OROVILLE EMERGENCY RECOVERY – SPILLWAYS
Board of Consultants Memorandum

DATE: May 29-30, 2018

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

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

SUBJECT: Memorandum No. 18

INTRODUCTION

On Tuesday May 29, 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 the Department of Water Resources (DWR) and their consultants for updates on construction progress and tracking of future work.

At 9:00 am, the BOC, representatives from the DWR Division of Engineering, the Division of Safety of Dams (DSOD), the Federal Energy Regulatory Commission (FERC), DWR Division of Operations and Maintenance, and industry consultants working on the Oroville Spillway Recovery project toured the FCO Spillway Chute, the Emergency Spillway area and the FCO slab test section to observe construction progress. The following construction features were observed:

- Demolition of the upper section of the FCO spillway;
- Hydro-demolition of the surface of an area of concrete chute slab (28E) near Sta. 21+00;
- Preparation of the FCO slab joints near Sta. 20+50 and at Sta. 43+00;
- Excavation of cross drainage trenches in the RCC portion of the FCO;
- Status of placement of the RCC apron on the right side of the emergency spillway (Phase 1);
- Excavation and foundation preparation for the RCC apron on the left side of the Emergency Spillway (Phase 2); and

- The FCO slab test section using the improved concrete mix designs and evaluating different construction techniques.

At 12:00 pm, the BOC returned to the Oroville Field Division Office Main Conference Room for additional updates on the:

- Flood Control Outlet (FCO) chute aeration research program;
- Summary of Revision 8 to plans and specifications including drainage details for Emergency Spillway's RCC aprons, monoliths and buttresses, FCO chute longitudinal drains, exterior wall drains and pervious backfill, and potential instrumentation for cavitation and aeration [redacted];
- Cast-in-place concrete laboratory mix design proportioning studies and placement modifications for 2018 construction;
- Geology update, including status of RCC apron foundation mapping, and forensic work in the FCO's demolished upper chute;
- 2018 construction season Gate Closure Plan update; and
- Overview of UC Davis final report on the assessment of the impact of woody vegetation and tree roots.

On Wednesday May 30, 2018 at 8:00 am, the BOC met at the Oroville Field Division Office Main Conference Room to deliberate and prepare their report. Descriptions and comments made on the individual presentations and the BOC's responses to the DWR questions are included in this report. During this time, BOC members Eric Kollgaard and Paul Schweiger also participated in a conference call with representatives from FERC, DWR, DSOD, and industry consultants to discuss spillway cavitation and aeration.

A reading of the BOC's draft report was made to representatives from DWR Engineering Division, DSOD, FERC, DWR Division of Operations and Maintenance, and industry consultants working on the Oroville Spillway at 1:00 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 the construction update or site visit?***

   Response

   The BOC is pleased with the progress of construction at the Emergency Spillway and the FCO chute. The construction site is very well organized, and the work

being performed is of high quality. The BOC is impressed with the contractor's resourcefulness in procuring a variety of specialized construction equipment to expedite various construction tasks. Removal of the RCC walls (in about 10 days), excavation of the drainage trenches in the RCC foundation, and milling of the RCC surface were completed ahead of schedule. Placement of the RCC apron at the Emergency Spillway, which commenced on February 28, 2018, is ahead of schedule, with approximately 226,000 cubic yards of the estimated 590,000 total required cubic yards of RCC placed. The contractor is producing the RCC aggregates, both coarse and fine aggregate, using an onsite crushing and processing plant in the quarry left of the FCO Chute.

The BOC understands that, to ensure meeting the required RCC production rate, the Contractor is planning to supplement the onsite sand production with sand from an offsite source. This will require additional RCC mix design testing using various blends of onsite and offsite sand.

Construction milestones since the BOC meeting of last April include:

- completed demolition of the upper section of the FCO spillway chute;
- completed 82 percent of the RCC apron placement for Phase 1 on the right side of the Emergency Spillway;
- completed milling of the RCC FCO chute foundation;
- removed the temporary RCC spillway walls;
- milled many of the underdrain trenches in the FCO RCC foundation;
- began drilling slab anchors in FCO RCC foundation;
- continued hydro-demolition work at the FCO dentates;
- obtained fly-ash source for RCC; and
- completed the FCO Gate Closure Plan.

BOC comments on specific work items observed during the site visit are provided in responses to other questions in this report that follow.

Select photographs of construction work observed by the BOC are presented on Figures 1 and 2.

Figure 1. Photographs of the completed demolition work at the upper section of the FCO chute (top) and the RCC apron at the Emergency Spillway (bottom).

Figure 2. Photos showing RCC spillway walls removed from the FCO and the milled RCC foundation looking upstream (top), and downstream (bottom).

2. Does the BOC have any recommendations or comments on construction update and schedule milestones?

Response

As noted in the response to Question 1, the construction work planned for the 2018 construction season is ahead of schedule. The Design Team and the contractor have repeatedly demonstrated their ability to effectively monitor the progress of critical-path work items, plan future work, and successfully overcome construction problems in a deadline-driven environment. Based on the progress observed to date, the BOC is optimistic that the remaining work will be completed on schedule.

3. Does the BOC have any recommendations or comments on the concrete mix design update?

Response

The Design Team and the Contractor began a cooperative effort early this season to determine if improvements could and/or should be made to the quality of the 2017 design mix of the Erosion Resistant Concrete (ERC). The goal is to reduce both shrinkage cracks and excessive temperature gradients in the placed concrete slabs.

The "2018 *Concrete Mix Design Properties Laboratory Program*" tested 15 ERC trial mix designs for slabs and 4 ERC trial mix designs for structural concrete. As a result, two new mix designs, both meeting current specifications, have been submitted by the Contractor, and approved by the Design Team.

The approved mix design for the chute slabs and wall footings is designated as 2018_ERC_520 and has a 56-day strength of 6,080 psi. The approved mix design for structural walls is designated as 2018_ERC_540 and has a 56-day strength of 5,720 psi; 90-day strength of 6,460 psi. Both mix designs have a water-cement ratio of approximately 0.44 which meets the BOC's previous comment that the water-cement ratio should increase slightly from 2017 values.

The Design Team is working with the Contractor to obtain a mix design designated as 2018_ERC_520 with 5% "Komponent" submitted and approved. This mix design substitutes 25 pounds of "Komponent" for 25 pounds of Type 2 Cement. "Komponent" is market name for a shrinkage compensating concrete additive and may be beneficial to control cracking in the chute slab and wall footing concrete.

The construction of a test slab to evaluate the proposed concrete mix designs and alternate construction methods demonstrates the Design Team's and the Contractor's ability to work together, as well as their commitment to continuously improve the quality of the constructed features of the project. The BOC was impressed with the new information gained by this effort, and particularly in learning what did not work well, so that adjustments can be made before permanent concrete placement work is resumed.

The BOC endorses the system approach that the Design Team followed to improve the concrete work by focusing on all aspects of the work including:

- Increasing the coarse aggregate volume;
- Lowering the cementitious materials volume;
- Decreasing fine aggregate volume;
- Optimizing the water-cement ratio;
- Improving curing methods;
- Improving aggregate moisture and temperature control;
- Improving the method of screeding;
- Evaluating various additives; and
- Other improvements.

The BOC was satisfied with the quality of the concrete placed in 2017, and believes that implementing the proposed improvements to concrete mix designs and placement and curing procedures, will produce sound concrete structures that will perform well and have a long service life. The BOC encourages the Design Team to publish and present technical papers to share with the dam safety community the valuable new information gained from their research.

During the site visit, the BOC spoke with the specialty subcontractor performing the hydro-demolition work on a FCO concrete slab placed in 2017. The BOC was pleased to learn that the removal of the erosion resistant concrete was more difficult than expected, despite the contractor being aware of its high strength properties. Using a water jet pressure as high as 35,000 psi with the maximum water output possible, the hydro-demolition work required almost twice the time originally planned. According to the subcontractor, the concrete being removed was the most difficult and erosion resistant that he has encountered. While inspecting the excavated concrete surface, BOC members noted pieces of aggregate exposed over almost ¾ of their surface area which could not be loosened with the kick of a boot (see Figure 3).

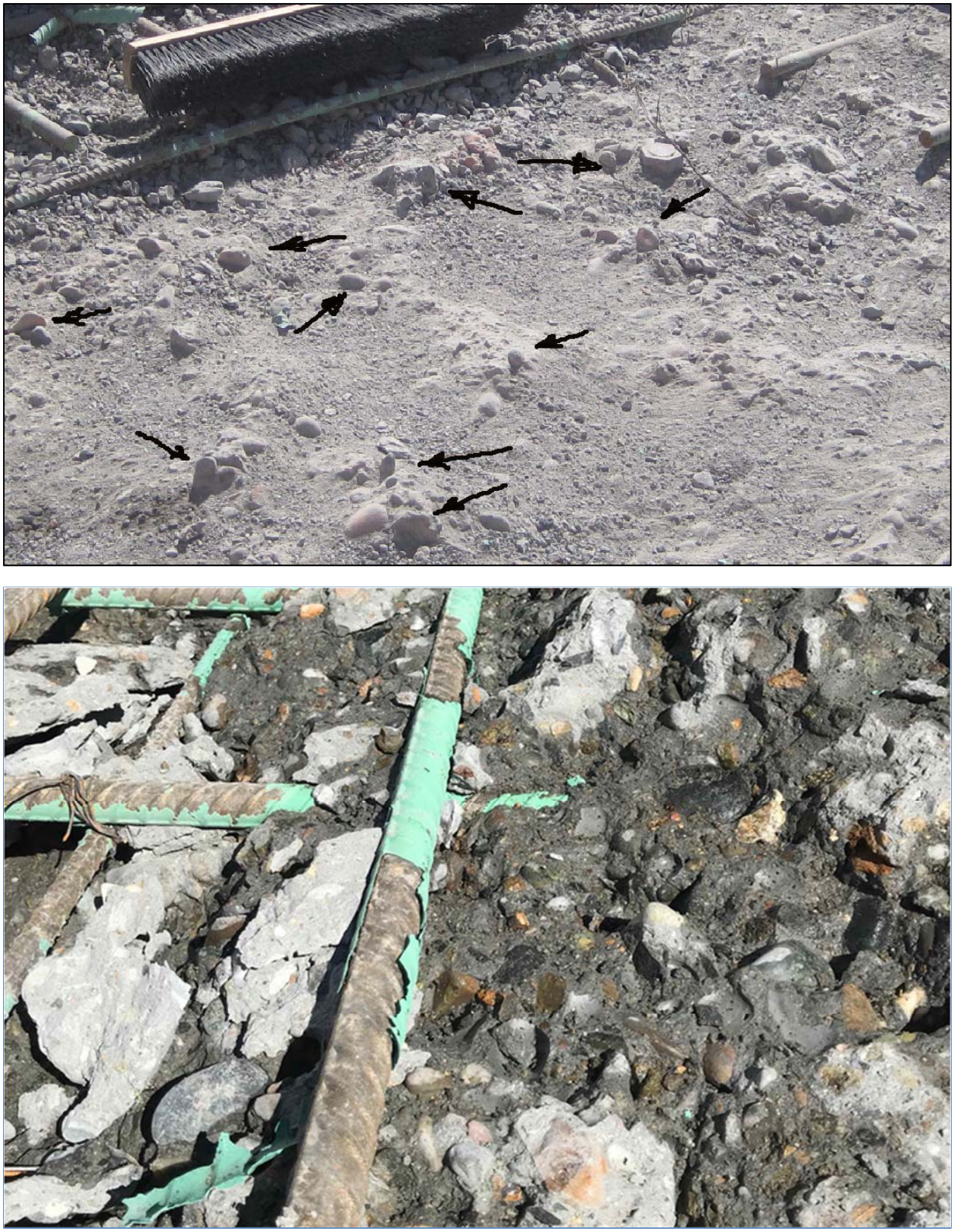

Figure 3. Photographs of the hydro-demolition equipment used on the FCO chute slab (top), and the excavated surface showing exposed aggregate tenaciously bonded to slab.

This information provides empirical evidence that the FCO chute concrete has superior erosion resistant properties. The BOC believes that this evidence should be considered by those involved in the aeration workshop and research. The BOC recommends that the spillway slab test section that was constructed to evaluate concrete mix designs not be demolished until the Design Team has an opportunity to consider its potential use for evaluating cavitation damage.

4. Does the BOC have any recommendations or comments on design revision no. 8?

Response

Design Revision No. 8 will be issued a general Drawing Document update covering a number of minor revisions and additions to be included in the construction during 2018. The revisions which were described during the presentations included the following:

- The location of the vertical drains for the Emergency Spillway RCC apron were shown in plan. Details of their installation were described. It is understood that additional drains may be installed as needed when the foundations of Phases 2 and 3 are exposed.
- A drainage blanket will be placed beneath the RCC apron in the low point of Emergency Spillway Phase 2 like that already placed in Phase 1. The drawings show the general configuration of the Phase 2 apron and the collector piping to discharge through the secant pile cutoff.
- The layout and details of the drain connections to the existing Emergency Spillway Monolith drains and collector drains beneath the added RCC buttresses feeding to outflow pipes exiting on the RCC apron have been included. Measurement of the flow from some monolith drains may become a monitoring item in the future depending on the amount of flows observed. The detail of the outfalls as shown would not permit easy measurement of flow. This could be readily solved by extending the pipe outlets or providing a channel to a measuring location.
- Longitudinal drains between cross-drainage in the RCC portion of the FCO chute were added to collect seepage at locations observed during the winter rainy season.

- The configuration of the pervious drain rock around the backfill drain piping in the area of the FCO wall footings was changed to improve constructability. It was discussed that the narrow area between the wall and the existing excavated rock slope does not provide sufficient space for the standard footing design and drain lines as presently depicted on the drawings. Because of the difficulty of trying to steepen this rock slope, it may be necessary to make some adjustments to the footing and drain placement. The design details for this condition have not yet been resolved.
- Assorted minor details for the location and cable runs for permanent FCO piezometer installations were shown.
- Provision of instrumentation monitoring facilities for anticipated future hydraulic measurement of flow and aeration in the FCO chute has been shown as a preliminary concept. The measurements needed relate to the flow [redacted] To facilitate such measurement, instrument [redacted] would be installed [redacted]

  The BOC recommends that further refinement of details for the installation [redacted] be undertaken [redacted] Installation should also be designed using materials for long-term use since the hydraulic flow studies may continue for a number of years.

  The BOC suggests that following points be taken into consideration:

  1. [redacted] should be made of a durable material such as stainless steel.
  2. [redacted] It should have adequate thickness [redacted] It is likely that commercial items of this description are available.
  3. The proposed [redacted] is believed to not be large enough and [redacted] is probably not the best material for this environment.

These details should be re-evaluated. [redacted]

4. Some tests may attempt [redacted] for analyses. [redacted]

5. While not shown on the preliminary drawing, the [redacted] would need to have local modifications and additional rebar would need to be detailed.

5. Does the BOC have any recommendations or comments on the aeration workshop and research?

Response

The objective of the aeration workshop and proposed research project is to provide the overall best final design solution for the FCO spillway. To accomplish this objective, the Design Team engaged leading experts in all aspects of this problem including experts in physical and numerical modelling, instrumentation, and cavitation. The BOC is pleased that the Design Team has engaged Dr. Hank Falvey, an internationally recognized authority on spillway cavitation, to help address this problem. FERC's contribution to the resolution of this issue, which includes expert advice from Dr. Nelson Pinto and others, is also appreciated.

The BOC continues to believe that considering the lack of clear evidence for the need for aeration, and the fact that design and construction of aerators is not possible during the current construction season, the best strategy is to proceed with the Design Teams' proposal to complete additional research on cavitation and aeration for the spillway. This research should be supported by instrumenting the spillway to monitor relevant hydraulic conditions. Results from this monitoring will contribute to the assessment of cavitation potential in this and other similar spillways.

If demonstrated by the proposed monitoring and research program that aeration is warranted, the spillway should then be modified to increase aeration and reduce the likelihood of cavitation damage. The design of the aerator(s) (number of aerators, their locations, size and details), if needed, should be performed with significant deliberation so that the modifications to the spillway are final. The

information gained by this research should be shared with dam engineers worldwide.

The BOC recommends that the Design Team develop a tentative schedule for the proposed plan that outlines specific objectives with milestones. The BOC recognizes that the schedule may be contingent on hydrologic conditions.

As part of the proposed research effort, the BOC recommends that a worst-case cavitation damage assessment be prepared for the probable maximum flood scenario. The BOC believes that given the erosion resistant of the chute slab concrete (as demonstrated by the difficult hydro-demolition of the slab surface at Panel 28E), the demanding placement tolerances and quality control for the new concrete slabs, and the relatively short duration of the PMF event, an outcome of the analysis will show that the maximum extent of cavitation damage to the spillway, assuming no aeration of the flow, could be limited to surface pitting and minor erosion, that may not require remediation following the flood event, or that can be easily repaired. This assessment should be related to case studies of cavitation damage that have been experienced at other spillways worldwide, such as the example shown on Figure 4. This important information should be considered in the deliberation over whether to modify the FCO spillway with aerators.

Figure 4. Example of cavitation damage in an open channel spillway chute (Source: The Constructor – "*Cavitation Damage to Concrete Structures Prevention Methods*")

6. Does the BOC have any recommendations or comments on reservoir operations?

Response

A presentation of the Reservoir Operation Plan was made with the three main objectives noted: (1) meeting water supply demands; (2) addressing environmental regulatory requirements; and (3) targeting low storage elevations in the fall to provide additional flood protection for unforeseen circumstances.

The reservoir at present is at Elev. 817 feet, with about 4 feet of water on the spillway gates. Current forecasts for reservoir elevation (based on total precipitation and snow pack estimates), indicate that the reservoir elevation may be drawn down to El. 800 feet by the end of June and El. 700 feet by the end of September, using "dry hydrology" projections.

7. Does the BOC have any recommendations or comments on the geology update and forensics?

Response

The presentation on geology and forensics discussed the status of RCC apron mapping; Technical Memorandum SRT-ORO-GO-12F; and the Upper (FCO) chute forensic work. The BOC comments on this information follow.

1. **Status of RCC Apron Mapping**. A map presenting the status of geologic mapping for the right side of the Emergency Spillway RCC foundation surface was presented to the BOC. This mapping shows line work (geologic and discontinuity contacts) such that an overall sense of the geologic structure can be observed. The completed mapping extends from the right limits of the emergency spillway to the approximate left limit of the Phase 1 RCC apron. The BOC looks forward to reviewing the completed geologic mapping of this area.

2. **Technical Memorandum SRT-ORO-GO-12F**. This technical memorandum and map showing the locations of planned groundwater monitoring wells and exploratory borings was presented to the BOC. Included in this plan will be 8 observation wells, 80-100 feet deep that will be placed in a row [redacted] In addition, there will be 2

exploration holes placed downstream of Emergency Spillway Monolith Nos. [redacted].

3. **Upper (FCO) chute forensic work.** Most of the presentation related to forensic work. Some of this work was detailed in a draft Technical Memorandum (SRT-FCO-GO-11) dated October 2017. Construction era geologic maps showing lithology, major discontinuities, and rock weathering of the final foundation surface were used to guide the placement of new exploratory borings to determine concrete thickness, rock conditions, and to document the interface conditions of the concrete and rock surface. This newer work was performed in support of the Design Team's needs, and as a follow-up to work performed earlier to address a request from the Independent Forensic Team (IFT) work.

   This existing forensic knowledge base about the FCO foundation is being updated by observing the ongoing construction work in the upper FCO chute from the gate structure down to the new structural slabs and walls placed in 2017 (Sta. 21+50). For example, as part of the removal of the old floor slab concrete, blast drill holes were drilled through concrete. The thickness of concrete at each hole was measured and this information compiled and presented in map view with a geologic map base. This shows how the rock weathering influenced depths of excavation and leveling concrete thickness during initial construction in the 1960s with the greatest concrete thicknesses (5 and 6 feet thick) located in areas of the "strongest" weathering. These observations show that in almost all the borings, the concrete thickness greatly exceeded the specified 15-inch minimum thickness.

Piezometers were placed underneath the upper FCO slab to address questions regarding the source of water that flowed through the drains. These piezometers were installed through drill holes that were made to obtain cores of the then existing concrete chute slab and foundation rock. Plots of groundwater elevation at three of the piezometers appear to show disassociation with reservoir levels, but the levels show direct response to rainfall and flow releases through the spillway gates. This response appears to originate from flow through joints and cracks in the chute slab concrete. Thus, during past spillway flows, water flowing through the spillway drain system came through the spillway floor and into the drain. Conversely, the historic flow in the drain system did not originate from ground water through the underlying bedrock, nor from the reservoir or the rock along the sidewalls.

8. Does the BOC have any recommendations or comments on the final tree root report?

Response

The BOC was very interested in the conclusions of the final tree root report. The report is impressive and the scientists who prepared the report are to be commended for a comprehensive and detailed treatment of this important issue. Although the findings of the report conclusively determined that tree roots did not contribute to the spillway incident, the investigations did find that tree roots, however small, did enter portions of the spillway drainage system.

The BOC was interested to learn that prior to the spillway incident, DSOD had required removal of the largest trees growing along the left spillway wall. DSOD's insightful direction to remove the trees demonstrates their active role and influence in correcting this potential problem. The BOC was surprised to learn that some of the tree roots extended as much as 100 feet from the trunk of the tree towards the drains. This important information needs to be conveyed to dam owners, regulators, and engineers nationwide. Based on this information, the generally accepted rule-of-thumb to remove trees from within 10 to 20 feet of the toe of dams and the footprint of their appurtenances may need to be revised.

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

Response

Many of the investigations that are being performed at Oroville Dam in response to the spillway incident are generating important new information and lessons-to-be-learned for the dam safety community. Specifically, the BOC believes that the planned instrumentation to measure flow dynamics at the interface of the water column and FCO spillway surface will provide needed information regarding the hydraulic forces that actually exist, rather than continuing to rely on decades old studies about cavitation pressures. This shows that DWR is willing to be a leader in this technical area and share this information with the industry. The BOC commends DWR for generously sharing this important information with the dam safety community as it becomes available.

The BOC believes that DWR's encouragement of members of the Design Team and the BOC to give presentations at national and international conferences and

seminars indicates transparency and a willingness to add to the body of knowledge regarding dam safety and the development of sound dam engineering practices.

BOC RECOMMENDATIONS SUMMARY

M18-1 The BOC recommends that the spillway slab test section constructed to evaluate concrete mix designs not be demolished until the Design Team has an opportunity to consider its potential use for evaluating cavitation damage.

M18-2 The BOC recommends a very robust design of the instrument [redacted] be investigated and developed.

M18-3 The BOC recommends that the Design Team develop a tentative schedule for the proposed aeration research plan that outlines specific objectives with milestones.

M18-4 The BOC recommends that a worst-case cavitation damage assessment be prepared for the FCO spillway for the probable maximum flood (PMF) scenario.

Respectfully submitted,

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

John Egbert **Paul Schweiger**