Evaluation of Karst Related Land-instability and Settlements of Buildings in Limestone Cave Environment; A Case Study from Nuwara Eliya District, Based on Geophysical Applications

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Abstract - Environmental impacts on karst settings are common as they are more sensitive than those of other rock terrains. Although the land subsidence phenomena are reported in karst environments of some areas of Sri Lanka, with the present investigations, such incidents have not been reported in the central highlands. Subsidence is the motion of earth's surface as it shifts downward relative to a datum such as sea level (Waltham *et al*., 2007). Such kind of land subsidence phenomenon, which may directly related to land instability and settlement of buildings were reported in Rotupihilla area in Nuwara Eliya district. This matter was examined and found that it could be related to the underground limestone cave, which may exists beneath the buildings of the area. Therefore the present investigation was conducted with the methods of combined Geoelectrical Resistivity and Ground Penetrating Radar methods to investigate the subsurface of the affected area. Geophysical investigation indicated a probable karst structure is present in the marble extending in direction south to north over a distance of more than 50 meters length hill slope.

The study disclosed that underground limestone cave present in the area has a direct relationship with the crack development of building structures of the area. Due to the dissolution and erosional processes in the underground cave environment, stability of the roof above the cave area appeared to be de-stabilized resulting slight subsidence related cracks on the walls. The study revealed that combined Geoelectrical Resistivity and Ground Penetrating Radar surveys can be used reasonably accurately to understand the subsurface cavities in view of studying environmental impacts in karst areas.

Index Terms - Karst environment, Geoelectrical resistivity, Limestone cave, Ground penetrating radar

1. INTRODUCTION

Natural hazards associated with intense rainfall during monsoon and inter-monsoon seasons are the most pressing natural disasters (landslide, flood, land subsidence etc.) in Sri Lanka. Intense rainfall events trigger unexpected disasters. Out of such disasters, landslides in sloping areas are the most common hazardous phenomenon in Sri Lanka. Therefore, the demand for flat terrains within the hilly areas in central highlands for human settlements is high, and hence are also increasingly populated.

Land morphology is extremely governed by geology, hence forming a flat terrain in a hilly area can be associated not only with structural pattern of the rocks but also with the rock type. Formation of ground slopes, hence, can truly be resulted by weathering process and it is well noted that high weathering rates create unstable slopes in such areas. Land instability caused by weathering is characterized mostly by landslides than land subsidence has not been considered often. Subsidence frequently causes major problems in karst terrains, where dissolution of limestone by fluid flow in the subsurface causes the creation of voids (Johnson, 1991). If the roof of these voids becomes too weak, it can collapse and the overlying rock and earth will fall into the space, causing subsidence at the surface. This type of subsidence can result in sinkholes which can be even many hundreds of meters deep (Castaneda *et al*., 2009).

Land subsidence can be observed in flat terrains of Matale and in Jaffna areas. Although land subsidence in Jaffna area is known for a long time and there have been received recent reports from Matale area too. In the village Poramadulla, a report was received that walls of three houses were started to crack after a heavy monsoon rains in December 2015. A prominent limestone cave called 'Rotupihilla Limestone cave' is extended about 2 km^2 area and the cracked houses were located just above the cave area.

In view of examining the possible relationship of the cave associated land settlement which may related with land subsidence may affect to the damages of walls and floors of the houses. Present investigation was conducted in the area using combined Geoelectrical Resistivity and Ground Penetrating Radar methods to get a clear sight of the underground limestone cave and discover the reason for the settlements of the buildings which were constructed in the karst terrain.

2. Problem Statement

Natural cavity formation in the karst terrain can be resulted by removing of underground soil or rock materials. Some rocks such as carbonate rocks (Limestone, Marble) are highly susceptible to dissolution and hence very easily underground cavities can be formed for a long period of time. Once those cavities are extended to near surface, thin ground surface is collapsed down suddenly forming sink holes and karst features.

Underground mining for economic mineral extractions can also create underground cavities due to poor refilling and lack of proper compaction and further expansion due to continuous weathering. Finally it causes sudden land subsidence. Extensive extraction of groundwater has been reported as another cause of land subsidence (Galloway et al., 2011).

The land subsidence recently reported in Bandarawela area has been a hot topic discussing in the country and it has been triggered by construction of underground tunnel of Uma Oya hydropower project. This is one of an excellent example for existence of underground cavities which have been connected to form a network of permeable zones.

Similar incident was occurred in Poramadulla area in the Nuwara Eliya district (Rotupihilla village) and it was reported as a landslide event to the Landslide Research and Risk Management Division of Nuwara Eliya district office, National Building Research Organization in December 2015. The walls of five houses of the Rotupihilla area has been cracked after the second high inter-monsoon rain occurred in November 2015.

It was reported that the cracks on the walls of houses had been developed with time. A popular "Rotupihilla Hirigal Cave" was located within this area and it was extended nearly 2 km^2 of the area beneath the houses. Some of the cave openings were observed about 100 m away from the cracked houses. Some cave openings were much larger which a man can walk away parallel to the ground surface in the underground.

These caves were directed in to the direction of the houses, where the walls has been cracked. A small stream was observed which flowing through the underground cave revealed that dissolution of the limestone cave may create wide opening of the underground limestone cave.

3. Methodology

A preliminary desk study was carried out using topographic and geology maps of the area to get an idea of the general geology and geological structures. 1:2000 survey map of the affected area was prepared at the ground topographic survey using a total station.

Cracked houses of the study area were examined and ten crack meters were installed on walls across the observed cracks of the walls. These crack meters were installed on walls of the observed crack houses in order to measure the vertical or horizontal displacements of the cracks. Installed crack meters were monitored weekly.

Along three parallel profiles, two dimensional resistivity and ground penetrating radar imaging were carried out using MCOHM, Profile 4 (model 2140 - OYO Cooperation) meter and field fox instrument and accessories.

The both types of images were compared and possible underground structure was modeled and related with the house damages.

4. Results and Discussion

The installed crack meters related with horizontal and vertical movements of the walls. The maximum movements were three millimeter vertical and two millimeter horizontal within a observed period of three months. The noteworthy feature was that cracks of the walls had been continued as cracks on the ground too.

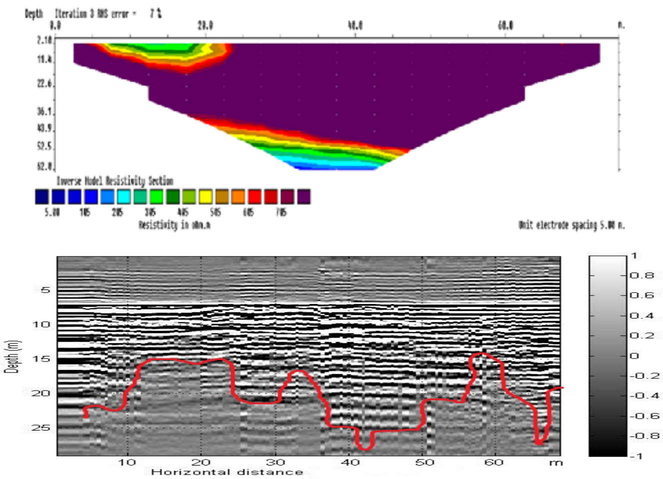

Fig. 1. Resistivity survey 2D image and GPR profile along the line A-B

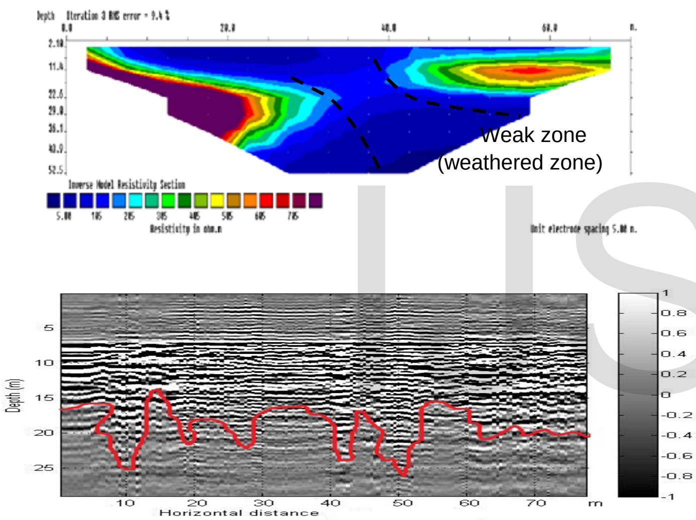

Fig. 2. Resistivity survey 2D image and GPR profile along the line C-D

The resistivity profile A-B (Figure 2) indicates a high resistivity zone which is comparable to a dry cave. The southern extension of this possible cavity can be observed. As a low resistivity zone in the profile C-D (Figure 3) probably indicating wet clay filled cave. The profile E-F (Figure 4) which is the southernmost profile also indicates the extension of this clay filled cave further south. The ground penetrating radar images along the same profiles also indicated the possible presence of the same weak zone. A model developed based on geophysical observation are shown in figure 5.

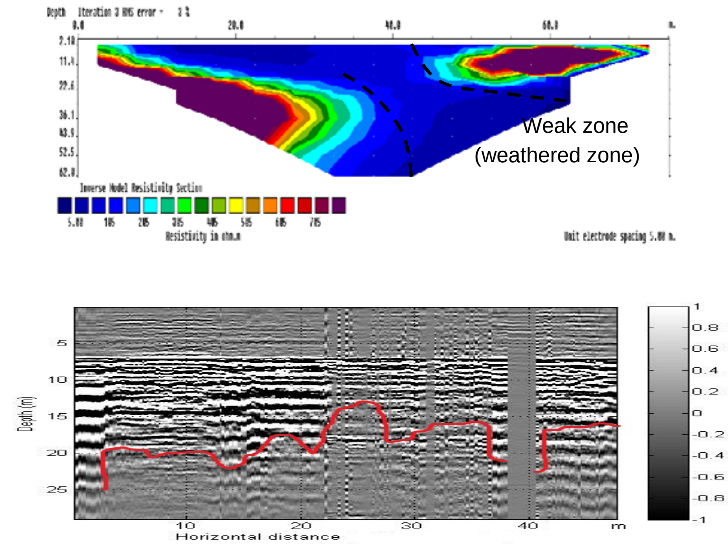

Fig. 3. Resistivity survey 2D image and GPR profile along the line E-F

It can be inferred that destabilization of the ground surface due to dissolution of limestone cavity has a direct relationship with the ground settlemet and associated house damages. It can be suggested that rapid groundwater level fluctuations during the times of intense rainfall can cause slight subsidence of the area, ground just above the wet part of the cave.

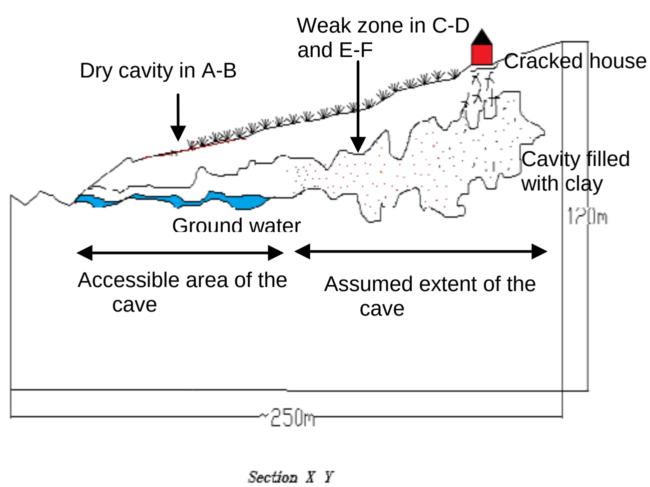

Fig. 5. A model developed based on geophysical observations

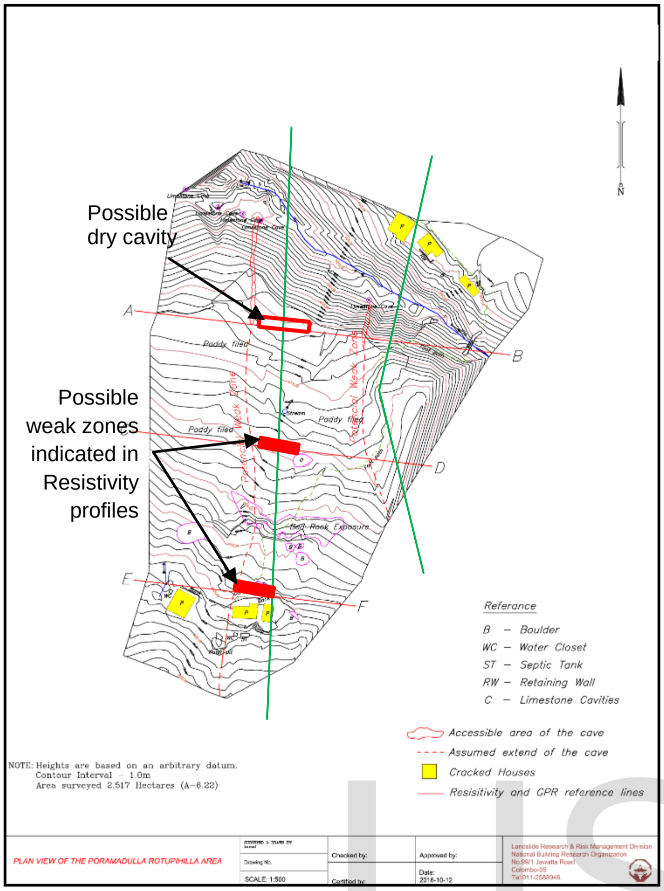

Fig. 6. Contour survey plan of the study area

6. ACKNOWLEDGEMENT

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5. CONCLUSION

Geological and geophysical observations made at the area of recently damaged houses of Poramadulla in the Nuwara Eliya district revealed that the damages can be related to a minor land subsidence event in associated with karst development processes in limestone bedrock. Land subsidence in the area is a slow process which can occur time to time during the periods of intense rainfall. Combined resistivity and ground penetrating radar surveys can be effectively used in subsurface characterization in the area of ground subsidence.

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