CESPK-ED-DS November 19, 2013

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

SUBJECT: ARGONAUT TAILINGS STORAGE DAM - SECOND INSPECTION

1. Introduction

On November 15, 2013, a second inspection of the Argonaut multiple arch dam was performed, to investigate the condition of the dam holistically with special interest given to the concrete arches, buttress walls, and struts. The inspection team included Chris Abela PE (USACE Structural Engineer), Ken Pattermann GE (USACE Geotechnical Engineer), and Dan Shane (EPA). A second inspection of the dam was performed based on the recommendation of the first inspection memo, which recommended that the existing vegetation be removed to allow access to the entire dam. The weather during the inspection was clear with the temperature in the mid to high 60s. 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 steel wire rope that passed through arches and buttress walls. Historical documents provided an inspection history of the dam from 1930 to 1933. Water overtopping the dam appears to be a common occurrence given the erosion on the tops of the arches and photos of water overtopping the dam as recently as 2006. The dam sits approximately a quarter mile from business within the Jackson community on private property owned by Ms. Van Horn. Current access to the dam is being coordinated with Mr. Ken Foley the property owner’s lawyer.

3. Seismicity of Argonaut Dam

According to the USGS 2008 Hazard Map (PGA, 2% in 50 years) Amador County is located in a moderate to low seismic region. (Appendix A)

4. Site Conditions and Inspection

Following recommendations from the initial inspection, much of the dense vegetation was removed allowing for better access to the concrete arches. Inspectors were able to inspect all 13 arches from both the downstream and upstream sides. (Figure 1)

4.1. Concrete Features and Condition

Appendix B provides an upstream elevation view of the dam with the arches, buttresses, and struts all numbered and locations identified.

4.1.1. Arches

The top surfaces of all the concrete arches showed signs of erosion possibly due to water running over the dam and / or possibly due to freeze thaw cycles, see Figure 2. All downstream faces of the arches have signs of efflorescence, rust staining from the embedded wire rope, and algae build up indicating that the dam has consistently seen water during its service life, see Figures 3 and 4. It is postulated that the areas of the efflorescence, rust staining, and algae build up coincide with locations of the wire rope. The wire ropes, due to improper concrete cover, may have corroded causing cracks in the concrete, which lead to efflorescence, rust stains, and water to leach out. Many of the arches also were observed to have large piles of soil between the buttresses. It is unclear if the soil piles were put their intentionally during the construction of the dam (due to left over formwork, Figure 5), or if it was deposited over time during overflow events.

Arch #1 on the far left side was found to be severely deteriorated and buried; perhaps due to the construction of the road for the subdivision above the dam. (Figure 6) Cracks were noticed at the upper left and right corners of Arches #7, #8, #9, & #10, which is consistent with observations made from the inspection in February 1933, where G.F. Engle, a previous inspector, who noted a crack at the right end (facing upstream) of Arch #9, see Figure 7. It is also important to note that water was observed to be pooling behind Arch #7. However, at this time it is unclear where the water is coming from. Arch #11 was discovered to have a hole through its right side, which does not appear to be a recent development due to the buildup of material beneath it. The hole diameter was approximately seven inches. Arch #13 was found to be mostly buried with very little exposed to perform a thorough inspection. (Figure 8) Overall the arches seemed to be performing adequately to resist the soil and water forces pressing up against the dam. However, some arches like Arch #11 do pose structural concerns.

4.1.2. Buttress Braces

All concrete braces extending between buttress walls showed signs of significant concrete cracking, delamination, and / or spalling. The brace in the worst condition was Arch #5, which had two large horizontal delamination cracks; one at the top 6” and one at bottom 4.5” of the member. In addition, a large vertical crack at the far left support was also observed that extended through the entire member’s cross section, see Figure 9. The large horizontal cracks, typical to all braces, is most likely due to the corrosion of the embed wire rope, which over time expanded causing the concrete to either crack, delaminate, and /or spall off the member completely. (Figure 10) In the case of <u>Arch #5</u> the bracing member <u>has completely failed</u> and is only being held in place by the bottom wire rope and supporting concrete seats. Because the braces play an important role in bracing the buttress walls along their weak axis, their poor condition raises serious concerns of the dam’s ability to withstand seismic events in the cross canyon direction (parallel to the dam).

4.1.3. Buttresses

Given the condition of the first arch, the first buttress wall was presumed to have been demolished during the construction of the road and subdivision. The exposed portion of the #2 buttress wall was found to be in severe deterioration with only the wire ropes holding the concrete together. (Figure 11) The #4 and #5 buttress walls showed signs of concrete cracking and spalling around the locations of the embedded wire ropes. The symptoms and cause of distress of the #4 and #5 buttress walls seemed to match those of the concrete brace, (corrosion of the embed wire rope). (Figure 12)

Buttress #6 was found to have a diagonal crack that appeared to pass through the entire walls cross section, see Figures 13 and 14. At this time it is uncertain whether the crack was caused by arch forces pushing on the buttress wall or if the soil/rock underneath the buttress has settled. It was also observed that Buttress #8 had a nearly identical crack in terms of size and location. (Figure 15)

The remainder of the buttress walls appeared to be in satisfactory condition, despite the surface staining of algae, efflorescence, and exposure of some of the aggregate. There is a general concern regarding the buttress wall's overall strength in both the weak and strong axis under seismic loading given the lack of proper reinforcement and the condition of the braces that extend between the taller buttress walls. Because of the significant role the Buttress's play in maintaining the dam's stability, it is recommended that cores be taken to determine the compressive strength, and unit weight of the existing concrete. If it is decided that a structural analysis will be funded, both of these values will be useful in performing an analysis on the dam's stability.

4.1.4. Spillway

The spillway, which is located on the far left side of the dam, was found to be completely demolished. Remnants of the spillway were found behind Arch #1. (Figure 16) The slot in the concrete shown in Figure 16 matches a sketch of the spillway from historical documents.

Figure 1 View of Concrete Arches (Looking at Downstream Side from the Furthest Left Arch)

Figure 2 View to the Left of Arch 8, Typical Worn Concrete Surface

Figure 3 Typical Efflorescence, Rust Staining, and Algae Build up on Arches and Buttress Walls

Figure 4 Rust Staining on Downstream Arch Face (insufficient cover around wire ropes)

Figure 5 Leftover Formwork from Construction of the Dam

Figure 6 Visible Remains of Arch 1

Figure 7 Crack in Arches 7, 8, 9, & 10 Typical Both Sides

Figure 8 Exposed Portion of Arch 13 on the Far Right

Figure 9 Concrete Brace at Arch 5

Figure 10 Bracing at Arch 7 Showing Signs of Cracking, Delamination, and Spalling (Typical)

Figure 11 Buttress Wall 2 in Severe Deterioration

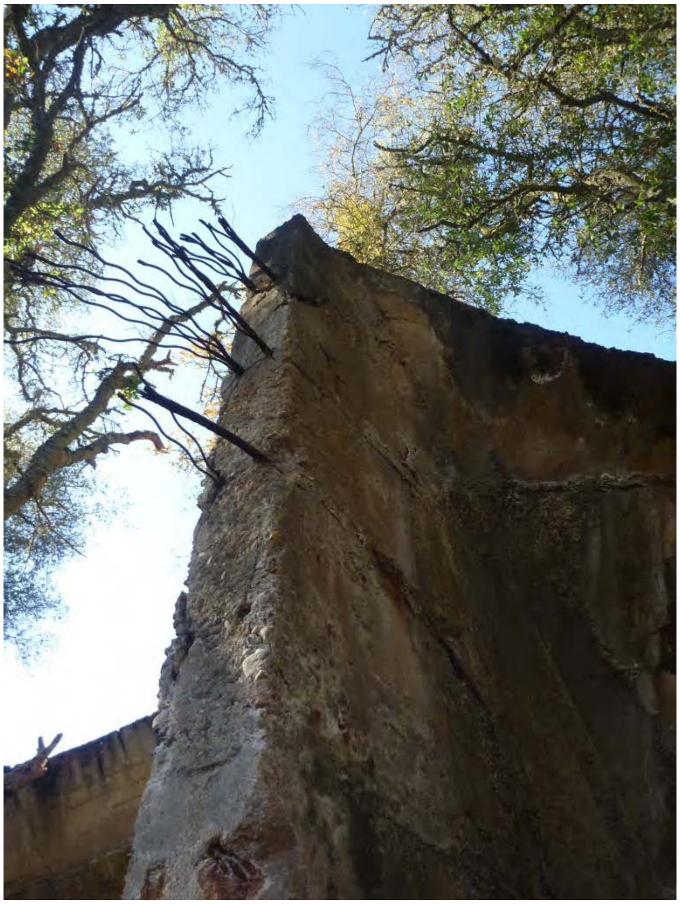

Figure 12 Butress Wall #4 Showing Signs of Cracking and Spalling Around Embed Wire rope

Figure 13 Diagonal Crack on Left Side Buttress #6

Figure 14 Diagonal Crack on Right Side of Buttress #6

Figure 15 Diagonal Crack in Buttress #8

Figure 16 Remains of Spillway

5. 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 close 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 and in some cases completely failed. 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 wire ropes 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.

6. Conclusions

Given the relatively close proximity of the dam to businesses, condition of the existing struts, and the fact that the dam is unreinforced, further investigation into the dam's overall stability is warranted. Of special interest / concern is the dam's stability against seismic loading conditions. As underscored by various FERC documents multi arch or buttress dams are susceptible to damage under lateral earthquake loading. The buttress walls are critical to holding back the existing tailings and ground water. Failure of a single buttress would most likely lead to failure of the dam and pose a life safety risk to businesses and people downstream.

7. Recommendations

The following are recommendations on how to begin evaluating the Argonaut dam's stability:

a) The dam should undergo a preliminary static stability and seismic evaluation in accordance with USACE standards, (ER 1100-2-1156, Phase I of Appendix AC) to identify stability and seismic deficiencies.

b) Upon receiving funding for the preliminary static stability and seismic study, several concrete core samples are recommended to be taken for determining the compressive strength and unit weight of the existing concrete. Sampling of the concrete cores should be performed under the guidance of the appropriate ACI codes and ASTM standards.

c) Provide recommendations on the repair and future analysis of the dam in the event that stability and/or seismic deficiencies are found.

d) Conduct Standard Penetration Test (SPT) drilling and geotechnical lab testing. (Pattermann and Abela, 2013)

e) Conduct geotechnical seepage and stability analysis of the upper earth tailings dam. (Pattermann and Abela, 2013)

8. Cost Estimate Update after Second Site Visit

An updated cost estimate to carry out both the preliminary stability and seismic study will be furnished in the final draft of this memo in the near future.

9. References

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

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

3. ER 1110-2-1156, (2011). Engineering Regulation "*Engineering and Design -Safety of Dams - Policy and Procedures,* United States Army Corps of Engineers, Washington, DC.
4. Pattermann, K. R., Abela, C. M. (2013) "Argonaut Tailings Storage Dam – Initial Inspection", United States Army Corps of Engineers Memorandum, July 30, 2013.

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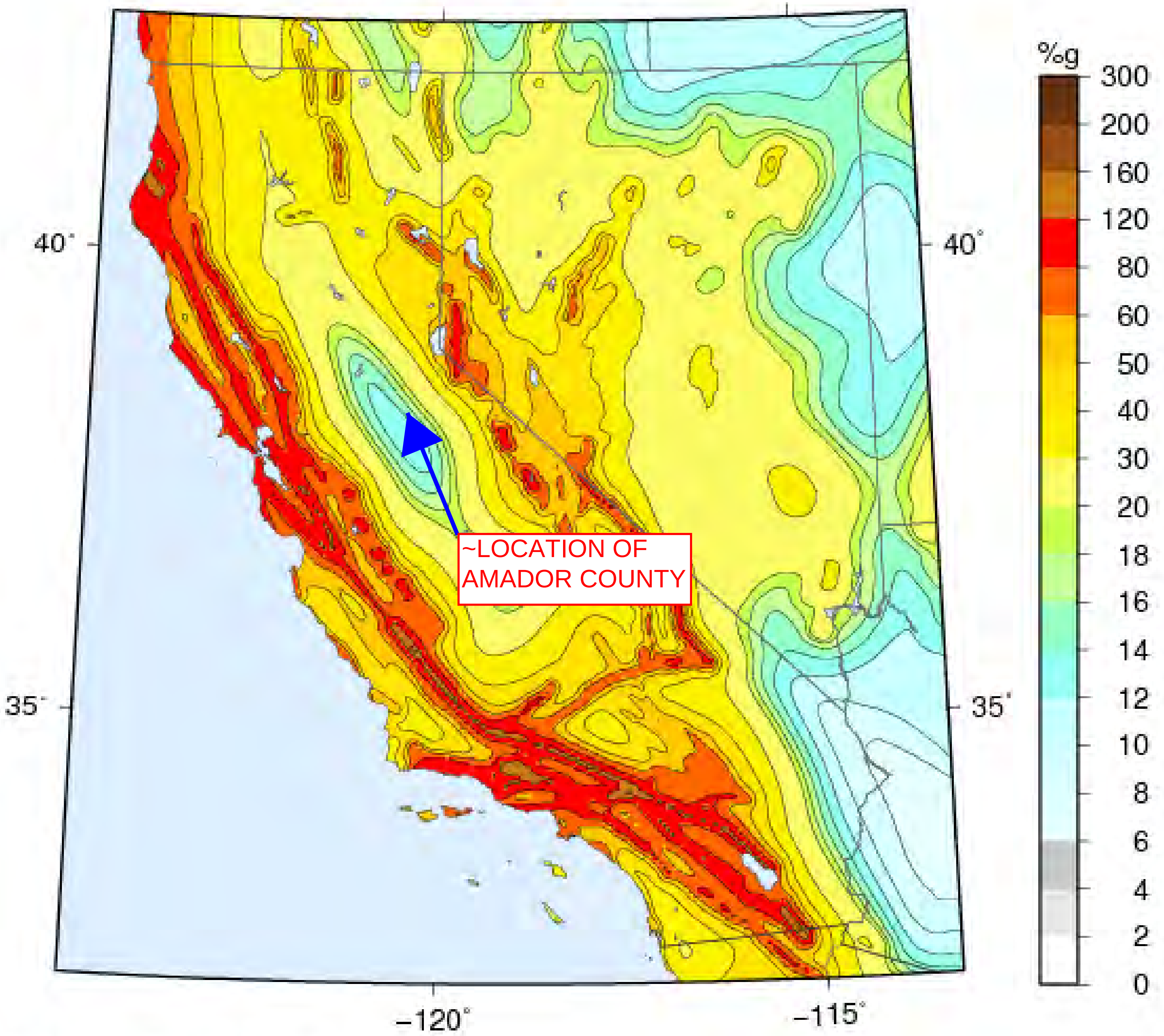
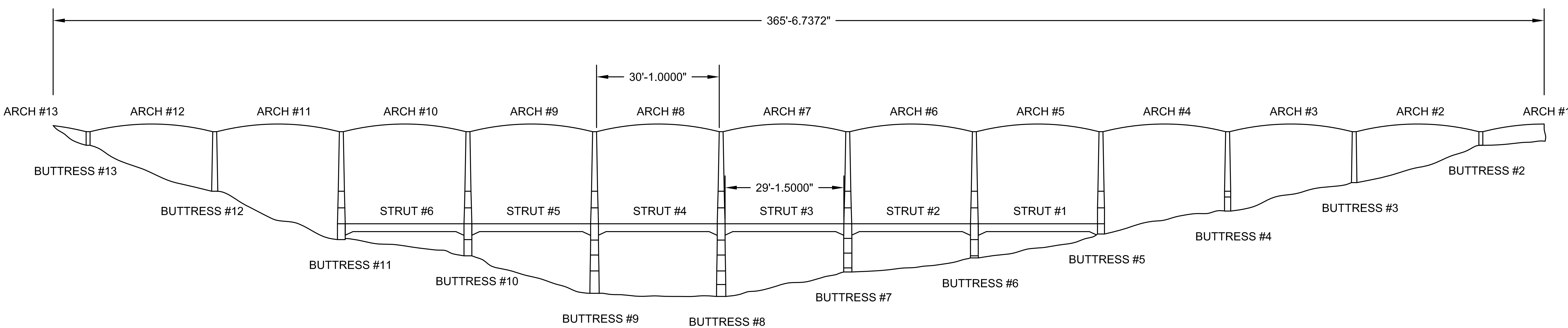
Appendix A

Custom Hazard Map



Peak Ground Acceleration

Appendix B



UPSTREAM ELEVATION VIEW