OROVILLE EMERGENCY RECOVERY – SPILLWAYS
Board of Consultants Memorandum

DATE: February 23, 2018

TO: Mr. Dale Brown, Project Manager
Oroville Emergency Recovery – Spillways
California Department of Water Resources

FROM: Independent Board of Consultants for
Oroville Emergency Recovery – Spillways

SUBJECT: Memorandum No. 15

INTRODUCTION

On Thursday February 22, 2018, the Independent Board of Consultants (BOC) met at the Department of Water Resources (DWR) Oroville Field Division Office Main Conference Room at 8:00 am for presentations made by DWR and their consultants on updates for the following:

- Recent Design Team Organization Changes, and
- Construction progress since the last BOC meeting held on December 1, 2017.

At 9:00 am, the BOC toured the dam site to observe construction progress. The following construction features were observed:

- New access road construction on the downstream side of the Flood Control Outlet (FCO) dentates,
- Interior of the FCO chute,
- Excavation and foundation preparation for the new Emergency Spillway Roller-Compacted Concrete (RCC) apron, and the
- Construction of the Emergency Spillway secant pile cutoff wall.

At 11:30 am, the BOC returned to the Oroville Field Division Office for additional updates on:

- Emergency Spillway Foundation Preparation Guidelines,
- February 2018 Plans and Specifications Revisions, and
- Pending Design Modifications related to:

- Emergency Spillway buttress and relief wells,
- FCO pervious backfill,
- Concrete mix design, and
- Aeration features for the FCO spillway.

On February 23, 2018 at 8:00 am, the BOC met at the Department of Water Resources (DWR) Oroville Field Division Office Main Conference Room for additional presentations made by DWR and their consultants for updates on:

- Instrumentation Plans, Installation and Monitoring,
- Emergency Spillway Channel Erosion,
- Independent Forensic Team (IFT) Report, and
- Preliminary Schedule for FCO Spillway Construction.

Representatives from the DWR Division of Engineering, the Division of Safety of Dams (DSOD), the Federal Energy Regulatory Commission (FERC), and industry consultants working on the Oroville Spillway Recovery project attended the meetings and participated in the tour of the dam site. Descriptions and comments made on the individual presentations and the BOC's responses to the DWR questions are contained in the section that follows.

A reading of the BOC's draft report was made to representatives from DWR Engineering Division, DSOD, FERC, and industry consultants working on the Oroville Spillway at 2:45 pm. The meeting was adjourned following the reading of the report. BOC members present were Eric Kollgaard, John Egbert, Kerry Cato, Faiz Makdisi and Paul Schweiger.

QUESTIONS FOR THE BOC

1. ***Does the BOC have any recommendations or comments on construction progress and construction schedule?***

   Response

   The contractor has made effective construction progress throughout the unusually dry winter season. The construction of the project remains on schedule. Items completed to prepare for the 2018 construction season include:

   1. Relocating the RCC batch plant immediately south of the Secant Pile wall. The RCC plant is fully functional and ready for RCC production.

2. The Secant Pile Cutoff Wall is nearly complete (see Figure 1). The Secant Pile Wall has progressed so that only 11 piles remain to be completed. The follow-up work involving pile cutoff, placing dowels and rebar, and constructing the grade beam continues with anticipated completion in March.

3. Foundation Preparation for the RCC apron and RCC buttress is well underway. A significant area for the RCC apron is ready for RCC placement. Foundation excavation and preparation provides for a minimum of 10 feet of RCC to be placed. Foundation preparation involves preparing fresh to slightly weathered rock near the broad crested weir and intensely weathered decomposed rock surfaces on the sloping surface down to the secant pile wall. Foundation preparation will be completed after the Secant Pile Wall contractor has demobilized.

4. Access to the FCO Terminal Structure and Dentate area is being constructed.

5. Minor remediation work in the FCO chute continues.

During the performance testing of the relocated RCC plant, an RCC Test Pad was constructed. The RCC test pad was used to explore RCC mix design options and will be used to test the trenching operation that will be used to construct the FCO slab underdrains within the RCC section foundation.

The BOC understands that the contractor's primary source of fly ash for the RCC mix will not be available until approximately July 1, 2018. The contractor is therefore securing an alternate source of fly ash. The use of slag was also considered but was dismissed because of poorer thermal properties.

The 2018 construction season will continue to be aggressive and will require considerable planning and monitoring to execute successfully. The BOC believes that the Contractor and Design Team have identified the critical path construction items and has confidence that the Contractor and Design Team are taking the appropriate actions to complete the remaining work by November 1, 2018. The BOC is in favor of beginning the 2018 construction work earlier than planned because of the lower than normal reservoir level, provided the risks associated with a late storm event are considered in the decision.

Figure 1. Photographs of Emergency Spillway Control Section (Top) and Secant Pile Wall (Bottom)

2. *Does the BOC have any recommendations or comments on instrumentation*?

Response

Interim Dam Safety Surveillance and Monitoring Plan (DSSMP)

The BOC reviewed the Oroville Dam Spillways 2017-2018 Flood Season Draft Interim Dam Safety Surveillance and Monitoring Plan (DSSMP) dated December 1, 2017. The plan was prepared to satisfy the FERC guidelines.

The plan provides detailed documentation of the instrumentation and monitoring procedures to assess the safe performance of the project components. The plan includes the frequency of inspections and instrument readings, and specifies threshold and action levels. Instrumentation and monitoring are specifically identified relative to corresponding potential failure modes (PFMs) identified in the most recent Potential Failure Modes Analysis.

The BOC anticipates all recently installed and planned piezometers that support the design and construction of both the FCO and emergency spillways will be incorporated into the DSSMP. The BOC also recommends that the results of all instrumentation and monitoring data be interpreted and presented in the Dam Safety Surveillance and Monitoring Report (DSSMR).

Instrumentation and Seepage Observations:

A presentation was made to the BOC on the status of instrumentation installation, site groundwater conditions, and seepage observations. The presentation included new instrumentation and ongoing efforts to monitor the FCO slab seepage, and general site groundwater conditions. About 17 new piezometers have been installed in the FCO chute slab and in areas adjacent to the FCO spillway and on the hillside downstream of the Emergency Spillway.

The groundwater data supports the results obtained from existing instrumentation which show that predominant fracture flow conditions exist in the groundwater contained in the bedrock. Downstream of the FCO and monolith structures, groundwater flows toward the river at moderate flow gradients ranging from 0.17 to 0.12. Groundwater is present in the bedrock up to about elevation 800 feet MSEL, which is approximately 100 feet above the reservoir level elevation of 700 feet which has been maintained for the winter months. Recent storms have raised the reservoir level to approximate elevation 725 feet.

Some instrumentation placed within the FCO chute slab to monitor groundwater pressures will be left in place and abandoned once their batteries cease to work. The BOC recommends decreasing the frequency of piezometer readings as much as possible to increase the functional life of these instruments so that data continues to be collected during as many future flow events as possible.

Minor seepage was observed in the RCC section of the FCO spillway chute at Station 33+00 (to the right of the middle of the slab), and at Station 33+50 next to the right training wall. The seeps were described as minor "weeps" that dried up in a short period after being first observed. The seeps were observed at locations that correlate to several seeps that were observed and documented during mapping of the excavation for the FCO chute foundation in the summer of 2017. However, it is likely that the principal source was from ponded water on the right side of the RCC that had occurred from precipitation. These seeps will continue to be monitored, as well as localized treatment of the weeping cracks. In addition, two vibrating wire piezometers and four permanent ones are planned to be installed near the locations of the seeps.

The BOC concurs with reviewing and lengthening the rock anchors throughout the RCC reach to ensure adequate penetration into competent bedrock. This is suggested for sections where the thickness of the RCC foundation supporting the new structural stab is less than 15 feet.

3. *Does the BOC have any recommendations or comments on the February 2018 Plans and Specifications?*

Response

The latest version of the drawing set and specifications which has been issued incorporates the as-built changes up to the end of the 2017 construction season and adds several changes to be included in the 2018 construction season. The main additions are:

1. Clarification on the routing of drain pipe outfall runs,
2. The plan of the new rock quarry for supplying the crushing plant operation during the 2018 construction season,
3. Drainage and backfill of an erosion channel having hazardous side slopes downstream of the emergency spillway secant pile cutoff wall,
4. Adjustment of anchor locations and lengths to be installed in the FCO chute section from approximately Sta. 12+97 to 20+50,

5. Installation of additional vibrating wire piezometers in the FCO chute,
6. Backfill and filter details for the FCO chute training walls to accommodate the various local conditions found,
7. Locations for light pole installation on the top of the spillway training walls,
8. Details of the grade beam on the secant pile wall and the weir cutoff wall,
9. RCC buttress outline and details including the erosion resistant concrete (ERC) transition to the existing monolith at the top of the RCC buttress, and
10. The plan and sections of the RCC apron downstream of the Emergency Spillway weir.

It was noted that the Joint sealant details on drawing S-302 and other drawings for chute panel expansion and contraction joints do not appear to conform to typical manufacture's recommendations that recommend the depth of the sealant be less than the width. This detail should be confirmed with the sealant manufacturer's recommendations.

The BOC has no other specific comments regarding the drawing changes or the specification updates. It recognizes the Design Team's effort required to keep the drawings current with the many modifications encountered to accommodate site conditions. The effort is now being directed toward the production of the drawing changes to be incorporated into the 2018 construction season.

4. Does the BOC have any recommendations or comments on pending design modifications?

Response

1. ***The Emergency Spillway Buttress and Relief Wells.*** The drawings and details of the Emergency Spillway Buttress are appropriate for addressing the sliding and overturning stability of the Ogee gravity section. Details for addressing the existing foundation relief wells have not been developed. The BOC agrees with assuming the drains are ineffective in the stability analyses for the design of the new buttress since their effectiveness cannot be determined or monitored. The BOC agrees that the design should include a means to discharge seepage from the existing relief wells. This may consist of a collector pipe with an outlet located at the lowest point along the toe of the Ogee Spillway section, or pumping could be considered. The BOC looks forward to reviewing the stability analyses for the Emergency Spillway Buttress.

2. ***FCO Pervious Backfill***. The BOC recommends that the details for backfilling the FCO spillway training walls be kept as simple as possible. The BOC suggests the Design Team consider just extending a narrow zone of the drain rock up the face of the spillway wall, with a similar zone of filter material, if needed, to eliminate backfill compatibility issues. This might simplify the options to a universal solution for all the different site conditions.

3. ***Concrete Mix Design***. The BOC agrees with the Design Team's approach to evaluate concrete mix designs with a higher water cement ratio, reduced cement content, increased volume of coarse aggregate, use of admixtures, and thermal controls to reduce the potential for shrinkage cracking. Concrete testing of several adjusted mixes is being conducted to determine an optimum production mix for the erosion resistant concrete (ERC) to be placed in 2018. The construction schedule allows time to complete the program before any placement of structure concrete is required. The BOC anticipates that the adjusted concrete mix will result in reduction of the occurrence of cracking in the chute panels.

4. ***Aeration Features for the FCO Spillway*.** It has been determined by the IFT and the Design Team that cavitation was not a contributor to the failure of the FCO spillway chute. No cavitation damage has been observed in the FCO spillway chute nor at the dentates over its 50 years of operation with peak flows up to about 160,000 cfs. Despite these findings, the Design Team has diligently performed extensive investigations to evaluate the need for aeration features for the FCO spillway as part of the recovery construction work. The investigations include performing numerical analyses, physical modeling, computational fluid dynamic (CFD) modeling, and a literature search of case studies of similar spillways worldwide.

   Numerical analyses show that for discharges greater than approximately 100,000 cfs, the cavitation index is computed to be below the theoretical critical threshold value of 0.2, indicating that cavitation damage can initiate below Station 31+00. This assumes that [redacted] the duration of flow is long enough to cause damage to the surface, and that the flow is not sufficiently self-aerated.

   The BOC notes that substantial improvements have been made to the FCO spillway design to reduce the potential for cavitation damage to occur, and to limit the extent of damage should it occur. These improvements include use

of higher strength erosion resistant concrete, thicker slabs with more steel reinforcement, rounded offset transverse joints, a smoother surface finish, larger slab anchors, and better foundation conditions. The BOC also notes that some of the investigations appear to show that sufficient self-aeration of the flow exists at discharges above 100,000 cfs to protect the chute from cavitation damage, or to limit the extent of any cavitation damage to a minor level.

The BOC is not convinced that additional aeration features are essential for the permanent FCO Spillway chute configuration. The BOC would be in favor of installing aeration features in the FCO spillway as a precaution to eliminate the risk of cavitation damage provided it can be demonstrated that they do not adversely impact the hydraulic performance of the spillway, and can be incorporated into the existing spillway configuration without significant impacts to the construction schedule and at a reasonable cost. The Design Team's conceptual designs for incorporating aeration features into the FCO spillway appear to require extensive modifications to the current spillway design that would significantly and adversely impact the 2018 construction schedule and construction cost.

Much of the investigative work performed by the Design Team is based on research and publications from internationally-recognized experts in spillway cavitation such as Dr. Henry Falvey and Dr. Nelson Pinto. These experts are professionally active and appear to be available for consultation. The BOC recommends that, given the extent of the adverse impacts to the project schedule and cost, the Design Team obtain input and recommendations from either or both of these experts before making a final decision on the aeration features for the FCO spillway chute. The BOC believes that their input should include an assessment or opinion of the potential for self-aeration, and the expected extent of damage to the spillway from cavitation, if any, up to the Probable Maximum Flood design event. It is conceivable that it may be more effective to repair minor cavitation damage to the FCO spillway, should it occur, than to modify the existing spillway with aerators.

5. Does the BOC have any recommendations or comments on the Emergency Spillway foundation preparation guidelines?

Response

The preparation of the Emergency Spillway RCC apron foundation is ongoing. All the foundation preparation work observed meets or exceeds the BOC's expectations. The BOC offers the following comments on the foundation preparation and drainage.

1. The RCC will be placed on a surface excavated into rock. The upstream, approximately 200-foot flat section was excavated by mechanical means and blasting to remove overlying material and expose a hard rock surface. Downstream, approximately 550 feet have been excavated all fill and alluvium removed to expose extremely- to highly-weathered rock. This surface mimics the natural topography, and this downstream area slopes towards the secant pile wall. Both the blasted rock surface and the extremely- to highly-weathered rock on the sloping surface will provide adequate support for the RCC apron.

2. Immediately downstream of the emergency spillway broad-crested weir, a near horizontal rock surface has been created by exposing slightly weathered to fresh rock. During the presentation on groundwater seeps, the BOC was informed of seeps that occur across this rock surface. Some groundwater seep locations correlate with mapped geologic features, but in general numerous seeps occur across this surface.

   The BOC believes this shows that groundwater pervasively moves through joints and fractures in this rock mass. If the reservoir level rises to the elevation of the broad crested weir, flow under the weir and into this fresh bedrock would likely occur. The Design Team should consider grouting at the upstream side of the broad crested weir to reduce the potential for reservoir water to flow under the weir.

3. The Design Team's structural studies of the RCC apron indicate seepage should not create unsafe uplift pressures, the BOC believes that the Design Team should address drainage for ground that will occur underneath the RCC apron. Observations of the RCC in the FCO spillway show that expansion cracks are occurring in the thick RCC mass every 80 to 100 feet. Similar cracks and spacing should be expected to occur in the Emergency Spillway RCC apron. These cracks will have the unintended benefit of providing some drainage, but additional drainage should be considered. The BOC recommends that the Design Team include drainage under the RCC apron to be placed on the lower weathered bedrock, and to consider a

continuous gravel blanket drain with outlets through the secant pile cutoff wall. An alternative would simply be to drill a pattern of vertical drain ("weep") holes through the RCC blanket on the sloping section.

6. Does the BOC have any other recommendations or comments?

Response

Estimate of Potential Volume of Erosion from Use of Emergency Spillway

A presentation was made of preliminary studies by the Design Team to estimate the volume of highly weathered material (downstream of the secant pile cutoff wall) which could be eroded due to different levels of discharge over the emergency spillway, should it ever be used. The BOC finds this informative and believes it will be useful for the Future Needs Alternatives Study underway by DWR.

Independent Forensic Team (IFT) Report on Oroville Dam Spillway Incident. The IFT conducted a thorough and comprehensive investigation of the Oroville Dam Spillway incident and prepared a detailed report with findings and opinions on the conditions that caused the damage to the FCO and the Emergency *S*pillway. The IFT cited a list of physical factors that were judged as likely contributors to the failure of the FCO Spillway Chute. The IFT determined the root cause of the initiation of the destructive damage to the FCO spillway to be water injection through cracks and joints in the chute slab resulting in uplift forces beneath the slab that exceeded the uplift capacity and structural strength of the slab at a location along the steep section of the chute. The uplifted slab section exposed the underlying poor-quality foundation rock at that location to unexpected severe erosion, resulting in removal of additional slab sections and more erosion.

In the preparation of the redesigned chute for the restoration of the FCO Spillway chute, the Design Team was cognizant of providing remedial measures and safeguards against all IFT cited factors in the development of the spillway replacement design. The BOC is confident that the design of the FCO Spillway Chute that is being constructed meets current standards of practice and provides a conservative solution to address all identified physical factors, except for addressing cavitation. The final IFT report states: *"An aerator is needed at Station 33+00 to protect the chute downstream of Station 33+00 for long-term operation with discharges higher than 100,000 cfs".* See Item 4 in BOC's

response to Question No. 4 in this report, for recommendations related to the need for aerator(s) to protect the FCO chute.

Physical factors that contributed to the incident with the Emergency Spillway were also cited by the Forensic Team. The Design Team has designed remedial measures to address these physical factors. The BOC believes the improvements being made to the Emergency Spillway will allow it to safely meet the criteria under the Interim Operational Period.

The BOC appreciates the work of the Independent Forensic Team (IFT) and thanks them for the important information provided in their two interim memorandums and in their final report.

BOC RECOMMENDATIONS SUMMARY

M15-1 The BOC recommends that all instrumentation and monitoring details be in included in the updated DSSMP, and the interpreted results presented in the DSSMR.

M15-2 The BOC recommends that the details for backfilling the FCO spillway training walls be kept as simple as possible.

M15-3 The BOC recommends that given the extent of the adverse impacts to the project schedule and cost, the Design Team should obtain input and recommendations from Dr. Henry Falvey and/or Dr. Nelson Pinto before making a final decision on the aeration features for the FCO spillway chute. The BOC believes that their input should include an assessment or opinion of the potential for self-aeration, and the expected extent of damage to the spillway from cavitation, if any, up to the Probable Maximum Flood event.

M15-4 The BOC recommends that the Design Team address drainage for groundwater that will occur underneath the RCC apron and consider grouting upstream of the broad crested weir.

Respectfully submitted,

Eric B. Kollgaard **Faiz Makdisi** **Kerry Cato**

John Egbert **Paul Schweiger**