Nevada Irrigation District

Staff Report

for the Regular Meeting of the Board of Directors, August 14, 2019

TO: Honorable Board of Directors

FROM: Keane Sommers, P.E., Hydroelectric Manager KSS
Dar Chen, P.E., G.E., Senior Engineer - Dam Safety DC

DATE: August 7, 2019

SUBJECT: **Bowman South Dam Seismic Stability Analyses**

HYDROELECTRIC

RECOMMENDATION:
Award a sole source contract in the amount of $225,581.30 to Quest Structures for the Bowman South Dam Seismic Stability Analyses, and authorize the General Manager to execute the necessary documents.

BACKGROUND:
Bowman South Dam is a 105-foot-high and 567-foot-long concrete arch dam built in 1927 in a small canyon south of Bowman North Rockfill Dam. Both of the dams form Bowman Lake, which stores and transmits water from 6 other reservoirs on Canyon Creek and the Middle Yuba River upstream to Canyon Creek and the Bowman-Spaulding Canal downstream.

According to the Federal Energy Regulatory Commission (FERC) and the Division of Safety of Dams of California (DSOD), Bowman South is classified as an extremely-high-hazard dam due to the potential impacts on the downstream lives and properties in the case of its failure. It is approximately 15 miles west of the Mohawk Valley fault, which can generate up to a magnitude 7.3 earthquake.

The last seismic stability analysis for the dam was performed in the mid-1990s. The study identified potential instabilities at the left abutment thrust block. Since then, the seismic criteria and the method of stability analyses have greatly evolved. Based on their dam safety inspections in 2012 and 2016, the FERC required Independent Consultants recommended that the District complete seismic stability analysis updates of the dam based on the latest seismic ground motions and methods of analysis, which include 3-D non-linear, dynamic, finite-element modeling of the dam.

Staff is recommending award of a sole source contract to Quest Structures. Quest Structures is a well-established consulting firm specialized in sophisticated structural analyses for water resource projects. The firm is located in Orinda, California and is led by Dr. Yusof Ghanaat, a renowned engineering consultant with experience in this specialty for 40 years in the United States and abroad. He developed the engineering guidelines on arch dams for the Federal Energy Regulatory Commission and several engineering manuals on concrete hydraulic structures for the U.S. Army Corps of Engineers.

In the 1980s, Dr. Ghanaat performed the simplified stability analyses for Bowman South and Combie Dams using 2-D, linear, finite-element modeling. He is the only consultant specialized in arch dam seismic stability analyses known to staff in Northern California. Quest Structures completed earlier this year the seismic stability re-evaluation for Combie Dam using 3-D, non-linear, finite-element modeling.

Quest Structures' proposal demonstrates excellent project understanding and approach, and the costs of services are reasonable. Staff recommends that the District retain Quest Structures for seismic stability updates of Bowman South Dam. This will ensure both project efficiency and good quality for the District.

Award of this contract supports District Strategic Plan Goals 1 and 2 by ensuring risks to existing infrastructure are understood and proactively managed while maintaining compliance with State and Federal regulators.

BUDGETARY IMPACT:
The 2019 Hydroelectric Department Budget includes $450,000 for dam safety related studies. To date, a minimal portion of this of this budget has been encumbered to complete required updates of the District's Emergency Action Plans.

MDC
KSS

Attachments (2):
- Quest Structures Proposal
- Presentation for Board of Directors Meeting

August 1, 2019

Mr. Dar Chen
Dam Safety Engineer
Nevada Irrigation District, Hydroelectric Department
28311 Secret Town Road
Colfax, CA 95713
chend@nidwater.com

Subject: Bowman South Arch Dam
Re: Proposal for static and seismic stability evaluations

Dear Mr. Chen:

Quest Structures is pleased to submit this proposal to perform static and seismic stability evaluations for Bowman South Arch Dam to address two Category III Potential Failure Modes (PFMs) identified by the FERC Independent Consultants. These PFMs include potential sliding of the left abutment thrust block and underlying rock mass under flood and seismic loading that could compromise the safety of the dam.

Quest Structures and Geoinsite, our engineering geologist subconsultant, have the right combination of experience and skills to meet the requirements of this assignment. The attached proposal describes the team's understanding of the scope of work, proposed approach, and methodology, and provides information about our relevant experience, proposed team members, project schedule, and compliance with the FERC and DSOD requirements.

We hope to build on our successful relationship with the NID and will be happy to confer with you regarding the details of our proposal.

Sincerely yours,

Y. Ghanaat

Yusof Ghanaat
President
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Proposal for
Static and Seismic Stability Evaluations of Bowman South Arch Dam
FERC Project No. 2266-CA

Nonlinear Analyses

Prepared for

Nevada Irrigation District
28311 Secret Town Road
Colfax, CA 95713

Prepared by

Quest Structures, Inc.
25 Orinda Way, Suite 305
Orinda, CA 94563

QuestStructures

August 1, 2019

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Static and Seismic Stability Evaluations
Bowman South Arch Dam

1. INTRODUCTION

Quest Structures is pleased to submit this proposal to perform three-dimensional nonlinear static and seismic stability evaluations to address two Category III potential failure modes (PFMs) identified for Bowman South Arch Dam under flood and seismic loading. Bowman South Dam is owned and operated by Nevada Irrigation District (NID) and is subject to license conditions from the Federal Energy Regulatory Commission (FERC Project No. 2266-CA) and dam safety regulations of the California Department of Water Resources, Division of Safety of Dams (DSOD).

Bowman Lake is located on Canyon Creek about 4.6 miles east of Graniteville, and 8 miles south of Sierra City, in Nevada County, California, in the upper reaches of the Nevada Irrigation District watershed. Bowman South Arch Dam and Bowman North Rockfill Dam impound the reservoir and operate together hydraulically, with the spillway located at Bowman South Dam (Figure 1).

Bowman South Dam is classified as a "High Hazard Potential" structure under the FERC guidelines. The Bowman South Dam Project is operated and maintained to store water for power generation and consumptive use within the NID system.

The scope of services includes review and data gathering, development of evaluation criteria, geologic reconnaissance and determination of foundation rock properties, finite-element models, and nonlinear time history stability evaluations of the arch dam including the left abutment thrust block and the underlying rock mass supporting the thrust block.

1.1 Dam Description

Bowman South Dam is a constant radius gravity arch dam, constructed in 9 monoliths, as shown in Figure 2. The dam was constructed in 1926-1928. The maximum structural height of the dam is approximately 135 feet above the lowest foundation elevation. The crest is at El. 5563 feet. The crest width is 5 feet, and crest length is 400 feet. The dam radius is 175 feet, and the central angle at the crest is about 131 degrees. The upstream face is vertical. The maximum base thickness is 65 feet. Freeboard, as measured from the spillway crest to the crest of the dam, is 5.83 feet. The crest of the dam is 4.0 feet lower than the crest of the rockfill dam. The arch has been designed to function as an emergency spillway in which overtopping of the dam would occur.

The right end of the dam is keyed into abutment rock. The left end of the dam is keyed into abutment rock up to El. 5525 feet, above which it abuts against a concrete thrust block, which also serves as the right abutment for the spillway structure. The thrust block is 14 feet wide at the top and is battered to a width of 18 feet at the base. The upstream face of the thrust block is vertical, and the downstream face is sloped 1½ H:1V. The thrust block is keyed into the foundation at four locations along the base. In 1955, the thrust block was grouted by 18 holes.

The dam and thrust block are founded on jointed but fresh granitic rocks. Seepage control is limited to the depth of the cutoff trench, nominally 5 feet deep. There is no grout curtain. A line of drains in the foundation provide drainage.

Several campaigns to reduce seepage and repair deteriorated concrete began shortly after construction. Shotcrete with an underlying drainage network was applied to the downstream face in 1995.

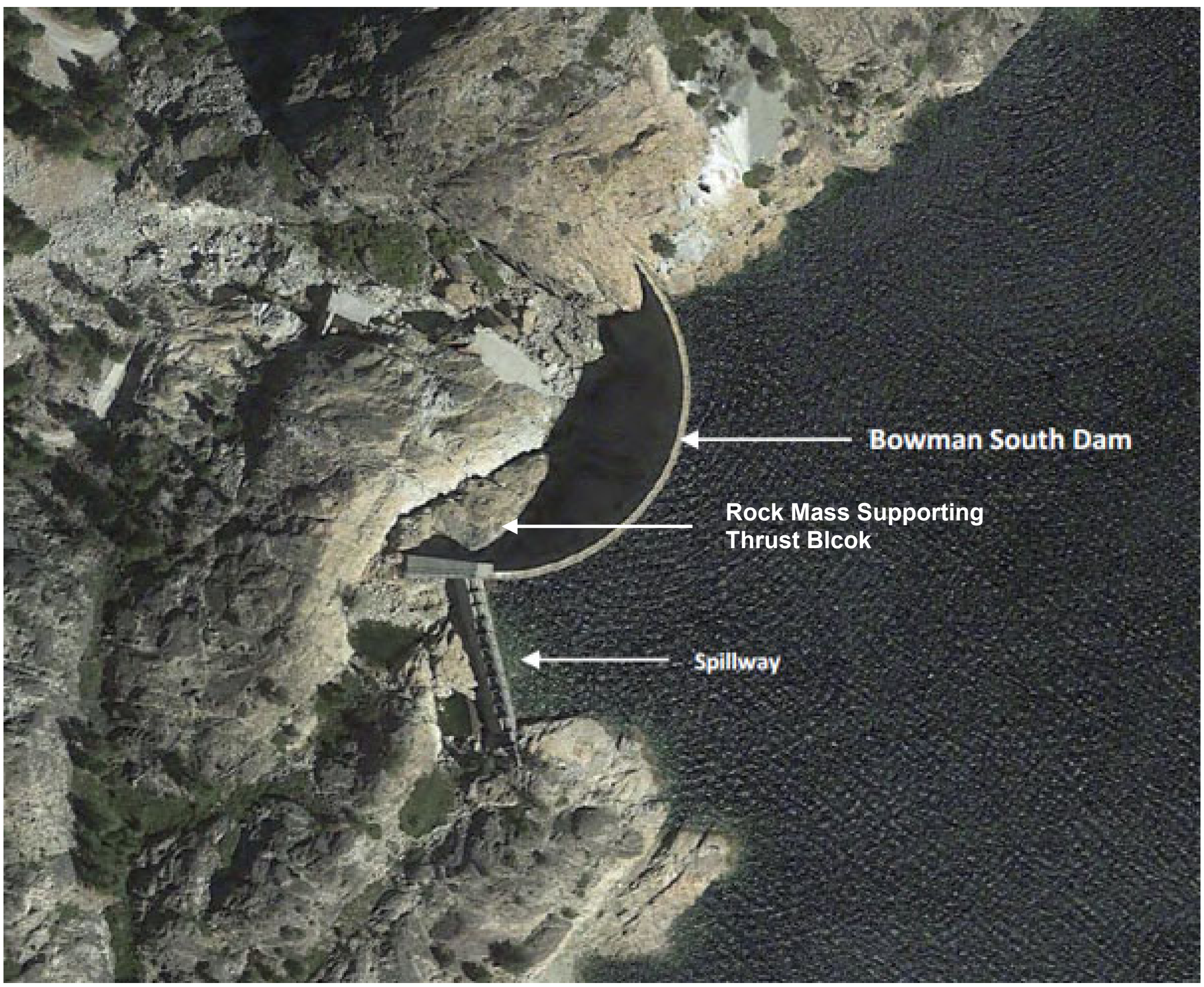

Figure 1. Bowman South Dam – plan view

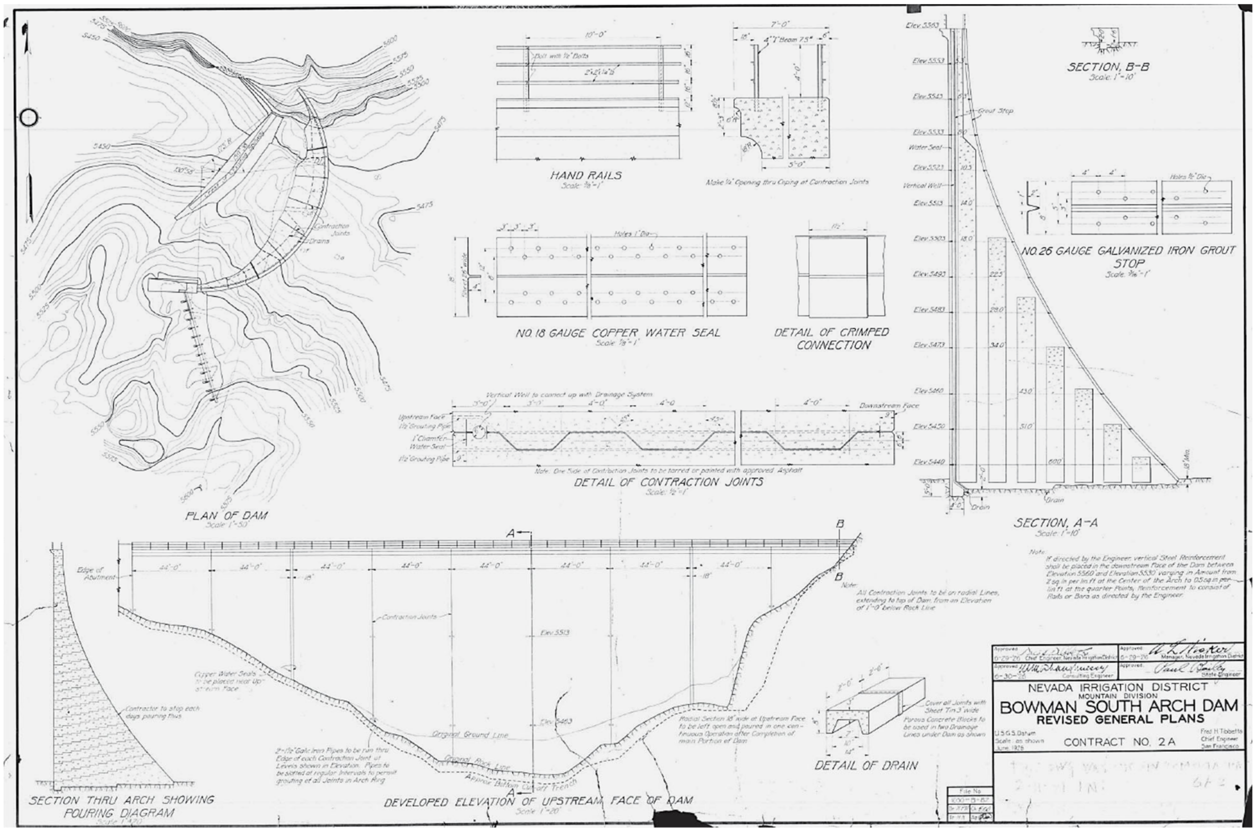

Figure 2. Bowman South Dam – plan, profile, and section views

2. PREVIOUS STUDIES

2.1 Previous Evaluations

Two previous main studies included a linear-elastic response spectrum and a nonlinear time history analysis of the dam, as summarized below.

Linear-elastic Analysis – A 1987 linear finite-element response-spectrum analysis by QEST Consultants (1987) concluded that the dam stresses were within the tensile strength of the concrete and that the left thrust block was stable against sliding at the concrete-rock contact. Response spectra for the governing maximum credible earthquake on Melones fault was a magnitude 6.75 event with a horizontal and vertical peak ground accelerations of 0.4g and 0.3g, respectively. The stability analysis of the left thrust block was also performed by Converse Consultants (1987) for sliding along a joint beneath the rock mass underlying the thrust block. The stability analyses were conducted in 2D parallel to the longitudinal axis of the block and downhill toward the channel parallel to the longitudinal axis of the rock mass.

Nonlinear Analysis – In 1993, PG&E performed a limited nonlinear analysis assigning zero tension resistance to lift joints and concluded that stresses in the dam meet the FERC criteria (PG&E, 1993). The contraction joints, however, were not modeled. The analysis assumed that 2 feet of the concrete on the lower 2/3 of the downstream was not effective due to deterioration and weathering effects. The safety evaluation earthquake for the 1993 analyses was assumed to be related to an event on the Mohawk Valley Fault zone with a magnitude of 7.5 resulting in a peak ground acceleration of 0.2g in the horizontal and 0.18g in the vertical direction. The stability of the left thrust block was evaluated assuming a potential sliding plane at the concrete-rock contact and did not include the rock mass beneath the block.

2.2 PFMA and Independent Consultant's Recommendations

A potential failure mode analysis (PFMA) review session was held in 2016 to review and revise the PFMs previously identified for Bowman South Dam to more clearly defined failure scenarios. Two PFMs originally classified as Category II were re-classified to Category III. These included PFM 2S for flood loading and PFM 3S for seismic loading, both of which were judged requiring new data.

PFM 2S – Flood Loading. The FERC Part 12 Inspection Report (SAGE, 201) defines this potential failure mode as:

> "*During large floods up to the PMF, long duration of high discharge through the spillway gates leads to erosion of rock forming the foundation of the arch dam's left thrust block. This leads to a sliding failure of the thrust block that then leads to failure of the left side of the arch dam resulting in an uncontrolled release of the reservoir*."

PFM 3S – Seismic Loading. This PFM involves seismic sliding failure of the thrust block and is defined in the FERC Part 12 Dam Inspection Report as:

> "*During the MCE, progressive failure along the shear zone underlying the rock mass supporting the thrust block along the right side of the spillway channel results in loss of support, sliding of the thrust block, loss of support for the arch, and progressive failure of sections between vertical joints leading to an uncontrolled release of reservoir.*"

The Independent Consultant Part 12 Dam Inspection Report (SAGE, 2017) recommended that the stability of the thrust block should be reviewed to determine the effects, if any, of foundation shears on the stability and that the stability analysis should be updated for the current ground motions and investigate for the adverse jointing that might exist in the foundation under the thrust block.

3. TECHNICAL APPROACH

We propose a technical approach based on nonlinear analyses and observed field conditions consistent with the FERC guidelines to address the identified Category-III PFMs discussed in Section 2.2 (i.e., PFM S2 and PFM S3). These structural PFMs involve overstressing and potential failure of the arch section as a result of sliding of the left abutment thrust block under the PMF or seismic loading. Sliding of the thrust block could potentially occur along the joint underlying the rock mass supporting the block resulting in loss of support for the arch, and progressive failure of dam sections between contraction joints.

To address the identified PFMs and meet the FERC requirements, we propose to conduct nonlinear static and dynamic analyses that model the opening and closing of the contraction joints, cracking at lift joints and concrete-rock contact, and potential sliding of the thrust block along the joint and shear zone underlying the rock mass supporting the block.

The contraction joints possess little or no tension resistance capability. They will be modeled to open if net tensile forces develop across the joints. Under static loading condition, with the effects of ambient temperature considered, the contraction joints might open partially at the downstream side as the dam contracts in winter and deflects downstream, or on the upstream side as the dam expands in summer and deflects upstream. Note that such joint openings are expected to be very small and penetrate through the dam section only slightly to release tensile arch stresses, while the joint remains closed in the remainder of the section. Under seismic loading, the contraction joints may repeatedly open and close due to the cyclic nature of the earthquake ground shaking that generate both compression and tension across the joint. The impact of the contraction joint opening on the stability of the dam will be determined by nonlinear analyses that allow opening and closing of the contraction joints and cracking at the concrete-rock contacts and possibly at some horizontal lift joints. The nonlinear analyses that we are proposing will also model the potential for the sliding of the thrust block along the underlying shear zone of the rock mass supporting the block, as recommended by the FERC Part 12 Independent Consultants.

We propose to accomplish this work using a 3D nonlinear model of the combined arch and thrust block that also includes the rock mass and shear zone beneath the thrust block, the spillway section, the reservoir water, and a portion of the foundation rock beneath all dam components, as described under Task 4 in Section 4. This modeling approach will more accurately portray the role of the thrust block and underlying rock mass as an abutment to provide support for the arch dam and spillway section. The nonlinear response will be limited to the contraction joints, the concrete-rock contact beneath the arch section, and shear zone underlying the left abutment rock mass.

First, we will test the 3D model for the linear-elastic behavior and then analyze for the nonlinear mechanisms described above to assess the stability of the arch dam and thrust block for the usual static, PMF, and seismic loading. The seismic input will include three sets of three-component spectrum-matched acceleration time histories discussed in Section 3.2.

3.1 Material Properties

The historical data reviewed contain no records about the geological and geotechnical investigations other than stability analysis of the right abutment rock bullnose. However, a concrete coring and testing program in 1992 provides measured properties for the dam mass concrete that are summarized below.

3.1.1 Concrete Properties

The available concrete properties are those obtained in 1992 by Berlogar Geotechnical Consultants (Berlogar, 1992) from two vertical borings drilled from the crest and seven horizontal borings from the downstream face of the dam. The 6-inch concrete core samples were tested for the unit weight, unconfined compressive strength, modulus of elasticity, and tensile strength of the dam concrete. Table 3.1 lists the average dam concrete properties measured and used in the 1993 analysis.

Variable	Average Values	
Unit Weight	152.7	pcf
Compressive Strength	4,260	Psi
Modulus of Elasticity	3.79E06	Psi
Splitting Tensile Strength	508	Psi

Further, an average compressive strength of 3,030 psi was reported for the thrust block and 5,840 psi for the spillway structure.

Regarding the condition of lift joints, a memorandum by Berlogar dated March 24, 1994, stated that "*While our review of the horizontal lift joint conditions generally indicates low bond strength, it is highly questionable that any single lift joint is continuously open or in a totally unbonded condition throughout its entire cross-sectional area*." Further, the Berlogar's memorandum confirmed that observation from several core-sections drilled horizontally through the lift joints appear to substantiate original design drawings that show the horizontal lift joints were intended to be formed as a series of horizontal shear keys. Based on this information, while the lift joints may possess very little if any tensile strength, they should be assumed to resist shear due to the presence of a series of horizontal shear keys.

The bond at the concrete-rock contact was reported to be superior to that of lift joints. Original design drawings show three horizontal shear keys, one 2 feet deep near the heel, another 1.5 feet deep near the midsection, and a third also 1.5 feet deep at the toe. This information suggests that a zero tensile strength may be assigned to the concrete-rock contact, but the shear resistance at the concrete-rock contact should be equal to that of the concrete due to the presence of shear keys.

3.1.2 Foundation Rock Properties

The December 1985 DSOD report provides the following information based on their files:

> *The South Arch Dam, constructed in 1927, was to replace an old timber crib structure downstream from the site. The foundation for the dam is reported to be a sound granitic rock. The as-constructed drawing shows that up to 17 feet of talus and stream channel deposits were removed from the channel section to expose an acceptable foundation for the dam. The cutoff is along the upstream face of the dam and is about four feet wide. Along the left abutment and in the channel section, the cutoff extends down five feet below foundation grade. On the right abutment, which is essentially vertical, the cutoff extends nearly 20 feet below the foundation grade on the lower half of the abutment and about three feet on the upper half. The cutoff depth on the right abutment was measured normal to the slope. There is no record of rock conditions encountered in the cutoff excavation, however, they probably are adequate.*

The 1987 Converse Consultants report (Converse, 1987) states that "*The arch dam and spillway structure are founded on tonalite and trondhjemite of the Bowman Lake batholith. The rock is hard, strong, and generally unweathered except for iron oxide staining along fracture surfaces. Fractures are mostly closed with spacing between fractures ranging from1 to 8 feet and generally 3 to 5 feet*."

These and all other available geotechnical and geologic data will be reviewed to establish deformation modulus of the foundation rock, shear strength parameters at the concrete-rock contact, and shear strength parameters for joints and shear zones for the rock mass underlying the thrust block.

3.2 Loads and Load Combinations

The following individual loads will be considered in the analysis:

1. **Dead Weight (DW)** – Gravity load due to dead weight (DW) of the concrete

2. **Normal Water Level (NWL)** – Hydrostatic at normal maximum water level El. 5562 feet.

3. **PMF** – Hydrostatic at PMF water level El. 5567.7 feet. At reservoir water El. 5567.7 feet, the depth of flow over the Bowman South Arch Dam Crest (El. 5563 ft) would be 4.7 feet. The walkway over the spillway section is at El. 5567 feet, and therefore could be overtopped by up to 0.7 foot during the PMF.

4. **Uplift Pressures (UP)** – The uplift is assumed to vary linearly from headwater to tailwater except within the cracked sections that will be assumed equal to full headwater.

5. **Silt Load (SL)** – No silt accumulation data has been reported at Bowman Lake and will not be considered in the analysis.

6. **Winter temperature changes (WT)** – Temperature loads in arch dams result from the differences between the closure temperature when the contraction joints are grouted, and the concrete temperature during the operation of the dam. Temperature drop in winter causes the dam to contract and deflect downstream. This tends to generate tensile stresses resulting in the opening of contraction joints. Previous analyses assumed a temperature drop of 5 degrees during winter.

   We propose to determine concrete temperature changes in winter from the air and water temperatures and apply as an additional load. The air and water temperature will be obtained from the District or estimated.

7. **Summer temperature changes (ST)** – Temperature rise in summer causes the dam to expand and deflect upstream, generating increasing compressive stresses and arch thrusts acting on the thrust block. The concrete temperature rise in summer will be determined from air and water temperatures by performing a transient thermal analysis, like that for winter temperature.

8. **Seismic loads (TH)** – The updated ground motions (AECOM, 2015) estimated the 84th percentile deterministic response spectra from the Mohawk Valley fault system, an M7.3 at 31 km on the strike-slip segment and an M7.0 at 25 km on the normal segment of the fault, and compared with the 84th percentile ground motions from the background earthquake. The results indicated that the 84th percentile ground motion from the background with peak ground acceleration of 0.25g controls and was selected for the evaluation of the seismic performance of the dam. The 84th percentile

background ground motion corresponds to an M6.5 event at 14.5 km from the dam site. Figure 3 shows the 84th percentile 5%-damped horizontal and vertical acceleration response spectra associated developed for Combie Dam. A comparison of the controlling deterministic response spectra with 2008 horizontal uniform hazard spectra (UHS) from the USGS indicates that equivalent return period is approximately 1,000 years. The updated ground motions (AECOM, 2015) also included three sets of three-component acceleration records spectrally matched to the controlling deterministic response spectra. These are shown in Figure 4 and will be used as the seismic input to nonlinear analysis.

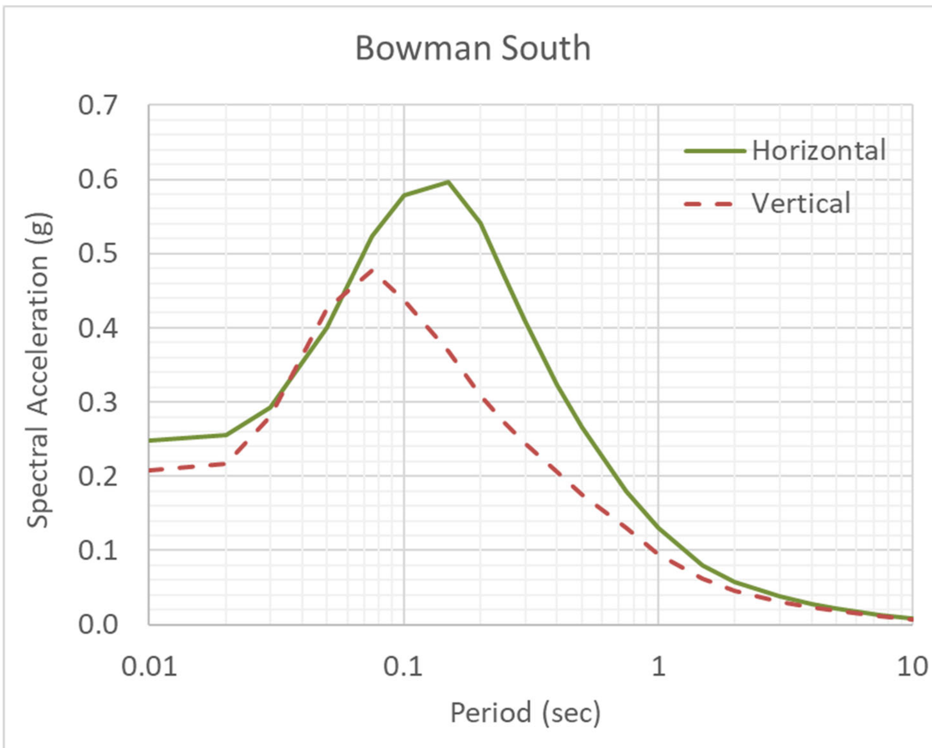

Figure 3. Bowman South Dam deterministic response spectra (AECOM, 2015).

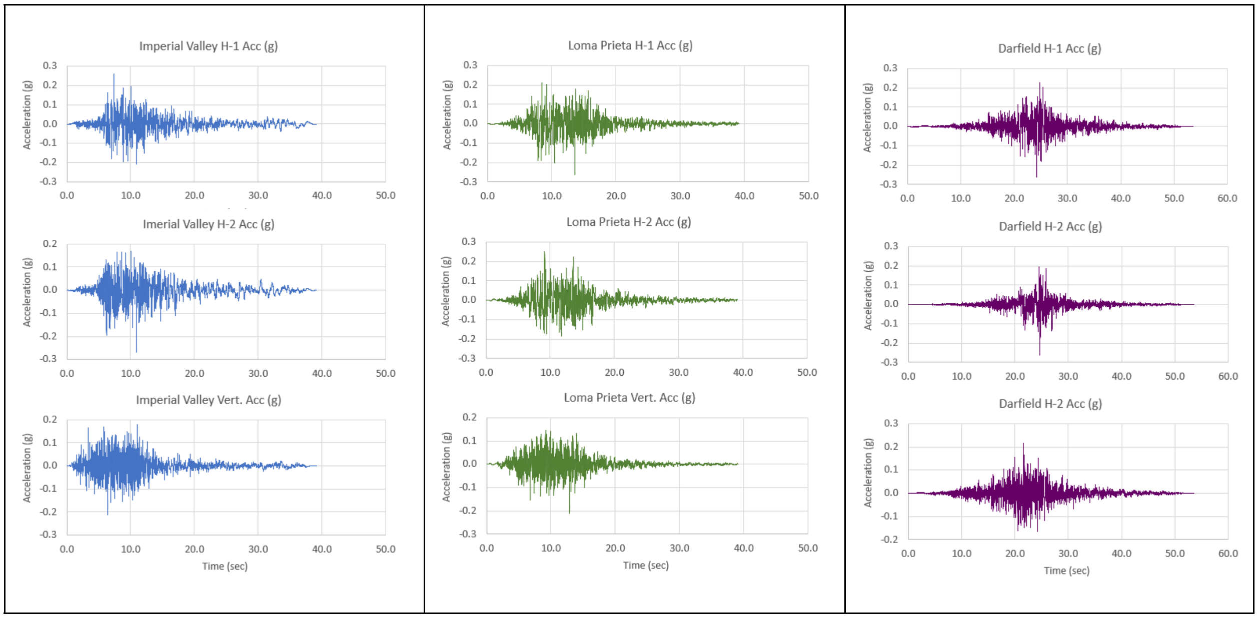

Figure 4. Spectrally matched acceleration time series for analysis of Bowman South Dam.

The dam will be evaluated for the following loading combinations:

1. Static Usual (SU1): DW + NWL + Uplift + ST
2. Static Usual (SU2): DW + NWL + Uplift + WT
3. Static Unusual (SUN): DW + PMF + Uplift + WT
4. Seismic Extreme (SE1): SU1 + TH01
5. Seismic Extreme (SE2): SU2 + TH01
6. Seismic Extreme (SE3): SU1 + TH02
7. Seismic Extreme (SE4): SU2 + TH02
8. Seismic Extreme (SE5): SU1 + TH03
9. Seismic Extreme (SE6): SU2 + TH03
10. Post-earthquake static analysis for usual loads considering seismic-induced cracking and changes in uplift pressure and shear strength at the concrete-rock contact

4. SCOPE OF WORK

This section describes our scope of work for the nonlinear stability analysis of the Bowman South Arch Dam, including the thrust block to address the identified PFMs.

Task-1: Review, and Data Gathering

This task involves a site visit by Dr. Ghanaat, a principal in charge, and Mr. Cole, an engineering geologist member of our team. The purpose of the site visit is to observe the overall condition of the dam, thrust block, and spillway structure for finite-element modeling, as well as the site geology, foundation rock, and rock mass and shear zone underlying the thrust block for estimation of material properties for intact rock and shear zone. We will review available information in our disposal to prepare for the site visit, which would allow us to identify other information we might need on geometry, material properties, and loading conditions that can be retrieved from District's files during our visit.

Task-2: Development of Evaluation Criteria

The evaluation criteria will be established using the existing data on geometry with measured or estimated properties of the concrete, foundation rock, and shear zone in combination with loading conditions, factors of safety, and allowable stress levels according to the FERC and DSOD requirements. The evaluation criteria will recognize that the dam might experience nonlinear response behavior in the form of contraction and lift joint opening, and possibly sliding along the shear zone underlying the rock mass supporting the thrust block. We will develop acceptance performance criteria considering the following:

- Amount of contraction joint opening should be less than the depth of shear keys so that the cantilever blocks remain interlocked and stable.
- Tensile stresses near the contraction and lift joints should be limited to the tensile strength of the joint and those within the dam blocks to the tensile strength of the parent concrete. We will assume zero tensile strength for the contraction joints and a nominal near-zero value for the lift joints. However, both contraction and lift joints will resist compression and shear through vertical and horizontal keys, respectively.
- Compressive stresses should be less than allowable values so that concrete crushing will not occur, especially during the contraction joint closing.
- The magnitude of non-recoverable dam monolith movements or thrust block sliding on the underlying shear zone, if any, should be small.
- The dam should maintain post-earthquake static stability despite seismic-induced cracking that might increase the uplift or seismic-induced movements that might reduce shear strength at the slip surface.

Task-3: Site Visit, Geologic Mapping and Foundation Rock Properties

This task involves a site visit by Dr. Ghanaat, principal engineer in charge of this study, and our engineering geologist Subconsultant, Mr. Cole and his staff. The purpose of the site visit is to conduct geologic reconnaissance and observe the overall condition of the dam, thrust block, and spillway structure for finite-element modeling, as well as the site geology, foundation rock, and rock mass and shear zone underlying the thrust block for estimation of material properties for intact rock and shear zone.

The foundation rock properties for the analysis will be established based on a field reconnaissance with a ground-based LiDAR (GBL) survey. The GBL survey will be required for scanning the left abutment rock mass for structural modeling.

The fieldwork involving geologic mapping using GBL Survey and associated data processing will be carried out by Mr. Cole and his staff.

Geologic Mapping based on Ground-Based LiDAR Survey

The scope of this task will include providing estimated shear strength parameters for the granite foundation rock, local shear zone, and dam-foundation interface, and preparation of a technical memorandum summarizing the findings of our work. The engineering geologic input will be based on: 1) an initial one-day site visit to observe rock conditions and pertinent dam features; 2) one day GBL scanning to cover the downstream left abutment area (2nd field day would be needed for right abutment, if needed); 3) one-day follow-up detailed geologic mapping using GBL-derived base maps; 4) data processing and review of existing information provided by the District, including pertinent maps, boring logs, photographs, reports, etc.; and 5) previous experience with similar rock types and environments.

Task-4: Development of Finite-Element Model

The nonlinear finite-element (FE) method will be used for the static and seismic analyses. The FE model will consist of the concrete arch, the thrust block with underlying rock mass and shear zone, the foundation rock, the impounded water, and possibly a simple model of the spillway structure to complete water barrier and pass loads to the thrust block.

The Bowman South Arch Dam, the left abutment thrust block, and spillway structure will be modeled using 3D solid elements with concrete material properties. The dam FE mesh will be arranged along horizontal and vertical grids to facilitate incorporation of nonlinear contraction joints and a few selected lift joints. The effects of dam-foundation interaction will be fully considered by a foundation rock model that includes both the inertia and damping effects. The rock mass and shear zone underlying the thrust block will be modeled to allow potential sliding along the shear zone. A fluid mesh with a non-reflecting boundary to allow radiation damping will represent the hydrodynamic effects of the impounded water due to seismic loading.

The nonlinear model will be developed and analyzed using the LS-DYNA software program (Section 5) and will consist of the following advanced features:

1) The overall dam model will consist of the arch structure, thrust block, spillway structure, shear zone underlying rock mass supporting the thrust block, foundation rock, and impounded water as a coupled system.

2) All contraction joints of the arch dam will be modeled by contact surfaces to allow for opening and closing of the joints under the static and seismic net tensile for forces. The shear keys will be modeled using cohesive elements with the capability to fail if shear demand exceeds the shear capacity of the key.

3) Contact surfaces will model the concrete-rock interfaces beneath the arch section and thrust block to allow cracking, separation, and potential sliding that might occur. However, the model will include the horizontal shear keys at the concrete-rock contact and the thrust block shear keys at four locations to account for the shear resistance provided by the keys.

4) Depending on the magnitude of cantilever stresses within the body of the dam, the dam model will include three or more lift joints using contact surfaces to allow cracking, separation, and potential sliding at the lift joint. Also, cohesive elements will be used in parallel with contact surfaces at lift joints to model the effects of stepped horizontal shear keys that are shown on design drawings and confirmed by drilling.

5) The spillway structure will be modeled only approximately to complete water barriers and pass loads to the thrust block. The stress results and stability condition of the spillway structure will not be considered.

6) The underlying rock mass supporting the thrust block and the shear zone beneath it will be recognized and modeled to address PFM 2S and PFM 3S involving potential sliding along the shear zone.

7) The foundation model will include inertia and damping effects and will extend two dam heights or more in the upstream, downstream, right abutment, left abutment, and downward directions. Non-reflecting boundaries will be introduced at the exterior surfaces of the foundation mesh to avoid erroneous seismic wave reflections.

8) The seismic input will be in the form of stress time histories applied at the non-reflecting bottom and side boundaries and will account for spatial variation of ground motion across the canyon.

9) The impounded water will be modeled using fluid elements and will allow for the transmission of water pressure waves in the upstream reach of the model to account for radiation damping.

Task-5: Input Stress Time Histories for LS-DYNA

Since the LS-DYNA model uses non-reflecting boundaries, seismic input must consist of stress time histories applied at the bottom and sides of the foundation model. The acceleration time histories described in Section 3.2 will be converted to stress time histories according to the following steps:

1. Perform deconvolution to obtain in-depth acceleration time histories at the elevation of the bottom of the foundation model using the ground-surface acceleration time histories as the input.

2. Integrate in-depth acceleration time histories to convert them into in-depth velocity time histories. Multiply the in-depth velocity time histories by ($2\rho c_s$) to convert them into in-depth stress time histories; where ρ and c_s are mass density and shear wave velocity of the rock, respectively. For normal stresses, compression wave velocity c_p is used instead of c_s.

3. Use stress time histories generated in Step-2 as the seismic input at the bottom of the foundation model.

4. Perform one-dimension wave propagation using in-depth stress histories from Step-2 as the seismic input to obtain free-field stress time histories to apply to the sides of the foundation model.

Task-6: Nonlinear Response History Analysis

The 3D nonlinear finite-element analyses will include nine static and seismic load combinations defined in Section 3.2. The nonlinear response will be computed using a direct step-by-step integration procedure and will be carried out for the entire duration of the earthquake acceleration time histories.

We will repeat seismic analyses for three sets of three-component acceleration time histories under summer and winter loading conditions for a total of six analyses (see Section 3.2). The seismic input will be applied as stress time histories at the nonreflecting bottom and side boundaries of the model following Task-5 procedures. In each case, the analysis will start with gravity, hydrostatic pressures, temperature, and uplift applied as quasi-static loads for five seconds, and then continued with the application of the seismic loads for the duration of the ground shaking. Contact surfaces will be activated during the application of static and seismic loads to allow for cracking and joint opening under both the static and seismic loads.

A 5% elastic damping will be used for elastic response plus any energy loss occurring because of joint opening/cracking and sliding.

Task-7: Evaluation of Nonlinear Results

Results of the nonlinear analyses will include structural displacements, stresses, contraction joint opening, cracking/opening at lift joints and concrete-rock interface and sliding displacements at dam joints and shear zone underlying the thrust block if any. More specifically, the following results will be retrieved, plotted, and evaluated.

- Maximum displacement time histories at the arch dam crest and top of the thrust block
- Contour plots and time histories of maximum compressive and tensile stresses on the faces of the dam for comparison with allowable values
- Identification and time histories of contraction joints, lift joints, concrete-rock contacts indicating opening or separation during the seasonal temperature fluctuation and earthquake excitation
- Location and extent of cracking at the concrete-rock contact beneath the arch, beneath the thrust block, at lift joints, and the underlying shear zone for both static and seismic loads
- Sliding displacement histories of the arch dam at the concrete-rock contact, if any
- Sliding displacements of the thrust block along the underlying shear zone, if any
- The magnitude of permanent displacements and their effects on the stability of the arch dam and thrust block
- Post-earthquake stability of the dam if seismic analyses indicate significant damage affecting uplift and shear strength

Task-8: Meetings

We propose to participate in three meetings to discuss the modeling and results as follows:

1. A kick-off meeting with the District to visit the dam and discuss modeling, data needed, and schedule
2. A second meeting with the District after completion of analyses to discuss the results and the contents of a draft report.
3. A third meeting with the FERC and DSOD, if required, to discuss the results and the contents of the final report.

Task-9: Report

A draft report will be prepared to describe the finite-element model, material and modeling assumptions, loads and load combinations, and criteria used in the analysis. The results will be presented graphically, interpreted, and discussed to address identified PFM 2S and PFM 3S. Conclusions will be drawn about dam safety for the MCE event. The draft report will be submitted to the District for review. The comments received from the District will be incorporated in a final report for submittal to FERC and DSOD.

5. COMPUTER PROGRAMS

The computer program LS-DYNA will be used for modeling and analysis. It is a general-purpose finite-element code for analyzing the static and dynamic response of structures with geometric and material nonlinearity including full foundation-structure and fluid-structure interactions. The program was originated at the Lawrence Livermore National Laboratory and is now available through Livermore Software Technology Corp. (LSTC) for commercial use [7]. A variety of element types, including solid elements, beam elements, membrane elements, discrete elements, rigid bodies, fluid elements, and contact elements are available. The LS-DYNA currently contains approximately one-hundred constitutive models and ten equations-of-state to cover a wide range of material behavior and has become the software of choice for nonlinear analysis by DSOD, Bureau of Reclamation, US Army Corps, and the dam industry.

We have used LS-DYNA for nonlinear static and seismic evaluations of the following projects:

- Seismic fragility for Mühleberg Dam in Switzerland
- Seismic fragility for gravity dams for the US Army Corps of Engineers
- Donnells Arch Dam per FERC and DSOD requirements
- Perris and Castaic Dams Outlet Towers for the California Department of Water Resources
- New Bullards Bar, Log Cabin, and Hour House Arch Dams per FERC and DSOD requirements
- Spillway piers at Grand Coulee Dam during dewatering of the spillway bays using a floating bulkhead
- Lookout Point Dam in Oregon for US Army Corps of Engineers
- Lake Hodges Multiple Arch Dam for static and seismic loads.

6. PROJECT TEAM

The project team will consist of the following firms and key staff (see Appendix A for resumes):

Quest Structures

Yusof Ghanaat will be the project manager to coordinate the team efforts. He will be responsible for directing the structural analysis to evaluate structural stability, and overall preparation of the draft and final reports for the project. He will also be responsible for coordination with Subconsultant Bill Cole of Geoinsite to conduct engineering geology review, and estimate dam-foundation interface shear strength parameters for the project.

Zachary Harper, Project Engineer, will be responsible for LS-DYNA model development and computer stability analysis with assistance provided by Ziqian Han.

Geoinsite

Bill Cole will lead the engineering geology and GBL surveying efforts during the site visit and review existing information to establish deformation modulus and shear strength of the foundation rock for input to the finite-element model.

7. SCHEDULE AND DELIVERABLES

7.1 Schedule

The schedule for the proposed scope of work is as follows:

Notice to Proceed	September 16, 2019
Finite-Element Model	December 31, 2019
Analysis Results / Meeting with District	March 31, 2020
Draft Report	April 30, 2020
District Comments	May 22, 2020
Final Report	June 19, 2020

7.2 Deliverables

- Draft and final reports summarizing the nonlinear analyses, findings, and recommendations.

8. ESTIMATED COST

Based on our present understanding of the project requirements, our estimated not to exceed cost is $225,581.30. A breakdown of our cost per task is given below.

Cost Breakdown

BOWMAN SOUTH ARCH DAM Nonlinear Static and Seismic Analyses		
TASK DESCRIPTION	Labor Cost	Expenses
1. Review, and Data Gathering • Review existing information, drawings, construction photographs, material properties, loading conditions, inspection reports, and previous stress and stability analyses	$6,912.00	
2. Development of Evaluation Criteria • Develop criteria for modeling, analysis, and evaluation of results	$2,288.00	
3. Site Visit and Foundation Rock Properties • Site visit • Foundation rock properties and shear strength parameters • Geologic Mapping with GBL Survey	$26,453.30	included
4. Development of Finite-Element Model • Develop a combined FE model consisting of arch section, left and right gravity sections including post-tensioned anchors, foundation rock, and reservoir water	$75,800.00	
5. Generation of Input Traction Time Histories • Develop a boxed-shape foundation model • Conduct de-convolution analysis to obtain in-depth ground motions • Develop traction time histories and perform site response analysis to check them	$9,732.00	
6. Nonlinear Response Analysis • Conduct static analysis to obtain boundary reaction forces • Conduct implicit modal analysis • Analyze for 3 sets of time histories	$35,468.00	
7. Evaluation of Nonlinear Results • Process results, prepare stress contours, sliding displacements, joint opening displacement, cracking maps, and stability condition of the dam	$17,400.00	
8. Meetings • Meet with the District to discuss the model and preliminary results • Meet with the District and FERC/DSOD to discuss final results	$10,848.00	
9. Report • Prepare a draft report to document the results for review by the District • Final report incorporating review comments	$34,680.00	
10. LS-DYNA License and cloud computing cost		$6,000.00
TOTAL TASK COSTS	**$219,581.30**	**$6,000.00**
GRAND TOTAL		**$225,581.30**

REFERENCES

AECOM (2015), Final Report, Nevada Irrigation District, Dam Seismic Safety Evaluation – Phase 1A, Site-Specific Seismic Hazard Analyses, FERC Project Nos. 2266, 2981, 5930, October 2015.

Berlogar (1992), Bowman South Concrete Angled Coring Letter to DSOD by Berlogar Geotechnical Consultants, August 11, 1992.

Converse Consultants (1987), Safety Analysis Bowman Arch dam, November 20, 1987

DSOD (1985), Bowman Rockfill Dam 61-2 Safety review Report, December 1985.

LS-DYNA, A general-purpose finite-element code for large deformations static and dynamic analysis including soil-structure and soil-fluid interactions, Livermore Software Technology Corp, Livermore, CA.

PG&E (1993), Static and Dynamic Stability Assessment – Nonlinear Finite Element Analysis, Bowman Arch Dam, December 1993.

QEST Consultants (1987), Stability Analysis of Combie Dam, April 1987.

SAGE Engineers (2017), Bowman Dams Safety Inspection report – FERC Project 2266-CA, March 2017.

Attachment A

Resumes

CONTACT INFO

Quest Structures, Inc.
25 Orinda Way, Suite 305
Orinda, California 94563-4402
USA

(925) 253-3555
yghanaat@QuestStructures.com

EDUCATION

Ph.D., Structural/Earthquake Engineering, University of California, Berkeley, 1980

M.S., Structural Engineering, University of California, Berkeley, 1976

REGISTRATION

Civil Engineer, California, 1982; Certificate No. C-34690

AFFILIATIONS

The United States Society on Dams Member, Committee on Earthquakes (USSD)

Association of State Dam Safety Officials (ASDSO)

American Society of Civil Engineers (ASCE)

Earthquake Engineering Research Institute (EERI)

Seismological Society of America (SSA)

HONOR AWARDS

Co-recipient of the US Army Corp of Engineers, Chief of Engineers, *"Design and Environmental Honor Award for 2002,"* as an independent technical reviewer to Los Angeles District on Design and Construction of Intake Tower at Seven Oaks Dam, California

SKILLS AND EXPERIENCE

Dr. Ghanaat has more than 38 years' experience in a broad range of structural, earthquake, dam, and geotechnical engineering projects. He has directed two decades of field measurements in the United States and China investigating dam-water and dam-foundation interaction effects on earthquake response of dams. Dr. Ghanaat has served on many technical advisory panels on seismic design, and dam safety projects in the United States and abroad providing advice to government agencies, public utilities, leading engineering firms, and the World Bank. His consultation practice has often involved a variety of issues in structural and geotechnical earthquake engineering, structural dynamics, design and performance criteria, seismic hazard assessment, earthquake ground motion specifications, risk analysis, nonlinear numerical modeling, fluid-structure interaction, soil-structure interaction, and concrete expansion due to alkali-aggregate reaction (AAR).

Dr. Ghanaat has directed, reviewed, managed, and conducted safety evaluations and advanced linear and nonlinear numerical modeling for many new and existing dams, navigation locks, intake/outlet towers, spillway structures, floodwalls, tunnels, and underground facilities for static and seismic effects. He has authored many engineering manuals for the US Army Corps of Engineers (USACE) and arch dam analysis guidelines for the Federal Energy Regulatory Commission. Following is a summary of his activities.

DAMS

Advisory Panels/Independent Peer Reviews/Panel of Experts

Upper Arun and Ikhuwa Khola Hydropower Projects, Nepal. Serving on a World Bank Dam Safety Panel of Experts to provide a review of key "Detailed Engineering Design and Preparation of Bidding Documents" at different timelines including the feasibility design of both HPPs at the inception phase, seismic hazard analysis, seismic design, as well as advice on any critical aspects that should be further studies for design optimization. (2019-2020).

Tina River Hydropower Development Project (TRHDP), Solomon Islands. Serving on a World Bank Dam Safety Advisory Panel (DSAP) providing independent review and advice on seismic hazard assessment and feasibility design of TRHDP consisting of an RCC dam, a powerhouse, and outlet works from 2013 to 2017, and continuing to provide review and advice starting in 2019 on detailed design, construction, and initial reservoir filling of the project works.

Naoro Brown Hydropower Project, Papua New Guinea. Serving on a World Bank Dam Safety Panel of Experts (DSPOE) to provide an independent review of the feasibility design and advice on any critical aspects that need further studies for design optimization. The DSPOE will also review and advise on seismic hazard assessment and design ground motions, seismic design, and matters related to dam safety and other aspects of the dam, its major appurtenant structures (2018-2019).

Phukot-Karnali and Betan-Karnali Hydropower Projects, Nepal. Providing review and consulting services to NEA Engineering Company Limited of Nepal on the seismic hazard assessment and design earthquake ground motion development, site and dam type selection, design guidelines for high dams in seismic setting of Nepal, and detailed design and analysis of the peaking run-of-river 103-m-high Phukot-Karnali and 86-m-high Betan-Karnali RCC Dams (2018-2019).

Upper Trishuli-1 Hydroelectric Project (UT-1), Nepal. Provided independent technical reviews and advice to the World Bank on the seismic hazard assessment and earthquake ground motions, seismic analysis and design, and 3D nonlinear dynamic analysis of the dam-foundation system for the seismic setting of Nepal (2016-17).

DESIGN / EVALUATION MANUALS

- Has developed the following engineering manuals for USACE:
- EC 1110-2-6000, "*Selection of Design Earthquakes and Associated Ground Motions*." Provides guidance on how to select design earthquakes and associated design vibratory ground motions for the seismic design and evaluation of all structures and other features of civil works projects.
- EM 1110-2-6053, "*Earthquake Design and Evaluation of Concrete Hydraulic Structures*." Provides guidance on performance-based design and evaluation of concrete hydraulic structures. It shows how to design or evaluate a hydraulic structure to have a predictable performance for specified levels of seismic hazard.
- EM 1110-2-6051, "*Time History Dynamic Analysis of Concrete Hydraulic Structures*." Describes procedures how to develop acceleration time histories and perform linear-elastic time-history dynamic analysis for seismic design and evaluation of concrete hydraulic structures.
- EM 1110-2-6050, "*Response Spectra and Seismic Analysis of Hydraulic Structures*." Provides guidance on how to characterize earthquake ground motions as design response spectra and how to use them in the process of seismic structural analysis and design.

John Hart, Ladore, and Strathcona Dams, Vancouver Island, BC, Canada. Serving on a B.C. Hydro Advisory Board to provide independent review and advice to the B.C. Hydro's Director of Dam Safety on the Campbell River Dams Seismic Upgrade Project on Vancouver Island, British Columbia, Canada. Reviews include seismic hazard assessment and earthquake ground motions, field investigations, advanced nonlinear seismic analysis, and analysis and design of retrofit alternatives (2015-20).

Katse & Muela Arch Dams and Matsoku Weir, Lesotho. Served on a dam safety panel of experts (DSPOE) to provide an independent assessment of the technical and engineering aspects of Katse (185 m high) & Muela (55 m high) Dams and Matsoku Weir 10-year review for Lesotho Highlands Development Authority, Kingdom of Lesotho (2018).

Poko Hydropower Project, Indonesia. Serving on a World Bank's Project Review Panel (PRP) to provide independent review and advice on the seismic hazard assessment and earthquake ground motion, seismic design criteria, structural analysis and design, and construction of the project. The project includes a 120-m-high RCC dam with an underground powerhouse with a total capacity of 128 MW(2018-23).

Matenggeng Pumped-Storage Hydropower Project, Indonesia. Serving on a World Bank's PRP to review and advice on the seismic hazard assessment, structural analysis and design of the dams and outlet works, and construction of the project. The project includes an upper and a lower dam (85m and 55m in heights), an underground waterway connecting the two reservoirs, and an underground powerhouse with a total output of 700 MW (2017-20).

Upper Cisokan Pumped Storage Hydropower Project, Indonesia. Served on a World Bank Project Review Panel (PRP) to review and advise on the seismic hazard, design, and construction of the project. The project includes two RCC dams 75.5m and 98m high, underground waterways, and an underground powerhouse with a total generation rating of 1040 MW (2010-16).

Porvenir-II Hydroelectric Project, Colombia. Served on a Peer Review Panel (PRP) convened jointly by Integral S.A. and ISAGEN S.A. to review the seismic hazard assessment, fault displacement hazard, and a proposed 140-m-high RCC arch-gravity design for the project on the Rio Samana Norte in Antioquia, Colombia (2015).

Felidia Dam, Cali, Colombia. Served on an International Technical Advisory Panel providing review and consultation to Consultoria Colombiana-Sedic-CPT Consortium for the seismic hazard assessment and feasibility design of a 120-m high RCC dam for the City of Cali, Colombia (2011).

Green Mountain Dam, Kremmling, Colorado. Serving on a Bureau of Reclamation's Consultant Review Board (CRB) to review and provide an expert opinion of the current seismic hazard assessment and earthquake ground motions, fault investigations, and advanced nonlinear seismic analyses performed to date and future work to be performed by Reclamation for the combined dam-spillway structure (2018-19).

Boca Dam, Truckee, California. Served on a Bureau of Reclamation's Consultant Review Board to provide review and expert opinion on the current and future investigations involving risk assessments, issue evaluation studies, dam safety modification studies, dam modification alternative development studies, and LS-DYNA soil-structure interaction evaluations (2012-15).

Folsom Dam Safety of Dams Project, California. Served on a Consultant Review Board to address U.S. Bureau of Reclamation (USBR) dam safety activities including a risk assessment for the Folsom Project. The Folsom Project includes a concrete gravity main dam flanked by two earth wing dams, an auxiliary earthfill dam (Mormon Island Auxiliary Dam), and eight earthfill dikes (Dikes 1 to 8) to effect closure of the reservoir rim (2004-08).

- Chapters 6 & 7 of EM 1110-2-2201, "*Engineering and Design: Arch Dam Design*." Provides engineering information and guidance on how to design, and construct concrete arch dams.

- ITL-93-1, "*Theoretical Manual for Analysis of Arch Dams*." Provides background and describes the procedures for the linear structural analysis of arch dams.

- Reviewed and co-authored EM 1110-2-2400, "*Structural Analysis and Design of Intake Structures for Outlet Works*." Provides guidance on the planning and structural design and analysis of intake structures and other outlet works.

- Review and consultation on the development of EP1110-2-12, "*Seismic Design Provisions for RCC Dams*." Provides preliminary guidance and direction for the earthquake-resistant design of new and evaluation of existing roller compacted concrete dams.

- Developed "***Chapter 11,** Arch Dams of FERC Engineering Guidelines for the Evaluation of Hydropower Projects*." Provides guidance on the criteria and procedures used by FERC to evaluate the safety and structural integrity of existing arch dams under its jurisdiction.

Monticello Arch Dam, California. Served on the Bureau of Reclamation's Consultant Review Board for dam safety investigations including risk assessment conducted at Monticello Dam involving earthquake ground motions, linear and nonlinear earthquake analyses, and development of state-of-the-art dam analysis capability (1998-00).

Horse Mesa and Mormon Flat Arch Dams, Arizona. Served on the Consultant Review Board for the Bureau of Reclamation's Dam Safety studies including risk assessment of Horse Mesa and Mormon Flat Arch Dams involving earthquake ground motions, seismic safety evaluation, and abutment stability analyses (1996-98).

TVA Flood Risk Evaluation from Multiple Seismic-induced Dam Failures, Tennessee. Served on a Participatory Peer Review Panel (PPRP) according to the US Nuclear Regulatory Commission's requirements to review methodology and implementation of the flood risk evaluation from multiple seismic-induced dam failures on the TVA's Nuclear Power Plants (2013-14).

Blue Ridge Dam, Georgia. Served on a TVA's Project Review Board to provide technical expertise, guidance, and recommendations on design, construction, operation, and maintenance of dam safety structures associated with the dam remediation work for static and seismic load cases (2012-13).

USACE Risk Management Center (RMC). Provided specialist review and consultation services to RMC to develop analysis methodology for risk analysis of dam spillway structures and gates (2016-18).

Quality Control and Consistency (QCC) Review, Dworshak Dam, Washington. Served on a QCC panel to review USACE Risk Assessment Documents on foundation and monolith stability of the 218-m-high Dworshak Dam for seismic and hydrologic loading (2016).

Quality Control and Consistency (QCC) Review, Green Peter Dam, Oregon. Served on a QCC panel to review USACE Risk Analysis Documents related to Issue Evaluation Study (IES) for seismic and hydrologic loading (2015).

Safety Assurance Review (SAR), Folsom Dam Raise Project, Folsom Dam, California. Serving on a SAR panel of experts to conduct Independent External Peer Review (IPER) of Engineering Reports for the emergency gate refinements for the USACE Folsom Dam Raise Project (2013-18).

Independent External Peer Review (IEPR), Lower Yellowstone Project, Montana. Participated in the independent external peer review panel to review the Intake Diversion Dam Modification Lower Yellowstone Project, Montana Draft Supplement to the 26 April 2010 Environmental Assessment as a subcontractor to Battelle (2013).

Safety Assurance Review (SAR), Folsom Dam Joint Federal Project, Folsom, California. Served on a SAR panel of experts to conduct Independent External Peer Review (IEPR) for design, plans, specifications, and construction of the approach channel, downstream chute, and stilling basin for Phase-IV of the Folsom Dam Auxiliary Spillway for USACE (2012-16).

Independent External Peer Review (IEPR) for Dam Safety Assurance Program (DSAP), Success Dam, California. Was selected to participate in an independent external peer review panel to review the Engineering Evaluation of the Geotechnical, Structural, and Risk Assessment Aspects of the Dam Safety Assurance Program Letter Report for Remediation of Success Dam, Porterville, California as a subcontractor to Battelle (2010-11).

Folsom Dam Auxiliary Spillway (Phase I to IV), California. Served on the USACE and Bureau of Reclamation Consultant Review Board (CRB) on the Folsom Joint Federal Project (JFP). The JFP assignment included a review of field investigations, rock excavation, seismic design, stability analysis, and construction of an auxiliary spillway structure with submerged tainter gates, spillway chute, approach channel walls, and

COMPUTER PROGRAMS

- Developed WebDams, a collection of web-based programs for analysis of dams:

  GDAP – Linear analysis
  EACD – Enhanced version
  GRES – FE incompressible fluid
  QDAP – Nonlinear analysis
  GPOST – Post-processor
  GEDIT – Editor
  QFLUSH – Soil-structure-interaction and embankment dam analyses

- Developed gITAP "*A finite-element Intake Tower Analysis Program*."

the stilling basin (2008-12).

Folsom Dam Mini-Raise and Outlet Works Modifications Projects, California. Provided independent technical review, analysis, and consultation on the USACE Folsom Dam Mini-Raise and Outlet Works Modifications Projects of the American River Water-shed Long-term Studies. These projects were studied as initial flood control measures and replaced by an Auxiliary Spillway alternative with submerged radial gates (2002-08).

Lake Isabella Dams and Outlet Works, California. Provided independent technical review (ITR) and consultation to URS/Kleinfelder/AMEC Joint Venture on the seismic evaluation, risk analysis, and alternative remediation development for the Isabella Embankment Dams and associated control towers and outlet structures owned and operated by USACE (2008-12).

New Orleans Levee Systems, New Orleans, Louisiana. Served on an Independent External Peer Review Panel to review the USACE revised procedures for designing flood T-Walls with unbalanced forces for the Hurricane and Storm Damage Reduction System in New Orleans (2007-09).

Pacific Gas & Electric Hydrogenation Facilities, California. Serving on a Dam Risk Panel to review a 10-Year Plan for incorporation of new seismic hazard analysis for PG&E Hydrogenation Dams for regulatory compliance and long-term risk reduction (2015-2020).

Walters Hydroelectric Project, North Carolina. Serving on an independent FERC Board of Consultants (BOC) convened by Duke Energy to oversee AAR investigations and numerical modeling at Walters Arch Dam owned and operated by Duke Energy Carolinas (2014-2018).

Susitna-Watana Hydroelectric Project, Alaska. Served on a FERC Board of Consultants (BOC) convened by Alaska Energy Authority to oversee and assess study plans, designs, and construction activities of an RCC dam proposed for the Susitna-Watana Hydroelectric Project in Alaska (2012-2015).

Panama Canal Risk Assessment Project, Panama. Served on a Panama Canal Authority (ACP) Technical Advisory Panel on risk assessment of Panama Canal Facilities including the existing and new locks and dams for extensive seismic and other natural hazards (2012).

Lake Skinner Outlet Tower, California. Providing independent engineering peer review services (IEPR) to the Metropolitan Water District of Southern California for the Lake Skinner Outlet Tower Seismic Assessment. The IEPR services include reviewing seismic hazard assessment and earthquake ground motions, design criteria, geotechnical data and dynamic soil-structure analysis methods, inputs, results, and reports prepared in conjunction with the tower seismic performance assessment (2019).

Briones Inlet/Outlet Tower Retrofits, California. Served on an East Bay Municipal Utility District (EBMUD) Technical Review Board (TRB) to review and advise on the nonlinear analyses, design, and constructability of the Tower retrofits to withstand the maximum credible earthquake (2016-18).

New Bullards Bar Dam Raise Feasibility Project, California. Provided review and consultation to GEI Consultants on structural evaluations of several dam- raise concepts for flood control improvement at the 645-foot-high New Bullards Bar, the tallest double-curvature arch dam in the United States, owned and operated by Yuba County Water Agency (YCWA) (2011-12).

Strathcona Dam, Vancouver Island, British Columbia, Canada. Served on a B.C. Hydro Advisory Board to provide expert advice to B.C. Hydro's Director of Dam Safety regarding the dam safety investigations conducted at Strathcona Dam in British Columbia, Canada (2003-12).

Karapiro Arch Dam, Waikato River, New Zealand. As a technical advisor to Mighty River Power of New Zealand (formerly ECNZ), conducted verification analyses and provided review and advice on seismic safety evaluation, structural stability, and retrofit design for Karapiro Dam consisting of an arch structure, a thrust block, and gravity sections on both sides (1997-99).

TVA Dams, Locks, and CCP facilities, Tennessee. Serving on the Tennessee Valley Authority Dam Safety Independent Review Board (IRB) providing independent technical review and advice on seismic hazard assessment and earthquake ground motions, dam safety investigations, analysis and design/evaluation for static and seismic loads, structural retrofits, risk analysis, construction, and rehabilitation of TVA dams, pumped storage plants, appurtenant structures, and Coal Combustion Product (CCP) Storage Facilities (2002-2020).

Brush Creek and Slab Creek Arch Dams, California. Served on a FERC Board of Consultants convened by the Sacramento Municipal Utility District to review dam safety investigations conducted as part of the FERC Part12 Dam Inspection Report (1994-95).

McKay's Point Arch Dam, California. Provided review and consultation to Electrowatt of Zurich and Gibbs & Hill of San Jose, California on the design of McKay's Point Dam, a double curvature concrete arch dam. Applied three-dimensional finite-element analyses in the design of the dam for static and seismic loads, as opposed to the traditional trial-load method.

Portugues Arch Dam, Puerto Rico. Provided review and consultation to the USACE on the design of Portugues Arch Dam to be built on Portugues River in Puerto Rico. Advised and trained Corps personnel in the use of finite-element stress analysis in the design of the dam for static and seismic loads (1987-90).#

SEISMIC HAZARD ASSESSMENT & EARTHQUAKE GROUND MOTION STUDIES

A summary of review and consultation on the seismic hazard assessment and development of earthquake ground motions for design and evaluation of numerous dam and hydraulic structure projects include the following:

- Phukot-Karnali and Betan-Karnali, Nepal
- Upper Trishuli-1 Hydroelectric Project, Nepal
- Poko Hydropower Project, Sulawesi, Indonesia
- Matenggeng Pumped-Storage Hydropower Projects, Java, Indonesia
- Upper Cisokan Pumped-Storage Hydropower Project, Java, Indonesia
- Tina River Hydropower Development Project, Solomon Islands
- Porvenir II RCC Dam, Colombia
- Fledia RCC Dam, Colombia
- Portugues Dam, Puerto Rico
- Mühleberg Hydroelectric Dam, Switzerland
- Swan Lake Arch Dam, South Alaska, USA
- Susitna-Watana RCC Dam, Alaska, USA
- Donnells Arch Dam, California, USA
- Smith Canal Floodwall and Gates, California, USA
- Green Mountain Dam, Colorado, USA
- Boca Dam, California, USA
- Folsom Dam, California, USA
- Monticello Arch Dam, California, USA
- Lake Hodges Dam, California, USA
- New Bullards Bar Dam, California, USA
- Our House and Log Cabin Dams, California, USA
- Barkley Lock and Dam, Kentucky, USA
- Olmsted Locks and Dam, Illinois-Kentucky, USA
- Montgomery Lock and Dam, Arkansas, USA
- Haysi Dam, West Virginia, USA
- J.T. Meyers Locks and Dam, Indiana, USA
- Prado Dam Intake Tower, California, USA
- Briones Dam Outlet Tower, California, USA

California State-Wide Seismic Hazard Assessment of Pacific Gas & Electric (PG&E) Hydrogeneration Dams: Reviewing state-wide probabilistic and deterministic seismic hazard and earthquake ground-motion development study conducted for the PG&E's entire inventory of dams in California (ongoing).

Regional Seismic Hazard Assessment: Tennessee Valley Region. Reviewed and provided advice on a valley-wide probabilistic and deterministic seismic hazard and earthquake ground-motion development study conducted for the Tennessee Valley Authority's entire inventory of dams (2004).

Regional Seismic Hazard Assessment: Willamette Valley in the Pacific North-West Region. Managed and reviewed a seismic hazard study to identify and estimate seismic hazards for 13 USACE dams in the Willamette Valley of Oregon. The study followed the guidelines included in the EC 1110-2-6000, titled "Selection of Design earthquakes," using probabilistic and deterministic assessments (2009).

Valley-wide and Site-Specific Seismic Hazard Assessment: Tennessee Valley Region. Reviewing an update of a valley-wide probabilistic and deterministic seismic hazard and earthquake ground-motion development study undertaken for the Tennessee Valley Authority's entire inventory of dams (ongoing).

DAM SAFETY EVALUATION PROJECTS

Has directed, managed, reviewed, inspected, and conducted structural analyses for seismic safety evaluation of numerous concrete arch and gravity dams some of which include:

- Agnew Lake Multiple Arch Dam, CA
- Balch Afterbay Arch Dam, California
- Balch Diversion Arch Dam, California
- Bear Valley Multiple Arch Dam, CA
- Bowman Arch Dam, California
- Broadwater-Missouri Gravity Dam, MN
- Brush Creek Arch Dam, California
- Caples Lake Arch Dam, California
- Claytor Gravity Dam in Virginia
- Combie Arch Dam, California
- Daniel Johnson Multiple Arch Dam, Canada
- Dongjian Arch Dam, China
- Donnells Arch Dam, California
- Florence Lake Multiple Arch Dam, CA
- Gem Lake Multiple Arch Dam, CA
- Grand Coulee Dam, Washington
- Haysi Arch Dam, West Virginia
- Hemlock Arch Dam, Washington
- Kerckhoff Arch Dam, California
- Lake Hodges Multiple Arch Dam, California
- Log Cabin Arch Dam, California
- Longyangxia Arch Dam, China
- Lookout Point Dam, Oregon
- Monticello Arch Dam, California
- New Bullards Bar Arch Dam, California
- Our House Arch Dam, California
- Portugues Arch Dam in Puerto Rico
- Quan Shui Arch Dam, China
- Ralston Afterbay Gravity Dam, CA
- Searsville Curved Gravity Dam, Calif.
- Slab Creek Arch Dam, California
- Smithland Gravity Dam in Kentucky
- Smith Mountain Arch Dam, Virginia
- Swan Lake Dam, Alaska
- Tulloch Gravity Dam, California
- Walters Arch Dam, North Carolina
- Xiang Hong Dian Arch Dam, China

Lookout Point Gravity Dam, Oregon. Principal in charge of developing and analyzing an LS-DYNA advanced nonlinear finite-element model of the dam-foundation-water system including spillway piers, bridge, gates, and trunnion assembly to predict potential failure modes for the risk assessment of dam failure (2018).

Combie Dam, California. Principal in charge of developing and analyzing a comprehensive LS-DYNA nonlinear finite-element model of the dam-foundation-water system including the arch section and post-tensioned gravity sections to assess the credibility of the potential failure modes identified for the dam. The potential failure modes include contraction joint opening/closing, and potential sliding of the arch and gravity sections (2018).

Lake Hodges Multiple Arch Dam, California. Principal in charge of developing and analyzing a comprehensive LS-DYNA nonlinear finite element model of the dam-water-foundation system. Lake Hodges Dam consists of 16 circular arches and associated buttresses with an overflow spillway section. Due to the thin-walled nature of the structure, the model uses layered-shell elements, with smeared rebar layers included in reinforced concrete components of the dam. (2017-18).

Grand Coulee Dam, Washington. Principal in charge of nonlinear finite-element analyses to assess the structural response of the spillway piers at Grand Coulee Dam during dewatering of the spillway bays using a one-piece floating bulkhead. The floating bulkhead consists of a single steel vessel 165 feet long and 65 feet high that would be floated into position and attached to the dam at the piers. (2016-18).

New Bullards Bar, Log Cabin, and Our House Dams, California. Principal in charge of nonlinear finite-element analyses to assess the seismic stability of these three arch dams and associated thrust blocks for the Yuba County Water Agency (YCWA). The computer program LS-DYNA was used to model dam-water and dam-foundation interaction effects, opening/closing of keyed vertical contraction joints, cracking at lift joints and foundation contact to evaluate the static and seismic stability of the dam and thrust blocks (2015-16).

Donnells Arch Dam, California. Principal in charge of nonlinear finite-element analyses to assess the seismic stability of

Donnells Arch Dam and thrust block for the Tri-Dam Project. The computer program LS-DYNA including dam-water and dam-foundation interaction effects, opening/closing of keyed vertical contraction joints, cracking at lift joints and foundation contact, followed by dam and thrust block sliding were used (2013-14).

Mühleberg Dam, Switzerland. Principal in charge of the seismic fragility assessment of Mühleberg Gravity Dam using Latin Hypercube Simulation and LS-DYNA three-dimensional nonlinear structural analysis with full dam-water and dam-foundation interaction effects. The nonlinear analysis includes concrete cracking and steel yielding, followed by sliding and rocking failure modes. Modifications are being designed to strengthen the dam and seismic fragility analyses carried out to estimate risk reduction benefits. (2007-12).

Salinas Arch Dam, California. Principal in charge of nonlinear finite-element analyses to assess the seismic stability of the Salinas thin arch dam with unusual geometry for the City of San Luis Obispo. Other project stakeholders include the USACE and the California Division of Safety of Dams. The nonlinear analysis involved consideration of dam-water and dam-foundation interaction effects, opening of vertical contractions, cracking of lift joints and dam-foundation contact joint (2007-11).

RESEARCH

Seismic Fragility of Gravity Dams. Principal in charge of the development of seismic fragility for concrete gravity dams using LS-DYNA advanced nonlinear analysis with Latin Hypercube Simulation. The US Army Corps of Engineers, Headquarters, Washington D.C. funded the research (2009-2012).

Research on Performance of I-Walls used as Flood Control Barriers. Principal in charge of numerical investigations of flood I-walls in support of the USACE's Phase-III research efforts. The study aimed to establish guidelines for performance evaluation of I-walls across the nation by expanding the current knowledge learned from Hurricane Katrina (2009-10).

National Science Foundation: Experimental Investigation of Arch Dams. Initially as a consultant to the University of California at Berkeley and later as the principal investigator has conducted 20 years of field measurements to investigate dam-water and dam-foundation interaction effects on earthquake response of arch dams. The investigation included Monticello in California and Xiang Hong Dian, Quan Shui, Dongjian, and Longyangxia Arch Dams in China (1980-00).

Measuring Techniques for Reservoir Bottom Absorption. Developed and applied two novel techniques for the in-situ measurement of reservoir bottom absorption, a parameter that can significantly influence the earthquake response of concrete dams. Dr. Ghanaat applied these methods to Dongjian and Longyangxia Arch Dams in China and Monticello, Pine Flat, Hoover, Glen Canyon, Morrow Point, Crystal, and Folsom Dams in the U.S (1994-95).

State-of-the-art Dam Analysis Computer Programs. Directed, managed, and developed WebDams, a collection of finite-element programs for analysis of concrete dams, soil-structure interaction problems, and intake towers. WebDams includes several independent dam analysis programs with sharing input capability and automatic post-processing of results in graphical forms.

NAVIGATION LOCKS

Barkley Lock. Conducted two-dimensional soil-structure-interaction (SSI) analyses to assess the seismic performance of the land wall Monolith L-8 at the Barkley Lock and Dam. The SSI model consisted of the lock monolith, backfill embankment soil, the foundation rock, and added-mass effects of water in the chamber and culvert. We analyzed the wall for the static and three different MDE time-history ground motions.

Wilson Main Lock. Provided technical review and advice to TVA on measurements of structural movements, finite-element analysis, and design of remedial measures to resolve concrete cracking and movements at the Wilson Main Lock. With an average lift of between 93 and 100 feet, Wilson Lock is the highest single lift lock east of the Rocky Mountains!

Chickamauga Lock and Dam, Tennessee. Provided technical review and advice to TVA on Alkali-Aggregate Reaction (AAR) investigations at the existing lock and dam, as well as on design and construction of a new lock to replace the existing AAR-affected lock.

Olmsted Locks and Dam, Kentucky. As a member of a technical advisory board and specialist consultant provided technical review and advice on the seismic design and analysis of Olmsted Locks and Dam located on the Ohio River near the Illinois-Kentucky border. Special features of the project were soil-pile-structure interaction, fluid-structure interaction, the seismic input characterization, pile design, and the seismic response evaluation of locks and dam structures.

Kentucky Lock Addition Project, Tennessee River. Provided Independent Technical Review (ITR), consultation, and specialized soil-structure-interaction analysis for the structural and seismic design of the Upstream Lock Monoliths.

Montgomery Point Lock and Dam, White River, Arkansas. Provided technical review and consultation on the seismic hazard analysis and selection of design earthquakes and associated ground motions for the Montgomery Point Lock and Dam.

BRIDGES

San Francisco-Oakland Bay Bridge, California. Provided structural and earthquake engineering review and consultation to the USACE's team convened to evaluate critical technical decisions made in the design of the east span of Bay Bridge retrofit and replacement alternatives.

INTAKE/OUTLET TOWERS

Castaic Dam Outlet Towers, California. Principal in charge of the nonlinear seismic evaluations of the Castaic Outlet Towers and Access Bridge for the California Department of Water Resources. The LS-DYNA 3D computer models with the concrete and steel nonlinear material models will be used (2015-2016).

Perris Dam Outlet Tower, California. Principal in charge of the nonlinear seismic evaluations of the Perris Dam Outlet Tower and Access Bridge for the California Department of Water Resources. The computer program LS-DYNA with the nonlinear concrete and steel material models were employed (2014-2015).

Pardee Dam Intake Tower, California. Principal in charge of seismic performance evaluations of the intake tower at Pardee Dam owned and operated by East Bay Municipal District, Oakland, California (2012-2013).

Santa Felicia Dam Intake Tower and Penstocks, California. Principal in charge of seismic performance evaluations for the fully submerged intake tower and steel penstock at Santa Felicia Dam owned and operated by United Water Conservation District (2011-12).

Isabella Dam Intake Towers, Kern County, California. Principal in charge of the seismic analysis and evaluation of partially embedded intake towers at Lake Isabella Main and Auxiliary Dams. The study was conducted using soil-structure-interaction (SSI) procedures to represent the dynamic interaction between the embankments, control towers, and outlet conduits.

EBMUD Outlet Towers, San Francisco Bay Area, California. Principal in charge of seismic evaluation and conceptual retrofit design for several East Bay Municipal Utility District's outlet towers including San Pablo, Sobrante, Chabot, Briones, and Pardee outlet towers.

Strathcona Dam Intake Tower, B.C., Canada. As an advisory board member, provided review and advice to B.C. Hydro on seismic analysis and retrofit design of the intake tower at Strathcona Dam.

Almanor Intake Tower, Lake Almanor, California. Provided technical review and consultation to URS on the seismic assessment of PG&E's Almanor Intake Tower.

Seven Oaks Outlet Works, California. Provided specialist technical review and consultation to USACE on seismic design and analysis of the Seven Oaks Dam Intake Tower. The 225-ft high tower is a reinforced concrete intake tower inclined against and anchored to the rock abutment. It was designed to withstand the earthquake forces generated by a maximum probable and the maximum credible earthquake events.

Prado Dam Intake Outlet Works, California. Provided structural engineering review and consultation to USACE on seismic design and analysis of Prado Dam Outlet Works located in southern California. The review included the Feature Design Memorandum (FDM) reports, design criteria, linear and nonlinear dynamic soil-structure-interaction analyses of the intake structure and access bridge, Structural plates, and independent verification dynamic analyses.

Cougar Dam Intake Tower, Oregon. Principal in charge of 3D finite-element dynamic analyses to verify the structural design modifications to an existing intake structure. Modifications included a new 302-foot-tall rectangular wet well to be attached to the upstream side of the existing intake structure and were designed to withstand ground motion levels equal to the maximum credible earthquake event.

Complete Design and Analysis of a 200-ft-high Tower to develop an example problem for the US Army Corps of Engineers' Engineer Manual EM 1110-2-2400.

Linear and Nonlinear Time-history & Pushover Analyses of Intake Towers. Principal in charge of research on the correlation of the analytical nonlinear response behavior of intake towers with experimental results from scaled model tests.

SPILLWAY STRUCTURES

Saluda Dam Spillway, South Carolina. Principal in charge of three-dimensional finite-element linear and nonlinear analyses to assess the seismic performance of Saluda Spillway structure and associated tainter gates.

Whittier Narrows Spillway, California. Principal in charge of 3D linear and nonlinear finite-element analyses to assess the seismic performance of the spillway structure at Whittier Narrows Dam for the USACE.

Whittier Narrows Outlet Structure, California. Principal in charge of 3D linear and nonlinear finite-element analyses to assess the seismic performance of the outlet structure at Whittier Narrows Dam for USACE.

INVITED PRESENTATIONS

- Invited Speaker "Quantitative Risk Assessment for Design and Evaluation of Concrete Dams," Retirement Symposium and Celebration of the Career of Anil K. Chopra, University of California, Berkeley, October 2-3, 2017.
- Invited Speaker "*Seismic Fragility for Risk Analysis and Risk-Based Design of Dams,*" ANCOLD 2014 Conference, Canberra, Australia, October 21, 2014
- Invited Speaker "*Performance-based Design and Evaluation of Concrete Dams,*" Pre-conference Workshop at ANCOLD 2014 Annual Meeting and Conference Meeting, Canberra, Australia, October 20, 2014.
- Invited Speaker "*Seismic Hazard Analysis, Design Earthquakes, and Associated Ground Motions for Dams,*" Feledia Dam design review meeting held at EMCALI offices in Cali, Colombia, March 9, 2011.
- Invited Speaker "*Advances in Seismic Design and Evaluation of Concrete Dams,*" Feledia Dam design review meeting held at EMCALI offices in Cali, Colombia, March 9, 2011.
- Invited Speaker "Folsom Gravity Dam Analyses: What are Acceptable Displacements?" 2009 FERC Western Regional Dam Safety Forum, San Francisco, California.
- Invited Paper "*Seismic Design and Evaluation of Concrete Dams – An Engineering Manual,*" The 39th US-Japan Joint Panel Meeting on Winds and Seismic Effects, Tsukuba, Japan, May 14-19 May 2007.
- Invited Speaker "Application of the Finite Element Method to Seismic Design and Evaluation of Concrete Dams," The 2006 Benjamin Franklin Medal Laureate Symposium for Professor Ray W. Clough, Villanova University Connelly Center, Villanova, Pennsylvania, April 26, 2006.
- Invited Speaker "*Earthquake Performance and Rehabilitation of Sefid Rud Dam, Iran,*" The 25th USSD Annual Meeting and Conference, Salt Lake City, Utah, June 6-10, 2005.
- Keynote Speaker "*Evaluation of Concrete Dams for Seismic Loading,*" The 3rd US-Japan Workshop on Advanced Research on Earthquake Engineering of Dams, San Diego, California, June 22-23, 2002.
- Invited Paper *" Structural Performance Evaluation and Damage Criteria for Concrete Dams,"* The 3rd US-Japan Workshop on Advanced Research on Earthquake Engineering of Dams, San Diego, California, June 22-23, 2002
- Invited Speaker "Dam-Water-Foundation Interaction Effects in Earthquake Response of Arch Dams," The UC Berkeley-CUREE Symposium in Honor of Ray Clough and Joseph Penzien, Berkeley, California, May 9-11, 2002.
- Invited Paper *"Seismic Design of Intake Towers,"* The USACE's 2001 Infrastructure Systems Conference, Reno, Nevada, August 14-16, 2001.
- Invited Paper *"Structural Performance & Damage Criteria for Concrete Hydraulic Structures,"* The USACE's 2001 Infrastructure Systems Conference, Reno, Nevada, August 14-16, 2001.
- Invited Paper *"Pushover Analysis of Concrete Hydraulic Structures,"* The USACE's 2001 Infrastructure Systems

Conference, Reno, Nevada, August 14-16, 2001.

- Invited Paper *"Performance-based analysis for Implementation of Systematic rehabilitating of Concrete Hydraulic Structures,"* The USACE-sponsored Seismic Evaluation and Rehabilitation of Hydraulic Infrastructure Workshop, Sacramento, California1, November 4-16, 2000.
- Invited Paper*" Field Measurements of Dynamic Interaction at Longyangxia Dam,"* The 2nd US-Japan Workshop on Earthquake Engineering of Dams, Tokyo, Japan, May 7-8, 1999.

SEMINARS

- Seismic Analysis of Concrete Dams – Made presentations on "*Field Experimentation of Concrete Dams*," and "*Response History Analyses of Concrete Dams with Nonlinearities*" and moderated sessions at a two-day workshop held at the 2017 USSD Annual Conference, Anaheim, California, April 6-7, 2017.
- Ground Motion Parameters and Seismic Design of Structures for Hydroelectric Projects in Nepal: A two-day seminar on the latest development of earthquake ground motion and seismic design of hydraulic structures including dams, inlet/outlet towers, and spillway structures for hydroelectric projects, Kathmandu, Nepal September 11-12, 2016.
- WebDams: *Web-based Programs and Visualization for Design/Evaluation of Concrete Dams* – California Department of Water Resources, Division of Safety of Dams, Sacramento, California, September 17, 2004.
- *Seismic Design and Evaluation of Intake Towers* (EM 1110-2-2400) – Seminar on the USACE Policy and Guidance on Seismic Design and Evaluation of Concrete Hydraulic Structures, Sacramento, California, August 1-2, 2004.
- *Time History Dynamic Analysis of Concrete Hydraulic Structures* (EM 1110-2-6051) – Seminar on the USACE Policy and Guidance on Seismic Design and Evaluation of Concrete Hydraulic Structures, Sacramento, California, August 1-2, 2004.
- *Earthquake Design and Evaluation of Concrete Hydraulic Structures* (EC 1110-2-6051) – Seminar on the USACE Policy and Guidance on Seismic Design and Evaluation of Concrete Hydraulic Structures, Sacramento, California, August 1-2, 2004.
- *Seismic Design and Analysis of Concrete Dams* – California Department of Water Resources, Division of Engineering, Sacramento, California, November 1, 2001.
- *Training Seminar on Soil-Structure-Interaction Analysis of Hydraulic Structures* – USACE, Nashville District, Nashville, Tennessee, October 16-18, 2001.

PUBLISHED ARTICLES

Available upon request.

CONTACT INFO

Quest Structures, Inc.
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Orinda, California 94563

(925) 253-3555
Zachary.Harper@QuestStructures.com

PROPOSED RESPONSIBILITY

Project engineer responsible for numerical modeling, computer analysis, post-processing of results, and assisting in reporting.

AVAILABILITY

70% to 80% percent of his time

YEARS WITH QUEST

5 years

EDUCATION

M.S., Structural Engineering, University of Florida

B.S., Mechanical Engineering, University of Florida

REGISTRATION

Engineering in Training, FL No. 1100017203

SKILLS AND EXPERIENCE

Mr. Harper has been a Project Engineer at Quest Structures for five years, where he performs linear and nonlinear finite-element modeling and analyses for the seismic assessment of dams, outlet towers, and other hydraulic structures, under the direction of Dr. Yusof Ghanaat. He has conducted detailed, advanced nonlinear analyses of many large dam structures, including the New Bullards Bar, Grand Coulee, Lookout Point, Lake Hodges, and Combie dams.

Mr. Harper has ten years of experience using LS-DYNA to solve explicit and implicit dynamics simulations. During his time at Quest, he has employed a variety of advanced modeling techniques to capture the nonlinear behavior of dam-water-foundation systems. These include the use of contact surfaces to model cohesive slip surfaces and fracture planes, the use of explicit fluid modeling to produce hydrodynamic mass and damping effects, and the use of non-reflecting boundary conditions and ground motion input to simulate soil-structure interaction with topographical effects on an elastic semi-infinite domain.

Before his work at Quest Structures, Mr. Harper graduated with a master's degree in Structural Engineering from the University of Florida, where he was a Graduate Research Assistant to Dr. Gary Consolazio. As a member of the UF Vessel Impact Research Group, he conducted LS-DYNA time-history analyses of barge impacts on maritime structures. For his master's thesis, he employed a finite element parametric study to develop temporary bracing guidelines for bridge girders subjected to high wind loads.

RELEVANT PROJECT EXPERIENCE

Combie Arch Dam, CA

Combie Dam, located on the Bear River on the California/Nevada border is an arch dam, constructed in 1928. The 440-foot-long arch section also functions as the spillway, which discharges into a plunge pool at the toe of the arch section. Multiple gravity sections on either side of the arch function as abutments. In 1991, post-tensioned anchors were installed into several of the gravity sections to improve their stability. Mr. Harper is responsible for developing and analyzing a comprehensive nonlinear model of the dam-foundation-water system including the arch sections and post-tensioned gravity sections to assess the credibility of the potential failure modes identified for the dam. The potential failure modes include contraction joint opening/closing, and potential sliding of the arch and gravity sections.

Grand Coulee Gravity Dam, WA

Grand Coulee Dam is a gravity dam located on the Columbia River in Washington state. The dam was constructed in 1942 with a storage capacity of over 9,500,000 acre-ft. The spillway section of the dam consists of 11 gate bays separated by piers supporting a bridge deck. A floating bulkhead design called the Drum Gate Maintenance Structure (DGMS) was proposed to address maintenance needs and allow the dewatering of individual gate bays without drawing down the reservoir. The DGMS redirects hydrostatic load into the surrounding spillway piers. Mr. Harper was responsible for developing a three-dimensional high-resolution nonlinear finite-element model of a single monolith and spillway pier, including all internal galleries and other voids. The model was used to evaluate the proposed design of the DGMS by characterizing the severity of cracking that may develop in the pier during a dewatering event.

Lookout Point Gravity Dam, OR

Lookout Point Dam is a composite concrete gravity and embankment dam constructed in 1953 on the Middle Fork Willamette River in Oregon. It spans a total length of 3,381.5 from the concrete dam right abutment to the embankment left abutment, and has three hydropower generating units capable of producing 50 megawatts each. The concrete section includes six spillway monoliths that support bridge piers and steel tainter gates. Mr. Harper was responsible for assembling a nonlinear finite element model to predict potential failure modes and stability conditions of the spillway gates and piers under seismic loading.

Lake Hodges Multiple Arch Dam, CA

The Lake Hodges Dam, located outside of San Diego, is a relatively uncommon multiple-arch dam. Constructed in 1918 and retrofitted in 1937, the dam consists of 16 circular arches with associated buttresses spaced 24-ft apart. The retrofit was intended to reinforce the buttresses laterally by thickening critical sections and adding web bracing between them. Mr. Harper is responsible for developing and analyzing a comprehensive nonlinear finite element model of the dam-water-foundation system. Due to the thin-walled nature of the structure, the model uses layered shell elements, with smeared rebar layers included in reinforced concrete components of the dam.

New Bullards Bar Arch Dam, Yuba County, California

New Bullards Dam is located on the North Yuba River 35 miles northeast of Marysville, California. It is a double curvature concrete arch dam, 645 feet high and 2,323 feet long including the thrust blocks and spillway. The arch section includes 24 80-foot-wide cantilever monoliths, interconnected by keyed vertical contraction joints. The dam is 35 feet thick at the crest and 195 feet at the base. The arch structure abuts against two thrust blocks 165 feet high at the left abutment and 145 feet high at the right abutment. As a project engineer, Mr. Harper was responsible for developing and analyzing a comprehensive nonlinear model of the dam-water-foundation system including the thrust blocks and spillway structures to assess the credibility of the potential failure modes identified for the dam. The potential failure modes included contraction joint opening, cracking at lift joints and foundation contact, followed by the dam and thrust blocks sliding along the cracked surfaces.

Castaic Dam Outlet Towers and Access Bridge, CA.

The Castaic Dam Outlet Works is an essential water delivery facility of the California State Water Project. DSOD requires that the outlet facility and all its components be structurally safe against seismic forces, and the outlet works must have the hydraulic capacity to lower the reservoir water surface elevation within DSOD guidelines. Mr. Harper was responsible for developing and analyzing nonlinear 3D finite-element models of the High and Low Towers and the Access Bridge to assess their performance under the OBE and MCE ground motions to determine whether or not they remain functional after a major earthquake.

Perris Dam Outlet Tower and Access Bridge, CA.

After the California Department of Water Resources (DWR) identified seismic deficiencies in the foundation of Perris Dam, the importance of the 105-foot-high Perris Dam Outlet Tower in providing emergency drawdown capabilities was highlighted. This finding prompted a nonlinear time-history evaluation to verify the ability of the outlet tower to withstand the updated estimate of design earthquake ground motions. As a project engineer, Mr. Harper developed and analyzed advanced 3D finite-element nonlinear models of the tower and Access Bridge to assess their performance for multiple MCE ground motion time histories.

Development of Finite Element Models for Studying Multi-Barge Flotilla Impacts, US Army Corps of Engineers

Developed high-resolution non-linear finite element models of cargo barges and barge flotillas. Performed dynamic time-history analyses of barges impacting bridge piers and other maritime structures, including the effects of soil-structure interaction.

Bridge Girder Drag Coefficients and Wind-Related Bracing Recommendations, Florida Department of Transportation

Conducted a parametric study of 50,000 nonlinear buckling analyses of braced bridge girders under construction. Synthesized the results into temporary bracing guidelines for the construction of precast prestressed concrete girder bridges.

PUBLISHED ARTICLES

Ghanaat, Y., Harper, Z.S., *Nonlinear Seismic Evaluation of Perris Dam Outlet Tower*, Proceedings of 37th Annual USSD Conference, Anaheim, California, April 3-7, 2017.

Consolazio, G.R., Walters, R.A., Harper, Z.S., *Development of Finite Element Models for Studying Multi-Barge Flotilla Impacts*, Final report to U.S. Army Corps of Engineers, Structures Research Report 2012/87754, University of Florida, 61 p. (2012).

Harper, Z. S. *Bridge Girder Drag Coefficients and Wind-Related Bracing Recommendations*. Master's thesis, University of Florida. Gainesville, FL (2013).

Harper, Z. S., and Consolazio, G. R. "Calculation Method for Quantifying Axial and Roll Stiffnesses of Rectangular Steel-Reinforced Elastomeric Bridge Bearing Pads," *Transportation Research Record: Journal of the Transportation Research Board*. No. 2331, pp. 3–13 (2013).

Ghanaat, Y., Harper, Z. H., "Nonlinear Seismic Evaluation of Perris Dam Outlet Tower" *USSD 37th Annual Conference* (2017)

Harper, Z. S., Edwards, S. T., Consolazio, G. R., "Drag Coefficients for Construction-Stage Stability Analysis of Bridge Girders under Wind Loading" *Journal of Bridge Engineering*. Vol 22, Issue 1 (2017)

Honig, J. M., Harper, Z. S., Consolazio, G. R., "Influence of Thermal Sweep on Girder Stability During Construction," *Transportation Research Board Annual Meeting* (2018)

CONTACT INFO

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zhan@QuestStructures.com

EDUCATION

PhD., Civil Engineering, University of Florida

M.S., Civil Engineering, University of Florida

B.S., Civil Engineering, Heilongjiang University of Science and Technology, China

PROPOSED RESPONSIBILITY

Project engineer responsible for numerical modeling, computer analysis, post-processing of results, and assisting in reporting.

AVAILABILITY

70% to 80% percent of his time

YEARS WITH QUEST

One year

SKILLS AND EXPERIENCE

Dr. Han earned his Ph.D. in Civil Engineering from the University of Florida in 2018. His research was related to the nonlinear finite-element structural analysis, and determination of barge impact loading on waterway infrastructures, including lock and dam structural components (e.g., dam pier, dam gate, and lock gate) and protective floodwalls. He joined Quest Structures in September 2018 as a Project Engineer to apply his structural engineering skill and experience with LS-DYNA software to perform linear and nonlinear finite-element stability analyses of dams, inlet/outlet towers, and other hydraulic structures.

RELEVANT PROJECT EXPERIENCE

Combie Arch Dam, CA

Combie Dam was constructed in 1928 with the maximum structural height about 100 feet and the total length of the dam 762 feet, including the overflow central arch section and non-overflow gravity sections on the left and right abutments. It is operated and maintained as a multi-use facility to address domestic and agricultural water needs. Dr. Han conducted the three-dimensional sliding and rotational stability analyses for the abutment gravity blocks by employing the resultant forces from the nonlinear static and seismic LS-DYNA simulations. He verified the stability analysis results by the hand calculations in a two-dimensional stability analysis. Dr. Han also assisted in the preparation of the project report.

El Capitan Dam Outlet Tower, CA

El Capitan Dam Outlet Tower is a reinforced-concrete structure with a height of about 210 ft. It is built to capture water at different elevations from reservoirs by opening the valves. Since the El Capitan Dam Outlet Tower is located at one of the seismically active areas, the safety of the tower under the seismic loading should be evaluated. Dr. Han modeled and analyzed the tower using 3-D shell element first and then 1-D frame element for comparison and verification in the computer program SAP2000. Section shear force and moment demands at different elevations along the tower height were computed using the mode-superposition response-spectrum analyses. Finally, the adequacy of the shear and moment capacities at the corresponding sections were evaluated.

Barrett Dam Outlet Tower, CA

The Barrett Dam Outlet Tower is a lightly reinforced-concrete structure with a height of 126 ft, located immediately upstream of the Barrett Dam right abutment. Previous seismic evaluations concluded that the tower is vulnerable to earthquake loading and would not remain functional for the emergency drawdown. To stabilize the Barrett Dam Outlet Tower under design earthquake, Dr. Han evaluated three retrofit alternatives including 1) bracing the tower to the dam, 2) post-tensioning tower to the foundation bedrock, and 3) steel jacketing the tower in the inside. The mode-superposition response-spectrum analyses were performed using SAP2000 to evaluate three alternatives to select a preferred alternative.

Determination of Barge Impact Loads for Probabilistic Design of Miter Gates (University of Florida)

Double-leaf steel miter gates, used as hydraulic control structures, are present at a significant number of the approximately two hundred navigational lock sites operated by the US Army Corps of Engineers. As a barge flotilla moves into a lock chamber, the potential exists for low speed (0.2 ft/sec – 2 ft/sec) impacts against the closed miter gates. Advanced nonlinear dynamic finite element impact simulation techniques were used by Dr. Han to quantify barge flotilla impact loads on miter gates. He formulated an empirical impact load prediction equation for use in structural design of miter gates.

Technical Reports

Consolazio, G. R., and Han, Z. (2018). Analysis of Concrete Floodwall Failure due to Impacts from Runaway Barges, Structures Research Report 126487, Department of Civil and Coastal Engineering, University of Florida, Gainesville, FL.

Consolazio, G. R., and Han, Z. (2018). Impact Loads for The Design and Assessment of Dam Piers and Tainter Gates, Structures Research Report P0022950, Department of Civil and Coastal Engineering, University of Florida, Gainesville, FL.

Consolazio, G. R., and Han, Z. (2015). Determination of Barge Impact Loads for Probabilistic Design of Miter Gates, Structures Research Report 118747, Department of Civil and Coastal Engineering, University of Florida, Gainesville, FL.

Consolazio, G. R., and Han, Z. (2015). Development of Low-Order Dynamic Code Module for Impact Load Prediction for Probabilistic Design and Analysis, Structures Research Report 118754, Department of Civil and Coastal Engineering, University of Florida, Gainesville, FL.

Presentations

“Dynamic Amplification Effects in Tainter Gates under Barge Impacts” Spring 2018 Structures Graduate Student Seminar, Gainesville, FL. (March 14, 2018).

“Determination of Barge Impact Loads for Use in Miter Gate Design” Spring 2016 Structures Graduate Student Seminar, Gainesville, FL. (February 10, 2016).

WILLIAM F. COLE

PRINCIPAL ENGINEERING GEOLOGIST

Mr. Cole, President of Geoinsite Inc., is a Professional Geologist, Certified Engineering Geologist, and Certified Hydrogeologist, with more than 30 years of experience in earth movement, seismic geology, and related earth hazard assessments. He has served on Independent Review Boards for jurisdictional agencies, including the California Department of Water Resources and the U.S. Army Corps of Engineers. He served a 2-year term on the Geology Technical Advisory Committee (GeoTAC) to the State of California Board of Professional Engineers, Land Surveyors and Geologists (BPELSG). Mr. Cole has participated in safety reviews of more than 100 dams in support of the Federal Energy Regulatory Commission risk reduction program.

Mr. Cole is recognized as an experienced geopractitioner, and has participated in numerous civil works projects involving fault, landslide, and coastal processes. He has a wide variety of experience, including investigation of subsidence and distress associated with construction of transit tunnels, research-level studies of earthquake-triggered landsliding, and mapping seafloor features and sub-seafloor geology for offshore structures and underwater pipelines. Project experience has been in geographically diverse regions, including the People's Republic of China, Mexico, the Ivory Coast, and Saudi Arabia, as well as Alaska, California, Hawaii, Washington, Utah, Nevada, Texas, and Louisiana.

REGISTRATION

Registered (Licensed) Geologist in California, Washington and Wyoming

Certified (Licensed) Engineering Geologist in California and Washington

Certified (Licensed) Hydrogeologist in California and Washington

PROFESSIONAL AFFILIATIONS

Geological Society of America

International Association of Engineering Geologists

U.S. Society on Dams

Earthquake Engineering Research Institute

Seismological Society of America

International Society of Rock Mechanics

American Rock Mechanics Association

Association of Environmental and Engineering Geologists

American Society of Civil Engineers

Engineers Without Borders

RECENT REPRESENTATIVE EXPERIENCE

Upper Feather River Dams (*State Water Project, California State Department of Water Resources*) –Current member of Dam Safety Review Board responsible for assessing performance and conditions of 3 dams in northeastern California. Work involves field inspections, review of design and construction documents, evaluations of instrumentation and monitoring procedures, assessments of seismic and geologic conditions, and preparation of findings reports (ongoing).

Howard Hanson Dam, Tacoma, Washington (*USACE*) – Member of Independent External Peer Review panel responsible for reducing excessive seepage through earthfill dam, and dam safety modifications identified through the USACE Risk Reduction Program. Scope of work included technical review of design and supporting documentation and during-construction observations of mitigation implementation. Drainage measures include vertical and horizontal drains and remediation of an existing drainage tunnel. Dam safety improvements include spillway anchors, upstream embankment armoring, and anchorages for new debris booms, associated with impacts from Probable Maximum Flood (2010-2015).

PROFESSIONAL APPOINTMENTS

- *1998, Geologic Consultant, Three Gorges Dam Project, Chang Jiang Water Resources Commission, People's Republic of China.*
- *2000-2004, Association of Environmental and Engineering Geologists, Committee Chair.*
- *2002-2003, Earthquake Engineering Research Institute, Committee Co-Chair.*
- *2009-2013, Dam Safety Review Board, Oroville-Thermalito, State Water Project, California Department of Water Resources.*
- *2010-2015, Independent External Review Panel, U.S. Army Corps of Engineers, Howard Hanson Dam Drainage Improvement Project.*
- *2012-2014, State of California Board for Professional Engineers, Land Surveyors, Geologists and Geophysicists, Technical Advisory Committee.*
- *2015-2018, Dam Safety Review Board, Upper Feather River Dams, State Water Project, California Department of Water Resources.*
- *2018-2019, Level 2 Risk Analysis (L2RA), Oroville Dam, California Department of Water Resources.*

EDUCATION

M.S., B.S. Geology, Texas A&M University, College Station, TX

New Bullards Bar Dam, Grout Curtain Remediation, Yuba County (*Yuba County Water Agency*) **–** Mr. Cole provided design support and onsite geology expertise to remediate a leaking grout curtain beneath a large concrete arch dam. Project work involved monitoring/recording of drilling, water testing and grouting; monitoring of foundation drain holes and uplift pressure instruments throughout exploration and grouting operations; and interaction with FERC and DSOD. Constraints to project objectives included high hydrostatic pressures and hydraulic communication between drains and grout holes (2013-2017).

Vorotan Cascade Hydropower System – Geologic Risk Assessment, Republic of Armenia, *Confidential Client.* Principal Geologist for seismic hazards assessment and seismic stability review of four dams built during the USSR-era in the Republic of Armenia. The project objective was to identify data gaps and contribute to risk assessment associated with transfer of the dams from government control to private entity. The investigation included review of drawings and reports (prepared in several different languages); geologic mapping from aerial photography and compilation from published works, research/identification/evaluation of seismic sources; slope stability assessments of embankment and abutment slopes; and reporting preliminary hazards analyses.

Concrete Dam Foundation Stability and Erodibility Assessments, Yuba and Nevada Counties, CA *(Quest Structures, Yuba County Water Agency, Nevada Irrigation District)* – Principal Geologist for investigation of foundation rock conditions at concrete dams in the Yuba River drainage area. Work included review and compilation of foundation geology information from construction drawings, photographs, and inspection notes, followed by geologic field mapping using ground-based Light Detection and Ranging (LiDAR) (GBL). The data compilation and field mapping were integrated into a database for kinematic analyses, rock stability analyses, and rock erodibility evaluations. Findings of the studies were summarized into detailed reports and will inform future failure mode analyses and dam monitoring and maintenance.

New Exchequer Dam, Rapid Spillway Assessment and Mitigation (*Merced Irrigation District*) – Geologic assessment and onsite expertise to support rapid evaluation and mitigation of potential spillway erosion in anticipation of runoff from historic snow pack. Mitigation approach consisted of concrete armoring of stacked riprap. The bedrock surface was prepared by removal of weak and sheared rock, followed by high-pressure water jet and vacuum cleaning. Expedited regulatory review helped to reach completion before the rising reservoir level reached the spillway gates (2017).

Rock Slope Instability/Foundation Erosion Assessment, Concrete Arch Dams, Upper American River (*Sacramento Municipal Utility District*) – Geoinsite provided engineering geologic assessments of dam foundations due to overspills and associated rock block failures. Work included geologic field measurements of joint and kinematic analyses of potential failure modes (2008-2010).

Fault Rupture Hazards Assessments, Miners Ranch and Little Grass Valley Dams (*South Feather Water and Power Agency*) – Seismic geology study of faults in vicinity of two dams, including evaluation of whether fault traces pass through dams, and potential for foundation displacement. Scope of work: photogeologic mapping from aerial photographs, geologic field mapping, assessment of fault activity, fault displacement estimates, development of seismic parameters for ground motion estimates, and review of seismic slope stability analyses (2010-2012).

Emergency Water Supply Outlet Tunnel, Warm Springs Dam, Sonoma County (*USACE*) – Lead Geologist for new emergency water supply (tunnel and pipeline alternatives) from Lake Sonoma to fish hatchery owned by U.S. Army Corps of Engineers. Responsible for geologic exploration along water supply routes, including supervising geology field team and assisting in logging 1,900 feet of core, calculation of Rock Quality Designation (RQD) and Rock Mass Rating (RMR), and selection of rock core samples for laboratory testing (2010-2011).

PG&E California Hydro Systems - Pit River-Battle Creek, Feather, Yuba-Bear, Mokelumne-Stanislaus, San Joaquin, and Kern River systems (*GEI, Pacific Gas& Electric Co.*) – Project Geologist for inspections and safety evaluations for multiple low-hazard facilities. Work involved site and air photo mapping, characterizing landslide and erosion hazards, assessing seismic sources for ground motion analyses, and preparing geology portions of STIDs (2007-2012).

Log Cabin and Our House Dams, Yuba River (*Yuba County Water Agency*) –Lead Geologist for foundation rock stability and erodibility evaluations for two concrete dams. Work involves geologic mapping, rock structure characterization and stability assessments of rock discontinuities using ground-based LiDAR surveys (ongoing).

McKays Point Diversion, New Spicer Meadow, Lake Alpine and Utica Reservoir Dams (*GEI, Northern California Power Agency*) - Project Geologist for inspections and safety evaluations for concrete and embankment dams on Stanislaus River system, Sierra Nevada. Work includes evaluations of instrumentation for large landslide complex (piezometers, inclinometers, dewatering wells, optical and GPS surveys), rockslope stability analyses, and seismic hazards assessments (2009-2010).

Don Pedro Dam, Tuolumne County (*Turlock Irrigation District*) **-** Project Geologist for inspection and safety evaluation for earth and rock fill embankments (main dam and associated dikes), concrete spillways, and rockfall mitigation measures to protect hydroelectric powerhouse. Work involved updating seismic hazards, including development of NGA ground motion parameters, and preparing geology portions of Part 12 report and updated STID (2011).

Upper American River Project, Sierra Nevada (*Sacramento Municipal Utility District*) – Team Geologist for FERC Pt 12D inspections and safety evaluations for 6 facilities in SMUD's UARP Project. Follow-up studies included focused analyses of foundation erosion and rock slope instability issues due to predicted PMF overtopping at Slab Creek and Junction Dams (2008 and 2013).

Bear River Canal Failure, Emergency Evaluation Services, Placer County (*SAGE, Pacific Gas & Electric Company*) –Geoinsite provided geologic support for emergency-level evaluation of failed canal-flume structure. Responsibilities included geologic field mapping, logging of rock core, and characterization of rock slope parameters, and delivery of key parameters to design team (depth to competent rock, joint and shear orientations, RQD, etc.). Emergency repair of the canal-flume structure was completed in July 2011.

Engineering Geologic Assessments of Rural Dams, Santa Clara County, CA, *Santa Clara Valley Open Space Authority (OSA)*. Principal Geologist for engineering geologic assessments of nine water impoundments located on rural properties managed by OSA. Primary issues of concern identified for the homogenous earth embankments included seepage, spillway erosion, and embankment erosion. Recommendations for mitigating or monitoring potentially adverse conditions were separated into Priority 1 and Priority 2 categories, based on severity of conditions. Prioritization of recommendations allowed OSA to develop a schedule for future correction and monitoring of the dams.

Seismic Hazards Investigation, Jack Ranch Vineyard, San Luis Obispo County, CA, *Confidential Client.* Chief Geologist and Project Principal for comprehensive assessment of geologic constraints impacting proposed hillside development and vineyard expansion in the hillside region of south-central San Luis Valley (Edna Valley). Work included geologic field mapping; geomorphic analyses using Light Detection and Ranging (LiDAR) and aerial photography; subsurface fault and landslide exploration (trenches, downhole-logging of large-diameter shafts, cone penetrometers); development of a geologic model of the property; and evaluations of fault hazards associated with the Los Osos and Edna fault zones. Field trenches and report were reviewed and approved by the County of San Luis Obispo.

Sustainable Water Project, San Luis Obispo County, CA, *City of Cayucos*. Principal Geologist for geologic hazards assessments of candidate sites for a new wastewater treatment facility and associated pipeline routes in western San Luis Obispo County. Geologic hazards addressed by the study included landslides, fault rupture, seismic shaking, liquefaction, soil erosion, and tsunami inundation. Subsequent work included more detailed investigation of selected sites and preparation of pertinent sections of the environmental impact report (EIR) for the project (including descriptions of the geologic environment, regulatory setting, and significance/impact analysis and mitigation).

Seismic (Fault Hazards) Investigation, Washoe County, NV, *Apple Computer*. Principal Geologist for geomorphic and paleoseismic investigation of a fault zone that impacted proposed sensitive building sites in western Nevada. The scope of work included Quaternary mapping (alluvial fans, debris flows, lacustrine, and sand dune deposits); geomorphic analysis using digital elevation models (DEM) prepared from LiDAR data sets and historical aerial photographs; identification of fault lineaments; mapping fault trenches; and assessment of fault hazards to proposed structures.

Attachment B

Schedule of Rates

QuestStructures

2019 Labor Rates

Labor Category	Fully Burdened
Principal Engineer	$286.00
Senior Engineer	$166.00
Project Engineer	$126.00
Administrative	$76.00

GEOINSITE, INC.

SCHEDULE OF CHARGES, LIMITATIONS, TERMS AND CONDITIONS

Personnel Charges

Principal	$ 200/hr
Senior Scientist/Engineer	$ 175/hr
Project Scientist/Engineer	$ 150/hr
Staff Scientist/Engineer	$ 130/hr
Field/Laboratory Technician	$ 105/hr
GIS, Computer Graphics, Technical Illustrating	$ 100/hr

Equipment and Supply Charges

Inclinometer System	$ 325/day
Laser Level Surveying Equipment	$ 250/day
Total Station Surveying Equipment	$ 400/day
Vehicle	$ .54/mi
Sample Storage	Pro Rata

Expert Witness Consultation

Expert witness testimony for depositions, court appearances and arbitrations shall be charged at a rate of $400 per hour (minimum two hour charge, time is billed portal to portal from our office). Preparation time for depositions, court appearances and arbitrations shall be charged on a time-and-expense basis in accordance with the Personnel, Equipment, and Expense charges listed herein.

Subcontracted Services

Certain services, which may include surveying, drilling, excavating, laboratory testing, or other professional or contractor services, will be subcontracted to an approved contractor or consultant. Such services shall be charged for subcontracted costs plus 15%. Laboratory samples shall be stored for 60 days after date of final report submittal unless special arrangements are made for longer storage.

Expense Charges (Cost Plus 10%)

- Travel expenses including air fare, lodging, vehicle rental, etc.
- Expendable field supplies
- Reproduction of drawings
- Special fees, permits, insurance, etc.
- Special mail service (air, electronic, courier, etc.)
- Special equipment rental or consultant fees

LIMITATIONS, TERMS AND CONDITIONS OF AGREEMENT FOR PROFESSIONAL SERVICES

COOPERATION AND PROJECT UNDERSTANDING - Client will make available to GEOINSITE, INC. all information regarding existing and proposed conditions of the site and/or property. The information shall include, but not necessarily be limited to, plot plans, topographic surveys, hydrographic data, and previous soils, geologic and geotechnical data, which may include borings, test pits, field or laboratory tests, and written reports or technical memorandums. Client will immediately transmit to GEOINSITE, INC. any new information that becomes available or any change in plans. GEOINSITE, INC. shall not be liable for any incorrect advice, judgment, or decision based on any inaccurate information furnished by Client, Client's agents, or Client's other consultants. Client will indemnify GEOINSITE, INC. against claims, demands, or liability arising out of or contributed to by such information. No warranty of any kind whatsoever, expressed or implied, is made or intended in connection with the work to be performed by GEOINSITE, INC., or by the proposal for consulting or other services or by the furnishing of oral or written reports or findings made by GEOINSITE, INC. No guarantee is given that reviewing bodies will grant project approval based on the work performed by GEOINSITE, INC. If additional studies are required by such reviewers, Client will have the option of requesting the additional work be performed by GEOINSITE, INC. at additional cost, or that no further work be performed by GEOINSITE, INC. and all outstanding invoices be paid.

INVOICES AND PAYMENT - Invoices for our services will be submitted, at our option, on a monthly basis or when the work is completed. Invoices will be due immediately, and will be considered to be delinquent if not paid on or before the 30th day following the date of the invoice. If payment is not so made, interest will be due on the amount of the invoices at the rate of 1.5 percent for each month of delinquency. If suit is filed, a reasonable attorney's fee, to be set by the court, shall be included in any judgment in our favor. If client objects to all or any portion of any invoice, then client agrees to notify GEOINSITE, INC. in writing within fourteen (14) calendar days of the invoice date, identify the cause of the disagreement, and pay (when due) that portion of the invoice not in dispute. In the absence of such notification, the balance stated on the invoice will be paid. This Agreement may be terminated by either party seven (7) days after written notice in the event of substantial failure of performance by either party, or if the proposed work is suspended for more than three (3) months. In the event of termination, GEOINSITE, INC., INC. shall be paid for services performed prior to the date of termination, plus the cost of any reasonable termination expenses, which may include, but are not necessarily limited to, the cost of completing analyses, records and reports necessary to document job status at the time of termination.

STANDARD OF CARE - Services performed by GEOINSITE, INC. under this AGREEMENT will be conducted in a manner consistent with that level of care and skill ordinarily exercised by other members of the profession currently practicing under similar circumstances and in the same locality. Client recognizes that subsurface conditions may vary from those encountered at the locations where borings, surveys or explorations are made, and that the findings and opinions of GEOINSITE, INC. are based solely on reasonable interpretations of information available at the time of service. GEOINSITE, INC. will not be responsible for the interpretations by others.

GEOINSITE, INC.

SCHEDULE OF CHARGES, LIMITATIONS, TERMS AND CONDITIONS

PROJECT SITE - Client shall grant free access and right-of-entry for planned field operations, including necessary equipment and personnel. The Client shall notify any and all possessors of the project site that Client has granted GEOINSITE, INC. free access to the project site. The acquisition of, and the payment for, any necessary permits, easements or other site approvals shall be the responsibility of the Client.

GEOINSITE, INC. will take responsible precautions to minimize damage to land from use of equipment, but our fee does not include cost of restoration of damage resulting from our exploration operations. GEOINSITE, INC. shall not be responsible for damage to lawns, shrubs, landscapes, walks or sprinkler systems caused by movement of earth or operation of equipment unless a specific agreement is made to the contrary. GEOINSITE, INC. shall backfill exploratory excavations, including borings and pits, on completion of GEOINSITE, INC.'s work unless monitoring is appropriate and included as part of the scope of work. Settlement of backfill may occur and Client shall fill excavation backfill that has settled as required.

Client shall locate for GEOINSITE, INC. and shall assume responsibility for the accuracy of representations as to the locations of all underground utilities and installations. GEOINSITE, INC. will not be responsible for damage to any such utilities or underground facilities, the locations of which were not accurately disclosed by the Client. Client agrees to defend, indemnify and hold GEOINSITE, INC. harmless from any claim or liability for injury or loss, including costs of defense, arising from damage done to subterranean structures and utilities not identified or accurately located. Any such damage may, and at GEOINSITE, INC.'s option, be repaired by GEOINSITE, INC. and billed at cost to Client.

Client agrees that there are risks of earth movement and property damage inherent in engineering geologic investigations, land development, and construction, and that GEOINSITE, INC. has not been authorized to perform an exhaustive and economically infeasible investigation necessary to eliminate such risks. Client agrees not to use or permit any other person or entity to use reports or instruments of service prepared by GEOINSITE, INC., which reports or other instruments of service are not final and which are not signed and stamped by GEOINSITE, INC.

SAMPLES - GEOINSITE, INC. will retain soil and rock samples for 30 days after the issuance of reports or notification to terminate work.

SAFETY - Client shall take reasonable steps to see that the property is protected, on and off site. GEOINSITE, INC. will not be responsible for the general safety on the site or the work of contractors and third parties.

OWNERSHIP OF DOCUMENTS - Unless otherwise agreed to in a separate agreement, all reports, test results, data, field notes, calculations, estimates and other documents prepared by GEOINSITE, INC. as instruments of service shall remain the property of GEOINSITE, INC. GEOINSITE, INC. shall retain all pertinent records relating the services performed for a period of 5 years following submission or report or termination of project services.

LIMITATION OF LIABILITY – GEOINSITE, INC.'s liability for any damages due to assigned professional negligence will be limited solely to the amount of fees charged for the services provided in performance of the scope of services stated in the proposal or contract. GEOINSITE, INC., INC. shall not be responsible for any loss, damage or liability arising from negligent acts by Client, or Client's contractors, agents, staff or other consultants employed by Client. This provision takes precedent over any conflicting provisions in this AGREEMENT.

If payment for GEOINSITE, INC.'s services is to be made on behalf of Client by a third-party, Client agrees GEOINSITE, INC. shall not be required to indemnify third-party, in the form of an endorsement or otherwise, as a condition of receiving payment for services. GEOINSITE, INC. shall not be liable for damages resulting from the actions or inactions of governmental agencies including, but not limited to, permit processing, environmental reports, project or plan approvals, or building permits.

CHANGE ORDERS AND DISPUTE RESOLUTION - If, during the performance of the work under this Agreement, it is determined that the scope of work has expanded or changed such that additional expenditures are required, the client shall be notified by Change Order and approval from the client shall be received in writing prior to the performance of the additional services. Neither party shall hold the other responsible for damages or delay in performance caused by acts of God, strikes, lockouts, accidents or other events beyond the reasonable control of the other party, it's employees or agents. In the event that Client makes a claim, at law or otherwise against GEOINSITE, INC. for any alleged error, omission, or other acts arising out of performance of the professional services of GEOINSITE, INC., and Client fails to prove such claim upon final adjudication, then the Client shall pay all costs incurred by GEOINSITE, INC. in defense of such claim, including, but not necessarily limited to, personnel-related costs, legal fees, court costs, and all other claim-related expenses. All disputes, claims, and other matters in controversy between Client and GEOINSITE, INC. arising out of or in any way related to this AGREEMENT will be submitted to alternative dispute resolution, such as mediation and/or arbitration, before and as a condition precedent to other remedies provided by law.

INDIVIDUAL RESPONSIBILITY - The individual or individuals who sign this AGREEMENT on behalf of Client guarantee that Client will perform its duties under the AGREEMENT. The individual or individuals so signing this AGREEMENT warrant that they are duly authorized agents of the Client.

Attachment C

Quest Structutres Summary of Capabilities

QuestStructures

25 Orinda Way, Suite 305
Orinda, CA 94563-4402

SUMMARY OF CAPABILITIES

Established in 1987, Quest Structures is a small business providing a comprehensive range of services in the dam, structural, and earthquake engineering. We have strong backgrounds in structural dynamics, finite-element analysis, and many years experience in earthquake engineering related to design and safety evaluation of hydraulic structures including dams, intake/outlet towers, spillways, gates, navigation locks, and other structures. We have also investigated and solved a broad range of problems involving the effects of other dynamic loads such as waves, blasts, and forced and ambient vibration as well as concrete expansion due to alkali-aggregate reaction (AAR).

Dam Engineering

Quest Structures has extensive experience in design, analysis, seismic input, structural field investigations, and safety evaluations of concrete dams. Backed by state-of-the-art technologies, field measurements of actual dynamic response, and a variety of project experience, we have developed and applied advanced finite-element (FE) procedures to design and seismic safety evaluation of concrete dams in the United States and abroad. We have undertaken various experimental and numerical investigations to study the effects of dam-water interaction, dam-foundation interaction, and the reservoir-bottom absorption on the earthquake performance of concrete dams.

Quest has developed WebDams, a family of web-based dam analysis programs with pre-processing, post-processing, and input file-sharing capabilities. These programs, which were either developed or enhanced by Quest Structures, are shown in the right column. Further, our engineers are proficient with commercial programs such as SAP2000, ANSYS, and LS-DYNA, and have applied these programs to many dam safety evaluation projects.

Selected Dam Projects

American Electric Power
Smith Mountain Dam, VA
Claytor Dam, VA
Leesville Dam, VA

BC Hydro
Strathcona Dam, BC, Canada
John Hart Dam, BC, Canada
Ladore Dam, BC, Canada
Ruskin Dam, BC, Canada

BKW FMB Energie AG
Mühleberg Dam, Switzerland

City of San Luis Obispo
Salinas Arch Dam, CA

Mighty River Power
Karapiro Arch Dam, New Zealand

Nevada Irrigation District
Combie Arch Dam, CA
Bowman Arch Dam, CA

Duke Energy
Walters Arch Dam, NC

Placer County Water Agency
Ralston Afterbay Dam, CA

Papua New Guinea Power Ltd.
Naoro-Brown Hydropower Dam, PNG

Tennessee Valley Authority
Cherokee & Fort Loudoun Dams, TN
Kentucky Lock and Dam, KY
Fontana & Hiwassee Dams, NC
Chickamauga Lock and Dam, TN

Smithland Hydroelectric Partners
Smithland Dam, KY

Sacramento Municipal Utility District
Brush Creek Arch Dam, CA
Slab Creek Arch Dam, CA

Tri-Dam
Donnells Dam, CA
Tulloch Dam, CA

US Army Corps of Engineers
Folsom Dam Auxiliary Spillway, CA
Folsom Dam Mini-Raise Project, CA
Portugues Dam, Puerto Rico
Hemlock Arch Dam, WA
Isabella and Success Dams, CA

US Bureau of Reclamation
Boca Dam, CA
Folsom Dam, CA
Monticello Dam, CA
Horse Mesa Dam, AZ
Mormon Flat Dam, AZ
Morrow Point Dam, CO
Green Mountain Dam, CO

Yuba County Water Agency
New Bullards Bar Arch Dam, CA
Our House Arch Dam, CA
Log Cabin Arch Dam, CA

NEA Engineering Company, Nepal
Phukot-Karnali Dam, Nepal
Betan-Karnali Dam, Nepal

PT PLN (Persero), Indonesia

- **Dam Engineering**
- **Structural-Earthquake Engineering**
- **Structural Dynamics**
- **Design and Safety Evaluations**
- **Peer Review**

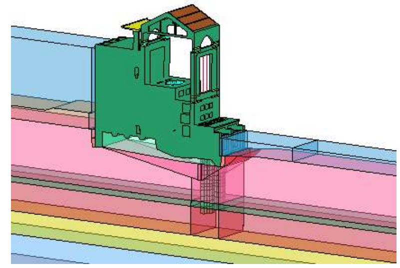
In-house Software Programs

- **GDAP**, a finite-element program for 3D static and dynamic analysis of concrete dams
- **QDAP**, a finite-element program for nonlinear earthquake response analysis of concrete dams
- **GPOST**, a post-processor for presentation and visualization of GDAP and QDAP results
- **QFLUSH,** a finite-element program for seismic analysis of earth dams and soil-structure-interaction problems

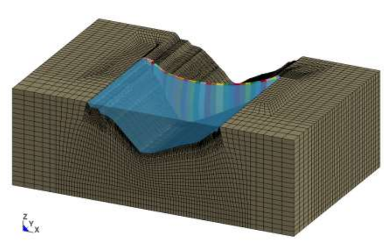
Commercial Programs

- **LS-DYN, ANSYS, SAP2000**

Mühleberg Dam



Mühleberg Dam Model



New Bullards Bar Dam Model

City of Sandiego
Lake Hodges Dam, California

Lesotho Highland Authority
Lesotho Arch Dam, Lesotho

Upper Cisokan Pumped Storage Dams
Matenggeng Pumped-Storage Dams
Poko Hydroelectric Dam

Integral S.A. and ISAGEN, S.A.
Porvenir-II Dam, Colombia

Structural-Earthquake Engineering

We have extensive experience in the dynamic structural analysis of conventional and unusual structures (including intake/outlet towers, spillway structures, navigation locks, underground structures, storage tanks, bridges, and buildings), soil-structure-interaction, and fluid-structure interaction problems. Further, we have developed and applied advanced structural software, and maintain a library of general-purpose and specialized applications programs for the static and dynamic analysis of linear and nonlinear systems. Our specialties include consideration of soil-structure interaction and fluid-structure interaction effects. We have reviewed and provided consultation on design criteria, seismic design, dynamic analysis, and specification of earthquake ground motions for various essential facilities.

Selected Inlet/Outlet Tower Projects

BC Hydro
Strathcona Dam Intake Tower, BC, Canada

DEPARTMENT OF WATER RESOURCES, CA
Perris Dam Outlet Tower, City of Perris, CA
Castaic Dam Outlet Towers, CA

East Bay Municipal District (EBMUD)
Briones Outlet Tower, California
Chabot Outlet Tower, California
Pardee Outlet Tower, California
San Pablo Outlet Tower, California
Sobrante Outlet Tower, California

Los Angeles County Department of Public Works
Eaton Wash Dam Outlet Gate Tower, California

Metropolitan Water District of Southern California
Lake Skinner Outlet Tower, California

Tennessee Valley Authority (TVA)
Blue Ridge Dam Outlet Tower, Georgia

United Water Conservation District
Santa Felicia Dam Submerged Intake Tower, California

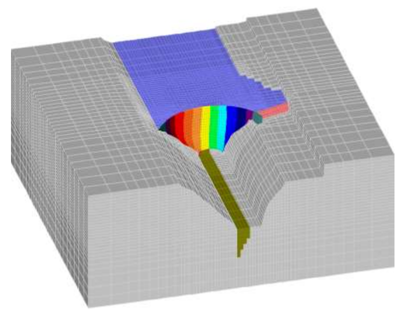
US Army Corps of Engineers
Isabella Dam Outlet Towers, California
Success Dam Outlet Tower, California
Cougar Intake Tower, Oregon
Prado Dam Outlet Tower, California
Seven Oaks Dam Intake Tower, California

Spillway/Outlet Structures

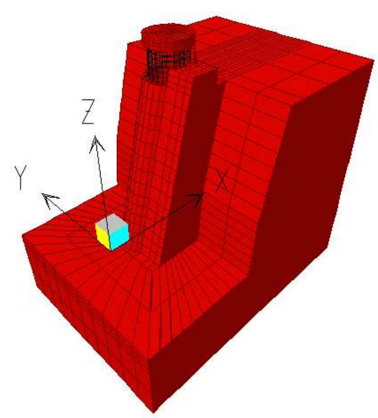
US Army Corps of Engineers
Boca Dam Spillway, Truckee, California
Isabella Dam Spillway, California
Saluda Dam Spillway Structure, South Carolina
Folsom Dam New Auxiliary Spillway, Folsom, California
Outlet Works at Whittier Narrows Dam, Los Angeles, California
Spillway Structures at Whittier Narrows Dam, Los Angeles, California

South Carolina Electric & Gas
Saluda Dam Spillway Structure, Columbia, SC

Independent Technical Review / Advisory Panel



Donnells Dam



Seven Oaks Inclined Tower

25 Orinda Way, Suite 305
Orinda, CA 94563-4402

Quest Structures has undertaken comprehensive, and independent technical reviews of safety evaluation, design, and construction of dams, intake towers, spillway structures, bridges, and navigation locks and gates for the US Army Corps of Engineers, US Bureau of Reclamation, Tennessee Valley Authority, B.C. Hydro, utility companies, A/E firms, Alaska Energy Authority, and the World Bank, and others.

Design Manual Publications

Quest has authored numerous manuals for design and safety evaluation of hydraulic structures for regulatory agencies and the US Army Corps of Engineers (USACE). Following are the most recent Engineer Manuals authored, co-authored, or reviewed by QUEST Structures:

EM 1110-2-2201: *Engineering and Design - Arch Dam Design*
Authored Chapters 6 & 7 of the manual on static and dynamic analysis of arch dams for USACE

EM 1110-2-2400: *Structural and Evaluation of Outlet Works*
Reviewed by Quest Structures, this manual provides guidance for the planning and structural design and analysis of intake structures, and other outlet works features.

EM 1110-2-6050: *Response Spectra & Seismic Analysis of Hydraulic Structures*
Developed jointly by Quest Structure and Geomatrix Consultants, this USACE manual provides guidance regarding how to develop site-specific response spectra for design earthquakes and how to use them in the seismic structural analysis and design of hydraulic structures.

EM 1110-2-6051: *Time-History Dynamic Analysis of Concrete Hydraulic Structures*
Developed by Quest Structures, this USACE manual describes procedures for the linear-elastic time history dynamic analysis and development of acceleration time histories for seismic design and evaluation of concrete hydraulic structures.

EM 1110-2-6053: *Seismic Design and Evaluation of Concrete Hydraulic Structures*
This manual is being developed by Quest Structures to provide guidance for the seismic design and evaluation of concrete hydraulic structures for USACE. The manual covers requirements for the seismic design and evaluation of plain and reinforced concrete hydraulic structures.

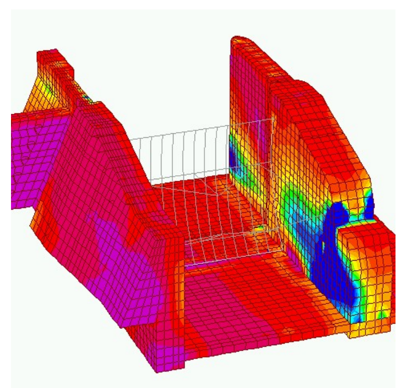
ITL-93-1: *Theoretical Manual for Analysis of Arch Dams*

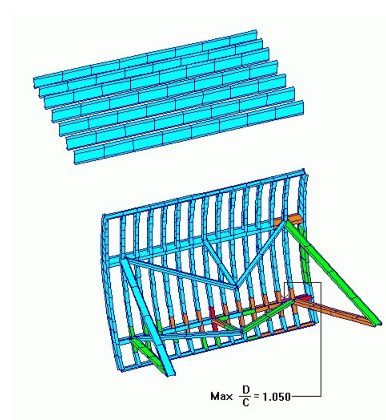
Developed by Quest Structures, this manual provides a theoretical background for the linear structural analysis of concrete arch dams.

FERC Engineering Guidelines for the Evaluation of Hydropower Projects

Developed "*Chapter 11, Arch Dams,*" of the manual for Federal Energy Regulatory Commission.

- **Technical Review**
- **Intake/outlet Towers**
- **Navigation Locks**
- **Spillway Structures**
- **Bridges**
- **Soil-Structure-Interaction**
- **Fluid-Structure-Interaction**
- **Seismic Input Specification**
- **Advanced nonlinear analysis**





Saluda Dam Spillway

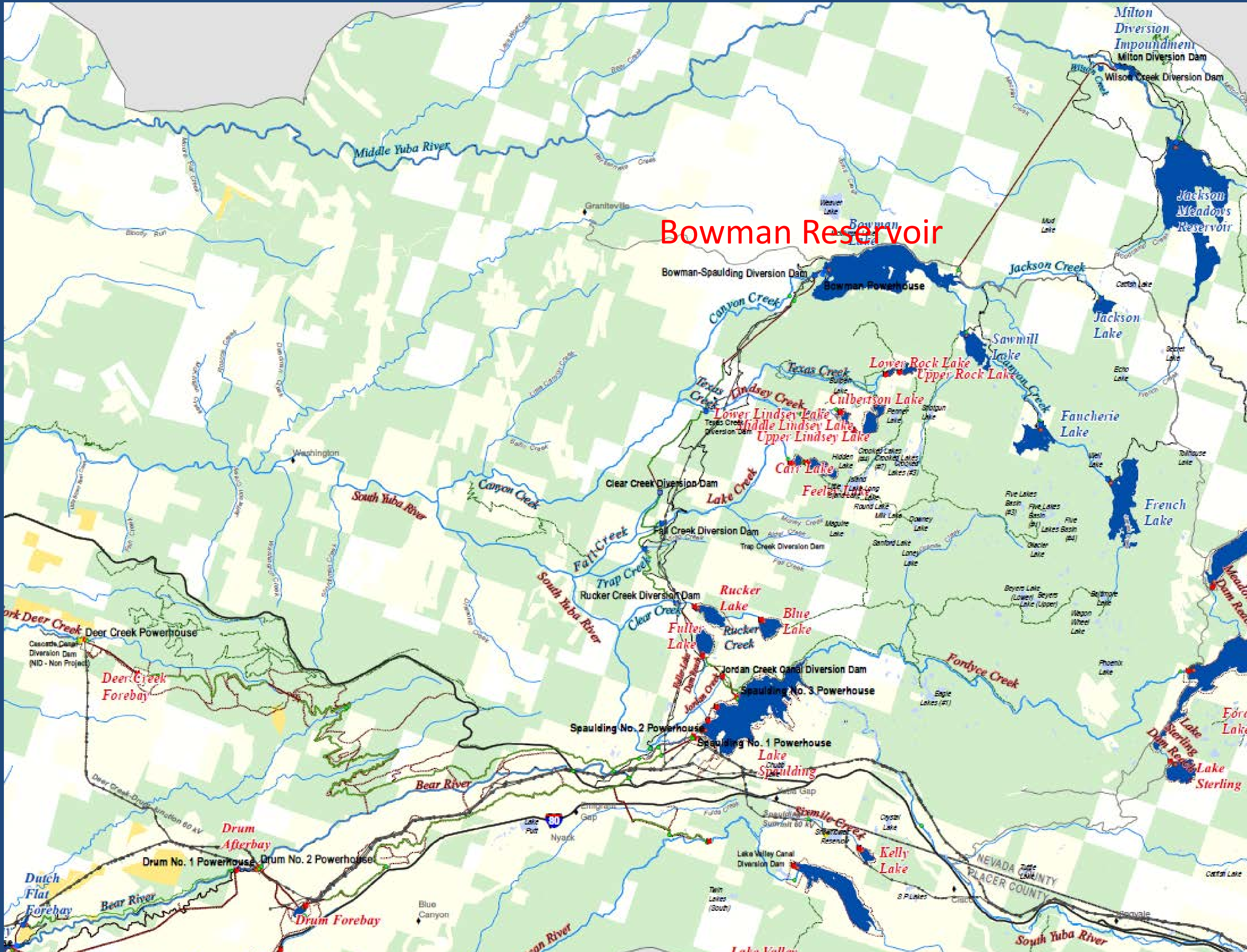
Board of Directors Meeting

Bowman South Dam
Seismic Stability Analysis

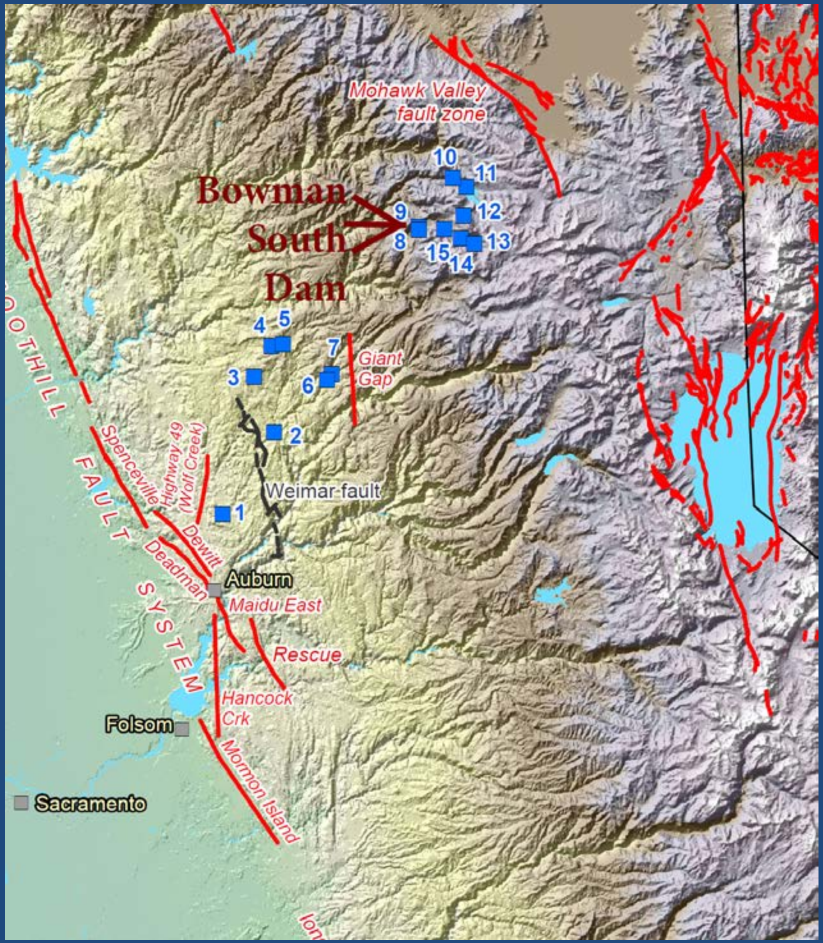
Presented by
Keane Sommers, Hydroelectric Manager
Dar Chen, Dam Safety Engineer

August 14, 2019

Bowman Reservoir Vicinity Map



Bowman South Dam and Faults Map



15 Miles to M=7.3 Mohawk Valley Fault

Bowman South Dam
Seismic Stability Analyses

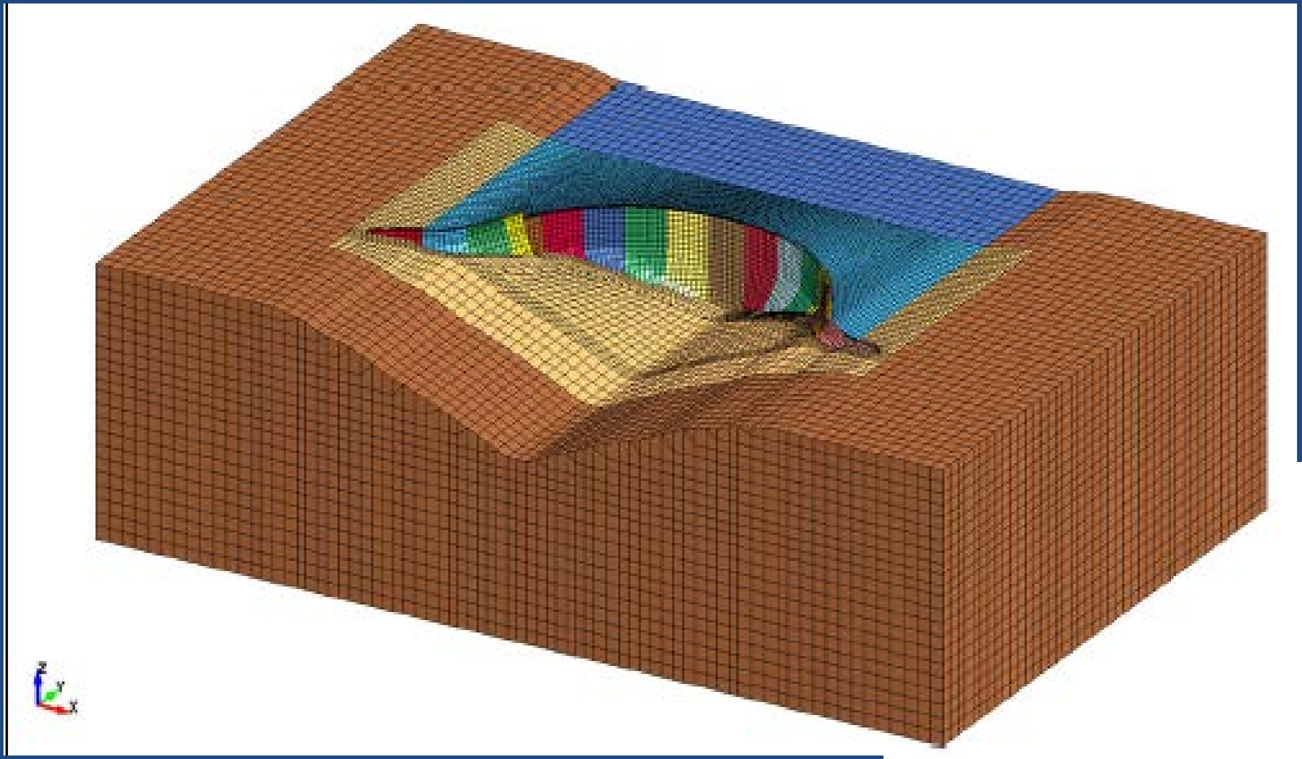
- FERC required updates of analyses, last performed in the 1990s.
- Will use the state-of-the-art 3-D, non-linear, dynamic finite-element modeling.
- Need to address the stability issues of the arch and the left abutment thrust block.

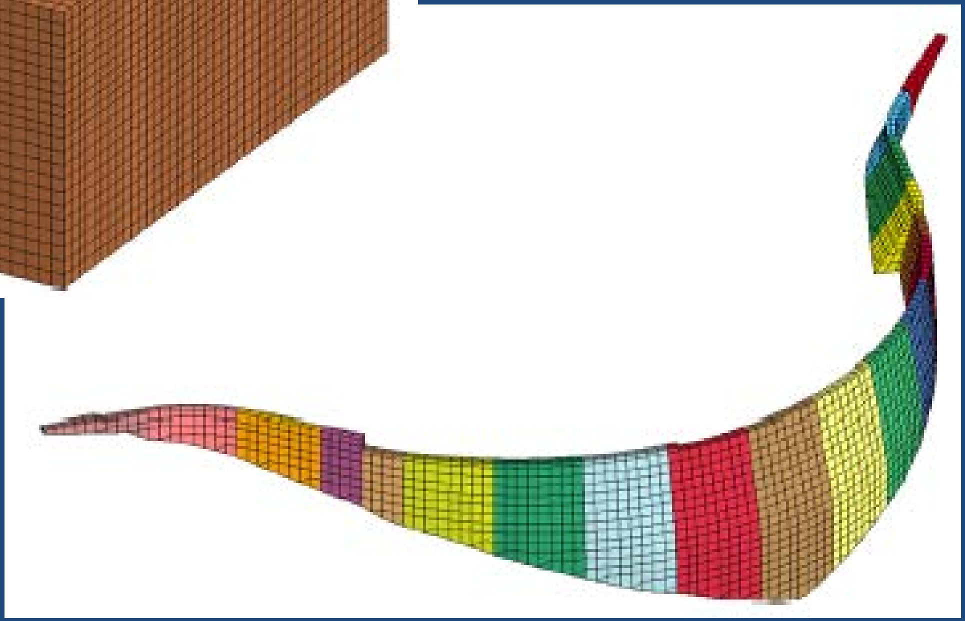
Quest Structures

- Dr. Yusof Ghannat is the key engineering consultant specialized in concrete hydraulic structures for 40 years in the U.S. and abroad.
- He developed the engineering guidelines on arch dams for FERC and engineering manuals on concrete hydraulic structures for U.S. Army Corps of Engineers.
- He is the only reputable specialist known to staff in Northern California.
- The proposal demonstrated excellent project understanding and approach with reasonable costs of services.

Combie Dam Dynamic Stability Analyses

(Completed in 2019.05)





LS-DYNA 3-D, Non-Linear, Dynamic, Finite Element Modeling

Recommendation

Award a sole source contract in the amount of $225,581.30 to Quest Structures for the Bowman South Dam Seismic Stability Analyses and authorize the General Manager to execute the necessary documents.