INDEPENDENT TECHNICAL REVIEW TEAM
RAGGED MOUNTAIN DAM

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Letter Report
November 23, 2010
Independent Technical Review Team
Ragged Mountain Dam Design and Construction

1.0 Introduction

This letter is an updated review of the Black & Veatch Report, dated August 30, 2010 to the City of Charlottesville, Virginia. This letter was prepared on November 23, 2010 by all three members of the Independent Technical Review Team (ITRT) following a meeting with Black & Veatch on November 22, 2010 at Rivanna's offices.

The ITRT was asked to consider the Black & Veatch conceptual design from the perspective of dam safety, technical adequacy and constructability to the extent practical with a conceptual level design. In addition, the ITRT queried Black & Veatch on certain matters related to their cost estimate and schedule. No independent in-depth assessment of cost or schedule was undertaken by the ITRT, as cost estimating and scheduling are not within the charge of the ITRT. We can only query and offer comments based on our collective experience with other projects.

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2.0 Dam Type

The Black and Veatch Report considers using the existing Lower Ragged Mountain Dam for inclusion in three alternative heights for the new dam. The alternatives included (a) upgrading of the existing dam with no increase in storage volume, (b) a 13-foot increase in reservoir surface level, and (c) a 45-foot increase in surface level. The 45-foot increase in surface level is equivalent to the current preliminary design prepared by Schnabel Engineering, LLC. It is this alternative that is the subject of this letter.

The Black & Veatch concept for the 45-foot pool raise (actually a 51-ft dam raise in the Black & Veatch concept) incorporates an RCC dam with a vertical upstream face, a 0.8 to 1.0 (horizontal to vertical) downstream slope and an embankment dam as the right abutment. It uses (a) the existing cyclopean concrete dam as an upstream component of the dam, (b) the existing outlet conduit and water supply pipeline as the outlet conduit, and (c) a new 100-foot wide spillway over the dam crest.

There is considerable evidence in the records (correspondence, boring logs, Lugeon testing, etc.) indicating that the integrity of the 100-year-old existing cyclopean concrete dam is highly questionable and has been since first filling. The ITRT seriously questions the overall safety of the existing dam with regards to seepage, overall integrity of the cyclopean matrix and sliding stability. The use of the existing dam as part of a new dam will require that the existing dam be remediated, including grouting as described below. The cost required to remediate the existing dam will be high and funds would possibly be better spent in constructing a new dam using modern engineering and construction technology, provided that the respective costs are comparable.

3.0 Design Evaluation

The Black & Veatch design needs further evaluation to consider several issues that were discussed at the meeting on November 23, 2010.

Strength of the Existing Cyclopean Concrete

The strength of cyclopean concrete has not been ascertained by testing, an issue that needs to be addressed with a formal investigation and analysis. Uniaxial testing of core samples, insitu strength testing and dilatometer/pressure meter testing should be considered. This issue is particularly relevant to the temporary anchors discussed below. The concrete will be subjected to highly concentrated loads from the anchor heads. Once the strength is determined, the stresses caused by the anchors under all loading conditions considered for the construction period and thereafter, should be analyzed. Appropriate factors of safety will need to be selected for comparing the existing strength of the concrete to the calculated stresses.

Use of Anchors

Black and Veatch has proposed the use of vertical pre-stressed rock anchors to provide temporary stability to the existing dam prior to the downstream buttress being removed. The ITRT supports this concept, but provides the following recommendations:

- Although the anchors may be regarded as "temporary," they should be designed and installed as if "permanent," (i.e., to Class 1 Corrosion Protection levels as defined in PTI (2004)). This will ensure their functionality even if construction of the overall scheme encounters delays, after the anchors are installed, as a result of geotechnical, construction or administrative impacts.
- The anticipated length and working load of these anchors argues strongly for the use of strand tendons, as opposed to bar tendons, as proposed by Black and Veatch.
- The installation of the anchors should follow completion of the grout curtain in rock and the grouting of the existing dam itself. This will be an important step in the management of the anchor construction risk relative to cost and progress.

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Broad Geotechnical Context

Although the exploration program conducted by Black & Veatch has been well described, the fact remains that it was of very limited scope (four borings). Black & Veatch reports that they have reviewed published information dealing with the regional geology. However, their report does not reference the detailed geological studies available in the previous reports. This site is known to have highly unpredictable rockhead conditions with the potential to cause significant cost and schedule increases during foundation preparation and treatment. It is essential, therefore, that Black and Veatch more carefully analyze the results from all the phases of investigations conducted at this site, with the goal of validating or modifying their current assumptions on the condition of the existing dam and its geological setting.

Foundation Excavation

The Black and Veatch drawings show limited excavation of the foundation soils in the valley bottom below existing grade. As evaluated independently by Schnabel and Gannett Fleming, the valley bottom has highly variable soils and weathered bedrock depths, ranging from 10 to 40 feet. An RCC Dam should be founded on competent bedrock foundation. Based on boring logs, geophysical investigations, and direct observations, the excavation will be deeper than evaluated by Black & Veatch. The excavation will subsequently be filled with RCC. The additional excavation and RCC placement will add substantially to the cost of a dam.

The Black and Veatch design does consider excavation of soils and weathered bedrock for the dam foundation on the abutments. As discussed in the report, there is no recent subsurface information on the left abutment of the proposed alignment. However, there are data from the existing dam construction and borings, as well as from the geophysical surveys that can be extrapolated to the planned location. The current information indicates that the foundation excavation needed for an RCC Dam could be considerably more than the 15 feet considered in the Black and Veatch design. Investigations should be made in this area prior to updating the cost estimates. Again, we note that this type of work generally adds substantially to the cost of a dam.

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Seepage Mitigation

The Black and Veatch design provides for drainage out of the dam by box drains at the toe of the existing concrete dam and an internal drainage gallery. It has no upstream barrier to seepage through the existing concrete dam or the RCC Dam. The "Grout Enriched Concrete" at the upstream face typically is not water tight and does permit seepage through RCC Dams. Considering the seepage that exists through the existing Dam, the proposed increased head of water on the old and new dam faces, and the positive drainage planned in the new dam, seepage will increase considerably from current conditions. There is no indication that the Black and Veatch study included seepage analyses. The prevention of a loss of water through seepage is a key consideration in both designs put forth by Gannett Fleming and Schnabel, as it should be for a water supply dam used for storage, where the economic value placed on loss of water through seepage may be significant.

Grouting of the Foundation

There is currently no consideration of foundation grouting beneath the existing dam or beneath the RCC Dam in the current area. The additional head on the foundation will increase the seepage and potentially cause erosion of soft rock, fines and biotitic materials left in place beneath the existing dam and new RCC Dam. The foundation erosion was discussed by both Schnabel and Gannett Fleming as an issue of long term dam stability that needed to be addressed. As shown in the project documents, the foundation condition is one of the main reasons to select an embankment dam alternative for the project.

The Black and Veatch concept calls for an earth fill at the right abutment to reduce the foundation excavation needed for an RCC Dam in that area. The embankment section does not include a cutoff trench or foundation grouting; therefore, seepage through that portion of the dam foundation will be uncontrolled. Seepage evaluation through the foundation in this area may result in the addition of a cutoff trench and a grout curtain. In addition, the contact between the RCC and the embankment fill must be well designed and constructed to ensure a stable RCC to fill dam transition.

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Grouting of the Existing Dam and Foundation

Black and Veatch reported on 25 packer tests conducted in vertical holes cored through the existing dam and into the bedrock (Table 2 of the October 29, 2010 Report). Only three tests were conducted in bedrock giving Lugeon values of 0.0, 0.0 and 3.9 respectively. The four interface tests gave Lugeon values of 0.0 in two holes, but 142 – 210 in the third whole (BV-2P). The 18 packer tests conducted in the cyclopean concrete indicate a range from 0.0 to 15 Lugeons, with 10 tests indicating 3 Lugeons or greater. Other studies have concluded that a grout curtain should be constructed under the entire length of the dam to systematically reduce the permeability of the foundation to a low residual value (< 3 Lugeons) and to guard against piping of fines or biotitic materials under future service conditions. The holes in each of the two curtain rows would be inclined off vertical to assure interception of the vertical/sub-vertical joints anticipated in the foundation. Such features would not have been intercepted by the vertical holes drilled by Black and Veatch. The ITRT supports the logic of the full length curtain, this being the appropriate level of "due diligence" in a variable foundation condition.

Equally, however, it is clear from the Black and Veatch tests that the existing dam is at least as permeable as the bedrock, a conclusion supported by the observations of face leakage during first filling and prior to the placement of the soil buttress. The mechanism of seepage (erosion and/or dissolution of the mortar matrix) argues that seepage under the new head conditions can be expected to increase, possibly in a non-linear fashion. Seepage through the existing dam will pose problems during construction and potentially afterwards. Therefore, the ITRT strongly recommends that the existing dam itself be grouted. This can be done most efficiently during the treatment of the underlying rock. As noted elsewhere, the dam and foundation grouting should be conducted before the pre-stressed anchors are constructed.

Furthermore, the potential need for "consolidation grouting" under the new RCC structure, as discussed with Black and Veatch, must be closely defined at the design

stage and allowed for in the construction documents. Evaluation by Black and Veatch of other studies relating to this activity is encouraged.

Dam Section

The selected dam section, with slopes as shown in the drawings, is typical for an RCC Dam. However, the crest width as proposed (12 feet) is atypically narrow for the RCC type of construction. Typically, minimum crest widths of RCC Dams are 20 feet, with most RCC Dam crests being 23 to 27 feet in width. The crest width must provide access for the large equipment used in RCC construction.

Gallery Design

The selected dam section includes a gallery to allow for drainage of the foundation under the existing dam. The gallery as shown on the Black and Veatch drawings is not constructible (due to the thin RCC zone against the existing dam face) and should be modified such that the upstream side of the gallery is against the existing dam. Also, the gallery dimensions should be increased to allow for a drilling rig to work inside in the event that additional grouting or drain holes are required in the future. The ITRT suggests that the height should be 8 to 10 feet and the width should be about 6 to 8 feet.

Thermal Considerations

The Black and Veatch concept presents several significant issues as regards to thermal contraction and expansion of the new RCC Dam as follows:

- The existing dam has no expansion/contraction joints whereas the new RCC Dam will have such joints. This lack of compatibility has to be addressed by Black and Veatch.
- The interface between the existing dam and the new RCC Dam has to be carefully addressed, specifically if a "rigid" interconnection or a "sliding" interconnection be adopted.

- Regardless of the type of interconnection that is adopted, a means of drainage of seepage through the existing dam has to be developed if seepage is allowed to continue.
- A sophisticated three dimensional finite element thermal analysis should be conducted to account for the "heat sink" offered by the existing dam and the restraint against expansion due to thermal differentials.

Dam Stability

The Black and Veatch study did not include stability analyses, even though these types of analyses are extremely important considering the condition of the existing dam and the variable foundation conditions in the valley.

A simplified stability analysis should be performed to validate the Black and Veatch design concept including the existing dam, temporary anchors, foundation conditions and boundary conditions between the existing dam and the new RCC Dam.

Black and Veatch call for pre-stressed anchors through the existing dam to provide for stability during excavation of the buttress fill and subsequent RCC Dam construction. The Report indicates that the anchors would be extended to the RCC Dam crest "to aid in overall stability". Although anchors have been widely used for remediation of existing dams, they are not considered a component of a new dam. The design of the reconstructed Lower Ragged Mountain Dam should not include anchors as a permanent component for dam stability. The dam itself must be shown to be stable on the planned foundation under all loading conditions without reliance on pre-stressing loads.

Outlet Works

The Black and Veatch design uses the existing intake tower and potentially the inlet gates. It is understood that the lowest gate has not been operated or exercised in several decades. The original design of the tower and the condition of the existing gate operators must be evaluated for the increased head. The 18-inch diameter conduit through the existing dam contains oakum/lead joints and does not have sufficient

capacity to permit the design flow of 25 to 30 mgd. A larger outlet conduit is needed to meet operating criteria.

Neither of the previous designers considered the re-use of the outlet works for the 45 ft pool raise option due to its age, condition, and size. The regulations for dam outlet capacity have changed since the existing dam was built and the current regulations may require a higher capacity outlet to meet reservoir evacuation criteria. The ITRT has concluded that this feature is not reliable over the long term, especially under increased head, and should be replaced.

The Black and Veatch design also considers use of the existing 18-inch supply pipeline beneath the soil buttress of the existing dam as the outlet conduit beneath the new RCC Dam. It is understood that this pipeline is founded on soil in the valley bottom. This pipeline would need to be removed during foundation excavation for the RCC Dam and replaced with a new pipeline founded on bedrock and concrete fill.

RCC Aggregate Borrow

There is no discussion of RCC aggregates in the Black and Veatch Report. As studied by both Schnabel and Gannett Fleming, this is a very important issue at the site, considering the lack of suitable RCC aggregate on the site and the cost and disruption of hauling RCC aggregates from off-site sources. Black and Veatch stated that they would borrow the aggregate from offsite and truck the aggregate, along with cement and flyash, along the narrow road past Camp Holiday Trails. This will necessitate temporarily widening for equipment and restoring the road to its existing narrow width after construction is complete. This issue must be considered in the preliminary design stage of the project, as it is a major cost consideration and social impact at this site.

Stock piles of aggregate, cement, and flyash must be accommodated on the site along with an RCC mixing plant. Layout and transport routes should be evaluated by Black and Veatch before committing to an RCC design.

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"Field Response" versus "Pro-active Philosophy"

At several points during the Black and Veatch presentation, the ITRT noted Black and Veatch's intention to deal with certain construction related issues "as a field response." While some level and extent of field response will always be part of a construction program, not every detail can be foreseen. Thusly, the ITRT feels that the financial and scheduling impacts of the issues in question merit a more pro-active philosophy.

The following are examples of major issues at hand:

- Excavation depth and likely variability of rock head.
- Handling of water ingress into the excavation both through the existing dam and from the foundation rock.
- Extent and location of "consolidation grouting" efforts.
- Contingency planning for post-construction seepage.

Reservoir Operating Plan

The reservoir will be operated during construction of the new RCC Dam to meet water supply requirements. Therefore, water will be stored by the existing dam. Seepage through the existing dam and its foundation will exist during the period of construction. It is understood that the seepage has not been measured, but has been estimated at about 17gpm (Discussions on November 22, 2010). The Letter Report by David J. Howell of February 11, 1913, indicates that cracks were observed and much of the downstream face of the dam was wet from seepage when the reservoir was partially full. In the opinion of the ITRT, handling of seepage water during construction of the RCC Dam has not been sufficiently considered in the Black and Veatch cost estimate.

After removal of the soil buttress, the downstream face of the existing dam will be prepared to meet design requirements for bonding with the new RCC. Seepage water will make this preparation difficult. Seepage at the toe of the existing dam will need to be managed so that it does not impact foundation preparation, initial dental/leveling concrete placement and RCC placement.

The design may require bonding of the existing concrete to the new RCC, possibly with use of a bonding agent. Seepage through the dam will make placement of a bonding agent, as well as the subsequent RCC, difficult. The performance of the boundary between the two concrete masses (existing dam and new RCC Dam) is very important to the performance (seepage and stability) of the project. This importance should be evaluated in initial stability analyses discussed previously.

If the reservoir remains relatively full during construction, the impact of seepage on construction techniques, design of the boundary between the existing dam and the new RCC Dams and the overall construction costs and schedule must be considered.

Summary

In the opinion of the ITRT, the RCC Dam alternative, as described in the Black and Veatch documents, needs further analyses and studies specific to the site and subsequent development of design to provide a safe, cost effective and operationally efficient project that meets the criteria of the owner and the State regulatory agencies. The current Black & Veatch design cannot be considered to be on the same plane as the work previously conducted by Schnabel and Gannett Fleming.

4.0 Project Cost Estimate and Schedule

4.1 The ITRT offers the following comments with respect to the Black & Veatch Cost Estimate:

- The Cost Estimate does not include a full grout curtain beneath or through the existing dam.
- The Cost Estimate does not adequately account for the anticipated deep and variable excavation, enhanced treatment of the excavation bottom, and the additional RCC required to bring the excavation to the existing ground surface.

- The Cost Estimate does not include the cost of the additional work associated with the outlet works, including the tower, gates, gate operators and discharge conduit.
- The Cost Estimate does not include upgrade/restoration of the access road and development of staging areas within reservoir footprint.
- There is a major difference in the quantity of RCC between the RCC concepts proposed by the three designers. The Black and Veatch quantity estimate includes 42,000 CY of RCC, whereas Schnabel and Gannett Fleming estimates of RCC are both in excess of 120,000 CY. The difference appears to be substantially more than the reduction in quantity gained by including the existing dam in the cross-section.

4.2 The ITRT offers the following comments with respect to the discussion between the ITRT and Black & Veatch on November 22, 2010 regarding the Project Schedule:

- Black & Veatch plans to perform additional site investigation, including borings, geophysical testing and laboratory testing before developing a final design. The ITRT agrees with Black and Veatch that this effort will require one to two months of effort.
- Black and Veatch estimates that they will require about six months for the design plus review time by Rivanna and the State.
- The time required to develop contract drawings and specifications, including the work outlined above, is estimated by Black and Veatch to be six to eight months after approval is given to proceed. The ITRT believes that this is an optimistic schedule and is doubtful that this schedule could actually be achieved.

5.0 Closing

The members of the Independent Technical Review Team appreciate the opportunity to be of assistance to the Authority in this assignment.

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