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Geological and Geophysical Study in Adheri Khola Area, Nalgad Hydroelectric Project, Jajarkot District, Lesser Himalaya, Western Nepal

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ABSTRACT

Subsidence in carbonate rock is one of common and challenging action in terms of engineering construction. Geological study and geophysical investigation carried out in the intake area of Nalgad Hydroelectric Project Jajarkot, western Nepal Lesser Himalaya. The main objective was to identify the cause of subsidence in the intake area of Nalgad Hydroelectric Project, Jajarkot. Geological study of the area was carried to understand the lithology, thickness and structure of the area.

The study area comprises two distinct rock units, namely, Dolomite Unit followed up by the Slate Unit. The Dolomite Unit is composed of light grey to grayish white stromatolitic dolomite which is thrusted over the Slate Unit near to Laikham village and Sepu Khola area. The Slate Unit is made up of grayish black to graphitic slate. A thin prominent calcareous horizon wasconfined between Slate Unit.

2D-Electric Resistivity Tomography (ERT) measurements were deployed in four different lines to investigate the cause of the subsidence in the carbonate terrain. A concentric very high resistivity patch shown by Tomogram ER-D-01 survey line was identified and interpreted as dry cavity. The result of the 2D- ERT survey was correlated with core log data of geotechnical exploration in the suspicious point to ensure the presence of karst in the Dolomite Unit at right bank of Nalsyagu Khola near dam axis of Nalgad Hydroelectric Project. The 2D – ERT survey together with geotechnical investigation is capable of identifying subsurface karst feature as the cause of surface collapse in the area.

Key words: Electrical Resistivity Tomography (ERT), dolomite, karst, cavity, Jajarkot

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INTRODUCTION AND BACKGROUND

Nalgad Hydroelectric Project (410 MW) is going construction in the Nalsyagu Khola in the eastern part of Jajarkot district. Geographically, the area extends from longitude 82o14'00"E to 82o19'12"E and latitude 28o47'28"N to 28o58'00"N.Nalsyagu Khola is locally known as the Nalgad Khola which meets the BheriNadi near Dalli, Nalgad municipality, Jajarkot. The location map (Fig. 1) shows the specific area of study. A surface collapse was observed during field work in Intake area of Nalgad Hydroelectric Project at the right bank of the Nalsyagu Khola near dam axis in theUdheri Khola area. Very thick to massive dolomite bedrock extensively exposed at the left bank just opposite to the collapse at the right bank in the area. The engineering construction in the carbonate rock is becoming challenging due to the presence of complex subsurface structures. It is difficult to define type and the condition of the substructure by surface observation. Surface collapse and subsidence occurs as a result of weak underground condition of rock either by the formation of cavity or due to presence of shear zone. The area of dam axis lies in the carbonate terrain arise a question on probability of karst feature in the area. Also the dam axis lies near to the lithological contact of dolomite and slate may present weak zone can be the cause of collapse in the area. Present study aims toinvestigate the cause of collapse and subsidence in the area by using suitable geophysical method. For this four ERT survey lines were selected and data acquisition has been carried out. The result shown by ERT is correlated with core log data obtained from geotechnical investigation to validate the result.

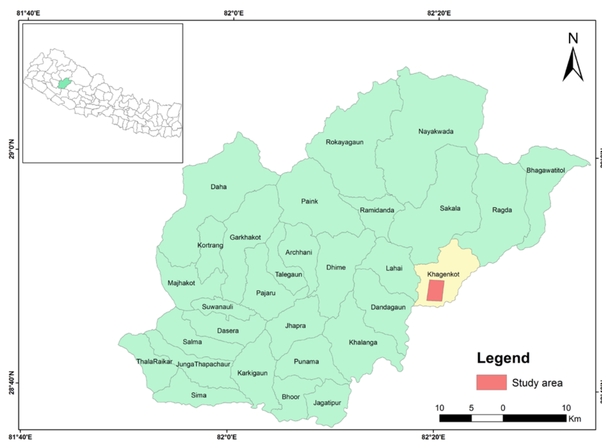

Fig. 1: Location map of the study area

Most of the subsidence and collapse in the carbonate rock is due to specific types of morphology formed by dissolution known as karst features. Geological and geomorphological study provides partial information about the degree of karstification development but cannot explain the internal structure of karst.

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Geophysical methods have been applied in the investigation and evaluation of geotechnical problem in 1960s.The structure of karst systems is complex and the related functioning mechanism of aquifers can be highly heterogeneous (Mangin 1975; Bakalowicz 1995; Ford and Williams 2007; White 2007). Karst primarily occurs on limestone and dolomite where ground cavity and dissolution landforms are developed best on fractured rocks whose intact unconfined compressive strength is generally 30-100 Mpa. Weaker limestones, chalk and unlithified carbonate sediments lack the strength to span large cavities, and develop limited suites of karst features that are generally smaller than those on stronger limestones (Higginbottom 1966; Jennings 1968; White 2000). The karst formed in such carbonate terrain create great problem in the engineering construction. Subsurface karst features can be investigated and identified by using geophysical methods.

Electrical resistivity techniques were used in cave detection (Cook and Nostrand 1954; Vincenz 1968; Dutta et al. 1970; Greenfield 1979; Militzer et al. 1979; Smith 1986). Greenfield (1979) investigated several geophysical methodsfor the detection of voids, caves and hazards. Moore and Stewart (1983) used seismic refraction, electrical resistivity tomography (ERT) and microgravity to delineate zones of increased fracture density.After 1990s, geophysical methods have been widely used to study and investigate karst as it has lower costs, simpler field procedures and more rapid inversion and interpretation of data.Iana (2008) has imaged karst terrain using electrical resistivity tomography. In his study he used multi- electrode array to gain best resolutions in the area with highly variable depth of bedrock. And found the depth of overburden and bedrock in the area. Chalikakis et al. (2011) studied and found each karst system unique and different parts having complex geometry and environment. He provided overview of methodological approach.

METHODOLOGY

Geological mapping have been done for better understanding about the lithology and structure of the study area. A common geophysical method, 2-D Electric Resistivity Tomography (ERT) was used to investigate the cause of collapse near dam axis of Nalgad Hydroelectric Project in Udheri Khola area. In ERT survey schlumberger array have choose for electrode arrangement. Finally geotechnical investigation was carried out to confirm the result of geophysical investigation i.e. core logging.

RESULTS

The results of the present study have been categorized in two sections:

Geology of the study area

Geological mapping was carried out in study area in the scale of 1:50000. The geological map (Fig. 2) of the Khara-Sepu area along Nalsyangu Khola is prepared. The rocks of the region can be separated into two lithological units: the Slate Unit and Dolomite Unit of Lesser Himalayan rock succession. Black Slate (somewhere calcareous), grey dolomite and grayish white limestone are the main rock types within the study area.

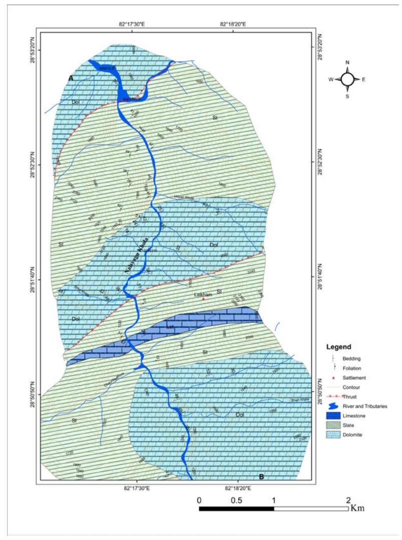

Fig. 2: Geological map of the Nalsyagu Khola area.

Dolomite Unit

The Dolomite Unit of thickness 1560 m lies conformably below the Slate Unit and extensively exposed at the left bank of the Nalysagu Khola near the Bheri Khola. The dolomite here is dark gray to bluish gray colored, medium to thickly bed with dome shaped stromatolite. Another part of the Dolomite Unit (630 m) is observed around dam axis of the Nalgad HEP which overrides the Slate Unit near Laikham village by a thrust. The Dolomite Unit and Slate Unit have a transitional contact which passes by the Udheri Khola. Thick to massive Dolomite bed is extensively at the left bank and poor exposure can be observed at the right bank of the Nalsyagu Khola. Another exposure of jointed, highly fractured dolomite with slaty cleavage can be observedin the Sepu Khola where leaching is notablethat overrides the black slate due to a local thrust.

Slate Unit

The Slate Unit is extensively exposed near Laikhamat the left bank and near the Udheri Khola at the right bank of the Nalsyangu Khola. The slate here is dark grey to black in color, thin to medium mostly calcareous with thickness about 235 m. Within wide area of exposure near Laikham, a thinly bedded dark black graphitic slate is observed. The slate in the study area is highly deformed, fractured and jointed. A is milky white to grey colored, thin to medium bedded and fine grained, prominent calcareous horizon (250 m) is confined between thin layered jointed and fractured black slate.Thickness of bed measured from geological cross section (Fig. 3) from A (NW) to B (SE) in geological map (Fig. 2).

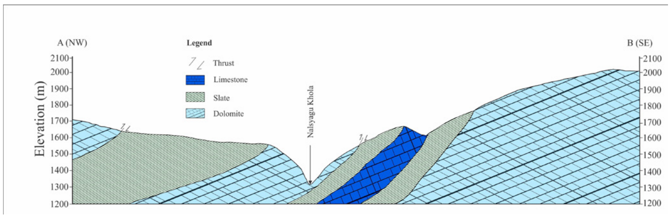

Fig. 3: Geological cross-section across the Nalsyagu Khola, Jajarkot along A (NW) - B (SE)

The Slate Unit is also observed in between the area of Audheri Khola and Sepu Khola wheregrayish black, thinly to medium bedded, highly weathered, highly fractured and jointed observed upstream from the Dam Axis of the project.

Geophysical Investigation

The Geophysical Survey was carried out together with field investigation to collect information on the underground cavity of the dam axis in the intake area of Nalgad Hydroelectric Project. The ERT 2-D data acquisition was performed in the study area in four different profiles illustrated in map (Fig 4) by red lines.

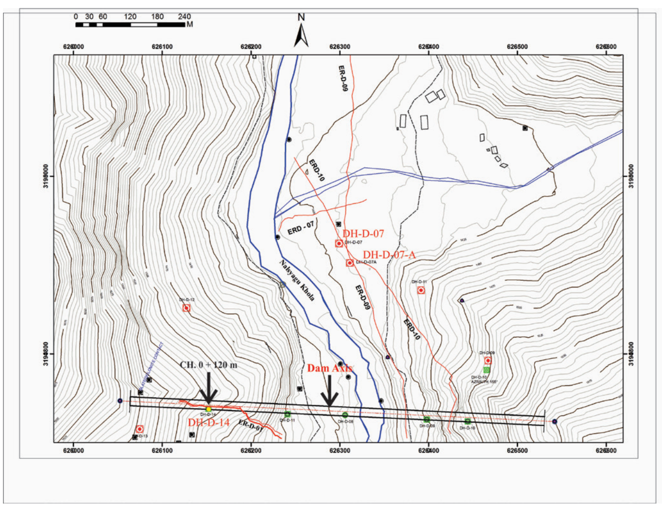

Fig. 4: Topographic map showing ERT lines and drill hole

The resistivity data measured with 2D ERT enables to interpret the pseudo-section resistivity profile after inversion and topographic correction using RES 2DINVsoftware.

The distribution of resistivity value in the subsurface soil of the study area presents wide variation of resistivity of slate and dolomite at different depth at the each profile line. The measured value of resistivity ranges from 100 Ohm m to a very higher value of 29139 Ohm m.

Four ERT lines namely ERT-D-01, ER-D-07, ERT-09 and ERT-10 (Fig. 4) were considered and investigated to find out the situation and characteristics of the karst feature in the area. Among which most representative one ERT-D-01 (Fig. 5) shows more resembled feature like dry cavity which is the central focus of the present study. In the profile various resistivity values is shown after the processing and inversion of observed resistivity data from the field. This ERT-D-01 line, is 175 m long, consist of 34 electrodes with the spacing of 5 m. In the resistivity tomogram medium resistive layer (1500 – 3000 Ohm-m) is present in the uppermost part almost throughout the line, which can be interpreted as colluvium deposit. This interpretation is also supported by the surface geological observation during field study. Whereas, few red patches of medium to high resistivity in between the Chainage 0 + 0 m to 0 + 80 m indicate the colluvium deposit with frequent very large boulders of dolomite and slate. The depths of these patches are mostly shallow (< 5 m).

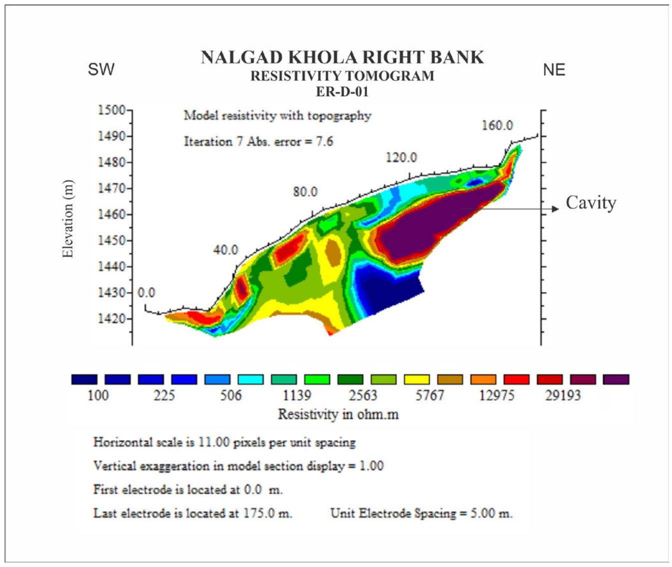

Fig. 5: Resistivity tomogram of line ER-D-01

The presence of very high resistivity patch starting from the Ch. 0 + 85 m to Ch. 0 + 155 mat the average depth of 11m, in the ERT-D-01 resistivity tomogram,shows concentric resistivity anomaly body (> 1500 Ohm-m). This concentric body can be interpreted as cavity. The surrounding of cavity shows high resistive layer (> 5000 Ohm-m) which represent the fractured dolomite. Very high resistivity value in the cavity area represent that the cavity is dry and could be vacant. Due to the presence of this cavity in carbonate terrain this feature can be referred as karst feature.

ER-D-07 survey was taken at the left bank of the Nalsyagu Khola. In the profile (Fig. 6) various resistivity values is shown after processing and inversion of observed resistivity data from the field. This ER-D-07 line is 115 m long, consists of 24 electrodes with the spacing of 5 m. in the resistivity tomogram low to resistive layer (100-2500 ohm-m) is present in the form of patches between CH. 0 + 20 m to CH. 0 + 21 m, CH. 0

+ 35 m to CH. 0 + 40 m and CH. 0 + 55 m to 0 + 70 m one meter below from the surface and at CH. 0+ 80 m to 0 + 95 m below 5 m which can be interpreted as collivium deposit with boulders. Whereas remaining part of the tomogram shows very low to low value of resistivity (100-500 ohm-m) that can be interpreted as the saturated soil. This interpretation is also supported by the surface geological observation during field. The surface of the area was observed swampy during the survey time.

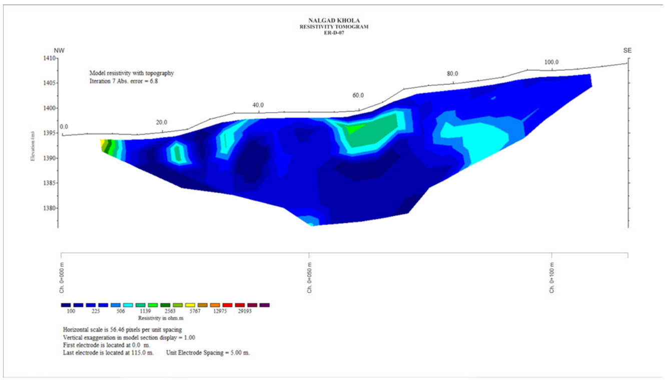

Fig. 6: Resistivity tomogram of line ER-D-07

The survey line ER-D-09 chosen was in the left bank of the Nalsyagu Khola. In the profile (Fig. 7) various resistivity values is shown after processing and inversion of observed resistivity data from the field. This ER-D-09 line is 470 m long, consists of 48 electrodes with the spacing of 10 m. In the resistivity tomogram (Fig. 7) Very low to low resistive layer (50- 700 ohm-m) is present in the right side of the tomogram towards NW direction throughout the line after CH. 0 + 230 m to CH. 0 + 470 m can be interpreted as water saturated strata. Whereas towards south east at CH. 0 + 60 m to CH. 0 + 150 m, the red patches in the tomogram showing the higher resistivity value (300 – 15000 ohm-m) indicates the colluvium deposit with frequent very large boulders of dolomite and limestone near surface. The continuous layering in the tomogram at the depth of 20-30 m with medium to high resistivity value (2000 – 14000 ohm-m) can be interpreted as highly fractured dolomite bedrock and at the depth of 40 m vertically downward from CH. 0 + 200 m, very high value of resistivity patch (>15000 ohm-m) showing the presence of very competent bedrock.ERT ER-D-10 was the last line considered for the investigation of karst in the area at the left bank of Nalsyagu Khola. . In the profile (Fig 8) various resistivity values is shown after processing and inversion of observed resistivity data from the field. This ER-D-10 line is 470 m long, consists of 48 electrodes with the spacing of 10 m. In the resistivity tomogram (Fig. 8), low resistive layer (150- 550 ohm-m) is present in the left side of the tomogram towards NW from CH. 0 + 0 m to CH. 0 + 190 m can be interpreted as moist sand and silt. Just below at the depth of 4 m tomogram shows the very low resistivity (50 – 300 ohm-m) can be interpreted as the water saturated strata.The resistivity near the surface with small concentric high values (6000 – 15000 ohm-m) at CH. 0 + 200 m and CH. 0 + 325 m represents the colluvium with boulder of the highly fractured dolomite in the area. The concentric patch of very high resistivity (>15000 ohm-m) in the tomogram at the depth of 10 m from surface from CH. 0 + 300 m to 0 + 410 m shows the possible cave in the area.

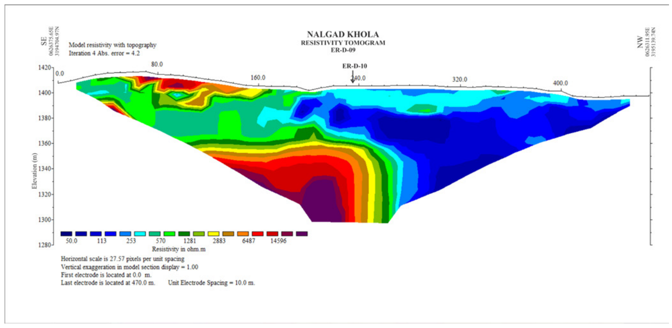

Fig.7: Resistivity tomogram of line ER-D- 09

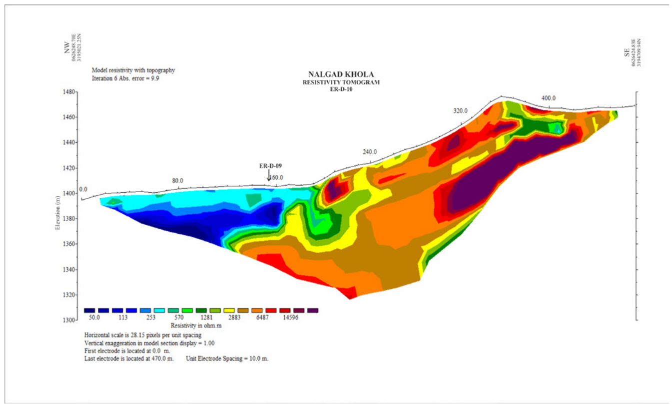

Fig. 8: Resistivity tomogram of line ER-D-10

Geotechnical exploration

To validate the result of geophysical investigation, geotechnical investigation was also carried out in the intake area of the project. Rotary Core drilling was done in different location around dam axis of the Nalgad Hydroelectric Project. The Core logging data near to the different ERT line has been studied. The result of core logging data presented (Fig 9shows the core loss of several meters in different drill hole. A drill hole DH-D-14 located near ERT-D-01 was observed and core logging data presented in the section (Fig. 9).

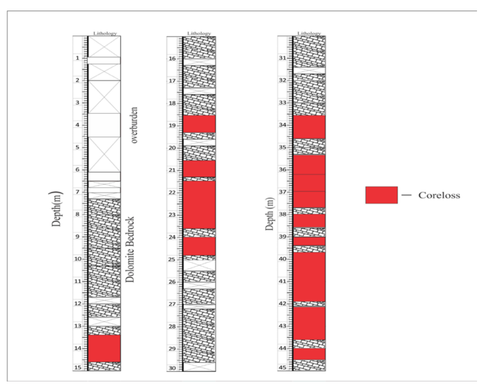

Fig. 9: Core log of drill hole DH-D-14 near ER-D-01

From the Core log data, overburden of rock fragments and fine colluvium was identified in first 7.3 m depth from surface. After the depth of 7.5 m core of highly fractured dolomite was observed to the depth of 12 m which indicates the presence of bedrock to the depth of 7.3 m. After 12 m depth core loss was observed frequently with a few insignificant core recoveries between large core losses.

DISCUSSION AND CONCLUSION

From the geological mapping in the study area two lithological units namely Dolomite Unit and Slate Unit is identified. The dam axis of Nalgad Hydroelectric Project lies in the Dolomite Unit. Black carbonaceous slate, dolomite with stromatolite and limestone are the main rock types in the area.

The 2D ERT survey was carried out in the study area. Result obtained from the inversion of resistivity data is displayed. The high resistivity zones are interpreted as Karstic feature, cavity and high level of fractured dolomite. Electrical Resistivity tomography survey was carried out in carbonate rock of Northwestern Tunisia (Redhaounia et al., 2016)to identify the karst feature. From the study, high value of resistivity was identified in the resistivity tomogram. The high resistivity anomaly was interpreted as dry cavity in the area.

Radiometric and geoelectric response of karst structure in Chamero Cave and Mahendra Cave (Gautam et al., 2000) found widely differ value of resistivity (a few hundred to several tens of thousands ohm-m) depending mainly upon lithology. The very high resistivity value (12800-25600 ohm-m) is interpreted as karst.

The result obtained from geotechnical study reveals the presence of cavity or open area starting at the depth of 12 m from surface below the bedrock of dolomite. Low percentage of core recovery conform the presence of cavity below the depth of 12 m from surface in near ERD-01.

The geophysical study (2D ERT) and geotechnical study have been correlated and presented (Fig. 10 (a) and (b)) to indicate and characterized the karst is present in the area.

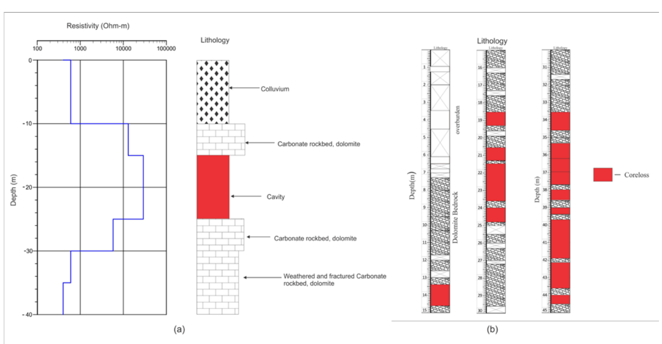

Fig. 10: Correlation between the litholog (a) from resistivity value of tomogram (b) from core log data

From the geological mapping, lithology in the area of subsidence is identified as dolomite. The analysis of resistivity value of 2D-ERT in the profile ERD-01 at right bank of the Nalsyagu Khola explains the cause of subsidence and collapse in the intake area near dam axis is due to the presence of karst feature i.e cavity. To ensure the result of ERT, result of core logging data are correlated with the resistivity value. Finally karst is identified as the cause of subsidence in the surface of Intake area of Nalgad Hydroelectric project.

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