S14-2
READABILITY TEST OF RFID TEMPERATURE SENSOR EMBEDDED IN FRESH CONCRETE

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ABSTRACT: The current concrete maturity method implemented with temperature sensors requires an extensive wiring, which is not often acceptable on construction site due to harsh working environment. Radio Frequency Identification (RFID) technology appears to provide a solution for the wiring issue because of its ability of sending data wirelessly. An RFID tag integrated with a temperature sensor and placed within fresh concrete may be able to read temperatures of concrete and transmit them to an RFID reader wirelessly in real-time. However the previous research illustrated that the RFID signal gets dispersed in liquid medium. One may speculate then whether RFID signals travel through fresh concrete with high water content. Would the tag's burying depth within fresh concrete affect its readability? The paper presents the preliminary results of our on-going investigation on the readability of RFID tags in concrete against water content and burying depth of tags.

Keywords: RFID; Concrete Maturity

1. INTRODUCTION

The premature removal of formwork has been one of the main causes of sudden collapse of buildings under construction, which often time resulted in casualties. Fourteen workers were killed and 34 were injured when the multi-story building in Fairfax County in Virginia collapsed in 1973 during construction. Fifty-one workers were killed when the cooling tower in Willow Island in West Virginia collapsed in 1978 during construction. Both incidents were cased by early removal of forms from the cast-in-place concrete structure. Estimating the strength development in the cast-in-place concrete students at the early stage of the curing process therefore has been of a major interest among construction professionals who want to speed up the concrete placement process but still secure the stability of the structure.

One of the most popular methods to figure out the strength development of fresh concrete placed in the form is utilizing test cylinders. Construction professionals could produce, if they want, test cylinders on the jobsite when concrete is being placed in the form and run the test to figure out the strength development of these cylinders as time goes by. When the strength of the test cylinder exceeded a certain capacity, the project manager gains confidence that the structure made of in-place concrete is strong enough and they can move on to the next activity.

Although the test cylinders are produced from the same batch of fresh concrete, they may exhibit a different strength development pattern against in-place concrete because of different curing conditions and environment. This may sometimes result in inaccurate reflection of actual concrete strength development. The best way to figure out the strength development of in-place concrete at its early stage of the curing process would be measuring its strength directly. Knowing that this would not be practical, many non-destructive methods have been suggested. Concrete maturity method is one of the many non-destructive methods suggested so far, and is currently gaining professionals' attention as it could provide an opportunity to determine concrete strength in real-time.

The concrete maturity method comes from understanding the relationship between the thermal history of concrete and its strength development at the early stage of the hydration process. Temperature within the in-place concrete increases as time goes by because of the hydration reaction. Understanding the co-relationship between this temperature change and concrete strength development gives us a chance to estimate concrete strength at a certain time during the concrete curing process. Nurse-Saul came up with an equation defining the maturity index of in-place concrete using temperature chances within concrete and elapsed time. If the maturity index can be used to determine the strength of concrete in real-time, all we have to do to get to know the strength of in-place concrete is to measure the temperature within concrete. Goodrum [1] demonstrated from the pilot project conducted in Puerto Rico that the in-situ concrete strength can be more accurately and consistently determined by the concrete maturity method than with other conventional methods. However, he also reported that 1) the strength development within in-site concrete was not uniform due to differences in temperature and hydration in different parts of a given structure, and 2) it was not easy to keep wires connected between data loggers and the computer system.

Goodrum's report suggests that the concrete maturity method can be better applied to tough construction job sites if we can handle wiring issues. One of the off-the-shelf technologies that may enable us to eliminate the use of wire in terms of applying the concrete maturity method is Radio Frequency Identification (RFID) technology. In fact, an RFID tag integrated with temperature sensor, which can read temperature and emit temperature data, was developed by an RFID vender and empirically tested by Michigan Department of Transportation [2, 3]. In this test, the RFID tags integrated with temperature sensor were placed inside the form before concrete was place. When the pouring was completed, the temperature inside concrete was monitored to determine the strength of concrete using concrete maturity method.

2. MOTIVATION

According to the Fletcher's study [4], however, Radio Frequency (RF) wave gets absorbed in liquid. The RFID readability decreases or stops if the tag is submerged in water. His study suggests that RFID tags embedded in fresh concrete that has high water content may hinder RF signals from traveling. Therefore, one may speculate that the burying depth of the RFID tag within fresh concrete may have some effect on its readability. This paper presents our on-going test to figure out how the RFID signal emitted within fresh concrete at various depths gets detected at the early stage of the curing process.

3. EXPERIMENT

Knowing that the thickness of concrete members varies with every project, and the water content reduces as the hydration process takes places, we decided to design the test with following variables: 1) burying depth of RFID tags, 2) Distance of reader from the tag, and 3) elapsed time after concrete is placed.

3.1 Size of concrete blocks

Considering various types and sizes of concrete members, it would not be possible to produce the reasonable outcome that can be generalized unless a significant amount of cases are prepared and tested. Before getting into a substantial size of investigation, we decided to test a limited amount of cases in terms of tag location, which would allow us to see the trend and come up with the plan for full-scale investigation. We then looked up a various sizes of concrete components used for commercial building projects in Texas and found that 2ft x 2ft x 2ft concrete may help us yield basic knowledge about the impact of 1) the tag location within the concrete block and 2) elapsed time after concrete is placed on the usability of RFID tags. We found, however, that the RFID tag is about 5 inch long (5.15in x 1.1in x 0.8in), and therefore each size of the tag would end up locating closer to the surface than where it is supposed be. For example, if the tag is place in the middle of 2ft x 2ft x 2ft concrete box, one size of the RFID tags would end up sitting 2.5 inch closer to the surface of the concrete block than the middle the RFID tag does, which may hinder us from collecting accurate data. In order to not to end up getting into this situation, we decided to increase the size of the concrete box to 3ft x 2ft x 2ft. We prepared four of them.

3.2 Tag location

For this test, we used an active RFID tag integrated with a temperature sensor. According to the vendor's information, the tag is capable of sending signals as far as 300ft. We placed three tags in the concrete box in such a way that they were at the same distance from top and front of the concrete box. The distance between two tags was decided by taking the size of each tag into consideration. Considering the tag's thickness of 1.1 inch, we decided to place the tag every 4 inches, which leaves a gap of about 3 inches between tags. If the distance between the tags is decreased by adding more tags within the box, then the difference between the observations may be insignificant. The tags were suspended by nylon thread and wooden dowels instead of metal chair. The use of any metal was avoided to minimize any other variation apart from decided variation. The nylon thread used for the test has a negligible thickness, which assured minimum interference. The tags were suspended at 4 inches, 8 inches and 12 inches from the surface as shown in the figure 1.

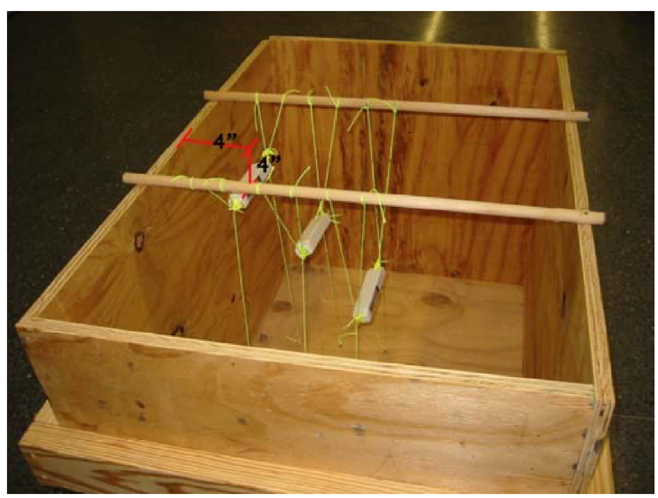

Figure 1: Tag locations

The tags were placed in such a way that their longer side is parallel to the longer edge of the box. This is to ensure that the signals emitted from the tag would travel approximately the same distance.

3.3 Reader

The reader used was a fully compliant PCMCIA (Personal Computer Memory Card International Association) Type II card that turns any compatible laptop, handheld or other computing device into a powerful Intelligent Long Range (ILR) active reader with a range of 300ft. An RFID vendor provided the software for the reader. After installing the driver and inserting the card into the slot of the laptop, the laptop served as a RFID reader.

3.4 Concrete

We used ready mix concrete for all 4 boxes to make sure that we don't get different result due to different concrete property. The concrete's target strength is 3,000 psi. The slump of concrete marked 5 inches. The water cement ratio of the concrete was 0.53 by volume.

3.5. Implementation of Experiment

The experiment was carried out at an open ground in Texas. The concrete was poured slowly into the box prepared in order to avoid any damage to the strings holding the tag in the box. The test started on 10/18/2007 and continued for 13 days. Highest temperature during the test period was 90°F and lowest temperature was 42°F. Humidity changed somewhere between 50% and 80%.

4. TEST RESULTS

The tags embedded either in 4 inches from the surface started giving readings 3-4 hours after concrete was placed. The tags at the depth of 4 inches were able to transmit the signal to a distance of 60 ft where as the tags at the depth of 8 inches were limited to the range of 30 ft. The signals from the tags embedded at the depth of 12" were weakest of all. After 7 days the range of the tags increased considerably. The tags at the depth of 8 inches were able to transmit the signal to a distance of 45 ft and the tags at the depth of 12 inches were able to transfer the data to a range of 15 ft.

A distance versus time graph was prepared for every tag, which marks the time at which the tag started giving the signal at a particular distance. Figure 2 shows variation of the range of tags at depth of 4 inches from the surface with time. The tag in Box 1 started giving the signal 4.5 hours after pouring the concrete. The reading range of the tag in box 1 was increased suddenly 23 hours after pouring the concrete. The tag in Box 2 started transmitting just 1 hour after concrete was placed. The range of the tag increased with the time and it started transmitting the signal at the range to a 60 ft 21 hrs after the concrete was poured. The tag in Box 3 started giving the signal 3 hours after the concrete placement. There was a sudden increase in the range around 20 hrs later. This tag installed in Box 4 started responding to the reader after 3 hrs. All the tags showed similar trend with time. The tags were not responding during the first three hours after pouring the concrete when water ratio was high in concrete. This illustrates our speculation that RFID might not be able to transmit the signal in fresh concrete. There was an increase in reading range as the concrete were getting matured and water content of the concrete deceased.

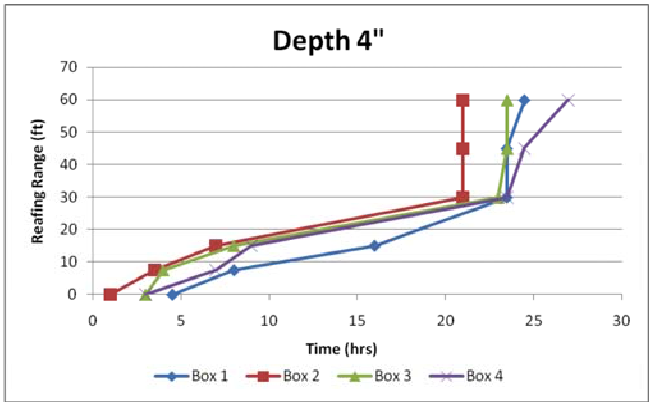

Figure 2: Reading range of RFID tags installed at 4 inches from the surface

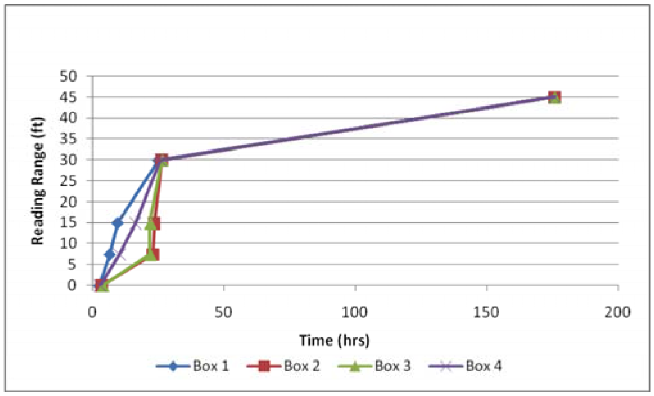

Figure 3: Reading range of RFID tags installed at 8 inches from the surface

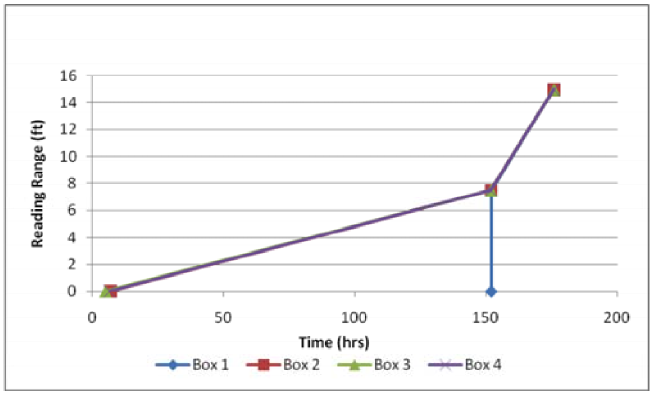

Figure 4: Reading range of RFID tags installed at 12 inches from the surface

Figure 3 illustrates increase in the reading range of tags embedded at 8 inches with time. The reading range was stabilized after a gradual increase till 26 hours after the time of pouring. The tags showed the increase in the reading range after 7 days of pouring.

Figure 4 shows the reading range variation of tags buried at the depth of 12 inches. These tags were last to respond and showed a lower reading range as compared with the tags at 4 inches or 8 inches in depth. The reading range of the tags was 15 ft 7 days after the time of pouring.

5. ANALYSIS

The tags embedded at 4 inches in the concrete box were first to respond after the pouring of the concrete and were the earliest to reach at an increased reading range. The tags at 12 inches in the concrete box were the last to respond and were last to get to the subsequent reading range. This observation suggests that the readability of the RFID tags may be reverse proportional to the depth of the tags within the concrete box.

The tags were not able to transmit the signal in the fresh concrete, but as the concrete matured and water content in concrete decreased, the tags were able to transmit the signal. One may speculate that the RFID tags were not able to transmit the signal during the first 3 hours due to high water content within the concrete box. This illustrates that RFID tag's readability may be affected adversely by the water content with in concrete.

6. CONCLUSION

Our test discovered that:

- The signal of RFID tag did not travel during the first three hours when they were imbedded in fresh concrete.
- The reading range of the RFID tags increased with time
- The reading range of the RFID tags was inversely proportional to the burying depth of the tag within concrete.

Although the results from this experiment cannot be generalized for the whole industry because a limited number of cases were tested using RFID tags provided by just one vendor, the presented test demonstrated that 1) the readability of the RFID tags embedded in fresh concrete was reversely proportional to the depth of the tag within concrete, and 2) the reading range of the RFID tags is inversely proportional to the burying depth of the tag.

One may speculate that the readability of RFID tags in fresh concrete was affected by the presence of water content because the reading range of the tags increased remarkably as the water content was getting reduced with time. The tag embedded at a greater depth had shorter range as compared to the tag at lesser depth even after a certain hydration process took place. This variation may not be just because of water content in concrete as water content reduces as time goes by. The reading range may also be affected by something relative to concrete composition. Further investigation therefore should be implemented to figure out the reason for this incident and derive a generalized conclusion. The variations in the reading range can be enticing for the researchers in the construction industry. Similar experiments should be carried out with tags from different vendors and at different locations.

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