16 March 2020
Supplement (2) to Witness Statements by Ernest Schrader

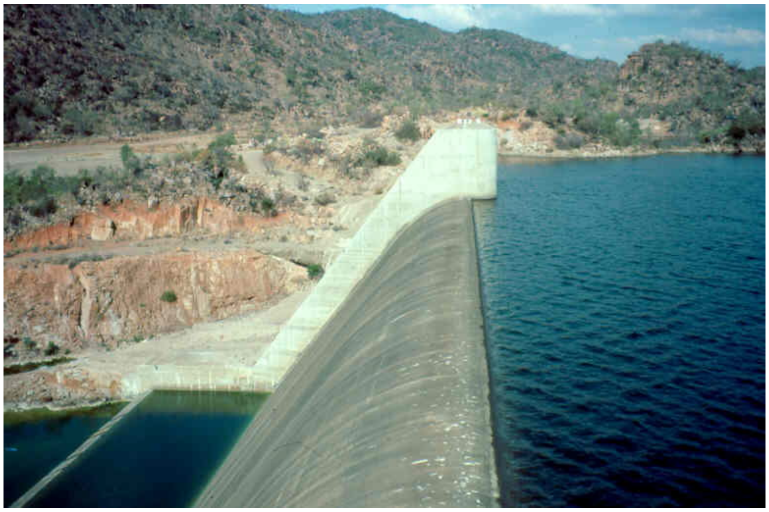
PDI would benefit from a series of photographs first to show that RCC dams are routinely designed, constructed, and operated without doing any shear tests. Counsel assisting seems to be under the completely false impression that not doing shear tests at Paradise represents bad engineering practice. This is incorrect. It is routinely done. In fact, it would be extremely unusual for a dam the size of Paradise to do any shear tests. The competing Thiess team did not do, or propose, any shear tests and, as tabulated in my Witness Statement 1, compressive strengths for their mixes were similar to the BDA mixes. Therefore cohesion would be expected to be similar, and because friction is almost totally dependent on aggregate, the friction angle with whatever mix the Thiess team would have used would have been similar to the BDA mixes.

A second series of photographs are then included that show the typical routine and good construction practices at Paradise dam without segregation or damaged lift surfaces. These photos are counter to what has been postulated by counsel assisting and people who never saw the construction or the RCC mix at Paradise. The RCC at Paradise typically had very good contact and compaction at lift joints without porosity at the bottom of the layer. This was continually observed and documented as the dam was built.

Finally this second supplemental statement briefly counters examples of other incorrect suppositions, postulation, and implications by people who were never at the jobsite and apparently have not accurately or thoroughly reviewed factual data such as records of extensive density testing. It also includes comparison of material properties for RCC mixes made with and without Goodnight material.

Following are some examples of RCC dams that did not do shear testing at the time of design, construction, or post-construction. They include dams with RCC mixes ranging from lean to high cementitious contents, no fly ash to high fly ash contents, wetter to drier consistencies, different quality aggregates, and maximum size aggregate from about 25 to 76 mm. This is just a small sampling from hundreds of examples. The vast majority of both RCC and conventional concrete dams around the world, including Australia, do not have shear tests, and possibly **all** RCC dams the size of Paradise do not have shear tests.

-Middle Fork Dam, USA.
-Low Cementitious, 66 kg/m^3
-No Fly Ash.
-Severe Exposure -40 C to +40 C
-76 mm Aggregate.
-Very Low Quality Marlstone
(Oil Shale) Aggregate.



- Copperfield Dam
- Australia
- Low-Med Cementitious.
- Dry Mixture.

- Loyalty Road Dam
- Australia
- Low Cement (80 Kg)

- Rompepicos Dam
- Mexico
- 109 Meters High
- It has contained several cyclones with no damage to the dam but severe damage to the downstream channel.

- Mujib Dam
- Jordan.
- 62 Meters High
- Low Cement, 80 Kg
- No Fly Ash.

- Burton Gorge Dam
- Australia
- Lean Mix, 80 Kg
- A major flood eroded the downstream channel, but there were no repairs to the dam or the RCC apron.

- Urugua-I Dam
- Argentina
- Low cement mix, 66 Kg
- Floods and major discharges every year at the rainy season.

- Buckhorn Dam, USA.
- The 10,000 year flood occurred a few weeks after completion. The tailwater was higher than the spillway crest. The downstream channel was damaged but the RCC dam and RCC apron were OK.

- Aoulouz Dam
- Morocco.
- 55 Meters high.
- Lean mix.

- Wyaralong Dam
- Australia
- Many of the same people worked on both Paradise dam and Wyaralong Dam.

The next series of photos shows that Paradise was built with good practice and quality. These photographs are of typical conditions, with the RCC being quite consistent, without segregation, clean lift surfaces, and typically no porosity at the bottom of the RCC layers. I was there. I saw it. I took the photographs. I know the typical good quality that was placed.

My direction to Jose Lopez and Roberto Montalvo was to keep excellent routine records of testing and LJQI, but to put emphasize on improving whatever could be improved. That is what they did. I was more concerned with the 1% that could be improved than I was with the 99% that was routinely quite acceptable. This is what Jose and Robert did. They concentrated on photographing items that could be improved, documenting this in memos, and using the information for constructive criticism during the work and with various PowerPoint presentations. Critics who were not on the job are now trying to find whatever they can to portray the work of Mr. Lopez and Montalvo as representing consistently faulty work. In reality all RCC dams have occasional issues such as low density readings that are then typically re-rolled or otherwise corrected.

Placing RCC directly from the conveyor into a confined area in December 2004. The RCC is very fresh, about 2 minutes after mixing when it is deposited. Placed on fresh bedding mix. The abutment contact is clean. There are three men assuring a clean surface with air for blowing and a large vacuum tube for sucking.

Typical rolled and clean RCC surface in December 2004. Moist and well cured lift. No damage. The roller leaves “ridges” and irregularities that represent “roughness” which is not represented by the small smooth surface of a core.

Freshly placed RCC. No segregation within the layer and none at the base of the layer. The surface in front of the RCC is clean and at ideal moisture for placing. That is, at or just less than saturated surface dry (SSD). This allows blowing off fine dust and sand grains. This moisture is also ideal for bonding. Compaction is occurring quickly, within about 5-10 minutes of placing.

Typical clean compacted surface of an RCC layer. This is ideal moisture for cure, at about Saturated Surface Dry (SSD). Someone expert in design (but not materials or construction) or who is not familiar with this type RCC might erroneously think it appears unacceptably dry.

Spreading fresh RCC towards the upstream face, over about a 5 meter width of fresh and well spread bedding. No segregation. Even *before* compaction there is no “porous” zone at the bottom of the RCC layer. Note the appropriate use of one dozer to push the RCC towards the face with another working parallel to the upstream face. Mr. Tarbox erroneously referred to spreading RCC towards the upstream face as being bad practice that caused segregation.

March 2005. Conveyor across the top of the dam. This eliminated the need for trucks to haul onto and off of the dam. It also eliminated about 95% of what would have been trucks hauling over the RCC with associated damage & contamination. The lift surface is clean and at appropriate SSD, or slightly wetter condition. This may look drier to an untrained eye, but this is ideal moisture. RCC is being placed at the far end of the dam.

Loading very fresh RCC into a truck from the conveyor for the short delivery to the close by area to the left that the conveyor configuration could not reach at this location and time. The mix is immediately being spread. Supervision and inspection are looking at the advancing face of the RCC.

March 2020. Note the very similar RCC mix and consistency throughput all the photographs. No segregation. No porosity at the bottom of the layer even before compaction. Routine clean lift surfaces. Proper moisture (SSD or just below). Fresh and properly spread bedding just in front of the RCC for the upstream zone.

Depositing RCC from the conveyor in windrows and spreading forward by the dozer. The windrows were deposited on top of the fresh RCC and kept to very low height in order to control segregation. If any segregation did occur, the dozer re-mixed it as he spread forward. Even though this is a downstream area where a lower quality lift surface could be tolerated, bedding has been spread over the isolated no-critical small spots of damage.

Aggregate was produced and stockpiled as an "all-in" gradation material. This helped consistency and reduced any tendency for segregation. The dozer kept the aggregate mixed and re-mixed without damaging the particles. Many special procedures were adopted to assure a uniform mix without segregation. Note that even before the cement is added and the material goes through the mixer it has little tendency to segregate.

Another special procedure used to assure quality and uniformity, as well as to cool the aggregates was continuous misting of the stockpiles. Note again the lack of segregation with this gradation and the procedures used. The gradation was also developed so that there would be adequate "paste," mortar, and compactability, and to achieve a good layer to layer RCC interface.

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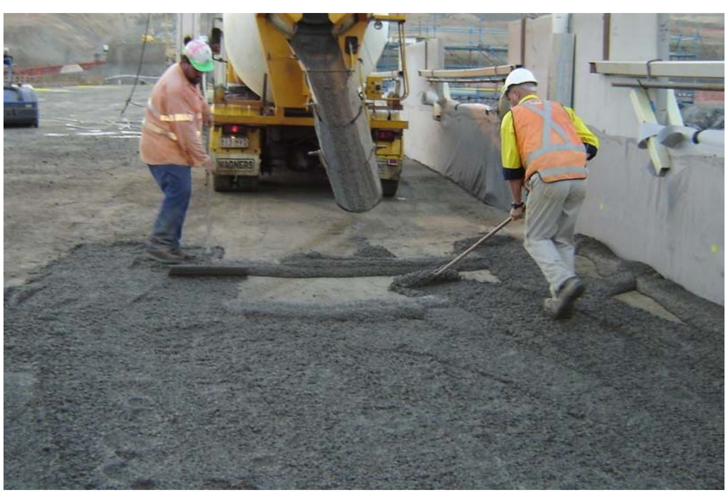
RCC mix rapidly being delivered on the conveyor belt at about 2 meters per second. Despite the high speed and steep angle of the belt at the start of construction, there is no segregation. The mix is very cohesive and the gradation tends to avoid segregation. Despite the implication by Mr. Dolan, this was an especially dry mix. It deliberately used a slight excess of water in order to provide cohesiveness and good layer to layer contact.

Overall view of placing. The mix reaches the lift within about 2 minutes of mixing. It then typically is spread within 5-10 minutes and then rolled in about the next 10-15 minutes. Clean surfaces. The lift in front of the placement is moving away from the middle of the picture and going towards the far end. The surface is appropriately just at or slightly below a Saturated Surface Dry (SSD) condition.



Another example of typical excellent placement at the upstream face. Fresh bedding is being placed over clean RCC that is appropriately just slightly drier than SSD. Properly spread.

RCC being dumped from a truck in one of the small areas where the conveyor could not reach. Loading was directly from the conveyor into the truck in a manner that minimized any segregation tendency. The mix was always dumped on top of the advancing fresh RCC so that if any segregation did occur it could be remixed and eliminated by the dozer as it spread forward. However, the normal situation, shown here, did not have segregation.

An example that, on rare occasion, some bad situation occurred in isolated areas. Here is an area where the mix is a bit segregated and dry at the surface. The condition is not extensive and the area is not near the critical upstream face. Someone could look at this photograph and be critical…… but see the next photo for what was done.

The affected area was removed down to the previous lift. It was then re-filled with fresh RCC. Note that there is no porous zone at the bottom of the lift, even though this was a problem spot. On various occasions we would excavate to the previous layer and fill the hole with water. I do not recall any occasion where the water seeped out and drained. This means that the bottoms of the lifts were bonded and watertight.

When I visited the project in 2008, above, the downstream face of the dam was dry. The photograph on the wall during testimony also showed that the face is dry, with the exception of one vertical monolith joint in the spillway where I was told by Mr. Wiley that it was probably just a leaky waterstop and not a major concern. The dry face is totally inconsistent with the supposition that the lift joints are weak, porous and should be considered 100% debonded. In fact, based on experience at other projects, if water seeps past an area of upstream bedding in just a few isolated places on a lift joint it will then spread out over the downstream area that does not have bedding and look like the entire lift is leaking whereas it only leaks at the upstream face from a few isolated locations.

The dry downstream face, especially since it is in an area of no bedding and the least restrictive lift joint inspection, is also inconsistent with the piezometers indicating that the lift joint are saturated, full of water, and under pressure. If this was the situation and the lift joints are bad, the lift joints would leak and not hold back the pressure.

The upstream membrane includes a designed drainage system that should take away any pressure and drain off seepage at the face. The designer should be consulted because, as I recall, he designed this in a way that allowed the drains to be cleaned. If they are clean and accessible, it should be easy to check if there is any standing water in them. If there is, the height of the water will establish the correct pressure to the upstream face of the RCC mass, and there will be no pressure above the level of standing water. If the drains have not been cleaned, they should be cleaned and monitored as soon as possible.

It is very important to understand that the upstream membrane is a special material that is specifically designed for dams. It is very elastic and can bridge cracks, if they were to occur, without tears or punctures. It basically is a surface waterstop that maintains a water tight seal. This has been demonstrated many time in practice and in high pressure tests of the membrane over concrete. The guideline that GHD has used as a basis for assuming full uplift in a crack (horizontal lift joint separation) does not really apply here. First the assumption that there is absolutely no bond and no tensile strength at all on any lift surfaces is based on flawed and insufficient investigations and tests. Second, the upstream face of the RCC mass is NOT directly exposed to the reservoir. It is separated from the reservoir by a water barrier. The result of these assumptions is a very overly-conservative and unrealistic stress and stability assessment of the dam.

The above comments are extremely important and quite critical to evaluation of the dam, its stresses, and its stability. These issues should be immediately addressed and certainly clarified or explained before any remedial action is taken.

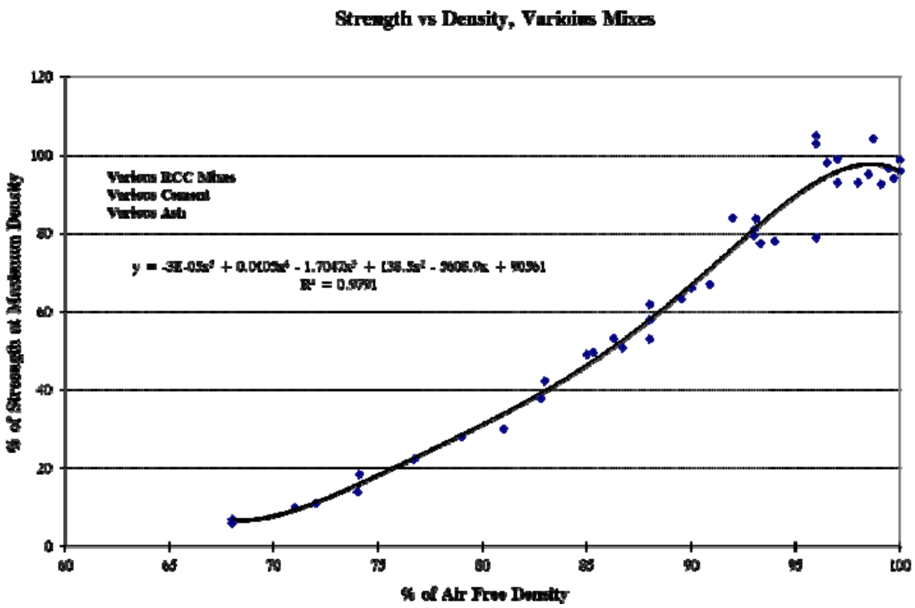
It is also essential to cut trenches into the dam both where there is upstream bedding and the best of construction, and where there is no bedding. If the trenches are excavated by heavy equipment such as a rock trencher (used at Wyaralong to excavate the gallery into previously placed RCC), or by excavator, the effort required will be a good indicator of quality, as will observation of whether the RCC tends to break out easily in layers that pop out, unbonded, from the mass. Or, does the RCC break though the mass and across lift joints that are bonded. If a wire saw is used, block samples can be careful removed and tested for shear strength, or bocks can be tested in-situ.

I have a lot of respect for Mr. Dolan personally and with regard to his experience with a different approach and type of RCC. However, as he stated, he is not a designer and apparently did not know what was required for lift joint quality (strength and bond) at the different parts of this particular dam. He simply considered the work faulty because everything, everywhere, was not "perfect." This is one way to approach a project but it is expensive, inefficient, not applicable to this design, unnecessary, and it would not provide what our client repeatedly asked for which was value for money.

Mr. Dolan was also emphatic that he believes the RCC is poorly compacted and that the bottoms of the lifts are essentially porous. As I have remarked in first Witness Statement Supplement, if the bottom of the lifts are porous we most likely do have near zero cohesion and reduced friction. However, as indicated in my testimony, prior witness statements, and evidenced by thousands of density tests along with observation and the photos above, this is simply not credible. Again, proper trenches would be definitive. They should be done.

In his testimony Mr. Dolan correctly pointed out that the density at the bottom of the lift has to be quite bad in order for the shear properties to diminish, but once a porous condition occurs shear properties drop of dramatically. He referred to the fact that it was very difficult to make samples that are bad enough for this to occur. My experience is that even without roller compaction, operation of the dozer and other equipment by itself on the lift will compact the type of RCC that we had to a density in the order of 93% to 97%. This has been verified by tests.

The figure below has been published many times in different formats. It shows the extent to which strength decreases with decreasing density. The decrease starts at densities less than about 96% or 97% of the theoretical air free density. Once density drops below this the loss of strength is considerable. But as discussed in my Witness Statement 2, the average density based on published data for Paradise was 97.8%, the range at any test location was 96.9% to 98.2%, and the specified minimum average for each location was 96%. A review of weekly QC summaries shows that, at time the range was more on the order of 96% to 100%. The data indicates that we did not have densities low enough to cause a dramatic loss of strength.



The Commission was a bit perplexed that engineers who are designers, such as Mr. Tarbox, Dr. Rizzo, and myself often use zones in some dams that have different mixes, both with and without bedding. We all have advised that this is routinely done. Very large dams of both conventional concrete and RCC, say higher than 200 meters usually have many different mixes within the dam, within any given monolith, from top to bottom, and from front to back. If the stress-strain properties of the material are significantly different for different mixes, and the levels of stress are high, there needs to be a check for strain compatibility, but this is seldom an issue and it can be dealt with by a non-linear finite element analysis that is much more complex than the simple rigid body analysis that is typically used in dams like Paradise. Also, the BDA did extensive stress-strain testing that did not show any strain incompatibility.

There have been a number of comments by people who never saw the mix and never were at the jobsite postulating that the mix was not very workable. This is simply not the case, as can be seen in the photographs and as experienced by the people who were there. Also the workability test results (VB times) were a bit higher, but not much different, than what Mr. Dolan prefers with his typical high cementitious content wetter mix. The reality is that during production I asked that the mix by made just a bit on the wet side for more workability and to help with bond between layers, but there was a limit after which the mix would tend to get too wet, rut under traffic, bleed, and the surface would become more difficult to clean.

During my testimony Commissioner Carter was particularly interested what impact the Goodnight material may have had on the properties and quality of RCC. I advised that I remember including that as part of our test program and that we concluded there would be essentially no difference as long as we wasted any questionable Goodnight excavation and we limited it to a maximum of 20% of the total aggregate. We also were conscious to produce and stockpile the aggregate in a way that kept the amount of Goodnight uniform. Commissioner Carter requested that he would appreciate if I could find any test results or comparisons.

As part of our comprehensive mix design and evaluation program BDA investigated Goodnight as well as other aggregate variables. Other variables in our initial mix design program were cement contents ranging from 70 to 120 kg/m^3, fly ash contents ranging from 0% to 60%, moisture contents above and below what was judged to be optimum, and various fines contents (passing 75 microns). When the field laboratory was available we continued with supplemental testing throughout the project.

Aggregate evaluations included different amounts of glassy ballast, vesicular basalt, natural sand, and Goodnight material. These mixes were made with a constant 80 kg of cement with no fly ash. The moisture content was kept the same at 4.7%. To the extent practical the fines content was kept constant, but varied within a small amount from 5.7% to 6.7% of the total aggregate. The resulting workabilities were similar for all mixes. All of the alkali expansion mortar bar tests had acceptable results well below allowable limits. Densities for the mixes were very similar with a range of 2469 to 2488 kg/m^3. An exception was mix W17 made with 80% vesicular basalt. It had an understandable slightly lower density of 2413 kg/m^3.

Compressive strengths, split tension strengths, and complete stress-strain curves were determined for each mix and sample at each age of 3, 7, 14, 28, 56, 90, 180, and 365 days, but I could only find the results through 180 days. They are tabulated below. The stress-strain curves all had the same non-linear shape and trends, but this is a mass of information so I am instead showing the results of the secant modulus of elasticity (E) at stresses that were 25%, 50%, 75%, and 100% of the ultimate load for each test sample. As clearly seen in the table below the addition of Goodnight material had no significant effect. The mix deisgn program and testing was very thorough, and much more than would normally be undertaken for a project the size and height of Paradise.

Mixes (80 Kg cement, no fly ash), Strengths and Modulus at 180 Days

Mix	Glassy Basalt	Vesicular Basalt	Natural Sand	Goodnight Beds	Comp (MPa)	Split Tens (MPa)	E25 (GPa)	E50 (GPa)	E75 (GPa)	E100 (GPa)
W13	95 %	0 %	5 %	0 %	21	3.0	29	25	19	5
W18	56 %	24 %	4 %	16%	20	2.7	28	27	21	8
W15	70 %	30%	0 %	0 %	17	2.5	24	22	17	5
W6	65 %	30%	5 %	0 %	17	2.4	22	19	13	6
W17	15 %	80 %	5 %	0 %	19	2.8	24	21	14	5

Finally, it should be noted experts offering opinion for GHD have very little, or essentially no, experience with lean types of RCC like what was used at Paradise. This applies to construction as well as material properties including shear testing. They have substantial experience and expertise with a very different type of RCC. Tatro and Hinds, as well as I, have extensive experience with all types of RCC.

Dr. Ernest Schrader