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November 20, 2003
Project 032810

Mr. Bobby Van Cleave
Geotechnical Engineer
Little Rock District
Federal Building, 7th Floor
700 W. Capitol Avenue
Little Rock, AR 72201-3285

Dear Mr. Van Cleave:

Re: Expert Consultant's Advisory Report (ECAR)
Regarding Seepage Issues for Clearwater Dam
U. S. Army Corps of Engineers, Little Rock District (USACE)
Contract DACW03-03-P.0296 dated August 2003

In accordance with the referenced contract, I provide below my review of seepage issues and proposed seepage-related remedial measures for Clearwater Dam, which is on the Black River near Piedmont, Missouri. I previously reviewed the draft specifications for the Foundation Drilling and Grouting Program, and the associated drawings, prepared by personnel of the Little Rock District. My report on the latter program was provided by letter dated October 7, 2003. In accordance with the contract, a draft of this report was submitted for comments, after which the report was finalized.

Potential safety issues other than seepage, such as those relating to seismic, hydrologic conditions at the site, were not included in this review. However, to develop an appropriate remedial design for this dam, it is important to examine the other safety issues. For example, the potential deformations of the dam and/or an undrained slope failure through the alluvium (liquefaction) due to seismic shaking should be evaluated sufficiently to determine whether any option selected for seepage control will be affected. Also the effect of major hydrologic events on the dam and on downstream flooding due to spillway discharge may require study to judge whether any alterations are needed. Integrated remedial options may then be developed for evaluation.

Recent USACE plans for interim investigations and remedial actions for seepage control at Clearwater Dam were begun due to the development of a sinkhole that was first observed on the upstream side of the dam on January 14, 2003 – eight months after the May 20, 2002, record-high pool level of El. 567.59. The top of the sinkhole was at El. 570, which is approximately 5 feet below the top of the seepage berm that was added on the upstream side of the dam in 1988.

All elevations are referenced to the USGS National Vertical Datum of 1929. The terms "left" and "right" are relative to an observer looking downstream at the dam. The crest of the dam is oriented northeast to southwest, the left direction being toward the northeast. (Note: Some of the documents refer to the left side as being to the east.)

The principal documents reviewed are listed in Attachment 1. A field trip to the site was held on August 28 and 29, 2003. The writer reviewed many original documents and photographs in the Little Rock District offices. Also, much discussion was held between the writer and personnel of the Little Rock District, both during the field trip and subsequently by telephone, to help clarify the writer's understanding of the documents and the history of this dam.

During this review, the writer was greatly informed and aided by Mr. Mark Brightwell, Mr. R. LeRoy Arnold, Mr. Steve Hartung and yourself. Also, Mr. Tony Batey provided an overview of the direction being taken by the Little Rock District to evaluate and remediate the seepage control and other potential safety issues for this dam. Mr. Keith Ferguson and Mr. Lee Wooten, both of GEI Consultants, Inc., ably assisted the writer during preparation of this report.

1.0 BRIEF DESCRIPTION OF DAM

Construction of Clearwater Dam was started in 1940 and completed in December 1948. No construction was done between 1941 and 1946 during World War II.

Attached for reference are two figures prepared by the Little Rock district for the Foundation Drilling and Grouting, Sinkhole Repair program. Figure 2 is a plan view of the entire dam and Figure 3 is a cross section of the valley segment of the dam.

The dam is approximately 4200 ft long. The valley segment of the dam, built on the former flood plain of the Black River, is approximately 138 ft high above the alluvial foundation that exists under the shells and 170 ft above the bottom of the core trench that was placed to rock to interrupt flow through the alluvial soils. This valley segment is about 2,250 ft long. The left ridge segment of the dam averages about 20-25 ft high and is 1,800 ft long. The left ridge segment rests on a peninsula of original ground that extends from the left toward the flood plain to the right. There is a 150 ft long transition between the valley and left ridge segments where the bottom of the core trench is stepped up along the right end of the peninsula of original ground. The left ridge segment rests on residual soils.

In 1987 a 3-ft high parapet wall was constructed on the upstream crest of the dam to increase the freeboard.

The upstream and downstream shells of the dam consist of compacted pervious alluvium from the site area. The downstream slope averages 2.5H:1V. The upstream slope originally averaged about 3:1. In 1988 a seepage berm was added to the upstream side. The average upstream slope was flattened to 4:1 at that time. An upstream sloping core of compacted clay separates the two shells. The sloping core rests on the core trench that extends through the alluvium to top of rock. The thickness of the sloping core at the contact with the core trench is approximately 60 ft. The top width of the core trench is approximately 160 ft and the bottom width is 40 ft. The fat clay and very silty clay soils used for constructing the sloping core and the core trench were obtained from the site area.

The seepage berm added in 1988 extends from a point 500 ft upstream of the current toe, to the toe and then up the original upstream slope to El 575, where a 30 ft wide bench exists. It was constructed largely of random fill (clay and rock fragments) from the spillway excavation. Its purpose is seepage reduction through and under the dam.

In the valley segment of the dam, the upstream and downstream shells, as well as the horizontal portion of the seepage berm, rest on a foundation of alluvial soils that range from approximately 30 ft to 40 ft thick and vary from fat clay to coarse sand and gravel. The alluvium is stratified with clays, silts, sands, and gravels. The horizontal permeability of the alluvium is likely to be very high due to horizontal stratification of the coarse granular soils. The vertical permeability is expected to be lower than the horizontal permeability.

The alluvium and core trench overlie dolomite bedrock of the Potosi formation that is pervasive in the region. The Potosi formation contains fractures and solution channels. The bedrock borings for the dam show the presence of many clay-filled and open cavities. The interconnections among these cavities are not known, but the writer assumes them to be present and numerous.

The right end of the valley segment of the embankment was compacted against dolomite bedrock that forms the right abutment. The contact slope is approximately 1:0.7 (50 to 60 degrees above horizontal). The bottom of the contact is about 300 ft from the centerline of the outlet tunnel, which lies farther to the right. The tunnel for the outlet works was driven through the dolomite bedrock in the right abutment.

Farther to the right there was a natural swale that was used to for the emergency spillway. The nearest side of the spillway is about 1,000 ft from the right end of the dam.

2.0 SEEPAGE LOCATIONS IN CLEARWATER DAM

The locations in Clearwater Dam where seepage may not be adequately controlled are listed below:

1. Through the dolomite bedrock of the Potosi formation beneath the entire dam.
2. Through the alluvium above the bedrock in the valley segment of the dam.
3. Through the sloping clay core of the dam. The suitability of the downstream filter is not known.
4. Through the core trench. The suitability of the downstream filter is not known.
5. Under and around the left ridge segment of the dam that is founded on residual soils. The residual soils are clayey toward the top and become coarse and pervious with depth. Within the residual soils there exist pinnacles of partially- or un-weathered dolomite of the Potosi formation.

6. Through the residual soils under the transition zone between the valley and left ridge segments of the dam.

7. Through the seepage berm. The inclined portion of the seepage berm was placed over riprap. The horizontal portion was place on the existing alluvium. The inclined portion of the seepage berm is not filtered against the riprap, to the writer's knowledge. Similarly, it is not known whether the horizontal portion of the seepage berm is filtered against the materials on which it was placed.

   The differential head to which the seepage berm has been subjected to date is not known, but it may be small. For this reason the differential heads across it may not have been large enough to date to test whether the seepage berm can sustain high differential heads over the long term.

8. Right abutment contact face.

3.0 EVALUATION OF SEEPAGE CONDITIONS IN CLEARWATER DAM

3.1 Valley Segment of Dam

Sloping Core and Downstream Filter – The sloping core consists of fat- to very silty-clays that were excavated from the flood plain deposits. Some samples of the core, taken while investigating the sinkhole, had low dry strength and low plasticity index. The filter on the downstream side of the sloping core is described in the plans as being the same as the granular alluvial deposits that were used in the shells, except that within 10 ft from the downstream face of the sloping core the filter must have "less than 50 percent greater than ¼ in."

The Little Rock District provided the writer with gradation curves for three core samples and for three samples of the shell upstream of the sloping core that were selected by us jointly during the field visit in late August. At GEI we evaluated the suitability of the three upstream shell samples to act as filter zone material for three core samples using the design guidelines in Natural Resources Conservation Service (1994), "Gradation Design of Sand and Gravel Filters," Part 633 National Engineering Handbook, Chapter 26. (Note: We used the upstream shell material because there were no samples of the downstream filter zone material, and because the upstream and downstream shells apparently are composed of similar soils.

One shell sample was coarser than required to provide a suitable d_{15} –value for retaining the finest of the core samples. All of the shell samples had gradations that were broader than recommended for preventing segregation during placement. Two of the core samples also had broad gradations that could have been susceptible to segregation during placement.

On the other hand, the filter zone is 10 ft thick and the entire downstream shell is composed of soils similar to those in the filter. These aspects of the design reduce the likelihood of piping through the sloping core. Further investigation of the core and filter is justified to reach a conclusion about the adequacy of the filter zone.

Core Trench and Downstream Filter – The filter on the downstream side of the core trench is a 2 ft thick zone of sand. Downstream from this filter is the natural alluvium. The alluvium was deposited in approximately horizontal layers and consists of materials that range from fat clays to very pervious sands and/or gravels. Therefore, it is likely that the filter sand itself would not be filtered by the alluvium at some locations. Under the influence of continuous seepage that occurs at normal pool, the soils in the cutoff trench and the filter could be subject to piping. At high reservoir levels the likelihood of piping increases and any incipient piping could develop more rapidly. Further investigation of the core trench clays, the filter zone, and the downstream natural alluvium is justified to help judge the suitability of the core trench filter to prevent piping.

Alluvium and Bedrock – The alluvium rests on top of natural dolomite bedrock that contains fractures and solution channels typical of the region. Continuous flow occurs through the alluvium and bedrock under normal pool, El 495. The head difference between the normal elevation of the reservoir and the tailwater level is about 45 ft. To date, the highest reservoir level has been El 567.59. At that time the differential head between the reservoir and tailwater was approximately 100 ft.

Water flows freely from the reservoir into the alluvium. Flow nets prepared by Little Rock District personnel show that such flow into the alluvium is deflected beneath the impervious core trench into the bedrock below the core trench. Flow along this path may cause piping into through the alluvium or the open joints and solution channels in the bedrock. The piping could lead to loss of soil at higher elevations, including the upstream shell. At normal reservoir levels the flow is continuous. At high reservoir levels the flow rate increases in proportion to the increase of the differential head. At PMF reservoir levels, the head and corresponding flow could be two or three times that at normal reservoir levels. Such continuous and fluctuating flows increase the likelihood of piping. Filled flow channels in the bedrock could be opened under the higher heads. Also any flow channels in the bedrock could be enlarged through dissolution of the dolomite.

3.2 Left Ridge Segment of Dam

Flow through Residual Soils – At present, a direct connection exists between the reservoir and the residual soils in the left ridge segment of the dam. The residual soils vary from clay, near the top to coarser, less weathered soils, as one moves down toward the bedrock. Seepage has been observed on the downstream side of the dam on the left side since the summer of 1948 when the reservoir level was rising as the dam was being completed. Later, one concentrated stream of seepage was dammed and a pipe inserted to allow measurement and sampling. In 1972 and 1980, two separate below ground drainage systems were installed nearby because the surface area downstream was frequently wet. The drainage systems have been successful in draining the water in this downstream area. Seepage also has been observed exiting from the side of the roadway that passes from the left end of the dam crest to the park below.

Personnel of the Little Rock district investigated these seeps to determine whether they were due to natural ground water flow from the land above, or whether they were due to seepage from the reservoir. They concluded that the flow probably originated from the reservoir, although the seepage may have been augmented by ground water flow.

This seepage through the residual soils in the left abutment and under the left segment of the dam is likely to cause piping at some reservoir levels because there is no filter system on the downstream side. (Note: The existing underground filter systems installed in 1972 and 1980 may be preventing piping, but they do not cover the entire area where seepage occurs.) To date, in none of the locations where seepage was seen has the water been turbid. However, piping is an intermittent process and the observations were infrequent.

Flow through Bedrock – A trial grouting program performed near the left ridge segment of the dam was unsuccessful because the grout was continuously lost both in the pervious residual soils above the bedrock and in the bedrock. This program confirms that the bedrock contains large cavities or solution channels. It is likely that high heads in the upstream shell could cause piping into such openings that would lead to sinkholes or other damage on the left side of the dam, if and when the gradients are high enough to move the soil grains.

3.3 Transition Zone between Valley and Left Ridge Segments of Dam

Flow through Residual Soils and Bedrock - As the core trench was stepped up the right end of the peninsula of natural ground on the left side of the valley, the bottom of the core trench was at first on bedrock and, at higher levels it was placed on residual soils. It is important to seal the areas that are subject to seepage flow through any pervious residual soils that remain below the core trench, since the residual soils become coarser with depth and are unfiltered on the downstream side. Seepage through this “window” under the transition zone between the valley and left ridge segments of the dam should be eliminated, as has been planned by Little Rock District personnel.

3.4 Seepage Berm

The upstream seepage berm was constructed in 1988 to reduce seepage. However, it is not known whether the seepage berm has been subjected to high differential heads from 1988 to date. During normal reservoir levels, flow occurs through the alluvium under the horizontal portion of the berm. But the heads under the berm may not be appreciably lower than the simultaneous reservoir levels above the seepage berm.

Based on the project drawings and photos from the sinkhole investigation, the inclined part of the seepage berm was placed directly on the riprap stone protection on the original upstream shell. Piping of the seepage berm material into the riprap is likely if high differential heads develop.

Some of the remediation options to be considered will require that the upstream seepage berm act as the principal barrier to seepage through the dam at all reservoir levels. For these options the likelihood of loss of berm materials into the underlying materials, when subjected to much higher differential heads than the seepage berm may have seen in the past, should be evaluated.

3.5 Right Abutment Contact Face

The embankment was compacted over the sloping dolomite bedrock in the right abutment. This geometry ensures that the weight of the embankment would close any openings between the embankment and the bedrock below. Also, if any settlement of the embankment occurs, it is unlikely that any permanent crack would open at the contact. If any cracks were to form, they probably would appear at the top of the embankment at locations vertically above the toe of the contact face.

The downstream side of this contact should be inspected for cracks and for water flow, especially at high reservoir levels, to confirm that the seal at the contact is performing well. Also the top of the dam and roadway should be inspected for transverse cracking that may have occurred due to settlement of the embankment in the vicinity of the contact face.

3.6 Solubility of Dolomite

Continuous flow of water through the bedrock, which occurs at all reservoir levels, could cause further dissolution of the rock and enlargement of the cavities and solution channels. Cavity or solution-channel enlargement, even to a small degree, could exceed a threshold at which critical flow paths become connected, which would increase the likelihood of piping that requires emergency action.

Therefore, a program of investigation into the solubility of this dolomite of the Potosi formation should be developed, and related past experience with dams in karst regions should be reviewed. This information may help provide insight into the degree to which a cutoff of a given depth into this dolomite will improve the lifespan of Clearwater Dam.

4.0 CAUSE OF JANUARY 14, 2003, SINKHOLE

As noted earlier, the sinkhole was observed on the upstream side of Clearwater Dam at Station 38+00 with an offset of 120 ft right (upstream of the centerline axis of the dam). It was 10 ft across at the top and 10 ft deep. It occurred on the slope of the seepage berm at approximately El 570, or 5 ft below the bench at El. 575 that forms the top of the berm.

The sinkhole was first observed on January 14, 2003, eight months after the record high reservoir level of 567.59 on May 20, 2002, according to the records supplied to the writer by the personnel tending the dam for the Corps of Engineers. This level was very close to the edge of the sinkhole that later formed.

The rainfall at the dam in May 2002 was 12.20 in., which is the highest monthly rainfall at the dam during the previous 10 or more years. The May 2002 rainfall was preceded by a March 2002 rainfall of 9.02 in. and an April 2002 rainfall of 5.43 in. In March and April, the reservoir reached high levels of El 520 and El 513, respectively. Within two weeks, the levels dropped back to the normal reservoir level. However the high pool of May 20, 2002, receded more slowly. It dropped to El 560 in two weeks and to normal reservoir levels (El 500) about 2.5 months after this record high.

The sinkhole occurred within several months following the record high reservoir level and that high reservoir level retreated slowly. These two events strongly suggest that the sinkhole was the result of the high gradients that were present in the dam during and after the record high.

The writer reviewed the substantial information about the sinkhole that had been gathered by the personnel of the Little Rock District. This information included several detailed discussions with Little Rock District personnel, records of the filling of cavities at the bottom of the cutoff trench during construction (the major cavities were near the location of the sinkhole), the excellent construction photographs, boring logs, the filter downstream of the sloping core and downstream of the core trench, the thorough sinkhole investigation made by excavating into the sinkhole and photographing the outline of the sinkhole, and the results of several very useful geophysical investigations in the area of the sinkhole.

Based on the above review, it is the writer's opinion that the immediate cause of the sinkhole most likely was the flow of water at high reservoir levels under gradients high enough to cause piping of the shell and natural alluvial material into an open joint or solution channel in the bedrock. There is also a likelihood that the sinkhole was created by flow of water through or at the bottom of the core trench (over the dental concrete) and through the downstream filter, ultimately reaching an open joint or solution channel in the bedrock. It is unlikely that the sinkhole formed through the sloping portion of the core. However, the results of the filter analyses done to date indicate that the sloping core materials could pipe through its downstream filter. Further information needs to be gathered about the adequacy of the filters downstream of the both sloping core and core trench.

Although the high reservoir levels of the previous year may have been the immediate cause of the sinkhole, it is likely that continuous flow of water through the alluvium at all reservoir levels had caused some piping at various times in the past. The sinkhole probably is the end result of long-term, intermittent piping and more intense piping when the reservoir has been high.

Review of the historical reservoir levels shows that the previous record high was El 566 in late May 1957. The seepage berm had been placed in 1988. This coincidence – that the sinkhole occurred soon after the first record reservoir level **following** construction of the seepage berm - was sufficient for the writer to consider the possibility that the sinkhole may have occurred partly because the seepage blanket had been placed without a filter between the berm and the riprap on the upstream shell. The sinkhole could have formed due to movement of seepage berm soils into the riprap. Upon further review the writer concluded that the water levels in the upstream shell of the dam probably were not much lower than the corresponding reservoir level, such that the differential heads across the seepage blanket were small. Although movement of fines could occur at high gradients, the gradients may have been too small to cause a significant loss of berm soil.

In addition, and more important, the exploratory excavation into the sinkhole and the geophysical studies both indicate that the sinkhole extended into the dam far deeper than to the top of the original upstream shell. Movement of fines into the riprap could not alone explain the deeper piping that has occurred.

5.0 CONCLUSIONS

1. The dolomite bedrock, which contains solution channels and open or clay filled cavities across the entire length of the dam, provides the most likely path that could lead to partial or full failure of the dam.

2. Another likely path for piping is through the alluvium downstream of the core trench filter zone. The filter on the downstream side of the core trench may be inadequate because it is only a 2-ft thick sand zone adjacent to the natural alluvium on its downstream side. The downstream alluvium contains very coarse granular materials, which could provide piping paths.

3. The residual soil in the foundation of the left ridge segment of the dam and the transition zone between them also provides a likely path for piping of the upper residual soils through the more pervious, deeper residual soils and/or into the bedrock below. The lack of any feature in this zone to control seepage leaves the dam exposed to piping and possible sinkholes in this part of the dam.

4. Another less likely potential path for piping is through the core where the core soils may not be not properly filtered, into coarse zones in its filter, into coarse portions of the downstream shell, and/or into the bedrock.

6.0 RECOMMENDATIONS

1. To control seepage through this dam, select and construct a remedial seepage barrier throughout the length of the dam as soon as practicable.

   Seepage barrier options a) through c) are discussed briefly below, subject to the following assumptions:

   - That the dam should be designed for the reservoir level that is most critical for each mode of failure. For the seepage issue, a full reservoir is the most critical.

   - That potential safety issues other than seepage control, e.g. seismic and hydrologic issues, will be considered during design development of the seepage barrier.

     - For example, seismic shaking at this dam could cause a slope failure due to liquefaction in either the upstream or downstream direction through the loose sandy soils that are prevalent in the alluvial stratum that underlies the shells. Even if liquefaction is not likely, the seismic shaking could cause sufficient deformations in the dam to disrupt the seepage control measures. If these two modes of failure may occur, any needed remedial measures should be considered during design development of the seepage barrier.

- Similarly, if a review of the site hydrology and the operation of the reservoir indicate the need for changes, they too should be considered during design of the seepage barrier.

a. Concrete or cement-bentonite seepage barrier through the entire dam, foundation soils, and 60 to 70 ft into the bedrock, with a total maximum depth of about 240 ft. The depth would have to be evaluated further. Such a barrier will be a likely solution if piping paths through the core, cutoff, alluvium, shell/filter, and residual soil cannot be discounted.

   The seepage barrier may be constructed from either the upstream bench at El 575 or from the crest. An impervious blanket from the top of the barrier to the dam crest would be required if the barrier is constructed from the El 575 bench. The new impervious blanket would have to be properly filtered below and protected on top from the effects of drying, frost action and waves. It would have to be carefully designed at the connection with the seepage barrier where a stiff barrier will meet the more flexible soils in the impervious blanket.

b. A concrete or cement-bentonite barrier could be placed near the toe of the original dam or near the upstream at the end of the 1988 seepage berm, as suggested by personnel of the Little Rock District. In both cases the existing seepage berm would have to be extended to the top of the dam. The writer recommends that the barrier extend through the alluvium and 60 to 70 ft into bedrock, for a total depth of about 115 ft. For these two options the barrier would have greater length but shallower total penetration than would be the case for the options in a) above.

   When the seepage berm is extended to the crest for these two options, the entire seepage berm would become the primary barrier to flow through the dam. The writer does not recommend placing a barrier at either of these locations due to uncertainty about the long-term viability of the seepage berm when exposed to high differential heads.

c. Use of a three-line grout curtain through the upper 60 to 70 ft of the bedrock, installed for example from the top bench of the seepage berm, could be considered as a seepage barrier. This solution could only be used if it were determined that the sloping core and core trench are adequately filtered on the downstream side. Installation of such a grout curtain in karst environments is very difficult, and the writer recommends use of a concrete or cement-bentonite barrier rather than a three-line grout curtain. Nevertheless, it will be important to be able to grout existing cavities on both sides of a concrete or a cement-bentonite barrier sufficiently so that the slurry used to construct the barrier in this rock will not be lost during construction.

2. Use the interim grouting and testing program as planned to further evaluate the cause of the January 2003 sinkhole and the piping path(s) that may have contributed to the formation of that sinkhole. During the same program (a) evaluate the feasibility of constructing a seepage barrier of concrete or cement-bentonite, and (b) investigate and

develop procedures that could be used to grout this karstic rock, especially for the purpose of containing the slurry that would be used to install a cement or a cement-bentonite flow barrier. The investigation should extend at least 60 ft into the bedrock.

3. Measure the crest elevation on a quarterly basis for one year to determine whether (a) any trend is observed, and (b) whether crest settled more near the sinkhole area. For the latter purpose, the spacing of measurement points should be 50 ft. or less in the vicinity of the sinkhole.

4. Evaluate the potential for dissolution of the bedrock to aid in judging the effect of dissolution on the lifespan of the dam.

5. Further examine experiences at other dams on karst formations to help judge the suitability of a deep cutoff, the depth required, construction methods, and whether there are any overriding reasons to abandon the site or replace the dam.

6. The existing instrumentation system should be evaluated and extended as necessary to understand the flow system through this dam and its foundation along at least three complete cross sections of the dam from the upstream to the downstream side. The instruments should be located at various depths, e.g. in the shells, in the natural alluvium, and one or more at different depths in the bedrock.

7. For any options considered that will rely on the existing core and core trench, collect additional soil samples during the interim testing and grouting program to evaluate the potential for piping through the sloping core and the core trench. For such options it would be necessary to seal the window that allows flow under the left abutment ridge.

   Collect samples of the sloping core, the downstream filter, and the shell material downstream at selected locations along the length of the dam. Similarly, take samples of the core trench, the adjacent filter sand, and the downstream alluvial soils. Determine the gradations of the samples and evaluate the potential for piping to gain insight into the long-term viability of the core and core trench as a seepage barrier.

8. To check whether piping occurs at known seeps, measure turbidity of seepage samples taken hourly at critical times and occasionally at non-critical times. Critical times include periods of significant rising and falling reservoir levels. Check in any locations where seepage is observable.

Respectfully submitted,

GEI CONSULTANTS, INC.

Steve J. Poulos
Principal

SJP/cc

ATTACHMENT 1

DOCUMENTS REVIEWED
for
CLEARWATER DAM

Expert Consultant's Advisory Report
November 20, 2003

These documents are listed alphabetically by source and then by date.

Anderson Engineering Consultants, (2003), Gradation Curves for samples of clay core, upstream shell, and natural alluvium, September 22 and 25.

Association of State Dam Safety Officials (ASDSO), (2003), Risk Categorization for Dams, Report of Steering Committee for the ASDSO, April.

Kansas Geological Survey – BOR, (2003), "Conclusions on Geophysical Investigations, Clearwater Dam, September 22, 20 Figures.

Kansas Geological Survey, University of Kansas Center for Research Inc., (2003), Seismic Investigation of Sinkhole on Clearwater Dam, Preliminary Report by Richard D. Miller, Julian M. Ivanor, David R. Laflen, and Joe M. Anderson, May 30, 36 pp.

USACE, Little Rock District, (1939), Section II – Regional Geology, Clearwater Dam, May.

USACE, Little Rock District, (1941 – 1950), Foundation Completion Report, Vol. II, Plans for Dam and Appurtenant Works.

USACE, Little Rock District, (1979), Left Abutment Seepage Study, Clearwater Dam.

Volume I	Text
Volume II	42 Plates

USACE Little Rock District, (1981), Comprehensive Seepage Analysis and Report for 1949 to 1981, Clearwater Dam, August.

Volume I	Text
Volume III	71 Plates
Appendices A	Correspondence
Appendices B	Reports Referenced in Volume I
Appendices C	Boring Logs

USACE, Southwestern Division, Laboratory, (1980-1982), Results of Classification Tests, Clearwater Dam, Little Rock District:

SWDED-LL Reports:

13087	May 1, 1980
13146	October 8, 1980

13190	December 10, 1980
13194	December 19, 1980
13209	January 26, 1981
13220	February 12, 1981
13222	February 25, 1981
13231	March 16, 1981
13240	March 30, 1981
13284	July 10, 1981
13472	September 7, 1982

USACE, Little Rock District, (1981), Seismic Analysis Report, Clearwater Dam.
Volume I, August
Volume II – 14 Plates, Revised October 1982.

USACE, Little Rock District, (1989), Grouting Completion Report, Right Abutment Sta. 53+00 to Sta. 56+55, Clearwater Dam, July.

USACE, Little Rock District, (2002), DRAFT, Safety Assurance Program Evaluation Report, Clearwater Dam, December.

USACE, Little Rock District, Field Office at Clearwater Dam, (2002-2003), Record of Reservoir levels for 2003 and 2003.

USACE, Little Rock District, (2003), Draft Specification Section 02249 – Foundation Drilling and Grouting, for sinkhole Repair, September, 8 Plates.

USACE, Little Rock District (2003), Clearwater Probability Survey, Economic Reliability Analysis, October 20.

USACE, Little Rock District, information as follows:

USACE (various), One aerial photograph of the dam and three compact discs with additional information in the files of the Little Rock District:

Aerial Photograph titled Clearwater Lake, P-Tubes/Weirs, Vertical View.

Photographs of excavation for sinkhole investigation and slides used for presentation of results, (2003), on compact disc.

Geophysical Survey data from U.S. Bureau of Reclamation, Engineering Research and Development Center and Kansas Geological Survey; Sinkhole photographs (2003); Sonic drilling photographs, Graphs of piezometer readings; and photographs of May, 2002 pool of record, all on compact disc.

Clearwater Dam 2003 Annual Report; Photographs during construction circa 1939-41 and circa 1946 – 1948, and 59; all on compact disc.

U.S. Army Engineering Research and Development Center, (2003), Draft preliminary Report on Geophysical Investigation of Foundation Conditions, Clearwater Dam by Troy R. Broslen and Julie Kelly, August 11, 20 pp.