SALUDA DAM, THEN AND NOW

Elena Sossenkina, Monitoring Coordinator, Paul C. Rizzo Associates
Scott G. Newhouse, P.E. Senior Engineer, Paul C. Rizzo Associates
Samuel H. Moxley, P.E. Construction Engineer, South Carolina Electric and Gas Company

Introduction

The Saluda Dam is currently being remediated to meet modern seismic safety requirements. An interesting aspect of the remediation is that it requires that Saluda Dam is built on the same site for the second time. Figures 1 and 2 provide an overview of the site and illustrate the Dam's size and geometry. The Dam is classified as a high hazard dam; an uncontrolled breach of the Dam would cause a downstream flood near the City of Columbia, probably entailing loss of life. Studies indicate that about 120,000 people would be at risk.

Saluda Dam is located on the Saluda River, 10 miles upstream of Columbia, South Carolina. The Dam impounds 41 mi-long Lake Murray. With more than 500 mi of shoreline, water area covering about 78 sq mi, and storage capacity of more than 2,100,000 ac-ft of water, Lake Murray is one of the largest lakes on the East Coast. Completed in 1930, the Dam is 200 ft high and nearly a mile and a half long. The Dam is earth fill, essentially homogeneous. The fill was placed semi-hydraulically, by sluicing from dumped piles. The liquefaction potential entailed by the semi-hydraulic fill compels the current remediation to improve seismic stability.

For making the Saluda Dam safe against earthquakes, engineers identified two primary remediation alternatives: 1. a massive rockfill berm on the downstream slope; 2. a new RCC gravity Dam downstream of the existing Dam. Engineers concentrated on the rockfill berm, as the more cost effective choice. In successive design iterations the size of the berm became successively larger.

This process produced the solution, a large new RCC/Rockfill Berm built immediately downstream of the existing Dam. In this approach, the existing Dam is left to impound Lake Murray. The new structure will be "dry," that is under normal conditions there will be a dry gap between the existing Dam and the Berm. However, if a seismic event causes the existing Dam to breach, the Berm will serve as a Backup Dam. For the purposes of this paper, the Berm will be referred to as a Backup Dam. The proposed remediation solution results in building the Saluda Dam a second time, in the same place. This unique event allows the comparison of engineering and construction of two Dams built on the same site, in different eras- the 1920s versus the 2000s.

Dam's Purpose

The existing Dam was built for power production. By 1912, there was need for additional electric power in Columbia, primarily to meet the growing electric demand from mills. In the 1920s Saluda Hydro station was the only substantial power plant in the state. As years have passed by the Dam's purpose has evolved to more of a recreational asset. Lake Murray has become a landmark of the local area. It is questionable whether the current remediation would be worth the expenditure for the hydro station power production alone, but Lake Murray has become a part of the community that can't be removed. That factor was prominent in the decision to renovate the Dam rather than abandon it.

The sole purpose of the Backup Dam is preventing uncontrolled release of water in case the existing Dam fails under seismic loading. If this unlikely event occurs, the new Dam will serve as the main Dam and will retain Lake Murray.

Design

As with any large Dam, it must be designed with material available at the site. Engineers designed the existing Dam for the materials at hand- soil from the local borrow pit, placed by construction methods that were fast and efficient at that time. Likewise engineers designed the Backup Dam using materials from the site, and state of practice construction methods. Modern design utilizes more than just soil. Rockfill, riprap, fine and coarse filter, aggregate for concrete and RCC are all mined and manufactured on site. Even fly ash from an on-site landfill found its application in the design.

Design- Then

The existing Dam, shown on Figure 3, is a semi-hydraulic fill structure with no internal seepage control (filter or drain protection) and essentially no seepage cut off. When completed in 1930, the Dam was 208 ft high and nearly a mile and a half long. The maximum width of the Dam at the bottom is 1,150 ft and crest width is 25 ft. Downstream slopes are 2.5H:1V, upstream slopes are slightly flatter at 3H:1V and protected with riprap against wave action and erosion.

The Dam's essentially homogeneous construction illustrates the knowledge and understanding of seepage and its effect at the time. It is safe to say that at present a 200 ft tall Dam would not be designed without provisions for drainage and seepage cut-off.

Major challenges facing the existing Saluda Dam construction included: diverting Saluda River, purchasing land, relocating churches and graveyards, and building a railroad, shown on Figure 4, for construction materials delivery. The Dam's construction era predated the widespread use of hydraulics in earth-moving equipment. In the age of steam-shovels, moving enough fill soil to build a Dam as large as Saluda Dam was a tall order. This constraint led to the use of railroads to deliver soil and sluicing dumped fill to construct the core, which was the only economical way to place eleven (11) million cu yd of soil fill at that time

Modern engineering practice dictates evaluation of seepage and settlement in the Dam foundation. The original design specified only grubbing and minimal excavation to remove top soil. A 15 ft deep trench was constructed beneath the core for seepage cutoff. Engineers probably thought the foundation soil was sufficiently impermeable to retard head and seepage, and no positive cut-off was required. Evidently, the design engineers also found the soil sufficiently dense to resist settlement, requiring no remedial measures in that regard. Foundation treatment appears to be another example of the state of knowledge regarding Dam design and seepage effects at the time.

As the Dam was subjected to first filling and put into service, some of the deficiencies of the design manifested, requiring modifications:

- Addition of riprap berms on downstream slope. Riprap currently covering the downstream slope was placed as a remedial measure shortly after first filling to improve stability of the Dam.
- Addition of drainage features- tunnels and drains filled with rockfill and gravel. The problems related to seepage also prompted the addition of some internal drainage measures. Tunnels were dug into the Dam on its downstream slope to lower the saturation line within the Dam, and relieve seepage pressures.
- Raising crest and addition of upstream sheet pile flood wall. Placement of the Dam by hydraulic fill entailed significant time-related, consolidation settlement. Consequently, the crest of the Dam settled, requiring raising the crest on two occasions. The flood wall was added to raise the effective height of the Dam even further as a result of PMF studies.

Design- Now

The main objective of the Backup Dam design is to withstand a seismic event similar to the Charleston Earthquake of 1886. The existing Dam will remain in place and function as the primary impounding barrier for Lake Murray. The Backup Dam will impound water if Saluda Dam ever fails. Hence, the Backup Dam is designed for both dry and wet conditions with a series of loading cases that reflect hydrostatic pressures and uplift pressures in the wet case and neither in the dry case. The modern design evolved from the following constraints:

- Lake Murray is in place and could not be drained;
- Top of Backup Dam elevation is set;
- Existing Powerhouse in place, limited footprint is available for the new Dam;
- No excavation into existing Dam (potential for Dam breach) establishes the centerline for the new Dam downstream of the existing one;
- SC Highway 6 on crest of the existing Dam to remain open;
- McMeekin Station and Saluda Hydro power plants to remain in operation- critical work associated with these plants to fit within scheduled outages; and
- Significant environmental constraints associated with wetlands and Saluda River.

These constraints formed the Backup Dam cross section depicted on Figure 5. A rockfill section was selected as the most feasible solution. However, site constraints preclude use of this section for the central portion of the Dam. An RCC gravity section was chosen for this area, because of a smaller footprint. Deep excavation at the toe of the existing Dam is required to reach suitable soil beneath the rockfill section, and to reach rock beneath the RCC section. Slope stability analyses performed for 26 cross-sections identified target levels for dewatering. Dewatering to lower head within the existing Dam and foundation was a major requirement. Target levels, or target piezometric elevations within the Dam were setup to provide adequate factor of safety against slope failure during excavation.

Foundation design in current engineering reflects the purpose of the remediation- to make the Backup Dam safe against earthquake loading. It also accounts for seepage and settlement control. Design measures address potential foundation liquefaction and under-seepage by excavating down to competent residual soil subgrade, established by SPT data. In some areas, excavation extends more than 50 ft below ground surface, significantly deeper than excavation for the existing Dam. Piping through the foundation, driven by seepage, is also addressed by use of a filter blanket on the soil foundation beneath the rockfill section. These measures are now days considered standard for Dam design. The only missing standard element from the new design is a cut off. Design engineers for the Backup Dam decided that a positive cut-off was unnecessary with the existing Dam in place. In evaluation of potential under-seepage engineers concluded that hydraulic gradients and seepage loss would be tolerable for the new rockfill structure.

The RCC section of the Dam is founded on sound rock. Design includes a drainage gallery and foundation drains to reduce uplift pressure. The specified foundation treatment is typical for a modern construction and includes dental excavation, cleaning, mapping and dental concrete placement. Over the last 70 years engineers learned to recognize importance of site geology and geological characteristics of the foundation. Extensive surveying and geological mapping of the foundation is required by the modern standards. No mention of such requirement could be found in the original design.

Like the existing Dam design, modern design also centers on material available at the site. Material on the site is used differently than it was in 1927, reflecting the changes in machinery and dam engineering. The borrow area is the heart of the Backup Dam design, supplying all material for the Dam. The materials in the cross section of the new Dam, depicted on Figure 5, include rockfill shell, select rockfill zone, coarse and fine filters, soil core zone, and the RCC section of the Backup Dam, comprised of RCC and conventional concrete leveling/shaping zones. All of these materials are supplied by the on-site borrow area. Even the fly-ash used in RCC mix comes from the site, from the power generating operation at McMeekin Station. Cement is the only substantial imported ingredient for building the new structure.

Comparing the 1927 and 2004 cross sections of the Saluda Dam, one sees drastic differences. Current Dam design reflects modern knowledge of Dam engineering and state of practice construction methods. The biggest difference in cross section then versus now is the use of rock. Where the 1927 cross section is entirely soil; the Backup Dam cross section includes only a thin core zone built of soil. Rockfill is used in the shell as a free draining material that is not subject to liquefaction or strength loss during shaking. The Backup Dam cross section includes filters to control internal erosion in the foundation and the soil core zone. The RCC section reflects the state of the art design for erecting a large concrete gravity Dam. Each piece of the Dam is made from rock mined on the site. The finished cross section results in a Dam that would have been very difficult to build in 1927. Without the modern day equipment to mine, crush, mix, blend, transport, place and compact the rock materials, the new cross section would be prohibitively costly and time consuming.

Construction

Construction Then

The owner of the Dam, South Carolina Electric and Gas Company, preserved a unique archive of documents pertaining to the Saluda Dam construction. The following section presents excerpts from the *Saluda River Hydro-Electric Development* book, published by SCE&G.

> The construction began by logging the site and building a three mile long railroad spur from Columbia. The railroad was essential for hauling construction materials and heavy equipment. Trees logged from the site provided lumber for the Dam's massive network of forms and trestles, shown on Figure 4. More than 2,000 workers were employed on the project. During construction, 11,000,000 cubic yards of earth fill had to be placed, requiring 60,000 feet of trestle work and 30 miles of railway tracks.
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> Earth fill was excavated from borrow pits adjacent to the Dam site by means of 12 steam-shovels, shown on Figure 6, which loaded it onto trains. The transportation equipment consisted of 17 standard gauge locomotives, two narrow gauge locomotives and 180 dump cars. With an average haul of about a mile from the borrow pits to the Dam, the daily transportation totaled about 300 train loads or 2,000 cars.
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> The Dam was built in three sections. The upstream and downstream sections, each comprising about a third of the fill, were of ordinary earth with the center of clay placed semi-hydraulically. Work began with two sections of fill being placed 1,000 feet apart and raised until they were 75 feet high. At this stage, the area of the basin between the two fills was pumped full of water to create a "segregation pool." This pool thereafter was maintained by pumping enough water to take care of evaporation and seepage. Atop the segregation pool patrolled five scows, each equipped with pumps and a giant nozzle. As trainload after trainload of dirt was unloaded, the scows sprayed 750 gallons of water a minute against the banks at a velocity of 125 feet per second. This process washed down the fine material into the pool, where it deposited to form a dense core for the Dam.
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> Near the top, these sluicing operations were stopped. The final 30 feet were built from selected soils. The upstream face of the Dam was then rip-rapped (layered with stone) and on the downstream face 100 acres of Bermuda grass were planted to prevent erosion. Figure 3 illustrates this construction method- showing in cross section the sluiced core and the washed soils used to form the core.
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> Filling of the Lake Murray was performed in stages over a four year period. The initial filling began in August 1929, when the Dam was only partially built. The lake was filled to an elevation of 290 ft MSL, and held at this point for eight months until April 1930, when the final storage of water began. In 1931 the lake level was raised from 340 to 350 feet MSL, and two years later to 360 feet. In 1988-1989, SCE&G constructed a sheet pile wall to raise the effective height of the Dam to 377 feet MSL as an added safety factor.

Environmental Factors Then

Environmental factors addressed in 1920s era construction primarily focused on protecting people and property from the environment. Mosquito control, for example, was a primary concern and significant job. Due to low swampy terrain at the construction site, and the construction method using sedimentation ponds daily spraying of shores with oil was required to kill mosquitoes and prevent malaria.

Construction Now

One can focus on the borrow area for a diagram of the modern construction effort. As mentioned above, discussing the design, all materials for the Backup Dam are taken from the borrow area. This construction requires modern earth-moving equipment for moving such large volumes of soil for the core, rock for filters, rockfill, and RCC aggregates. Such an operation was not economical in 1927.

Daily blasting in the borrow area provides rock for the construction. Haul roads lead from the borrow area to the crushers, and directly to the rockfill Dam sections. A fleet of 10 heavy haul trucks (CAT 777 and CAT 773) take the soil overburden from the borrow area and blasted rock directly to the new Dam, where it is placed and compacted to create the core and the outer shells. Blasted rock is also taken to the primary crusher and broken to make all products for the Dam: select rockfill; fine and coarse filters, and RCC aggregates. Fifteen 40 ton trucks take filter materials and select rockfill from the crusher plant to the rockfill Dam. RCC aggregates are fed from the crusher plant into the RCC batch plant.

The RCC section of the Dam is built using conveyors. RCC is delivered to the Dam from the batch plant along a conveyor, as seen on Figure 2. The conveyor runs 3,200 ft along a bench above the excavation from one end of the RCC section to the opposite end. This conveyor provides an interesting comparison to the 1920s railways that were erected along the existing Dam. Where in the 2000s the material is RCC moved along the Dam's length by conveyor, in the 1920s the railway moved soil fill along the Dam. The construction problem was essentially the same, and the solutions are similar- reflecting technology then and now. With trucks and conveyors more than 12,800 cy of RCC and 20,000 cy of soil or rockfill can be placed in a single day.

The borrow area is the heart of Backup Dam construction. However, foundation excavation is another significant construction operation. Excavation is performed in cells to minimize risk associated with excavation at the toe of the large Dam. The project entails excavation of 2.2 million cu yd. The contractor excavates with large track-mounted excavators, and heavy haul trucks, as shown on Figure 6. Spoils are taken to the borrow area and placed as backfill. Excavation to expose the rock surface entails significant problems with geometry- irregular rock surface, depressions, trenches, deep ravines in the rock. Eight classes of excavators with different size and stick length are deployed for the task.

A total of 350 people are employed on the project. This number is 6 times smaller than the total number of people involved in the original construction. To build the dam of the same size at the same amount of time (3 years) the modern construction relies heavily on sophisticated machinery rather than on manual labor. High cost of labor makes it economically prohibitive to build a Dam the way it was done 70 years ago.

Environmental Factors Now

Environmental factors now, versus then, are much more extensive, complicated, and regulatory driven, and designed to protect the environment from us, rather than vice versa. One of the most interesting comparisons in environmental factors, then and now, is mosquito control. As discussed, during 1920s construction malarial control was a significant effort, protecting construction personnel from mosquitoes. In construction now, there is a significant effort to protect mosquitoes from construction, in the form of wetlands conservation and permitting. No mosquito's home will be destroyed without a permit and without building him a new home elsewhere. Construction now requires daily spraying, as did the 1920s operation; but today that spraying is from a water truck to suppress dust. Dust suppression is carefully controlled, and required by permit- again to protect the environment from us.

Cost and Schedule

Cost and Schedule Then

The existing Dam's construction cost was $20 million. Duration of construction was 3 years, from 1927 to 1930. In February 1927 the Federal Power Commission accepted an application for a Dam and a powerhouse construction. The license was issued four short months later. Logging began in spring 1927. By mid-1928, over 2,000 men were employed on the project. Lake filling began on August 31, 1929, even before the Dam was fully completed. It's a saying among engineers that building of a Dam usually brings a flood. Construction of the Saluda Dam was not an exception. The greatest flood of record occurred on the Saluda River in usually dry late September 1929. The flood caused a major slide in the partially finished Dam and significant Damage to the unfinished powerhouse. Despite the delay caused by the flood, the first electricity was generated at 7 a.m. on December 1, 1930, merely 3 years after the license was received and less than 6 years since the design began.

Cost and Schedule Now

Estimated construction cost for the Backup Dam is $275 million. Just like the existing Dam's, its scheduled construction duration is 3 years. The engineering phase of the remediation lasted for more than 10 years. Debates and discussions over seismic, liquefaction and post-seismic stability analyses of the existing Dam, results and conclusions of those analyses, stretched the preparation phase for years. Depending on the parameters used, the conclusions about safety of the Dam and the need for remediation to make it safe varied drastically. Ultimately engineers and the Federal Regulator ended that debate by concluding that the existing Dam would have to be renovated. The design of the remediation began in May 1999. The project was awarded in July 2002 and excavation began in February 2003. The Backup Dam is currently being constructed. Expected substantial completion date is December 2004.

Public Reaction/Perception

Public Reaction/Perception Then

The original construction generated a lot of publicity. One of the biggest problems confronting the success of the project was purchase of land. More than 5,000 people had to be relocated to make room for the reservoir. On the plus side, the project created many jobs and business opportunities for the community. Historic headlines of the day capture some of the public perception. Charleston and Columbia newspapers reported the progress of the project "Mammoth Hydro-electric Development To Rise on Saluda River"..."The Dam Will Be Higher Than Any Skyscraper On Main Street In

Columbia"..."The Dam Will Be Nothing Less Than A Mountain Rolled Into Place"..."Epitome of Hugeness"..."The World's Greatest Earth Dam Is Achieved."

Public Reaction/Perception Now

Current public perception is focused on impacts of construction on the lake. The lake level had to be lowered 15 ft during construction phase to provide additional safeguard for excavation at the toe for the Backup Dam construction. The main subject of local media coverage is impact on recreation and related lakeside business (e.g. marinas and boat launches). The project progresses with constant press and public scrutiny of meeting the schedule for allowing the lake elevation to again rise.

Conclusion

This project provides a unique example of the same Dam built on the same site twice. Cross sections of the two Dams indicate significantly different design. That difference in design reflects the state of engineering practice at the time each Dam was designed. The 1920s engineering design reflects the tools available for placing such a mass of fill at one time (hydraulic fill). It further reflects the engineering profession’s understanding of earthquake engineering and seepage at that time.

Modern remediation design reflects the advances in civil/Dam engineering since the 1920s. It may be the most interesting facet of the entire comparison- evaluating what was important and stressed in the 1920s design versus that in the 2000s. There is a definite lesson in the Dam’s problems manifest at first filling (seepage break-out on the downstream slope and resulting instability). Engineering knowledge that a Dam 200 ft tall should not be homogenous, and should include positive seepage control measures such as internal drainage and a cut-off, is not a new lesson provided by this case. State of the art held these facets long ago. The case does however provide yet another useful illustration of why these Dam design features are now standard.

Comparison of construction methods is fascinating. Use of the railroad in initial construction compared to use of the RCC conveyor in the modern project illustrates nearly identical solutions to the material transportation problem, each with a mode reflecting the technology of the time. In the 1920s that technology was the railroad. In the 2000s, it’s a high speed conveyor, driven by electric motors.

The contrast in public sentiment and perception is also interesting, reflecting a distinct difference in the times. In the 1920s the focus was not at all the recreational aspect of Lake Murray, or the economics of related lakeside business. At that time the public’s concern was the vast amount of land that would disappear to the project. In the 1920s, the public’s interest was captured by the size of the project- reflected in the newspaper headlines. The Dam built today is just as big. It’s interesting that the Dam’s size- or any details of the remediation do not capture the modern public’s attention. Since the 1920s engineering feats including space travel have evidently made the construction of a big Dam not so impressive.

Figure 1 Project Site

Figure 2 RCC Batch Plant and Conveyor

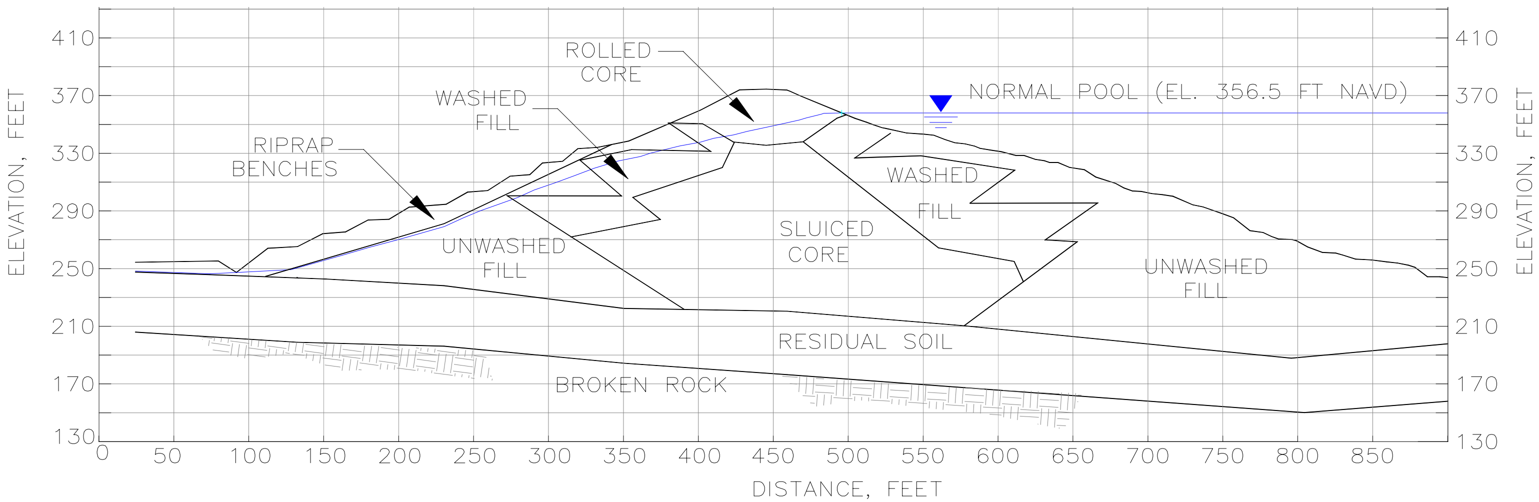


FIGURE 3 Typical Cross Section. Existing Dam

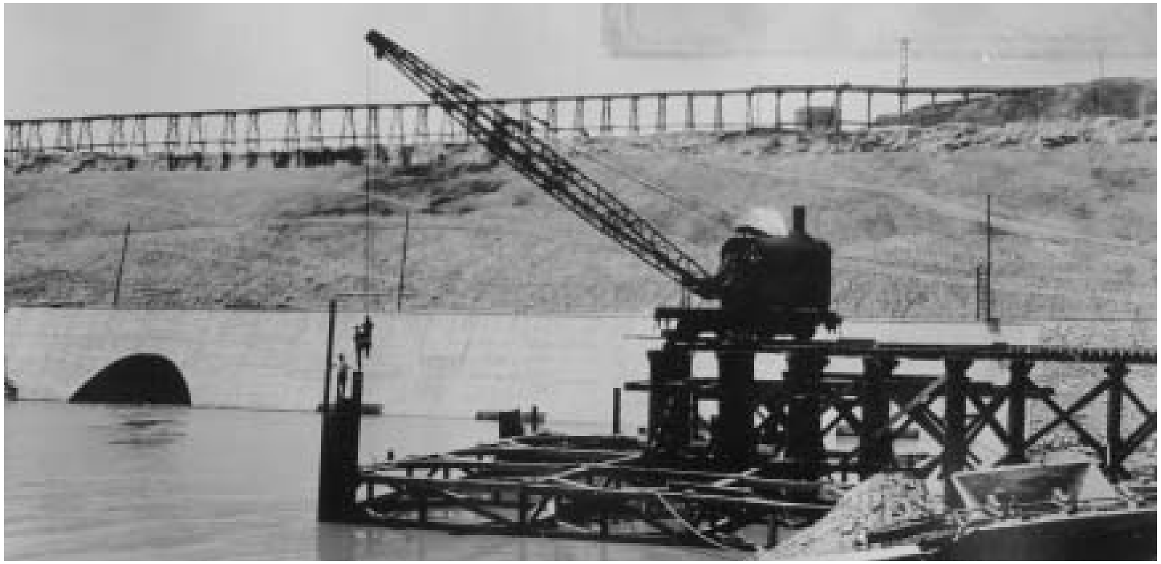
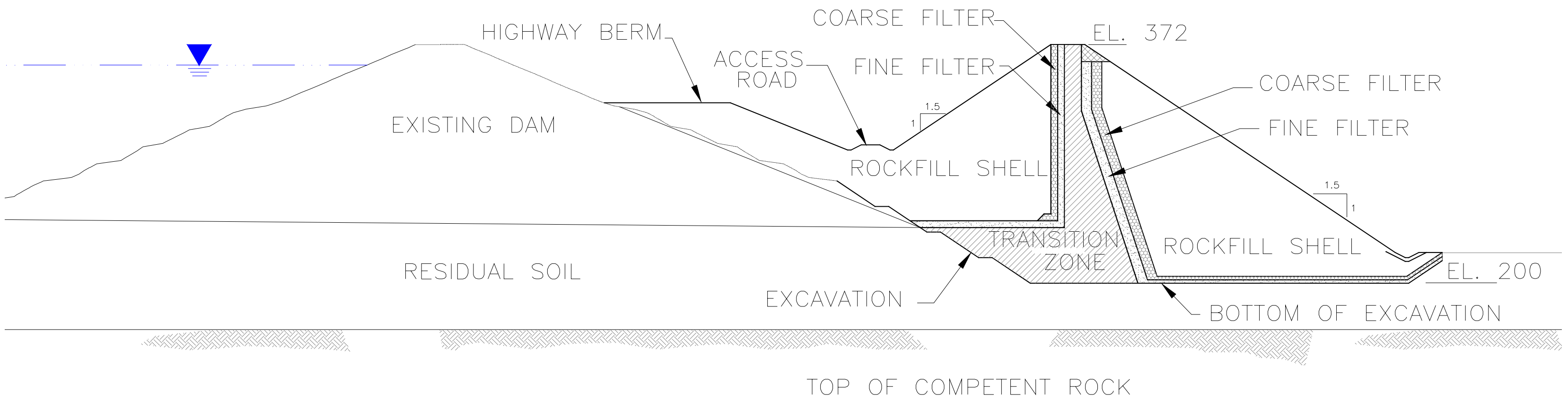


FIGURE 4 Construction of Saluda Dam. Trestles, 1929

Rockfill Section



RCC Section

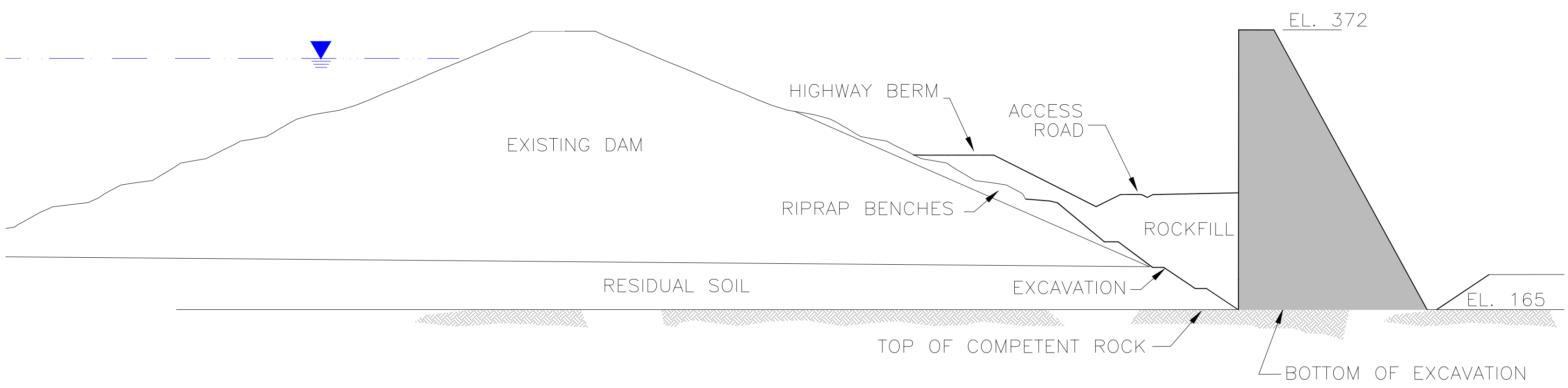


FIGURE 5 Backup Dam typical Cross Section

Saluda Dam Construction, 1929

Backup Dam Construction, 2003

FIGURE 6 Equipment used for construction