ГЕОФИЗИКА, ГЕОФИЗИЧЕСКИЕ МЕТОДЫ ПОИСКОВ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

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A Case Study on Usage of Electrical Resistivity Tomography for Dam Seepage Location, Chesterfield, Missouri

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Four Electrical Resistivity Tomography (ERT) profiles and borehole data were acquired on the front face of the earth-filled dam and on the flanks, constituting Lake #1, in order to locate the seepage zone, the flow path, and to determine possible reasons of the seepage. The seepage, observed a year after the construction in the southwestern part of the lake, was severe and could cause further softening, slippage and erosion of soil, developing of pipe holes, increasing the water outflow and risk to the embankment integrity. The owner agreed to drain the lake in order to acquire geophysical and borehole data. Based on the analyses of the acquired ERT and borehole data, four solution-widened fracture zones trending from southwest to northeast were identified. It was concluded that the seepage pathway beneath the dam was through a solution-widened fracture zone, the top of which constituted the original stream channel.

Keywords: *dam seepage; resistivity and borehole data; fracture zone; ERT profiles.*
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Introduction

The earth-filled dam was constructed and the lake was subsequently filled in 2008 (Figure 1). The embankment is 30 ft high, the normal surface area of the lake is 20 acres, and its height is 51 ft with a length of 425 ft. Lake #1 was constructed on a creek (Figure 2), with a purpose of recreation and housing development. The maximum water depth in the lake is 20 ft.

A year later, after the construction the wet area was noted on the downslope near the southwest corner of the lake. Initially the wet area was considered to be due to groundwater seeping from the higher ground south of lake.

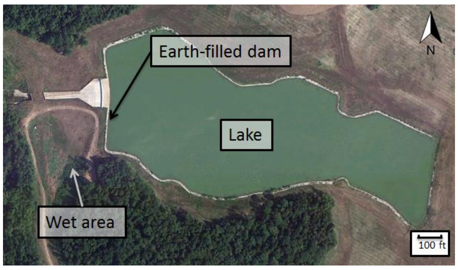


Figure 1. *Aerial image of the study site Lake #1, Missouri*

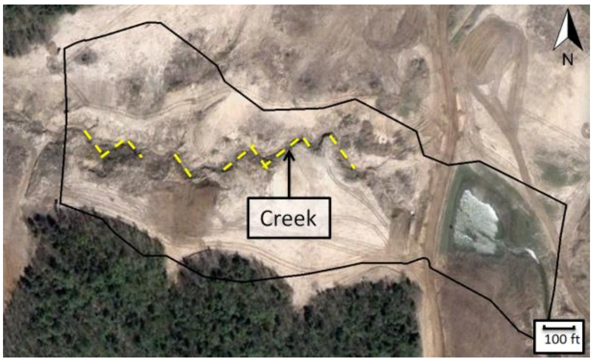


Figure 2. *Aerial image of the study site prior to the lake construction. The dam was constructed in the valley with a creek. Black outline shows the lake area, constructed later. Yellow dashed line shows the stream flow, following the joints sets orientation in the study area*

The visual observation and measurements of the lake level and drainage from an outfall were conducted on a periodic basis after the wet area was noted. Later, based on the review of these observations and site photographs, it was concluded that the seepage area was a result of escaping lake water. Previous investigations showed that ERT is a reliable tool for studying of the fault and karstic features [6, 7]. Total four ERT profiles and nineteen boreholes data sets were acquired at the study site in order to locate the seepage zone and to determine possible reasons of the seepage.

Site location and geological settings

The study site was located in the east-central Missouri (Figure 3) and the geophysical and borehole investigation was focused on rocks of the late Mississippian System and overlying Quaternary soil [5].

The Mississippian rocks are exposed or occurred near the surface in about one-fourth of the state of Missouri (Figure 3). The formations vary laterally and vertically, and often their successions differ in different parts of the state. The Mississippian System is divided into four series: the Kinderhook, Osage, Meramec, and Chester, which have been deposited between the rising Ozark dome and the Transcontinental Arch.

The Kinderhook is mostly comprised of the Hannibal Formation clayey sandstone and fissile siltstone. The Chouteau Group is overlying the Hannibal, and mostly is represented by a sequence of interbedded limestone. The Kinderhook rocks of the Mississippian are followed by a thick limestone section of the Osagean Series of more than 100 ft of thickness. Meramecian Series conformably overlie the Osagean Series in the east-central Missouri and consist of up to 100 ft thick limestone of the Warsaw, Salem, St. Louis, and Ste. Genevieve Formations [8].

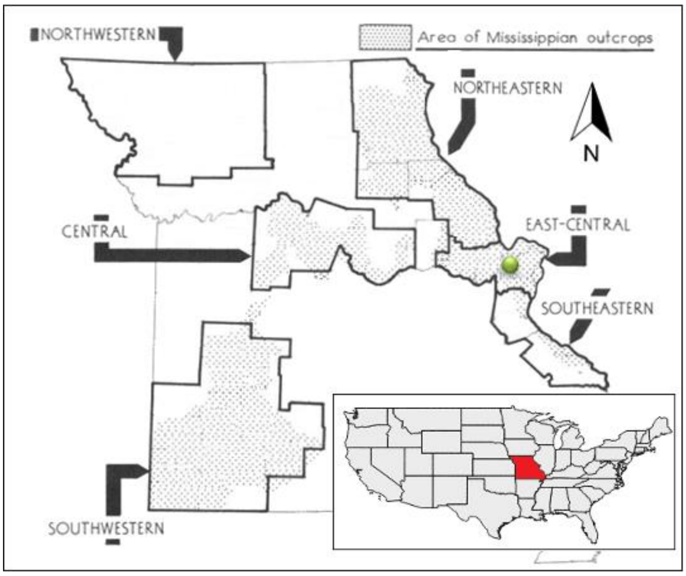


Figure 3. *Regional distribution of outcrops of the Mississippian System in Missouri (modified from [8]). Study site is marked as the green dot*

Surficial material is represented by alluvium comprised of sorted and unsorted gravelly to clayey sediments, colluvium weathered from Pennsylvanian-, Mississippian-, Devonian- and Ordovician-age bedrock, loess, and man-made fill or cut [1].

The thickness of the surficial sediments is variable because of irregularities in the bedrock surface upon which it was deposited. According to the borehole data depth to bedrock at the study site varies from 40 ft to over 60 ft (bedrock was not encountered at the depth of borehole termination).

The study area is located in one of the major karst regions in the state [9]. It is estimated there are about 1,500 caves in the Mississippian rocks through the state of Missouri. Springs are also associated with karst development, and over 1,100 springs are on record [10]. Sinkholes occur in Mississippian and Ordovician carbonate rocks. Mapped faults, known sinkholes and springs in the study area are shown in Figure 4 according the GIS data from [2, 3]. Majority of the faults are trending northwest to north-northwest. It is interesting to note that the major rivers in the area have the same orientation of the flow as the faults. This is related to the joint sets orientation.

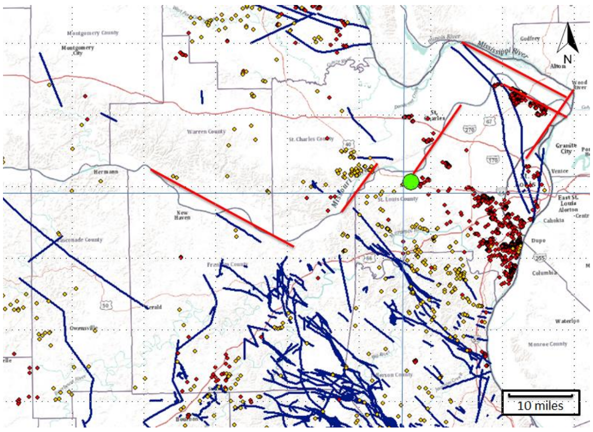


Figure 4. *Mapped faults (marked as blue lines) in the study area trending SSE- NNW. Orientation of the preferential surface water flow (marked as red lines) is similar to the faults orientation. Known sinkholes are marked as red dots. Yellow dots show locations of known springs. Study site is marked as the green dot*

Methodology and layout of study site

Borehole data. Total nineteen boreholes were drilled at the study site. Boreholes B-104, B-103, B-101, B-1, B-102, B-106, B-107, B-112 were located near or on Traverse A (Figure 5). Boreholes B-101, B-106, B-107, B-112 were located approximately at the elevation of 520 ft, at the same elevation as the crest of the dam. Weathered bedrock and fragments of chert were encountered in these boreholes at the depth of 28.5 ft to 40.5 ft. The variation in the depth to bedrock might be explained by the fact that the lake was constructed in the old stream channel valley and the boreholes were located south from the original channel.

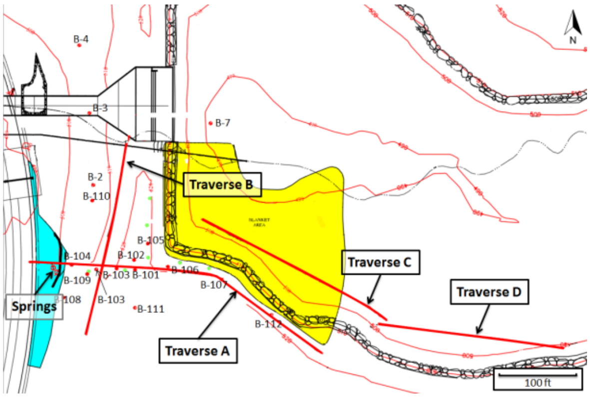


Figure 5. *Map showing location of ERT traverses and boreholes*

Electrical resistivity tomography (ERT) data. Four electrical resistivity profiles were acquired on the surface along A, B, C, and D traverses (Figure 5) in an effort to determine the seepage zone on the west downslope of the embankment dam south of the spillway.

The ERT data were acquired using an AGI SuperSting R8/IP resistivity unit equipped with a dipole-dipole array consisted of 64 electrodes. Typical depth of investigation is 20 percent of the length of the electrical resistivity array. With 64 available electrodes and the required minimum depth of investigation of 60 ft, a 5 ft spacing between the electrodes was chosen for this ERT survey. The ERT data were acquired in January, after several days of heavy rains.

ERT Profile A, acquired on 510-ft Traverse A, was a result of concatenation of two data sets. ERT Profiles B, C and D, acquired on Traverses B, C and D, were 315 ft long each. Traverse A, oriented west-east, was located partially on the constructed embankment and partially on the southern flank of the lake. Traverse B was located on the front face of the embankment and oriented south-north. Traverses C and D were located on the bottom of the lake, which was drained two weeks prior to the ERT data acquisition (Figure 6). The acquired ERT field data were of good quality and were processed using RES2DINV software [4].

Figure 6. *Photograph of the study site on the bottom of the lake (looking west,). ERT cables are set along Traverse C*

Results of interpretation and discussion

All electrical resistivity field data sets were transformed into contoured two-dimensional resistivity images. The contoured values on each ERT profile show distribution of the resistivity in the subsurface along the respective traverses. The depth of investigation extends to the depth of approximately 70 ft in the middle portion of the profiles and decreases toward the ends of the profiles to 0 ft.

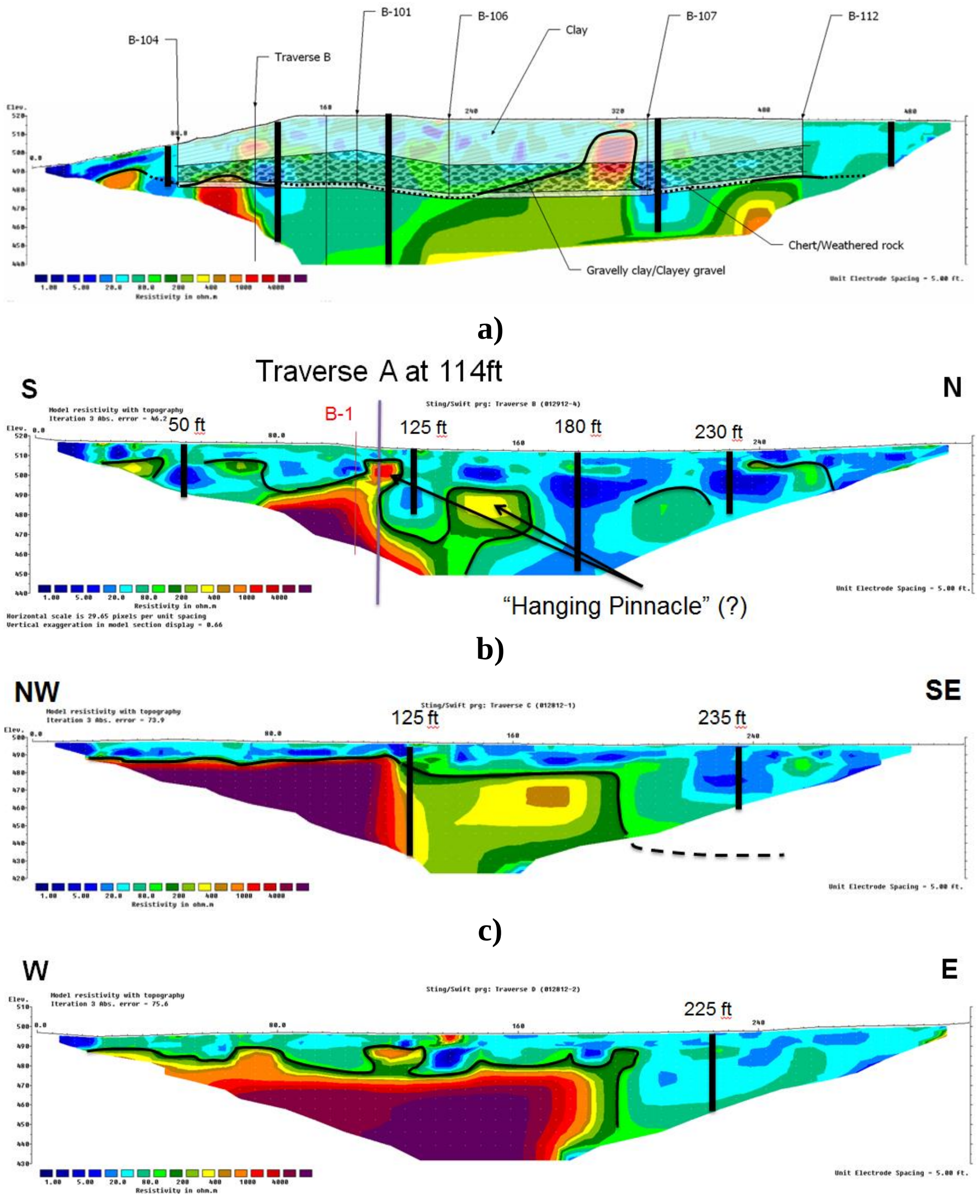
The estimated top of bedrock, where imaged, has been correlated across each resistivity profile (Figure 7). The depths to bedrock correlation was based on available borehole control and the contoured resistivity values. Bedrock, as mapped on the profiles, is typically characterized by resistivity values equal to or in excess of 200 ohm-m, whereas soil and fragments of weathered rock, and chert are typically characterized by resistivity values lower than 200 ohm-m.

Linear features, observed on all four profiles, were interpreted as sets of solution-widened joints, characterized by different degree of clay infill.

The first set of solution-widened joint trends southwest-northeast and was imaged on resistivity Profile A (centered at 70 ft mark; Figure 7a) and resistivity Profile B (centered at 180 ft mark; Figure 7b). This prominent geologic feature, on Profile A, is characterized by a zone (~30 ft wide, extending from top of rock to depths in excess of 20 ft) of anomalously low resistivity values (relative to surrounding resistivity at comparable depths on the same profile and other profiles). This zone of anomalously low bedrock resistivity was interpreted as an area in which rock has been extensively leached and partially replaced by clay or other fine-grained sediment. The same feature, on profile B, is characterized by a zone (~35 ft wide, from top of rock to depths in excess of 20 ft) of low resistivity (relative to surrounding resistivity at comparable depths on the same profile and other profiles).

The fourth set of solution-widened joints trends southwest-northeast and was imaged on resistivity Profile A (centered at 460 ft mark; Figure 7a) and resistivity Profile C (centered at 235 ft mark; Figure 7c). This prominent geologic feature, on Profile A, is characterized by a wide zone (~70 ft wide, extending from top of rock to depths in excess of 30 ft) of anomalously low resistivity values (relative to surrounding resistivity at comparable depths on the same profile and other profiles). This zone of anomalously low bedrock resistivity was interpreted as a possible area in which rock has been extensively leached and partially replaced by clay or other fine-grained sediment. The same feature, on Profile C, is characterized by a zone (~40 ft wide, from top of rock to depths in excess of 40 ft) of low resistivity (relative to surrounding resistivity at comparable depths on the same profile and other profiles). Unfortunately, the ERT image at this location was limited in depth and no conclusion regarding the extent of this lineament could be drawn.

A solution-widened fracture zone mapped on profile D at 225-ft mark (Figure 7d) appears to be wide (over 40 ft) that may be caused by the orientation of this zone. Most likely, this zone is oriented north-west at oblique angle relative to a profile line; however, the orientation cannot be determined confidently due to lack of data. All four mapped lineaments were superposed on a photograph (Figure 8) and a map of faults and structural lineaments in Missouri (Figure 9).



d)

Figure 7. *Interpreted ERT Profiles: a) Profile A with superposed borehole cross-section; b) Profile B; c) Profile C; d) Profile D. Black contour line represents depths to interpreted bedrock (dashed black line represents estimated depth to bedrock). Interpreted solution widened joints are marked as black vertical lines*

Conclusion

Based on the analysis of the acquired electrical resistivity profiles and borehole data, four sets of solution-widened joints trending southwest-northeast were mapped. Orientation of the interpreted solution-widened fracture zones is supported by the geologic studies and mapped faults and lineaments in the study area. It was concluded that the seepage pathway beneath the dam was through a trending southwest-northeast solution-widened fracture zone.

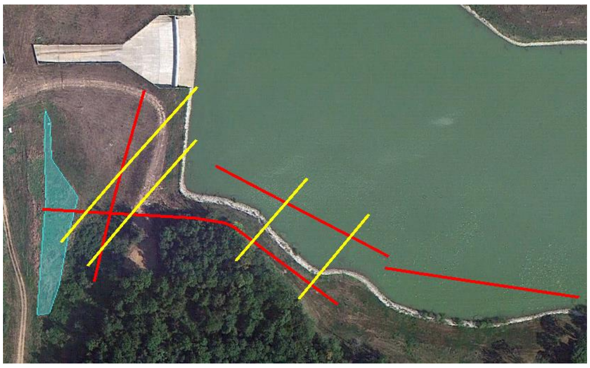


Figure 8. *Interpreted solution-widened joint sets superposed on an aerial photograph of the study site (mark as yellow lines). ERT profile locations are marked as red lines. Lineaments orientation is southeast-northwest*

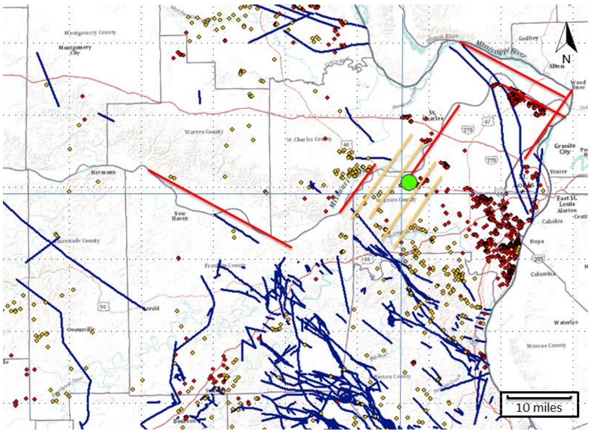


Figure 9. *Interpreted solution-widened joints superposed (not to scale) on a map of known faults and structural lineaments in Missouri [Geoport]. Study site is marked as the green dot. Yellow lines trending southwest-northeast represent orientation of the interpreted lineaments. Red lines show orientation of major rivers in the study area*

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Пример использования метода электротомографии для определения мест утечки в теле плотины, Честерфилд, Миссури

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В статье представлены результаты исследования земляной плотины пруда и её флангов по данным четырех профилей электротомографии (ERT) и сети скважин для определения зон повышенной проницаемости, путей фильтрации и выяснения возможных причин утечки воды. Утечка в юго-западной части водоема, выявленная через год после окончания строительства, могла привести к разуплотнению, деформации и суффозии грунта, развитию сквозных размывов, обусловливая при этом увеличение стока и риск разрушения дамбы. Владелец согласился осушить водоем для сбора геофизических и скважинных данных. На основе анализа полученных данных электротомографии и бурения были выявлены четыре зоны трещиноватости, ориентированные с юго-запада на северо-восток. В результате работ было установлено, что повышенный уровень фильтрации воды под телом плотины связан с зоной трещиноватости, в верхней части которой образовался канал утечки.

Ключевые слова: *утечка плотины, электротомография, скважинные данные, зона трещиноватости, профили ERT.*