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BORANG PENYERAHAN TESIS

Judul: ULTRASONIC PULSE VELOCITY (UPV) IN CONCRETE UNDER COMPRESSION: A STUDY ON THE EFFECT OF ORIENTATION OF MEASUREMENT

SESI PENGAJIAN: 2001 - 2004

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(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat tetap: 19, KANOWIT GARDEN, 96700 KANOWIT, SIBU, SARAWAK.

ASSOC. PROF. DR. NG CHEE KHOON
(Nama Penyelia)

Tarikh: 22 March 2004

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Title: **ULTRASONIC PULSE VELOCITY (UPV) IN CONCRETE UNDER COMPRESSION: A STUDY ON THE EFFECT OF ORIENTATION OF MEASUREMENT**

Name of the author: **CHIA FUK JING**

Matrix number: **6384**

was read and certified by:

1/4/2004

Assoc. Prof. Dr. Ng Chee Khoon

Supervisor

Date

ULTRASONIC PULSE VELOCITY (UPV) IN CONCRETE UNDER COMPRESSION: A STUDY ON THE EFFECT OF ORIENTATION OF MEASUREMENT

CHIA FUK JING

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To my beloved parents

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ABSTRACT

This research project describes the preliminary findings on the effect of the orientation of measurements; by determining the ultrasonic pulse velocity in the concrete under compressive stresses. The laboratory investigation was carried out to analyze the changes of transit time corresponding to the effect of concrete ages, grades and the size ratio of prisms. Tests were performed to compare the accuracy between Direct Method, semi direct and In-direct Method of Ultrasonic Pulse Velocity Method (UPV) in detecting the location of defects during the early age concrete. The tests results for the prisms at the age of 7 days and 28 days were found to have similar trends. Between direct, semi direct and in-direct method, the direct method gave more reliable results as compared to the semi and in-direct measurements. It was found that the transit time dropped at the early stage of stress-strength ratio, and increased beyond 2 or 3% of stress-strength ratio. Since the transmission path length and direction are not well defined in the semi and in-direct method, the results are less satisfactory and not reliable. For the decrease of compressive stress-strength ratio, the results are less reliable, and the chart showed random propagation as a result of the opening voids.

ABSTRAK

Projek tahun ini menghuraikan kajian tentang keberkesanan teknik pengorientasi, dengan menggunakan kaedah Ultrasonic Pulse velocity dalam memampatkan tekanan ke atas konkrit. Penyelidikan makmal dijalankan untuk menunjukkan perbezaan pemindahan masa berhubungkait dengan kesan ketahanan konkrit, gred, and saiz perizam. Kajian telah dijalankan untuk membuat perbandingan ketepatannya dengan menggunakan sukatan secara langsung, separuh langsung dan secara tidak langsung bagi meransangkan kecelaan pada tahap awal ketahanan konkrit. Keputusan kajian ini menunjukkan ketahanan konkrit pada hari ketujuh dan kedua puluh lapan hari mempunyai kecondongan yang agak sama. Dengan menggunakan ketiga-tiga sukatan tersebut, teknik secara langsung menunjukkan keputusan yang lebih nyata dan jelas jika dibandingkan dengan kedua-dua teknik yang lain. Cara secara langsung telah membuktikan kejituannya dalam merangsang kecelaan, dimana, kejatuhan masa berlaku pada permulaan kemampatan tekanan sehinggalah tekanan sampai ke-2 atau 3 peratus. Oleh sebab arah dan kejauhan pemindahan gelombang tidak dapat dikenalpasti dalam konkrit, jadi keputusannya adalah tidak memuaskan. Bagi penurunan pemampatan tekanan pula, keputusan yang didapati juga tidak memuaskan, ini mungkin adalah akibat daripada kebukaan cela dalam konkrit yang tidak dapat ditutupkan semula.

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f'c	-	Compressive strength of concrete
E	-	The dynamic modulus of elasticity;
v_L	-	the velocity of a pure longitudinal wave;
d	-	Density; and
μ	-	Poisson's ratio.
α	-	Empirical parameter

CHAPTER 1

INTRODUCTION

1.1 General

The ultrasonic pulse velocity (UPV) method uses transmission of the traveling waves through the materials or concrete to yield the information or the conditions of concrete. In this study, the measurements of ultrasonic pulse velocity are determined by using direct, semi-direct and indirect method. The effect of orientation in measurement with respect to the ultrasonic pulse velocity of concrete is studied.

Ultrasonic pulse velocity test are measured for concrete prism under different level of stresses, revealing the effect of stresses on ultrasonic pulse velocity or transit time using direct, semi-direct and indirect method.

Essentially, two major purposes are identified for the experimental works. Firstly, the effect of the compressive stresses in concrete versus ultrasonic pulse transit time, with gradual increment of every 0.7% stress of the compressive strength is studied. Secondly, the comparison of the orientation in measurement by using ultrasonic pulse velocity device is also studied. Therefore, the results and graphs for the compressive strength and different types of measurements versus pulse traveling time are determined and plotted.

1.2 Aims and Objective

The main objective of this project is to study the effect of compressive stresses in concrete on the ultrasonic pulse transit time using direct, semi-direct and indirect methods of measurements.

The technique is applicable where destructive testing is not desirable and can be applied to concrete, ceramics, stone and timber. The main strength of the method is in finding general changes in condition such as area of weak concrete in the structure. The applications may include: -

(a) Determine the relationship of UPV and concrete strength.

(b) Study the effect of compressive stress on UPV, and

(c) Study the orientation of measurement.

CHAPTER 2

LITERATURE REVIEW

2.1 Ultrasonic Pulse Velocity (UPV)

Nondestructive evaluation using ultrasonic testing methods has been used on concrete for more than half a century. Powers (1938) and Obert (1939) were the first to develop and extensively use the resonance frequency method, while Cheesman and Lislie (1949) developed instruments for measuring the ultrasonic pulse velocity. Besides, Houssam (2003) stated that an ultrasonic pulse velocity instrument was designed by the National Aeronautics and Space Administration (NASA) for gas bubble identification and recalibrated for identification of voids and cracks in concrete beams or slabs. The concrete samples casted were used to validate the instrument for crack, flaws or voids identification.

The UPV uses ultrasonic waves where the wave velocity depends on the inertia and elastic properties of the transmission material. It combines an easy test procedure and accuracy, at a relatively low cost (Jones and Gatfield, 1960). Ultrasonic pulse velocity testing is rapid and convenient method of measuring the time taken for an ultrasonic pulse to travel through a known length of concrete.

This technique can detect areas of internal cracking, internal delamination, and relative strength parameters (Kaplan, 1960, Malhotra and Carino, 1991). The UPV technique is often employed to establish the uniformity and relative qualities of concrete, such as permeability and porosity.

The variations in concrete such as voids, flaws, honeycombing and so on will cause an increase in the transit time. Moreover, the density of the concrete may also influence the transit time of UPV as well. The concrete became less dense due to the increase in water cement ratio and poor compaction that may directly decrease the strength of concrete. Consequently, the pulse velocity will reduce when transiting through the prisms tested.

2.2 Compressive Strength of Concrete

Compressive strength is the common basis of design for most structures, where it required common method of routine quality testing. Presently, Leming (1990) and CEB-FIP (1994) has been reported that the compressive strength for 28-days is up to 84 MPa (12 ksi). By practically achievement, compressive strengths of concrete have increased steadily over a period or years. Leming (1990) had observed that the mechanical properties varied significantly depending on the source and type of the coarse aggregates used for mixing.

Fracture mechanics in the type size effect on the compressive strength of concrete specimen was studied, with the diameter, and the height over cross-section area ratio considered as the main parameters. Gonnerman (1925) showed that the ratio of the compressive failure stress to the compressive strength decreases as the specimen size increases in a test program. This phenomenon of reduction in strength dependent on specimen size is called "The Reduction Phenomenon".

According to High-Performance Concretes: A State-of-Art Report (1989-1994) by Carrasquillo et al. (1988), Tanigawa et al. (1990), Baalbaki et al. (1992) and Fu et al. (1991), the testing variables that have a considerable influence on the measured of compressive strength are: the mold type, specimen size, end conditions, and rate of loading.

2.3 Relationship of Compressive Strength With Ultrasonic Pulse Velocity

According to Simeonov (1965), he had found a similar correlation between compressive strength and velocity of waves. He reported that the velocity of sound or waves in concrete cured under controlled laboratory conditions increased steadily with time and responded well to the increase of strength measured mechanically.

However, as Pawlowski and Raniszewski (1965) warned, evaluation of the quality of concrete based upon ultrasonic pulse velocity must be related to the type of concrete used. As mentioned, the velocity mainly depends on compositions, age, porosity, loadings, method of reinforcing, and micro-cracks.

Apart from that, Mikhailov and Radin (1956), and Bungey (1980) provided the values as shown in Table 2.1 as the standard for the quality of concrete, especially the strength tested in concrete.

Table 2.1 Ultrasonic velocity ratings for concrete structures (Bungey, 1980)

Velocity (m/s)	Structure condition
4575 and above	Excellent
3660 to 4575	Good
3050 to 3660	Questionable
2135 to 3050	Poor
Below 2135	Very poor

A fairly good correlation can be obtained between the cube compressive strength and pulse velocity (Malhotra, 1980, Popovics, 1998). These relations enable the strength of structural concrete to be predicted within ±20 percent, provided the types of aggregate and mix proportions are constant.

From the American Society for Nondestructive Testing, the analyses of four interfering factors are appropriate with the anticipation that improves future research on the ultrasonic determination of concrete strength. The factors are:

i. The complexity of the internal structure of concrete.

ii. The insensitivity of the longitudinal pulse velocity to small but important changes in the internal structure of concrete.

iii. The lack of a theoretically justifiable relationship between strength and wave velocity.

iv. The factors that affect the strength may affect the pulse velocity differently, especially since the strength of a typical structural concrete is controlled by the strength of the cement paste, whereas the pulse velocity is controlled by the properties of the aggregate.

For instance, from the simplifying assumptions that the material is linearly elastic, isotropic and homogeneous (no porosity), the following theoretically formula can be derived for the calculation of the dynamic modulus of elasticity:

$$E = \upsilon_L^2 d \frac{(1+\mu)(1-2\mu)}{1-\mu} \tag{2.1}$$

where E = the dynamic modulus of elasticity; v_L = the velocity of a pure longitudinal wave; d = density; and μ = Poisson's ratio.

Equation (2.1) can also be used to determine the velocity of transmission of longitudinal pulses through solid of any shape of size. It provided the smallest lateral dimension perpendicular to the path of travel and not less than the wavelength of the pulse vibrations. Based on the American Society for Testing and Materials (ASTM) Standards, the magnitude of the pulse velocity passed through the concrete materials is mainly affected by the factors such as the aggregate size grading and content, water to cement ratio, degree of compaction, curing conditions and age of concrete, moisture condition, temperature and acoustical contact within the concrete.

Actually, there is no theoretical relationship between strength f and pulse velocity v exists even for homogeneous, linearly elastic materials. It is generally true that higher concrete strengths are usually associated with higher ultrasonic pulse velocity. However, efforts to convert this rule of thumb into a reliable numerical relationship have been unsuccessful. An example by Pessiki and Carino (1987) is the combination of formula with the empirical formula recommended by the American Concrete Institute (1992):

$$E = \alpha\sqrt{f} \qquad (2.2)$$

where f = compressive strength of the concrete; and α = empirical parameter

Actually, there is no simple correlation between the cube strength and pulse velocity as the correlation is affected by many factors. If the pulse velocity results are to be expressed as equivalent cube strength, it is referable to calibrate the particular concrete used by making a series of test specimens with same materials and mix proportion.

2.4 Effect of the Orientation of Measurements

The arrangement or placement the transducers on the surface of the prisms may yield different results. Basically, there are three types of waves generated when ultrasonic pulse travels through the concrete tested. The waves are longitudinal (compression), shear and surface wave, whereas the longitudinal wave is the fastest and mainly use for the measurements.

Generally, the three types of orientation in measurements are direct, semi-direct and indirect measurement. The direct transmission arrangement is the most satisfactory one since the longitudinal pulses leaving the transmitter are propagated mainly in the normal direction to the transducer face.

In the semi-direct and indirect arrangement of measurement, it preformed least satisfactory because apart from its relative insensitivity. It presents pulse velocities, which are usually influenced by the concrete layer near the surface, and this layer may not be represented in deeper layers. The strength of the pulse detected in this case is only about 1 or 2% detected of the path length.

2.5 Effect of Compressive Stresses in Concrete on Ultrasonic Pulse Velocity.

Ngu (2003) had attempted the tests to investigate the effect of compressive stresses on ultrasonic pulse velocity by using concrete grades varying from 20 MPa to 40 MPa. From his findings, the UPV values were initially increased by about 1 to 2% when the stress-strength ratio is increased from 5 to 10%. Under this condition, the volume of the voids in the concrete cubes was actually reduced and resulting in denser concrete, which it allows waves to travel faster.

As just the state of stress increased from 10 to 25% of stress-strength ratio, the UPV values decreased about 1 to 2% as well. However, the decrease in UPV values was not significant.

When the state of stress was increased to more than 25% of compressive stress-strength ratio, the internal elements became unstable. The pulse velocity dropped rapidly due to the opening of voids, micro cracks, and other flaws that occurred within the concrete. The human eyes usually cannot detect these internal defects and it causes an increment of transmission time through the concrete.

The effect on the cubes for 7 days and 28 days gave almost similarity results. However, the cubes at the age of 28 days are proved to be more stable than the cubes at 7 days.

CHAPTER 3

METHODOLOGY

3.1 Ultrasonic Pulse Velocity Testing (UPV)

The ultrasonic pulse velocity method consists of measuring the time travel of an ultrasonic wave passing through the concrete prism. The time of travel between the initial onset and reception of the pulse are measured electronically. The relationship between pulse velocity and strength are affected by the number of variables, such as the age of concrete, moisture condition, aggregate and cement ratio, type of aggregate and so on.

Generally, the velocity of ultrasonic pulse traveling in a solid material (concrete) depends on the density and elastic properties of that material. The quality of the concrete sometimes is related to their elastic stiffness. Thus, the measurement of ultrasonic pulse velocity can often be used to indicate their quality as well as to determine its elastic properties.

The ultrasonic waves can only exist within the mass media and unlikely with other forms of electromagnetic transmission, which can travel through vacuum. Thus, during the testing of prisms, the transducers are intimated to the contact surface to allow the transmission of waves.

Actually, the pulse velocity is not sensitive to the temperature in the range of 5 to 30^0. The pulse velocity is decreased at higher temperatures, while it is increased at temperatures