The measured compressive strength and modulus of elasticity of high-strength concretes tested in this study are compared to the predicted values according to Eq. 1 and Eq. 2, respectively, in Fig. (3). It can be seen that the proposed

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equations worked so well for high-strength concrete and the variation is in reasonable limits, particularly in the case of modulus of elasticity.

4. Conclusions

The relationship between compressive strength and elastic modulus for normal-strength concrete cannot be extended to high-strength concrete. Equation 1 and Eq. 2 are proposed for estimating the compressive strength and modulus of elasticity of high-strength concrete, respectively. The proposed equations are reasonably accurate.

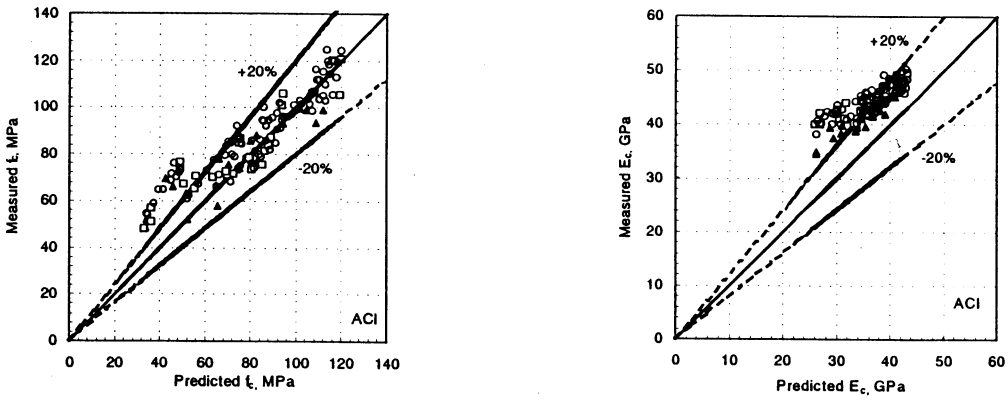

Fig. (1) Comparison of measured values of f_c and E_c and predicted values according to ACI

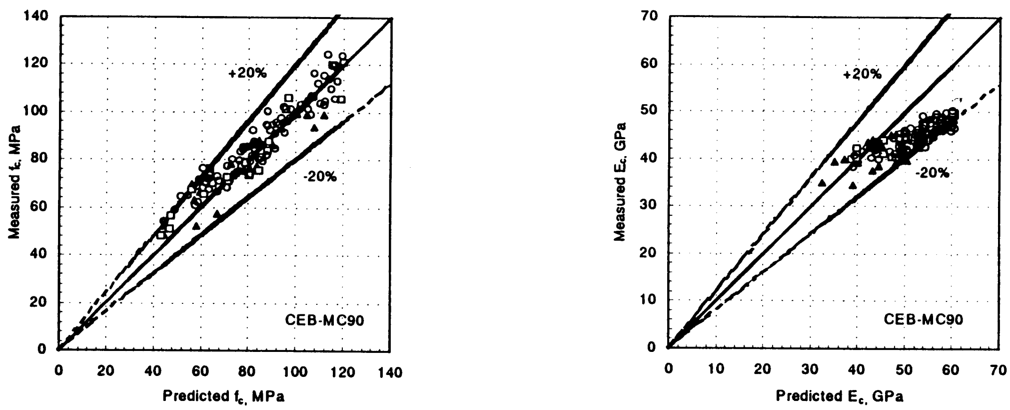

Fig. (2) Comparison of measured values of f_c and E_c and predicted values according to CEB MC90

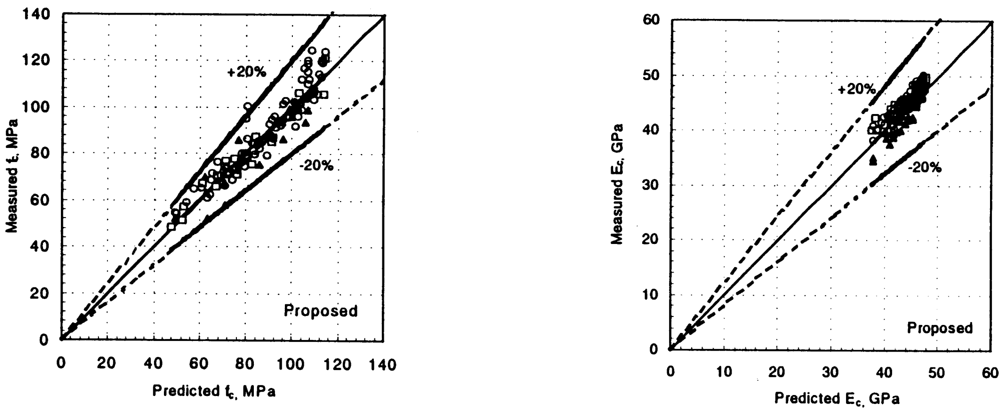

Fig. (3) Comparison of measured values of f_c and E_c and predicted values according to Eq. 1 and Eq. 2

[References]

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