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# Evaluation of Road Pavement Density Using Ground Penetrating Radar

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**Abstract:** This study describes an analysis of Ground Penetrating Radar (GPR) measurements at frequency range of 1.7-2.6 GHz to get a relationship between attenuation and density for nine road pavements slabs with different densities. There are about four different frequencies had been tested. The method is simple, fast, non-destructive and accurate way to determine the density of road pavement. Density is a one of the important parameter in order to determine the compressive strength of road pavement for road user safety. In laboratory, the measurement system consists of a signal generator (250 kHz-3 GHz) as a source, spectrum analyzer (100 Hz-8 GHz), directional coupler with adapter and horn antenna. The first part of the measurement system setup is to determine the amplitude of transmitted wave (received signal strength). A few of received signal strength and attenuation for nine road pavement slab samples were taken at four different frequencies. An instantaneous method for measuring the density of road pavement was developed by using microwave reflection technique and free space method. The MATLAB software is used to analyze the measurement data and also for the graphs comparisons. At the end of this study, it is found that density plays an important factor in causing a major in the recorded signal strength as well as the differences of attenuation of the GPR signal.

**Key words:** Density, pavement slab, received signal strength, attenuation, road pavements

## INTRODUCTION

Roads or any highways carrying vehicular traffic are described as having pavements. All road constructions are made up with asphalt and aggregates and one major indicators of condition is the compressive strength of the road pavement. Pavements thickness has traditionally been determined by drilling and extracting cores and pavement condition by excavating trial holes. The disadvantages of these coring methods are expensive, damage to road pavements and drilling are done at certain points. Therefore Ground Penetrating Radar (GPR) technique has been introduced in this study to analyze the compressive strength of the road pavement.

Ground Penetrating Radar (GPR) has been used extensively in the highway pavement for quite some time and was performed in early 1980s (Saarenketo and Maijala, 1994). Most of the research and development works in highway application has been performed with low frequency (1000-5000 MHz) in order to evaluate and survey the road pavement layers condition (Saarenketo and Söderqvist, 1993).

Ground Penetrating Radar (GPR) operates by radiating electromagnetic waves into a structure and examining the reflected signal for information about the subsurface objects (Saarenketo and Roimela, 1998). GPR is a promising technology and had shown great potential as an effective tool for nondestructive evaluation (NDE) of highway structures (Soo *et al*., 2002). In order to rebuild and pave

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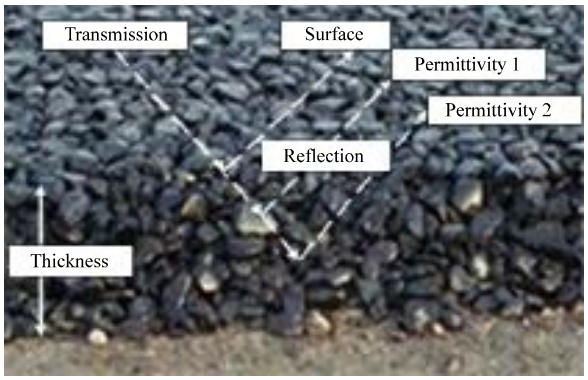



Fig. 1: Typical GPR reflections from a pavement slab

existing highways that show signs of cracking and significant deterioration, it is important to effectively control the paving process by determining the final quality of the compacted mat where its density determines the effectiveness of compaction (Jaselskis *et al*., 1998). Figure 1 shows the phenomenon of GPR environment.

In Fig. 1, the permittivity 1 is asphalt and permittivity 2 and 3 are aggregate. These two types of parameters were used in this study. The microwave techniques used are free space method and reflection technique.

A typical GPR system is comprised of several parts such as signal generator. This device would produce an electromagnetic wave that will propagate through the pavement slab. The wave will be transmitted by the antennae and reflected by the pavement slab sample and a spectrum analyzer was used to collect the received signal strength or received power data and attenuation. In earlier studies, the antennas can be set in two modes: monostatic and bistatic (Bahr, 1998). In monostatic mode, one antenna acts as both transmitter and receiver, whereas bistatic uses separate antennas. For this experiment, only monostatic mode is used.

The analysis of parameters such as frequency, density and attenuation were discussed in detailed in this study. This study described more about the relationship between attenuation and parameters used in attenuation equation and also the influence of those parameters to the relationship between attenuation and density. The results from the GPR measurement were used and were elaborated in data analysis.

The main objective is to see the relationship between density with received signal strength and attenuation as well as to evaluate the Road Pavement Density by Using Ground Penetrating Radar.

**Road Pavement Sample**

This study begins with preparation of pavement slab sample. In laboratory, there have nine pavement slabs with different densities. The pavement slab samples were made according to the suitable proportion and aggregate calculation. The pavement slab samples used in this measurement consists of asphalt and aggregates that put in one container. The asphalt is natural asphalt. The dimension of each pavement slab sample is 0.5×0.42×0.05 m as shown in Fig. 2.

The volume for all road pavement slabs is similar. The density of these nine road pavement slabs sample are 1533, 1700, 1883, 1913, 2047, 2100, 2106, 2133 and 2333 kg $m^{-3}$.

The relationship between received signal strength and density was easily analyzed because the specimen involved is limited to only asphalt and aggregates. Based on try and effort, the nine road pavement slabs are adequate for analysis. This is also in the effort of reducing the cost by using minimum material by estimating the amount of asphalt and aggregates for road pavement slab.

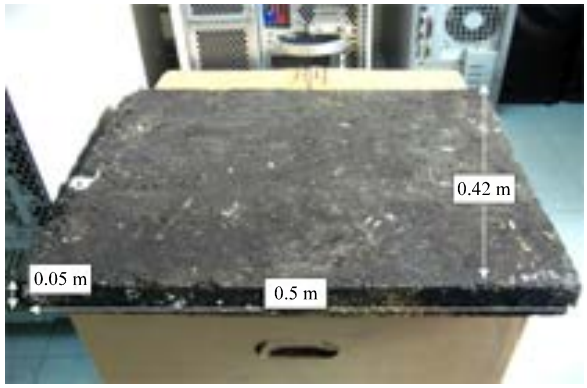



Fig. 2: Slab sample of road pavement

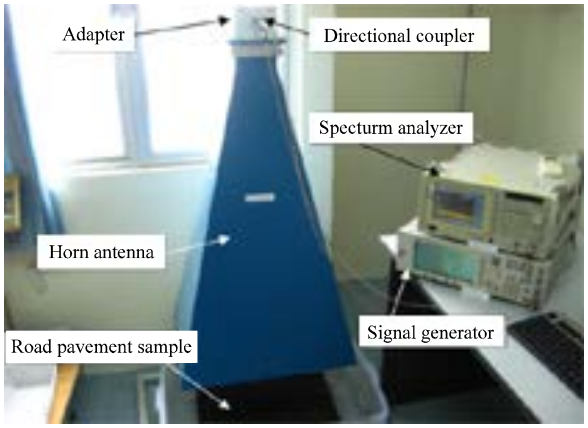



Fig. 3: GPR measurement setup

The road pavement slab sample was prepared in a container. So, as to ensured to have flat surface on cover by using this container. Therefore the samples all have flat surface is to avoid the specular reflection or scattering on the surface of sample.

**GPR Measurement Setup**

In this set up, the distance between horn antenna and sample was fixed in between each other, about 0.3 m height. The horn antenna is a device for radiating and receiving electromagnetic waves (Nyfors and Vainikainen, 1998). The antenna used in this study is horn antenna. The model of this antenna is WR430 with frequency range from 1.7 to 2.6 GHz and nominal gain is 20 dB. This horn antenna was designed and manufactured by Pasternack. The effect of container was considered by addition of container attenuation. The GPR measurement system was set up as shown in Fig. 3.

**GPR Measurement Procedure**

In measurement part, the horn antenna would sends many electromagnetic waves into the pavement slab sample, then spectrum analyzer will record the received signal strength or received power in dBm and it will be converted to attenuation for graph analysis. The wave generated by signal

generator travels from the transmitting part of horn antenna to the receiving part of antenna that controlled by directional coupler. Reflection and transmission occur at the media and received signal strength will be detected on receiving antenna part.

The pavement slab density used is in unit kg $m^{-3}$ and about four different frequencies had been tested. There are 1.7, 2.0, 2.3 and 2.6 GHz. For each GPR transmission and reflection to the pavement slab sample with specific density, about fifty data in dBm were taken for each frequency. For each road pavement slab, the fifty data were taken in 100 min. During the measurement, the correct reading of received signal strength is obtained only when the reading of the measured sample is kept constant at the spectrum analyzer.

By using the received power and transmitted power values, it was converted to attenuation by using the suitable formula. All data were saved in personal computer and the relationship between attenuation and density for different values of densities were performed using MATLAB software. The results will be discussed in the next part.

## RESULTS AND DISCUSSION

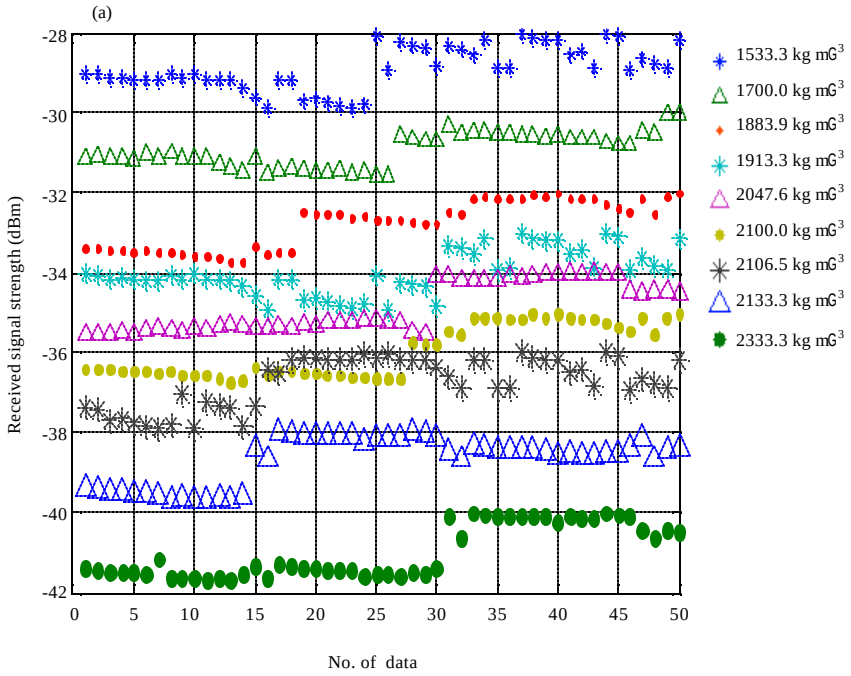
### Received Signal Strength Result

Figure 4 show the relationship between received signal strength (dBm) and number of data of GPR reading. The results obtained are from nine road pavement slabs at four different frequencies. From the figure, we can see that the different density of road pavement produce different results of received signal strength. The highest density of road pavement slab causes the lowest of received signal strength when compared with the other lower density of slab samples at each frequency. As an example, the mean of received signal strength -40.985 dBm for 2333.3 kg $m^{-3}$ is lower than -34.896 dBm for 2047.6 kg $m^{-3}$ and -28.884 dBm for 1553.3 kg $m^{-3}$ as can be seen in Fig. 4a. This trend also can be seen at Fig. 4b-d. So, it can be concluded that the highest density of slab causes the lowest value of received signal strength. It is interesting to note that the highest density of slab absorbs more energy of electromagnetic from the horn antenna than the lower density of road pavement. In addition, the SD is also calculated in order to see the spread of among values as listed in Table 1. The values of standard deviation are 0.6583, 0.6130 and 0.5551 for 2333.3, 2047.6 and 1553.3 kg $m^{-3}$, respectively as seen in Table 1.

Besides, in terms of differences frequencies, when we compare among Fig. 4a-d, it can be seen that the highest frequency, 2.6 GHz at Fig. 4a produce the lowest range value of received signal strength which is -47.09 to -61.09 dBm when compared with the other lower frequencies for example frequency 1.7 GHz, the range is from -28.88 to -40.98 dBm. The range value of standard deviation is from 0.4608 to 0.5328 for frequency 2.6 GHz whereas 0.6583 to 0.5551 for frequency 1.7 GHz. From these results, it is interesting to note that the lower value of received signal strength produce the higher of attenuation. This is simplified can be said that the higher frequency causes the higher attenuation. The reason is that there was possibility that the higher frequency led to the lower wavelength resulting the poor penetration and also the lower traveling distances effect due to scattering. This is valid for all pavement slabs. Besides, the variation of ripples in the waveform was due to variation of received signal strength data taken during measurement as can be seen in Fig. 4. The differences range of standard deviation show the variation of the received signal strength for each pavement slab at different frequency. The detail of the received signal strength with standard deviation values for these nine road pavement slabs at four frequencies is depicted in Fig. 4a-d and also listed in Table 1.

### Attenuation Result

Figure 5 shows the attenuation in dB versus number of data of GPR reading for nine road pavement slabs at four different frequencies. This purpose is to see the variation of attenuation for



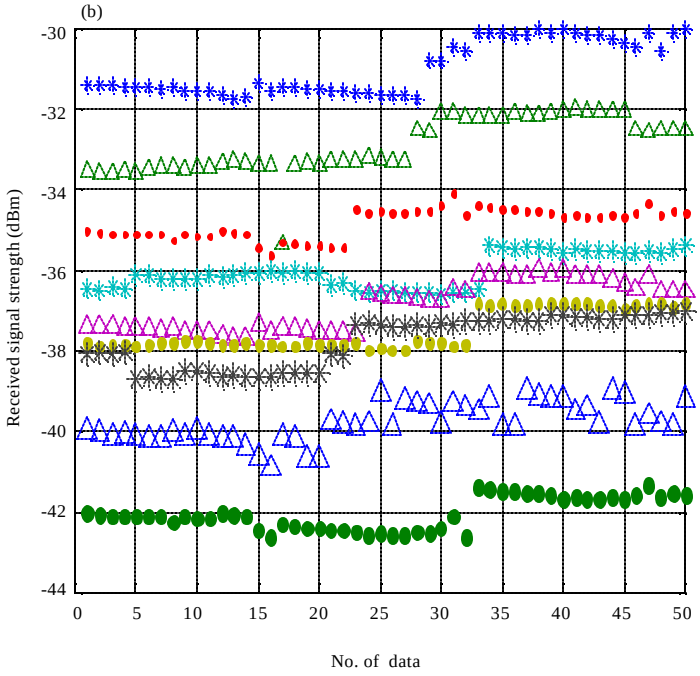




Fig. 4: Continued

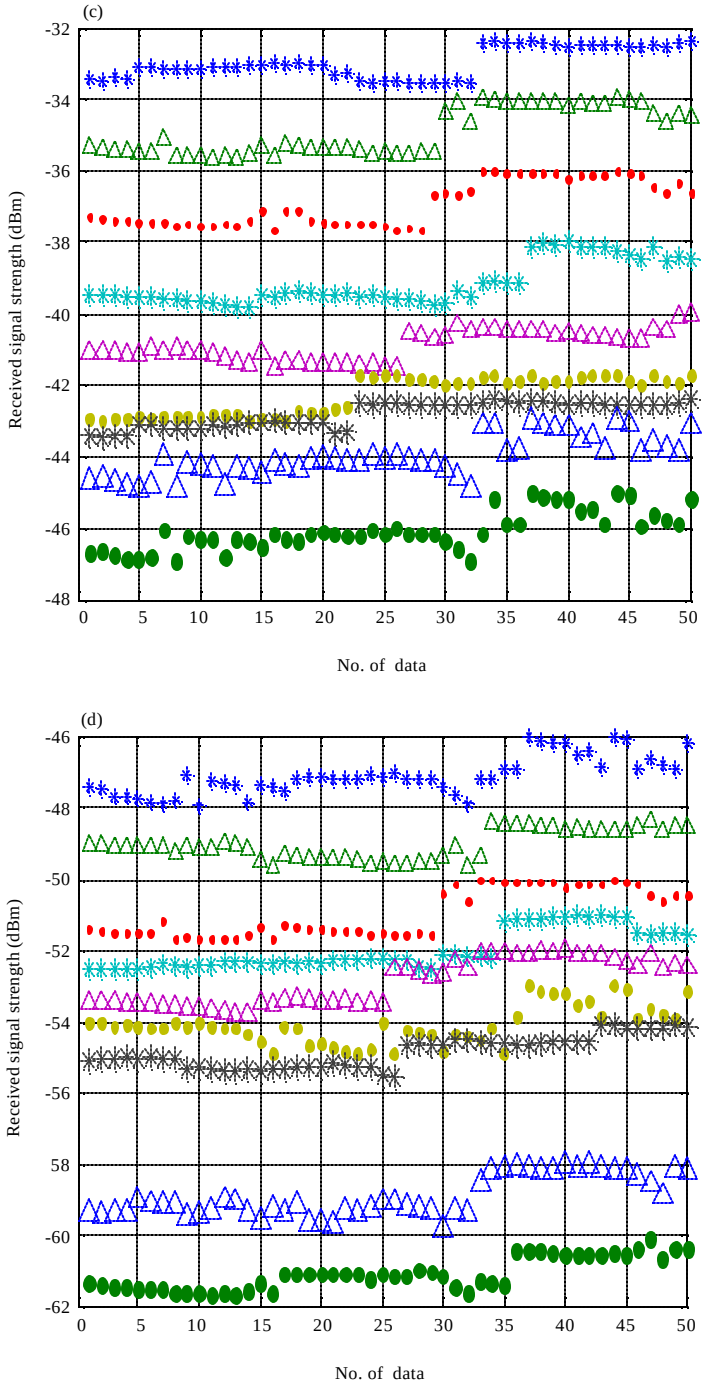



Fig. 4: Received signal strength (dBm) versus number of data of GPR reading for nine road pavement slabs at four different frequencies (a) 1.7 GHz (b) 2.0 GHZ (c) 2.3 GHz and (d) 2.6 GHz

Table 1: Mean value and standard deviation of received signal strength at four frequencies

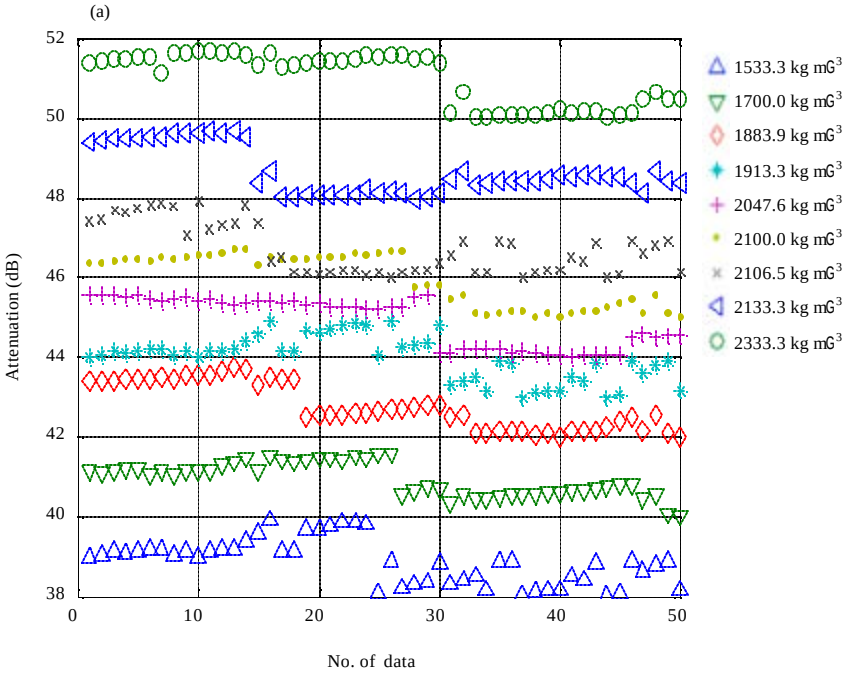
| Frequency (GHz) | Slab | Mean (dBm) | SD (dBm) |
|---|---|---|---|
| 1.7 | 1 | -28.884264 | 0.555129479 |
| | 2 | -30.940796 | 0.421326496 |
| | 3 | -32.782322 | 0.592370838 |
| | 4 | -34.004264 | 0.556594972 |
| | 5 | -34.896572 | 0.613087790 |
| | 6 | -35.962326 | 0.656231647 |
| | 7 | -36.719770 | 0.635779405 |
| | 8 | -38.671040 | 0.592170026 |
| | 9 | -40.985612 | 0.658320086 |
| 2.0 | 1 | -30.982324 | 0.664658418 |
| | 2 | -32.896572 | 0.694420258 |
| | 3 | -34.837264 | 0.375930974 |
| | 4 | -36.330318 | 0.420538057 |
| | 5 | -36.901006 | 0.608158413 |
| | 6 | -37.488326 | 0.480224108 |
| | 7 | -37.773704 | 0.646687919 |
| | 8 | -39.804258 | 0.479393718 |
| | 9 | -42.037264 | 0.404252921 |
| 2.3 | 1 | -33.010318 | 0.422914972 |
| | 2 | -34.965612 | 0.661067557 |
| | 3 | -36.939414 | 0.625925306 |
| | 4 | -39.158164 | 0.597095238 |
| | 5 | -40.940796 | 0.421326496 |
| | 6 | -42.282418 | 0.526853314 |
| | 7 | -42.810318 | 0.353852172 |
| | 8 | -44.056606 | 0.561919507 |
| | 9 | -46.804258 | 0.479393718 |
| 2.6 | 1 | -47.099774 | 0.532817330 |
| | 2 | -49.057264 | 0.396280481 |
| | 3 | -50.965612 | 0.661067557 |
| | 4 | -51.996566 | 0.562681468 |
| | 5 | -52.938158 | 0.642444672 |
| | 6 | -54.104264 | 0.510771561 |
| | 7 | -54.871140 | 0.442397404 |
| | 8 | -58.952992 | 0.576702266 |
| | 9 | -61.093962 | 0.460800223 |

different road pavement slab density. In Fig. 5a, it clearly can be seen that the highest density of road pavement slabs gives the highest value of attenuation when compared with the other lower densities. The mean of attenuation for the highest density, 2333.3 kg $m^{-3}$ at 1.7 GHz is 51.39 dB whereas 39.02 dB for lowest density, 1553.3 kg $m^{-3}$ as can be seen at Fig. 5a. This is to note that the more absorptions of the energy from the highest density of road pavement that causes the highest attenuation when compared with the other lower density of pavement slabs. The highest value of attenuation is because of the lowest value of received signal strength that based on the results in Fig. 4.

When compared among Fig. 5a-d, it can be investigated that the highest frequency, 2.6 GHz gives the highest attenuation values when compared with the other lower frequencies, 2.3, 2.0 and 1.7 GHz. It can be proved in Fig. 5d that the range value of attenuation in the highest frequency, 2.6 GHz is around 57.09 to 71.09 dB whereas the lowest frequency, 1.7 GHz gives only around 39.01 to 51.39 dB of attenuation. This occurs because the highest frequency is poor penetration that causes high attenuation. These trends are valid for frequency 2.3 and 2.0 GHz as can be seen in Fig. 5c and b.

**Relationship Between Attenuation and Density**

Here, the relationship between attenuation and density will be discussed thoroughly. From the previous part, the results from the mean received signal strength in dBm were converted into attenuation in dB by using suitable equation. Thus, there have one attenuation value for each slab



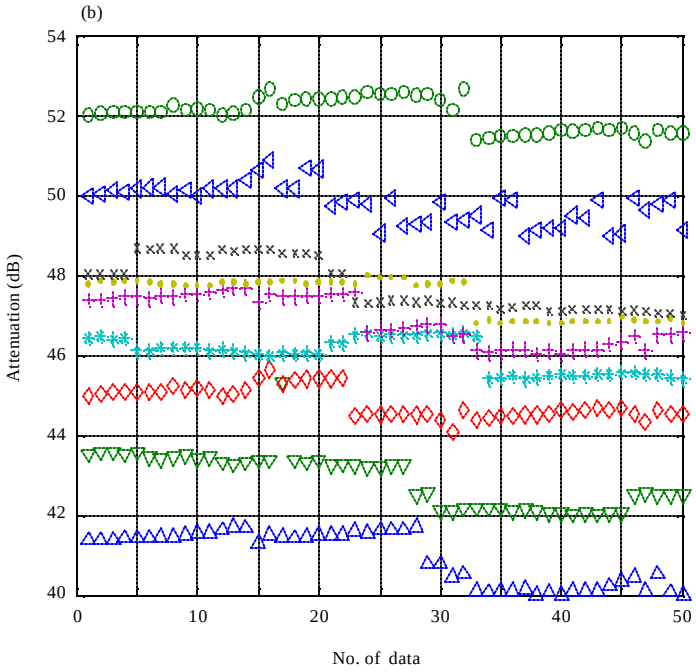




Fig. 5: Continued

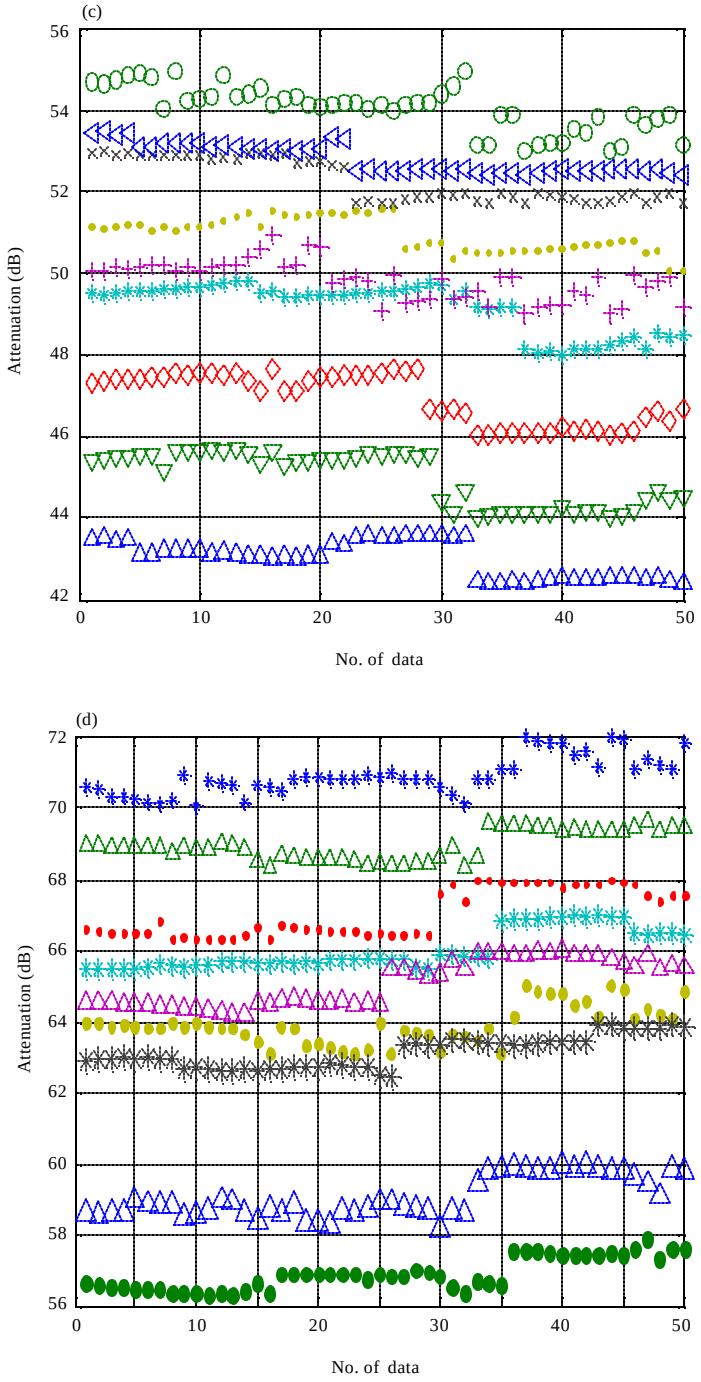



Fig. 5: Attenuation (dB) versus number of data of GPR reading for nine road pavement slabs at 4 different frequencies (a) 1.7 GHz (b) 2.0 DHz (c) 2.23 GHz and (d) 2.6 GHz

sample at each frequency as can be seen in Fig. 6. Then, the relationship between attenuation and density can be plotted for all type of frequencies. From the Fig. 6, it can be found that the density of the road pavement is proportional with attenuation for all the frequencies. In other words, the high density would produce the high attenuation. This due to the fact that the more electromagnetic energy will be absorbed more by the molecules of the road pavement with high density compared with the lower density. This is valid for all frequencies as can be seen in Fig. 6a-d. Besides, it also clearly can be seen that the increasing of the frequency would produced the highest attenuation. It can be proved in Fig. 6d, the highest frequency, 2.6 GHz produce the range of the attenuation is from 57.09 to 71.09 dB whereas the lowest frequency, 1.7 GHz produces the range from 38.88 to 50.98 dB as can be seen in Fig. 6d and a, respectively. Thus, it is interesting to note that density plays an important factor in causing a major difference in the attenuation of GPR signal.

From Fig. 6, as expected, the attenuation increases with the increasing of density. Generally, the measured attenuation of various road pavement samples shows a good agreement and acceptable results. The proportional relationship between the attenuation and density show that this approach is suitable in this purpose. From the results, it is interesting to consider that based on the characteristic

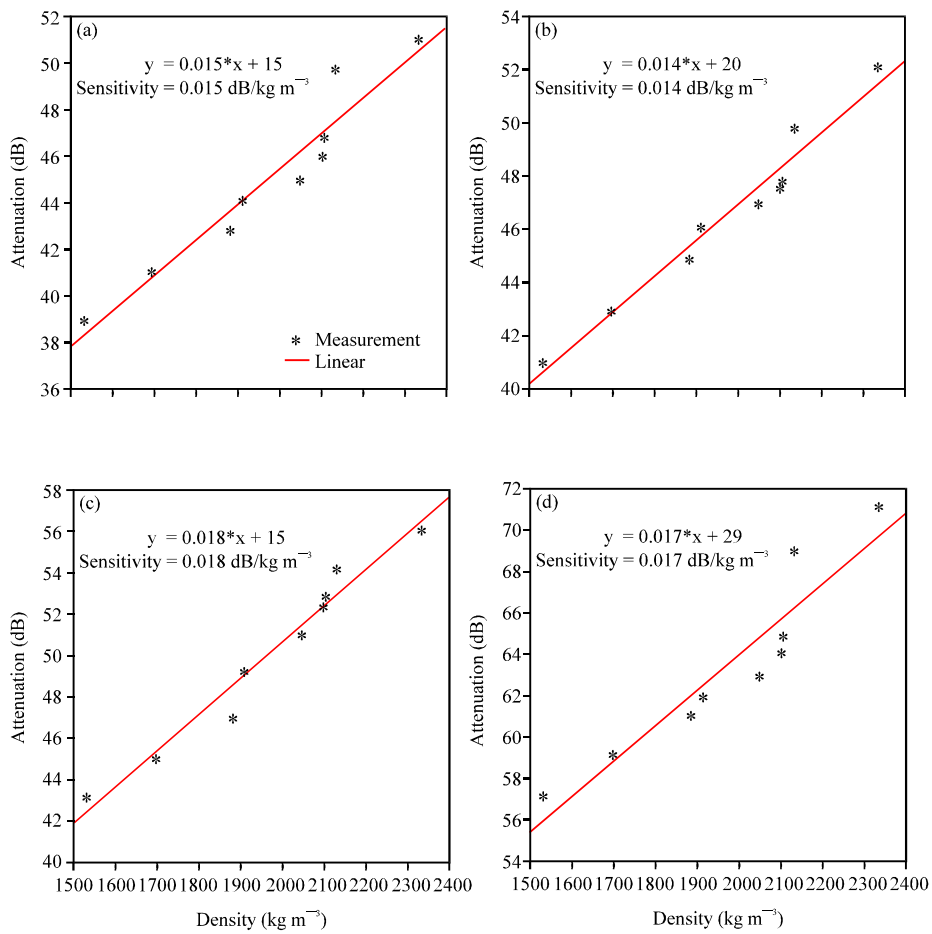



Fig. 6: Attenuation (dB) versus density of GPR reading for nine road pavement slabs at 4 different frequencies (a) 1.7 GHz (b) 2.0 GHz (c) 2.3 GHz and (d) 2.6 GHz

of road pavement molecules, a microwave passing through the road pavement is absorbed by the molecules and the quantity of attenuation change according to the density. Besides, this road pavement sample has a various composition to be mixed. There are asphalts and aggregates.

In Fig. 6, it is also clearly shown that the sensitivity of received power is strongly affected by the density of road pavement sample. The sensitivity of measurement which is defined as the change in attenuation per change in density is in fact the gradient of the calibration line. The sensitivity are 0.015, 0.014, 0.018 and 0.017 dB/kg/m$^3$ for frequency 1.7, 2.0, 2.3 and 2.6 GHz, respectively. According to these results such as the sensitivity of 0.014 dB/kg m$^{-3}$ density, it means that for every 1 kg m$^{-3}$ change in density, it can be represented by corresponding 0.014 dB changes in attenuation. When we compared among these four values, most of the higher sensitivity came from higher frequency compared than lower frequency. As an example, the frequency of 2.6 and 2.3 GHz produce the sensitivity of 0.017 and 0.018 dB/kg/m$^3$, respectively whereas 0.015 and 0.014 dB/kg/m$^3$ were produced by frequency 1.7 and 2.0 GHz, respectively. From this finding, it can be concluded that the higher attenuation causes the higher sensitivity at higher density of road pavement. This is can be interested to show that the microwave passing through the pavement slab sample will be absorbed highly at high pavement density and the quantity of received power change according to the density.

Besides, the least square curve fitting have been done for all graphs in Fig. 6. The best fitting straight line can be completely specified by the linear regression equation using the method of least squares (Lapin, 1990). The purpose is to get the new equation that shows relationship between measurement data with the simulation data. The best fitting equations are $y = 0.015x+15$, $y = 0.014x+20$, $y = 0.018x+15$ and $y = 0.017x+29$ for frequency 1.7, 2.0 GHz, 2.3 GHz and 2.6 GHz, respectively where y represent attenuation and x represent density of road pavement. These four best fitting equations also produce the linear equations where the density will increase with the increasing of attenuation. The figure can be used as a calibration chart where the values of density can be read out directly once the attenuation value are known at various testing.

**Relationship Between Attenuation and Frequency**

From the Fig. 7, it shows that the increasing of the frequency will causes increasing of the attenuation. The range of attenuation is from 38.9 to 71.1 dB for four signal frequencies, 1.7 to 2.6 GHz. Besides, it was also observed that the highest density of pavement slab, 2333.3 kg m$^{-3}$

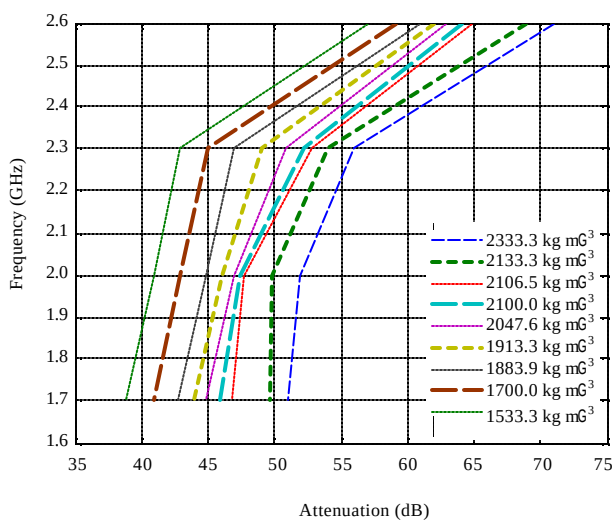



Fig. 7: Relationship between frequency and attenuation for nine pavement slabs with different density

produces the highest attenuation and vice versa. For example at frequency 2.6 GHz, the attenuation value of 71.1 dB for 2333.3 kg $m^{-3}$ is higher than 68.9 dB for 2133.3 kg $m^{-3}$ as can be seen in Fig. 7. This is also interesting to note that the high frequency is poor penetration that releases more electromagnetic energy into heat from the road pavement when compared with the other lower frequencies which are 2.3, 2.0 and 1.7 GHz.

## CONCLUSION

This study discussed an approach to get a relationship between attenuation and density for various densities of pavement slab samples. From the results, it can be concluded that the different density of pavement slab sample gave an effect for received signal strength and attenuation where the attenuation will increase with the increasing of the density. It is found that density plays an important factor in causing a major difference in the recorded signal strength. Therefore ground penetrating radar data is influenced greatly by density, the void from the materials that will cause power strength data difference and frequencies used whether in the range of 1.7 GHz towards 2.6 GHz. It is also can be found that the increasing of the frequency will causes increasing of the attenuation. The recommended frequency in this study is 1.7 GHz because it gave a more consistent reading and low sensitivity compared with other frequencies such as 2.6 GHz. The four best fitting equations from the results also produce the linear equations where the density will increase with the increasing of attenuation. The figure can be used as a calibration chart where the values of density can be read out directly once the attenuation value are known at various testing. In future development, the GPR result from this study can be used for further GPR research that capable to characterize more properties of road pavement sample.

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