Red Rock Hydroelectric Project – New hydro development at an existing flood control dam

Projet hydroélectrique Red Rock – Nouveau développement hydroélectrique à un barrage anti-crue existant

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Abstract. The Red Rock Hydroelectric Project converted the existing Red Rock Dam near Pella, Iowa, from a non-powered dam into a multi-purpose dam. The existing flood control dam was constructed by the U.S. Army Corps of Engineers (USACE) in the 1960s on the Des Moines River near Pella, Iowa. The hydroelectric project was developed by Western Minnesota Municipal Power Agency and generates up to 55 MW with an average annual energy output of 178 gigawatt-hours. The new intake, penstock and powerhouse are located immediately adjacent to the spillway. Construction required large excavations into the upstream and downstream sides of the existing embankment dam and two penetrations through the existing gravity dam monoliths. Extensive water and earth-retention systems, prescriptive construction staging, and a robust dam safety surveillance program were designed to maintain and monitor the integrity of the existing dam throughout construction and avoid impacts to active USACE flood control operations. Construction was completed in 2020. This paper provides an overview of the unique challenges involved with the design and construction of a new hydroelectric project at an existing and active flood control dam.

Résumé. Le projet hydroélectrique Red Rock a converti le barrage Red Rock existant près de Pella, Iowa, d'un barrage non motorisé en un barrage polyvalent. Le barrage anti-inondation existant a été construit par le Corps des Ingénieurs de l'armée américaine (USACE) dans les années 1960 sur la rivière Des Moines près de Pella, Iowa. Le projet hydroélectrique a été développé par la Western Minnesota Municipal Power Agency et produit jusqu'à 55 MW avec une production d'énergie annuelle moyenne de 178 gigawattheures. La nouvelle prise d'eau, la conduite forcée et la centrale

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électrique sont situées immédiatement à côté du déversoir. La construction a nécessité de grandes excavations dans les côtés amont et aval du barrage en remblai existant et deux pénétrations à travers les monolithes du barrage gravitaire existant. Des systèmes extensifs de rétention d'eau et de terre, des étapes de construction normatives et un programme robuste de surveillance de la sécurité des barrages ont été conçus pour maintenir et surveiller l'intégrité du barrage existant tout au long de la construction et éviter les impacts sur les opérations actives de lutte contre les inondations de l'USACE. La construction a été achevée en 2020. Cet article donne un aperçu des défis uniques liés à la conception et à la construction d'un nouveau projet hydroélectrique sur un barrage anti-crue existant et actif.

1 Introduction

Construction of the Red Rock Hydroelectric Project (Project) is completed at the existing US Army Corps of Engineers (USACE) Red Rock Dam on the Des Moines River near Pella, Iowa, USA. The USACE constructed Red Rock Dam between 1960 and 1969 to impound Lake Red Rock for flood control purposes; recreation and fish and wildlife purposes were later added. As originally constructed, the Red Rock Dam did not include provisions for hydroelectric generation.

Lake Red Rock is Iowa's largest lake with more than 15,000 acres of water and 35,000 acres of land for visitors to enjoy. Located on the Des Moines River just 45 miles southeast, and downriver, of the city of Des Moines, Iowa, the reservoir collects runoff and drainage from a 12,320 square-mile area in Iowa and southern Minnesota. The dam, reservoir and adjacent land are federally owned and operated by the Rock Island District of the USACE.

The Red Rock Hydroelectric Project is being constructed immediately adjacent to the dam’s existing spillway. The purpose of the Project is to provide a new source of hydroelectric power, making electrical power from a renewable source available to the regional electric grid. The current Federal Energy Regulatory Commission (FERC) license authorizes power generation at Red Rock Dam through 2062. At peak generation, the Project will generate up to 55 MW with an average annual energy output of 178 gigawatt-hours.

The existing Red Rock Dam is an earthfill dam with a chimney filter and blanket drain. There is a central concrete control structure consisting of 13 gravity monoliths which house 14 sluice gates and five radial crest gates. The Dam is 6,260-feet-long and 110feet-high with a crest elevation of approximately El. 797 (all elevations are in feet). A two-lane road (Marion County Highway T15) traverses the length of the dam along the crest. An aerial photo of the dam prior to construction is shown in Fig. 1.

Fig. 1. Aerial photo of Red Rock Dam prior to Hydroelectric Project Construction (photo provided by USACE).

The reservoir is typically maintained at or above El. 742 for recreation purposes, except during the autumn and winter months when it is maintained at or above El. 744. The flood control pool for Lake Red Rock is El. 780; the maximum reservoir is El. 791.2. The water level in the tailrace is typically around El. 690 but fluctuates above a minimum release elevation of El. 684.2 based on spillway releases. The minimum environmental release of 300 cfs is made through the bottom sluices at the spillway. During permanent operation, the project will operate as run of release (i.e., all normal releases will pass through the powerhouse) but flows will be determined by the USACE.

Geologic units at the Project include the Warsaw Limestone and the St. Louis Limestone of Mississippian age. The oldest unit exposed is the Warsaw Limestone, which consists of dolomitic and argillaceous shales. At the site, the Warsaw is present below El. 638. It is overlain by the St. Louis Limestone, which is the upper bedrock unit at the site. The St. Louis Limestone consists of alternating beds of limestone, sandstone, dolomite, and discontinuous basal evaporite beds. It is exposed as the top of rock at the Project site, extending from approximately El. 674 to El. 638. Bedrock is horizontally bedded and gently dipping from upstream to downstream.

The Project was developed by Missouri River Energy Services (MRES) as agent for the FERC licensee, Western Minnesota Municipal Power Agency (WMMPA). WMMPA acquired the FERC license from a developer who had applied for and obtained the license to install hydropower at this non-powered dam site through a process that included feasibility-level drawings of the final arrangement, generation estimates, and a budgetary cost estimate. WMMPA/MRES developed the Project from final design through construction and owns and operates the Project.

The Project was constructed immediately to the left (looking downstream) of the existing spillway, largely within the steeply sloping sand fills upstream and downstream of the concrete gravity monoliths. A reinforced concrete intake structure founded on drilled shafts and two 21-foot-internal diameter penstocks convey the maximum licensed flow of 10,235 cfs from the intake to the powerhouse. The penstocks penetrate the existing dam's concrete gravity section and are steel-lined downstream of the concrete monoliths. A 69-foot-high cantilevered retaining wall retains the existing embankment dam along the new intake approach channel. It was constructed using 130-foot-tall T-shaped concrete diaphragm wall elements socketed 30 feet into rock. A second diaphragm wall along the axis of the embankment dam formed a seepage cutoff for construction and permanent conditions. The powerhouse houses two vertical Kaplan turbine-generator units. The Project also includes a tailrace channel bridge, multiple retaining walls, access roads, a 69-kV substation and transmission line, and public recreational access along the tailrace.

As illustrated in Fig. 2 and Fig. 3, significant modifications to the dam were required to construct the Project.

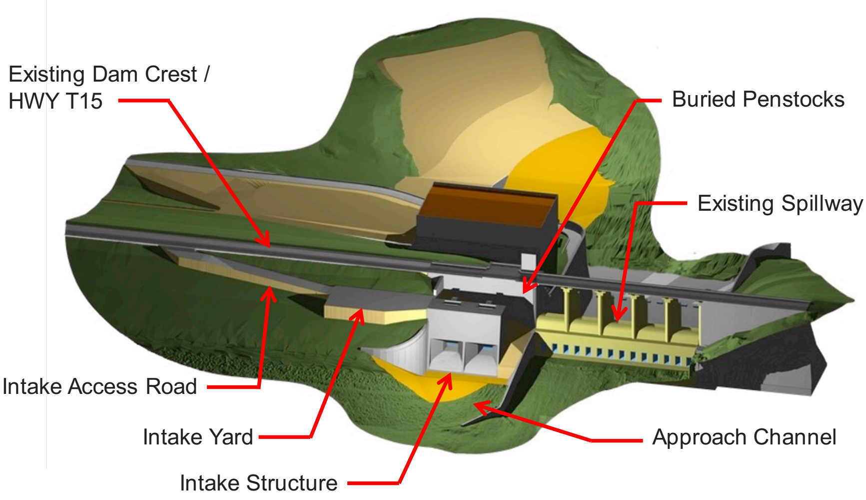

Fig. 2. Upstream features of the Red Rock Hydroelectric Project.

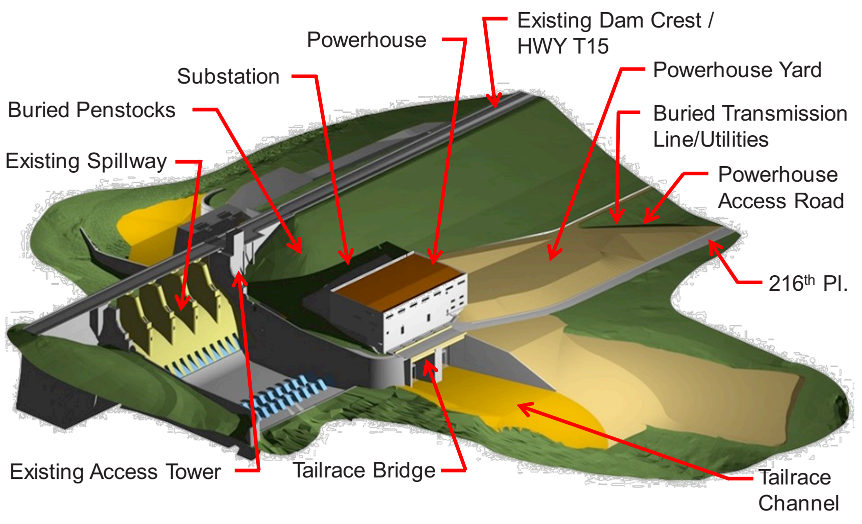

Fig. 3. Downstream features of the Red Rock Hydroelectric Project.

The construction of the permanent works required upstream and downstream cofferdams and several excavations up to 70-foot-deep into the existing dam and its foundation, plus penetrations through the existing concrete gravity monolith. The intrusive nature of this work heightened the need to establish construction and monitoring requirements to reduce potential impacts to the dam's integrity and maintain dam safety throughout construction.

2 Design and construction constraints

Because of the importance of Lake Red Rock for flood control operations and local recreation, as well as environmental conditions in the FERC licence, certain constraints were placed on the final design criteria and allowable construction methods, including:

- The Project could have no detrimental impact to dam safety during construction or permanent operation.
- Any changes from the project layout shown in the feasibility-level license drawings needed to be relatively minor to avoid a major license modification which would have required significant time and effort to implement.
- The spillway could not be obstructed during construction.
- The arrangement of the permanent works could not impact hydraulic performance of the dam's spillway.
- A minimum continuous release of 300 cubic feet per second (cfs) needed to be maintained in the event of a unit trip, which would interrupt operation and discharge through the turbine-generator unit.
- Dissolved oxygen levels in the tailrace had to be maintained.
- The USACE retains full control of reservoir operations and releases.
- Recreation mitigation was required to comply with the FERC license.

As the project engineer, Stantec (formerly MWH) prepared designs for all the temporary works and construction sequence drawings were developed to prescribe the staged construction of the Project. The sequence defined by those drawings became part of the design criteria for the final design of the temporary and permanent structures as they outlined the loading conditions during each phase of construction. Additionally, Stantec designed and implemented a rigorous surveillance inspection and instrumentation monitoring program to evaluate the performance of the dam as well as the temporary and permanent works during and after construction.

3 Addressing the challenges

3.1 Intake structure and approach channel

The design and construction of the upstream works were identified as the single greatest area of construction risk to the project. Of particular concern were the cofferdam scheme, large temporary and permanent excavation into the existing embankment dam, the permanent connections to the existing dam, the position of the intake relative to the penstock penetrations, and the operational impacts of spillway operations. The entirety of the upstream works were constructed within or on the sloping faces of the upstream side of the existing dam, both above and below reservoir level. Prior to the start of construction, there were no flat or gently sloping areas available from which heavy equipment could operate, nor vehicular access to the area of the future intake structure.

The FERC License located the intake structure immediately to the left of the spillway and directly against the upstream face of the concrete gravity monoliths. The location of the intake structure introduced challenges. Its close proximity to the spillway and left spillway approach wall limited the size of the cofferdam since spillway operations could not be affected during construction. Its position against the upstream face of the dam introduced challenges for penetrating the concrete gravity monoliths during penstock construction. Ultimately, the intake structure was shifted slightly upstream to help facilitate the penetration through the gravity monoliths, to locate the water passage geometry transitions for the intake and penstock entirely upstream of the concrete monoliths. This also reduced the lateral pressure acting on the new intake structure from the existing embankment.

Following heavy storm events, significant debris tends to accumulate upstream of the spillway. The concern was that this debris would also extend in front of the adjacent intake structure and limit flows into the powerhouse or require additional maintenance to maintain optimal flow conditions. Rotating the intake structure so that it would slant toward the spillway was considered to minimize the amount of accumulated debris, as it would tend to naturally sluice toward the spillway. However, computational fluid dynamics modelling showed that while there would be some reduced debris accumulation, it would not be beneficial enough to merit the increased complications associated with cofferdam and penstock construction for a rotated alignment of the intake structure.

The design of the intake structure was sized to accommodate the minimum size of the intake opening at the trash rack, which were determined based on the conditions defined in the FERC license to minimize fish entrainment that required the approach velocity immediately upstream of the trash rack be 1.9 feet per second (fps) at a rated discharge of 8,900 cfs, and 2.2 fps at the maximum discharge of 10,235 cfs with a trash rack bar spacing of 3.75-inch.

A heavily reinforced cantilevered concrete diaphragm wall, with a T-shaped cross-section, was designed to retain the upstream slope of the dam's embankment along the left side of the approach channel and intake structure. During preliminary design of the Project, a number of options were evaluated to form the left side of the intake approach channel. Excavation to lay back the upstream slope of the dam would have undermined the crest of the dam; steel sheeting was determined to be infeasible for the required excavation depths; a tied-back system was considered but ultimately discarded due to the disturbance anchors would cause to the clay embankment and for long-term maintenance issues. The diaphragm wall was designed to control deformations and minimize the potential for cracking of the embankment. Following intake approach channel excavation upstream of the new intake structure, the upstream diaphragm wall has an exposed face up to 69-feet-high.

The height of the upstream cofferdam to construct the intake needed to be designed to account for reservoir level fluctuations levels and construction considerations associated with the existing 2H:1V slopes adjacent to the spillway. Since Lake Red Rock fluctuates from a normal pool elevation of El. 742 to a flood control elevation of El. 780, shorter cofferdams would have resulted in more frequent construction stoppages during raised lake levels. Taller cofferdams could have allowed construction of the intake year-round regardless of lake level but would have required a large structure to be built on the 2H:1V slopes without obstructing the immediately adjacent spillway, which would have been prohibitively expensive. A statistical analysis of the daily lake elevations since the initial reservoir impoundment in the 1960s determined that a cofferdam elevation at El. 750 (8 feet above normal reservoir levels) would reasonably minimize the frequency and duration of flooding to allow sufficient time to construct the upstream works.

Once the location of the intake structure and height of the cofferdam were defined, the cofferdam scheme could be finalized. The perimeter of the cofferdam was formed by the approach wall on one side and a reinforced concrete secant pile wall on the remaining three sides. The approach wall and secant pile walls were internally braced using large-size structural steel shapes. The layout of the internal bracing was designed to provide as much open working space as possible. A lightweight concrete platform along with some excavation in front of the diaphragm wall were used to provide a work platform at El. 750 and minimized imposing additional loads on the existing spillway training wall. Fig. 4 presents an aerial photograph of the completed intake cofferdam with internal bracing.

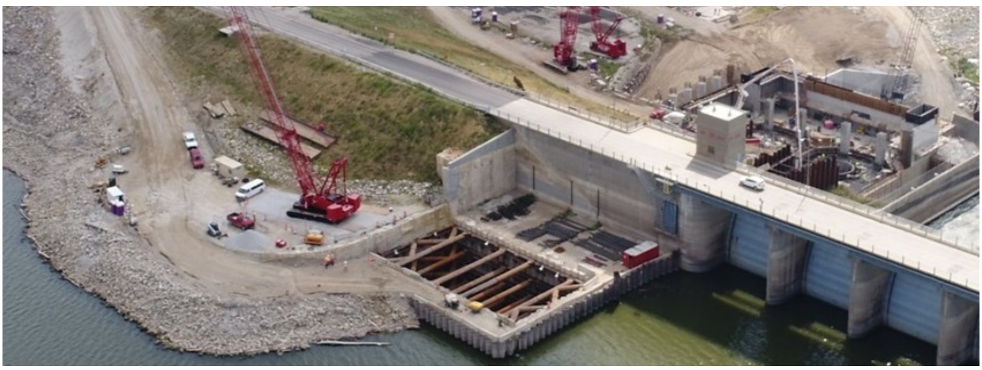

Fig. 4. Completed upstream cofferdam with intake support of excavation installed (photo provided by MRES).

The FERC license requires that the project maintain a dissolved oxygen (DO) concentration of no less than 5.0 milligrams per liter. To help maintain the DO concentration, a submerged weir of soil protected by riprap was left along the upstream side of the intake channel so that the intake draws water from above El. 717.50, where higher concentrations of DO have historically been measured.

3.2 Powerhouse and tailrace

The powerhouse is located at the toe of the downstream embankment, immediately next to the existing stilling basin wall. This kept the project within the footprint of the FERC license and avoided significant license modifications. The detailed design set out to optimize the unit capacity and it was determined that two (2) units of the same capacity could be used instead of three (3) units of varying capacities. The unit capacities were selected to capture the additional available flows from April through July due to higher reservoir elevations (flood season), which also coincide with peak power demands. Otherwise, the excess flows would pass through the dam spillway outlets without capturing their energy potential. The use of two (2) units enabled a relatively small powerhouse footprint to be maintained. It also eliminated the requirements for additional spare parts and maintenance concerns associated with different sized units.

The draft tube deck on the downstream side of the powerhouse was elevated to match the elevation of and connect with the existing access road to the USACE access tower. This bridge also allows the USACE to access their access tower adjacent to the spillway.

Downstream construction features are shown in Fig. 5.

Fig. 5. Aerial photograph of the downstream penstock, powerhouse, and tailrace features (photo provided by MRES).

The FERC license requires a minimum river flow of 300 cfs to maintain downstream water quality at all times. A 48-inch diameter bypass pipeline connecting to each penstock upstream at the spiral case entrance, running through the powerhouse and discharging across the tailrace from beneath the tailrace bridge address this requirement in the event of a unit trip. The bypass pipeline discharge was fitted with aeration nozzles so that the bypass could also be used as a means to increase the DO in the tailrace, if and as needed, to meet the license requirements for DO.

The original FERC license drawings did not include a substation within the project boundary. Later when the transmission line interconnection location was changed, a 69 kV substation was added on the upstream side of the powerhouse to minimize the electrical losses that longer low-voltage connections would introduce and to avoid displacing recreation areas downstream of the dam.

3.3 Penstocks and dam penetration

Adjacent to the gravity dam, both downstream penstock excavations were designed to remain open simultaneously to perform the penetrations through the dam's gravity section and finally connect the upstream works with the downstream works. Prior to the dam penetration occurring, the upstream features were required to be watertight to prevent the potential for a possible uncontrolled release through the penetration prior to completion of the penstocks. This meant that the intake needed to be complete, with gates tested and closed, and the upstream portion of the penstock needed to be complete and tied into the intake and concrete gravity dam. The dam penetrations were performed from the downstream side by removing concrete using wire saw cutting methods to avoid damaging the dam's concrete monoliths.

The downstream penstocks and their excavation support systems (internally braced combi-walls) were designed for the 2H:1V cross-slope (toward the stilling basin) acting across the penstocks. This cross-slope also drove the need to perform the penstock excavations in series instead of in parallel, as having both penstock excavations open simultaneously was assessed to result in unacceptable deformations to the existing embankment.

3.4 Dam safety monitoring

A Temporary Construction Surveillance and Monitoring Program (TCSMP) was developed considering the anticipated construction sequence of the Project for the existing, temporary, and permanent structures. A Potential Failure Mode Analysis (PFMA) conducted with representatives from the USACE, FERC, and the Project's Independent External Peer Review (IEPR) panel identified several potential failure modes (PFMs) for the conditions during construction. The PFMs considered to have the greatest significance were related to potential deformations associated with the large excavations inducing cracking in the embankment, which would shorten the seepage path, increase exit gradients and possibly increase the potential for internal erosion. To address the PFMs, the temporary and permanent earth retention systems were designed to minimize deformations, the diaphragm wall along the axis of the embankment dam was designed to address seepage concerns associated with potential construction-induced cracking of the embankment, and a robust surveillance and monitoring program was developed. A key part of the monitoring program for the TCSMP were the groupings of different instrumentation types and assessing the associated threshold values and action levels for each area of the Project.

A total of 125 individual instruments (including 16 existing) were used to monitor existing dam features and temporary construction works. All existing USACE instrumentation within the project boundary was incorporated into the instrumentation program, including survey points on the stilling basin wall and the embankment crest. An additional 109 temporary individual instruments were specified in the program. This included piezometers, inclinometers, survey points, push-in pressure cells, flow meters, strand load sensors and Rossum sand testers. The instrumentation worked together to provide a means to monitor the Project throughout construction. In addition to survey points placed on Project features to monitor potential movement, clusters of instrument types were developed around key project components to more effectively monitor the performance of the systems. The instrumentation was coupled with routine inspections to visually observe conditions and correlate any instrumentation results.

The primary PFMs that required monitoring were related to construction and performance of the upstream diaphragm wall because excessive deformations of the upstream diaphragm wall could lead to embankment cracking and a seepage path opening upstream to downstream or progressive slope failure. Therefore, the most heavily monitored portion of the upstream project works is the upstream diaphragm wall, which contains multiple piezometers, inclinometers and survey points, as shown in Fig. 6. The construction sequencing of the upstream exposed different portions of the diaphragm wall at different phases of construction. Deformations of the wall were estimated using Plaxis and ABAQUS finite element models. The assessed deformation values helped to determine the critical monitoring values for inclinometers and survey points, while the locations were designated based on the critical analysis sections (i.e., an inclinometer or survey point would be located in the same area as an analysis section). These locations were chosen to compare calculated displacements for each sequence to those seen during construction. Piezometer monitoring values were developed based on the phreatic levels that were used as the design basis for the excavation support systems.

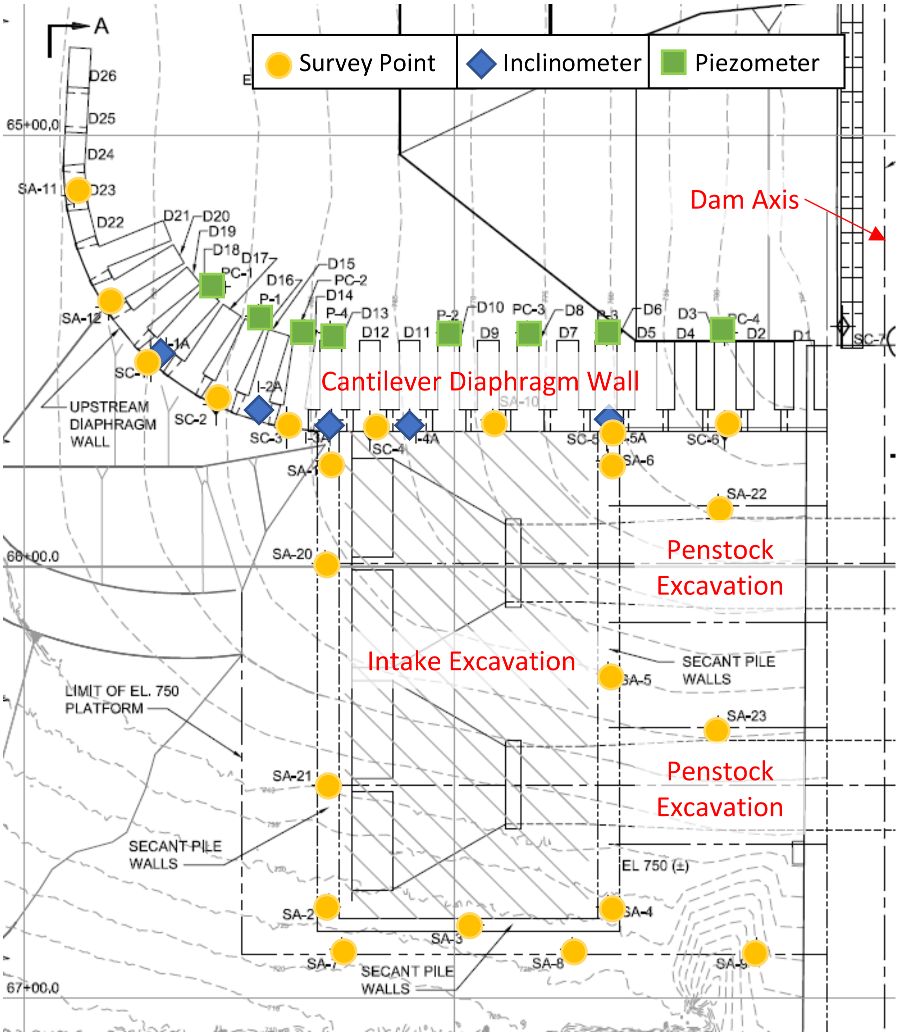

Fig. 6. Plan view showing temporary instrumentation for the upstream project works, including the diaphragm wall, intake and penstock excavations.

4 Conclusion

While conceptually a simple project, the complexity of the final design was revealed through the many details that needed to be resolved to meet the FERC license requirements and maintain dam safety. The fact that the hydro facility is located at an existing USACE dam immediately adjacent to the spillway with significantly varying upstream reservoir levels brought unique intricacies with it. The dam safety monitoring program provided confidence in the performance of the temporary construction works and the safety and stability of the dam.

With the addition of the Red Rock Hydroelectric project to the previously non-powered dam, Lake Red Rock is now a true multi-purpose reservoir and brings additional clean, renewable energy benefits to the surrounding community.