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DETERMINATION OF COHESION AND INTERNAL FRICTION OF PLAIN CONCRETE

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This study investigates the ultimate friction angle and cohesion of plain concrete from its ultimate compressive strengths. Long concrete blocks (depth>=width) with 6 inch (15 cm) square loaded faces were crushed by mild steel loading plates of 1 - 6 inches (2.5 - 15 cm) width with an incremental step of 1/2 inch (12 mm). The experimental results reveal that the ultimate failure stresses of plain concrete increases with the increase in depth of concrete blocks and decreases with increasing width of loading plates. The failure stresses are related reciprocally to the ratios of the width of loading plates to the width of concrete block. A stronger concrete was found to possess greater cohesion and lesser friction angle than a weaker concrete. The cohesion of plain concrete was found to be practically equal to its allowable stress.

Key words: Concrete, Cohesion, Friction angle.

Introduction

Concrete is a versatile construction material used extensively in foundations and in super structures. Because of its versatility and importance, construction engineers are greatly interested to its mechanical properties under stress. Like other classical cohesive materials, concrete possess unit weight γ, void space e, cohesion C and friction angle ϕ. These properties are indispensible for a clear identification of concrete and are the prime parameters for theoretical analysis and experimental investigation. Weight and void of concrete can be easily calculated by the conventional weight and measure technique. But this technique however fails to give any information on either the cohesion or internal friction angle of concrete. This study, focuses on the determination of mechanical properties of concrete in particular C and ϕ.

Experimental

Problemformulation. The maximum load bearing capacity of a plain concrete block is its ultimate failure strength, f'_c. Short concrete block under strip loading fails through tension failure, while long block (depth >= width) collapses through shearing [1]. A loaded concrete mass collapses through progressive failure forming a series of failure planes in the concrete mass. The external load applied on the concrete block is resisted by shearing resistances induced along the failure planes. In practice, the bearing capacity of a plain concrete is expressed by its unconfined compressive strength and its expression for any cohesive granular material is [2].

$$q_u = 2C \tan (45° + 1/2\phi) \qquad (1)$$

in which C and ϕ are respectively the cohesion and friction angle at failure condition of the material. For plain concrete, $q_u = f'_c$.

The contact area between the loading plate and concrete block $A_c = Lb$. In which L is the length of concrete block and b is the width of loading plate. In this study L was 6 inch. The failure stress q is a measure of the collapse load divided by A_c which varies with b as L is fixed. Hence q depends on the variables C and ϕ of eq(1) in addition to b. In terms of variables

$$q = f(C,\phi,\gamma,b)$$

which after rearrangement gives

$$q = f(C, B\gamma, b/B, \phi) \qquad (2)$$

in which q, C and $B\gamma$ have the same dimensions. The dimensionless form of eq(2) can be obtained dividing both sides by f'_c. Thus

$$\frac{q}{f'_c} = f\left(\frac{C}{f'_c}, \frac{B\gamma}{f'_c}, \frac{b}{B}, \phi\right) \qquad (3)$$

The first two terms within bracket of eq(3) are constants for a particular type of concrete block. Neglecting these constant terms, eq(3) can be rewritten as

$$\frac{q}{f'_c} = f\left(\frac{b}{B}, \phi\right) \qquad (4)$$

Eq(4) is a one degree parabola of b/B ratio. The plot of experimental q vs b/B will give the trend of changing q with b/B ratio. For detail analysis, it is necessary to identify the nature of linearity of q on b/B ratio.

Materials and Methods

Loading plates of 7 inch length and widths ranging between 1 – 6 inches with 1/2 inch incremental steps were made from a 1/4th inch thick plate of mild steel. The longitudinal edges of loading plates were made as straight, sharp and vertical as possible. Long concrete blocks were taken as test samples for shearing responses at failure.

Concrete blocks of 6x6x6 and 6x6x8 inches were cast from a concrete mix of proportion 1:2:4 and slump 1 inch. Coarse and fine aggregates were first class brick khoa (1 inch down graded) and river sand (fineness modulus 1.75) respectively. Concrete blocks were made filling the steel mold with prepared concrete mix in three layers temping each by 25 blows with 1 inch diameter mild steel rod.

A total of 66 concrete blocks for each size were made in three successive days. The concrete blocks were kept in the mold for one day and then cured in water for 25 days. Before crushing, they were air dried for 2 days to make a total 28 days of curing period. The concrete blocks were crushed at a loading rate of 45 – 50 psi per second placing the loading plate at the top 6x6 inches surface as shown in Fig. 1. The average of 3 closer failure loads out of 6 concrete blocks was taken as the representative test result for a particular loading plate.

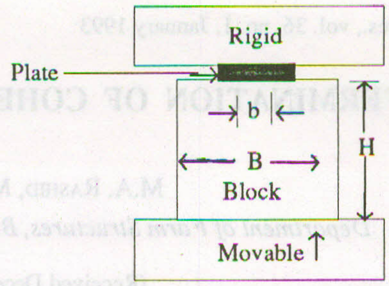

Fig. 1. Leading method.

Results and Discussions

The experimental results presented in Fig. 2 indicate that the failure stress q directly increases with the increase in depth of concrete block. It is mentioned elsewhere that the failure stress q is the induced resistance along the failure planes which were found to start from the contact region of the loading plate and concrete block. The major planes propagated obliquely towards bottom of the block. In deep blocks, the failure planes were obviously longer than those of short blocks, for which induced resistances along these longer planes resulted higher failure stresses in deep blocks [1].

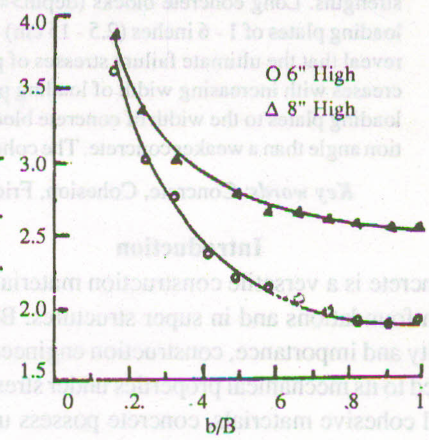

Fig. 2. Ultimate crushing strength of concrete .

The failure stresses, however, reduced with the increase in b/B ratio for both sizes of concrete blocks. During loading some failure planes directed outward and the outward obliquity of the failure planes were greater at higher b/B ratio. This caused an early splitting of peripheral layers of the concrete mass and numerous minor planes crossed vertical faces without reaching the bottom. These splitted portions reduced the net resisting area which resulted less q at higher b/B ratio.

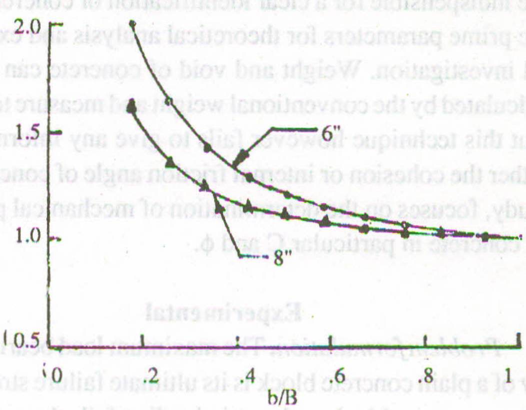

Fig. 3. Stress ratio of concrete.

Fig. 3 shows the plot of dimensionless parameter q/f'_c vs b/B ratio. It is to notice that Figs. 2 and 3 follow the same trend and the trends indicate the following two basic characteristics.

1. q or $q/f'_c \rightarrow$ infinity when b/B $\rightarrow 0$ and
2. q or q/f'_c becomes constant when b/B=1

The above characteristics clarify that q or q/f'_c is reciprocally related to b/B ratio. The mathematical expression for representing the above mentioned characteristics of Fig. 3 is [3].

$$q/f'_c = a + m/(b/B) \quad \text{...}(5)$$

Eq(5) is a reciprocal linear model with intercept 'a' and slope

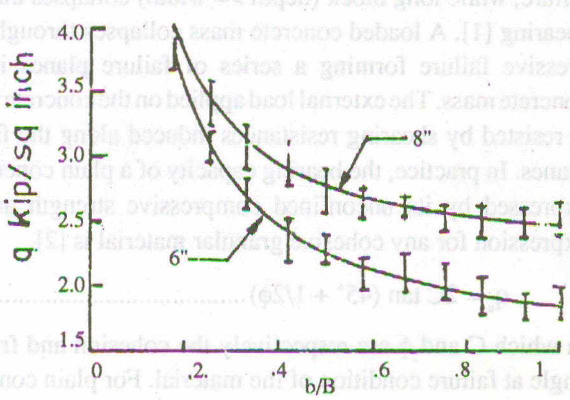

Fig. 4. Estimated q of concrete.

m. The slope m representes the effect of angular variables on which q/f'_c is dependent. Eq(4) clarifies that ϕ is the only angle on which q/f'_c depends. It is worth while to mention here that eqs(4) and (5) are identical to each other but expressed in different forms. For which $m=f(\phi)$ and because of slope $m=\tan\phi$. Thus the slope angle of regression line represents the ultimate friction angle ϕ of plain concrete. The ultimate ϕ is thought as a material property and is believed to be a constant value [4]. Table 1 shows the values of ϕ obtai-ned from regression analysis of eq(5).

Fig.4 shows the estimated q from regression data together with the range of its experimental values. Due to heterogeneity of concrete ingredients and variation in workmanship, single valued strength for different blocks of same concrete is absolutely impractical. For which failure stresses indicated by the stress- curve (Fig. 4) are representative of the experimental values. The values of C calculated from eq(1) are also given in Table 1.

TABLE 1. MECHANICAL PROPERTIES OF PLAIN CONCRETE.

H, inches	f'_c, psi	$*f_c$, psi	C, psi	ϕ
6	1875	750	760	11.96
8	2500	1000	1108	6.89

* f_c is the allowable stress in concrete = $0.4f'_c$

Strength of concrete, in fact, is a quantitative measure of its inter granular bond which, in other word, is termed as the cohesion. The cohesion of any granular material is inversely related to its friction angle. For perfectly cohesive material $\phi=0$ and ϕ is maximum for a cohesionless material. The results shown in Table 1 follow the similar maxim, i.e. a stronger concrete possess higher C and lesser ϕ than a weaker concrete or vice-versa.

According to ACI code provision, the allowable stress f_c in concrete is 40% of its ultimate compressive strength f'_c [5]. It is to notice from Table 1 that C is practically equal to f_c.

Conclusions

The adopted technique of estimating C and ϕ of plain concrete is very simple and self explanatory. The high light of this analysis is the use of compressive load for calculating mechanical properties of plain concrete. The results are comparable to those of existing values and hence, are safe for practical use and suitable for rigorous investigations.

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