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Geological and hydrogeological concepts in the interpretation of electrical sounding: an example from Xiakou Landslide, Yaan City area, Sichuan, China

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ABSTRACT

Due to unfavourable geological and hydrogeological condition the electrical resistivity data interpretation even from a small area such as a landslide can be affected. However, good results can be achieved by using geological and hydrogeological concept during modeling. The outputs of this work are based on the concepts prepared during qualitative analysis. After the modeling of the sounding curves by using geological and hydrogeological concepts the results were found surprisingly good than the results without concepts. Furthermore, there is a comparison between the vertical electrical sounding (VES) modeling results and drill hole information. It shows that VES modeling results provide better assessment of the rock mass in the subsurface than the drill core interpretation only.

INTRODUCTION

In recent years, there has been widespread increase in the application of new techniques of geophysical exploration for the study of landslides. It has become vital to explore the subsurface of a landslide in a short time and cost effective way. At present most popular methods are seismic refraction and electrical resistivity. New data acquisition and processing techniques have been developed for these methods to explore 2D and 3D subsurface structures. In addition to the above mentioned methods, there are other geophysical methods such as electromagnetic (including georadar) and seismic reflection, gaining foot in the exploration landslides.

A landslide is composed of different materials that have different physical properties. Measurement of *in situ* physical properties can be carried out by different geophysical methods. Through study of the physical properties the state of a landslide can be assessed. Different geophysical methods could be applied to study subsurface of a landslide. Examples of such applications are found in Bogoslovsky et al. (1977), Mauritsch et al. (2000), Pant (1998) and Pant et al. (1999).

Other means of getting subsurface information of a landslide is by making a drill hole. There is a tendency to equate drill hole information with geophysical methods. In some cases geologist and civil engineers choose the option to increase the number of the drill holes instead of conducting geophysical investigations. However, one should understand that geophysical methods are helpful to reduce the number of drill holes, and hence the cost. Few drill holes can provide valuable information that can be useful for the development of geological concept necessary for reliable interpretation of outputs of geophysical data processing. However, one should understand that drill hole information not always be taken for granted. During correlation of the drill hole information and geophysical results one should bear in mind that geophysical information represents the physical property, volume. Geophysical information helps to assess the overall state of a block of the material in the subsurface. Information obtained by a drill hole represents only single-point information in lateral dimension. Volume information estimated by the extrapolation of drill hole information could lead to the wrong conclusion about the subsurface of a landslide.

1D electrical resistivity method (VES), which has got wide application, is economical and easily available method of investigation. Although this method is slowly replaced by 2D and 3D electrical resistivity methods, 1D method will remain useful to explore simple layered structure. There can be large database of VES for any particular area, which can be very useful to analyze with the aid of present-day computing system. During an investigation a geophysicist feels that depth to any interface is of much more concerned to a geologist and geotechnical engineer than the physical properties of the layers. In some geological situations the principle of equivalence is one of the main obstacles during an interpretation of VES. Theoretically the equivalence of the determination of layers' parameters (thickness and resistivity) during an analysis of VES curve is widely known.

Variation of the layers' parameters in an unacceptable range (sometime more than 100%) detracts a geologist and civil engineer for the recommendation of the geophysical methods. Variation in physical properties in a range could be acceptable whereas wider range of variation in depth to an interface can be annoying. Thus this calls for realistic assessment and use of the equivalence.

GEOLOGY AND HYDROGEOLOGY

Xiakou Landslide is located on Southwest-Central China, 9 Km north of Yaan City (Fig. 1) on the left bank of Lungxi River. The landslide is on the way leading to Xlaii. The first reported event of the landslide was in 1981. Fieldwork was carried out during November 1995. Since 1995, the landslide has been jointly investigated by Chinese and foreign investigators. To appreciate geologic and hydrogeologic controls and its relation with the sliding mechanism, detailed investigation of the landslide has been carried out by using a geophysical methods and drill holes. The monitoring of the displacement has been carried out in the boreholes and on the surface by GPS. Furthermore, chemical analyses of the water and pressure measurements were also carried out (ITECO 1998).

The landslide is formed by a wide cone of material formed due to the recurrent rockslides along dip slope. Interbeded marly claystone and sandstone of Jurassic period form the bedrock. In 1987 a drill hole (DH0) near the road has reached the bedrock at 38 m. The drill hole has crossed layers of boulders/gravel with marly matrix. It has found two water tables. The first water table is at depth $\sim$3.5 m and the second at $\sim$21 m. Sliding motion during 1981 may have taken place along two slip surfaces. The deepest slip surface is at a depth of 40-50 m toward the valley side and between 10-30 m at the hillside. The shallowest slip surface is at a depth of 10 to 15 m in the upper and middle part of the slope. The material of the slide is mainly constituted by plastic clay with more or less bouldery/gravelly layers and lenses (ITECO 1998). The shallow slip surface is within the Quaternary deposits and deepest at the base of the Quaternary. Furthermore, the investigation in the following years suggested that there is a possibility of the third slip surface within the upper part of the bedrock.

Distribution of materials of higher and lower permeability in the Quaternary deposits creates a situation of permeability stratification. Permeability stratification in the Quaternary leads to the formation of perched water table within the Quaternary deposits. There can be several perched water tables related with the different impermeable and semi permeable Quaternary deposits. There is a spring near the road. The electrical conductivity of the spring is 250 µS/cm. Total dissolved solids calculated from this conductivity is 160 mg/L. This is near about the value deduced from chemical analysis of the water samples from the drill holes (ITECO 1998). Hydrological investigation has revealed that some of the springs are temporary and related with the leakage of the water from the canal, although there was no water supply through the canal during the period of the geophysical investigation .

According to the information revealed by DH0 the lower half of the Quaternary includes mostly clay with intercalation of few layers of permeable materials. The maximum thickness of the single permeable layer is less than 4 m. Relatively thick layers of clay with fragments of boulders separate permeable layers. The water in these permeable zones can be in artesian conditions. The observation of the water loss in Longxi River suggests the presence of permeable layers in the bed. The loss is either due to the permeability of the debris relic of the 1981 landslide accumulated on the riverbed or to the high permeability of the material accumulated below the riverbed (ITECO 1998).

In the following years the landslide has been explored by four additional drill holes. These new drill holes reveal geological setup similar to the previous drill hole DH0. The Bedrock attitude is towards the toe of the slide. This attitude may favour a situation of the rockslide within the bedrock. In such a geological setup sliding rock mass on the top of the parent bedrock may be mistakenly considered as intact bedrock. Monitoring of the displacement in DH4 has found that this area is creeping. The contact between claystone and the underlying sandstone is found to be at 18 m and 19.4 m at DH4 and DH3, respectively (ITECO 1998). Nothing is mentioned about the depth to the top of the stable bedrock.

EQUIVALENCE

The true resistivity distribution of a subsurface is difficult to measure and model but it can be approximated by

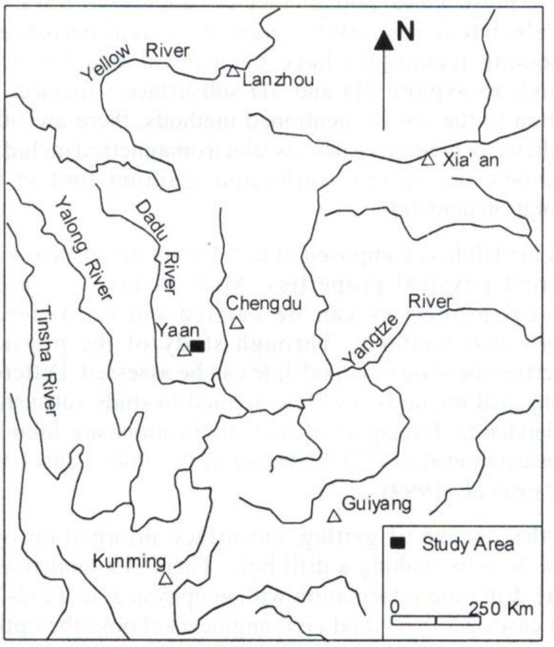


Fig. 1: Map of Southwest-Central China showing the study area.

surface electrical resistivity methods. Approximated electrical resistivity of a layer or body is influenced by other layers' or bodies' electrical resistivity in the vicinity. Depending on the geological and hydrogeological setup of the area under investigation, the approximated resistivity can be both overestimated or underestimated. Furthermore, it is also influenced by other factors such as near surface heterogeneity, insufficient penetration of the current into the target depth, and electrode arrangement used. Due to relatively long cable layout along the slope, heterogeneity of the near surface materials may influence the farther point in a sounding curve. In addition, grounding condition near a potential electrode will have a greater influence on the measured data. Both 1D and 2D electrical resistivity methods are not exempt from such effects. However, during processing of 2D measurement effects due to lateral variation along survey lines are relatively easier to handle than for VES (1D) curve.

It is well known that the reliable quantitative interpretation of VES curves is hampered by the principle of the equivalence. Discussion about the classical examples of the principle of equivalence can be found in Parasnis (1997) and Reynolds (1997). These examples show that same effect of the sounding curves can be obtained from different subsurface layers. Koefoed (1969, 1979) has shown that the principle of equivalence is only a result of natural circumstances and not one of the theories. The role of the geological concept to minimize effect of the equivalency during an interpretation of VES curve for groundwater has demonstrated by Flathe (1976). Possible ways of getting out from the effect of the principle of equivalence of VES curve interpretation applied for groundwater exploration has been discussed in Dorn (1985) and Van Overmeeren (1989).

Despite the classical explanation of the principle of the equivalence and its effects in the ambiguity of the interpretation, there is other factor supporting the non-uniqueness in the interpretation of a VES curve, it is a random or a systematic influence on the measured apparent resistivity values, due to geological, physical and experimental influences. The geological influences are heterogeneity in the surface material, deviation of the layers from the horizontal, abrupt bedrock depth variation, relative change in the surface topography, and lateral change in the bedrock resistivity and macro anisotropy in the overburden. By opting modern equipment, appropriate field design and layouts effects from physical and experimental influence can be minimized. However, the geological influences cannot be minimized. They can only recognized and taken into consideration during an interpretation of VES curves.

DATA ANALYSIS

Vertical electrical soundings (VES) were carried out by Schlumberger configuration. Few VES were conducted by using half Schlumberger configuration (Fig. 2). Current and potential cables were spread along the slope. Two levels of

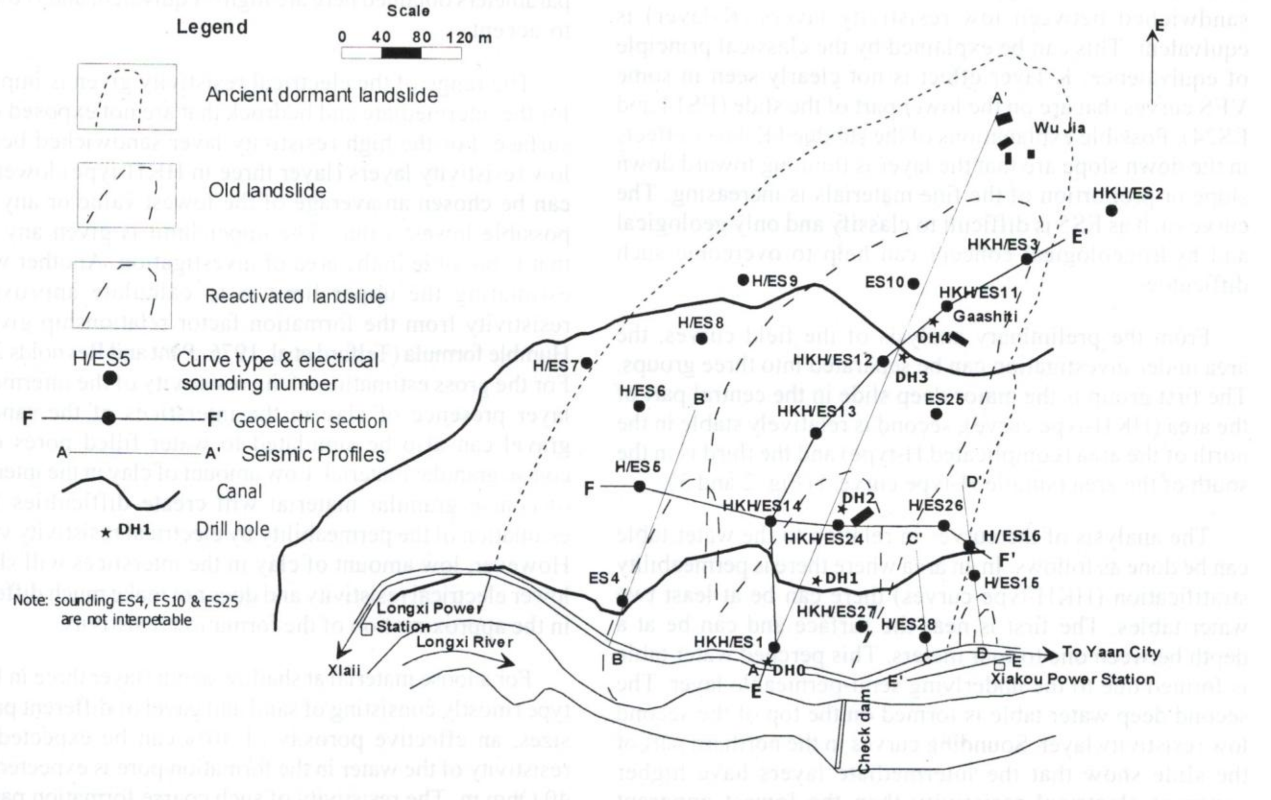


Fig. 2: Location of electrical soundings and seismic profiles, Xiakou Landslide, Yaan City area, Sichuan.

information can be obtained from a VES curve. Primary level information is obtained by making visual analysis of the field curves. This is useful to develop a general concept of the subsurface of a landslide. Advance level information is obtained by matching field curves with theoretically calculated curves. This stage is carried out with the help of a computer.

PRELIMINARY ANALYSIS OF THE FIELD CURVES

The shape of a VES curve has a geological and hydrogeological significance. Curve types in the study area are H and HKH type. In a landslide investigation a curve type is also an indication of geology and depth. The curves that are smooth and not deviating much from the simple two or three-layered ideal curve are usually the indicative of simple geology and shallow depth. In the present study H-type curves are the example. The curves where H-type is observed are either the depth to the bedrock is shallow or the area is stable or can be both (Fig. 3). Parts of the slide where HKH-type is present are active or prone to sliding.

There is possibility of having several slip surfaces in the slide zone. However, looking into the sketch section one can say that there is at least two slip surfaces: one shallow and other deep. This can be inferred from HKH-type curves. HKH-type curve is purely an indication of permeability stratification. In this type of curve a higher resistivity layer sandwiched between low resistivity layers (K-layer) is equivalent. This can be explained by the classical principle of equivalence. K-layer effect is not clearly seen in some VES curves that are on the lower part of the slide (ES14 and ES24). Possible explanations of the subdued K-layer effects in the down slope are that the layer is thinning toward down slope or proportion of the fine materials is increasing. The curve such as ES5 is difficult to classify and only geological and hydrogeological concept can help to overcome such difficulties.

From the preliminary analysis of the field curves, the area under investigation can be separated into three groups. The first group is the major deep slide in the central part of the area (HKH-type curve), second is relatively stable in the north of the area (complicated H-type) and the third is in the south of the area (simple H-type curves) (Fig. 2 and 3).

The analysis of the curves in relation to the water table can be done as follows. In an area where there is permeability stratification (HKH-type curves) there can be at least two water tables. The first is near the surface and can be at a depth between one to four meters. This perched water table is formed due to the underlying semi-permeable layer. The second deep water table is formed on the top of the second low resistivity layer. Sounding curves in the northern part of the slide show that the intermediate layers have higher apparent electrical resistivity than the lowest apparent resistivity values in HKH-type and H-type in the central and the southern part of the slide. These materials that form the intermediate layer in sounding curves in the northern part of the landslide are permeable to semi-permeable. The major recharge of the deep water table is probably taking through this material. Sounding curve ES4 is HK type. This is the only type of the curve met in the area. This curve cannot be used to draw a geological and hydrogeological concept. We think that only a group of similar type curves are useful to derive geological and hydrogeological concept. The only information that can be guessed from the curve ES4 is that the bedrock is possibly at depth more than 40 m. ES10 and ES25 has been rejected due to the poor data quality.

COMPUTER AIDED ANALYSIS

The preliminary analysis of the field curves and geological and hydrogeological observation of the site gave insight to the geological setup of the area. This information together helped to form the geological and hydrogeological concept for the processing and interpretation of the VES curves. Let us take two VES curves for example from the slide: first simple H-type (S26) and the second HKH-type (S11). Let us make analysis in two ways: without having any geological concept (Fig. 4) and with geological and hydrogeological concept (Fig. 5). The result of the curve matching without geological concept for sounding ES11 shows that the resistivity can vary from 133 to 556 Ohm.m and depth can vary from 36 to 73 m. Similarly for ES26 the resistivity can vary from 58 to 152 Ohm.m and depth can vary between 11 to 23 m. The inversion parameters obtained here are highly equivalent and is difficult to accept.

The range of the electrical resistivity given is important for the intermediate and bedrock that are not exposed on the surface. For the high resistivity layer sandwiched between low resistivity layers (layer three in HKH-type) lower limit can be chosen an average of the lowest value or any other possible lowest value. The upper limit is given any value that is possible in the area of investigation. Another way of estimating the upper limit is to calculate approximate resistivity from the formation factor relationship given by Humble formula (Telford et al. 1976; Pant and Reynolds 2000). For the gross estimation of the resistivity of the intermediate layer presence of clay in the interstices of the sand and gravel can also be simulated to water filled pores of the coarse granular material. Low amount of clay in the interstices of coarse granular material will create difficulties in the estimation of the permeability by electrical resistivity values. However, low amount of clay in the interstices will slightly lower electrical resistivity and does not make much difference in the approximation of the formation resistivity.

For a loose material at shallow depth (layer three in HKH-type) mostly consisting of sand and gavel of different particle sizes, an effective porosity of 40% can be expected. The resistivity of the water in the formation pore is expected to be 40 Ohm.m. The resistivity of such coarse formation partially saturated by clay and water can be near to 200 Ohm.m.

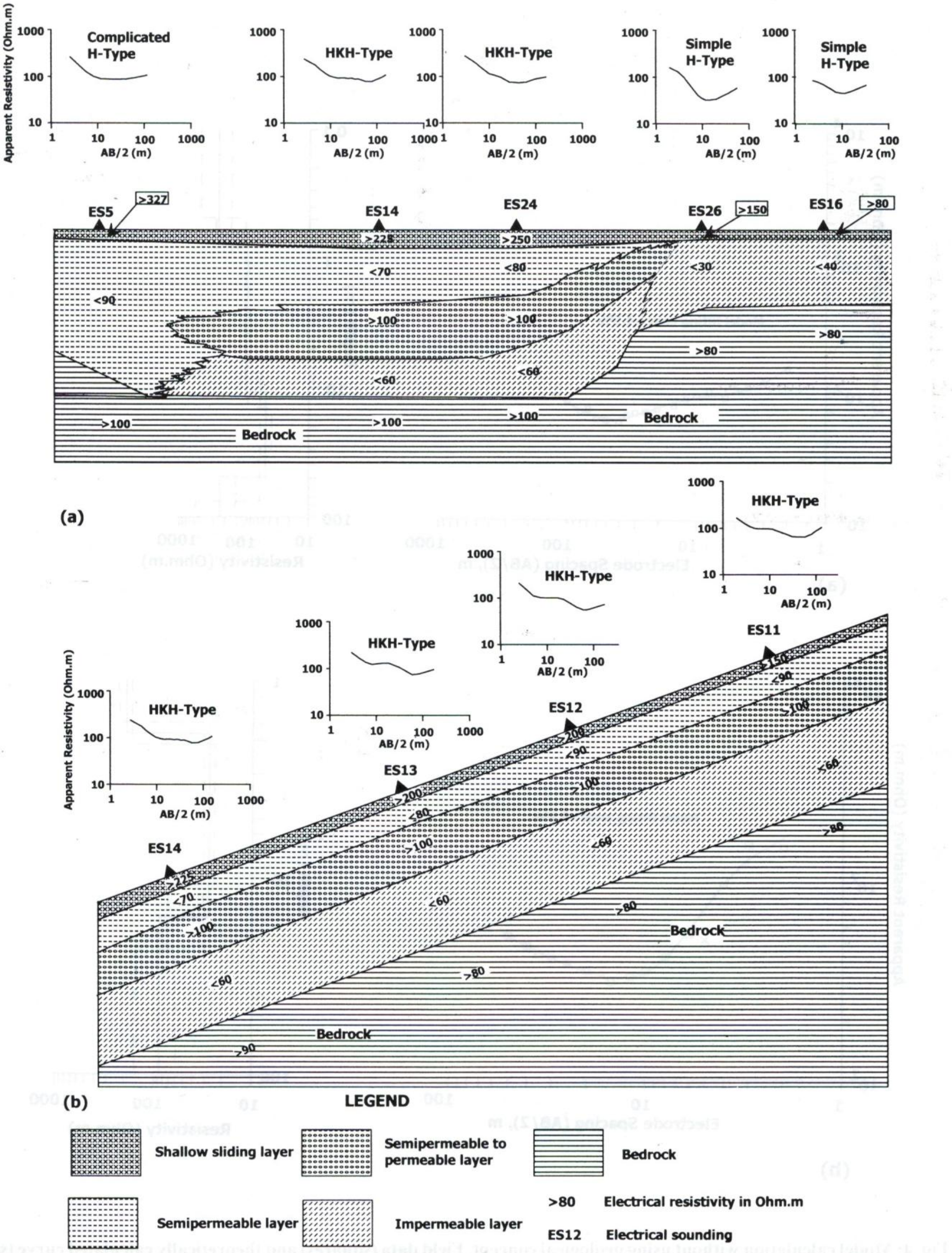


Fig. 3: Sketch cross sections prepared by using VES curves information (a) across the slope and (b) along the slope of the landslide.

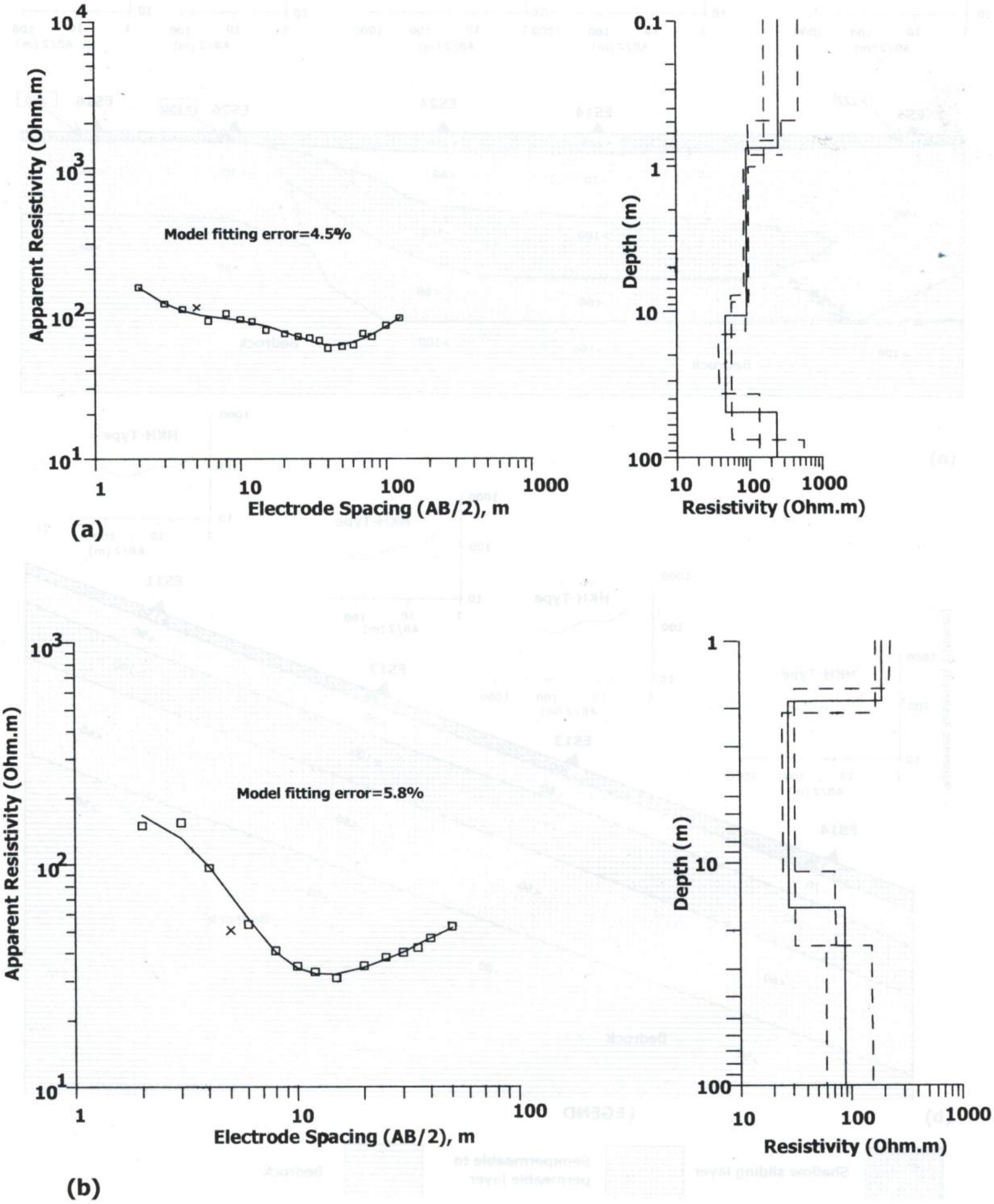


Fig. 4: Model calculation without using geological concept. Field data (squares) and theoretically calculated curve (solid line) with equivalence model (a) VES No. S11 and (b) VES No. S26.

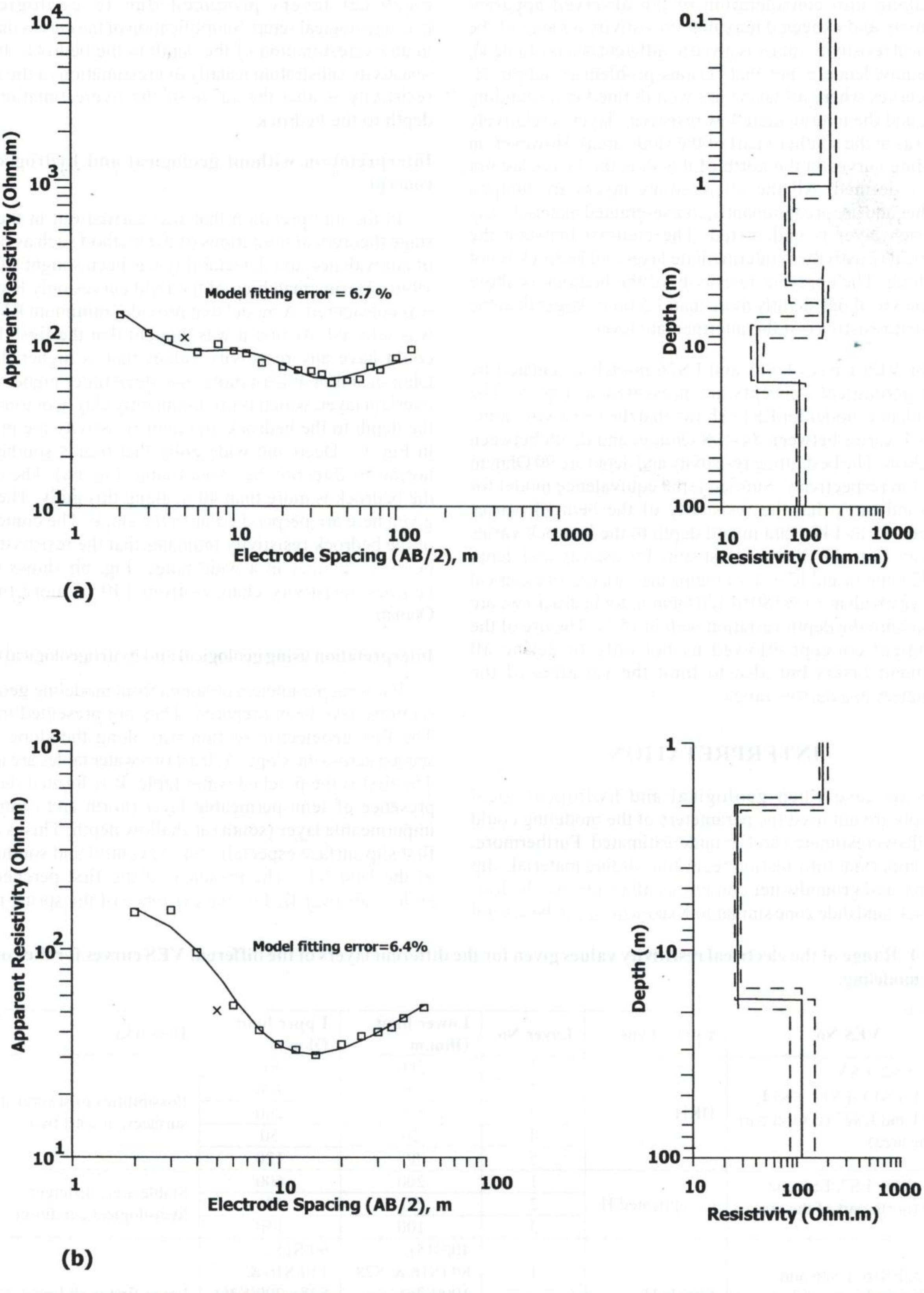


Fig. 5: Model calculation using geological concept. Field data (squares) and theoretically calculated curve (solid line) with equivalence model (a) VES No. S11 and (b) VES No. S26.

Taking into consideration of the observed apparent resistivity and expected maximum resistivity a range of the electrical resistivity values is given to different layers (Table 1). The equivalence is not that serious problem in simple H-type curves where all layers are well defined in a sounding curve and the intermediate low resistivity layer is relatively thick (as in the southern part of the study area). However, in sounding curves in the north of the slide the layers are not clearly defined. All the intermediate layers are lumped together and are predominantly coarse-grained material. Any clay rich layer is undetected. The contrast between the electrical resistivity of intermediate layer and bedrock is not very high. The apparent resistivity of the bedrock is about 1.3 times to about slightly more than 1.5 times larger than the apparent resistivity of the intermediate layer.

For VES curves ES11 and ES26 models calculated by using geological concepts are presented in Fig. 5. The equivalence model for ES11 shows that the resistivity of the bedrock varies between 84-108 Ohm.m and depth between 15 to 20 m. The best fitting resistivity and depth are 90 Ohm.m and 17 m respectively. Similarly, the equivalence model for ES26 indicates that the resistivity of the bedrock varies between 85 to 147 Ohm.m and depth to the bedrock varies between 15 to 17 Ohm.m. Best suited resistivity and depth are 112 Ohm.m and 17 m. By limiting the variation of electrical resistivity with in 33 % (80 to 120 Ohm.m for bedrock) we are able to limit the depth variation with in 15 %. The use of the geological concept allowed us not only to define all prominent layers but also to limit the variation of the parameters in a narrow range.

INTERPRETATION

In the case when geological and hydrogeological concepts are not used the parameters of the modeling could be both overestimated and/or underestimated. Furthermore, some important information regarding sliding material, slip surfaces and groundwater conditions of a slide may be lost. In a thick landslide zone similar to Xiakou there can be several electrical layers produced due to geological and hydrogeological setup. Simplification of the curves may result in an overestimation of the depth to the bedrock. In a high resistivity substratum usually overestimation of the bedrock resistivity is also the cause of the overestimation of the depth to the bedrock.

Interpretation without geological and hydrogeological concept

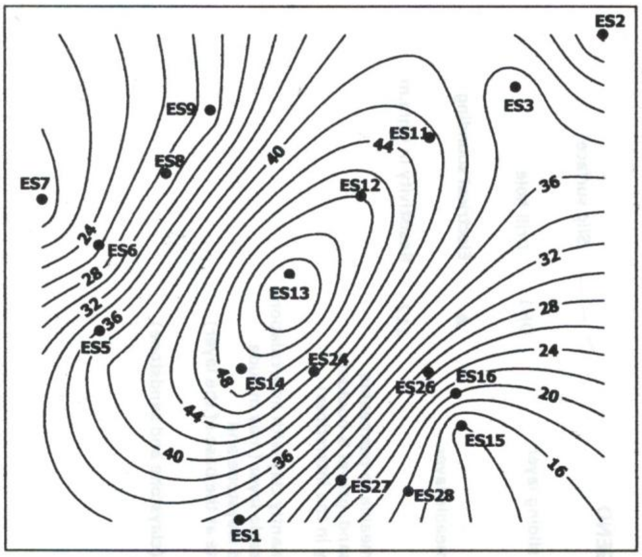
In the interpretation that was carried out in the earlier stage theoretical limitations of the method such as principle of equivalence and detectability has been sought (ICIMOD 1996). During matching of the field curves only RMS error was considered. A model that provides minimum RMS error was selected. At first it was thought that the fresh bedrock could have any resistivity values that is higher than 120 Ohm.m and/or at least more than three times higher than the overlain layer, which is predominantly clay. Contour map of the depth to the bedrock and their resistivity are presented in Fig. 6. Deep and wide gully that trends southeast and northwest direction has been found (Fig. 6a). The depth to the bedrock is more than 40 m along this gully. The depths given here are perpendicular to the slope. The contour map of the bedrock resistivity indicates that the resistivity of the bedrock changes in a wide range. Fig. 6b shows that the bedrock resistivity changes from 140 to more than 300 Ohm.m.

Interpretation using geological and hydrogeological concept

By using parameters obtained from modeling geoelectric sections have been prepared. They are presented in Fig. 7. The first geoelectric section was along the slope and the second across the slope. At least two water tables are inferred. The first is the perched water table. It is formed due to the presence of semi-permeable layer (north and central) and impermeable layer (south) at shallow depth. This is also the first slip surface especially for the central and southern part of the landslide. The presence of the first perched water table is also verified by the existence of the spring near the

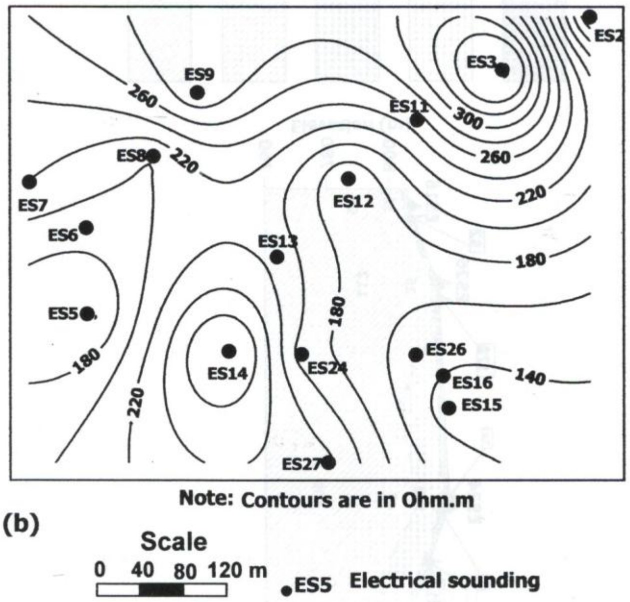
Table 1: Range of the electrical resistivity values given for the different layers of the different VES curves for the computer aided modeling.

VES No.	Curve Type	Layer No.	Lower limit Ohm.m	Upper limit Ohm.m	Remarks
ES1, ES2, ES3, ES11, ES12, ES13, ES14, ES24 and ES27 (central part of the area)	HKH	1	200	400	Possibilities of several slip surfaces, at least two
		2	60	100	
		3	100	200	
		4	20	50	
		5	80	120	
ES5, ES6, ES7, ES8 and ES9 (north part of the area)	Complicated H	1	200	600	Stable area, different hydrological condition
		2	50	100	
		3	100	150	
ES15, ES16, ES26 and ES28 (south part of the area)	Simple H	1	40(S15), 80 (S16 & S28), 100(S26)	60(S15), 150(S16 & S28), 200(S26)	Layer first is sliding
		2	20	50	
		3	80	120	



(a)

Note: Depth counters are perpendicular to the slope
Contours are in meters



Note: Contours are in Ohm.m

(b)

Fig. 6: Bedrock depth contour map (a) and bedrock electrical resistivity (b) prepared from the modeling without using geological and hydrogeological concept.

road. The second water table is at the base of the third layer, which is identified as semi-permeable to permeable layer. The existence of the spring on the left bank slope of Longxi River is probably related with the second water table. This water table was identified by the drill hole DH0 in 1987. The materials are fully saturated below this water table. The lowest resistivity layer in the geoelectric section is interpreted as clay rich zone, with intercalation of few permeable layers.

The contour map of the depth to the bedrock reveals a deep gully, which trends southeast to northwest direction. This is a thick quaternary accumulation zone. Since the layouts of the electrodes were along the slope the depth contour map presented in Fig. 8a is perpendicular to the slope. The depths are smaller than the vertical depths in 15 to 20% except for ES1. The difference with the Fig. 6a is that it shows a narrower gully and its lateral extension is also limited in the southeastern part.

Bedrock resistivity contour map is presented in Fig. 8b. It indicates that the resistivity is increasing towards the north. The following explanation can be given as:

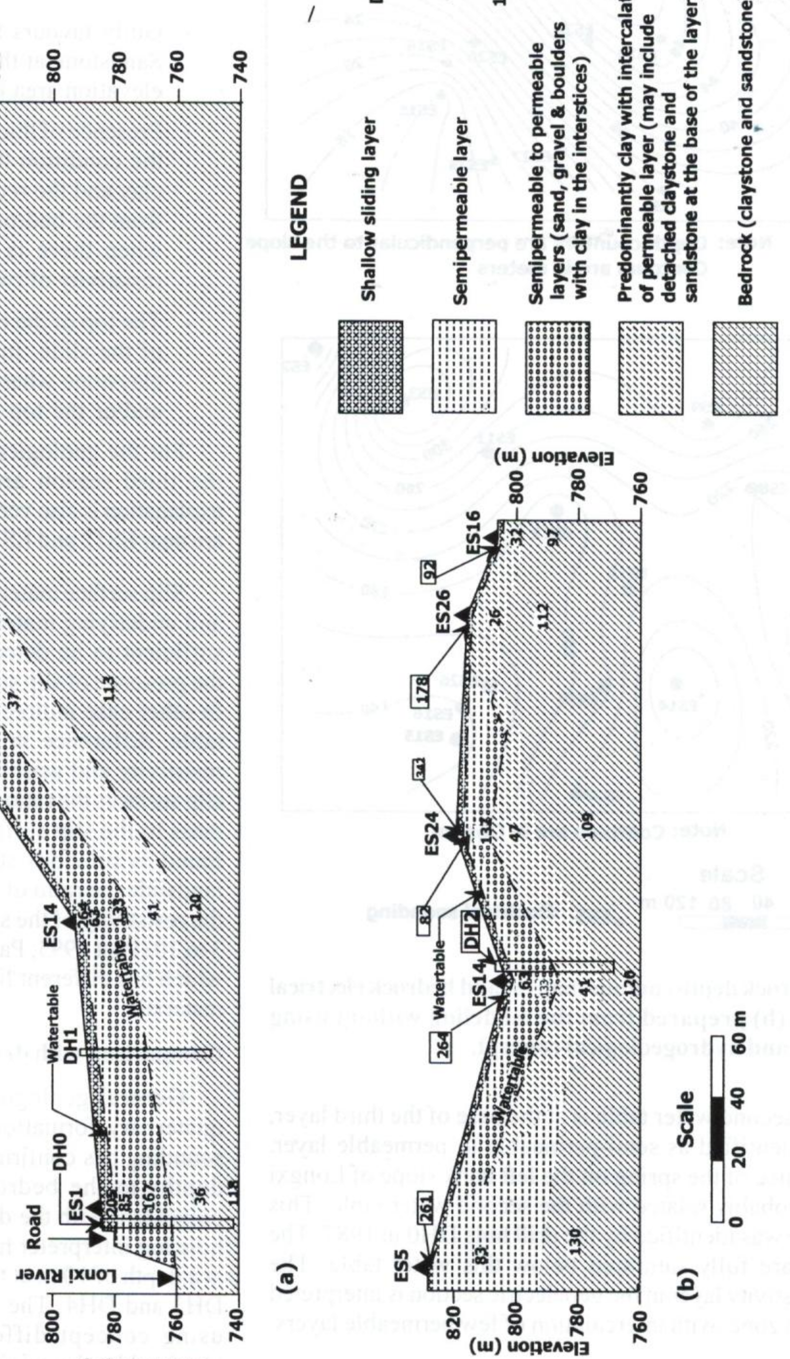
- Gully favours the accumulation of the groundwater. Sandstone at the base of the gully and in other lower elevation area is fully saturated.
- Presence of thick clay in the intermediate layer favours the condition that the current be concentrated in the clay and the reduced value of the electrical resistivity from the bedrock is obtained. This is usually the case when there is large difference between electrical resistivity of two beds (Pant and Reynolds 2000).
- The top of the bedrock is different at the different part of the slide. In the central and southern part thicker claystone whereas in the northern part thin claystone and/or the top is sandstone.

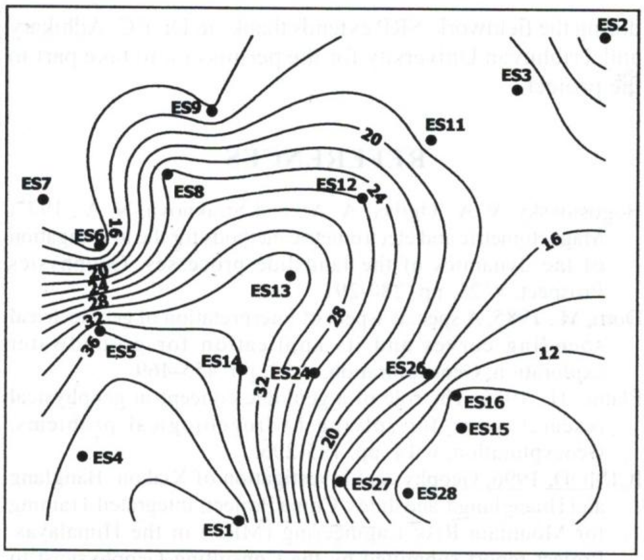
For the geological setup of the study area the first and the third reason are most likely to happen. The third explanation is also verified by drill holes DH3 and DH4, which are near ES12 and ES11.

Slip surface materials are fine materials than the overlying and underlying materials. If the thickness of the material is sufficient to be detected by the geoelectrical method then the presence of slip surface materials can be easily identified. In other case indirect method has to be used such as water table, difference in the depth provided by the electrical resistivity and seismic refraction. For the first and second slip surfaces the ratio of the electrical resistivity of the sliding mass to the slip surface is found to be more than 3. It was found in previous studies undertaken in Nepal that for a landslide the ratio of the resistivity of the sliding material to the resistivity of the slip surface material will range between 3 to 10 (Pant 1993; Pant 1998). This is the case for a landslide, which has different lithology between slide and slip surface materials.

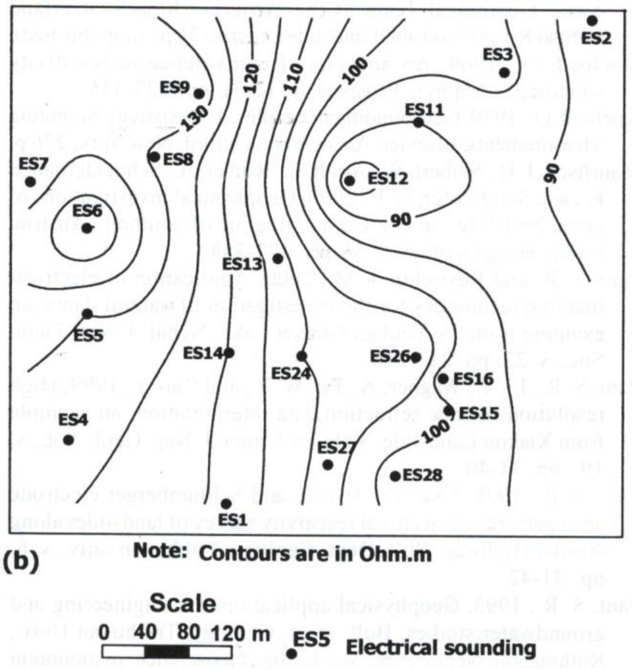
Comparison with drill hole information

General geological and hydrogeological setup of the quaternary formation indicated by the vertical electrical sounding has confirmed by four additional drill holes. The depths to the bedrock indicated by the soundings are coincident with the drill hole in DH0, DH1 and DH2. Drill hole log interpreter has interpreted that the claystone is met at a depth of 10 m at the base of the quaternary at location of DH3 and DH4. The depths obtained by VES modeling by using concept differed substantially from the depths obtained by the original interpretation of the drill hole log. Subsequent monitoring in DH4 has found that the claystone


(a)
Elevation (m)
920
900
880
860
840
820
800
780
760
740
ES3
447
26
97
ES11
DH4
219
27
90
DH3
ES12
124
78
23
82
ES13
318
37
113
ES14
264
63
133
41
120
Watertable
DH1
DH0
ES1
Road
Lonxi River
85
167
36
118
Watertable
(b)
ES5
261
83
130
264
Watertable
ES14
DH2
63
133
41
120
82
ES24
342
132
47
109
178
ES26
26
112
92
ES16
32
97
Scale
0
20
40
60 m
LEGEND
Shallow sliding layer
Semipermeable layer
Semipermeable to permeable layers (sand, gravel & boulders with clay in the interstices)
Predominantly clay with intercalation of permeable layer (may include detached claystone and sandstone at the base of the layer)
Bedrock (claystone and sandstone)
Slip surface
DH1 Drill hole
Electrical sounding
112 Resistivity in Ohm.m



(a) **Note: Depth counters are perpendicular to the slope**
Contours are in meters



(b) **Note: Contours are in Ohm.m**

Fig. 8: Bedrock depth contour map (a) and bedrock electrical resistivity map (b). The depths calculated are perpendicular to the slope.

at the base of the quaternary is creeping and depth to the contact between creeping claystone and sandstone is at 18 and 19.4 m at DH4 and DH3 respectively. The modeling of ES11 and ES12 suggest perpendicular depths 17 m and 26 m respectively and this depth is most likely the depth to the deepest slip surface in that part of the slope.

The water table depth information provided by the drill hole DH0 and DH1 are coincident with the electrical sounding interpretation. The first is referred to perched water table and the second to main water table. The measurements of the displacements in DH1 and DH4 have revealed two major slip surfaces. The first slip surface is at the interface of quaternary with bedrock and the second slip surface is at several meters from the ground surface (ITECO 1998). VES has identified these two slip surfaces in addition to the shallow near surface creeping.

Comparison with seismic refraction

Seismic refraction data were interpreted to determine the thickness of the quaternary or depth to the stable rock. Two types of processing were carried out. The first was plus-minus method (ICIMOD 1996) and the second was generalized reciprocal method (Pant et al. 1999). The interpretation of the seismic results indicates a velocity of the bedrock between 3100 to 3600 m/s. It suggests that the target refractor (top of the bedrock) is predominantly claystone. Seismic refraction method was not able to discern any intermediate layer. The average velocity of the lumped intermediate layer in a thick zone is between 1667 to 1718 m/s. This velocity can be referred to a clay dominant material, which may also include some loose unconsolidated saturated coarse-grained material.

In the area where quaternary formation is thin (less than 15 m) VES depth interpretation is in good agreement with both methods of seismic data interpretation. In the area where quaternary formation is thick such as in profiles A-A' and B-B' the depth obtained by generalized reciprocal method (optimum XY=45 m) are larger than VES results by 15 to 20 %. The depths deduced are in good agreement with the present VES interpretation only in the lower half of the profile. In the upper half, depths were overestimated by generalized reciprocal method. Probably a different optimum XY, lower than 45 m is needed for the upper half of the profile. However, the velocity information provided by generalized reciprocal method is useful to guess about the physical state of the rock.

The depths to the intact bedrock estimated by plus-minus method are shallower than estimated by VES. A difference of about 15 % was in Profile B-B' and in the lower part (near the road) of Profile A-A'. In the middle and upper part of the Profile A-A' the difference reached between 25 to 44%. Possible explanations for the differences are as follows:

- Since the profile A-A' lies in an actively sliding zone than the profile B-B' there can be major velocity inversion zones at least on and along the major slip surfaces.
- Second option is that the wave has been critically refracted from the top of the disconnected blocks and/or from the top of the compacted quaternary sediments. Probably the depths calculated by seismic are the depths to the top of the second slip surface.

If we compare both methods of seismic refraction interpretation the first is most likely to happen. Since the generalized reciprocal method of interpretation includes correction for the velocity inversion.

CONCLUSIONS

Based on the geological and hydrogeological concept derived from the geological and hydrological observation, and by making preliminary analysis of the field curves the area under investigation has been categorized into three parts. These three parts are north, central and south. For each part electrical resistivity of the different layers has been given in a range. These ranges are those, which are most likely to occur in the area. The equivalence analysis shows that the outputs are greatly improved. In the central part the slide is very active in a thick quaternary accumulated in deep gully. In this part two slip surfaces have been found with in the quaternary and the third slip surface possibly at the interface of quaternary and bedrock. The third slip surface may also include some detached blocks of rocks from the parent rock and probably moving very slowly. The northern part of the area is relatively stable and a shallow sliding is taking place in the southern part of the area (10-15 m thick).

Due to the change in depth to water table in different season of the year it is not easy to guess about the slip surface in a landslide. During rainy season both perched water table and main water table becomes higher so there can be substantial difference in the depth of slip surface and water table. During dry period of the year and if there is no recharge from the canal there can be little difference between water table and slip surface. By knowing the water table slip surface can be guessed.

Electrical sounding are useful to judge overall physical state of the sliding mass. The findings of the VES interpretation are in good agreement with the drill hole information at DH0, DH1 and DH2. The example of the misinterpretation of depth to bedrock in drill hole DH3 and DH4 shows that the drill hole interpretation cannot always be taken as granted. Bedrock was interpreted at a depth of 10 m in DH3 and DH4.The monitoring of the displacement in DH4 has proved that the original depth interpretation obtained from the drill core was a mistake. It may happen that detached blocks that lie on the top of the bedrock can be recognized as intact bedrock. Only subsequent monitoring and correlation with geophysical interpretation can help to resolve such ambiguities.

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