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Calaveras Dam Replacement Project

FEATURE

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Dam Foundations and Differing Site Conditions — Calaveras Dam Replacement Project

Note: The following is a shortened version of a paper presented during the USSD 34th Annual Meeting and Conference, April 2014, San Francisco.

Background

In 2002, the San Francisco Public Utilities Commission embarked on a capital program to improve seismic and water supply reliability on its Bay Area water storage, treatment and conveyance systems. This $4.6 billion capital program will enable the SFPUC to provide reliable, affordable, high quality water in an environmentally sustainable manner to its wholesale and retail customers in the Bay area. Many of these projects involve significant risks due to complexities in below grade construction and geologic conditions that include soft soil and weak rock in a high seismic source zone. The Calaveras Dam Replacement Project is one such project.

Introduction

The Calaveras Dam Replacement Project (CDRP) is in year three of a six-year construction project to replace the original earth fill dam, which is vulnerable to a Maximum Credible Earthquake on the adjacent Calaveras Fault System. At this stage of construction, site development for access to borrow areas and disposal sites is complete, and substantial progress has been made in the construction of the new intake and outlet works, as well as in preparation of the foundation to receive new embankment fills.

Figure 1. Site Vicinity Map.

Although the design phase of the project recognized complexities in the geologic conditions and their potential impacts on construction, the subsurface conditions have turned out to be even more challenging than anticipated, particularly in excavation works to establish the left abutment for the new dam. This paper discusses risk management techniques for substantial subsurface construction projects, three specific and significant changes during construction on CDRP and their impacts on design and construction. In addition, this paper reviews the very positive approaches that have been taken by the Project Team to keep the project moving forward and to minimize, to the fullest extent practical, impacts to costs and schedule for completion.

Project Description

The Calaveras Dam Replacement Project is located on Calaveras Creek in the Diablo Mountain Range in Alameda County, California. The existing 220-foot-high earth-fill dam was completed in 1925 and is being replaced to address seismic stability concerns with the existing dam. The new structure will be a zoned earth and rock fill embankment including a new concrete-lined un-gated ogee-crested spillway and a new intake tower and shaft. Some key statistics are noted below:

- Reservoir storage 96,850 acre-feet, or 40 percent of the local water storage and 66 percent of the local water yield
- Reservoir has been operating at 25 percent of capacity since 2001 due to seismic safety concerns
- New dam will include a robust design that could accommodate the Maximum Credible Earthquake, the Probable Maximum Flood, and potential future enlargement

A site overview is presented in Figure 2 and a typical cross section of the new zoned rock fill dam is shown in Figure 3. The new dam will include a wide central core constructed of clay which will be obtained from an on-site borrow source located just south of the reservoir. The upstream and downstream shells will be obtained from an on-site rock borrow site and excavation into the left abutment, respectively. The materials for the internal filters and drains will be imported from off-site local aggregate quarries.

Construction of the new intake tower includes a new 22-foot-diameter, 151-foot-deep intake shaft and tunnels through the existing intake tower and connecting to the existing adits. A key feature of the new outlet works is a 72-inch-diameter steel pipe from the new intake tower to be connected with the existing outlet conduit, with activities constrained to periods when the reservoir can be taken out of service.

Site and Subsurface Conditions

Geologic and geotechnical investigations for the proposed construction began during 2003 and continued through 2007 during various phases of work. Extensive design phase geologic and geotechnical investigations were completed for the Project; and the Project further benefited from access to construction records and mapping performed during construction of the original dam.

Figure 2. Site overview.

Approximately 80 HQ-3 wireline core borings were drilled in the dam site and rock borrow area to characterize the subsurface conditions; totaling about 10,900 linear feet. In addition to drilling, pre-construction investigations included 80 test pits, 19 seismic refraction survey lines, and a number of fault trenches (URS, 2008). The depth and scope of investigation were commensurate with the known geologic and tectonic conditions surrounding the site.

The Dam is located in the tectonically active and geologically complex Coast Range and is approximately 500 yards from the active Calaveras fault. Additionally, there are multiple secondary faults, Tertiary sedimentary bedrock, a diverse suite of Franciscan assemblage rocks, and numerous active, inactive and dormant landslides (Kelson, 2014).

Looking downstream and working from left to right, the geologic profile along the dam centerline varies from sandstone of the Tertiary Temblor Formation to Franciscan Mélange, consisting of weak black shale, siliceous shale and siliceous schist matrix within surrounding blocks of more competent greywacke, greenstone, bluschist and serpentinite.

Regulatory Environment

As with any project in California, the CDRP was required

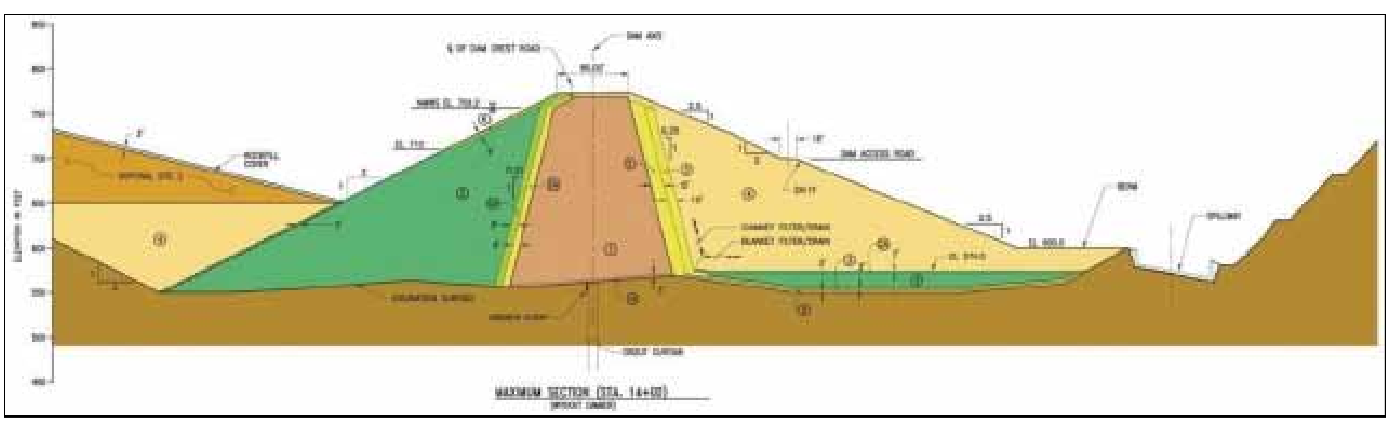

Figure 3. Typical dam cross section.

to comply with the California Environmental Quality Act. Environmental surveys conducted prior to construction disclosed a number of threatened and endangered species in the Project area, including the California Tiger Salamander, Alameda Whipsnake, Red Legged Frog and American Bald Eagle. A significant part of on-going work at the Project site involves protection of these and other species, including trap and relocation programs for the California Tiger Salamander.

The Contract Documents entail an extensive system to protect the quality of the water — both within the reservoir as well as Calaveras Creek. All storm water is collected and passed through an active treatment system prior to discharge. This involves several miles of piping, a 1.3-million-gallon sediment pond for storage during peak flows, and an active treatment system capable of handling 2,400 gallons per minute.

In addition to the "usual" types of environmental protection taken with regard to species and water quality, the CDRP is challenged by the presence of Naturally Occurring Asbestos (NOA) in some of the bedrock, including portions of the dam foundation as well as the on-site rock borrow source. Although detailed discussion of NOA is beyond the scope of this paper, protection of public health and exposure due to NOA is a key component of the construction taking place. This work involves careful mapping of exposures to document the occurrence of NOA and levels of personal protection in selected work areas that include respirators, personal breathing zone monitoring, decontamination systems and other measures. In addition, a comprehensive air monitoring program is in place adjacent to the work, at the project perimeter, and at ambient stations located downwind of the project area.

Risk Management Strategies

Given the risks inherent with the CDRP, the SFPUC incorporated a number of key risk management provisions in its implementation of the project; a number of these approaches have significantly benefited the project and allowed for impacts to cost and schedule to be controlled while navigating changes associated with differing site conditions.

Risk Planning

A comprehensive risk management strategy was developed for the overall Water System Improvement Program (WSIP) and applied to CDRP. This included development of a risk register during the design phase which was subsequently maintained and updated by the project team both prior to and during construction. The risk register includes a detailed description of each risk including the cause and effect as well as the likely cost impacts. The trigger dates guide the project team as to when action is required. Detailed action items include specific responsibilities for individuals or groups to address each risk. This system has been very effective at mitigating known risks. Where mitigation was not possible, the register was an effective tool to provide advance notice which allowed for planning to reduce cost and schedule impacts. In particular, the risk register was very useful in aiding coordination efforts involving diverse groups; e.g., pre-planning for shutdowns.

Several key risks identified during the design phase of the project were mitigated through incorporation of design elements in the project. For example, it was recognized that the existing landslide in the right abutment could become unstable during foundation excavation. The costs and impacts to schedule were deemed to be too severe to carry this risk into construction without appropriate mitigation in design. As a result, a soldier beam and tieback retaining wall was designed and successfully installed to mitigate the risk of potential slope instability in the right abutment. Other risk factors were not mitigated in design, but instead were carried into construction. One example was the risk of significant overruns in grout quantities associated with the consolidation grouting program.

Contractor Pre-qualification

Due to the complexities in the CDRP, SFPUC wanted to assure that contractors competing for the work had experience with the same types of construction, and further, that the staff assigned to the work had this experience as well. Key aspects of the pre-qualification process included construction of zoned rockfill dams in California, large earthworks experience, a detailed (scored) reference check, and expertise of the individuals proposed for the job.

The SFPUC received three bids from pre-qualified contractors with each developing a specific approach to the work reflective of their combined experience and expertise.

Early Environmental Mitigation

The SFPUC recognized the limitations due to various environmental restrictions as well as the key initial milestones in the project schedule. Several key work activities were planned to be completed prior to construction, but after receipt of final environmental approvals. This allowed the SFPUC to proceed with initial construction activities virtually immediately following approval of the Project Environmental Impact Report and roughly three months prior to final notice-to-proceed (NTP) of the main contractor.

Specific construction items, including installation of environmental fencing, trapping and relocation of endangered species, and clearing of habitat were completed prior to construction.

Flexible Payment Provisions

Construction payment provisions should provide for an equitable management of risk. Where scope and quantities can be defined, lump sum payment provisions are typically preferable. However, in the case of CDRP, several items were bid as unit price where quantities could not be adequately defined.

In addition to unit price estimates, the SFPUC requested direct labor and equipment rates. These payment provisions have allowed the project team to better define additional work in terms of the contract and the existing project specifications.

Partnering

The SFPUC adopted a formal partnering process for all WSIP projects. Additionally, and equally important, the Contract Documents provided a formal program for resolution of issues at the lowest possible level with a Dispute Resolution Board provided as a final step. To be effective, partnering and the issue escalation ladder must be carried out in practice every day, not just when formal partnering meetings are held. Specifically, those at the higher levels must avoid involvement in specific issue resolution until it has been formally escalated. This creates a level of trust among all parties and assures that the principles outlined in the Contract are carried out in practice.

Dealing with Change

As of the writing of this paper, the SFPUC is a little over two years into what is now estimated to be a six year project. As compared to the original estimate, both cost and schedule have increased by more than 50 percent. The original bid price was about $260 million.

Much of the change is attributable to differing site conditions in the three following areas:

Disposal Site 3 Dike. The dike was designed to span an existing draw on the west side of the reservoir allowing for disposal of unsuitable excavation materials. However, questionable soils were found at depths approaching 40 feet; as compared to a planned excavation depth of five feet.

Excavation of Observation Hill. The left abutment was fairly steep prior to construction (approximately 1 horizontal to 1 vertical) and a substantial excavation into the existing abutment was required to provide room for a new overflow spillway and also to expose a suitable foundation for the new outlet pipe. Additionally, the planned construction sequence called for excavated material to be placed directly in the dam. When first the temporary ("false cut") and then the permanent slope were found to be unstable, the team faced extra-ordinary challenges.

Spillway Foundation. The concrete overflow spillway design called for the structure to be founded on rock. During construction several variations in geologic conditions indicated a potential need for change. Over-excavation beneath the spillway was required to achieve suitable subgrade. Further complicating matters, was the need to "replace" the excavated material with concrete — essentially rebuilding the planned rock foundation.

Figure 4. View from left abutment.

The First Challenge — Disposal Site 3 Dike

As with most dam construction, a significant excavation to reach suitable subgrade is one of the opening acts. In this case, even prior to dam excavation, work to ready a disposal site was required. With the reservoir level reduced, the dike could be constructed in the dry utilizing material from the on-site borrow sources.

Although limited geotechnical information was available in the area of the dike prior to bid, an assumed excavation depth and unit price quantities would allow for change during construction. Detailed geotechnical explorations in this draw were completed immediately following final environmental approvals for construction and prior to contractor mobilization. While these investigations might better have been conducted during the design phase of the project, intrusive work in this location required several environmental permits which, in turn, presented what were perceived to be unacceptable schedule impacts at the time of bid preparation.

Results of the subsurface drilling over much of the length of this 1,500 foot long dike were roughly as expected; however, a 150-foot-long segment revealed unsuitable sediment to depths approaching 40 feet — as compared to an assumed depth of five feet. Further complicating these findings were the following factors:

- Construction of the dike and preparation of the disposal site were on the critical path. Any time delays would necessarily extend the construction project.
- The entire schedule was driven by planned shutdowns of the outlet works. Thus, any schedule delays had to be fully recovered prior to the shutdown or risk extending the schedule by an additional year.
- Initial disposal of "clean" materials not containing NOA would be key to later project work that would involve disposal of asbestos containing material — which had to be placed above the normal waterline. Thus, finding an alternate location for current spoils would cause major problems down the road when excavation of asbestos-containing materials was to begin.
- Rock for the construction of the dike was planned to be obtained from the on-site rock borrow source. However, full development of the planned quarry was years away and only a limited amount of material was readily available. Thus any increase in quantity would have a major impact on how the work was accomplished.
- Additional excavation, beyond the assumed five feet, would encroach on the reservoir; potentially requiring in-water work.

Although unit prices were available in the contract, the complexity of the work and the required schedule sequence limited their application. Further complicating matters, the reservoir levels were being held low to facilitate this specific construction effort. With the rainy season approaching, substantial delays had the potential to extend the project for a full year. So, the team found themselves less than a month into the project and facing a potential significant delay at a cost initially thought to be around $30 million.

Project Team Collaboratively Managing Risk

Within weeks of NTP, and prior to submission or approval of a baseline schedule, the entire Team began work to completely re-sequence the project to alleviate potential impacts. The final answer included deep soil mixing over a limited portion of the dike foundation and conventional construction for the remainder of the dike. However, this construction would take months; effectively halting all other construction and requiring extensive re-sequencing of planned work activities.

Following a series of brainstorming sessions, a number of taskforce groups were assembled to identify specific areas for potential schedule acceleration. These groups included representatives from the owner, designer, CM team, contractor, Consultant Technical Advisory Panel and California Division of Safety of Dams. By calling all responsible parties into a room to work together, ideas could be quickly evaluated and either judged to have potential merit or eliminated from consideration. Those ideas with merit were further considered during break-out sessions.

Task force groups were assembled around four key areas:

- Mass Concrete
- Temporary Support of the Existing Outlet Pipe
- Grouting
- Downstream Outlet Works

Each of the proposed changes were fully vetted and analyzed by a diverse project group in real-time. Following smaller task force meetings, the larger group — consisting of numerous professionals and including representatives of the contractor — was gathered to jointly consider all potential schedule enhancements. This allowed for the Team to consider potential "enhancements" versus anticipated cost for each "enhancement."

Between design and construction, the project was delayed about four months. Total cost of the delay, including both hard and soft costs, was about $15 million. A substantial savings versus initial estimates approaching $30 million, but still amounting to almost 50 percent of the contingency for this four year construction project — all in the first several months of construction.

More (and Bigger) Challenges

Shortly after the change order for Disposal Site 3 had been approved, the contractor began experiencing instability in the cuts in the left abutment, referred to as Observation Hill, so named because it towers more than 400 feet above the existing reservoir and nearly 700 feet above the lowest foundation grade of the new dam. Supplemental geotechnical investigations in these previously inaccessible areas (to conventional track-mounted drills) disclosed the presence of large ancient landslide complexes with adverse conditions that could affect the stability of the left abutment. After careful consideration of Contract Conditions, a differing site condition was acknowledged. Further to this changed condition, analyses by the Design Team indicated that not only was the "false cut" unstable, but the permanent cut slope was also deemed to be potentially unstable. Ultimately, the redesigned slope configuration in the left abutment required a layback to approximately 2 horizontal to 1 vertical, as shown in Figure 5.

The change in slope configuration in the left abutment was significant from several important perspectives.

The planned excavation of the Temblor Sandstone in the left abutment would be used to construct the downstream

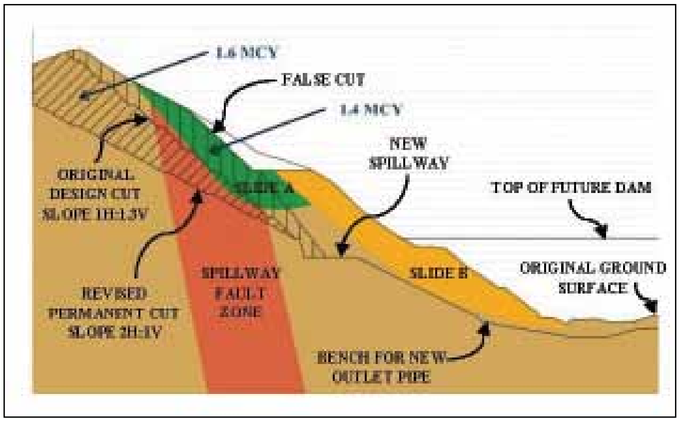

Figure 5. Cross section of left abutment.

shell of the dam. Given the limited space on the site, and the expense of double-handling, the contractor assumed that an initial "false cut" would be made to remove poor quality rock that could be taken directly to disposal.

The excavation would be followed by a second cut to permanent grades at a time when better quality rock could be placed directly in the new embankment.

Preliminary evaluations of the excavated slopes were based (in part) on observations of the existing, undisturbed slopes which were steeper than 1 horizontal to 1 vertical; including near vertical cliffs approaching 20 feet. The fact that the pre-construction slopes had remained stable for the last 80 years provided confidence that the proposed slope would be stable, and further supported the stability assessment completed by the Design Team prior to construction. However, initial excavation revealed conditions that were significantly worse than anticipated.

The left abutment excavation was required to install the new outlet pipe near the base of the excavation; a critical path activity. As a result of this change, an additional three mcy of material would have to be moved prior to installation of the new outlet.

The 1.4 mcy depicted in Figure 5 is the difference between the false and permanent cut. This material was intended to be placed directly into the new dam. However, with the differing site conditions and the resulting instability in the left abutment slope, this material would have to be hauled to a temporary storage location and then double handled for final placement in the downstream dam shell. The 1.6 mcy represents the volume of material between the planned final cut slope and the new final cut slope. This material would have to be hauled and permanently disposed of on-site.

Therefore, this single change would nearly double the total amount of unsuitable excavation material and require double-handling of over a million cubic yards of materials. In an extremely constrained site, how would the additional storage capacity be achieved and at what environmental cost?

This would have a major impact on the construction sequencing, requiring a complete new look at the progress of the work. All re-sequencing would have to be framed around the planned shutdown windows. How could the additional work be re-sequenced to minimize impacts to other on-going work?

Building on the trust developed during the disposal dike change and reviewing previously considered schedule enhancements, the team again worked to minimize schedule impacts. Even with a concerted effort involving the entire project team and several regulatory agencies, the overall impact of this change would be monumental. Total impacts exceeded $100 million with a predicted schedule extension of 20 months.

In this case, a discrete estimate based on the existing contract was not practical or feasible as much of the work would occur beyond the original contract. The Team worked very closely in developing the best construction sequencing and then evaluating what permit conditions were required to facilitate construction.

While many of the acceleration and other schedule enhancements previously developed during the construction of the Disposal Site 3 Dike would serve to lessen the impacts of the left abutment change, more was needed. Again, representatives from the owner, designer, CM team, contractor, and DSOD worked closely together in partnership to develop alternate solutions to reduce the overall impacts. The task force groups that were assembled for the previous disposal site change served as an excellent introduction and team building exercise. Therefore, at this stage, these discrete entities had truly become an integrated Team. Major items explored to address schedule and cost included the following:

Disposal Options — Numerous options were identified for temporary and permanent storage. Cycle times were key to schedule and costs so the Team looked for nearby locations. Additionally, optimizing disposal locations had to consider the excavation stage. Referring to Figure 6 (next page), the best disposal location at the start of the left abutment excavation would be very different than the optimal location when excavating at the base of the dam, nearly 700 feet down. And, all additional storage locations would have to be designed, permitted, and readied for construction; in real-time while minimizing any impacts to existing operations.

Final Design of Cut Slope — Stability analyses and final design was on-going while additional subsurface information was being obtained; however, during these

Figure 6. Aerial view of left abutment.

studies and investigations, the contractor needed clear direction on where to use a fleet of 17 scrapers. Idling this amount of equipment would have serious cost implications. Worse still, stand-by charges would not pay for the total costs of the equipment. If near-term work could not be planned, the contractor would be forced to demobilize this equipment and put it to use elsewhere, further impacting the project.

Several additional items are highlighted below:

- Environmental considerations — Some of the closer disposal sites would not be accessible in a timely manner or at reasonable cost due to critical environmental habitat. Therefore, the project team worked closely with owner environmental staff and state regulators to actively address and resolve issues.
- Haul equipment — The construction planning had to consider when to make the switch from scrapers to the drill and blast excavation technique.
- Acceleration of other construction items — The Team assessed what construction activities that were planned to occur following the installation of the outlet pipe could be accelerated and completed now, lessening the schedule impacts of the additional left abutment excavation?
- Grouting — Original plans assumed a typical bottom of the valley to top of the valley grout curtain installation. The additional excavation would significantly extend the grouting schedule and effectively delay the start of grouting on the left abutment. The Team worked closely with DSOD to develop acceptable methods so that grouting could begin in the upper portion of the cut slope. Transverse grout curtains were planned at several locations to facilitate start of grouting from mid-slope.

During the development and resolution of this issue, other aspects of the construction continued. Managing change required mobilizing a dedicated team (separate from the day-to-day CM staff), to evaluate impacts, negotiate cost, and agree on the merit and quantum.

Spillway Foundation

As previously mentioned, the new overflow spillway is cut into the left abutment slope primarily consisting of Temblor Sandstone (refer to Figure 5). This geologic unit consists of two general zones: a weathered upper zone, generally brown in color, and an underlying gray zone that is slightly weathered to fresh. Pre-construction information generally indicated that the quality of the sandstone improves markedly below a depth of about 100 feet.

With the spillway foundation roughly 150 feet below existing grade, the design assumed a foundation consisting of gray, relatively un-weathered sandstone. As the work approached the spillway foundation elevation, additional unexpected conditions were unveiled. What had been termed "Area B – Geologic Feature" would entail a significant over-excavation to achieve suitable foundation conditions for the new spillway. With the location of the spillway fixed, limited options existed; the final design will essentially include re-building portions of the rock foundation with concrete. As of the writing of this paper, the SFPUC, working with the CM Team, designer and contractor, are diligently exploring alternate construction sequencing to minimize the impacts of this additional work.

Concluding Remarks and Lessons Learned

- Contingency and Risk: Identify risks early and fully understand each of their potential impacts.
- Take action early to deal with risk: Successful risk mitigation employed at Calaveras includes pre-qualification, early environmental mitigation, fair payment provisions, and partnering, among other things.
- Risk management is more than developing a risk register: it requires discrete planning and continuous effort from design through to construction.
- Change happens: focus on how to manage change rather than preventing it.
- Don't shoot the messenger: keep talking and be accepting of additional information — even when the news is less than optimistic.
- Experience pays: expertise of contractor and CM staff are key to effectively dealing with change.
- Pre-qualify: even within the bounds of a public contracting vehicle, you can achieve the desired end.
- Stay focused on the day-to-day: don't lose the core project amidst the changes. Mobilize additional resources to help with managing change.

Despite the challenges, Calaveras is an excellent example of what can be achieved during construction to manage change with a highly experienced and highly motivated team.

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