PETROPHYSICAL INVESTIGATION OF MATERIAL FROM VIETNAMESE RIVER DIKES

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Abstract: *Samples from a dike segment in Nam Dinh province are investigated by petrophysical methods. The samples are taken from dike foundation and dike body. The complex electrical conductivity is determined in a low frequency range (2mHz –750 Hz). The spectra of complex dielectric constant are measured in a frequency interval from 1 MHz up to 1 GHz. Additional experiments yield water content, grain density and magnetic susceptibility. The data provide useful information on the variation of the petrophysical parameters of the material of dike foundation and dike body. It is verified that the electrical properties depend on water content.*

Further investigations will include other parameters like clay content and type, porosity, water saturation and water salinity. The work aims at a prediction of geotechnical parameters from petrophysical data which are acquired by geophysical surveys.

1 INTRODUCTION

The dike system in the North of Vietnam has a total length of more than 5000 km. The dikes protect population and infrastructure from floods in the rainy season. The water flow in the monsoon period results in strong pressure on the dikes and their foundation. Despite all efforts, damages caused by seepage, landslides or fractures in the dikes occur occasionally. The instability of dikes results from defects in the dike foundation or in the dike body. Severe problems are related to dike sections that cross old river beds. Sandy lenses with higher permeability cause seepage effects. Soft clays in the dike foundation affect the stability of the dike body. Leakage effects occur near sluices and passages. Another problem of Vietnamese dikes is related to the activity of termite infestation. The origin of these defects is usually not directly visible.

Geophysical methods have proved to be successful in dike inspection [2]. Lithologial changes in the dike body, termite nests and sluice structures are investigated by geoelectrical methods. This method can also be applied to explore the dike foundation. Some successful tests have been made with ground penetrating radar (GPR). Unfortunately, the depth of penetration of radar signals is limited by the silty material of dike body. The self potential method, infrared geothermal surveys, seismic methods, well logging or other technologies have been applied in dike inspection. A successful application of a geophysical method requires a significant contrast in the relevant petrophysical parameter. However, there has not been any systematic petrophysical investigation of dike materials, so far. It is necessary to investigate samples of dike material in the laboratory in order to create a database that can be used to plan the geophysical survey and to enable a reliable interpretation of the measured field data.

Our investigation aims at a comprehensive petrophysical characterization of material from river dikes. The variability of different parameters is studied and correlations between various parameters are investigated. The results will provide useful information on the applicability of geophysical methods for dike inspection.

2 SAMPLING

The dike segment Yen Tho in Nam Dinh province is selected to be the first location for our petrophysical study. This segment is affected by sliding dike flanks. The geoelectrical survey has proved that the dike is located at an extended clay layer which affects the stability of the dike. More than 25 samples were collected from different locations along this dike segment. Twelve samples were taken from two boreholes which were drilled up to a depth of 24 m in order to investigate the dike foundation. The first borehole is located at km 138.358. Nine samples were taken from 2 to 24 m depth. Only two samples were collected from the second borhole at km 138.446.

Other 14 samples were taken from different locations close to the surface of the dike. A set of six samples has been collected from the cross-section at km 138.246, where three samples originate from the land side flank and another three samples from the river side flank. A second cross-section has been sampled at km 138.446.

The loose material of all samples has been packed in plastic bags in order to reduce the humidity loss. Unfortunately, the original stratification could not be preserved.

3 LABORATORY MEASUREMENTS

3.1 Electrical properties

The electrical properties were determined in two different frequency ranges. The low frequency measurements were carried out by a SIP-Fuchs equipment in order to determine the complex electrical conductivity of the samples in the frequency range of spectral induced polarization (SIP) from 3 mHz to 750 Hz. In order to reduce the influence of electromagnetic noise and temperature fluctuations, the samples were kept in an incubator at a constant temperature of 20 °C. The material is filled in a cylindrical sample holder with a diameter of 40 mm and a length of 75 mm. Two circular electrodes with a distance of 55 mm at the inner surface of the sample holder monitor the potential difference while a sinusoidal current signal of a fixed frequency is passing through the sample. The resulting spectra of in-phase and out-of-phase (quadrature) electrical conductivity provide useful information on the pore space structure and pore filling of the sample. Useful correlations are available to derive the hydraulic properties [1,5] or the pore throat distribution [3] of sedimentary rocks.

The electrical properties at higher frequencies were investigated by a dielectric measurement system (DEMS). The equipment consists of a vector analyzer and a condenser-like sample holder. Small samples with a maximal diameter of 13 mm and a thickness of 4 mm are placed between the two electrodes of the sample holder. The loose material is filled in small rings made of Teflon or Perspex which are closed by aluminum foil to guaranty good contact to the electrodes. The influence of the ring is eliminated in a special correction procedure.

The system operates in a frequency range from 1 MHz up to 1 GHz. The spectra of real and imaginary part of dielectric constant are determined. The data are used to predict velocity and attenuation of radar signals. The spectra of sample XB110 which was taken from the dike cross-section at km 138.446 are presented in Fig. 1. Both real and imaginary part of dielectric constant show a strong dispersion. The real part is related to dielectric displacement currents and the imaginary part reflects the electrical conductivity which vanishes at higher frequencies.

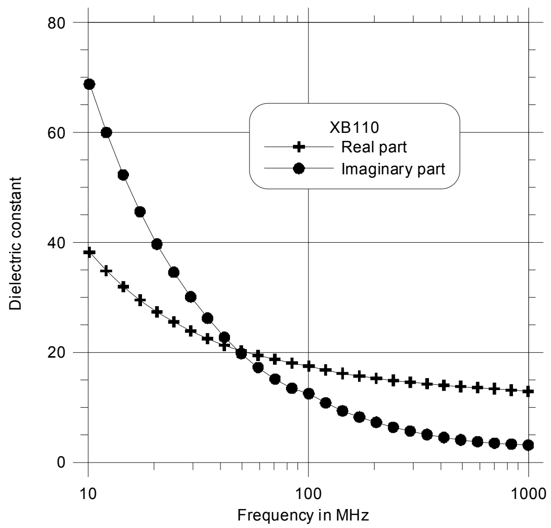


Figure 1. *Dielectric spectra of sample XB 110.*

3.2 Water content

The water content of the material was determined by observing the weight loss during the drying process. First, the samples were dried at room temperature at atmospheric conditions. Later, the drying process was continued in a vacuum oven at a temperature of 35° C. A first value of water content was measured with the original material. Another value of water content was determined using the material from the SIP experiment which might have slightly changed the water content.

The water content of the samples which were used for the dielectric measurements has been determined separately. It is obvious that during transport and preparation the original state of the samples has been changed considerably. Thus, the values of water content do not reflect the true conditions in the dike. But the water content is needed to investigate the relations to other petrophysical parameters.

3.3 Density and magnetic susceptibility

The grain density of the samples is determined after drying the samples. The volume of the solid material is measured in a gas pycnometer (Ultrapycnometer 1000) using helium which is able to penetrate into the smallest pores when higher pressure is applied. Knowing the volume and the weight of the mineral grains, the density is calculated.

The grain density can be used to derive the porosity of the sample if the total volume is known. Since the samples are disturbed, the resulting porosity value might differ from the original state.

The magnetic susceptibility of the samples is measured in a kappa-bridge KLY-2. The data are normalized to the volume of the sample which has to be estimated.

4 RESULTS

4.1 Dike foundation

The clayey material from the boreholes is characterized by high conductivity. As shown in Fig. 2a, the in-phase conductivity of all samples slightly increases with rising frequency. Regarding the frequency of 2.9 Hz, the in-phase values vary from 190 to 470 mS/m with an average of 362 mS/m. This result is in good agreement with the inverted vertical section of the resistivity survey that shows resistivity values down to 2 Ωm (500 mS/m) for the clay layer.

The quadrature conductivity (Fig. 2b) stays at low values (< 3 mS/m). For some curves, the current signal lags behind the voltage signal. Consequently, the quadrature conductivity becomes negative. This effect can be explained by chemical reactions between organic material and clay minerals.

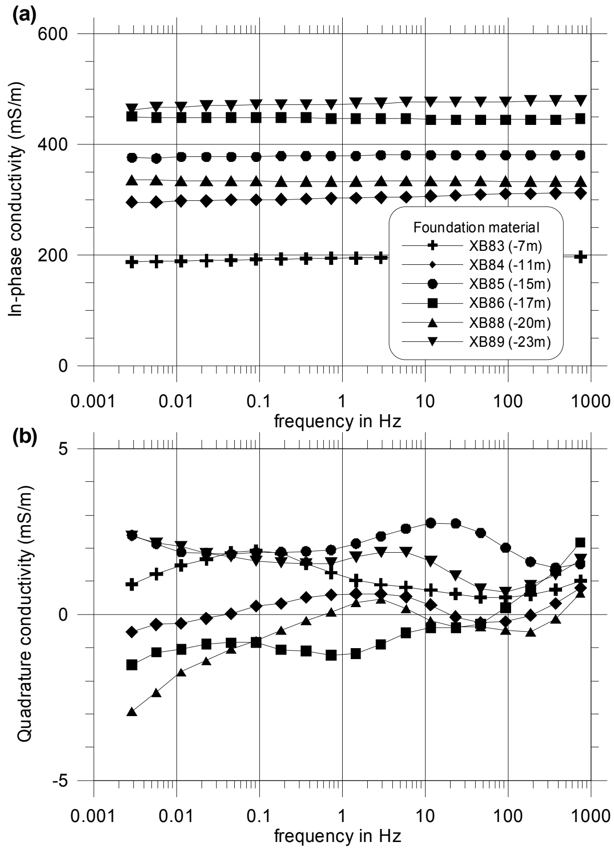


Figure 2. *Complex conductivity spectra of material from dike foundation. The samples are taken from the borehole at km 138.358. (a) In- phase conductivity. (b) Quadrature conductivity.*

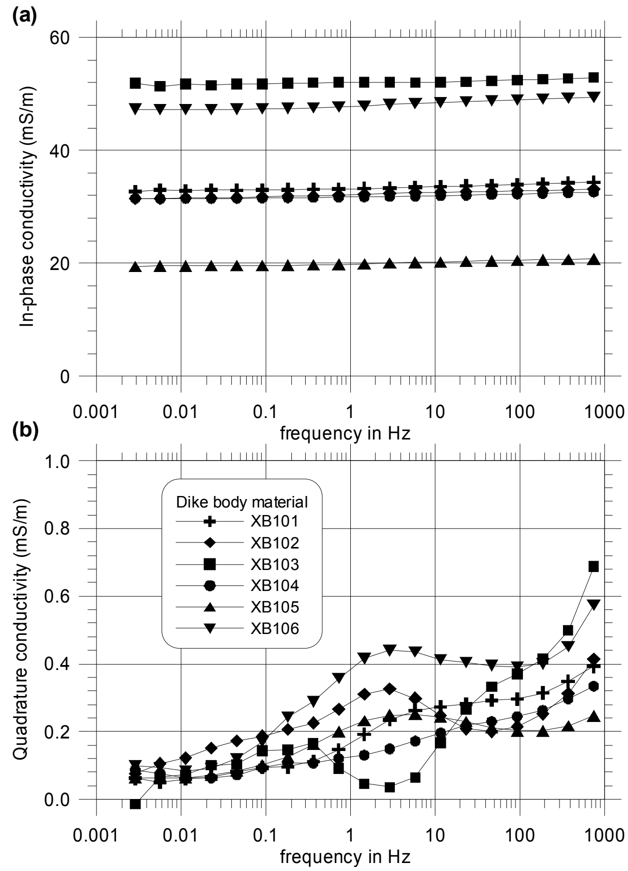
The water content of the clayey material reaches around 54 percent. The real part of dielectric constant at 100 MHz varies between 37 and 47 with an average of 40.

The average magnetic susceptibility of the samples from the borehole amounts to $270 \cdot 10^{-6}$ (SI-unit). The grain density varies between 2574 and 2715 kg/m^3.

4.2 Dike body

The silty samples from the dike body show lower conductivity. The real part of conductivity at 2.9 Hz ranges from 18 to 80 mS/m with an average of 50 mS/m. Most curves show a slight increase of quadrature conductivity from lower to higher frequencies (Fig. 3b). Some curves show a maximum in the classical IP frequency range from 1 to 10 Hz.

Figure 3. *Complex conductivity spectra of*



material from dike cross-section at km 138.358. (a) In-phase conductivity. (b) Qadrature conductivity.

The average water content is only 29 percent. The real part of dielectric constant varies from 9 to 32 at 100 MHz.

It is interesting to note that the average magnetic susceptibility value considerably varies between the first cross-section at km 138.246 where it reaches $411 \cdot 10^{-6}$ (SI-unit) in comparison to the second location at km 138.446 with a value of $105 \cdot 10^{-6}$. This significant difference could be only explained by a varying content of ferromagnetic minerals.

The average grain density does not differ significantly at both locations. It varies between 2653 and 2710 kg/m^3.

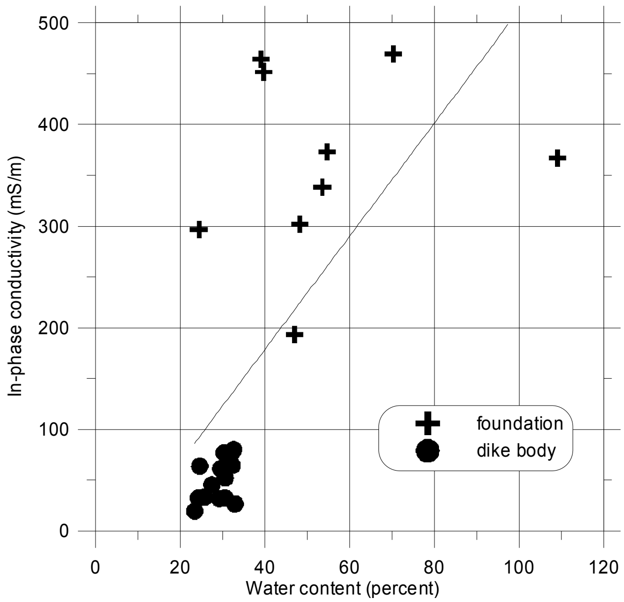


Figure 4. *Relation between water content and in-phase conductivity at 2.9 Hz.*

5 DISCUSSION AND CONCLUSIONS

The diagram in Fig. 4 shows the relation between water content and in-phase conductivity. Generally, an increase of in-phase conductivity is observed with rising water content. But the correlation coefficient reaches only 0.42. The data points that belong to the material from the dike body form a narrow cluster in the lower right section of the diagram. The data points of the clayey material of the underlying layer are scattered in the upper part of the diagram.

The in-phase conductivity is mostly related to the electrolytic conduction in the pore space. The quadrature conductivity results from polarization phenomena that are caused by the electrical double layer or by the constrictivity of the pore channels. Thus, the spectra of quadrature conductivity which differ significantly in size and form provide additional information concerning the internal structure of the pore space and the physicochemical conditions at the liquid-solid interfaces [4].

The relation between water content and dielectric constant, which is displayed in Fig. 5, shows less scatter and consequently a slightly higher correlation coefficient (0.56). Both conductivity and dielectric constant do not depend only on water content. Other parameters that should be considered are clay content and type, porosity, water saturation and water salinity.

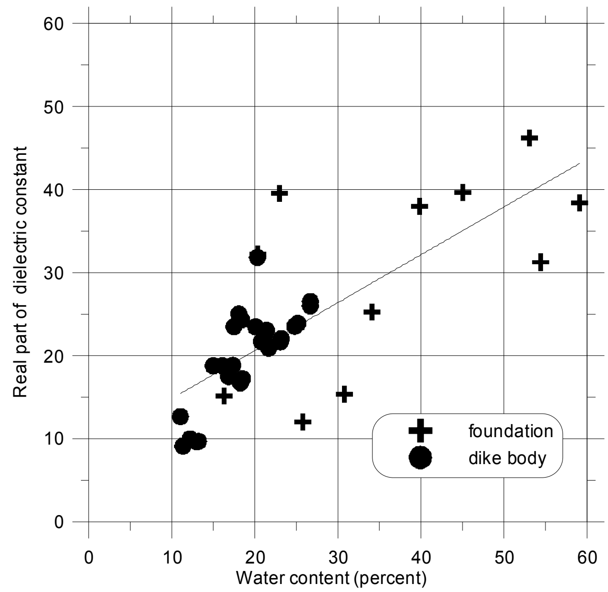


Figure 5. *Relation between water content and real part of dielectric constant* at 100 MHz.

The small number of data which has been acquired up to now does not allow reliable statistical conclusions. More samples should be collected from river dikes in order to establish a comprehensive data basis that can be used to derive criteria for the use of geophysical methods in dike inspection.

Up to now, classical geoelectrical methods are widely used to investigate lithological changes in the dike foundation and dike body. The only parameter that can be derived from a geoelectrical survey is the absolute value of electrical conductivity that reflects changes in water content, clay content and compaction as an integrated effect. It should be verified whether an additional use of SIP yields the needed information to separate the different effects. The determination of the type and extent of clay minerals in the material and a comparison with the complex conductivity spectra will be a first step in this direction.

Further investigations are needed to quantify the relations between the petrophysical properties and the geotechnical parameters that are needed to assess the stability of the dike.

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