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Calculation of sand–aggregate ratio and water dosage of ordinary concrete

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Abstract

In the calculation of concrete mix proportion, sand–aggregate ratio and water dosage are determined by referring table, which is fairly arbitrary. In this paper, according to the concept of coordination number and Bingham model rheology, we deduced the formulas of sand–aggregate ratio and water dosage, respectively, and then utilized the experimental data to test and verify the formulas. Thereby, the calculation of sand–aggregate ratio and water dosage is more exact. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Concrete; Sand–aggregate ratio; Water dosage

1. Introduction

Sand–aggregate ratio, water dosage and water–cement ratio are three basic parameters for the calculation of concrete mix proportion. Amongst them, water–cement ratio can be calculated with the help of Bolomey formula, but sand–aggregate ratio and water dosage are mainly determined by referring table, which are fairly arbitrary. In this paper, according to the concept of coordination number and Bingham model rheology, we deduced the formulas of sand–aggregate ratio and water dosage, respectively, and then utilized the experimental data to test and verify the formulas.

2. Theoretical analysis

2.1. Water dosage

According to Ref. [1], fresh concrete could be approximated as a Bingham fluid. Therefore, according to the rheology, the rheological equation of the concrete mix can be written as that of the Bingham fluid

$$\tau = \tau_0 - \mu D$$

where τ is the shear stress, τ_0 the yield stress, μ the plastic viscosity and D is the rate of shear or the velocity gradient.

The workability of fresh concrete was tested by means of a slump test in accordance with GBJ 80-85: Part 3.1:1986 (The State Standards of the P.R., China). In the slump test, the slump of the concrete is the deformation caused by gravity. Beginning from the top of the slump cone, the shear stress is increased with the depth, and the deformation could produce just under the point of $\tau = \tau_0$. The most shear stress and velocity of the deformation will produce near the bottom of the slump cone. In addition, when the bottom shear stress $\tau_m = \tau_0$, the deformation will stop [2].

If we ignore the inner frictional force and the inertia of the deformation, the bottom shear stress τ_m can be written

$$\tau_m = \frac{\rho h}{2}$$

where ρ is the specific gravity of the concrete mix and h is the initial height of the mix cone. So, the slump is

$$T = 30 - h = 30 - \frac{2\tau_m}{\rho} = 30 - \frac{2\tau_0}{\rho}$$

where T is the concrete slump (cm) and 30 is the height of the slump cone (cm).

In fact, the effect of the inertia is always existent in the deformation. So, $\tau_m > \rho h/2\tau$. At the same time, due to the

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effect of the inner frictional force, $\tau_m < \rho h/2\tau$. So, we write it as $\tau_m = k\rho h$ and then

$$T = 30 - \frac{\tau_0}{K\rho} \tag{1}$$

where k is the experimental constant (Eq. (1)).

Tomas [3] has made a large number of experiments to study the rheological properties of Bingham model and brought up the relation of $\tau_0 = 16.7 S_v^3$ according to his results, where S_v is the solid density. Similarly, in the "Mechanics of Sediment Transport" [4], the authors point out that $\tau_0 \propto S_v^n$, where n is the index number. The solid density of 1-m^3 fresh concrete is $(1 - W)$, so

$$T = 30 - \frac{(1-W)^n}{K\rho} \tag{2}$$

where W is water dosage (10^{-3} kg).

In the engineering report of a certain engineering unit of the Hydroelectric Power Department of China, it puts forward the formula: $\rho = a + b\lg D$. It means that the specific gravity ρ has close correlation with the maximum grain size of coarse aggregate D. Therefore, the concrete water dosage depends on slump and the maximum grain size of coarse aggregate. Because the specific gravity ρ of normal concrete is generally in the region of 2400 kg/cm^3 and has little change in same area, we can ignore the effect of their differences on slump and write Eq. (2) in a general form (Eq. (3)):

$$T = 30 - K(1-W)^n \tag{3}$$

where K is the experimental constant.

2.2. Sand–aggregate ratio

Ref. [5] recommends the experimental evidence of Barnal and Mason. For the equal-sized ball, if they are filled naturally, the coordination number is 5–6. If they are filled by vibration, the coordination number is 6–7, and when the coordination number is equal to 6, the experimental value of porosity is 0.4. Taking the coordination number equal to 6 as an example, the pore is filled with the sand and cement slurry. In concrete, the volume of the sand is

$$V_s = 0.4 - \left(\frac{C}{\rho_c} + \frac{W}{\rho_w}\right) = 0.4 - \frac{C}{\rho_c}\left(1 + \frac{\rho_c}{\rho_w}\frac{W}{C}\right)$$

where C is cement content in 1-m^3 concrete, ρ_c and ρ_w are the density of cement and water, respectively, and ρ_c/ρ_w equal to 3.15 approximately.

To obtain the sand–aggregate ratio, the above expression should be divided by aggregate. However, to simplify the formula and for the convenience of applications, we ignored the effect of cement slurry on the aggregate and added this effect in experimental constant. We obtain

$$S_p = A - B\frac{C}{\rho_c}\left(1 + 3.15\frac{W}{C}\right) \tag{4}$$

where S_p is sand–aggregate ratio, W/C is water–cement ratio, $C/\rho_c(1+3.15W/C)$ is defined as cement–water volume, A is the influence coefficient of coordination number and B is the experimental constant. It contains the effect of the workability.

Analyzing Eq. (4), we can see that sand–aggregate ratio mainly depended on water–cement ratio. At the same time, it is relevant to the variety and content of cement.

3. Experiment and analysis

3.1. Water dosage

According to the experimental data of our laboratory, in the near future, we sorted out and got the 1432 group data (the range of water–cement ratio varies from 0.31 to 0.78, water dosage from 160 to 240 kg, slump from 16 to 23.5 cm and sand–aggregate ratio from 0.32 to 0.48). Analyzing these data, it can be concluded that there is obvious correlation between water dosage and slump for normal concrete (no admixture) and that it can be described as Eq. (5) (Fig. 1), coefficient of correlation being 0.9. In this way, in the design of concrete mix proportion, water dosage could be determined directly according to the slump but not dependent on the referring table. It is more convenient and exact.

$$T = 30 - 160(1-W)^9 \tag{5}$$

In addition, for concrete that uses admixture, the discrepancy between different admixture is fairly big. Especially, the water-reducing ratio of different water-reducing agents has big discrepancy. So, there is no obvious statistical correlation between water dosage and slump, and water dosage is stable in a certain limit. Shown as in Fig. 2, for normal concrete (C_{20}–C_{60}), the range of water dosage is 160–230 kg, average value is 195.72 kg and variance is 16.78 kg.

Calculating water dosage according to Eq. (5) and referring table [6] according to slump and the maximum

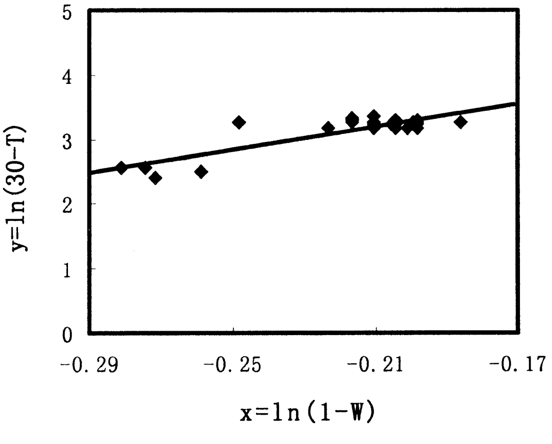

Fig. 1. Relationship between water dosage and slump (no admixture).

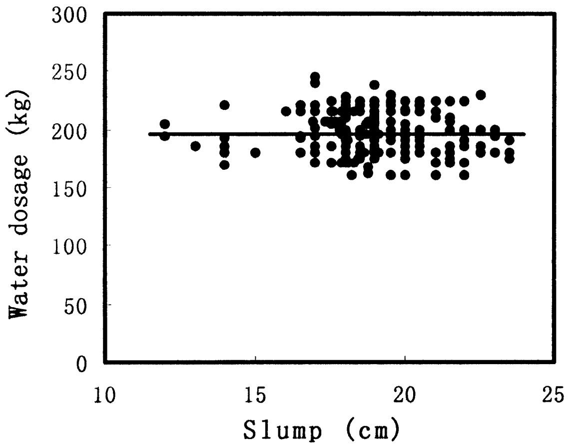

Fig. 2. Relationship between water dosage and slump (mixing admixture).

grain size of coarse aggregate to determine water dosage and comparing them with the actual water dosage, we found that the value obtained from Eq. (5) and the table is close to each other and identical with the actual value (Fig. 3).

3.2. Sand–aggregate ratio

Regressing the 1432 group data according to Eq. (4), we obtained: when the maximum grain size of coarse aggregate was $D_{\max}=15$–25 mm, $A=0.56$ and $B=0.48$; when the maximum grain size of coarse aggregate was $D_{\max}=31.5$–40 mm, $A=0.66$ and $B=1.13$

$$S_\mathrm{p} = 0.56 - 0.48\frac{C}{\rho_C}\left(1 + 3.15\frac{W}{C}\right) \quad (D_{\max} = 15{\sim}25\,\mathrm{mm}) \tag{6}$$

$$S_\mathrm{p} = 0.66 - 1.13\frac{C}{\rho_C}\left(1 + 3.15\frac{W}{C}\right) \quad (D_{\max} = 31.5{\sim}40\,\mathrm{mm}) \tag{7}$$

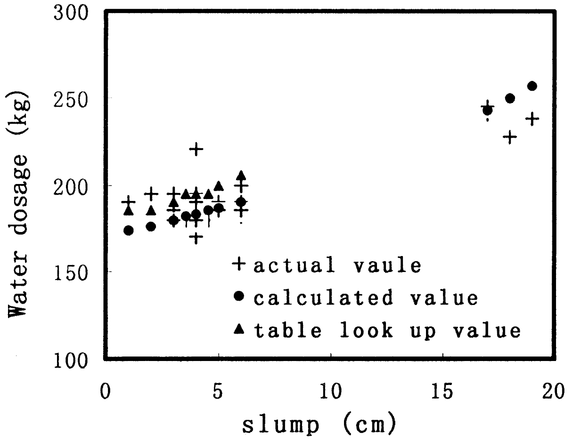

Fig. 3. The contrast of water dosage obtained from different ways.

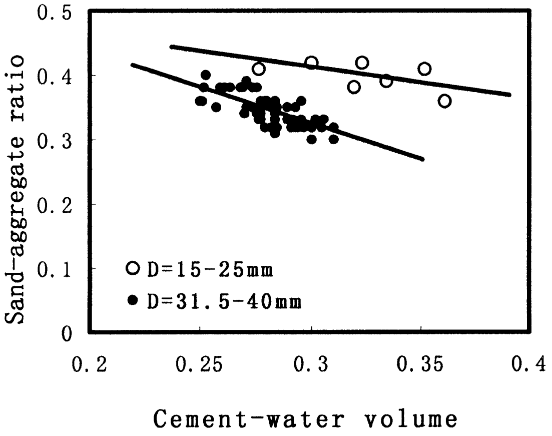

Fig. 4. Relationship between sand–aggregate ratio and water–cement ratio and cement variety (no admixture).

Analyzing the parameters of the above equations, one can get the following picture (Fig. 4), where cement–water volume expresses $C/\rho_\mathrm{c}(1+3.15W/C)$. With the increase of the maximum grain size of coarse aggregate, A is decreasing, in accordance with the actual condition. B is increasing with the increase of the maximum grain size of coarse aggregate due to the fact that the effect of coarse aggregate on concrete workability will increase with the increase of the maximum grain size.

Calculating sand–aggregate ratio according to Eqs. (6) and (7) and at the same time referring table [7] according to water–cement ratio and the maximum grain size of coarse aggregate, one can get the homologous sand–aggregate ratio. Comparing them with the actual sand–aggregate ratio (as in Fig. 5, the two right lines are the upper limit and lower limit of value obtained by referring table, respectively), we found that the calculated values are basically contained in the region composed by the two right lines. However, parts of actual values are out of this region, because the actual sand–aggregate ratio has been adjusted by experiment. It is thus clear that Eqs. (6) and (7) are correct and reliable and could be used in the design of concrete mix proportion to

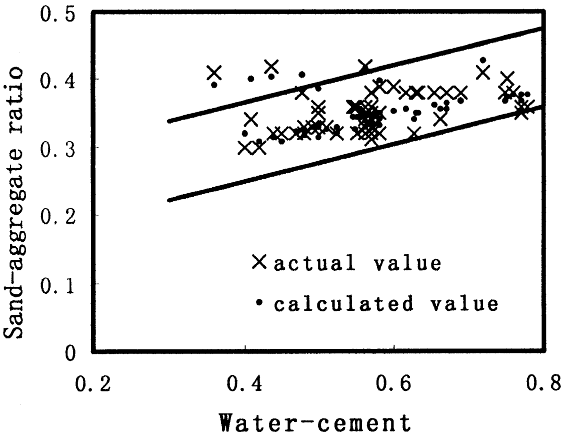

Fig. 5. The contrast of sand–aggregate ratio obtained from different ways.

determine sand–aggregate ratio. It is more convenient and exact than referring the table.

4. Conclusions

(1) In traditional calculation of concrete mix proportion, water dosage is confirmed by referring values of slump and the maximum grain size of coarse aggregate from tables. The normal concrete water dosage depends on slump and the maximum grain size of coarse aggregate. In this paper, through analyzing the 1432 group data, we obtained Eq. (5). Then, in the design of concrete mix proportion, water dosage could be confirmed directly according to the needed slump but not depending on the table. It is more convenient and exact.

(2) For the concrete that uses admixture, the discrepancy between different admixture is fairly big. Especially, the water-reducing ratio of different water-reducing agents has big discrepancy. So, there is no obvious statistical correlation between water dosage and slump, and water dosage is stable in a certain limit. Therefore, we can choose water dosage in the range directly and adjust it by trial mix.

(3) In traditional design of concrete mix proportion, the best sand–aggregate ratio is confirmed by referring table according to water–cement ratio and the maximum grain size of coarse aggregate. Sand–aggregate ratio of normal concrete depends on water–cement ratio and the maximum grain size of coarse aggregate. However, in fact, sand–aggregate ratio is not only dependent on above factor but also is affected by cement variety. In this paper, considering this effect, we brought up Eq.(4). Through analyzing the 1432 group data, we got Eqs. (6) and (7), which correspond to different particle-size limit, respectively, to calculate sand–aggregate ratio of concrete (no admixture). So, the selection of sand–aggregate ratio is more exact and reliable. As shown in Fig. 4, taking the maximum grain size of coarse aggregate equal to 25 mm as boundary, sand–aggregate ratio is obviously divided into two regions. In fact, at present, the maximum grain size of coarse aggregate used in high-performance and high-strength concrete is generally under 25 mm. For concrete that uses admixture, due to the water-reducing effect of the water-reducing agent, there is no obvious statistical relationship between sand–aggregate ratio and water–cement ratio.

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