Ultrasonic Testing for Assessing Concrete Quality in Structures

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Abstract

Ultrasonic pulse velocity is widely correlative not only with strength but also with other important concrete properties such as unit weight, water absorption and dynamic modulus of elasticity, and can even give a quality information of concrete in structures. The earlier the age after 24 hours of concrete subjected to ultrasonic measurement is, the more effective the given information becomes; this can meet requirements of early evaluation necessary for quality control. Ultrasonic method is of particular significance when the potential quality of concrete in structures must be known at a very early age in a nondestructive manner.

1. Introduction

Ultrasonic method, together with rebound method, has been once expected to be a feasible nondestructive test method for the evaluation of concrete quality in structures thanks to the availability of simple devices, which however appears to have been underestimated in concrete technology due to its lower degree of precision in the estimation of compressive strength.

If the concrete quality is totally represented by its compressive strength as usually believed by practitioners, the notoriety may be acceptable. Considering a contradiction to know fracture strength without fracture, ultrasonic method can still be reconsidered because information about concrete quality should be preferably given directly from structures and not from specimens.

Strength and ultrasonic pulse velocity (hereinafter referred to as UPV) are the properties commonly attributed to a character of the structure of concrete, thereby attention should be focused on the cause of the correlation between strength and UPV. For quality control and inspection, quick information is more important than compressive strength that is not always representing the total concrete quality.

We have taken ultrasonic method and rebound method as easy-to-use nondestructive testing methods and applied them to the quality evaluation of concrete in structures [1-2].

In this paper, we will deal solely with ultrasonic method, reconsider its significance and summarize the overall consequences in terms of the following three topics, anticipating the wide use for the quality assessment of concrete in structures.

1. Detection of heterogeneity of concrete in full-scale model structures.
2. Relationship between UPV and strength, dynamic modulus of elasticity, unit weight and water absorption.
3. Appropriate ages of concrete for UPV measurement and an emphasis of early evaluation.

UPV measurement in this study was a direct (transmission) method with PUNDIT at a frequency of 54 kHz.

2. Heterogeneity of Concrete Structures as a Function of The Depth of Placing

2.1 Data sources

Data presented here came from two series of experiments on full-scale model structures [3]. Specimens and mixture proportions are shown in Fig. 1 and Table 1. Only UPV data are discussed here whereas the experiments were carried out with a variety of purposes.

2.2 Variation of Properties as a Function of The Depth of Placing

Variation of properties as a function of the depth of placing obtained in the series I and II experiment are shown in Fig. 2 and Fig. 3. Each measured value was normalized with a value of the top part, and was the mean value of all the horizontal measurements. Ranges of discussion will be limited within a series, as the major difference between series I and II can be attributed to the mixture proportion.

In the series I experiment, we found that

1. Each property increased with depth.
2. UPV and rebound number showed nearly equal values.
3. Nondestructive measurement was less sensitive than fracture strength measurement.
4. Nondestructive measurement could however detect the structural changes in concrete manifested in the change of strength.

In the series II experiment, the same tendency was observed though the variation was less than that in series I.

Variation of water absorption obtained in the series I and II as function of the depth of placing is shown in Fig. 4, where a variation of pore structure of concrete can be represented particularly in the series I experiment.

With the above observation, ultrasonic and rebound method could be indicator of macro structural variation in concrete structures [4].

3. Relationship between UPV and Strength, Unit Weight and Water Absorption

3.1 Data Sources

Data sources presented here are the same as section 2.

3.2 Relationship between UPV and Strength

Relationship between UPV and compressive strength is shown in Fig. 5, where the correlation coefficient, even for the merged data of the series I and II, was as high as 0.86 though the mixture proportion varied over a wide range as shown in Table 1. Resulting regression line was fairly close to that of AIJ [5], whereas the mean error was 26%. The use of superplasticizer, one of the characteristics of the experiments, had no significant influence on the relationship.

3.3 Relationship between UPV and Unit Weight and Volumetric Water Absorption

Relationship between UPV and unit weight is shown in Fig. 6. A fairly well correlation with a correlation coefficient of 0.82 was observed. A wide variety of unit weight was due to a large variation of mixture proportion and quality of concrete in the full-scale structure. However, UPV could coincide with the variation and can be evaluated as a quality assessing indicator of concrete in structures.

Relationship between UPV and volumetric water absorption is shown in Fig. 7. Although the correlation coefficient of 0.76 was less than that of unit weight, the volumetric water absorption could also be a quality assessing indicator of concrete in structures taking into account of the result shown in section 2.2 [6].

4. Relationship between UPV and Dynamic Modulus of Elasticity

4.1 Data Sources

Total number of sample was 689 comprising 273 specimens with a wide variety of materials, mixture proportion, moisture content, ages and histories during these 10 years, 195 cores taken from the full-scale model structures, 221 cores from existing concrete structures, by which a relation of UPV and dynamic modulus of elasticity was determined [7].

4.2 Relationship between UPV and Dynamic Modulus of Elasticity of Concrete under Variable Conditions

Relationship between UPV and dynamic modulus of elasticity is shown in Fig. 8. Fairly good correlation, which appears to be univocal, can be seen between them and influences of the variation of condition were very small. The dynamic modulus of elasticity that cannot be directly obtained from structures is thus determined with ultrasonic method.

With close correlation to dynamic modulus of elasticity that is an important property of concrete, ultrasonic method can be a quality assessing indicator of concrete in structures.

5. Recommendation of Early-stage Testing

5.1 Data Sources

Evolution of UPV in concrete with ages is much faster than that of strength, thereby we studied an appropriate age of concrete for UPV measurement, and found that UPV measurement became more effective when applied at the earliest possible age of concrete [8].

The appropriate age of concrete for UPV measurement was determined by taking into account of the sensitivity of UPV to the change in quality of concrete at each age and the correlation of UPV to the strength at 28-day.

In this way, a timely UPV measurement can lead to an early-stage prediction of a potential strength at 28-day, and a possibility of the method that can inspect quality of concrete in structures in direct and nondestructive manner at an early stage was suggested as a desirable mean in the quality control. Subsequently, UPV method was further developed in combination with the rebound method [2].

This study owes much from the work of Elvery and lbrahim [9] who showed a possibility of assessing the 28-day strength from the ultrasonic measurement at the age of 24-hour.

5.2 Optimum Age of Concrete for UPV Measurement

Typical evolution profiles of UPV and dynamic modulus of elasticity with ages of concrete are shown in Fig. 9, where both properties are normalized with respect to 28-day value and expressed as the degree of evolution in percent with the age. UPV evolution was faster than that of strength at very early ages, attained 70% in a day and reach 90% in three days, whereas it increased only 2% after 91 days and showed no progress until 332 days. Evolution of dynamic modulus of elasticity with ages was faster than strength and slightly slower than UPV but became nearly equal to UPV after 28 days.

The comparison of sensitivity of each property to the quality of hardened concrete is shown in Fig. 10, where the sensitivity, normalized with respect to the original (at W/C:0.3) value, was defined as a difference of each property with a change of water-cement ratio from 0.3 to 0.7 under constant amount of aggregates.

The order of sensitivity was strength, dynamic modulus of elasticity and UPV at each age, thereby nondestructive method was less sensitive than strength.

Decrease of the sensitivity was generally observed in each property in which the decrease in UPV and in dynamic modulus of elasticity were more conspicuous than strength.

UPV and dynamic modulus of elasticity are now compared in terms of the correlation to the standard-cured, 28-day strength of concrete in order to evaluate their capabilities of assessing the potential quality at each age. Results of UPV and dynamic modulus of elasticity, their respective correlation coefficients and mean errors at each age are shown in Fig. 11 and Fig. 12.

UPV showed good correlation to the 28-day strength though the mean error was not small. Dynamic modulus of elasticity showed better correlation to the 28-day strength and the mean error was relatively small. As the sensitivity study showed in Fig. 10, sensitivity of dynamic modulus of elasticity was superior than UPV thereby the quality control practice in factories may be preferably made with a combination of samples and resonance method.

The earlier the age of the test was, the higher the correlation coefficients and the lower the mean error became as shown in Table 2 and 3.

We may conclude that an effective UPV measurement can be made at the earliest possible age after 24 hours. Reasons of selecting the 24-hour as the earliest possible age for the UPV measurement are as follows:

1. Variation of measurement became instantly small and stable after an age of 12 hours as shown by Elvery and lbrahim [9].
2. Variation of measurement became moderate after an age from 12 to 24 hours as shown by Kakuta and Kojima [10].
3. Measurement practice within working hours is easier in 24 hours than in 12 hours.

5.3 Emphasis of Testing at Early Stages

An optimum concrete age for UPV measurement to assess the concrete quality is practically 24-hour, and a subsequent measurement tends to decrease its sensitivity to a potential quality and a correlation to 28-day strength.

The potential quality information of concrete in structures is required as early as possible after placing, thereby an early-stage testing like UPV measurement is recommended.

Partial removal of form may occasionally be necessary in the practice of the test, when a selection of a component of less load-bearing such as a spandrel wall, or placing an additional dedicated component for measurement should be considered.

6. Conclusions

From the experiment of full-scale model structures with a wide variety of mixture proportion, the followings are found.

1. Ultrasonic pulse velocity, though less sensitive than strength, can be an indicator of structural variation of concrete along with the depth of placing.
2. Ultrasonic pulse velocity fairly correlates with compressive strength, unit weight and water absorption of concrete.
3. Ultrasonic pulse velocity has a univocal, very close relation with dynamic modulus of elasticity of concrete tested under a wide variety of mixture proportions and samples from existing structures.
4. From the experiment focusing that the evolution of ultrasonic pulse velocity with ages of concrete is faster than that of strength, the age of concrete appropriately assessed by ultrasonic method is 24-hour after mixing, taking into account of its sensitivity to variation of concrete quality and its correlation to 28-day strength.

Ultrasonic pulse velocity method is a significant mean that can assess the potential quality of concrete in structures at early stages in a nondestructive and versatile manner.

Acknowledgments

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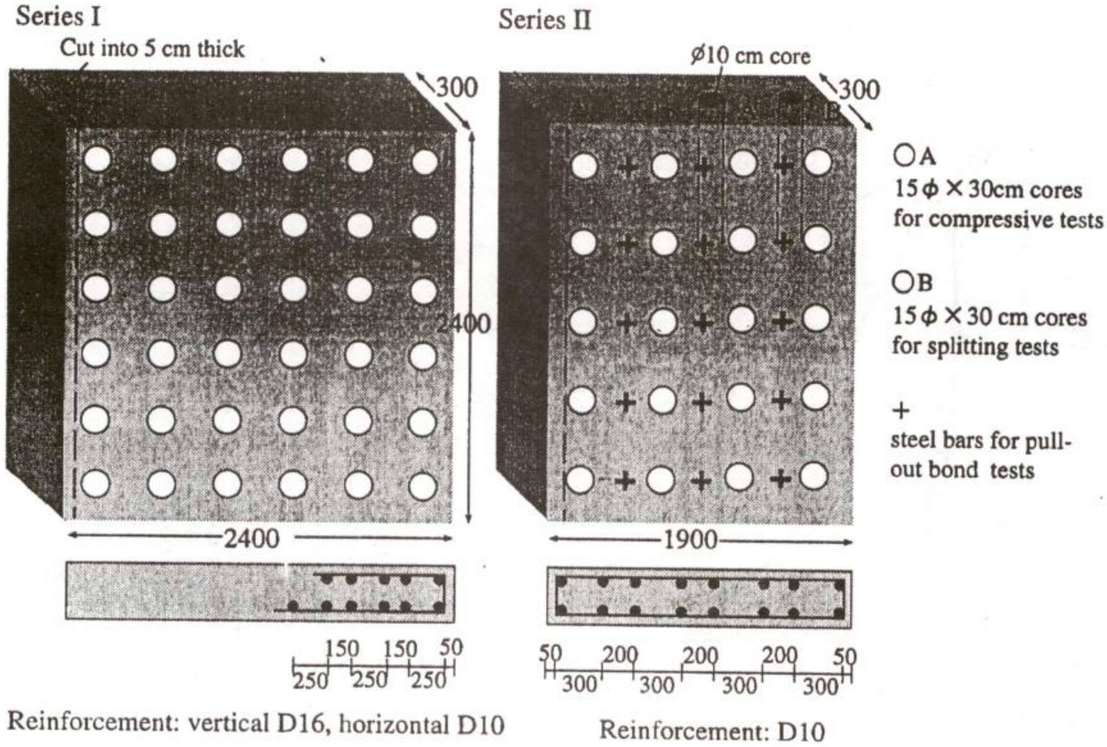

Fig.1 Dimensions and coring positions in the model walls.

Table 1 Mixture proportions of concrete.

Series	Type of concrete	Notation	W/C (%)	s/a (%)	Air (%)	AEA (l/m^3)	SP (l/m^3)	Slump (cm)
I	Plain	No	68.6	49.0	1.2	-	-	21.0
	Conventional	Na	61.0	48.7	3.9	3.57	-	21.0
	Base	B	61.0	48.7	4.0	3.19	-	12.0
	Superplasticized	F	61.0	48.7	4.4	3.19	1.55	21.0
	Excessively plasticized	F'	61.0	48.7	4.2	3.19	1.98	23.5
II	Conventional*	N	62.3	45.1	4.1	0.11	-	18.0
	Conventional**	N'	58.6	42.9	5.0	0.11	-	17.0
	Base	B	60.5	45.5	5.4	0.10	-	10.0
	S.E.C.***	S	60.6	45.3	3.6	0.10	-	7.5
	Superplasticized	F	59.1	45.7	4.8	0.10	1.045	19.5
	Superplasticized S.E.C.	SF	61.9	45.1	4.5	0.10	1.435	18.5

Note:
AEA : Air entraining admixture
SP : Superplasticizer
* : Normal workability: N
** : Poor workability with segregation: N'
*** : Sand enveloped with cement (Two stage mixing with divided water for segregation prevention)
Maximum size of aggregate was 25 mm for the Series I and 40 mm for the Series II.

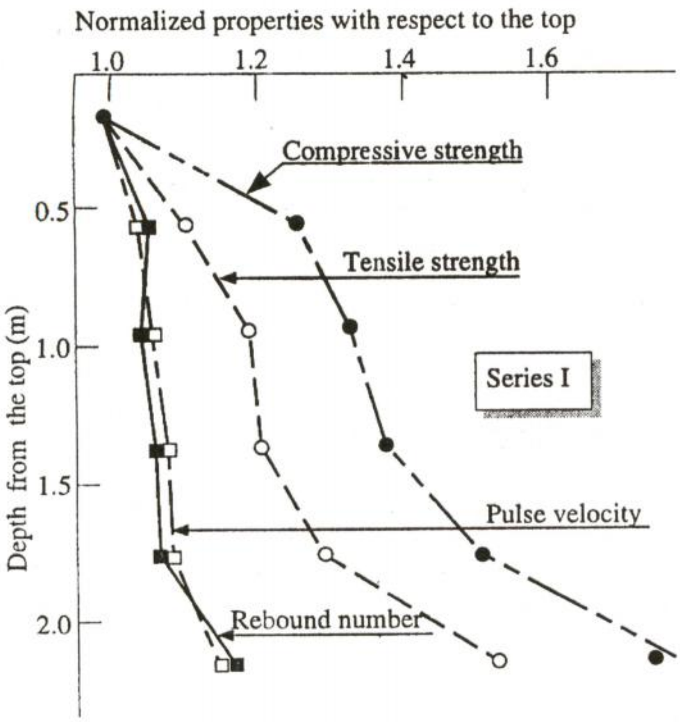

Fig.2 Effect of depth on characteristics.

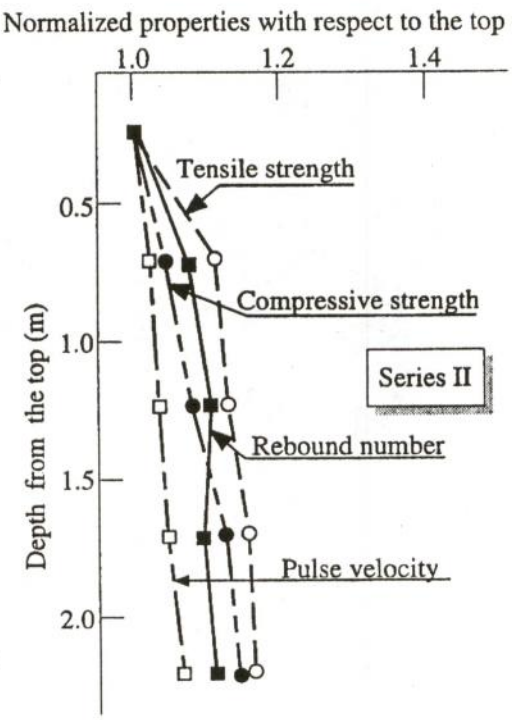

Fig.3 Effect of depth on characteristics.

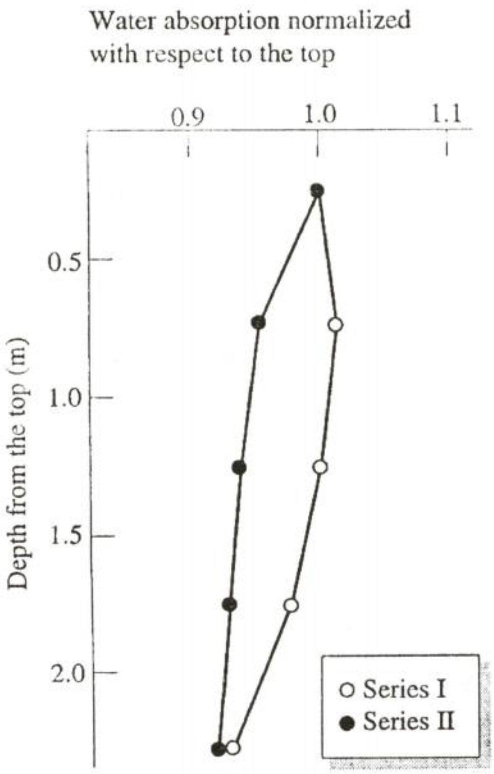

Fig.4 Effect of depth on the water absorption ratio.

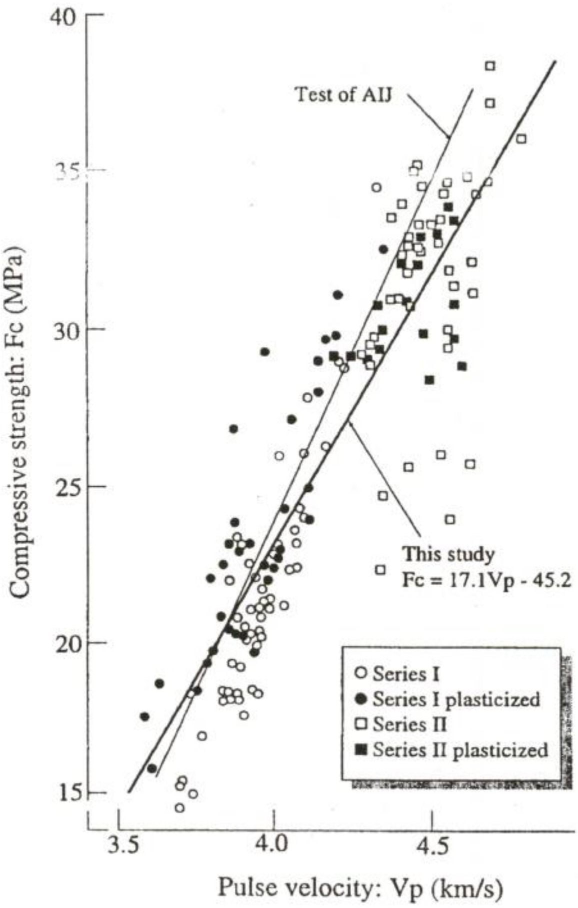

Fig.5 Correlation between pulse velocity and compressive strength of concrete.

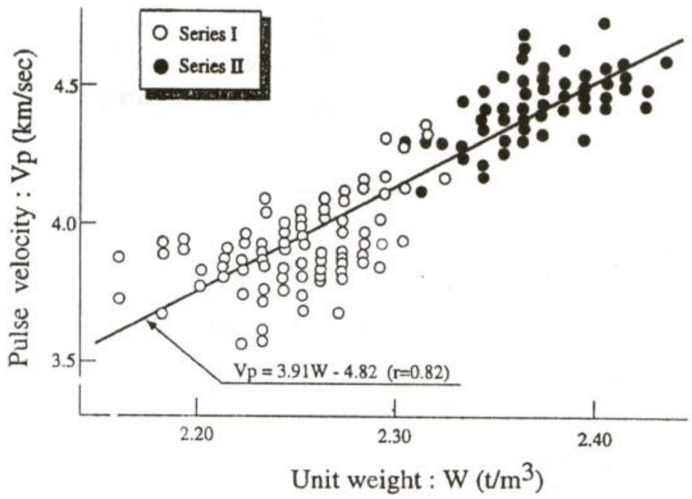

Fig.6 Correlation between pulse velocity and unit weight of specimen.

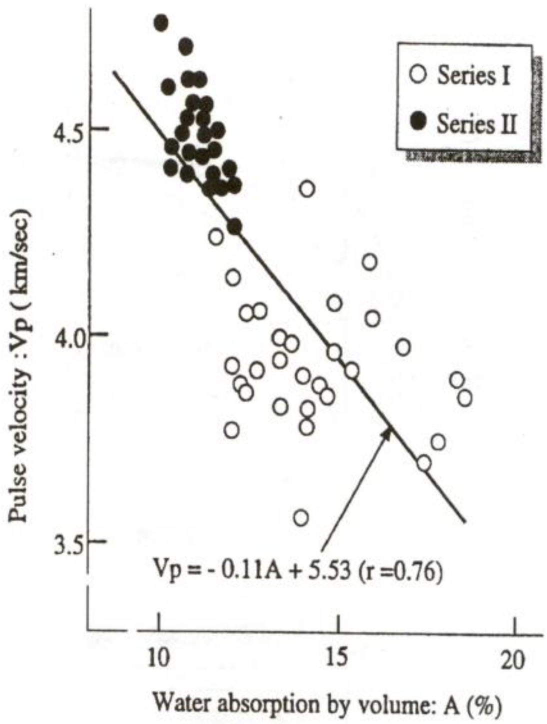

Fig.7 Correlation between pulse velocity and water absorption.

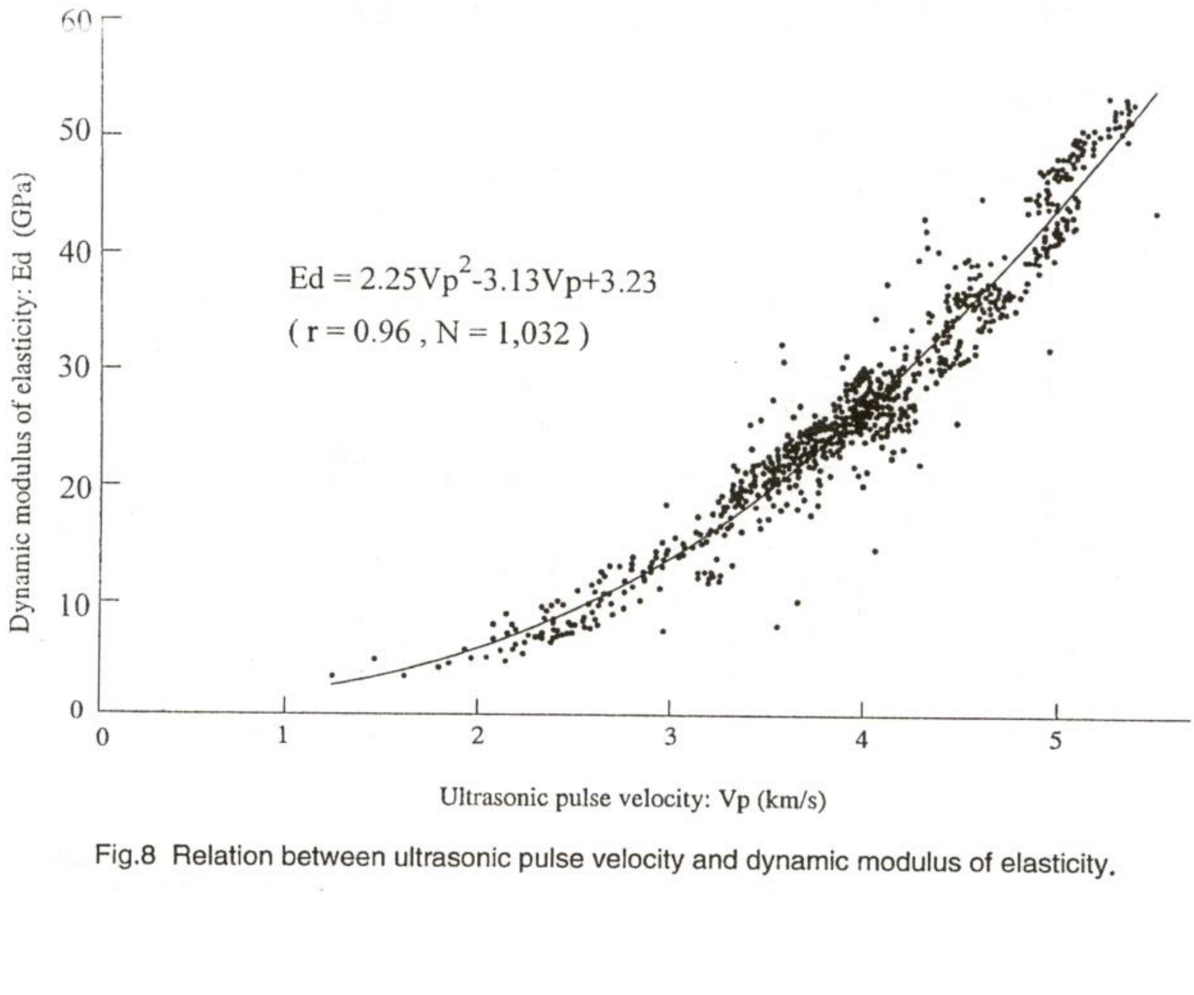

Fig.8 Relation between ultrasonic pulse velocity and dynamic modulus of elasticity.

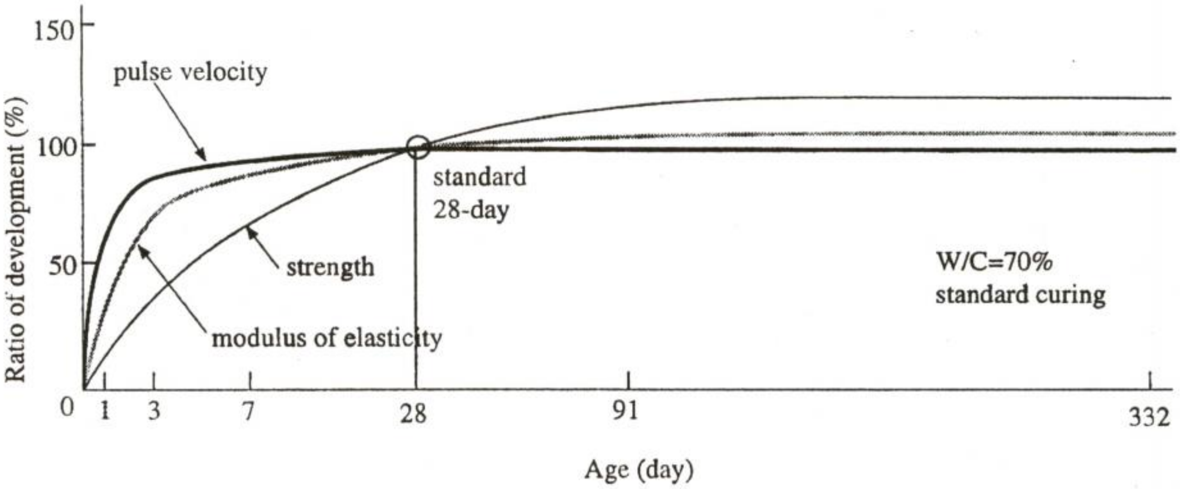

Fig.9 A typical development ratio with age of the three characteristics.

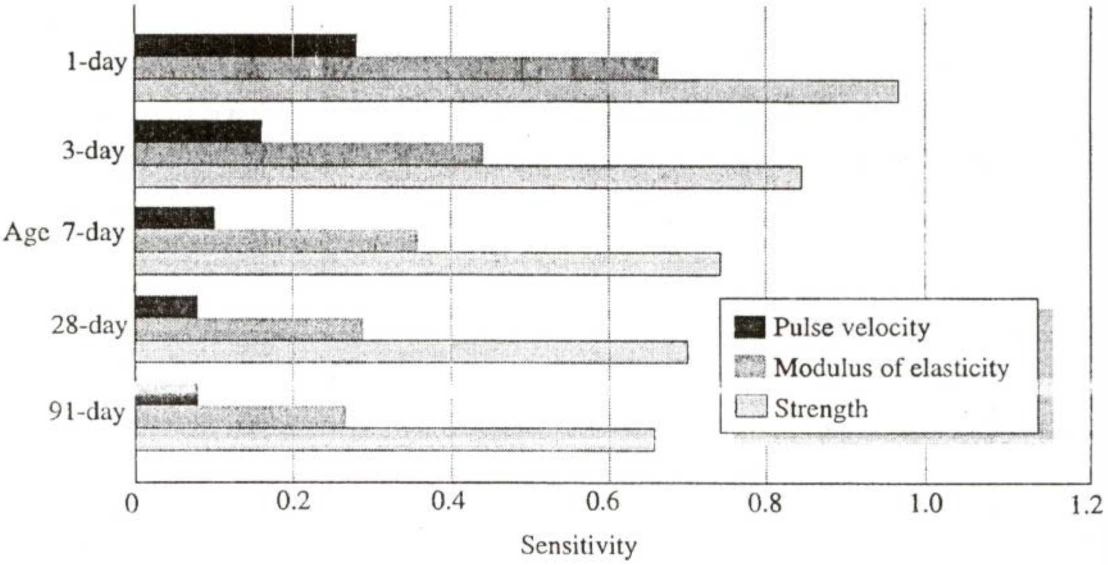

Fig.10 Sensitivity of three characteristics to change of concrete quality.

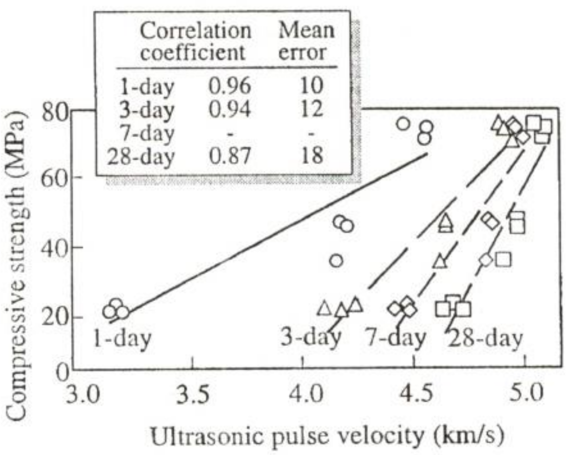

Fig.11 Correlation between UPV and 28-day strength.

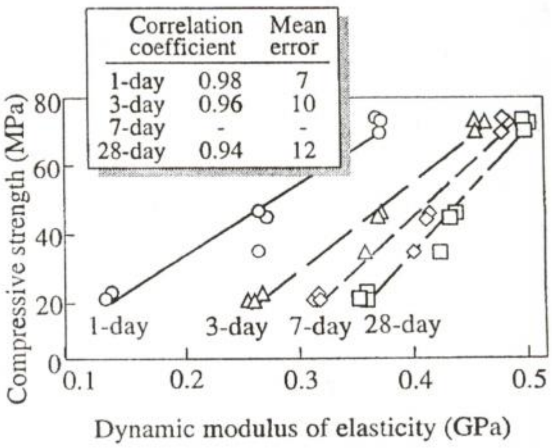

Fig.12 Correlation between dynamic modulus of elasticity and 28-day strength.