Prediction of Piping Erosion Under Levees Using Empirical Model

Description

This research explores the use of an empirical model that uses traditional design variables in addition to previous levee performance and river geomorphology to identify locations most susceptible to piping during flood events. The research focuses on levees of the Prairie Du Rocher and Fort Charles Levee Districts of southwestern Illinois and the Sacramento and Feather River levees in Sacramento, CA. Observation of excessive seepage or piping incidents made by personnel present during past flood events were used in the modeling as an indicator of levee performance. Among the variables that proved to be significant in building the empirical model were the confining layer thickness on the land side of the levee Z_b, the effective aquifer grain size parameter D_{10}, a variable designed to reflect the geomorphologic conditions G, and an indicator variable designating the location of previous excessive underseepage conditions along the levee. Evidence of previous piping locations was shown to be the best indicator of future piping locations. In cases where previous piping locations were unknown, the geomorphology underlying and surrounding the levee was the next best indicator. This concept of levee alignment and the influence of geomorphology on seepage is widely accepted and described in TM 3-424, (Waterways Experiment Station 1956).

The model is applied using a Geospatial Information System (GIS) that defines selected levee properties, model parameters and the levee footprint, in real-world coordinates. The model run is performed within the GIS and results are displayed in map form for immediate use. The results include a base map, which is usually a digital ortho-photo quadrangle with the levee footprint identified and separated into 200-ft-long segments. Each segment is categorized by the model run as having a high, medium or low probability of piping in future floods. The segments are color coded by category; high (red), medium (yellow) and low (green). The model parameters can also be displayed graphically, such as contours of the Z_b and D_{10}, geomorphology, and previous piping locations.

Issue

As floodwaters rise against the riverside slope of a levee, hydrostatic pressure builds within the foundation and the embankment soils. Conventional underseepage analyses include the estimation of hydrostatic pressures within these soils to permit the incorporation of prevention methods, such as relief wells on the land side of the levee, to reduce the potential for piping. However, once a levee is subjected to excessive hydrostatic pressures and sand boils (internal erosion or piping) develop they tend to reoccur during later floods.

Corps of Engineers field personnel have noticed sand boils reoccurring at the same locations during floods of the same or lower stage than that which initiated the boil. This has led engineers to revisit the term “cumulative effects of piping,” which was first described in the 1950’s (e.g., Turnbull et. al., WES TM 3-424). This concept implies that the levee foundation is deteriorating with subsequent piping and could eventually fail if not rehabilitated.

The conventional seepage analysis will predict whether piping is likely to occur along a typical levee reach using average material property values. The analysis cannot predict where in the reach that it is likely to occur, because sand boils coincide with anomalous properties. Therefore in typical practice, the levee reach is designed uniformly based on expected hydrostatic pressures, assuming constant soil properties applied along its length.

Further, such representative soil properties are based on local experience and samples collected from sparsely spaced borings, generally 1000 ft or more apart. Thus, the amount of site specific data collected for a levee reach is small, however the variation of soil properties within that reach can be significant. Therefore, conventional analyses are often inaccurate and the reliability of the analysis is uncertain. Further, the documented contribution of cumulative piping effects is not considered in such analyses. Thus, an empirical study of piping incidence is warranted, given our limited data available for seepage analyses and the inherent variance of natural materials. An empirical study of piping incidence can further our understanding of the influencing parameters and be used to evaluate the reliability of previous seepage analyses.

Potential Users

Engineers who conduct levee seepage analyses. Decision-makers, levee inspectors and field personnel who monitor levee performance during normal and emergency response operations.

Products

Technical Report ERDC-TR-04-7: Describes development of the prediction tool and application to Mississippi River levees.

<u>Empirical statistical model</u> for the prediction of piping

<u>Piping observation sheet</u> developed to define seepage severity and standardize documentation of seepage and piping throughout the Corps and geotechnical community concerned with levee performance

Extensive piping spatial database for Prairie Du Rocher, Ft. Chartres, East Sacramento River and Feather River levee systems

Extensive database of seepage and piping technical references

To be completed September 2008:

<u>Guidance manual</u> for USACE and private or commercial application of the model

<u>Technical report ERDC TR-08-X</u> documenting application of prediction tool along Sacramento and Feather River Levees, CA

Benefits

The visual results from the model are simple to interpret and therefore immediately useful. The maps may be used by a levee inspector monitoring levees during flooding, by decision makers concerned with measuring levee performance, and prioritizing maintenance based on vulnerability to piping, hydraulic engineers conducting possible inundation mapping, etc.

Most importantly, a levee design engineer conducting seepage analyses can use the results from the analysis to quickly identify likely problem areas, before levee reaches are defined for seepage analysis. Statistically, the four most significant parameters correlated to the incidence of piping under Mississippi River levees have been defined by this research, previous incidence of piping being the most significant. If any of these four parameters can be mapped along a proposed or existing levee alignment, the most likely areas for piping incidence can be identified. The engineer can then give these areas extra consideration.

This research exemplifies the value of consistent and thorough record keeping during flood fights. In addition, the research suggests that the piping process progressively deteriorates the ability of the subsurface to withstand flow, making a particular location increasingly susceptible to further piping.

The model can be applied to other river levee systems for vulnerability assessment of levee conditions to piping conditions.

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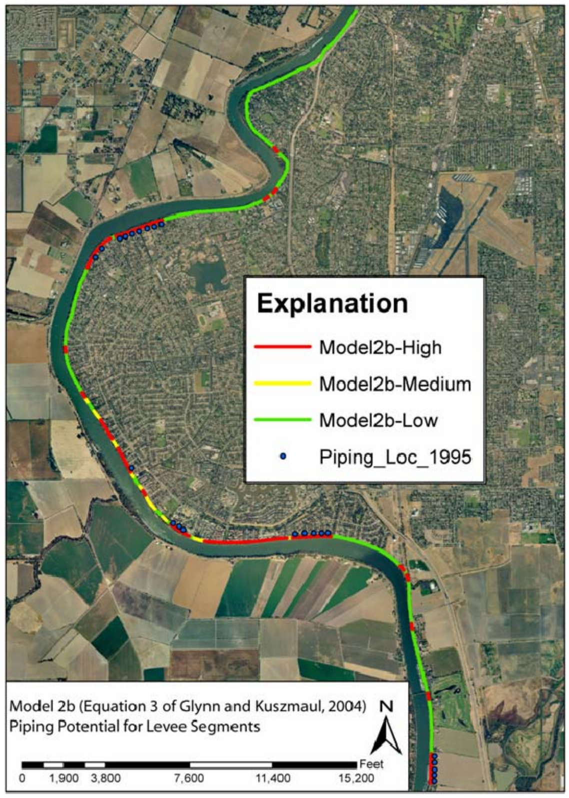

Model results illustrating vulnerability to piping using coded levee segments in relation to locations of piping observations in 1995, Sacramento River, California.