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Arlington, Virginia 22217-5000

Navy Case No. 68,547

SURFACE ELECTRODE PROBE
FOR ASSESSMENT OF CORROSION ACTIVITY IN REINFORCED CONCRETE

FIELD OF THE INVENTION

This invention relates to a method for determining the location and level of reinforcement corrosion activity in concrete structures, and more specifically to a non-destructive testing device for locating and measuring corrosion activity in reinforced concrete structures by direct detection of electrochemical current flow.

BACKGROUND OF THE INVENTION

Corrosion of the metal reinforcement in concrete structures presents a serious threat to durability. It is not the deterioration of the concrete itself, but the corrosion of reinforcement that represents the greatest threat to the durability of concrete structures. Cracking and spalling of concrete under pressures created by the formation of voluminous corrosion products is a common occurence. By determining the extent of corrosion activity, life estimates can be made or preventative measures taken.

Presently, potential measurement methods require electrical connection to the reinforcement, and this only indicates that corrosion has taken place, it does not indicate the level of corrosion activity. The standard method of field investigating of corrosion behavior employs "half-cells" for determining the potential of the reinforcement at selected locations. The basic test configuration is shown in Fig. 1, where a high impedance voltmeter is employed to determine potentials relative to a copper-copper sulfate ($Cu/CuSO_4$) reference electrode. Potential readings at the area of measurement are considered to indicate the following activity:

$E_{corr} > -.20$ volts	90% probality no corrosion
$-.20 > E_{corr} > -.35$ volts	Corrosion uncertain
$E_{corr} < -.35$ volt	90% possibility corrosion occurring

This method of potential measurement can result in useful data for structures such as bridge decks, particularly with the construction of equipotential contour maps. However, it has undeniable limitations. First, electrical connection with the reinforcement is required. Connection in an existing structure requires removal of concrete at numerous sites to insure electrical continuity to all areas being surveyed. This may be impractical for most inspections. Additionally, in highly conductive marine environments, concrete affects readings in a manner similar to nonconductive coatings; greatly increasing in the area associated with a single measurement (decreasing measurement localization). There is also the questionable range of potential between -.20 and -.35 volts ($Cu/CuSO_4$) associated with the standard test method.

Investigation of pitting behavior with instrumented steel samples embedded in concrete clearly showed a drop in potential associated with the onset of pitting. During an induction period where no current flow is observed, a slow decrease in potential occurrs. At approximately -.25 volt (saturated calomel electrode [SCE]) there is a marked rise in current accompanied by a sharp drop in potential. This potential, -.32 volt ($Cu/CuSO_4$), is close to the -.20 volt (Cu/SO_4) specified as indicative of no corrosion activity. However, below -.50 volt SCE (-.57 volt $Cu/CuSO_4$) current tapers off with a continued decrease in potential. Therefore, potential measurements in themselves may serve more as an indicator of corrosion history (that corrosion has been initiated) than giving the level of corrosion activity.

SUMMARY OF THE INVENTION

According to the present invention, a non-destructive testing device is provided for locating and measuring corrosion activity in reinforced concrete structures by direct detection of electrochemical current flow. The device consists of a surface probe valved to present alternating paths for current flow when measuring the potential of an internal electrode relative to a remote reference. This allows measurement of IR drops associated with the corrosion of reinforcement. By grid surveys of concrete structures, areas suffering internal corrosion, the primary cause of marine concrete deterioration, can be located and the level of activity can be determined.

It is an object of the present invention, therefore, to provide a non-destructive means for locating and measuring corrosion in reinforced concrete structures.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompaning drawings where like reference numerals refer to like components in each of the figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram showing a prior art test configuration for measuring to determine if there is any corrosion.

Fig. 2 is a schematic diagram of the preferred embodiment of the invention showing the basic probe system.

Fig. 3 is a schematic diagram showing one valving arrangement for determining IR drop magnitude in the system of Fig. 2.

Fig. 4 is a schematic diagram showing a second valving arrangement for determining IR drop magnitude in the system of Fig. 2.

Fig. 5 shows another valving arrangement, employing close tolerance tubes for rapid cycling.

Fig. 6 is a diagram illustrating corrosion pit location and pitting current direction.

Fig. 7 is a schematic diagram showing use and location of an auxiliary electrode in a circuit as in Fig. 3.

Fig. 8 shows a typical recorder output for probe measurements using a device of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The basic probe 10 of the device consists of a wire electrode 11 inside a nonconductive shell or housing 13 which is sealed to the surface 14 of a concrete structure 15. Shell 13 can also be made of other compatible materials with a base 16 of nonconductive material which when pressed against the concrete surface 14 presents a high resistance interface. The voltage measured at 17 between the wire electrode 11 and a remote reference electrode 18 with a stable potential includes the IR drop attributable to corrosion currents through the current path between the two electrodes 11 and 18 due to corrosion of the reinforcement 20. When held against surface 14, hole 22 in the base of the otherwise watertight probe limits this current path to the interface bewteen the probe base 16 and the concrete surface 14 and through the concrete structure 15 itself.

Valving: A baseline is established by first measuring the freely corroding potential of the wire electrode 11 relative to the reference electrode 18, and then measuring the voltage through the base of probe 10 by making it the lowest resistance path. Valving is used to change the voltage measurement paths. Initially a voltage reading (baseline reading) is taken by measuring the freely corroding potential of wire electrode 11 relative to the reeference electrode 18, and then reading the voltage after making the opening 22 through the base of probe 10 the lowest resistance path between the two electrodes. The change in the two voltage readings is V.

There are a number of possible mechanical valving arrangements for determining the magnitude of the IR drop; two arrangements are illustrated in Figs. 3 and 4.

As shown in Fig. 3, a tubular section 25 communicating to the interior of probe 10, with a means, such as flap 27, operates to provide a path through the probe housing to the seawater outside. Any suitable means, not shown, can be used to open and close flap 27. With flap 27 open, the resistance path from electrode 11 via the water path through tube 25 to reference electrode 18 is much less than the resistance path from electrode 11 via the probe housing and concrete structure 15 to reference electrode 18 with the flap closed.

In Fig 4 is shown a variation of the scheme used in Fig. 3 where a tube 29 extends from the interior of probe 10 to the end of reference electrode 18 which it encloses. A means for allowing access to the seawater, such as flap 31, can be opened and closed by any suitable means. In this scheme, however, the resistance of the path via tube 29 with flap 31 closed is much greater than the resistance from the probe through the concrete structure to the reference electrode 18 with flap 31 open.

The arrangement shown in Fig. 3, has proven satisfactory as relatively high interface resistances between the probe base and the concrete surface are readily achieved eliminating the need for a high resistance reference/wire electrode path arrangement as shown in Fig. 4 and giving a higher output voltage for a given current.

The effect of drift in the wire electrode's potential is minimized by rapid valving, making the composition of the wire of little importance.

Valving may be accomplished through any number of suitable variations in construction which suit the particular application. Where surveys are required, IR drops can be determined simply by computing differences in voltage readings with the probe 10 pressed onto the concrete surface 14 and with it lifted off. The valving process must be carried out rapidly enough to minimize the effect of electrode potential drift. However, with suitable recording instrumentation drift and "instantaneous" drop are discernable.

Water flow past the wire electrode 11 can also change its potential enough to affect V. One method of reducing this effect when probe 10 is moved is placement of a sponge or other porous plug 32, as shown in Fig 5 for example, in opening 22 of the base 16 which allows electrolyte contact with electrode 11, yet prevents water flow. The interior of probe 10 may also be filled with conductive gel or the electrode 11 isolated by a salt bridge (not shown) to prevent water flow past the electrode.

Another method involves the use of an external valve constructed so that it does not evoke water flow or increase pressure in the sealed probe 10. Such a valving arrangement is shown in the schematic of Fig. 5 which employs close tolerance tubes, includes a valve arrangement 37 which may be pneumatically operated, as shown, or cycled by other means such as by rotation. In the scheme of Fig. 5 probe 10 is pressed against the concrete surface 14 and valve 37 actuated by pneumatic displacement from air pressure, etc., from a source 40, closing and opening aperture 41 to a seawater path from outside the probe. A spring arrangement 43 can be used to return the pneumatically operated cylinder 44 to where aperture 46 is aligned with aperture 41 once air pressure is released. For behaviorial logs, the probe may be sealed to the concrete surface 14 and the valve cycled over a period of time.

Pit Location: The magnitude of V will be proportional to the detected current flow, given a constant path resistance (R_p). Assuming this to be true, active corrosion sites (anodic sites) may be located by simple surface surveys. V will will be greater directly over corrosion pits. Here current density will be greatest and assuming current radiating from the pit, all current (positive) will flow from the center outward relative to the probe base, such as illustrated in Fig. 6. With distance from the pit, current density is diminished and there is flow in two directions relative to the probe circumference. Therefore, V is high over the pit due to higher current density and additive current elements.

In practice R_p can vary greatly and it is necessary to determine corrosion current values to locate active areas.

Corrosion Current: In order to derive the current flow associated with V, the resistance of the volume of concrete observed by the probe must be determined. This is accomplished by an auxiliary electrode 51 placed in the surface probe 10 along with electrode 11, as shown in Fig. 7. Electrode 51 is connected through a power source 53 to an external counter electrode 55.

The shift in the primary electrode 11 potential for a given current is then determined. This can be done for a range of currents to produce a calibration curve, or to verify linearity and calculate probe/interface resistance. For proper operation the induced current should "see" the same volume of concrete as the current between the primary electrode 11 and the reference electrode 18. Then the current associated with the IR drop can be calculated.

$$I_{det} = \frac{V \text{ measured}}{R_p}$$

I_{det} has proven to be proportional to total pitting current; however, the exact detection boundaries are uncertain.

Output Instrumentation: Probe response is readily determined from a strip chart recording. Initial voltage is nulled with a countervoltage to where small (i.e. less than 0.1 mV) changes with valving can be detected. A buffer amplifier 58 is used between the probe 11 and recorder 59 to prevent polarization of the electrodes.

With a movable probe used in surveys, R_p varies with surface 14 irregularities and the interface pressure between probe 10 and the concrete structure 15. In survey applications, R_p can be monitored continuously through input of a fixed current pulse from power source 53 through the auxiliary electrode 18. Since measured response to this current input and the response to any detectable IR drop are both functions of R_p, I_{det} at a particular location is simply the pulse current times the ratio of V to the voltage shift produced by the pulse. Typical recorder output is shown in Fig. 8, by way of example. Fig. 8 shows the pulse voltage shift (small fluctuations) superimposed on V for fourteen locations (the large shifts mumbered 1 to 14).

The concrete reinforcement inspection probe system provides a simple means for investigating corrosion activity in concrete structures. No electrical contact with the reinforcement rebar, etc. is required, eliminating any need for concrete removal to make a connection. Surveys using the present device can locate anodic areas underwater where conventional potential measurements give only an overall potential. In the present system current is measured directly, giving an account of instantaneous activity as opposed to merelycorrosion history.

Numerous probe 10 sizes, base 16 configurations, and construction materials can be used to suit particular applications. Small probes are more accurate for locating active pits; however, more sites need to be tested to center the probe electrode over a pit for maximum V. A loss in resolution and sensitivity may be required in obtaining a probe size practical for large scale surveys.

Probe 10 can include self contained electrolyte, electrodes, and valving for use above water as well as for underwater testing.

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ABSTRACT OF THE DISCLOSURE

The probe is a nondestructive testing device for locating and measuring corrosion activity in reinforced concrete structures by direct detection of electrochemical current flow. The device consists of a surface probe valved to present alternative current flow paths when measuring the probe potential with respect to a remote reference electrode, allowing the measurement of IR drops associated with corrosion of reinforcement "rebar." By grid surveys of concrete structures, areas suffering internal corrosion (the primary cause of marine concrete deterioration) can be located and the level of corrosion activity determined.

(Patent Application, Ser. [illegible])

FOR ASSESSMENT OF CORROSION
ACTIVITY IN REINFORCED CONCRETE
INVENTOR: DANIEL R. POLLY NC68547
ATTY: J. M. ST. AMAND SHEET 1 OF 2

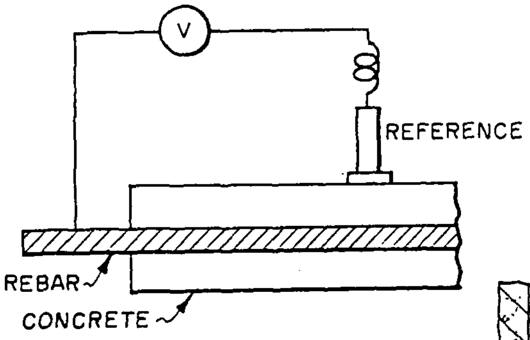

Fig. 1. PRIOR ART

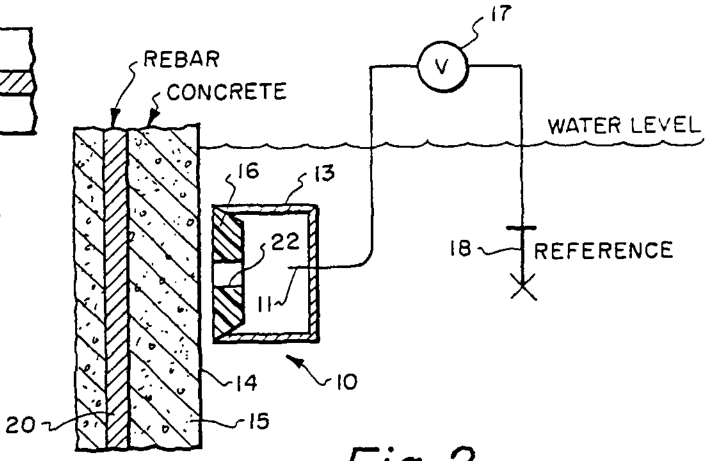

Fig. 2.

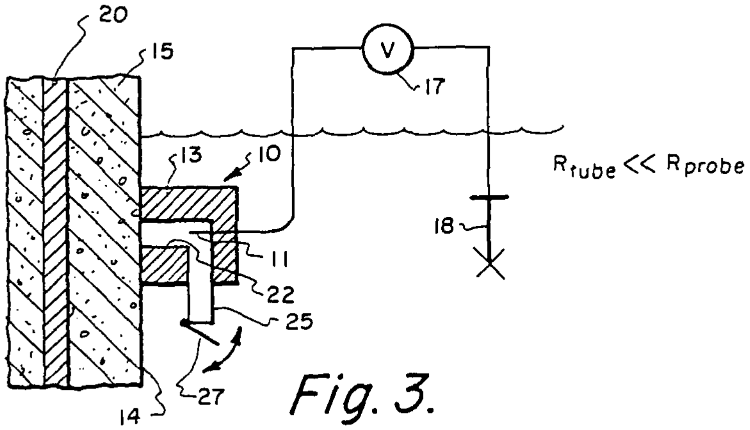

Fig. 3.

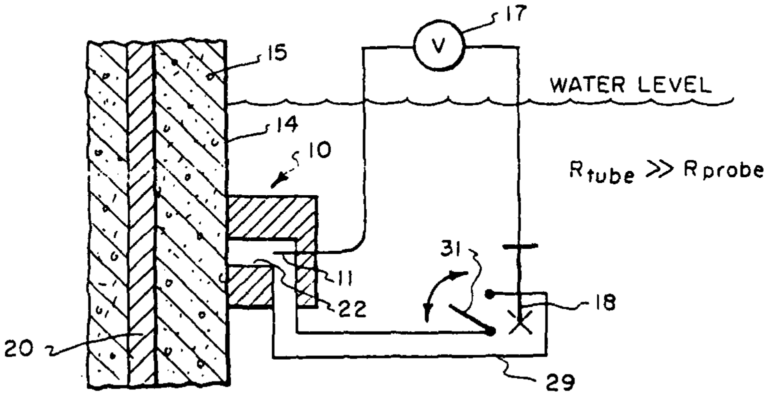

Fig. 4.

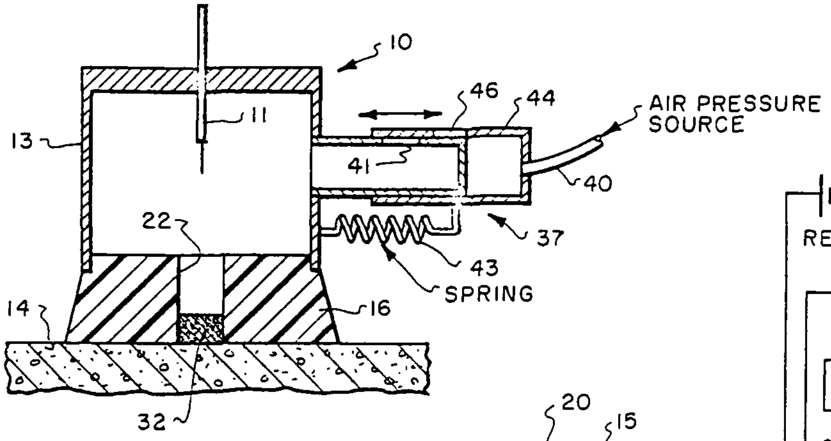

Fig. 5.

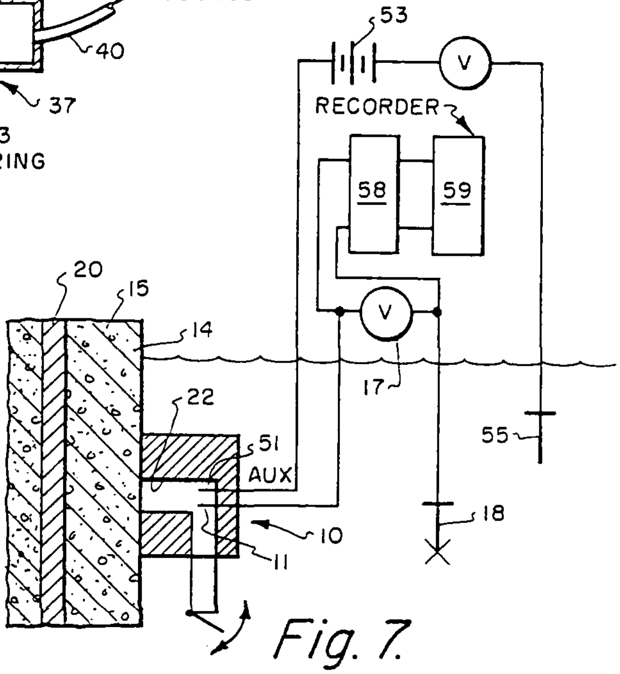

Fig. 7.

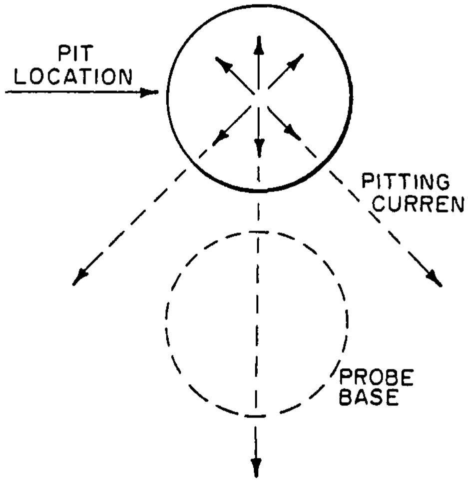

Fig. 6.

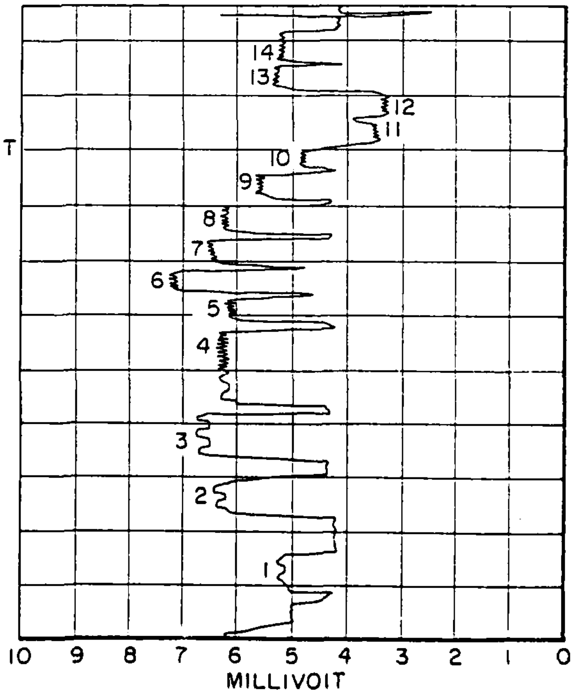

Fig. 8. PROBE RESPONSE RECORDING