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CORRELATIONS OF AGE AND STRENGTH WITH VALUES OBTAINED BY DYNAMIC TESTS ON CONCRETE

by

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MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

The compressive strength, dynamic modulus of elasticity, and pulse velocity of concrete show increase with age. The compressive strength at 7 days is 78 per cent of that at 28 days, whereas the dynamic modulus of elasticity and the pulse velocity were 87.6 and 94.4 per cent of the 28-day values respectively for concrete with water/cement and aggregate/cement ratios of 0.59 and 6.57.

The linear correlation coefficient for the relationship between the dynamic modulus of elasticity and the 28-day compressive strength is significant at the 5 per cent level with a value of 0.703. There appears to be a curvilinear correlation between dynamic modulus of elasticity and flexural strength. The correlation between the compressive strength and the pulse velocity is rather poor.

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CONTENTS

TABLES

FIGURES

Figures (contd)

INTRODUCTION

Since 1938 dynamic testing techniques have been used for evaluating concrete, both in the laboratory and in the field. In addition to measuring the fundamental properties of concrete in the laboratory, these methods have been used to check the quality of concrete in bridge piers, road pavements, and concrete hydraulic structures (1, 2, 3). However few published data are available regarding the effect of the maturity of concrete on the pulse velocity and the dynamic modulus of elasticity. In 1949 Jones (4) published data on the influence of age on pulse velocity, and recently Galan (5) has published data on the influence of age and moisture content on the pulse velocity and on the damping constant of concrete.

This report presents relationships showing the effect of maturity on the compressive strength, the dynamic modulus of elasticity, and the pulse velocity of concrete. Correlations of the dynamic modulus of elasticity with the compressive and flexural concrete strengths at 28 days are presented. Comparisons of the dynamic moduli obtained using two different types of specimens and two different makes of resonant-frequency testers are also included.

This investigation report is part of a co-operative research project on concrete jointly undertaken by the Construction Materials Section, Mineral Processing Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa; the Department of Civil Engineering, University of Ottawa; Dominion Building Materials Ltd. (a ready-mixed concrete supplier from Ottawa); and Phil McNeeley and Associates, Consulting Engineers, Ottawa. This project has been especially designed to determine the speed at which the strength of concrete can be estimated, during construction, by using conventional and new techniques.

SCOPE OF INVESTIGATION

In this investigation 37 concrete batches were sampled. The water/cement ratio varied from 0.47 to 0.70 and the aggregate/cement ratio from 5.2 to 8.2, thus providing a wide strength range. Ten 6 x 12-in. cylinders and six 3 x 4 x 12-in. prisms were cast from each mix, to be tested at ages varying from 28½ hours to 1 year*. Before testing at each age, pulse velocity and resonant frequency measurements were made on both prisms and cylinders. All concrete was obtained from a local ready-mixed concrete plant during normal production runs.

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* One-year test results are not yet available and will be reported later.

SAMPLING AND TESTING OF CONCRETE

The investigation was begun in July 1969 and was completed in March 1970. Sampling of concrete was carried out either at the construction site or at the batch plant. In each case, a 4½-cu-ft sample was taken from a ready-mixed truck and half of the sample in open containers was transported in about 15 minutes to the Mines Branch Laboratory, the other half being used for strength determination under field conditions. The concrete was re-mixed in a Lancaster pan mixer for one minute and temperature, slump, unit weight, and air content were determined; these together with the mix design data are summarized in Table 1.

The 6 x 12-in. cylinders were cast in steel moulds using standard ASTM procedures. Prisms were cast in steel gang moulds, which were held vertical during casting, and were compacted on a laboratory vibrating table. For the first 24 hours all moulded specimens were covered with wet burlap and left in the laboratory air except for the two cylinder specimens which were used for accelerated strength testing after 23 hours as part of another investigation(6). After 24 hours all the test specimens were removed from the moulds and transferred to the moist-curing room maintained at $70^{o} \pm 3^{o}F$ and 90% relative humidity. All curing and capping of test specimens and testing in compression and flexure was carried out using standard ASTM methods. The specimens were tested at 28½ hours, 7 days, and 28 days; immediately before testing, both prisms and cylinders were subjected to longitudinal resonant-frequency and pulse-velocity measurements.

Test specimens were weighed to a probable accuracy of ±0.001 lb.

Ultrasonic pulse velocity was determined by a UCT electronic concrete tester*. This instrument operates at 100 kc with a 0.1-microsecond sensitivity.

Longitudinal resonant frequency was determined by an Electro Sonometer** using ASTM Standard Method C 215-60 (Unit A, Figure 1). This instrument operates on 50-60 cps with 20 cps dial reading accuracy. In addition, some of the specimens were subjected to longitudinal resonant-frequency determination using an electrodynamic materials tester*** made in Great Britian (Unit B, Figure 2).

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* Manufactured by A. E. Cawkell Electronic Engineers, G-7 Victory Arcades, The Broadway Southall Middx, England.

** Manufactured by Electro Products Laboratories, Chicago 40, Illinois, U.S.A. The driver and pick-up units were replaced by those manufactured by M. Falk and Co. Ltd., England.

*** Manufactured by M. Falk and Co. Ltd., England.

All cylinders were tested in an Amsler testing machine of 600,000-lb capacity. Prior to testing all cylinders were capped with a sulphur flint mixture.

Flexural strength was determined by testing 3 x 3 x 12-in. beams according to ASTM Standard Method C 293-68 for centre-point loading. The beams were tested in a manually operated, lever-type Tinius Olsen testing machine, the accuracy of which, in the 10,000-lb range, is 1 lb.

ANALYSIS OF TEST RESULTS

Number of Test Results

A total of 37 batches were sampled and 481 test specimens have been tested to date: 185 test specimens, consisting of 111 prisms and 74 cylinders, are yet to be tested at one year and these results will be reported later.

Analysis of Test Results

The typical relationships between age and compressive strength, dynamic modulus of elasticity, and pulse velocity are shown in Figures 3-5 respectively. Also shown on these figures are the between-batch standard deviations and coefficients of variation. Attempted correlations between the 28-day strengths and the dynamic properties of concrete for all the batches sampled are shown in Figures 6-8. The comparison of dynamic moduli determined by using the two resonant-frequency testers of different makes is shown in Figure 9 for a limited number of test results.

The nature of the investigation did not permit the use of all the test results obtained from all the batches sampled in the various correlations outlined above. For example, for the correlations shown in Figures 1, 2, 3 and 6, test results from batches having a constant water/cement ratio 0.59 and aggregate/cement ratio 6.57 were used; whereas for that shown in Figure 10 only a limited number of test results from the two resonant-frequency testers were available for comparison.

DISCUSSION OF TEST RESULTS

Between the ages of 28½ hr and 28 days, the compressive strength, dynamic modulus of elasticity, and pulse velocity of concrete increase with maturity, the compressive strength showing the greatest rate of increase (Figures 3-5). The compressive strength at 7 days is still only 78 per cent of that at 28 days, while the dynamic modulus of elasticity and pulse velocity were 87.6 and 94.4 per cent of the 28-day values respectively.

Data on the influence of age in pulse velocity, as obtained by Jones (4) and Galan (5), are shown in Figure 11. Also superimposed on this figure are the results of this investigation. It is seen that generally there is little increase in velocity after 7 days. Jones (4) reported that the pulse velocity of concretes made with crushed limestone and granites showed greater increase at later ages than the pulse velocity of concrete made with river gravels. A possible cause of this, according to Jones (4), was the gradual formation of the bond between the surface of the stone and the mortar. The relatively small increase in the pulse velocity after 7 days points out the difficulty of predicting compressive strength of concrete from this parameter.

The average between-batch coefficient of variation for 28-day compressive strength is 11.7 per cent, while the corresponding values for the dynamic modulus of elasticity and pulse velocity are 3.2 and 4.0 per cent respectively. The low values of coefficient of variation for pulse velocity and of dynamic modulus of elasticity should not be taken to mean that the reproducibility of the latter tests is superior to that of the compressive strength test; on the contrary, the low values indicate the insensitivity of these two tests to accurately predict the compressive strength of concrete. This is more pronounced for pulse velocity than for the dynamic modulus of elasticity and is in accord with the published data (1, 2, 3).

The linear correlation coefficient for the relationship between dynamic modulus of elasticity and 28-day compressive strength (Figure 6) is significant at the 5 per cent level with a value of 0.703. There appears to be a curvilinear correlation between dynamic modulus of elasticity and flexural strength (Figure 7). The correlation between compressive strength and pulse velocity is rather poor (Figure 8) in spite of the fact that test data from concrete mixes having the same water/concrete ratios were used for this correlation. The lack of a high degree of correlation between strength properties and pulse velocity is once again in line with the work reported by Jones (1), Whitehurst (2), and others (3, 5).

Published data (1, 2, 3) indicate that the correlations between strength properties and dynamic modulus and pulse velocity of concrete are greatly affected by changes in the mix design. In the concrete under investigation, the ranges of water/cement and aggregate/cement ratios used were rather narrow. Most of the concrete batches sampled had water/cement and aggregate/cement ratios of 0.49 and 6.57 respectively; thus it was not possible to determine the effect of the mix design on some of the relationships under investigation.

The dynamic modulus of concrete determined on prismatic specimens is somewhat higher than the values obtained using cylindrical specimens (Figure 10). Considering that both types of specimens were cast from the same batch of concrete, this difference may be due to the bias of a small sample, i.e., 27 test results.

The longitudinal resonance frequency determined by unit A* was consistently lower than the value determined by unit B (Figure 9). For unit A, the calibration charts are supplied by the manufacturer; thus the two units were not calibrated against a common standard and it was not possible to determine whether the difference between the two units was due to errors in calibration or to their being of different makes.

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* It is suspected that the difference in results is probably due to the higher precision of Unit B as compared to Unit A.

TABLE 1

Mix Design Data and Properties of Fresh Concrete

Mix Design Data		Properties of Fresh Concrete			
Nominal Water/cement Ratio by weight	Aggregate/cement Ratio by weight	Temperature, deg F	Slump, in.	Unit Weight, lb/cu ft	Air Content, per cent
0.70 to 0.47	8.2 to 5.2	67 - 78*	0.75-3**	142.4-152.8	1.5 to 7.3

* In one case temperature dropped to 58°F.

** In one case slump exceeded 6 in.

Note:
1. Two different brands of normal portland cement were used.
2. Maximum size of aggregate used was 3/4-in. crushed limestone; fine aggregate was natural sand.
3. All mixes contained a water-reducing agent whereas an air-entraining agent was used in some of the mixes only.

CONCLUDING REMARKS

Within the ageing period studied, the compressive strength, dynamic modulus of elasticity, and pulse velocity increased in value with the age of concrete, the increase being greatest for compressive strength and least for pulse velocity.

The correlation between dynamic modulus of elasticity and 28-day compressive strength of concrete is significant at the 5 per cent level with a linear correlation coefficient of 0.703. The correlation between the dynamic modulus of elasticity and the 28-day flexural strength appears to be curvilinear and is less than satisfactory. Extreme caution should be exercised in using these correlations for predicting strength of concrete.

The correlation between compressive strength of concrete and its pulse velocity is generally poor, and the use of pulse velocity to estimate compressive strength of concrete is not recommended.

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2. Whitehurst, E.A., "Evaluation of Concrete Properties from Sonic Tests", American Concrete Institute, Monograph No. 2, Detroit (1966), pp 94.

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5. Galan, Andrej, "Estimate of Concrete Strength by Ultrasonic Pulse Velocity and Damping Constant", Proceedings, American Concrete Institute, Vol. 64, No. 10, October 1967, pp. 678-684.

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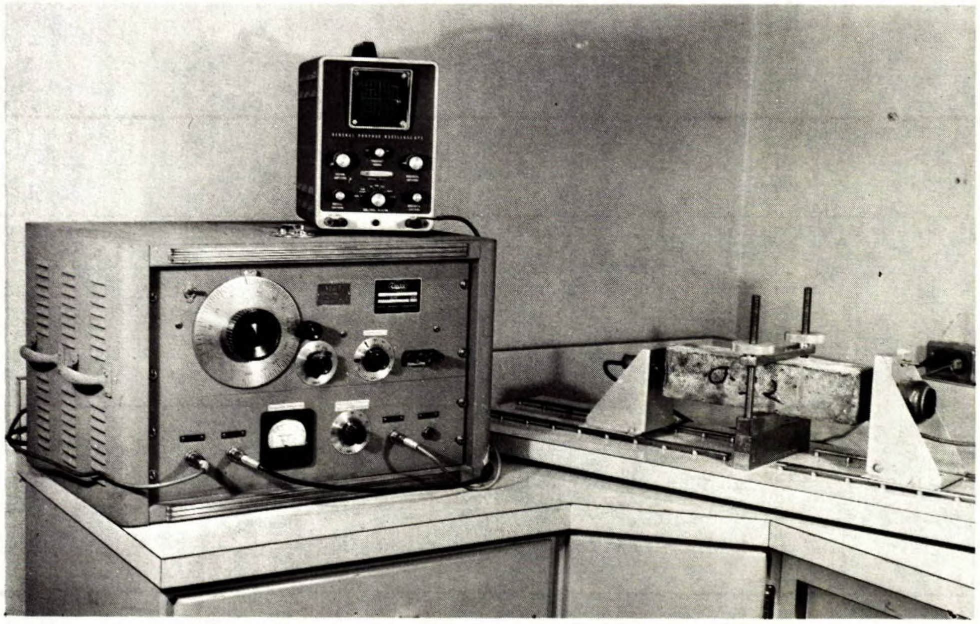

Fig. 1 - A 3 x 3 x 12-in. concrete prism being longitudinally vibrated by a resonant frequency tester manufactured in the United States.

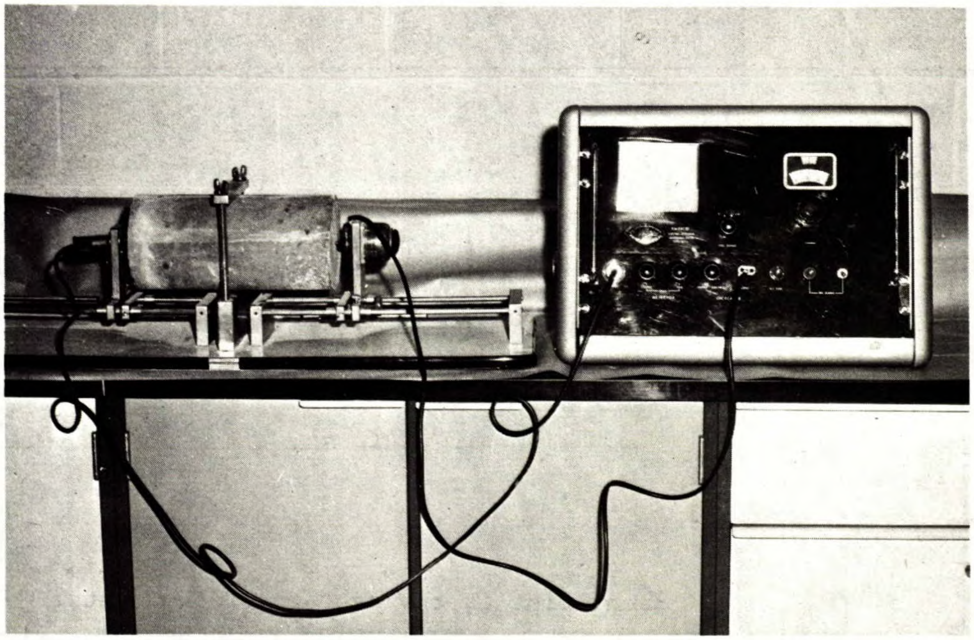

Fig. 2 - A 6 x 12-in. cylinder being longitudinally vibrated by an electrodynamic tester made in Great Britain.

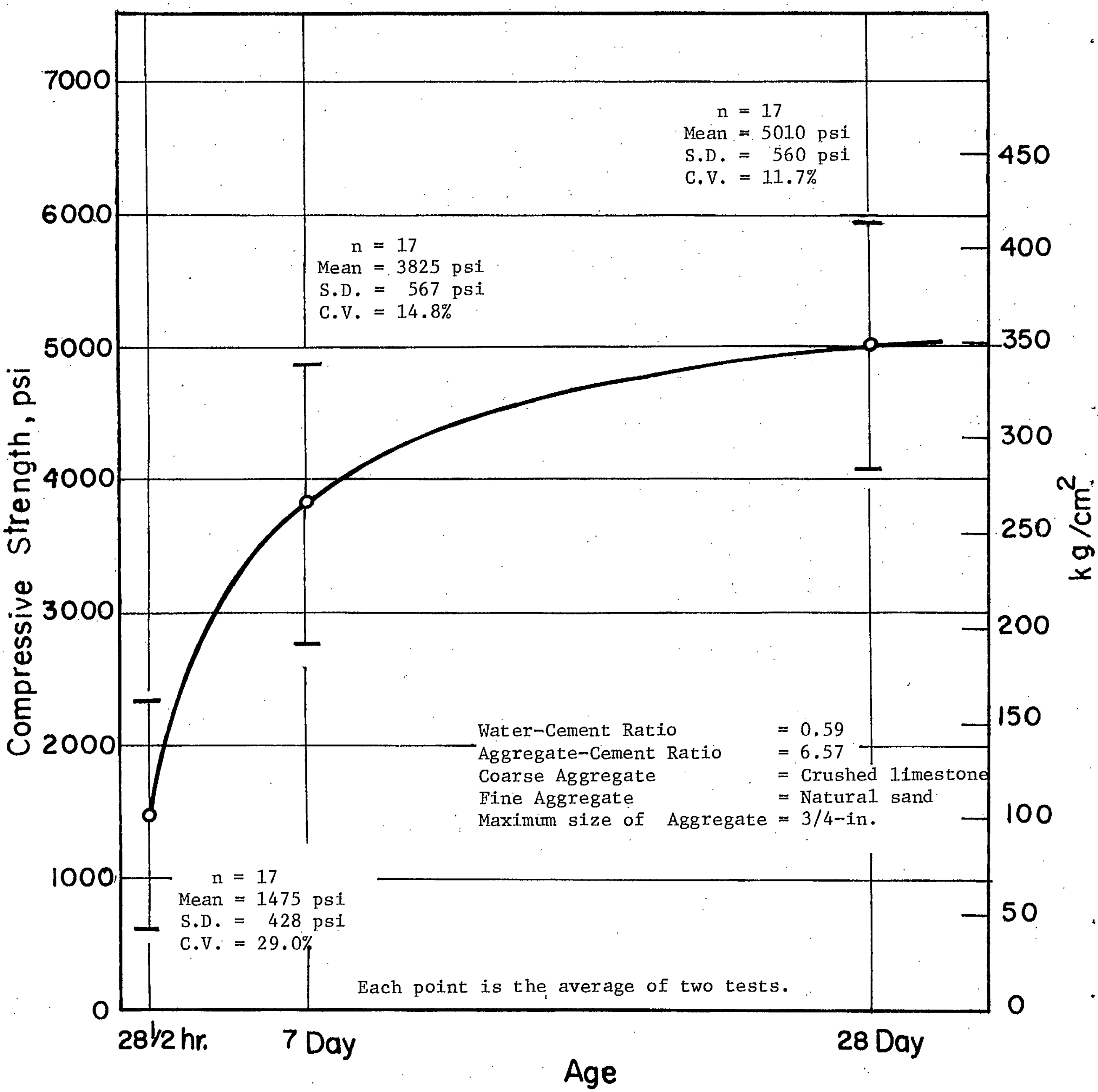

Fig. 3 - Relationship of age of concrete to compressive strength.

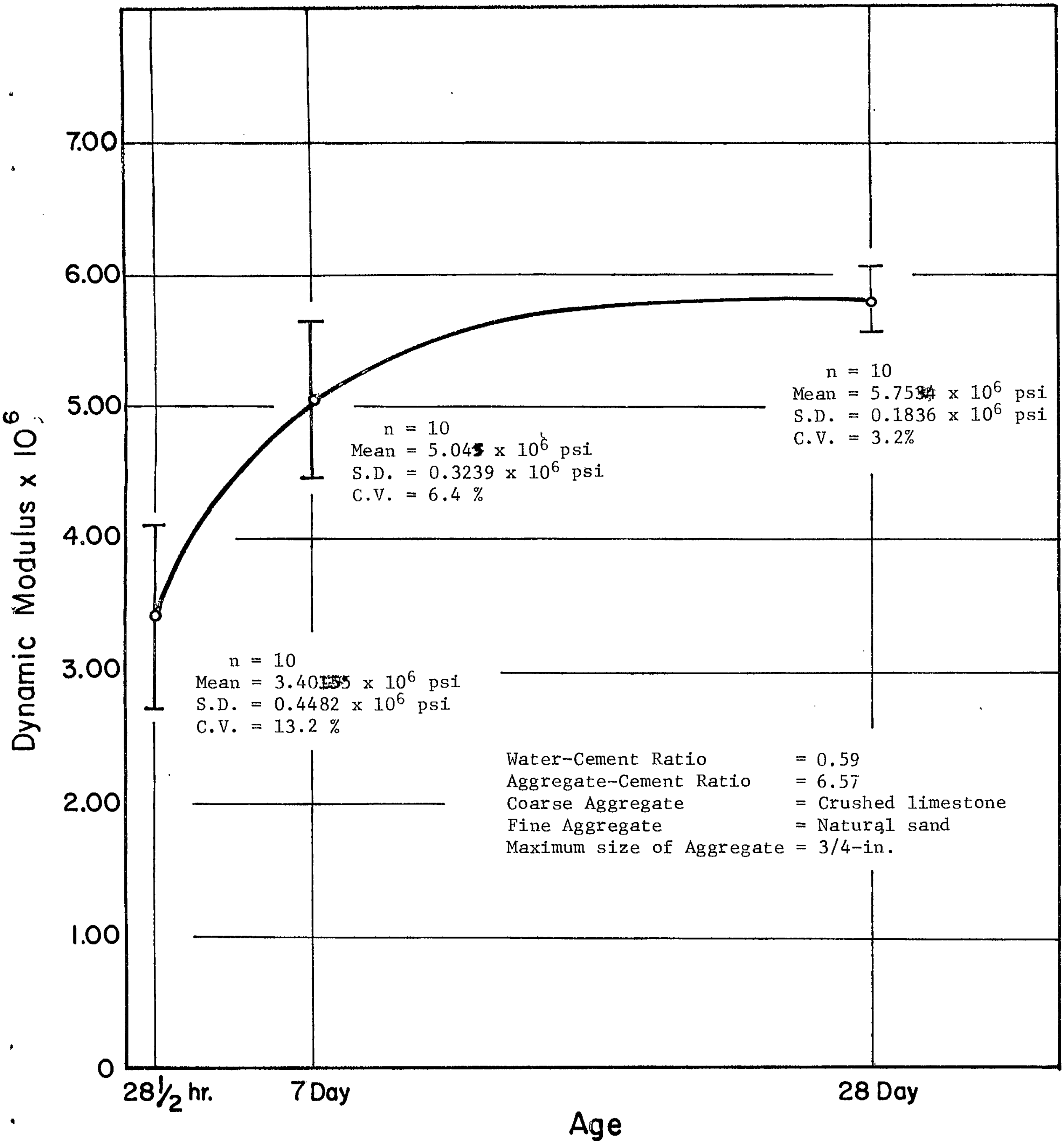

Fig. 4 - Relationship of age of concrete to dynamic modulus of elasticity.

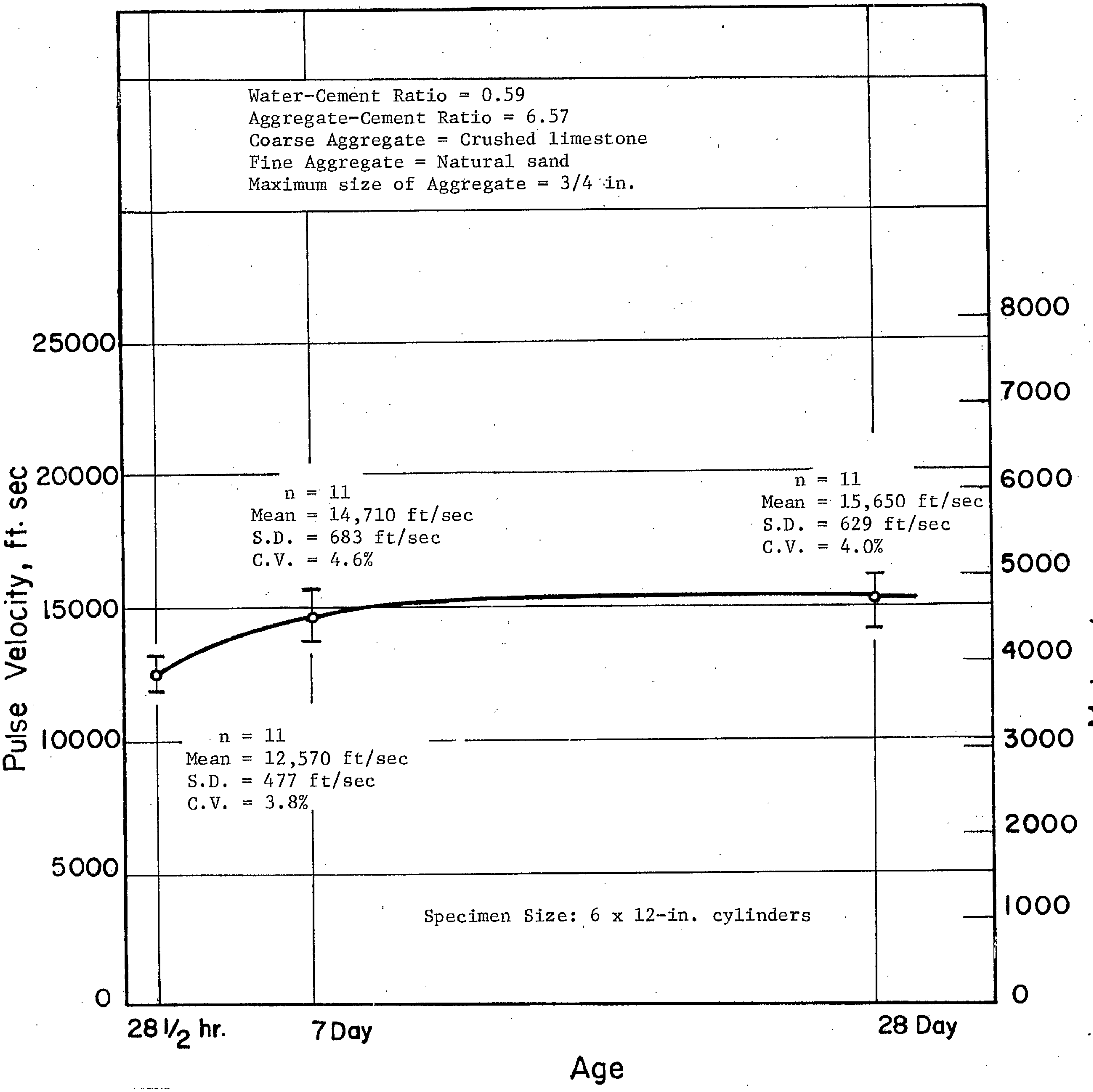

Fig. 5 - Relationship of age of concrete to pulse velocity.

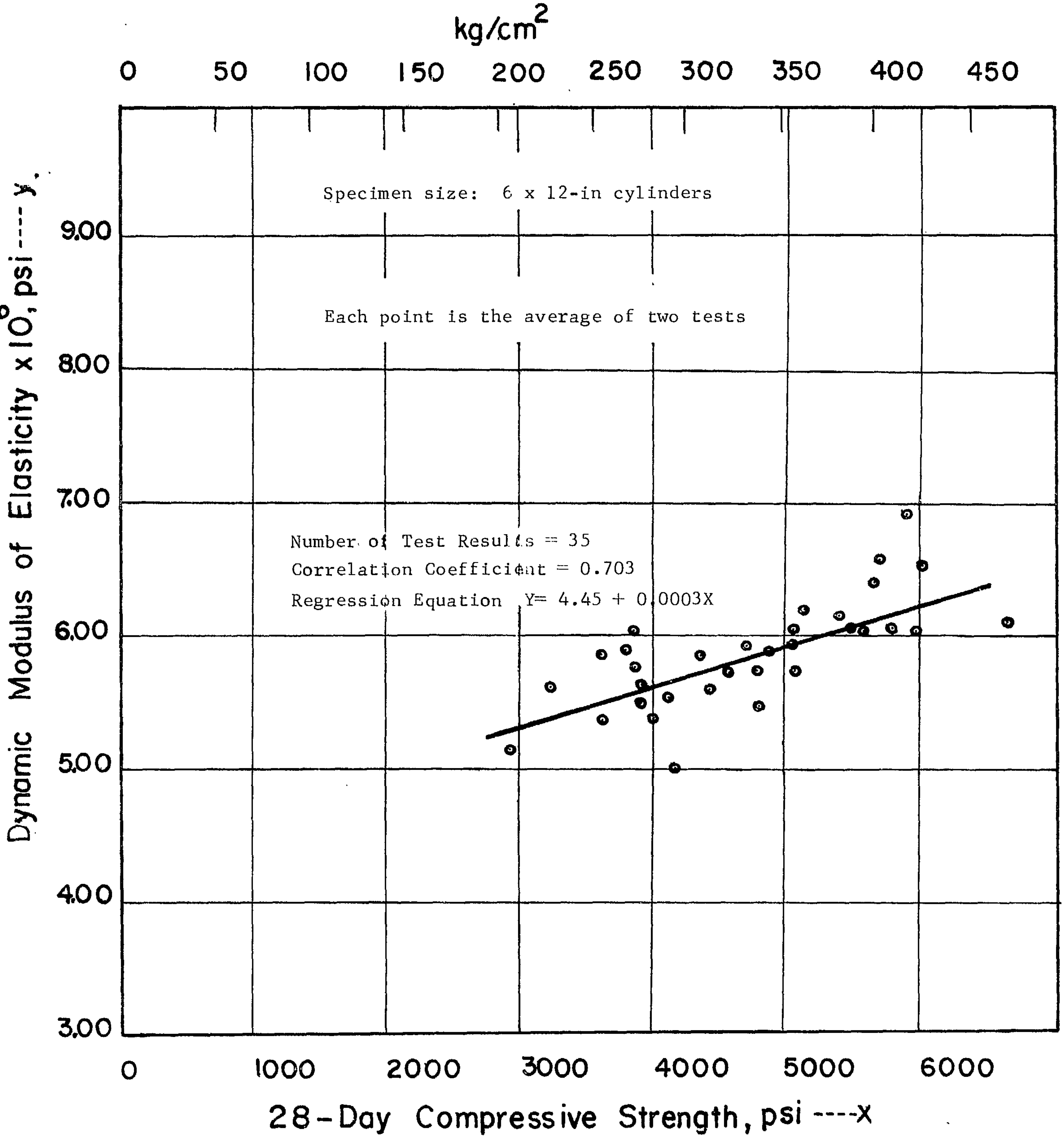

Fig. 6 - Relationship of dynamic modulus of elasticity to 28-day compressive strength of concrete.

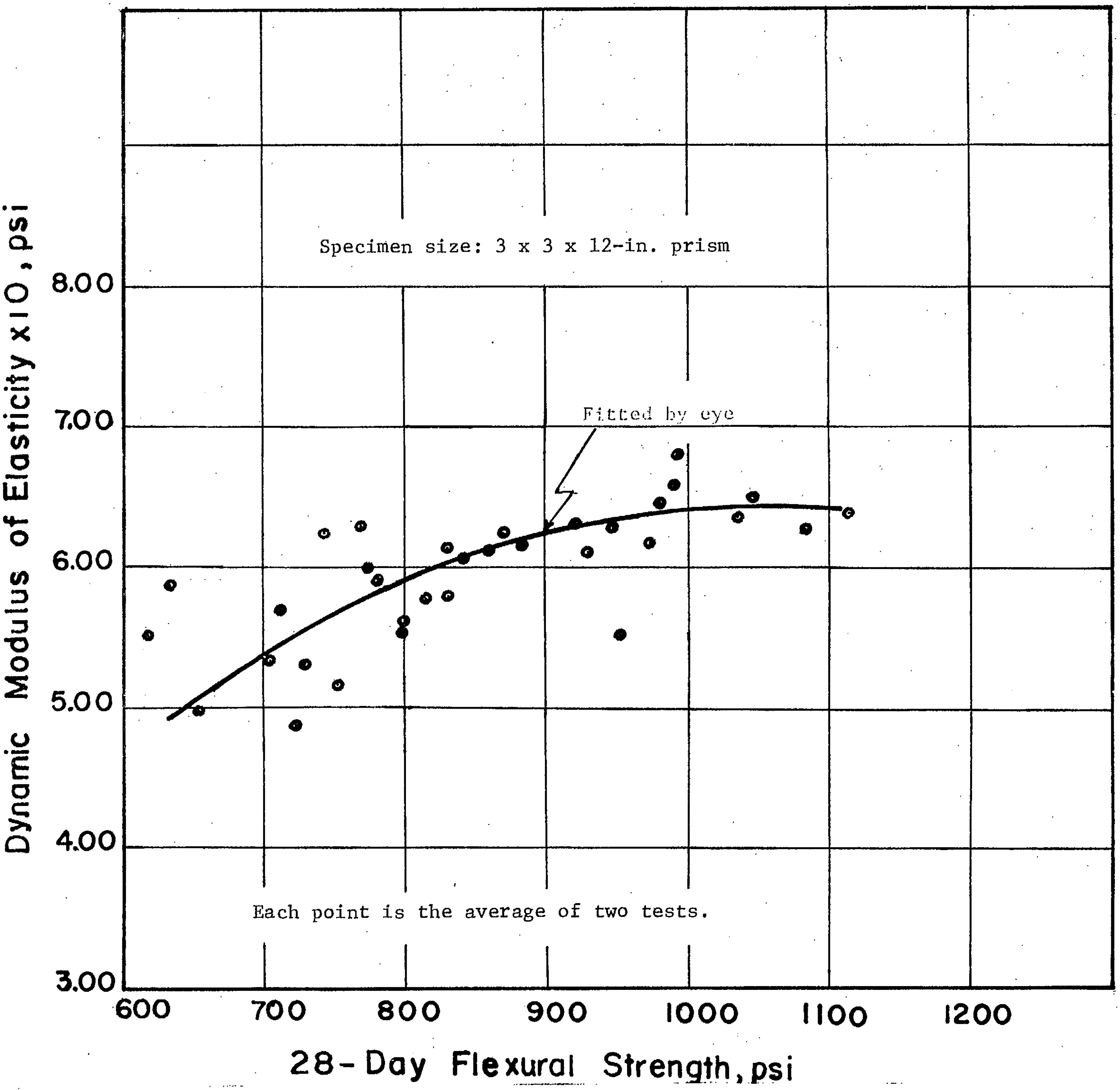

Fig. 7 - Relationship of dynamic modulus of eleasticity to 28-day flexural strength of concrete.

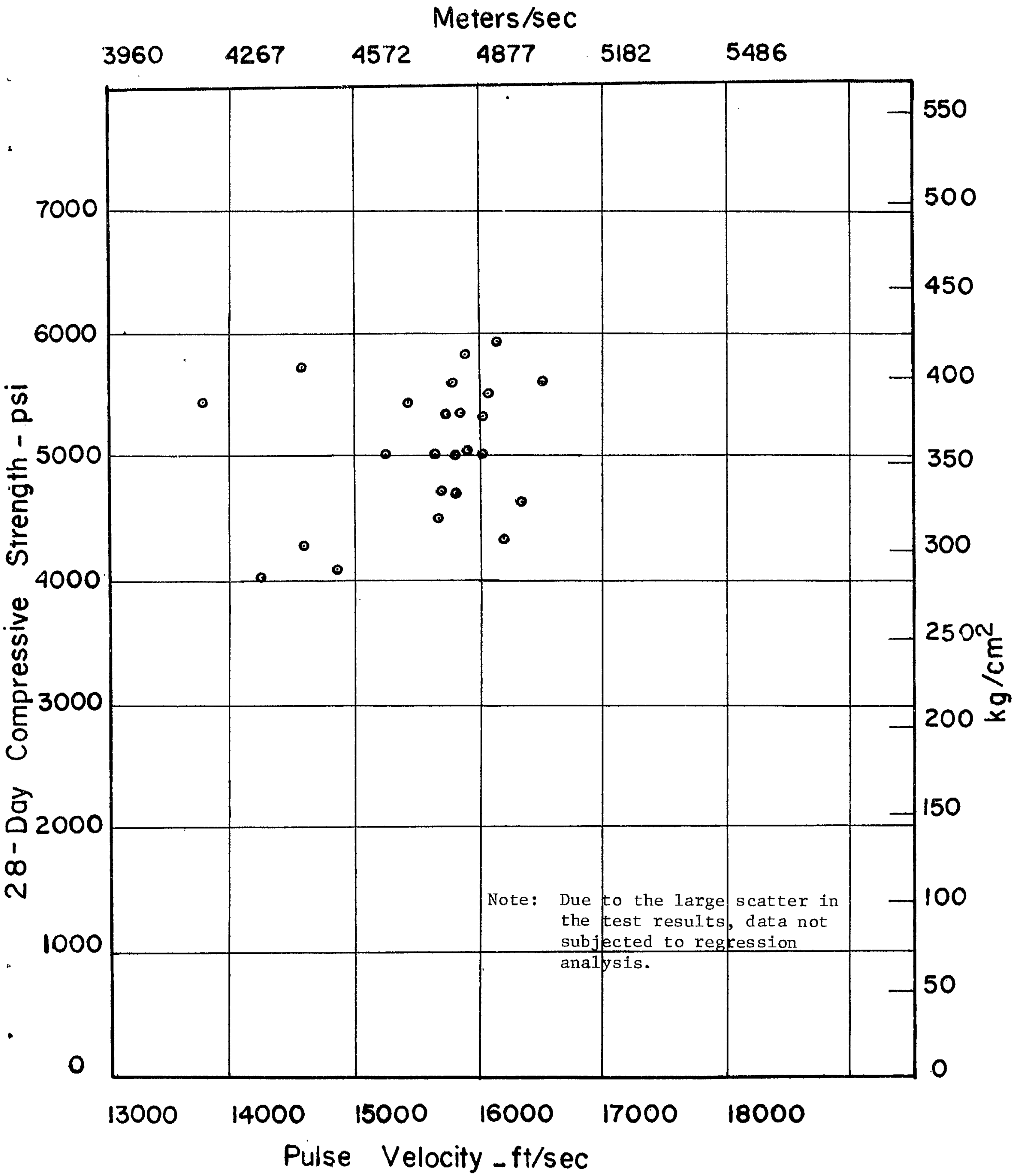

Fig. 8 - Relationship of pulse velocity to 28-day compressive strength of concrete.

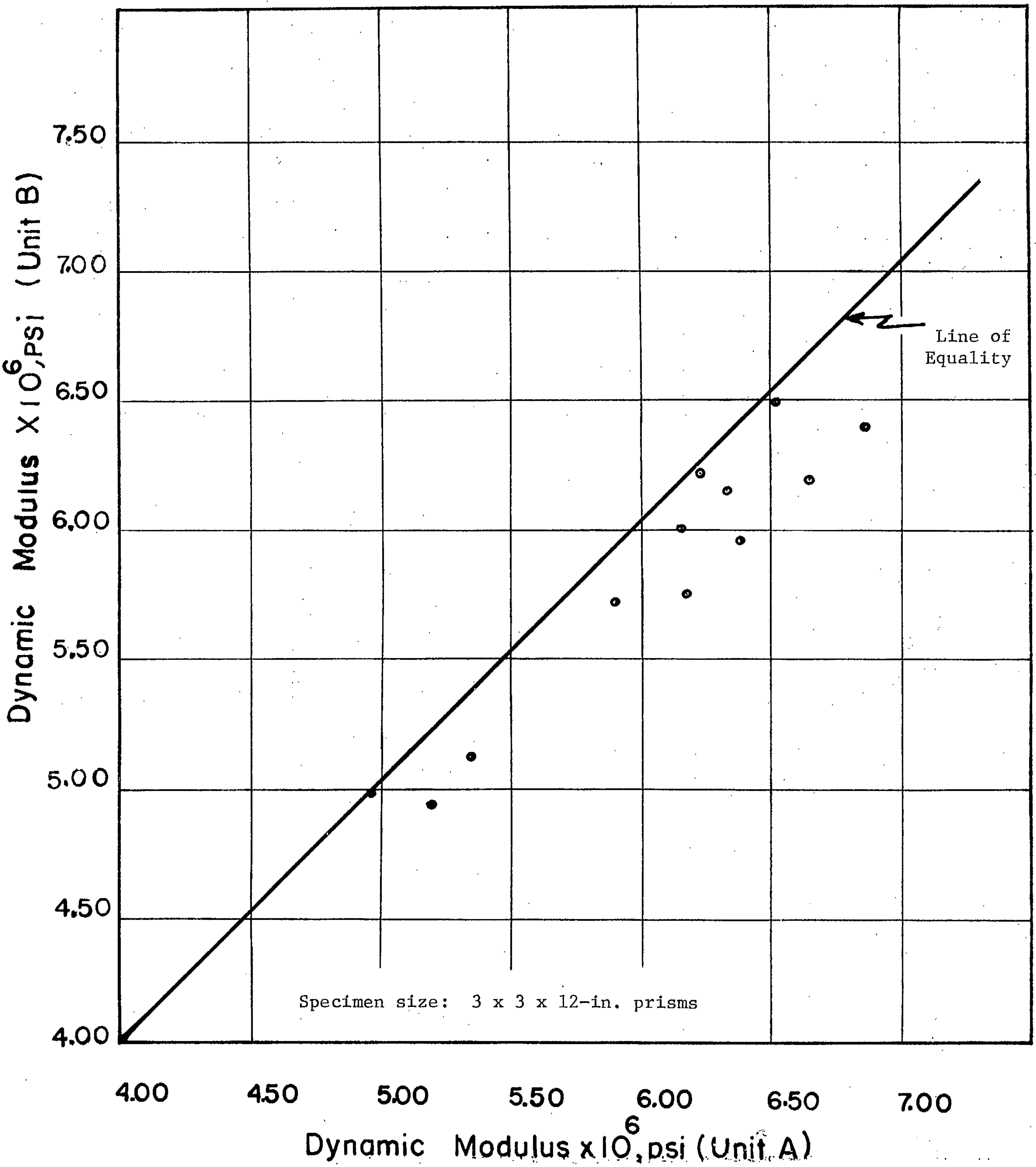

Fig. 9 - Comparison of dynamic moduli of elasticity using two different resonance frequency testers.

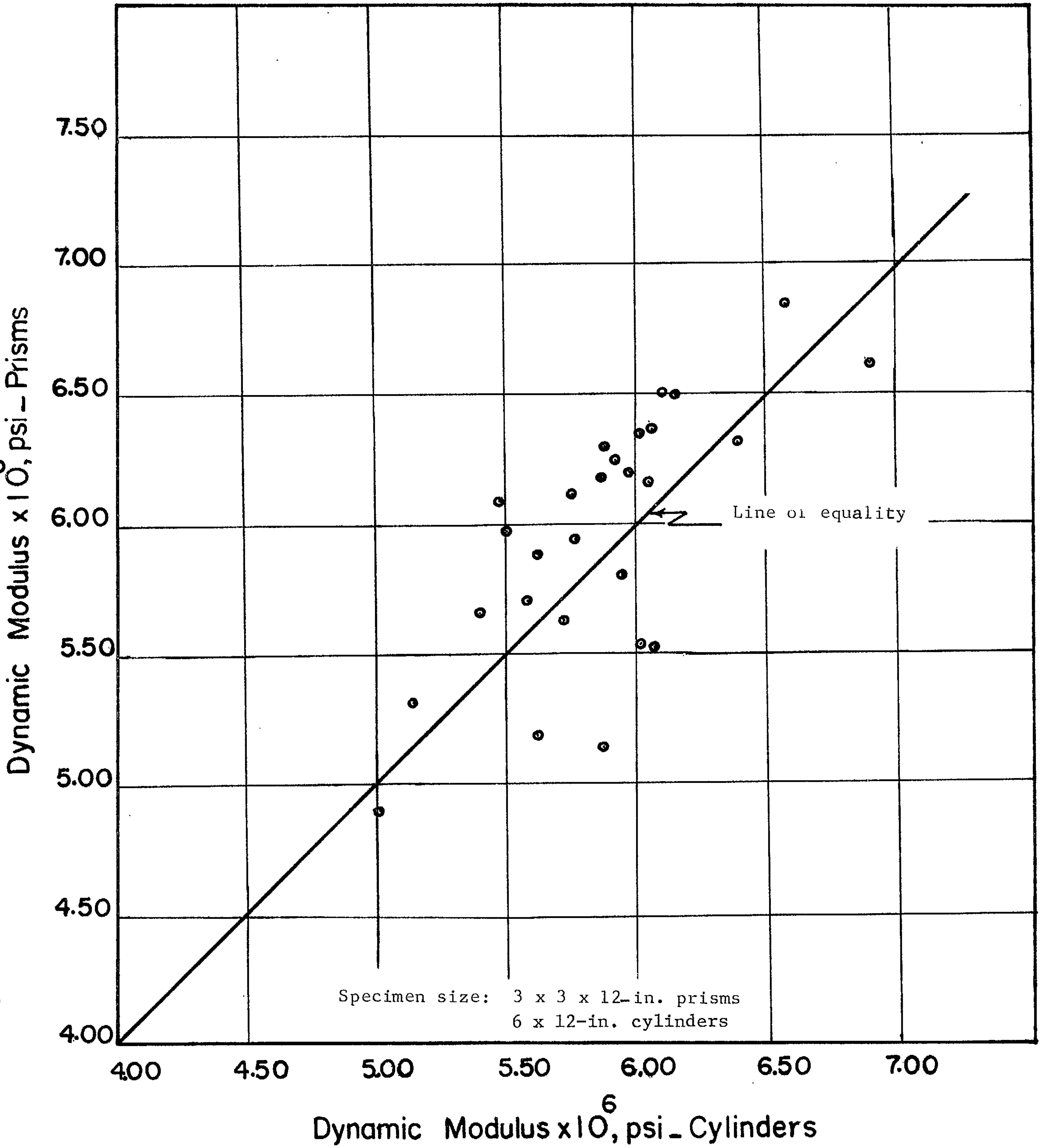

Fig. 10 - Comparison of dynamic moduli of elasticity using cylinders and prisms.

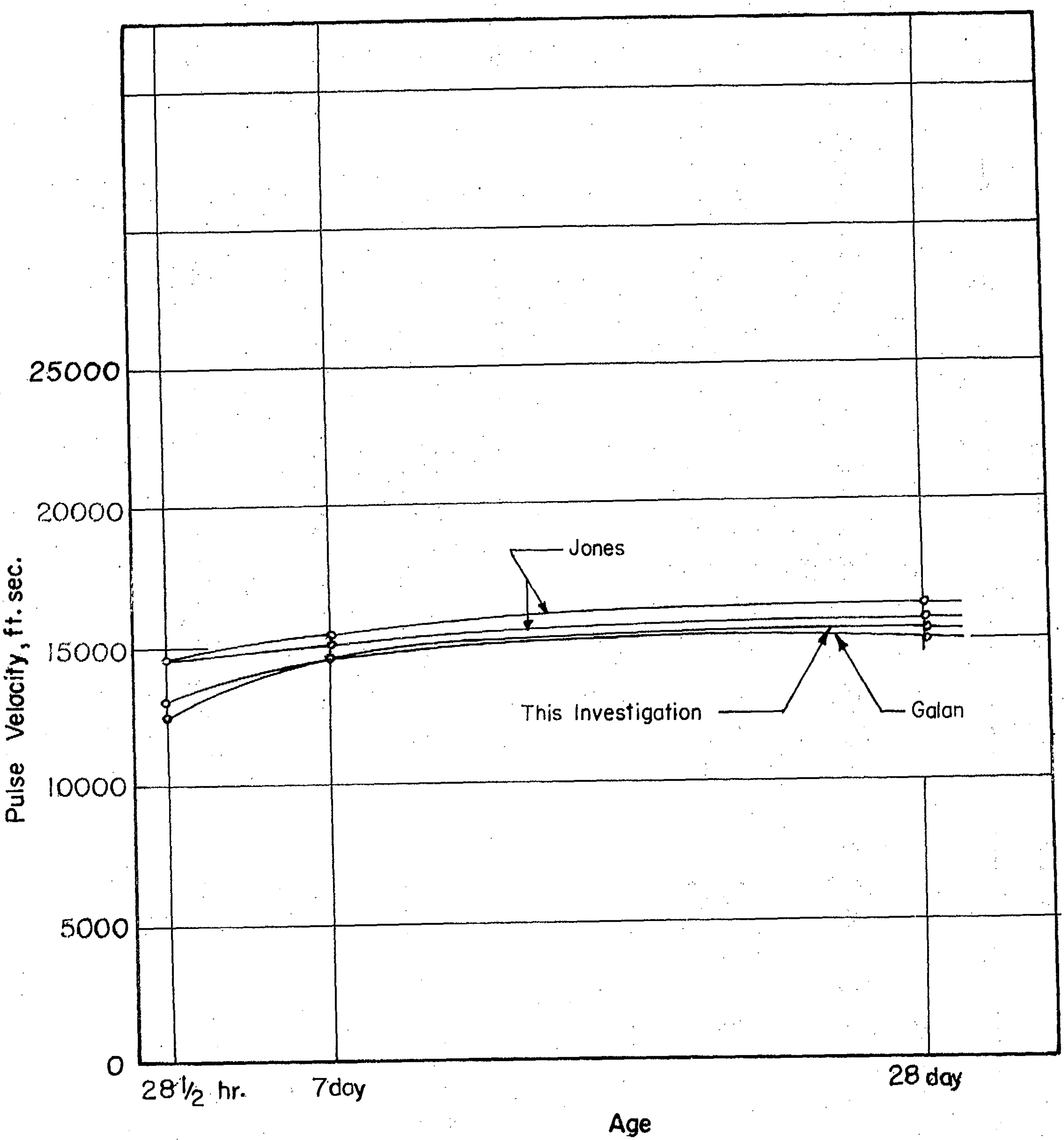

Fig. 11 - Relationship between age of concrete and pulse velocity
as obtained by different investigators.