Jun 1st

Construction Problems with an Earth and Rockfill Dam

Hasan Hejazi
Tennessee Technological University, Cookeville, Tennessee

Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 3.24

Construction Problems with an Earth and Rockfill Dam

Hasan Hejazi
Associate Professor of Civil Engineering, Tennessee Technological University, Cookeville, Tennessee

SYNOPSIS: Earth and rockfill dams became popular in the 1960's primarily because of increased heights of dams, poor foundation conditions that rule out concrete dams, and vast improvements in excavation and vibratory compaction equipment. Such equipment made excavation and processing of rock and placement of rockfill much more economical than in the past.

Due to the unique composition and the critical zone construction of earth and rockfill dams, they are subject to different types of problems. Some problems may be discovered and corrected during construction. Such problems cause changes in contract documents and delays in work, as in the case of Bay Springs Dam on the Tennessee-Tombigbee Waterway. Other serious problems may cause complete failure of the embankment, as in the case of Teton Dam in Idaho which failed in 1976.

This paper presents a case history of problems that were experienced during the construction of Bay Springs Lock and Dam, Figure 1.

Figure 1. Aearial View of Bay Springs Lock and Dam.

INTRODUCTION

Earth and rockfill embankments are by necessity constructed of different sizes and types of materials; each must be compacted by equipment compatible with the type of material involved to obtain the optimum density to limit settlement and meet design assumptions.

The embankment consists of zones: the core, the filters, and the shell. The core is the internal zone. It consists of impervious material and provides the water retention capability of the dam. The core is relatively thin and must function as an impermeable barrier to the passage of water. The transition zones or filters are located on both sides of the core. They are designed as graded filters, composed of rock materials changing gradually from fine on the side of core, to coarse on the side of shell. Their function is to retain the core material and to provide internal drainage control. Properly designed and constructed filters will act to heal the core if internal cracking should occur. The shells are the exterior zones adjacent to the filters. They slope outward forming the upstream and downstream slopes of the embankment. The shells retain the interior zones and give the dam bulk and stability.

Because of the critical function of each zone, as outlined above, it is essential that the embankment be designed and constructed properly to prevent failure through erosion and piping. Therefore, special care and attention should be given to the selection, gradation, placement, and compaction of the construction materials.

DAM LOCATION

Bay Springs Lock and Dam is located on the Tennessee-Tombigbee Waterway which connects the north-flowing Tennessee River, at Pickwick Lake, to the south-flowing Black Warrior-Tombigbee Waterway at Demopolis, Alabama, Figure 2. The Waterway runs south from Pickwick Lake across the Tennessee Valley Divide in a deep cut, south down Mackey's Creek to the Tombigbee River, and down the Tombigbee River to Demopolis. Then, the existing Black Warrior-Tombigbee Waterway runs south 217 miles from Demopolis to Mobile. The distance from Pickwick Lake to Demopolis is 232 miles which makes the total length of the waterway, from the Tennessee River to Mobile 449 miles. It provides a continuous navigation route from the Tennessee, Upper Mississippi, and Ohio River Valleys to Mobile, Alabama, on the Gulf of Mexico. The Waterway provides savings of 829 miles in navigation distance from the Tennessee River to Mobile, as it reduces the distance from 1278 miles via the Mississippi River to 449 miles via the Waterway. The Tennessee-Tombigbee Waterway was designed and constructed by the U.S. Army Corps of Engineers. The channel width varies from 280 to 300 feet. Construction commenced in 1972 and it was completed in 1984, at a cost of about 2 billion dollars.

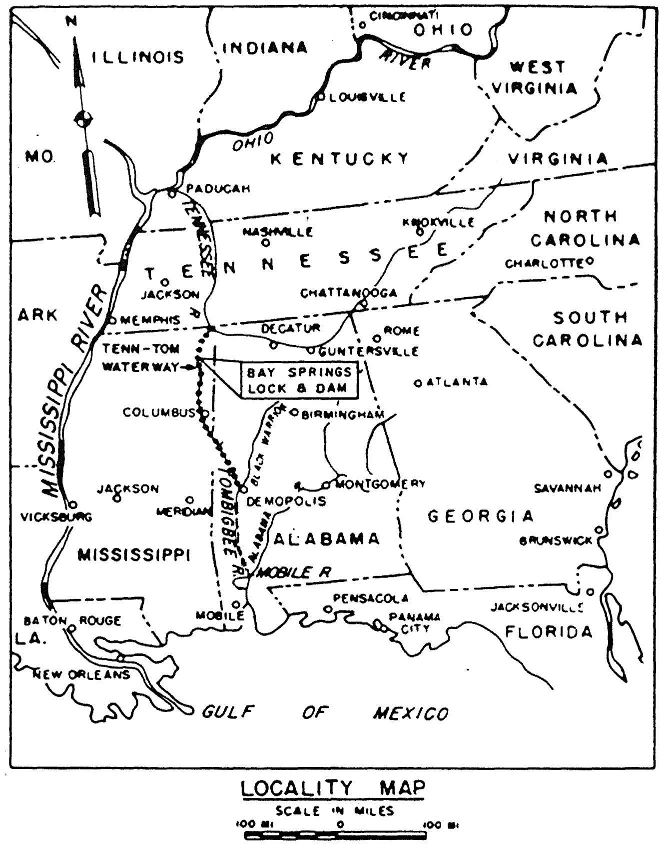

Figure 2. Tennessee-Tombigbee Waterway Locality Map.

The water level difference between the Black Warrior-Tombigbee Waterway at Demopolis and the Tennessee River, just above Pickwick Lock and Dam, is 341 feet. Bay Springs is the tenth and last Lock and Dam on the Waterway above Demopolis. The dam has a 600-foot long by 110-foot wide lock with a normal lift of 84 feet to provide navigation through the Divide Cut. The dam is located, on Mackey's Creek, in the Southwest corner of Tishomingo County, Mississippi. Construction of Bay Springs Dam commenced in 1979 and it was completed in 1983.

GEOLOGY

General information on the geology of the area was obtained from the U.S. Geological Survey, Tennessee State Geological survey, Mississippi Geological Survey, Alabama Geological Survey, and Tennessee Valley Authority. Additional data were obtained from exploratory drilling at the dam site conducted by the Mobile and Nashville Districts of the U.S. Army Corps of Engineers.

To supplement the drilling, an electric logging device was used in a number of the early Nashville District borings, prior to 1952, and downhole geophysical equipment was used in 77 borings drilled in the second phase of Nashville District Exploration which started in 1973.

The dam is located in the extreme eastern part of the Mississippi Embayment, a synclinal structure which is part of the Gulf Coastal Plain. This embayment has been divided into a number of physiographic districts. The dam site is located in the Fall Line Hills District which occupies the periphery of the embayment from Alabama to southern Tennessee. In this district, outcrops of Mississippian, Cretaceous, and Quaternary sediments are exposed. Most of the Mississippian rocks are overlain by Cretaceous and Quaternary clays, silts, sands, and gravels. The Mississippian rocks crop out only along the valleys, and like the Cretaceous and Quaternary sediments, have a westwardly regional dip toward the axis of the syncline.

The valley floor at the dam site is approximately 2,000 feet wide at Elevation 385 feet, with Mackey's Creek occupying approximately 35 feet of the flood plain and flowing on bedrock. In general, bedrock is covered by 15 feet of overburden except in the abutment areas of the dam where the average thickness is about 40 feet. Vertical cliffs of sandstone, rising approximately 50 feet above stream level, are common in the area upstream from the dam axis.

OVERBURDEN

Materials overlying the Mississippian rocks at the dam site consist of clays, silts, sands, and gravel of Cretaceous age as well as alluvial sands and gravels of Quaternary age. Immediately and unconformably overlying the Mississippian rocks are unconsolidated sediments of the Gordo formation (Tuscaloosa Group). This formation is thin in the site area, averaging 20 feet in thickness. These varicolored sands, gravels, and clays are overlain by interbedded and interlaminated micaceous clays and glauconitic sands of the McShan formation that averages 40 feet in thickness. Overlying the McShan formation are approximately 30 feet of slightly glauconitic and micaceous sands and dark gray clays of the Eutaw formation. Also present along the valley slopes of Mackey's Creek are thin and intermittent terrace deposits which are not easily distinguished from the underlying sediments. Materials overlying the valley section along the axis of the dam are alluvial deposits of mostly sands, clays and some gravel. These deposits were mostly derived from the Eutow formation, and partly from the McShan, Gordo, and Mississippian formations. In addition, large detached blocks of Mississippian sandstone have separated along joint and bedding planes and are common along the base of the bluffs.

EMBANKMENT DESCRIPTION

Bay Springs Dam has a zoned earth and rockfill embankment consisting of a central core, transition filters, select rockfill shells, and a cutoff trench, Figures 3 and 4.

The core has a top width of 10 feet with 4V on 1H side slopes. It consists of low plasticity clay compacted in a nine-inch loose lift by tamping or sheepfoot roller. The filters, fine and coarse, are eight feet wide with the fine filter No. 2, adjacent to the core, placed in 12-inch lifts compacted by a vibratory roller and having a gradation ranging from a No. 4 to a No. 100 standard sieve size. The coarse filter No. 1, between the shell and the fine filter is placed in 12-inch lifts compacted by a vibratory roller, and ranges in size from four inch to No. 4. The shells are placed in 24-inch lifts compacted by a vibratory roller and ranging in size from a maximum size of 16 inches to not more than 5% passing the 3-inch screen.

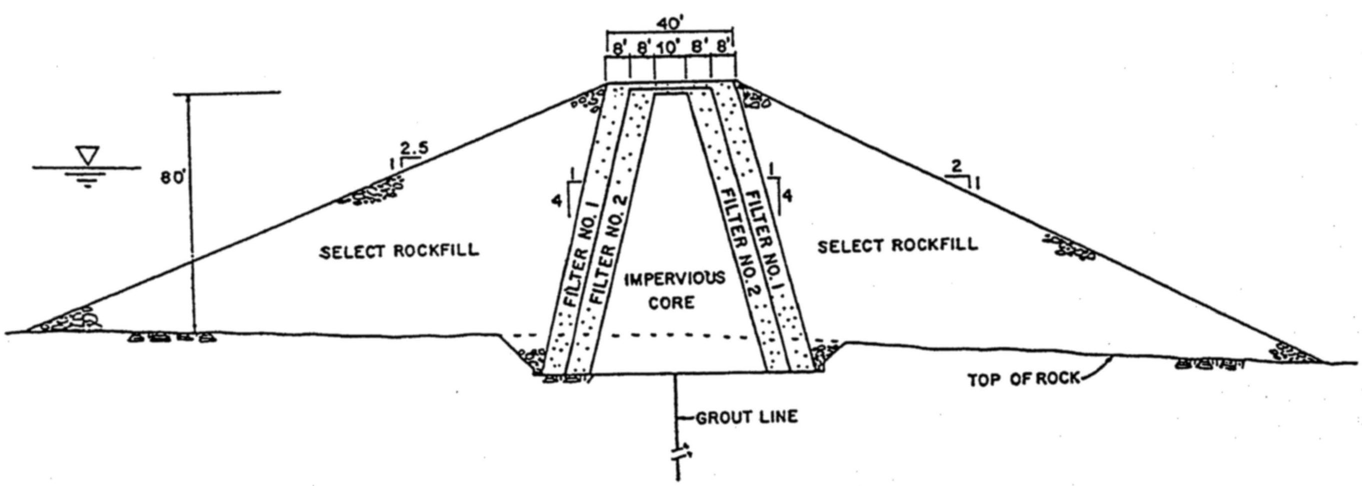

Figure 3. Section on Rock.

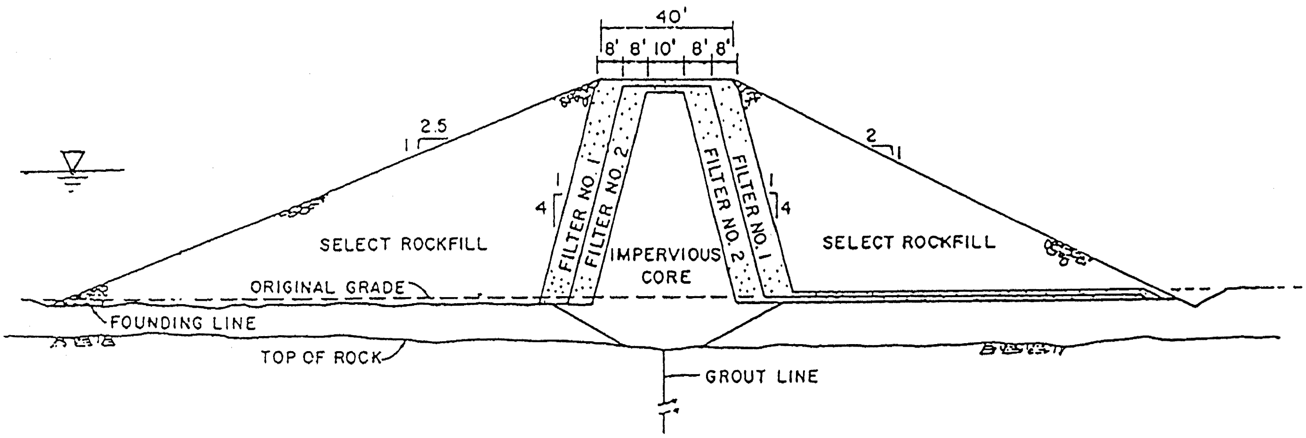

Figure 4. Section on Overburden.

A cutoff trench extends to rock in locations where the dam is founded on overburden. A grout curtain is provided to reduce seepage through the foundation. Measures were taken to dewater the area around the cutoff trench to reduce seepage during grouting and foundation preparation.

The embankment is 2750 feet long with a crest width of 40 feet. Upstream and downstream slopes are 1V on 2.5H and 1V on 2H, respectively. The embankment is approximately 80 feet high throughout most of its length, with a maximum height, located in the Mackey's Creek valley, of approximately 120 feet.

CONTRACT REQUIREMENTS

Some of the contract requirements that pertain to the problems discussed in this paper are as follows:

a. Filters No. 1 and 2 are each to be 8 feet wide (measured horizontally) with the following gradations:

Filter No. 1		Filter No. 2	
Sieve No.	% Passing	Sieve No.	% passing
4"	100	No. 4	92-100
3"	85-95	No. 8	75- 95
1 1/2"	60-90	No. 16	35-85
3/4"	35-60	No. 30	10-63
3/8"	7-32	No . 50	5-45
No. 4	0- 7	No. 100	0-15

b. Select rockfill material is required to be sound sandstone which is reasonably well graded from a maximum dimension of 16 inches to not more than 5 percent passing a 3-inch screen. This gradation requirement is to be met prior to placing select rockfill in the embankment.

c. The rockfill portions (select, random, and filters) of the embnakment are required to be constructed of processed sound sandstone, dumped, and pushed into place in specified lifts. Rockfill is to be placed in such a manner as to produce a reasonably well-graded mass, with the smaller stones adjacent to the contacts with the internal zones of the dam. The larger size material is to be dispersed within the mass of the rockfill. The resulting embankment should have no pockets of small stones or clusters of larger stones. The placing shall be supplemented by whatever hand methods required to obtain even surfaces. A tolerance of plus or minus 6 inches from the slope and grade lines shown on the drawings is required at the boundaries of the internal zones of the embankment.

d. The lift thicknesses of the embankment materials before compaction are required to be not more than 12 inches for the filters, and not more than 24 inches for the select and random rockfill materials.

e. Minimum compaction for filters, select-, and random-rockfill materials requires 6 complete passes of a vibratory roller weighing 10-12 tons, operating at a maximum speed of 3 mph having a drum vibration frequency between 1,100-1,500 frequencies per minute.

f. Unless otherwise directed, the embankment is required to be maintained at approximately the same level throughout its construction, regardless of the number of types of materials being placed.

THE PROBLEMS

The problems encountered in this project fall under two categories: rock gradation and zone construction.

ROCK GRADATION

Soils and rock fragments, minus 6 to 8 inches, are usually graded by the sieve size which is the size of a square opening.

The contractor obtained his rocks by blasting from a designated area near the dam, where he set up a grizzly operation for rock processing. The grizzly is a rugged machine or platform with sloping rails and bars that are set at the desired spacing. The specifications for the shell material called for a maximum size of 16 inches. The contractor interpreted maximum size as the size of his grizzly spacing. As a result of the fast grizzly operations, the contractor was stockpiling flat and long oversize rocks that did not meet gradation specifications. Work was stopped to discuss the specifications and to establish the meaning of the term maximum size. After lengthy discussions and checking the specifications of other organizations, it was established that larger rock fragments have been graded in several ways, including size and weight. The terms maximum size and maximum dimension have been used interchangeably, and they are intended to mean the size of a square opening; a terminology borrowed from soils gradation. However, the terms may be taken literally to mean the maximum dimension in any direction.

After about two months of work delay, a compromise was reached. The contractor was allowed to use any piece of rock that fits into the 2-foot lift thickness, provided that its maximum dimension is not greater than three times any other dimension.

ZONE CONSTRUCTION

Placement of material in the zones became the most critical factor in the construction of the embankment. Placement must be done in a manner to minimize segregation. The core and filters should always lead the outer shell rockfill, but not far enough to cause spilling of the leading zones over those lagging.

The contractor rockfill placement proceeded faster than the core and filter placements due to weather conditions. Site visits during early construction indicated that there were larger rock clusters adjacent to the filters. Areas of concern were:

a. The filters did not appear to be the full width, and they appeared to extend into each other.

b. The shell appeared to contain zones of segregation and numerous oversize rocks.

Further discussions led to questions concerning the integrity of the embankment. In order to determine the extent of the problem, work was stopped to conduct the investigations. Test pit excavations were made, at randomly selected locations at the shell and coarse filter contact. Excavations extended from the surface of the inplace embankment fill down to the top of the drainage blanket. Trenches were then extended from some of the pits, through the two filters, into the impervious core. Results of the test pit excavations revealed the following:

a. The filter zones were not constructed to specified lines and grades.

b. The shell rockfill was badly segregated and it contained up to 12% of oversize (+16 inch) rock.

c. The select rockfil was not as dense as would be expected for rockfill placed as specified.

d. The filter zones and the core were intermingled and overlapping, as shown in Figures 5 and 6.

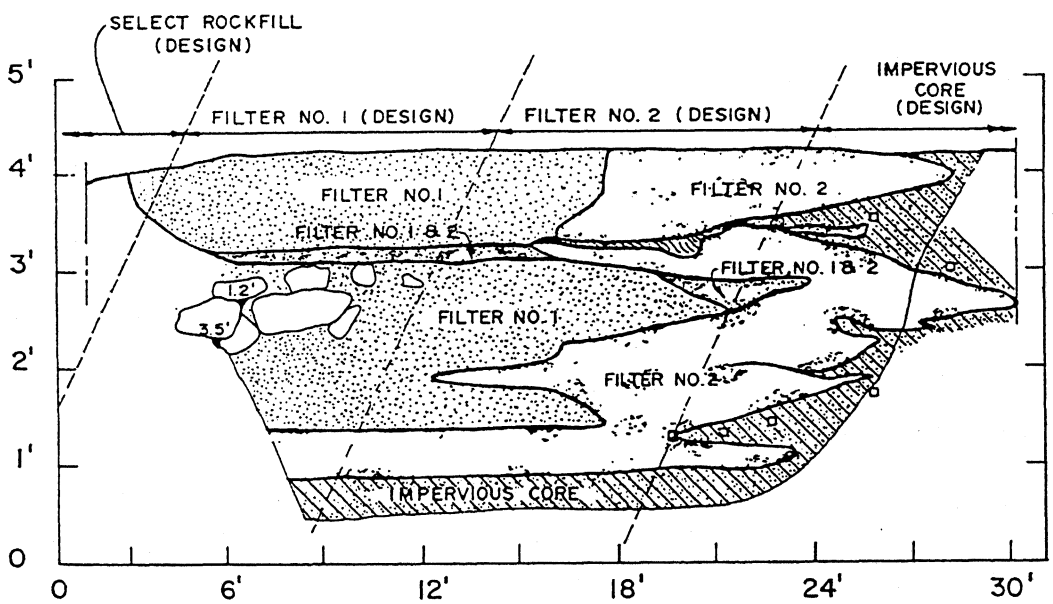

Figure 5. Overlapping Zones on Upstream Side of Embankment.

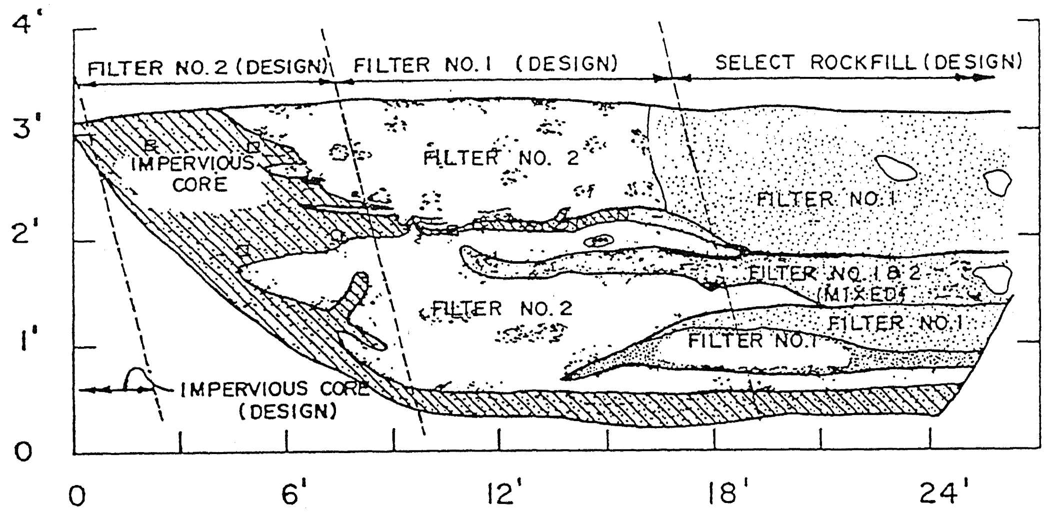

Figure 6. Overlapping Zones on Downstream Side of Embankment.

CONCLUSIONS

The findings of the investigations rendered portions of the embankment in place unacceptable. The contractor was directed to proceed with the remedial work. He removed the unacceptable portions and replaced them according to specifications under rigid control. For the continued construction, the zones were constructed as near level as possible. Continuous monitoring of the proper location for the zones was maintained.

Periodic inspection reports indicate that the embankment condition and performance have been satisfactory. No problems have been detected since the dam was completed in 1983.

The embankment construction problems could have resulted in the ultimate failure of the structure, if they had not been discovered early and corrected properly. This incident illustrates a very important geotechnical engineering fact. It shows that critical design parameters, including shear strength, compressibility, and permeability come under the control of the Resident Engineer and his inspection team, once construction has begun.

Finally, very important lessons can be learned from this valuable experience:

1. Specifications must be followed.
2. Close attention must be paid to details, because many details that can become critical can easily be overlooked.
3. Inspectors must be qualified, experienced, and they must maintain a watchful presence in the field.
4. Quality assurance inspection must be thorough to insure that all details are being met.

ACKNOWLEDGEMENTS

This paper is part of a research project sponsored by the Faculty Research Program at Tennessee Technological University. I am grateful to Dr. Rafael B. Bustamante, Chairman, Department of Civil Engineering and to Dr. Dean V. Adams, Director, Center for the Management, Protection and Utilization of Water Resources, for their support. Thanks to Mr. Frank B. Couch, Chief, Geotechnical Branch, and Mr. James E. Paris, Chief, Soils and Embankment Design Sections, U.S. Army Corps of Engineers, Nashville District, who provided me with some data and with whom I had the pleasure of working on the Tennessee Tombigbee Waterway, during the summers of 1975 through 1983.

REFERENCES

Jansen, R.B. (1967), "Evaluation of Dam Safety in California", Journal of Soil Mechanics and Foundation Division, ASCE, Vol. 93.

Leps, T.M. (1968) "Recent Experience with Earth and Rockfill Dams", Conference on Recent Developments in Design and Construction of Earth and Rockfill Dams, University of California, Berkley.

Sherard, J.L. (1963), "Earth and Earth Rock Dams", John Wiley and Sons, Inc., New York, New York.

Terzaghi, Karl and Peck, R.B. (1967), "Soil Mechanics in Engineering Practice", John Wiley and Sons, Inc., New York, New York.

U.S. Army Corps of Engineers, Nashville District (1986), "Embankment Criteria and Performance Report, Bay Springs Lock and Dam", Tennessee-Tombigbee Waterway, Nashville, Tennessee.

U.S. Department of the Interior (1976), "Summary and Conclusions on Failure of Teton Dam", from report by Independent Panel to review cause of Teton Dam Failure, Washington, D.C.