# Development of Titanium Wire Sensor for Corrosion Monitoring in the Concrete Structures

Headquarter Technical Division, Rahmita Sari RAFDINAL
Headquarter Technical Division, Toshiyuki AOYAMA
Headquarter Technical Division, Naotoshi FUKAGAWA

Abstract : This study was carried out to propose the titanium wire sensor with 3mm diameter as the new model of embeddable reference electrode to use in corrosion monitoring of concrete structures. The performance of titanium wire sensor exposed to variant temperature and linear polarization which compared to silver-silver chloride electrode (SSE) as a verification electrode in feasibility study conducted first. Then wire sensor embedded into the concrete structures and testing by half-cell potential method was carried out to observe the reliability of wire sensor with various type of lengths (0.1 m, 1 m, and 2 m). The result indicates that wire sensor exhibits stability in ambient temperature and reliable to monitor the change of rebar potential in concrete as same as like the SSE electrode. Moreover, the potential measured by embeddable wire sensors applied to observe corrosion potential of rebar in the concrete and the average value of the natural potential of rebar measured by SSE in the same section of wire sensor position indicated similar trend. Also, wire sensor has features being able to measure rebar potential in concrete in wide range by changing the wire sensor length.
*Keywords* : Titanium wire sensor, reference electrode, natural potential of rebar, corrosion monitoring

## 1. Introduction

Reinforced concrete may undergo physical deterioration (frost, cracking, fire, etc.), chemical degradation (acid attack, sea water attack, alkali-aggregate reaction, etc.) and steel corrosion. Reinforcement steel corrosion is viewed as a major problem in the maintenance of the structural integrity of concrete structures.

Half-cell potential (HCP) method is used worldwide as one of the non-destructive tests to detect and inspect the corrosion of reinforcing steel in concrete by measure the natural potential of rebar. In this method, the presence of corrosion on the rebar is judged by difference of the value of the potential between the reference electrode and the rebar by using the digital multimeter. In the HCP method, the natural potential of rebar is measured only in the vicinity where the movable reference electrode applies on the surface of the concrete. This electrode is not efficient to use to investigate the deterioration of concrete structures with a large area. Also, reference electrodes are expensive, and the potential readings are very influenced by the wet or dry conditions of the surface layer of the concrete.

On the other hand, a new generation of electrode called embeddable reference electrodes that are beneficial in corrosion monitoring of concrete structures for long-term monitoring and inexpensive, and could be connected to the internet based wireless system. It is difficult to count influence by the moisture content of concrete.

Therefore, in this research, attempts have been made on the corrosion monitoring of reinforcing steel in concrete structures by employing a small size embeddable titanium wire sensor with the flexible application. Stability of wire sensor exposed to variant temperature, linear polarization test, and the natural potential of rebar in reinforced concrete (RC) beam measured by wire sensor against SSE as verification electrode was reported.

## 2. Feasibility Study of Titanium Wire Sensor

### 2.1 Experimental Outline

The wire sensor consists of titanium probe activated with iridium-enriched mixed metal oxide and 3 mm in diameter was used as sensor electrodes in this study. Photo-1 shows the schematic of the embeddable titanium wire sensor (WS) for concrete structures.

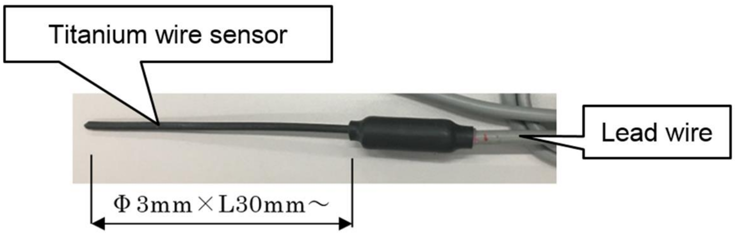


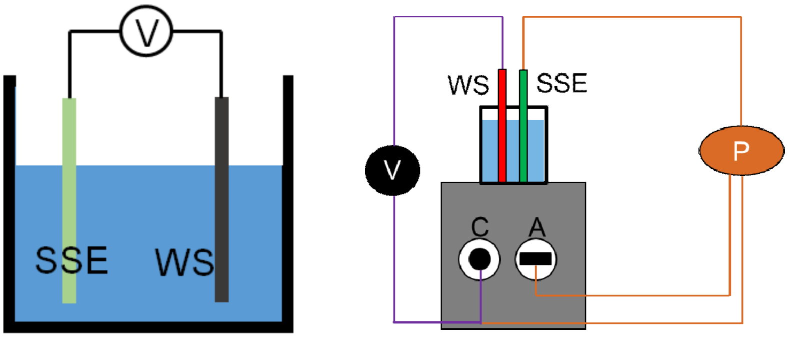

Photo-1 Titanium wire sensor fabricated by P.S. Mitsubishi

Electrical contact is through the body length of wire sensor. Fifteen wire sensors were used to observe during this feasibility study. Sealant was designed to keep long-term durability of WS and lead wire connection. The fifteen wire sensors with 100 mm length exposed to under the variant of temperatures, i.e., 0 °C, 31 °C, 48 °C, and 66 °C.

### 2.2 Response Test of Wire Sensor Electrode

All the electrochemical tests were performed using voltmeter and potentiostat devices.

The potential of WS electrode was measured under different temperatures (0 °C, 31 °C, 48 °C, and 66 °C) to investigate the influence of environmental temperature on the electrode potential. Furthermore, the temperature coefficients of these WS was measured and compared with reference electrodes such as CSE, Pb and Mn/MnO2. Stability test and effect of temperature test for WS is illustrated in Figure-1(a).




(a) Type 1 (b) Type 2

Figure-1 Potential measurement method for wire sensor

The linear polarization condition corresponded to a potential sweep rate of 1 mV/s and potential ranges of +200 to -1500 mV from the open circuit potential. Linear polarization measurement of WS compared to SSE. The overview of this test is depicted in Figure-1(b). Here, “A” means Anode and “C” means cathode.

## 3. Wire Sensor Embedded in RC Beam (150x2100x150 mm)

### 3.1. Outline of Specimen

The dimension of the specimen is 150 x 150 x 2100 mm as shown in Figure-1. The main rebar and stirrup use D13 as reinforcing steel with longitudinal and transversal distance arrangement of 75 mm and 200 mm, respectively. Wire sensors applied to the concrete with various lengths of wire sensor; 5pcs @ 0.125 m, 1pcs @ 1 m, and 1 pcs @ 2 m embedded longitudinally in the concrete near the main rebar. Water-cement ratio of 40 % used in this RC beam as shown in Table 1.

Table 1.Mix concrete proportions

| W/C (%) | kg/m$^3$ | | | | |
|---|---|---|---|---|---|
| | W | C | S1 | S2 | G1 |
| 40 | 170 | 425 | 298 | 447 | 991 |

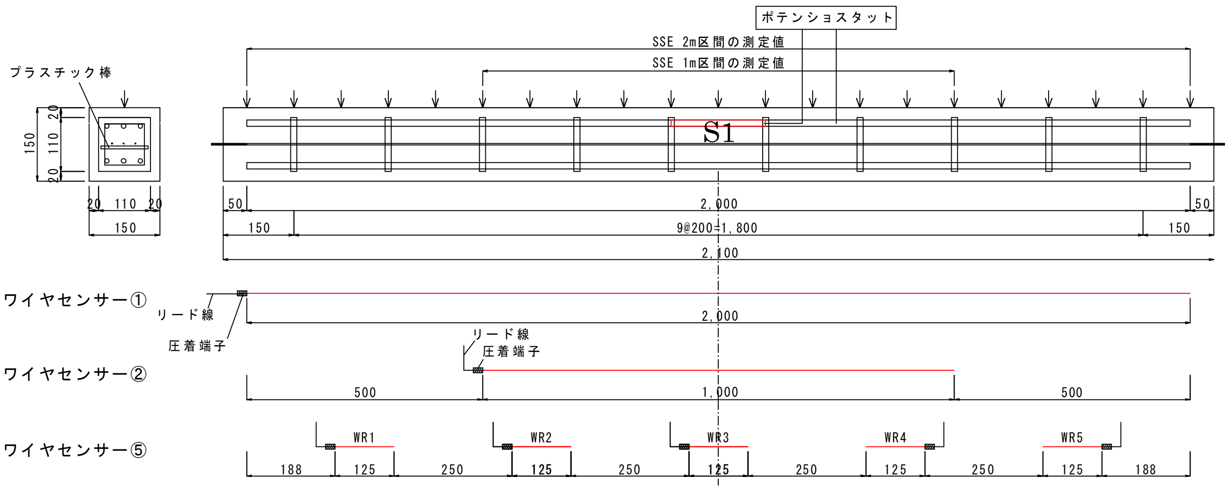



Figure-2 Outline of RC beam specimen

### 3.2. Test Method

When the potential of rebar reading shifts from positive to more negative value, it means the rebar in concrete corrodes. In this experiment, to partially change the potential in the axial direction of the specimen, the potential of the red bar in the vicinity of the central part of the specimen (S1) was forcibly changed to -300 mV and -500 mV using the Potentiostat device. The potential of rebar in the axial direction of the specimen measured with a commercially available reference electrode (referred to as SSE) from the concrete surface as shown in Figure-2. The measurement of SSE was carried out at intervals of 100 mm from the concrete surface. Furthermore, the potential of rebar measured with embedded WS electrodes with 0.125 m, 1 m and 2 m lengths of sensors against to SSE.

## 4. Test Results

### 4.1. Effect of Temperature

Temperature is one of the external factors which affect the potential of a reference electrode (RE). Potential of RE changes with temperature for the reason that both electrochemical reactions and chemical solubility. In electrical resistance, a temperature coefficient describes the relative change of a physical property that associated with a given change in temperature. It is necessary to know the temperature coefficient (TC) to minimize errors in potential reading and to know the electrical resistance of RE. Equation (1) estimates the TC as following:

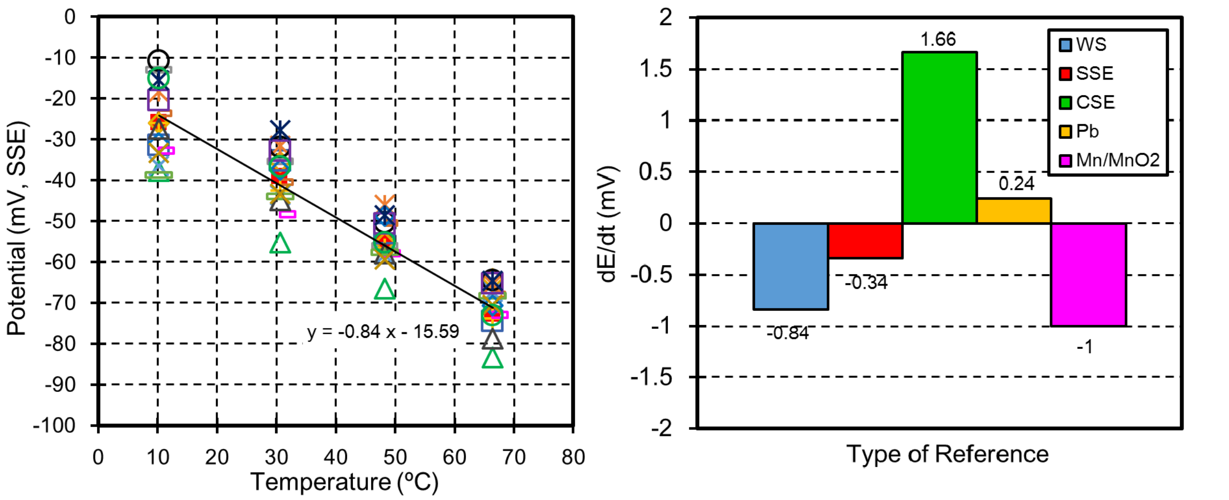
$$E = E^0_{25} + (t - 25)\ dE/dt \qquad (1)$$

Here, E is potential of RE at t (mV), $E^0_{25}$ is potential of RE at t = 25 °C (mV), t is temperature (°C) and dE/dt is temperature coefficient (mV/°C).

Figure-3(a) illustrates the effect of temperatures (i.e., 10 °C, 31 °C, 48 °C, and 66 °C) on the potential of

WS against SSE electrode. From this test, it was observed that potential of WS steadily decreased with the raised of temperature.

Furthermore, the bar charts in Figure-3(b) exhibit the temperature coefficient for several reference electrodes namely Titanium Wire Sensor (WS), Copper Sulphate Electrode (CSE), Plumbum Electrode (Pb) and Manganese Dioxide Electrode (Mn/MnO2). Accordingly to this figure, the TC of CSE and Pb have the positive temperature coefficient which means the higher coefficient, the greater increase in electrical resistance for a given temperature increase. Meanwhile, WS, SSE, and Mn/MnO2 have the negative temperature coefficient which means the lower the coefficient, the greater decrease in electrical resistance for a given temperature increase. It means even though WS reference electrode shows stability at ambient temperature, but it had a decrease in electrical resistance when the temperature raised.




(a) (b)

Figure-3 Potential of wire sensor exposed to variant temperatures (a) and temperature coefficient (b)

4.2. Linear Polarization

The graphs in Figure-4 show the potential of rebar during linear polarization measurement measured by WS and SSE. The potential of the rebar was varied from + 200 mV to -1500 mV (vs. SSE). The data measured by the WS electrode exhibits the same trend as the SSE electrode even with 57 mV in difference. It indicates that WS is reliable to monitor the change of rebar potential in concrete as same as SSE electrode.

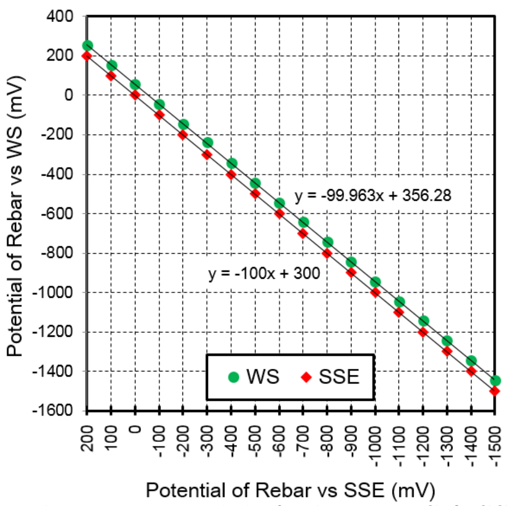
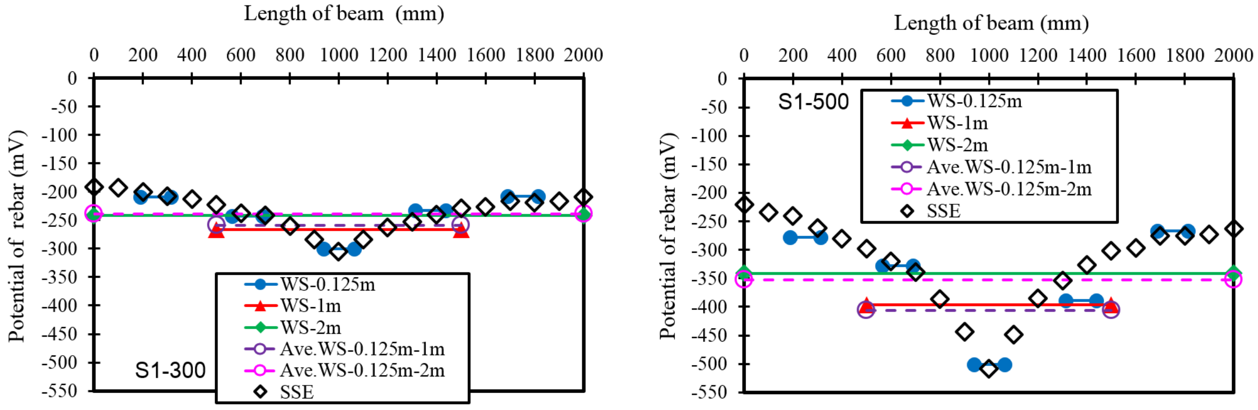



Figure-4 Potential of rebar vs WS & SSE

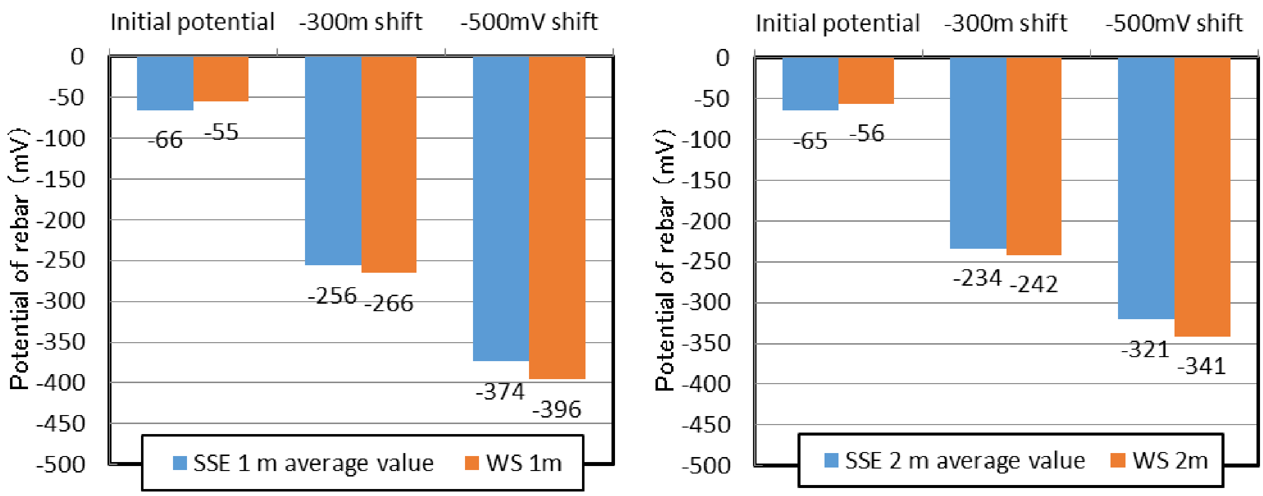
4.3. Potential of Rebar Measured by Wire Sensor Electrodes

Figure-5 shows the potential distribution of rebar measured by 0.125 m, 1 m and 2 m lengths of wire sensor, and SSE electrodes in the RC beam. Wire sensor 0.125 m was able to detect the anode potential given in S1 position as same as SSE value. The small wire sensor was able to detect the local position if the position of embedded close to the corrosion point. The potential readings by wire sensor 0.125 m shown the same as SSE result in the same section position of measurement. Meanwhile, the potential of rebar measured by 2m wire sensor indicates the same as the average potential of 0.125m wire sensors in the 2m position of embedded.




(a) (b)

Figure-5 Potential of rebar with potential shift -300 mV (a) and -500 mV (b) at S1 position, respectively




(a) (b)

Figure-6 Potential of rebar with potential shift -300 mV (a) and -500 mV (b) at S1 position, respectively

Also, from the graphs in Figure-6, it is experimentally confirmed that potential of rebar measured by 1 m and 2 m wire sensor has identical value with the average potential in 1m and 2m interval measured by SSE. From Figure-5 and Figure-6 above, it's concluded that potential of rebar measured by 1 m and 2 m wire sensor will equal with the average value of SSE in the same section of measurement.

Also, from this results, it can be seen that wire sensor has features being able to measure rebar potential in a wide measurement area in concrete by changing the wire sensor length. It means titanium wire sensor is reliable to utilize as a reference electrode as same as like SSE electrode and user-friendly to use in the wide measurement area.

## 5. Conclusions

Based on the experimental results, the following findings are derived:

1) Wire sensor reference electrode shows stability performance at ambient temperature, but it had a decrease in electrical resistance when the temperature raised.

2) During linear polarization test to rebar, potential reading by wire sensor electrode indicates the same trend as the SSE electrode. It means that wire sensor is reliable to monitor the change of rebar potential in concrete.
3) Wire sensor 0.125 m was able to detect the local corrosion in concrete if the position of embedded close to the corrosion point.
4) Potential of rebar measured by 1 m and 2 m wire sensor has similar value with the average potential in 1m and 2m interval measured by SSE. It means wire sensor has features being able to measure rebar potential in concrete in wide range by changing the wire sensor length.

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