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EFFECT OF COMPRESSIVE STRESS IN CONCRETE ON ULTRASONIC PULSE VELOCITY WITH DIFFERENT ASPECT RATIOS

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ABSTRACT

This study was conducted to explore the effect of compressive stress in concrete on the measured ultrasonic pulse velocity (UPV). Ultrasonic pulse velocities were measured by equipment called PUNDIT and test frame was used to test on the prisms concrete at the stress condition. The UPV values were measured at every load steps at 5% increment of the average compressive strength. This study was carried out by the concrete strength ranging from 25 to 30 N/mm^2. The prisms with size of 100mm x 100mm x 200mm, 100mm x 100mm x 300mm and 100mm x 100mm x 400mm were used and tests were carried out at the age of 28 days. The tests results of these three prism sizes showed that almost similar characteristics.

When the concrete prisms subjected with stress/ strength ratio from ranging 0.00 to 0.05, the UPV value increases slowly by 0.1% to 9%. After this state which is at 0.40 of stress/strength ratio, the UPV values increased rapidly. Under a higher compressive stress of 0.40 stress/ strength or higher, the measured of UPV values decreased rapidly but it greater than the original UPV value around 4% to 19%.

The results obtained indicated that the compressive stress on concrete has significant effect on the measured of UPV values, particularly when the state of stress in the concrete is 40% or more of the compressive strength.

ABSTRAK

Projek ini dilakukan untuk mengeksplorasi keberkesanan tekanan mampatan dalam konkrit dengan menggunakan pengukur pulsa ultrasonik (UPV). Kelajuan pulsa ultrasonik diukur dengan alat yang disebut PUNDIT dan ujian frame digunakan untuk menguji prisma konkrit dalam keadaan tekanan. Nilai UPV adalah diuji pada setiap beban yang dinaikan sebanyak 5% daripada kekuatan konkrit. Projek ini dilakukan dengan menggunakan kekuatan konkrit yang bermula dari 25 dan 30 N/mm^2. Ukuran bagi prisma yang digunakan adalah dengan ukuran 100mm x 100mm x 200mm, 100mm x 100mm x 300mm dan 100mm x 100mm x 400mm dan ujian dilakukan pada hari ke-28. Keputusan ujian bagi tiga berlainan ukuran prisma adalah menunjukkan ciri-ciri yang hampir sama.

Ketika konkrit dikenakan nisbah tekanan/ kekuatan bermula dari 0.00 hingga 0.05, maka nilai-nilai UPV meningkat perlahan-lahan dan mencatatkan nilai antara sekitar 0.1% hingga 9%. Setelah keadaan ini di peringkat 0.40 bagi nisbah tekanan/ kekuatan, nilai-nilai UPV meningkat mendadak. Berdasarkan tekanan pada 0.40 atau yang lebih tinggi bagi nisbah tekanan/ kekuatan, nilai UPV yang diukur adalah menurun dengan cepat tetapi nilai ini 4% hingga 19%lebih besar daripada nilai asal.

Keputusan yang diperolehi menunjukkan bahawa tekanan pada konkrit adalah penting dalam mempengaruhi nilai-nilai UPV terutamanya apabila tekanan pada konkrit adalah lebih atau sama dengan 40% bagi nisbah tekanan/ kekuatan.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 CONCLUSION

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ASTM – American society of testing materials

BS – British Standard

G_i- Energy release rate

mm – Millimeter

MPa- Mega Pascal

NC- Noncontact operation

NDT- Non destructive test

P - Primary wave

% - Percentage

PUNDIT- Portable Ultrasonic Nondestructive Digital Indicating Tester

R - Rayleigh

S – Shear wave

S/A – Ratio of fine aggregate to total aggregate

UPV – Ultrasonic Pulse Velocity

w/c – Water cement ratio

WRF – Wave Reflection Factors

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter discusses on the background, research significant, limitation of the study, problem statements, objectives and the structure of the thesis.

The application of ultrasonic pulse velocity (UPV) to the nondestructive evaluation of concrete quality has been widely investigated for the decades. Numerous data and the correlation relationships between strength and pulse velocity of concrete have been presented and proposed. Ultrasonic measurements are used in structural engineering to determine material properties, detect defects and asses deterioration. Ultrasonic wave propagation characteristics that can be used for these purposes are velocity, attenuation, frequency and energy. In assessing material deterioration, a reference property value such as ultrasonic pulse velocity is determined using laboratory specimens. Field measurements are compared with the reference property value to assess the condition of the material. The ratio of field UPVs to the reference UPV indicates the level of material deterioration (Tomsett

1980; Swamy and Al- Hamed 1982; Ravindrarajah 1992; Udegbunam *et al.* 1999).

In the laboratory, access is generally available to opposite surface of a test specimen and ultrasonic tests are commonly conducted using direct transmission. Direct transmission is defined as the propagation of ultrasonic stress waves along a straight-line path between the opposite surfaces of a specimen. In the field, however, access to opposite surfaces of a component may not be readily available and tests may need to be conducted using indirect transmission. Indirect transmission is defined as the propagation of ultrasonic stress waves between points that are located on the same surface of the material.

1.2 Background

UPV measurement is typically performed using a pair of transducers in contact with the specimen through a coupling medium. Piezoelectric transducers are the most common types for generating ultrasonic waves. Ultrasonic waves are generated by exciting the piezoelectric element in one transducer by an electrical voltage signal in the shape of a spike which causes it to vibrate at its resonant frequency. These excite the material with a wide range of ultrasonic frequencies through contact and generate stress waves that are transmitted through the material to the receiving transducer. The time it takes for the ultrasonic wave to propagate to receiving transducer is measured and defined as the time of flight. The UPV is computed from the distance between transducers and the measured time of flight.

Ultrasonic through transmission measurements have been used as an indicator of the change in elastic properties of concrete and hence the state of concrete. It has been demonstrated by several researchers that the wave velocity depends on the state of concrete and course of setting and hardening (Boutin and Arnaud 1995; Keating *et al.* 1989; Niyogi *et al.* 1990). Nondestructive sensors for predicting the in place strength gain of concrete that utilizes microwaves to monitor changes in the dielectric properties produced by progressing hydration have also been developed (Moukwa *et al.* 1991; Beek 2000).

1.3 Research significant

Since the ultrasonic wave propagation in concrete is dependent on the extent of microcracks, the relations between the velocity variation and the strength of concrete can serve as a basic for developing a non- destructive test (NDT) technique for concrete structure monitoring. In addition, if the ultrasonic velocity of concrete can be measured precisely, it can possibly serve as a tool for the study to evaluate the in situ concrete strength by comparing the measured in situ UPV values of the stressed concrete. This paper demonstrated that the ultrasonic pulse velocity correlated with the measured concrete strength can be used to evaluate the in situ concrete strength. The results and the measurement method developed in this paper can serve as an important reference for further study on the effects of concrete strength under stress.

1.4 Limitation of the study

The study used the common materials in preparing the normal strength concrete. This study excludes the other mineral and chemical admixtures. These materials are unlike the metallic materials that are usually assumed homogeneous, but for the concrete which consists of cement, sand and coarse aggregates of different sizes are heterogeneous. Therefore, the finding in this research may not be fully generalized by the effect of the materials.

This study is conducted for three sizes of concrete specimens with two different concrete grades. The concrete under stress- free condition and under compressive stress will be investigated.

1.5 Objective

1.5.1 General objective

The main objective of this work is to assess the field applicability of the ultrasonic pulse velocity technique for evaluation of concrete strength.

1.5.2 Specific objectives

The specific objectives of this research program are to reconsideration of the relationship between the concrete strength and the ultrasonic pulse velocity in a new light and then help plan future directions of studies to improve the application of it. Specifically issues related to the sensitivity of the UPV technique in concrete under compressive stress will be evaluated. The effect of aspect ratio will also be studied.

1.6 Summary

This chapter has outlined the introduction, background, research significant, limitation of the study and research objectives. The next chapter will discuss the relevant literature of the study, follow by the methodology and continue with results and discussion used in this study. Finally, this project also stated the conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the literature review related to the study. The discussions cover the ultrasonic pulse velocity applications to evaluate the concrete strength under the stress condition.

2.2 Differences between the direct and indirect velocity

Jones (1962) explained the discrepancy between the direct and indirect velocity as being due to wave dispersion. Direct transmission is defined as the propagation of ultrasonic stress waves along a straight-line path between the opposite surfaces of a specimen. Indirect transmission is defined as the propagation of ultrasonic stress waves between points that are located on the same surface of the material.

With verified Jones's (1962), researcher finding by demonstrating that accurate algorithms for determining the time of flight reduce the difference between direct and indirect velocities (Popovics *et al.*, 1998).

British Standards (BS 1881), recommended an indirect velocity measurement procedure using a relationship between transducer spacing and time of flight, obtained by repeating time-of-flight measurements with increasing distance between the transducers. Furthermore, it is stated that measurements on the surface are indicative of properties of only the layers that are close to the surface.

Quixian *et al.* (1996) proved that direct wave velocities were higher than the indirect wave velocities. Primary (P), Shear (S) and Rayleigh (R) wave velocities were determined by surface measurements on concrete specimens with dimensions of 500 x 500 x 200 mm. Measurements were performed at six transducer spacing ranging from 50 to 300 mm in 50 mm increments and indirect velocities were computed by recommended by British Standards (BS 1881) from time of flight versus transducer spacing relation. Direct velocities were measured for comparison to indirect velocities but on different specimens made using the same concrete batch.

Sansalone *et al.* (1997) presented an application indirect transmission on concrete. A Primary (P) wave velocity measurement technique was developed for impact-echo testing. The technique was proposed for determining the thickness of concrete elements and to locate defects in concrete. Two transducers with pointed tips were placed on the surface of a concrete slab and generated at a point along a line drawn between the axes of the two transducers. The wave velocity was calculated as the ratio of the distance between the transducers to the time of flight between the transducers.

Benedetti (1998) showed that a simplified analysis technique similar to that used in geophysical testing (Richart, Hall, and Woods 1970) could be used, however, a more realistic analysis assuming linear variation of ultrasonic pulse velocity (UPV) through the damaged zone showed that the fastest wave path between the transmitting and receiving transducers was a cycloid. In addition, Benedetti (1998) made recommendations for optimum transmitting and receiving transducers spacing for achieving maximum measurement resolution.

Yaman *et al.* (2001) stated that the indirect UPV was statistically similar to direct UPV measured on the concrete slab specimens provided that there were uniform properties including moisture gradient along the surface and along the depth. Two approaches were used for indirect measurements. In the first approach, indirect UPV was computed as the ratio of wave path length between the transmitting and receiving transducers to the time of flight. Using different definitions for wave path length such as centre to centre or edge to edge of the transducers and resulted in large differences in indirect UPV. In the second approach, measurements were made along a line on the surface of the concrete specimens with increasing separation between transmitting and receiving transducers. UPV was determined with significantly lower variability from the inverse of the slope of the linear relationship between transducers separation and time of flight.

2.3 Technique for testing the strength of concrete

Subramaniam *et al.* (2002) developed the ultrasonic technique that continuously monitors the setting and hardening of the concrete. This experimental procedure is based on high frequency ultrasonic measurements and consists of monitoring the wave reflection factor (WRF) at the interface between a steel surface and concrete. The WRF technique was a sensitive to the mixture composition of concrete. The trends in the WRF measurements differ significantly for the three mixtures tested in this experimental. The observed trends in the WRF measurements were very similar to these observed in the strength gain. The percentage change in the WRF and strength with time was very similar.

Lin *et al.* (2003) predicted the concrete pulse velocity to estimate the concrete strength. The pulse velocity of hardened concrete could be predicted with errors less than 2.5% and this errors occur could be caused by the irregular distribution of aggregate particles. With regular distribution of aggregate, the relative errors would become smaller that is between +1 and -1%. The change in ratio of fine aggregate to total aggregate (S/A) have relatively little influence on the pulse velocity of concrete for various water cement ratio (*w/c*) and pulse velocity decreased by increasing the volume fraction of cement paste especially for concrete with high *w/c.*

Purnell *et al.* (2004) showed that low-power Noncontact operation (NC) ultrasonic can be used as a nondestructive diagnostic technique for concrete up to 75 mm thick. The correlation between strength and speed of sound thus measured is strong but differs from that measured using traditional equipment. The discrepancy is due to preferential coupling effects and the NC system is more sensitive to paste properties and the PUNDIT is more sensitive to aggregate. Since the properties of concrete are more highly dependent on the state of the paste than the aggregate, the NC method would appear to offer a more sensitive method for diagnostics in concrete. NC operation removes the need for surface preparation, couplants and the operator error associated with the contact transducers and may be desirable in some hazardous applications. There is significant potential for optimisation and increased penetration through using higher-power transducers and investigating a range of chirp frequencies, bandwidths and shapes.

Komlos *et al.* (1996) showed that the applications of pulse velocity for testing concrete were more detailed than ASTM. Therefore, it is recommended that future standards rate the reliability of the applications of the longitudinal pulse velocity for the users. The most reliable application of longitudinal pulse velocity in concrete testing is monitoring changes in the concrete over time. Checking the uniformity of a concrete mass can also be done with acceptable reliability although here the presence of reinforcement can cause uncertainties. Strength estimation is a distant third in the rating even when a good calibration curve is available. Without such curve the