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# Generalized relationship for determining soil electrical resistivity from its thermal resistivity

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**Abstract**

The knowledge of soil electrical and thermal resistivity finds its application in many of the real life engineering projects like laying of high voltage buried power cables, ground modification techniques etc. This necessitates determination of soil electrical resistivity and thermal resistivity and development of a relationship between them. However, as these resistivities mainly depend on the type of the soil (i.e. its physical composition) and its saturation, efforts have been made in this paper, to develop a generalized relationship to relate them. Validation of the relationship has been conducted vis-à-vis the results obtained from the laboratory experiments and those reported in literature.
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*Keywords:* Soil; Thermal resistivity; Electrical resistivity; Laboratory investigations; Generalized relationship

## 1. Introduction

The knowledge of soil electrical resistivity has been used to predict various soil parameters, phenomenon and mechanisms occurring in soils, such as for obtaining the soil water content [1], degree of compaction [2] and saturation [3], estimating liquefaction potential of the soil [4], detecting and locating geomembrane failures [5], to estimate corrosive effects of soil on buried steel [6], for designing earthing resistance of the grounding systems [7], to study the electro-osmosis phenomenon in soils [8], investigating the effects of soil freezing [9] and for estimating the soil salinity for agricultural activities [10]. These studies highlight that determination of soil electrical resistivity is quite cumbersome and depends on several parameters such as frequency of the current used, geometry and type of the electrodes used etc. [11].

On the contrary, it has been demonstrated by previous researchers that soil thermal resistivity can be determined easily and rapidly using the transient heat method [12,13]. Based on this study, generalized relationships for determining soil thermal resistivity were developed [14,15]. It must be noted that determination of thermal properties of geomaterials is important for safe execution of various civil engineering projects such as design and laying of high voltage buried power cables [16], oil and gas pipe lines [17], nuclear waste disposal facilities [18], ground modification techniques employing heating and freezing [19] etc.

In such a situation, determination of soil electrical resistivity by relating it to its thermal resistivity seems to be an excellent and handy solution. Such a relationship would also encompass the coupled electrical and thermal processes in soils. A generalized relationship to relate these resistivities has been developed and reported in literature [20]. However, this relationship incorporates the effect of soil type only, and cannot take into account the effect of saturation, which influences both soil electrical and thermal resistivities [3,11,21].

With this in view, efforts were made to modify the generalized relationship between soil thermal and electrical resistivities, reported in literature [20] by incorporating the influence of saturation of the soil. This paper presents details of the methodology developed for this purpose followed by the validation of the derived relationship.

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**Nomenclature**

| | | | |
|---|---|---|---|
| $A$, $B$ | constant parameters | $R$ | resistance of the soil |
| $\boldsymbol{a}$ | constant parameter | $R_{\mathrm{E}}$ | electrical resistivity of the soil |
| $C_{\mathrm{R}}$ | constant parameter | $R_{\mathrm{Ess}}$ | electrical resistivity of the silty soil |
| $e$ | void ratio | $R_{\mathrm{Ewc}}$ | electrical resistivity of the white clay |
| $F$ | percentage sum of the sand and gravel fractions in the soil | $R_{\mathrm{T}}$ | thermal resistivity of the soil |
| $G$ | specific gravity of the soil | $S_{\mathrm{r}}$ | saturation |
| $I$ | current | $V$ | voltage |
| LL | liquid limit | $w$ | gravimetric water content |
| $M$ | molarity | $X$, $Y$, $Z$ | constant parameters |
| PI | plasticity index | $\gamma_{\mathrm{d}}$ | dry unit weight of the soil |
| | | $\gamma_{\mathrm{w}}$ | unit weight of water |

## 2. Description of the test setup

As depicted in Fig. 1, a Perspex cubical box termed as "electrical resistivity box", which is 100 mm in dimension and 10 mm thick was fabricated and used for estimating the electrical resistivity, $R_{\mathrm{E}}$, of the soil sample. Each face of the resistivity box is provided with three brass electrodes, of length 12.5 mm and diameter 2.5 mm, and spaced at 30 mm center-to-center interval, as shown in the figure. Such an arrangement facilitates nine pairs of electrodes viz. 1–1′, 2–2′, ..., 9–9′. Electrodes numbered from 1 to 9 are depicted in Fig. 1 and electrodes 1′–9′ are the mirror images of electrodes 1–9. These electrodes can be screwed into the compacted soil sample with embedment length being equal to 2.5 mm [22].

A known voltage, $V$, was applied between these nine electrode pairs and the current, $I$, passing through the soil sample was measured. Hence, the resistance, $R$, of the soil sample can be expressed as

$$R = V/I. \tag{1}$$

The computed value of $R$ can be correlated with electrical resistivity, $R_{\mathrm{E}}$, using a parameter, $\boldsymbol{a}$. This parameter depends on the geometry of the box, as expressed by Eq. (2), and can be determined by measuring resistance of the standard KCl and NaCl solutions of known electrical resistivity [21,22]:

$$R_{\mathrm{E}} = \boldsymbol{a} \cdot R. \tag{2}$$

As nine sets of resistivity values can be obtained with the help of the resistivity box, inhomogeneity, stratification, and change in water content due to compaction of the soil sample can be taken care of appropriately.

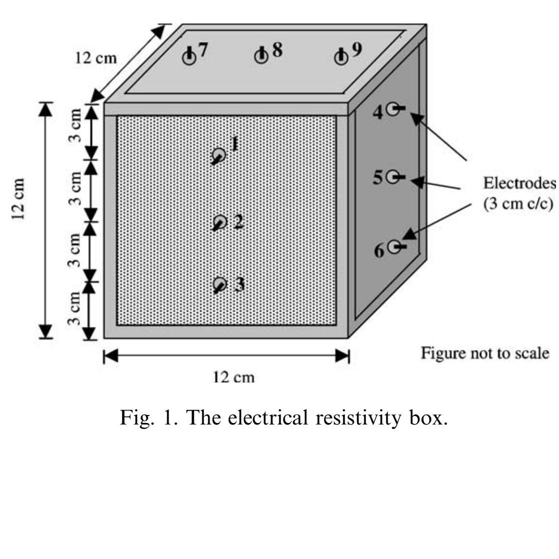


Fig. 1. The electrical resistivity box.

## 3. Experimental investigations

### 3.1. Calibration of the test setup

Standard solutions of NaCl and KCl, with different molarity, were used for determining the parameter $\boldsymbol{a}$, as discussed in the following. Electrical conductivity values of these solutions were measured with the help of a water quality analyzer (Model PE-138, Elico Limited, India). The obtained conductivity values were corrected to 25 °C after applying temperature correction. Further, the conductivity values were converted to resistivity values.

Using a constant voltage AC power supply, values of current $I$ corresponding to different voltages $V$ were recorded for different molarity solutions of NaCl and KCl solutions. The power supply operates at 50 Hz and yields a output voltage varying from 0 to 50 V, in step of 5 V. For the sake of brevity, only the response of 0.1 M NaCl solution is being presented herein, as depicted in Fig. 2. It was noted that $I$ versus $V$ response of all the electrodes is a straight line and the coefficient of regression is very close to unity. Another observation from this exercise is that the maximum difference between the measured values of $I$, corresponding to different voltages for the same electrode, is less than 10%.

Further, to demonstrate that the adjacent electrodes have negligible influence on the performance of indi-

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