
DYNAMIC STABILITY ANALYSIS OF SAN PABLO DAM

Contra Costa County, California

Prepared for:

East Bay Municipal Utility District

375 Eleventh Street

Oakland, CA 94607

October 2004

Project No. 8758

Volume 1 of 2

EXECUTIVE SUMMARY

The following report presents results of a study performed by Geomatrix Consultants, Inc. (Geomatrix) of the seismic stability of San Pablo Dam (State Dam Number 31-6). The dam is located in Contra Costa County, California and is owned and operated by the East Bay Municipal Utility District (EBMUD). The California Department of Water Resources, Division of Safety of Dams (DSOD), recently reviewed previous seismic stability reports for the dam and concluded that the seismic hazard at the dam site has increased from that estimated in previous studies. The DSOD also determined that San Pablo Dam required a re-evaluation of its seismic stability using modern dynamic analysis techniques.

The scope of work for Geomatrix's study included reviewing the existing data, performing field exploration and laboratory testing, developing design earthquake ground motions, performing engineering analyses to evaluate the dynamic stability of the dam, and preparing this report summarizing the results of the study.

Ground motions were estimated for a maximum credible earthquake (MCE) on the Hayward-Rodgers Creek fault with a moment magnitude of $7 \frac{1}{4}$, at a distance of 3 km from the site. The peak ground acceleration for this event is about 0.91g. The 84th percentile response spectrum and spectrum-matched time history were developed for use in the analyses.

Based on a review of available data, and the field exploration program performed for this study, three embankment cross-sections were developed showing the various material zones. The profile through the maximum height of the embankment was selected for the stability analyses.

The results of classification tests on the embankment zones and foundation alluvium were used together with the modified Chinese criteria of Andrews and Martin (2000), and Seed et al (2003) to assess the liquefaction susceptibility. The results of this assessment indicated that the clayey puddle core, the fine-grained zones of the foundation alluvium, and the compacted upstream and downstream buttress materials are not susceptible to liquefaction; however, the hydraulic fill shell zones and the coarse-grained alluvium are susceptible to liquefaction.

Standard penetration test (SPT) blow counts were measured (during this study) in eight borings drilled within the embankment and foundation. The results of the SPT data were used to estimate the cyclic resistance of the soils for the liquefaction assessment.

Static finite element analyses were performed to evaluate initial stresses within the embankment and foundation before the earthquake. The results of these analyses were used to estimate the dynamic properties and the cyclic strength of the embankment and foundation zones.

Dynamic analyses were performed to estimate the earthquake-induced stresses, accelerations, and seismic coefficient time histories for potential sliding surfaces within the upstream and downstream slopes of the dam. Dynamic material properties were based on shear wave velocity measurements. Strain dependent modulus and damping relationships were estimated using published relationships. The results of the dynamic analysis were used to assess the potential for liquefaction, and the earthquake-induced deformation of the upstream slope.

Earthquake-induced stresses were compared with the cyclic strength (cyclic resistance ratio) of the embankment and foundation soils to estimate factors of safety against the triggering of liquefaction. The computed factors of safety were less than 1.0 for all of the saturated zones within the embankment and foundation, indicating that liquefaction likely will occur in most of the saturated, coarse-grained zones of the shell and foundation alluvium.

Slope stability analyses were performed for the upstream and downstream slopes. The stability analyses were performed for conditions during or immediately following earthquake shaking. The effects of liquefaction that may be induced by earthquake shaking were incorporated into the stability analyses using undrained residual strengths appropriate for the liquefied soils.

A post-earthquake factor of safety of 1.24 was computed for the upstream slope, indicating that the slope should remain stable after earthquake shaking, even if liquefaction occurs within the shell and foundation alluvium beneath the upstream buttress. Permanent deformations for the upstream slope were estimated using the yield acceleration concept. The estimated permanent deformations of the upstream slope are about 2 to 3 feet.

The computed factor of safety for the downstream slope was 0.59, indicating an unstable slope. The permanent deformation within the embankment, including the downstream slope, was then estimated using nonlinear, effective stress and total stress, dynamic finite difference analyses.

The effective stress analysis uses a non-linear hypoplasticity constitutive model with strength parameters calibrated using SPT data. The total stress analysis uses a Mohr-Coulomb constitutive model and total strength parameters based on the undrained residual strength of the liquefied soils.

The effective stress analysis was first performed using an acceleration time history recorded in the vicinity of the dam during the 1989 Loma Prieta earthquake. The results of this analysis were compared to the observed performance of the dam during the earthquake. The computed crest settlement was on the order of 2 inches. Since the inspection of the dam after the earthquake reported negligible settlements (i.e. less than an inch), the results of the analysis appear to be slightly conservative.

Analyses of the embankment were then performed using the ground motions from the MCE on the Hayward-Rodgers Creek fault. The reservoir elevation was assumed at its maximum operating level. The results of the analysis indicate that the embankment would deform in the downstream direction. The computed total crest settlement at the end of earthquake shaking exceeded 30 feet, indicating that the dam will be overtopped for this reservoir level. The analysis was repeated with the reservoir level drawn down 20 feet. The computed crest settlement was about 35 feet. The analyses were repeated for the lower reservoir level using the total stress approach. The computed crest settlements were between about 30 and 34 feet, for the range of residual strengths used in the analysis.

To verify the results of the nonlinear finite difference analyses, limit-equilibrium slope stability analyses were performed on the deformed embankment shapes. The results of the post-earthquake stability analyses indicate that the deformed embankment with the lowered level will have a stable configuration after the earthquake.

Based on the results of the studies described in this report, Geomatrix recommends that remedial measures be explored to stabilize the downstream slope of the embankment.