United States Society on Dams

Managing Our Water Retention Systems

29th Annual USSD Conference
Nashville, Tennessee, April 20-24, 2009

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IS DAM SUCH A BAD WORD?
A REVIEW OF THE PERCEPTION OF DAMS

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ABSTRACT

We struggle with the perception of dams and their role and impact on society. Perhaps our struggle is misguided. We are well-versed with the famous dams around the world and their socio-economic benefits, as well as current books and movies where dams are frequently presented as impressive structures. However, the negative impacts of dams have also been increasingly brought to the forefront. For example, the unequal distribution of benefits and associated corruption are two themes frequently tied to dams and their development. This perception is at the center of a recent book, *The Last Flight of the Scarlet Macaw, One Woman's Fight to Save the World's Most Beautiful Bird*. Interestingly, the word dam is not in the title, but it is the proverbial windmill being tilted. In these types of discussions, the intangible benefits of dam development, such as improvements to health, sanitation, food production, and education are often overlooked. The complexity of how dams are perceived is presented through the eyes of three members of the World Commission on Dams in the book *Deep Water: The Epic Struggle Over Dams, Displaced People and the Environment*.

The sustainability of dams is often mentioned in the same breath as the corruption that can be connected with them. This aspect is explored in the publication *Dams and Development* by the World Commission on Dams and other publications and guidance documents by well-reputed organizations such as the World Wildlife Fund, International Hydropower Association, and the United Nations, and even in the recently released documentary movie *FLOW: For the Love of Water*. Recognizing that dam developments are routinely constructed with essential planning and vision, the concepts of feasibility, planning, design, construction, operation, and maintenance as a whole sometimes differ from paper to reality. The dams community must recognize that the sustainable operation of new and existing projects must incorporate not only the requisite technology and science but also must address the social improvement and public relations aspects required to result in a successful, ethical, balanced, and sustainable project. This paper highlights the efforts of a few organizations' attempts to address corruption and sustainability and provides examples of the effects of corruption on sustainability as illustrated in the above publications. The authors wish to note that this paper is not a fully-exhaustive report but merely an attempt to bring these issues to light so that we in the dams community can remain vigilant and these concepts and challenges remain in the forefront to encourage discussion and innovation.

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EVALUATING CALIFORNIA CENTRAL VALLEY LEVEE SYSTEMS

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ABSTRACT

Reflecting California Governor Arnold Schwarzenegger's commitment to improving flood safety to prevent possible catastrophic flooding and loss of life, the State of California's Department of Water Resources (DWR) is undertaking unprecedented efforts to evaluate and upgrade aging and deteriorating levees along the Sacramento and San Joaquin River Valleys and Delta. To begin, DWR is evaluating more than 325 miles of urban project levees in these areas, with plans to survey the entire 1,600 miles of project levees in the Central Valley. The team is composed of blended DWR and consultant team staff, which is an innovative approach to the evaluation process.

As an essential first step in providing improved flood protection for communities in the Central Valley, DWR, supported by URS Corporation and subcontractors, is conducting a geotechnical evaluation program consisting of field exploration, testing and analysis of state/federal levees that protect the highly-populated urban areas of greater Sacramento, Stockton/Lathrop, and Marysville/Yuba City. To expedite flood control efforts aimed at protecting these communities, geotechnical levee evaluations are being conducted in a fast-track manner over a three-year period. A comprehensive study of these levees is underway, including:

- Reviewing existing levee historical data – both construction processes and past performance information.
- Conducting LiDAR topographic and bathymetric surveys.
- Conducting comprehensive geomorphological studies, field explorations and geophysical surveys.
- Performing laboratory testing on selected soil samples.
- Evaluating the stability, seepage and erosion conditions of levees.
- As appropriate, the team is preparing preliminary design and conceptual construction estimates to upgrade deficient levees.

The project goal is to provide a strong base of information, allowing for planning and funding upgrades of urban levees to a 200-year level of flood protection. This paper presents an overview of DWR's Urban Levee Geotechnical Evaluations Program, evaluation criteria, analysis protocols, and typical results.

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AN EXAMINATION OF DAM FAILURES VS. AGE OF DAMS

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ABSTRACT

Dam safety professionals often express surprise when a dam fails, or has a significant dam safety incident, after it has been in service for an extended period of time. Owners often resist making improvements to a dam by questioning why a consultant or regulator is concerned about the safety of a dam after it has been in service for 50 years. This surprise and reluctance is not supported by the data.

Analysis of more than 1100 dam failures and safety related incidents indicates that, while the infancy of a dam is clearly the most dangerous period, with about a third of failures taking place during construction or within five years of completion, there is still a significant probability of failure later in a dam's life with approximately half of failures that occurred after the first five years of operation occurred after 50 years of operation.

This paper examines the distribution of failures over time for the aggregate body of dams, as well as the distribution over time for specific types of dams and failure modes, and explores the reasons that some failures occur in the dam's earliest years while others occur after an extended period of, apparently, satisfactory operation.

It is hoped that the information presented will provide dam safety professionals information to assist in managing the risks associated with our water-retaining infrastructure.

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NOTES

CENTER HILL DAM — MITIGATING EFFECTS OF ALKALI AGGREGATE REACTION WITH VERTICAL SLOTS

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ABSTRACT

Center Hill Dam is a 1382 ft long by 250 ft high concrete gravity dam located near Nashville, Tennessee. The dam was constructed during the 1940's utilizing aggregates from an on-site quarry. No testing of the aggregate was done and the cement's alkali content is unknown. In 1983 binding spillway gates, closing bridge expansion joints and misalignment of gate machinery indicated that movements, possibly from a concrete volume change, were occurring. Laboratory testing and in-situ stress measurements confirmed that concrete expansion from alkali-aggregate reaction (AAR) was taking place. Alterations to spillway gates and bridge joints were necessary in 1985 and 2000. A 3D finite element model of the dam was used to analyze the effects of both past and future concrete expansion. The analyses indicated high concrete shear stresses at the spillway pier to crest interface. The FE model was used to evaluate the effect of cutting vertical slots in the non-overflow section at each side of the spillway. The analysis showed that two 15mm wide slots through the dam from the top of the dam to 5 ft below the spillway crest would alleviate the high shear stresses and allow the structure to grow without further closing of the spillway. Corps personnel performed the slot cutting in 2006 and 2007. This paper details the history of the AAR problems at the dam, the use of 3D finite element analyses to simulate the concrete "growth", the slot cutting procedure and its results.

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TRUNNION ANCHOR ROD FAILURES, WEST POINT DAM PROJECT

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ABSTRACT

The Corps of Engineers (COE) embarked on a nationwide mission to construct navigation and hydroelectric projects during the decades of 1960~1970. During this time period, the use of post-tensioned trunnion anchor rods became the standard for the COE. Although the suppliers of these steel rods were very limited and the rods had to be handled very delicately, the economics and the benefits out-weighted the previously used steel beam and plate type design.

The basic design required the anchor rods to be assembled in groups, positioned in rows and columns. Each rod was placed in a round protective casing pipe, whose diameter was one-half inch larger than the diameter of the rod. In most projects the rod was anchored within the concrete pier with a steel plate. After the pier concrete had cured the rod was tensioned to the specified amount. Post-tensioning stresses normally exceeded 100,000 pounds per square inch. To retain the required tension in the rod, a grip nut was placed on the free end of the anchor rod. Then either grout or corrosion preventative grease was injected to fill the space between the rod and protective casing pipe. The anchor rod assembly was then covered with a metal box to provide protection from the environment.

This report will summarize the results of the field observation, laboratory and field testing, and preliminary structural analysis of the failed anchor rods at the West Point Dam, Alabama.

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A METHOD OF EVALUATING THE SAFETY OF DETERIORATING BUTTRESS DAMS

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ABSTRACT

The concrete slab and buttress structure was a popular design for dams in the early part of the 20th century. Today, it is common for engineers to have concerns regarding the strength capacity of the reinforced concrete members in these types of dams, because many of them show signs of concrete deterioration and reinforcement corrosion. A major question confronting owners and operators of these structures is how much deterioration is permissible before repairs are needed. Unfortunately, there is very little guidance for analyzing buttress dams. The guidelines currently accepted and used in the structural engineering practice regarding concrete dams focus on concrete gravity and arch dams, which are constructed of mass concrete. The evaluation of mass concrete is based on the allowable strength capacity of the material, which is typically equal to the ultimate strength divided by an appropriate factor of safety for a corresponding loading condition (i.e. 3.0 for usual, 2.0 for unusual, and 1.0 for extreme). The strength based evaluations of mass concrete are not applicable to reinforced structures, such as buttress dams. Furthermore, the modern reinforced concrete design codes do not consider the multiple levels of risk defined for dam engineering, making it difficult to apply their provisions to the analysis of buttress dams.

This paper presents an analytical procedure that bridges the problem of applying modern reinforced concrete design to older buttress dams using the concept of permissible capacities of structural components. It also describes a methodology that evaluates the effect of deterioration on the factor of safety against failure for a given structural component. An example of the method is applied to a concrete multiple arch buttress dam to show how the results of the analysis may be used by the owner to assess the level of risk inherent in the structure based on observed conditions in the field.

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RCC TRENDS IN EARLY 21ST CENTURY MID-SIZED DAMS IN THE U.S.

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ABSTRACT

Roller-compacted concrete (RCC) continues to gain recognition as a competitive material for the construction of new concrete arch and gravity dams, and for rehabilitation of existing dams. During the past two decades, many design details and construction methods have been implemented to improve this relatively new dam construction method with the goal of enhancing the product while maintaining the RCC's competitive edge associated mainly with speed of construction.

More than 370 RCC gravity and arch dams in excess of 50 feet in height have been constructed to date worldwide. Forty-three of these dams are located in the United States. Many more RCC gravity dams less than 50 feet high have been built as well.

The first two large RCC gravity dams in the U.S.; Willow Creek in Oregon and Upper Stillwater in Utah, were built in the 1980s and they experienced seepage through lift joints and at shrinkage cracks. Design engineers, owners and contractors are constantly looking for new innovative methods to limit seepage, while improving durability and aesthetics. Several facing systems are now being used, including air-entrained conventional concrete with crack inducers and water stops, precast concrete panels, and waterproofing membranes.[14]

This paper focuses on important RCC design details, mix designs, and construction means and methods based on several recently constructed mid sized RCC gravity dams in United States.

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STAGED CONSTRUCTION THERMAL ANALYSIS FOR SAN VICENTE DAM RAISE PROJECT

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ABSTRACT

The existing San Vicente Dam is a 220-foot (67 m) concrete gravity dam that was completed in 1943 with 90,063 acre-feet (111 GL) of storage. In order to meet San Diego County Water Authority's emergency water storage needs, San Vicente Dam will be raised by 117 feet to about 337 feet (102.7 m) high, creating an approximately 242,200 acre-foot (299 GL) reservoir. To minimize construction costs and reduce the period of construction, the dam raise design utilizes roller-compacted concrete (RCC) placing methods.

Staged construction thermal and structural analyses were performed to predict concrete temperatures in the dam and to estimate the stress state along the interface of the existing concrete and the new RCC during and after construction. The normal and shear stress at the interface of the existing concrete and new RCC were investigated at several stages of construction and after the dam has reached steady state temperatures. The finite element thermal and structural analyses were performed using the computer program ANSYS Version 8.0, in general accordance with U.S. Army Corps of Engineers, ETL 1110-2-365, "Nonlinear, Incremental Structural Analysis of Massive Concrete Structures".

The paper describes the analysis methods, input parameters, results and conclusions drawn from the staged construction finite element analyses.

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REHABILITATION OF LAKE SHERBURNE DAM OUTLET WORKS USING SILICA FUME CONCRETE

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ABSTRACT

Lake Sherburne Dam, located on Swift Current Creek, a tributary of the St. Mary River, near the east boundary of Glacier National Park, is a principal component of the Milk River Project, which furnishes water for the irrigation of approximately 110,300 acres of land in north central Montana, approximately 90 miles northeast of Kalispel. The dam was completed in 1921. The outlet works and spillway both discharge into a double-barreled conduit. Each barrel of the conduit is 6-feet-wide by 8-feet-high, with a crown radius of 3 feet and an invert radius of 5 feet. Active landslide activity in areas along the reservoir rim results in the entry of a significant amount of gravel, cobbles, and boulders into the reservoir. A portion of this debris eventually travels to the intake structure of the outlet works and is carried by high velocity flows through the double-barreled conduit during reservoir releases. The abrasive action of this debris on the conduit over the years has resulted in significant erosion of the conduit inverts and walls. A project was completed in 2007 and 2008 which rehabilitated the conduit by restoring the original geometry of the inverts and walls using silica fume concrete. The high compressive strength of silica fume concrete is believed to provide a longer service life than a conventional concrete repair given the severe abrasive loading acting on the conduit. The repair thickness varied between 5 to 6 inches and included one layer of #4 reinforcement. The repair was anchored to the existing concrete using epoxy concrete anchors. Contraction joints were spaced at 10 feet along the length of each conduit, and hydrophilic strip waterstop surrounded the perimeter of each repair section.

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OUTLET TUNNEL SLAB DAMAGE AT SEVEN OAKS DAM

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ABSTRACT

The Seven Oaks Dam project is a flood control dam located on the Santa Ana River in San Bernardino County, California. The project consists of a 550-foot-high earth dam, a rock-lined spillway, and an outlet works. The outlet works includes a multilevel intake structure, pressurized outlet tunnel, control gate structure, non-pressurized outlet tunnel, and an energy dissipation pool. During the construction of the dam, extensive concrete erosion occurred in the lower reach of the outlet tunnel and the plunge pool apron as a result of flood flows diverted through the structure prior to completion of the outlet works. A concrete overlay was placed on the damaged portion of the tunnel. After the dam was constructed, a series of tests was conducted on the right main regulating outlet (RO) works gate. During the test, several loud booming sounds, followed by grinding sounds and wide-scale vibrations were experienced by test personnel at both ends of the access tunnel. Inspections after the testing was commenced revealed an erosion hole along the right side of the outlet works tunnel and in the direct path of the jet from the tested right outlet gate. Background information and observations of the damaged site and possible causes of the damage as determined by the U.S Army Corps of Engineers (Corps) and various consultants contracted by the Corps are discussed.

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DYNAMIC UPLIFT OF CONCRETE LININGS: THEORY AND CASE STUDIES

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ABSTRACT

Dynamic uplift of concrete linings due to severe pressure fluctuations is of major concern to design engineers. The phenomenon has been extensively studied because of major failures in the sixties and seventies. Nevertheless, despite major advances in measurement technology and data acquisition, a safe and economic design method for any kind of concrete lined stilling basin is still missing today. Especially the dynamic or even transient character of pressure pulsations and their two-dimensional spatial distribution above and underneath the lining are not fully assessed and implemented.

The present paper briefly outlines the main historic steps of the state-of-the-art in lining design and then presents a new design method for concrete lining uplift. This new physically-based method combines laboratory measurements of net uplift forces, prototype-scaled transient pressure recordings inside artificially generated lining fissures and numerical modeling of air-water pressure pulsations. This defines the time-dependent pressure field underneath the lining. At the upper face of the lining, a spatially distributed but time-averaged pressure field is considered. This finally provides a time-dependent net uplift pressure and impulsion on the concrete lining. Based on the differential equation of a spring-mass system accounting for lining inertia and anchor bar elastic properties, the most critical net uplift impulsion on the lining is then transformed into an equivalent most critical stress of the lining anchor bars, allowing sound dimensioning of the latter.

In the following, the main steps of the new design method are presented and illustrated with real-life studies in the western US and in central Switzerland.

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FAST TRACKING EMERGENCY SCOUR REPAIRS AT ALLEGHENY DAM 6 CLINTON, PENNSYLVANIA

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ABSTRACT

The U.S. Army Corps of Engineers, Pittsburgh District, is in the final phases of repairing a fixed crest navigation dam on the Allegheny River located 36.6 river miles northeast of Pittsburgh, Pennsylvania. Through fast-track emergency construction, from October 2008 to January 2009, the Pittsburgh District stabilized a portion of the dam at Allegheny Lock and Dam No. 6 that was in a state of active failure. The navigation facility consists of a single lock chamber on the right abutment with a fixed crest dam and a hydroelectric power plant on the left abutment. The dam was built in 1928 and is composed of mass concrete cast on a rock and gravel-filled timber cribbing supported on a timber pile foundation system. Scour had eroded the downstream riverbed material, the timber cribbing, and derrick stone placed downstream of the dam. This condition resulted in the loss of lateral soil restraint to the timber piling supporting the dam, resulting in a condition of active failure. However, despite the serious progression of scour, the timber piling had not buckled. The focus of the design/construction effort was to fill the void beneath the dam with a flowable tremie concrete infill to re-establish support to the timber foundation piles.

The serious conditions at Allegheny Dam 6 and the required emergency repairs highlight the need for national investment to maintain aging, but critical infrastructure to guarantee reliability and performance of these facilities into the future.

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SEISMIC FRAGILITY ASSESSMENT OF CONCRETE GRAVITY DAMS

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ABSTRACT

Concrete gravity dams are one of the most important infrastructures so maintaining of them in good conditions is an important concern for dam owners. They should able to continue their function after a disaster such as earthquake. But most of them are aged dams with some have been built near faults. Indeed, there are some concerns regarding the performance of these dams under the effect of seismic loads. In recent years some criteria about linear performance of these dams have been developed. But the same cannot be said about nonlinear performance of these dams, which seem to lack well-developed criteria. In this paper we shall try to devise a set of criteria concerning nonlinear performance of concrete gravity dams that have been affected by near field earthquakes. Having done that, we shall then apply these criteria in order to illustrate seismic fragility curves for Pine Flat Dam. The fragility curves show the dam is very vulnerable when an earthquake strikes it with the peak ground motion more than 0.25g.

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CALIBRATING A PROBABLE MAXIMUM FLOOD SIMULATION ON THE LOWER SUSQUEHANNA RIVER

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ABSTRACT

Recent advances in unsteady flow modeling enable engineers to predict the effects of dam failures and other unanticipated releases on low-lying areas, thereby reducing the risk to lives and property. Using a one-dimensional hydrodynamic model of the lower Susquehanna River, the authors re-created the flood of record (Hurricane Agnes) event of June 1972, simulated the Probable Maximum Flood (PMF), and estimated downstream impacts associated with the failure of a southern Pennsylvania dam.

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SPILLWAY WIDENING OPTIMIZATION FOR PASSING INCREASED PMF

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ABSTRACT

L.L. Anderson Dam impounds a 135,000 acre-foot reservoir in the headwaters of the Middle Fork of the American River in Placer County, California. The rock channel spillway of L.L. Anderson Dam needs to be modified to pass the current, increased probable maximum flood (PMF), as routing the PMF indicates that the spillway does not have enough capacity and the dam would be overtopped by the flood.

Several alternatives involving spillway gate and channel widening and invert excavation were developed in HEC-RAS to pass the PMF prior to performing a 1:20 scale physical model test. The selected alternative from the physical modelling involves approximately a 34-foot widening of the spillway channel and gates, lowering the invert downstream of the gates, and includes a narrowing exit channel that tapers to a 14 foot widening before a 40+ foot drop to the existing escape (discharge) channel. The new control structure will have two 37.5 feet wide gates with wire-rope hoists, a shaped pier between the two gates, and upgraded with state-of-art controls that will have provision for future remote wireless operation at the dam site.

Other features of the project design include using the existing spillway gates as the cofferdam and constructing the new, widened spillway control structure immediately downstream. This required design of a temporary rock "plug" left in place while the spillway is widened upstream and downstream of the existing gates. In addition, in order to optimize widening design and reduce excavation volumes, benches were eliminated for the spillway channel widening.

The overall project design considerations, including results of the physical modeling, geotechnical considerations, and gate design, are reported in this paper.

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THE (COST, TIME, …) BENEFITS OF USING CFD HYDRAULIC MODELS FOR VARIOUS DAM PROJECTS

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ABSTRACT

Computational Fluid Dynamics (CFD) analysis in the dams industry has emerged as a powerful alternative design tool in recent years because of the cost benefits to many projects and recent advances in computational mathematics that produce similar results to physical model and prototype structures. Based on authors' recent experience with one of the most popular code, FLOW-3D, this paper presents the general requirements for a CFD model and discusses many of the benefits as well as some limitations of applying the CFD models in a dam-related project as to a conventional physical model.

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SCOUR UPSTREAM OF DAM PIERS

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ABSTRACT

Scour has occurred immediately upstream of several dam piers of Lock and Dam 24, Lock and Dam 25, and Melvin Price Locks and Dam on the Mississippi River. The scour has eroded the upstream protection and shortened the seepage path which could lead to piping of the sand foundation of the pile founded structures. Voids were found under the dam piers upstream of the cutoff wall at Lock and Dam 24 and Lock and Dam 25, which have a portion of the foundation piles upstream of the cutoff wall. At Melvin Price Locks and Dam, the scour was below the bottom of the concrete. Rock was placed at Melvin Price Locks and Dam to fill the holes. A Phase 1 Dam Safety Modification Report has been written for Lock and Dam 25 to address the scour problem. The results show those piers which have voids to have a low reliability of satisfactory performance. Consequences of unsatisfactory behavior were determined and alternatives were developed. The alternatives were analyzed to determine the economic impacts of doing nothing and taking corrective measures. Complete and immediate correction by placement of additional stone for the upstream scour protection is economically justified and is necessary to provide a reliably operating dam. A similar study is planned to be conducted for Lock and Dam 24.

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MONTE CARLO SIMULATION FOR SENSITIVITY STATISTICS FOR GEOMETRY OF PLUNGE POOLS DOWNSTREAM OF SKI-JUMP BUCKET SPILLWAY

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ABSTRACT

The plunge pool formed downstream of ski-jump bucket type energy dissipater may affect the safety and stability of the structure. The hydraulic variables involved in plunge pools, such as discharge, flow depth, and velocity, are stochastic in nature, which are represented by relevant probability distributions. Therefore, the optimal design of a plunge pool needs to be modeled by probabilistic methods. Probabilistic analysis method is presently being performed in almost all fields of engineering depending upon the specific field and its particular area. Probabilistic risk analysis, also called quantitative risk analysis is a central feature of hydraulic engineering structural design. Actually, probabilistic methods, which consider resistance and load parameters as random variables, are more suitable than conventional deterministic methods to determine the safety level of a hydraulic structure. This paper is concerned with the reliability-based assessment of the geometry of the plunge pool downstream of a ski jump bucket. The accuracy of the developed equations was examined both through statistical and experimental procedures with satisfactory results. In addition, for validation of selected equation for predicting geometry of plunge pools, Cholesky decomposition is used in the Monte Carlo method for simulating systems with multiple correlated variables.

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INTEGRATION OF WATER MANAGEMENT INTO RISK REDUCTION: BLUESTONE DAM

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ABSTRACT

The goal of this paper is to describe the actions required by the Huntington District's Water Management personnel to modify operational parameters and address deficiencies at Bluestone Dam both prior to the publication of Engineering Circular (EC) 1110-2-6064, Interim Risk Reduction Measures for Dam Safety, and post publication. This comparison will show that prior to publication, the Dam Safety Assurance Team produced a recommendation which was handed off to Water Management Team who did not have a standard process or method to address the project deficiency. Post publication, procedures were established to not only identify interim risk reduction measures in a standard way but also to carry out the necessary documentation required prior to any operational change. As this publication originated within the Dam Safety community of practice, it also provided a logical document for implementation.

The paper will introduce the Dam Safety issues at Bluestone Dam, summarize the proposed Interim Guidance, and describe Water Management's response to this Interim Guidance. It will then summarize the requirements of EC 1110-2-6064 and describe the District's Interim Operating Plan and its implementation. In summary, it is expected that the paper will show how EC 1110-2-6064 addressed Water Management needs in implementing the Interim Risk Reduction Measure of an Interim Operational Pool Elevation thereby integrating Water Management into the Dam Safety Assurance process.

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UPGRADING YOUR DAM — PREPAREDNESS PLANNING FOR SPARTANBURG WATER'S LAKE BLALOCK DAM

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ABSTRACT

The current drought in the southeast is now considered the drought of record for many areas and has brought increased attention from water utilities on the affects of climate variability on the availability and quality of water resources. One mitigation method that water utilities are increasingly exploring is raising the surface water level of their existing reservoirs to increase the available water storage.

H. Taylor Blalock Reservoir (hereafter, referred to as Lake Blalock) was constructed on the Pacolet River as an earthen embankment dam in 1983 for the purpose of supplying drinking water. In order to increase the safe yield of the reservoir and to satisfy state dam safety standards, the dam was modified by reconstruction of the principal spillway, construction of a new emergency spillway and installation of new gates and valves. In addition to improving the dam, Spartanburg Water also made efforts to protect the dam by developing a new Emergency Action Plan (EAP) for the reservoir.

This paper will detail the eight year process from design, through construction to increase storage volume, to preparedness planning for Spartanburg Water's Lake Blalock in Spartanburg, South Carolina.

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FIT FOR SERVICE ASSESSMENTS FOR HYDRAULIC STEEL STRUCTURES

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ABSTRACT

The U.S. Army Corps of Engineers is updating EM 1110-2-2105, "Design of Hydraulic Steel Structures". This Engineering Manual currently covers the design requirements for hydraulic steel structures (HSS) using Allowable Stress Design (ASD), Load and Resistance Factor Design (LRFD) and fracture control design requirements. New criteria will be added in the updated manual that will include Fitness for Service (FFS) evaluation procedures.

A Fit-For-Service (FFS) assessment is a quantitative engineering evaluation that is performed to demonstrate the structural integrity of an in-service hydraulic steel structure (HSS) that contains a flaw or damage or change in operating conditions. The assessment is required when an HSS inspection finds defects, deterioration, degradation, or damage that potentially puts safety at risk with continued use or operation. The USACE Engineering Manuals (EM) and Engineering Regulations (ER) provide requirements and standards for the design, fabrication, and inspection of new hydraulic steel structures but do not address structural and material wear of existing structures in service, deficiencies from original fabrication or a change in operating conditions.

The basic steps to conduct a Fit-For-Service assessment involve review of operating history, original design and current operating conditions. It includes conducting a flaw and damage assessment (based on Level 1-3 evaluations), stress analysis as well as determining critical damage size, level of deterioration, failure modes and remaining life. It also involves development of an in-service monitoring plan and repair or replacement plans.

A FFS assessment may be recommended if the potential of failure of an HSS could lead to a loss of normal operation, a major economic loss or an environmental hazard. Acceptance criteria is based on the extent of flaws, damage, corrosion and level of stress based on an analysis that considers flaw size, stress levels, load cycles, life safety vs. property damage, weld standards and operational restrictions.

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COST EFFECTIVE MODIFICATION OF FLOOD RELEASE GATES FOR AQUATIC BASE FLOWS

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ABSTRACT

On March 1, 2005 Alcoa Power Generating Inc.'s (APGI) new license became effective for the Tapoco Hydroelectric Project. Based on a Relicensing Settlement Agreement developed over a period of several years amongst APGI and its' stakeholders, the Federal Energy Regulatory Commission issued an order approving settlement and issuing a new license. The new license provides additional capacity, protects fish and wildlife affected by the project and enhances recreation. In order to protect aquatic resources, the biological integrity and water quality in the Cheoah River bypass reach, APGI agreed to release aquatic base flows from Santeetlah Dam. The existing dam had no provisions for the release of a limited quantity (40 to 100 cfs) of surface water from the dam.

Each of the two controlled spillway sections at Santeetlah Dam contains three remotely operated 25-ft wide by 12-ft high Tainter gates. The size of these gates made them impractical for controlled releases in the range of 40 to 100 cfs. The most cost effective approach to provide for aquatic base flows was to modify the existing Tainter gates. Modification to the existing Tainter gates for aquatic base flows consisted of installing four new automated stainless steel mini-gates on two of the existing Tainter gates. This allowed coverage of the entire range of flows for the range of normal headpond elevations. An automated control system was provided for operation of the mini-gates.

This paper describes the challenges and considerations associated with the installation of the four mini-gates within the confines of the existing Tainter gate while maintaining the functionality and integrity of the gate. One of the concerns was the potential effect of flow induced vibrations on the Tainter gates created by the addition of the mini-gates, during Tainter gate operation and whether further operational restrictions would need to be placed on normal gate operations.

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REPLACEMENT OF THE LOW-LEVEL OUTLET CONTROL AT SAN PABLO DAM

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ABSTRACT

San Pablo Dam is a 170-foot-high, 1,200-foot-long earthfill embankment that impounds drinking water for the East Bay Municipal Utility District (District). The low-level outlet was constructed in 1921 and modified most recently in 1980, when a 60-inch hydraulically-operated butterfly valve was installed in what is now a nearly-inaccessible chamber approximately 140 feet below the reservoir surface. In 2006, the butterfly valve failed to open in an exercise to ensure that the reservoir could be lowered for construction of dam seismic upgrades in 2008. After evaluating alternatives, the District decided to replace the butterfly valve with a knife gate located at the upstream end of a 46-foot high vertical intake pipe to improve accessibility for maintenance and repair. This required a seismic evaluation to assess the adequacy of the intake pipe during a magnitude 7.25 earthquake on the nearby Hayward Fault, and to ensure that the custom knife gate could resist seismic forces that would be imparted on it from an overhead trash rack and cap. Installation restrictions included a 9-week construction window, with the potential need to evacuate the outlet tower during storm releases. Installation challenges included underwater visibility of less than 12 inches, difficult access to the butterfly valve, and the presence of hydraulic oil in the valve chamber. Work was completed on time so that the embankment upgrades could proceed as scheduled. This project demonstrates the benefits of regular exercise of valves and gates, and installing them where they are readily accessible for inspection and maintenance.

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LAKE TOWNSEND DAM REPLACEMENT PROJECT, GREENSBORO, NC

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ABSTRACT

Lake Townsend Dam impounds the primary water supply for the City of Greensboro, North Carolina. The concrete gated spillway is suffering from severe deterioration due to alkali silica reactivity (ASR) and has inadequate hydraulic capacity to meet spillway design flood (SDF) requirements of North Carolina Dam Safety.

The selected alternative consists of a replacement spillway designed to have hydraulic capacity similar to the existing gated spillway. The embankment will be armored to allow overtopping for storms up to the SDF. Subsurface investigations revealed soft and loose alluvial clays and sands in the original stream and floodplain. Excavation and replacement of these soft loose soils will be necessary for support of the new spillway and earth embankments.

The effect of spillway submergence suggests that a fixed crest labyrinth weir is more appropriate than a gated spillway. In addition, the City of Greensboro prefers a fixed crest to a gated spillway to limit operation and maintenance. The selected replacement spillway will consist of a seven cycle, 300 ft wide labyrinth with a weir height of 20 feet. Articulating concrete blocks (ACB) will be used to armor the earthen embankments for overtopping flows.

Final design included hydraulic modeling using computational fluid dynamics (CFD) and a physical model study of the labyrinth and energy dissipater. The structural design included finite element modeling of the labyrinth weir. Plans and specifications were completed in 2008 and construction is scheduled to commence in the spring of 2009.

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STABILITY EVALUATION OF THE HINZE DAM LOWER INTAKE TOWER

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ABSTRACT

As a part of a 14.75-meter raise of the Hinze Dam, a central core rockfill dam owned by the Gold Coast County Council in Queensland, Australia, the existing 12.5-m-diameter, 60-m-high reinforced concrete intake tower is being raised by approximately 15 meters. The water supply reservoir will remain in operation throughout construction. As part of the intake tower raise design, URS undertook a series of finite element analyses to evaluate the need to install post-tensioned anchors to stabilize the structure. The finite element analyses were used to predict the shears and moments in the intake tower during the extreme (seismic) loading condition. Traditional response spectrum analyses (assuming a fixed base) indicated that the driving moments exceeded the restoring moments at the base of the tower. These results indicate that the tower has the potential to crack and/or rock if the base is, in fact, fixed. To develop a lower bound of the response of the structure, a nonlinear rocking analysis was run in which the base of the tower was allowed to separate from the foundation. The results from this analysis indicated that some rocking would likely occur and that this rocking would reduce the induced moments in the tower by approximately 70 percent. The analysis results also indicated that the magnitude of separation between the tower base and foundation would be sufficiently small (on the order of 1 centimeter) such that minimal damage could be expected during the design earthquake. Based on these results and the low probability associated with the design earthquake, post-tensioned anchors were deemed unnecessary and were not included in the final design.

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A PUBLIC ALERT SYSTEM FOR DAM DISCHARGE USING WIRELESS SENSOR NETWORK

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ABSTRACT

Wireless sensor networks have become a promising method for disaster monitoring such as real-time forest fire detection, radiological monitoring, earthquake detection, and more. In this thesis, we propose to apply the wireless sensor network technology to monitoring and alerting flooding incident in association with dam discharge. Using a wireless sensor network, adaptive query, and cell broadcasting service, the public alert system for dam discharge can provide the right alert information to the right person at the right time, and we can obtain abundant information by real-time sampling the environmental situations for decision-making in an emergency situation. As proof of this concept, we have developed a prototype dam discharge alert system that employs the adaptive querying technique on top of a wireless sensor network. We have identified that the new cutting-edge technology would provide new services producing a high-quality information service for both the service provider and mobile users. This work will further demonstrate how such ubiquitous computing techniques could be used for environmental issues.

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THERMOGRAPHIC IMAGING OF VOIDS BEHIND CONDUITS AND DRAINS

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ABSTRACT

One of the most prevalent failure modes for embankments is static failure due to internal erosion. This internal erosion is often associated with the development of seepage and voids around conduits and outlet works constructed in unconsolidated foundation materials or in the embankment itself.

The use of a thermographic imaging camera could provide a continuous picture of conditions behind conduit walls. The thermal anomaly associated with either an air-filled or water-filled void behind a conduit provides a relatively straight- forward interpretation and a continuous image of the conduit to show interconnection of voids. While the void size resolution and the effectiveness inside different types of conduits (metal, concrete, or plastic) of the thermographic imaging system vary, thermographic imaging provides a rapid assessment of internal erosion conditions outside conduits and drains.

A proof-of-concept test was developed to ascertain the viability of using thermographic imaging to detect voids behind conduits. Three simplified models were constructed along with a limited number of test scenarios sufficient to verify the concept of thermographic imaging of a simulated void. The models provided the opportunity to image simulated voids behind a ¼-inch steel pipe, a 4-inch thick reinforced concrete slab, and a 24-inch diameter Corrugated Steel Pipe (CSP). The simulated voids, constructed of polyvinyl chloride (PVC) pipe, either were air filled or water filled, or had low volume flows during the imaging process. Artificial heating of the pipes was often required to better highlight the void's dimension and location.

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EXCAVATION NEAR CRITICAL DAM INFRASTRUCTURE AT HOWARD HANSON DAM

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ABSTRACT

The U.S. Army Corps of Engineers (USACE) has partially completed a deep (140 feet) excavation in fractured volcanic rock at Howard Hanson Dam in Washington State for a fish passage facility immediately adjacent to critical dam infrastructure. To protect the existing critical flood control infrastructure, controls on the methods of excavation have been instituted, instrumentation to measure the effects of excavation on the rock mass and structures have been installed, threshold values for instrumentation have been developed, and the instrumentation measurements have been compared to thresholds and data from other case studies. Controlled blasting methods have been successfully utilized to limit blast induced deformation. No distress in the excavation rock face or nearby structures has been observed to date despite measured blast induced vibration of 16 in/sec on nearby structures and despite rock face strain as high as 0.1%. Measured rates of deformation have consistently attenuated with time after blast induced stress release and subsequent elastic rebound. The results of instrumentation monitoring have been and will continue to be used to modify our site excavation practices.

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IMPLEMENTATION AND MANAGEMENT OF A SUCCESSFUL GIS FOR THE FERC RELICENSING PROCESS — LESSONS LEARNED

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ABSTRACT

The expansion of geospatial technology and the varied applications of a Geographic Information System (GIS) are important tools in assisting in the Federal Energy Regulatory Commission (FERC) relicensing process. Geospatial technology such as handheld Geographic Positioning Systems (GPS), digital aerial photographs, Light Detection and Ranging (LiDAR) data, and intuitive desktop applications, such as ESRI's ArcGIS, all aid in the growth and functionality of a productive GIS.

During relicensing, it is important for the licensee to respond in a timely and efficient manner to all FERC requests and mandates and be flexible and organized to provide an informed response to stakeholder inquiries in order to address their concerns. A well planned and managed GIS provides the ability to quickly and efficiently respond, as well as be flexible enough to explore alternative solutions, while organizing all spatial data into a central location for future use.

Geospatial technology and the implementation of a GIS aided with the successful relicensing of the Tapoco Project. This paper presents the lessons learned during the initial planning stage, the implementation stage and the management stage of the Tapoco GIS. In particular, this paper focuses on data acquisition and specification, effective data management, storage and organization and planning a GIS to respond to questions today and in the future. The experience from the implementation and management of the Tapoco GIS has been applied to the relicensing of the Yadkin Project and will be applied to future projects. The Tapoco GIS continues to generate benefits during implementation of the Settlement Agreement and License compliance by allowing quick responses to stakeholder inquiries. Thus, a GIS facilitates good relations with stakeholders even after the issuance of a new license.

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SATELLITE POSITIONING AND MONITORING SOLUTIONS FOR DAM, LEVEE AND OTHER WATER RETENTION SYSTEMS

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ABSTRACT

Optimization of water retention system design, construction, safety, and management is critical during this time of high visibility for government spending. This is especially true for structures and projects where homeland security and safety-of-life issues are concerns. Three examples will be given where systems have been implemented on levee and dam projects using solutions that provide simple yet high precision and accuracy positioning and monitoring, with outputs that can be easily communicated to financial decision makers and the general public. A general description of the Global Navigation Satellite Systems (GNSS) positioning techniques is given, and the benefits of using GNSS will be highlighted. Examples are drawn from post- Katrina levee research performed by the Louisiana State University Center for GeoInformatics using a Trimble VRS™ network. Earthen dam monitoring using GPS as operated by the USCOE in Pennsylvania and automated monitoring of an earthen dam by Seattle Public Utilities using Trimble Integrity Manager software is reviewed. Trimble VRS™ networks use wide area modeling of GNSS error sources including ionospheric, tropospheric and satellite orbit correction parameters to produce the industry's highest precision and efficiency method of positioning using GNSS. Trimble Integrity Manager software provides a suite of motion engines designed to detect and quantify any movement in a range of scales from slow, creeping movement like subsidence, through sudden events such as plate tectonics. GNSS data will be shown to be invaluable in monitoring dams and levees and making management decisions about existing and new water retention systems.

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EVALUATING GNSS MONITORING OPTIONS IN A REAL-TIME NETWORK ENVIRONMENT

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ABSTRACT

Water retention, supply, and distribution systems management of a large utility requires high precision positional integrity monitoring of infrastructure. Seattle Public Utilities (SPU) is a city department providing drinking water, directly and via an extensive purveyor program to a substantial segment of the population of Washington State, as well as solid waste and surface water management.

A recently implemented Asset Management program within SPU mandates measurable reductions in operations costs; this was the primary driver for a GPS[80]/GNSS[81] (Global Navigation Satellite Systems) high precision positioning and monitoring initiative piloted at a city owned earthen water supply dam. SPU also administers the Washington State Reference Network (WSRN)[82], a statewide public/private cooperative of 95+ GNSS sensors providing correctors for GNSS observables yielding sub-centimeter precisions.

The pilot has proven multiple positioning and monitoring options that can result in substantial cost savings and as new tools to evaluate the integrity of the SPU infrastructure for both operational and critical event management; tools to compliment, or possibly replace conventional monitoring elements.

New tools tested leverage the inherent integrity of the WSRN statewide network as active control, utilizing a number of motion engines applied within the Trimble Integrity Manager suite, also used to manage the WSRN statewide GNSS network.

A partnership was formed with the Geodesy Lab of Central Washington University to monitor elements of the statewide network comparing localized structural movement resulting from regional tectonic movement. Multiple motion engines provide GNSS measured displacements, that serve to compliment and contrast the otherwise computed displacements traditionally derived from seismographic data.

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[80] GPS – Global Positioning System – generally refers to the Navstar satellite constellation of the U.S.

[81] GNSS – Global Navigation Satellite Systems – refers to multiple navigation satellite constellations to include the U.S. Navstar system, the Russian Federation GLONASS system, the Chinese COMPASS system, the European Galileo system and others.

[82] Washington State Reference Network – www.wsrn.org

INVERSE CALCULATION OF SHEAR WAVE VELOCITY OF ROCKFILL ZONE USING MICROEARTHQUAKE RECORDS

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ABSTRACT

The earthquake with magnitude about M3.2 occurred near Yeongwol in South Korea on January 19, 2006. The microearthquake records were obtained from two accelerometers which were installed on Hoengseong multi-purpose dam. Located about 77km from the epicenter, this dam has a height of 48.5m and a length of 205m. Dam type is center-cored rockfill dam. Using the microearthquake records, the fundamental frequency of the dam was calculated by the evaluation of acceleration response spectrum ratio between the foundation and the crest of dam. In this study, numerical analyses on various shear moduli of rockfill zone were carried out. From the comparison between the results of numerical analyses and that of measured record (fundamental frequency and crest acceleration response), the shear wave velocities with depth, which is closely related to shear modulus, were inversely calculated. The back-calculated shear wave velocities were compared with those by the empirical recommendation method.

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CHARACTERIZATION OF DAM FOUNDATION BLOCKS USING DIGITAL PHOTOGRAMMETRIC MAPPING AND BOREHOLE GEOPHYSICAL LOGGING TO CREATE COMPREHENSIVE 3D FOUNDATION MODELS

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ABSTRACT

The U.S. Department of Interior, Bureau of Reclamation (Reclamation) has greatly enhanced its geologic mapping capabilities by employing close range digital photogrammetry to map geologic structure and to obtain topography in steep or relatively inaccessible areas. Analytical modeling for static and dynamic foundation stability evaluations is most realistic when three-dimensional (3D) geologic structure is included in the model, allowing for a more accurate analysis of potential sliding surfaces. Realistic models must be developed which can be utilized in the limit equilibrium and finite element programs, including non-linear coupled analysis. These new capabilities are being developed through Reclamation's Science and Technology Program. Photogrammetric mapping is also extremely valuable for new construction where topographic and geologic structure data can be obtained quickly for stability analysis and determination of excavation, support, and treatment options as well as documentation of as-built conditions for future reference. Ground-based (terrestrial) photogrammetry is very useful to accurately measure joint orientation, spacing, roughness, and other discontinuity properties for foundation stability analysis. Six projects are discussed in this paper to highlight how Reclamation is using the new and exciting capabilities offered by ground based digital photogrammetry. Photogrammetry was integrated with data from exploratory drilling; borehole geophysical logging; surface mapping and analysis of construction photographs to develop a comprehensive 3D model of the geologic structure in several existing large concrete dams, including East Canyon Dam, Arrowrock Dam, and Folsom Dam. Also included are two river studies conducted using photogrammetry models developed from aerial photographs taken from a small camera platform mounted on a portable helium balloon.

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EVALUATION OF SHEAR STRENGTH OF MÉLANGE FOUNDATION AT CALAVERAS DAM

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ABSTRACT

The existing 220-foot-high Calaveras Dam, located within 1,500 feet of the active Calaveras Fault, is a composite hydraulic fill and rolled earthfill dam. The existing dam was found to have inadequate seismic stability and the potential to undergo very large seismic deformations. Alternative studies to remediate or replace the dam determined that a replacement dam should be constructed downstream of the present structure.

The new Calaveras Dam will be a modern earth- and rockfill dam that will be founded on Franciscan mélange in the valley bottom and right abutment. Franciscan mélange, which covers a large part of northern California, is a classic example of a rock formation that exhibits block-in-matrix characteristics. Block-in-matrix rock is comprised of an assemblage of harder stronger rock blocks within a matrix of softer weaker rock. Previous studies have shown that evaluating the shear strength of block-in-matrix rock on the basis of the strength of the weaker matrix alone can be overly conservative. For example, at Scott Dam in northern California, the shear strength of the Franciscan foundation was shown to be a function of the proportion of harder blocks in the rock mass.

This paper describes the geologic studies, geotechnical characterization, laboratory testing, and engineering evaluation utilized to obtain the shear strength parameters for use in stability analyses of the new dam foundation. The process described will be useful to dam design practitioners for evaluating the shear strength of block-in-matrix foundations.

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SEEPAGE, ROCK STABILITY & BANK STABILIZATION, ABIQUIU DAM & RESERVOIR, NEW MEXICO

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ABSTRACT

Abiquiu Dam and Reservoir is located on the Rio Chama, approximately 35 miles northwest of Española, New Mexico. The dam consists of a rolled earth fill dam with impermeable core, controlled outlet works and an uncontrolled rock-cut spillway. The dam was authorized for flood control and sediment retention and was designed as a dry dam, holding flood pools for relatively short durations. The dam is founded on the highly fractured sedimentary mudstone, sandstone and conglomerate of the Abo Formation and the Poleo Sandstone Lense. Construction was completed in 1963 and the first pool was impounded in 1964. Due to water resource issues in the desert southwest, the dam has been utilized to store water year round. Seepage along both the right and left abutments has also been a concern historically. Seepage and rock stability along the left abutment continues to be a persistent problem presenting hazards to personnel, outlet works structures and the County of Los Alamos hydroelectric plant. In 2004, the Albuquerque District initiated a study into the kinematics of rock failure along the left abutment as well as developing Factors of Safety (F.O.S.) using 2-d limiting equilibrium analysis. Results of this study will be presented as well as recommendations for slope repairs.

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RISK EVALUATION OF DAMS ON KARST FOUNDATIONS

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ABSTRACT

The U.S. Army Corps of Engineers (USACE) has numerous dams built on limestone foundations that are susceptible to solutioning (karst). Significant dam safety issues related to the karst foundation have developed in many of these projects. Screening risk analysis of the USACE portfolio of dams has shown that defects related to karst foundations is one of the largest contributors to our risk. To better evaluate this risk, a method to estimate the probability of failure from piping into karst foundations has been developed by a team of experts from the University of New South Wales, URS Corporation, the Bureau of Reclamation, and the US Army Corps of Engineers. This paper summarizes the primary failure modes associated with dams on karst foundations and the methodology developed to perform risk analysis. A summary of USACE case histories with karst foundation issues and recent projects to remediate the foundations are also included.

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DAMS ON CARBONATE FOUNDATIONS IN THE UNITED STATES

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ABSTRACT

Large multipurpose dams and reservoirs are critical elements of our nation's infrastructure. Functionally, these dams are permanent facilities essential for water supply, energy production, and flood protection. Many of these structures in the United States are located in carbonate regions, and their foundations have inherent special risks with respect to seepage and dam safety. Many of these dams are in the 40-70 year age group and are exhibiting problematic long-term performance behavior. Typically, their performance is the combined result of the site conditions, design elements, and construction practices. Remediation is both difficult and costly, and historically the effectiveness of remedial programs has been inconsistent. The number of large dams on carbonate foundations is sufficient to permit an overview of historical construction practices, common risks associated with these structures, and issues associated with successful remediation.

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CHARACTERIZATION OF GEOLOGIC FEATURES AFFECTING SEEPAGE THROUGH CARBONATE DAM FOUNDATIONS

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ABSTRACT

Physiography, lithology, stratigraphy and geologic structural influences all play a significant role in the behavior of carbonate bedrock underlying many dam foundations constructed in humid regions of the eastern and central United States. Understanding these influences is essential to the evaluation and successful mitigation of seepage through carbonate dam foundations, many of which were conceived, investigated and constructed in the middle of the last century. Integration of essential geologic contextual information with historic records and well planned and carefully executed non-intrusive and intrusive investigations will yield data essential for solving complex carbonate rock problems. However, careful and continuous compilation and analysis by experienced geologists and engineers is required if data from investigations are to be converted into sound science and engineering solutions. Recently completed and ongoing seepage remediation projects for dams founded on carbonate bedrock provide the back drop and frame of reference for a review of commonly deployed investigative techniques.

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DESIGN, CONSTRUCTION AND PERFORMANCE OF SEEPAGE BARRIERS FOR DAMS ON CARBONATE FOUNDATIONS

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ABSTRACT

The design, construction and performance of concrete cut-offs, and grout curtains, as dam seepage remediations in carbonate foundations is reviewed. Recent experiences when attempting to build concrete cut-offs through hard and highly permeable rock masses have led the authors to develop the concept of "composite cut-offs" for seepage control. A campaign of high quality drilling, permeability testing and grouting is first conducted to pretreat the very permeable and/or clay-filled zones, to seal the clean fissures, and to provide an extremely detailed geological basis upon which to design the location and extent of the subsequent concrete wall (if in fact needed). Bearing in mind that the average cost of a concrete wall is many times that of a grouted cut-off, and that there is currently a shortfall in industry capacity to construct the former, the concept of a "composite wall" is logical, timely and cost effective.

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DESIGNING A NEW DAM AT A KARST GEOLOGY SITE

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ABSTRACT

Increasing residential and industrial populations required the city of Portland, Tennessee to evaluate ways to augment their current water supply. CDM completed the preliminary design of a new 470-mg reservoir to be used as a supplemental water supply source during drought conditions. In order to better understand the results of various proposed alternatives, a dynamic simulation model of the watershed was developed which included the existing water supply sources as well as the proposed new reservoir. The innovative model was developed with GoldSim® software to simulate complex systems and account for numerous uncertainties in input data and relationships between system elements. The completed model allowed CDM to understand tradeoffs between system yield, instream flow targets, and lake levels in a probabilistic framework. The model provided substantive guidance that suggested the city could meet their projected demand while simultaneously augmenting instream flow levels during periods when instream flow is excessively low.

The proposed reservoir site is located in a karst geologic region. CDM performed a detailed geologic and geotechnical investigation including *in situ* hydraulic conductivity testing, geophysical surveys using microgravity, and dye trace tests to evaluate potential karst features in the dam foundation bedrock. Based on the results of the geologic/geotechnical testing and the hydrologic/hydraulic analyses, CDM developed conceptual designs and cost estimates for dam and spillway alternatives. The selected alternative is a combination 30-foot-high, 1,000-foot-long roller compacted concrete (RCC) and earth embankment dam with a 100-foot-long conventional concrete or RCC spillway.

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SEEPAGE CONCERNS AT KEYSTONE DAM, OKLAHOMA

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ABSTRACT

Keystone Dam is located on the Arkansas River just upstream of Tulsa, OK. Failure of this dam would lead to catastrophic loss of life and significant economic loss in the Tulsa, OK area.

Through on-going inspections, new seepage has been observed during flood pool operations in each abutment of Keystone Dam. In addition, a recent assessment of foundation materials and construction documentation for Keystone Dam indicate that a filter was not installed in a cutoff trench in the foundation during construction of the dam. A Screening Portfolio Risk Assessment (SPRA) conducted in 2006 identified seepage through the abutments in the sandstone and limestone bedrock, and potential piping of embankment material as a deficiency.

Recent investigations have included a geophysical survey to further identify seepage locations, installation of piezometers in the left abutment, and the use of sonic drilling through the embankment core and foundation to investigate the areas of concern. In addition, an external panel of experts were engaged to review and assist in planning further investigations and studies.

This paper discusses the identified areas of concern, results of previous investigations, and describes the ongoing investigations and analyses.

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RE-ANALYSIS OF THE FAILURE OF TETON DAM

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ABSTRACT

The failure of the 305-foot-high Teton Dam in Idaho upon initial filling of its reservoir in June 1976, which resulted in 14 fatalities and over $400 million in economic losses, has been one of the most publicized events involving a large earthfill dam in recent history. Because Teton Dam was designed and built using modern standards, its failure has received significant attention from engineering experts around the world. Based on numerous investigations that were subsequently conducted, several theories pertaining to plausible failure mechanisms have been put forward, but no clear consensus has apparently been reached as to which theory represents the most convincing explanation of what happened on that fateful day. Through the application of modern computer-aided finite-element modeling of the probable seepage patterns in the vicinity of Teton Dam around the time when it failed, this paper provides additional insight into the major underlying causes of the dam collapse. Using the subsurface flow patterns derived from the finite-element seepage analyses, embankment stability conditions are then analyzed for selected cross-sections, corresponding to representative portions of the dam that either failed or did not fail. The results are then presented in a manner that will likely augment the current understanding on the plausible mechanisms of the collapse of Teton Dam – a unique showcase from which priceless lessons can be learned.

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HERBERT HOOVER DIKE SEEPAGE REMEDIAL DESIGN CONCEPTS

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ABSTRACT

Herbert Hoover Dike (HHD) encircles the 720 square mile (143 mile perimeter) Lake Okeechobee in south central Florida. Original Congressional authorization for construction of HHD followed catastrophic damages and massive losses of life during the hurricanes of 1926 and 1928. Flood damage reduction has been accomplished for more than 75 years; however, concerns related to seepage instability have existed at HHD since the early 1980's. They have since become more pronounced during high lake events and through project evaluations, and are generally due to the lack of hydraulic controls and the characteristics of embankment and foundation materials. Lake Okeechobee is operated according to a regulation schedule, but water managers lack the control needed to release enough water during high inflow periods. Surge from large and sustained wind events can cause lake stage to increase by several feet within a short time period. The ability to regulate lake stages is further hampered by seepage-related concerns which exist for lake stages within the regulation schedule. No continuous features exist at HHD to relieve excess pore pressures, control seepage, and arrest material piping during high lake events. The design of such features is in progress, and is complicated by non-uniform subsurface conditions, geotechnical properties of materials, and fairly stringent design criteria resulting in remedial design challenges. This paper offers an overview of HHD seepage-related aspects, discusses design approaches for managing related concerns along 4.9 miles of HHD, and presents a summary of current rehabilitation alternatives. Alternatives involve the construction of two primary components: a partial-depth seepage/piping barrier through the embankment and near-surface consolidated strata, and a landward seepage berm coupled with an often necessary pore pressure relief system.

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COMPREHENSIVE FOUNDATION REHABILITATION AT BEAR CREEK DAM

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ABSTRACT

TVA's Bear Creek Dam is a high hazard embankment dam in northwest Alabama that provides water supply, flood control, and recreation benefits. Since its initial filling, the Dam has experienced significant seepage through its karst limestone foundation. After experiencing limited or temporary success at controlling seepage using supplemental grouting programs and downstream seepage collection systems, TVA elected to embark on an extensive rehabilitation effort for the existing structure's deficiencies, which are primarily foundation seepage causing a potential loss of dam material at the foundation contact and the risk of loss of the embankment dam during an overtopping flood event associated with the PMF. Paul C. Rizzo Associates, Inc. (RIZZO) was hired to design a robust, permanent solution for the Dam's issues. Performance of this rehabilitation consists of construction of a downstream RCC reinforcement structure to prevent loss of the Dam during PMF overtopping and installation of a composite seepage barrier consisting of a two line grout curtain with cutoff wall panels at select locations to control potentially hazardous foundation seepage. The existing emergency spillway as well as sluiceway tunnel and associated intake structure will be preserved as a part of this new construction.

This paper presents the means and methods employed to effectively treat the karst limestone geology present at the Dam, with emphasis on the progressive nature of the design and construction of the final seepage barrier, wherein continuous, 'real time' evaluation of the geologic conditions encountered during each phase of the foundation treatment process was used to tailor the scope and design of the next step of the rehabilitation.

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INTERNAL EROSION INCIDENTS AT BUREAU OF RECLAMATION DAMS

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ABSTRACT

The Bureau of Reclamation has an inventory of a few hundred dams, including more than 220 embankment dams plus many more dikes and smaller embankments. The ages of the dam embankments range from recently constructed to more than 100 years old. During the approximate 100-year history of Reclamation, there have been numerous instances of the initiation of internal erosion in Reclamation embankment dams or their foundations. Some of these incidents have occurred as recently as 2007 and in one case an incident occurred along the outlet works of a relatively new dam. In only one dam (Teton) has the initiation of internal erosion led to complete dam failure, although others have experienced very serious erosion that nearly led to failure. However, the vast majority of incidents have not led to failure or placed the structure in immediate jeopardy, either because the manifestation of erosion occurred in a non-critical area, or because early evidence of excessive seepage, material transport, or unusual behavior led to successful intervention and mitigation of the developing problem. This paper will highlight some of the incidents, enumerate and categorize the types of incidents, and develop the historical rates of initiation of internal erosion at Reclamation dams. The insights from this study of incidents can be used when evaluating risks of internal erosion failure of embankment dams. The study results will also serve as a reminder to dam professionals to remain diligent for seepage related failure modes both in monitoring and in managing risk.

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LONG-TERM PERFORMANCE OF SEEPAGE BARRIERS, FINDINGS FROM CASE HISTORIES AND ANALYSES

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ABSTRACT

The paper presents the results of a study investigating the long-term performance of seepage barriers in dams through case studies and analyses. Mechanisms of erosion and piping that are uniquely related to seepage barriers have been investigated through review of measured performance of existing dams and through analytical studies. A compendium of 30 case studies of dams that have had seepage barriers in place for over 10 years has been assembled, and observations and insights garnered from these case studies were compiled. Finite element seepage and deformation analyses have been performed to provide better understanding of the performance of seepage barriers and the mechanisms that affect their performance. The observations and insights acquired in this study were distilled into conclusions regarding the long-term performance of dams with seepage barriers.

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3D GEOSTATISTICS TO EVALUATE EMBANKMENT AND FOUNDATION SEEPAGE

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ABSTRACT

Martis Creek Dam is a rolled earthfill embankment dam with a maximum height of 113 feet and a crest length of 2673 feet, has a storage capacity of 20,400 acre-feet at gross pool and is located near Truckee, CA. The project has had a history of seepage problems since its construction in 1972 and was mainly designed for flood control with an option to store water in the future depending on performance. The embankment consists of an upstream impervious zone tied into an upstream impervious blanket, random fill zones, and vertical and horizontal graded drains. The embankment was founded mainly on permeable glacial outwash materials predominantly located at the left abutment. Seepage collection and control features include 20 relief wells, 26 observation wells, 32 piezometers, a left abutment seepage and stability blanket, and a right abutment groin seepage collection system. Recent project studies have been implemented to thoroughly investigate the seepage problem. In order to manage the large amount of geotechnical and geologic data, three-dimensional (3D) geostatistics and computer visualization techniques have been employed to better examine the relationships between the seepage control features and the geologic conditions. This paper presents some of the more interesting aspects of the geotechnical and geologic conditions using the 3D program GMS (Groundwater Modeling System) to visualize the system and conduct material probability geostatistics. The geostatistical models will eventually be used to conduct seepage analyses for possible seepage remediation techniques.

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USING GEOPHYSICS TO EVALUATE AN EMBANKMENT DAM SINKHOLE

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ABSTRACT

Located near Knoxville, Tennessee, Chilhowee Dam is 80 feet high and 1,500 feet long with two embankment sections, a concrete gated spillway, and two concrete non-overflow sections. A six-foot deep sinkhole formed near the left abutment on the upstream slope of the Chilhowee Dam's embankment in February 2000. Geotechnical investigations were performed to evaluate the sinkhole, including borings, test pits, instruments, and geophysics. The dam posed two distinct challenges to a geophysical investigation: 1) a very complex geometry of the embankment with upstream sloping clay core, many filters each side of the clay, rockfill shells, and a steeply sloping rock foundation contact; and, 2) restrictions from the hydro power generation at the dam. The focus of this presentation is the multiple surface geophysical methods used for subsurface evaluation to help determine dam remediation.

Two geophysics methods were used: 1) Self-potential (SP) survey to evaluate dam seepage, and 2) three dimensional (3D) seismic refraction survey to evaluate the extent of soft clay found in previous borings. The seismic investigation used an innovative 3D refraction technique to evaluate the internal embankment materials, and represents to our knowledge the *first* refraction data set ever collected, processed, and presented in full 3D format at an existing dam.

SP results indicated two distinct preferential flow paths through the embankment. One of these flow paths crossed the sinkhole, the other was adjacent and near parallel.

Geophysics results and conclusions were used together with results of geotechnical investigations, embankment design and as-built information to make engineering evaluations of dam safety, the impact of the sinkhole, and extent of remediation.

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RE-EVALUATION OF THE SEISMIC STABILITY OF CHABOT DAM

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ABSTRACT

Chabot Dam is a 135-foot-high earthfill embankment located within 1 km of the Hayward Fault, in the San Francisco Bay Area of California. The dam was built in the late 1800's by teams of horses and wagons from locally available clayey soils, and was buttressed downstream with hydraulic fill. The dam withstood the magnitude **M** 8 Great San Francisco earthquake of 1906 without reported damage.

This paper describes a recent seismic stability evaluation of the dam, including the assessment of seismic hazard at the site and the analysis of seismic stability and deformations. The paper highlights procedures for evaluating the cyclic strength of clayey soils and the implementation of nonlinear finite element techniques for the analysis of seismic deformations. In addition, the paper contrasts the results and techniques of the recent evaluation with those of previous evaluations and with the seismic performance of the dam during past earthquakes.

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USE OF SEISMIC DEFORMATION ANALYSIS IN REMEDIATION DESIGN

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ABSTRACT

Corps of Engineers guidance requires using seismic deformation analysis in validation of remediation design of seismically deficient embankment dams. Accordingly, the design team for the seismic rehabilitation of Success Dam, California used the computer code FLAC with the liquefaction model UBCSAND as the main tool in designing and optimizing the remediation. A major challenge in design was the selection of reliable parameters for characterization of soil materials from their liquefaction potential point of view. The commercially available FLAC program, from Itasca Consulting Group, Inc. and the constitutive model UBCSAND, developed at the University of British Columbia, were selected for the deformation analysis. Several refinements were made to the original version of UBCSAND to address specific conditions at Success Dam. The results of the FLAC seismic deformation analysis were compared with the results of less sophisticated, and generally more conservative, procedures like QUAD4M coupled with limit equilibrium analyses assuming post-liquefaction residual strength in potentially liquefiable zones using the UTEXAS4 computer program. Several remediation options were analyzed, which included partial excavation of the existing dam, excavation and replacement of a portion of liquefiable alluvial foundation, and construction of buttresses either downstream only or both upstream and downstream of the existing shell. The selection of the optimum variant was based on balancing dam safety by limiting deformations to allowable levels, the initial cost of remediation, and the potential cost of repairs following a strong earthquake occurrence in the vicinity.

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SEISMIC INPUT MOTION UNCERTAINTY FOR EMBANKMENT DAMS

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ABSTRACT

Common practice for embankment dam safety evaluation often represents each specified seismic scenario with a single spectrum-compatible horizontal input acceleration history to be used for dynamic response analysis. This approach does not guarantee proper capture of the randomness of natural ground motion. To quantify the related uncertainty, the authors evaluated an example embankment dam through parametric nonlinear analyses. Three increasingly demanding earthquake scenarios were successively considered. Each scenario used four sets of horizontal and vertical input histories that complied with the specified response spectra and duration of shaking. Furthermore, each time history and its "opposite" (all values multiplied by -1) were successively considered. Therefore, for the three specified sets of seismic criteria, forty-eight different analyses were conducted to assess the variability of dam response.

For the study embankment dam, this investigation demonstrated the importance of checking the sensitivity of dam response to the specified input motion. The standard deviations of the computed peak deformations and crest settlements (expressed in percent of the mean predictions) were defined and illustrate the uncertainty in the calculated response. The use of a single input acceleration history seems insufficient and is no longer justifiable, as the rapid and continuous improvement of computers greatly facilitates making several successive analyses of a same dam. Especially, using several sets of input motions based on the same criteria seems essential for dams exposed to potentially severe ground motion or shown to be marginally stable.

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CHALLENGES AND OPPORTUNITIES IN REHABILITATING AND ENLARGING A 100-YEAR-OLD ON-CHANNEL RESERVOIR

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ABSTRACT

The San Luis Valley Irrigation District (District) serves and delivers water to land located in the San Luis (Rio Grande) Valley in Alamosa, Rio Grande, and Saguache Counties in Colorado. It owns and operates the Rio Grande Reservoir in Hinsdale County, Colorado. Located on the headwaters of the Rio Grande, the reservoir is a unique on-stream, pre-Rio Grande compact facility. Construction of the dam began with the outlet tunnel, bored in 1909. The large earth and rockfill dam, completed in 1914, is 111 feet high and approximately 600 feet wide along its center axis. The dam was constructed using a puddle-basin technique for the upstream earth-fill section, and dumped and hand-placed rock as the downstream rockfill section. The left abutment of the dam rests largely on a landslide that originates from cliffs to the north. The right abutment rests on welded-tuff bedrock, through which the outlet tunnel is bored. Issues with the outlet works became apparent when the reservoir was first filled in 1914. Two of the five original gates were plugged with concrete due to severe operation-related vibrations. Currently the gates still leak, and are only partially operable. At certain release rates, a hydraulic jump develops in the outlet tunnel causing severe vibrations and pounding in the outlet tunnel which can be felt on the dam crest. Seepage through the left abutment is significant (>2500 gpm) when the reservoir stage is high. A dam rehabilitation and enlargement preliminary design was recently completed and a detailed geologic investigation of the area was performed due to evidence of numerous landslides in the vicinity, and of a fast-moving, catastrophic landslide that occurred approximately 5 miles upstream of the reservoir. The inflow design flood was recalculated using the new Extreme Precipitation Analysis Tool (EPAT) developed for the State of Colorado. The preliminary design addresses the geotechnical issues, hydrologic and hydraulic problems related to the outlet works and undersized spillway. A new outlet tunnel, spillway reconstruction, grout curtains for seepage control and landslide monitoring were among the recommendations. In addition, the benefits potentially available to several water users in the basin, including agricultural, domestic, environmental, and recreational uses, Rio Grande Compact and river administration and flood protection were examined. This paper will discuss the unique challenge facing the project team and the ultimate recommendations made.

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MULTI-USE OF A REHABILITATED RESERVOIR FOR IMPROVED RIVER ADMINISTRATION, FLOOD CONTROL, AGRICULTURAL, DOMESTIC, ENVIRONMENTAL AND RECREATIONAL BENEFITS

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ABSTRACT

The San Luis Valley Irrigation District (District) serves and delivers water to land located in the San Luis Valley in Alamosa, Rio Grande and Saguache Counties. The District owns and diverts its water through the Farmers Union Canal, which diverts from the Rio Grande. It also owns and operates the Rio Grande Reservoir in Hinsdale County, Colorado. Located on the headwaters of the Rio Grande, the reservoir is a unique on-stream, pre-compact facility. Additional storage will provide the State of Colorado with an invaluable tool to store and better manage delivery of the water it is obligated under the Rio Grande Compact (compact) to deliver to the Colorado-New Mexico border. An enlargement could also assure that Colorado retains all of its water available for its own use under the compact. Re-regulation of deliveries under the compact could also address instream flow needs for fish and river habitat. Additional storage can also help to reduce the wide fluctuations and result in more equitable allocation of the curtailment on irrigators in order to meet Colorado's compact obligations. This will provide irrigators with a more consistent water supply during the irrigation season while assuring that Colorado has stored water that may be needed to meet any remaining compact obligation after the irrigation season ends. A study and preliminary design was conducted to examine rehabilitation alternatives, develop potential enlargement configurations, provide stakeholder input, and create a preliminary design to examine geotechnical aspects of rehabilitation and enlargement and environmental impacts. An investigation into the hydrologic characteristics of the basin downstream of the reservoir was conducted to analyze the potential benefits of reoperations of a rehabilitated or enlarged reservoir to allow for improved river administration, flood control and storage for agricultural and domestic uses and retiming of releases for environmental and recreational benefits. As a result of the detailed studies and preliminary design, the owner has determined to proceed with rehabilitation only at this time. The operation of the rehabilitated reservoir and compact delivery practices could be modified to realize the several benefits a rehabilitated reservoir would yield to the river system and basin water users. Draft agreements have been developed to provide for beneficiaries of a rehabilitated or enlarged re-operated reservoir to share in the financial costs of the project. This paper will present the alternatives evaluated and discuss the multiple benefits associated with each.

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LEVEE SCREENING TOOL

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ABSTRACT

A Levee Screening Tool (LST) methodology is being developed by the United States Army Corps of Engineers (USACE) to support risk informed decisions within the USACE Levee Safety Program. The screening tool relies on existing data, engineering assessment, and consequence estimation to characterize the relative risks posed by levees within a portfolio in terms of a relative probability of failure and potential life safety and economic consequences. A simplified probabilistic framework is used to account for the likelihood of flood loading, performance of the levee, and consequences due to levee breach. Flood loading estimates are made based on available design records, flood insurance studies, gage records, or other flood related data. Probability of failure estimates are based on an engineering assessment of relevant performance based items from the levee inspection checklist and a review of available design, construction, and past performance records. Consequence estimates are made using readily available data from the National Levee Database (NLD), United States Geologic Survey (USGS) National Elevation Dataset (NED), and Federal Emergency Management Agency (FEMA) HAZUS databases.

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RELIABILITY EVALUATION OF THE NATOMAS LEVEE SYSTEM AS PART OF THE SACRAMENTO RIVER FLOOD CONTROL PROJECT SACRAMENTO, CALIFORNIA

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ABSTRACT

This paper presents the results of the geotechnical reliability evaluation of the Natomas levee system in Sacramento and Sutter Counties California. The levee system protects a population of 70,000 residents within the 43 square mile Natomas Basin located north of Sacramento. The flood protection system consists of about 40 miles of levees constructed along the east bank of the Sacramento River, the north bank of the American River, the west banks of the Natomas East Main Drainage Canal and the Pleasant Grove Creek Canal, and the south bank of the Natomas Cross Canal. The geotechnical evaluation of existing levee conditions was based on available geographical and geotechnical data, geomorphology of the area, and past performance. The available geotechnical information included subsurface investigations performed for the design and construction of recent levee modifications supplemented with more recent investigations. The risk analysis was performed in general accordance with USACE guidelines. The probability of failure was evaluated by examining foundation and embankment conditions and assigning values for the probability moments of the random variables considered in the analyses. Performance functions considered for the risk analyses included slope stability and seepage. Judgment was included in the analysis by consideration of past performance, erosion, maintenance, encroachments, penetrations, and existing vegetation. No additional judgment factor was included with respect to the uncertainty of future hydrologic conditions of the basin. A set of conditional-probability-of-failure versus river stage elevation graphs was developed. Reliability analysis was performed using Taylor's Series Method.

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SIMPLIFIED APPROACH TO ASSESS LEVEE SEISMIC VULNERABILITY

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ABSTRACT

This paper presents an overview of the California Department of Water Resources Urban Levee Program simplified seismic vulnerability method, its development, analysis protocols, and typical results. The methodology is based on a Newmark-type of deformation evaluation, with specialized charts to evaluate levee response to seismic loading, similar to the widely-used Makdisi-Seed simplified approach to evaluate dams. Example seismic hazard, cyclic-stress ratio, maximum seismic loading and deformation estimation charts are presented with details on how they are used to evaluate levee seismic vulnerability in a screening level program.

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V-LINE CANAL FAILURE

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ABSTRACT

The twenty-seven mile long V-Line Canal is a feature of Reclamation's Newlands Project in Nevada. The V-Line canal was designed and built by the Reclamation Service in 1904 -1905. On June 11, 2008, the V-Line Canal breached at the Lewis Check and Wasteway Structure (Lewis Spill) releasing water into the wasteway and then into the Carson River. The Lewis Spill is located approximately eight miles west of Fallon, Nevada. Information was collected after the failure took place to determine the probable failure mode. This information included records of operations prior to and after the failure, available information regarding site geology, eyewitness observations during the failure, post-failure interviews, and a site inspection. An evaluation of the potential failure modes was performed based on the collected information. The most likely failure mode was Internal Erosion of embankment materials into the Floatwell Discharge Pipe. This conclusion was reached based primarily on corroded pipes found after the breach, eyewitness accounts, and routine operations performed prior to failure.

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GEOTECHNICAL ASSESSMENT OF INDIANA DAMS AND LEVEES DURING THE JUNE 2008 MIDWEST FLOOD

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ABSTRACT

During early June 2008 severe weather conditions and heavy precipitation impacted the central and southern portions of Indiana, with portions of the White and Wabash River basins receiving over 10 inches of rainfall. On 9 June the President issued a State of Emergency Proclamation and declared 30 counties in Indiana a major disaster area opening up the region to receive federal aid and FEMA assistance. Considering the heavy flooding experienced and the continued forecast of heavy precipitation, emergency assessments of all high hazard regulated dams in all counties declared disaster areas were undertaken. On 12 June the authors were deployed and provided support as part of efforts to provide real-time geotechnical evaluations of Indiana dams and levees which had been and were being stressed by record pool levels and river crests in order to provide a basis for risk-related decision-making. From this work, this paper provides many examples of observed geotechnical conditions posing threats to earthen structures including overtopped dam erosion, spillway erosion, downstream embankment erosion, slope failure, and underseepage-related foundation erosion. Examples are provided of how implemented recommendations such as recommending emergency downstream evacuations, keeping tail water on boils rather than pumping, sand bagging, closely documenting areas where distress was observed, and recommending future remedial investigation and construction contributed to minimization of current and future risk and real-time prioritization of resources during this event. Additionally, this paper serves as an example of ways to effectively approach similar emergency efforts in the future, such as having up-front compilation of all project data, utilizing GPS and GIS, having good communications established, and having experienced teams ready to deploy. Observed conditions and reconnaissance challenges during the June 2008 Midwest Flood demonstrate the need for proactively recognizing and addressing potential geotechnical-related risks associated with many of the Nation's high hazard dams and levees.

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POTENTIAL FAILURE MODES OF THE TRUCKEE CANAL FAILURE AT FERNLEY, NEVADA

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ABSTRACT

At approximately 4:00 a.m. on Saturday, January 5, 2008, the downhill embankment of the Truckee Canal failed at approximate canal station 714+00, releasing water into the town of Fernley, Nevada. Nearly six hundred and ninety homes were flooded. The canal drained through the breach from both the upstream and downstream directions. Reportedly, water flowed through the breach for up to 9 hours and water depths of up to 8 feet occurred in some locations, with water depths of 1 to 4 feet common throughout the housing developments. No fatalities occurred as a result of the flooding. Damages were estimated to be approximately $50,000,000.

Prior to January 4, 2008, the Truckee Carson Irrigation District (TCID) had been diverting water through the canal at an approximate daily rate of 370 cfs. A storm event in the Reno/Sparks area on January 4, 2008 generated 1.91 inches of precipitation which resulted in significant increases in the Truckee River flows and diversions into the Truckee Canal. Based on USGS gauging station data about 4 miles upstream of the breach site, it is estimated that the flow in the canal was approximately 750 cfs at the time the breach occurred.

This paper will present: 1) technical information pertinent to the failure, 2) investigations of the canal and breach site, and 3) the potential failure modes to help explain the cause of the failure.

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SEEPAGE CUT-OFFS FOR LEVEES: A TECHNOLOGY REVIEW

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ABSTRACT

Seepage through and under existing levees and embankment dams is a major threat to such structures all across the country, and programs of unprecedented scale have been initiated to remediate this problem. In other publications, the authors have described methods used to create cut-offs for dams, hundreds of feet deep through overburden, fill and rock (principally karstic limestone and dolomite). However, much work is projected or is actually underway to considerably shallower depths in Sacramento, New Orleans and Lake Okeechobee, as examples. The paper provides a technology review of the various methods used to install such cut-offs, principally in softer ground conditions. These technologies include:

- Category 1 cut-offs involve backfilling of a trench previously excavated under bentonite slurry. Examples include the use of backhoes, grabs and hydromills.

- Category 2 cut-offs involve the mixing of the levee and foundation soils in situ. Examples include conventional (vertical axis) Deep Mixing, the TRD method and CSM method.

For each, the pros and cons, methodologies, applicability and budget costs are provided, as are details from recent case histories and a comprehensive bibliography.

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ACCURATE AND RELIABLE CONSTRUCTION COST ESTIMATES

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ABSTRACT

Today, it can be said with reasonable certainty that the accuracy and reliability of construction cost estimates pose challenges and problems for designers, engineers, managers, and owner/operators of civil construction projects. This is especially true in dam, canal, and other water resource construction. In the rapidly changing world of design and construction, the constraints imposed by the demands and expectations of the owner or buyer and the dwindling availability of credit and funding have significantly contributed to the awareness and sensitivity of the need for accurate and dependable estimates of construction cost. Design and construction of dams pose even further challenges given the nature of their unique engineered features, site conditions, and schedules. Additional complications include escalation and the lack of reliable cost databases for this type of work. A systematic approach to developing the cost estimate may lend itself to easing some of the disparity between the budget and the responses on bid day. This paper explores the approach to and methods used by a dam constructor in estimating construction cost versus the more streamlined approach utilized by many engineer designers in developing construction cost estimates. The paper further explores the root of common oversights in estimating construction cost and reveals some of the methods used to avoid such oversights. This paper discusses these challenges and offers recommendations for dealing with such issues as direct and indirect costs, contractor overhead and markups, risk, escalation, contingency and other costs in order to produce consistently better construction cost estimate results.

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MORMON ISLAND AUXILIARY DAM — ASSESSING CONSTRUCTION RISKS FOR SEISMIC REMEDIATION ALTERNATIVES

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ABSTRACT

Mormon Island Auxiliary Dam (MIAD) has been assessed as having unacceptably high seismic risks according to Reclamation dam safety public protection guidelines. Studies are underway to determine the most prudent means to reduce the seismic risk. The technically preferred method to reduce this risk is to construct a key-block beneath the downstream toe of the dam. A risk estimating team was formed to develop procedures for estimating risks the agency would be accepting during construction and identifying ways to effectively reduce this temporary increase in risk. The primary concerns were for downstream embankment slope instability with an open excavation at the toe of the dam. The risks were found to be sensitive to the depth of excavation and the likelihood of high reservoir water surface elevations while the excavation was open. A method is proposed for assessing and comparing risks for a variety of construction scenarios.

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INNOVATIVE REHABILITATION AT THE COBBLE MOUNTAIN DAM OUTLET WORKS FACILITY

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ABSTRACT

Construction of Springfield Water and Sewer Commission's (SWSC) Cobble Mountain Reservoir Dam, located in Granville, Massachusetts, was completed in 1931. For the past 75 years the reservoir has served as the primary drinking water source for the City of Springfield, Massachusetts and its surrounding communities. In 2001, a rehabilitation project was planned for the diversion tunnel high-pressure outlet works facility, which included replacement of two 42-in x 30-in Larner-Johnson needle valves. The project also included rehabilitation of the two 40-in Escher Wyss rotary (ball) valves that guard the needle valves. The outlet works operates under 200-ft of static head. The needle valves were replaced with 30-in diameter jet-flow gates, which discharge directly into the 1500-ft long 12-ft diameter diversion tunnel. There were no isolation gates installed upstream of the guard valves in the original design of the dam and tunnel, so the valves could not be dewatered prior to disassembly. These conditions required the design of a unique non-entry mechanical plugging system, which allowed insertion of a 40-in diameter pneumatic bulkhead plug, from the gate chamber (in the dry), through the valve and into the upstream conduit. This was accomplished while the system was under 200-ft of static head. After the plug was inflated within the conduit, and mechanically restrained in the gate chamber, the guard valves could be dewatered and disassembled for rehabilitation in the dry. The new jet-flow gates and rehabilitated guard valves were commissioned in August 2006. This paper describes the history, inspection, testing and evaluation of the existing valves and piping; project design objectives and details, and the results derived from hydraulic testing of the new outlet works after commissioning.

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CARTER LAKE DAM OUTLET WORKS ADDITION

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ABSTRACT

Construction of a new, second outlet works was recently completed at Carter Lake Dam, Colorado, an existing, 214-foot high, zoned embankment dam that was constructed in the early 1950s by the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) and is operated by the Northern Colorado Water Conservancy District (Northern Water). The new outlet works provides operational flexibility and redundancy to more reliably meet water demands, which have changed over time from primarily irrigation water to primarily municipal and industrial water. The new outlet works consists of a 110-foot high, multi-level intake structure with an access bridge; a 72-inch diameter steel-lined, tunnel conduit through the right abutment of the dam; a concrete-encased downstream steel pipe to deliver water to the St. Vrain Canal; a meter vault; and a valve house equipped with a sleeve valve for dissipation of energy before the water is delivered to the canal. The project was funded entirely by Northern Water and was designed by a team consisting of URS Corporation and Reclamation. Construction management was provided by Northern Water, with construction phase engineering provided by URS and Reclamation. One of the significant challenges successfully met by the project was a design and specification that provided for construction with a lowered reservoir period extending only from October 1, 2007 through February 28, 2008, which minimized impacts on water operations.

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DESIGN AND CONSTRUCTION METHODS OF A ROCKFILL COFFERDAM THROUGH 200 FEET OF WATER

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ABSTRACT

Increased water storage utilizing a new dam is one alternative under study as part of the Upper San Joaquin River Basin Storage Investigation (USJRSI) in the State of California. A potential storage location is near the upper end of the existing Millerton Lake, a reservoir impounded by Friant Dam, a part of the Bureau of Reclamation's Central Valley Project as shown on Figure 1. Benefits of a new dam at this location include an additional 1.3 million acre-feet of water storage that can be used for restoration of the Upper San Joaquin River, as well as the Bay Delta. Feasibility design is currently underway for a dam approximately 640 feet high.

One of the challenges for this alternative is the construction of a large dam at the site of an existing reservoir. Typical annual reservoir operation results in water depths between 130 and 200 feet. Draining Millerton Lake for the construction of the dam is unacceptable due to the significant negative impact to downstream water users. A plan was needed for construction of cofferdams through the reservoir so the new main dam could be built in the dry using conventional techniques. Due to the depth of Millerton Lake at this site and potential floods during construction, the upstream cofferdam has an approximate height of 280 feet and the downstream cofferdam has a height of 220 feet.

This paper describes the design of the rockfill cofferdams including the use of both diaphragm and central core barrier methods. A description of the construction methodology is also given on the two stages of cofferdam construction. The first stage will be construction in the wet (through the reservoir during low pool) and the second stage in the dry. A detailed 9-step construction sequence is presented along with the associated construction methods.

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A.V. WATKINS DAM MODIFICATION: CEMENT-BENTONITE SLURRY CUTOFF WALL

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ABSTRACT

A.V. Watkins Dam is an earthfill dam approximately 14.5 miles long with a structural height of 36 feet. Located just north of Ogden, Utah, the dam impounds approximately 215,000 acre feet of water and is founded on compressible lakebed sediments of the Great Salt Lake. In November of 2006, a piping incident occurred which nearly resulted in the catastrophic failure of the dam and reservoir. While constructive measures (including a drawdown of the reservoir which greatly impacted storage capacity) were immediately taken to save the dam, the Bureau of Reclamation (Reclamation) needed a permanent solution which would effectively reduce the risk of failure below the guidelines established by the Reclamation Safety of Dams Act.
For most of 2007, Reclamation drill crews conducted an extensive program of forensic analysis and geotechnical exploration in the dam embankment and its foundation for several miles on either side of the incident area. In early 2008, engineers decided that the installation of a 5-mile long, 30-inch wide Cement-Bentonite (CB) cutoff wall, along with the reconstruction of the dam embankment through the incident area, would achieve risk reduction goals and allow the reservoir to be put back into full service.

A $17.4 million construction contract for the work was awarded in latter May, and on July 21, 2008, the contractor team of Geo-Solutions (New Kensington, PA) and Nordic Industries (Marysville, CA) began excavating and backfilling the 5-mile long CB wall. After making field adjustments to the CB slurry mix and cresting the learning curve, the contractors were able to continuously produce over 2 cubic yards of slurry per minute and excavate over 9,000 square feet of wall per shift. In addition to the CB wall, the project also included a bio-polymer drainage trench and a new toe drain system.

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OTTER RAPIDS SEEPAGE AND PIPING REMEDIATION

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ABSTRACT

Otter Rapids dam was constructed in 1907 and has a documented history of void development and repairs in the powerhouse floor that dates back to the 1960s. A potential failure mode analysis conducted in 2003 identified critical failure modes related to seepage and piping which did not meet FERC safety guidelines. Therefore, remedial measures were evaluated to reduce the piping concerns. The selected remedial alternative involved a seepage barrier with a sheetpile cutoff, a grout curtain, and a concrete apron. This paper presents a detailed description of the analysis and design of the seepage barrier, including the seepage and piping evaluation, as well as construction data illustrating field performance.

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A STRUCTURED APPROACH TO INCORPORATING UNCERTAINTY INTO A DAM SAFETY RISK ASSESSMENT

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ABSTRACT

A nested model is presented for considering variability and knowledge uncertainties in a dam safety risk assessment of an existing dam and risk reduction alternatives:

1) Failure Event Model comprising an event tree risk model of the failure modes.
2) Variability Submodel for generating realizations of the effects of variabilities (aleatory uncertainties) in reservoir pool elevations on system response probabilities (SRPs) and consequences, and the effects of diurnal variations in populations at risk and warning system effectiveness on life loss.
3) Knowledge Uncertainty Submodel for the level of development of the failure mode and for generating realizations of the effects of knowledge (epistemic) uncertainties on SRPs, breach parameters and consequences.
4) Risk Reduction Alternatives represented by changes in SRPs and consequences, including the effects on their variabilities and knowledge uncertainties.
5) Sensitivity Cases such as exploring the degree of reliance on intervention.

The effects of variabilities on estimated risks are presented as cumulative distributions of the probability of failure, annualized life loss and economic risk cost, and an F-N representation of estimated life loss. Many cumulative distributions are generated to represent knowledge uncertainties. The effects of variability and knowledge uncertainty on consequences are presented as ranges.

ANCOLD and Reclamation tolerable risk guidelines are evaluated at selected percentiles of variability and percentiles (levels of confidence) of knowledge uncertainty. The incremental cost-per-statistical-life saved and benefit-cost ratio for risk reduction alternatives are estimated and evaluated at selected percentiles of variability and knowledge uncertainty to examine the case for risk reduction beyond the limit values in the tolerable risk guidelines.

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INTERIM TOLERABLE RISK GUIDELINES FOR US ARMY CORPS OF ENGINEERS DAMS

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ABSTRACT

The United States Army, Corps of Engineers (USACE) is working closely with the Bureau of Reclamation (Reclamation) and the Federal Energy Regulatory Commission (FERC) to develop a common dam safety risk management framework that includes tolerable risk guidelines. The USACE has developed interim tolerable risk guidelines, which are based on the current the Reclamation guidelines described in their 2003 "Guidelines for Achieving Public Protection in Dam Safety Decisionmaking", the risk evaluation guidelines published by the Australian National Committee on Large Dams (ANCOLD) in its 2003 "Guidelines on Risk Assessment", and the 2006 adaptation of the ANCOLD guidelines implemented by an Australian regulator, the New South Wales Government Dam Safety Committee (NSW DSC).

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A COMPARISON OF METHODS FOR ESTIMATING LOSS OF LIFE FROM DAM FAILURE

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ABSTRACT

There are several methods or procedures available for estimating the loss of life resulting from dam failure. These models have been prepared by Reclamation, Utah State University and BC Hydro. These models are used to: assign hazard potential classifications, manage risks associated with a portfolio of dams, and identify weaknesses in systems designed to protect the public in the event of a dam failure.

Similarities in each of the methods or procedures used for estimating loss of life will be presented. A summary of each method, including strengths and weaknesses, will be given. Uncertainty associated with chance (aleatory uncertainty) and with our lack of knowledge of how the system operates (epistemic uncertainty) will be discussed and suggestions for considering these two types of uncertainty will be presented.

All of the available methods for estimating loss of life suffer from the need to do research and development work on sociological issues. Do people remain in harm's way when dangerous flooding arrives? People receive information in various ways during an emergency event – from remote dam instrumentation, direct observation using senses of sight and sound, from internet computer news, cell or land-line calls, radio, television, sirens, public address systems, and from friends, neighbors, relatives and co-workers. How do people make decisions based on data and information that they receive? Dam owners, public safety officials, and people-at-risk must process information perfectly and take appropriate action to eliminate loss of life in the event of a dam failure. Do they?

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RISK ANALYSIS FOR SHASTA DAM RAISE

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ABSTRACT

Shasta Dam is a large concrete gravity structure located on the Sacramento River, approximately 9 miles northwest of Redding, California. The dam was designed and constructed by the Bureau of Reclamation and was completed in 1945 as a feature of the Central Valley Project. Feasibility-level studies are currently underway to raise Shasta Dam. The proposed 18.5-foot dam raise will accommodate a 20.5-foot increase in the top of joint use storage. The dam raise is intended to increase the survival of anadromous fish in the Sacramento River with an increased and more reliable water supply. As part of the evaluation of the dam raise, Reclamation has performed risk analyses to compare baseline risks to risks under the raised conditions. One of the goals of the proposed modifications is to avoid any significant increase in risk under the raised conditions and to remain within acceptable limits. Several potential failure modes were evaluated for the existing and raised conditions, some being applicable to both conditions, but others being unique to either the existing or raised conditions. This paper describes the studies performed and risk analysis results for the proposed raise of Shasta Dam.

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DAM FAILURE ANALYSIS AND CONSEQUENCE ESTIMATION

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ABSTRACT

The United States Army Corps of Engineers (USACE) Dam Safety Program is transitioning to a centrally managed and decision driven portfolio risk management process that relies on various levels of risk assessment from screening through detailed studies. This tiered approach of risk assessment requires methods that can be scaled to the level of effort needed to achieve the required level of accuracy. Dam failure analysis and consequence estimation are essential inputs to risk assessments. Because the downstream consequence from a dam failure are dependent on both the dam failure model results and the loss of life or damage estimates, consistent and compatible methods must be developed. The use of Geographic Information System (GIS) based tools such as HEC-RAS, HEC-GeoRAS, HEC-FIA, and LifeSim provide the necessary framework for a compatible and scalable dam failure analysis and consequence estimation methodology. Depending on the number of river miles being modeled, simplified dam failure models with good baseline data can be developed in a matter of hours to a few days using readily available and existing data sets. The baseline dam failure model can then be easily updated and enhanced as more accurate data becomes available or increased modeling detail is required. Likewise, a baseline consequence model can also be developed quickly and updated with more accurate datasets as required. Results from dam failure modeling can be readily transferred to the consequence model using GIS techniques and combined with other existing data sets to obtain an estimate of the consequences.

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MANAGING DAM SAFETY RISK THROUGH A JOINT EMERGENCY ACTION PLAN FUNCTIONAL EXERCISE

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ABSTRACT

Hydropower projects licensed by the Federal Energy Regulatory Commission (FERC) are required to develop and regularly exercise an Emergency Action Plan (EAP), a response plan for dam failures. FERC EAP functional exercises are used to exercise and evaluate the direction and control of disaster management, the decision making process, and communication and information sharing amongst agencies during a dam failure-related emergency. These exercises also allow for the evaluation of the allocation of resources and manpower by participants, the overall adequacy of resources required to respond to the situation, and the adequacy of current policies, plans, and procedures. Joint exercises, those that include dams owned by two or more owners within the same river basin, impose added complexity that has not been previously exercised as a part of the FERC functional exercises requirements. These joint exercises address additional complexities such as the detailed interface and coordination between the dam owners, as well as between multiple dam owners and emergency management agencies (EMAs).

Alcoa Power Generating Inc. - Yadkin Division (APGI-Yadkin) recently teamed with Progress Energy to conduct the largest joint EAP functional exercise in the United States to date. With a primary goal of ensuring that all agencies understand and are able to use the appropriate EAP, care was taken to discuss the differences between the two owner's dams and the relative impacts associated with the flooding that could result from the failure of each of the dams. The joint functional exercise provided a forum for evaluating the communication, coordination, and information sharing between the two owners and emergency management agencies under postulated conditions designed to provide realism and a stressful environment for the players. Additionally, the exercise allowed for the evaluation of the decisions, direction, and control of disaster management and the current emergency management policies, plans, and procedures.

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EMERGENCY ACTION PLANNING DATABASE OF RISK REDUCTION MEASURES

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ABSTRACT

The FERC requires licensees to periodically perform higher level Emergency Action Plan (EAP) exercises, such as tabletop, functional, and full scale exercises. These exercises simulate the operational readiness, timeliness, and responsiveness of key licensee and emergency response personnel responsible for actions during a dam safety emergency. The EAP exercises reveal the strengths and weaknesses of the EAP. In addition, the exercises often provide risk reduction measures to ensure people can be evacuated before being harmed by a dam failure. These risk reduction measures are relative to available resources, communication and coordination requirements, key personnel roles and responsibilities, and public awareness. By compiling the risk reduction measures into a database with a usable format, the measures can be utilized as a Tool to benefit EAP training, emergency planning and early warning systems for other projects. The database of EAP risk reduction measures (EAP Tool) can be utilized by the dam safety community to help identify improvements to the EAP process.

This paper discusses the development and uses of the database including a discussion of what constitutes a credible risk reduction measure; an overview of FERC's EAP program; the type of EAP testing involved; and how the database is organized. Discussions on how the database can be used to improve EAP testing, emergency planning and early warning systems will be included. In addition, continual updates and additions with input from future comprehensive EAP exercises will be discussed as well.

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CRITICAL INFRASTRUCTURE AND KEY RESOURCE INFORMATION SHARING ENVIRONMENT IMPLEMENTATION

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ABSTRACT

Critical infrastructure protection is a shared responsibility among Federal, State, local, and tribal governments and the owners and operators of the Nation's Critical Infrastructure - Key Resources (CIKR). The CIKR Information Sharing Environment (ISE) provides an organized framework and enhances the ability for CIKR members to exchange comprehensive risk, threat and hazard information to enhance their ability to assess risks to CIKR assets, make prudent security investments, and take appropriate protective actions.

The CIKR ISE is being implemented through the development of mission-driven information sharing policies and the coordinated development of core and enhanced mission-related information sharing processes. Guiding this process is the CIKR ISE Capability Maturity Model (CMM). The CMM depicts five levels of maturity that ultimately allow a sector to achieve a robust and synchronous, private/public collaborating community.

Over the course of a few short months, the Dams sector's Information Sharing Working Group utilized the CMM and a defined capability development process to collaborate with DHS IP, the National Infrastructure Coordinating Council (NICC), the DHS Protected Critical Infrastructure Information (PCII) Office and other relevant DHS offices both in person and by phone to further develop and document its core capabilities.

This paper explains the rationale and methodology of the Critical Infrastructure and Key Resources (CIKR) Capability Maturity Model (CMM), the development of information sharing processes and content management for the CIKR sectors. Specifically, the paper outlines the pilot in the Dams sector and the path forward for other CIKR sectors.

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REHABILITATION OF MARMET DAM — CONDITION ASSESSMENT BASED EVALUATION OF RISK AND RELIABILITY

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ABSTRACT

Marmet Dam and Locks is a U.S. Army Corps of Engineers (USACE) project, located on the Kanawha River at Marmet, near Charleston, West Virginia. Construction was completed in 1934. The project consists of a non-navigable gated dam with three locks: twin locks as a part of the original construction, and a new single lock placed in operation in early 2008. The dam consists of five roller gates, each of which spans approximately 100 feet between concrete piers. A three-unit hydroelectric power plant with a generating capacity of 14.4 MW is situated at the left abutment of the dam. Marmet Dam is being evaluated for rehabilitation to extend its useful life an additional 50 years. Each element of the dam is being evaluated to determine how best to affect its rehabilitation.

Each element was evaluated using three strategies for rehabilitation: Fix-As-Fails Strategy, a Scheduled Repair or Rehabilitation Strategy and an Immediate Rehabilitation Strategy. The selected plan is comprised of the rehabilitation strategy, for each element, that has the greatest benefit/cost ratio as determined by event tree analyses.

Risk and reliability analyses were used as input to event tree analyses. For this work, the probability of unsatisfactory performance was calculated for each component of the gates using the hazard function method. A condition assessment based process was developed to calculate the hazard functions. This method was proposed as an alternative to the traditional Monte Carlo simulation method. Using condition assessments as a basis for probabilistic evaluation has been previously contemplated; this work is the first implementation. The proposed method was calibrated with the traditional method.

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CONSEQUENCE RATINGS: A STREAMLINED METHOD FOR DEVELOPING LOSS OF LIFE ESTIMATES

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ABSTRACT

The Bureau of Indian Affairs (BIA) has recently developed an objective, streamlined method for developing potential loss of life estimates for its dams (termed Consequence Ratings). For each potential failure mode for a dam, a different Consequence Rating value is determined, reflecting estimates regarding how quickly dam failure could occur and the warning time that might be available for evacuating the Population-At-Risk (PAR). The developed Consequence Rating values take into account: (1) the reservoir size at the time of dam failure, (2) the estimated population in the dam failure flood inundation area within 25 miles of the dam, (3) the current state of the Emergency Action Plan (EAP) and evacuation plans for the dam, including whether they are being regularly and appropriately exercised, and (4) the possible existence of an Early Warning System (EWS) at the dam, and its current operational status. The only aspect of using the method that requires significant time and effort relates to the unavoidable work effort to define the PAR, including identifying approximate numbers, and associated distances downstream of the dam. With that information in hand, Consequence Ratings can then be determined quite rapidly, with limited potential variability caused by use of the method by different users. The ratings can be easily adjusted in the future as improvements in the EAP and/or EWS take place. The method is viewed to be most applicable for comparative assessments of the potential for loss of life for portfolios of relatively small dams.

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DAMSE METHODOLOGY FOR SECURITY ASSESSMENT OF DAMS: COMPARISON TO DHS SCREENING OUTCOMES

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ABSTRACT

Dams are a vital and critical part of Europe's infrastructure, providing extraordinary benefits to society, such as renewable hydroelectric power, flood protection, drinking water, irrigation and recreation. However, they also represent a public safety issue, as dam failures can result in severe loss of life, economic disaster and extensive environmental damage. Since the events of September 11, 2001, there has been an increase in awareness of security threats to critical infrastructures, which has resulted in changes to security processes within many industries and regions.

As a result of the increase in awareness of security threats, an international initiative known as the DAMSE project has been undertaken to develop and validate a risk-based methodology for the security assessment and management of European dams against threats such as terrorist attacks, sabotage and malevolent intrusions.

The DAMSE screening methodology is presented within this document. In addition, in cooperation with the US Department of Homeland Security (DHS), a comparison of the screening methodology among DAMSE and DHS procedures is presented.

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CONSEQUENCE-BASED TOP SCREEN METHODOLOGY FOR DAMS

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ABSTRACT

The Dams Sector Sector-Specific Agency has coordinated the development of a screening methodology that can be used to effectively identify and characterize the subset of high-consequence facilities whose failure or disruption could potentially lead to the most severe impacts. The methodology will facilitate the consequence-based prioritization of critical assets within the sector. This screening methodology is scalable and it can be implemented at different portfolio levels (national, regional, and state levels) by adopting consequence thresholds that appropriately represent the corresponding scope under consideration. This paper describes the basic elements of the screening methodology and the proposed prioritization schemes.

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A COMPARATIVE STUDY ON RISK ASSESSMENT METHODOLOGIES FOR SECURITY AND PROTECTION OF CRITICAL INFRASTRUCTURE

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ABSTRACT

In 2006, the U.S. Army Corps of Engineers (USACE) initiated a preliminary risk methodology comparison study for civil infrastructure projects. The research study focused on a review of the state-of-practice of critical infrastructure security risk assessment, evaluating their effectiveness in addressing security and protection requirements. As a continuation to that effort, USACE and the Department of Homeland Security (DHS) established an interagency agreement to further this study by evaluating comparative advantages and limitations of a number of risk assessment methodologies and identifying requirements for a risk assessment methodology that could support risk-informed decisions considering a wide spectrum of consequences, vulnerabilities, and threats. A comprehensive evaluation process was developed to provide a standardized and objective method for comparing two or more risk methodologies. This paper discusses the preliminary findings and recommendations resulting from this joint USACE-DHS effort.

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USACE-DHS COLLABORATIVE EFFORTS ON RISK ASSESSMENT AND BLAST MITIGATION FOR DAMS

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ABSTRACT

This paper describes collaborative research efforts conducted between the U.S. Army Corps of Engineers (USACE) and the U.S. Department of Homeland Security (DHS). The USACE, through its U.S. Army Engineer Research and Development Center (ERDC), has focused efforts on the development of improved engineering models for prediction of blast-induced cratering effects on embankment dams. Currently, cratering calculations present a challenge in numerical simulations due to the extreme range of loadings and severe deformations that occur during the associated blast damage process. These research studies will evaluate several material modeling approaches currently used in numerical models, and identify their limitations using the field data as a benchmark scenario. Other areas of collaboration involve improving and expanding the modeling capabilities associated with damage estimation through the development of a blast assessment tool. This tool, which will also feature improved interfaces and mapping capabilities, can assist in vulnerability evaluations and provide realistic damage levels as part of the risk assessment process.

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METHODOLOGY FOR ESTIMATING ECONOMIC CONSEQUENCES FOR DAM FAILURE SCENARIOS

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ABSTRACT

The Bureau of Reclamation (Reclamation) is a Federal water resource management and development agency authorized to operate in 17 western states. In carrying out its mission, Reclamation develops water resource projects where dams play a major role in the viable development of the resources.

Reclamation is one of the Dam Sector's key partners in building a safer, more secure and more resilient sector. Reclamation's methodologies used to estimate the consequences of a dam failure will allow for greater coordination efforts, development and communication of dam security and security-related strategies, integration of dam safety and security initiatives, and development of regional disaster resilience initiatives.

Reclamation's current methodology and tools used to generate direct economic losses, including downstream property damages, lost project benefits and replacement costs from a dam failure are presented as well as a methodology for estimating indirect impacts from a failure event. Data constraints and future considerations are also addressed.

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APPLICATION OF THE HOMELAND SECURITY EXERCISE AND EVALUATION PROGRAM (HSEEP) FRAMEWORK TO THE 2008 DAM SECURITY EXERCISE SERIES (DSES-08)

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ABSTRACT

The U.S. Army Corps of Engineers (USACE) Critical Infrastructure Security Program (CISP) is focused on enhancing protection efforts against manmade attacks and improving preparedness, response, and rapid recovery in the event of an attack, natural disaster, and other emergencies. In collaboration with other partners across the Dams Sector, USACE has recently initiated a series of exercise efforts aligned with the Homeland Security Exercise and Evaluation Program (HSEEP), maintained by the U.S. Department of Homeland Security (DHS). This is a performance-based exercise program that provides standardized methodology and terminology for exercise design, development, conduct, evaluation, and improvement planning, and that can be adapted to a variety of scenarios and events (from natural disasters to terrorist incidents). The first series of exercises, collectively called the "2008 Dam Security Exercise Series – Bagnell/Truman" (DSES-08), was designed to test existing interoperability and communications protocols between government and non-government entities facing a catastrophic event involving two dams located along the same river basin. DSES-08 was comprised of multiple events: an Emergency Action Plan Workshop, an Inundation Modeling and Mapping Workshop, a Tabletop Exercise, and a Functional Exercise. This paper describes some of the findings and recommendations resulting from this effort and how these can be applied in future Dams Sector exercises.

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EXPANDING THE SECURITY INFORMATION BASE AMONG DAM AND LEVEE OWNERS AND OPERATORS

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ABSTRACT

Owners and operators of many of the nation's more than 82,000 dams and thousands of miles of levees may have limited opportunities to participate in conferences and traditional training programs that can assist them in developing and implementing protective programs and contingency plans at the facilities under their control. Widespread access to this information is crucial, however, because the security and safety of these dams and levees may be very important at local, regional, and state levels.

Supplying this information across the assets that constitute the Dams Sector was made possible through the law that established the Department of Homeland Security and the Presidential Directive that established the mechanisms for the private sector and federal and state government officials to form partnerships. Realizing the need for widely sharing this information and recognizing that much of it already exists in a variety of sources, the Dams Sector Security Education Workgroup spearheaded development of foundational reference materials to aid owners and operators of dams and levees in the development or enhancement of their protective programs.

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CUYAHOGA RIVER RESTORATION PROJECT: BALANCING HISTORY AND ENVIRONMENT

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ABSTRACT

Due to increased awareness of environmental impacts and the recent introduction of stricter water quality standards, many communities are considering the removal of non-essential dams. The Kent Dam, built in 1836, is a historic structure and a symbol of the City of Kent. As one of the oldest arch stone masonry structures in the country, it is listed on the National Register of Historic Places. However, a total maximum daily load (TMDL) study conducted in 1999 by the Ohio Environmental Protection Agency (OEPA) identified water quality concerns in the pool behind the Dam. The Kent Dam lies within the middle reach of the Cuyahoga River, an area considered by OEPA to be in non-attainment of its Warm Water Habitat (WWH) classification due to substandard dissolved oxygen concentrations in the backwater pool above the dam, lack of fish passage through the dam reach, and lack of aquatic habitat upstream of the dam. To mitigate these impacts and achieve the WWH classification, OEPA stipulated the complete removal of Kent Dam in its TMDL plan for the middle reach of the Cuyahoga River.

To balance the conflicting interests of stakeholders, including area historic preservationists who were opposed to the TMDL stipulation and the City's environmental community who supported the plan, the project team had to develop a solution that met OEPA regulatory requirements while preserving the regional landmark. After conducting an extensive feasibility study, Camp Dresser & McKee Inc. (CDM) prepared and oversaw the construction of a design that preserved historic features of the dam while mitigating WWH non-attainment conditions. This paper will describe the innovative solution which included removing a previously damaged lock structure and creating an open water bypass channel to alleviate water quality concerns, as well as creating a public park to incorporate green space and increase the quality of life for residents of the community.

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FLOOD CONTROL DAM (HANTANGANG DAM)

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ABSTRACT

Until mid 1990s in Korea, many dams had been constructed for flood control and water management without much resistance from the public. However, nowadays, dam proposals are entangled in severe conflicts with local governments, local residents, and environmental NGOs. This paper examines these influences in the changes in the Hantangang dam project. The Hantangang dam was proposed in 1998 to prevent flood disasters in the Imjin river basin after three severe floods in the Imjin river basin in the northwest of South Korea. These floods caused 128 deaths, displaced 31,439 flood victims, and resulted in $900 million in property losses. At first, the Hantangang dam (H: 85 m, W: 694 m, RCD type) was designed as a multi-purpose dam in 2002. However, due to social conflict, the Hantangang dam's purpose changed to flood control dam with eco-corridors. Instead of fishway (spiral step type, culvert type, and elevator type), the eco-corridor approach was adopted. This study shows the specific design of flood control dam, eco-corridor and primary design changes made to build public consensus.

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HIDING IN PLAIN SIGHT — USING THE NATURAL LANDSCAPE AS A VISUAL BARRIER

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ABSTRACT

This paper presents a demonstration of the use of the visual horizon concept in the planning and execution of a large civil engineering project in a visually sensitive area. The execution of large civil engineering projects are often constrained by environmental factors such as wetlands, forested areas, and areas of pristine visual beauty. For this major dam construction project located on the top of a mountain, the visual impact of construction activities was mitigated using an adapted version of the landscape architecture principal of visual horizon called a shadow-line survey.

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TRUCKEE RIVER BELOW DERBY DAM RESTORATION PROJECT

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ABSTRACT

The Truckee River originates high in the Sierra Nevada Mountains at Lake Tahoe and flows north east through Nevada and California to its terminus at Pyramid Lake, Nevada. The US Bureau of Reclamation Derby Dam is located approximately 20 miles east of Reno, NV on the Truckee River and diverts water for irrigation. The Truckee River channel below the Derby Dam, during low summer flow conditions, becomes a wide shallow channel which experiences unnatural high temperatures and low dissolved oxygen (DO) during. This sag in DO is of particular concern given the presence of the threatened Lahontan cutthroat trout (Oncorhynchus clarki henshawi) and the endangered cui-ui (Chasmistes cujus) in this reach of the river.

In order to improve aquatic habitat and reduce thermal gain in the River, the Cities of Reno and Sparks (Cities), under a US Bureau of Reclamation grant are proposing restoration of the site to a more natural functional condition. Many studies indicate that water quality benefits such as lower temperatures and higher DO may be achieved through the introduction of shaded riverine habitat (SRH). As a result, re-vegetated banks were designed below the dam to improve shading of the channel during periods of low flow. This design may increase the potential for greater shaded aquatic habitat, a more protected fish migration route, increased dissolved oxygen and lower channel temperatures.

The major components of the project were an environmental assessment, stream channel survey, data collection, native vegetation survey, hydrologic analyses, hydraulic analyses, and design.

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BIOLOGICAL INDICATORS OF CONDITIONS BELOW DAMS IN THE WESTERN UNITED STATES

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ABSTRACT

Aquatic macroinvertebrates were collected below 43 Reclamation dams in the western United States. Multivariate analysis indicated that dam height was an important variable in structuring macroinvertebrate communities. Dam height represents a multitude of impacts which includes those related to temperature and thermal regime modification, sediment transport, hydraulic residence time, and water quality. There appeared to be limited association of hydrologic flow metrics with biological assemblages, perhaps because of the generally homogenous flow characteristics of dammed rivers. Declines in biological values were associated with increased dam height and reservoir surface area. An ecological index, the Biotic Dam Index was designed to classify biological impacts associated with dams. Metrics used in the index included taxa and EPT (Ephemeroptera, Plecoptera, Trichoptera) richness, proportion of non-insects in the community, and periphyton biomass.

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APPLICATION OF STOCHASTIC TIME SERIES MODELING IN THE DEVELOPMENT OF INSTREAM FLOW RECOMMENDATIONS

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ABSTRACT

Historically, the development of instream flow recommendations for the protection of aquatic resources have typically relied on a single observed hydrologic regime within a river system for a given period of record. The observed flows represent only one realization of the potential range of hydrologic regimes and do not necessarily reflect the true range of inherent variability or uncertainty that may exist for future flow regimes that are important when formulating instream flow recommendations. In order to both address the limited range of variability inherent in a single observed flow regime and to take advantage of the broader stochastic nature of hydrologic flow regimes, the authors fit a periodic autoregressive moving average model to an estimated forty year time series of monthly unimpaired flows. The stochastic time series model was used to generate one thousand time series of the monthly 40-year flow regime. Concurrently, one hundred stochastic time series were randomly selected and used to compute habitat time series for target anadromous species and life stages on a monthly basis. The resulting range of monthly flows from the one thousand stochastic flow regimes and the range of monthly habitat values from the one hundred habitat time series where then utilized to formulate monthly instream flow recommendations as a function of annual flow exceedences. Incorporation of both flow and habitat variability based on stochastic time series modeling facilitated a rational basis for making instream flow recommendations and directly addressed the uncertainty of the flow regime into the recommendation process.

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DETECTION OF DREISSENA SPECIES: ZEBRA/QUAGGA MUSSELS IN YOUR WATER SYSTEM

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ABSTRACT

Early detection of Dreissenid species in your system is critically important to maintaining structure and function of dam related structures. If mussels are detected early, facility operators may have approximately three to five years to adjust systems before the population of mussels are large enough to restrict the flow of water, clog pipes and water intakes, effect cooling systems, and power generation. However, early detection of Dreissenids in water with the current methods has some inherent issues with variability in sampling and reliability with analytical methods which creates management decision dilemmas. Since current control methods of these mussels are very limited in regulated water systems, Reclamation is conducting intensive research for effective Dreissenid control. Reclamation research efforts include testing with coatings, filtration, and newer chemical and biological treatments. This paper presents an overview of the early detection issues; the biologic, ecologic, economic, and water delivery system problems that Dreissenid species present, and some of the research technologies that are being tested to reduce negative impacts.

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ENVIRONMENTALLY CONSIDERATE LUBRICANTS FOR DAMS AND HYDRO POWER PLANTS

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ABSTRACT

Hydro power stations, lock gates and dams are complex systems with a large variety of technical installations which need to be lubricated. Dams are a key element in the hydrologic circle supplying drinking water to mankind and supplying "raw material" for high-pressure power plants. Clean water is an obvious need for meeting the public expectations related to "clean drinking water and clean energy deriving from hydropower". It is crucial that in case of incidental leakage, the lubricants in these units have no or only a minimal impact on the environment. So called Environmentally Considerate Lubricants (ECLs), which meet both technical requirements as defined by the OEMs, and ecotoxicity requirements as outlined by various national and international so called Eco-Labels (e.g. the European Eco-Label or the USDA BioPreferred®), are suitable for this demanding application.

Key requirements are outlined for the physical and chemical characteristics of the base fluid components and the additives. Top tier lubricant components are the basis for long drain intervals. In particular the performance differences between lubricants based on saturated and unsaturated base respectively are addressed. A wrong selection of lubricant components cannot be corrected by intensive and costly lubricant monitoring programs.

In addition, results of comparative Life Cycle Analysis of ECLs and mineral oil are reported. From this research it can be concluded that when considering all impacts from "cradle to grave", the switch to ECLs is beneficial for the environment.

It is now more than 20 years since top tier ECLs were introduced as lubricants for dams, hydraulic bridges and hydropower plants. Well-documented field experiences demonstrate however that this technology is still reliable with respect to the environment. For appropriate selection of ECLs, technical, environmental and economical aspects have to be taken into account. This paper gives an overview of the key selection criteria.

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APPROACH TO MANAGEMENT OF RISKS ON THE SAN VICENTE DAM RAISE PROJECT

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ABSTRACT

To create storage space for both emergency water and seasonably available water for subsequent use, the San Diego County Water Authority has embarked on the San Vicente Dam Raise and Carryover Storage Project as part of its Capital Improvement Program. This project involves the placement of roller-compacted concrete to raise an existing concrete dam by 117 feet, providing 152,000 acre-feet of additional storage in the reservoir. Due to the complexities posed by a project of this magnitude, from the technical challenges to environmental constraints to significant coordination efforts among multiple parties, a systematic approach to managing potential risks was deemed necessary. This paper presents the methodology currently being used to help manage potential risks on the San Vicente Dam Raise Project. The approach involves listing risk elements that can adversely affect the project, and then ranking the risk elements based on their probability of occurrence and potential impact to the project. The results are systematically tabulated in a Risk Register, and then mapped into a probability-versus-impact matrix, which serves as a quasi-objective guideline for singling out the critical items that may need closer attention and monitoring. The Risk Register is then revisited and updated accordingly as the project progresses. Information provided in this paper can serve as an invaluable guide for planning and executing similar projects in the future.

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ASSET MANAGEMENT — WHERE SHOULD OUR MONEY GO?

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ABSTRACT

Asset management, in general terms, is the management of the financial assets of an organization to maximize "return". In the case of the Great Lakes and Ohio River Division (LRD) of the U.S. Army Corps of Engineers, the "return" is the continued safe use of locks and dams in our area of responsibility. USACE infrastructure nationwide is aging and in need of continued financial support in order to maintain our projects to a satisfactory level. It is our responsibility to be proactive to ensure our limited Operations and Maintenance (O & M) funding levels keep our projects not only open, but safe for the general public. This responsibility has led to a newly instituted asset management program within LRD.

As part of the asset management program, facility condition assessments have now been performed for all LRD projects to determine a baseline condition rating for all major operational and dam safety features of the projects. USACE will use these rankings in combination with risk assessments to determine exactly where our limited O & M funding will be spent. The goal of the program is to ensure operation of all facilities at or above the minimum acceptable service level and to target those items which, if left unattended, could cause either an operational or dam safety failure. This paper will describe how LRD is using the newly developed asset management approach to determine yearly funding for individuals projects. A description of our condition rating criteria will be provided as well as some results from our baseline assessments.

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SEEPAGE, PIPING, AND REMEDIATION IN A KARST FOUNDATION AT WOLF CREEK DAM

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ABSTRACT

In 1968, about 17 years after first being impounded, wet areas, muddy flows in the tailrace and sinkholes in the downstream toe of the embankment signaled serious foundation seepage problems at Wolf Creek Dam. The Nashville District Corps of Engineers began an emergency investigation, instrumentation, and grouting program that was generally credited with saving the dam. Data generated revealed an extensive interconnected network of solution features in the limestone foundation and inadequate foundation treatment measures taken during construction.

It was decided grouting alone could not be relied upon as a long term solution in such geology. Thus, from 1975 through 1979, a concrete cutoff wall was installed through the embankment and into the rock foundation. Since that time the project has been closely monitored. Based on instrumentation readings, investigations, and visual observations, it is apparent seepage has found new pathways through features left untreated by the first wall. The Nashville District will be installing a new wall upstream of the existing wall to a greater depth and lateral extent to cut off remaining seepage paths.

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THE EVOLUTION OF INSTRUMENTATION AND MONITORING AT WOLF CREEK DAM FOCUSING ON POTENTIAL FAILURE MODES

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ABSTRACT

Wolf Creek Dam, a large embankment and concrete dam with the largest man-made reservoir in the eastern United States, was determined to be vulnerable to piping through its karst limestone foundation. Since 1968 when the first problems occurred, instrumentation of the dam has been an evolutionary process. Over the years, at various times, a large number of instruments have been installed for various reasons, including over 300 piezometers. When seepage problems resurfaced in the early 2000's, the engineering evaluation and rehabilitation process lead to a proposed, more extensive barrier wall 70 feet upstream of the existing diaphragm wall. In response to increased distress indicators and proposed construction of a barrier wall, Nashville District has progressively reevaluated and enhanced the instrumentation program to better monitor the performance of the project. This evolving instrumentation and monitoring program focuses on potential failure modes identified in detailed risk-based failure analyses and ongoing performance of the dam.

Accordingly, existing instrumentation was evaluated for applicability, and new instruments were installed to address areas of concern and specific failure modes. This included expansion and improvement of the large existing piezometer system, adding nested vibrating wire transducers, which permits comparison to individual standpipe piezometers, and automating data collection to monitor the generally temporary effects of drilling and grouting. Monitoring of movement indicators, including inclinometers and surface monuments, were also increased in frequency. Embankment extensometers were installed in critical areas of the dam to provide early detection of internal erosion due to piping or plastic deformation of the embankment. The instrumentation is closely monitored for early detection of distress indicators, for determining the impacts of construction activities on the embankment, and for measuring the effectiveness of the rehabilitation work. This presentation describes the effort to implement this program, performance of the instrumentation and the resulting benefits.

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MAPPING TECHNIQUES FOR COMMUNICATING POTENTIAL CONSEQUENCES OF DAM FAILURE AT WOLF CREEK AND CENTER HILL DAMS

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ABSTRACT

A vital element of effective and transparent communication with the public, and within the U.S. Army Corps of Engineers (USACE), regarding the risk and reliability of our system of dams is the manner in which potential impacts resulting from a failure of any portion of the system is visually displayed. The importance of such communication has been underscored within the Nashville District (LRN), USACE, where Wolf Creek and Center Hill dams are undergoing Major Rehabilitation construction efforts intended to reduce the risk of dam failure. Innovative dam failure inundation mapping has been developed for each, as one component of a comprehensive communication strategy.

These efforts have served as a springboard to rapidly advance the state-of-the-art in dam failure inundation mapping within USACE from static, paper-based, maps to interactive, digital, and potentially web-based map presentations. These innovations will enhance our ability to update mapping within existing Emergency Action Plans (reflecting operational restrictions that may be in place through Interim Risk Reduction Measures); facilitate a determination of the consequences of failure using GIS-based techniques; support management of security on critical infrastructure; enhance the ability of agencies such as the National Weather Service to issue emergency notifications and warnings; and ensure consistent and comprehensible communication to the affected population and local officials responsible for emergency planning and response efforts.

This paper will offer an overview of the recent developments in dam failure inundation mapping within the Nashville District, USACE. Shortcomings with the mapping identified through communication with the general public and coordination with local officials, and the manner in which those concerns were addressed within next generation mapping products will be presented.

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TURNING DATA INTO INFORMATION AT WOLF CREEK DAM

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ABSTRACT

AMEC Earth & Environmental (AMEC) is collaborating with the US Army Corps of Engineers (USACE), Nashville District to manage historical and current data associated with the Wolf Creek Dam, located near Jamestown, Kentucky. The vast amount of data available for the 1940s era dam construction documentation, geotechnical investigations, remedial grouting programs, diaphragm wall construction, instrumentation readings, photos, borings and observations from various investigations. The USACE has accumulated and archived these data over the past 60 years in a wide array of data formats, creating an intimidating and complex volume of data to manage.

AMEC and the USACE have developed a Geographic Information System (GIS) geodatabase, which includes data from multiple sources and formats. The resulting information is made available through a web-based interactive map viewer equipped with a search engine. In addition, the system incorporates a three dimensional (3-D) model to aid in the visualization of critical project features in the project database.

The end result provides USACE with ready access to integrated data, in a comprehensive, easy to understand, visual format. This integrated database management system provides "real time" access to data to an unlimited number of users specified by the USACE, with no special software or expertise required. The tools developed for the project provides the USACE a means to quickly evaluate site data, perform analyses expeditiously, and to effectively communicate results, and facilitates management of disparate data collected by many entities throughout the history of the project.

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IMPACTS OF POOL RESTRICTIONS ON THE CUMBERLAND RIVER BASIN RESERVOIR SYSTEM OPERATION

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ABSTRACT

The Nashville District of the Corps of Engineers (Corps) operates a system of ten multi-purpose water resources projects in the 17,913 mi^2 Cumberland River Basin. Two dams in this system, Wolf Creek Dam on the Cumberland River near Jamestown, KY and Center Hill Dam on the Caney Fork River near Lancaster, TN, have been classified as Dam Safety Action Classification-1 (DSAC-1) structures. In 2007 pool restrictions were implemented at both projects as part of an overall interim risk reduction effort. These restrictions severely impacted the operation of the entire Cumberland River Basin reservoir system. Therefore, Nashville District prepared and circulated for public and agency review an Interim Operating Plan to address operation of the reservoir system during the pool restriction period. One of the major components of this plan was to establish an order of priority for management of the available water. Dam safety and flood damage reduction continue to be the top system priorities. Otherwise, the order is 1) water supply; 2) water quality; 3) navigation; 4) hydropower; and 5) recreation.

A combination of pool drawdowns at the two largest storage projects within the reservoir system and a prolonged period of moderate to severe drought resulted in severe impacts to the volume and location of available water in 2007 and 2008. This resulted in new and innovative operations at several projects within the reservoir system as water managers reacted to dynamic demands for water. The reservoir system continued to meet the primary needs of the region without acute environmental consequences despite significant impacts to several operating objectives.

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EMERGENCY ACTION PLANNING AT WOLF CREEK DAM

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ABSTRACT

The Wolf Creek Dam located in Jamestown, Kentucky impounds Lake Cumberland. The reservoir is the largest man-made reservoir east of the Mississippi River. At flood control pool it has 6,089,000 ac-ft of storage. Constructed from 1941-1952, the dam is founded on karst limestone geology. Seepage and piping of soil through the foundation is a significant dam safety concern with this type of foundation. Throughout the life of the project, seepage indicators have been noted and previously treated. Signs of increasing seepage in the last several years caused safety concerns that lead to the completion and approval of a major rehabilitation report in 2005.The rehabilitation will consist of the installation of a diaphragm cutoff wall and a grouting program to eliminate the seepage through the foundation. The Emergency Action Planning at the County, State, and Federal level have been a critical asset during the planning phase, will continue to be vital during construction, and will improve emergency action planning once the rehabilitation project has been completed. The planning process provides the emergency responders with the understanding of the problem at the project, familiarity with Corps of Engineers' processes, and a sound basis for completing their emergency response to a dam failure.

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