Numerical modeling of soil cracks using electrical resistivity tomography method

Ibrahim M. Abbas

Abstract— **Cracking of soils can significantly affect their engineering properties. However, soil cracks have complex patterns that are difficult to characterize. In this work, Electrical Resistivity Tomography ERT method is used simulate soil cracks in dry soils at different situations. The results showed that, in all tested models, the simulated crack has a high resistivity signature that can be distinguished from the background, and the depth of the crack can reasonably be detected, even with a 5% resistivity noise added. The results indicated that the ERT method can be used to characterize cracking of soil which is of a high importance in geological and engineering applications.**

Index Terms— **Resistivity, cracks, soil, modeling.**

I. INTRODUCTION

In the resistivity method, the numerical modeling can be used to simulate real scenarios and to exam the effectiveness of the method applied before carrying out costly actual laboratory and field measurements [1]. Numerical modeling has been used as an effective and an inexpensive tool to plan and design the field surveys to choose the optimal array and electrode spacing, the optimal inversion parameters, and to test the success and limitations of the method. Examples of using numerical modeling for simulating different geologic situations in resistivity literature are numerous. For instance, numerical modeling has been used for, simulating fractures in crystalline rocks [2], hydrocarbons contaminants [3], landslides [4, faults [5] . Reference [6] used numerical modeling to compare the resolution and efficiency of 2D ERT in resolving five synthetic geological models; a buried channel, a narrow conductive dike, a narrow resistive dike, dipping blocks and covered waste ponds using 10 electrode arrays. In the current work, soil cracks in dry soils have been simulated using 3D ERT method.

II. METHOD

RES3DMOD and RES3DINV programmes [7] have been used to simulate cracks in dry soils. RES3DMOD is a finite difference forward modeling resistivity program that determines the apparent resistivity values for a synthetic survey carried out with a user defined electrode arrangement and subsurface resistivity distribution using a rectangular grid of resistivity electrodes [8]. The program is based on the finite different method [9] which solves the 3D potential distribution due to point current source in a half space subsurface. A 3D subsurface model is created using rectangular blocks of cells with a number of electrodes at the nodes. The user must supply the resistivity of each cell in addition to other parameters such as minimum electrode spacing, type of the electrode array, mesh size, and the number and thickness of the model layers

RES3DINV is a 3D inversion program uses the smoothness-constrained least-squares inversion technique [7] to produce a 3D model of the subsurface from the apparent resistivity data. Basically, the program attempts to determine the resistivity of the cells in the inversion model that will closely reproduce the observed apparent resistivity. The model divides the subsurface into a number of rectangular prisms and the inversion scheme attempts to determine the resistivity values of the prisms. For particular data set, the program automatically chooses the optimum inversion parameters. However, these parameters can be modified by the user to suite the model. The optimization method reduces the difference between the calculated and measured apparent resistivity values by adjusting the resistivity of the model iteratively. This difference is expressed by the root mean square (RMS) error and the user, however, choose the model at the iteration after which the RMS error does not change significantly [7].

In the current study, to investigate the effectiveness of 3D ERT method to detect small cracks in dry soil, a model consisting of six layers is generated. The minimum electrodes spacing is set to be 5cm. A resistivity value of 1000 Ohm.meter for dry clay has been chosen. In addition, because the crack is filled with the air that is an infinitely resistant, model blocks containing a crack were simulated by setting its resistivity to 3000 Ohm.meter. Once the model file is supplied, RES3DMOD program is used to calculate the apparent resistivity at each node and the results are saved to be used for input into RES3DINV inversion. Three situations; one, two and three cracks are tested.

III. RESULTS AND DISCUSSION

Figure (1) shows a 7- cm depth crack model in dry soil model. Figure (2) shows the inverted section resistivity section. The crack of high resistivity can easily be distinguished from the intact soil [10,11], and the depth of the crack is clearly indicated. Figures (3) and (4) show the 3D visualizations of the inverted model using 3D visualization slicer and dicer program http://www.slicerdicer.com

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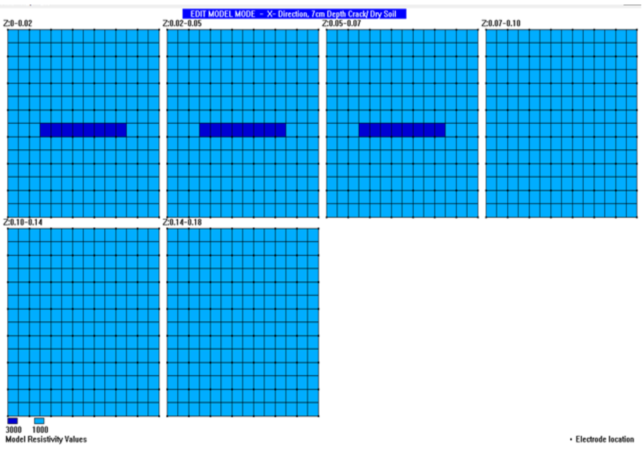

Fig. 1: A 7 cm depth x-direction crack model in dry soil.

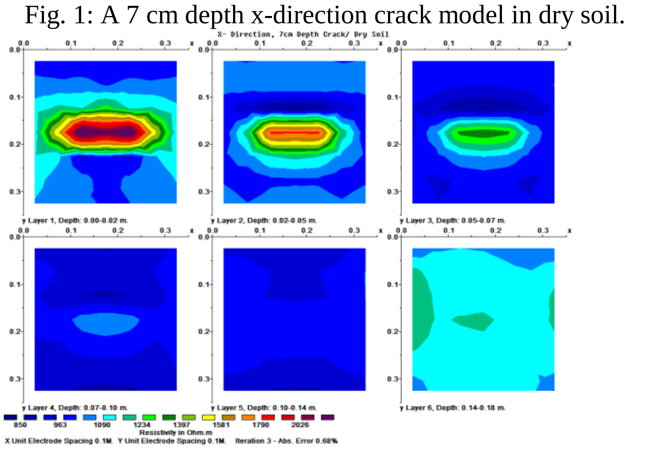

Fig. 2: The inverted section of 7 cm- depth x-direction crack Model in dry soil.

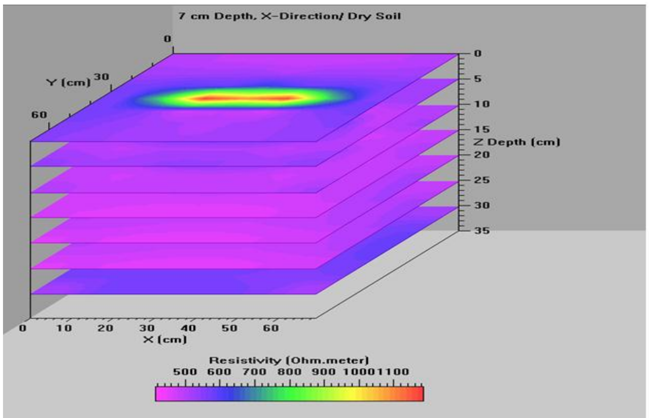

Fig. 3: 3D horizontal slices of the 7cm- depth x-direction crack model in dry soil.

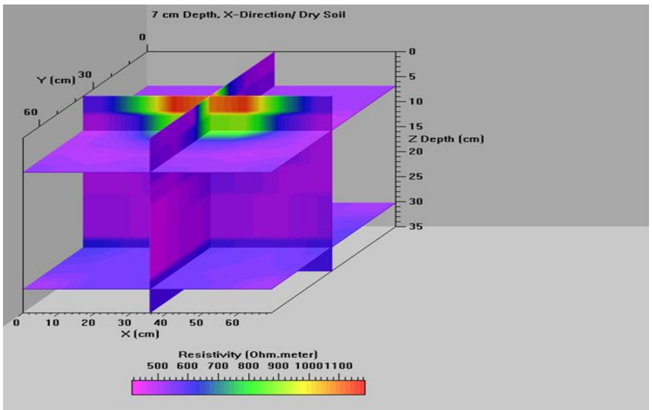

Fig. 4: Vertical and horizontal slices of the 7cm depth x-direction crack model in dry soil.

As the resistivity contrast between air and soil is large, the crack forms a high resistivity object comparing to the intact soil [11]. The 3D visualizations of this model clearly show the visibility of the simulated crack and ability of ERT method to resolve the cracking soil of a centmetric scale in dry soils.

To simulate real field situations, adding 5% resistivity noise is a common practice in resistivity modeling ([1],[12]). A scattered 5% resistivity noise was added to the simulated models. Figure (5) shows the inverted section and figures (6) and (7) show the 3D visualizations of the inverted model with 5% noise in dry soil.

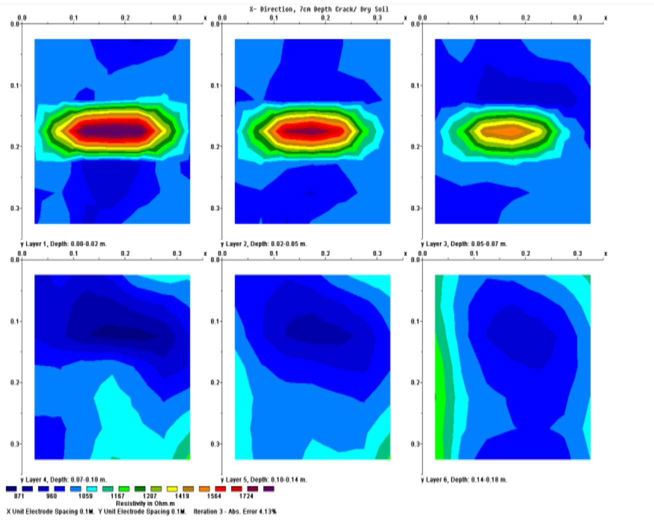

Fig. 5: The inverted section of 7 cm- depth x-direction crack model in dry soil with 5% noise.

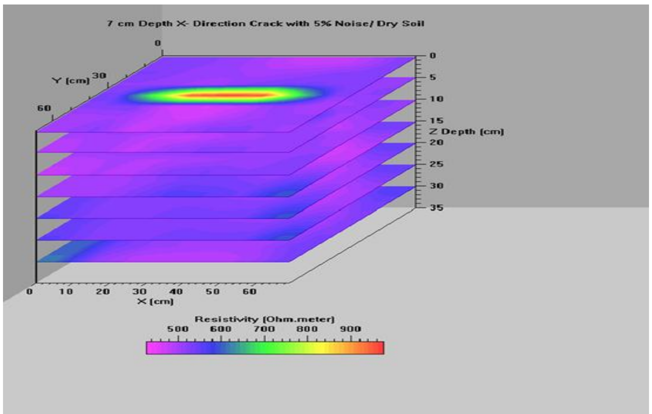

Fig. 6: 3D horizontal slices of the 7cm depth x-direction crack model in dry soil with 5% noise.

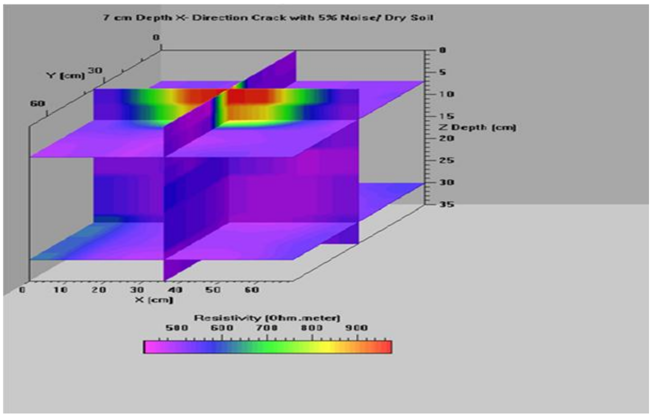

Fig. 7: Vertical and horizontal slices of the 7cm depth x-direction crack model in dry soil with 5% noise

As the resistivity contrast is significantly high, the crack can still be distinguished even with 5% added resistivity noise.

Following the same procedure, figure (8a,b and c) shows the result of 7cm-depth two perpendicular cracks model. Figure (9a,b, and c) shows the result of 7cm-depth 3 parallel Y-direction cracks model

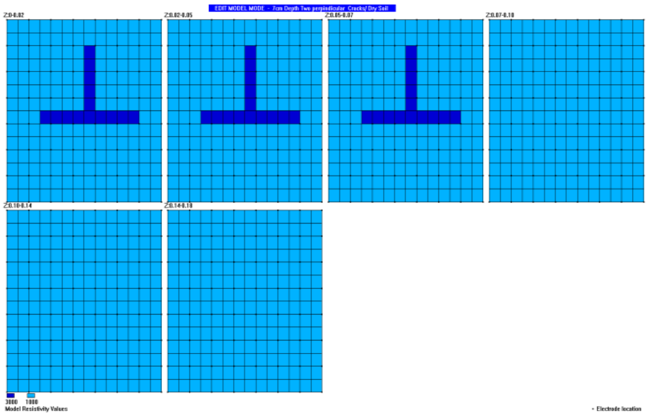

Fig. 8 (a): The 7 cm- depth two perpendicular cracks model in dry soil.

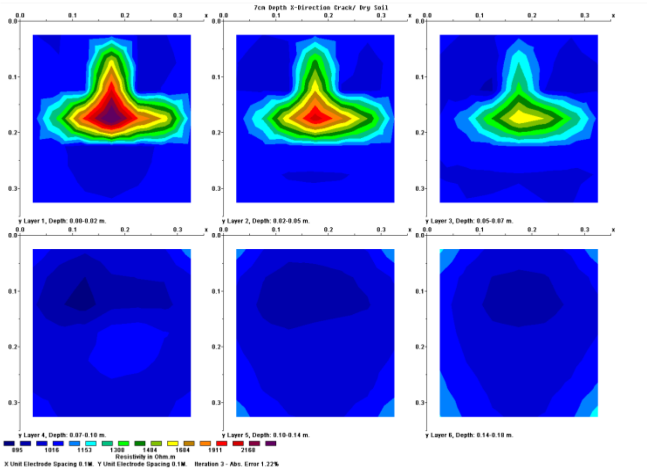

Fig. 8(b): The inverted resistivity section of the 7- cm depth two perpendicular cracks model in dry soil.

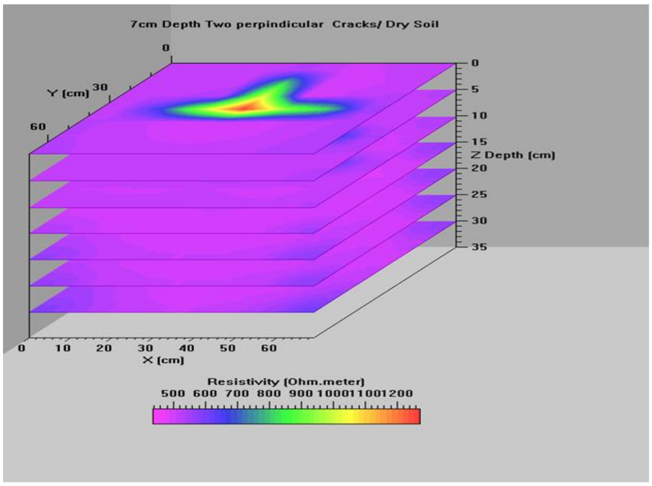

Fig. 8(c): 3D horizontal slices of the 7cm- depth two perpendicular cracks model in dry soil.

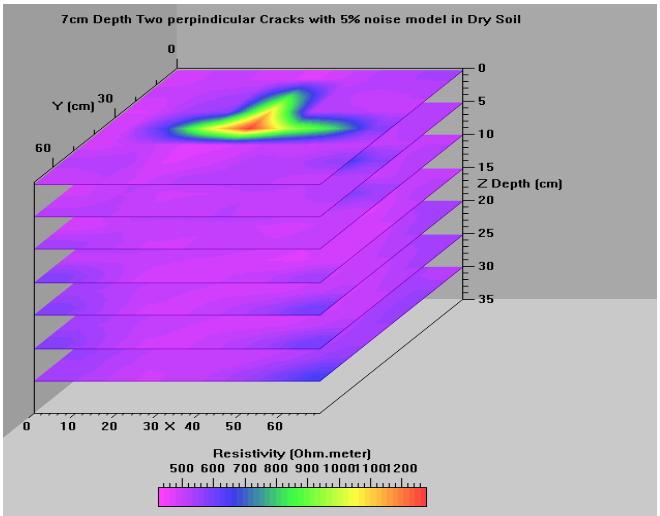

Fig. 8(d): 3D horizontal slices of the 7cm- depth two perpendicular cracks with 5% noise in dry soil.

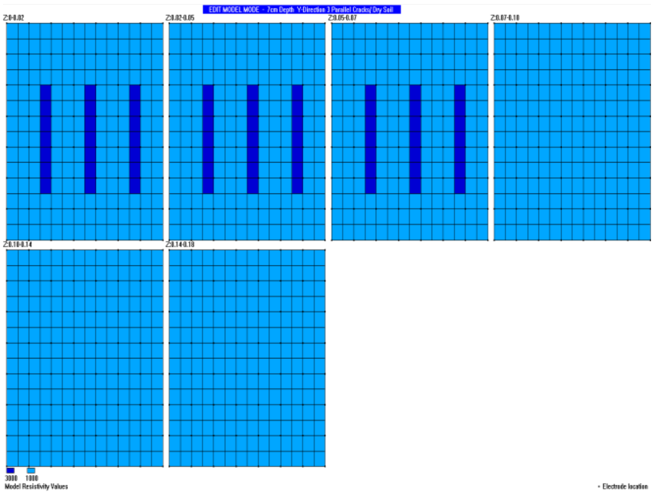

Fig. 9(a): The 7 cm- depth 3 parallel Y-direction cracks model in dry soil.

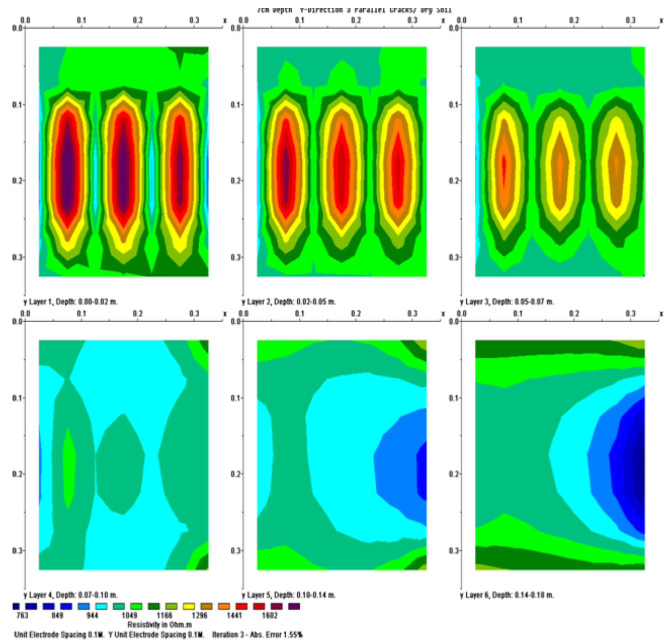

Fig. 9(b): The inverted resistivity sections of the 7 cm- depth 3 parallel Y-direction crack in dry soil.

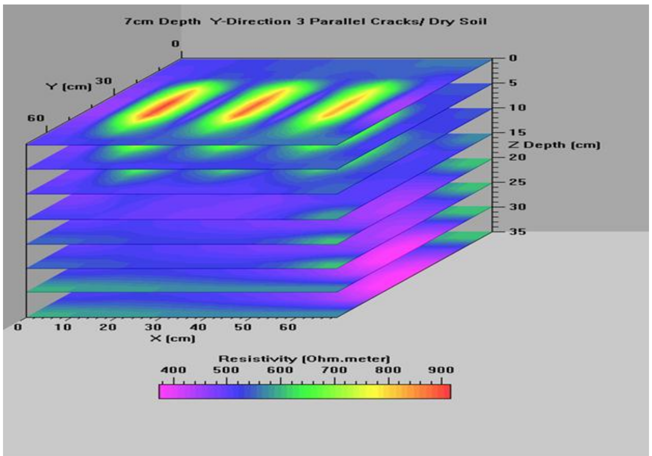

Fig. 9(c): 3D horizontal slices of the 7cm depth 3 parallel Y-direction cracks model in dry soil.

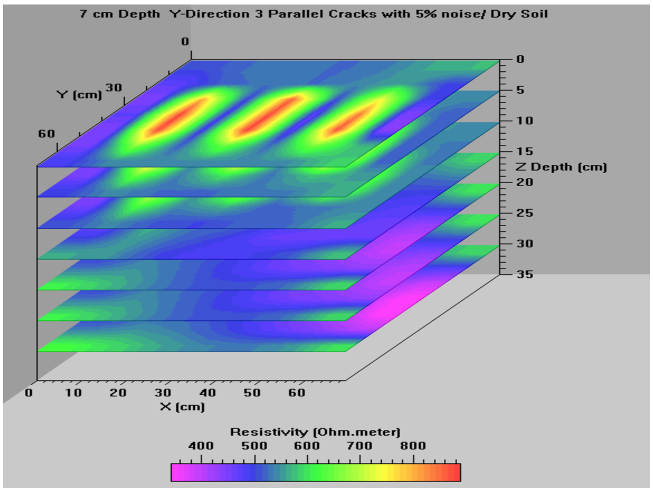

Fig. 9(d): 3D horizontal slices of the 7cm depth 3 parallel Y-direction cracks model with 5% noise in dry soil.

In theory, the resistivity method is based on delineating the resistivity contrast of subsurface materials. Figures 8 and 9 showed that the simulated cracks can also be distinguished from the intact soil. In all discussed models, the crack has an anomalous high resistivity value that can be identified from the background. The horizontal slices at 7cm depth showed the sensitivity of the method to detect the depth of crack.

IV. Conclusions

In this work, the 3D ERT method is adopted to simulate soil cracks in dry soil. one, two perpendicular and three cracks are tested. In all tested models, the simulated crack is characterized by a high resistivity signature that can be identified. As the resistivity contrast between the air-filled crack and the surrounding soil is significantly high, the cracks can be distinguished even with a 5% noise added. It can be concluded that the ERT method can effectively be used to characterize soil cracks which is of great importance in geological and engineering investigations.

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