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EFFECTIVENESS OF ULTRASONIC PULSE VELOCITY AND IMPACT- ECHO NDT TECHNIQUES TO ASSESS THE QUALITY OF CONCRETE

SHIBLI RUSSEL HJ. MOHIUDDIN KHAN

FK 2002 82

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By

SHIBLI RUSSEL HJ. MOHIUDDIN KHAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

July 2002

UPM

Specially dedicated to my mother Haja Begum Rokeya
and my Late Father Haji Mohiuddin Khan

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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July 2002

Chairman: **Associate Professor Ir. Dr Mohd Saleh Jaafar**

Faculty: **Engineering**

The deterioration of concrete in structure is a result of several internal or external degradation mechanism and which results in distress of the structure i.e. decrease in strength and integrity of the structure. The state of distress is often hidden from view and is only evident at a stage where there is significant reduction in strength of the structure. Defects are often introduced during construction and are viewed during in-service life. Some deterioration is viewed physically in the early age or during the service life of the structure in terms of spalling, surface crack, swelling and honeycombing. This deterioration collectively or individually results in reducing the load carrying capacity in terms of the distress of the structure.

In this project, the common defects in the concrete structures and mapping techniques by nondestructive test are presented. Among the various techniques of the nondestructive tests, the Ultrasonic Pulse Velocity (UPV) and DOCtor's Impact-echo were chosen for their effectiveness. The UPV is used to estimate the concrete strength, detecting flaws such as voids and cracks and also to investigate the effects of smaller diameter bar in the concrete. In detecting various sizes of voids by the

Impact-echo test techniques a format was suggested to identify them from the frequency spectrum. In the bridge condition assessment by nondestructive test techniques most common problem encountered were correlation of cube crushing strength to the UPV values, in order to determine residual strength of the structure in different environmental conditions. Also the other defects such as cracks and voids in the concrete, which does not have any standard guideline to identify them by the above NDT techniques to use in the bridge condition assessment. This project has dealt with large number of specimens between the actual condition and those of the values given by the NDT results. A number of beam specimens were also cast with known defects in the concrete in order to obtain and suggest standard investigation procedure. 108 standard cubes with different grades and environmental conditions were cast. Also eight beams and a slab were cast having known common defects.

From the strength-UPV correlation nine numbers of regression equations were suggested. A standard transducers spacing has been suggested for detecting crack depth of 50 to 125mm range. The effect of bar sizes on UPV test results was also obtained. Reinforced concrete slabs or decks having bar diameter greater than 10mm diameter will be affect the readings of UPV. Based on the obtained results a computer database system for NDT has been made to accommodate and fulfill necessary requirements of knowledge base system. Hence this knowledge base system will be used for bridge condition assessment.

Abstrak tesis yang dimukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KEBERKESANAN KAEDAH HALAJU DENYUT ULTRASONIK (UPV) DAN KESAN GEMA DOCTOR'S UJIAN TANPA MUSNAH (NDT) BAGI MENILAI KUALITI SESUATU STRUKTUR KONKRIT

Oleh

SHIBLI RUSSEL HJ. MOHIUDDIN KHAN

Julai 2002

Pengurusi: **Profesor Madya Ir. Dr Mohd Saleh Jaafar**

Fakulti: **Kejuruteraan**

Kerosakan konkrit pada sesuatu struktur adalah disebabkan oleh pelbagai mekanisme penurunan dalaman dan luaran yang menyebabkan berlakunya kehilangan tegasan seperti penurunan di dalam kekuatan dan integrasi sesuatu struktur. Tahap kehilangan tegasan ini selalunya tersembunyi dari pandangan penglihatan dan hanya boleh dilihat sewaktu jangka hayat khidmat (service). Kebanyakan kecacatan boleh dilihat secara fizikal di awal usia pembinaan dan boleh dilihat sewaktu jangka hayat khidmat sesuatu struktur dari segi kesan tanggal, retak pada permukaan, pengecutan dan lubang (honeycomb). Kecacatan ini secara kolektif atau secara individu telah menyebabkan pengurangan dari segi keupayaan menanggung beban disebabkan oleh kehilangan tegasan pada sesuatu struktur.

Di dalam projek ini, kecacatan biasa di dalam struktur konkrit dan teknik melakar oleh Ujian Tanpa Musnah diperkenalkan. Di antara pelbagai teknik Ujian Tanpa Musnah, Halaju Denyut Ultrasonik (UPV) dan Kesan Gema Doctor's dipilih bagi mengetahui tentang keberkesanannya. Ujian UPV digunakan bagi

menganggarkan kekuatan konkrit, mengesan kecacatan seperti terdapat liang (void) dan retakan dan juga bagi menyelidik kesan diameter tetulang keluli yang lebih kecil di dalam konkrit.. Di dalam mengenalpasti pelbagai saiz liang (void) dengan menggunakan teknik Ujian Kesan Gema satu format telah dicadangkan bagi mengenalpasti kecacatan ini melalui spectrum frekuensi. Di dalam penilaian keadaan jambatan oleh teknik Ujian Tanpa Musnah kebanyakkan masalah yang timbul berkaitan dengan pemecahan kekuatan sesuatu struktur di dalam keadaan persekitaran yang berbeza. Kecacatan lain seperti retakan dan liang di dalam konkrit yang mana ianya belum lagi mempunyai garis panduan piawai bagi mengenalpasti kecacatan-kecacatan ini dengan teknik NDT yang dinyatakan di atas yang digunakan di dalam penilaian keadaan jambatan. Projek ini melibatkan jumlah spesimen yang besar di antara keadaan sebenar dan nilai yang diberikan oleh keputusan NDT. Sebilangan spesimen rasuk telah disediakan dengan kecacatan yang diketahui di dalam konkrit bagi memperolehi dan mencadangkan penyelidikan tentang prosedur penyiasatan. Sebanyak 108 kiub piawai dengan gred yang berbeza dan keadaan persekitaran yang berbeza telah disediakan. Sebanyak lapan rasuk dan sebuah papak telah disediakan bagi mengetahui beberapa kecacatan yang biasa.

Menerusi korelasi kekuatan UPV sembilan persamaan regresi telahpun dicadangkan. Satu jarak tranduser piawai telahpun dicadangkan bagi mengesan kedalaman retak dari julat 50 hingga 125 mm. Kesan saiz tetulang keluli di dalam keputusan ujian UPV juga diperolehi. Papak konkrit bertetulang mempunyai diameter tetulang keluli yang lebih besar daripada 10 mm diameter akan memberi kesan kepada bacaan ujian UPV. Berdasarkan kepada keputusan yang diperolehi, satu sistem pengkalan data berkomputer untuk ujian NDT telah dihasilkan bagi memudahkan dan memenuhi keperluan sistem pengkalan data maklumat. Sistem pengkalan data maklumat ini akan digunakan bagi penilaian keadaan jambatan.

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SHIBLI RUSSEL HJ MOHIUDDIN KHAN

I certify that an Examination Committee met on 2nd July 2002 to conduct the final examination of Shibli Russel Hj Mohiuddin Khan on his Master of Science thesis entitled "Effectiveness of Ultrasonic Pulse Velocity and Impact-Echo NDT Techniques to Assess the Quality of Concrete" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the examination Committee are follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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Date: 20.08.2002

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CHAPTER 1

INTRODUCTION

1.1 Background

Nondestructive test (NDT) is the branch of engineering concerned with methods of detecting and evaluating flaws in materials. Flaws can affect the serviceability of the material or structure. NDT is useful tool to indicate performance of structures throughout its service life.

Nondestructive methods have been of considerable value in the testing of concrete. They are most useful in the testing of in situ concrete structures. In the laboratory, their special usefulness lies in the repetitive testing of the same specimen when evaluating the influence of time. These are the two aspects of testing in which the nondestructive test methods are better suited than the destructive methods. It is however, essential to understand the limitations of nondestructive testing methods in view and to exercise due caution in interpreting the results of these methods because they are normally not deterministic.

1.2 What are NDT and its Limitations?

Nondestructive test technique is a descriptive term used for the examination of materials and components in such a way that allows materials to be examined without changing or destroying their usefulness.

The subject of NDT has no clearly defined boundaries; it ranges from simple techniques such as visual examination of surfaces to the well-established methods available in the structural field.

Many research have already been performed to detect the various defects of the concrete structure, especially concrete bridges. To detect the distress of bridge structure such as delaminations, voids, honeycombs, cracks, corrosion in the reinforcement and also the chemical attack / content e.g. chloride in the concrete structure the various technique of NDT are used. The details of nondestructive test technique, their strength and limitations, purpose of each NDT test e.g.- mechanical properties i.e. strength, elastic modulus etc. - physical properties i.e. density, permeability, uniformity etc. - chemical properties i.e. chloride content, alkali-aggregate reaction are described in related section of this thesis.

1.3 Classification of NDT and their Commercial name

The non-destructive test can be categorized as follows:

- Non-destructive test
- Semi-destructive test

1.3.1 Nondestructive test

Each non-destructive test can be carried out using several equipments with different commercial name. The test procedure for each equipment is also different although they have similar test objective. Most commonly used non-destructive test techniques can be summarized as shown in **Figure 1.1.**

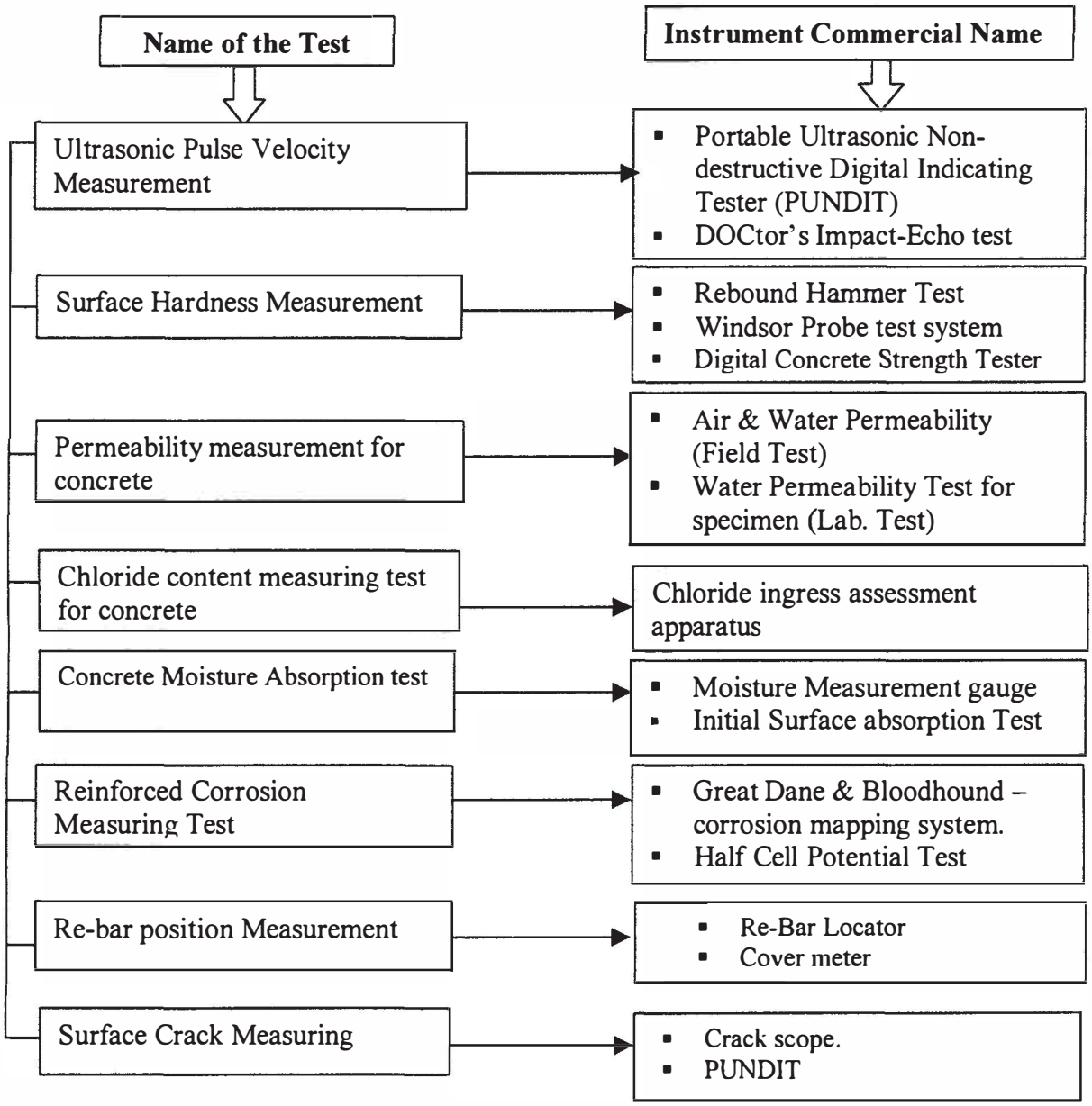

Figure 1.1: Schedule of the NDT techniques and the related Instruments.

1.3.2 Semi-destructive test

Semi-destructive test may be used to confirm some of the test results obtained from the non-destructive test. The accuracy of the NDT varies and is depends on the reliability of the commercially available equipments. Therefore, the semi-destructive test always plays a significant role to confirm reliability of non-destructive test. Hence this reliability brings semi-destructive test to be prominent in the structural field. It also concurrently represents the results of destructive test for the particular location of the structure. For example, Pullout test or concrete coring may be used to obtain in-situ concrete strength or analysis for chemical and physical properties.

1.4 Objective

Distresses of concrete structure are most common in concrete bridges or structures exposed to severe environmental condition. The main cause of these common defects e.g. voids, cracks; corrosion is mainly due to overloading, faulty design and bad construction practice. Early detection and rehabilitation of these common defects may help to limit further distress. The nondestructive tests techniques, which are commonly used includes Ultrasonic Pulse Velocity Test and Impact-echo test for diagnosing such defects. In this regard a study has been conduct with the following objectives.

1. To determine suitable prediction equations in estimating concrete strength by Ultrasonic Pulse velocity method in three different environmental conditions i.e. oven dry (OD), air dry (AD) and saturated (SAT).
2. To determine the optimum transducers spacing for different depths of crack in the concrete beam by Ultrasonic Pulse Velocity Test Technique.
3. To determine the effects of small diameter bar in the concrete beam and slab on the Pulse Velocity.
4. To determine the frequency ranges obtained by the Impact-Echo method on different sizes or locations of voids and cracks.
5. To create a database of UPV and Impact Echo techniques for development an expert system for bridge condition assessment

1.5 Scope of Study

In order fulfill the objectives of this study the scope of work has been limited to the followings.

1. Standard concrete cube specimen prepared in the laboratory condition for grades between 10MPa to 40MPa.
2. Cracks & voids were introduced in the beam, which were cast in the laboratory and the concrete used was grade 30.