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Exploration of highly inclined silty sandstone beds using Geophysics

SYNOPSIS: Geophysical profiling is proposed to help locate the position and extent of loose sandstone layers together with their strikes and dips so as to investigate their interaction with future work. Electrical prospection and Seismic surveying are applied. After finishing the field work, a numerical model is built to simulate the effects of inclined layers in regard to ground resistivity.

INTRODUCTION

In the project for outlet work rehabilitation at Wushantou Reservoir, Tainan, Taiwan, two incidents happened during tunnel excavation works. There cause was determined as the encountering of highly inclined silty sandstone beds, which were softened and fully saturated, and containing internal has high water pressure. The review team decided to change the tunnel alignment and use a groundwater pumping system to control the water.

Geophysical profiling is proposed to help locate the position and extent of sandstone layers together with their strikes and dips so as to investigate possible interaction with future work. Electrical prospection and Seismic surveying were applied. After finishing the fieldwork, a numerical model was built to simulate the effects of inclined layers in regard to ground resistivity. Laboratory sand tank simulation was performed to study the variations of x-t curve influence caused by the inclined layer.

The results of the field investigation for the incident site are given in the following drawing (Fig.1). Overburden of the tunnel excavation was about 25 meters. Geological survey revealed that the overburden was formed by mudstone mainly with inclined loose silty sandstone beds as presented in the drawing. The loose silty sandstone beds found at the site were saturated and so loose to make retention using temporary lining impossible. The disaster happened in the form of large amounts of mud flowing into the excavated tunnel section. The ground surface was subsided for more than 50cm over a very large area.

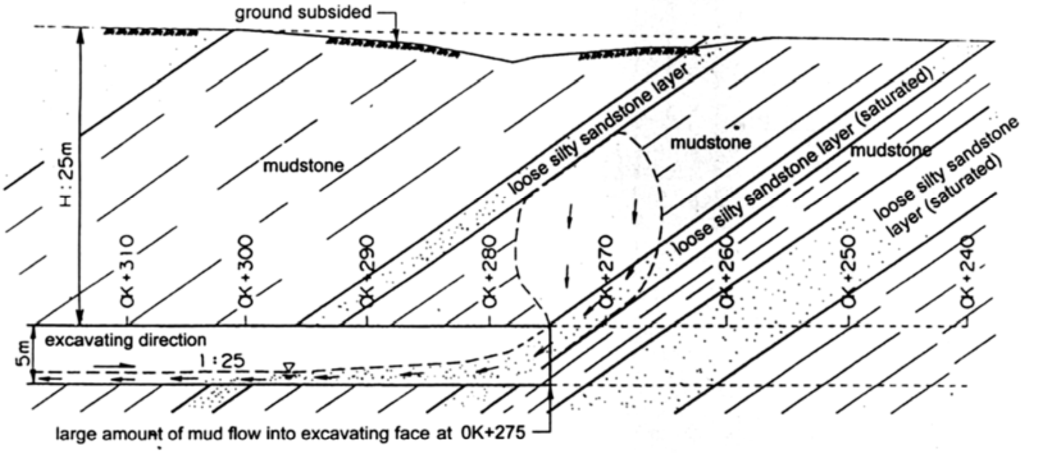

Fig.1 Draw of incident condition and its cross section

Field Geology

Geological investigations were performed in the planning stage. Together with field reconnaissance, the plot was provided as in Fig.2 to show the distribution of mudrock and sandstone layers in the projected tunneling elevation. Many loose sandstone layers were found. But the inclination, which is an important factor in tunneling, must be defined in advance.

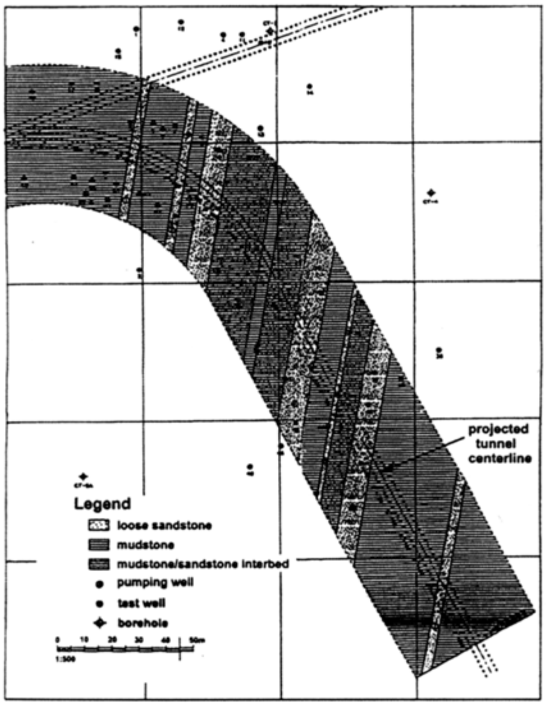

Fig.2 Geological drawing for the tunnel in WuShantou reservoir

Geophysic surveys were called to help on this point. Sesmic and resistivity profiling were proposed.

Electrical Resistivity Method

Electrical resistivity investigations are based on the theory of applying electric current to the ground using two electrodes and measuring the potential difference of two other electrodes. The distance between the electrodes and the measured potential difference are the data used to make interpretations of subsurface conditions.

Electrode configurations can be different for different purposes. Separate theories are then chosen for the interpretations for specific configuration types. In geological surveying, electrode configurations can be divided into horizontal profiling and vertical profiling based on different purposes. In horizontal profiling, the electrode spacing is kept constant and the whole configuration moved along a predefined direction with readings taken at regular intervals. The depth of the investigation is constant for all stations. Basically, the horizontal profiling chosen here can detect changes in apparent ground resistivity laterally above a specified depth.

Horizontal Profiling across a vertical target

Apparao et al (1992) reported a simulation result using an aluminum sheet to form a vertical inductive target. Wenner's configuration was used. Test results showed a very clear ω shape existed when electrodes crossed the target as presented in Figure 3. The larger the electrode spacing, the wider the ω shape became.

Numerical Formulation

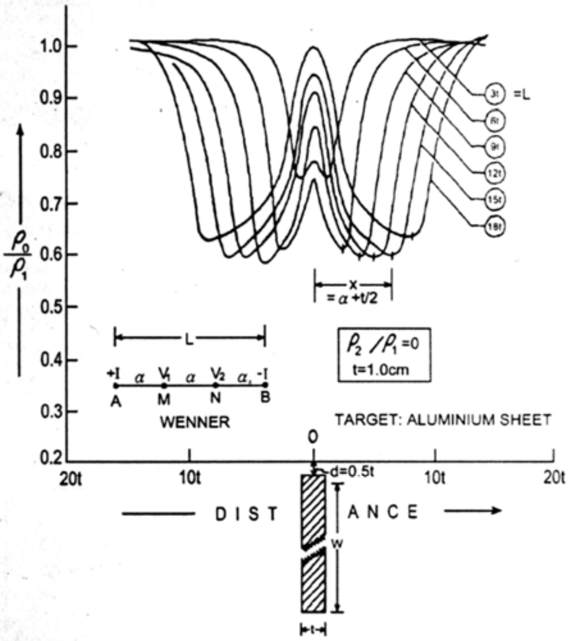

Fig.3 Plot of resistivity ratio for different electrodes spacing (by Apparao et. Al,1992)

In order to simulate horizontal profiling across the steeply inclined loose sandstone layer embedded in the mudstone, the Finite element method was used to calculate the electric potential distribution.

The Galerkin approach is used with a weight function to solve the following integration.

$$\iint_A \gamma \left[\frac{\partial}{\partial x}\left(K \frac{\partial \varphi}{\partial x} \right) + \frac{\partial}{\partial y}\left(K \frac{\partial \varphi}{\partial y} \right) \right] dA = 0 \qquad (1)$$

$\gamma = N \cdot \psi$, ψ are vectors for each nodal point for an element. By expanding the above equation, we can get

$$\iint_A \left\{ \left[\frac{\partial}{\partial x}\left(rK \frac{\partial \varphi}{\partial x} \right) + \frac{\partial}{\partial y}\left(rK \frac{\partial \varphi}{\partial y} \right) \right] - \left[K \frac{\partial r}{\partial x}\frac{\partial \varphi}{\partial x} + K \frac{\partial r}{\partial y}\frac{\partial \varphi}{\partial y} \right] \right\} = 0 \quad (2)$$

with further expansion to

$$\iint_A \left[K \frac{\partial r}{\partial x}\frac{\partial \varphi}{\partial x} + K \frac{\partial r}{\partial y}\frac{\partial \varphi}{\partial y} \right] dA \iint_A K \left[\frac{\partial r}{\partial x} \; \frac{\partial r}{\partial y} \right] \begin{Bmatrix} \frac{\partial \varphi}{\partial x} \\ \frac{\partial \varphi}{\partial y} \end{Bmatrix} dA \qquad (3)$$

$$= \sum_e \psi^T \left[K_e \int_e \overline{B_T}^T \overline{B_T} dA \right] \overline{\varphi}^e = \sum_e \overline{\psi}^T \overline{K_T \varphi}^e = 0$$

The above equation is solved using gaussian iteration. The following plots (Fig.4 and 5) are the voltage ratio versus the distance for different inclination.

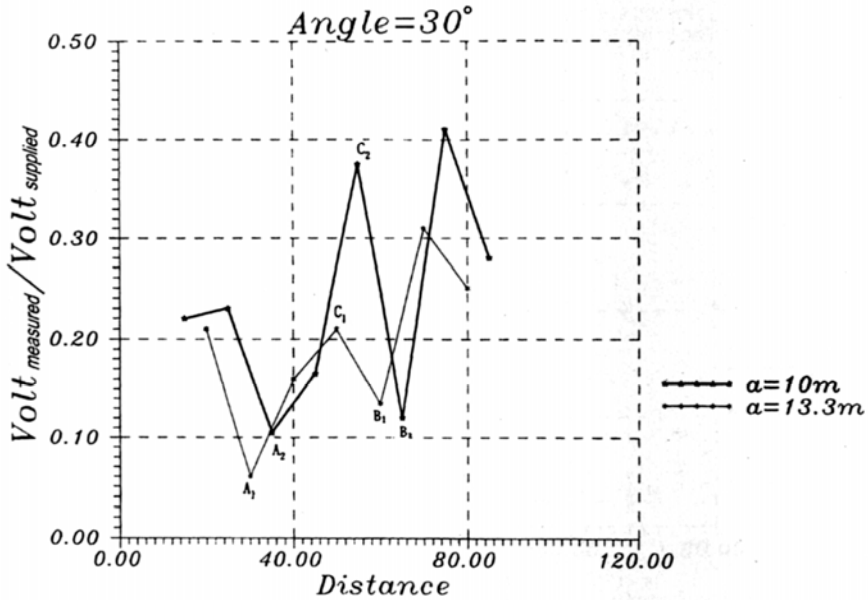

Fig.4 Plot of voltage ratio versus distance for 30° inclination

Field Resistivity test

A few lines of survey for horizontal resistivity profiling were performed to verify the numerical result presented above. Two field $\rho - x$ plots are given in Fig. 6 and 7 to show the change in resistivity when crossing the loose sandstone bed which is low in ground resistivity. In each figure, data for different electrode spacing is given to show the effect. Both figures show very clearly the unsymmetrical ω-shape.

The model developed for analyzing the electrical prospecting results of the inclined sandstone bed shows the unsymmetrical ω-shape for the apparent resistivity versus the distance, which is verified by field data. The method for analyzing field seismic refraction data was built with the results from sand tank simulations. Finally, all information including drilling logs were put together to define the total extent of these highly inclined silty sandstone beds as in Fig. 8. The design of the pumping well system could be performed thereafter.

CONCLUSIONS

Horizontal profiling of ground resistivity was capable of defining the highly inclined layers, which were low in resistivity. Numerical simulated results predicted the

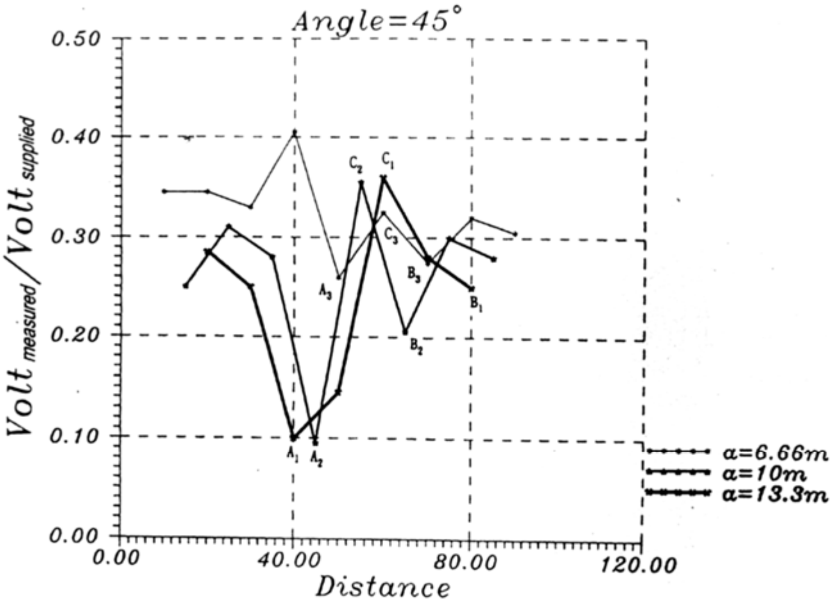

Fig.5 Plot of voltage ratio versus distance for 45° inclination

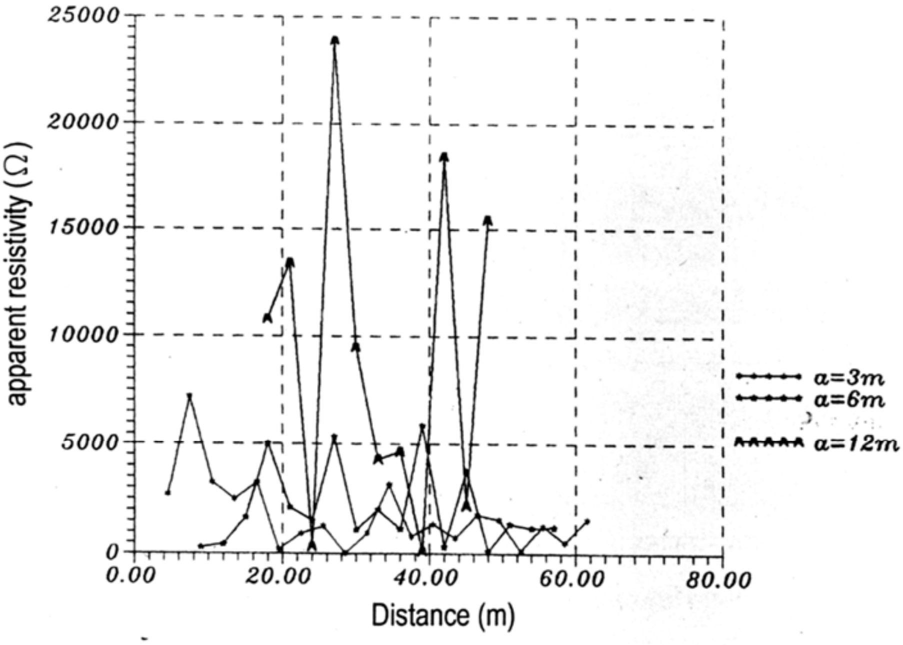

Fig.6 $\rho_a - x$ plot for horizontal profiling along V1 line

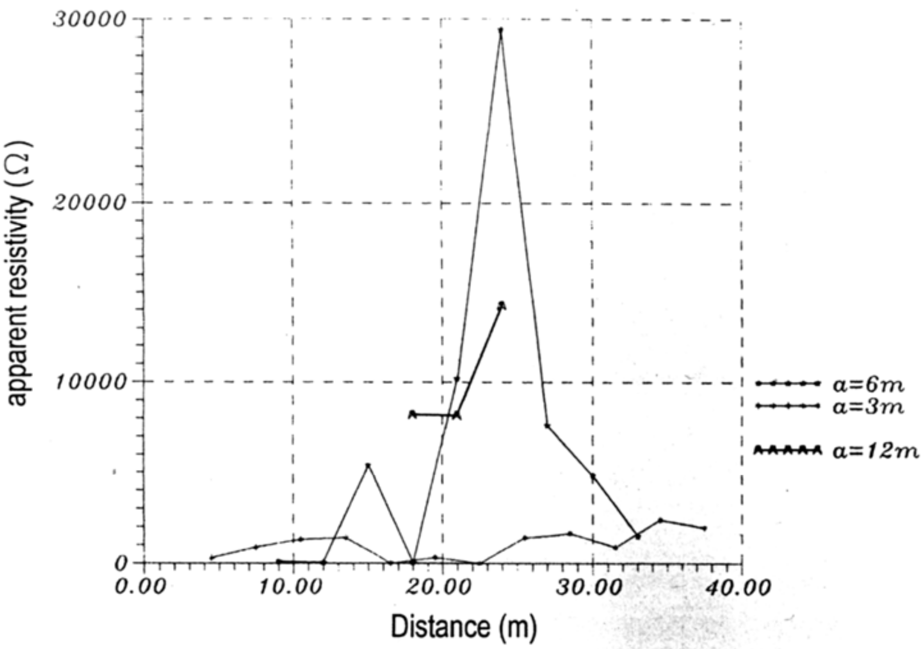

Fig.7 $\rho_a - x$ plot for horizontal profiling along V2 line

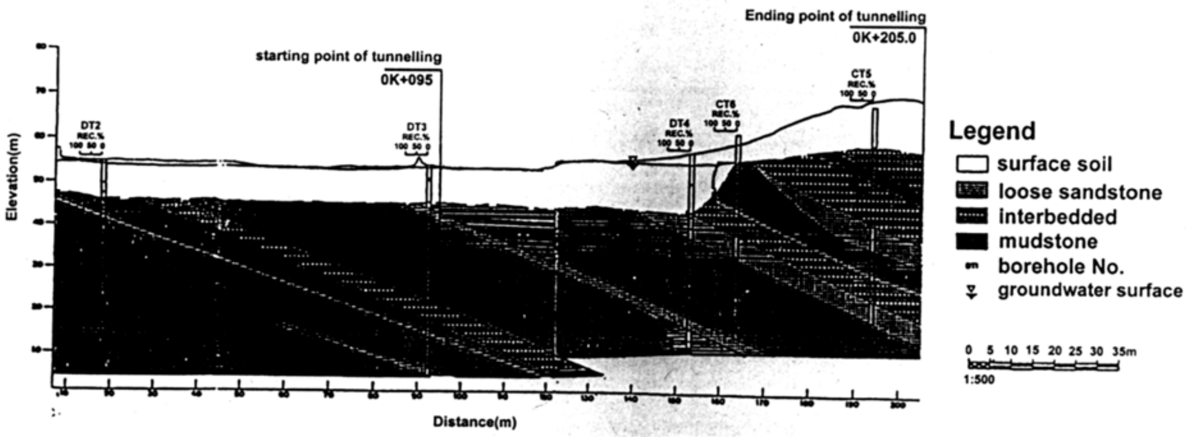

Fig.8 Final geological cross section map

unsymmetrical ω shape in ρ-Distance plot found in the field, which proved the applicability. Highly inclined loose sandstone layers have a large influence in public works in sedimentary rock situations, open-cut or tunneling where water exists. In the test field site, high-pressure water filled in the sandstone layers, which created a shearing zone in the massive mudstone layer, which can cause very severe disasters in tunneling.

REFERENCE

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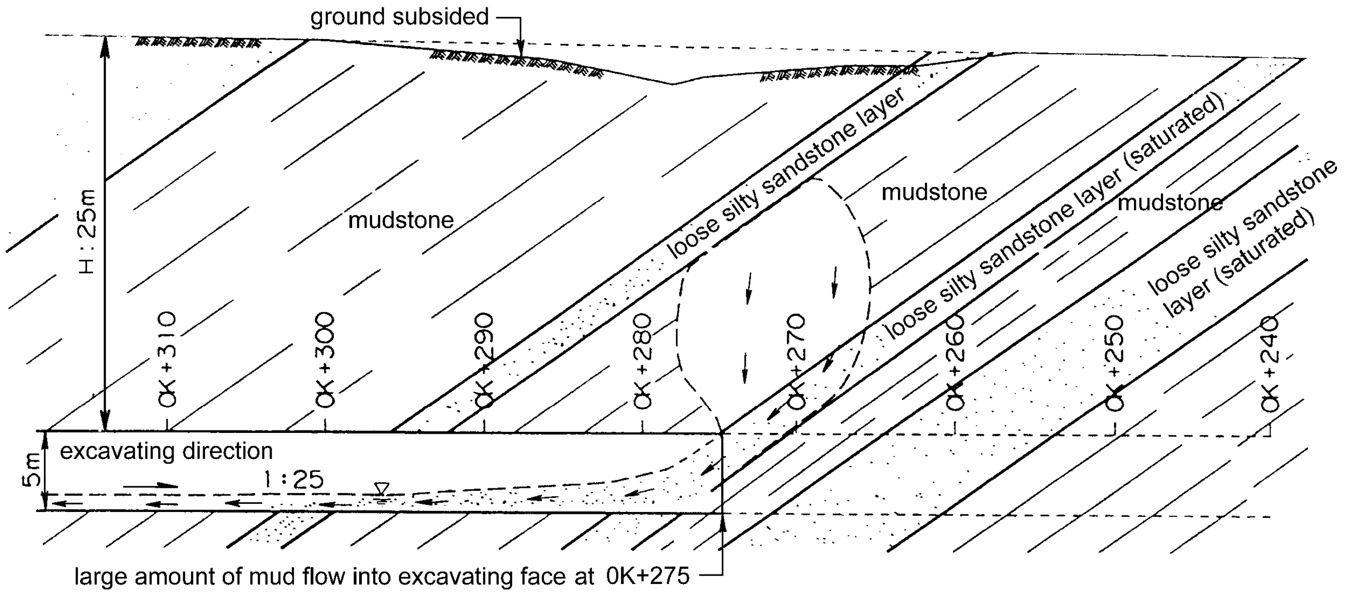

ground subsided
H : 25m
mudstone
loose silty sandstone layer
mudstone
loose silty sandstone layer (saturated)
mudstone
loose silty sandstone layer (saturated)
OK +310
OK +300
OK +290
OK +280
OK +270
OK +260
OK +250
OK +240
5m
excavating direction
1 : 25
large amount of mud flow into excavating face at 0K+275