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CHARACTERISTIC OF MOISTURE MEASUREMENT ON BASE MATERIAL OF FLEXIBLE PAVEMENT

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***Abstract*— Moisture is one of the influential factors of pavement structural condition generally, and base layer specifically. Having that said, owning adequate data of moisture condition may prevent unwanted damage in the future. At the moment, in Thailand a proper field moisture measurement and time-series data are still unknown. Therefore, in this study moisture sensor is installed in an unbound base layer of road section to monitor the moisture fluctuation all day for a long period. The expected benefit from this study is to obtain the knowledge of how the moisture changes over time on a daily basis, and to gain the information of plausible specific time of moisture measurement on road pavement.**

***Index Terms*— unbound base layer, moisture measurement, moisture sensor, flexible pavement**

I. INTRODUCTION

There are many factors influencing the quality and performance of a pavement structure. Design, material, traffic, construction quality, and also environmental factor such as moisture and temperature conditions are among those affecting factors [1]. Flexible pavement having a thin surface layer on a thick unbound base layer, a typical setup in this region, must mostly rely on a strong support from its base layer.

Moisture condition of pavement layers has a significant influence in building strength and modulus of unbound materials. Variation in the amount of moisture inside the unbound base layer can sensitively cause structural deformation and mechanistic performance of flexible pavement. An excess of water may break material bonding inside pavement layer, which eventually cause the deformation and performance degradation. Roughness, rutting, and cracking are among several damage that might appear due to moisture problem [1,3,10]. At a certain value of moisture content, the modulus of unbound base layer might be reduced to a significant level. Moreover, it can eventually reduce pavement service life. This is a condition we want the least to happen.

In general, water movement inside a pavement structure has two components, lateral movement and vertical movement. Vertical movement may consist of surface infiltration, infiltration caused by layer permeability, or even water suction due to difference of potential. Lateral movement is mainly comprises of runoff, drainage related, and can be a water suction [2,9] as well. Either way, the water movement remains unexpected, and thus leaves us with the changing value of moisture condition as well.

Considering the risk it may bring, and the need of preventing early damage, it is necessary to have adequate information about the moisture condition of the base layer over time. There are many alternatives, in terms of measurement method, to obtain adequate moisture measurement. However, a comfortable and reliable method should be preferable.

Some examples of moisture measurement methods that are popularly used until now are gravimetric analysis, dielectric method (moisture sensor), ground penetrating radar, and nuclear gauge.

II. BACKGROUND

A. Soil Moisture Measurement Methods

Ground moisture condition is a typical important parameter in geotechnical-related matter. There are two general classification of measurement method comprises: direct (gravimetric) and indirect (e.g. nuclear gauge, ground penetrating radar, moisture sensor).

Gravimetric has been the most fundamental and basic moisture content measurement until now. This type of measurement is a lab-scale activity, which requires samples to be obtained from the field.

Gravimetric moisture content is expressed as the ratio of water mass to the dry mass of a given solid mass sample. The representative formulas are given below.

Volumetric MC: $\theta = V_w/(V_S + V_P)$ (1)

Gravimetric MC: $w = m_w/m_S$ (2)

$$w = \theta * \rho_w/\rho_S \quad (3)$$

Where,

θ is volumetric moisture content
w is gravimetric moisture content
V_w is volume of water
V_S is volume of the solid particle
V_P is volume of pore
ρ_w is the density of water (=1)
ρ_S is the bulk density of the soil sample (=m_S/V_S)
m_S is mass of solid particle
m_w is mass of water

A sample taken is comprised of three main components: air, water, and solid particles (might be soil particle, gravel, etc.) as shown by the picture above. By removing the water through heating process, we may obtain the weight or volume of the rest components. This is the basic principle of oven-sampling method.

The fact that it requires field samples for the lab test causes this method as an utter field-destructive method, and it takes fairly much time. Despite of its fundamental principal and usage, gravimetric method has been commonly used as reference for other methods of measurement, instead of as routine measurement.

An indirect method offers a soil moisture measurement alternative that disturb soil sample the least and can be operated at site. Some widely used indirect methods at present are ground penetrating radar (GPR), nuclear density/moisture gauge (NDG) and dielectric moisture sensor.

A GPR system consists of three main parts, comprises of the control unit, the antenna and the survey encoder. The antenna has a transmitter and a receiver. When the signal returns to the antenna, travel time and amplitude will be reported on the screen of the survey encoder. The antenna itself has a wide range of frequencies (control unit) for different specific uses. High frequencies are used for shallow depth of observations whereas low frequencies are used for deep depth and large targets of observations.

Radar signal can travel faster in a low dielectric medium than in a higher dielectric medium. As water has higher dielectric constant than others, the signal travels longer when water exists. This petrophysical relation between volumetric moisture content and dielectric constant is the background principal that makes the use of GPR versatile to moisture estimation.

Nuclear Density/Moisture Gauge (NDG) is a radiation-based instrument. NDG works by releasing gamma radiation, ‘fast’ neutrons into the material. When the ‘fast’ neutron collides with another atom that similar in mass with it, it may lose some amount of energy and be slowed down. Hydrogen, which forms water particle, has fairly same mass as the neutron released by the nuclear gauge. Therefore, principally the gamma radiation will be slowed down whenever there is an interaction with hydrogen atom specifically, or water generally.

NDG detectors will count the gamma rays that passed through the material during radiation. This counted number is the basis to estimate the moisture content. Basically, the more neutrons counted, the higher the moisture content of the material.

B. Moisture Sensor (Dielectric Method)

The most common indirect method is moisture sensor. A moisture sensor works on an electrical-based principle, which implements the nature of electrical impulse in its relation to water presence. Speed of electrical impulse is determined which is affected by the amount of water on its wave path.

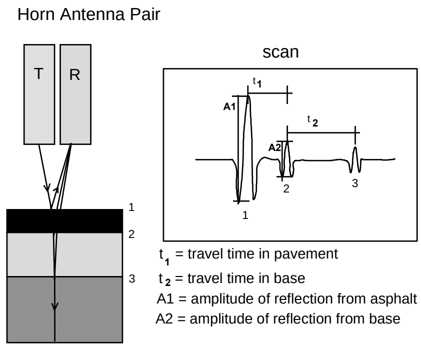

Fig. 1. **Basic GPR Working Principle [14]**

C. Implementation and Evaluation of Moisture Sensor

Moisture sensor has widely been used in agriculture environment, and fairly used in engineering matter. It is considered very useful for both industrial and academic research.

Some studies have conducted experimental research to evaluate the adequacy of moisture sensor during ground moisture measurement (i.e. soil). It has been found that moisture sensor is commonly sensitive to material type and temperature, or combination between both (and salinity for some types).

Cataldo et. al. (2009) tested TDR-based moisture sensor to monitor moisture value on granular materials, such as siliceous sand and feedstuffs, experimentally. The study concluded that TDR-based moisture sensor is classified as valid tools for granular materials moisture measurement based on the accuracy of the result. In the study, they used TDR sensor on previously moistened granular samples.[5]

A moisture sensor using dielectric method estimates the moisture content based on dielectric constant (ε_r) of the measured medium. Dielectric constant is a value that represents the velocity of an electromagnetic wave propagated through a medium (i.e. soil). In other words, dielectric constant represents the ability of a medium conducting electric force. The most fundamental basis of dielectric method is that water has significantly higher dielectric constant (ε_r -water = 80) than other materials. The velocity of a wave going through a certain medium will be highly determined by the existence of water. Hence, it can help us estimate the moisture content.

There are many variations of dielectric measurement methods depending on the material type, sample geometry, and frequency range, of which three different types. Those are Time-Domain Reflectometry (TDR), Frequency Domain, and Amplitude Domain Reflectometry (ADR). Each type has significantly different working principles but as mentioned before, they estimate moisture content based on dielectric constant. Choosing one from the other is commonly based on the usage suitability.

The relationship between dielectric constant and volumetric water content has been developing for the last several decades. The most drawing attention is the works of Topp et al. (1980), as following.

$$\theta = -5.3\times10^{-2} + 2.92\times10^{-2}\varepsilon_r - 5.5\times10^{-4}\varepsilon_r^2 + 4.3\times10^{6}\varepsilon_r^3 \quad (4)$$

Where,

θ : volumetric moisture content
ε_r : dieletric constant

This equation is compatible for various kinds of soil type. However, there are still doubts about its accuracy if used in specific soil type.

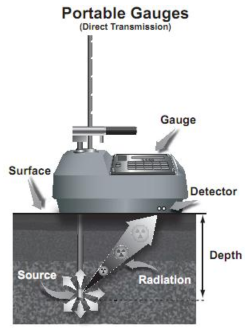

Fig. 2. **Nuclear Gauge Basic Working Principle [4]**

Moisture sensor performs differently on two different material type (soil and clay) when the temperature is varied. Soil samples were placed in a container and embedded with moisture sensor, and inserted into oven to find out the effect of temperature in measurement. Temperature was found having more significant effect on clay measurement than on sand (Merlin et.al. 2007).[11]

In conclusion, NDG and GPR are both quite comfortable to use, in addition NDG even gives a fairly fast result of measurement. However, both are highly priced and could only be done once at one point of time. Oven-sampling method with gravimetric analysis as being mentioned is a long-process and destructive method. Moisture sensor on the other hand has suitably reasonable price, is comfortable to use, and gives fast result.

III. OBJECTIVES

This study aims to implement an electrical-based moisture sensor for a case of typical pavement structure, and more importantly to find adequate information of how moisture inside unbound base layer changes over time.

In this study, electrical-based measurement is considered to be relatively suitable and reliable in terms of field moisture measurement over a long period. We are aiming to collect time-series data using a set of moisture sensor.

Secondly, the specific objective is to analyze the characteristic of moisture measurement result from the sensor into a general preliminary suggestion in base layer moisture measurement. We aimed to find several characteristics, such as measurement timing, moisture value alteration-trend, and plausible information in summary.

IV. METHODOLOGY

In order to obtain the information related to moisture changes over time inside the unbound base layer, we conducted a monitoring process on a typical flexible pavement section. The pavement site locates in Saraburi province of Central Thailand region. The base moisture monitor is an automatic process, comprises of a set of main instrument: an ML2x Thetaprobe, and an automatic GP1 data logger as illustrated in Figure 4.

Fig. 3. **ML2x Thetaprobe (left) and GP1 Data Logger (right)**

A. ML2x Thetaprobe

ML2x Thetaprobe is an amplitude-domain-reflectometry-based sensor, which uses electrical pulse as a tool to detect water content of a medium. Electrical wave sent from the probe will interact with water inside the medium that will produce a reading on the logger. The measurement area is relatively small, taking shape of a cylinder (about 1.2-inch) [12]. The reading will be presented in percentage value that represents volumetric moisture content.

B. Installation

We chose a feasible road section that has typical structure to avoid specific measurement bias. To keep the logger safe from unexpected weather factor, or might as well theft, we set up the logger on a nearby shelter on the road shoulder. Bird-eye view of field set up is shown on Figure 5.

In order to reach the base layer with the moisture probe, a coring-machine with 4-inch diameter head is used to remove the surface layer. The depth of coring is 50 mm (surface layer thickness). The distance between center-point of the hole to the edge of pavement is 600 mm. Before insertion, we drilled 4 small holes to enable the probe insertion easier.

The ML2x Thetaprobe is embedded in the base layer and buried with aggregates. Then hot mix asphalt with fine-graded aggregates is applied on the upper portion to seal the hole on surface layer, and ultimately to repair the surface in order to prevent water penetrates easily into the observed base layer.

The moisture sensor is connected to GP1 data-logger that is kept under a shelter nearby. This is to keep out the logger from external distraction. GP1 data-logger is set to record moisture value of the base layer every 15 minutes all day every day. Recorded data is stored in memory, and can be collected each time of site visit without stopping the logging process.

C. Duration and Maintenance

The moisture measurement is set to operate continually for a long period. In this article particularly, we have collected a portion of moisture measurement data for 15 weeks to find any characteristic pattern of moisture changes inside the base layer. The obtained data is in the period of 1-December 2013 to 15-March 2014.

The performance of this kind of moisture sensor actually relies on the power supply, or specifically in this case, the battery level. Manual explained that ML2x Thetaprobe needs at least 5.0V battery power to produce good measurement. Therefore, we do periodical site visits and battery replacement.

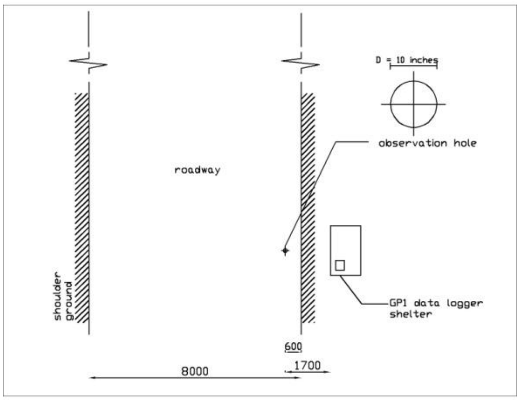

Fig. 4. **Top View of Field Observation Site**

V. RESULTS, ANALYSIS AND DISCUSSION

The objective of this study is to investigate the characteristic of moisture measurement on base layer of road section. The result of this study is specific for measurement using moisture sensor technology, and mainly focusing on characteristic of moisture changes in a specific period of time.

Figure 7 illustrates the moisture in base layer measured in 15 weeks. The result shows that moisture definitely fluctuates over the weeks of measurement. In larger scope, the increasing and decreasing activity shows an approachable pattern. This brings to the smaller scope where volumetric moisture content is apparently changing over 24 hours every day. The fluctuation is different for each day, with fluctuation range is vary between 0.2% and 0.7% of reading value (volumetric moisture content).

In Figure 7, we can also see there is some inconsistency of measurement in between 10-January and 22-January, specifically shown by the green highlight. The distortion of data logging was found out to be caused by battery power insufficiency. Therefore, measured data on that period of time is omitted from further analysis.

A. Sinusoidal Pattern

Based on this 15-week logged data between December 1st, 2013 and March 13th, 2014 we found that volumetric moisture value fluctuates following a pattern similar to sinusoidal graph. The blue line in small graph inside Figure 7 can show us visually the sinusoidal shape of the fluctuation, in which each column represents one day data.

It is observed that the moisture content fluctuation may be symmetric. Therefore, a sinusoidal regression is conducted to validate the relevancy of sinusoidal approach to our existing data. Assuming that the mean of moisture values is linear in one day, we fitted sinusoidal equation to moisture data on each day, and collect the R-square for each day.

In this study, the regression is conducted using PAST 3.01 statistical software. The sinusoidal fitting process inside the software used the general formula of sinusoidal equation as:

$$y = A\cos(Bx - C) + D \qquad (5)$$

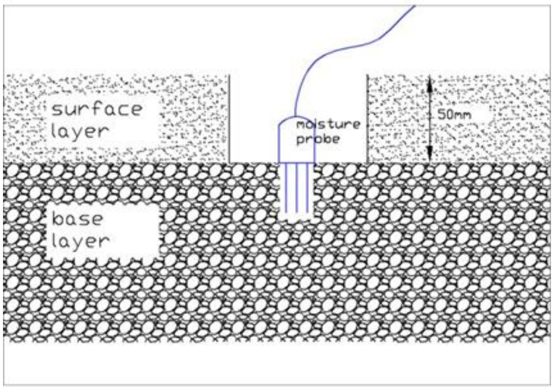

Fig. 5. **Detailed View of Observation Hole**

Where:

A = amplitude
B = 2π/T
C = phase shift
D = mean offset
T = period (minute)

The unknown variables to be found are: A, B, C and D. Instead of set as fixed, period is set to be fitted as well to see the difference of moisture fluctuation period for each day. Since the logging interval is every 15 minutes, period value is in minute unit. In the data of each day, time of zero minute is equivalent to 00:00 hour (mid night). The result is presented on next Table 1:

The results of all R-square values from our data are above 0.850 and average R-square value is 0.900 which indicate a very good fitting. Based on these results, we may conclude that sinusoidal approach is suitable to use as reference for daily moisture changes under the condition stated in the first paragraph of this section. Figure 6 illustrates a fitting sample from one of the existing data.

B. Sinusoidal Fitting

In the fitting process, the fitted equations are actually different from each other day because of moisture daily variation.

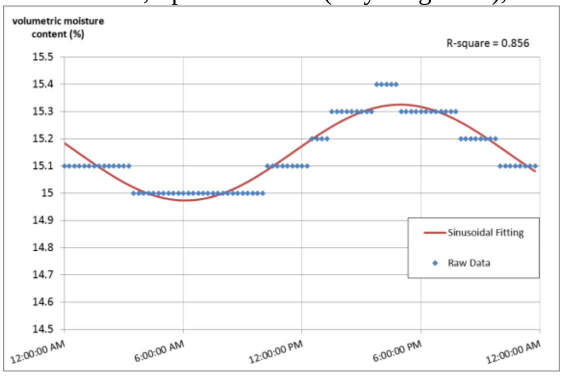

Fig. 6. **Sample of Sinusoidal Fitting on 23-February**

Moreover, it is also found that it is possible to fit one sinusoidal equation for similar data from several days. However, due to the inconsistency and unexpected changes of moisture changes, it is considered unreasonable to set the number of days for one sinusoidal equation.

Figure 8 gives an illustration regarding the variations of sinusoidal equation for each day. The distribution of amplitude value is widely spread away from the red line (average). Amplitude size represents the range of fluctuation value on each day, which means the larger the amplitude, the bigger the moisture fluctuation range. There are many factors that can cause these daily variations, of which environmental factor might be the most probable factor in this case.

On the other hand, the period (T) value shows fairly similar value on each day fitting. We may use this finding as reference to determine our measurement timing for daily measurement.

C. Measurement Timing

Moisture measurement might not be possible to do using monitoring system every time for each case study. For maintenance matter, we could measure the moisture on a daily basis. Moreover, we can save a lot of measuring time by knowing the right time to obtain volumetric moisture value that fairly represents the day.

In this study, we found that moisture is actually fluctuates leaving two extreme value at different time on each day. Logged-data showed that the volumetric moisture content reaches minimum value in the early morning and reaches maximum value in the mid-afternoon.

In Figure 8, we can see the period variation on each day from included data of 15-week logging. While the red line represents the average value of the period, the distribution of each day period is fairly consistent and not immensely scattered. We found an average value of 1,300 minutes represents the period variation of the collected data. This value can be used as reference to conduct measurement in the field by using moisture sensor based equipment. While period is the distance between the same extreme values, our measurement timing should have half-period time distance. In conclusion, the time difference between the first and second measurement should be 650 minutes (approximately 10 hours).

Figure 9 shows the overall fitting results of each day data. It reveals that minimum volumetric moisture value of each measurement day is consistently found between 5:45 and 6:15 hour in the morning. On the other hand, the maximum volumetric moisture value of each measurement day is consistently found inside 16:30 – 17:00 time range in the afternoon. The area between two adjacent red lines represents the time area where extreme values should be measured.

By using this information and the recommended measurement time difference, we can plan two measurement times between those time period and include a space between measurement approximately 10 hours.

D. Average Volumetric Moisture Content

As previously mentioned, the representing value of volumetric moisture content is considered best taken from average value for each day. On its relation to this matter, it is advantageous to use the sinusoidal approach. The generalized sinusoidal formula as presented before shows D as an offset value, which is actually the mid-value of the sinusoidal graph. Based on trigonometric, the offset value can be calculated by averaging the two extreme measured values (maximum and minimum).

In summary, we can simply obtain the average volumetric moisture content value to represent each day by collecting only both maximum and minimum value of the day.

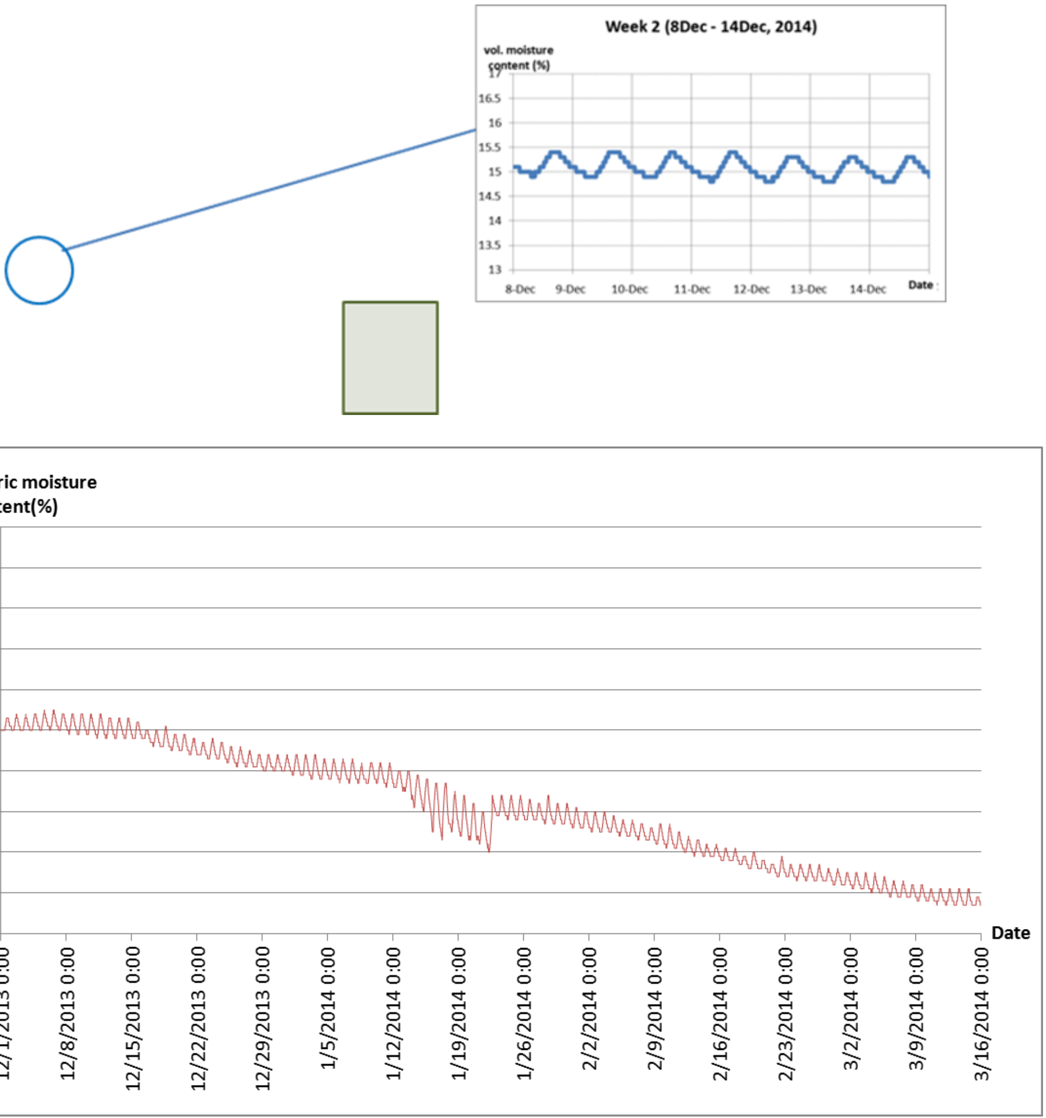

Fig. 7. **Moisture fluctuation on base layer during 15-Week data logging**

Figure 8 shows the offset variations over time in 15 weeks. The trend shows a decreasing movement from time to time in the period of measurement. This is normal knowing that Thailand is entering summer season during the logging activity at the moment, in which a long dry condition is normally expected to be happened.

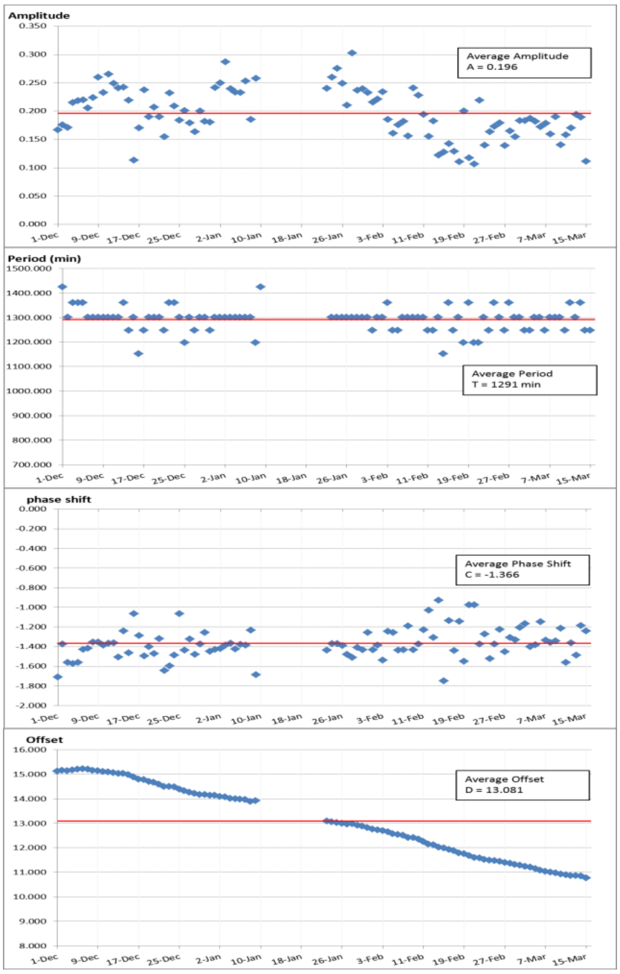

Fig. 8. **Variation of amplitude (A), period (T), phase shift (C), and offset (D) over time**

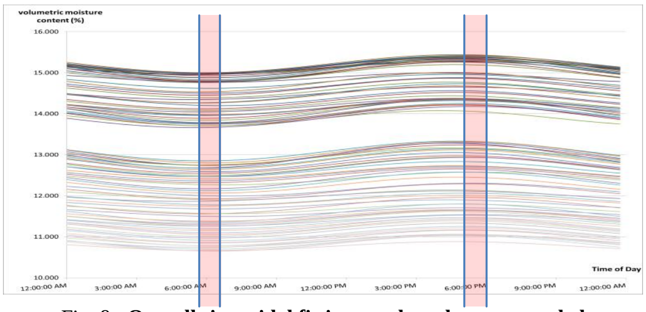

Fig. 9. **Overall sinusoidal fitting result and recommended measurement time of day**

VI. CONCLUSION

Moisture is one of the key factors affecting modulus and strength of unbound materials in flexible pavement structure. In this study, moisture condition in the unbound base layer is the main focus, particularly its alteration. The volumetric moisture content of unbound base layer was monitored for a long period on a flexible pavement section representing a typical thin surfaced structure. The results of moisture measurement over a period of 15 weeks in summer season reveal that moisture content in unbound base layer changes in sinusoidal pattern over each day. Based on the regression analysis, the average sinusoidal period is 21.67 hours.

The research finding suggests that moisture monitoring over time should be applied to obtain sufficient moisture data for determining the mean value of moisture content to represent the condition for each day. Based on the analysis in this study, it is suggested that extreme measurement values locate between 5:45 to 6:15 hr in the morning for the first measurement, and anytime between 16:30 to 17:00 hr in the afternoon for the second measurement of the day. A moisture measurement task should simply capture at least these two time pockets to obtain the reasonable average moisture value.

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