Assessment of Levees Using Field Instrumentation and Geophysical Methods.

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ABSTRACT

Levees along the Mississippi River play an important role in ensuring the security of life and property in flooding events. The degree of saturation and moisture content of levees containing high-plastic clay soils can increase their vulnerability to shallow slope failures. The frequent fluctuation of the water levels of the Mississippi River increases the potential of water infiltration which in turn increases the risk of shallow slope problems. Therefore, it is critical to monitor the water level inside the levees to evaluate the effects of the water table elevation on the levee performance. Field instrumentation and Electrical Resistivity Imaging (ERI) are used to investigate the soil subsurface conditions in terms of soil moisture variation, and perched water zones. The objective of the current study is to integrate the data collected from electrical resistivity imaging (ERI) with the change in subsurface water pressure to evaluate the performance of two levee sections on the Mississippi east levee system in Norfolk north of Mississippi. A piezometer was installed at the toe of each levee section to monitor the water table levels. Moreover, a 2D ERI test was conducted along three survey lines at the crest and middle of each levee slope to investigate the soil subsurface conditions in terms of soil moisture variation and perched water zones.

I. INTRODUCTION

Levees along the Mississippi river are earthen structures raised along the banks of the river and its Tributary to retain water and to protect life and property in flooding events. In the past, many catastrophic levee failures were recorded due to three main reasons: Overtopping, piping failure or internal erosion, and instability and slope failures (9). The instability and slope failures are sensitive to the structures, materials, impacting forces and configurations of the levee (1). Many of the levees along the Mississippi river lie on an alluvial material, those alluvial materials are usually eroded soils deposited by the river during previous flooding events, and those materials are usually loose or unconsolidated, which can be problematic during high water events. The differential hydrostatic head resulting from high water events allows seepage through the pervious layers which elevates the hydraulic gradient and increases the moisture through the impervious blanket above (10).

Seepage problems, high uplift pressures, and differential settlement can develop cracks that weaken the foundation layers of the embankment and allow perched water zones to develop within the impervious blanket and may lead to slope instability and slope failures (1). The stability of the side slopes of an embankment depends on the resisting forces against driving forces (19; 4).

The primary visual indicators of levee slope instability are cracks, bulges, depressions, and slides (7). The presence of cracks, bulges and depressions indicate the beginning stages of an embankment slide and generally do not provide adequate indication of the severity of the slide through progression. Levee blankets constructed with expansive soils are prone to cracking problems caused by the variations of the soil moistures because it impacts its physical volume change (12). It is usually challenging to discover problems caused by moisture variations since it is usually hidden within subsurface soils (6). Since the moisture content variation is one of the primary reasons behind soil strength and slope stability (13), understanding the relationship of moisture variations in the levee foundation in respect to the changes to the Mississippi river stages can help with assessing the levee performance.

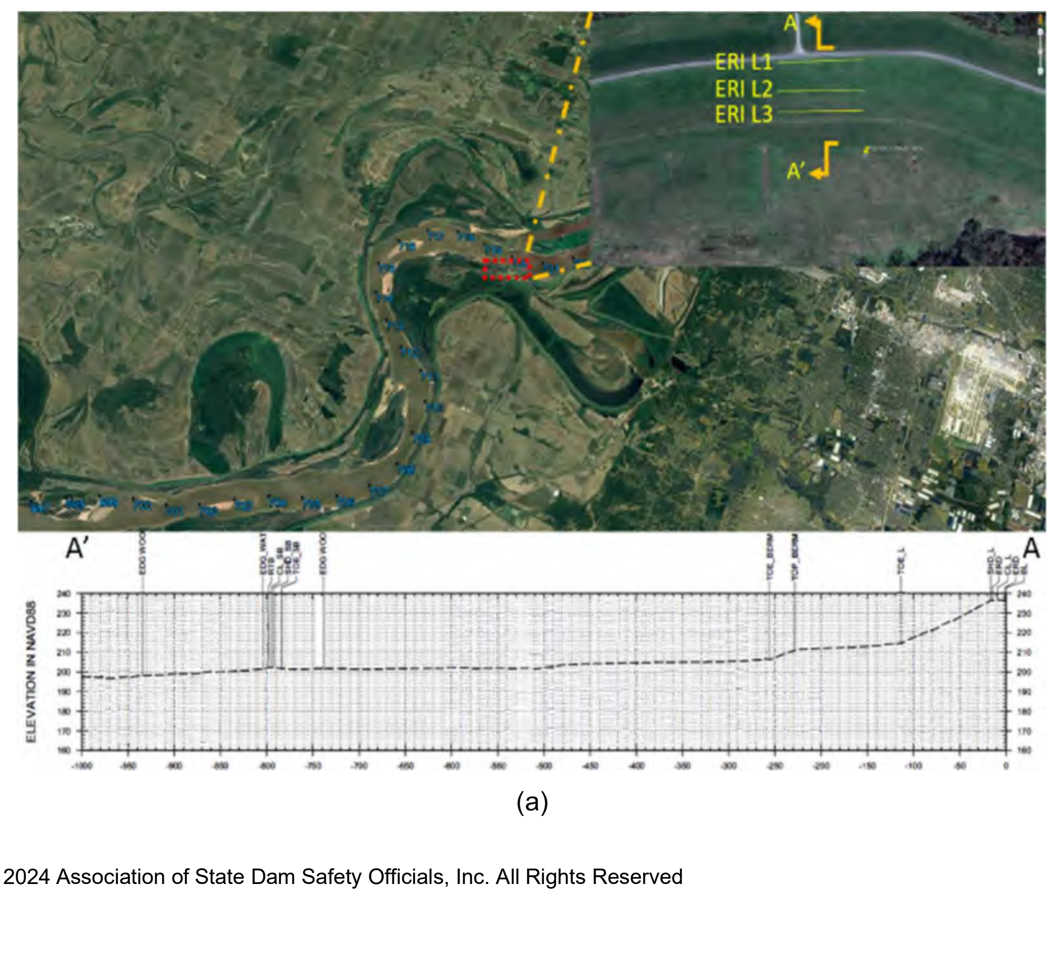
The soil moisture content can be estimated either directly by laboratory testing or determined in the field by advancing CPTs or other destructive methods, such as vane shear (VST) and standard penetration test (SPT) (5), however those methods of estimating moisture content are destructive, costly, require extensive planning and preparation, and generally only provide one point of measurement data. On the other hand, Geophysical techniques are indirect methods that can be used to estimate and understand the moisture content variations of soils (2). Electrical Resistivity Imaging (ERI) is a non-destructive geophysical method that can be used to study slopes seasonally to capture the variations of soil moisture contents and to monitor the slope performance to take early actions (16). The ERI can capture the soil resistivity based on the porosity, saturation, and the material texture which can be used to detect the moisture content, perched water zones, and crack development (14). Furthermore, depending on the electrodes spacing the electrical currents can penetrate large depths in soils, thus engineering judgment based on the project is needed to determine the spacing and configuration of the electrodes to help understand the soil resistivity (18). ERI started to get more popularity in the recent years to produce subsurface maps that can help understand the and identify the moisture content of the soils (3; 15).

II. SITE LOCATION AND SELECTION

The study was conducted on two different levee sections of the Yazoo Levee system, in Norfolk, Mississippi. Site 1 is a 1000ft levee section between river miles 718 and 720 with height of 34ft and landside slope of 1V:4.35H the inspected landside slope is approximately 6000ft away from the Mississippi riverbank. Site 2 is a 480ft levee section between river miles 708 and 709 with height of 18ft and landside slope of 1V:5.5H. The inspected landside slope is approximately 1240ft away from the Mississippi riverbank. Figure 1. Below represents the two inspected levee sites.

Table 1. Study site's location and configuration.

Study Site	Distance from MS river (ft)	Landside Slope	Latitude	Longitude
Norfolk 1	6000	1V:4.35H	34°59'56.26"N	90°14'23.20"W
Norfolk 2	1240	1V:5.5H	34°55'33.03"N	90°14'4.28"W



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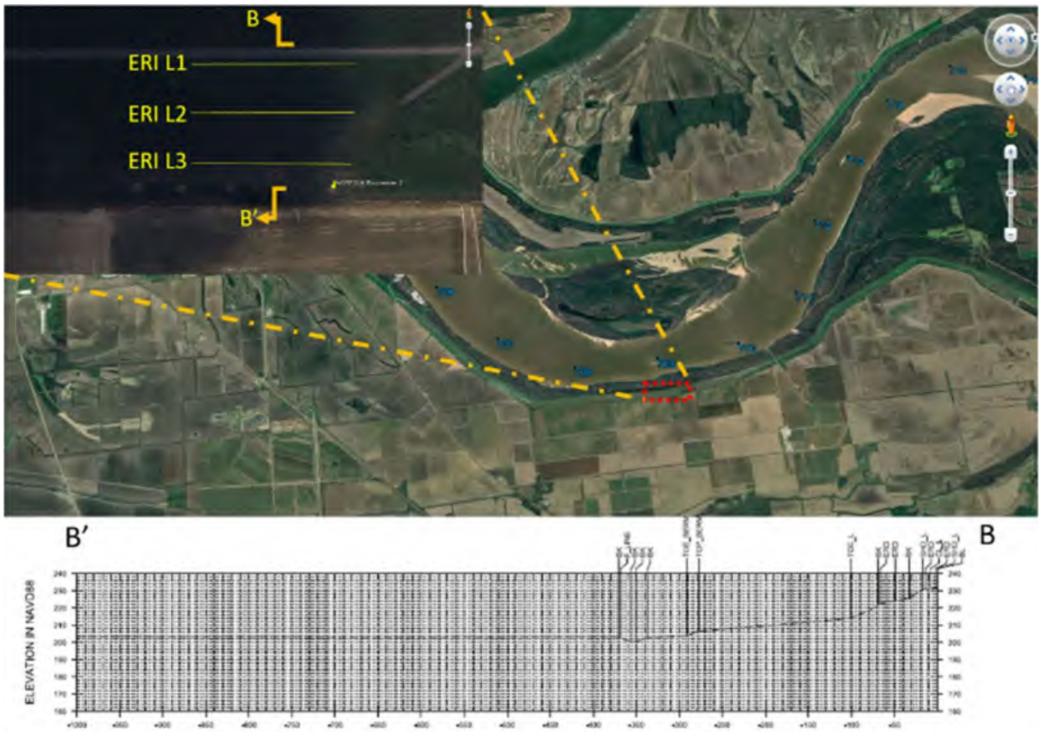

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Figure 1. (a) Norfolk 1 site location and details (b) Norfolk 2 site location and details.

III. BACKGROUND

Electrical Resistivity Imaging (ERI): ERI is a non-destructive direct current (DC) geophysical method that can be performed to produce a 2D electrical resistivity measurement of the soil subsurface. Measurements are made by injecting electrical current into the ground through two source electrodes and measuring the voltage at two receiving electrodes (8). The distribution of potential can be related to the ground resistivities and their distribution. The values from the resistivity surveys are interpreted in the form of apparent resistivity and expressed in ohm-meters (ohm-m). The data of the apparent resistivity can be presented by the equation below (11).

$$U = \rho \frac{I}{2\pi r} \qquad (1)$$

Where, U= the potential measured in volts (v), $\rho =$ resistivity of the medium, and r = distance from the electrode. Figure 2. Represents the principle of ERI measurement.

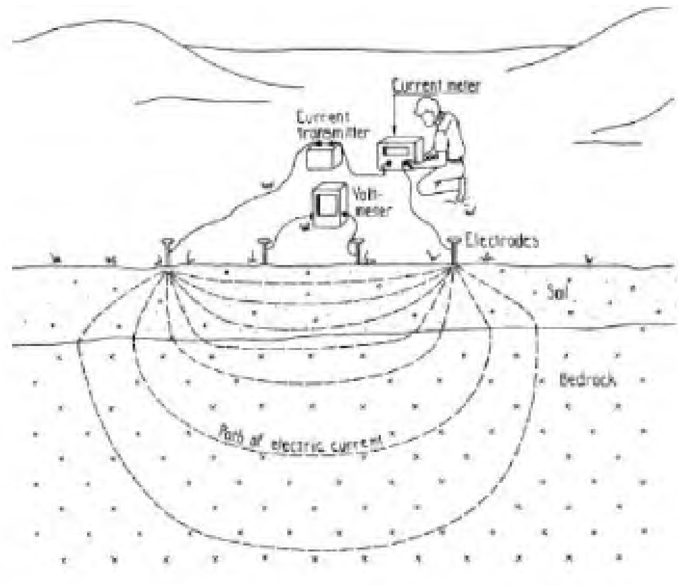


Figure 2. Principle of ERI measurement (Robinson and Coruh 1988).

IV. METHODOLOGY

ERI Test

An ERI test was performed to examine the surface resistivity of the shallow subsurface on the levee landside slope and toe of the two sites. The study was conducted by performing three different ERI survey lines at each site during spring and summer. The equipment used for the study is a SuperSting R8/IP resistivity meter manufactured by Advanced Geosciences Inc. (AGI). The SuperSting R8/IP is a multichannel system that includes 8 channels to conduct the survey and has 8 receivers that can take 8 readings for each current injection reading. To run this multichannel system a total of 56 electrodes were used. The electrodes were hammered at least 6 inches into the ground and spaced at 5 ft. center to center spacing covering 275 ft, the depth of penetration for the ERI test is a function of the electrodes spacing, since the targeted depths are the top 30ft of soils and with the 5ft spacing ERI can penetrate to depths around 60-70ft which serves the goals of the investigation. length for each ERI 2D survey line. The electrodes were connected through cables on a dipole-dipole array. Line A was located at the top of the slope near the crest and the second line B was located at the middle of the slope and line C was located at the levee toe for both sites.

Figure 3. ERI test equipment and survey line placement.

Field Instrumentation

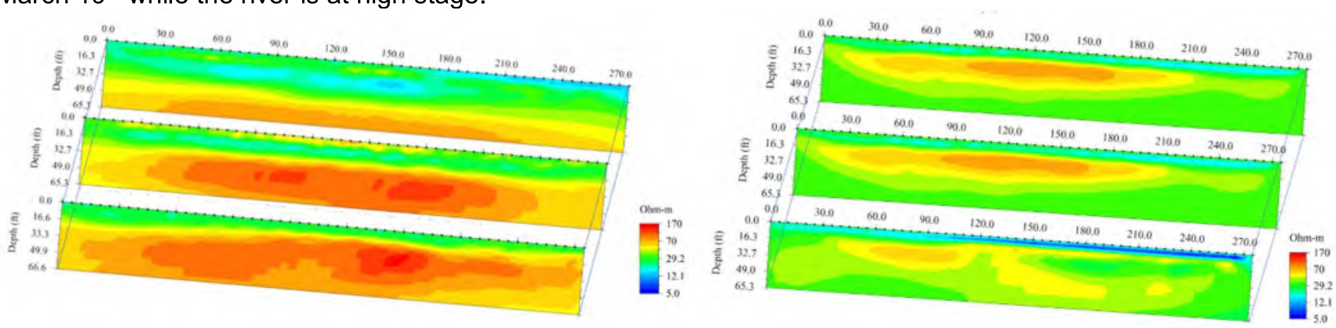
A vibrating wire (VW) piezometer sensor was installed at 48ft depth on each site to monitor the fluctuation of the water table in the levee foundation with the change of the river stages over time. The sensors are installed in the relief wells at the landside levee toe of each levee section. The sensors are connected to a data logger placed at the side of the relief well screen. The data is recorded every 15 minutes increment. The pressure readings collected by the piezometers were converted to total head and plotted against the river gage reading of the Mississippi water levels at each corresponding river mile. The data from the river gages at each river mile was interpolated between the Memphis gage (between RM 734 & 735) and the Mhoon landing river gage (between RM 687 & 688). Figure 4. Shows the used VW sensors installed in site 1.

Figure 4. (a) Geokon 8940 series data logger (b) Geokon 4500B VW Piezometer sensor (C) Piezometer installation at Norfolk 1 site.

V. RESULTS

Norfolk Site 1

The ERI data is taken in the spring (March 19th) and summer (July 1st) over three lines A, B, &C.
Figure 5(a). and (b). represents the ERI survey data collected at each season. Figure 5(a). represents the ERI results for Line A, Line B, and Line C on March 19th, the river stage was around 192 ft. at that time, but ERI Line C shows high resistivity values 70-170 ohm-meters, which indicates that the foundation soils beneath the blanket are still dry. Figure 5(b). represents the ERI results for Line A, Line B, and Line C on July 1st, the river stage was around 184 ft. at that time, ERI Line C in this case is showing lower resistivity values 20-50 ohm-meters, which indicates that the foundation soils beneath the blanket are saturated. Figure 5(c). represents the data interpolated between the Memphis and Mhoon landing gages with the data collected form the piezometer sensor. Due to the long distance between the levee toe and the Mississippi river, the change in the water levels in the soil foundation based on the piezometer sensor is not reflecting the river stages in the short term which explains the high resistivity values on March 19th while the river is at high stage.



(a) (b)

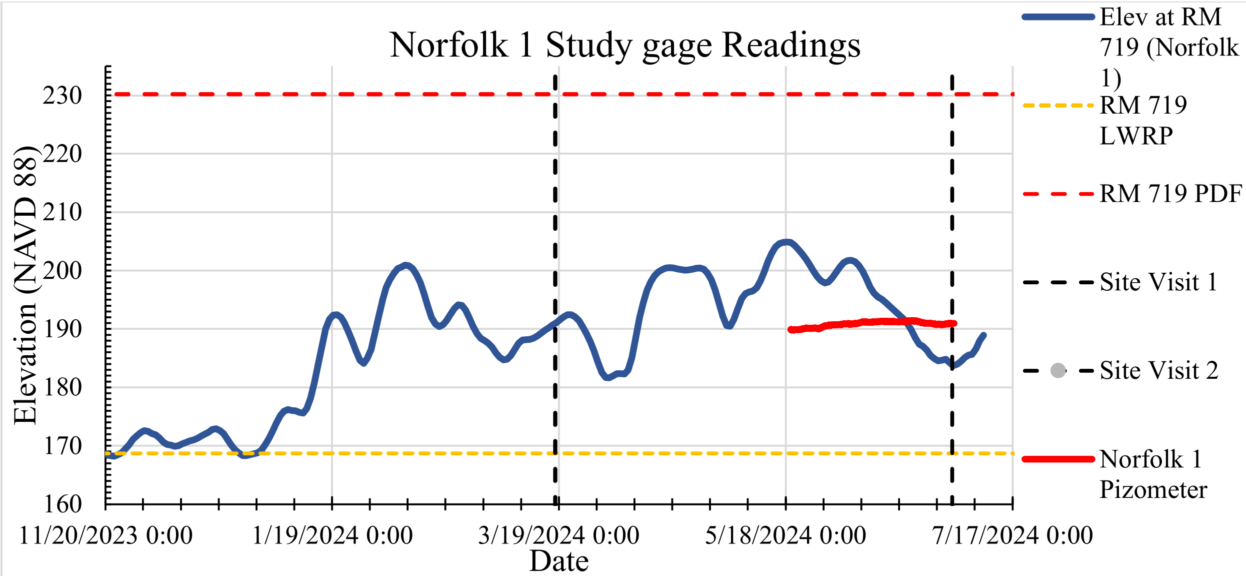


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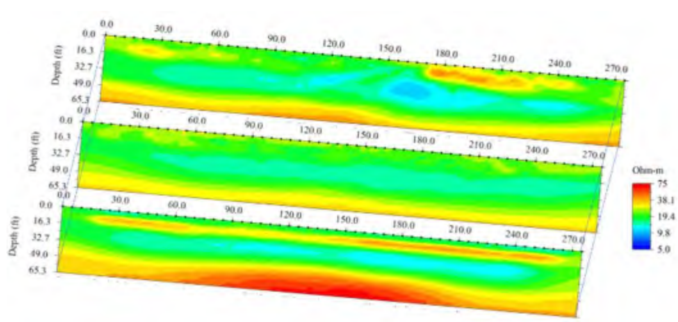
Figure 5. (a) ERI Survey Lines on March 19th (b) ERI Survey Lines on July 1st (c) Interpolated River stages at river mile 719 with piezometer sensor data.

Norfolk Site 2

The ERI data is taken in the spring (March 19th) and summer (July 1st) over three lines A, B, &C. Figure 6(a). and (b). represents the ERI survey data collected at each season. Figure 6(a). represents the ERI results for Line A, Line B, and Line C on March 19th, the river stage was around 184 ft. at that time, but ERI Line C is showing relatively low resistivity values 15-35 ohm-meters, which indicates that the foundation soils beneath the blanket is saturated. Figure 6(b). represents the ERI results for Line A, Line B, and Line C on July 1st, the river stage was around 180 ft. at that time, ERI Line C in this case is showing almost the same range of resistivity values 15-35 ohm-meters However, looking at the blue areas (Low resistivity) it is evident that the high river stages on March 19th reduced the foundation resistivity. Figure 6(c). represents the data interpolated between the Memphis and Mhoon landing gages with the data collected form the piezometer sensor. The short distance between the levee toe and the Mississippi river, reflects directly on the change in the water levels in the soil foundation based on the Piezometer sensor which explains the lower resistivity values on March 19th while the river is at high stage.



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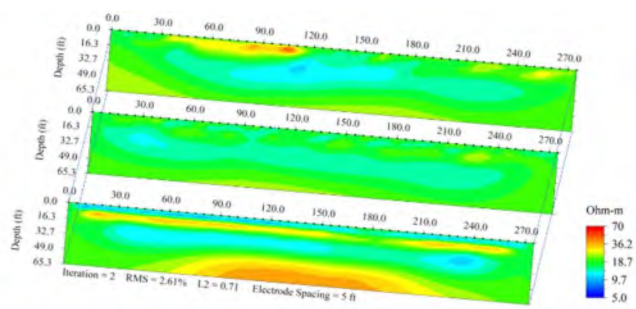

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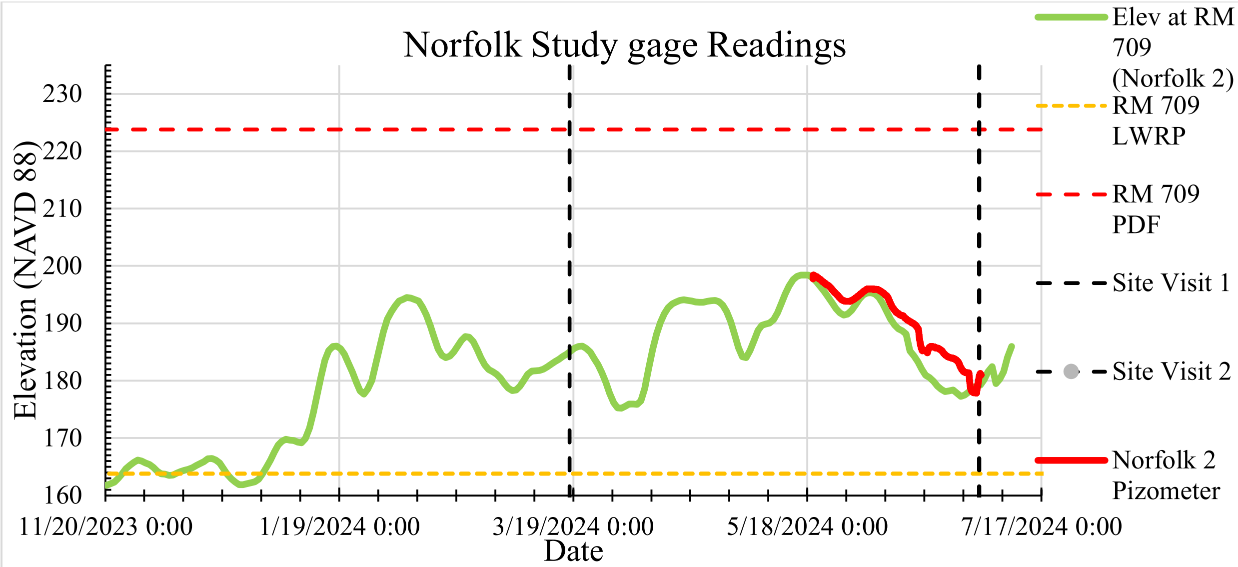

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Figure 6. (a) ERI Survey Lines on March 19th (b) ERI Survey Lines on July 1st (c) Interpolated River stages at river mile 719 with piezometer sensor data.

VI. DISCUSSION

The goal of using the ERI survey is to produce 2D resistivity maps of the foundation soils beneath the levee on seasonal basis to capture the change in soil resistivity with the changes of the river stages, this data can later be correlated with the subsurface geologic profile. The analysis for the data collected from the field is performed using the EarthImager-2D software by AGI.

The EarthImager-2D software converts the apparent resistivity (r) data to a 2D cross section color indexed profile using the finite element technique (FEM), the software runs an iterative process to reduce the Root Mean Squared (RMS) below 5% and to remove all noisy data.

For the first trial the software performs the inversion process using the apparent resistivity data collected from the field. Then, the model predicts certain datasets by a forward modeling process, and it compares it with the initial model and root mean square error (RMS) of the first iteration. The initial model is then updated based on the findings of the previous iteration. This process of updating the model and forward modeling and updating the model is carried out in several iterations and a final model is determined. Figure 7. Shows the final inversion after the removal of all noisy data.

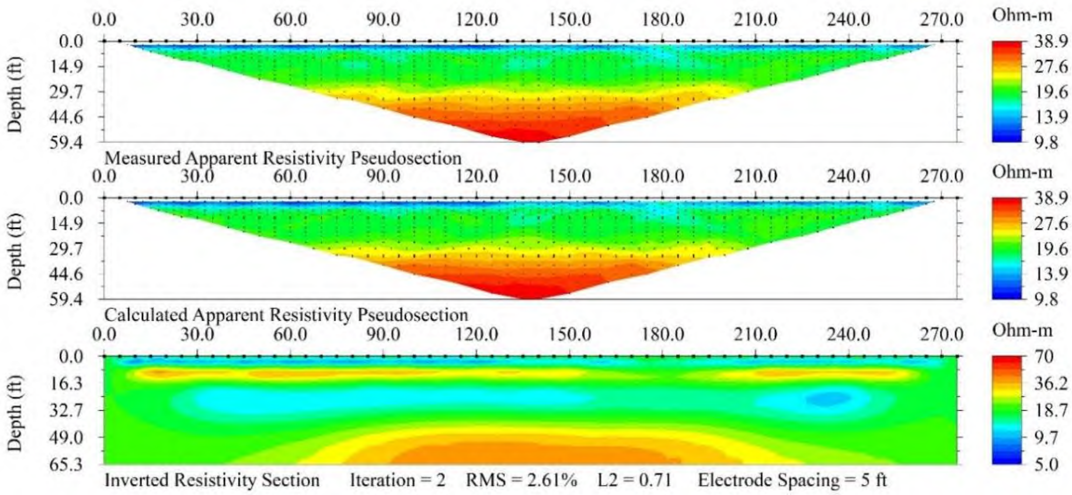

Figure 7. ERI Line C, Norfolk 2 Site inversion.

VII. SUMMARY AND CONCLUSION

Levees along the Mississippi river are either comprised of naturally deposited alluvial materials by the meandering of the river or man-made levees of engineered and compacted materials. The study sites are in an area of point bar and channel deposits formed from the meandering of the Mississippi River. Clay plugs throughout the Mississippi east levee system in Norfolk were formed due to meanderings which can potentially contain perched waters.

The blanket material of the levee consists predominantly of lean clay, fat clay, and silt with occasional strata of clayey or silty sands to a depth of 6 to approximately 65 feet. Most of this surface material extends to a depth ranging from 15 to 35 feet. The surface deposits are underlain by poorly graded sand interspersed with poorly graded sand with silt. These deposits extend to the Tertiary at a depth of approximately 100 to 170 feet depending on the location in the project. Most of the tertiary depths in the project are 140 feet or less. the formation of the clay blanket can be problematic because it undergoes high volume change due to wetting or drying because of different seasonal moisture variations. Those volumetric changes can destress the levee blanket and essentially form cracks.

The current study using field instrumentation ERI intends to evaluate the performance of the landside levee slope formed of clay soils. Piezometers were installed at the landside levee toe of each site to monitor the groundwater variations with the Mississippi river stages. Moreover, the 2D ERI tests were conducted at the slope to image the continuous soil subsurface profile in terms of moisture variation. The possibility of using geophysical investigation and field instrumentation to measure the subsurface ground resistivity with the fluctuation of the Mississippi river stages has been demonstrated and the outcome of the study has been summarized below:

- Norfolk 1 site, the effect of the Mississippi river stages is not reflected on the soil resistivity immediately due to the long distance from the landside toe and the river, approximately 6000ft.
- Norfolk 1 site, the changes in the water table due to the changes in the river stages is slow and it was almost at a steady stage.
- Based on the notable lag of the ground water changes Norfolk site 1, it can be hard to evaluate the effect of the river stages fluctuations using the ERI, but it can be useful to understand and back calculate permeability parameters of the foundation soils.
- Norfolk 2 site, the effect of the Mississippi river stages is reflected on the soil resistivity immediately due to the short distance from the landside toe and the river, approximately 1240ft. It was noted that the resistivity of the soil foundations drops when the river stages go up.
- Norfolk 2 site, the changes in the water table due to the changes in the river stages is rapid and it was affected directly by the river stages.
- ERI can be a good field investigation option because it allows continuous monitoring of the site conditions over seasonal changes.

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