DETAILED GPR SURVEY FOR DETECTING BOULDERS BURIED IN A SUBGRADE OF A HIGHWAY UNDER CONSTRUCTION

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Abstract

We conducted a detailed GPR survey to detect buried boulders in a highway under construction. The size of boulders were observed against the regulation for embankment subgrade materials. The illegal-size boulders should be removed because they might cause undulations of road surfaces. The survey area was 540 m in length and 20 m in width. First, two parties surveyed the area by using the same GPR tools combined with network RTK-GNSS positioning system. Next, we processed the acquired datasets by using a criterion that we established. The criterion was established based on GPR diffraction patterns to extract anomalies generated from buried boulders. A total of 148 anomalies were extracted. Then, we marked all locations of the anomaly on the road surface, and immediately dug at the extracted points to confirm whether illegal-size boulders were buried or not. As a result, boulders which was bigger than 20 cm in size were removed at 146 points. It took 6.5 days for this survey from a preliminary survey to excavations at all anomaly points. Such a quick handling contributed to minimize the delay of construction. This high hitting ratio demonstrated the effectiveness of dense GPR survey for detecting buried boulders.

Introduction

Irregular-size boulders were found in a subgrade of road embankment under construction when the subgrade was dug for embedding a drainage pipe. The subgrade consisted of 5 compacted layers. A thickness of each layer was about 20cm. Boulders filled in the subgrade were size-regulated to be smaller than the thickness of each compacted layer. Since the lift height before compaction was 30cm, a boulder which was bigger than 30cm shouldn't fill in the subgrade. If such boulders were buried in the subgrade, they would cause insufficient compaction. In addition, the boulders would cause undulations of road surfaces. If worse comes to worst, serious accident might happen because of insufficient trafficability. Therefore, it needed to confirm whether irregular-size boulder was buried in subgrade or not in subgrade. Furthermore, rapid survey was demanded because road construction was suspended until completion of the survey and removal of the boulders. We conducted an urgent survey to detect boulders (Aoike et al., 2017). In this survey, we used combined measurements of GPR and network RTK-GNSS located system (Aoike et al., 2015, Inazaki et al., 2016). This system can acquire GPR data with high-precision positioning of which accuracy is within +/- 1 cm under RTK-FIX solution. This high performance enabled us to obtain high-resolution GPR images and accurate boulder location at the same time.

Field Survey

A GPR survey had already been conducted by a company before we surveyed. However, they couldn't detect any boulders buried in the subgrade by using their GPR system. They concluded that GPR survey couldn't be applicable for detecting boulders. As a reason for this, we considered that dielectric constant of boulder and subgrade materials were almost the same. In order to acquire reflection waves generated by a boulder, a high contrast of the dielectric constants is necessary. The dielectric constant of water is known as 81. When water infiltrated into the ground, the difference of dielectric constants between boulders and subgrade materials will be expected because the dielectric constant of subgrade will be greatly increased, and that of boulder will be hardly change. We considered that boulders might be detected after rain by applying GPR methods.

A field experiment to verify GPR performance

First, we verified whether GPR could detect a buried boulder. This preliminary survey was carried out on a rainy day. Three boulders which was bigger than 30 cm in size were buried in an embankment (**Figure 1**). A top of the depth of each boulder was set about 45 cm in depth. We used GSSI Utility-scan DF. **Figure 2** shows an example of 800-MHz antenna's profile. Each boulders were clearly imaged by the reflection waves generated by the upper and bottom parts of boulders. The upper reflection waves were shown as positive polarities, and the bottom reflection waves were shown as negative polarities. This result proved that the dielectric constant of soil was higher than that of boulder. In other words, infiltrated water causes changes of the contrast in dielectric constants between boulder and soil. This field experiment demonstrated the effectiveness of GPR for detecting irregular-size boulders.

Figure 1: Photographs of the field experiment. Three different sizes of boulders were set in a pit (**a)**. Then we covered the boulders with embankment materials. GPR survey was conducted (**b)**.

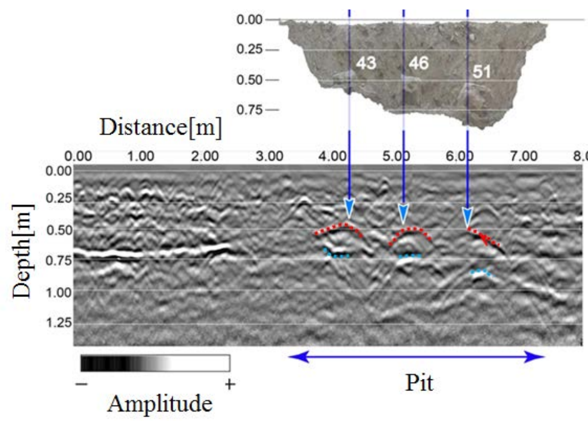


Figure 2: An example of GPR profile. Red dotted line indicate the reflection waves generated by the upper parts of boulders. Blue ones indicate the reflection waves generated by the bottom parts of boulders.

Quick survey

After the field experiment, we immediately started on-site surveys. For a rapid survey, two groups were formed. Each team used same data acquisition system. The survey area was 540 m in length and 20 m in width. The survey lines were set with 30 cm interval. A total length of survey line was about 43 km. We covered the whole survey line in 2.5 days. In this survey, we dug at one point to confirm an anomaly as shown in **Figure 3**. This was confirmed as boulder whose size was bigger than 80cm.

In house processing

Next, each profiles were processed by using a criterion shown in **Table 1**. The criterion was established based on the result of field experiment. The extracted anomalies which were interpreted as boulders were bigger than 30 cm in size. Rank A was bigger than 50 cm in size and could be identifiable the upper and the bottom reflection waves. Rank B was smaller than Rank A and could be identifiable both reflection waves. Rank C could be identifiable only the upper reflection wave. Because a thin boulder, which was shorter than the wavelength of transmission wave, could not reflect distinguishable upper and bottom reflection waves. As a result, a total of 148 anomalies were extracted (**Figure 4**).

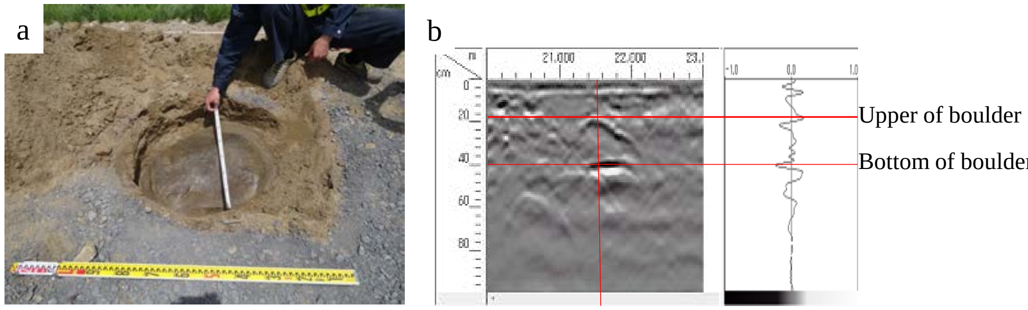
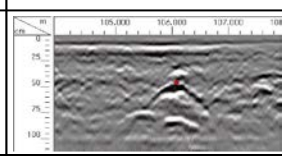
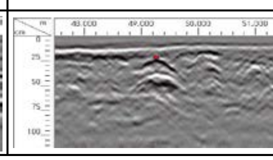
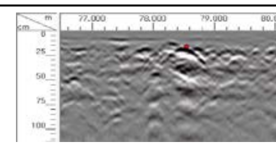


Figure 3: An unearthed boulder (a) and its GPR profile (b). A boulder was found at 15 cm in depth. As shown in b, the upper reflection waves generated by the buried boulder was positive polarities, and the bottom reflection waves generated by buried boulder were negative polarities.

Table 1. A criterion for extracting anomaly

Rank	A	B	C
Characteristics of anomaly	Upper and bottom refelection waves were acquired		Upper reflection wave was acquired
Polarity of reflection wave	Upper reflection wave : positive Bottom reflection wave : negative		Upper reflection wave : positive
Estimated size	Bigger than 50cm	From 30 cm to 50cm	Bigger than 30 cm
Example			

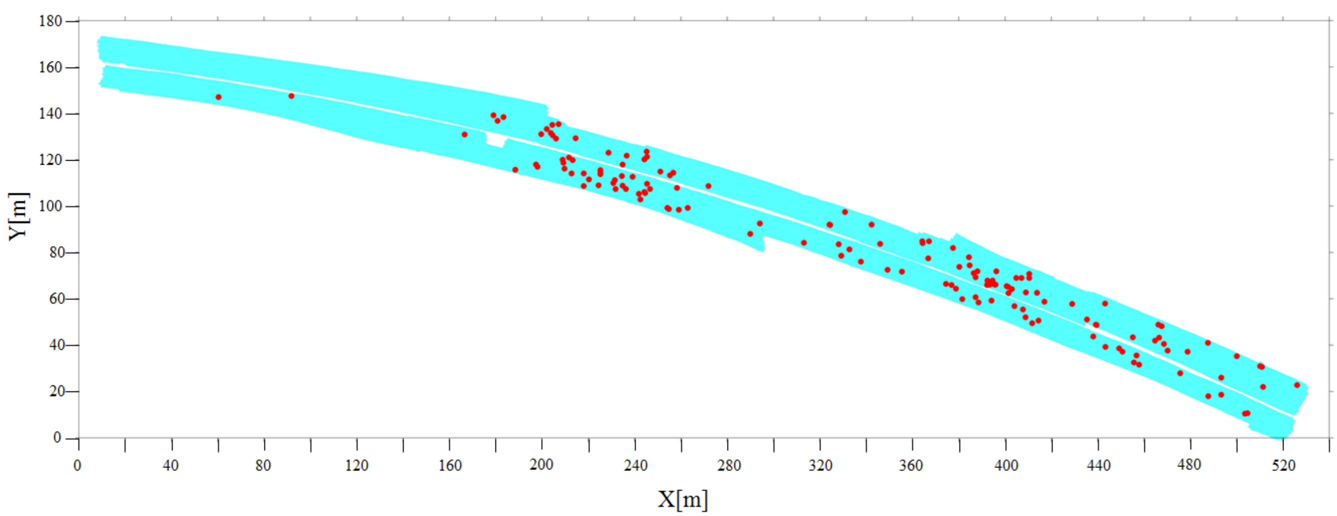


Figure 4: Location map of boulders. Blue zones indicate the survey area. Red circles were extracted anomaly points which were interpreted as locations of irregular-size buried boulders.

Reconfirmation and results

Finally, we confirmed whether anomalies were due to irregular-size boulders or not. All anomaly points had the location information of latitude and longitude. All locations of anomalies were marked on the surface (**Figure 5a**). Then, all points were dug by three backhoes immediately to verify whether boulder was buried. **Figure 5b** shows examples of excavated boulders and GPR profiles. As a result, irregular size boulders were removed at 146 points.

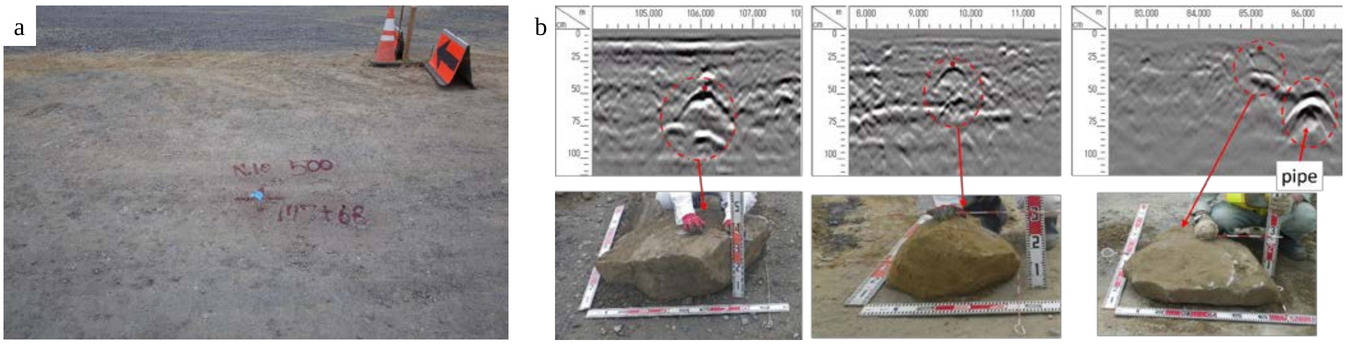


Figure 5: Photo of a marked location of anomaly (a) and examples of removed boulders and GPR profiles (b).

Conclusions

We conducted detailed GPR survey to detect irregular-size boulders buried in subgrade of a highway under construction. A total of 148 anomalies were extracted, and boulders were removed at 146 points. In addition, this urgent survey was completed in 6.5 days. We contributed to minimize the delay of road construction. Combined measurements of GPR and network RTK-GNSS provided high precision locations of buried boulders. The performance was good enough to complete a rapid survey. Thus, GPR survey is useful for quality improvement of road constructions.

References

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