

# A COLLABORATIVE SUCCESS – CONSTRUCTION OF THE MORMON ISLAND AUXILIARY DAM KEY-BLOCK FOR SEISMIC REHABILITATION

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## Abstract

Seismic rehabilitation of Mormon Island Auxiliary Dam benefitted from the collaborative effort of the Bureau of Reclamation and the construction contractor team, consisting of Shimmick Construction (general contractor), Malcolm Drilling Company (drilling subcontractor), and Brierley Associates (contractor's engineer), that successfully built the challenging key-block project. Previous remedial work using in-situ soil improvement techniques proved insufficient to reduce the seismic risk to an acceptable level. In response, Reclamation designed a downstream key-block with overlay to reduce the potential risk of failure of the dam due to foundation liquefaction and subsequent deformation of the structure. The key-block consists of a mass of lean concrete founded on moderately weathered bedrock and overlain by structural backfill built at the toe of the dam. Factors considered in selecting the key-block concept included the site conditions, the overall Folsom Project dam safety modification schedule, environmental and community impacts, cost, and dam safety risks.

Reclamation awarded the construction contract through a best value proposal evaluation process (including technical and price factors). Performance requirements for the unique site conditions were developed to minimize dam safety risks during construction while maintaining full reservoir conditions and to allow visual documentation, data collection, and testing for the confirmation of the key strength parameters assumed for design. However, the means and methods for temporarily supporting the excavations required for the key-block construction were not explicitly specified; thereby allowing development of the most-cost effective approach to the project. The contractor faced difficult subsurface site conditions including a high groundwater table, coarse-grained soils with gravels and cobbles, and bedrock. These geotechnical conditions presented challenges for the design and construction of support systems for the up to 80-foot deep excavations required to construct the key-block. In the end, the project reaped the benefits of recent developments in drilling equipment, tooling and procedures which allowed the economical construction of an internally braced secant pile wall system in the difficult ground conditions. The contractor's structural wall system was integrated into a revised final seismic design of the key-block to maximize the use of these elements, to the benefit of the overall project.

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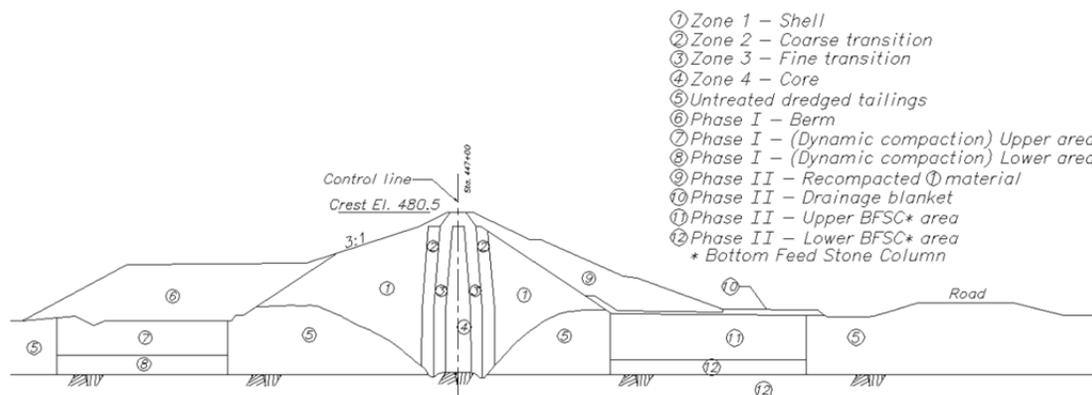
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## Background Information

Mormon Island Auxiliary Dam (MIAD) is one structure of the Folsom Project which is part of the Central Valley Project located near Folsom, California. The Folsom Project was designed and constructed by the U.S. Army Corps of Engineers between 1948 and 1956, which upon completion was transferred to Reclamation for operation and maintenance. MIAD was completed in 1953 and is located southeast of the Folsom Main Dam and is one of twelve structures that contain Folsom Lake.

MIAD is a zoned earthfill embankment dam consisting of a central core, two transition zones and an outer shell on the upstream and downstream sides of the core as shown in Figure 1. The crest length is 4,820 feet. The embankment has a maximum height above streambed of 105 feet and a maximum structural height of 175 feet. Foundation conditions vary along the length of the dam. The entire core and finer transition zones are founded directly on weathered amphibolite schist (bedrock). The second transition zones and shells of the dam are founded directly on bedrock on the right (west) side of the dam, while on the left (east) side these zones are founded on Quaternary alluvial deposits. There are two types of alluvial deposits present in the dam foundation. The younger deposit has less fines content and was dredged for its gold content multiple times. The dredged portion of this deposit is about 900 feet wide near the maximum section of the dam where an old river channel existed, and is a mixture of sand, gravel and silt with some cobbles and boulders.



**Figure 1.** Typical Cross Section of MIAD with Dredge Tailings and Upstream and Downstream Seismic Modifications Performed 1991 to 1994

During the late 1980's the Corps of Engineers determined that the dredge tailings were very loose and that "Extensive liquefaction and slope instability would be likely in (this) portion of the dam and foundation" and also that "Catastrophic loss of the reservoir could well result" (Hynes, et al 1990). As a result of this study, design and construction of remedial measures due to potentially large seismic deformations of the dam were completed. During remediation studies Folsom reservoir experienced an extremely low reservoir level due to lower than normal flows which allowed for densification of foundation soils under the upstream shell using dynamic-compaction over a 150-foot by 900-foot area (Phase I dynamic compaction area shown in Figure 1). A portion of the upstream shell was removed and recompacted, and a

new upstream berm was constructed. Following this work it was determined that the upper 40± feet of the upstream foundation had been densified significantly while a majority of the lower 25± feet had not been densified to the extent desired. Although it was recognized that additional densification may still be needed, to date none has been performed.

The downstream foundation was densified in 1993 and 1994 by constructing bottom-feed-stone-columns in a 9-foot triangular pattern over a 200-foot by 900-foot area (Phase II area shown in Figure 1). During construction the target densities were confirmed as part of the approval process. To allow for construction of the stone columns, a portion of the downstream shell was excavated. The downstream shell was reconstructed with an added downstream blanket filter zone beneath the shell.

### ***Dam Safety Risk Analyses***

MIAD has been assessed as having high seismic risks associated with foundation liquefaction leading to embankment failure, according to Reclamation dam safety guidelines (Bureau of Reclamation 2003). According to these guidelines, remedial actions are required to reduce the dam safety risk to the public.

## **Seismic Risk Reduction Studies – Modification Alternatives**

Studies were completed to determine the most effective means to reduce the high seismic risk. Scoping-level designs were evaluated, and a preferred option selected. The selected option was to construct a key-block of high strength material beneath the downstream toe of the dam by excavating potentially liquefiable foundation soils to bedrock and replacing them with stronger, non-liquefiable materials. Variations of key-block construction were studied to optimize the design. A downstream overlay is also to be constructed to add weight to the key-block to reduce embankment crest deformations. The design includes a wide downstream multi-staged filter zone that will act as a crack-stopper within the dam to control leakage through potential earthquake-induced cracks.

The selection of the general concept of an excavated foundation replaced with stronger materials to construct the key-block was a relatively simple process. This selection provided the most cost-effective method for construction. However, the determination of the most appropriate means to construct the key-block, given the project site conditions and dam safety risks, was a more difficult task. The preferred method was selected with consideration of the following project conditions: the Folsom Project dam safety modification schedule, site conditions, environmental and community impacts, cost, and dam safety risks.

### ***Project Conditions***

The Folsom Project dam safety modification program includes multiple construction projects which will reduce the high potential dam safety risks. Modifications started in 2006 and are anticipated to be finished by about 2017. The largest and most extensive of these projects is the auxiliary spillway which is being constructed into the left abutment of the Left Wing Dam adjacent to the main concrete dam. The spillway project spans the entire schedule and will include at least five construction contracts. There are at least seven other modification contracts completed or planned on other portions of the project including two for MIAD. Timing of construction to meet available budget and use of physical space and resources, such as rockfill stockpile materials, is critical to meet the project goals.

The foundation of MIAD in the area of the required modification consists of the younger Quaternary alluvial deposits that were repeatedly dredged for gold from the mid-1800s up until

right before the dam was constructed. These mostly sand and gravel deposits were left in an “unnatural state” with the finer, more silty, material (40 to 70 percent non-plastic fines) at the bottom of the deposit and more gravel/cobble material in upper zones of the deposit. Large cobbles and small boulders (up to 18 inches) were identified in many areas, which make drilling and other construction techniques more difficult. The optimal location of the key-block is within the area of previous bottom-feed stone column construction which left the upper zones more dense and the lowest zones loose. The bedrock at the site is fractured amphibolite schist with a variable weathering profile. The uppermost layer of highly weathered rock was planned for removal to ensure a good foundation for the key-block. The groundwater level at the site typically varies from 5 to 10 feet below the toe of the dam; however, during heavy rainstorms groundwater can rise to near the ground surface. If dewatering was required for construction, the upper zone could have potentially been dewatered, but the lower silty zones would likely have been more challenging to drain. Issues with dewatering bedrock would also have needed to have been addressed.

Environmental and community impacts were additional project constraints. An existing county road downstream of the dam limits the area available for construction. Downstream of the road the land is managed by the government but much of this area is designated as a protected wetlands. These factors made road realignment impractical because impacts to the road and wetlands would have required additional years of planning and supplemental studies, which would have increased project costs and delayed the schedule.

A detailed risk analysis was performed to determine the potential dam safety risks during construction. Several methods for construction of the key-block were considered; comparing different options with differing durations and levels of dam safety risk. It was found that potential slope instability during key-block construction could increase dam safety risks significantly. Dam safety risks during construction were balanced with costs and other factors to determine a preferred alternative.

### ***Selection of Key-block Construction Method***

Several “Excavate and Replace” methods were considered for construction of the key-block. Three main types of Excavate and Replace methods were considered, namely: 1) open-cut excavation, 2) in-situ treatment and 3) open-cut excavation with structural wall system.

Open excavation with dewatering was considered first due to the relatively low costs, and the simplicity of design, construction and contracting methods. However, relatively high dam safety risks during construction were estimated due to concerns with effectiveness of dewatering and the potential for slope instability. In addition, impacts to the downstream road and wetlands would be quite significant in terms of increased cost and schedule impacts. Based on this evaluation, in-situ methods were the next alternative considered.

In-situ methods considered for key-block construction accounted for the foundation materials at the site which include cobbles and small boulders. Bottom-feed stone columns were used previously as a densification method at the site with mixed results. Therefore, only in-situ mixed replacement methods were considered. Two in-situ methods were considered to be viable methods for this site, namely, soil-mixing and jet grouting. Due to the subsurface materials and design requirements to construct a good contact with the bedrock, jet grouting was determined to be the more suitable of the two. A jet grouted test section, consisting of nine rows and/or clusters of columns with varied injection parameters and column center-to-center distances, was constructed in 2007. Coring was used to determine in-place treatment quality and potential final design strength parameters. The test section included both double

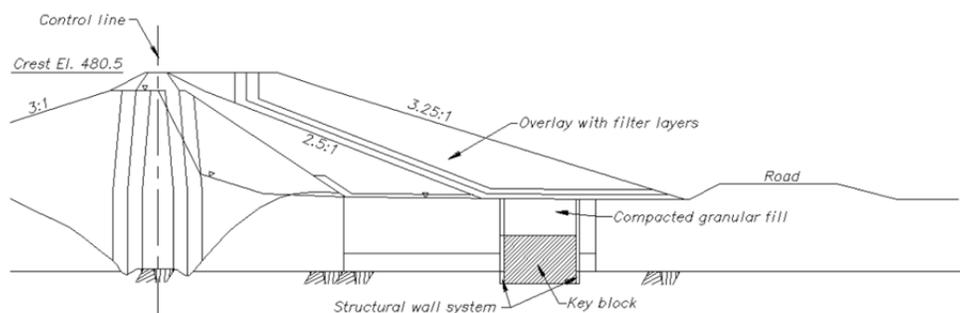
and triple jet injection methods. The results of the test section showed that the spacing of columns would have to be closer than assumed for feasibility level designs. Also, areas of unmixed zones especially near the bedrock contact caused significant concern regarding the effectiveness of the design (i.e., risk reduction could be questioned) and would require a larger treatment area. As a result of the test section, the estimated costs and schedule duration for the project increased significantly. This option was abandoned as a result of the test section performance. The design team was compelled to consider other options.

Alternative designs which utilized excavate and replace methods, other than an open sloped excavation with dewatering, were considered. The most promising design alternatives included the use of a structural wall system to facilitate the excavation of the key-block (see Figure 2). Many different wall options and excavation arrangements were considered. Options with partial excavations of varying depths and different arrangements of cell size and numbers of cells constructed at one time were considered. Each of these combinations had varying risks during construction due to length of cell opening and duration of open excavations [Harris and Scott, 2009].

Several different materials were considered for construction of the key-block, which required a small amount of bond with the bedrock to minimize the width of the key-block. To achieve the bond, the key-block required a material with a cementitious component as required for the design, therefore, both cement modified soil and a lean concrete were considered.

## Seismic Risk Reduction – Final Design

The final design selected by the management team for MIAD seismic risk reduction consists of a downstream foundation key-block constructed on bedrock with an overlay buttress for weight. The overlay buttress includes a filter system which protects the dam from internal erosion caused by seepage flow through large cracks that may develop following a major earthquake. The design allows for the upstream portion of the dam to deform significantly as a result of an earthquake and still maintain the integrity of the new downstream portion of the dam long enough to avoid breach. Following a large earthquake, Folsom Lake would be lowered to inspect the project structures and evaluate damage. The dam requires an added downstream filter to reduce static internal erosion piping risks and the wide seismic filter system satisfies this design requirement. The selected key-block construction method uses the Excavate and Replace method with a structural wall system to minimize dam safety risks during construction. Figure 2 shows a cross-section of the design including the location of the key-block and overlay features.



**Figure 2.** Key-Block Construction Using Structural Wall System

The selected final design of the key-block is 55 feet wide and 900 feet long. The key-block is constructed of low strength concrete with a high slump, which allows the material to be pumped into place and onsite aggregates to be used, thus minimizing costs. The preferred alternative specified that the key-block be constructed with no more two cells open at a time, with no one cell longer than 150 feet, and a minimum clear spacing between open cells of 300 feet. This arrangement minimizes dam safety risk during construction. Other advantages for this design include: minimal road and wetland impacts, less expensive than in-situ methods, structural wall system allows for placement of the key-block in a more efficient location – reducing the width of the key-block, no long term operation costs, risks during construction are no greater than existing conditions (no increased dam safety risks to the public), less uncertainty of construction effectiveness due to visual documentation of rock/key-block construction. Further details of the preferred design and construction can be found in “Seismic Remediation Design and Construction of Key-Block – Mormon Island Auxiliary Dam,” USSD 33rd Conference [Harris and Romansky, 2013].

## **Procurement Methodology**

### ***Owners’ Perspective***

Whenever underground construction is to be performed, special care is given to collect subsurface data for use in conducting engineering designs. These data include subsurface material properties for soil and bedrock. It is the owners concern that adequate data is collected for design, and that the data is provided to the contractor so they can account for the project specific geotechnical conditions, thereby minimizing delays and maximizing the efficiency of the contractor’s operations. As owner, Reclamation, desired to minimize these construction risks, as for any project, but also recognized that any delay during the excavation and backfilling process would increase the risk to the public as well. Decision-making was centered not only on potential construction delays and cost increases, but also increased risk to the public.

When Reclamation began the final design process it identified that the type of construction using temporary deep structural wall systems was one that was not performed commonly within its design group. Also, it was recognized that even if Reclamation was to perform a final design for excavation support, or contracted to have it designed, it was very likely that each contractor submitting a proposal would likely have a somewhat different method for performing the work. The reason for this is that the contractor is a team with three key parts that influence the work, namely: (1) general contractor, (2) wall constructor, and (3) the contractor’s design engineer. Even if the general contractor and the wall constructor are essentially the same company, a discussion would be conducted regarding the means and methods that are most-suitable and cost-effective for the project. Reclamation realized that even if it provided detailed drawings and a step-by-step construction sequence, the contractor would likely propose modifications to the design based on his equipment, methods, and experience. Also, Reclamation would spend a significant amount of effort in design knowing that a revised design was likely to be submitted later that could be performed in a much more efficient and cost-effective manner. Therefore, after completing a final design used for cost estimating purposes, Reclamation turned its efforts to including general design requirements and submittal processes that would ensure adequate safety and oversight as specified in the construction bid documents.

### ***Key-Block Construction Bid Document Details***

The key-block design requirements were included in bid documents for solicitation to contractors. Contractors were required to design their own structural wall shoring system. This allowed each contractor to use its own proprietary design procedures and construction methods, while meeting stability and constructability issues for the given site conditions. In this way the wall system was as cost-effective as possible while maintaining adequate design to minimize risk to the dam during construction. Also, criteria to control water pressures below the base of the excavated bedrock surface were included as part of the contract during mapping, key-block concrete placement and initial curing to ensure that a good bond was created at the bedrock/concrete interface. The type of structural wall system to be used for this work was left up to the contractor, as long as it met the criteria provided in the specifications.

Due to the complexity of the foundation materials, Reclamation specified that a test section be constructed to confirm the performance of the contractor's construction means and methods. If the contractor's methods proved satisfactory, they would be given notice to proceed with construction of the remaining portions of the key-block. The contract required that the depth of the wall system be adjusted based on the depth and quality of bedrock encountered during the wall installation phase of the work. As part of the construction process for each cell, a period of two days of mapping of the bedrock for foundation documentation was provided once the upper, more-weathered portion of the bedrock was removed, cleaned, and prepared for concrete placement. The construction documents provided a maximum depth for bedrock removal and gave a refusal criteria, when if met, further bedrock removal would not be required.

Reclamation awarded the construction contract through a best value proposal evaluation process (including technical and price factors). The contract was separated into two schedules. Schedule I included the test section which was a 55-foot square portion of the key-block. The test section provided for additional data to be gathered on the bedrock and a means for confirming the key-block design strength values. Upon successful completion of the test section, Schedule II was to be awarded based on evaluation factors listed within the bid documents.

### ***Contractors' Perspective***

The design of the excavation support system, including the development of the detailed design loading, was the responsibility of the contractor's engineer. Reclamation's RFP provided performance requirements for the system and a vast amount of geotechnical data to define the anticipated soil conditions and depth to top of rock in the vicinity of the key-block. This contracting approach allowed the contractor-team to select construction means and methods and a design approach that they believed would be most cost-effective.

As noted above, the structural wall system had to be installed through saturated, cohesionless soils with cobbles and boulders and had to penetrate into hard rock. Additionally, the shored excavation had to be relatively dry so that the bedrock at key block subgrade could be cleaned and inspected prior to the placement of the lean concrete. Further, the support system had to accommodate the removal of up to 8 feet of bedrock from the bottom of the excavation. Although potentially less expensive, neither sheet piles nor deep soil mixing were deemed to be compatible with the site conditions. The two diaphragm wall options that were evaluated in more depth for the challenging soil and rock conditions were secant piles and slurry walls. During the bid process, the contractor team concluded that, with the use of appropriate drilling equipment and construction means and methods, the installation tolerances

required for this project could be achieved using secant piles, and that this wall type would be the most cost-effective solution for this project.

Secant pile walls are formed by constructing a series of overlapping “primary” and “secondary” concrete-filled drill holes. The primary piles are constructed first, followed by secondary piles, which are cut into the previously placed primary pile concrete. For this project wide flange steel reinforcing members were installed in the secondary piles to give the wall its principal structural strength. For deep excavations, layout control and drilling tolerance for secant piles become increasingly critical. Increased pile diameter and improved verticality control can both increase the viable depth of a secant pile excavation support system. Pile diameters of 3 to 4 feet are typically employed for 50 to 100-foot deep excavations. Due to increased unit costs associated with large diameter piles, the construction methods selected for this project were aimed to optimize verticality in order to minimize pile quantity and the corresponding overall project costs. For this project, for which the excavation depth was anticipated to be up to 80 feet, 1m (3.28-foot) diameter secant piles were selected by the contractor-team.

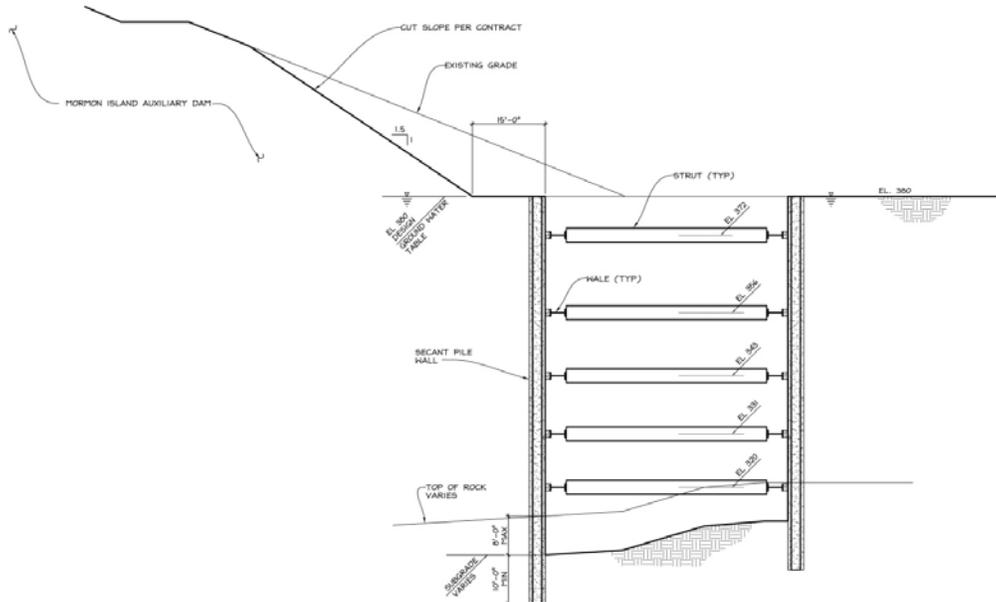
Bauer BG40 top drive rotary crawler drills (Figure 3) were utilized to advance the drill tools concurrent with the 1m diameter casing while maintaining strict verticality tolerances. The depth of excavation and geotechnical conditions called for the use of sectional heavy wall drill casing, advanced concurrently with the drill tool, which performed the dual function of maintaining boring stability in the saturated cohesionless soils and also stiffened the drill string in order to limit deviation at depth. Kelly drilling methods allowed a range of soil and rock tooling to be employed within the casings such that different tools could be utilized to accommodate variations in ground type as the drill hole was advanced.



**Figure 3.** Top Drive Rotary Crawler Drill

Until recently, there was no ready means of evaluating the verticality of an open drill hole; however, downhole survey techniques that permit measurement of both the diameter and plumbness of a drill hole are now available. For this project, the Sonicaliper® sonar device was employed periodically to provide a 360 degree profile of drill holes at multiple depths. The downhole surveys provided confirmation that critical drilling tolerances were being met.

The secant pile walls were restrained with internal bracing as excavation proceeded. Because the key-block was required to be constructed in a total of 7 cells (the test cell, plus 6 Schedule II cells), a modular bracing system was designed with bolted connections for ease of installation, removal, and re-use. As shown in Figure 4, five levels of bracing were typically employed at each cell.



**Figure 4.** Section Showing Full Depth Shored Excavation

### **Benefits of a Test Section**

A test section was selected as the initial portion of this contract. For this project the test section was included as a portion of the overall key-block. The decision to include the test section as part of the final key-block was based on the assumption that the contractor would be able to complete the test section successfully.

#### ***Dewatering Design Evaluation***

Construction of the secant pile walls, bracing installation, and excavation were performed satisfactorily at the test section. The bedrock was excavated and cleaned; however, water was seeping from the rock into the excavation. The contractor employed a vacuum pump system connected to numerous shallow sealed well points across the floor of the excavation. Even with the large number of well points there was still some seepage emanating from the rock so small rock-filled fabric “burrito drains” were employed to direct the flow to a sump location so that a good seal could be achieved at the bedrock contact during concrete placement.

While the test section was being backfilled several dewatering options were discussed. The contractor at first proposed using the same dewatering system used for the test section for the remainder of the key-block. Reclamation had concerns with this approach due to the potential that higher under-seepage pressures and flows could be encountered in the other cells, although Reclamation believed that the vacuum system could be appropriate in localized areas as a backup method for seepage control. The contractor proposed other methods for controlling seepage, but Reclamation was not convinced that these alternatives provided a

positive control of the groundwater that was flexible enough to target areas of potentially large flows.

Reclamation decided that it wanted a deep well system installed into the rock and provided a modification to the contract for its installation. The cost for the system was higher than the initial cost of those other methods proposed but had limited risk of not working properly, had the ability to be augmented with additional pumps, and limited any downtime for the contractor.

### ***Refinement of Key-block Design***

During the test section the key-block design team integrated the structural wall system elements into the numerical modeling tools used previously for final design. New studies were completed to check performance during the critical design earthquakes. These studies showed that the wall system constructed into bedrock added significant strength to the key-block. A revised final design report was produced to document that the key-block as-constructed with the to-be-constructed overlay would limit deformation to the dam as a result of the critical earthquake.

### ***Equipment and Construction Method Verification***

The test section also permitted the contractor to evaluate and refine its construction means and methods under actual field conditions. Secant pile drilling methods were verified for efficient advance through the overburden soils, and the secant pile concrete placement and casing extraction processes were refined. Additionally, the drilling methods utilized at the test section proved capable of advance through the bedrock; however, the bedrock across the site was found to be more variable in weathering compared to the test section. Aggregate for lean concrete production and granular backfill was adjusted for materials onsite, and the crushing and screening operation was conducted at a larger scale to meet the demands of the project.

## **Summary of Construction of Final Portions of the Key-Block**

### ***Remaining Portion of the Key-Block Construction Summary***

Once the test section was completed, the contract provided for a period of time to evaluate the test section and to give notice-to-proceed for Schedule II, for the remaining portions of the key-block construction. Notice-to-proceed was given in July 2011 for Schedule II. As noted above, during the evaluation period, a more robust dewatering system was devised by Reclamation with input from the contractor. This upgrade in dewatering included a steel pipe casing "blockout" that was attached to and installed with each wide flange secant pile reinforcing beam. Once secant pile drilling at a cell was completed the casings were opened and holes were drilled 20 feet into rock below the secant pile tip. The holes were flushed and tested for water flow. Pumps were then installed in a select number of holes to create a system of deep wells within the bedrock. The pumps were connected to a manifold system and flows were carried away from the excavation and treated. The holes in which pumps were not installed were used as observation wells. The flow from each well was recorded at regular intervals. During the excavation pumps could easily be added to augment the dewatering system. This flexibility to add pumps was used several times in areas of the excavation where additional drawdown was needed to control underseepage. This system was effective and allowed construction to proceed quickly. As one cell was completed, the dewatering system was moved to the next cell to be constructed.

Construction, in general, followed the methods used for the test section and progressed in a timely manner. Secant pile wall system installation was the key critical path item at the outset of Schedule II; drilling lasted from August 2011 through May 2012. Over 1,000 secant piles were constructed for this project. Excavation of the first two cells for the Schedule II work (after the test section) started in December 2011 and the last two cells were completed in December 2012. Data collected during construction verified the critical design assumptions.



**Figure 5.** Photo of Internally-Braced Secant Pile Wall System Used for Key-Block Cell Construction with Dewatering Wells and Manifold System



**Figure 6.** Photo of the Excavated and Cleaned Amphibolite Schist Bedrock Surface Being Mapped



**Figure 7.** Aerial Photograph Showing Construction Underway at Two Key-Block Cells



**Figure 8.** Key-Block Concrete Placement

## Conclusion

Mormon Island Auxiliary Dam (MIAD) was assessed as having high seismic risks according to Reclamation dam safety guidelines. A key-block with embankment overlay downstream of the dam was selected as the preferred method to minimize the risk of dam instability due to potential foundation liquefaction. The selected method of key-block construction was an internally-braced secant pile wall support system for excavation stability and groundwater control. The method of excavation support was not specifically prescribed in the bid documents, but rather guidelines were provided and the contractor proposed the most cost-effective solution for site conditions. The key-block excavation was divided into cells, as required in specifications, which reduced dam safety risks during construction while maintaining full reservoir conditions.

Reclamation awarded the construction contract through a best value proposal evaluation process (including technical and price factors). Performance requirements for the unique site conditions were developed to minimize dam safety risks during construction and to allow visual documentation, data collection, and testing for the confirmation of the key assumed design strength parameters. The contractor faced difficult subsurface site conditions including a high groundwater table, coarse-grained soils with gravels and cobbles, and bedrock. These geotechnical conditions presented challenges for the design and construction of support systems required for the excavations extending to a depth of up to 80 feet. An initial test section was performed, which allowed for the confirmation the proposed construction means and methods, an adjustment to groundwater control methods, and fine-tuning of construction methods to maximize productivity.

Seismic rehabilitation of Mormon Island Auxiliary Dam benefitted from the collaborative effort of the Bureau of Reclamation and the construction contractor team that successfully built the challenging key-block project. In the end, the project reaped the benefits of recent developments in drilling equipment, tooling and procedures which allowed the economical construction of an internally-braced secant pile wall system in the difficult ground conditions. The contractor's structural wall system was integrated into a revised final seismic design of the key-block to maximize the use of these elements, to the benefit of the project. The project team overcame the difficult site conditions, while minimizing environmental and community impacts, cost, and not increasing dam safety risks.

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