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DEVELOPMENT OF PROCEDURES FOR NONDESTRUCTIVE TESTING OF CONCRETE STRUCTURES

Report I

PRESENT PRACTICES

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Concrete Laboratory (CL) of the U. S. Army Engineer Waterways Experiment Station has used nondestructive testing (NDT) in the evaluation of concrete and concreting materials since the creation of the CL (1946). In recent years, more emphasis has been placed on the inspection and structural evaluation of completed Corps of Engineers structures. The need for a capability to predict, prior to placement, certain properties of concrete mixtures after hardening has been realized. This report discusses the history, progress to date, and needs for future research and development in the field of NDT.

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PREFACE

Authority for this research was contained in Engineering Form 4417-R, dated 1 May 1976, covering CWIS Work Unit 31138, "Investigation of Testing Methods and Apparatus," paragraph 15b(3). The Technical Monitor for this work was Mr. James A. Rhodes of the Office, Chief of Engineers, U. S. Army (DAEN-CWE-C).

Additional reports in this series will give results of work done to develop, adapt, and improve methods to enhance the capability for nondestructive testing of concrete structures.

This report was prepared by Mr. H. T. Thornton, Jr., Engineering Physics Branch, Engineering Sciences Division (ESD), Concrete Laboratory (CL), U. S. Army Engineer Waterways Experiment Station (WES). The study was under the general supervision of Mr. Bryant Mather, Chief, CL; Mrs. Katharine Mather, Chief, ESD; Mr. J. M. Scanlon, Chief, Engineering Mechanics Division (EMD); and Mr. B. R. Sullivan, Chief, Engineering Physics Branch.

The Directors of WES during the preparation and publication of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

DEVELOPMENT OF PROCEDURES FOR NONDESTRUCTIVE TESTING OF CONCRETE STRUCTURES

PRESENT PRACTICES

PART I: INTRODUCTION

1. In order to properly plan a research program for the development of procedures for nondestructive testing (NDT) of concrete structures, it is first necessary to establish the sorts of procedures now used or available for this purpose. The Concrete Laboratory (CL) of the U. S. Army Engineer Waterways Experiment Station (WES) has used NDT in the evaluation of concrete and concreting materials since the creation of the laboratory (1946).

2. Methods of NDT used at the outset included dynamic or vibration methods and petrographic methods. X-ray diffraction has also been used for about 25 years.

3. These nondestructive methods and techniques have been used in conjunction with various destructive methods to quantify some physical properties and determine the general quality of concrete or concreting materials. During the 1950's,[1] and through the 1960's, nondestructive methods for testing concrete structures became recognized as rapid, economical, and satisfactory means of evaluating the quality of concrete in structures of various types. Some of the types of structures and materials investigated nondestructively during this period included retaining walls,[2] missile sites,[3,4] launch pads,[5] hospital buildings,[6] prestressed concrete pilings,[7] portland cement concrete pavements,[8] navigation locks and dams,[9] and power dams.[10] Recently, NDT has received considerable acclaim as one of "the optimum ways of getting the information needed on condition of concrete construction without destroying or damaging the construction."[11]

PART II: PROGRESS TO DATE

4. CRD-C 26[12] (ASTM Designation: C 823[13]) "Standard Recommended Practice for Examination and Sampling of Hardened Concrete in Constructions," outlines procedures for visual examination and sampling of hardened concrete, provides a basis for laying out in situ testing of the concrete, and supplies procedures for providing materials for any of a wide variety of destructive or nondestructive tests. WES incorporates these methods and procedures in a program of investigation called the "condition survey," which is designed to evaluate a structure by component parts (i.e., foundation, concrete structure, and concrete-foundation interaction). All parts of the structure are studied relative to structural integrity, existence of any critical conditions that could cause early failure, deterioration of materials, existence of severe cracking, and movement. This program can be used in its entirety, or selected methods and procedures may be applied to specific problems. Various destructive and nondestructive tests provide input to the analysis procedures needed in the condition survey. A brief discussion of the most extensively used NDT's follows.

Dynamic Methods

Ultrasonic pulse velocity

5. The ultrasonic pulse velocity method, CRD-C 51-72[12] (ASTM C 597[13]), involves the measurement of the time of travel of electronically pulsed compressional waves through a known distance in concrete. From known time and distance, the pulse velocity through the concrete can be calculated. This method is used extensively in the field for determining the general quality of concrete, locating cracked and inferior concrete, and providing input to condition surveys of concrete structures. The equipment is portable, has sufficient power to penetrate 50 to 70 ft (15 to 21 m) of good continuous concrete, and has a high data acquisition-to-cost ratio. Standard transducers and those used in boreholes are available and serve to eliminate most problems of

access to surfaces, including those underwater. Empirical correlations between pulse velocities and compressive strengths have proved very useful for specific structures and concretes and can be established with limited coring. Figures 1 and 2 show the apparatus used to measure ultrasonic pulse velocity.

6. Ultrasonic pulse velocity data have provided input for at least five condition surveys including Locks and Dams 52,[14] 53,[15] Emsworth,[16] and Montgomery[17] on the Ohio River, and Locks and Dam 3[18] on the Monongahela River.

Resonant frequency

7. The resonant frequency method, CRD-C 18-59[12] (ASTM C 215[13]), involves determination of natural frequencies of vibration of concrete specimens from which various physical properties of concrete may be determined. These properties include dynamic Young's moduli of elasticity and rigidity (shear modulus), and Poisson's ratio. This method is used almost exclusively in the laboratory, and at WES it is used extensively for detecting changes in the dynamic moduli of test specimens undergoing accelerated freezing-and-thawing tests. It is also used as a monitor for the progress of deterioration of bars in sulfate resistance tests. Variations of this method and equipment have been applied to areas such as damping properties of concrete and other materials, but this type of work has not been extensively pursued at WES. Figure 3 depicts resonant frequency vibration apparatus.

Dynamic deflection

8. The dynamic deflection method of NDT applies a sine wave repetitive force or oscillatory load to a slablike or continuous system such as floor slabs or pavement and measures the deflection produced in the system. By evaluating the deflection measurements, the shape of the deflection basin can be determined. The dynamic deflection method is a very practical and useful tool for the evaluation of highway and airport runway pavements, as well as other types of flat slab concrete construction. The evaluation is not limited to the quality or condition of the structural member but can be extended into such areas as assessing support parameters, assessing joint efficiency, and

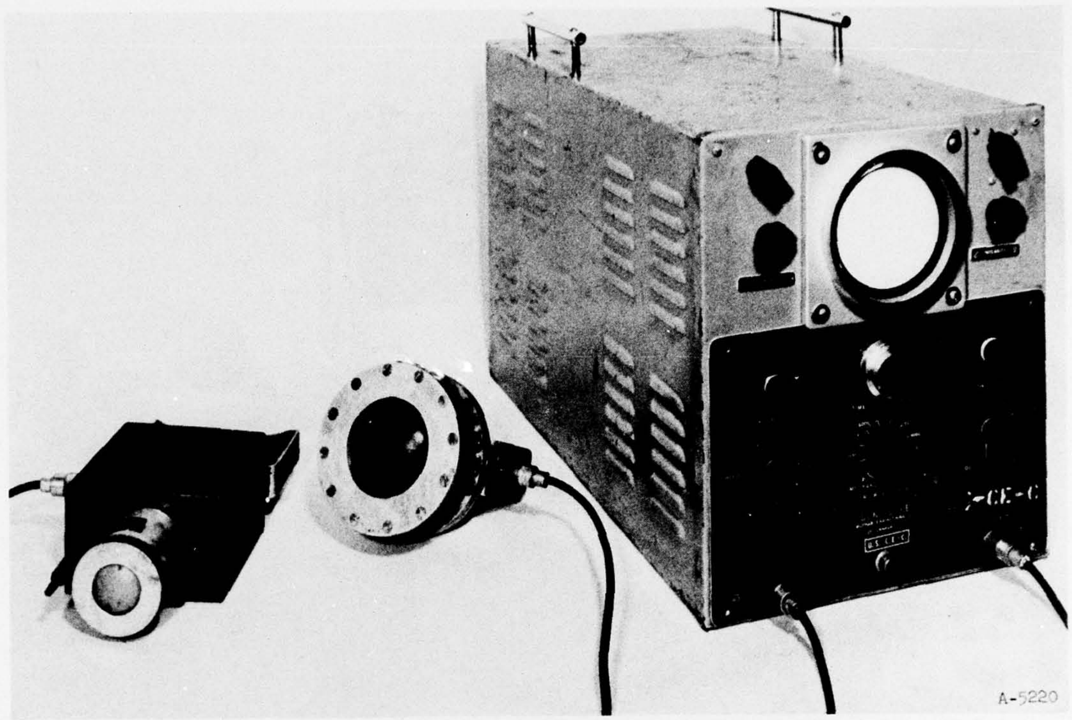

Figure 1. Ultrasonic pulse velocity apparatus

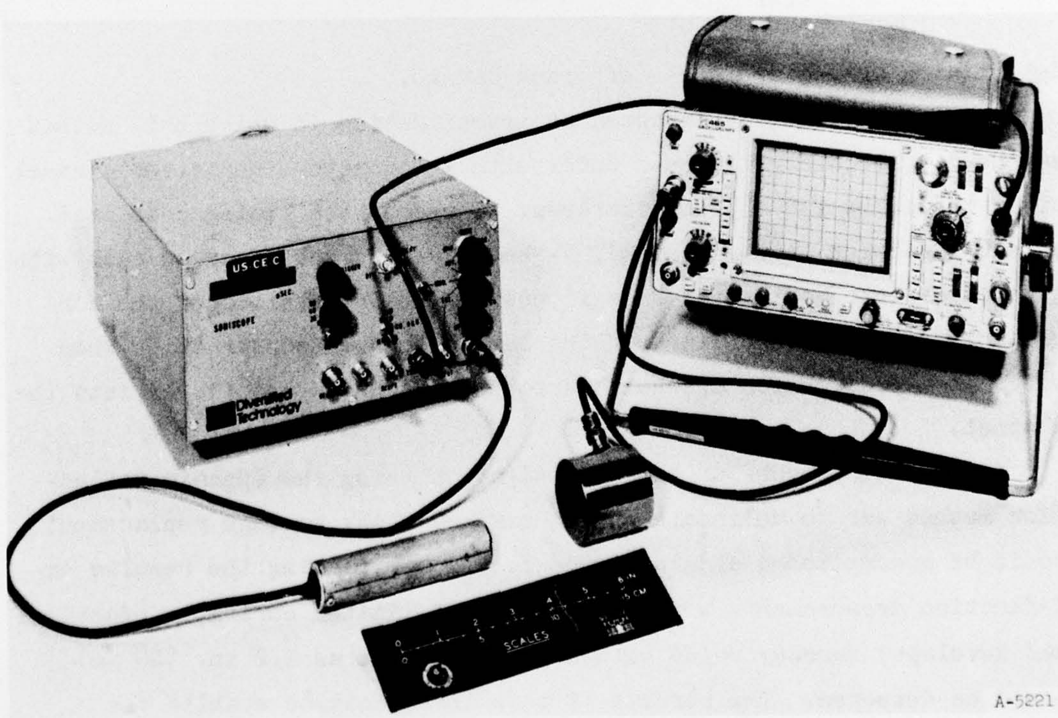

Figure 2. Transistorized ultrasonic pulse velocity apparatus with digital readout and optional oscilloscope

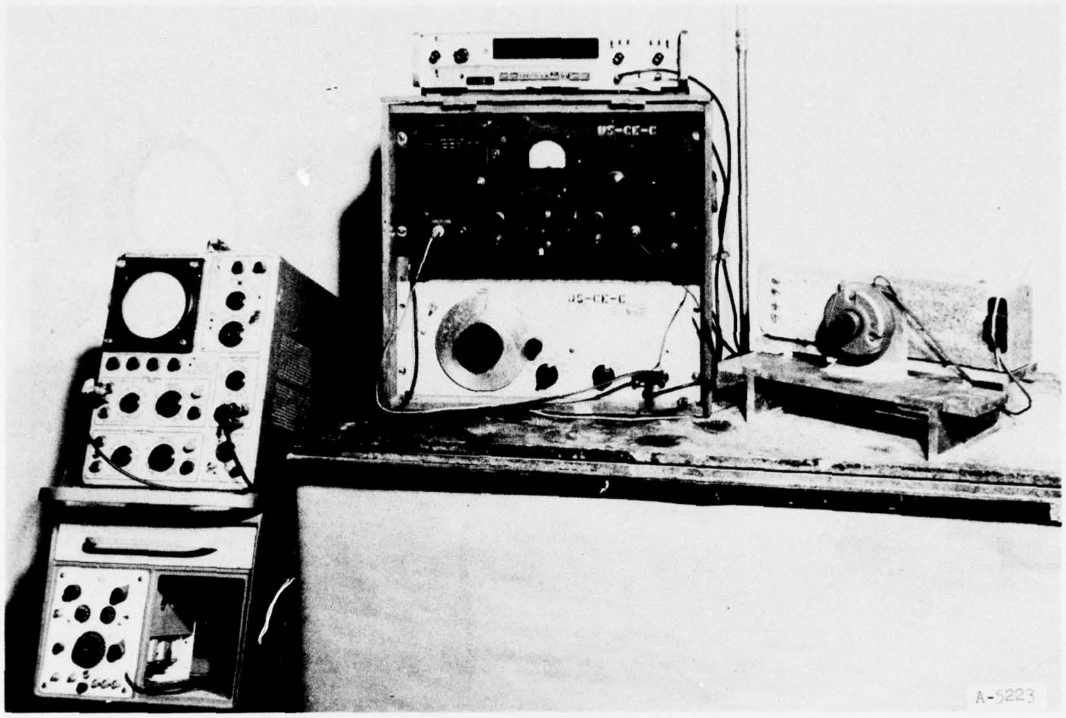

Figure 3. Resonant frequency vibration apparatus with test specimen and optional oscilloscope

determining extent or degree of crack damage.

9. WES recently directed an investigation in which this method was used to locate void areas underneath a concrete-lined river channel after the channel had been dewatered. The concrete lining consisted of a 6-in.-thick (150-mm-thick), V-shaped reinforced concrete slab with 1 vertical on 6 horizontal side slopes. Certain portions of the concrete lining were undermined in the late stages of construction when water in the diversion channel overtopped its banks and flowed into the channel.

10. The purpose of the investigation using the dynamic deflection method was to delineate the undermined slabs so that replacement could be accomplished at minimum cost. By correlating the results of deflection measurements with the results of limited coring, a procedure was developed whereby voids with depths as small as 1/2 in. (10 mm) could be detected. The results of this investigation enabled the

sponsor to realize substantial cost savings.

Rebound hammer

11. The Rebound Hammer Method, CRD-C 22-66[12] (ASTM C 805[12]) has been useful for testing the surface hardness of concrete structures (Figure 4). The operation of the rebound hammer entails pressing a

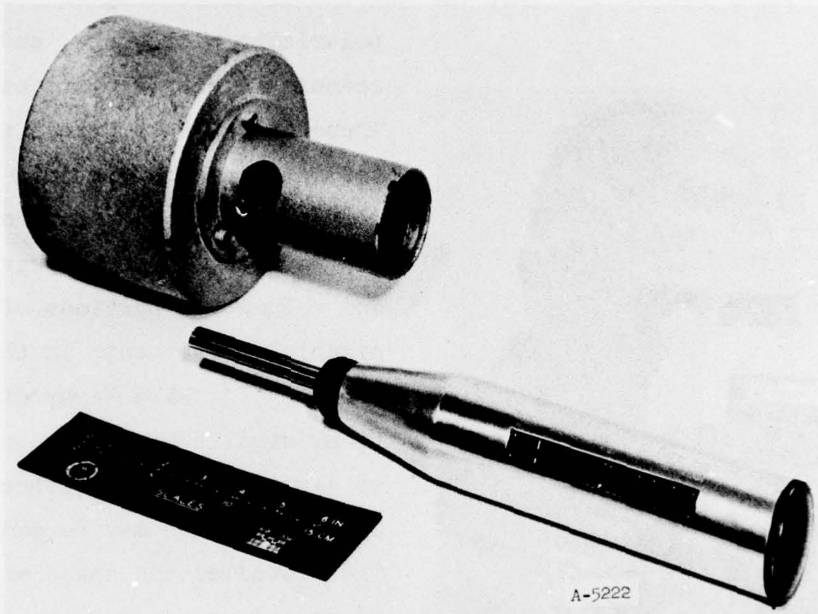

Figure 4. Rebound hammer with calibration anvil

plunger against a smooth surface of the concrete being tested and releasing a spring-loaded mass, thus causing impact of the plunger on the concrete surface. A rebound number is then read from a scale on the hammer and recorded. These numbers may be compared with numbers obtained from other parts of the structure or may be roughly related to other mechanical or elastic properties of the concrete using a calibration chart. Strength predictions of a particular concrete must be based on a specific correlation of strengths versus rebound numbers. At least two previous investigations[22,23] have been made using the rebound hammer as the primary investigative tool.

Petrographic and X-Ray Methods

12. Although the techniques require samples of concrete obtained by destructive means, the petrographic and X-ray methods of testing are nondestructive. Petrographic methods provide for visual examination of the concrete by use of the eye, the stereomicroscope (Figure 5), the polarizing microscope, and the scanning electron microscope. These instruments permit the determination of: air void content, differences in composition of concretes of different appearance, and volumetric portions of recognizable constituents in the concrete.[19-23] With X-ray diffraction, studies of the composition of aggregates and of concentrates of cement paste may be made. These studies and associated ones of secondary reaction products provide a qualitative assessment of the phase composition and of the physical and chemical condition of the concrete. X-ray emission spectroscopy provides data on the presence and amounts of specific elements and is used to determine the composition of the cement or aggregates in the concrete. Figure 6 shows an X-ray diffractometer used for the examination and identification of crystalline materials.

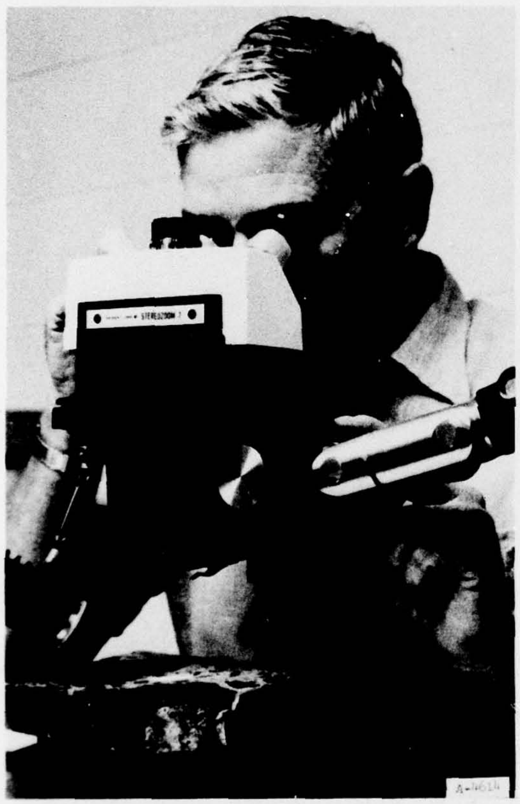

Figure 5. Use of stereoscopic microscope to examine concrete

Figure 6. X-ray diffractometer for the examination and identification of crystalline materials

PART III: NEEDS FOR FUTURE RESEARCH AND DEVELOPMENT

13. The nondestructive methods and equipment already discussed provide means by which the physical characteristics, integrity, and general condition of a structure may be assessed. This assessment is accomplished satisfactorily, in most cases, by using a combination of nondestructive methods in conjunction with some destructive methods. In some cases, however, destructive procedures are undesirable, and are always costly. In other cases, nondestructive methods are not applicable or suitable to the problem encountered and therefore, fail to yield data pertinent to the solution of the problem. From such instances arise the need for the development of new and better methods and systems.

Pulse-Echo

14. Situations arise frequently that call for the capability to develop data on a concrete structure which has only one accessible surface. These situations do not lend themselves to inspection and determination of problem parameters by use of existing nondestructive methods. Therefore, considerable expense and destruction of the structure are often incurred in defining the problem. These undesirable features can be drastically reduced or eliminated by development of a reliable pulse-echo system. Such a system will be of the reflection type and employ compressional wave transmissions. This technique will differ from the previously described ultrasonic technique in that the energy pulse will be transmitted and received at the same surface. The pulse will travel through the material and reflections will be returned from interfaces such as those presented by a crack or void. The boundaries of the crack or void will then be defined by measuring the time lapse between the transmitted and received pulse and calculating the distances using the established velocity of the material. Positive results were obtained in the laboratory using such a system in April 1977 when slab thicknesses were successfully measured. After limited field testing the system was

used to determine the depths of precast concrete piles that form the substructure of an ocean terminal wharf. Some difficulty with signal analysis was encountered because of reflections received from boundaries other than those provided by the piles, but it is anticipated that incorporation of better sensing devices and signal processing techniques will eliminate any future problems of this nature. As the development of this system progresses, the capability for NDT of concrete structures will be greatly enhanced.

Other Areas

15. The growing emphasis on NDT of concrete in recent years has produced many efforts to predict or correlate certain properties of concrete such as strength, modulus of elasticity, and density with ultrasonic pulse velocity. Attempts to correlate strength with pulse velocity have not been very successful,[24] although there are indications[24,25] that the application of the multiphase theory to the interpretation of pulse velocity results may lead to progress in this area. The multiphase theory assumes a three-phase series (uniform stress) model consisting of coarse aggregate, fine aggregate, and cement paste. The total transit time is taken as the sum of the respective transit times through these components. Thus, if the volume fractions and the velocity of propagation through the aggregates are known, the apparent velocity of transmission through the cement paste can be calculated.

16. There is good correlation between the paste pulse velocity and the strength of concrete.[24] The relationship appears to be influenced by the type of aggregate. Thus, for a given paste pulse velocity, concrete made with different aggregates might have different strengths. Through appropriate research, this approach could conceivably lead to a method by which better predictions of strength could be made from results of velocity measurements.

17. Reasonably good empirical correlations between the stiffness

constants (ρV^2)* and Young's moduli for concrete and some other materials have been obtained.[24] Since there is available equipment suitable for field measurement of pulse velocity and density of concrete, some research in this area may be appropriate.

18. WES has the equipment, facilities, and experience to do research in most of the areas mentioned above. An alternate purpose in the preparation of this report was to stimulate interest in and awareness of the needs for future research and development in the field of NDT and the benefits that can be derived by the Corps of Engineers from such research and development.

19. Work has been reported[26] on the development of an acoustical imaging system that could be used to obtain information on the configuration of surfaces of submerged concrete structures.

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* ρ = density, V = pulse velocity.

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