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Case Studies of CSAMT Method Applied to Study of Complex Rock Mass Structure and Hidden Tectonic

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***Abstract*—**In projects like waterpower, transportation and mining, etc., proving up the rock-mass structure and hidden tectonic to estimate the geological body's activity is very important.

Integrating the seismic results, drilling and trenching data, CSAMT method was carried out at a planning dame site in southwest China to evaluate the stability of a deformation. 2D and imitated 3D inversion resistivity results of CSAMT method were analyzed. The results indicated that CSAMT was an effective method for defining an outline of deformation body to several hundred meters deep; the Lung Pan Deformation was stable in natural conditions; but uncertain after the future reservoir was impounded.

This research presents a good case study of the fine surveying and research on complex geological structure and hidden tectonic in engineering project.

***Keywords*—**CSAMT Surveying, Deformation Stability.

I. INTRODUCTION

THE southwestern area of China is rich in water and hydro power resources. It is the most important hydro power energy base of China. With the Great Western Development Strategy in western region of China, many hydro projects are constructed or under construction in this area.

Because these constructed and planning hydropower constructions are located at the mountains structure zone of the eastern edge of the plateau caused by the Indian plate dives to the Asian plate, both inside and outside dynamic effect of the constructions are very strong. The structural integrity of dams will be attributed to good design, good quality construction, and the effective management.

Tiger Leaping Gorge power station is a planning large hydropower project, the primary site is near the Lung Pan where was defined a slope deformation in term of geology. Study of the stability of Lung Pan deformation body is the key of the site selection.

In order to identify the form and structure of the right bank of Lung Pan slope deformation, CSAMT method was carried out by Institute of Geology and Geophysics Chinese Academy of Sciences, from 2002 to 2005 [6]. From drilling investigation and seismic survey carried out before, the range of deformation, rock internal heterogeneity and stress characteristic can be estimated. They are bases of understanding the geoelectric characteristics of the deformation and are geophysical evidence for further evaluation.

II. GEOLOGICAL BACKGROUNDS IN THE RESEARCH REGION

Tiger Leaping Gorge on the Jin sha River locates in the northwest of YunNan province, China, crossing the border of LiJiang and Diqing states. It locates in the western border of Yunnan-Guizhou Plateau which is on the transition zone to the eastern part of Qinghai-Tibet Plateau. The geological structure is complicated in this region, with strong new tectonic movement. In this special structure-landscape environment, there are much complicated slope stability problems in area of Tiger Leaping Gorge. The right bank of Lung Pan deformation is possible a potential threat to the planning reservoir engineering project; the geological characteristics of the region must be made clear before constructing.

The river reach of CSAMT survey area locates in the middle Hengduan Mountain. ShuoDuo hillock is a bound of the river mouth; up part of it, the river valley is open in U form, river valleys are vertical to the river, the angles of bank slope change from 20° to 40°, some are more than 70°; river flows stably. First lever terraces distribute in two banks; there are a large number of settlements and plantation. Entering the Tiger Leaping Gorge dam site, river valleys are V form being typical gorge terrains. The mountains around it are 800 to 1000meters compared; terrain angles are about 70-80°. The valley is deep down, with big water level drop and rushing flow. The part from river mouth to up Tiger Leaping Gorge dam site is transition area of river valley to gorge.

The exposed bedrocks in research area are a set of light-based metamorphic rocks, mainly schist, slate, sandstone carbonate, the geological years are Paleozoic Cambrian and Devonian-Triassic, Variscan west period of extrusive rocks (basalt) are distributed among them. Quaternary hill slope accumulation and alluvial deposits distribute broadly along two sides of the river, their ingredients are complexity. High and steep slopes along the river develop; with deeply weathered rock; landslides, deposits distribute more.Please submit your manuscript electronically for review as e-mail attachments. When you submit your initial full paper version,

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prepare it in two-column format, including figures and tables.

III. THE APPLICATION OF CSAMT METHOD TO THE TIGER LEAPING GORGE LUNG PAN DEFORMATION

A. CSAMT Method

Controlled-source audio-frequency magnetotellurics (CSAMT) is an electromagnetic (EM) exploration method developed in the 1980s. After nearly 20 years of technical study, updating and transformation of this technology, a lot of research results have been made in field of theoretical methods, forward modeling, data processing and interpretation [7], [16]. Its applications deal with mineral exploration - detection of controlling and containing structural of mining, the distribution patterns and locations of abnormalities [11], [1]; mapping lithology, groundwater - detection of fracture-water storage structure by the Karst fissure water features [2], [13]; and prevention geological disasters in mining – detecting the water body distribution in roof and floor, caverns and faults to understand, prevent and treat of the potential disaster [3], [5].

The aim of this CSAMT studies is to provide geoelectric basis of the slope deformation by understanding the resistivity characteristics, the distribution of scope, scale, shape, *et al*.. Because there are villages and effect of power lines in the research region, and the larger rising and falling terrains, conventional method such as the DC methods, IP methods, and high-density electrical are not ideal to this area [12]. CSAMT method has many advantages for survey in this area. It uses an artificial signal source (typically in the range 0.1Hz to 10 kHz) and provides stronger and more reliable signal; electric and magnetic fields are measured at the same time, adverse effects, like terrain effect, are decreased [14], [9], [4].

B. Design of CSAMT Survey and Acquisition of Data

To trace the borders of the deformation and make clear the two known faults and fracture zones in directions of south-north (SN) and west-east (WE), six CSAMT measuring lines are laid (Fig. 1). Three lines are parallel to the contours (SN), respectively in the line DFSN-1, DFSN-2 and DFSN-3; other three lines are perpendicular to contours lines, respectively in the line DFWE-1, DFWE-2 and DFWE-3. The position of line DFWE-2 is almost the same with the refraction seismic main survey line LPP carried out before the CSAMT work; the line DFSN-1 and DFSN-3 in SN direction were near the refraction seismic survey lines LPS1 and LPS2.

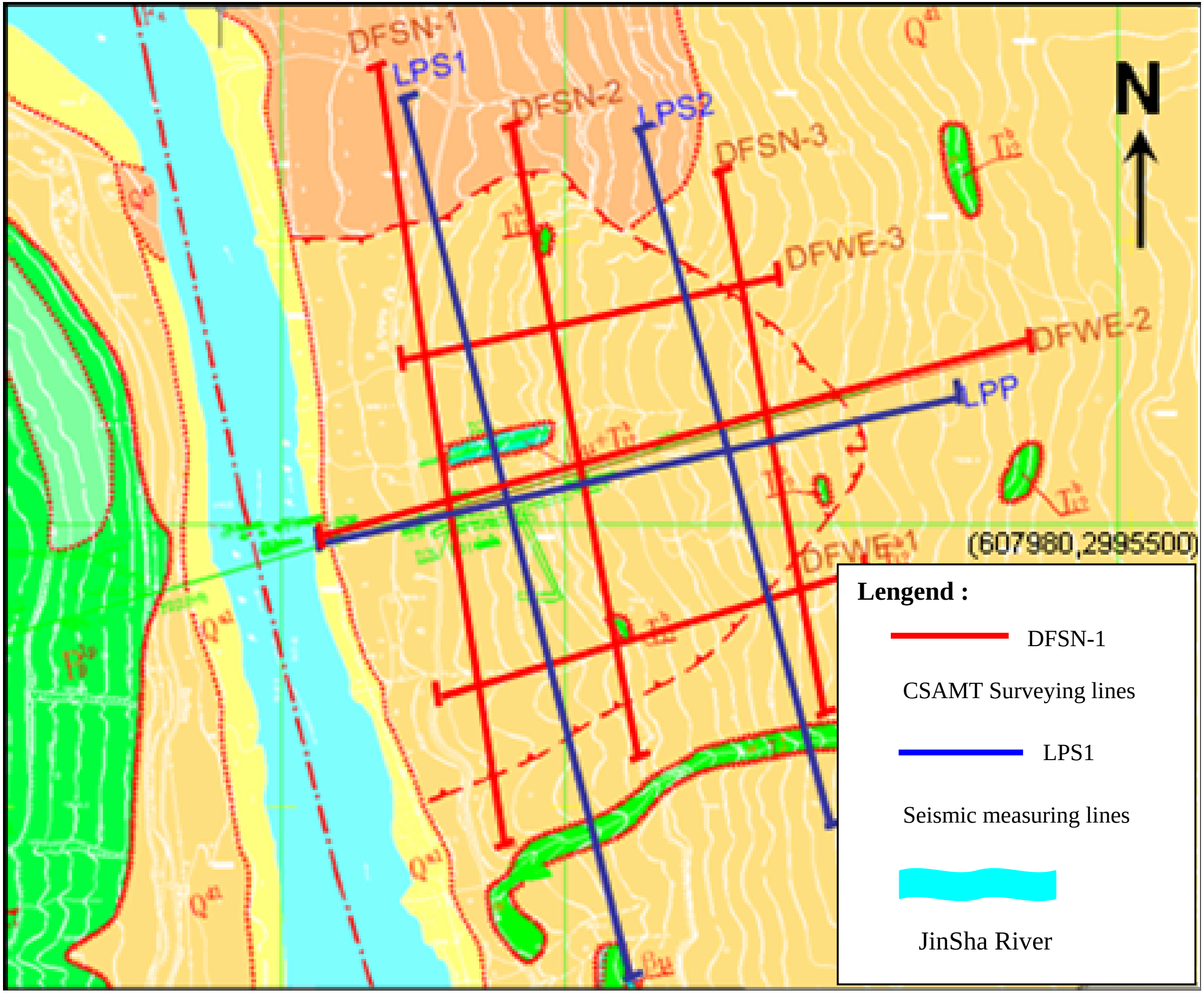
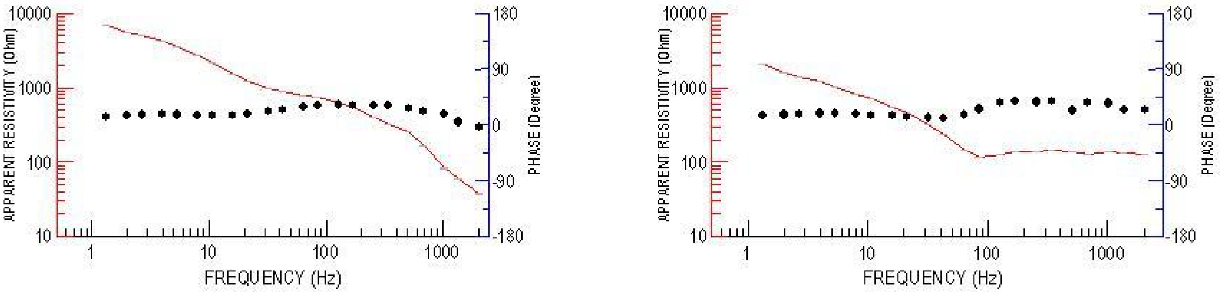


Fig. 1 The positions of CSAMT survey lines for Tiger Leaping Gorge on the Jinsha River

The distance between two adjacent survey stations is 20 m; distance between the transmitter and receiver was 4000 m, long enough to ensure the designed exploration depth 400 m. The distance of source dipole was 1000 m; current power supply was more than 10A. Because the survey lines outspreaded by two directions, the direction and location of source dipole must be changed accordingly [15]. SN source dipole was located the west bank of the Jin Sha river, the centre of source dipole (AB) was located at the perpendicular bisector of survey lines. The laying principle of source dipole in direction EW was the same.

Before the CSAMT work is carried out in large areas, surveying experiment and parameters choosing are necessary, especially for the transmitting and receiving frequency, as well as the distance R between launching and receiving. In the Lung Pan research area, considering the relative shallow exploration goal, high-frequency band was used mainly and the frequency range was 2^{13}-2^{-1} Hz. This frequency band assured that depth from the surface to 1000 m underground can be detected. The exploration depth of CSAMT method is controlled not only the frequency but also the distance R between launching and receiving; here to ensure the 500 m detecting depth, the R was 4000 m.

Though there are disturbances from the power lines over the survey region, the collected data are well. In order to illustrate the characteristics of the raw data, two survey stations' original curves are illustrated in Fig. 2.



(a) (b)

Fig. 2 Typical CSAMT curve in double logarithm coordinates (a) The original data of measuring point 2100 in Line N20; (b) The original data of measuring point 2360 in Line N20

The original abnormity curve of deformation body and the original curve of normal stratum are illustrated respectively in Fig. 2(a) and Fig. 2(b); the solid curve is the correlation curve between apparent resistivity and the frequency; dots curve is the correlation curve between the phase and the frequency.

In Fig. 2(a), the apparent resistivity curve is ladder like shape, the change scope of apparent resistivity is larger. In the high-frequency band (>500Hz), apparent resistivity curve changes dramatically, from low resistivity to high; in the medium-frequency band (500Hz-10Hz), apparent resistivity curve rises slowly, represents the resistivity changes from middle value to high; in low-frequency band (10Hz-0.5Hz), apparent resistivity curve still changes upward, however, this part represents the near field effect region, the data need to be corrected for near field effect. But this part of the curve doesn't go up in 45° theoretically; it means resistivity under this area changes from high-middle to middle-low value. Similar trend can be also gotten from phase curve.

C. The Data Processing and Discussion of the CSAMT Results

Data processing of CSAMT method includes noise suppression for the field data, filtering and near-field correcting; and drawing curve to analysis the points which maybe affected by static influence; then determining the initial inversion model by the curve shape. One dimension (1D), 2D and 3D forward modeling and inversion methods for the CSAMT data were processed [10].

Because the position of line WE-2 is almost same with the position of refraction seismic main measuring line LPP, so the base of intense weathering layers got from refraction seismic is also presented in Fig. 3. The low resistivity parts on surface are estimated deposit bodies; dark color high resistivity parts are estimated the presents of deformation bodies; the contours thicker parts and resistivity values change greatly area, are estimated as the presents of faults. As showed in the Fig. 3, F_1 to F_3 broken lines are inferred faults; the bottom broken line is the base of deformation body. It is obvious that the deformation is controlled by faults and is separated in two parts; the base of the deformation is about 100 m.

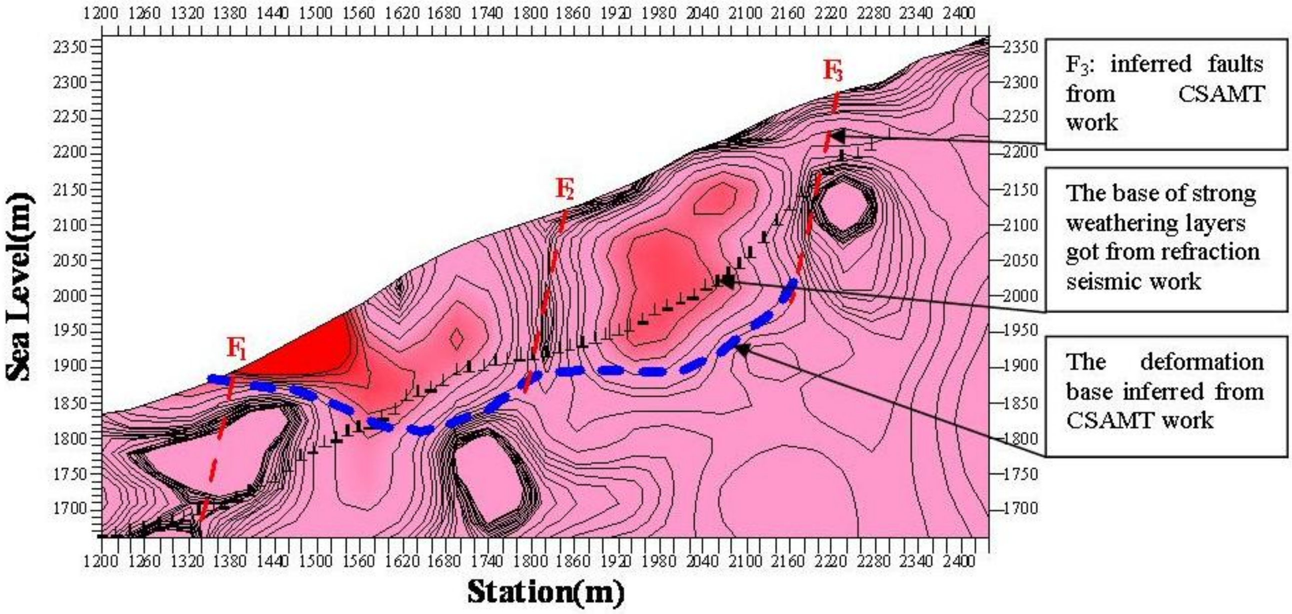


Fig. 3 The CSAMT inversion resistivity section of line WE-2. The nails Curve in the figure is the base of strong weathering layers got from refraction seismic

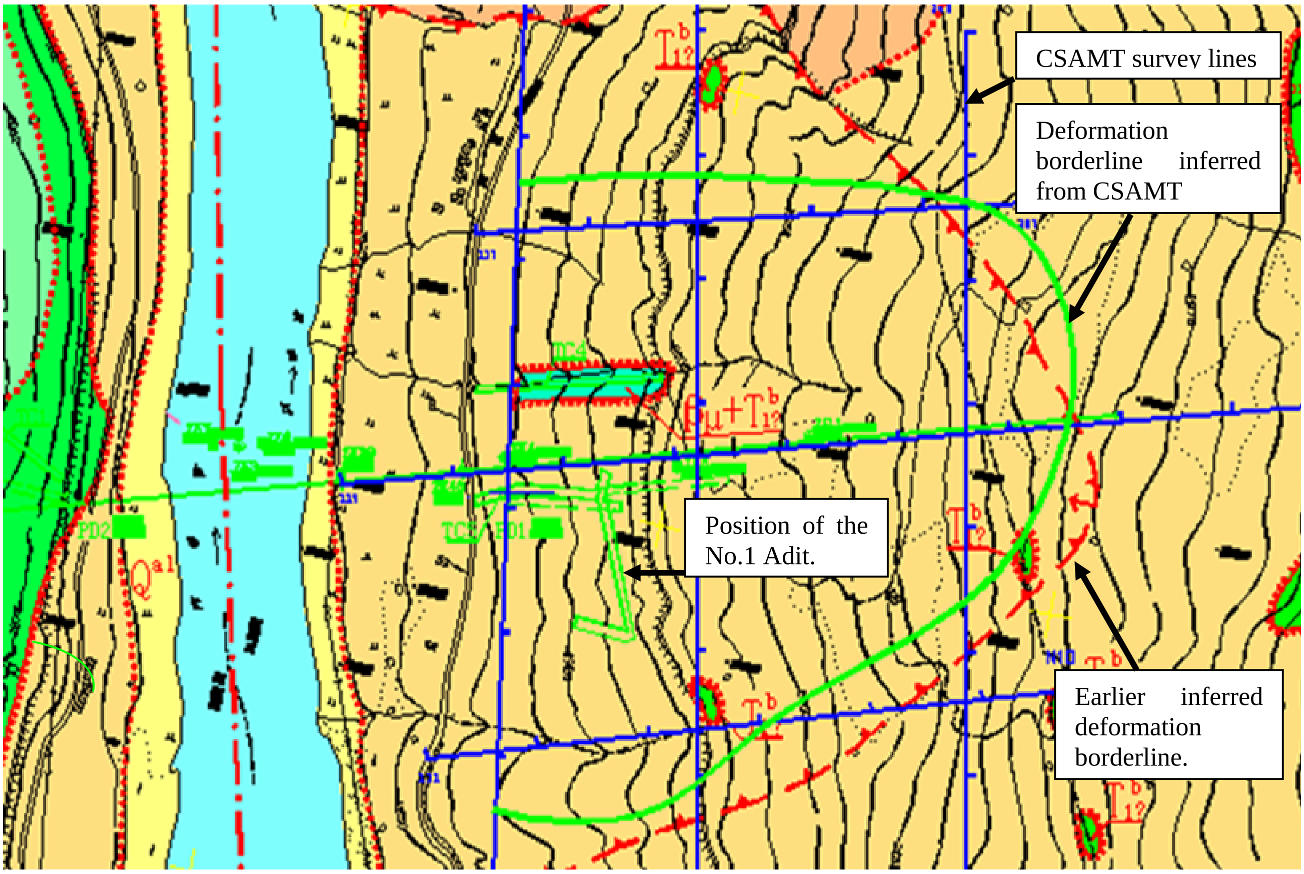


Fig. 4 The inferred borderline of Lung Pan deformation body

The borderline of Lung Pan Deformation body was presented in Fig. 4, based mainly on the abnormities of inversed resistivity sections above.

It is obviously that the area of the deformation resulted from CSAMT is smaller than the area inferred from earlier geological works. Because lateral resolution is higher by CSAMT method, the new border area result of the deformation body is more believable.

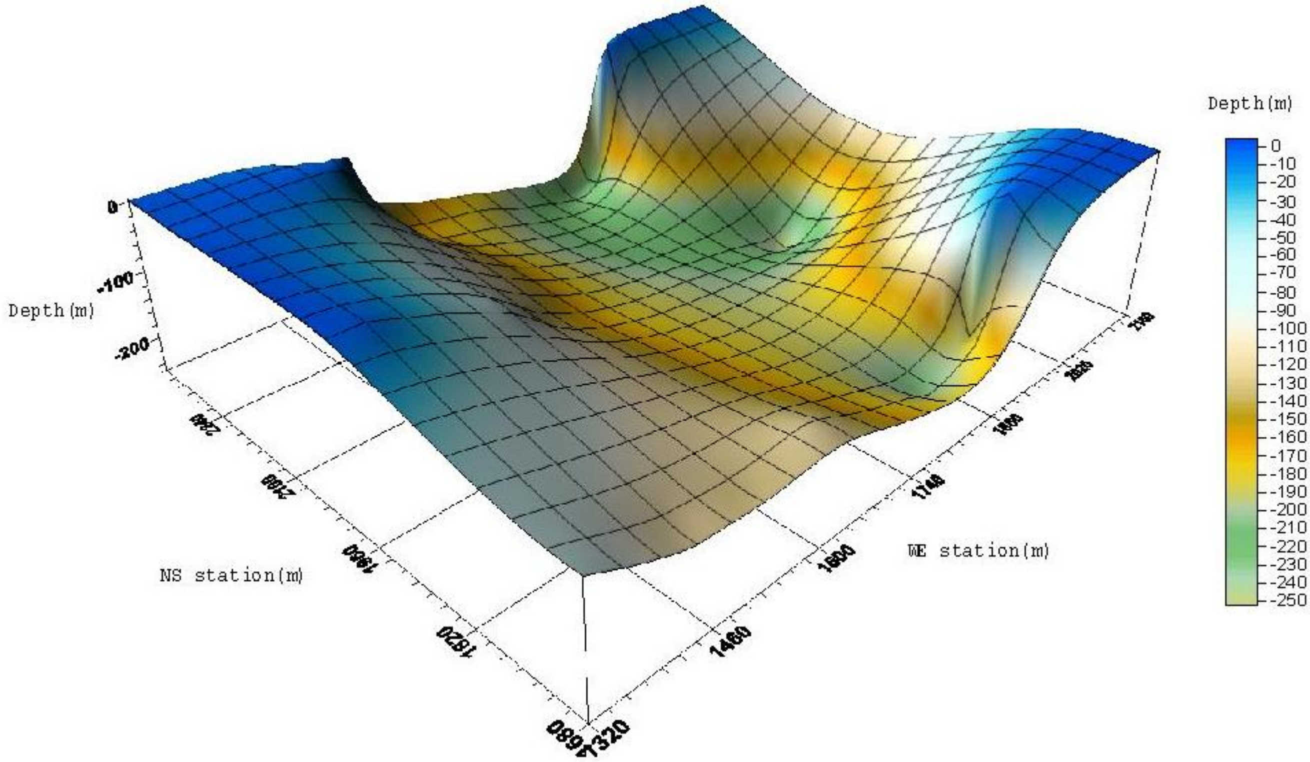


Fig. 5 The inferred shape of Lung Pan deformation base borderlines

To understand the spatial distribution of the deformation body, abnormity data were taken out in depth direction to get a 3D abnormity data group. Because the 3D inversed image with terrain data is difficult to get, Fig. 5 represents the imitated 3D inversion result with depth. The around dark and white parts in the Fig. mean zero value and the interpolation result, do not mean the base shape of deformation body; the orange yellow parts and inside of them are the inversion result which present the base of the deformation body. The left coordinate axis means the NS direction, right coordinate axis means the WS direction, vertical coordinate axis means the depth direction; the wave shape and the color in figure mean the depth changing. It can be found from the figure that the base of deformation body is deeper in the up part (incline direction), shallower in the down and two sides. It means the deformation base is gently relatively to the terrain; this is good for the stability of the deformation. Also because the deformation is wide in NS direction, this is helpful to its stability. Generally, this deformation volume is bigger and it is in stable situation.

Analyzing results of the monitoring data from the No. 1 Adit also proved the CSAMT results. Six settlement observations indicated that the mouth of No. 1 Adit was rise relative to the inside of the main Adit. The horizontal deformation observations of the No. 1 Adit indicated that the mouth part was in a compressed situation and the areas near distending cracks also were compressed situation. This means there are some distortions in the deformation body; or the result means the possibility of local strain or was influenced by the data quality. To make it clear, it is necessary to increase the surveying range, to verify the data reliability, and to do the Total Station observations and analyzing. The slope is stable situation in nature condition or under impound; but there is a possibility of landslide under the coupling impact of earthquake and rainstorm.

IV. DISCUSSIONS AND CONCLUSION

The CSAMT survey is an effective method for detecting deformation body in condition of high slope terrain area. It can get credible data in interferential surroundings, presents not only the scope of deformation but also the faults under the slope deposits, and is an effective shallow geophysical means of detecting the slope structure so as to determine the stability of the slope.

Integrating the result of CSAMT with the results of seismic method and engineering geological works, the range, depth and extend direction of Lung Pan deformation can be estimated effectively. It is stable in natural conditions. But after the reservoir is impounded, the pore water in the deformation rock will increase, and the deviator stress which is the guarantee of preventing shearing deformation for the deformation stable will decrease, and thereby induce the stable slide. Farther prospecting and surveying are necessary to study if the stable slide can develop toward an unexpected instable slide.

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