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A METHOD FOR MEASURING WATER CEMENT RATIO IN FRESH CONCRETE BY USING VIBRATION

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SYNOPSIS

In the symposium (held in 1979 by Japan Concrete Institute) on Rapid estimation for concrete qualities, the authors have already presented a method for measuring water cement ratio in fresh concrete by using vibration and proposed a new principle of measurement and suggested that the method has practicability for utility.

From the above presentation on, we have studied on this measuring method continually, and consequently it has become possible to improve the accuracy for measurement and make sure the practical utility. Then we describe synthetically the results which have studied so far in this paper on the same title as before.

The method proposed in this study estimates water cement ratio rapidly with easy operation by merely inserting a kind of handy vibrating tester into fresh concrete. Experimental results show that this method permits water cement ratio of a given concrete to be measured at the accuracy within ±3% in a shorter period than 1 minute without extracting a sample from fresh concrete.

This paper describes a principle of measurement, apparatus for measuring and some results of investigation for practical application, and presents a measuring method for water cement ratio in fresh concrete on a final mechanism planning.

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1. INTRODUCTION

With interest focused on the method for measuring the water cement ratio of fresh concrete as a means to control the quality of concrete early, many testing methods have hitherto been proposed [1].

When the future of concrete technology is envisaged, however, a method capable of measuring the water cement ratio rapidly and easily at any place without taking sampling is needed in the field of quality control. And if such a method is possible, new development would be expected of application technology.

From such a viewpoint, we published a paper [2] entitled "A Method for measuring water cement ratio in fresh concrete by using vibrations", proposed a new principle and suggested a possibility of its being realized at a symposium concerning early estimation of concrete quality held previously (sponsored by Japan Concrete Institute).

We continued making studies and improvement on this method. As a result, the accuracy for measurement has been improved and prospects are bright enough to expect that this method can be put to practical use. So, we have decided to compile results of the study hitherto as same entitlement.

That is, this study concerns a method designed to detect water cement ratio instantly by merely inserting a vibrating, handy detector into fresh concrete. This study is oriented to a simple and easy technique in contrast to the method of heat of solution by hydrochloric acid previously proposed which may be defined as a precision technique based on analysis [3].

In this paper we mentioned the principle of measurement, measuring apparatus used in this experiment and results of a study on the practical experiments and proposed a measuring method based on a plan for final measuring apparatus.

2. PRINCIPLE OF MEASUREMENT

2.1 Basic Concept

Fresh concrete may be taken as one in which a large particle as gravel, middle particle as sand and fine particle as cement are each suspended like a spring and distributed evenly via mortar, cement paste and water as a dispersion medium. Therefore, concrete containing large particles, mortar containing middle particles and cement paste containing fine particles each will presumably have natural frequency against the forced vibration of single-degree-of freedom.

When a sensitive plate affixed at the tip of a vibration driver generating a single sinusoidal vibration frequency ratio is inserted into concrete and a forced vibration matching the natural frequency as cement paste avoiding the natural frequency as concrete is given, the degree of viscous damping due to a change in concentrations of cement paste as a suspension (i.e., water cement ratio) may be grasped as a difference in amplitude values from a resonance curve for the vibration frequency ratio and amplitude magnification factor in the resonance phenomenon of the vibration driver.

For the degree of the amplitude value being damped by the viscosity of cement paste from forced vibration to be grasped as the damping amount corresponding to the concentration of the paste, the direction of vibration and shape of a sensitive plate play an important role. If a laminar flow of cement paste is created lateral to the sensitive plates in concrete which is essentially a Binghm's fluid by having the sensitive plates vibrated in a period repeating access and disaffection each other on the same plane (shearing motion), it is possible to take cement paste approximately as a Newtonian fluid and thus a value corresponding to the coefficient of viscosity proportional to the velosity gradient as a shear flow curve may be obtained.

Accordingly, on the premise that the viscosity is proportional to the concentration in cement paste, it is theoretically possible to detect an amplitude responding only to the concentration of cement paste in concrete without being affected by gravel and sand.

2.2 Details of the Principle

The motion of the above-mentioned vibration driver can be taken as viscous damping forced vibration system of single degree of freedom and therefore it is expressed by a differential equation as follows :

$$F_o \sin \omega t = m\frac{d^2x}{dt^2} + C\frac{dx}{dt} + Kx \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$F_o \sin \omega t$: Vibromotive force (N)

$m\frac{d^2x}{dt^2}$: Inertia force (N)

$C\frac{dx}{dt}$: Viscous damping force (N)

Kx : Restitution force (N)

Where the mass (m) of moving element of the vibration driver and spring constant (K) have been fixed, the water cement ratio can be found by the equilibrium between the amplitude value (x) according to a change in the viscous damping constant (C) of the sample and vibromotive force ($F_o \sin \omega t$). Therefore, the vibration characteristics influenced by the structural element of the vibration driver and the viscous element of the sample may be expressed by the following theoretical equation derived from the relationship between the frequency ratio and amplitude magnification factor.

$$\frac{X}{X_o} = \frac{1}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left(2\frac{C}{C_c} \cdot \frac{\omega}{\omega_n}\right)^2}} \quad \ldots\ldots\ldots (2)$$

$\frac{X}{X_o}$: amplitude magnification factor — X : amplitude (m); X_o : strain when the force worked routinely (m)

$\frac{\omega}{\omega_n}$: frequency ratio — ω : drive frequency (rad/s); ω_n : natural frequency (rad/s)

$\frac{C}{C_c}$: damping ratio — C : viscous damping constant($N \cdot m^{-1} \cdot s$); C_c : critical damping constant ($N \cdot m^{-1} \cdot s$)

Then it follows that the resonance curve shows the maximum amplitude magnification factor at the frequency ratio of 1 in case of the damping ratio (C/C_c) being zero. Accordingly, if this characteristic is used, the water cement ratio can be grasped as the size of amplitude value (X) from the change in the viscous damping constant of cement paste.

The sensitive plates that make shearing motion in concrete are shaped to have less sectional area in the direction of vibration so that the hammering effect of sand be eliminated and a laminar flow of cement paste is created along the side of the plate to find a difference in the viscous resistance corresponding to the concentration of cement paste.

Assuming that the sensitive plate is a thin plate, the behavior of particles on its interface can be imagined as shown in Fig.1. When the sensitive plate is made to vibrate by a fixed vibromotive force (F) in concrete, there occurs a cement paste lamina on the interface of the sensitive plate, but the motion of cement particles in the direction of the interface is a little and the vibromotive force is subject to damping due to a difference in the space of cement particles (ΔC) and keeps a balance with the displacement amount (χ) in the direction of vibration.

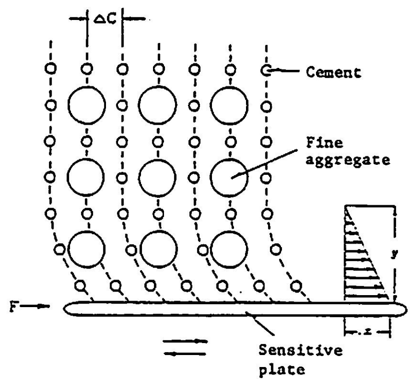

Fig.1 Behavior of particles on the interface of the sensitive plate by shearing motion

When the sensitive plate vibrates and makes a shearing motion, a liquefiable tendency is increased. So, if it is assumed that there is no sliding on the interface and that the propagational distance of vibration (y) illustrated in Fig.1 undergoes little change vis-a-viz a difference in the water cement ratio since the direction of vibration runs in parallel with the interface, the rheological behavior of the cement paste layer may approximately be applicable to the following equation based on the Newtonian flow.

$$\frac{F}{A} = \eta \frac{dv}{dy} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

F : vibromotive force (N)

A : area of the sensitive plate (m^2)

η : coefficient of viscosity of cement paste (Pa·s)

$\frac{dv}{dy}$: velocity gradient of the laminar flow (s^{-1})

That is, the displacement amount (χ) is proportional to the velocity (v) where the vibration frequency is constant. Therefore, a value equivalent to the coefficient of viscocity (η) corresponding to the water cement ratio can be obtained from the displacement amount (χ) by applying a fixed vibromotive force (F).

This motion, if changed into a model of a mechanical system, may be expressed as illustrated in Fig.2. That is, the motion may be substituted by the constant (k) as a mechanical spring element, the damping constant (c) as a dash pot and a system of forced vibration as an element to move the mass (m) by the displacement amount (x) via these elements. So, a difference in the damping constant correlated with the coefficient of viscosity may be found from the amplitude response value (x).

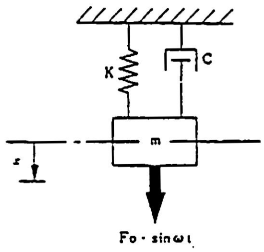

Fig.2 Motion expressed as a model of mechanical system

3. MEASURING APPARATUS

The measuring apparatus used in the experiment is composed of an oscillator, frequency counter, amplifier, ampere meter, vibration driver and meter as shown in Fig.3.

That is, the apparatus is of the mechanism by which the required frequency coming from the oscillator is checked up with the counter and the signal thereof is amplified with the amplifier to excite the electromagnetic vibration driving source in the vibration driver. It is so designed that the output can be set with an ampere meter.

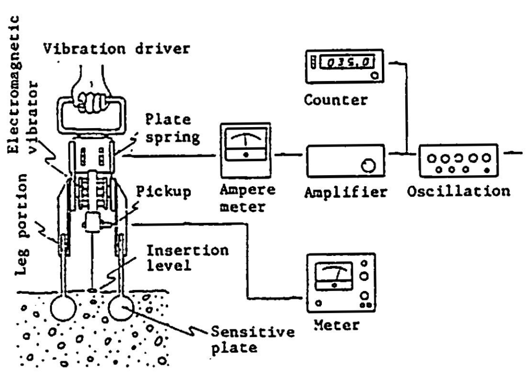

Fig.3 Measuring apparatus used in the experiment

A single simusoidal vibration is applied to two opposing legs affixed via a plate spring of the vibration driver and the sensitive plate at the tip of the leg is inserted into concrete. The displacement amount arising from the viscous damping of the amplitude of the sensitive plate commensurate with the concentration of cement paste is caught by a noncontacting type pickup affixed in the center portion of the vibration driver and measured with a meter.

The vibration driver is characteristically of the tuning fork type mechanism whereby a pair of legs equal for the mass of moving element below the plate spring are made to vibrate for a period repeating access and disaffection for eliminating the reaction to the handle so as to make hand-operated measurement possible. And the condition as the respnance mechanism is set with the constant of spring and mass of the moving element taken into consideration so that the required natural frequency can be obtained, inasmuch as the tuning fork type vibration mechanism exhibits a highly sensitive resonance phenomenon.

Since the depth of insertion at the leg affects results of the measurement, a simple device was provided in the space between the two legs so that a fixed level be maintained.

4. CONFIRMATION OF THE PRINCIPLE AND CONSIDERATION OF EXPERIMENTS

4.1 Relationship between the Shape of the Sensitive Plate and Resonance Figure

As for the shape of the sensitive plate, a spade type thin steel plate was used in a study reported earlier [2]. This plate was less affected by the consistency of concrete (corresponding to slump) and was able to detect the viscosity of cement paste (corresponding to the water cement ratio), but it had a drawback that grains of coarse aggregates come in contact with the interface of the vibrating sensitive plate to cause noise resulting in the measuring amplitude values being not always stable.

With an aim to improving the accuracy for the measuring apparatus, the shape of the sensitive plate was changed to a round convex lens type which is slightly thick in the center and has a sharp angle at the edge so that the sensitive plate can sort out grains of coarse aggregates effectively and give a stable amplitude value. By experimentally confirming its applicability, it was compared with the spade type sensative plate as to the resonance characteristics.

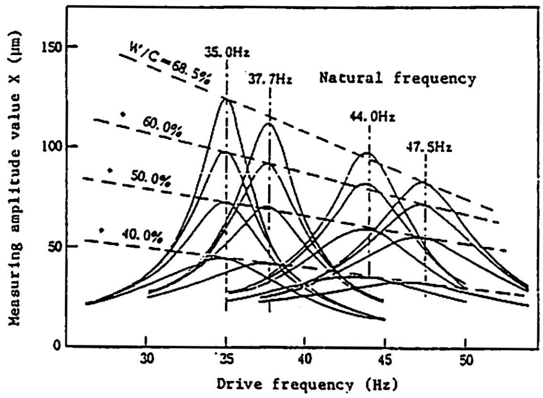

Fig.4 Relationship between the changes of natural frequency and measuring amplitude value

To begin with, the natural frequency in concrete was changed to 4 stages between 35 ~ 47.5 Hz by fixing the constant of the plate spring and changing mass of the legs in order to find the natural frequency for the vibration driver most suitable as conditions for measurement using the convex lens type sensitive plate and then the relations between a difference in the natural frequency corresponding to changes of drive frequency and measuring amplitude values were found. The results are as illustrated in Fig.4. In this experiment, the amplitude value Note 1) for concrete of various mix proportion (normal portland cement used; maximum size of coarse aggregate 25 mm; slump 8 cm; 4 varieties of water cement ratio between 40 ~ 68.5%) was measured with the vibromotive force kept constant (1.6A) and with the drive frequency changed.

According to results of the measurement, the lower natural frequencies tend to be more susceptible to damping corresponding to a difference in the water cement ratio, and the largest amplitude value is shown by the system of 35 Hz. Where the natural frequency is lowered below that level, the vibrating action becomes unstable in stiff consistency concrete. Accordingly, setting the natural frequency damped in concrete at 35 Hz appears to be appropriate as the conditions for measurement.

Here comparison was made of the spade type thin steel plate mentioned in the previous report and the convex lens type sensitive plate of an improved model as to the resonance characteristics by using the relationship between the frequency ratio (ω/ω_n) and amplitude magnification factor (X/X_o) with natural frequency of 35 Hz in the sense of confirming the theory mentioned earlier under 2.2. The results are as illustrated in Fig.5.

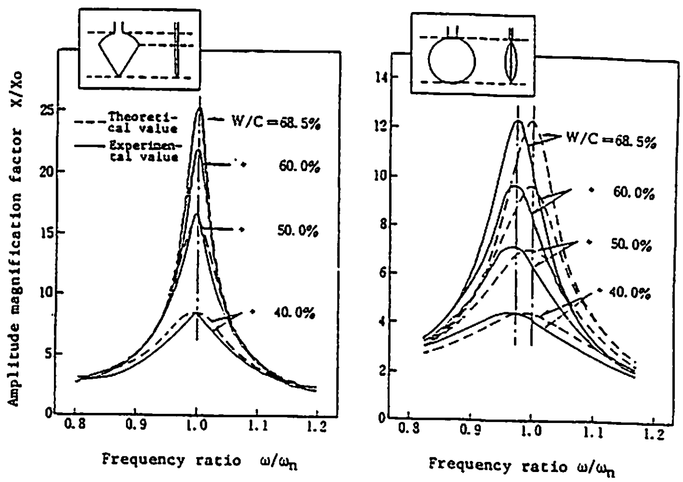

Fig.5 The shape of the sensitive plate and resonance figure

In the former (Fig.5, left), the natural frequency of the vibration driver remains almost the same either in the air or in concrete, and therefore the difference in the water cement ratio presents itself at the maximum as the difference in the amplitude magnification factor at the resonance point where frequency ratio is 1.0; the experimental value is consistent with the theoretical value, but as the water cement ratio becomes larger, the amplitude

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Note 1) : The amplitude value in the figure is 1/50 of the total amplitude at the tip of the sensitive plate.

magnification factor fails to increase proportionately and tends to present itself as a relatively small value. In the latter (Fig.5, right), the sensitive plate has the curvature on both sides and is slightly thick in the center, resulting in an increase of the resistance in concrete to the vibromotive direction; consequently, the natural frequency of the vibration driver becomes smaller by 0.9 Hz (0.025 in terms of the frequency ratio) in concrete than in the air Note 2). In this case, therefore, the resonance phenomenon can be created by adjusting the drive frequency to the natural frequency damped in concrete.

The latter has the advantage in that it grasps the greater difference in the viscous resistance stemming from difference in the water cement ratio than the former due to the action of laminar flow of cement paste along the surface of curvature, thereby improving the accuracy for measurement. Furthermore, the relationship between the water cement ratio and measuring amplitude value can be linealized by selecting the curvature, making the direct display of the amplitude value easier. On account of these advantages in the measurement, the latter is more suitable for detection of the water cement ratio in concrete.

Then, the relationship between the water cement ratio and measuring amplitude value was found where the drive frequency was changed by using the latter sensitive plate. The results are as illustrated in Fig.6. This is an experimental example where the drive frequency was changed to the higher and lower side than the natural frequency of 35 Hz at which the resonance point can be obtained in concrete.

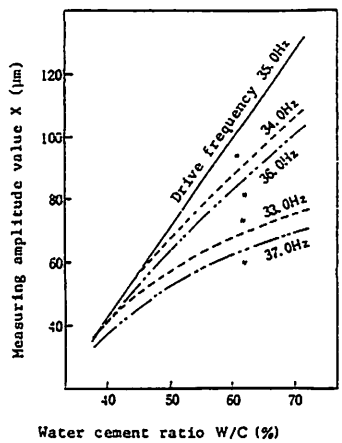

Fig.6 Relationship between the water cement ratio and measuring amplitude value with the drive frequency changed

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Note 2) : This phenomenon may be interpreted to mean that the resistance in the vibromotive direction is increased with an increase in the sectional area of the sensitive plate, resulting in changes of the viscous damping frequency meaning consistency as well which in turn leads to slight displacement of the resonance point.

From this figure, it can be seen that changes in the measuring amplitude value in relation to the changes in the water cement ratio take a linear relationship at the resonance point Note 3) and that a difference in the water cement ratio can be grasped the most as a difference in the measuring amplitude value.

Where the drive frequency is on the side lower than the resonance point, the inertia force and damping action of the vibration driver are small and thus the vibromotive force becomes equal to the restitution force of spring. Where the drive frequency is on the side higher than the resonance point, the most of the vibromotive force is spent to overcome the inertia force but the vibromotive force becomes linear at the resonance point at which the inertia force is large and reasonably balanced with the spring.

On the basis of results of these experiments, it was decided to use a convex lens type sensitive plate having the curvature on both sides (55 mm in diameter, 11 mm in thickness) as the sensitive plate, a system of vibration enabling the natural frequency in the air to be 35.9 Hz as the vibration driver and 35 Hz matching the natural frequency damped in concrete as the drive frequency from an oscillator in setting conditions for the method of measurement.

4.2 Relationship between Vibromotive Force and Measuring Amplitude Value

Basic conditions for measurement will be met, if selection of the vibromotive force is added to the above-mentioned setting of conditions.

So, how the measuring amplitude value differs between various types of concretes with different water cement ratio was examined by making the drive frequency (35 Hz) constant and changing the amperage corresponding to the vibromotive force of the measuring apparatus within the range of 1.2 ~ 2.0A. As for concrete used in the experiment, normal portland cement was used and the water cement ratio was changed to 45, 50, 55, 60 and 65% on AE concrete with the maximum size of coarse aggregate being 25 mm and with the slump set at 8 cm for stiff consistency and 21 cm for soft consistency.

Results of the experiments with the water cement ratio of 45% and 60% for example are as illustrated in Fig.7. According to the figure, a difference due to a difference in slump presents itself for each water cement ratio, but the relationship between the vibromotive force and the measuring amplitude value becomes linear so long as it is within the limit of elasticity (equivalent to amplitude value of 200 μm).

Given that the amplitude value is the function of vibration velocity and that the motion of the sensitive plate in concrete produces laminar flow of cement paste without slide on its interface, it is considered that the relationship between the vibromotive force and measuring amplitude value may be replaced by the relationship between the velocity gradient (dv/dy) of the system of dispersion and the sheering stress (τ).

Note 3) : Theoretically it shows a change like an exponential function in relation to changes in absolute viscosity, but in concrete it will exhibit a linear change due partly to the morphological effect of the sensitive plate.

This means that the measuring amplitude catches the variation of viscosity close to the Newtonian fluid as shown by the equation (3) under 2.2 even in fresh concrete primaryly showing a plastic Bingham's flow, inasmuch as a decline in the restraining force between particles due to the vibrating effect of the sensitive plate accelerates the liquefiable tendency and reduces the resistance to the stress (vibromotive force) to bring about a yield value-free state.

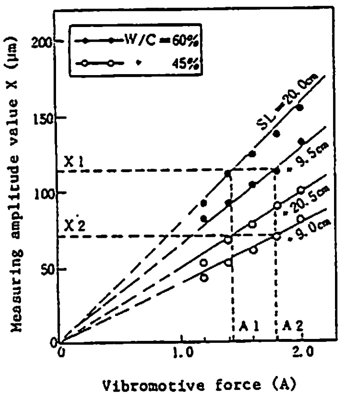

Fig.7 Relationship between the vibromotive force and measuring amplitude value

As described above, the measuring amplitude value can catch the difference in the water cement ratio as one corresponding to the difference of gradient shown in Fig.7 without producing the yield value. However, it will encompass the influence of a difference in slump as well, if a certain fixed vibromotive force is set. Then, measures to change the vibromotive force in proportion to the consistency (meaning slump) were taken to eliminate the influence due to a difference in slump on the measurement of the water cement ratio.

4.3 Setting of Vibromotive Force Commensurate with a Difference in Slump

With the slump value regarded as already known, the vibromotive force proportionate to it was set and a way to remove the influence of the vibromotive force on the measurement was studied from a viewpoint of simplifying the structure of the measuring apparatus and making the measuring procedure as easy as possible for enhancement of the accuracy in the practical use.

Using the experimental results under 4.2 as a guide, the degree of changes in the vibromotive force required to get the same measuring amplitude value was expressed as a setting drive current (I) for concrete of different slump with the same water cement ratio. The results are as illustrated in Fig.8. With the measuring amplitude value X_1, X_2 in Fig.7, a difference in slump can proportionately be expressed as a difference in the vibromotive force since the vibromotive force becomes almost equal to A_1, A_2, if the slump is the same even in concretes different in the water cement ratio.

According to Fig.8, the relationship between the slump and setting drive current tends to be almost same for concretes different in the water cement ratio. This gives a representative equation as follows.

$$I = -0.028 \cdot SL + 2.04 \quad \cdots\cdots\cdots (4)$$

I : Setting drive current for the measuring apparatus (A)
SL : Slump of concrete (cm)

The influence of slump is a little, so that not necessarily strictly measured values but values roughly estimated with the eyes may use as the value of slump to be used for calibration.

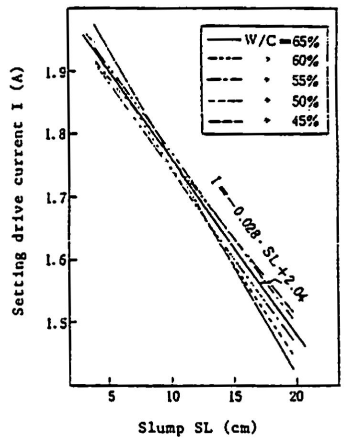

Fig.8 Relationship between slump and setting drive current

If the roughly estimated value of slump is found, the drive current for the measuring apparatus can be set by the equation (4) and the influence of consistency on the measuring amplitude value can be removed in measurement. Accordingly, the experiments thereafter were performed after calibration for measurement had been done by the method mentioned above.

In the study mentioned in the previous report [2], the influence of the amounts of sand on concrete with a wide range of mix proportion was seen, slight as it was, where a spade type thin steel plate was used as the sensitive plate, and an ideal level for the basic principle (concept) of measurement mentioned under 2.1 was not always reached. However, remodelling of the sensitive plate into a convex lens type carried out thereafter in parallel with calibration by the method mentioned above resulted in elimination of the influence of the amounts of sand, enabling highly accurate measurement for concrete with a wide range of mix proportion.

4.4 Relationship between the Water Cement Ratio and Measuring Amplitude Value

On the basis of the conditions set under 4.1 with the drive current corresponding to the slump value set as mentioned under 4.2, the applicability of this measuring method was examined on concrete with a wide range of mix proportion.

In this experiment, the relationship between the water cement ratio and the measuring amplitude value was examined on plain concrete using normal portland cement with the maximum size of coarse aggregate set at 25 mm and with the water cement ratio varied over the range of 36.0 ~ 68.5% and the slump changed to 3 to 21 cm and concrete using AE agent and water-reducing agent (including both air entraining type and non-air entraining type).

The results are as shown in Fig.9. The measuring amplitude value is found to converge into a linear relationship (γ = 0.99) against change in the water cement ratio even with various concretes different in the mix proportion. This confirms that the variation of concentration of cement particles against water as the colloidal phase is almost proportional to the viscous resistance as presumed under 2.1 and that the measuring amplitude value is subject to damping corresponding thereto. At the same time it is found that a slight influence of the variation of plastic consistency corresponding to the slump of concrete (or flow of mortar) arising from the variation of aggregate mix preparation on the measuring amplitude value can be eliminated in the practical use by changing the drive current value.

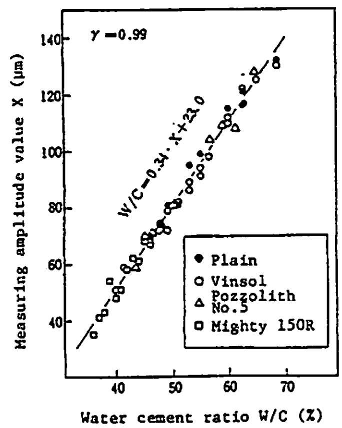

Fig.9 Relationship between the water cement ratio and measuring amplitude value

On the basis of these experimental results, the relationship between the water cement ratio and measuring amplitude value of concrete having plastic consistency within the workable range was found as an equation of regression line shown below, and with this as a calibration line for measurement, the water cement ratio was detected.

$$W/C = 0.34 \cdot X + 23.0 \qquad (5)$$

W/C : water cement ratio of concrete(%)
X : Measuring amplitude value (μm)

5. ACCURACY FOR MEASUREMENT

5.1 Theoritical Value and Measured Value

The accuracy for measurement by the method of measurement in this experiment was examined by comparing the theoretical value with the measured value using a wide variety of concretes different in the kinds of material used (cement, fine and coarse aggregates, admixture and conditions for mixing) as the subject on the basis of the conditions studied and decided on under 4.

Table 1 Items of various concretes used to study accuracy for measurement (material used and conditions for mix proportion)

Cement	Coarse aggregate	Fine aggregate	Admixture	Water cement ratio (%)	Slump (cm)	Air content (%)
Normal portland cement (5 brands incl.) High early strength portland cement Blast-furnace slag cement (B type) Fly-ash cement (B type)	River gravel Crushed stone*	River sand Crushed sand Pit sand Hill sand	Plain Vinsol Pozzolith No.5 Mighty 150 R	Range of 36 ~ 70	Range of 5 ~ 22	Range of 1.5 ~ 6.5

* In the case of crushed stone, the maximum size of coarse aggregate is 20 mm.

The items of materials used and mix proportion conditions for various concretes used as the subject is as presented in Table 1. Using these concretes, comparison was made of the two. The results may be expressed as the relationship shown in Fig.10.

As can be seen from the figure, the theoretical value for the water cement ratio is almost in agreement with the measured value and this method of measurement may be applied at a considerably high accuracy from a viewpoint of practical use under a wide range of mix proportion conditions unless cases are exceptional even where different materials are used.

That is, it can safely be said that the difference in the kinds of cement inclusive of a difference in brand, and the kinds of aggregates and admixture exerts little influence on the accuracy for measurement so far as the subjects used here are concerned.

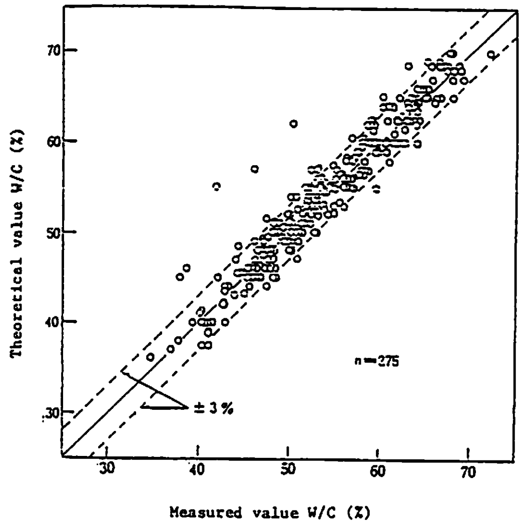

Fig.10 Relationship between the theoretical value and the measured value for the water cement ratio

When these are examined in detail, the measured value is sometimes extremely high over the theoretical value; this is a special case of crushed stone containing a very fine part of sand in large amounts, and the influence of vagueness of the criterion for judging of surface-dry-condition may be included in the results. Accordingly, the amount of the very fine part of sand, if not exceeding the level of practical use, will have little influence on the accuracy for measurement, nor will the shape of crushed sand exert any direct influence on the accuracy for measurement.

Where an water-reducing agent (Mighty 150R, Pozzolith No.5L) has been used as admixture, the measured value tends to become larger, very slight as it is, than the theoretical value. Because of the fluidity being increased by the water-reducing effect, this concrete may be slightly different from other concretes as to the implication of evaluation on the consistency by the measurement of slump. Presumably, changes in the vibromotive force is unable to follow the increase in fluidity. Since this poses no major problem when considering the accuracy in the practical use, this method of measurement may be applied to plain concrete and AE concrete using AE agent regarding these two concretes as the same. As to AE concrete, it was found to have no influence on the accuracy for measurement even where there is a considerable change in the air content.

To summarize the results above, this method of measurement is capable of measuring the water cement ratio at accuracy of ±3% in the practical use on most of the concretes in general use, with improvement made over the accuracy for measurement reported in the previous study.

5.2 Consideration on the Factor of Errors in Application

In using this method of measurement, attention should be paid to the possibility of matters as enumerated below becoming factors of errors in terms of principle.

1) Amount of admixture : Fly-ash, pozzolan and blast-furnace slag powder are measured as the amount of cement.

2) Lapse of time after mixing : Increased viscosity due to soluble component from cement results in a small water cement ratio. So, care should be exercised so that concrete be used before the consistency changes sharply.

3) Special case of increasing viscosity : Where the use of superplasticizer has caused the so-called "thick malt syrup phenomenon" making it difficult to measure the slump, the viscosity of cement paste is markedly different from that in other ordinary concretes and thus, this method is not applicable to such a case [Note 4)].

6. TESTING METHOD

6.1 Final Measuring Apparatus

According to a plan of final measuring apparatus based on results of the studies hitherto conducted, the apparatus is of the process as illustrated in Fig.11, consisting of two divisions, namely, the vibration driver and one box containing all elements from oscillation to the detecting system, so that it is handly to carry. Additionally, the box will have a dial for calibration of slump mentioned under 4.3 and a built-in direct reading meter for the water cement ratio.

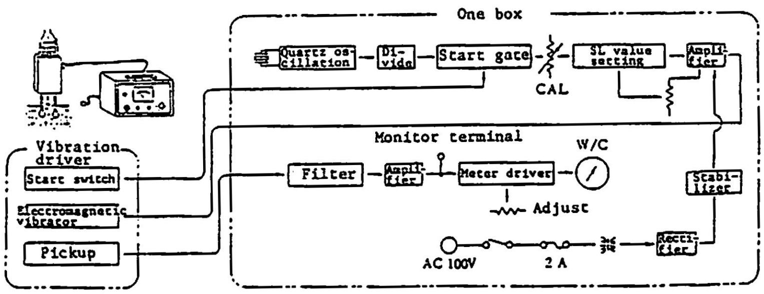

Fig.11 Final measuring apparatus and process

Note 4) : As for fluid concrete with super-plasticizer added later, it may be controlled by measuring the water cement ratio on base concrete.

6.2 Measuring Procedure

Where the measuring apparatus mentioned under 6.1 is used, the water cement ratio is measured by the following procedure.

1) Turn the power switch of the unit ON, adjust the dial for calibration so that a desired amplitude value be obtained and set the needle to the scale of a meter for adjusting the measuring apparatus.

2) Set the slump-setting dial to slump Note) of concrete to be measured.
Note) Rough values measured by the eye may be used for slump.

3) Bring the vibration driver into motion by pushing the switch for starting, insert the leg portion of vibration driver into concrete while applying a motion Note) to get it familialized with concrete and keep it at a prescribed level.
Note) Move the wrist of the hand holding the vibration driver in the vibromotive direction several times and get the driver familialized with concrete in the same way as with spading of concrete.

4) Read the maximum value where the indicator of the water cement ratio meter has become stable.

7. CONCLUSION

The method for detecting the water cement ratio of fresh concrete making use of vibration in this study is capable of measuring the water cement ratio at the accuracy of ±3% in only a minute or so without the trouble of collecting a sample by a very simple procedure consisting merely of inserting sensitive plates of the vibration driver and reading the meter.

This study is based on the concept of picking up changes in only the viscosity from the resonance phenomenon out of the viscoelasticity of concrete containing two elements, i.e., the viscosity relating to the concentration of cement paste that controls the strength and necessary consistency for practice, thereby determining the water cement ratio.

This method is based on a combination thinking of mechanics, rheology and concrete engineering and has reached a stage of practical use after going through a developmental process of improvements made over the study published previously, increased accuracy for measurement and a study of making the apparatus compact.

To mention the structural characteristics making the principle of measurement applicable, the vibration driver is of the mechanism of tuning fork so that the reaction associated with insertion into concrete can be eliminated, and the direct reading system is adopted in detecting the water cement ratio with consideration given to various conditions for the sensitive plate and vibration. Various findings obtained in this study will go a long way toward the progress of measuring technique and quality control of concrete.

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