IN-SITU TESTING OF CONCRETE

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ABSTRACT

The increasing demand to assess structural components of concrete before exposing them to service has been the impetus for developing the in-situ testing as a reliable tool in many fields. Examples include quality assurance, diagnostic evaluation, standards compliance, durability, etc.

In this paper, a brief review of in-situ test methods was presented. The objectives of in-situ testing, its test methods and its testing program were delineated. Several in-situ test methods were illustrated; their application and the influencing factors were discussed.

INTRODUCTION

The increasing number of deterioration of concrete structures in the Arabian Gulf countries and elsewhere within a short span of service exposure has been the subject of main concern and research (1,2). These incidences necessitate careful assessment of the structures before exposing it to service in order to verify and comply with the standards and codes of practice. Moreover, if a structure shows any sign of deterioration during its service, it will need an assessment. These sorts of assessments have been the real impetus for the development of in-situ testing technique in order to cope with the large demand over the world.

In-situ testing of concrete plays a very important role in many fields such as quality assurance program or as part of a diagnostic evaluation of the causes of concrete problems with regard to durability, cracking and compliance to prescribed specifications. In-situ testing is also required to assess the final product of the construction work. Consequently, and before any repair, restoration, and/or preventive maintenance, a well-planned site investigation is required. With the guidance of in-situ testing, the engineer can pursue the cause of default and can prevent it before repairing the default itself. In-situ testing can be used to give a good indication about development of concrete strength with time. It also helps in identifying the deteriorated parts of a structure and recognize those parts which are in need of immediate maintenance so that appropriate actions of repair can be made.

In-situ testing is a versatile process; however, literature (3) indicates that the main objectives of in-situ testing are:

1. To check the compliance of contractual work to preset requirements and specifications. Those compliance tests are either for strength of concrete or constituents of concrete.

2. To test for strength of concrete at different locations in a fast procedure.

3. To check the uniformity of the whole structure and to make sure that all parts are according to requirements.

4. To check the durability of concrete, which is its ability to resist the effects of service conditions such as loading, weathering, chemical attack and abrasion.

5. To check performance of the structure in service with time and check its rate of deterioration.

In-situ testing can virtually be divided into three groups, depending on the amount of destruction that will happen to the concerned structure when performing a specific in-situ test. These groups are:

1. Non-destructive tests: This group does not cause any damage to the structure. Some of these tests include surface hardness, pulse velocity and half-cell potential tests.

2. Semi-destructive tests: This group will cause some damage to the structure which can be repaired with ease; the damage is usually localized and therefore, can be restored at the end of testing. Examples include pull-out, coring, and break-off tests.

3. Destructive tests: This group will cause a total or partial damage to the structure when performing the test. The purpose of this test is to record data on the behavior or performance of some important parts of the structure which can be used for future design. Examples include sampling after demolition of the structure and weight loss of reinforcing steel.

In-situ tests can also be categorized under two of these groups according to the purpose. This type of combined tests is usually used to predict strength and some other properties. Table 1 shows a list of strength-related tests with their cost, speed of operation, damage to concrete, representativeness and reliability of strength prediction. Table 2 lists the other properties, other than strength, which can also be determined for concrete and the applicable tests.

Once a decision is made to pursue the in-situ testing program, the following considerations should be taken into account:

a. Objective and purpose of the test program.
b. The time and cost constraints.
c. Required degree of accuracy and reliability of the measurements.

These considerations should be preceded by and based upon a thorough visual inspection to determine general problems encountered and structural integrity of the whole structure. Thereafter, a condition survey of the structure should be carried out to identify problem locations and to estimate the needed budget. According to these two investigations, a plan of the needed tests, number of tests and location of tests can be designed. Once the in-situ tests are conducted, the final stage of the test program is to interpret these results and specify the conclusions. A flow chart of the in-situ testing program is shown in Figure 1.

After this introduction on in-situ testing, its objectives, its test method and the test program, a brief description will be forwarded on the individual tests used in in-situ testing, focussing on the factors affecting each technique.

Table 1: Strength Tests - A Comparative Assessment

Test Method	Cost	Speed of Operation	Damage to Concrete	Representa-tiveness	Reliability of Strength Prediction
Cores	Mode-rate	Slow	Moderate	Good	Good
Rebound Hammer	Very low	Fast	Nil	Surface only	Poor to Fair
Ultrasonic	Low	Fast	Nil	Good to Moderate	Fair to Good
Pullout	Mode-rate	Fast	Minor	Near Sur-face	Moderate
Breakoff/ Pulloff	Mode-rate	Slow	Miderate	Moderate to Good	Moderate
Lok Test	Mode-rate	Moderate to Fast	Moderate	Moderate	Good to Moderate

Table 2: Test for Properties Other Than Strength

Test Required For	Test Available
Delamination, void	Bar chain, ultrasonic pulse cores, pulse echo, infrared thermography
Crack monitoring	Acoustic emission, ultrasonic pulse
Corrosion detection	Half-cell potential
Rebar location	Magnetic method, X-radiography
Density/Thickness	Gamma radiography, core
Carbonation	Phenophthailein
Moisture content	Microwave absorption, radar scanning, nuclear method
Concrete deterioration	Chemical analysis, ultrasonic pulse
Uniformity	Ultrasonic pulse, hammer rebound
Cement content	Chemical analysis, nuclear method
Composition (gradation, air content)	Chemical analysis, Linear traverse (micrometric), flourescence spectroscopy
Rating, performance	Load test
Permeability	Flow Tests

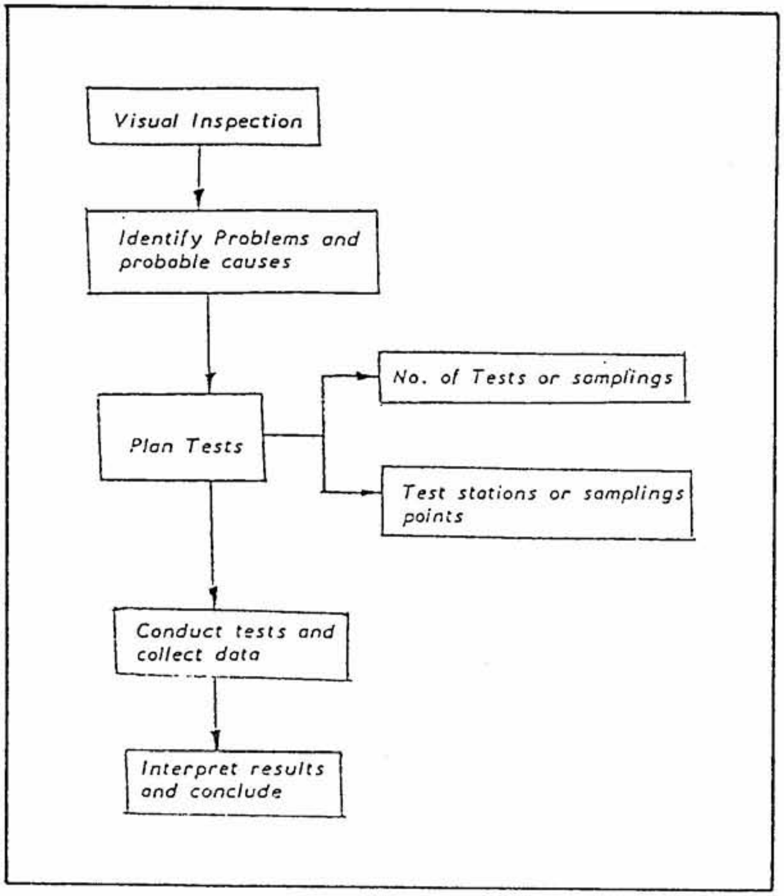

Figure 1. Flow chart of an in-situ test program.

SURFACE HARDNESS TESTS

Surface hardness tests depend primarily on the rebound principle, whereby a load is hit at the concrete surface, and the degree of rebound that the hit travels is measured. This value gives an indication of the strength of the surface layer which is considered to represent the whole structure. Surface hardness can also be measured by the width and/or the depth of an indentation caused by the load when hitting the surface.

Schmit rebound hammer (Figure 2) is one of the most popular equipment used for measuring surface hardness. The main reasons for its popularity are its ease of use, low cost and light weight (4). The hammer weighs about 1.8 kg and is suitable for use in both laboratory and field. The rebound distance is measured on an arbitrary scale marked from 10 to 100. The rebound distance is recorded as a "rebound number" corresponding to the position of the rider on the scale. A calibration chart is usually attached to the casing of the hammer which can be used to correlate the rebound number to the compressive strength of concrete. The rebound number has been reported to be influenced by:

I. Mix characteristics, such as cement type, cement content, coarse aggregate type, etc.

II. Member characteristics, such as surface smoothness, size, shape and rigidity of the specimen, age and curing type, moisture condition, surface carbonation, stress state, temperature, and compaction.

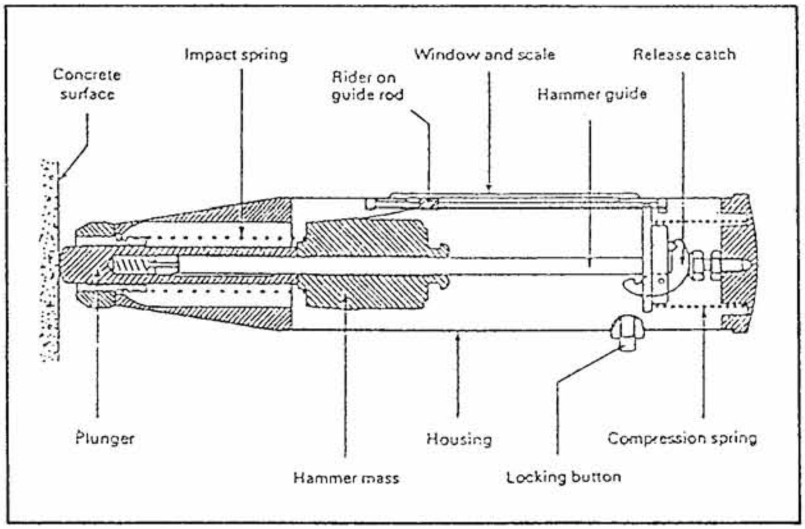

Figure 2. Typical rebound hammer.

According to the above factors, the Schmit hammer has to be calibrated for various mixes. In calibrating the hammer, the test is run several times on various faces of the test specimen; compression test is thereafter run on the specimen to develop such a prediction.

Although Schmit hammer gives a reading about the hardness of the outer 30 mm of the structure, it will give an idea about the strength of the structure as a whole. Schmit hammer is generally used for one or more of the following applications:

1. Checking the uniformity of concrete from one location to another.

2. Comparing a given concrete with a specific requirement, especially in precast industry.

3. Determining the properties of the concrete surfaces which have a direct influence on its performance, and its durability (3).

4. Providing a relative indication on the strength of concrete.

ULTRASONIC PULSE VELOCITY METHOD (UPV)

The main idea behind UPV is the fact that the velocity of mechanically-generated pulses through concrete depends primarily upon the elastic properties of the material and almost independent of its geometry. Therefore, UPV testing provides a means of generating a pulse, transmitting this pulse to the concrete, receiving and amplifying the pulse and measuring and, thereafter, displaying the time taken. Repetitive voltage pulses are generated electronically and transformed into wave bursts of mechanical energy by the transmitting transducers which must be coupled to another portion of the concrete surface through a suitable medium. A similar receiving transducer is also coupled to the concrete at a known distance from the transmitter. The UPV electronic testing device measures the time interval between the onset and reception of the pulse and displays the time of a travel.

There are three basic forms in which the transducers may be coupled to the concrete; each arrangement (shown in Figure 3) depends on the pulse path through the material. These arrangements are: opposite faces (direct transmission), adjacent faces (semi-direct transmission), and same face (indirect transmission).

In each case, the distance between the transmitter and receiver have to be measured and divided by the time of travel the pulse has taken from travelling from the transmitter to the receiver (given by the pulse velocity machine) to obtain the velocity of the pulse through the material. For the case of opposite face arrangement, direct distance is measured. For adjacent faces arrangement, radial distance is measured. For the same face arrangement, a number of points in a straight-line are taken, then a graph of distance versus time is drawn, the slope of that line is taken as the velocity of the pulse.

UPV is known to be influenced by many factors such as (5):

1. Aggregate type and shape and cement type,
2. temperature,
3. stress level,
4. path length between transmitter and receiver,

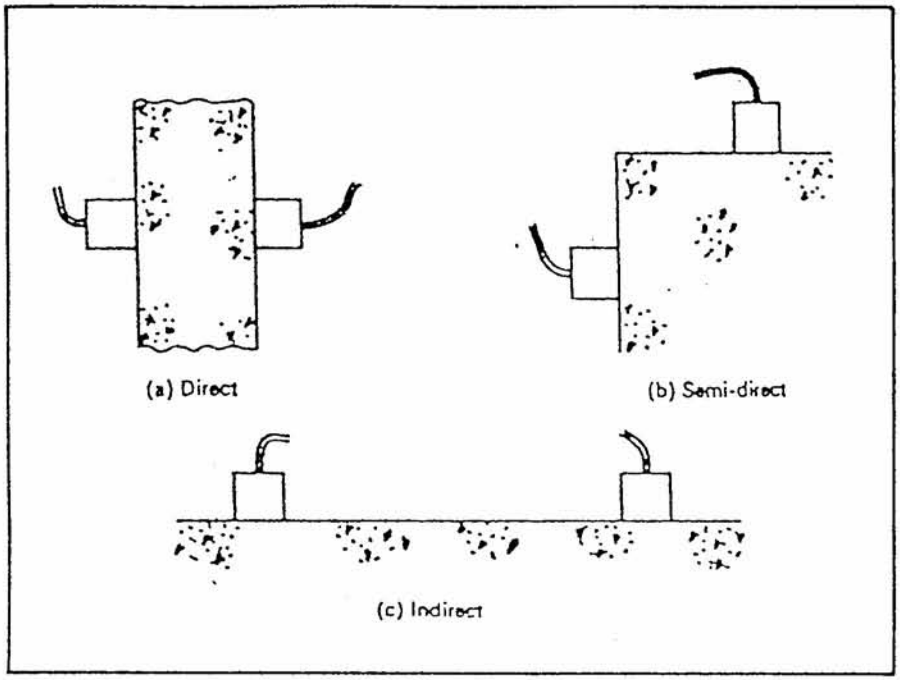

Figure 3. Types of reading.

5. moisture conditions of the sample being tested, and
6. reinforcement location and depth. Reinforcement is usually avoided by using a technique known as the "R" meter to allocate the reinforcement thereby avoiding taking the UPV at these locations if possible.

To take these factors into account, the pulse-velocity apparatus should be calibrated for the various mixes. The relationship between the pulse velocity and the compressive strength of concrete is an exponential type of the format:

$$f_c' = Ae^{\beta V} \tag{1}$$

where, A and ß are material constants.
V is the pulse velocity
f_c' is the 28-day compressive strength of concrete.

UPV is a powerful tool to delineate the general quality of concrete. However, it is frequently used for the following applications:

a. Measurement of concrete uniformity.

b. Detection of cracking and honeycombing.
c. Assessment of concrete deterioration.
d. Measurement of layer thickness.
e. Measurement of elastic modules.
f. Monitoring of strength development.

PULL-OUT TEST

The pull-out test measures the force required to pull an embedded metal that is inserted with an enlarged head from a concrete specimen or a structure (3). An empirically-established relationship is usually used for conversion of the measurement to the cylinder compression strength of concrete. An illustration of the pull-out technique is shown in Figure 4. The "insert" is pulled out by a loading ram seated on a bearing ring which is concentric with the insert shaft, whereby the bearing ring transmits the force to the concrete. As the insert is pulled out, a conical-shaped fragment of concrete is extracted from the concrete mass. The pull-out force is recorded by the pull-out machine. Through the predetermined correlation between the pull-out force and the compressive strength of concrete, which usually takes a format of straight line, the compressive strength of concrete can be more directly calculated. The generated format of the pull-out force-compressive strength relationship is:

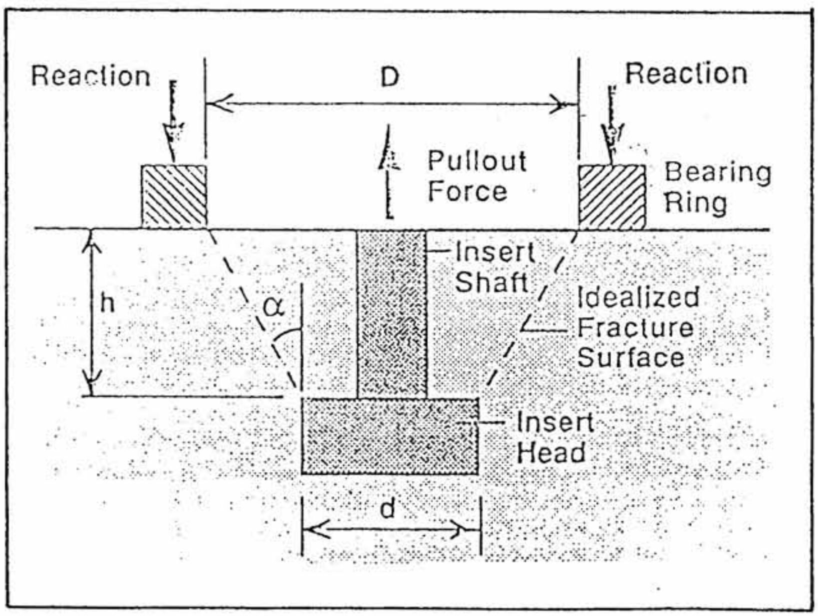

Figure 4. Pullout test procedure.

$$P = A f_c' + B \tag{2}$$

where: A and B are material constants.
P and f_c' are the pull-out force and compressive strength of concrete respectively.

The main advantages of the pull-out test emerge from the fact that it overcomes some of the limitations of the standard compressive strength, which consists of inherent errors in sampling and the fact that concrete in structure is placed, compacted, transported and used differently from that cast in cylinders or cubes. The pull-out test provides an effective way of obtaining considerable amount of test data at a relatively little cost and short time, which is considered to be a major advantage. Two standard tests are usually used in determining the pull out strength of concrete, depending on the "insert" insertion time. If the "insert" is inserted in concrete before casting and left there to give the strength after the hardening of concrete, then the test is called ***Lok-test*** (Figure 5). If the "insert" is inserted inside an already-hardened concrete, then it is called ***Capo-test*** (Figure 6). Accordingly, the Lok test is conducted when a solid part is extracted from the concrete by means of an embedded disc which is pulled out under application of a counterpressure. The pull out "insert" is a 25 mm diameter special steel disc held 25 mm from the testing surface by a removable shaft, which may be attached to the formwork using an adjustable screw. In the Capo test, a hole is made, perpendicular to the surface, with a special tool, with 18 mm diameter, to a depth of 50 mm and at least 20 mm away from reinforcement position, and thereafter undercut with a diamond miller and positioned 25 mm from the concrete surface to a depth of 10 mm. An expanded insert is placed in the hole and is expanded with a special expansion unit. The unit and the insert are then attached to a pull bolt, which is coupled to the Lok-test instrument with a counterpressure ring placed on the testing surface and loaded. The capo test strength is recorded as the maximum reading during pull-out.

CORE TESTS FOR ASSESSMENT OF CONCRETE STRENGTH

Extracting cores and testing them is one of the most widely used techniques to determine a variety of physical and chemical characteristics of existing concrete structures. Concrete cores allow the visual inspection of the interior matrix of concrete members. Some of the physical properties which can be measured from cores include:

- Density
- Water absorption
- Aggregate gradation
- Void content
- Compressive strength

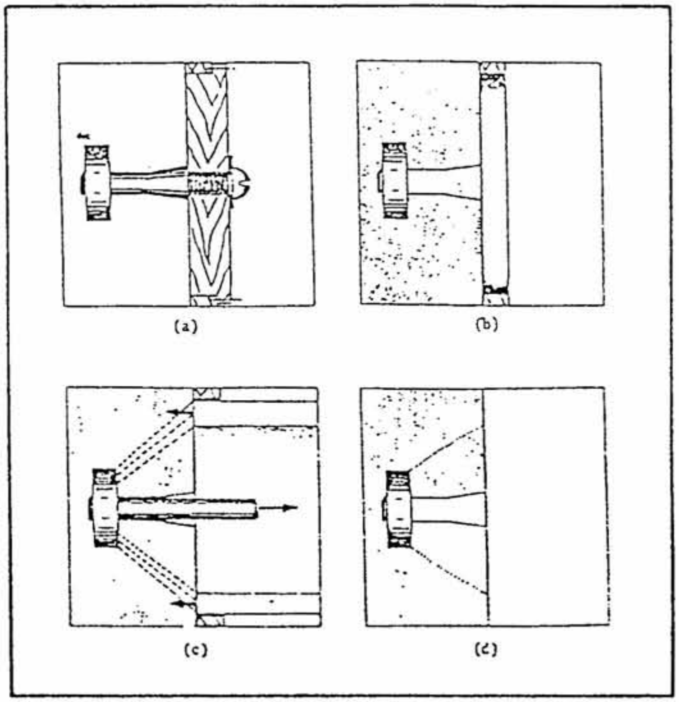

Figure 5. Lok-test procedure.

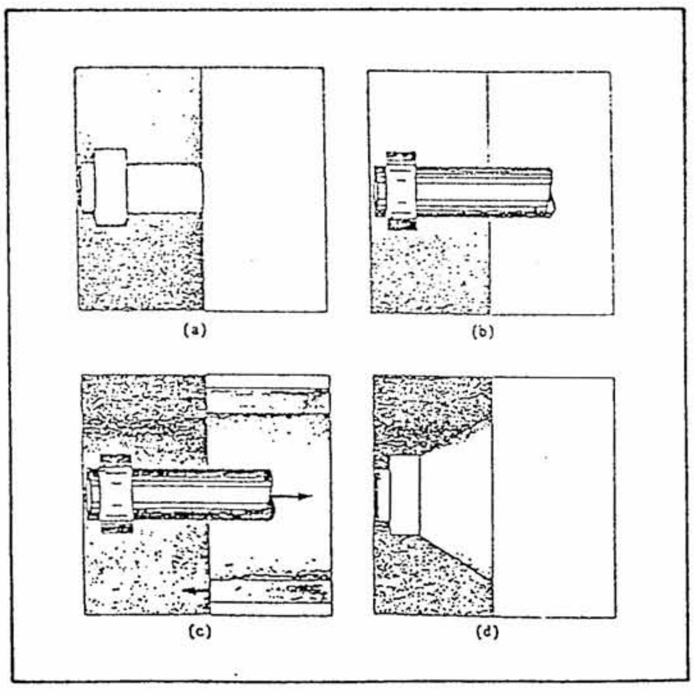

Figure 6. Capo-test procedure.

Cores are also used for chemical analysis of concrete. These cores provide the most reliable information about the internal structure of concrete; however, they also cause an enormous damage to the structure and they are slow and expensive compared to other semi-destructive methods. Cores are always cut by means of a rotary coring machine equipped with diamond bits. The equipment is portable and heavy and it must be firmly supported and braced against the concrete to prevent any relative movement, which will result in a distorted or broken core; water supply is also necessary to lubricate and cool the cutter. For testing of cores in compression, cores have to be capped to insure a full contact between the pressure heads and the sample faces. A great deal of information can be gained from visual examination of the core such as aggregate size, shape and distribution, porosity, presence of honeycombing, reinforcement and degree of compaction.

Core compressive strength may be influenced by several factors such as:

- Curing time and regime: strength is affected to a great deal by the curing time and curing history.
- Voids: presence of voids in the core will lower its strength.
- Type and dimensions of the structure affect the compressive strength of the core. Cores extracted at the top of a column are usually 15 to 20% lower in strength than those present at the middle and lower portions.
- Strength to diameter ratio of the core: as this ratio increases, the measured strength will decrease due to the stress distribution across the specimen.
- Diameter of the core: as the diameter of the core increases, the measured strength will decrease.
- Direction of drilling: vertically-drilled cores have higher strength than horizontally-drilled one.
- Presence of reinforcement will usually decrease the compressive strength of the core.

Caution should, therefore, be exercised when testing cores and modification factors should be used to adjust for these variables.

CORROSION MONITORING OF REINFORCEMENT

Reinforcement corrosion in concrete structures can be monitored in two ways: destructive and non-destructive techniques. In the destructive technique, a sample of the rebar is retrieved by taking a core from a structure and determine its loss in weight and hence the corrosion rate. With the limitations imposed on this technique (as being destructive), the second type of comes into picture. One of the most popular techniques is the half cell potential technique (ASTM C 876), which depends on the idea of monitoring the potential of the reinforcement. The set-up typically used to measure the potential difference is shown in Figure 7. It consists of a copper-copper sulfate electrode connected to a high impedance voltmeter and moved around or on the surface of concrete; the other end of the voltmeter is connected to a reinforcing steel which is connected to the embedded reinforcement bars. This corrosion potential measurements provides information on the state of passivity of the reinforcing steel. Interpretation of the half-cell potential values, viz-a-viz the corrosion status of rebars, is base on the following criterion (ASTM C 876):

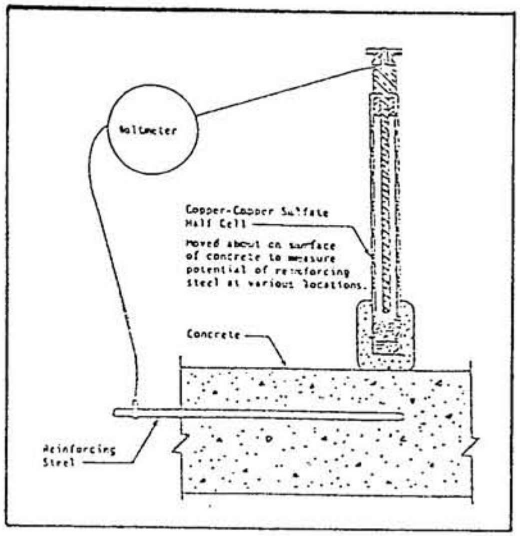

Figure 7. Half-Cell Potential Measurement Set-up (ASTM C 876).

Voltage* (millivolt)	Probability of Corrosion
< - 350 mV	> 95%
> - 200 mV	< 5%
- 200 to -350 mV	≈ 50%

*With respect to copper-copper sulfate electrode

It is worth mentioning that the copper-copper sulfate electrode does not provide stable potential readings and, therefore, it is recommended to use the Calomel-saturated electrode in laboratory studies on corrosion (7).

Contour maps for the corrosion of the whole structure can be drawn; the corrosion potential criterion can then be applied to identify the possible corroding reinforcements. Some difficulties are associated with potential measurement techniques such as:

- It is difficult to use when a dielectric layer of high-resistance is present on the concrete surface, such as an asphalt layer.
- It is difficult to use as a monitoring technique in cathodic protection systems.
- The interpretation of potential measurements on structures containing metal coated or epoxy-coated steel is still uncertain.

Literature search indicates that there are many other sophisticated electrochemical techniques that are capable of measuring the corrosion rates in reinforcement embedded in concrete structures. These techniques have been discussed elsewhere (8).

CHEMICAL TESTING OF CONCRETE

The physico-chemical analyses of concrete are employed to evaluate the quality of concrete in terms of standard specifications prescribed for its composition. These analyses also aid in estimating quantitatively and qualitatively the chemical deleterious components like chloride and sulphate responsible for the deterioration of in-situ hardened concrete. Since the selected method for chemical analysis should be precise and accurate, the following criteria are used in selecting the method:

- The method should be accurate enough to predict the constituents of concrete.

- The method should require simple testing apparatus normally available in the average testing laboratories.

- The method should be in use in many laboratories or have been sufficiently tested to establish their validity.

- It should be sufficiently rapid to permit routine use for the examination of large numbers of samples.

Chemical testing of concrete is frequently conducted to identify one or more of the following parameters:

1. Cement content: The analytical method depends on detecting the presence of calcium and silica in the concrete sample, because these materials are the major constituents of cement and they can be diluted in hydrochloric acid.

2. Aggregate content and aggregate gradation: by breaking the sample down into fractions of 2 to 3 inch, igniting it at 550°C to destroy the strength of concrete, then separating the coarse and fine aggregates by sawing and cleaning by hydrochloric acid.

3. Chloride content: Concern of the chloride content is mainly due to its adverse effect on the corrosion of reinforced concrete. One of the most popular methods in detecting chloride content is Volhard method. It depends on the fact that chloride in solution reacts with silver to form a silver chloride when a definite volume of silver nitrate is added and the excess silver nitrate can be measured by using standard ammonium thiocyanate solution with Volhard's indicator.

4. Sulfate content: Due to the adverse effect of sulfate on concrete, the quantity of sulfate is usually measured. The gravimetric procedure is usually used to predict sulfate content. This procedure depends on the fact that barium chloride reacts with sulfate to form insoluble barium sulphate which is purified, dried and weighed to measure sulfate in concrete.

CONCLUDING REMARKS

The present paper is formatted to provide the readers with a brief introduction on "in-situ testing" of concrete. This topic, by itself, is very attractive and it really needs considerable experience when applied to real concrete structures. Due to time and space limitatin, some other in-situ testing methods have not been discussed. Because of its extensive applications in the Arabian Gulf countries and over the whole world, the in-situ testing of concrete requires much more literature than what is presented in this paper. Interested people are referred to a recent Short Course on "In-Situ Testing of Concrete" conducted at the Department of Civil Engineering, King Fahd University of Petroleum & Minerals, in December 1991.

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