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Relationship between Moisture Content and Dielectric Values of Concrete using Ground Penetrating Radar Method

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ABSTRAK

The moisture content (MC) in concrete structures is an agent that may result in corrosion of steel reinforcement and further deterioration of concrete. The non-destructive technique (NDT) of the Ground Penetrating Radar (GPR) is a technique to assess concrete structures' condition. However, the propagation of GPR electromagnetic waves (EW) is strongly influenced by the MC of propagation medium. Hence, the objective of this study is to determine the effect of MC on EW velocity and dielectric value based on different MC of concrete and at various steel reinforcement diameters. Antenna frequency of 1.6 GHz is used based on the depth of the reinforcement which is less than 0.5 m. A concrete slab of 0.15 x 0.20 x 0.35 m^3 was prepared using three different sizes of steel reinforcement of 12, 16, 20 (mm) at different depths of 25, 60 and 120 (mm). After 28 days wet cured, the sample is oven-dried to remove moisture. Next, the sample was immersed in water for 5 min, 10 min, 30 min, 60 min, per hour to 6 hours, from day 1-9 to obtain different MC. The effect of concrete MC on GPR EW can be seen through the hyperbola image, which begins to fade on the 3rd day of immersion, at MC of 2.31%. The dielectric values obtained are 10.11 for concrete that are immersed for more 9 days (MC 2.54%). The range of dielectric values obtained are within the range in ASTM D-6432, which is 5-10 for concrete. Finally, the percentage difference (%) of the diameter steel reinforcement obtained for relative MC is 0.3% for size 12 mm, 28.56 for size 16 mm and -7.7% for size 20 mm. The percentage difference (%) increases when MC increases. Relationship between %MC within the value obtained and dielectric value is proposed.

Keyword:
Moisture Content, Ground Penetrating Radar, Dielectric Value, Size of Rebar, Rebar Depth

1. Introduction

Concrete protection plays an important role in protecting structural elements, particularly reinforcement. Concrete cover is a barrier to moisture, carbon dioxide and chloride which can cause corrosion of steel reinforcement. Therefore, the characterization of concrete cover is important to the resistance of concrete structures [3]. A non-destructive technique (NDT) of

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Ground Penetrating Radar (GPR) shows its effectiveness in evaluating concrete structures. According to Hasan and Yazdani [7] GPR was initially used in geophysics to determine the nature of the land and then applied in the civil engineering sector. GPR is used to assess concrete or masonry structures in determining slab thickness or reinforcement location, as well as to determine moisture content (MC) in concrete. Most usage of GPR are related to rebar detection and mapping. The layout, MC and voids in the structure can also be assessed using GPR [9]. The GPR electromagnetic wave velocity is associated with the content and MC in a substance, such as soil and rock.

The relationship between GPR electromagnetic wave velocity and MC had been reported by Sbartaï *et al*. [13] and Senin and Hamid [14]. The wave velocity changes are indicated by direct wave amplitude and reflected wave amplitude. Direct waves are waves that are from the surface reflection of the concrete while the reflection wave is a reflection from the metal object. Figure 1 shows an inversely proportional relationship between the electromagnetic wave velocity and MC between 0 to 16 %. The electromagnetic wave velocity decreases when MC increases. Rodriguez-Abad *et al*. [12] has also shown the effect of MC on electromagnetic wave velocity. The two way-travel times of the reflected wave increased when the samples were immersed in the water. The wave amplitude peaks of the reflected decreased when the sample were immersed into water. The shift in the two-way travel time of the reflected wave recorded when the sample was immersed into water and when the sample was dry (Figure 2). This causes the EM wave propagation velocity to decrease, and thus resulting in the increasing of dielectric value.

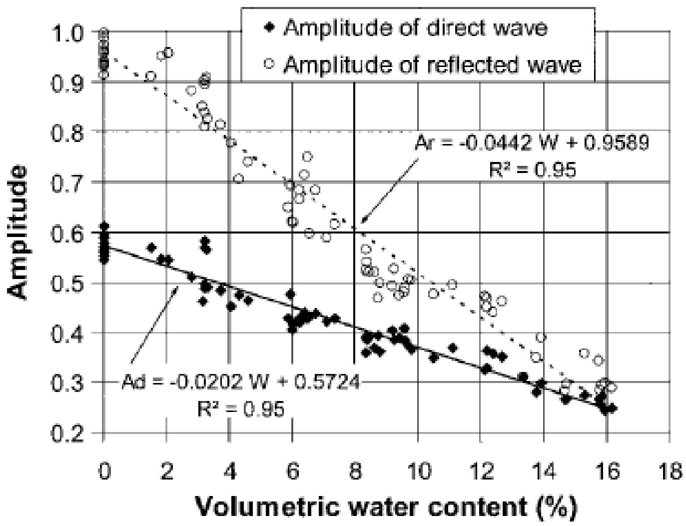

Fig. 1. Relationship between EM wave velocity and moisture content (%) [13]

According to Kapanvural *et al*. [8], the decrease in EM wave velocity due to MC had caused the dielectric value to increase. Relative dielectric permittivity of the media can be estimated from the radargrams using the hyperbola fitting. By fitting the hyperbolas to the first reflections from the rebar, the velocity of the concrete can be calculated which gives information about the water content in a concrete (Figure 3). The dielectric value increase when there is a presence of moisture content in the concrete. Leucci [11] shows the relationship between the dielectric value and MC between 4 to 16 %. Observing the plot in Figure 4, it can be seen that it is a polynomial relationship between dielectric value and moisture content suggesting a strong relationship between both.

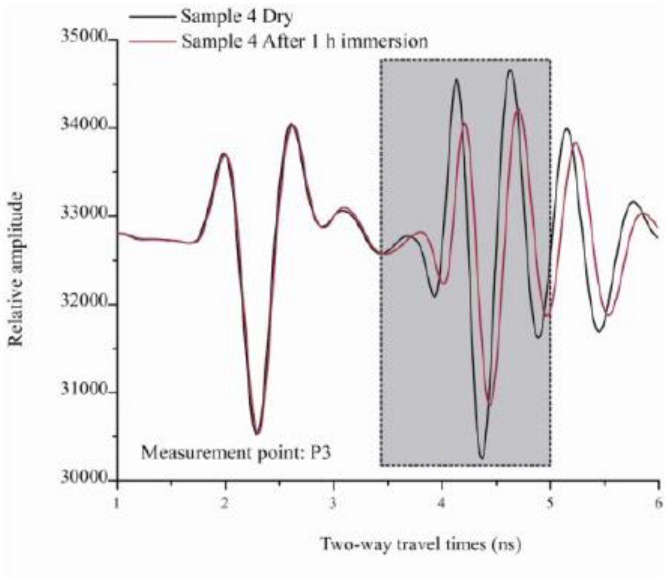

Fig. 2. Signals recorded for sample 4 when it was dry and after 1h immersion in water [12]

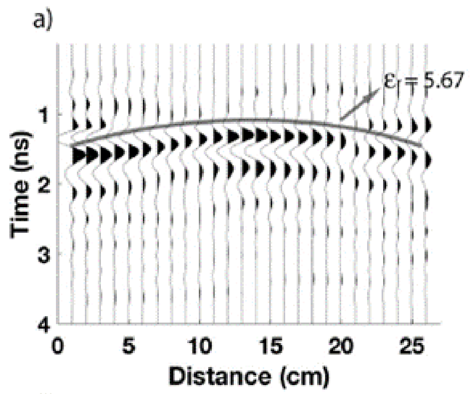

Fig. 3. The radargrams of measurements at 3rd day [8]

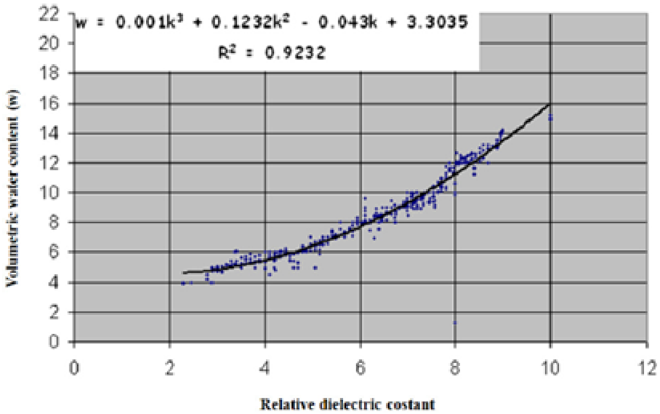

Fig. 4. Volumetric water content (w) as a function relative to dielectric constant (k) [11]

According to Dinh *et al*. [4], amplitude reduction of the GPR radar wave changes based on wave propagation in a medium. The wave amplitude will decrease when the medium is deep and the distance travel increases. The reflection strength (amplitude) of a steel reinforcement increases with the size and decreases with depth or presence of moisture content. The size of steel reinforcement can be estimated from reflection strength on a comparative basis, but cannot be accurately measured [10]. For concrete structures that have two layers of steel reinforcement, the visibility of the second layer depends on the spacing in the first layer and on the amount of attenuation and scattering in the concrete. Wave attenuation occurs when there is a reduction in signal wave strength during transmission and reduces the penetration of electromagnetic waves. Another factor that causes wave attenuation is high conductivity material. Many studies have been conducted in determining the size of steel reinforcement, but it still have many limitations [7]. For example, study by Utsi and Utsi [16] showed that there is a problem in interpreting the images when the distance between the steel reinforcement close to 200 mm.

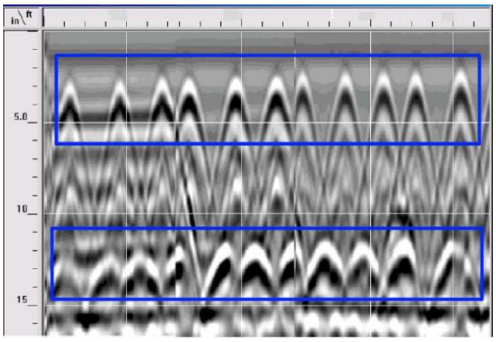

Fig. 5. Two closely spaced layer of rebar [6]

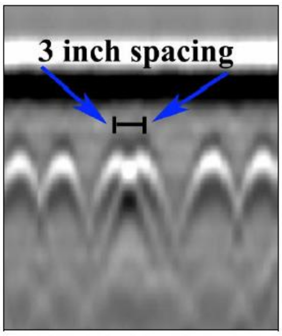

Fig. 6. Two cables 3 inch apart [6]

Figure 5 and 6 shows a steel reinforcement layer that has a distance of 25 cm vertically. The steel reinforcement layer at the top is clear. The second layer of steel reinforcement becomes more difficult to see as most of the electromagnetic waves transmitted are reflected from the top layer and does not penetrate the second layer completely. Furthermore, in order to obtain separate hyperbola reflection, the lateral spacing of the reinforcement must be at least 3 inch or 7.5 cm (GSSI) (Figure 6).

1.2 Basic Concept of GPR

A GPR system emits an electromagnetic wave into the ground through transmitting antenna and receive the response. Figure 7 shows the principles of GPR system. If there is a change in electric properties in the ground or if there is an anomaly that has different electric properties than the surrounding media, a part of the electromagnetic wave is reflected back to the receiver. The system scans the ground to collect the data at various locations.

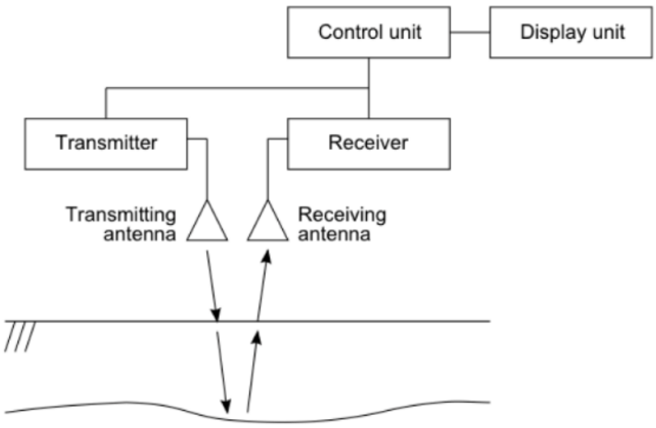

Fig. 7. Basic principles of GPR system [2]

1.2.1 Electrical Conduction and Dielectric Constant

Dielectric value depends on density, texture, mineral content, temperature and water content. However, the dielectric value of a material is highly influenced by the amount of water content. The dielectric constant affects the propagation of GPR electromagnetic wave velocity in terms of speed and reflection. If the dielectric constant is higher, the reflection of electromagnetic wave signal is also increasingly difficult to obtain. Therefore, water plays an important role in determining the dielectric in a substance.

1.2.2 Dielectric Value

According to ASTM D432-11, which is a guideline use of the GPR method, if the dielectric value, ε_r is unknown, the electromagnetic wave velocity can be estimated using equations:

$$v = \frac{2D}{t} \tag{1}$$

where, v = velocity of electromagnetic waves, D = the depth of the object and t = time of two-way waves and the dielectric value, ε_r can be obtained using equation

$$v = \frac{c}{\sqrt{\varepsilon_r}} \tag{2}$$

where, c = light speed, 3×10^8 m/s and ε_r = dielectric value.

In this research, the effect of MC on the determination of steel reinforcement depth in concrete and their determination of diameter sizes are studied. The MC affects the value of dielectric constant of the concrete slab. Different sizes of reinforcement are placed at different depth in grade 20 MPa slab. The slab is wet cured for 28 days and later dried in oven until constant weight is achieved (marked as 0% MC). Next, to obtain the relative MC, the slab is immersed in water and GPR testing to determine the depth and diameter of steel reinforcement were done at various periods to obtain different % MC. The slab was also weighted to determine the percentage increase of moisture content.

1.3 Experimental Design

1.3.1 Sample Preparation

The sample is Ordinary Portland Cement (OPC) concrete with water/cement ratio of 0.57. The compressive strength of the concrete is 20 MPa. The mix design proportions of the sample are summarized in Table 2.

Table 1
Type of medium and dielectric value

Cements kg/m^3	Sand kg/m^3	Aggregates kg/m^3	Water kg/m^3	W/C ratio
333.3	907.6	943.1	216.3	0.57

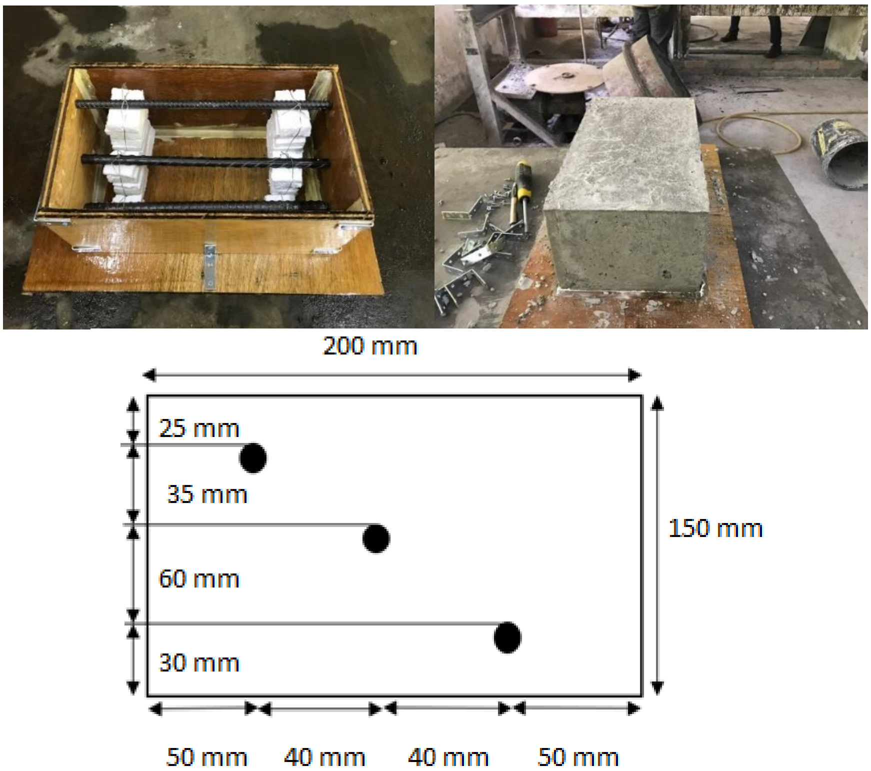

Fig. 8. Concrete samples preparation and schematic diagram of the steel reinforcement location

The dimensions of the reinforced slab are 0.15 x 0.20 x 0.35 m^3 with three different sizes of reinforcement bar which are 12 mm, 16 mm and 20 mm. The steel reinforcement is located at different depth of 25 cm, 60 cm and 120 cm respectively (Figure 8). After casting, the concrete slab was cured for 28 days. The absorption rate of concrete was measured according to ASTM C1585-04. Before the immersion process started, the samples were placed in an oven at a temperature 50 ± 2° C for 3 days. Then, the samples were placed inside a sealable container for 15 days. Storage in the sealed container for at least 15 days results in equilibration of the moisture distribution. The mass of the concrete was 22.40 kg for relative moisture content 0 %. The samples are then immersed in the water with different period of time stated in Table 2 (based on ASTM C1585-04).

1.3.2 Testing

GPR measurement were carried out using SIR 3000 system with 1.6 GHz antenna, developed by Geophysical Survey Systems Inc. (GSSI). GSSI cart was used to collect the data in distance mode, sampling rate of 256 sample per trace, based on automatic configuration in the system.

Table 2
Times and tolerances for the measurement schedule

Time	5 min	10 min	30 min	60 min	Every hour up to 6 h	Once a day up to 3 days	Day 4 to 7 (3 readings)	Day 7 to 9 (1 reading)
Tolerance	10 s	2 min	2 min	2 min	5 min	2 h	2 h	2 h

3. Results and Discussion

The GPR readings were taken for the first 9 days, up until the amount of MC was found to be constant, that is when there was no further increase in the mass of the slab. Table 3 show the percentage of moisture content obtained based for different period of time.

Table 3
Example (TNR, 10, single spacing, bold, centre)

Days	Time (s)	Mass (kg)	Δ Mass (kg)	Relative MC (%)
-	0	22.40	0	0
-	300	22.64	0.24	1.06
-	600	22.70	0.30	1.32
-	1800	22.73	0.33	1.45
-	3600	22.76	0.36	1.58
-	7200	22.78	0.38	1.67
-	10800	22.80	0.40	1.75
-	14400	22.81	0.41	1.80
-	180000	22.82	0.42	1.84
-	21600	22.84	0.44	1.93
2	193200	22.92	0.52	2.27
3	268500	22.93	0.53	2.31
5	432000	22.94	0.54	2.35
6	527580	22.95	0.55	2.45
7	622200	22.96	0.56	2.50
9	777600	22.97	0.57	2.54
10	864000	22.97	0.57	2.54
11	950400	22.97	0.57	2.54
12	1037000	22.97	0.57	2.54

3.1 Effect of Moisture Content on Hyperbola Reflection

The raw data obtained from GPR are filtered and processed (zero-time correction, background removal and migration) using *Radan* 7. Zero-time correction is done to remove the delay time from the first reflection to correct the effect of transmitter and receiver antenna distance and possible variation of direct wave arrival time. This process also filters and removes the airspace that is located on the surface of the medium at the top. Lastly, migration process is aimed at highlighting the hyperbola curved point and hence knowing the travel time of two-way electromagnetic waves and the velocity of the electromagnetic wave (GSSI).

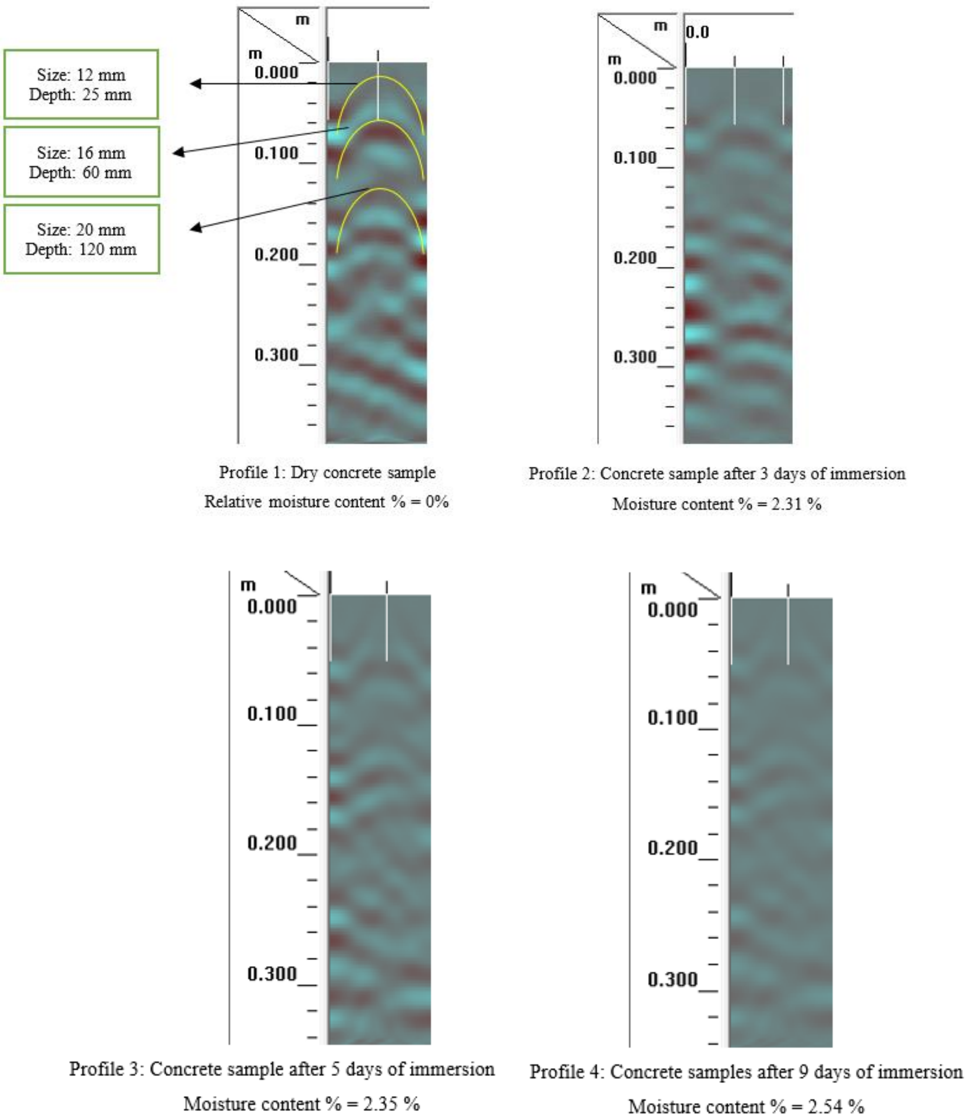

Fig. 9. Profile of hyperbola reflection

The resulting hyperbola is in the same position, parallel, whereas the lateral spacing for each steel reinforcement is 4 cm. This is because based on GSSI, in order to obtain separate hyperbola, the spacing between the steel reinforcement should have at least 7.5 cm (Figure 6). Therefore, the resulting position is inaccurate. However, the depth obtained is within the correct range which is 25, 60 and 120 mm based on Figure 9.

Based on Figure 9, the effect of concrete MC on GPR can be seen through the hyperbola reflection, which is fading due to the increase of MC in concrete. Profile 1, which is at relative MC 0%, shows a relatively clear hyperbola to determine the depth of steel reinforcement. The hyperbola began to be less visible on day 3 where the moisture content is 2.31%, which is Profile 3. The increase in concrete MC affects the GPR in detecting steel reinforcement. Variation of water content causes the propagation velocity of electromagnetic waves to be less accurate. Hyperbola that are less visible will cause the determination of steel reinforcement depth to be difficult.

3.2 Dielectric Value based on the Moisture Content in Concrete

In order to determine the dielectric value at different MC, the electromagnetic (EM) velocity must be estimated first. The EM velocity can be estimated based on the two-way travel time through hyperbola fitting. Hyperbola fitting is the most common method to estimate the wave velocity. When there is a steel reinforcement in a concrete, it is easy to estimate the velocity using a hyperbola fitting since there is a hyperbola on the radargram (Figure 10). Hyperbola are fitted on the first reflection of steel reinforcement, which is the steel reinforcement with a depth of 25 mm. Therefore, the velocity of electromagnetic waves can be calculated by using equation (1). After the electromagnetic wave velocity is obtained, the dielectric value can be calculated using equation (2).

Table 4 shows the two-way travel time at various % MC. The presence of water in the concrete has shown a significant change in the reflected wave parameters. The electrical properties of a medium can be determined based on travel time of the EM wave. The GPR electromagnetic wave travel time increases, when MC increases. The two-way travel time for relative MC 0 % is 0.36 ns, while for concrete that has been immersed after 9 days with 2.54 % moisture content is 0.53 ns.

Table 4
Dielectric value based on moisture content (%)

Days	Moisture Content (%)	Two-way travel time (ns)	Velocity (m/ns)	Dielectric value (ε)
0	0	0.36	0.1389	4.67
300	1.06	0.37	0.1351	4.93
600	1.32	0.37	0.1351	4.93
1800	1.45	0.38	0.1316	5.19
3600	1.58	0.39	0.1282	5.48
7200	1.67	0.40	0.1250	5.76
10800	1.75	0.40	0.1250	5.76
14400	1.80	0.41	0.1220	6.05
180000	1.84	0.42	0.1190	6.35
21600	1.93	0.43	0.1163	6.67
193200	2.27	0.46	0.1087	7.62
268500	2.31	0.47	0.1064	7.95
432000	2.35	0.49	0.1020	8.65
527580	2.45	0.50	0.100	9.00
622200	2.50	0.52	0.096	9.73
777600	2.54	0.53	0.094	10.11

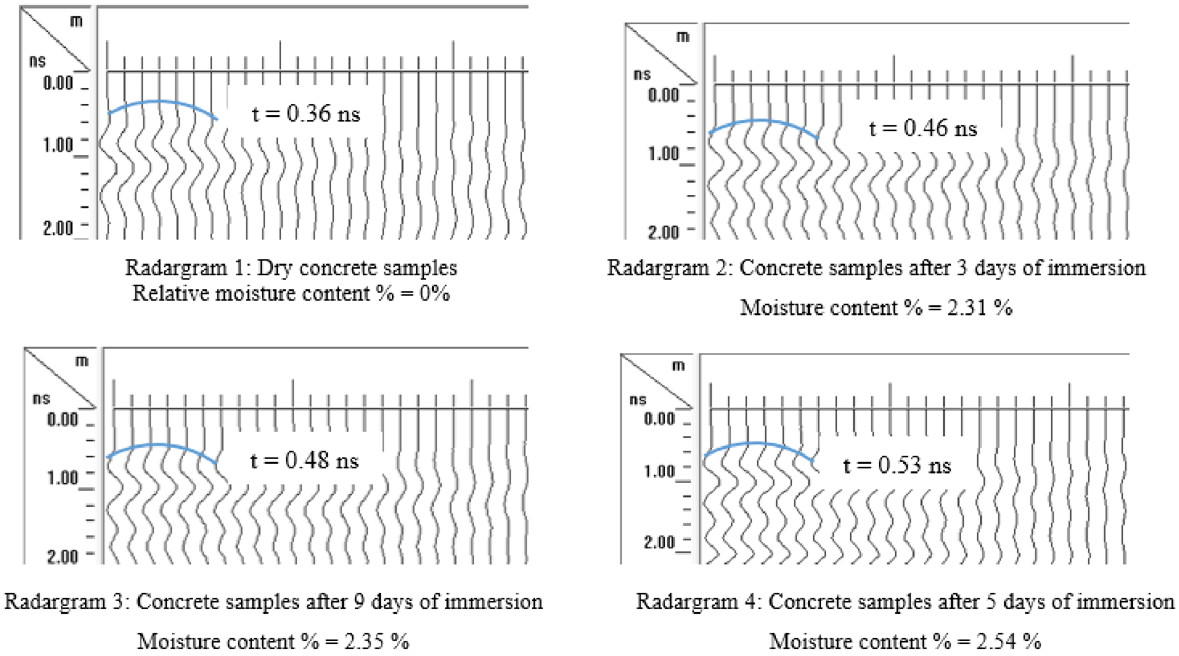

Fig. 10. Radargram of two-way travel time

Figure 11 shows that the velocity of GPR electromagnetic waves decreases as MC increases. MC in the concrete sample has a significant impact on the propagation of EM wave velocity, where the velocity decreases. Based on the study, the velocity of the EM wave at 0% relative MC was 0.1389 m/ns, while at 2.54% MC was 0.094 m/ns. This is because EM waves move slower when propagating in concrete with higher MC, compared to dry concrete. The relationship between the GPR EM wave velocity and MC is:

$$\varepsilon = -0.0031MC + 0.1439 \quad (3)$$

where the % MC are between 0 to 2.54%. The relationship is inversely proportional where the EM velocity of GPR decreased when the MC in the concrete increased. Sbartaï *et al.*, [13] also shows an inversely proportional relationships based on Figure 1.

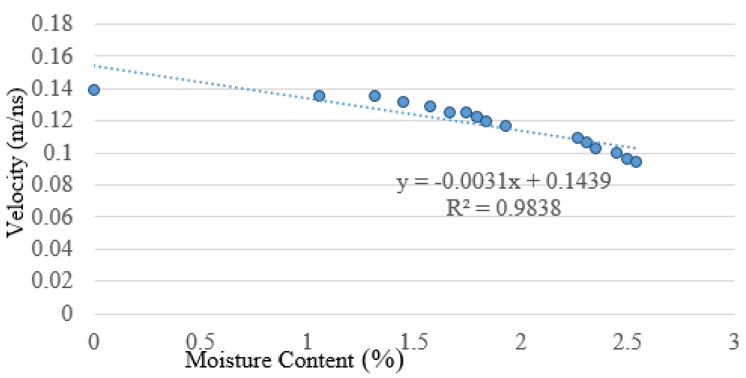

Fig. 11. Electromagnetic wave velocity vs moisture content (%)

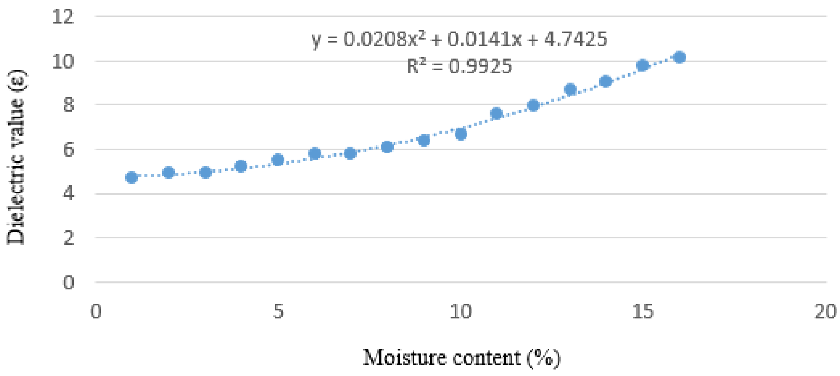

Fig. 12. Dielectric value (ε) vs MC (%)

The reduction of GPR's EM wave velocity thus affects the dielectric value (equation (2)). The reduction of EM wave velocity due to the presence of MC results in high dielectric value. Based on Figure 12, the dielectric value increases when the %MC increases. The dielectric value is 4.67 in dry concrete, and 10.11 in sample with 2.54% MC. The dielectric value range obtained is within the range given by ASTM D-6432, which is 5-10 for concrete. The relationship between the dielectric value and the MC is:

$$\varepsilon = 0.0208x^2 + 0.0141MC + 4.7425 \quad (4)$$

where % MC are between 0 to 2.54%. The relationship is polynomial which indicates a strong relationship between dielectric value and MC. Leucci [11] also obtained a polynomial relationship between moisture content and dielectric value based on Figure 4.

3.3 Determination of Steel Reinforcement Diameter

The diameter of steel reinforcement is [10]

$$\frac{E}{2} = \frac{\lambda}{4} + \frac{H}{\sqrt{\varepsilon+1}} \quad (5)$$

$$R = \frac{L-E}{2\pi} \quad (6)$$

where, E = radius energy, λ = wavelength of the radar energy, H = depth from the surface to object, ε = dielectric value, L = length of scan, R = radius of steel reinforcement.

To obtain the length of scan, L the *GPRViewer* software is used to determine the number of scans based on the amplitude. The number of scans obtained is 61, 72 and 101, based on the depth of steel reinforcement.

Table 5
Diameter or steel reinforcement

Moisture content (%)	Dielectric value (ε)	Steel reinforcement (mm)	E	L	D (mm)	Different (%)
0	4.67	12	11.47	15.25	12.15	0.3
		16	14.41	18	11.43	-28.56
		20	19.45	25.25	18.46	-7.7
1.06	4.93	12	11.43	15.25	12.15	1.25
		16	14.3	18	11.78	-26.38
		20	19.23	25.25	19.16	-4.2
2.31	7.95	12	11.05	15.25	13.37	11.42
		16	13.39	18	14.67	-8.32
		20	17.4	25.25	24.99	24.95
2.35	8.65	12	10.98	15.25	13.59	13.25
		16	13.24	18	15.15	-5.32
		20	17.1	25.25	25.94	29.7
2.45	9	12	10.96	15.25	13.66	13.83
		16	13.17	18	15.37	-3.94
		20	16.96	25.25	26.39	31.95
2.5	9.73	12	10.9	15.25	13.85	15.42
		16	13.04	18	15.79	-1.31
		20	16.7	25.25	27.22	36.1
2.54	10.11	12	10.88	15.25	13.91	15.92
		16	12.98	18	15.8	-1.25
		20	16.58	25.25	27.6	38

Table 5 shows that the presence of MC in concrete gives a high percentage difference in determining the size of steel reinforcement compared to dry concrete. For dry concrete, the percentage difference (%) from actual diameter are 0.3% for 12 mm, -28.56 for 16 mm and -7.7% for 20 mm. The highest percentage difference for 16 mm reinforcement occurs due to the close vertical spacing between the steel reinforcement which is about 35 mm. Referring to Figure 6, if there are two layers of steel reinforcement, the second layer detection depends on the distance to the first layer. The vertical spacing of 35 mm might still be insufficient for GPR to detect two layers of reinforcement and causes the measurement to be inaccurate.

The percentage difference of reinforcement diameter to actual size increased when MC increased. The percentage difference at 2.54% moisture content is 15.92% for size 12 mm, -1.25 for size 16 mm and 38% for size 20 mm. This is because MC will cause attenuation of amplitude signal to occur and reduce propagation of EM wave. The wave attenuation occurs when there is a reduction in wave signal strength during transmission and reduces penetration of EM waves. The reduction of wave signal strength occurs due to the presence of MC which causes propagation of electromagnetic wave velocity to be less accurate. In addition, the equations (5) and (6) used to obtain the size of the steel reinforcement also do not take into account the MC could also contributes to the high percentage difference of the diameter.

4. Conclusion

The aim of this study is to focus on the effect of MC on GPR electromagnetic wave signal detection in determining the depth of steel reinforcement. The hyperbola reflection starts to fade when MC increases, which can cause the depth determination to be difficult. The dielectric value obtained in this study are in the range of 4.67 to 10.11, which is within the range dielectric values given in ASTM D-6432, which is 5-10 for concrete. The determination of reinforcement diameter has high percentage of error, up to 38% when there is an increasing MC in the concrete. Thus, further studies need to done by taking other factors such as MC and spacing of reinforcement to obtain more accurate measurement of steel bar sizes using GPR method.

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