Estimation for Drying Shrinkage of Concrete by Composite Model
Using Coarse Aggregate Properties

by

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The factors which affect drying shrinkage of concrete are material properties and environmental conditions, and so on. It is said that the type of coarse aggregate is one of the most dominant factors which affect concrete drying shrinkage. Therefore, it is important that the length-change properties of coarse aggregate particle are grasped when concrete drying shrinkage strain is estimated. Moreover, it is a practical benefit that concrete drying shrinkage strain is estimated by using coarse aggregate properties to be obtained the result early, regardless of the mix proportion of concrete. From the above backgrounds, in this research, we tried to estimate concrete drying shrinkage strain by composite model which has been proposed by KISHITANI & BABA, and investigated applicability of the model by using the initial tangent modulus or the secant modulus for coarse aggregate. For this study we used 19 types of crushed stone from different regions and of different qualities. As a result, the estimation of concrete drying shrinkage strain by KISHITANI & BABA equation was made different results of accuracy due to types of modulus of elasticity to be used for calculation. The calculated value against the experimental value was a range of -30 to +10% when using the initial tangent modulus, and was a range of -30 to +30% when using the secant modulus.

Key words:
Drying Shrinkage, Coarse Aggregate, Initial Tangent Modulus, Secant modulus, Composite Model

1 Introduction

There is a growing interest in controls of cracking of concrete due to shrinkage, therefore concrete drying shrinkage related regulations are being reviewed and revised. In JSCE standard specifications for concrete structures, as a general rule, the design values of the shrinkage strain of concrete must be determined on the basis of the values obtained from shrinkage strain tests of the concrete to be used or past performance data.

Concrete drying shrinkage is determined as the length change after 6 months of drying, using the method indicated in JIS A 1129: Methods of Measurement for Length Change of Mortar and Concrete. However, this test takes a long time. There has therefore been a need for a method for simply estimating concrete drying shrinkage strain.

There are many factors which affect concrete drying shrinkage. Recently, among the constituent materials of concrete, it has been reported that the type of coarse aggregate is one of the most dominant factors which affect drying shrinkage of concrete. We have demonstrated that the mean value of the coarse aggregate drying shrinkage strain measured by using wire strain gauges and concrete drying shrinkage strain are high mutually related.

On the other hand, it is a practical benefit that drying shrinkage of concrete is estimated by using coarse aggregate properties to be obtained the result early, regardless of the mix proportion of concrete. In general, the estimation of concrete drying shrinkage is used the empirical equations which are based on a large amount of experimental data. However, as an entirely different approach, composite model for estimating the influence of aggregate contents and properties on concrete shrinkage has been proposed, and it has been said good accuracy on prediction.

Considering these circumstances, in this research, we tried to estimate concrete drying shrinkage by composite model. Young’s modulus of coarse aggregate is included in a parameter of the model, and is used the secant modulus in general. However, it has been reported that the mutual relationship with concrete drying shrinkage strain is better the initial tangent modulus rather than the secant modulus for concrete. Therefore, we investigated the relationship between the drying shrinkage strain of concrete and the calculated Young’s modulus of coarse aggregate, and considered the applicability of estimation by composite model by using the initial tangent modulus or the secant modulus for coarse aggregate.

2 Composite Model

Recently, it is said that a new composite model is TERANISHI & SATO equation which is regarded the concrete as 3-phase materials composed of cement hardened

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Shrinkage of concrete is estimated by using coarse aggregate. It has been reported that the type of coarse aggregate is one of the most dominant factors which affect concrete drying shrinkage. Recently, among the constituent materials of concrete, it has been said good accuracy to estimate concrete drying shrinkage strain by composite model which has been proposed by Hashin & Hansen (2018). The composite model which has been proposed by HASHIN & HANSEN (1964) is written as equation (1).

\[
\frac{E_c}{E_m} = \frac{n + 1 + (n - 1)\psi_c}{n + 1 - (n - 1)\psi_c}
\]

where, \(m = \varepsilon_0 / \varepsilon_m\), \(n = E_c / E_m\), \(\varepsilon\) is drying shrinkage strain, \(E\) is Young’s modulus (N/mm²), \(\psi_c\) is volume ratio of coarse aggregate, suffix of \(c\), \(a\) and \(m\) is concrete, coarse aggregate and mortar, respectively.

We obtained the value of the parameter for equation (1) by experiment except for Young’s modulus of coarse aggregate. An Elastic modulus of coarse aggregate is desired to be determined on the basis of the test by using a test piece sampling directly from a raw stone. However, in this study, we measured the modulus of elasticity of concrete and mortar, and estimated the Young’s modulus of coarse aggregate from equation (2) which has been proposed by Hashin & Hansen (1964).

\[
E_c = E_m \left(1 - (1 - mn)\psi_c, n + 1 - (n - 1)\psi_c\right)\left(n + 1 + (n - 1)\psi_c\right)
\]

Table 1 Coarse aggregate types and characteristics.

| Classification | No. | \(G_{mm}\) - mm | Density - g/cm³ | Water absorption - % | Soundness - % | Drying shrinkage strain of coarse aggregate - x10⁻⁶ |
|---------------|-----|------------------|-----------------|--------------------|---------------|--------------------------------------|
|               |     |                  |                 |                    |               | Average | Standard deviation | Minimum | Maximum |
| Volcanic rock | G1  | 25               | 2.25            | 6.43               | 27.5          | 383     | 155               | 198     | 611     |
|               | G2  | 25               | 2.63            | 1.66               | 3.8           | 126     | 46                | 50      | 228     |
|               | G3  | 25               | 2.29            | 5.58               | 52.7          | 334     | 170               | 167     | 613     |
|               | G4  | 25               | 2.47            | 2.74               | 72.9          | 348     | 51                | 288     | 446     |
|               | G5  | 25               | 2.44            | 3.91               | 54.2          | 646     | 328               | 248     | 1296    |
|               | G6  | 15               | 2.65            | 2.67               | 14.8          | 416     | 129               | 210     | 628     |
|               | G7  | 25               | 2.29            | 6.53               | 56.5          | 550     | 494               | 130     | 1583    |
| Plutonic rock | G8  | 25               | 2.53            | 1.47               | 22.3          | 180     | 89                | 33      | 348     |
|               | G9  | 25               | 2.37            | 4.96               | 89.7          | 1529    | 496               | 486     | 2753    |
|               | G10 | 25               | 2.45            | 3.33               | 56.4          | 620     | 138               | 408     | 828     |
|               | G11 | 25               | 2.65            | 0.5                | 3.3           | 86      | 30                | 29      | 147     |
|               | G12 | 20               | 2.64            | 0.69               | 11.4          | 139     | 31                | 78      | 198     |
|               | G13 | 20               | 2.57            | 1.56               | 34.8          | 459     | 62                | 357     | 561     |
|               | G14 | 20               | 2.59            | 1.54               | 27.9          | 935     | 413               | 267     | 1719    |
|               | G15 | 20               | 2.64            | 0.99               | 17.3          | 528     | 117               | 233     | 686     |
| Clastic rock  | G16 | 25               | 2.48            | 4.38               | 45.3          | 255     | 109               | 59      | 532     |
|               | G17 | 25               | 2.28            | 7.17               | 70.2          | 907     | 445               | 245     | 1766    |
|               | G18 | 20               | 2.71            | 0.26               | 1.5           | 21      | 6                 | 10      | 31      |
|               | G19 | 20               | 2.7              | 0.29               | 0.7           | 26      | 4                 | 18      | 31      |
| Pyroclastic rock | G20 | 25       | 2.56          | 1.58               | 3.5           | -       | -                 | -       | -       |
| Biogenic rock  | G21 | 25               | 2.25            | 6.43               | 27.5          | 383     | 155               | 198     | 611     |
|               | G22 | 25               | 2.63            | 1.66               | 3.8           | 126     | 46                | 50      | 228     |
|               | G23 | 25               | 2.29            | 5.58               | 52.7          | 334     | 170               | 167     | 613     |
|               | G24 | 25               | 2.47            | 2.74               | 72.9          | 348     | 51                | 288     | 446     |
|               | G25 | 25               | 2.44            | 3.91               | 54.2          | 646     | 328               | 248     | 1296    |
|               | G26 | 15               | 2.65            | 2.67               | 14.8          | 416     | 129               | 210     | 628     |
|               | G27 | 25               | 2.29            | 6.53               | 56.5          | 550     | 494               | 130     | 1583    |
| River sand    | -       | 2.56          | 1.58               | 3.5           | -       | -                 | -       | -       |

For the Young's modulus of concrete, mortar and coarse aggregate in equation (2), the initial tangent modulus and the secant modulus were used, respectively, to compare the applicability of composite model.

3 Outline of Experiment

3.1 Coarse aggregate

Table 1 shows the types and characteristics of coarse aggregate used in this research. The selected aggregates consisted of crushed stone from different regions and of different qualities, and in order to cover the impact of a wide range of coarse aggregate quality, some coarse aggregates selected satisfied JIS A 5005: Crushed Stone and Manufactured Sand for Concrete, while others did not.

Drying shrinkage strain of a coarse aggregate particle was measured by using wire strain gauges. In the measurement, a coarse aggregate particle of nearly maximum particle length-change was measured in an environment at a temperature of 20°C and a relative humidity of 60%, and the strain of change in length at ultimate was evaluated. A number of test pieces were more than 7 particles for each type of coarse aggregate.
of the aggregate.

3.2 Mix proportion for concrete and mortar

Ordinary Portland cement was used. River sand shown in Table-1 was used. Coarse aggregate shown in Table-1 was used respectively. AE water reducing agent (C×0.31%) was used. Mix proportions of concrete were identical as follows except for coarse aggregate to be used. Unit water content was 165 kg/m³. Water-cement ratio was 55%. Sand-total aggregate ratio was 46%. Target air content was 4.5%.

Other than the coarse aggregate, all dosage of the materials for the concrete was identical. Therefore, fresh properties of the concrete were varied dependent on the each coarse aggregate. Fresh concrete test results were as follows: slump of 3.5 to 18.6cm, air content of 4.0 to 6.2%.

The mortar was prepared using the river sand shown in Table 1 with the following mix proportion: water-cement ratio of 55%, sand-cement ratio of 2.73. Ordinary Portland cement was used. AE water reducing agent (C×0.31%) was used.

3.3 Length-change test for concrete and mortar

The specimens used in length-change test of concrete of the size of 100x100x400mm and mortar of the size of 40x40x160mm were removed from their molds at the age of 1 day, and then water curing was performed until the age of 7 days. The initial length of the specimens was measured after the curing, thereafter, the length-change of concrete and mortar was measured in accordance with JIS A 1129-3 (Method with Dial Gauge) in an environment at a temperature of 20°C and a relative humidity of 60%. The concrete length-change strain after 6 months of drying was evaluated, and the mortar length-change strain after 28 days of drying was evaluated.

3.4 Measurement of Young’s modulus for concrete and mortar

The specimens used in measurement of Young’s modulus of concrete and mortar were removed from their molds at the age of 1 day, and then water curing was performed until the age of 28 days.

The secant modulus of concrete and mortar was measured in accordance with JIS A 1149 (Method of Test for Static Modulus of Elasticity of Concrete).

The initial tangent modulus of concrete and mortar was also measured. The strain for this measurement was obtained by every loading rate of 1.27 N/mm². The initial tangent modulus was determined from a slope of the tangent line connecting the origin to the point of 1.27 N/mm².

4 Results and Discussion

4.1 The relationship between drying shrinkage strain...
of concrete and Young's modulus of coarse aggregate

Fig. 1 shows the calculated results of Young's modulus of coarse aggregate. The initial tangent modulus and the secant modulus for coarse aggregate were calculated by equation (2) by using their experimental values obtained the concrete Young's modulus test, respectively. The secant modulus of coarse aggregate was about 60% against the initial tangent modulus of them.

Fig. 2 shows the relationship between the drying shrinkage strain of concrete and the calculated value of Young's modulus of coarse aggregate. It was observed that larger initial tangent modulus and larger secant modulus corresponded to smaller the drying shrinkage strain of concrete. However, there was not much correlation relationship between the calculated Young's modulus of coarse aggregate and the drying shrinkage strain of concrete.

4.2 Estimation by composite model for concrete drying shrinkage strain

Although it is possible that concrete drying shrinkage strain which changes with time is estimated by equation (1), it has been reported⁶ that the calculated values are larger than the experimental values. It has been said that this reason is due to difference of volume-surface area ratio (V/S) of specimens of mortar and concrete. However, it has been said that specimens size of mortar and concrete is hardly affected to estimate for the ultimate value of concrete shrinkage. Therefore, in this study, the composite model was used to estimate concrete drying shrinkage strain at ultimate. For values to be used in equation (1), the mortar drying shrinkage strain was $903 \times 10^{-6}$, and the initial tangent modulus and the secant modulus for mortar were 34.8 and 34.0kN/mm², respectively.

Fig. 3 shows the calculated results by composite model. Looking at the left figure, the calculated value by using the initial tangent modulus could be estimated the range of -30 to +10% against the experimental value, and it was observed that the calculated value was smaller trend than the experimental value. Looking at the left figure, the calculated value by using the secant modulus could be estimated the range of -30 to +30% against the experimental value. The values of the initial tangent modulus and the secant modulus for mortar by using calculation were not large difference. Therefore, it is able to be said that the difference of Young's modulus of coarse aggregate to be used for calculation was affected the estimation range against the experimental value.

Moreover, in 3-phase model, it has been reported⁷ that the calculated value is able to estimate the range of ±100µ against the experimental value. Therefore, it would not be said that our results are equally estimation accuracy comparing with the 3-phase model.

5 Conclusions

Our results were as follows.

(1) The secant modulus of coarse aggregate to be obtained by calculation was about 60% against the initial tangent modulus of coarse aggregate to be obtained by calculation.

(2) The calculated value by 2-phase composite model against the experimental value was a range of -30 to +10% when using the initial tangent modulus, and was a range of -30 to +30% when using the secant modulus. In 3-phase composite model, it is said that the calculated value is able to estimate the range of ±100µ against the experimental value. Therefore, it could not be said that our results are equally estimation accuracy comparing with the model. However, when to grasp the approximate value of concrete drying shrinkage, it
would be said that using 2-phase composite model is one of effective methods to estimate it.

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