Lake Oroville Spillways Emergency Recovery

Board of Consultants Memorandum No. 7 – May 31, 2017

Prepared by the California Department of Water Resources

Summary & Response

Question 1

Question 1 relates to the hydraulic design of the spillway. Essentially how the water will flow through the spillway at the maximum design flow from a maximum probable flood inflow. The design inflow corresponding to the maximum probable flood is nearly 4 times the historical inflow into the reservoir. Although the spillway has not experienced any evidence of cavitation, the BOC discusses the need for further study regarding aeration in the spillway which helps prevent cavitation.

The BOC also suggests further study regarding the hydraulic design of the emergency spillway and requests DWR to consider a model study to understand the flow conditions at this spillway.

Question 2

Question 2 relates to ongoing studies to estimate the PMF. The PMF is the design maximum inflow of water into the reservoir during this very rare event. The PMF is the basis for the design of the spillways to prevent the dam from overtopping. The BOC recommends ensuring the most up to date information be used in designing the spillways.

Question 3

Self explanatory.

Question 4

The BOC has reviewed the plans and specifications and notes the new design will correct deficiencies from the original design of the FCO. The first comment from the BOC notes that designing a vertical offset between the concrete slabs is redundant and not necessary. The second comment is in regards to the placement temperature of the concrete. In some cases, the concrete needs to be cooled during mixing so that excessive heat during placement of the concrete does not occur. The BOC is recommending the contractor provide a plan to ensure this does not occur.

Question 5

Question 5 relates to required foundation conditions beneath the proposed spillways and notes more specific definitions are needed for the foundation beneath the emergency spillway.

The BOC notes that it is the control structure that is the sole feature that must be protected for the emergency spillway.

The BOC recognizes the extensive exploration that was conducted in the upper chute of the FCO.

OROVILLE EMERGENCY RECOVERY – SPILLWAYS
Board of Consultants Memorandum

DATE: MAY 31, 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. 7

INTRODUCTION

On May 30, 2017, the Independent Board of Consultants (BOC) met at offices of the California State Department of Water Resources (DWR) between 9:00 am and 2:00 pm for presentations on the Spillway hydraulics, the PMP re-study, DSOD review of the hydrology and hydraulics, geology, and the structural design, and DSOD and FERC design review comments. Representatives attended from DWR Engineering Division, DSOD, FERC, and industry consultants working on the Oroville Spillway recovery project; the attendees at the meeting are shown on the attached attendance lists. Following the presentations, the BOC met with members of the Design Team by discipline to review the individual design drawings, details and specifications. The meeting ended at 6:30 p.m. An agenda for the meeting is attached.

The BOC reconvened on May 31 at 8:30 am and continued to meet with members of the Design Team by discipline to review the design drawings, details and specifications. The meeting ended at 5:00 pm after a reading of the BOC's draft report.

The BOC reviewed the status of past comments and recommendations in the log that is included in the attachments.

The BOC was pleased to welcome new BOC member Paul Schweiger who replaced BOC member Jack Cassidy who resigned due to health issues. All BOC members were present on both days.

QUESTIONS FOR THE BOC

1. Does the BOC have any recommendations or comments on the Spillway hydraulics?

Response

The BOC received a thorough briefing on the preliminary hydraulic analyses performed for the FCO Spillway and the Emergency Spillway. The FCO Spillway hydraulics are being evaluated for flows up to the peak Probable Maximum Flood (PMF) design flow of 296,000 cfs using a spreadsheet (simplified one-dimensional model), a CFD model (Computational Fluid Dynamic, FLOW 3D), and a 1:50 scale physical model prepared at the hydraulics laboratory at Utah State University. The Design Team evaluated different Spillway rehabilitation configurations, including modifying the recently scoured area into a plunge pool. Based on the physical model simulations of various plunge pool configurations, and an evaluation of the original Spillway design, the Design Team decided to rehabilitate the Spillway with the same configuration as the original Spillway. The BOC agrees with this decision.

For the Peak PMF design flow of 296,000 cfs, the steady state spreadsheet calculations show the flow in the Spillway accelerating throughout the length of the Spillway from 63.4 fps (43.2 mph) from the FCO structure at Station 12+50 to 167 fps (114 mph) at the energy dissipater at Station 43+00. The PMF reservoir water surface elevation for the analysis was assumed to be 917.5 feet. The spreadsheet computations with air entrainment show the required top of Spillway training wall elevations to be approximately 2 feet higher than the existing wall heights. The BOC agrees with raising the Spillway walls as proposed in design memorandum SRT-FCO-HR-04. The height of the raised wall profiles should be confirmed with the physical model study. The BOC also recommends that the physical model be used to evaluate unbalanced releases from the Spillway gates.

Photographs and videos of the Spillway flowing during past events, including the historical peak flood in 1997 when the Spillway flowed at approximately 161,000 cfs for 6 hours were presented. The video of the 1997 event confirms the successful performance of the Spillway geometry, except for a flow surge near the upstream end of the Spillway that nearly overtops the Spillway training wall. The BOC commends the Design Team for procuring photographic and video documentation of past FCO Spillway discharges, and for carefully

examining this important information to assess the hydraulic performance of the Spillway. The BOC encourages the Design Team to try to determine the water surface profiles from the photographed events (the peak of the 1997 event, in particular), and use this information to confirm their numerical and physical models.

It was noted that the capacity of the gated FCO control structure at the design reservoir elevation of 917.0 feet appears to be limited to passing 277,000 cfs when fully open instead of the assumed design flow of 296,000 cfs. Although this does not appear to be a critical factor during passage of the PMF, and is not a critical path design feature, the BOC recommends that an accurate determination of the actual discharge from the FCO control structure at the design elevation of 917.0 be determined.

Similarly, during the design pool at elevation 917.0 with both the FCO Spillway and the Emergency Spillway flowing at maximum capacity, the total discharge capacity of both Spillways is assumed to be approximately 624,000 cfs. An unknown is the combined approach flow conditions to both Spillways and the influence of these conditions on the overall stage-discharge capacity for the Spillways and the performance of the Spillways. The BOC recommends that a 2D hydraulic model or CFD model of the Spillway approach conditions be developed to evaluate approach hydraulics and confirm the performance of the Spillways during events up to the PMF.

Cavitation damage within the Spillway Chute upstream of the terminal structure prior to the slab failure has not been observed. Although cavitation was probably not the root cause of the slab failure, it may have contributed to the slab failure. Calculations presented by the Design Team show that cavitation damage has the potential to occur within the lower portion of the Spillway Chute during the peak design flow if the flow is not sufficiently aerated. The need to provide additional features within the Spillway to aerate the flow at selected locations within the Spillway, such as installing one or more air troughs, ramps, steps or a combination of these near the beginning of the steep portion of the Chute and further downstream should continue to be evaluated. Aerating the flow on the steep FCO Spillway slope appears to be the most effective way of reducing or eliminating potential cavitation damage. Given the accelerated design and construction schedule, the BOC acknowledges that there may not be sufficient time to design and test new aeration features for the Spillway for extreme flood events. The BOC encourages the Design Team to try and resolve this issue as

part of the current Spillway design. If this is not possible, the BOC recommends that the Design Team consider including features within the new Spillway design to accommodate, as much as possible, future modifications to the Spillway to provide flow aeration, where it may be needed, unless additional analyses determine that it is not required.

Regarding the hydraulics of the Emergency Spillway, the BOC recommends that a physical model study of the ogee spillway with the proposed RCC buttress section be performed. The physical model study could consist of a cross section analysis of the maximum section of the Spillway. The purpose of the physical model study would be to evaluate the flow pattern over the top and downstream face of the stepped RCC buttress section incrementally for the full range of potential flows. There is a concern that the overtopping flow could jump the steps rather than dissipate the flow energy on the stepped downstream face of the structure. See photograph below from a physical model study of an initial downstream stepped face Spillway which showed this phenomenon.

2. Does the BOC have any recommendations or comments on the PMF analysis?

Response

As noted by DWR H&H consultant, estimates of the Probable Maximum Flood (PMF) are periodically updated for reservoirs throughout the United States due to

enhanced understanding of atmospheric conditions that lead to the probable maximum precipitation (PMP), improved hydrometeorological monitoring, improved watershed rainfall-runoff-routing model capabilities, and changed atmospheric, hydrologic, hydraulic, or operational conditions. The PMF analyses for Oroville Dam have been reviewed and revised several times since the dam was designed in 1965 (in 1968, 1980, 1983, 2003 and 2012). During the period from 1965 to 2003, the peak PMF inflow/outflow varied from a low of 718,000 cfs/624,000 cfs (original design) to a high of 1,167,000 cfs/798,000 cfs (1983 assuming Butt Valley Dam breached due to overtopping during the PMF). The current PMF has a peak inflow of 725,000 cfs with a peak outflow of 671,000 cfs. The current PMF estimate does not include the failure of Butt Valley Dam. All of the PMF analyses assume the initial pool of Oroville dam is full at El. 900.0 feet. None of the previous PMF evaluations resulted in overtopping of Oroville Dam. The total Spillway capacity of Oroville Dam with zero freeboard is estimated to be 828,000 cfs with 308,000 cfs passing through the FCO Spillway and 520,000 cfs passing over the Emergency Spillway.

The comprehensive review of the 2003 PMF in 2012 identified several issues that warranted additional investigation. DWR subsequently authorized their consultant to re-estimate the PMF in 2016, just before the Spillway incident arose. To support design of the restored Spillways, work on the PMF estimation has been accelerated, with a tentative completion date of July 4, 2017. The BOC is in agreement with the PMF update approach proposed as outlined in SRT-ORO-HY-03 and presented at the May 30 BOC meeting. The BOC recommends that the confirmed stage-discharge relationships for the FCO Spillway and Emergency Spillway that takes into account restrictions of the Spillway gates and the Spillway approach conditions be used in the PMF analysis.

3. Does the BOC have any recommendations or comments on the technical memoranda?

Response

The BOC reviewed and provided comments on a number of draft technical memoranda in its previous reports. The BOC has the following additional recommendations and comments on the technical memoranda. The BOC will continue to provide more detailed comments in future documents.

The BOC recommends that a structural design basis technical memorandum be prepared summarizing the methodology, material characterizations, loading

assumptions and other relevant criteria together with the results of the analyses as part of the final design report. This would include the design calculations of DM SRT-ORO-ST-11, Calculations of Structural Design.

4. Does the BOC have any recommendations or comments on the plans and specifications?

Response

Prior to the meeting, the BOC members reviewed the Plans and Specifications last updated on May 18, 2017. Comments were provided to technical leads of the Design Team, by discipline, reviewing individual drawings and specifications in detail. The comments will be addressed by the Design Team. The BOC is of the opinion that the current design of the FCO Spillway Chute for the Oroville Spillway Recovery Project will function well and corrects the deficiencies in the original design of the existing Chute. The BOC concurs that the plans and specifications will be ready for approval and issuance for construction once the comments have been satisfactorily addressed.

In addition to the review comments provided during the aforementioned working session with the designers, the BOC offers the following suggestions in the spirit of improving the overall design:

1. Consider shortening the height of the ¾" vertical offset at the transverse slab joints as part of the computational fluid dynamics (CFD) analysis. It is the opinion of the BOC that the proposed transverse slab joint detail which includes continuous steel reinforcement, a keyway, dowels and anchorage of the slabs to bedrock and RCC provides sufficient restraint to limit differential vertical movement of the slabs.

2. It is recommended that the concrete specification require the Contractor to develop and submit a Thermal Control Plan for the Spillway slabs and walls prior to their construction. A thermal control plan is the temperature monitoring procedure that the contractor intends to follow when placing concrete in hot weather, cold weather, or for mass placements, including cooling methods, curing methods, use of thermal blankets, etc., and how they are going to monitor concrete temperatures to prove compliance with the specifications. As part of the plan, the contractor must determine the maximum allowable concrete temperature and temperature differential that will prevent concrete cracking during the heat dissipation period. In addition,

the contractor must identify the type of equipment, location, and frequency of concrete temperature measurements. Thermal Control Plans are often specific to a particular mix design.

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

Response

1. During the meeting, DSOD and FERC representatives made presentations on the geology, structural engineering, hydraulic, and other design issues. The BOC appreciated the presentations and the discussions that they prompted.

   During the discussions, it was pointed out that the section of the RCC buttress shown on Drawing S-701 shows excavation of a shear key below the foundation level of the overflow weir block. The BOC agrees that a shear key is not required and the foundation of the buttress should be founded on fresh or slightly weathered rock.

   For the Emergency Spillway repairs it was noted that the foundation preparation criteria for the RCC apron foundation are poorly developed or do not exist. Comparatively, the FCO Spillway Chute foundation is specified to be placed on moderately weathered rock, except in areas of lower quality rock where treatment will occur. As shown on the current version of the plans, the Emergency Spillway RCC apron foundation will be excavated to a grade. DSOD pointed out that substantial areas of the RCC apron may be placed on apparent soil-like material or intensely weathered rock. The BOC recognizes that DWR is still developing the Emergency Spillway repair design and encourages the development of material criteria for the RCC apron foundation that are similar to those developed for the FCO Chute foundation, but modify those criteria to be appropriate for the Emergency Spillway.

   It was also pointed out that the foundation at the left and right ends of the Emergency Spillway overflow weir (“the speed bump”) appears to be founded on intensely weathered rock and that this could present a problem regarding water seepage under the structure during high reservoir conditions. Based on the updated hydrology analysis presented at this meeting, the frequency and duration of high reservoir conditions that produce Spillway flows are rare and of relatively short duration. It is important to remember that the primary goal of the Emergency Spillway structure is to pass these flows without breaching the control section. The BOC believes that some event seepage under the

Emergency overflow weir may occur, but will not threaten the integrity of the structure. As part of the continued development of the Emergency Spillway repair design, it may be prudent for the Design Team to verify that seepage will not produce any issues or instability in the RCC apron.

The BOC believes that the FCO chute design is well-developed and should not be significantly changed. Certainly it is prudent to consider ideas that could minimize concrete cracks and improve the underdrain design.

2. The BOC understands that a total of 56 borings and concrete cores were drilled into the concrete slab of the upper chute. This section will remain in place during the 2017-2018 flood season. Information from the retrieved cores provided documentation of the quality of the contact between the concrete slab and the supporting foundation material. A number of these cores indicated clean contact with hard, fresh rock; others showed highly weathered rock or residual soil; and in some cases, a cavity beneath the slab. The locations of some of these exploration points were selected to target areas identified in earlier construction geology reports as representing highly weathered and sheared rock, or areas of poor foundation cleaning and treatment. The BOC recommends that this information be reviewed to estimate the percentage of cores out of the total sample explored that indicated good contact between the slab and underlining competent rock foundation. This information could be included in one of the updated Geologic/Geotechnical Technical Memorandums, and would provide additional support to the conclusions of the Design Team regarding the more favorable foundation conditions beneath the upper portion of the Spillway Chute.

BOC RECOMMENDATIONS SUMMARY

M7-1 The BOC recommends that the physical model of the FCO Spillway be used to evaluate unbalanced releases from the Spillway gates.

M7-2 The BOC recommends that the photographs and videos of the FCO Spillway taken during past flow events be used to determine the water surface profiles for known discharges, and that this information be used to confirm the numerical and physical models developed for the Spillway.

M7-3 The BOC recommends that an accurate determination of the actual discharge capacity from the FCO gated control structure at the design elevation of 917.0 be determined.

M7-4 The BOC recommends that a 2D or CFD model of the Spillway approach conditions be developed to evaluate approach hydraulics and confirm the performance of the Spillways during events up to the PMF.

M7-5 The BOC encourages the Design Team to continue to investigate the need for aeration of the flow within the FCO Spillway to prevent the possibility of cavitation at any discharge. Since modifications of the design to provide aeriation may not be possible during the current construction season, provisions should be considered in the Chute construction to allow for future modifications, if aeration is determined to be needed.

M7-6 The BOC recommends that a physical model study of the proposed buttressed section of the Emergency Spillway be performed.

M7-7 The BOC recommends that the confirmed stage-discharge relationships for the FCO Spillway and Emergency Spillway that take into account any restrictions of the Spillway gates and the approach conditions, be used in the PMF re-analysis.

M7-8 The BOC recommends that a structural design basis technical memorandum be prepared.

M7-9 The BOC concurs that the current design of the FCO Spillway Chute provides for a safe and adequate facility for construction and corrects the deficiencies in the original design of the existing Chute.

M7-10 The BOC recommends consideration of reducing the ¾” vertical offset at the transverse slab joints.

M7-11 It is recommended that the concrete specification require the Contractor to develop and submit a Thermal Control Plan for the Spillway slabs and walls prior to their construction.

M7-12 The BOC recognizes that the design of the RCC buttress shown on Drawing S-701 – Emergency Spillway RCC Buttress and Apron, is preliminary and will be refined when foundation geology information becomes available. The BOC agrees that a shear key is not required and the foundation of the buttress should be founded on fresh or slightly weathered rock.

M7-13 The BOC recognizes that the Design Team is still developing the Emergency Spillway repair design as the geotechnical exploration data becomes available and encourages the development of material criteria for the RCC apron foundation appropriate for the Emergency Spillway.

M7-14 The BOC recommends that the information from core drilling of the existing Spillway Chute be reviewed to estimate the percentage of cores out of the total sample explored that indicated good contact between the slab and underlining competent rock foundation to support the conclusions of the Design Team regarding the more favorable foundation conditions beneath the upper portion of the Spillway Chute.

Respectfully submitted,

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John Egbert **Paul Schweiger**