NDT methods in inspecting road and highway structures

T S T Amran¹,², M S M Amin¹, M R Ahmad¹, N M Azreen¹, S Sani¹, M A K Adnan¹, N A Razak and S Sayuti¹

Non-Destructive Testing - Material Structure Integrity group (NDT-MSI), Industrial Technology Division, Malaysian Nuclear Agency, 43000 Kajang, Selangor, Malaysia

²sarah@nm.gov.my

Abstract. This paper presents an overview of the non-destructive testing (NDT) methods that can be used to determine the quality and safety of road and highway structures in Malaysia. These NDT methods offer a relatively quick and inexpensive mean for regular inspection, which shall help alert the responsible agencies of critical structural damages even before heavy deterioration is visually apparent.

1. Introduction

The Federal Road network contains bridges with a bridge deck area, tunnels and a large number of other highway structures like retaining walls, noise protection walls and structures for traffic signs. The maintenance programs prepared for this purpose do not only require a high budget, but also influence the traffic infrastructure and, thus, the economy and society as a whole. The safety of the structures has to be ensured under consideration of environmental aspects [1]. At the same time the structure owner has to make sure that the maintenance activities are carried out in the most efficient way. The programs for lasting and systematic maintenance of these structures tie up a large percentage of the budget. This increase is influenced by insufficient durability of most of the structures which were built during the years 1960 to 1980. Further important aspects are the growing volumes of traffic and higher gross weights of trucks which lead to a reduction of the expected lifetime of bridges. Considering the fact that financial resources are restricted, the maintenance costs have to be spent in a way to obtain the greatest possible benefit [2].

Non-destructive testing (NDT) is expected to gain an increasingly important role in the management of structures. Efforts should be made to integrate the NDT data into the systematic maintenance system. This will improve the quality of information by eliminating the subjectivity associated with current visual inspection techniques. NDT methods can be used in future under the condition that results of investigations can be quantified and translated into rating resulting from road and highway inspection [3]. The term NDT used in this connection represents the techniques that are based on the application of physical principles employed for the purpose of determining the characteristics of materials or components or systems and for detecting and assessing the inhomogeneities and harmful defects without impairing the usefulness of such materials or components or systems.

NDT is not an integral part of most inspection procedures. Within the last decade, NDT gets more important for quality control of the workmanship after finishing the construction process and as a non-disruptive tool for the evaluation of current condition [4]. Only a few destructive samples are needed
for verification and validation of the result. The condition assessment of the inner structure can localize quite fast hidden construction defects and determine the extent of damage caused by external impact or deterioration. Several NDT techniques have been developed to enable more efficient assessments of road and highway structure. This paper presents an overview on the NDT techniques that have been apply in one of the case studies done for highway inspection that showed that NDT techniques can give faster data acquisition, more contained cost and the capability to be performed in-situ over longer distances.

2. Case study
The development of voids beneath highways can lead to major pavement failures, a serious hazard. Voids typically develop because of subsidence and erosion of the base and subgrade materials. Void-related highway problems have often developed as a result of surface water intrusion into the road base. This may allow fines particles to be carried away, resulting in local base or foundation erosion, and the formation of weak areas, which eventually become voids. Voids continue to increase in size as the load from vehicles using the highway continues. The development of voids beneath highways is a serious hazard, making their early detection an important aspect of infrastructure maintenance and remediation. Early identification of concealed subsurface voids under a highway structure is critical to prevent major failures from occurring.

One of the most effective tools in use is ground penetrating radar (GPR) method. GPR has advanced to a level where the subsurface condition of a highway can be inspected and diagnosed with confidence. GPR is a non-destructive geophysical device used for subsurface exploration and operates by transmitting an electromagnetic pulse from an antenna into the ground and then capturing the partial reflections from subsurface layers [5]. A hyper spectrum (350 MHz) GPR system by GSSI was used in this case study. The highway inspection using GPR data were collected along nine scan lines, parallel to the road with 1-meter spacing. The highway data collection was conducted for 3.7 km length. The interpretation was done manually by identifying the areas showing relatively high amplitude response. This case study was carried out because there is a request from client to do the highway inspection. Therefore, due to the privacy and confidentially agreement of client, the exact location of the case study cannot be disclosed. Other techniques used as a complimentary technique to confirm GPR data was geoelectrical resistivity imaging (GRI) [6]. GRI is used in estimating the resistivity distributions of the subsurface based on several measurements of discrete voltage and current. This paper summarizes the case study, the technology overview, the inspection methodology and results of identified anomalies for the highway.

3. Methodology
The inspection for highway was conducted by quickly survey the area for potential sinkholes that might exist under the road surface. This survey was conducted using a GPR system with a 350 MHz antenna mounted on a survey cart. Subsequently, a more detailed survey of those areas was performed to confirm the existence and to determine the distribution and dimension of the potential sinkholes identified in the preliminary survey using GRI techniques.

3.1. Ground penetrating radar (GPR)
GPR is the general term applied to techniques that employ electromagnetic waves (radio wave range) to profile structures and features in the subsurface [7]. Although typically used for ground (soils) applications, GPR can be used to identify features beneath other surfaces. GPR method is based on transmission, reflection and detection of radio waves. A short pulse of high frequency (250-900 MHz) radar wave is produced and transmitted into the ground or other medium (i.e., concrete). The pulse spreads into the subsurface materials and is affected by the properties of the surrounding material. Waves are reflected at the interface between materials of different dielectric constants (Figure 1). A receiver records the reflected energy at the surface. Processed radar data are plotted as surveyed horizontal distance (meters) versus two-way travel time in nanoseconds (2D mode). When GPR data
are collected in grids, 3D data processing and interpretation can be applied. GPR can locate both metallic and non-metallic targets. Penetration depth and detectability of targets will depend on antenna frequency, target orientation and the conductivity of the host material.

![GPR principle and reflection profiling](image)

**Figure 1:** GPR principle and reflection profiling

A GSSI GPR device equipped with a 350 MHz hyper stacking antenna was used (Figure 2). Nine scan lines were selected along the highway with the antenna separation between the lines was 1 m (Figure 3). Data processing was done by the RADAN processing and analysis software package. The interpretation was done manually by identifying the areas showing relatively high amplitude response. Please note that the anomalies can be caused by numerous reasons. Including but not limited to: different electrical properties in the host material (i.e., different water content, different minerals), void space, embedded human-made objects (tank, concrete, metal or plastic pipes etc.).

![GSSI GPR system 350 MHz Hyper stacking antennas](image)

**Figure 2.** GSSI GPR system 350 MHz Hyper stacking antennas.
3.2. Geoelectrical resistivity imaging (GRI)

Geoelectrical resistivity imaging (GRI) technique is a non-invasive technique that can map out subsurface structure based on electrical properties of subsurface material for example resistivity and conductivity which can be used to verify GPR data. Unlike the GPR Technique, GRI can investigate much deeper structure as compared to GPR but with lower resolution. The effective depth of GRI depends on the choice of electrode configuration and spacing. In this project, data acquisition was carried out as 3 sets of electrode spacings which are 40m, 100m and 200m with respect to the effective depth of 5m, 10m and 20m, respectively.

A set of ABEM Terrameter SAS 4000 (Figure 4) and a switcher unit were used to control the induction of current and potential readings from electrodes connected by multicore-cable along the survey line. The depth of the data obtained is depending on the length of the survey line, electrode spacing and the protocol file used in the survey. In this study, Pole-dipole protocol was selected.

Subsurface resistivity distributions are measured (Figure 5) by applying electrical current into the ground by using two current electrodes. The potential differences caused by the flow of current between any two points in linear line with the current electrodes are then measured by a pair of
potential electrodes. From the measured voltage (V) and current (I) values, the resistance at the specified point in the subsurface can be determined. In a homogeneous ground, the penetration depth is directly proportional to electrodes spacing, and changing the electrode’s separation gives information on sub surface’s stratification [8]. For 2-D resistivity imaging, it is important to have a large set of data recorded along a survey line to effectively map the complex resistivity distribution of subsurface structure. The most practical way to acquire such a large amount of data is by using automated multi-electrode data acquisition system.

4. Results and discussion

4.1 Ground penetrating radar (GPR)
The 350 MHz hyper stacking GPR system provide sufficient data quality, although the signal penetration depth was limited to approximately 3.0m probably due to soil conditions. Figure 6 illustrated typical pavement layers of highway for normal condition as detected by GPR system. It is consisting of asphalt, road base, subbase and subgrade.

Figure 5. Data collection using GRI.

Figure 6. Typical pavement layer of highway.
Ground penetrating radar survey identified 55 anomaly areas which can be categorized into 4 types which are disturbed profile, contaminated profile, displacement and concrete structure profile. Detail of the anomalies profile are summarized in Table 1. GPR survey able to penetrate up to the 3-meter depth and the depth of asphalt, base and sub-grade can clearly identify. Grid scanning improved the quality of GPR data and enable to estimate the size of the defect. The example of GPR anomalies profile is shown in Figure 7. Six potential void-like structures are identified and from the 6-potential void-like structure, GRI test has been carried out at two location and the result shows good agreement with GPR result.

### Table 1: Details of GPR anomalies profile

| Profile                  | Definition                                                                                                                                 |
|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Normal Profile           | the condition whereby pavement layers such as asphalt layer, sub-base and subgrade can easily be identified from the radargram              |
| Contaminated Profile     | the condition whereby different layers beneath the road surface could not easily be identified due to the contamination of the layer by water and clayey materials. |
| Disturbed Profile        | the condition whereby the layer has lost its continuity due to a physical disturbance or modification such as previous maintenance work or the existence of void like structure |
| Displaced Profile        | the condition whereby the continuity of the layers is displaced from the original position                                              |
| Reinforced Concrete      | the condition whereby the radargram is showing the existence of constant tiny hyperbolic signals as a result of the high reflection of radar wave by the equally-spaced metal reinforcement bars. |

#### 4.2 Geoelectrical resistivity imaging (GRI)

Resistivity surveys were carried out at two location named profile A and profile B along the highway. The locations were selected based on GPR data which show the most severe location. Resistivity survey lines for profile A were shown in figure 8. The saturated zone was delineated with dotted lines while the weathered and fractured granite bedrock was delineated with a dashed line. Resistivity survey line with a distance of 40 m detailed out the water content that may be filled within the saprolitic soil. Resistivity survey line with a distance of 100 m showed the top of weathered and fractured granite bedrock. The resistivity survey line with a distance of 200 m finally revealed that the weathered and fractured granite bedrock was in the form of the boulder.

Resistivity survey lines for profile B were shown in Figure 9. The saturated zone was delineated with dotted lines while the weathered and fractured granite bedrock was delineated with the dashed line. Resistivity survey line with a distance of 40 m indicated that the weathered fractured granite started to form at the near surface. Resistivity survey line with a distance of 100 m highlighted saprolitic kaolin between the weathered and fractured granite bedrock. The resistivity survey line with a distance of 200 m finally revealed that the subsurface formation herein was mainly composed of weathered and fractured granite bedrock with some saprolitic soil within.
Figure 7. Example of GPR anomalies profiles.
Figure 8. Electrical resistivity tomography at Profile A a) resistivity survey line of 40 m, b) resistivity survey line of 100 m and c) resistivity survey line of 200 m.

Figure 9. Electrical resistivity tomography at Profile B a) resistivity survey line of 40 m b) resistivity survey line of 100 m and c) resistivity survey line of 200 m.
4.3 Comparison GPR-GRI data

![Figure 10. Comparison between GPR radargram and GRI 2-D image at anomalies (red dotted line) which shows in good agreement](image)

GPR result shows a contaminated area and this is in agreement with GRI data which is represented by a conductive area.
5. **Conclusion**

The work investigates the effectiveness of Ground Penetrating Radar (GPR) and Geoelectrical Resistivity Imaging (GRI) methods for the inspection of road and highway conditions in Malaysia. Based on our measurements, these two methods complement each other, specifically in detecting anomalies beneath the road surface. It is upon these observations that the authors propose the use of these aforementioned NDT methods for the regular inspection of road and highway in Malaysia.

**Figure 11.** Comparison between GPR radargram and GRI 2-D image at anomaly which shows in good agreement.
6. References

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