Evaluating the Levees in California’s Central Valley

by Anirban Bhattacharyya and Graham Bradner, GEI Consultants, Inc., Rancho Cordova, California; and Mike Inamine, California Department of Water Resources, Sacramento

California’s Central Valley, one of the fastest growing regions in the country’s most populous state, faces significant flood risks from a number of major rivers, their tributaries and other watercourses. Flood control in the Central Valley is carried out jointly by the State of California and the federal government, primarily though a vast network of levees stretching throughout the valley. These levees were constructed in stages during the last 150 years. Many were poorly built or placed on inadequate foundations, while others have been inadequately maintained. Recent inspections have raised serious questions regarding the integrity of this aging levee network. In 2006, Governor Arnold Schwarzenegger signed Executive Order S-01-06, directing the State of California, Department of Water Resources to identify the levee deficiencies and repair the critically damaged levees. In response to this, DWR (continued on page 20)

Boulanger, Davis, Hertel and Knight Elected

In recent balloting, Ross W. Boulanger, Walter L. Davis, Daniel J. Hertel and Karen A. Knight were elected to three-year terms on the USSD Board of Directors. Boulanger and Knight were elected to their first terms; Davis and Hertel to their second. Other candidates were William Christman, Joel Galt, Gerard E. Reed III and John S. Wolfhope. The new Board Members will begin serving their terms during the 2009 Annual Meeting in Nashville.

(continued on page 38)

Hinze Dam Upgrade Construction Progressing

by Mark G. Barkau, PE, URS Australia Pty Ltd, Surfers Paradise, Queensland, Australia

Hinze Dam is located approximately 25 kilometers southwest of Surfers Paradise in the Gold Coast region of southern Queensland, Australia. The dam was initially constructed in the mid-70s (Stage 1) and was later raised in the late 80s (Stage 2). In October 2006, the Gold Coast City Council (GCCC) contracted the Hinze Dam Alliance to design and deliver the Hinze Dam Stage 3 Upgrade and in December 2007, ground was broken. The project is scheduled for completion by December 2010.

Stage 1 Overview

The Stage 1 dam was designed by the Department of Local Government (DLG) on behalf of the GCCC. Construction was carried

(continued on page 24)

Additional Items of Interest

News of Members ......................................... 23
Seismic Performance of Rockfill Dams .............. 30
New Members ........................................... 40
California Levees (continued)

initiated a program to comprehensively evaluate approximately 1,600 miles of Project levees and appurtenant non-Project levees in the Central Valley. This program is currently underway.

Introduction

California’s Central Valley stretches from Shasta County in the north to Kern County in the south, covering an area that is approximately 450 miles long and 40 to 60 miles wide. This area is largely composed of the floodplains of two major rivers — the Sacramento and the San Joaquin — as well as several other rivers and tributaries. The Central Valley encompasses 18 counties with a total of over five million people and over 42,000 square miles — one-sixth of the population and more than two-fifths of the land area of the state. The valley contains some of California’s fastest growing urban centers, as well as vast swathes of agricultural lands.

California is known nationally and internationally for the breadth and productivity of its agriculture. Some of the most productive of California’s agricultural counties are in the Central Valley, commonly referred to as the “fruit basket of the world.” Of the Valley’s 18 counties, 15 are among the 25 most productive of the state’s agricultural counties. In 2002, four of the top five counties in agricultural sales in the U.S. were from the Central Valley, with combined sales of more than $9 billion.

While agriculture remains the primary industry in much of the Central Valley, urban populations in Yuba City/Marysville, Sacramento and the Stockton/Lathrop areas have also developed diverse economies.

Vulnerability to Flooding

The Central Valley’s flood protection system includes approximately 1,600 miles of state and federal levees (termed “project” levees) and thousands of additional miles of privately-owned and locally-maintained levees (“non-project” levees). The levees were initially built in the mid- to late-19th century to prevent flooding on prime agricultural land. Most of the land was at sea level, and levees were frequently constructed on top of natural-occurring earthen barriers, or escarpments, that formed along rivers and sloughs near the margins of the active meander belt. Initially, the levees were built using hand shovels and wheelbarrows. Later, clamshell dredges were used to remove material from adjacent riverbeds, which was then placed on the levees to increase their sizes. Because dredging relied on these native soils, many of the levees were built of gravel, sand and silt, making them susceptible to erosion, seepage and breaches. To make matters worse, many of the levees were founded on unconsolidated, highly variable and permeable materials.

The region has been devastated by a number of floods in the past 150 years, resulting in billions of dollars in damages, as well as the loss of human life. The major floods that have occurred in the Central Valley within this period are summarized below:

- 1862 — Parts of Sacramento are inundated by up to 20 feet of flood waters.
- 1955 — Floods in northern and Central California result in 67 deaths.
- 1986 — Central California flooding leaves 14 dead and causes more than $1.5 billion in property damage.
- 1997 — Flooding kills nine people and causes more than $2 billion in property damage; 48 counties declared disaster areas; 120,000 people had to be evacuated from their homes.
- 2004 — Upper Jones Tract levee break in June results in federal disaster declaration and $90 million in damage.

The 1997 flood was one of the most devastating flood events in the State’s history. Significant flooding occurred on fifteen rivers where historical peak flows were approached or exceeded. More than 30 levees failed, leading to the inundation of approximately 300 square miles of the Central Valley. Estimated indirect costs and costs associated with the disruption of the state’s economy exceeded $5 billion. Figures 1 and 2 illustrate the impacts of the 1997 floods. A recent study by DWR estimated that a catastrophic flood in the Sacramento area would result in flood damages of $11.2 billion. The true, long-term cost of human and financial consequences would be staggering.

Challenges

In past years, maintenance of these levees has been intermittent, non-strategic and often inadequate, due to lack of funds and a lack of comprehensive knowledge of the aging flood system and its many components. In addition to deferred...
maintenance, other factors threaten to dramatically increase the risk of flooding in the Central Valley including climate change, land-use decisions, urban growth and development, design deficiencies and outdated floodplain maps. Climate change, which affects air temperature, precipitation, runoff and sea level, is alone likely to exert a significant impact to future flooding in deep floodplains. A 2002 report by the California Regional Assessment Group on the potential impacts of future climate change in California states that climate change could lead to increased precipitation, leading to increased flooding in parts of the United States. Flows currently associated with 100- and 500-year floods (a 500-year flood is a flood that has a 0.2 percent chance of occurring in any given year) may occur more frequently due to increased precipitation (Reference 2). The report also states that the western United States are particularly vulnerable to such increases. Climate change could influence flood heights to rise in high-risk areas causing current areas of low vulnerability to become high-risk areas in the future.

As the risks of levee failure and corresponding damage increase, California’s courts have generally exposed public agencies, and the State specifically, to enormous financial liability for flood damages. The November 2003 Paterno vs. State of California decision found that when a public entity operates a flood control system built by someone else, it accepts liability as if it had planned and built the system. The Paterno ruling held the State responsible for defects in a Yuba County levee foundation that existed when the levee was constructed by local agricultural interests in the 1930s. This landmark decision found the State liable for $500 million in damages for this single event.

A 2004 report by the Association of State Floodplain Managers Foundation concludes that the concept of a 100-year flood standard may not be sufficient since it likely oversimplifies the complicated concepts related to flooding (Reference 3). Such a standard may provide a false sense of security because developments tend to cluster just outside the 100-year floodplain boundary, an area that is not necessarily free from flood risk.

**Addressing the Problem on a Statewide Basis**

On February 24, 2006, Governor Schwarzenegger declared a State of Emergency for California’s levee system. After that declaration, the Governor signed Executive Order S-01-06 directing the California Department of Water Resources to identify and repair critically eroded levees and to identify non-visible deficiencies. Subsequently, in November 2006, California voters approved Propositions 1E and 84, providing nearly $5 billion in state bond funds for flood protection projects statewide. Of this, approximately $3.2 billion is intended for evaluation, repair, and improvement of levees and flood projects in the Central Valley. Several bills passed in 2007, adding new state laws related to flood management in the Central Valley and impacting how DWR and local entities work to manage flood risk. As a result of Senate Bill 5 (Machado), DWR is required to evaluate the current level of performance of the state-federal flood protection system in the Central Valley.

In response to the Governor’s declaration and the passing of the propositions and bills, DWR started a multi-faceted initiative called FloodSAFE California to improve integrated flood management throughout California, with an emphasis on better managing flood risk related to the state-federal flood protection system in the Central Valley. Following is a listing of the FloodSAFE goals:

- Reduce the Chance of Flooding – Reduce the frequency and size of floods that could damage California communities, homes and property, and critical public infrastructure.
- Reduce the Consequences of Flooding — Take actions prior to flooding that will help reduce the adverse consequences of floods when they do occur and allow for quicker recovery after flooding.
- Sustain Economic Growth — Provide continuing opportunities for prudent economic development that supports robust regional and statewide economies without creating additional flood risk.
- Protect and Enhance Ecosystems — Improve flood management systems in ways that protect, restore and where possible enhance ecosystems and other public trust resources.
- Promote Sustainability — Take actions that improve compatibility with the natural environment and reduce the expected costs to operate and maintain flood management systems into the future.

A major component of the FloodSAFE initiative is a system-wide analysis of the Central Valley Flood Control System, incorporating hydrology, hydraulics, economics, environmental impacts and geotechnical risks. This latter component is an unprecedented, comprehensive evaluation of 350 miles of urban levees (i.e., levees that protect at least 10,000 people) and 1,250 miles of non-urban levees (i.e., levees that protect less than 10,000 people) located within the Central Valley. Furthermore, DWR is evaluating over 500 miles of appurtenant non-project levees that impact performance of project levees. This program is critical to develop local, State and federal investment strategies and resulting flood protection improvements.

These evaluations are being performed through the Urban Levee Evaluation (ULE) project and the Non-Urban Levee Evaluation (NULE) project, using teams comprised of State managers and staff, and numerous consulting firms of various disciplines. The Corps of Engineers is a key partner in this program. Local stakeholders provide performance history, local experience and the initiative to develop local, State and federal projects. The objective of the ULE and NULE projects is to evaluate project and associated non-project levees to determine whether they meet defined

---

_USSD Newsletter — March 2009_
geotechnical criteria and, where needed, identify remedial measures, including cost estimates, to meet those desired geotechnical criteria. These evaluations are being conducted with the goal of providing 200-year (0.5 percent chance on any given year) level of protection in urban areas and an appropriate level of protection in non-urban (rural) areas. DWR has convened a team of highly-regarded civil and geotechnical engineering consultants. The geotechnical team is led by URS Corporation, and includes GEI Consultants, Inc., Fugro, AMEC Geomatrix, Kleinfelder, Inc., Shannon & Wilson, Inc. and others.

Geotechnical exploration, testing, and analysis of state and federal levees protecting highly populated urban areas of greater Sacramento, Stockton/Lathrop, and Marysville/Yuba City are being performed as an essential first step in providing improved flood protection for communities in the Central Valley. This program is being implemented simultaneously with urgent levee repairs. To expedite flood control efforts aimed at protecting these communities, levee evaluations are being conducted in a fast-track manner over a two- to five-year period. During this time, technical specialists are reviewing existing levee historical data; conducting field explorations (including drilling and geophysical methods, along with associated laboratory testing); performing geotechnical engineering analyses; and preparing preliminary design and construction estimates for repairing and upgrading the levees where needed. As part of its mission, DWR is also responding to requests to assist various local agencies by providing data/analyses during the evaluation process.

Ongoing Geotechnical Levee Evaluation
The ongoing geotechnical levee evaluation focuses on the past and projected performance of levees related to seepage, stability, erosion, settlement and seismic factors. A wide range of critical levee properties are being studied, including the following:
- Geotechnical conditions
- Geomorphology
- Historical events
- Levee and channel topography
- Man-made features
- Subsurface conditions
- Erosion conditions

In addition to the basic geotechnical evaluation program of drilling and boring to collect levee and foundation soil samples, other proven and innovative technologies are being used to develop a comprehensive understanding of subsurface conditions. These methods include regional geomorphic assessments, detailed mapping of geomorphic features and surficial geologic deposits, Light Detection and Ranging (LiDAR) topographic surveys, geophysical electromagnetic (EM) surveys, and underwater bathymetric surveys. Data collected from these and other methods are being used to assess the levees' structural integrity and identify which areas are most in need of critical improvements and/or repairs.

Geotechnical Conditions (Subsurface Exploration)
Much of the evaluation of the geotechnical condition of the levees and their foundations is being conducted by traditional methods (e.g., mud-rotary and vibratory boring methods, cone penetration testing) to collect soil samples and analyze subsurface conditions. The subsurface explorations are typically being conducted at 1,000-foot intervals along the levees, with additional explorations on the landscape of the levees. Looking closely at subsurface soil conditions such as moisture, density, and soil grain size distribution helps identify potential problems or weaknesses in the flood control structures.

Geomorphologic Assessments
By studying the evolution of landforms and the processes that alter them, geologists and engineers can better understand the geologic characteristics of the soil materials beneath existing levees and the geomorphic processes (e.g., erosion, deposition) responsible for those materials, which can aid in assessment of the levees' stability. For the levee evaluation projects, experts are preparing comprehensive surficial geologic maps of the project areas based on field reconnaissance observations and review of vintage aerial photos, topographic maps, geologic maps, and satellite imagery. Certain geomorphic conditions (e.g., cut-off meanders, crevasse splay deposits, etc.) can be strong indicators of soils that may be susceptible to seepage and/or stability problems, and can guide field investigations when searching for weak points along a levee alignment.

Light Detection and Ranging (LiDAR) Topographic Surveys
Light Detection and Ranging (LiDAR) technology deployed in low-flying helicopters is being used to electronically gather data about the topography and configuration of the flood control levees. In spring 2007, helicopter flights equipped with LiDAR performed aerial topographic surveys over approximately 500 miles of levees throughout the Central Valley. Airborne LiDAR produces accurate elevation models for terrain, which is helpful in evaluating the geotechnical and erosion characteristics of the surveyed levees.

Geophysical Surveys
Another way to evaluate levee subsurface conditions is by conducting geophysical electromagnetic (EM) surveys. Like LiDAR, this technology has been deployed during helicopter flights over the levees. An EM survey sensor, which resembles an airborne torpedo, is suspended from the helicopter about 100 feet above the levees. The EM technology senses variations in the ground’s electrical conductivity to depths of more than 100 feet underground. The goal is to map important changes in soil types and ground conditions, identifying zones where permeable soils are present or excessive water penetration is taking place. These surveys were
conducted in late summer 2007 along more than 200 miles of levees on the Feather River, Bear River, American River, Sutter Bypass, Yolo Bypass, Sacramento River, Stanislaus River, San Joaquin River and tributaries. Ground-based Direct-Current resistivity surveys were also performed extensively along levee crowns and toes to provide additional information pertaining to the permeability and water content of the levee and shallow subsurface. These surveys provide a level of detail not achievable using the helicopter methods, but are generally more time consuming to perform.

Bathymetric Surveys
Underwater bathymetric surveys are explorations conducted by boats equipped with special multi-beam sonar. These surveys produce detailed topographic data of the riverbed and riverbanks that essentially form the base of the levee systems. The collected data provide an image of the levees’ underwater structure that cannot be obtained by conventional land topographic methods. The data are especially important in revealing underwater erosion of the riverbanks. Bathymetric surveys were conducted from December 2007 to January 2008 along parts of the Sacramento, American, San Joaquin and Calaveras Rivers. The ultimate purpose of the surveys is to supplement the above-water topographic data collected during the LiDAR surveys. Together, this information will be used to assist in the geotechnical evaluation of the levees.

Closure
California’s FloodSAFE initiative significantly advances the State’s ongoing flood management programs, especially given the progress over the past three years since Governor Schwarzenegger called for improved maintenance, system rehabilitation, effective emergency response and sustainable funding. The ULE project is expected to be concluded in 2010 and the NULE project in 2012. The information developed through the ULE and NULE projects will be implemented by DWR, FEMA, the Corps of Engineers and local agencies, to make critical repairs and improvements, as well as to guide long-term investment strategies for flood control projects.

References
3. Association of State Floodplain Managers Foundation, Reducing Flood Losses: Is the 1% Chance (100-year) Flood Standard Sufficient?, September 2004
4. State of California, Department of Water Resources, Flood Warnings: Responding to California’s Flood Crisis, January 2005

News of Members
Joseph A. Ahearn has been elected a distinguished member of ASCE.
Adda Athanasopoulos-Zekkos is an Assistant Professor at the University of Michigan.
AECOM has acquired TCB. Boyle Engineering and STS Consultants.
Dean B. Durkee, Phoenix, Arizona, has been named a stockholder of Gannett Fleming, Inc.
Geomatrix Consultants, Inc. has merged with AMEC and is now AMEC Geomatrix.
Ernest Gomez, Jr., Issaquah, Washington, has retired from the Corps of Engineers.
Garith K. Grinnell has retired from the Las Vegas Valley Water District.
James V. Hamel of Hamel Geotechnical Consultants, Monroeville, Pennsylvania, received the Distinguished Practice Award from the Engineering Geology Division of the Geological Society of America.
Kenneth D. Hansen, Greenwood Village, Colorado, has retired from Schnabel Engineering. He is a private consultant specializing in RCC and soil-cement applications.
HDR Engineering, Inc. has acquired Devine Tarbell & Associates, Inc. DTA will now conduct business as HDR/DTA.
I. M. Idriss has been elected a distinguished member of ASCE.
Joe Jarboe, Waco, Texas, has retired from Brazos River Authority.
Terence M. King has retired from the Corps of Engineers.
David B. Paul received the Superior Service Honor Award from the Bureau of Reclamation.
Robert Pyke, Lafayette, California, is now affiliated with ARCADIS U.S.
Richard L. Volpe has retired from the Santa Clara Valley Water District.
Robert L. Whedon is now affiliated with Jacobs Engineering in Oak Hill, Virginia.
Seismic Performance of Rockfill Dams

by Gilles Bureau, P.E., G.E., GEI Consultants, Inc., Oakland, California gbureau@geiconsultants.com.

Editor’s note: The author attended the International Seminar on Earthquake and Dam Safety, March 29 - April 4, 2009, in Beijing, China. He prepared the following summary of the paper he presented during the Seminar. The complete paper, titled “Seismic Performance Review of Zipingpu Dam,” is available at www.ussdams.org/seismic.PDF.

Introduction

Zipingpu Dam, China, a 512-foot-high concrete faced rockfill dam was severely shaken by the May 2008 Wenchuan Earthquake (Mw 7.9). The observed performance of this embankment and other rockfill dams affected by historic earthquakes was used to update a previously developed empirical relationship between relative crest settlements and the “Earthquake Severity Index” (ESI). The new relationship and associated uncertainty are consistent with measured or calculated crest settlements for rockfill dams.

Wenchuan Earthquake

The Wenchuan earthquake of May 12, 2008, was a particularly devastating earthquake, which caused more than 69,000 deaths and considerable damage. The shaking lasted about 120 seconds. The associated thrust rupture (Longmenshan Fault) was about 240 kilometers long by 20 kilometers deep, with relative movements of up to 30 feet. More than 1,800 small dams of low storage capacity were damaged, but four large concrete and embankment dams performed satisfactorily.

Seismic Performance of Zipingpu Dam

Zipingpu Dam was about 17 kilometers east of the epicenter, and even closer to the fault rupture. Photos 1 and 2 show the dam before the earthquake (photos provided by Martin Wieland). It remained stable and maintained its reservoir-impounding capacity, but experienced crest settlements of 2.4 to 3.3 feet. Maximum reservoir capacity is 0.9 million acre-feet, but only 0.16 million acre-feet were impounded at the time of the earthquake. Partial dislocation of several concrete slabs occurred at construction joints, with a maximum outward bulging of 5.9 inches. The crest slab moved downward about 2 inches relative to the embankment. Portions of the parapet wall collapsed. Open cracks up to 1.2 inch wide were observed on the downstream side, between the crest road and the rock slope protection. Instruments recorded a base motion of about 0.51 g, with a crest motion reported as about 2.0 g. Parapet wall and banister collapses may have influenced this second recording. Limited increase in seepage was observed, but concerns about potential failure of upstream man-built and landslide-caused reservoirs led to about 2,000 troops being sent to accelerate reservoir release and repair the cracks. Previous dynamic analyses of the dam had used input motions considerably less demanding (0.26g PGA, 17-second duration) than the Wenchuan Earthquake.

ESI-Based Methodology

At the 1985 ASCE International Symposium on CFRDs, Bureau, Volpe, Roth and Udaka used the observed performance of rockfill dams to develop an empirical relationship between the Earthquake Severity Index (ESI) and the expected relative crest settlement ($\Delta H/H$) of rockfill dams. The 1985 historic data were supplemented by the results of nonlinear dynamic deformations analyses of a hypothetical 325-foot high CFRD. The ESI is a quantifier of the local intensity of seismic shaking, and accounts for both its maximum amplitude and duration. It is expressed as: $\text{ESI} = \text{PGA} \times (M - 4.5)^3$.

Earthquakes after 1985 nearly double the number of observed case histories, which is now 62. Using the updated database, rigorous regression analyses were performed using rockfill dams for which information on measured crest settlement and recorded or estimated ground motion was available. A quadratic relationship provided the lowest standard deviation ($\sigma$). It is expressed as:

$$\log(\Delta H/H) = -0.51931 + 0.54388 \log(\text{ESI}) + 0.26284 (\log(\text{ESI}))^2$$

with $\text{ESI} = 0.1$

The $\sigma$ that corresponds to the variable $\log(\Delta H/H)$ is equal to 0.37507. The corresponding curves and available historic data points are plotted on Figure 1.

The new empirical relationships between ESI and crest settlement should be conservative, because several rockfill dams historically shaken by earthquakes had no reported earthquake-induced deformations. These dams were not included in the analyses. The equation relating $\Delta H/H$ and the ESI can be used to make
preliminary estimates of the crest settlement of rockfill dams. As any simplified procedure, it may inaccurately predict what might occur in reality, but should be more reliable than the 1985 relationships. Applied to Zipingpu Dam, the calculated crest settlements (50th percentile: 2.2 feet; 84th percentile: 5.2 feet) are consistent with the post-earthquake field measurements.

In summary, the updated ESI-based simplified predictions should be useful to quickly assess whether a rockfill dam is safe or not, as long as liquefaction is not a potential issue. The mean estimate should be adequately conservative for well-constructed rockfill dams founded on competent bedrock. If the estimated 84th percentile crest settlement leaves sufficient freeboard, the dam should have an adequate margin of safety, especially if a low probability of occurrence is associated with the specified earthquake parameters. In that case, the need to implement a more detailed approach may not be justified, again, as long as there are no liquefiable gravelly zones within composite rockfill dams or in any foundation alluvium left in place.

**Conclusion**

First and foremost, the ability of Zipingpu Dam to survive an earthquake considerably more demanding than what had been considered for its design testifies to a proper choice of embankment materials and to the excellent quality of its construction. The post-earthquake emergency response was outstanding. This experience confirms that rockfill dams and especially, CFRDs, have an inherently high resistance to large seismic loads.

The ESI-deformation curves should be useful for preliminary safety evaluations, for the risk ranking of several dams and for preliminary design of new rockfill dams, e.g., to assess initial freeboard requirements. For existing dams, if the procedure suggests a large margin of safety, it might eliminate the need for complex and costly dynamic response analyses.

---

**Figure 1. Updated Relative Settlement vs. ESI Relationships.** Note: the top curve is the 84th percentile, the middle curve is the 50th percentile, and the bottom curve is the 16th percentile.