MECHANICAL PROPERTIES OF LIGHTWEIGHT AGGREGATE CONCRETE FOR STRUCTURAL USE

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(Received May, 1965)

Summary

The paper describes the results obtained in an investigation of mechanical properties of lightweight aggregate concrete for structural use. Four typical domestic lightweight aggregate and a normal weight sand-and-gravel aggregate for comparison were selected, and the mechanical properties of the concrete produced with these aggregates and the relationships between these properties were investigated, to obtain the generalized structural design data.

Comparing these kind of concrete, the values of static or dynamic modulus of elasticity of lightweight aggregate concrete are somewhat lower than the values of normal weight aggregate concrete of comparable compressive strength, but the Poisson's number, the relationships between various strengthes do not extremely differ from them of normal weight aggregate concrete. And the empirical formulas on the relations between compressive strength and static or dynamic modulus of elasticity, which are applicable to both lightweight and normal weight structural concretes, are derived. These formulas are useful to estimate the secant modulus or the compressive strength of concrete when they can not be determined by test.

Introduction

With the increased use of artificial lightweight aggregate for structural concrete in recent years, the demand for suitable design data for the structural analysis of lightweight aggregate concrete member has created. However, generalized structural design data, which are applicable to both lightweight and normal weight aggregate concretes, are very few at present.

In the present paper, four typical lightweight aggregates manufactured in our country and a normal weight sand-and-gravel aggregate were selected, and the mechanical properties of the concretes produced with these aggregates and the relationships between these properties were investigated, to obtain the structural design data.

Test Procedure

1. Aggregate and Concrete

Four kinds of artificial lightweight aggregate and a normal weight sand-and-gravel aggregate indicated in Table 1 were selected. And the concretes having the mixing proportions in Table 2 were produced with these aggregates and an ordinary portland cement (compressive strength by JIS R 5201 was about 380 kg/cm^2 at the age of 28 days) respectively.

The concrete specimens were cured in a water tank of $20° \pm 3°C$, and were tested at the age of 28 days.

TABLE 1. Aggregates

Aggregate No.	Grade	Material	Specific Gravity	Unit Weight (kg/l)	Fineness Modulus	Coef. of Water Abs. (%)
1	Coarse	River Gravel	2.56	1.64	6.96	0.65
	Fine	River Sand	2.56	1.61	3.12	1.6
2	Coarse	Exp. Fly Ashes (pelletized)	1.38	0.84	6.47	1.4
	Fine	River Sand	2.56	1.61	3.12	1.6
3	Coarse	Exp. Shale (pelletized)	1.22	0.68	6.59	6.2
	Middle	〃	1.20	0.78	3.20	14.6
	Fine	River Sand	2.51	—		3.0
4	Coarse	Exp. Shale	1.30	0.78	6.57	8.5
	Fine	〃	1.82	1.16	3.05	18.2
5	Coarse	〃	1.26	0.74	6.51	8.0
	Fine	〃	1.82	1.02	2.89	9.7

TABLE 2. Mixing Proportions

Concrete No.	Used Aggregate	Mix. Ratio by Weight	Water-Cement Ratio (%)
No. 1 Concrete	No. 1	1 : 3.51 : 3.51 1 : 2.97 : 2.97 1 : 2.56 : 2.56	50, 55, 60, 65, 70 45, 50, 55, 60, 65 40, 45, 50, 55
No. 2 Concrete	No. 2	1 : 3.51 : 3 51 1 : 2.97 : 2.97 1 : 2.56 : 2.56	55, 60, 65, 70 45, 50, 55, 60 40, 45, 50, 55
No. 3 Concrete	No. 3	1 : 3.51 : 3.51 1 : 2.97 : 2.97 1 : 2.56 : 2.56	50, 55, 60, 65, 70 45, 50, 55, 60 40, 45, 50, 55
No. 4 Concrete	No. 4	1 : 3.51 : 3.51 1 : 2.97 : 2.97 1 : 2.56 : 2.56	50, 55, 60, 65 45, 50, 55, 60 40, 45, 50, 55
No. 5 Concrete	No. 5	1 : 3 51 : 3.51 1 : 2.97 : 2.97 1 : 2.56 : 2.56	50, 55, 60, 65 45, 50, 55, 60 40. 45, 50, 55

TABLE 3. Specimens

Testing Method	Specimens	
	Shape	Size (cm)
Compressive Test	Cylinder	$\phi\, 10 \times 20$
Split Test	〃	〃
Dynamic Test	〃	〃
Torsional Test	Hollow Cylinder	Out. Dia. 21.5, length 67.0, Inner. Dia. 12.5

2. Specimens and Testing Methods

The shape and size of specimens, and the testing method are shown in Table 3.

Compressive test specified in JIS 1108 was carried out, and longitudinal and lateral strains, secant modulus at 0.3 F_c, initial tangent modulus, Poisson's number and so on were obtained in addition to the compressive strength F_c.

Tensile strength was obtained by the split test specified in JIS 1113.

Dynamic testing apparatus produced in author's laboratory was used for dynamic test. And dynamic modulus of elasticity, logarithmic decrement and dynamic modulus of rigidity were determined by following relations respectively

$$E_d = 4 \cdot f_L^2 \cdot l^2 \cdot \rho \tag{1}$$

$$\Delta = \pi (f_2 - f_1)/f_L \tag{2}$$

$$G_d = 4 \cdot f_T^2 \cdot l^2 \cdot \rho \tag{3}$$

where

E_d: dynamic modulus of elasticity,
f_L : resonance frequency in longitudinal vibration,
f_1, f_2: frequencies on either side of longitudinal resonance at which the amplitude of vibration is 0.707 of the maximum value,
Δ : logarithmic decrement,
G_d: dynamic modulus of rigidity,
f_T : resonance frequency in torsional vibration,
ρ : unit weight of concrete,
l : length of cylindrical specimen.

Torsional test was carried out by using the previously reported torsional testing apparatus made in author's laboratory[1], and the torsional strength, static modulus of rigidity at 0.3 F_{to} (F_{to} is torsional strength) were obtained.

Test Results and Discussion

1. Stress-Strain Diagram

It may be possible to obtain a satisfactory approximation by expressing the stress-strain curve within comparatively low stress level by the empirical relation

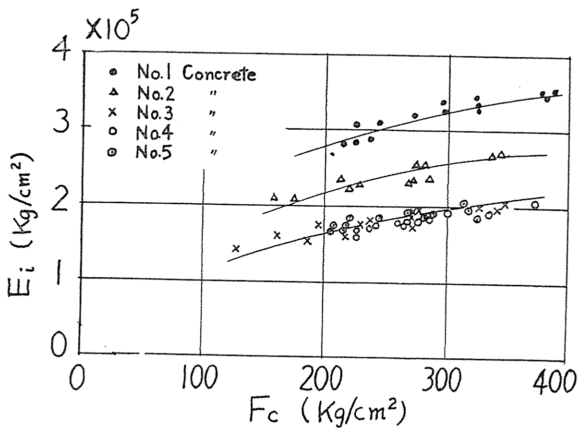

FIG. 1

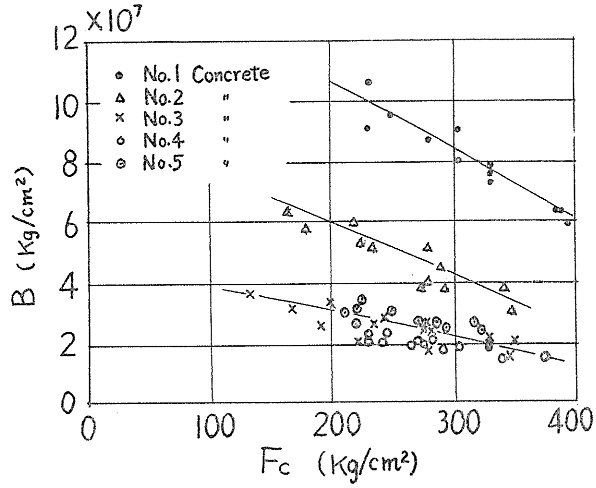

FIG. 2

of the form

$$\sigma = E_i\delta - B\delta^2, \quad (4)$$

where σ: stress, δ: strain,

and empirical constant E_i in this equation indicates the initial tangent modulus, and constant B relates to non-linearlity of stress-strain curve. The relationship between compressive strength F_c and empirical constants E_i or B are shown in Fig. 1 and Fig. 2 respectively. Each plotted point in these figures indicates mean value of three specimens.

It seem that there are three separate correlations for every three groupes of unit weight of concrete. The values of constant E_i and B of lightweight concrete are somewhat lower than the values of normal weight concrete of comparable compressive strength.

2. Dynamic Properties

It is considered that the dynamic modulus of elasticity E_d and the logarithmic decrement Δ relate to the constants E_i and B in the equation 4 respectively. These relationships are illustrated in Fig. 3 and Fig. 4 respectively.

By these illustrated results, it is found that the values of E_d of normal weight concrete (No. 1 concrete) are about 20 per cent larger than the values of E_i, but the values of E_d of lightweight aggregate concrete (No. 2, 3, 4, and 5 concrete) do not particularly differ from the values of E_i. The values of logarithmic decrement decrease with decrease of the constant B in the equation 4 regardless of the kind of aggregate.

Results illustrated in Fig. 1, 2, 3, and 4 mean that the lightweight aggregate concrete behaves something like Hook's material under the low stress level.

The relationship between dynamic modulus of rigidity G_d and the static modulus of rigidity G_s is shown in Fig. 5, for reference.

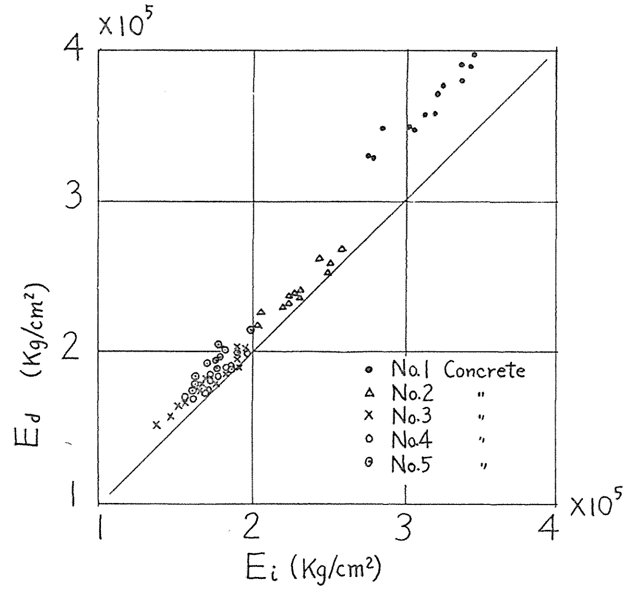

FIG. 3

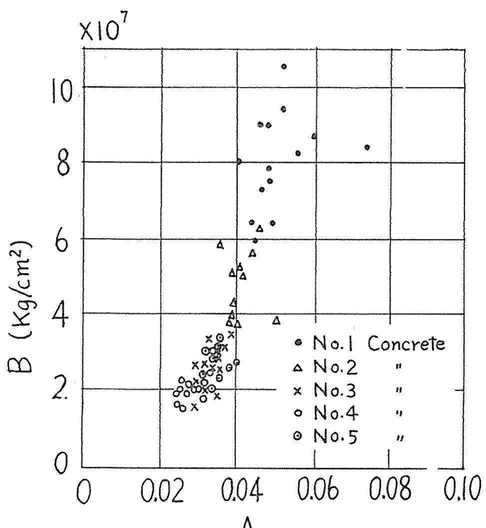

FIG. 4

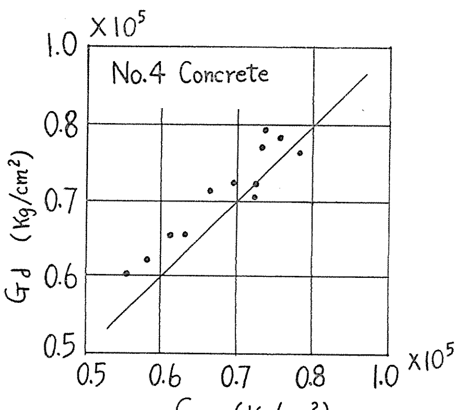

FIG. 5

3. Relationship between Compressive Strength and Modulus of Elasticity

The relationships between compressive strength F_c and secant modulus $E_{0.3F_c}$ are shown in Fig. 6. Each plotted point in this figure indicates a mean value of three specimens.

It is found that the value of $E_{0.3F_c}$ of lightweight concrete is somewhat lower

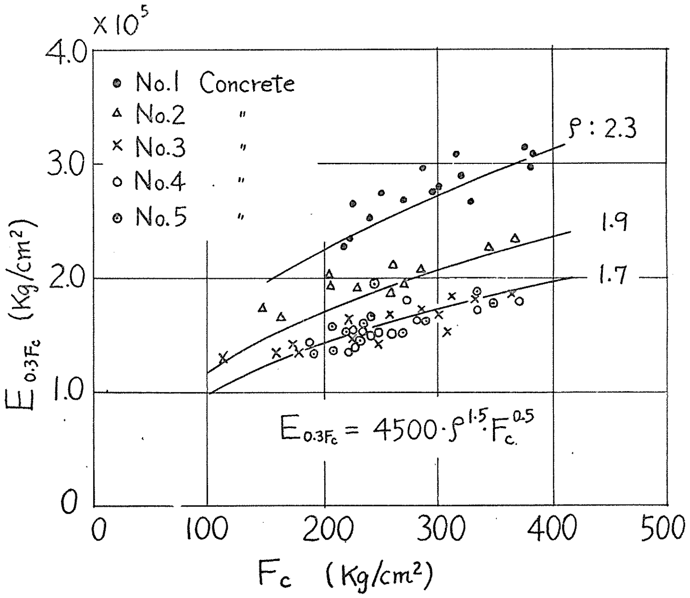

FIG. 6

than the value of normal weight concrete of comparable compressive strength, and there are three separate correlations for every three groupes of unit weight of concrete, so far as this investigation is concrened.

It is often convenient to apply the following empirical formula recommended by Pauw[2)] for these relationships, although Pauw's empirical constants can not be adopted because of the difference of used materials,

$$E = A \cdot \rho^{\alpha} F_c^{\beta} \quad (5)$$

where A, α and β: empirical constants, ρ: specific gravity of concrete.

Sesant modulus $E_{0.3F_c}$ for the present concrete can be estimated by following approximate empirical relation

$$E_{0.3F_c} = 4500 \cdot \rho^{1.5} F_c^{0.5}. \quad (6)$$

Similar relationships are obtained between dynamic modulus of elasticity E_d and compressive strength F_c as in Fig. 7. Empirical relation for this relationships is as follows

$$E_d = 12500 \cdot \rho^{2.0} F_c^{0.3}. \quad (7)$$

Equation 7 is useful to estimate non-destructively the compressive strength when E_d can be determined by vibrating method.

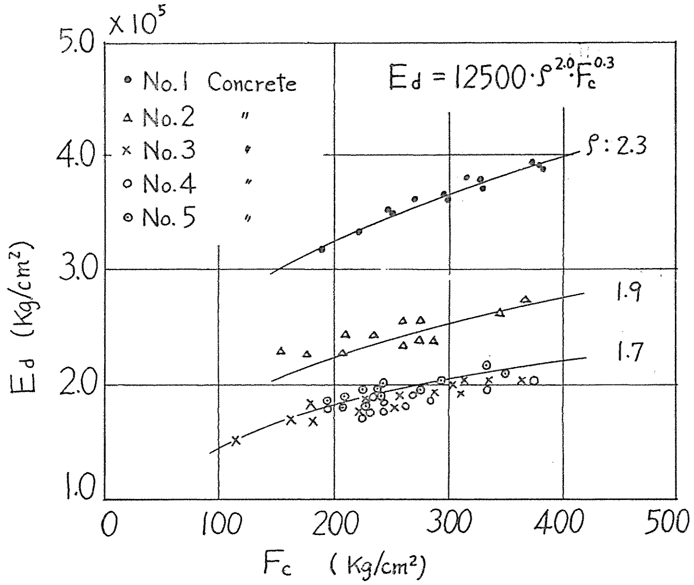

FIG. 7

TABLE 4. Poisson's Number

Concrete No.	Poisson's Number		
	$0.1\ F_c$	$0.3\ F_c$	$0.9\ F_c$
No. 1 Concrete	6.0	6.5	2.0
No. 4 Concrete	6.0	5.5	3.5

4. Poisson's Number

Poisson's number was determined for only No. 1 and No. 4 concrete. The values of Poisson's number of these concrete are given in Table 4.

Generally, the values of Poisson's number of lightweight aggregate concrete do not particularly differ from the values of normal weight aggregate concrete of comparable compressive strength under low stress level, but the values of Poisson's number of lightweight concrete under the high stress level do not decrease extremely as in normal weight concrete.

5. Relationships between Various Strengthes

The relationship between compressive strength F_c and tensile strength F_{sp} by the split test are given in Fig. 8. The results on normal weight sand-and-gravel concrete by some investigators[3] are indicated in this figure for comparison.

It seems that the value of tensile strength of lightweight concrete slightly higher than the value of normal weight concrete having comparable compressive strength, especially for the high strength concrete.

Torsional strength F_{to} was obtained for only No. 4 concrete. The relationships between torsional strength F_{to} and compressive strength F_c or tensile strength

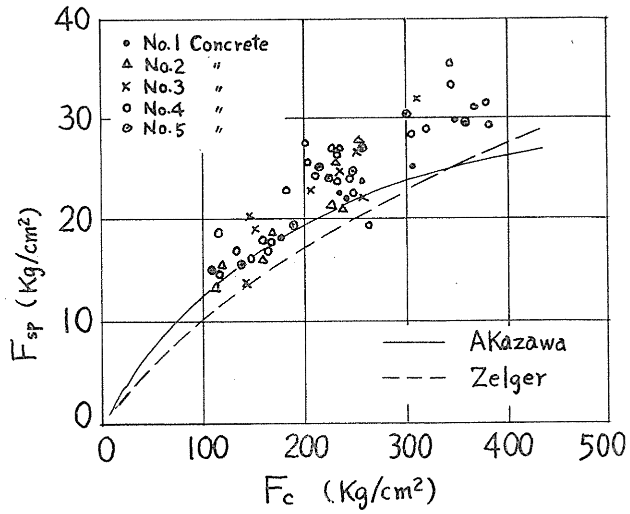

FIG. 8

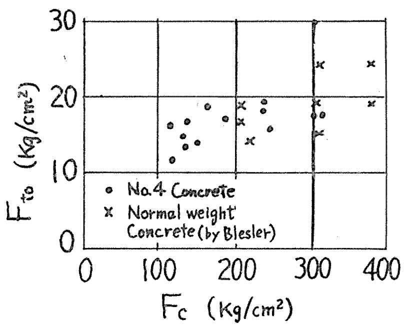

FIG. 9

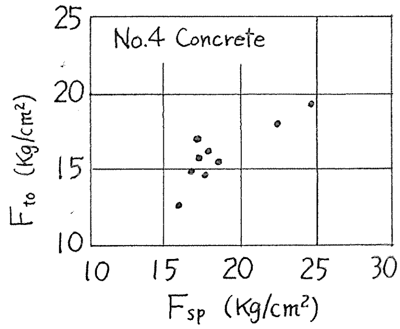

FIG. 10

F_{sp} are illustrated in Fig. 9 and Fig. 10 respectively. These relationships do not extremely differ from the relations of normal weight concrete reported by some investigators[4].

Conclusion

The summary of results is as follows, so far as this investigation is concrened;

1. Dynamic modulus of elasticity E_d of lightweight aggregate concrete does not extremely differ from initial tangent modulus.
2. Lightweight aggregate concrete behaves something like Hook's material under the low stress level.
3. Secant modulus of elasticity or dynamic modulus of elasticity can be determined by the above mentioned equations (Eq. 6, and 7), which are applicable to both lightweight and normal weight concrete for structural use.
4. Poisson's number of lightweight concrete almost coincides with the value

of normal weight concrete under the low stress level.

5. Tensile strength of lightweight concrete is slightly higher than the value of normal weight concrete having comparable compressive strength.

Acknowledgement

This investigation was undertaken in the laboratory of Department of Structural Engineering of Faculty of Engineering of Osaka University, under the support of Professor M. Okushima, and author thanks for his kindly advices and suggestions.

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