11 March 2020
Supplement to Witness Statements 1 & 2 by Ernest Schrader

After testimony yesterday and earlier today, the following brief comments are provided to assist the PDI and supplement what I have said in my Witness Statements 1 & 2.

There still seems to be a perception that BDA simply assumed that a lean RCC mix was the best and only approach to the dam, and also that much better strengths would automatically have been achieved with a high cementitious content mix with fly ash.

The BDA team did not start with the pre-conceived idea that lean mix with no ash would be the best solution. Our mix deisgn and initial investigations included higher cementitious content mixes and various ash contents. Our specifications were developed and implemented to cover both high and low cementitious content mixes, with and without fly ash so that we were not locked in to one option and could adapt to whatever turned out to be the ultimate best approach based on test results as it because available, and also on input from the owner. If results of mixes with ash, including accelerated testing, or input from the owner (client) indicted that using ash and a different mix was technically and economic better our design process and our specified construction equipment allowed this adjustment to be made up until the start of RCC placement with no impact on schedule.

There are several reasons for avoiding ash if it is not necessary. Although ash produces only a small amount of additional heat, it causes the RCC to become more brittle in the long term. This means that the RCC is more prone to cracking when the dam cools after several years. This problem has been experienced at a number of projects where low heat of the ash was initially considered a big plus, without adequately evaluating all of its impacts. One example is Platanovryssi dam where a proper re-analysis of the original thermal study indicated that, after award of the construction contract, the number of monolith joints had to be doubled, dam construction and RCC placement had to be stopped for the entire summer despite using 100% ice for mix water, and the structure was still stressed to its maximum. In fact, cracking developed after several years with serious maintenance and repair consequences. It was remediated by installation of the same membrane used at Paradise.

Other reasons for avoiding ash include concern about availability of consistent material at the rate required, minimizing truck traffic to the dam, simplicity in proportioning and mixing at the concrete plant, and eliminating the potential of putting ash into the silo where the cement should go. These problems are real and occur despite normal preventative measures.

There also seems to be a perception that lift joint quality is not an issue, or at least much less of an issue, in higher cementitious content mixes with fly ash. The reality is that lift joint cleaning and inspection arguments have been a major issue and problem at these types of dams, just like they can be on lean mix RCC. An example is the recent San Vincente dam in USA, now completed. A very major problem was significant delay by disagreements in the field over what constituted adequate lift joitn cleaning and preparation (the LJQI was not used). The contractor was given a very significant ward for a claim regarding this problem.

Another very significant problem, cost, and cause of construction delays with high cementitious content mixes, as well as poor final appearance and safety concerns during construction, is the fact that these types of mixes produce much more pressure against forms (shutters) than typical lean mixes. They push out due to this pressure. The supports can fail unless the rate of placement is decreased. This occurred at both Olivenhain dam and San Vincente dam. By the way, both of these projects with high cementitious content RCC mixes used the same upstream membrane (Carpi) as used at Paradise.

The point is that there are tradeoffs with different advantages and disadvantages for both types of RCC. Neither one is without issue.

As support for the statement that the BDA considered fly ash and higher cementitious content mixes, the very initial mix program of about 20 different mixes was, carried out to completion, included mixes with 0% to 60% fly ash and cement contents of 70 to 120 kg/m^3. Fly ash mixes performed very poorly both from the standpoints of strength and by the fact that they did not noticeable extend the length of time before the mix hardened or set.

As discussed in my Statement 1, this is consistent with results of the Thiess high cementitious content mix design program. Those mixes used cement (only) contents similar to the BDA lean mixes but with added 135 to 155 kg of fly ash. They achieved essentially the same long tem compressive strengths as the lean mixes without fly ash. The maximum achievable shear cohesion is directly related to compressive strength, so it both types of mixes can be expected to have similar shear strengths.

This poor performance of fly ash and high cementitious content mixes at Paradise is a bit peculiar, but has occurred elsewhere with similar basalt and materials. Mujib included some vesicular basalt along with glassy basalt, similar to the Paradise material. Mujib also included quarry contamination that was found to be less than ideal, but acceptable and economical for the needs of the project. Mujib mixes made with high cementitious contents and high fly ash contents had similar strengths to lean mixes without fly ash. The project was initially designed, tendered and, awarded for construction based on a high cementitious content, high ash, mix, but this was then questioned and re-evaluated. Investigations showed that the better alternative was a lean mix (85 Kg) with no fly ash. It used bedding at the upstream face in the zones to avoid cracking and to provide an area of higher cohesion for added shear stability (friction 45 degrees). As reported in my witness Statement 1, the redesign added an upstream membrane, but it was eliminated after initial construction because the quality of lift jojnts was judged to be very good and water tight due to excellent inspection by the full time on-site RCC engineer Jose Lopez (our primary on-site RCC & QC Engineer at Paradise).

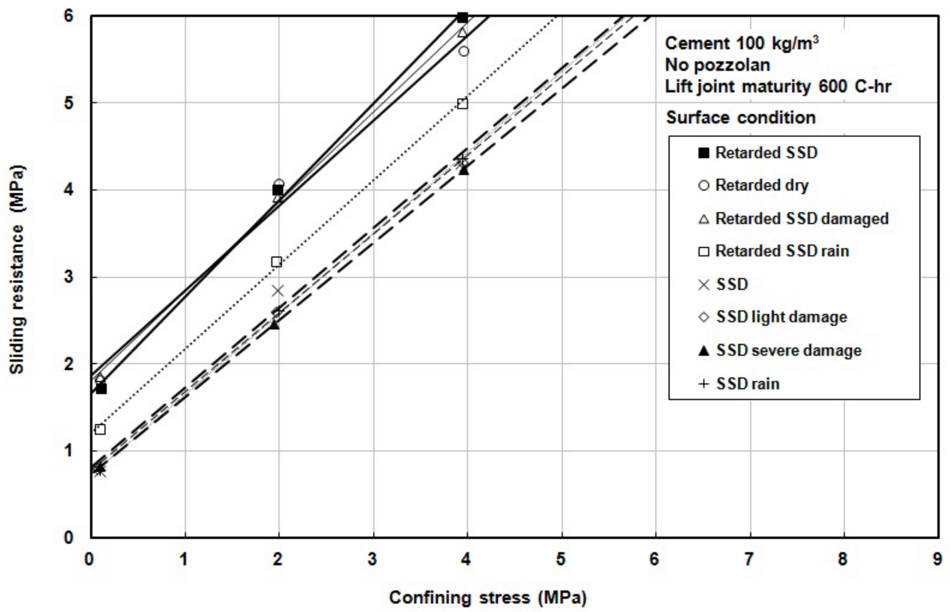
Lean mixes for Willow Creek Dam also had excellent results with glassy basalt and quarry overburden contamination, as did Burton Gorge where weathered and “contaminated” rock was deliberately included in the mix to lower the modulus. “Contamination” and rock fines produced in this type of operation have proven to be detrimental to higher cementitious content mixes, but beneficial to lean mixes. Basalt rock fines can be pozzolanic (similar to “free” effective fly ash) in lean mixes, but not in higher cementitious content mixes with ash.

The point is that for the conditions and materials at Paradise using a different type of mix with high fly has content and high total cementitious content probably would have had similar shear friction and cohesion. It also would have had its own types of problems and issues, including lift joitn quality.

There has been discussion about the nuclear gauge used for checking density. There are two types of meter. The cheaper and easier one to operate has a single probe. The probe is inserted to different depths in the lift, from top bottom, usually at 100 mm or 50 mm increments. The goal is to include a reading at the bottom of the lift, which might be less than 300 mm at times. The probe can only be locked in position for testing at 50 mm increments. The single probe gauge sends nuclear radiation from the end of the probe to the base plate of the gauge. The density at the bottom of the lift has only a very slight influence on the actual density that is reported for that depth. This can be very misleading.

The single probe gauge is most commonly used in RCC because out is lighter, easier, much more available, and from contractor's perspective it tends to show better results, especially at the bottom of the lift. At paradise I insisted on having the double probe gauge because it confidently indicates the real density at every depth checked. It uses two probes, each of which is lowered in the lift to the designated depth. The radiation is emitted from one probe and registered at the other probe. The nuclear gauge at Paradise was also very carefully calibrated so that it would accurately indicate density at every depth with the particular RCC used at the project, not just with a standard calibration block as is usually done with questionable credibility.

The 1999 published shear article by myself includes justification for the impact of different lift joint conditions on both friction and shear. One of the most useful figures showing this is Figure 7 of the article, below.



This is a relatively lean dry mix with no fly ash (pozzolan). SSD mean Saturated Surface Dry, which is when the surface just starts going from damp to dry at the surface. That is, it is still saturated. Clearly, cohesion is affected by different lift surface conditions but the friction angle essentially stays the same regardless of lift joitn condition - SSD, dry, rain, light damage severe damage.

Figure 9 of the article, below, demonstrates that the fiction angle is also independent of cementitious content, lift joitn maturity, whether the mix is retarded, and whether or not it has bedding.

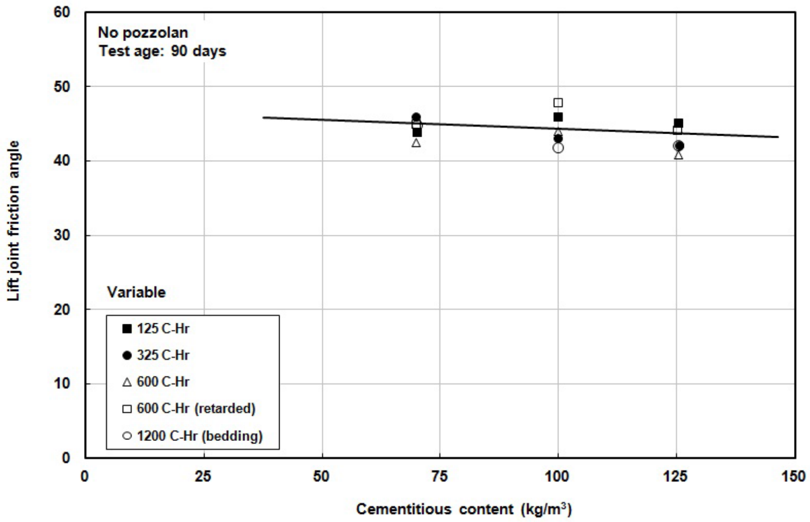
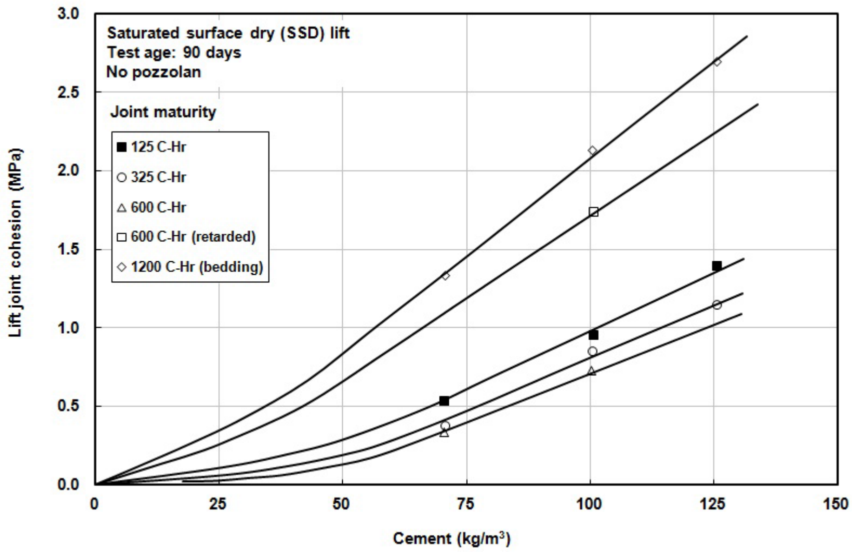


Figure 11 of the article, below, shows that cohesion is definitely affected by cementitious content and lift joint maturity. It also shows that full cohesion of a very mature joint (1200 degree hours) can be re-established by using a bedding mix. It can also be accomplished by using a high dosage of retarder as is typically done for high cementitious, high ash content RCC. At Paradise we attempted to gain longer maturity time with the use of retarders but with only marginal results.



Mr. Dolan and I are in agreement on his main concern that if the bottom of the lift is porous and not well compacted it can be expected to significantly reduce friction. If, in fact, the bottom of a layer is loose and very poorly compacted it will decrease friction. I suspect we may have some isolated places (without bedding) where this may have occurred but I expect that they are very small areas that are discontinuous and have little influence on the overall frictional lift surface sliding resistance. The issue is whether the overall average in-situ condition at the bottom of each critical is adequately compacted. Hence the need to saw or excavate trenches into the RCC in order to actually see what is really inside.

Dr. Ernest Schrader