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To cite this article: Vitalii Protsiuk 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **708** 012023

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# Georadar technologies application during determination of deformation characteristics of subgrade soils

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**Abstract.** One of the main reasons that largely affects the premature destruction and shortening of the pavement service life is the mismatch of the pavement to the actual conditions of operation, which is due to incomplete information about the change in the estimated humidity, strength and deformation parameters of subgrade soil. In the calculations of road structures, the main parameter of the soil base is the modulus of elasticity. Dependences of the soil elasticity modulus with humidity, dependences of the dielectric constant with humidity were obtained, and the relation between the elasticity modulus and dielectric constant were established. Therefore, the article are formulated and solved the task of developing a express-method estimation of soil deformation parameters in the field using modern advanced technologies. The results of laboratory studies have shown that with increasing humidity the soil dielectric constant is doubled: for sanding loams from 4 to 9; for loam from 13 to 27; for clays from 15 to 31. The results obtained can be applied in the highways inspection process in the calculation period, as well as for the calculation of pavement stress-strain condition, taking into account changes in humidity.

## 1. Introduction

The highway is a complicated engineering and technical complex, which consists not only of the subgrade and pavement, but also a considerable number of road transport structures (DTS), which have a given functional purpose. The study of subgrade, pavement, DTS and their structural elements is an urgent task [1-3]. In the process of highway operation and DTS in modern conditions, an important problem is to ensure a high transport and operational condition of pavement. With the increase in intensity, axial loads, the increase of multi-axle vehicles in the flow, there is an accelerated destruction of road pavement, which causes a decrease in the speed of vehicles, as well as an increase in economic costs. Annually, the state's losses from poor road transport operational status are up to 4% of gross domestic product due to a decrease in the speed of traffic, an increase in losses from road accidents, an increase in unscheduled emergency repairs. Therefore, the task of increasing the pavement durability and ensuring a standard transport and operational status during the lifetime is urgent. These requirements have to be taken into account at the development stage of road repair and reconstruction projects.

## 2. Analysis of recent research and publications

One of the main reasons, which largely affects the premature destruction and shortening the pavement service life is the mismatch of the pavement to the actual conditions of operation, which is due to incomplete information about the change in the estimated humidity, strength and deformation



parameters of subgrade soil and erroneous determination at the stage of pre-project investigations [4]. These characteristics can be obtained as a result of soil testing by pressing the stamp with static loading in the field or in the laboratory. However, when testing soil in the field, it is necessary to use heavy and cumbersome equipment for large diameter stamping. The disadvantage of testing soil in a laboratory is the inability to express assessment, because it is necessary to form soil samples and then determine their calculation characteristics.

Therefore, we were tasked to develop the express-method for assessment of deformation and strength parameters of soils in the field using modern advanced technologies that operate on the principle of georadiation.

### **3. The main part of the study**

The main parameter measured by ground penetrating radar is the signal transit time and its amplitude, which are determined by the dielectric properties of the medium – the dielectric constant ( $\epsilon$ ). According to theoretical concepts [5], the dielectric constant characterizes how many times the force of interaction of electric charges interaction in the medium is less than in vacuum. The value of the dielectric constant determines the propagation speed of the electromagnetic impulse in the medium under study [6]: increasing the value of the dielectric constant leads to an increase in the propagation speed of the electromagnetic impulse decreases. This is the basis for the principle of positioning zones of high humidity in soil masses [6], since the dielectric constant for air is 1, for water - 81, for dry soil  $\epsilon$  varies from 3 to 9, depending on the soil composition and the central frequency of the georadar signal [6]. Different percentages of water and air in the soil will determine the value of its dielectric constant, the propagation speed of electromagnetic waves and the amount of signal attenuation in the study medium.

This opens up the fundamental possibility of establishing a relationship between the dielectric constant value of soils and their moisture content using field georadar. The first results in this direction were obtained in [7], where, based on experimental studies, a relationship was established between soil moisture and their electrophysical characteristics. At the same time, in order to solve the problems of designing, building and operating roads, it is necessary to solve the problem in the opposite statement – to estimate the soil moisture by the value of dielectric constant. The possibility for using a field radar to solve this problem was confirmed in [8, 9]. In turn, knowledge of soil moisture allows you to evaluate its most important calculation characteristics – modulus of elasticity ( $E$ ) specific adhesion of soil ( $C$ ) and the angle of internal friction ( $\phi$ ). Therefore, the problem of the study was to establish a relationship between the deformation (modulus of elasticity ( $E$ )), physico-mechanical (humidity ( $W$ )) and electrophysical characteristics of soils (dielectric constant ( $\epsilon$ )).

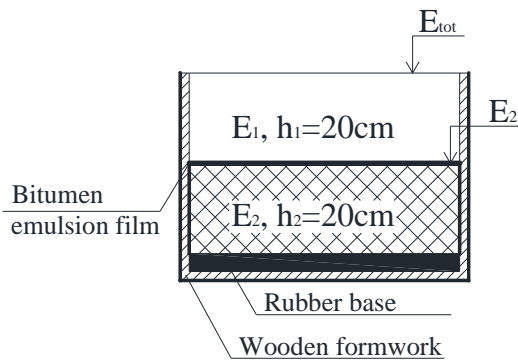
### **4. Experimental studies of electrophysical and deformation characteristics of soils**

Experimental studies on the correlation of electrophysical and deformation parameters were performed on soil models in laboratory. The following soil types were selected for the study: sandy loam, loam heavy dusty, clay light dusty. Soils for the study were selected from the subgrade. For the formation of soil models, preliminary studies have been conducted to determine the parameters of the models. According to the results of previous studies, the moisture content at the yield point and the moisture at the break point were determined, the maximum density and the optimum moisture content for maximum compaction, and the particle size distribution of soils was investigated. To perform the series of studies, two-layer soil models of 60x60 cm in size were formed in plan, the thickness of the soil layer was 20 cm (figure 1). The sizes of the models were determined according to [8] based on the conditions of preventing the appearance of boundary effects. Soil density was monitored during model formation.

Conducting studies on the relationship of moisture to the dielectric constant and the modulus of elasticity required changing the humidity values of the soil model. Humidity was gradually increased by introducing the required amount of water into the soil model. Soil moisture was gradually monitored by the thermo-weight method.

In the first series of experiments, the soil models were scanned with the georadar complex “ODIAG-1” (figure 2). The transceiver unit with a central impulse frequency of 1.2 GHz was mounted on the model at a height of 35 cm.

The data obtained using the radar were processed in a computer program “Geovizy”. The use of the dielectric permittivity algorithm implemented in “Geovizy” made it possible to estimate the time delays of the signals reflected from the boundaries of the layers, as well as the amplitudes of the incident and reflected signals.



**Figure 1.** Soil model for determination elasticity modulus



**Figure 2.** Soil model sounding by georadar complex “ODIAG-1”

Further calculations in the algorithm allowed, based on the calculated reflection coefficients from the boundaries of the medium ( $R_{n-1,n}$ ), to obtain the values of the soil dielectric constant for different values of humidity using the equality [10]:

$$\sqrt{\varepsilon_n} = \sqrt{\varepsilon_{n-1}} \frac{1 - R_{n-1,n}}{1 + R_{n-1,n}} \tag{1}$$

The results obtained during the experiments allowed us to establish a relationship between humidity and dielectric constant, which is fairly accurately described by a second-degree polynomial:

$$W_{soil} = A \cdot \varepsilon^2 + B \cdot \varepsilon + C, \tag{2}$$

where  $W_{soil}$  – soil relative humidity, fraction of units;  $\varepsilon$  – dielectric constant.

The values of the coefficients  $A, B, C$  are shown in table 1.

**Table 1.** Dielectric constant humidity dependence coefficients (1) and correlation coefficient

Type of soil	Dependence coefficients (1)			Correlation coefficient, R
	A	B	C	
Sandy loam	-0,0014	0,06	0,29	0,9661
Loam	0,0003	0,0133	0,34	0,9937
Clay	0,00004	0,0127	0,32	0,9981

In the second series of experiments, the soil model's elasticity modulus was measured to establish a relationship between the moisture and the elasticity modulus. Determination of the elasticity modulus was performed on the lever press. The basis of the experimental procedure were the of experimental determination methods of the soil elasticity modulus at different moisture in accordance with [11].

The load on the soil was passed through rigid round stamps 75 mm and 100 mm in diameter. The load on the stamp was applied in four stages: 0.05 MPa, 0.01 MPa, 0.15 MPa and 0.20 MPa until complete deformation attenuation with alternate unloading after each application of the load until

complete deformation attenuation. Vertical displacement of the stamp was measured by two electronic sensors DIGICO 10 with a point value of 0.001 mm. The sensors were located at the edges of the stamp along the diameter line. The displacement value was taken as the arithmetic mean of the two sensors.

According to the obtained values of inverse deformations at different soil humidity, the general elasticity modulus on the soil model surface is determined by the equations:

$$E_{el} = \frac{\pi \cdot p \cdot (1 - \mu^2) \cdot D}{4 \cdot l} \quad (3)$$

where  $E_{el}$  – soil model elastic modulus, MPa;  $p$  – the pressure transmitted to the soil model through the stamp, MPa;  $\mu$  – Poisson's ratio (sandy loam  $\mu=0,31$  [11], loam  $\mu=0,37$  [11], clay  $\mu=0,41$  [11]);  $D$  – the diameter of the stamp, m;  $l$  – elastic deformation of soil model, m.

However, the obtained values characterize the total elasticity modulus ( $E_{tot}$ ) on the surface of the two-layer model (figure 1). Therefore, to obtain the elasticity modulus value of the soil study ( $E_{soil} = E_1$ ) (upper layer only), the elasticity modulus ( $E_2$ ) of the lower layer of the model was measured. Substituting the values of the measured modules ( $E_{tot}$  and  $E_2$ ) for calculation of the top layer of the model, we obtained the values of the elasticity modulus of the studied soil (table 2).

**Table 2.** Values of the elasticity modulus for different soil types.

Relative soil moisture, $W_{soil}$	Soil type		
	sandy loam	loam	clay
	$E$	$E$	$E$
0,51 $W_T$	106	83	58
0,56 $W_T$	92	71	49
0,61 $W_T$	78	59	33
0,66 $W_T$	61	44	23
0,71 $W_T$	57	30	17
0,76 $W_T$	47	20	10

Summarizing the experimental studies results (tables 1, 2) allowed us to establish a relationship between the deformation and dielectric parameters of the soils (figures 3).

As a result of the approximation of the experimental data, relation was established between the elasticity modulus and the dielectric constant of the soils, which are described by a second-degree polynomial and have the form:

– for sandy loam:

$$E_{soil} = 404W^2 - 745W + 383 \quad (4)$$

– for loam:

$$E_{soil} = 392W^2 - 760W + 374 \quad (5)$$

– for clay:

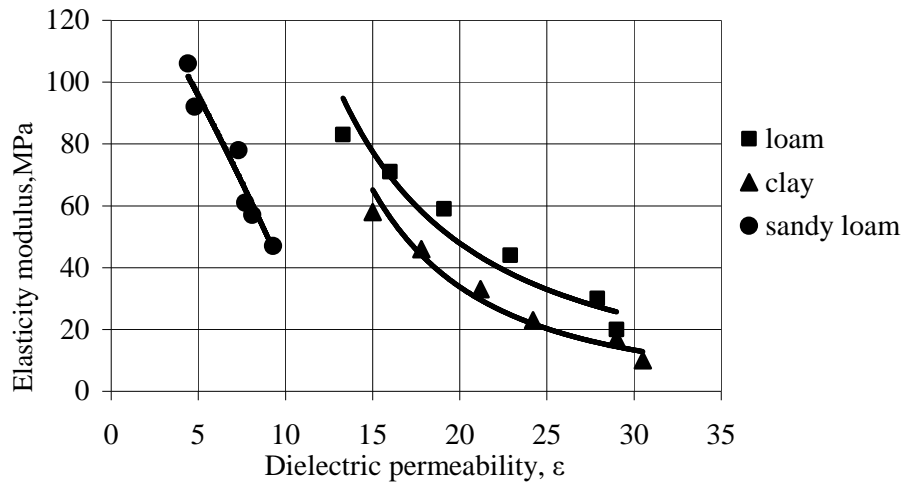
$$E_{soil} = 394W^2 - 701W + 316 \quad (6)$$

where  $E_{soil}$  – the elasticity modulus of soil studied, MPa;  $W$  – is the moisture content of the soil in units of  $Wt$ .

The results obtained and the character of the dependencies correlates with the results of other authors' research [12].

The dependences (4) - (6) allow us to estimate the elasticity modulus of by the values of dielectric constant established on the georadar studies basis.

The research results are the basis for the development of algorithms for the interpretation of subsurface sensing data in order to assess the humidity and deformation parameters of soils.



**Figure 3.** Diagram of relationship between dielectric constant and soil modulus

## 5. Conclusions

Thus, the application of georadar technologies allows real-time monitoring of the humidity and deformation characteristics of soils without destroying the integrity of the pavement.

In the course of laboratory studies, the dependences between dielectric constant and humidity were obtained - humidity increase leads to increase of soil dielectric constant twice: for sandy loam from 4 to 9; for loam from 13 to 27; for clays from 15 to 31, and also obtained the dependence the elasticity modulus with the humidity. Based on these dependences, the dielectric constant relations with the elastic modulus were obtained.

These results can be used in the survey of pavement during the calculation period, and also for the calculation of the stress-strain state of pavement, taking into account changing humidity conditions.

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