Identification of Ground Subsidence due to Collapse of Solution Cavities in Marble Rock

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Abstract

Ground subsidence can occur due to reasons such as; oil/gas/water extraction, mining, and dissolution of carbonate rocks. Identification of potential subsidence locations are usually difficult due to limited information and complexities in the subsurface profile. This research focuses on the ground subsidence occurring due to the collapse of solution cavities in marble rocks. Accordingly, two locations in Matale and Badulla districts which had previously encountered subsidence in the marble rock band of the Highland Complex were surveyed using Ground Penetrating Radar (GPR) to generate cavity profiles of 2D trace analysis of the radargrams. The GPR interpretations were validated using the well-log data and the records on the previous ground subsidence reports. Several GPR surveys conducted in Matale region indicated the presence of solution cavities in marble rock. The increasing number of cavities towards the river in the region can be considered as the influence of the groundwater movements on cavity formation. The resultant cavity profiles of TO1-TO2 were compatible with available well-log data (MA 182) and indicated that the accuracy of subsurface details that can be gathered using GPR technology. Similar conditions were observed in the Badulla area and showed the evidence of groundwater induced solution cavities in marble rock. Hence, to minimize the ground subsidence hazards, it is recommended to conduct GPR surveys to obtain subsurface information, prior to future construction or development activities on the regions where marble bearing bedrock is present.

Keywords: Ground Penetrating Radar, Sinkholes, Carbonate rocks, Metamorphosed limestone

1 Introduction

Subsurface movement of earth materials by sudden sinking or gradual settling of the earth's surface is called ground subsidence. Ground subsidence in carbonate rocks mostly occur due to the collapse of cavities formed by the acidic groundwater and resultant carbon dioxides. In Sri Lanka ground subsidence incidents have been mainly reported in marble rocks within the Highland Complex. There are also reports of minor subsidence on Miocene limestone sedimentary rocks in north-west of Sri Lanka [1].

This study is on the ground subsidence occurring due to the collapse of solution cavities in marble rocks. The two study locations were Matale [2],[3] and Badulla [4] where previous ground subsidence had been reported in the Marble rock band.

Identification of potential ground subsidence locations are impossible without detailed subsurface investigation results [5]. Because, signs of cavities cannot be found till the collapse and sinkhole opening happens with cracks on surface structures. Generally, invasive techniques such as; construction of drill holes, trenches or pits are not feasible to identify solution cavities due to the extent of the area and high costs involved. Hence, non-invasive (geophysical) methods such as resistivity, gravity, seismic or Ground Penetrating Radar (GPR) techniques which can rapidly explore large areas are most suitable to identify ground subsidence hazardous locations [5].

1.1 Study Area I

After the heavy rain fall in mid of December 2012, a significant ground subsidence encountered in the areas of Dorakubura, in Matale District [2],[3]. Dorakubara area off Thotagamuwa junction is located on A9 road between Matale and Dambulla. Ground subsidence location and GPR survey lines are shown in Figure 1.

1.2 Study Area II

Meegahakiula, Thaldena [4] in Badulla district experienced a ground subsidence on 21.10.2017 at a paddy

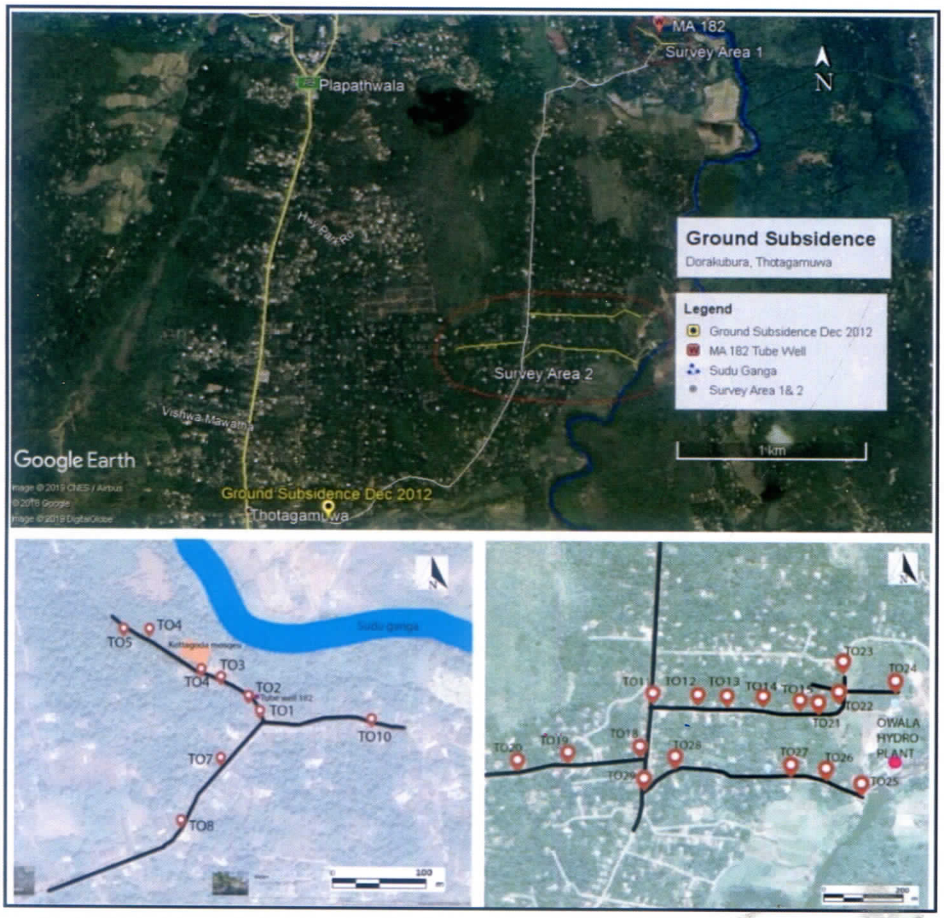

Figure 1: Ground Subsidence at Thotagamuwa, Matale and Survey Area 1 & 2.

field near by Badulu Oya. The location is to the left side of the Thaldena Bridge on Badulla to Mayanganaya B36 road. The sinkhole and GPR traverses are shown in Figure 2.

2 Methodology

2.1 A literature survey was conducted on ground subsidence caused by the failure of cavities in carbonate rocks and applicability of GPR method for cavity identification

2.2 The published and unpublished reports and maps on ground subsidence in marble rock bands of the Highland Complex in Sri Lanka were referred to identify the most suitable areas for this study.

2.3 Conducted GPR surveys along selected lines in the two study areas. Then, a subsurface profile was generated using 1D and 2D trace analysis of the radargrams [6] to identify cavity locations.

2.4 Subsurface cavity profiles developed from the GPR survey results were validated using the well-log data and the information from previous ground subsidence reports.

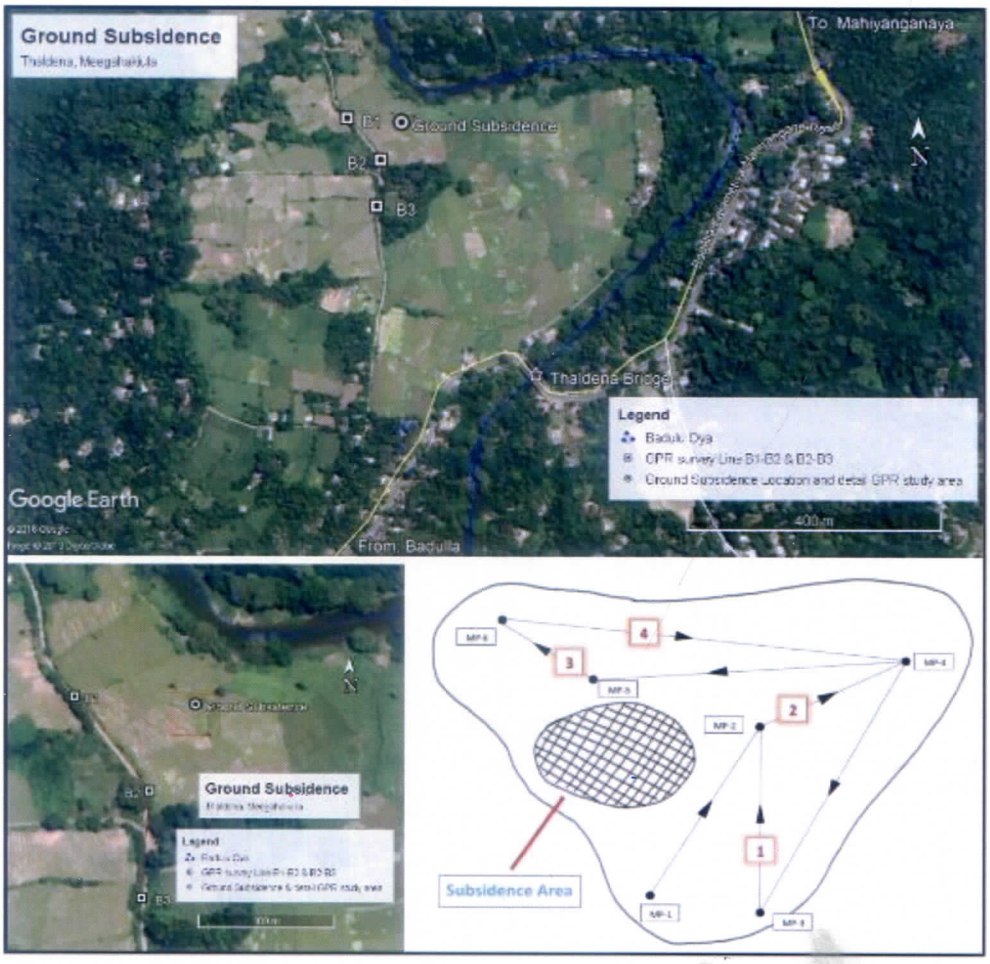

Figure 2: Ground Subsidence at Thaldena, Badulla and GPR Survey Areas.

2.5 Proposed a mechanism to minimize and manage the hazards from solution cavities in the marble rocks of the Highland Complex.

3 Results and Discussion

The data gathered using Akula 9000C GPR instrument using Gekko 60 antenna (Penetration depth ~50m) at the field were analyzed using GPR soft Pro software at the laboratory. The Gekko 60 antenna was selected for the survey as the expected cavity depths were more than 20m.

Survey area 1 of Matale GPR line TO1– TO2 GPR profile, radargram and corresponding cross section of the tube well log (MA-182) is shown in Figure 3. Presence of cavity at depth about 15-20m, at the location close to MA-182 on TO1-TO2 survey line was identified in the GPR profile. In the available well log data, cavity is indicated at 16-19m depth. Therefore, the cavity profile created from the GPR survey was compatible with the available well log data (MA 182) for the above location.

Survey area 2 was selected closer to the reported ground subsidence location in 2012, to identify whether there are cavities which have potential to collapse.

In survey area 2, GPR traverses were conducted perpendicular to the strike (E-W direction) of the marble rock band (Figure 1). GPR profile related to eastern side of the road especially closer to Sudu Ganga, several cavities were identified within the depths from 20-30m (Figure. 4). However, GPR profiles related to western side of the road, which was away from the Sudu Ganga, no cavities were identified (Figure 5).

The results indicated the presence of solution cavities towards the direction of the river in the area. It may be due to the presence of groundwater, and their movements had influenced the formation of cavities in the marble rock.

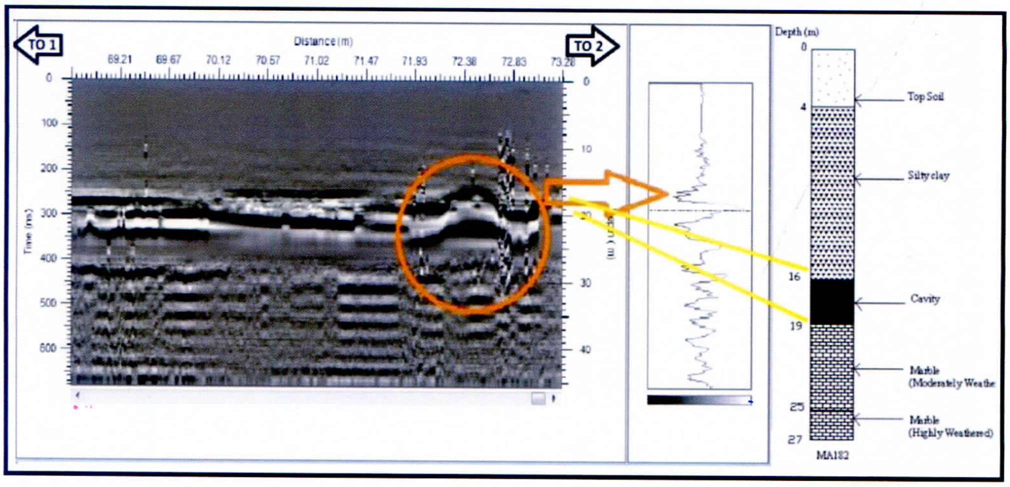

Figure 3: GPR Profile of Survey Line TO1-TO2 and Well-log at Location MA 182.

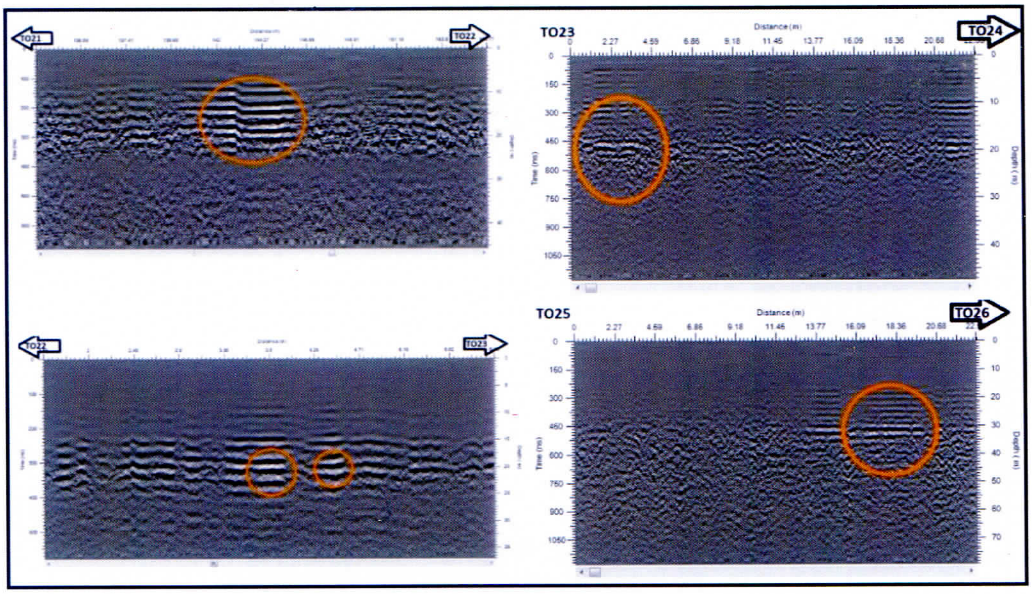

Figure 4: GPR Profile of Survey Line TO21- 22, TO22-23, TO23-24 and TO25-26.

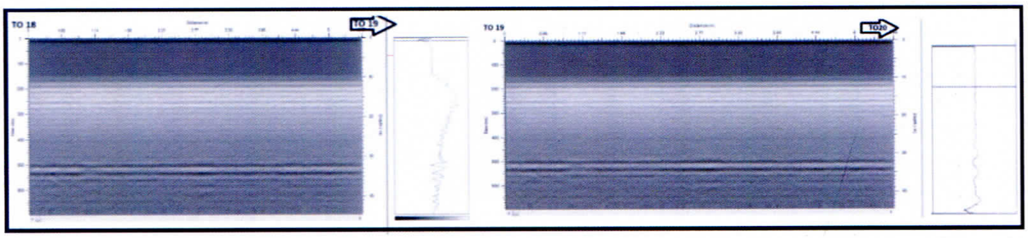

Figure 5: GPR Profile of Survey Line TO18-19 and TO19-TO20.

GPR survey lines MP 1-6, were conducted closer to the ground subsidence location at Thaldena, Meegahakiula, and lines B1-B2 and B2-B3 near the road (Figure 2).

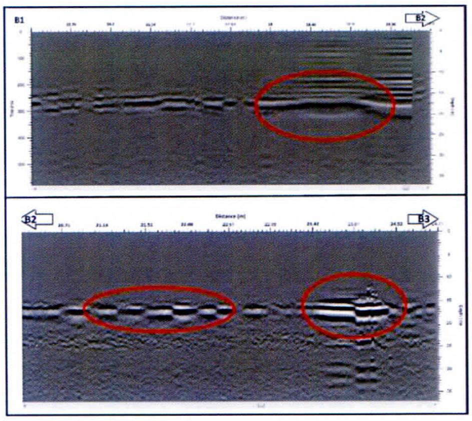

Figure 6: GPR Profile of B1-B2-B3.

GPR profiles of B1-B2 and B2-B4, only a few cavities were identified at about 20 m depth (Figure 6).

In the GPR profiles MP3-MP2 (approximately N-S) the cavities were identified at about 15-17 m depths from the surface (Figure 7) and MP6-MP4 (approximately E-W) the cavity identified at 18-20 m depths (Figure 7).

The cavities identified in the profiles B1-B2-B3 may be in connection with already collapsed cavity with an underground water path towards Badulu Oya.

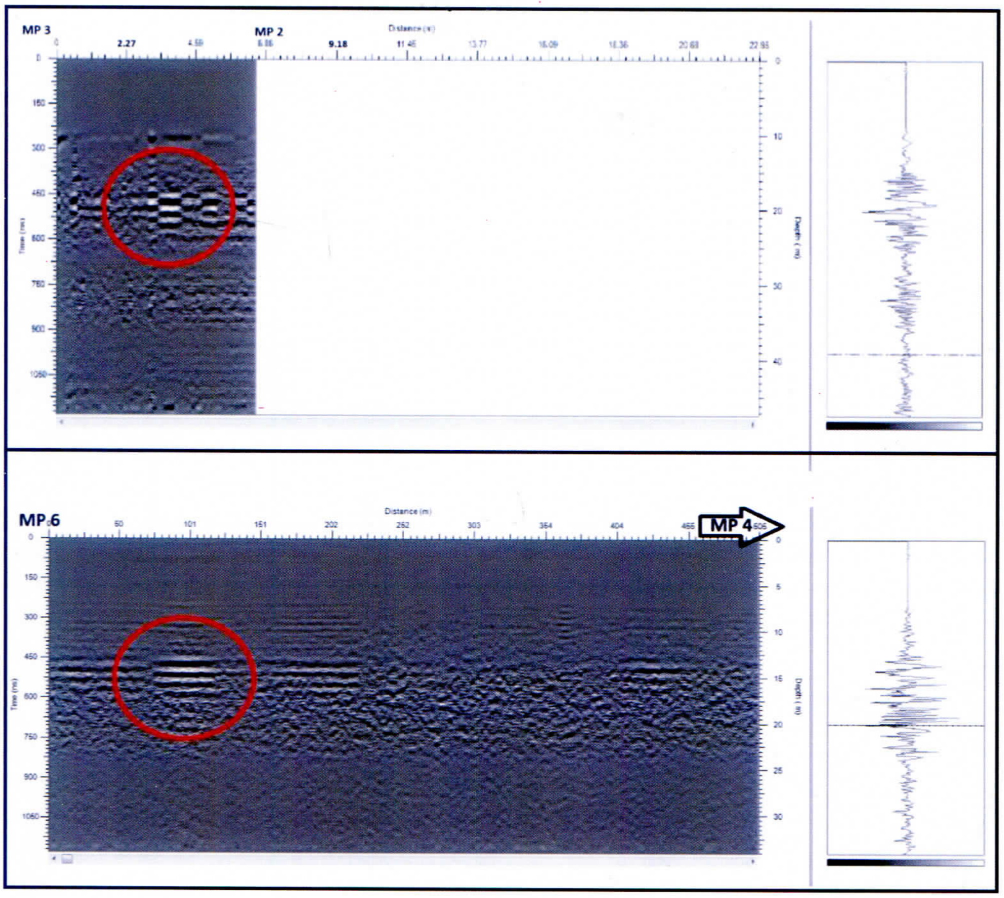

Figure 7: GPR Profile of Survey Line MP3-MP4 & MP6-MP4 at Ground Subsidence.

4 Conclusions

Presence of cavities are identified in the profiles generated from the GPR survey lines. Previous ground subsidence reports and available well log data (MA 182) confirm the accuracy of cavity profile interpretations.

The cavities identified in Matale and Badulla regions indicated an increase in numbers towards the river. Influence of the groundwater movements on formation of solution cavities in marble rocks can be inferred from the results.

5 Recommendations

A higher number of solution cavities were identified towards the water ways, and it is recommended to manage the potentially hazardous conditions associated with the marble rocks through detailed subsurface investigation prior to construction or development activities in the both study area.

In general, to minimize the ground subsidence hazards, it is recommended to conduct GPR surveys to obtain subsurface information, prior to future construction or development activities on the regions where marble bearing bedrock is present.

Acknowledgement

The authors are grateful to the Head, Research Projects Coordinator, all academic, academic support and non-academic staff members of the Department of Earth Resources Engineering, University of Moratuwa, for their kind assistance and guidance given during this research study.

References

[1] KNJ Katupotha, (2014). The Landslide Hazards and their Impact on Environment and Society - The Experience of Sri Lanka. 1st ed. Sri Lanka: Department of Geography, University of Sri Jayawardanapura.

[2] Nawagamuwa, U.P., Wijewickrama, M., Sugathapala, K., Karunawardena, W. and Bandara, R. (2010). Matale ground subsidence and overlooked construction basics. The Institution of Engineers, pp.19 - 26.

[3] De Silva MSTL, De SilvaMSTL, Chiyamvarnan K, Niroshini R, Abeysinghe AMKB and Jayawardena CL (2018) Application of GPR to Identify Carbonate Rock Cavities Related to Ground Subsidence at Matale, Sri Lanka, Proceedings of the International Symposium on Earth Resources Management & Environment (ISERME) pp.173-178.

[4] "Divaina" newspaper on 21st October 2017, published by Upali Newspaper (Pvt) LtD.

[5] Davis, J. and Annan, A. (1989). Ground-Penetrating Radar for High-Resolution Mapping of Soil & Rock Stratigraphy1. *Geophysical Prospecting*, 37(5), pp.531-551.

[6] Geoscanners (2017). Geophysical survey solutions User Manual.