Experimental researches

DETERMINATION OF THE APPARENT RESISTIVITY OF HETEROGENEOUS GROUND WITH MULTI-LAYER

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In this work, we propose to determine the apparent resistivity of heterogeneous ground to several layers. To this end, we evaluate by the Matlab programming the model of ground with two layers on the one hand and stress a relation allowing calculating the apparent resistivity of the ground model to several layers on the other hand. These results confirm those found by the finite element method and the relation suggested by IEEE [2000] which makes simply the resistivity average of the various ground layers.

KEY WORDS: Apparent resistivity, heterogeneous ground, multi-layer

1- INTRODUCTION

The protection of electric installations, people and goods requires a systematic and global solution to minimize the risks related to transitory overpressures and other disturbances. For example, no lightning conductor can collect and run out without risk the energy of the lightning without an earthing reliable. Earthing in electrical supply networks appears to be relatively simple; however it did not cease presenting difficulties. Recent progress accomplished in electrical engineering and electronics of power revealed new problems, which are not perfectly solved, because of the coexistence of sensitive electronics components with installations that can produce short-circuit currents of several tens of kiloamperes.

The study of the ground network behavior requires the preliminary analysis of the distribution of the potential in the ground around the ground network. This distribution is a function of the electric characteristics of the ground, in particular its resistivity: this is why the design of the ground network of an electric installation must begin with a study of the nature of the ground on which it will be carried out.

This work is justified by many damage caused by the short circuits and the lightning these last years in the installations of great extent and in particular on the transformers of the electrical supply network of SBEE (Société Béninoise d'Energie Electrique). It aims to determine the apparent resistivity of an heterogeneous ground to several layers.

2 - Method

2.1- Description of the four-point method

The most used measurement method of the apparent resistivity of grounds is that of Wenner in which four electrodes are laid out on line and equidistant.

The measuring material is a traditional tellurometer. The two extreme electrodes are those of current injection with measure I; the two power stations are the electrodes of potential measure ΔV as it is shown in figure 1.

The point O of the resistivity measure is in the medium of a symmetrical system between the potential electrodes. The distance a between the two adjacent electrodes is called "measurement bases"; the distance between extreme electrodesis "the transmission line"; (it is equal to 3a according to Wenner method).

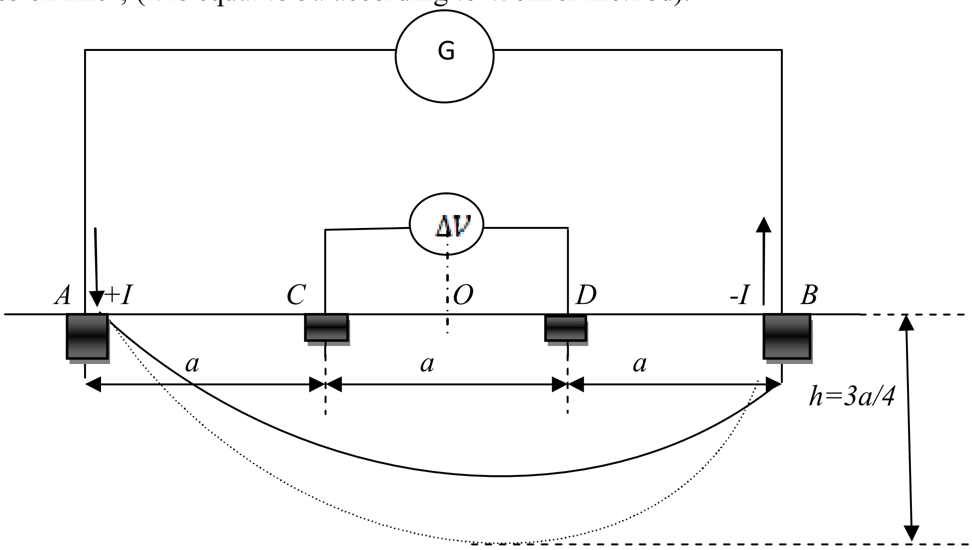

Figure 1: Four-point method of measurement of the ground resistivity

The general formula giving the value of the cumulated apparent resistivity of the ground layers located under the point of measurement is simplified by the four-point Wenner method. It becomes:

$$\rho_\alpha = 2\pi a R, \quad (1)$$

ρ_α: apparent resistivity in (Ω.m); a : measurement base in (m); R : value of resistance in (Ω), read on the tellurometer to obtain the balance of the galvanometer.

2.2 Application of the four-point method

2.2.1 Case of an heterogeneous ground with two layers

2.2.1.1 Analytical method [3,4]

Let us admit a model of ground with two layers whose road base has a thickness h and a resistivity ρ_1 while the sub-base is characterized by a resistivity ρ_2.

Let us apply the four-point method to this model of ground with two layers of figure 2.

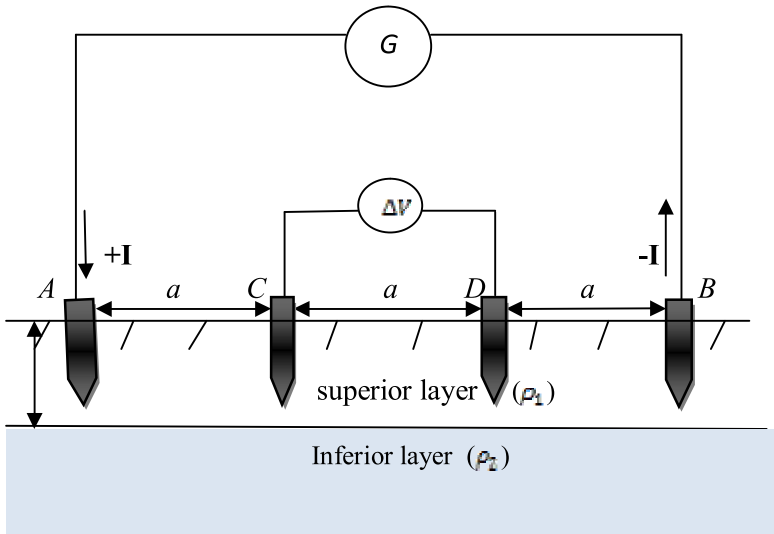

Figure 2: Representation of the model with two layers

We obtain then

$$\rho_a = \rho_1\left[1 + 4\sum_{n=1}^{\infty}\left(\frac{k^n}{\left\{1+\left(\frac{2nh}{a}\right)^2\right\}^{1/2}} - \frac{k^n}{\left\{4+\left(\frac{2nh}{a}\right)^2\right\}^{1/2}}\right)\right] \quad (2)$$

where ρ_α is the apparent resistivity of the model with two layers considered and k the reflection coefficient given by the relation $K = (\rho_2 - \rho_1)/(\rho_2 + \rho_1)$.

This equation is very significant and is the base of a certain number of calculation methods of the apparent resistivity of the ground.

2.2.1.2 Programming the analytical expression of apparent resistivity

To design earth electrodes economically, it is necessary to obtain the precise value of the ground resistivity. The aim set in this paragraph is to develop a numerical method which could evaluate the apparent resistivity of a ground model with two layers. This method based on the formula of the apparent resistivity previously established is done in MATLAB.

The three parameters which characterize the ground model with two layers are selected like input variables and the apparent resistivity is the output variable as it is represented in table 1.

Table 1: Input and output v*ariables*

Input variables	Output variable
Resistivity of the road- base ρ_1 Thickness of the road- base *h* Resistivity of the sub-base ρ_2	Apparent resistivity of ground ρ_α

Numerical implementation

Code

```
clear all;
clc;
syms has Ro1 Ro2 H
a=input(' gives the value of a: ');
Ro1=input(' gives the value ofρ1: ');
Ro2=input(' gives the value ofρ2: ');
h=input(' gives the value of H: ');
k=(Ro1-Ro1)/(Ro1+Ro2);
for n=1:1000
   g=(k^n)/sqrt(1+(2*n*h/a)^2);
   f=(k^n)/sqrt(4+(2*n*h/a)^2);
   t(n)=(g-f);
end
S=sum (t);
Roa=Ro1*(1+4.*S)
```

2.2.2- Case of an heterogeneous ground with several layers

This ground modeling to several layers requires numerical or graphic methods because the analytical methods are limited.

In order to reach a more realistic modeling scheme, we propose to break up the heterogeneous ground with N layers into grounds models with two layers as represented on figure 3. So, $\rho_{\alpha 1}$, $\rho_{\alpha 2}, \ldots, \rho_{\alpha(n-1)}$ are the apparent resistivities of the ground models with two layers respectively (ρ_1, ρ_2, h_1), (ρ_2, ρ_3, h_2), (ρ_3, ρ_4, h_3), …, (ρ_{n-1}, ρ_n, h_{n-1}); where h_1, h_2 ,h_3 , …, h_{n-1} are the depths of the various layers of the ground such as it is indicated in figure 3.

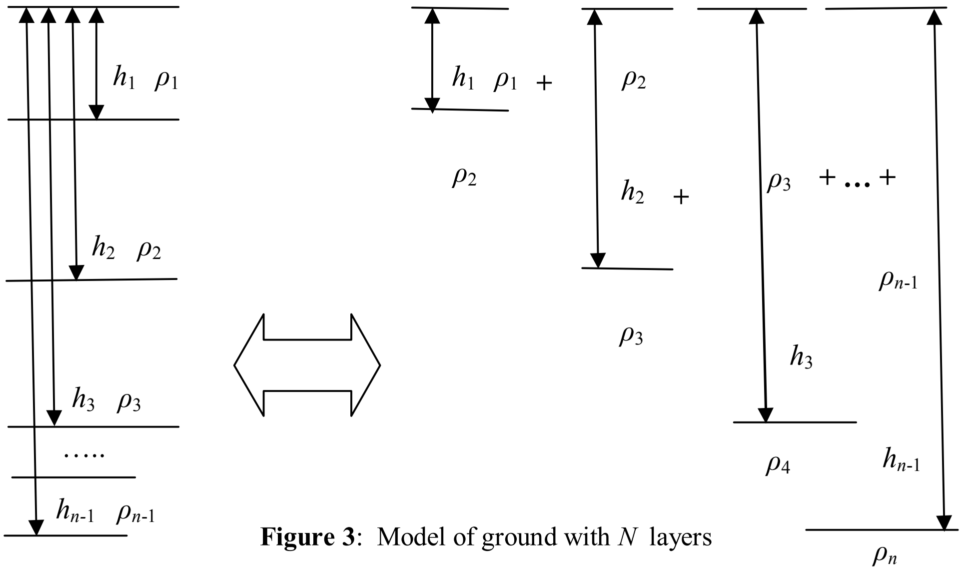

Figure 3: Model of ground with N layers

One can also regard the ground as uniform instead of ground in several layers with different resistivities. The apparent resistivity ρ_α of the ground assumed to be homogeneous can, in this case, being found by the relation 3:

$$\rho_a = \frac{\sum_{i=2}^{n} \rho_{a_{(i-1)}}}{n-1} = \frac{\rho_{a_1} + \rho_{a_2} + \rho_{a_3} + \dots + \rho_{a_{(n-1)}}}{n-1} . \qquad (3)$$

3- Results of simulation and validation

3.1- Case of a heterogeneous ground with two layers

For the validation of the calculation method of the apparent resistivity in the case of the ground model with two layers, two simulations series were carried out. The results of these simulations are consigned in tables 2 and 3.

For the following simulation, while fixing the distance a between the electrodes with 4 meters, we will carry out a variation thickness of the road-base.

Table 2: *Results of simulation for a = 3*

Input variables			apparent resistivity of ground by [4]	apparent resistivity of ground by [4]	Apparent resistivity of ground by using the code	Error expressed as a percentage compared to the analytical results
ρ_1	ρ_2	h	Analytical	F.E.M	Code	
a = 3						
100	100	2	100	100,60	100	0,00
100	200	2	127,135	126,60	127,135	0,00
100	300	2	143,156	142,18	143,156	0,00
100	400	2	153,83	152,57	153,834	-0,003
100	500	2	161,502	160,00	161,502	0,00
500	100	2	291,49	291,06	291,487	0,001
500	200	2	358,59	357,85	358,588	0,001
500	300	2	413,87	412,93	413,871	-0,0002
500	400	2	460,32	459,01	460,330	0,002
500	500	2	500	49910	500	0,00

Table 3: *Results of simulation for a = 4 and H variable between 3 and 4*

Input variables			apparent resistivity of ground by [4]	apparent resistivity of ground by [4]	Apparent resistivity of ground by using the code	Error expressed as a percentage compared to the analytical results
ρ_1	ρ_2	h	Analytical	F.E.M	Code	
$a = 4$						
100	100	3	100	100,08	100	0,00
100	200	3	122,59	122,20	122,598	-0,0066
100	300	3	135,73	134,85	135,738	-0,0066
100	400	3	144,41	143,03	144,414	-0,003
100	500	3	150,06	148,81	150,064	-0,003
100	100	4	100	99,39	100	0,00
100	200	4	113,44	112,18	113,439	0,0009
100	300	4	121,03	119,04	121,034	-0,003
100	400	4	125,96	125,86	125,961	-0,0008
100	500	4	129,43	126,88	129,434	-0,003

One can notice that in tables 2 and 3 the errors of results found by simulation compared to the analytical results are practically nulls. These results are more accurate than those found in [4] by the finite element method.

With relation 2, we find a regular variation of ρ_a with respect to a, distance between two adjacent electrodes like it is shown in figures 4 and 5. The resistivities ρ_1 and ρ_2 take the values 100 Ω and 200 Ω respectively.

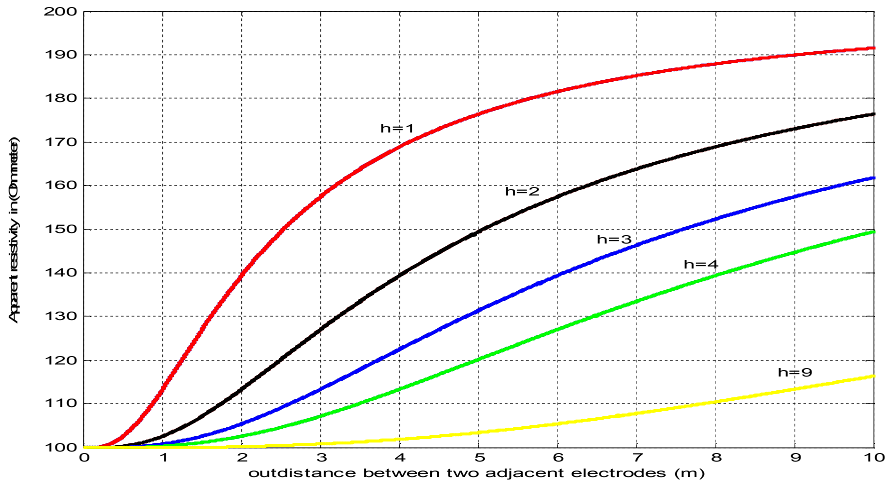

Figure 4: $\rho_a = f(a)$ for ground model with two layers $(\rho_1 < \rho_2)$

Let us look at curves in figures 4 and 5, one can note that:

- when resistivities increase with respect to the depth, the apparent resistivity of the ground increases with respect to the distance a between the two adjacent electrodes.
- if resistivities decrease with respect to the depth, the apparent resistivity of the ground also decreases with respect to the distance a between the two adjacent electrodes.

3.2- Case of an heterogeneous ground with several layers

The validation of this relation is done and compared to that proposed in IEEE [2000]. It makes simply the average of the various resistivities of the ground with several layers,

$$\rho_a = \frac{\rho_{a(1)} + \rho_{a(2)} + \rho_{a(3)} + \dots + \rho_{a(n)}}{n}. \quad (4)$$

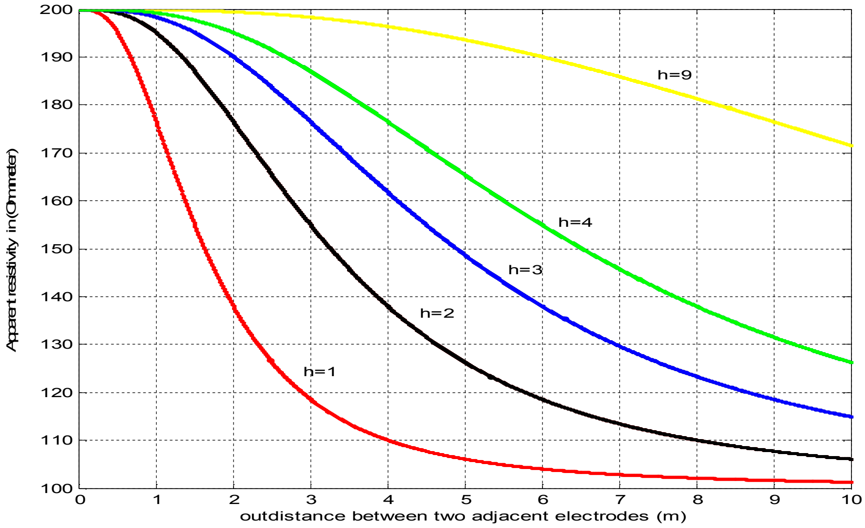

Figure 5: $\rho_a = f(a)$ for a ground model with two layers $(\rho_1 > \rho_2)$

The values $\rho_{a(1)}, \rho_{a(2)}, \rho_{a(3)}, \ldots, \rho_{a(n)}$ of N various layers of the ground measured by the method of the four electrodes are resistivities.

Model of ground with three layers with $h_1 = 2$ and $h_2 = 5$

Table 4: Apparent *resistivity for a ground with three layers*

Variables			Outdistance between two adjacent electrodes	Apparent resistivity obtained by the relation (3)	Apparent resistivity obtained by the relation (4) [IEEE ,2000]
ρ_1	ρ_2	ρ_3	a		
100	100	100	3	100	100
100	200	300	3	166,0554	200
100	200	300	4	174,655	200
200	100	50	3	125,5861	116,66
200	100	50	4	115,2872	116,66
200	100	50	6	101,2153	116,66

Model of ground with four layers with $h_1 = 2$, $h_2 = 5$ and $h_3 = 10$

Table 5: Apparent r*esistivity of a ground with four layers*

Variables				Outdistance between two adjacent electrodes	Apparent resistivity obtained by the relation (3)	Apparent resistivity obtained by the relation (4) [IEEE ,2000]
ρ_1	ρ_2	ρ_3	ρ_4	a		
100	100	100	100	3	100	100
100	200	300	400	3	210,9755	250
100	200	300	400	4	217,0445	250
400	300	200	100	3	283,778	250
400	300	200	100	4	275,7077	250
1000	500	200	400	4	448,6107	525

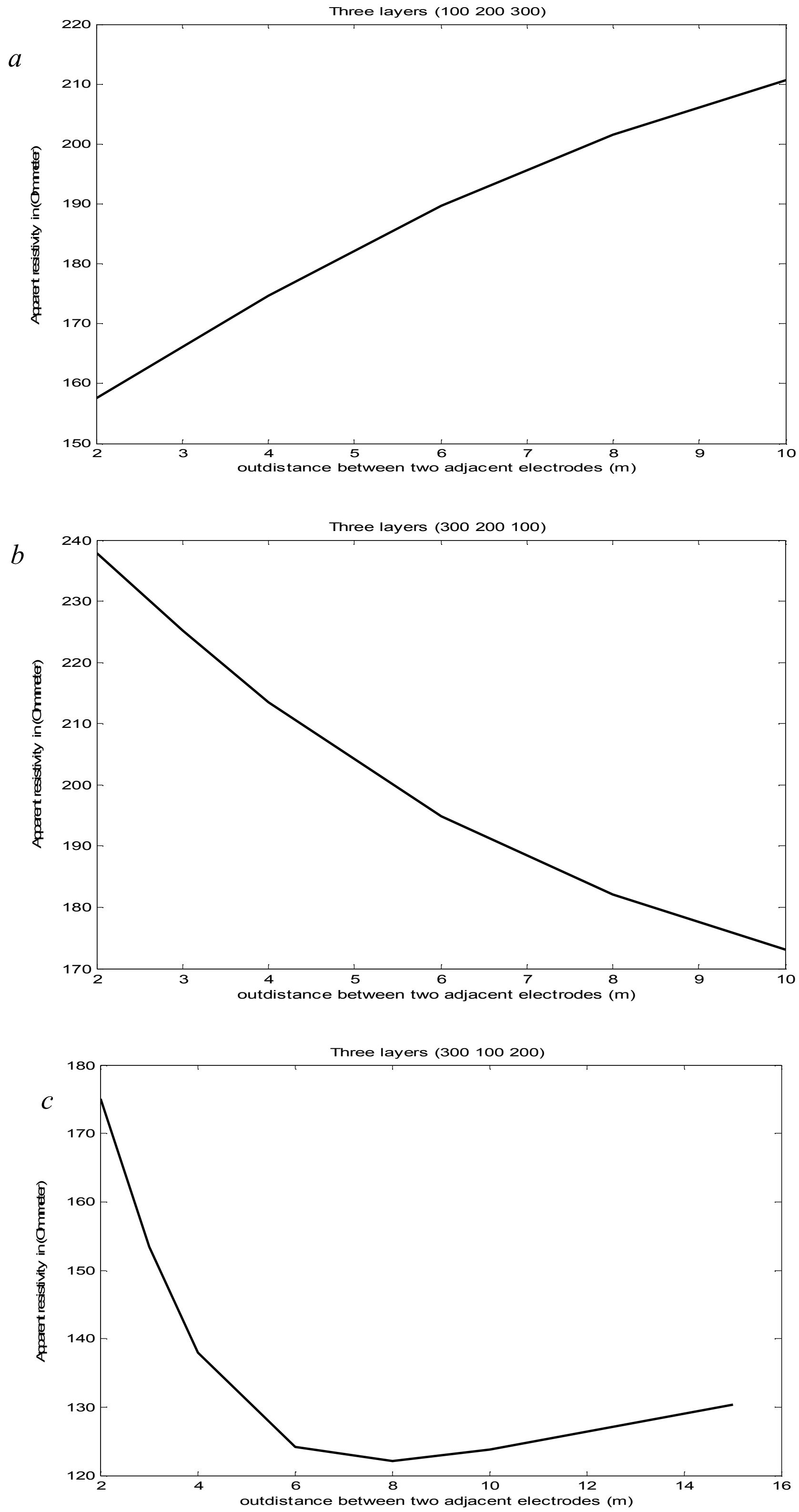

Figure 6: Variation of the apparent resistivity according to *a* for a model with three layers with $h_1 = 2$ and $h_2 = 5$

In tables 4 and 5, it is indicated:

- when the resistivities of the various layers of ground increase with respect to the depth, the apparent resistivity of ground also increases with respect to the distance **a** between the adjacent electrodes of measurement,
- when the resistivities of the various layers of ground decrease with respect to the depth, the apparent resistivity of ground also decreases with respect to the distance **a** between the adjacent electrodes of measurement.

Figures 4 and 5 justify more these remarks. What is not the case of the results obtained by the relation 4 which gives the same value for any resistivity variation of different ground layers even if the distance **a** increases. The following figures 6.*a*, 6.*b* and 6.*c* show the variation of the apparent resistivity of the ground model with three layers for example according to the structure of the ground. On the curves in figures 6.*a*, 6.*b* and 6.*c*, we remark that:

- when the resistivity increases with respect to the depth, the curve of the apparent resistivity is increasing,
- if the resistivity decreases with respect to the depth, the apparent resistivity is decreasing,
- when the variation of the resistivity is not monotonous in depth, that of the apparent resistivity changes direction.

4- Discussion

The percentage of error compared to the relation of [IEEE, 2000] varies from 1.17% to 16.97%. Nevertheless, this calculation method of the apparent resistivity has the advantage of approaching the real physical situation which can be applied to grounds with several layers and different resistivities; it is validated in comparison with the results obtained by the relation of [IEEE, 2000] which is nota model since it makes simply the average of the resistivities of the various ground layers. We think that our results are more realistic since they take into account the reflection factors of the adjacent layers, the depth of each layer, the variation of the resistivities (increasing or decreasing) according to the depth and the distance between two adjacent electrodes of measurement. When the variation of the apparent resistivity according to the electrode spacing of measurement changes direction once, we retain that the ground is heterogeneous and present a ground model with three layers: it is a necessary and sufficient condition.

5- Conclusion

The design and the realization of a ground network must always begin with a study of the nature of the ground in which it will be carried out. The determination of the apparent resistivity of a heterogeneous ground, when its parameters are known, is the fundamental base in the process of realization of earthing.

Our work constitutes a significant projection in the case of a heterogeneous ground with several layers. The decomposition of this ground in models of ground with two layers enabled us to elaborate a model of calculation of the apparent resistivity which takes into account the reflection coefficient between two layers of different resistivities.

Experimental studies must be conducted in order to better measure the error made in the analytical establishment of this model.

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ОПРЕДЕЛЕНИЕ ИСТИННОГО УДЕЛЬНОГО СОПРОТИВЛЕНИЯ РАЗНОРОДНОГО ГРУНТА В ЗАВИСИМОСТИ ОТ ЧИСЛА ЕГО СЛОЕВ

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В статье сделана попытка определения истинного удельного сопротивления многослойного разнородного грунта. Авторы апробировали применение программы Матлаб на примере грунта из двух слоев, но с другой стороны, приведенные соотношения дают возможность подсчитать истинное значение удельного сопротивления грунта из большего числа слоев. Полученные результаты были сравнены с аналогичными данными, полученными с помощью МКЭ другими авторами. Теперь легко подсчитать для применения средние значения удельного сопротивления грунта из различных слоев.

КЛЮЧЕВЫЕ СЛОВА: истинное удельное сопротивление грунта, разнородный грунт, многослойность.

Расчет тонких упругих оболочек

АНАЛИЗ НДС СФЕРИЧЕСКИХ ОБОЛОЧЕК ТРЕХМЕРНЫМИ ЭЛЕМЕНТАМИ

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Развит подход моделирования массивных и тонкостенных элементов конструкций сложной геометрии, заданных в сферических координатах трехмерными конечными элементами. Трехмерный объект задается параметрами единичного куба, который разбивается на конечные элементы. Решение в элементе представляется в виде интерполяционного эрмитового кубического сплайна трех переменных. Выполнен анализ напряженно-деформированного состояния тонкостенной сферической оболочки с локальным углублением.

КЛЮЧЕВЫЕ СЛОВА: сферическая оболочка, метод конечного элемента.

Введение. Для обеспечения безопасной работы конструкций и сооружений необходимо совершенствовать каждый этап его создания: создание материала, технологии, проекта и т.д. Особую роль в этой цепочке играет возможности оценки прочности и надежности элементов конструкций и объектов исследования в целом.