IDENTIFICATION OF HETEROGENEITIES IN LATERITIC SOILS

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ABSTRACT

Lateritic soils are widely spread across the southern and central parts of India. Formed due to tropical weathering, the physical and chemical properties of lateritic soils vary over a wide range and stark differences are observed even within a given deposit, along horizontal and vertical directions. Lateritic formations usually have soft sediments (lithomargic clays) entrapped between the hard to medium soft lateritic rock which are leached due to the ingress of water during rainy seasons creating hollow sections or cavities which span over large lengths, which may cause excessive settlement to structures founded on such soils. However the macroscopic behavior of such soils has been studied due to their usage as construction materials, literature on the performance of insitu lateritic soils is sparse. Potential soft soil locations which are susceptible to cavity formation need to be identified and treated well in advance to minimize potential geotechnical failures in such soils. Though excavations in past reported number of cavities in lateritic soil and formation of sink holes in region, very limited attempts were made to map scientifically and treat them well in advance for important projects. This study presents an investigation to map heterogeneities in the subsurface profile of a project site in southern Peninsular India. The area of survey was approximately 400,000 sq.m and detailed geophysical surveys were carried out *viz.* Ground Penetrating Radar (GPR) and Multichannel Analysis Surface Wave (MASW) as per ASTM D6432-11 recommendations. 100 MHz and 500 MHz (for confirmative survey) Ground Coupled Antennae were used, with an interline spacing of 2.5 m for the GPR survey to detect changes in the macroscale dielectric properties of the subsurface. With the generated radargrams, heterogeneities in subsurface are identified through changes in the nature of the obtained waveforms. Based on such GPR radargrams observed along multiple parallel survey lines, doubtful locations were identified and detailed GPR cross surveys with reduced spacing between lines and MASW survey were carried out. Suspected cavity locations based on at least two geophysical surveys are investigated by drilling boreholes, which are used as an inlet to fill/close the cavity. This paper highlights a case study of a geophysical investigation at a large scale project and methodology involved in the identification of cavities in lateritic deposits, through integrated geophysical surveys.

Keywords: *Lateritic soils, Cavities, GPR survey, MASW, Electrical Resistivity*

INTRODUCTION

Since 1800's the terminology regarding laterite has been changed over and again. Lateritic soils have a typical taxonomy as they do not fall under the general classification of rocks like igneous, sedimentary or metamorphic rocks but more type of a sedimentary residual product. The laterites of Angadipuram in Kerala, India are considered as national geological monument as it was here were name the 'laterite' was devised from a Latin word "later" which means brick by English surgeon Francis Buchanan in 1807. Buchanan reported this material as full of cavities and voids, soft enough for excavation and can be easily carved into blocks by any iron instruments, but on drying it becomes as hard as brick and is further resistant to action of air and water (Aginam et al. 2015). Past 19^{th} century laterite has been defined by many researchers in various manners like Alexander and Cady, (1962) have described laterite as highly eroded material with prolific amount of aluminum or iron oxides. Laterites are either hard or capable of hardening on exposure to wetting and drying. This terminology was regarding genesis and induration of laterite. Lohnes and Demirel, (1973) slightly modified Alexander and Cady's definition by claiming that laterite was sufficiently indurated that it could not be easily excavated by shovel or spade. In the Malabar region of Kerala, India laterite bricks have been widely used since past centuries for construction of residential structures, forts, churches, temples and other infrastructure. Removal of laterite cover for mining and bricks have proved to be beneficial alternately by clearing the area for cultivation also it was observed to increase the ground water recharge (Kasthurba et al. 2007).

Vermaat and Bentley (1954) studied the Ceylon (Sri Lanka) laterite while no significant study has been done to highlight the sinkhole formation phenomenon in Malabar (Indian) laterite. Typical laterite lithology had a mottled zone consisting of red honeycomb like structure having voids filled with yellowish or pinkish to white kaolinite clay overlying a crust layer. It is found that with depth the honeycombing framework became lighter and the size of the cavities or voids increased. The material filled in the voids remained soft on exposure to dryness and could be washed away. Kay (1972) and Robertson (1979) studied the sinkhole and pseudokarst caves in the lateritic origins of Australia. They credited the sinkhole formation to the subsidence into cavities formed by water flow in the underlying rock. Grimes and Spate (2008) studied the Australian laterite karst and found that the laterites are formed due to intensive chemical weathering of rock minerals over a long period of time. It is observed that caves with a hard surface on the top could form if the piping was localized. Grimes and Spate (2008) found the dissolution of Australian Mullaman lateritic beds to form sinkholes or caverns needed a few favorable conditions like biogenic reactions that is disintegration caused due to bacteria, fluctuating water level that is consecutive wetting and drying season and at the last rising of alkaline water from the limestones beneath during high water table conditions which facilitate dissolution of siliceous strata above. Geophysical methods like ground penetrating radar and seismic refraction have been widely used in subsurface identification of heterogeneities and sinkholes in karst and lateritic terrains in past decades. Ground penetrating radar is effective in the identification of fractures and karstic features at shallow depths (El-Qady et al. 2005). Anirudhan, (2014) observed that in lateritic deposits seismic refraction technique can be used in addition to point testing methods for identification of solution cavities.

The mineral composition of laterites in the Malabar region may vary from Ceylon to Australian Mullaman beds but the intensive weathering process and favorable conditions which help in sinkhole formation are much similar to all of the three places. As the Malabar region enjoys two rainy seasons the southwest monsoon and the northeast monsoon, which provides enough rainfall along with plenty of sunlight there is a constant fluctuation of the water table which assists in creation of piping condition. Cavities are identified in the study area under consideration. It is observed that most of the cavities are in irregular shape and identified due to sudden subsidence of the top hard surface. The ground surface above some of the cavity locations are so hard that they didn't collapse under moving loads of trucks and bulldozers. In view of the importance of structure, it was recommended to carry out detailed geophysical surveys of complete area for subsurface lithology. The literature study reveals that the lateritic profiles are highly heterogeneous in nature with properties varying significantly, it is recommended to use an integrated geophysical approach which shall cover large areas in short duration and provide a continuous subsurface lithological profile.

STUDY AREA

The paper presents a project site in the southern peninsular India, which is well known for its humid equatorial tropical climate with mean daily temperature ranging from 16° C to 35° C. The average annual rainfall is reported as 3438 mm. The laterite formations are found over origin rock types like charnockite, leptynite, anorthosite and gabbro, mainly near the coastal regions. The main bedrock found under the study area is charnockite and granite gneiss. Because of the weathering process it is highly heterogeneous and stratified in nature as seen in Figure 1. The laterites of these regions are found to be acidic, which is caused due to high rainfall and leaching of alkaline material.

INTEGRATED SUBSURFACE INVESTIGATION

Two geophysical methods, namely ground penetrating radar (GPR) survey and multichannel analysis of surface waves (MASW) were performed over the study area.

GROUND PENETRATING RADAR (GPR) SURVEY

GPR is a quick, non-destructive, non-invasive geophysical subsurface imaging technique which uses high frequency (10 MHz to 3 GHz) propagating electromagnetic waves to identify the changes in shallow subsurface strata by observing changes in electromagnetic properties. The electromagnetic properties like dielectric permittivity, conductivity and magnetic permeability in geological formation are dependent on subsurface material, water content and bulk density (ASTM D6432-11). GPR consists of four main components, transmitter, receiver, display unit and control unit. The transmitting antenna radiates a high frequency electromagnetic signal into the ground. When the propagating electromagnetic waves encounter change in electromagnetic properties, they get refracted, diffracted and reflected from the boundary of the subsurface material. The reflected signal is then received by the receiving antenna, recorded as a function of two way travel time for display and further processing. In the present study, Mala ProEx 100 MHz and 500 MHz (center frequency) continuous wave, ground coupled, shielded dipole antenna GPR were used for subsurface investigation.

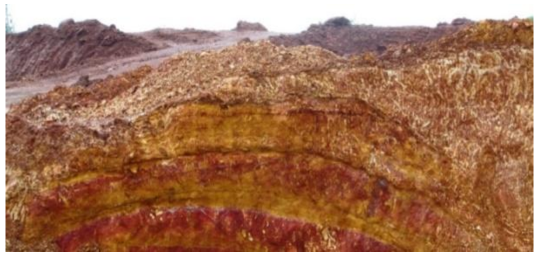


Figure 1. Soil stratification of a cut-section in laterite deposit.

The maximum penetration depth for Mala ProEx 100 MHz antenna is around 25 m and for 500 MHz is around 4 – 5 m which depends on the ground conditions like soil type, moisture content, salt content, etc. The preliminary survey was conducted over the identified areas of the construction site by 100 MHz frequency antenna longitudinally along the length at a regular interval of 2.5 m. The line lengths of the survey are marked for the full length. The distance traversed by the GPR equipment is measured by a standard distance measuring wheel attached to the antenna. 500 MHz antenna was used for the confirmative survey to obtain high resolution 2D images of the subsurface. The survey data at the site is recorded as radargrams and processed using RadExplorer (Mala GeoScience) software. Signal processing steps like DC Removal (removing constant component of the signal), time adjustment (time-zero correction due to gap between transmitter and receiver), background removal (removing horizontal banding in profiles due to system and surrounding electromagnetic noise), band-pass filter (increasing signal to noise ratio), amplitude correction (gain control) and time-depth conversion (using dielectric permittivity or wave velocity value) are applied to the radargrams. The average depth of penetration is observed to be around 5 to 6 m below ground level.

SEISMIC SURVEY

The seismic survey helps in determining the geotechnical properties of subsurface material by means of measuring their reaction to elastic or seismic action or disturbance. There are three types of seismic surveys, namely reflection, refraction and surface-wave. The surface wave survey method is the most convenient way to determine the elastic properties of shallow subsurface material as the depth-variation of shear wave, Vs is a governing factor among other elastic properties like density and depth-variation of P and S-wave velocities from which the dispersion property of surface waves is determined.

In the current study the seismic survey was performed by Multichannel Analysis of Surface Waves (MASW). The MASW survey was performed using 12 or 24 channel seismograph with 4.5 Hz OYO geophones. The seismic wave for this survey was generated from an active source by hitting a 7 kg sledge hammer on a 300 mm x 300 mm size metal plate with 5 shots. A typical view of the MASW survey conducted at the site can be seen in Figure 2. These waves were recorded by geode with 12 or 24 receivers placed at an offset of 1 m. The shot – offset distance for each line was kept at 5 m. The recorded surface wave data were used to extract dispersion curve and calculate the variation of shear wave velocity with depth using the inversion technique.

Figure 2. MASW survey being carried out at site

RESULTS AND DISCUSSIONS

This study tries to demonstrate that in case of areas consisting of laterite deposits, which are prone formation of cavities, an integrated geophysical investigation approach is required to obtain more detailed information of the subsurface lithology. As the soil in the study area mainly consists of laterite soil, the GPR profiles get influenced due to attenuation of radar signals due to presence of clay content and high moisture content. The average penetration depth of the radar wavelets is limited up to 7 m for 100 MHz antenna and 3.0 m for 500 MHz. Two geophysical surveys, GPR survey and MASW survey were performed over the study area. The results from three typical locations conducted by both the surveys are presented in the following sections.

LOCATION 1

An open cavity was idewntified location 1. The cavity had formed just 0.7 m below the ground surface and was of irregular shape (Fig. 3). It was observed that the top surface of the cavity was hard enough for a small car to stand over it. Figures 4 (b) and (c) show the radargram image for 100 MHz antenna while Figures 4 (d) and (e) show the radargram image for 500 MHz antenna.

Figure 3. Survey conducted by 100 MHz ground penetrating radar over the known cavity (Location 1).

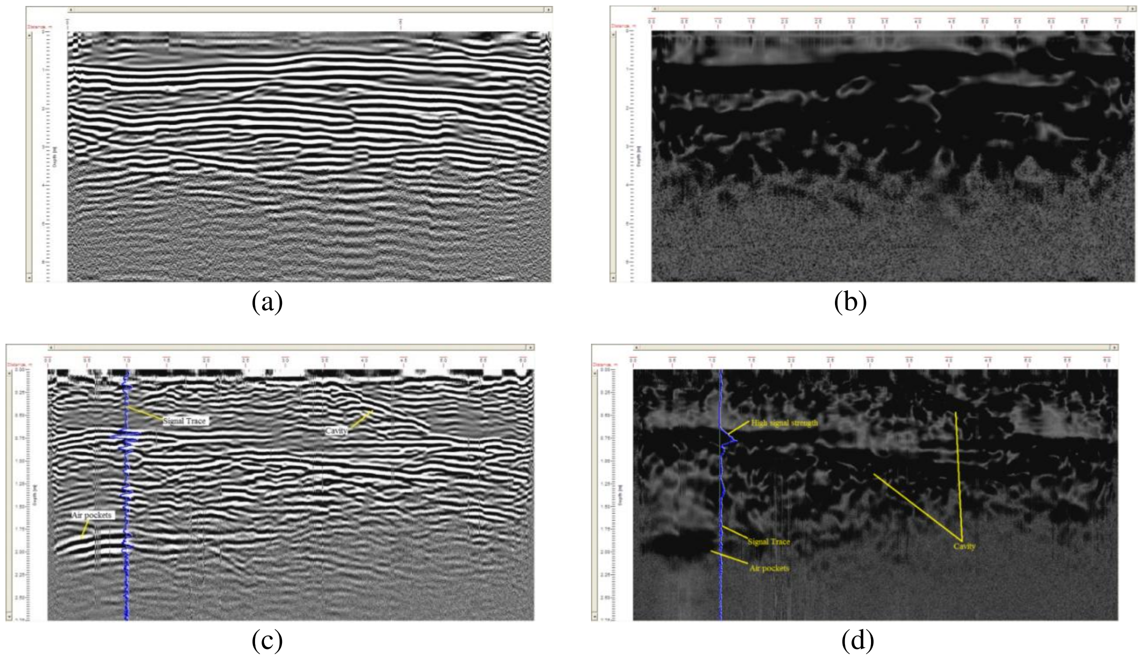
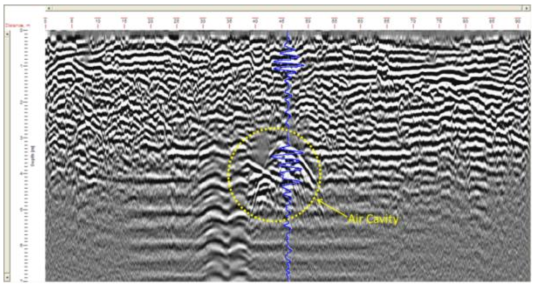


Figure 4. (a) and (b) 2D processed radargram and signal strength strength envelop for 100 MHz antenna, repectively, (c) and (d) 2D processed radargram and signal strength strength envelop for 500 MHz antenna, repectively over cavity location.

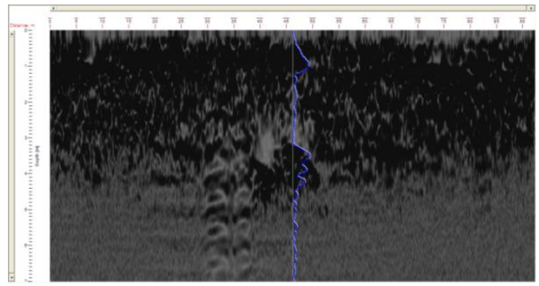
It can be easily observed from the images that the radargram with 500 MHz antenna had a higher resolution and details as compared to 100 MHz antenna. Figures 4 (b) and (d) show the respective 2D radargram for both the antennas which shows higher reflections at the interface of cavity structure and air pockets. Figures 4 (c) and (e), which represent the reflection strength of the electromagnetic (EM) signal in the subsurface, the strength of the signal is higher (darker) in air filled zone. On observing the signal trace in the radargram, it can be ascertained that a peak is observed in the signal amplitude as the signal strength and energy increases in air/water filled voids/cavity area.

LOCATIONS 2 AND 3

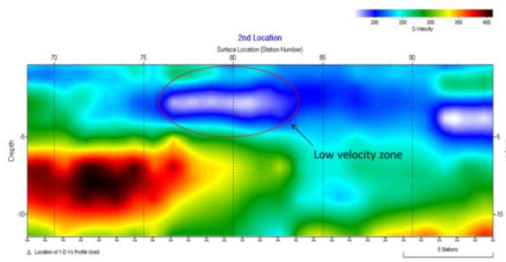
The GPR survey with 100 MHz antenna was conducted over the granular sub base (GSB) layer at Location 2 and Locations 3 over plain cement concrete pavement (PCC). From the GPR survey an anomaly was observed at a depth of 2.5 to 3 m in both the locations. MASW survey was carried out at these locations to confirm the presence of the cavity/sinkhole to obtain the shear wave velocity of the subsurface. Figures 5 and 6 ((a) & (b)) show the 2D radargram of and signal strength envelop for survey line at locations 2 & 3 respectively, while Figures 5 and 6 (c) represent the 2D shear wave velocity profile obtained from the MASW survey at the respective locations. In Figures 5 and 6 (a) hyperbolic reflections can be observed at around 3 m depth, which represents the EM wave reflections over air filled cavity. Figure 5 and 6 (b) represent the reflection strength of the electromagentic signal is higher (darker) in air filled or porous zone. Similarly to location 1, a peak is observed in the signal amplitude in signal trace in the cavity area as the signal strength and energy increases in air/water filled voids. The anomaly observed in radargram was confirmed to 2D shear wave velocity profile (Figure 5 and 6 (c)) by identifying the low velocity zone which resembles a loose or porous area.



(a)

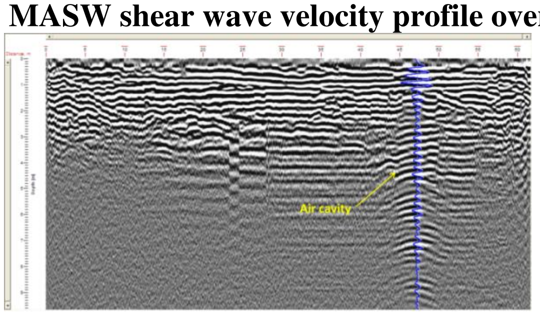


(b)

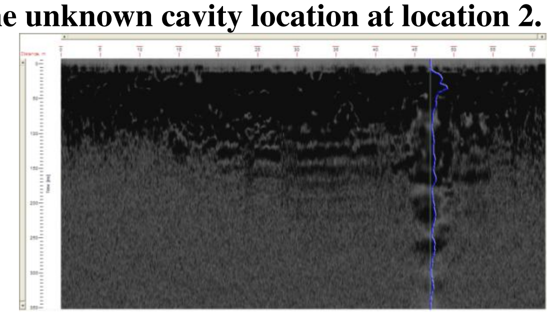


(c)

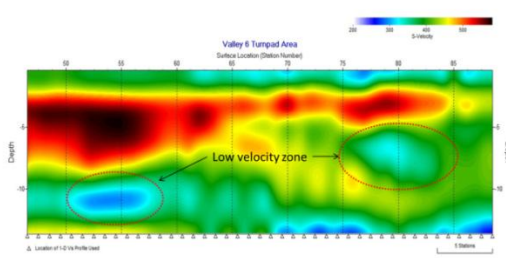
Figure 5. (a) 2D processed radargram and (b) 2D strength envelop for GPR survey (c) 2D MASW shear wave velocity profile over the unknown cavity location at location 2.



(a)



(b)



(c)

Figure 6. (a) 2D processed radargram and (b) 2D strength envelop for GPR survey (c) 2D MASW shear wave velocity profile over unknown cavity at Location 3

REMEDIAL MEASURES

Cavities and soft soil locations identified by Geophysical survey locations, which are physically validated and treated so as not to cause any future failure. The locations of the identified cavities are identified and marked at site. Boreholes of 100 mm dia are drilled up to the suggested depth, covering the complete area. Change in strata at heterogeneity/cavity level is recorded on the basis of the drilling time and ease of penetration. The drilled boreholes are grouted with free flowing concrete to plug the cavity and avoid any ingress of water in the future. In case the flow of concrete continues and demand, excess amount than the estimated amount based on GPR data. The locations are excavated and backfilled in layers with good earth up to ground level.

CONCLUSION

The objective of this study was to investigate the formation and location of cavities in lateritic soils. It is widely known from the literature study and visible proofs that laterite soils have a honeycomb like structure with small cavities. These cavities tend to increase in size and wash off under continuous variation of the water table. To identify the cavities a forensic subsurface investigation was conducted using integrated geophysical techniques. Two geophysical methods, namely GPR and MASW are used to collect subsurface data for identifying cavities. A first GPR survey was conducted to identify anomalies and then MASW survey was performed for confirmation of presence of cavity.

As the reflections of EM wave from air filled cavity are distinct from signals obtained from normal soils, they generate readily distinguishable anomalies. Based on the signal trace it was easy to identify the position of the cavity as the amplitude of the signal increases in air or water filled cavity. The processed data highlighted the hyperbolic signature due to the presence of cavity at a depth of 3 m. Also, some anomalous zones like small air pockets are highlighted which represent the karstic features of lateritic deposits. It is recommended to use higher frequency GPR for near surface or shallow investigation as it provides higher resolution Also from the MASW survey, the presence of cavity was confirmed by low velocity zones surrounded by high velocity zones in the shear wave velocity profile.

The results obtained from the survey helped in identifying cavity locations which helped in taking necessary precautions. The study recommends preliminary geophysical investigation by integrated approach along with geotechnical investigation to arrive at detailed profiling of the subsurface for large scale projects. Mitigation measures and timely monitoring need to be carried to avoid formation of cavities in the future.

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