Abstract

Select Topics on the Static and Dynamic Response and Performance of Earthen
Levees

by

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Flooding is one of the most dangerous and costly natural hazards. The U.S., like
many other countries around the world, has suffered many floods through the years.
Flood-protection systems are therefore important engineering systems for handling
water resources, but also protecting urban areas, important civil infrastructure elements
and agricultural land properties that lie in or cross potential floodplains.

As part of a collaborative research investigation carried out to study the
performance of the New Orleans flood-protection system during and after the passage of
Hurricane Katrina, in August 29, 2005, funded by the National Science Foundation
(NSF), together with the Center for Information Technology Research in the Interest of
Society (CITRIS), the performance of levees at two sites during the passage of
Hurricane Katrina have been investigated. The investigation of these two levee sites
included forensics, geotechnical field investigations, field and laboratory testing, finite
element analyses, and conventional limit equilibrium slope stability analyses.

The London Avenue Canal North breach and distressed sites provided a
challenging and important pair of case-histories. The analyses were able to successfully
capture the observed field performance of the breach on the west bank, and also the
distressed section on the east bank. Slight differences in geometry resulted in the failure at one bank (i.e. west bank), whereas the other one (i.e. east bank) remained marginally stable. The primary mode of failure for the west bank was a lateral translational foundation failure at the interface between the silty clay and the underlying clayey sands. This sliding was made possible by the high porewater pressures in the foundation soils at and near the base of the inboard-side levee toe due to underseepage. This agrees well with field evidence of sand boils observed at the inboard side of the floodwall at the east bank site.

The 17th Street Canal breach at the east bank of the canal was also a very challenging case study to analyze. The subsurface soil conditions were rather complex, and studying the regional geology was particularly useful for identifying the critical soil layers. A thin organic silty clay layer, formed during a previous hurricane was identified at many different locations across the site. Laboratory vane shear testing showed that this soil layer was weak, and also highly sensitive. Overall, it was concluded that there were three potentially critical failure modes at this site: (a) a lateral translational foundation failure along the sensitive organic silty clay layer within the “marsh” deposits, (b) lateral frictional failure through the “marsh” deposits due to increased pore-pressures and, (c) a deeper rotational foundation failure through the silt grey clays. The results of the analyses showed that the former was the weakest of the three. This mode of failure agrees very well with field evidence of part of the levee having translated horizontally though a lateral distance of approximately 49 ft.

Finally, distress was also observed at the west bank, directly across the east bank breach, at the 17th Street Canal. Field investigation showed very similar subsurface soil conditions between the two banks, however, differences in the thickness of the
marsh deposits and the location of the sensitive organic silty clay layer with respect to the tips of the sheetpiles, rendered this levee section slightly more stable for the storm surge level. The analyses also showed that an additional one to two feet of storm surge would have resulted in a breach at this location, as well.

In the wake of Hurricane Katrina and the devastation in New Orleans, Californians have been urged to address the flooding risk associated with potential failures of the aging and deteriorating flood protection systems in the Sacramento and San Joaquin River Valleys and Delta, an intricate system of dams, levees, weirs and bypass channels that was constructed over the past 140 years. The present day levees are at risk from many sources of failure including seepage (both underseepage and through seepage), overtopping, erosion, and instability due to unforeseeable defects. In the State of California, however, there is an added risk due to the seismotectonic setting.

In the second part of the study, an approach for studying the dynamic response and performance of levees was developed by performing 2-D, equivalent-linear, finite element analyses using QUAD4M and a simplified procedure for the evaluation of the seismic vulnerability of levees in select California regions was developed. A wide range of input ground motions were used in an effort to capture and assess the variability in response and performance due to multiple possible earthquake scenarios.

Three aspects of the dynamic response and performance were studied in more detail: the site and topographic effects on the peak ground acceleration, the shear stresses and the cyclic stress ratios for a series of profiles throughout the levee sites, and the permanent seismic deviatoric-type displacements for select “Newmark-type” sliding surfaces. Recommendations for assessing these three aspects of dynamic response of the three levee sites are presented and discussed.
Information regarding the site conditions and levee geometries at various locations in Central California was collected, and 3 representative cross-sections were developed for use in the analyses. The three levee cross-sections that were analyzed are representative of (A) the Stockton area, (B) the West Sacramento area and (C) the Marysville (Yuba) area. The three levee sites showed different site response. Levee B was the “softer” site and Levee C was the “stiffer” site. For the topographic effects, the analyses showed a crest amplification factor of 1.15 to 1.7 depending on the shaking level and the site conditions.

Equivalent cyclic stress ratio spatial contour charts have been developed for the three levee sites for a range of shaking levels. These charts are recommended for use as part of a soil liquefaction triggering evaluation for levee sites with soil layers that are potentially susceptible to liquefaction. The recommended CSR$_{eq}$ charts are for four different shaking levels, and should not be extrapolated to higher intensity levels of shaking.

Four critical sliding surfaces have been selected for the evaluation of permanent seismic deviatoric type displacements for each of the three representative levee cross-sections studied. The variability of the seismic coefficients for each surface was found to be strongly correlated with the degraded site period, indicating that for earth embankments of small heights (~35 feet and less), the overall site response is more important than the response of the sliding (displacing) mass itself. Seismic displacements were calculated using a decoupled equivalent-linear, Newmark-type approach. The observed variability in the computed seismic displacements due to the different input ground motions was also significant. The seismic displacements were best correlated to the Peak Ground Velocity (PGV) of the input ground motion.
The simplified procedure developed in this study was used to calculate the liquefaction potential and the expected resulting seismically induced displacements for two case-studies of levee performance during an earthquake event. Unfortunately, such case studies are limited as was the available geotechnical information for the two cases that were used for this study. Therefore, the comparison of the computed vs. the observed behavior is only a first order cursory check of the proposed procedures. The comparison showed satisfactory results. For the Industrial site that experienced only minor cracking, the proposed simplified procedure estimated the displacements to be 2cm (probability of exceedance 50%), with ranges between 1 cm and 4 cm for a probability of exceedance 16% and 84% respectively. For the Artichoke Farm, that experienced 60 cm of lateral spreading, the proposed simplified procedure estimated the displacements to be 30 cm (probability of exceedance 50%), with ranges between 15 cm and 60cm for a probability of exceedance 16% and 84% respectively.


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