# TEMPERATURE COMPENSATION ON SMART STEEL ANCHOR SYSTEM BASED ON CARBON FIBER SENSOR

Ibaraki University Student Member H. Huang
Ibaraki University Member of JSCE Z.S. Wu

## 1. Background and Propose

### 1.1. Current situations

Recently a new sensing system for important structures that require high reliability is generated, which is called structural health monitoring (SHM). In the geotechnical slope engineering, steel anchor is adopted to improve the stability of unstable slope. Those steel anchors usually have very long service life. Engineers have been trying to monitor the damage of those long term serviced steel anchors. It is quite difficult to succeed an accurately and real-time SHM by current monitoring methods. Now a carbon fiber sensor (CFS) has being developed, as a new effective self-health monitoring one. Here I propose to develop a smart steel anchor (SSA) system with CFS that it can succeed SHM by the anchor itself, and the monitoring process is very simply that a worker can get the job finished only need one multimeter.

### 1.2. Performance of CFS

CFS is made of carbon fiber, sometimes using one type of carbon fiber, sometimes using several types, it is depending on the monitor requiring. Studies show that when tensile the hybrid CFS along the fiber direction, the electrical resistance of hybrid CFS will change. An important calculating parameter, resistance changing rate ($\Delta R/R_0$), is referred to show the strain state on hybrid CFS.

As a result has be discovered that, $\Delta R/R_0$ changed in two states: in the initial low strain range, $\Delta R/R_0$ increases slowly, in proportion to the strain due to the piezoresistivity of carbon fibers; in the high strain range, $\Delta R/R_0$ changes in a step wise manner with the gradual ruptures on hybrid carbon fiber, as shown in Fig. 1.

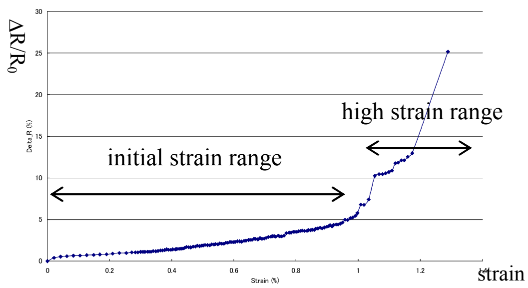


Fig. 1 $\Delta R/R_0$ vs. $\varepsilon$ of CFS

### 1.3. Proposition of SSA

According the tension mode, there are two parts in the body of an embedded steel anchor, the free deformable part and anchored part. In this study, the main theory of SSA system is bonding a CFS to the anchored part, and use CFS to monitor the steel anchor, the main content is showed in Fig. 2.

For SSA, it has three main purposes:

(1) When SSA is in working order, the CFS on it can show the strain state as a strain gage;

(2) When SSA is close to the yield strength range, the value of CFS will change a lot that it can be easily detected as a failure alarm;

(3) When damage has happened on SSA and it caused SSA failed, the CFS can record this damage that does not let the monitor operator miss it.

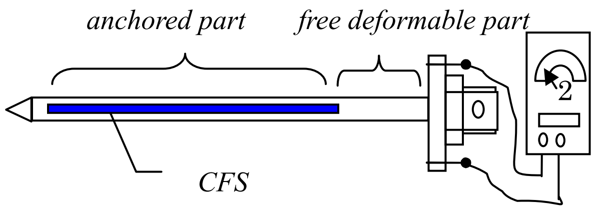


Fig. 2 imagination of SSA

## 2. Working Ability of SSA

Link to properties of SSA's the body materials and CFS, two simulative curves can be drew in Fig. 3.

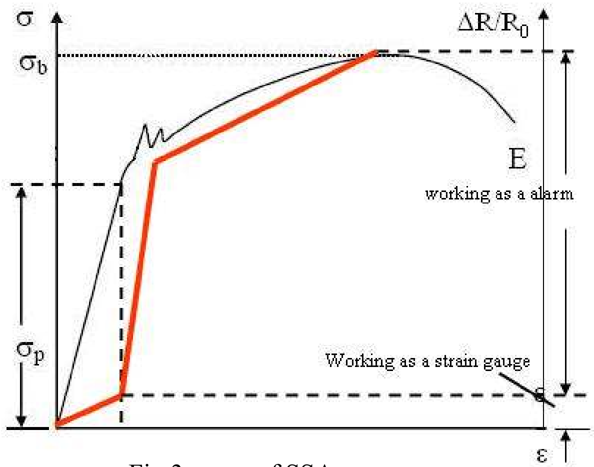


Fig.3 curve of SSA

The curve in black shows the $\sigma$–$\varepsilon$ diagram of the steel rod of anchor body. And the red one is a imagine $\Delta R/R_0$-$\varepsilon$ curve that use $\Delta R/R_0$ of SSA to show the strain state on it. There are three zones in the whole $\Delta R/R_0$-strain curve. In Zone I, within the proportional limit $\sigma_p$, $\Delta R/R_0$ should have a linear relationship to the strain, so that SSA will act as a strain gage. This relationship may be defined as:

$$\Delta R/R_0\text{-}\varepsilon \text{ function} \quad \varepsilon = S_{CFS} \times \frac{\Delta R}{R_0}$$

where $S_{CFS}$ is the slope of $\Delta R/R_0$-$\varepsilon$ curve; $\varepsilon$ is strain; $\Delta R$ is resistance change; $R_0$ is initial resistance.

In Zone II, when SSA is get over the yield strength $\sigma_s$, its $\Delta R/R_0$ greatly changed and warning that SSA is in dangerous. In Zone III, SSA is get close to the ultimate strength $\sigma_b$, it shows that SSA is going to or almost failed. During Zone II and Zone III, the value of SSA changed greatly that it is quite easy be notice, so at that time SSA take a responsibility of fail alarm.

## 3. Temperature Compensation

The primary monitoring part of SSA is CFS. During the research I found that CFS usually has a larger gauge factor than a foil gauge, but at the same time it is more sensitive to temperature than normal foil strain gauge does. In this paper, the study focuses on to remove the temperature influence. Two compensation methods are used to remove the temperature influence on CFS.

With these two methods $\Delta R/R_0$ of CFS may correspond to a linear relationship to temperature. So this linear relationship, there is compensation fact can be added to the $\Delta R/R_0$-ε function as:

$$\varepsilon = S_{CFS} \times \frac{\Delta R}{R_0} + S_T \times \Delta T$$

where $S_T$ is the slope of $\Delta R/R_0$-T curve.

At the same time another method can fig this more easily. This study put two same CFS in a series circuit, and the following function shows the main theory of it:

$$\because \Delta R_1 = \Delta R_\varepsilon + \Delta R_T, \Delta R_2 = \Delta R_T;$$

$$\therefore \Delta R_1 - \Delta R_2 = \Delta R_\varepsilon;$$

$$\therefore \varepsilon = S_{CFS} \times \frac{\Delta R_1 - \Delta R_2}{R_1}$$

Where $\Delta R_1$ is the one being tensile; $\Delta R_2$ is the one in a free state; $\Delta R_\varepsilon$ is the change cause by strain; $\Delta R_T$ is the change cause by temperature.

Fig. 4 shows the curves of $\Delta R/R_0$-strain in the morning, noon and evening, and those data are directly measured without any compensation. Fig. 5 shows the result with compensated, that the data in Fig.4 and Fig.5 are gathered in the same time.

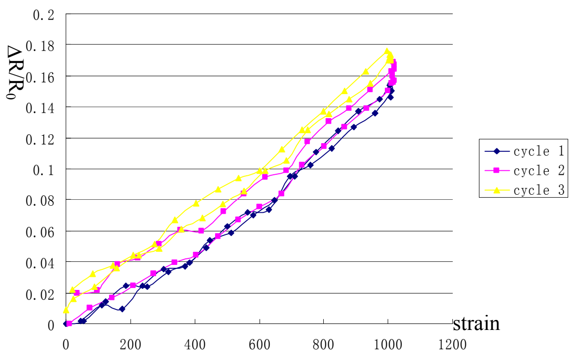


Fig. 4 three cycles without compensation

In Fig. 4, three curves show the same evolution current but affected by the temperature, it shows discreteness. And in Fig. 5, three curves almost evolutes in a very close range.

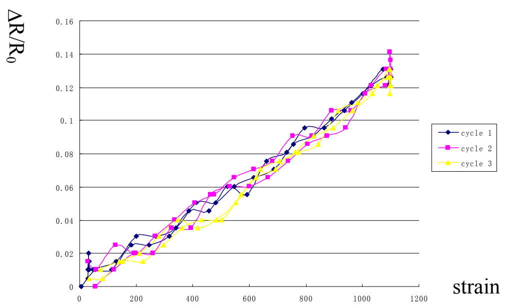


Fig. 5 three cycles with compensation

It means that with this compensation method, the temperature influence of SSA has been decreased.

## 4. Evaluating Experiments

To evaluate the working ability of SSA in different thermal environment, an axial tensile experiment of SSA is adopted here. In axial tensile experiment, CFS is bonded on the equal tensile area. In theory every point on CFS has same strain state. Base on the $\Delta R/R_0$-ε function I noticed above, to repeat this experiment twice within the proportional limit, and use $S_{T1}$ (the slope of $\Delta R/R_0$-T curve that calculated in cycle1) multiplying by $\Delta R/R_{02}$ (the resistance changing rate that measure in cycle2).

In cycle1 $S_{CFS} \times \frac{\Delta R}{R_0} + S_T \times \Delta T = a \cdot P$

where P is the load; a is a constant coefficient.

after temperature compensation, $S_T \times \Delta T = \mathbf{0}$

so $S_{CFS\mathbf{1}} = \dfrac{a \cdot P_1}{\dfrac{\Delta R}{R_0}_{\,1}}$,

then use $S_{CFS1}$ and $a \cdot P_2$ (measured in cycle 2) to calculate a calculated value of $\Delta R/R_0$ in cylce2.

Compare this calculated value with measured value of $\Delta R/R_0$ in cycle2, at last get the following figure.

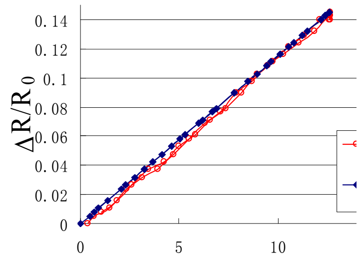


Fig. 6 inspection by axial tensile test

As shown in Fig. 6, the calculated value curve is same with the measured value. This inspection proves that SSA can show the strain state on it by itself in an unstable temperature condition.

## 5. Conclusion

This study has been undertaken with main purpose of developing a self monitoring anchor system, SSA. Its $\Delta R/R_0$ conforms to the $\Delta R/R_0$-ε function as:

$$\varepsilon = S_{CFS} \times \frac{\Delta R}{R_0} + T$$

where T is the error that cause by temperature.

With the temperature compensation that introduced above, this error T can be removed. This is an important basic research from which can develop a suitable SSA.

## Reference


(1) Z S Wu, C Q Yang, Y H Tobe, L P Ye, T Harada. "*Electrical and Mechanical Characterization of Hybrid CFRP Sheets*" Journal Of Composite Materials, Vol. 40, No. 3/2006,pp.227-244.

(2) "*Strain Gage Thermal Output and Gage Factor Variation with Temperature*" Strain Gages and Instruments, Tech Note TN-504-1, VISHAY MICRO MEASUREMENTS.