

# Lake Oroville Spillways Emergency Recovery

## Board of Consultants Memorandum No. 8 – June 23, 2017

Prepared by the California Department of Water Resources

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### Summary & Response

This 8<sup>th</sup> meeting of the Board of Consultants (BOC) occurred in the field at Oroville Dam. Part of the meeting was to allow the BOC to inspect construction progress.

#### Question 1

Question 1 relates to construction progress of the cut-off wall within the ground downstream of the emergency spillway. Construction is just beginning in this area at the time of the BOC inspection.

#### Question 2

Question 2 relates to whether aeration considerations should be part of the design for the main spillway. Spillways are sometimes designed to introduce aeration into the flow to prevent cavitation of the concrete. The BOC notes that historically there has been no signs of cavitation which matches the design predictions. The BOC also note that changing the design to introduce aeration, may cause a delay in the construction. Since there has been no signs of historical cavitation and based on the calculations thus far, the BOC recommends that construction of the spillway chute should not be delayed. Further consideration of aeration features could be studied and modifications to the spillway could be done later if necessary.

#### Question 3

The BOC recommends that DWR review and confirm the contractor's construction schedule.

#### Question 4

Question 4 relates to a test section for placement of the roller compacted concrete (RCC). The purpose of the test section is to allow the contractor to demonstrate their method of placement and allow any adjustments in construction or design that may be necessary in advance of full production of RCC placement.

#### Question 5

Question 5 relates to 2 issues associated with general construction. The first issue relates to flowable fill. This is concrete type material that has a very fluid consistency to allow the material to get within all cavities and allow a flatter surface for construction of the RCC.



The second issue is related to a method of construction associated with future drains in the RCC.

**Question 6**

Question 6 relates to several issues.

The first issue relates to how DWR has investigated and documented the foundation conditions. The BOC then discusses the cleaning of the foundation. Typical for dam construction, the rock surface needs to be clean of loose material prior to placing concrete.

The second issue relates to recent investigations of the existing concrete chute. The BOC notes that material was not placed as part of the original construction.

The third and fourth issue are self-explanatory.



# OROVILLE EMERGENCY RECOVERY – SPILLWAYS

## Board of Consultants Memorandum

DATE: June 23, 2017

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

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

SUBJECT: Memorandum No. 8

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### **INTRODUCTION**

On June 21, 2017, the Independent Board of Consultants (BOC) met at the DWR Oroville Field Division Main Conference Room offices at 7:00 am for a safety briefing and then visited the site for a demonstration of roller-compacted concrete (RCC) placement at the RCC Test Section that lasted until about 10:30 am. Representatives from DWR Engineering Division, DSOD, FERC, and industry consultants working on the Oroville Spillway recovery project also witnessed the RCC placement demonstration. Following the RCC test section demonstration, the BOC was given a tour of the Flood Control Outlet (FCO) spillway to observe construction progress. During the afternoon, a meeting was held to provide an overview of the construction work by the construction contractor (Kiewit). This was followed by a presentation on the onsite RCC aggregate production, RCC mix design, and RCC placement approach. The BOC then visited the area immediately downstream of the Emergency Spillway to observe the preparatory work for the construction of the secant pile erosion cut-off wall. The BOC returned to the Oroville Field Division Main Conference Room offices at 3:30 pm to discuss observations, and departed for the day around 4:00 pm.

The BOC reconvened on June 22 at 9:00 am at the DWR Oroville Field Division Main Conference Room offices for briefings on the geology and geotechnical exploration investigations, the secant pile wall design, the FCO Spillway aeration study, the latest revisions to the construction plans and specifications, the Technical Memoranda, and an update on the forensic exploration of the FCO Spillway failure and the Emergency Spillway erosion. BOC members Cato and Egbert stayed on site to observe the secant pile guide wall installation, and placement of the final lift of RCC on the Test Section. They departed at about 6:00 pm.

On Friday, June 23, the BOC continued their deliberations from 8:00 am until 11:00 am. This was followed by a reading of the BOC's draft report with representatives from DWR Engineering Division, DSOD, FERC, and industry consultants working on the Oroville Spillway. The meeting was adjourned at noon.

BOC members present were Eric Kollgaard, John Egbert, Kerry Cato and Paul Schweiger. Faiz Makdisi was out of the country and did not attend this meeting.

### **QUESTIONS FOR THE BOC**

#### **1. Does the BOC have any recommendations or comments on the secant pile wall design?**

##### *Response*

The BOC viewed construction progress of the north end of the secant pile erosion cut-off wall where working platforms with guide walls for the secant drilling are being prepared from about Sta. 12+50 to Sta. 18+00 (see Figure 1). The Contractor has created level working platforms and about 300 to 400 feet of scalloped concrete guide walls with another 500 feet of exposed trench where guide walls have yet to be formed. The BOC was informed that about 200 feet of the northern end of the cutoff wall has been removed and this leaves 1,500 feet of total secant pile wall that will be constructed.



**Figure 1. Photo of secant guide wall trench at approximate Station 13+00. View to the south.**

As part of the Geology presentation, the BOC was shown a geologic cross section that has the planned bottom of the wall depth superimposed. The geology is based on seismic refraction data and 12 geotechnical exploration borings. The wall is designed to have about 15 feet of embedment within slightly weathered rock. The BOC observed exposed amphibolite rock in the southern end of the trench that is intensely to slightly weathered (see Figure 2). At the location of the aforementioned rock exposure, the planned depth of the cutoff wall will be approximately 65 feet. The BOC believes this is good construction progress and awaits the actual drilling progress information for the wall construction, especially in areas where better quality rock is close to the natural ground surface.



**Figure 2. Photo of moderately weathered amphibolite rock exposed in a portion of the secant guide wall trench near approximate Station 17+00.**

A significant portion of the Contractor's work platform appears to be constructed on fill material previously placed at varying thicknesses above Natural Grade. Moreover, the top of the Contractor's scalloped concrete guide wall template matches the elevation of the work platform.

While the BOC has not seen the Contractor's submittal, the note on Drawing S-601, Section D, requiring "Approx. 3' 0" to 5' 0" soil to be removed prior to

drilling Secant Pile” and further requiring that soil removal to extend below Natural Grade may be in conflict with the Contractor’s means and methods.

**2. Does the BOC have any recommendations or comments on the FCO Spillway aeration?**

*Response*

Since the last BOC meeting on May 31, the Design Team completed additional investigations regarding the potential for cavitation damage from flows in the FCO Spillway and the need to provide additional features to aerate the flow to prevent cavitation damage. The investigations were summarized in the following draft technical memoranda:

1. Preliminary Estimates of Flow Depth and Uplift Forces along the Gated Spillway Profile – *Draft SRT-FCO-HR-03*,
2. Recommended Wall Heights and Drain Heights for the Gated Spillway Profile – *Draft SRT-FCO-HR-04*,
3. Cavitation and Aeration of FCO Spillway, *Draft SRT-FCO-HR-05*,
4. Aeration Ramp Design Criteria - *Draft SRT-FCO-HR-06*, and
5. Recommendations for FCO Spillway Chute Aeration Design – *Draft SRT-FCO-HR-07*.

The Design Team evaluated the past performance of the FCO Spillway, the spillway design flow (probable maximum flood - PMF), the theoretical potential for spillway cavitation, and the existing spillway aeration. Important findings from the recent analyses include:

1. During the 50-year period since 1969, the FCO Spillway has flowed 25 times (on average every other year) with peak flows exceeding 150,000 cfs, which is more than 50 percent of the spillway design flow of 296,000 cfs. During this period there have been no reports of cavitation damage to the spillway.
2. When the cavitation index ( $\sigma$ ) for a spillway is less than 0.2, and the flow is not adequately aerated, the spillway has the potential to sustain cavitation damage. The Cavitation Index ( $\sigma$ ) along the spillway profile computed by the Design Team for the full spectrum of flows falls below the desired minimum value of 0.2 beginning at Sta. 31+00, approximately 1,800 feet downstream of the gated control structure, and continues to decrease over the remaining 1,200 feet of the spillway chute to a minimum value of 0.10 at the dentated terminal structure.

3. The Design Team computed the theoretical air content along the profile of the spillway for a range of flows due to the upstream piers and from self-aeration. The computations show the spillway flows are initially aerated immediately downstream of the piers and gradually lose entrained air until a minimum equilibrium air content is reached. The flows then begin to experience increased entrained air from self-aeration when the boundary layer reaches the free surface. The point of increasing entrained air from self-aeration is a function of the spillway discharge and occurs further downstream for increasing discharges. The minimum equilibrium aeration increases with flow, and for the design discharge of 296,000 cfs, the minimum equilibrium aeration was computed to be 5.7 percent.
4. Examination of photographs and videos of the FCO Spillway shows aeration of the flow through the majority of the chute length for a wide variety of flows, and appears to corroborate the air concentration conditions computed by the Design Team.
5. A review of the computed cavitation index and entrained air along the FCO Spillway profile for the full range of flows shows that the cavitation index is either higher than the minimum desired value, or the mean air concentration is higher than the minimum recommended value to prevent cavitation damage. Therefore, the analyses indicate that there is no need to add aerators within the spillway to prevent cavitation damage.
6. The design and construction of one or more aeration features within the FCO Spillway could delay completion of the spillway chute during the 2017 construction season.

Based on the above, the BOC believes that the contribution of the downstream free-surface aeration is an important factor that needs to be included in the decision of whether or not supplemental aeration features are needed within the FCO Spillway. The BOC recommends that the Design Team continue to research the performance of similar spillways without aeration features (Itaipu Dam, Brazil, which has experienced large flows for sustained periods). If possible, the cavitation and aeration analysis of the FCO Spillway should be independently confirmed with a physical model of the spillway. The model could be a sectional model at an appropriate scale to simulate aeration.

The Design Team assumed a Manning's "n" value for the chute to be 0.012 and a roughness height ( $k_s$ ) for concrete to be 1 mm. This is smoother than the current spillway chute concrete roughness. As the concrete surface of the new spillway roughens over time, the effect of this change should be understood. The BOC recommends that a sensitivity analysis be performed on the computed cavitation index, the self-aeration air content, and the top of wall elevation along the profile of the spillway, as they relate to the assumed roughness of the concrete chute.

The BOC recommends that the construction of the spillway chute not be delayed by the design of additional aeration features, especially since the recent analyses indicate that aerators are not required. If a decision is made to add aerators in the FCO Spillway, they should be thoroughly evaluated and tested to make sure that they do not adversely impact the performance of the spillway.

**3. Does the BOC have any recommendations or comments on the FCO construction sequence?**

*Response*

Now that the design of key elements of the spillway has been completed, the BOC recommends that the Design Team evaluate the Contractor's progress and ability to complete the new concrete lining of the FCO Spillway within the 2017 construction season. This should include a review of the Contractor's proposed construction schedule with an emphasis on identifying critical path work items and an assessment of realistically achievable production rates.

The BOC will defer a definitive response regarding the FCO construction sequence pending future presentation of DWR's evaluation and determinations on this issue.

**4. Does the BOC have any recommendations or comments on the RCC design or test section?**

*Response*

The RCC test section was used to test and demonstrate critical aspects of proposed RCC construction including the workability of the RCC mix, the performance of the RCC plant, the adequacy of the proposed placement and compaction equipment, various construction methods, and workmanship (see



Figure 3). The BOC observed the RCC placement and found the RCC mix to be workable with no segregation, easily compacted, and can be placed within the temperature restrictions, despite high ambient temperatures exceeding 100 degrees Fahrenheit. The Contractor's workers demonstrated the necessary skills. The equipment used to spread and compact the RCC appeared to be new and appropriate for the work. The BOC was pleased with the demonstration.



**Figure 3. Photo of RCC placement of lift 8 and the vibratory finish of the 1H:1V slope.**

**BOC Comments:**

1. Because of the accelerated construction schedule and need to remove the RCC test section to provide access for construction equipment, there will be no opportunity to obtain, examine and test core samples to confirm bonding of RCC lifts with “Hot Joints”, the effectiveness of the grout-enriched vibratable RCC (GEVR), and in-place RCC properties. The BOC recommends that during removal of the RCC test section, efforts be made to learn as much as possible regarding these features. For example, the effectiveness of the “Hot Joint” treatment

can be confirmed by the lifts of RCC remaining bonded and coming apart in monolithic chunks during demolition as opposed to the RCC coming apart in unbonded layered slabs. Similarly, the GEVR should be examined during demolition to see how well the RCC mix has been consolidated.

2. Prior to removing the RCC test section, the BOC recommends that the exposed 4H:1V RCC slope receive “Cold Joint” cleaning treatment to determine what the surface will look like prior to placing the new concrete slabs (see Figure 4). Photographs of the 4H:1V surface should be taken prior to and after it has been pressure washed in accordance with the specifications for cold joint treatment.



**Figure 4. Photo of the 4H:1V ramp on the RCC Test Section that is planned to be formed by vibratory rollers.**

3. At the time that BOC Meeting No. 8 ended, all eight horizontal RCC lifts had been placed for the test pad and a trial lift is planned to be placed and compacted on the 4H:1V slope to prove out the ability to use the compaction rollers on this slope. The BOC believes that this needs to be demonstrated, as it may be an important procedure in construction of the chute foundation, and looks forward to a presentation of the test results.

## 5. Does the BOC have any recommendations or comments for project construction?

### *Response*

- 1. Use of Flowable Fill in FCO Spillway Foundation.** It appears that less flowable fill will be placed in the lower portions of the FCO Spillway foundation than originally anticipated, and that more RCC is planned to be placed instead. The flowable fill that has been placed is in the bottom of the downstream scour hole (see Figure 5). Placement of RCC in tight spaces and around large boulders that project above the lift surface appears challenging. The infilling of the upper scour hole has not been started since access to the area will cross the lower RCC placement. The BOC is of the opinion that the use of additional flowable concrete in these bottom areas of the infilling to provide working surfaces for RCC placement would facilitate construction.



**Figure 5. Flowable fill that has been placed in the scour hole near approximate Station 32+00.**

As the RCC infill is raised, there will also be narrow crevices that can only be effectively filled by flowable fill or dental concrete. The BOC suggests that a combination of RCC and flowable fill placed concurrently be considered in tight spaces where compaction of RCC cannot be accomplished with equipment.

2. **FCO Spillway Slab Underdrains within RCC Foundation.** The BOC recommends that the Design Team consider constructing the slab underdrain trenches within the top of the RCC foundation by removing the RCC within the trenches by milling or saw cutting rather than forming the blockout with inserted metal strips and breaking out the RCC for the drains.

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

*Response*

1. **Mapping of FCO foundation and inspection, assessment and acceptance of cleaned foundation.** The BOC commends the Design Team for a methodical and extremely thorough mapping of the FCO Spillway foundation and surrounding area. The use of high-resolution drone aerial imagery in combination with GIS software is state-of-the-practice and provides an excellent record of foundation conditions and completed work. The gridded layout of the foundation and use of standardized worksheets will help maintain records, coordinate completed work with the Contractor, and provide a means to forecast future productivity and schedule requirements.

The cleaning of areas of the chute foundation for placement of RCC or leveling concrete that were observed by the BOC (see Figures 6 & 7) appear to have been well done and represent a significant improvement in contrast to the prepared foundation surface for the original FCO Spillway construction.

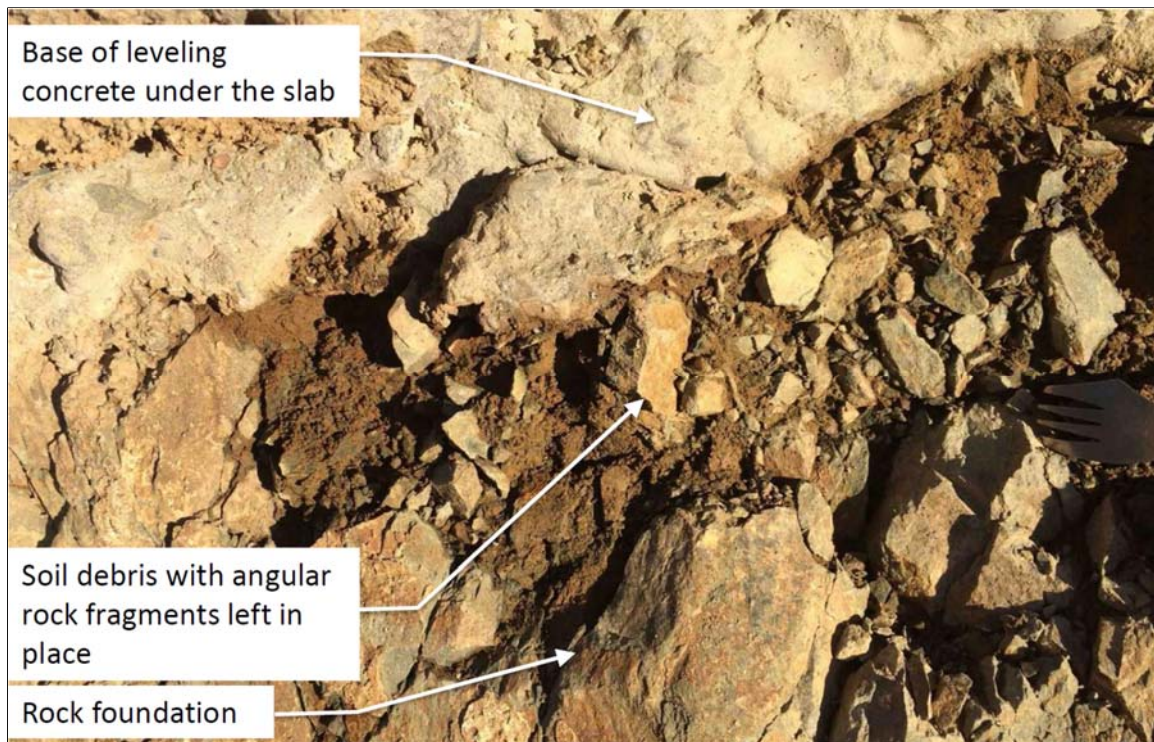
2. **Update on investigation of existing FCO spillway chute foundation condition.** The BOC was provided an update to findings on the investigation of the interface between the concrete and rock material. Four concrete cutouts were excavated and exposures described. Subsequently, and as part of the concrete removal, the Contractor created a 200-foot-long centerline exposure of the interface from Stations 25+00 to 27+00. Where present, the soil material that did exist appeared to be semi-consolidated fines and angular rock debris that was not removed as part of the initial (1960's era) foundation surface cleanup. The interpretation of the investigators was that the localized occurrence of the soil and its angular nature did not appear to be fill that was purposefully placed as bearing material. A photo of this material is shown as Figure 8.



**Figure 6. Cleaned FCO spillway chute rock that has been geologically mapped and is close to being accepted for concrete placement. Near approximate Station 33+00.**



**Figure 7. Close-up of cleaned rock surface near Station 33+00 in FCO spillway chute foundation.**



**Figure 8. Soil material left in place in the existing FCO chute spillway foundation interface. Location is near Station 25+30. Tool at right is 1.5 inches wide.**

- 3. Contractor's Construction Approach, Use of Site and Mobilized Equipment.** The BOC is favorably impressed with the Contractor's general approach, use of the job site and the mobilized equipment. Critical elements including the conventional concrete plant, the RCC batch plant, the aggregate production facility, the access roads, crane pads, staging areas and office complex appear to be thoughtfully located, carefully laid out and well organized. Almost all of the critical construction equipment appears to have been mobilized and ready for major construction work to begin. Most of the equipment is new, and appropriately selected and sized for the kind of work that will be performed.
- 4. Updating Estimated Quantities in Bid Schedule.** The BOC recommends that the "Estimated Quantity" for the items listed below from the Bid Schedule be updated and reviewed as appropriate to reflect current known conditions. The original estimated quantities contained in the Bid Schedule appear to be based on original plans which have subsequently been revised twice.

Item No.	Spec. Section	Item	Unit	Estimated Quantity
11	02217	Foundation Preparation	SY	
12	02217	Foundation Preparation – Dental Excavation	CY	
13	02217	Foundation Preparation – Dental Concrete	CY	
14	02220	Selective Demolition (Upper FCO Chute)	CY	
15	02200	Selective Demolition (Lower FCO Chute)	CY	
15a	02200	Selective Demolition (Emergency Spillway)	CY	
20	02300	Rock Excavation	CY	
51	03300	Structural Concrete	CY	
52	03300	Erosion Resistant Concrete	CY	
54	03300	Mass Concrete	CY	
55	03300	Leveling Concrete	CY	
59	03304	Emergency Spillway Secant Pile Cut-Off Wall	SF	
63	03800	Roller-Compacted Concrete (FCO Chute)	CY	
63a	03800	Roller-Compacted Concrete (Emergency Spillway)	CY	

### **BOC RECOMMENDATIONS SUMMARY**

- M8-1            The BOC believes good construction progress is being made on the secant pile erosion cut-off wall and looks forward to seeing actual drilling progress information in the near future.
- M8-2            The BOC believes the contribution of the downstream free-surface aeration is an important factor that needs to be included in the decision of whether or not supplemental aeration features are needed within the FCO Spillway.
- M8-3            The BOC recommends that the Design Team continue to research the performance of similar spillways without aeration features (Itaipu Dam, Brazil, which has experienced large flows for sustained periods).
- M8-4            If possible, the cavitation and aeration analysis of the FCO Spillway should be independently confirmed with a physical model of the spillway. The model could be a sectional model at an appropriate scale to simulate aeration.

- M8-5 The BOC recommends that a sensitivity analysis be performed on the computed cavitation index, the self-aeration air content, and the top of wall elevation along the profile of the spillway, as they relate to the assumed roughness of the concrete chute.
- M8-6 The BOC recommends that the construction of the spillway chute not be delayed by the design of additional aeration features, especially since the recent analyses suggest that aerators are not required. If a decision is made to add one or more aerators in the FCO Spillway, they should be thoroughly evaluated and tested to make sure that they function as desired and do not adversely impact the performance of the spillway.
- M8-7 Now that the design of key elements of the spillway has been completed, the BOC recommends that the Design Team evaluate the Contractor's progress and ability to complete the new concrete lining of the FCO Spillway within the 2017 construction season. This should include a review of the Contractor's proposed construction schedule with an emphasis on identifying critical path work items and an assessment of realistically achievable production rates.
- M8-8 The BOC recommends that during removal of the RCC test section, efforts be made to learn as much as possible regarding the bonding of the RCC lifts, the consolidation of the GEVR and other RCC properties.
- M8-9 Prior to removing the RCC test section, the BOC recommends that the exposed 4H:1V RCC slope receive "Cold Joint" cleaning treatment to determine what the surface will look like prior to placing the new concrete slabs. Photographs of the 4H:1V surface should be taken prior to and after it has been pressure washed in accordance with the specifications for cold joint treatment.
- M8-10 As of the time of the close of BOC Meeting No. 8, all eight horizontal RCC lifts had been placed for the test pad and a trial lift was planned to be placed and compacted on the 4H:1V slope to prove out the ability to use the compaction rollers on this slope. The BOC believes it is important that this be demonstrated and looks forward to a presentation of the results.



- M8-11 The BOC is of the opinion that the use of additional flowable concrete in the bottom areas of the FCO Spillway infilling to provide working surfaces for RCC placement would facilitate construction. The BOC suggests that a combination of RCC and flowable fill placed concurrently be considered for filling narrow crevices and small areas where RCC compaction is not possible.
- M8-12 The BOC recommends that the Design Team consider constructing the slab underdrain trenches within the top of the RCC foundation by removing the RCC within the trenches by milling or saw cutting.
- M8-13 The BOC commends the Design Team for a methodical and extremely thorough mapping of the FCO Spillway foundation and surrounding area. This also applies to the cleaning of the spillway rock surface.
- M8-14 The BOC is favorably impressed with the Contractor's general approach, use of the job site and the mobilized equipment.
- M8-15 The BOC is pleased with the level of foundation cleaning being done for foundation preparation of the RCC and leveling concrete in the FCO chute reconstruction.
- M8-16 The BOC recommends that the "Estimated Quantity" for the items from the Bid Schedule that appear to be critical to meeting the Contractor's schedule be updated and reviewed as appropriate to reflect current known conditions.

Respectfully submitted,



**Eric B. Kollgaard**

(Not present)  
**Faiz Makdisi**



**Kerry Cato**



**John Egbert**



**Paul Schweiger**