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# Ground Penetrating Radar Signals, An Efficient Way to Estimate Fouled Ballast

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**ABSTRACT** Mud pumping is a serious problem in railroad structures. Mud is often found in ballast structures, which can decrease the lifespan of sleepers and rail structures. Currently, the role of ground penetrating radar in investigating ballast condition is more useful than visual inspection. Ground penetrating radar can see the condition inside the ballast with the reflection of high-speed electromagnetic waves. One of the outputs from the ground penetrating radar is the graph of the signal reflection strength. Electromagnetic waves in ground penetrating radar have different reflectance strengths depending on the interfaces between different materials they pass through. For example, water-like material has a stronger signal reflection strength than gravel and soil. There are different colors used to indicate the level of signal reflection strength. Bright colors indicate a stronger level of signal reflection strength compared to dark colors. It has already been found that the dark colors of the scanning results are fouled ballast, respectively. To interpret fouled ballast conditions on the ground penetrating radar output graph, it is necessary to sort out the different colors. Therefore, this study aims to utilize design software to facilitate color selection on the ground penetrating radar output graph and determines the estimation of fouled ballast.

**KEYWORDS** Mud Pumping; Fouled Ballast; Ground Penetrating Radar; Reflection Signal; Design Software

## 1 INTRODUCTION

The railroad structure in Taiwan is generally built traditionally, consisting of railings, sleepers, ballasts, and subgrade composed of in-situ soil materials (see Figure 1). When a train crosses the track, it generates cyclic loading. With the traditional structure, the cyclic load from the train can be transferred to the subgrade. The ballast structure is one of the structures whose conditions must be considered. The ballast structure itself consists of gravel, which stabilizes the rail sleepers as well as dampens vibrations. In addition, the ballast structure also functions as water drainage and prevents the growth of weeds. When it rains, the groundwater mixed with soil can rise to the ballast structure, contaminating the ballast.

The mud pumping mechanism is the process of soil particles or eroded ballast rock rising from subgrade to the ballast structure. According to Duong et al. (2014) the worst degrading process for railway ballast structure is mud pumping, which is characterized by the rapid upward movement of subgrade fine particles via the ballast voids. Several mechanisms, some of which seem to contradict one another, have been proposed to explain mud pumping. Suction created by the upward and downward movement of sleepers has been hypothesized by Takatoshi (1997) as the cause of mud pumping. However, Alobaidi (1996) and Alobaidi and Hoare (1999) hypothesized that water pressure created at the interface of the subgrade and ballast layers was primarily responsible for this phenomena. It is still necessary to verify, using appropriate experimental data, the applicability of the models presented by Van (1985) for characterizing the mud pumping in the pavement setting.

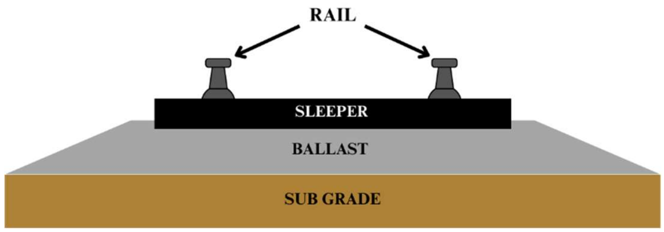


Figure 1. Railway structure

Currently, Ground penetrating radar (GPR) is an efficient way to observe ballast conditions on railroad structure, especially for mud pumping phenomena. GPR is a geophysical method using reflected electromagnetic waves to produce images as output. By using electromagnetic waves from GPR, we can see the strong reflection signals of different materials inside the railway structure. From the results of the GPR scanning, a data processing method is needed to define the color of the GPR output. The author took the GPR scanning data along the Neiwan Line in the city of Hsinchu. This paper using color selection method with Adobe Photoshop 2023 software to define fouled ballast phenomena from GPR results.

## 2 MUD PUMPING PHENOMENON

Ballast and subgrade is the main structure of the railroad. The ballast structure will continue the cyclic load of the train to the subgrade. According to Kuo et al. (2018) deflection is caused by repeated loads as train passes. Pump effect, also known as mud pumping, is a process in which a vacuum is created, lifting a saturated foundation upwards.

When the railroad foundation is wet with rainwater or groundwater, repeated loads caused by trains may cause the subgrade to deform. Additionally, ballast may be forced into the subgrade when the foundation of the railway is saturated. As a result, there may be track irregularities, and both mud and ballast forced into the subgrade may create water pockets. When trains pass, the mud in the water pocket rises through the cavities in the ballast, which results in mud pumping. According to Takatoshi (1997) mud pumping might result in a vacuum-like phenomena due to the force transferred through the ballast to the saturated foundation (see Figure 2).

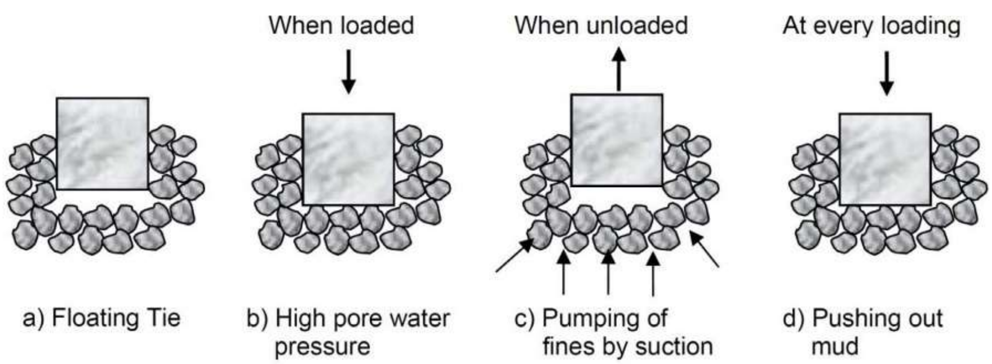


Figure 2. Mechanism of mud pumping Takatoshi (1997)

Subgrade mud pumping occurs as a result of several natural phenomena in the area of the subgrade that alter the subgrade's water content and compactness. In addition to the recurrent train loads, the pressure from the soil and porewater also affects the subgrade's strength and stability. There is evidence of mud pumping of both the ballast-bed type and the subgrade kind, as claimed by (Yang (2002), Yi (2013), and Wang et al. (2014). During the process of ballast-bed mud pumping, mud gathers inside the ballast bed and rises through the spaces in the ballast due to external fine-grained soil penetration or ballast abrasion. This pressure will also be exerted on the railway structure by surface water and train weight, which causes the structure to be under constant stress. The surface of the roadbed remains undisturbed by this kind of mud pumping, as it solely takes place within the ballast bed.

In order to analyze the mobility of tiny particles in the railway substructure, Duong et al. (2014) developed a physical model. According to the study, the main element influencing the migration of small particles and the subsequent formation of interlayers, as well as mud pumping, is the development of pore water pressure in the subsurface.

## 3 METHODS

### 3.1 Research Location

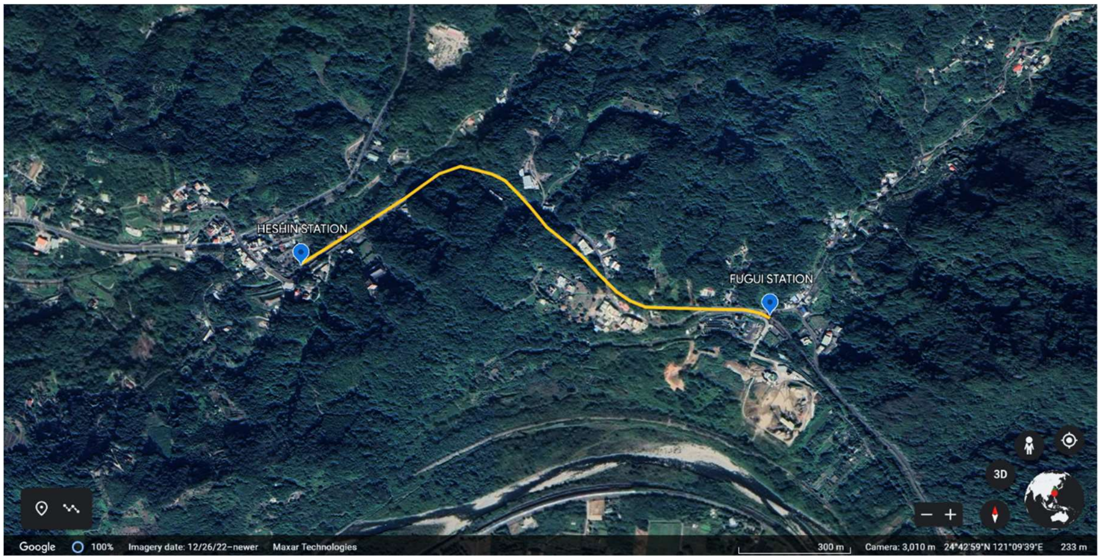


Figure 3. Location of Heshan Station and Fugui Station (Source: https://earth.google.com/)

In this study, collect the data along the train line from Heshin Station to Fugui Station which is included in the Neiwan Line. The Neiwan Line began operating on September 11, 1951 and has a track length of 28 km with a track width of 1,067 m. Located adjacent to the Touqian River with geological conditions in the mountains. Data collection was carried out in the 24K+400 segment with fouled ballast conditions.

### 3.2 Ground Penetrating Radar (GPR)

In this study using Ground Penetrating Radar (GPR) to investigate ballast conditions. Ground Penetrating Radar (GPR) is a geophysical method that utilizes reflected electromagnetic signals presented in the form of graphic images. According to Spears et al. (2023) GPR is applied to the assessment of structures such as pavements, reinforced concrete, railway ballasts. Soil geological conditions and objects planted in the ground.

Basically the way GPR works is to emit electromagnetic wave pulses with a frequency of 10 -1000 Mhz which is generated by the transmitter antenna (see Figure 4). Electromagnetic waves are transmitted into the ground then objects in the ground such as soil, rocks, water, or others will reflect them until they are detected by the receiver (Rx) in nanoseconds.

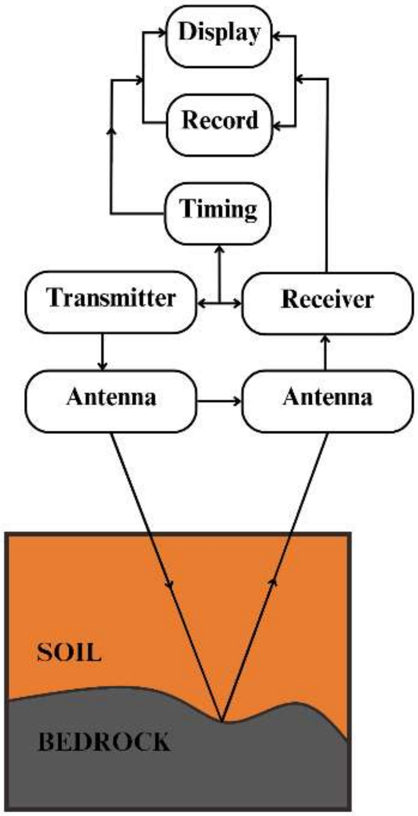


Figure 4. Mechanism of Ground Penetrating Radar

The Ground Penetrating Radar used in this study was produced by Geophysical Survey Systems Inc (GSSI) in 2001 with the SIR-20 type. The antenna used has a frequency of 400 MHz with a range of up to 5 m and is analyzed using GSSI-RADAN V5 software. The parameters used can be seen in Table 1.

Table 1. Local testing parameter configurations

| Item | Parametric value |
|---|---|
| detecting depth (m) | 2 |
| samples/scan | 512 |
| bits/sample | 8 |
| diel constant | 14 |
| scans/second | 32 |
| scans/meter | 80 |
| meters/mark | 1 |
| position | 0 ns |
| range | 50 ns |
| range gain (dB) | 5.0/34.0/54.0/61.0/64.0 |
| Vert IIR LP | N = 1/F = 800 MHz |
| Vert IIR HP | N = 2/F = 30 MHz |

Signal reflections of various intensities are represented in hexadecimal colors. The color block and color scale of the signal reflection from the analysis software (RADAN) can be seen in Figure 5. Color grouping based on signal strength, namely weak, secondary weak, and strong reflections signals.

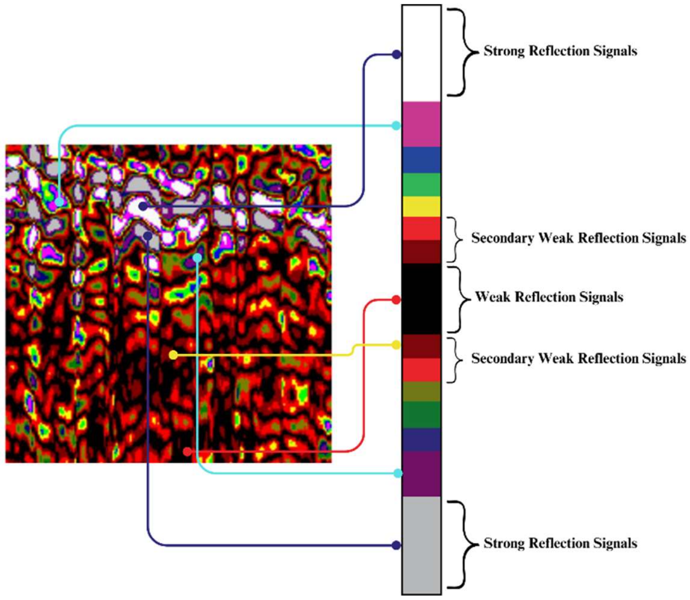


Figure 5. Color block and color scale setting

## 4 RESULTS AND DISCUSSION

### 4.1 Ground Penetrating Radar Survey Result

GPR scanning is done at 50 m intervals. The data review focuses on the 24K + 400 to 24K + 450 segments with a ballast depth of 50 cm. There are 3 survey lanes, namely the left, middle and right lanes. Figure 6 is the result of GPR scanning in the field. From the scanning results it can be seen the level of signal reflection strength from the resulting color.

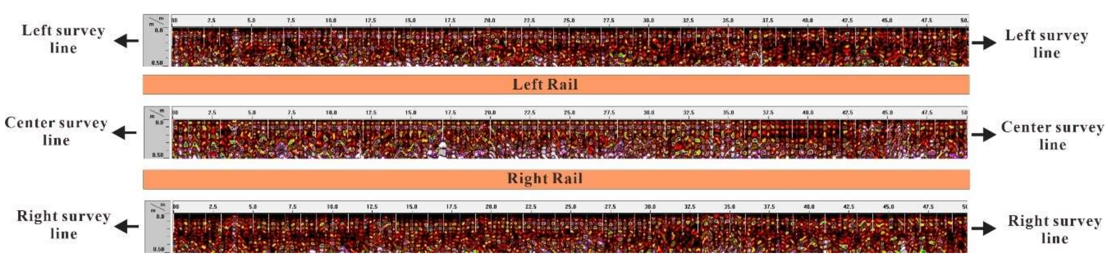


Figure 6. Results of ground penetrating radar scanning along the Neiwan Line segment of 24K + 450

Kuo et al. (2018) in his experiment made a glass box containing pebbles, clay, silt, and sand with a height of 10 cm with two conditions, dry and saturated. In this study the material was scanned using GPR. In the results of the GPR scan, it can be seen that in saturated conditions, dominated by dark colors belonging to weak and weak secondary reflection signals. Meanwhile, the white and purple colors represent the water sacs placed in the pile of material.

Figure 6 shows the same results as those carried out in the Kuo et al. (2018) experiment. The scanning results in the field are dominated by dark colors which are assumed to be saturated in the ballast. The condition of ballast in the field has long experienced accumulation of soil material and is due to weather conditions at the time of data collection, namely the rainy season. That way the condition of the ballast which is mixed with soil material becomes saturated.

In research Kuo (2021) the author investigated fouled ballast using two methods, namely the estimation method using the characterized grid method and the conventional method by digging ballast as evidence. The results of the two methods show that the condition of the fouled ballast is indicated by a dark color indication, namely weak reflection signals. Clean ballast conditions are indicated by bright colors which include strong reflection signals. At the boundary between dark and light colors there is a transition zone with an indication of brownish red which is included in the secondary weak reflection signals.

### 4.2 Interpretation of Fouled Ballast Condition Using Color Selection Method

The color selection process from the GPR scanning results uses Photoshop 2023 software. The reason for using this software is because it has a color selection level for each pixel. That way the color selection results get a very detailed output. Can be seen in the Figure 7 is the color range feature which functions to take color samples and select the selected color. Figure 8 is an example of color selection on a GPR scan result.

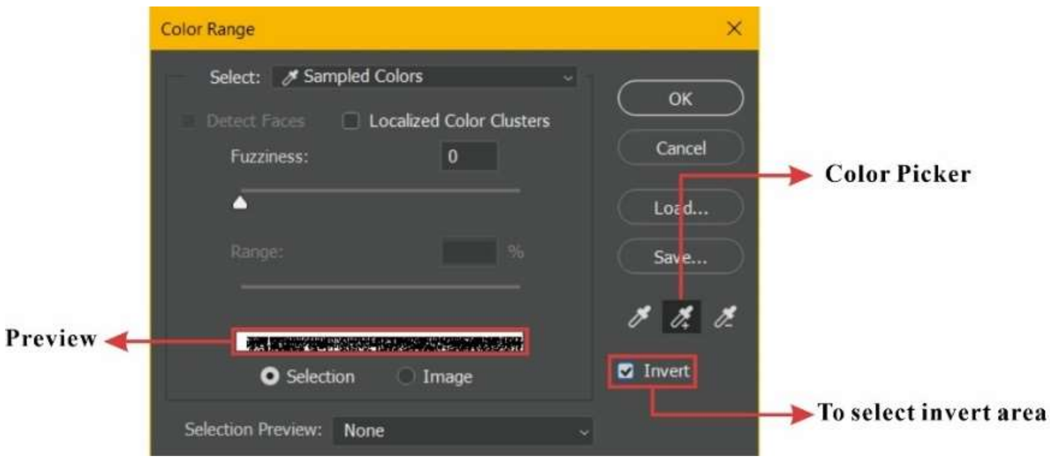


Figure 7. Color range feature in Photoshop 2023

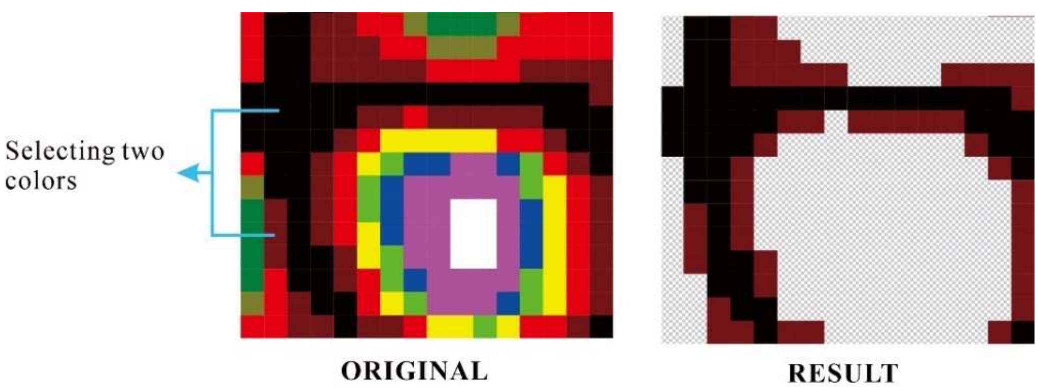


Figure 8. Selecting black and marron color

The color selection this time focuses on dark colors, namely black and dark red, which are included in the weak reflection signal and secondary weak reflection signal categories. The dark color is an interpretation of the condition of the fouled ballast in the field. This refers to Kuo (2021) research which obtained results of color comparisons with the original conditions in the field. Figure 8 is the result of maroon and black color selection on the GPR scan results in the 24K + 450 segment.

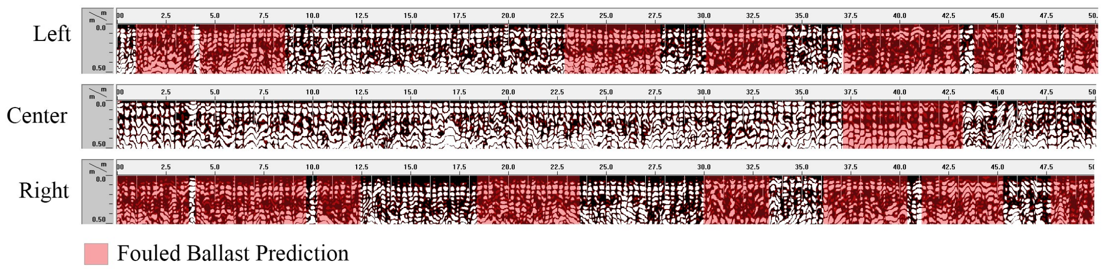


Figure 9. Color selection result in segment 24K + 450

From Fig 9, it can be seen that the areas marked in red are prediction areas for fouled ballast conditions. Prediction of fouled ballast areas can be done by looking at areas that have a high dark color intensity. In this research done manually. The right and left survey lines have 8 prediction areas for the occurrence of fouled ballast. Meanwhile, the middle survey line has only 1 prediction area for fouled ballast. The color selection method makes it easier to analyze GPR scanned images by separating the other colors with a detailed level of selection accuracy.

## 5 CONCLUSION

In railway construction, it is very important to check the condition of the ballast. An investigation is required using a Ground Penetrating Radar (GPR) tool to save time and money. GPR data processing using the color selection method can simplify image analysis and predict fouled ballast areas. Utilization of the color range feature in the Photoshop 2023 software provides accurate color selection results and is easy to operate. In the future, this research requires comparative evidence on the original conditions in the field so that predictions are in accordance with field conditions. Further studies are needed to determine the prediction of fouled ballast areas to make it more practical.

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