Geophysical Investigation of Flood Control Levees in the Sacramento-San Joaquin Estuary, CA.

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The California State University
WATER RESOURCES AND POLICY INITIATIVES

The Levee Project

The Levee Project is a collaborative educational project between CSU Stanislaus, Merced College, and Delta College. Its goal is to have students from the different institutions meet, work collaborative in the data acquisition, and develop interest in graduating from college with a STEM degree. Our "graduates" have used the data to prepare posters (AEG, GSA, WRPI, COAST, NASA, and JPL) and to apply for graduate school. Besides, there is nothing like a sunny day in the estuary!

Figure 3: The surge of water caused by the 1969 levee break on the South side of Sherman Island.

The Research Area

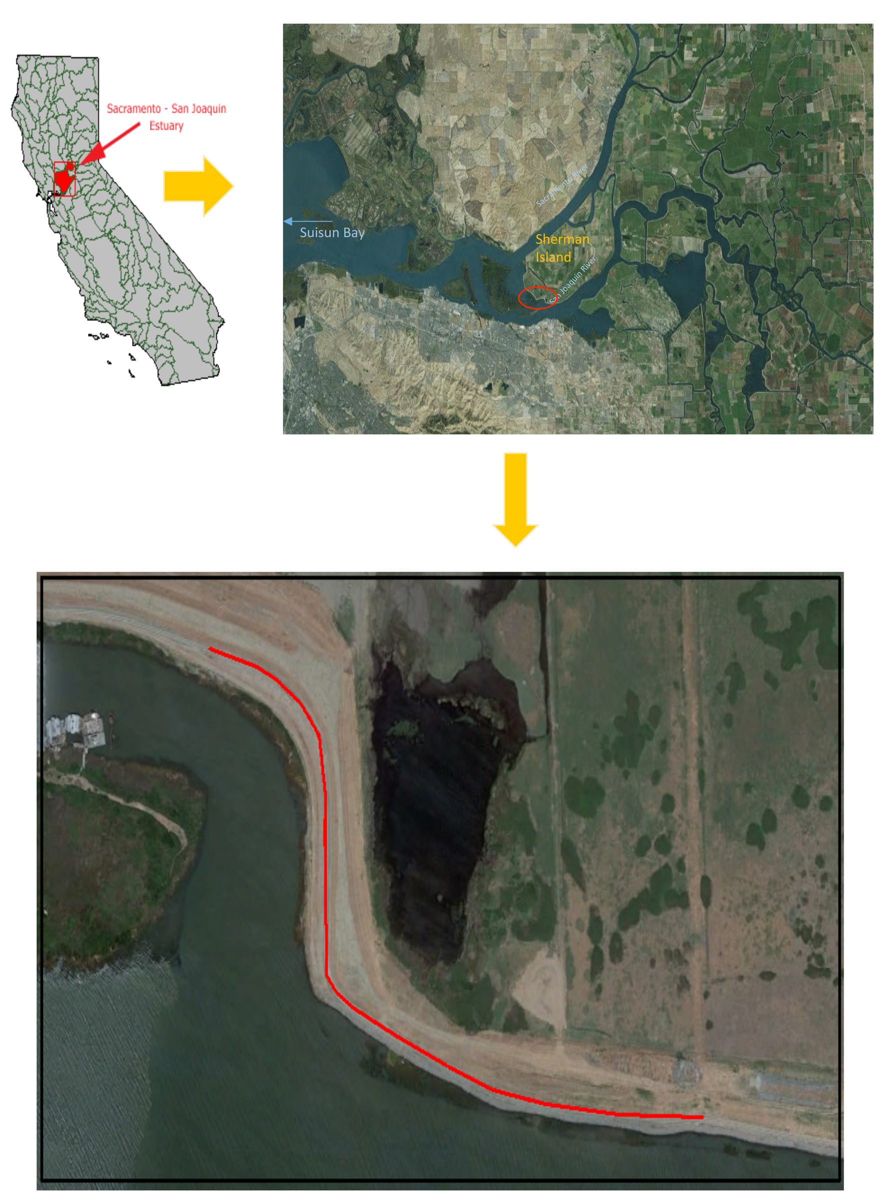
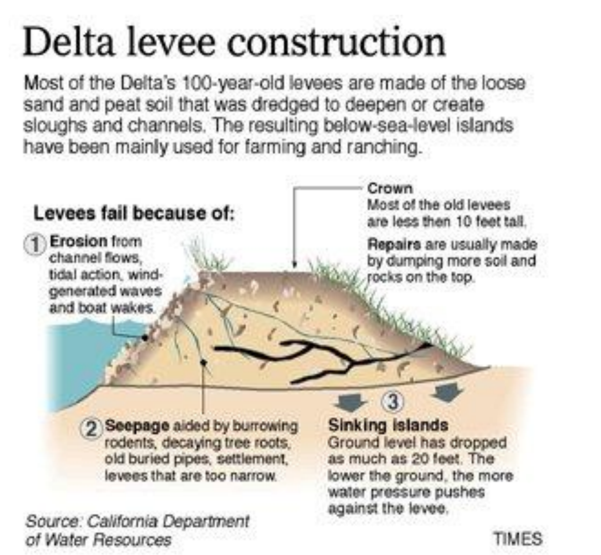


Figure 1: Images of the research area.

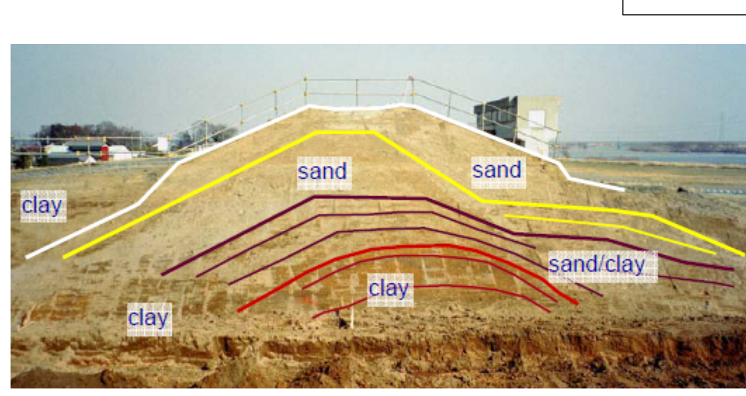
Reasons for concern:

- Over 25 million Californians are provided drinking water from water that has been channeled through the estuary.
- 19th century farmers built up natural levees using the material available; mostly the fertile, organic rich soil they were using for farming. These early levees did little to hold back the rivers.
- Late 19th – mid 20th century levees were mostly built up by materials that were dredged from the river bottoms.
- 450,000 acres had been reclaimed for agriculture by 1930 and $500 million in agriculture come out of the estuary region today.
- Due to the oxidation of peat from drainage and groundwater pumping, subsidence rates of 1-3 in/yr are pervasive, decreasing the lateral support of the levees.
- The materials that compose the levees are a major factor in the structural stability of the levee. The dredged, poorly compacted sediments that make up the levee foundations vary compositionally from island to island depending on the material present. The heterogeneity of the materials throughout individual levees lead to unequal saturation and seepage, which can add to the instability of a particular levee.



← The construction of the flood control levees in the California Estuary and their inherent weaknesses.

In comparison, below, the ideal construction of a flood control levee complete with a clay core to inhibit the seepage of water.



Challenges

- 1000 + miles of levee system
- Ground deformation due to peat oxidation
- Internal flaws within the levee cannot be seen on the surface

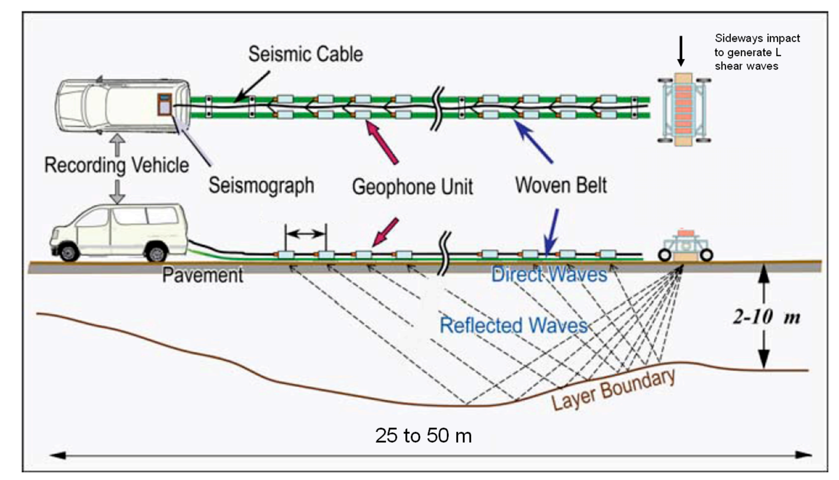
Research objectives

- To test methods of geophysical surveying to determine if they are viable methods to distinguish the constitution and properties of the materials of which flood control levees are composed.
- To understand the heterogeneity of the levee materials that were constructed through the early 1900's and understand the materials used to repair a 1969 levee break on the South side of Sherman Island.
- To determine the effectiveness of our geophysical surveys and diagnose the current health of the levees. A priority is to distribute our results to levee owners who support our research.
- To introduce students of Junior Colleges to research at the university level; this includes the collection, processing, analysis and presentation of the geophysical data.

Geophysical methods

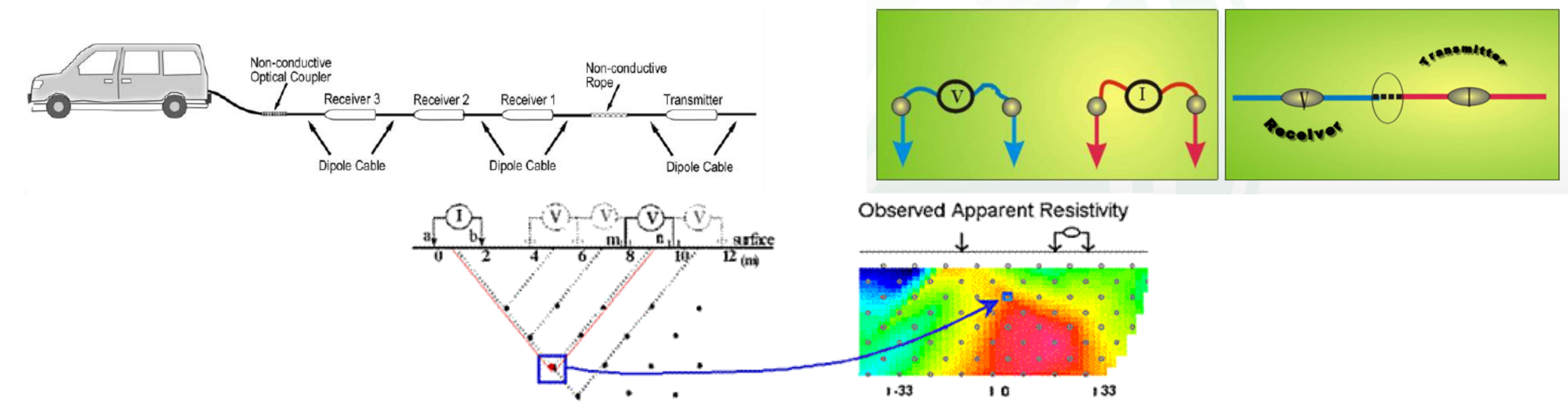
Considering the extensive mileage of the levee system, we decided to concentrate on techniques that would combine ease of deployment, capability to develop tomograms, reproducibility, and correlation with geotechnical properties.

Shear-wave velocity surveys



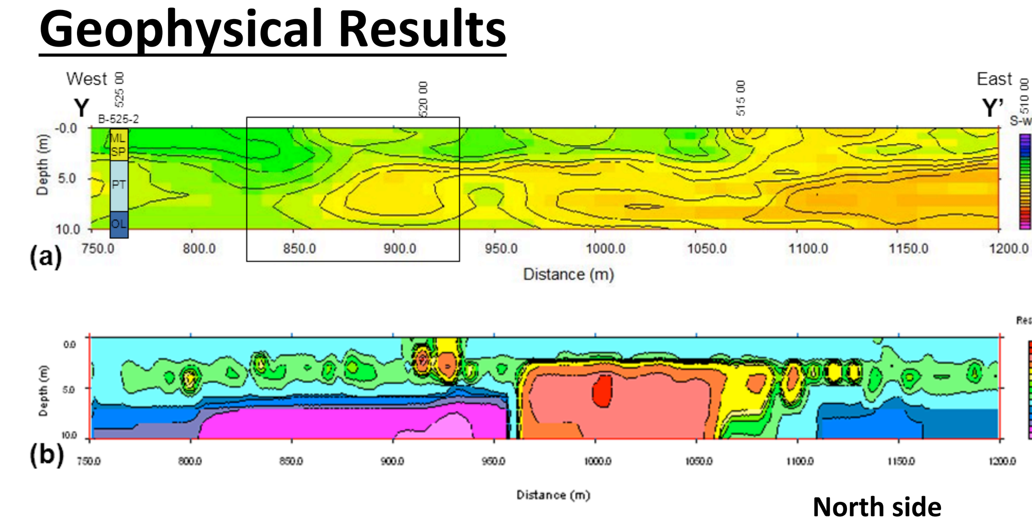
- Geophones are mounted on a landstreamer, which can then be quickly repositioned every 2.5 m to acquire a set of data.
- We generate a shear wave by impact of a hammer on a beam.
- The shear wave thus produced disperses based on wavelength. Longer wavelengths penetrate deeper before reflecting.
- The time-distance records are transformed into a frequency-velocity spectrum, from which the shear-wave velocity can be determined for different depths.

Capacitively-coupled resistivity (CCR) surveys



- The CCR survey is a dipole-dipole survey that uses one transmitter and several receivers that are dragged behind a person or vehicle, as shown.
- The data in the survey is collected at variable depths depending on the transmitter and receiver geometry.
- We used five receivers, separated from each other by distance *a*, so each electric pulse of the transmitter generates 5 data points at different depths. The array is dragged along the ground at a slow speed (60 m/min) and a new pulse is delivered every 0.5 sec, so apparent resistivities are gathered every half meter (the precise number is determined by GPS), so in a very short time a dense swath of five data points at different depths can be acquired over a distance of several hundreds of meters. Our survey lines had typical lengths or 500 to 1,000 m.

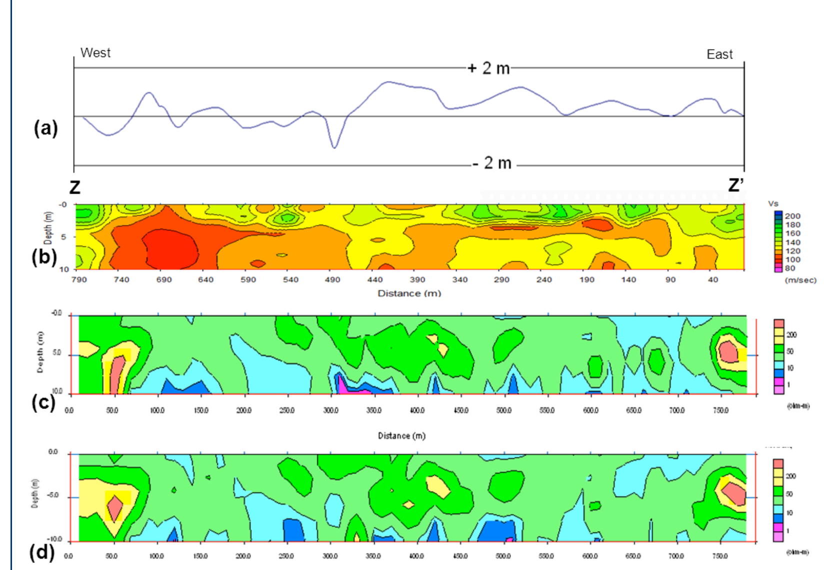
Geophysical Results



South Side

- Note layering.

The resistivity tomogram (Figure b) shows two features of considerable interest. The first one is the low resistivity interval from 825 to 960m, which corresponds fairly well with the reported location of the 1969 breach. We speculate that this may represent the abundance of conductive clays in the sediment that was pumped in between the skeleton of boulders during the repair. The second striking feature is the zone of high resistivity between 960 and 1100 m in Figure 11b. This feature is so striking that we repeated the survey on two different occasions, and on the second occasion used forward and reverse surveys to test for reproducibility, with consistent results. We believe it could be a sand or gravel-filled paleochannel that, at some point, might have cut through the marshland that eventually would turn into fibrous peat.



North side

- Note the loss of layering in resistivity (c and d).

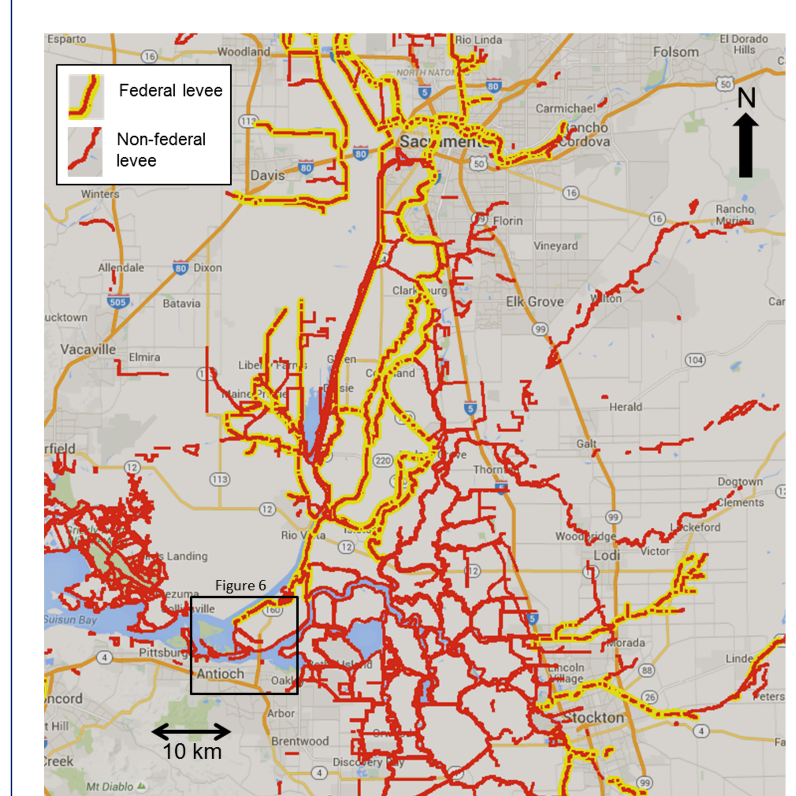
The two data sets were taken during two different surveys and resulted in very similar inversions proving our results are very reproducible.

Figure b (on the left) depicts the shear-wave velocity tomogram for Stretch 3.

The seismic shear-wave velocity is generally below 160 m/s for both the body of the levee (upper 4 m) and the underlying ground. This is particularly true for the interval between 750 and 600m.

There does not seem to be an obvious correlation between the shear-wave velocity (b) and the degree of deformation of the crown of the levee (a), however, which make us think that the deformation is due largely to differential compaction of deep subsurface materials (hence the "disorganized" resistivity tomogram (c)), rather to changes in the internal strength of the levee itself.

Significance of the Research



- The estuary of the Sacramento and San Joaquin rivers comprises 700 miles of waterways and intervening islands bound by over 1,100 miles of levees critical for the region's agriculture.
- Since 1900 there have been 160 levee failures for reasons related to four fundamental problems: (1) heterogeneity and irregular compaction of levee materials, (2) oxidation of peat and uneven subsidence of the adjacent land and levee structures themselves, (3) weakening of the levees due to burrowing, landsliding, and soil cracking, and (4) overtopping due to high stage flooding.
- Levee failures, although not common, have on occasions led to large losses of life and property, which is why maintaining them in proper function is such a large priority among levee owners and disaster-management agencies. Honing the methodology used to "audit" flood-control levees for integrity and stability would allow levee owners, management districts, or responsible agencies to perform maintenance or levee reconstruction on a timely basis.
- The levees of the estuary also play an important role in conveying water from the Sacramento River to the CVP and SWP pumping plants. By concentrating flow to narrow, deep channels, the levees contribute to the high water transmissivity of the upper estuary.

Conclusion

- With over 1,100 miles of levees, the California estuary supports $500 million in local agriculture and drinking water for 23 million Californians. It is paramount that this infrastructure is maintained and monitored closely. The estimated repair cost for a breech ranges from $40 to $200 million. With subsidence rates of 1-3 in/yr and the constant risk of an earthquake on the faults of the San Andreas Fault system, the century old levees of the estuary will be sorely tried in the future. The methods of investigation in this study have been combined to produce a new approach for the assessment of levee condition in the California estuary. This study is meant to emphasize the ability to gain high resolution images of problematic areas within the levees. The results of these techniques have been compared to borehole log data and are currently being compared to electromagnetic data previously collected.
- Our results conclude that our geophysical methods for levee investigation yield usable images of the clear heterogeneity and inherent weakness of the levees. Capacitively- coupled resistivity inversions map the different materials that constitute the levees and their foundations, clearly identifying the underlying peat layers, the clay matrix used to repair the 1969 levee breech, and likely paleochannels where seepage could concentrate. The surface-wave shear velocity inversions indicate areas of low shear strength, thus pinpointing areas of poorly compacted sediment. The 1969 break is clearly imaged by both surveys proving that geophysics provides a viable way of monitoring the levee system that makes up the California estuary.
- The geophysical methods most importantly represent a cost- effective, non-invasive technique to image the subsurface of the flood control levees, and to diagnose potential problems in the form of saturated or materials with low compaction and strength within the soils that constitute the levees.
- The incorporation of Community College students to work on the project gives the students invaluable experience collecting data and conducting research that benefits their community.

Acknowledgements

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- The multiple student volunteers who aided us in data collection and analysis, notably Rene Toth, Reno Bianchi, Eilbron Younan, and Matthew Uychutin.