

Development of Concrete Test Hammer

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Abstract

The theoretical and experimental analyses for development of new test equipment for measuring the strength of concrete by hammer blows are described in this paper. Although we have had the Schmitt Test Hammer as the test equipment in non destructive manner for a long time, there are many questions as to its accuracy and its complicated method of use. Thus, we initiated a project to develop a more simple and accurate method for determining the concrete strength in non destructive manner using a simple hand hammer blow.

Introduction

The purpose of this research work is to develop a new measurement equipment which will give the index value of concrete strength and the surface integrity index by impacting the concrete surface similar as that of a hand hammer, that is, no impact force controls are necessary to measure the strength of the concrete and also no needs for data correction factors for the gravity angles of the hammer blow. Therefore the name of this research work is “The concrete test hammer project”. As an ordinal measurement equipment for concrete strength as non-destructive method, the Schmitt test hammer was well known. The Schmitt test hammer measures the rebounding rate when the hammer mass collides with the concrete surface and the rebounding rate is transferred to the compressive strength of the concrete. In Japan, this method was introduced in 1958 and established as the standard concrete test method. However there were many questions as to the accuracy of this method from each engineering field where concrete is utilized.

Theoretical background

Basic theory

The concrete structures can be considered as the semi infinite elastic body where the measuring surface will be free boundary. If the hammer whose mass is denoted M collides with the concrete surface with an initial velocity V , the kinetic energy of the hammer is described as Equation (1).

$$E_M = \frac{1}{2}MV^2 \quad (1)$$

On the other hand, if the maximum displacement of the concrete surface caused by the hammer collision denotes D , the potential energy of the concrete surface is,

$$E_T = \frac{1}{2}KD^2 \quad (2)$$

Although elastic waves are generated by the hammer collision, both energies of Equations (1) and (2) are considered the same from a practical point of view. The K in the Equation (2) is the elastic coefficient and from the Hook's law it is the spring constant of the concrete surface when the mass M collides. From the law of the energy equilibrium, Equation (3) is given.

$$MV^2 = KD^2 \quad (3)$$

Form the Hook's law,

$$F_{\max} = KD \quad (4)$$

The maximum force working against the hammer is defined as Equation (4). The equation (4) can be rewritten as equation (5) as follows.

$$D = \frac{F_{\max}}{K} \quad (5)$$

Substituting Equation (5) to Equation (3)

$$MV^2 = \frac{F_{\max}^2}{K}$$

Then, the Equation (6) is given.

$$\sqrt{MK} = \frac{F_{\max}}{V} \quad (6)$$

Here, \sqrt{MK} is the contact mechanical impedance of the hammer and the concrete surface. And if the spring constant K relates the characteristic value index of the material elasticity as the Young's modulus, and if the compressive strength of the concrete has some functional relationship to the young's modulus of the concrete, the value calculated as Equation (7) can be used as an index value of the strength of the concrete.

$$\sqrt{K} = \frac{1}{\sqrt{M}} \frac{F_{\max}}{V} \quad (7)$$

Theory of Measurement

In Equation (7), the maximum force F_{\max} and the initial velocity of the hammer V are unknown. If the hammer has an accelerometer, the force working against the hammer can be measured as follows.

$$F(t) = Ma(t) \quad (8)$$

Where, $a(t)$ is the acceleration measured by the accelerometer attached to the hammer. The value needed to be measured is the maximum values of the force, and then consequently the maximum force can be determined using equation (9).

$$F_{\max}(t) = Ma_{\max}(t) \quad (9)$$

As shown in Equation (9), the maximum force of the hammer is given if the acceleration of the hammer is measured.

The next factor to be determined is the initial velocity of the hammer. The acceleration of the hammer is the acceleration works to reduce the velocity of the hammer after the hammer collides with the surface of the concrete. If the hammer is stopped by this negative acceleration, the initial velocity of the hammer is determined as the integration of the acceleration during the hammer blow. Then, the initial velocity is given as follow.

$$V = \int_0^{\infty} a(t)dt \quad (10)$$

Signal treatment

A typical example of the measured wave form is shown in Figure 1. The vertical axis of Figure 1 is the A/D value of the acceleration. The force reaches its maximum value at around 300 micro second. There is a difference between the time to reach the maximum value and the time to fall to 0 again after the maximum value. The wave form is not line symmetrical at the time when the force becomes the peak value.

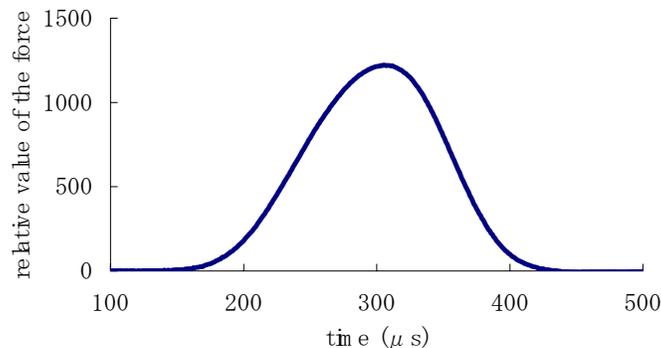


Figure 1: The typical wave form measured by the hammer blow for actual concrete

Considering the process of the hammer blow, the time period before the force becomes its maximum value is the time period during which the hammer is pushing the concrete surface, and the time period after the maximum value is during when the concrete surface is pushing out the hammer. Therefore, the former time is called the “active process”; the latter “reactive process”. If the concrete surface is deteriorated, plastic deformation of the concrete surface will be observed when the active process and the length of time for the force to reach its maximum value might be delayed. On the other hand, during the reactive process, plastic deformation of the concrete surface is already finished, and thus only the elastic rebound is observed. This is the reason why the active process time is longer than reactive process time as shown in Figure 1. The contact mechanical impedance of the active process is called as the active impedance denoted Z_A and that of the reactive process is the reactive impedance denoted Z_R in this paper. And defined as follows;

$$Z_A = \frac{F_{\max}}{2V_A} \quad V_A = \int_0^T a(t)dt \quad (11)$$

$$Z_R = \frac{F_{\max}}{2V_R} \quad V_R = \int_T^{\infty} a(t)dt \quad (12)$$

Here, T means the time for the force to reach its maximum value. The reason why the velocity used in the equations is doubled is because the integral time is divided into two parts of active and reactive process. During the reactive process, only the elastic deformation of the concrete is reflected, then the Z_R can be used as the index value of the elasticity of the concrete itself. And if the plastic deformation of the concrete surface is reflected on the active process, the Z_A is useable as the index value of the deterioration of the concrete surface.

Velocity dependency

The previous discussion was based on the vibration theory of mass spring system. However, the velocity dependency characteristics of the mass - elastic body system should be considered. The maximum force value depends on the initial velocity of the mass when the mass collides with the surface of the elastic body, well known as the Hertz's law. As the Hertz's law tells, the contact time of the mass colliding on the surface of the elastic body becomes 0.2 powers of the initial velocity of the mass. This fact leads us to the need to change the equations of the contact impedances.

To make this phenomenon clear, an experimental study was carried out using the standard test anvil as our impact echo method equipment, made from MC nylon with a size of 0.15m diameter and 0.5m length, by changing the initial velocity of the hammer

ranging 10 times in variation. Figure 2 shows the typical wave form of the hammer acceleration. The wave form is almost in line symmetry similar to the shape of hanging temple bell.

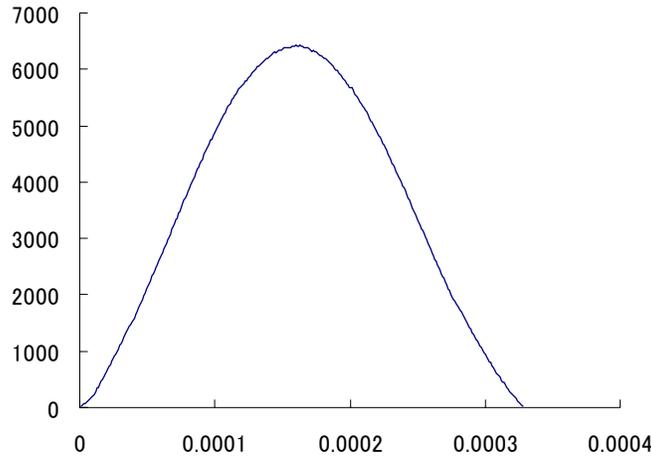


Figure 2: The typical wave form of the hammer acceleration for MC nylon

Figure 3 shows the relationship between the contact time and the initial velocity of the hammer. As shown in Figure 3, the contact time depends -0.22 powers of the initial velocity. Here it can be said that the value of 0.22 is an actualized value of the theoretical value of 0.2.

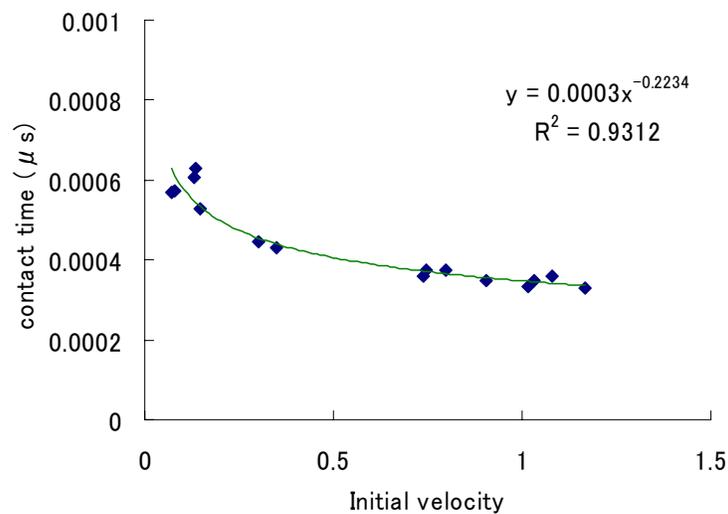


Figure 3: Relationship between Initial velocity and contact time

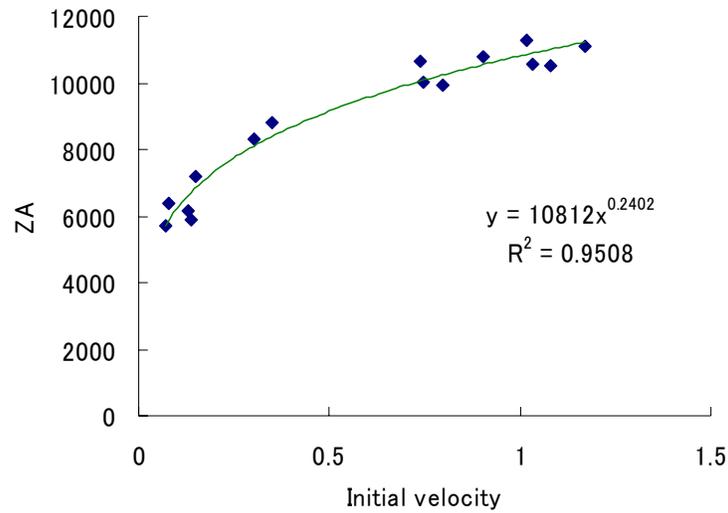


Figure 4: Relationship between Z_A and initial velocity

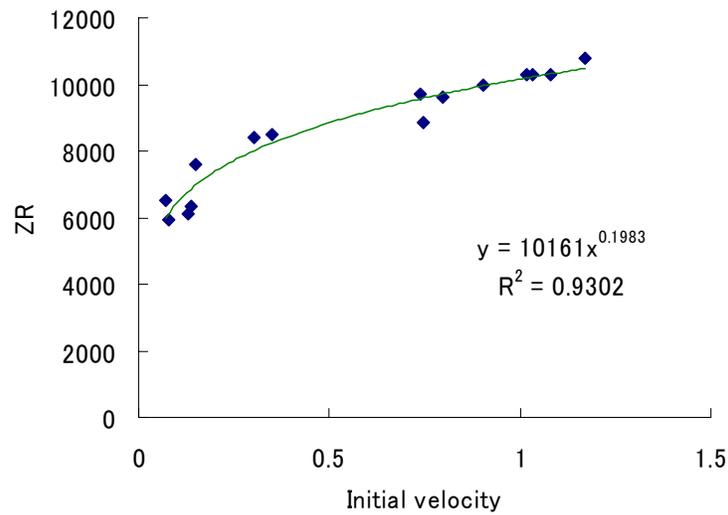


Figure 5: Relationship between Z_R and initial velocity

The relationships between the impedance index values and the initial velocity of the hammer are shown in Figure 4 and 5. As shown in Figure 4 and 5, the impedance values depend on the initial velocity of the hammer and the regression coefficients in power serial are almost 0.2, in accordance with Hertz's law.

To make clear the reason why the impedance values have initial velocity dependency,

the relation between the maximum force value and the initial velocity of the hammer is examined and shown in Figure 6. As shown, the regression coefficient in power serial is 1.22, and this value seems to be an actualized value of 1.2 deduced from Hertz's law.

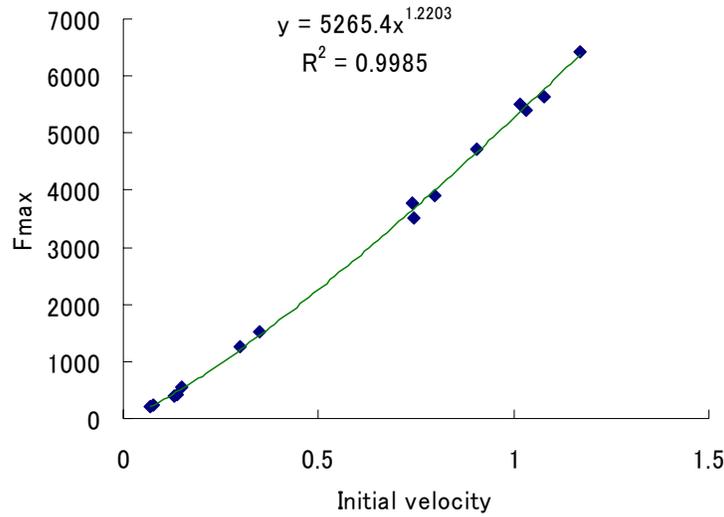


Figure 6: Relationship between F_{\max} and initial velocity

Revision of the impedance index

The impedance value is defined using Equation (13) as follow.

$$Z = \frac{F_{\max}}{v_{\max}} \quad (13)$$

However, the relationship between the maximum force F_{\max} and the initial velocity of the hammer is described as Equation (14).

$$F_{\max} = ZV_{\max}^{1.2} \quad (14)$$

Hence, the impedance value where the initial velocity corrected will be defined as Equation (15).

$$Z_R = \frac{F_{\max}}{v_{\max}^{1.2}} \left(\frac{v_{\max}}{2V_R} \right) = \frac{F_{\max}}{2V_R} \left(\frac{1}{v_{\max}^{0.2}} \right) \quad (15)$$

Using Equation (15), the influence of the initial velocity on the impedance values is removed. The results of revision of the impedance values are shown in Figure 7 and 8. As shown in Figure 7, it is clear that there is no relationship between the impedance index value and the initial velocity of the hammer.

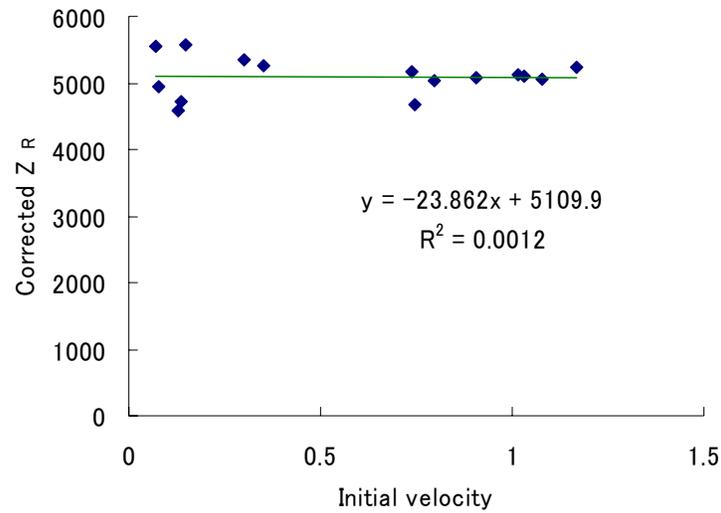


Figure 7: Relationship between initial velocity and Z_R

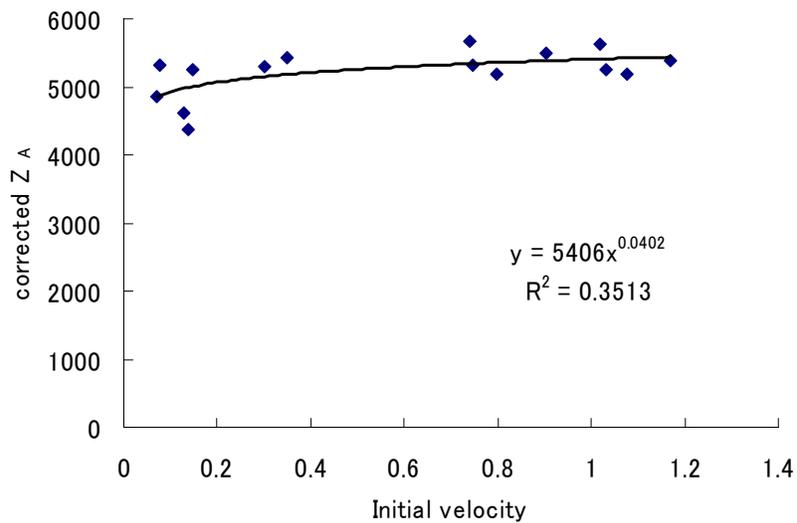


Figure 8: Relationship between initial velocity and Z_A

Wave form and signal processing

Reproducibility of wave forms of hammer blow

The wave forms of the concrete test hammer of fifty blows at 27N/mm² designed strength concrete test pieces are shown in Figure 9 in layers. The wave forms are

normalized by the maximum value of acceleration. It is clear from Figure 9 that the wave forms are similar to each other and the variation of the contact time is small. And wave forms are almost in line symmetry. Then it can be said that the hammer developed here works like an impulse hammer for the measuring equipment.

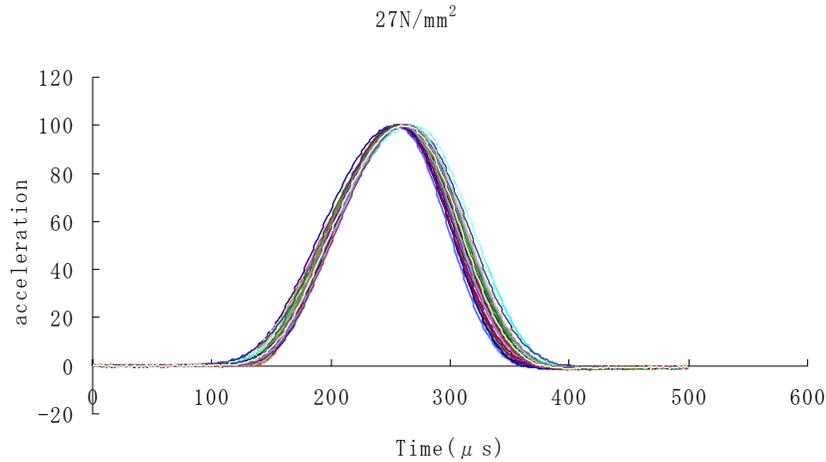


Figure 9: Wave forms when 27N/mm² concrete

Variance of index values

Table 1 shows the measured index values and the variances for each concrete test piece. The variance of Z_R is 5.4% to 6.7%, while the variance of Z_A is 6.5% to 7.5%.

Although the differences of the two variance values are small, the variance of the active impedance is a little bit larger than that of the reactive impedance.

Table 1: mean values and variance of index values

concrete	Z_R	Z_R deviation	Deviation rate	Z_A	Z_A deviation	Deviation rate
27	5935.128	399.0113	0.0672	5161.091	385.4923	0.0746
30	5746.558	311.5779	0.0542	4939.804	320.4417	0.0648
33	5906.674	363.5125	0.0615	5199.379	358.0209	0.0688
36	5973.656	343.1453	0.0574	5375.218	394.2205	0.0733

The variance of the index values seem to be due not only because of error in measurement but also the strength variance of the concrete surface. From this fact, it is necessary to introduce a measuring procedure to recover the strength variance of the concrete surface. If the variance of the mean value of the measured index values follows t distribution, the confidence interval of the mean values is as follows.

$$\mu = \hat{x} \pm 1.96 \frac{s}{\sqrt{N-1}} \quad (16)$$

Where, s is a measured variance, N is a number of data and \hat{x} is the mean value. Let the required accuracy of the measurement 2% and if the variance of the measurement is 7%, the number to be measuring times is more than 48. That is, to get an index value, fifty times of measurement and there mean value are required

Estimation of the concrete strength by the index value of Z_R

The experimental works for finding the relationship between the index value of Z_R and the compressive strength of the actual concrete were performed using concrete specimens of 0.5m in width and length, 0.2m in thickness. The range of the designed strength is 15N/mm² to 36N/mm² at 3N/mm² intervals. Three test pieces for each designed strength specimens were made with cores of 0.1m diameters and 0.2m lengths were sampled. After the hammering tests according to the procedure designed as previously explained, uni-axis compressive tests were performed.

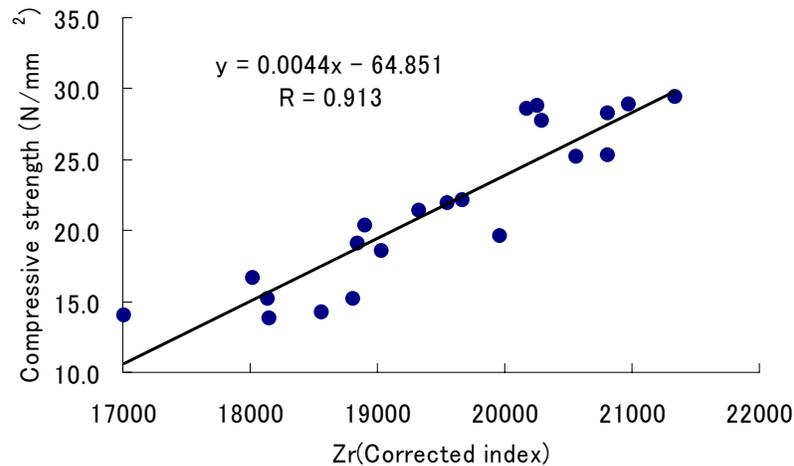


Figure 10: Relationship between compressive strength and Z_R

Figure 10 shows the relationship between corrected Z_R and the compressive strength of the concrete. As shown in Figure 10, a higher correlation between them is given. Therefore it is concluded that the corrected index value Z_R can be the index value of the compressive strength of the concrete.

Conclusions

As the results of theoretical and experimental approaches towards the development of estimating methods on the compressive strength of concrete by hammer blows instead of the Schmitt Test Hammer, the following conclusions are given.

- (1) Reactive contact impedance value is useful as the index value of the strength of the concrete.
- (2) Correction factors for velocity of the hammer and angle of hammer blows are not necessary if the initial velocity correction function is introduced in the contact impedance calculation.
- (3) The strength of the concrete can be estimated by the reactive impedance value Z_R in non-destructive manner.
- (4) Fifty blows and the mean value are necessary to give the precise value of the strength estimation.

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