CESPK-ED-DS July 23, 2013

MEMORANDUM FOR: Dam Safety Section (ATTN: K. Pattermann)

SUBJECT: Argonaut Multiple Arch Dam, Jackson, California

1. Introduction

On July 9, 2013, an inspection of the Argonaut multiple arch dam was performed. The inspection team included Chris Abela PE (USACE Structural Engineer), Ken Pattermann GE (USACE Geotechnical Engineer), Dan Shane (EPA), and three members of the US Coast Guard Strike Force team. For this memo unless stated otherwise the orientation of right and left is based on facing the downstream direction.

2. Background

The Argonaut dam is a multiple arch concrete dam that was constructed around 1916 for the purpose of storing mining tailings. The dam, from historic documents, was stated to be 420ft long and 46ft tall at its highest point and ranging in thickness from 30” at the base to 12” at the top. In addition, the dam consists of 13 arches, which were reinforced with a 1” or 1 1/8” diameter hoisting cable that passed through arches and buttress walls. Historical documents provided an inspection history of the dam from 1930 to 1933. The dam is believed to be under the jurisdiction of Amador County.

3. Site Conditions and Inspection

Dense vegetation obstructed the team’s ability to visually inspect the dam. Only 3 arches, presumed to be arches 9, 10, and 11, were accessible for inspection from the top of the dam, and 3 arches presumed to be arches 1, 9, and 10 were accessible for inspection from the base of the dam, see Figures 1 & 2.

3.1. Concrete Features and Condition

3.1.1. Arches

The top surfaces of the concrete arches showed signs of wear possibly due to water running over the dam and or possibly due to freeze thaw cycles, see Figure 3. The downstream end of arches 9, 10, and 11 had signs of efflorescence staining and algae build up, indicating that the dam has been consistently leaking over time, see Figure 4. A crack was noticed at the upper left corner of arches 9 and 10 (facing downstream), which may be consistent with observations made from the inspection in February 1933, where G.F. Engle, a previous inspector, noted a crack at the right end (facing upstream) of arch 9, see Figure 5. In addition, at the base of the dam rust staining was visible on the downstream face of arch 9 where the cable had little or no concrete cover, see Figure 6.

3.1.2. Buttress Braces

The concrete braces extending between buttresses showed signs of significant spalling. The spalling was most likely due to the corrosion of the embedded cable, which over time caused the concrete to crack and eventually spall, see Figure 7. Although significant spalling was only observed on the braces associated with arches 9 and 10, it is speculated that all buttress braces are in a similar condition. The brace for arch 11 was not visible due to vegetation overgrowth. The buttress brace dimension was determined to be 12”x 22”.

3.1.3. Buttresses

The buttresses were sounded with a geologic hammer and no hollow spots were audible. The concrete surface although stained with efflorescence and algae growth appeared to be in satisfactory condition given the age of the dam. A crack was noted in the buttress wall that extended from the base towards the top of the buttress, see Figure 8. Exposed aggregate on the buttress surface was also noted in various areas, see Figure 9. The upper portion of Buttress 1 was found to have completely cracked off and hanging from its cables, see Figure 10.

3.1.4. Abutments

The right abutment was covered in moss and algae, but what was visible appeared intact and in satisfactory condition, see Figure 11. In contrast the left abutment was missing and presumed to have been destroyed during the construction of a road. Cables protruding from the ground provided some evidence of where the right abutment could have rested, see Figure 12. In addition, it was observed that a portion of an arch that connected Buttress 1 and the left abutment was also destroyed during the road construction, see Figure 13.

Figure 1 Dense Vegetation Obstructing View of Arches

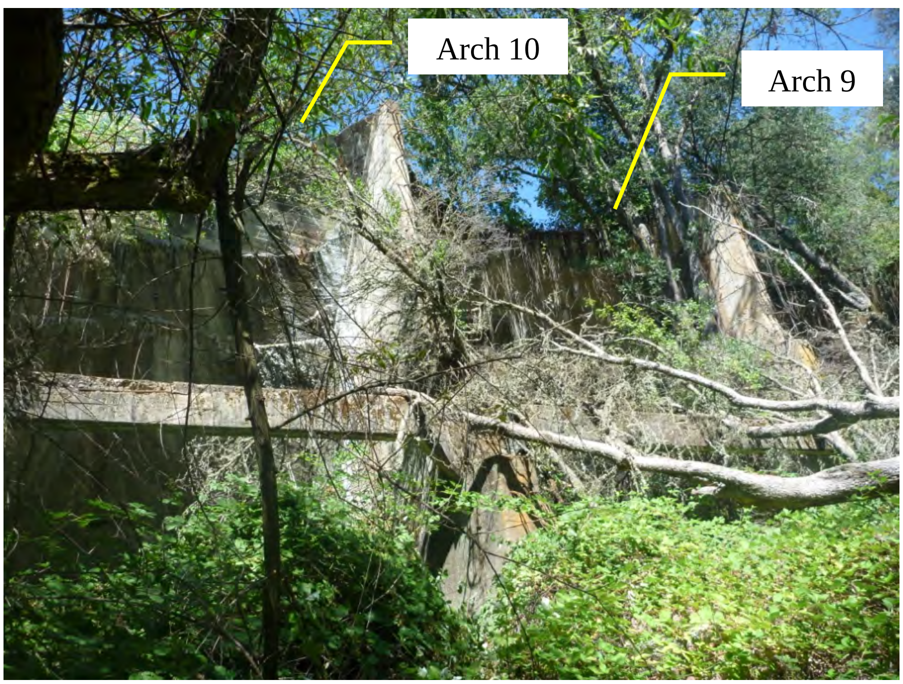

Figure 2 Arches 9 and 10

Figure 3 Worn Surface of Concrete (Typical)

Figure 4 Typical Efflorescence on Arches and Buttress Walls

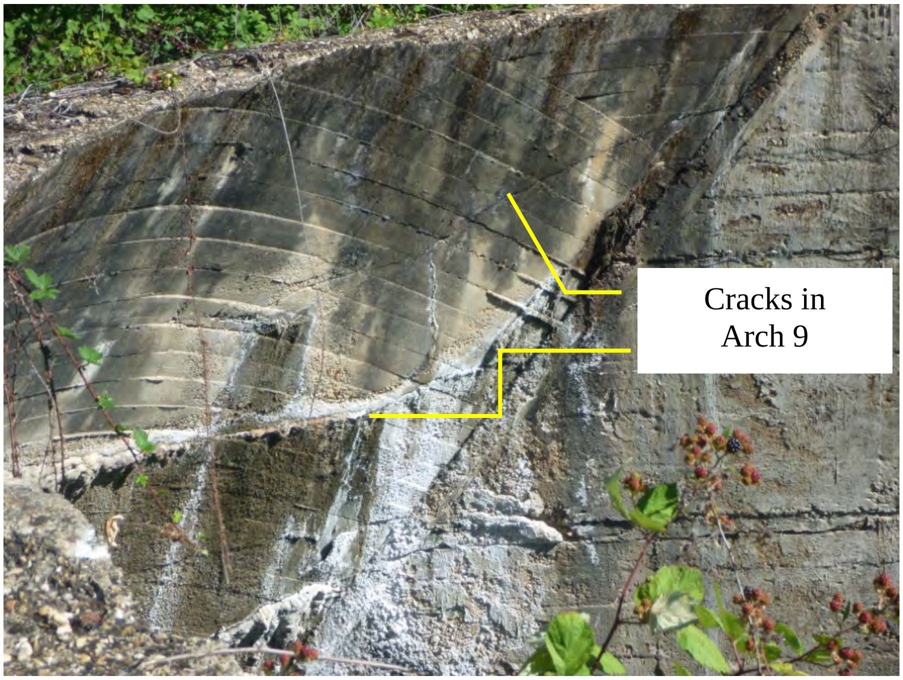

Figure 5 Crack in Arch 9 (Typical)

Figure 6 Rust Staining from Embedded Cable

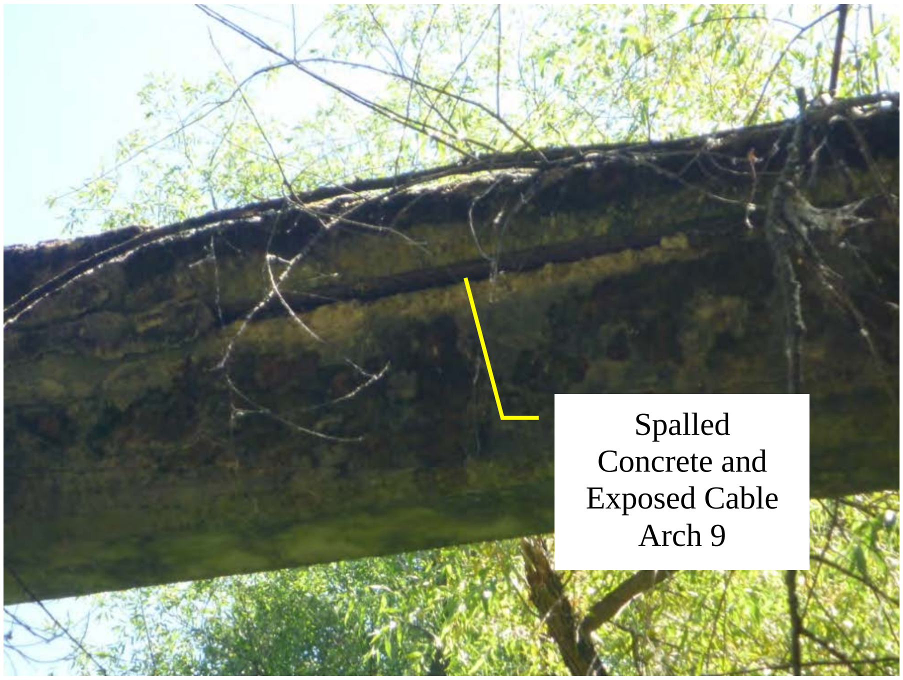

Figure 7 Buttress Brace with Spalled Concrete and Exposed Cable

Figure 8 Crack in Buttress Wall of Arches 9 & 10

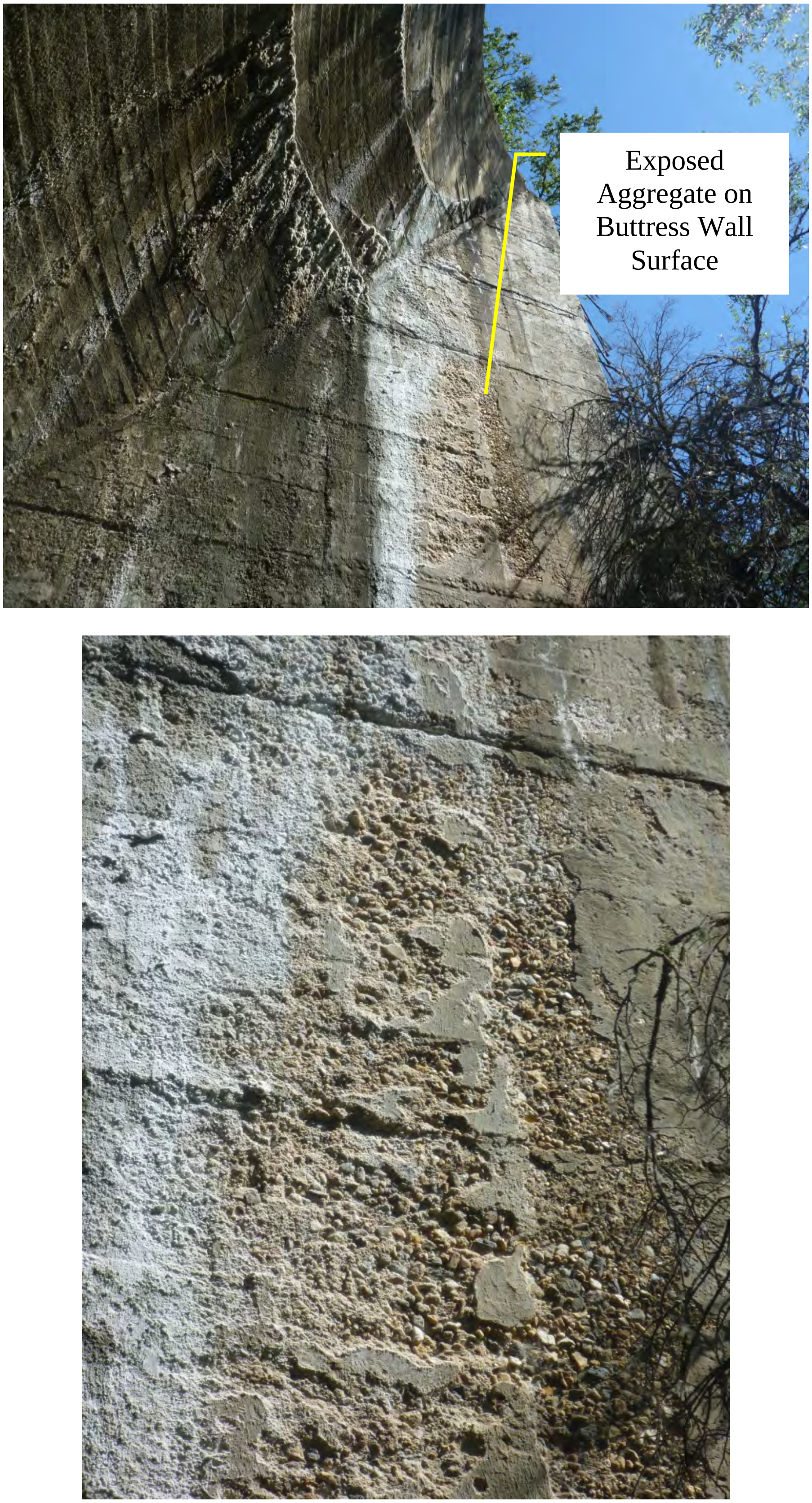

Figure 9 Exposed Aggregate of Buttress Wall

Figure 10 Upper Portion or Remains of Buttress 1

Figure 11 Right Abutment

Figure 12 Possible Remains of Left Abutment

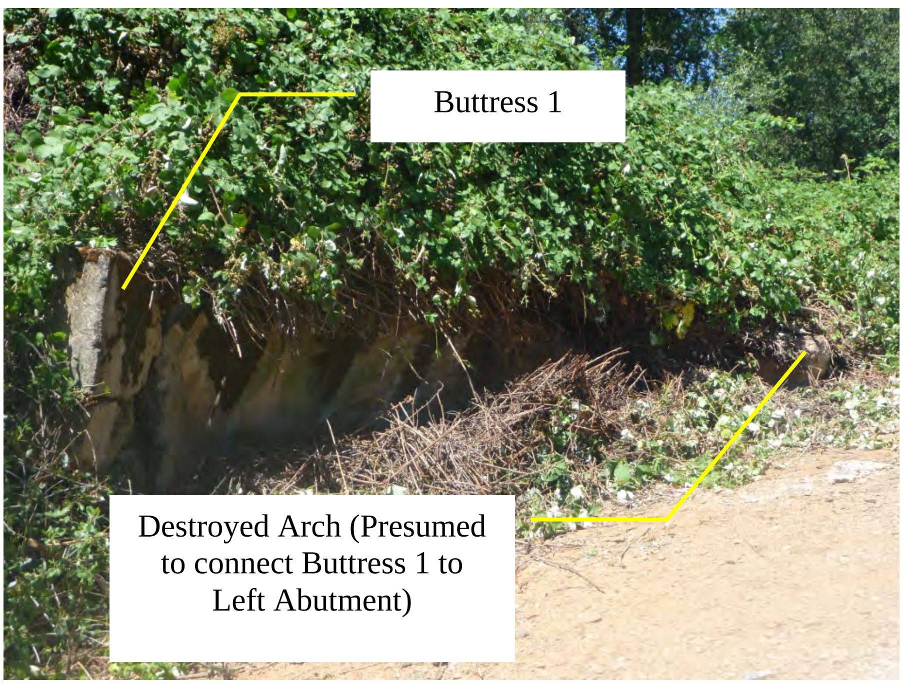

Figure 13 Arch Connecting Buttress 1 to Left Abutment

4. Historic Performance of Arch Dams

According to the Federal Energy Regulatory Commission (FERC) of 600 dam incidents (including failures) only 2 have involved multiple arch dams. These two multiple arch dam failures included: Gleno Dam in Italy, which was completed in 1923 and failed only 30 days after filling, and Leguaseca Dam in Spain, which was completed in 1958 and failed in 1987 due to deterioration from aging and freeze thaw cycles.

According to (FERC, 1999) from a seismic perspective arch dams have an excellent record of performance with respect to earthquake motion. No failure has occurred in an arch dam as a result of an earthquake. However, it should be noted that very few MCE earthquake have occurred closed enough to arch dams to truly test their performance and durability. In addition, (FERC 1997) also noted that buttresses, like those used in multiple arch dams, when unreinforced or unbraced, are susceptible to damage from lateral earthquake loading. This statement is especially concerning in regards to the Argonaut dam whose buttresses are essentially unreinforced and whose lateral braces were found to be deteriorating. It is important to note that for a buttress to be considered reinforced the reinforcement pattern should offer confinement and allow the buttress to fail during a seismic event in a ductile manner. The existing cables embedded within the Argonaut dam do not offer any confinement and it is probable that during a significant seismic event a brittle failure mode could develop within the buttresses.

5. Recommendations

From observations made during the site visit and given the close proximity of buildings and other structures downstream of the dam, the following are the structural recommendations for Argonaut dam:

a) The dam should undergo a preliminary seismic evaluation in accordance with USACE standards.

b) Vegetation downstream of the dam should be cleared and removed exposing the remaining condition of the arches, buttress braces, and buttress walls.

c) A second site visit after the vegetation has been cleared should be performed by a structural engineer to investigate the condition of the remaining 10 arches that could not be previously inspected.

d) If the seismic study is funded, several concrete core samples should be taken to determine the compressive strength of the existing concrete. Sampling of the concrete cores should be performed under the guidance of the appropriate ACI codes and ASTM standards.

6. Cost Estimate

Preliminary Seismic Study:

a) Perform hand calculations, construct 3D FEM model, perform analysis, and provide assessment report: $15, 921.60 (160hrs)

b) QC review of calculations, FEM model, and report: $5,168.80 (40hrs)

c) Final approval and review: $1, 335.90 (10hrs)

d) Follow up site visit: $995.10 (10hrs)

Final Cost Estimate: **$23,421.40**

7. References

1. Federal Energy Regulatory Commision, (1997) "Chapter 10 Other Dams" Engineering Guidelines for the Evaluation of Hydropower Projects.

2. Federal Energy Regulatory Commision, (1999) "Chapter 11 Arch Dams" Engineering Guidelines for the Evaluation of Hydropower Projects.

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