Site Investigation of Sinkhole Damage in the Armala Area, Pokhara, Nepal

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ABSTRACT: Since November 2013, numerous sinkholes have been forming in the area of Armala, Pokhara Valley (Nepal), posing serious threat to the local residing community. As briefly summarised in this paper, the Authors visited the affected area in June and November 2014 in order to conduct survey sinkhole damage. In June, the majority of the sinkholes appeared completely filled, due to disaster mitigation works done by government agency. However, in November 2014, many new sinkholes were found, as well the re-activation of earlier backfilled sinkholes was observed. By means of surface wave explorations and dynamic cone penetration tests, qualitative characterization of soil profile was attained. Weak shallow soil layers could be identified, which are believed to be possible location for future sinkholes. Causes of such sinkholes are discussed based on available geological data and feasible countermeasures are proposed to minimize the impact of such natural hazard in the highly-populated Pokhara area.

1 INTRODUCTION

The Pokhara valley in the central part of Nepal (Fig.1) is an intermontane basin filled with large quantities of quaternary deposits, including layered clastic deposits (gravel, silt and clay), brought from the Annapurna mountain range probably by series of catastrophic debris flows (Yamanaka et calcareous material in the sediments, karst structures (subsurface flow channels, solution cavities, sinkholes etc.) are widely developed both at the surface and subsurface (Gautam et al., 2000). The main problem associated with sinkholes (already collapsed or not) is that they pose serious threat to properties like buildings, agricultural farmland, roads, etc. An example of Karst-related destruction in Pokhara valley is the collapse of a highway bridge over the Seti River (Dhital and Giri, 1993).

Since November 2013, the unpredicted formation of a significant number of sinkholes has been observed in Armala, Pokhara Valley (Figs. 1 and 2). Sinkholes are common naturally occurring geological phenomena. However, in the case of Armala, their abrupt development and increasing frequency pose hazards to approximately 70 households.

A team from the University of Tokyo, composed by the Authors, visited the damaged area in June and November 2014 to investigate about the cause of such natural disaster. This paper briefly reports on the field observation and geotechnical in-situ investigation conducted to characterise the soil profile and evaluate possible location for future sinkhole formation.

Fig.1 A map showing location of Pokhara Valley and Armala Area

2 SINKHOLES

The Armala area is essentially formed by silt containing lime, which was deposited by the Seti River flowing through the Annapurna range. Chemically, it generally contains CaO = 35% and MgO = 2% (Technical Research Report, 2014). As result, the main characteristic of this loose silt is that it easily dissolves in the water.

In the damaged area, the surface water seepage ultimately saturated the calcareous silty material, which was dissolved in the water. The muddy silty water outlet at the Kali Khola riverbank is the evidence that there is in act an erosion and cave-in process within the subsurface of the damaged area.

2.1 *Sinkholes observed in June 2014*

During the June 2014 survey, the trace of a number of sinkholes previously formed in November 2013 could typically be observed in the east side of the field survey area (Fig. 2). In Fig. 2, the sinkholes (light dots) as well as filled areas around these dots are concentrated along the Duhuni Khola, a stream of the Kali Khola River.

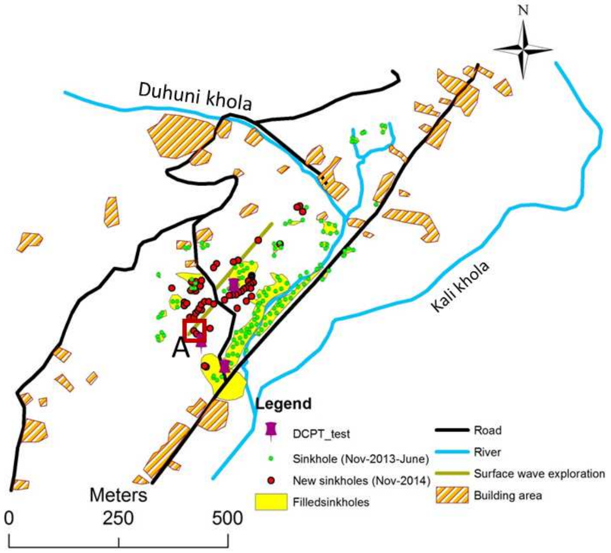
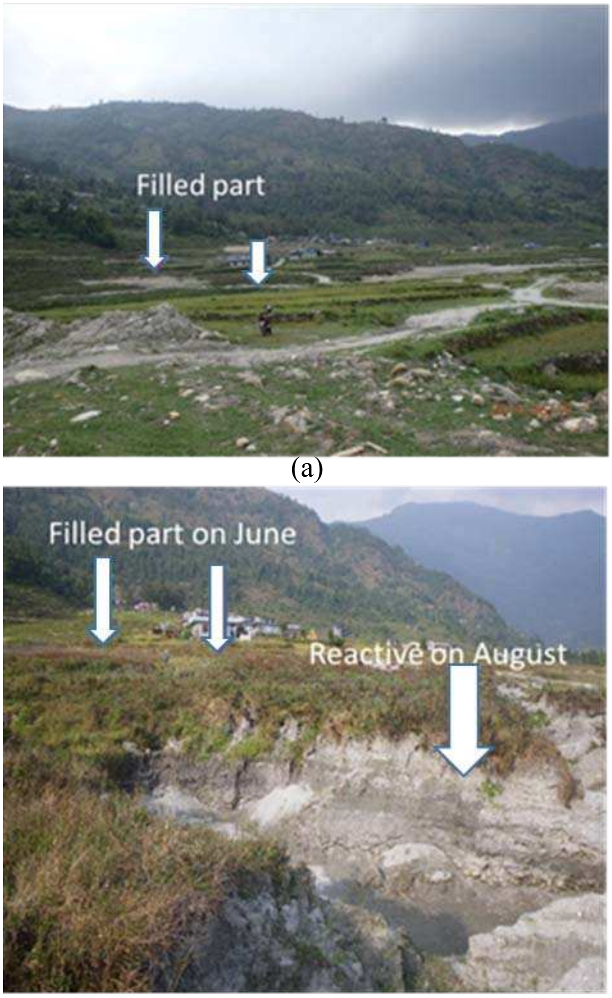


Fig. 2 Detailed map of sinkhole damage area

Immediately after the occurrence of sinkhole formation, a wide area affected by the cave-in was backfilled government agency by using gravelly soil retrieved from nearby quarries. At the time of our first damage survey in June 2014, most of those sinkholes gave the impression to be essentially fully backfilled (Fig. 3a). However, photos taken in November 2014 clearly show that the backfilling was not an adequate solution as most of former sinkholes re-activated (Fig. 3b), likely in August 2014 during the rainy season.

Moreover, in November many recently-formed sinkholes were observed, due probably to a change in underground water flow conditions resulting from previous sinkhole formation/filling.



(a)

(b)

Fig. 3 Re-activated sinkholes: (a) backfilled sinkholes as seen in June 2014, and (b) reactive sinkholes as observed in November 2014

2.2 *Sinkholes observed in November 2014*

During the November 2014 survey, a number of sinkholes of recent formation, understood to be developed in August 2014, were mostly observed in the west side of field survey area. In Fig. 2, new sinkholes (dark dots) are mostly concentrated in the western side of the damaged area. These new sinkholes are quite far away from the Duhuni Khola River, towards uphill side of the investigated area. From the sinkholes pattern it can be understood that the new sinkholes are extending towards the recharge area.

Among many, sinkholes N1, N2 and N3 were found of particular interests. These sinkholes are within the square area ‘A’ in Fig. 2. They were developed in a delimited area of approximately 10×20 m, as shown in the schematic map reported in Fig. 4. They have a circular pattern and a diameter ranging from 4.6 m (N3) up to 6.8 m (N1). Their depth measured at the top of collapsed soil varied from 2.2 m (N1, N3) to a maximum of 3.5 m (N2). According to local residents, N1 was the first sinkhole to be formed. Few days later, N2 was caved-in and finally N3 was developed.

The progressive formation of these three sinkholes along a straight line (moving along upstream direction from N1 to N3) may suggest that the collapse of N1 caused the complete disruption of underground water flow. Consequently, water started to erode the soil just adjacent N1 until a new cave-in (N2) was formed. In similar way, N3 was later developed.

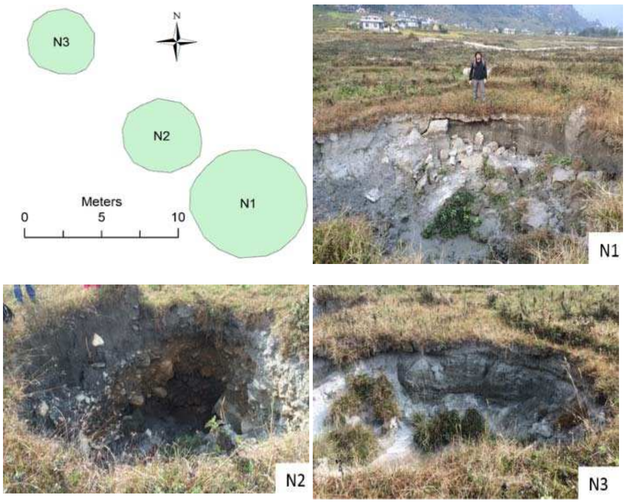


Fig. 4 Three sinkhole appeared in the area A in Fig.2

3 FIELD INVESTIGATION

A major challenges faced in this sinkhole damage site investigation was the identification and delineation of underground cavities. These structures are usually unpredictable and their effects can either lead to a slow and gradual subsidence or to a catastrophic sudden collapse (Zhou and Beak, 2011). Usually, geological and geomorphological methods are used to map geological formations for probable sinkhole. Yet, they are not adequate for the detection and precise location of cavities. The problem becomes more complex in such area where the presence of natural cavities is not known. Alternatively, to identify the location of cavities in the subsurface as well as the presence subsurface channels a geophysical method can be used.

Therefore, in this survey dynamic cone penetration tests and surface wave exploration methods were used to identify the thickness of the cavity bearing formation and their location.

3.1 *Dynamic Cone Penetration Test (DCPT)*

Dynamic Cone Penetration Test (DCPT) has been widely used as practical and suitable in-situ method for obtaining continuous soil properties and estimating soil strength.

DCPTs were carried out in three different location of damaged area (Fig. 2) in June 2014. The objective of these tests was to find out the thickness of the cavity bearing formation and bearing capacity of the layers. The first DCPT was carried out at the bottom of non-filled sinkhole, the second one was carried out just adjacent to the sinkhole as shown in Fig. 5, and the third test was carried out at top of the filled material.

As already mentioned earlier, this area is composed of recent flood plain deposits. There is a thick gravel layer at shallow depth. Thus, all the DCPTs at all the points could not penetrate more than 7 m depth. T the first location, penetration depth was up to 6.5 m. The remaining two were 2.5 m and 3.9 m, respectively.

In the case of DCPT No. 2, the converted DCPT-*N* values are plotted in Fig.5. The upper layers of surface soil could be penetrated until reaching the gravel layer, where even by hitting more than 150 times the penetration process stopped.

From the third DCPT, it is concluded that the used filling material is also gravelly soil. However, the compaction at the surface is not good enough because the *N*-value measure is very low.

From these test results, it is assumed that likely the cave-in started just below the gravelly layer. Then progressively the cavity size increased and finally the loose upper layer collapsed.

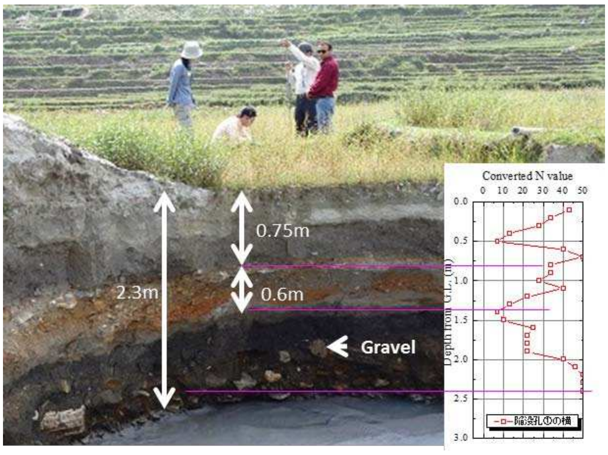


Fig. 5 Soil profile and DCPT result in the location 2 observed in Sinkhole on June 2014 (Kuwano, et al., 2014)

3.2 *Surface wave exploration*

This is a non-destructive geophysical method to investigate subsurface structures. In this method the near surface problems are studied by using dispersive character of Rayleigh waves.

As shown in Fig.2, surveys were performed along two different lines using surface wave exploration, for a total length over 250 m. The testing conditions consist of: 24 vertical-component geophones deployed with 1 m interval; and a 5 kg hammer used as a source of surface waves. Source was also moved with 1 m interval. The nearest source to receiver offset was 0.5 m. An OYO MCSEIS-SW was used for data acquisition. Fig. 6 shows typical surface wave exploration alignment used in this investigation.

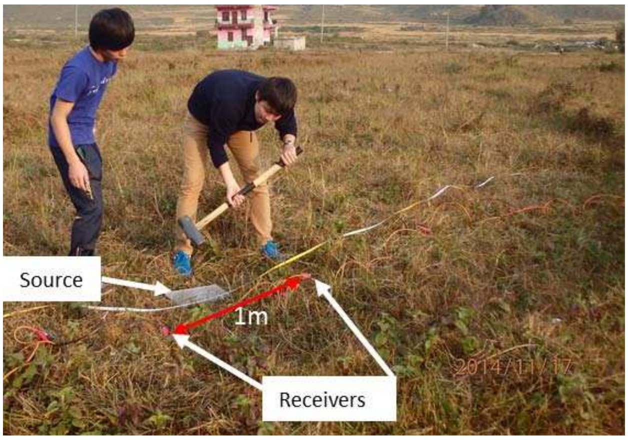


Fig. 6 Surface wave exploration method used in this invetigation

Typical results of surface wave exploration are shown in Fig.7. In fig.7 a 25 m distance is taken as one section. One can see that the shear wave velocity at the surface layer is in the range of 150-180 m/s is very loose layer. The thickness of this loose layer is 1.5 m. The gravel has higher velocity than surface layer about 240 m/s. The stiff soil below 4 m depth has a shear wave velocity greater than 350 m/s. Note that, the results obtained below 15 m depth are not reliable because the properties of the surface wave measurement.

4 CONCLUSIONS

The recent fluvial deposits of the Armala area is very soft and calcareous in nature. The easily seepage of surface water creates cavities in the subsurface which ultimately caused sinkhole formation. The backfilling of sinkhole, done by the government agency, was clearly not adequate since the majority of the re-activated. The new sinkholes appeared during the rainy season suggested that flow of underground water is the main cause of the sinkholes. When old sinkholes are filled the ground water changes its course and the new sinkholes appeared next to the old ones. The result of the DCPTs and surface wave exploration shows there is a loose layer laying on the top of a gravelly layer. Below this gravelly layer there is a very stiff clayey silt layer which is water soluble in nature and is considered as the sinkhole formation layer.

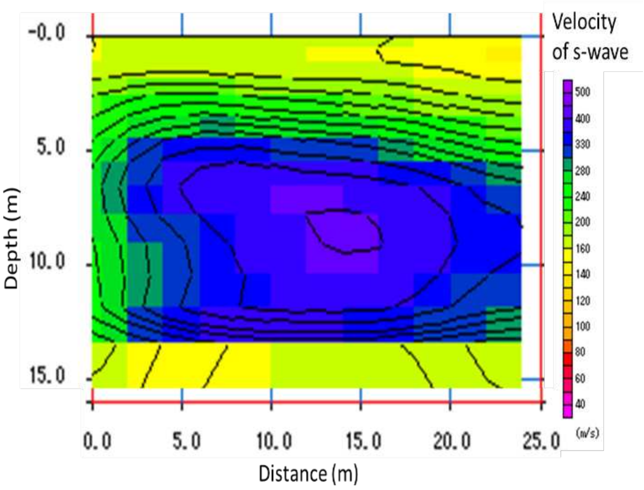


Fig.7 Result of surface wave exploration method

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REFERENCES

Dhital, M.R. and Giri, S., (1993). Engineering-geological investigations at collapsed the Seti Bridge site, Pokhara. Bulletin Department of Geology, Tribhuvan University, 3 (1), 119-141.

Gautam, P., Pant, S. R., and Ando, H., (2000). Mapping of subsurface karst structure with gamma ray and electrical resistivity profiles: a case study from Pokhara valley, central Nepal. Journal of Applied Geophysics, 45(2); 97-110.

Kuwano, R., Kiyota, T., Katagiri, T., Pokhrel, R.M., (2014) Quick report on preliminary survey for sinkholes in Pokhara, June 9-10, 2014. ERS Seminar Presentation (03/07/2014).

Technical Research Team (2014). Technical research report of ground subsidence at Jaimure phant, Aramala V.D.C., Kaski District. Technical Report, Pokhara, Kaski.

Yamanaka, H., Yoshida, M. and Arita, K., (1982). Terrace landform and Quaternary deposits around Pokhara valley, Central Nepal. Journal of Nepal Geological Society, 2, 95-112.

Zhou, W. and Beck, B. F., (2011). Engineering issues on Karst, in Karst management, Springer, Tampa, USA, 9-45.