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Use of two dimensional electrical resistivity tomography (2D- ERT) synthetic modelling to detect collapse masses

Dilli Ram Thapa

Birendra Multiple Campus, Tribhuvan University, Nepal
E-mail: dilliramthapa14@hotmail.com

ABSTRACT

The presence of collapse masses in the subsurface causes severe problems in the geotechnical design activities. In this study, two dimensional Electrical Resistivity Tomography (2D-ERT) synthetic modelling techniques were used to detect collapse masses commonly found in the river bank. Two dimensional (2D) resistivity models are first created utilizing prior information of collapsed masses in the river bank and afterward inverted to reconstruct the resistivity distribution in the subsurface. The resulting two dimensional models exhibits that collapsed masses can be better detected particularly at low resistivity noise level (2%) than the high noise levels (5% and 10%). The models are particularly very useful prior to executing the field investigations in the river bank sites and furnish the subsurface geology as well as the successful interpretation of the results with confidence.

Keywords: 2D electrical resistivity tomography; Resistivity inversion; Collapse mass

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INTRODUCTION

The presence of collapsed masses in the subsurface causes severe problems in the geotechnical design of any engineering structures. Therefore, geophysical investigations are often perquisite and fundamental for understanding the subsurface conditions systematically. The reliable geophysical methods can be used to identify the geometry and depth of collapsed rock masses. Among the commonly used geophysical methods, the electrical resistivity method is now the widely applied active source geophysical survey technique which is non invasive and accurate enough to map out the geometry of the subsurface (e.g., Griffiths and Barker, 1993; Seminsky et al., 2016; Hojatet al., 2019). Over the last two decades, a growing number of studies have applied the electrical resistivity methods in the search of groundwater resources, archaeological and environmental investigations, mining applications, and to address engineering problems because of its cost effectiveness and availability of computers with comprehensive processing and analyzing softwares (see, for example, Candansayar and Basokur, 2001; Ha et al., 2010; Wilkinson et al., 2010; Ramazi and Mostafaie, 2013; Galazoulas et al., 2015; Kazakis et al., 2016; García-menéndez et al., 2018).

The two Dimensional Electrical Resistivity Tomography (2D-ERT) method also known as the two dimensional Electrical Resistivity Imaging (2D-ERI) technique is especially capable of well resolving the subsurface features (Loke, 2001). In fact, 2D image of the the resistivity subsurface patterns can be prepared by using the resistivity data obtained from the electrical resistivity tomography survey or by creating synthetic models and inversion. As reported in the literature, several studies in the past have prepared 2D image of the resistivity subsurface patterns using the resistivity data, however there have been some research works focusing on producing two-dimensional resistivity images of subsurface numerically by creating synthetic models (e.g., Putiska et al., 2012a; Putiska et al., 2012b; Hassan, 2017; Mohammed and Sawsan, 2019; Thapa, 2019).

The aim of the present study is to prepare 2D image of the subsurface using ERT synthetic method and to investigate the effectiveness of the synthetic method before conducting the field survey. For this purpose, two dimensional (2D) resistivity models are first constructed utilizing prior information of collapsed masses (i.e. forward modelling) and the models are subsequently inverted to reconstruct the subsurface true resistivity distribution (i.e., inverse modelling). The resulting models provide an initial insight for subsurface patterns prior to executing the field investigations in the river bank areas and could be helpful for achieving the target as well as the successful interpretation of the results.

METHODOLOGY OF ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT)

The basic principle of the commonly used traditional resistivity method is to inject the current (I) into the ground through two current electrodes and measure the resulting potential drop (V) across other two electrodes (Reynolds, 1997). The measured voltage drop is directly proportional to the electrical resistivity that can be generally associated with the characteristic properties of the medium is given below as:

$$\rho = K\frac{\Delta V}{I} \quad \text{.........} \quad (1)$$

where, ρ represents the resistivity (Ohm.m), K represents the geometric factor (meter) that accounts for the electrode array, ΔV represents the voltage drop (Volts), and I represents the current (Amps). Using resistivity data either obtained from the electrical resistivity field measurements or by creating synthetic models and inversion, 2D image of the subsurface of the region of interest can be constructed.

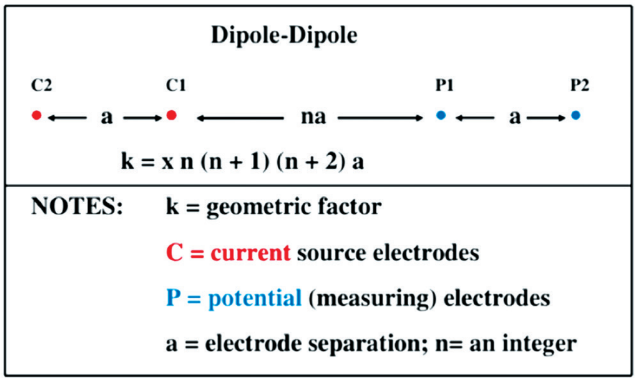

Fig. 1: Electrical resistivity configuration of dipole-dipole array with the geometric factor (Oldenburg and Jones, 2007).

In this study, 2D-ERT synthetic modelling of the collapsed masses is employed to simulate realistic scenarios and examine the effectiveness of the methodology applied before the geophysical field investigations. The synthetic ERT modelling carried out in the present study includes two main steps. The first step is the construction of the 2D electrical resistivity model of the collapsed masses based on the user prior information (i.e. forward modelling) by employing the forward modelling program RES2DMOD (Loke, 2001). The algorithm is based on least-square method involving the finite-element method (FEM) and finite-difference method (FDM) (deGroot-Hedlin and Constable, 1990; Sasaki, 1992) and is applicable for different geological conditions with choosing appropriate array. This program works for all type of arrays, the present study used the dipole-dipole array (Fig.1) and FDM. To prepare models, fourteen parameters (name of model, number of electrodes, number of pseudosection data levels, type of survey, unit electrode spacing, user defined mesh lines depths, offset of the first blocks from first electrodes, number of blocks in user defined model, number of resistivity values in the model, number of nodes per unit electrode spacing, the model resistivity values, number of rows of rectangular blocks in the model, the depth of the horizontal grid mesh line and the usual model codes) were used. The second step is the inversion of models using the inversion program RES2DINV (Loke, 2001). The smoothness-constrained least-squares method used in this study is based on the following equation specified below:

$$(J^T J + uF)d = J^T g \quad \text{.........} \quad (2)$$

Where

$$F = f_X f_X^T + f_Z f_Z^T \quad \text{.........} \quad (3)$$

In which f_X represents the horizontal flatness filter, f_Z represents the vertical flatness filter, J represents the matrix of partial derivatives, u represents the damping factor, d represents the model perturbation vector and g represents the discrepancy vector. The final outcomes of this study are the three resistivity sections (synthetic apparent resistivity section, calculated apparent resistivity section and final inverse resistivity model). The study consider two models; one is for the single collapse mass buried in the alluvium (hereafter referred to as the collapse mass I) and the other is for the two detached collapse masses (hereafter referred to as the collapse mass II) buried in the alluvium and covered by colluviums materials.

RESULTS AND DISCUSSION

The synthetic ERT modelling of the collapse masses commonly found in the river bank have been carried out in this study. Figs. 2-5 show resulting electrical resistivity models created for the collapse mass I, whereas the similar models created for the collapse mass II are shown in Figs. 6-9.

Fig. 2 exhibits the resistivity model for the collapse mass I. It can be seen from the model that there are two subsurface layers with resistivity values of 300 Ω-m, and 1400 Ω-m. The two layer model shows the more resistive body is buried in the saturated alluvium materials.

Figs. 3-5 demonstrates the inverted resistivity sections for the collapse mass I at 2%, 5% and 10% noise levels, respectively. One can easily view from each figure that the resulted resistivity sections of the model consisting of the synthetic apparent resistivity pseudosection (up), the calculated apparent resistivity pseudosection (middle) and the inverse model resistivity section (lower). The results of the resistivity models exhibits that the collapse mass I can be reasonably detected particularly at low noise level (2%) than the high noise levels (5% and 10%).

Fig. 6 exhibits the resistivity model for the collapse mass II in the bank of the river. It can be clearly viewed from the model that there are four subsurface layers with resistivity values of 6000 Ω-m, 300 Ω-m, 1100 Ω-m, and 2000 Ω-m. The model contains unsaturated colluvium, saturated materials, collapsed rock mass, and bedrock.

Figs. 7-9 show the inverted resistivity sections for the collapse mass II at 2%, 5% and 10% noise levels, respectively. It can be observed from the each figure that the resulted resistivity sections of the model consisting of the synthetic apparent resistivity pseudosection (up), the calculated apparent resistivity pseudosection (middle) and the inverse model resistivity section (lower). The qualitative interpretation by the visual analysis of the resistivity model with low noise level (2%) clearly exhibit more clear resolution than those of models containing high noise level (5% and 10%).

In a nutshell, the results of synthetic resistivity

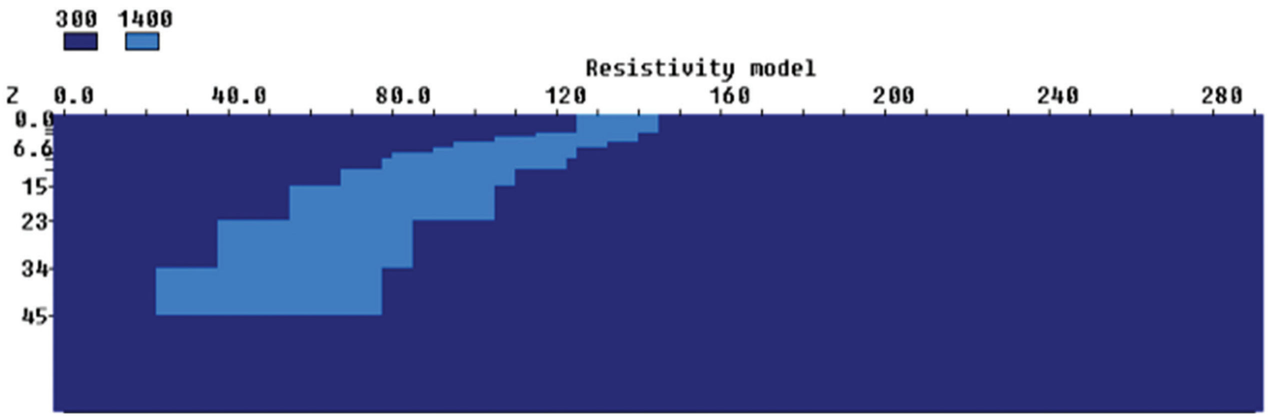

Fig. 2: Resistivity model for the collapse mass I.

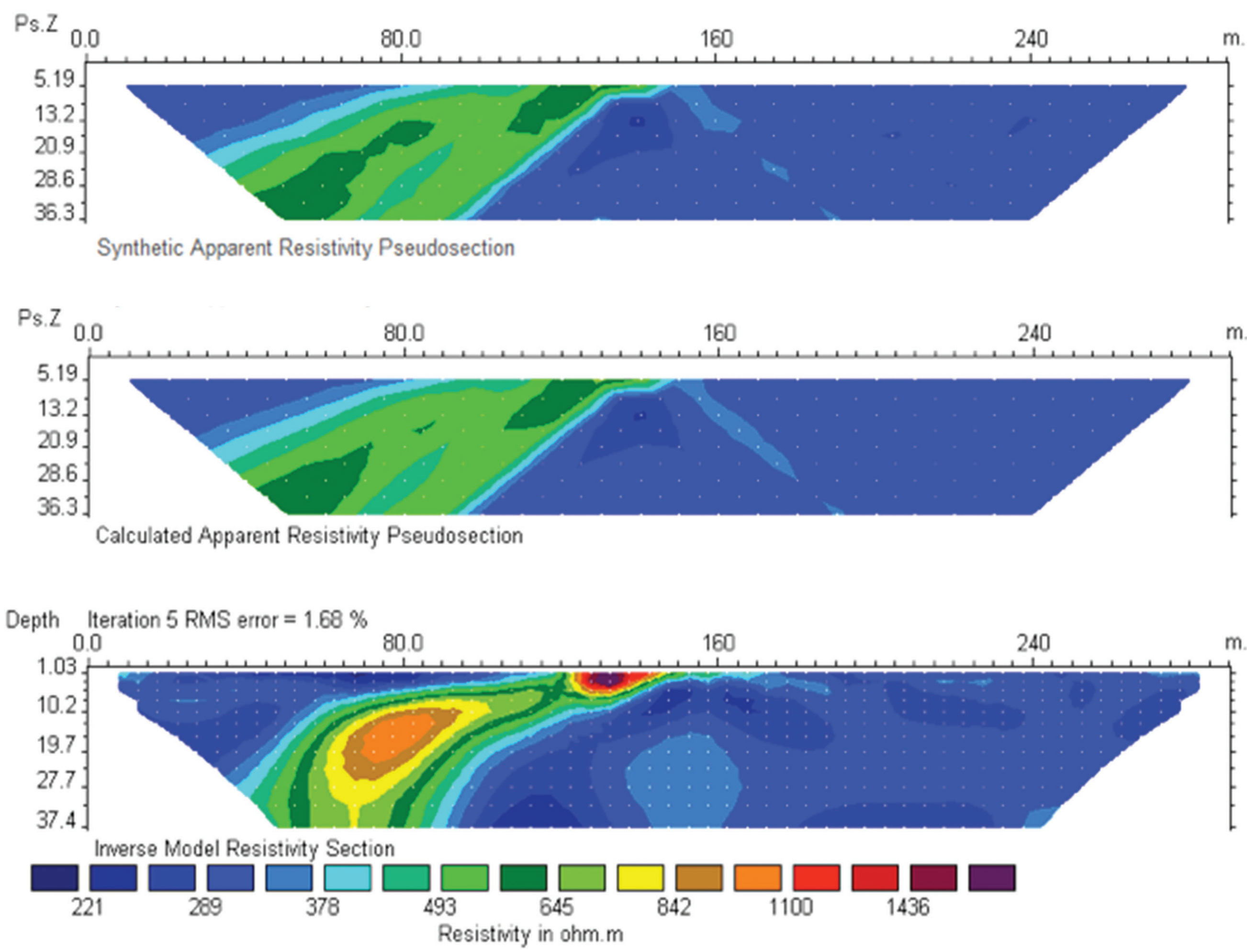

Fig. 3: Inverse resistivity sections for the collapse mass I at 2% noise level.

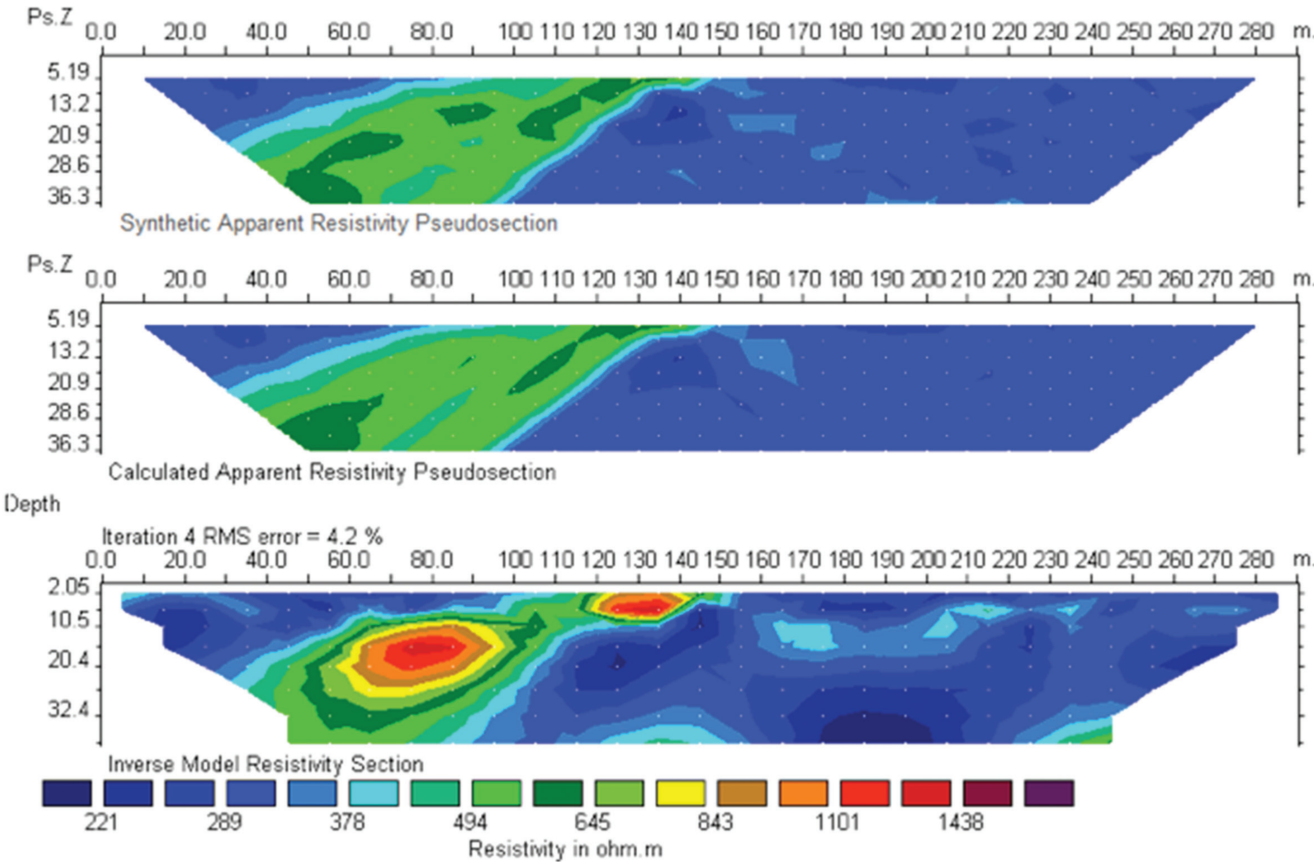

Fig. 4: Inverse resistivity sections for the collapse mass I at 5% noise level.

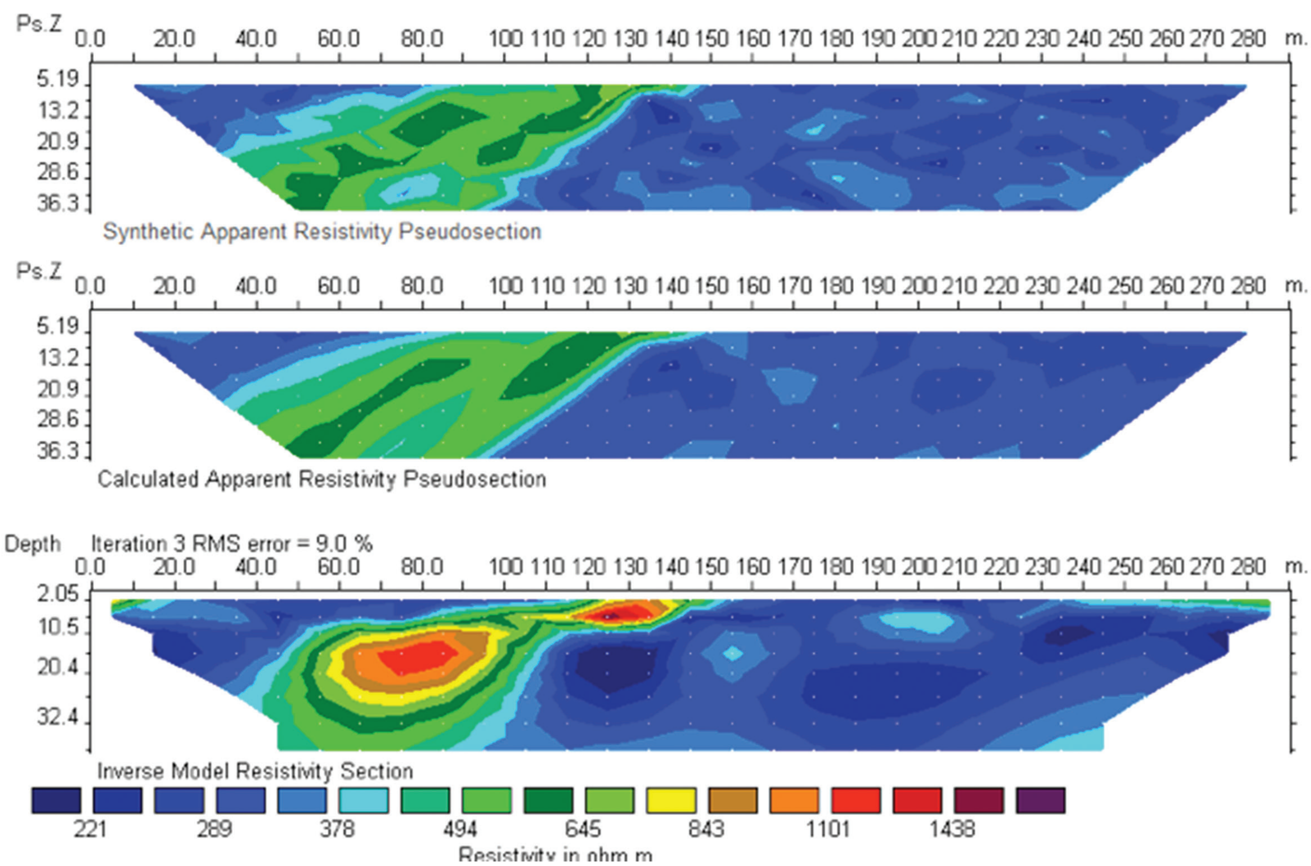

Fig. 5: Inverse resistivity sections for the collapse mass I at 10% noise level.

modelling enhance the understanding about applicability of ERT technique to furnish the subsurface resistivity structure before executing the geophysical field survey in the river bank sites and would help to interpret the data more confidently. The results of this study is in line with Mohammed and Sawsan (2019) who performed the electrical resistivity tomography synthetic modelling and highlighted that the models are useful before conducting on the field survey for a successful and meaningful interpretation.

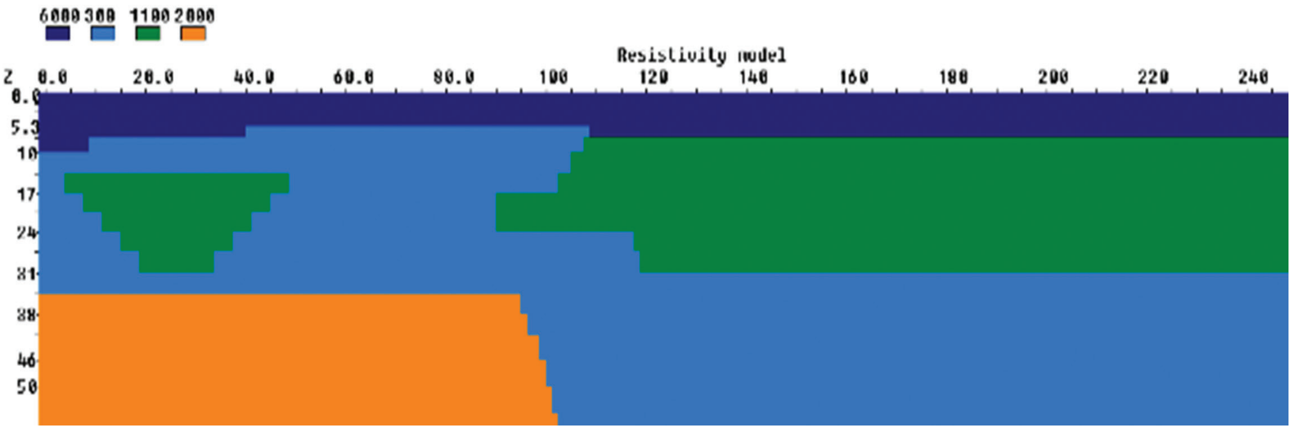

Fig. 6: Resistivity model for the collapse mass II.

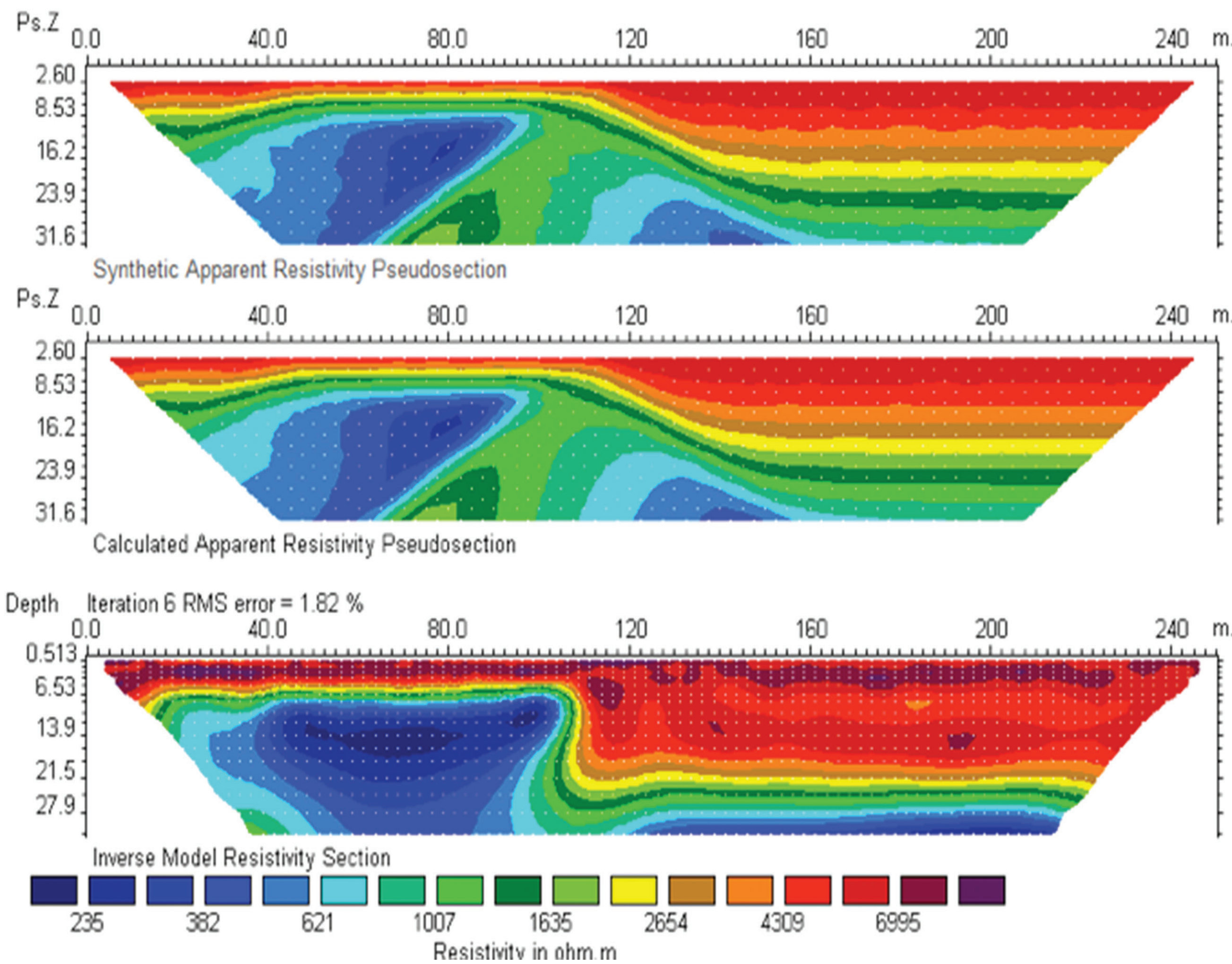

Fig. 7: Inverse resistivity sections for the collapse mass II at 2% noise level.

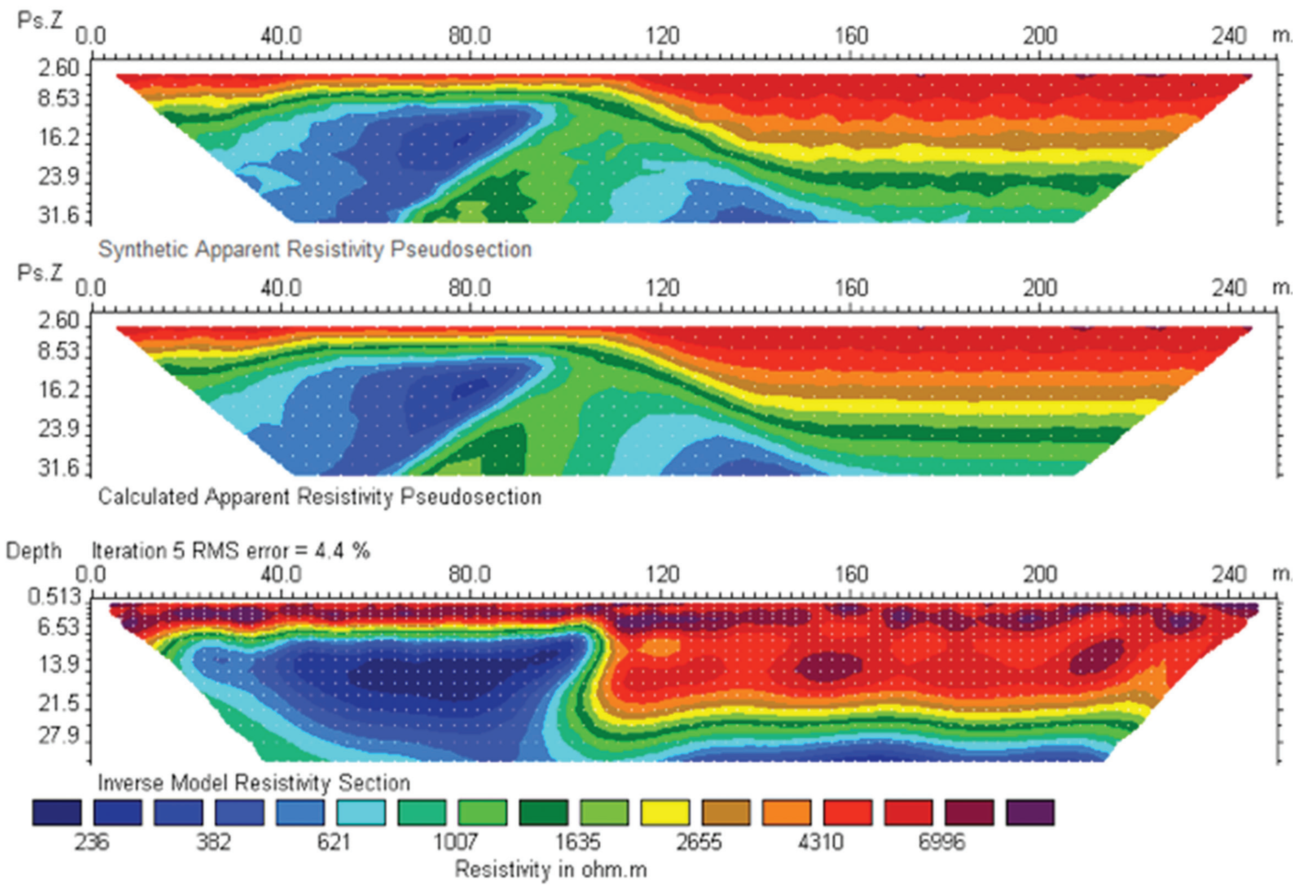

Fig. 8: Inverse resistivity sections for the collapse mass II at 5% noise level.

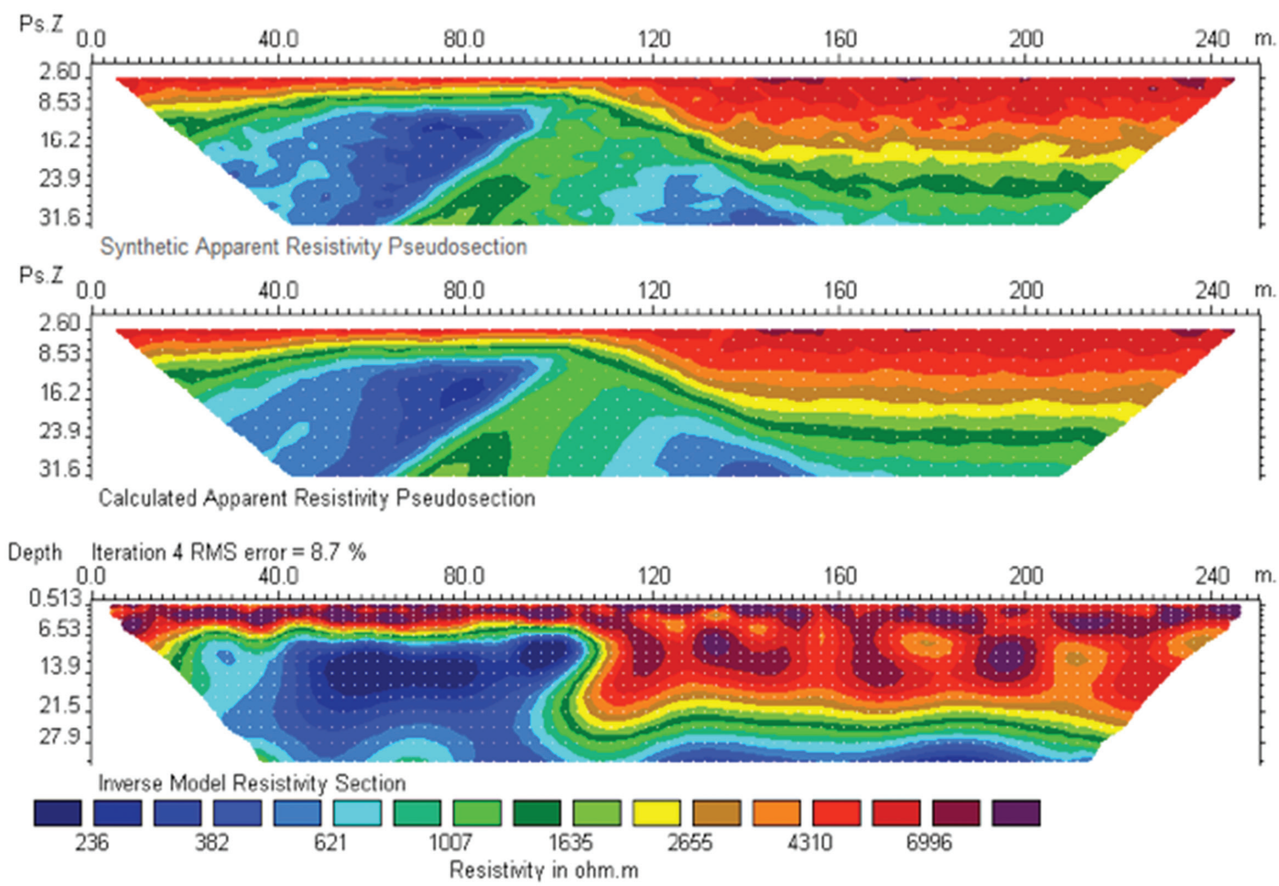

Fig. 9: Inverse resistivity sections for the collapse mass II at 10% noise level.

CONCLUSIONS

The present study used the 2D Electrical Resistivity Tomography techniques to study the collapsed masses in the subsurface. Firstly two dimensional (2D) resistivity models of the collapsed masses in river bank were constructed by utilizing prior information and subsequently inverted herein to reconstruct the subsurface resistivity features. The qualitative interpretation by the visual analysis of the resistivity model of the present study reveal that collapsed masses in subsurface is well detected and provided better resolution particularly at 2% noise level than at 5% and 10% noise levels. Thus, it is concluded herein that data containing low degree of noise as far as possible are recommended to effectively furnish resolve the shallow subsurface geology and successful interpretation of the results with confidence. Moreover, synthetic resistivity modelling enables to increase our understanding about applicability of ERT technique about subsurface resistivity structure before executing the geophysical field survey in the river bank sites and would help to interpret the data confidently.

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