ABSTRACT

This case history presents the design and construction of a grout curtain, trench drain and collector system, and quality control and verification testing for the Tarrant Regional Water District’s Cedar Creek Dam (Joe B. Hogsett Dam) project on Cedar Creek Reservoir in Malakoff, Texas. The demand to maintain fresh water supplies required plans to design, build, and maintain operations of a raw water infrastructure to tap into existing resources. Since the original construction of the reservoir embankment, seepage related issues have slowly developed that have resulted in wet and marshy areas that are difficult to maintain, and may indicate a possible reduction in dam safety. Measures installed to limit these issues, such as relief wells, are now aged and difficult to maintain. The modifications for the project includes a series of contracts to address these issues, and this discussion deals specifically with a grout curtain used to reduce seepage through a cap of terrace deposits around the cutoff and through the left abutment.

For this project, two significant work phases included the construction of a 1,400- foot double row grout curtain along the left abutment area and approximately 1,300 feet of a trench drain and collector system.

The grout holes were spaced 10 feet on center and battered at 15° from vertical to an average depth of 80 feet. The design required work in two different grout zones. The upper grout zone was composed of terrace deposits typically consisting of sands and gravels, while the lower grout zone consisted primarily of fractured shale.

Since the upper grout zone would be unstable during drilling, the geotechnical contractor utilized a ported PVC pipe to maintain an open hole. Following completion of the upper grout zone, drilling in the rock portion allowed for final grouting. This required a suite of balanced stable grout mixes. In addition, all grouting operations utilized the geotechnical contractor’s proprietary iGrout™ system, allowing the owners and engineers to monitor the operations and progress remotely. Permeability tests completed along the centerline confirmed achievement of the performance requirements.
The final stage of construction included installation of a drainage trench and collector system to handle additional water. The trench consists of two short legs and one long leg forming a “Y.” Excavating the trench into a permeable sand layer allowed for transport of water into the trench drain and collection in a controlled manner. The flow will be monitored through a weir along the drain alignment.

INTRODUCTION

The Tarrant Regional Water District’s (TRWD) Cedar Creek Dam, built from 1961 to 1965, includes a 7,700-foot-long, 91-foot-high main embankment. In addition, the levee, which extends to the northwest from the main embankment, is 9,800 feet long with a maximum height of 35 feet.

The embankment (Figures 1 & 2) includes a zoned earth fill dam with an open-cut cutoff trench. The internal drainage system consists of a blanket-type sand drain under portions of the downstream shell and numerous relief wells. The upstream slope protection consists of 30 inches of rock riprap at higher levels and 24 inches of rock at lower levels of the dam face.

Figure 1. Aerial view of the Cedar Creek Dam main embankment, located on Cedar Creek Lake in Malakoff, Texas.
DESIGN

The Owner authorized a study of the project based on on-going seepage and maintenance related issues that made many areas difficult to mow and inspect, and hindered access to relief wells. Because of this, many of these areas have developed brush and tree stands that further complicate inspection activities. A comprehensive evaluation of the Cedar Creek Dam included the review of historical data, geophysical testing of the embankment and foundation, 25 soil borings with laboratory testing, sonar investigations of the spillway basin and outlet conduit, additional field inspections, and clearing and excavation to identify the potentially damaged internal drainage and relief well systems. During the course of the study, terrace deposits (Qt) were identified at the left abutment, as noted on Figure 3.

Figure 2. Typical cross-section of Cedar Creek Dam.

Figure 3. Geologic Atlas Map with Left Abutment circled. (USGS National Geologic Map Database Catalog, 2013)
These terrace deposits included a wide variety of material types, but were relatively clean and coarse between Elev. 270 and 285, as shown in Figure 4.

Investigations revealed the fill embankment generally consisted of clay and sandy clay underlain by an alluvium formation containing sand, clayey sand, gravel, and clay with sand. Below the alluvium formation, the soils primarily consisted of weakly cemented sandstone and shale of the Wilcox Group.

Because it was suspected that these deposits were exposed on both the upstream and downstream sides of the left abutment, these deposits allowed for through seepage around the left abutment of the dam. Because of the length of the seepage path, internal erosion was not considered a probable failure mode, but the seepage contributed to wet surface conditions at the left groin and surrounding downstream area. The seepage is likely intensified by the termination of the dam cutoff at about Station 155+50 that occurred due to constructability issues related to the excavation depth. This resulted in a section that likely exposed the base of the dam embankment to a window of granular terrace deposits between Station 162+00 to 164+00. Because the source of this seepage differs from the known underseepage issue, the left abutment improvements and the main embankment improvements were divided into separate improvement contracts.

Various cutoff options were explored and the project was identified as a candidate for injection curtain grouting because of the relatively discrete zone of coarse granular terrace deposits in the abutment. The injection grouting also allowed the creation of a lower permeability zone to establish the cutoff along the full length of the dam and to redirect the terrace deposits seepage further downstream of the dam to reduce exit gradients and provide a filtered exit along a collector trench.

Development of the grout curtain geometry was achieved in part with the use of SEEP/W, GeoStudio 2012 developed by GEO-SLOPE International Ltd. The “plan view” model option was used to approximate seepage behavior through the confined granular deposits. The analysis was performed to study flow paths and subsurface pressures within
the mapped terrace deposits for the proposed improvements. The results indicate that a permeability reduction of two orders of magnitude will result in approximately 80 to 90% reduction in seepage quantities, and that the resulting pressure regime significantly reduces horizontal gradients and reduces the potential for internal erosion.

The selected grout curtain geometry extended from dam centerline Station 160+00 to 167+00 to establish an improved cutoff and reduce seepage through windows remaining from the original construction. The grout curtain then turned 90° downstream for a distance of 700 feet to direct seepage east and downstream of the dam and improve maintenance in the valley area around the left abutment. The design injection depth was selected to target the granular terrace deposits, but was extended 10 feet into the underlying Wilcox Group to address potential permeable or jointed zones in the shale and sandstone material. Refer to Figures 5 and 6 for plan and cross section views.

![Figure 5. Plan View of Grout Curtain Alignment.](image-url)
The analysis indicated about 20 to 40 gpm of seepage could potentially pass through the grout curtain and daylight at the dam toe. A secondary system downstream of the grout curtain was included for the filtration and collection of this seepage. Although this system (Figure 7) was not critical for stability, it was desirable to the owner as it would reduce the potential for wet downstream areas and improve access for maintenance and inspection. The collector was divided into two sections to collect seepage from the left groin (Line B) and parallel to the abutment topography (Line A) and discharge into a vault with a weir system. A third line (Line C) was then used to divert the seepage into an existing outfall channel for the relief well system. These perforated collection lines were placed in trenches that included a gravel pipe backfill with a fine sand filter layer. The location of the lines were selected so that the depth of the trench would intercept the granular terrace deposits.
Figure 7. Centerline Cross Section at Left End with Qt Deposits Noted.
CONSTRUCTION

Phase 1

Drilling. Grout hole drilling was performed utilizing two techniques: a rotary-duplex method for the drilling of the embankment overburden, and a single rotary method for the foundation rock. All drilling was completed utilizing water as the flushing fluid to remove the cuttings. The duplex drilling (Figure 8) through the embankment involved the advancement of the outer steel casing to the required minimum 6-inch embedment into the rock beneath the earth embankment. After the drill tooling was advanced to the proper embedment, the inner tooling was withdrawn and a 4-inch-diameter flush-threaded PVC casing was installed inside the steel casing to mitigate potential stability concerns and to protect the embankment during future grouting related activities. The annulus between the steel and PVC casings was then grouted utilizing a bentonite-cement grout. Following extraction of the steel casing, the PVC casing was re-grouted in-place to ensure the casing was properly sealed. The PVC consisted of two different sections of pipe to accommodate the grout curtain design: the upper portion was a plain pipe and the lower portion placed through the intended grout zone was a PVC sleeve-port pipe. The PVC sleeve-port pipe provided grouting access to the sands and gravels that were schedule for treatment by the designated grout zone. After grouting of the upper zone was completed, the rock portion below the PVC casing was typically drilled in a single stage using a roller-bit with a water-flush. The average drilled rock depth was approximately 8 feet.

Figure 8. Rotary duplex drilling on Cedar Creek Dam (2014).

Grouting. The curtain grouting was completed in two separate phases. The upper grout zone, sands, and gravels treatment utilized the ported pipe and was performed in an upstage, bottom-up manner. The lower grout zone consisted of a shale bedrock and was completed utilizing a combination of upstage and downstage treatments, pending hole stability. The stage length was varied but typically did not exceed a length of 10 feet. The grout curtain design was a double row approach that was comprised of four hole series: A-line primary, A-line secondary, B-line primary, and B-line secondary. The grouting
operation would move in a particular order starting with A-line primary, then completing the A-secondary series, following by B-line primary and secondary. The sequencing is critical for consistent and accurate evaluation of the grouting operations.

Grouting was completed using balanced stable grout mixes and performed through inflatable packers that were sized to match the drill hole diameter. Each grouting mix was batched on-site using a high-shear colloidal mixer. The grout was then sent to the hole location through 1-inch high pressure grouting lines arranged in full circulation to allow for proper controls of all pressures imposed by the soil and rock formations. An inflatable packer was lowered into the hole to the appropriate depth and then inflated. The connection between the grout manifold and the packer was a hydraulic hose with the ability to be pulled or reeled up to each depth required. After the packer inflation, the desired grout mix was injected into the formation and specific grouting criterion was utilized for the proper closure of each stage. When upstage grouting, the packer was pulled up and inflated to begin grouting on the next stage immediately following the completion of grouting the previous stage. When downstage grouting, the packer was removed and operations continued to the next scheduled hole.

**Refusal Criteria.** The GIN, or Grouting Intensity Number, was the refusal criterion for terminating a grout stage. Following refusal of the first stage, the packer was pulled and the grout was allowed to reach initial gel time prior to the washing of the ported PVC pipe. However, if grout refusal was not established from the previous requirements, the hole was rested for 4 hours, or until initial gel time completion, and then flushed with 5 to 8 cubic feet of water. Following the water flush, the hole was grouted in accordance to the general procedures.

The refusal criterion for this project was based on closure confirmation on the GIN method, or limiting envelop. The required GIN for this project was established as 150. The following equation was utilized for calculating the GIN (Deere Lombardi 1993):

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GIN = p \times V
\]

where:

- GIN: constant, specific energy
- p: pressure (psi)
- V: grout volume (ft³)/length of stage (ft)

The refusal criteria for this project remained the same throughout the entire grouting process; however, the approach to achieving the required closure varied by the engineer and contractor to meet desired seepage reductions while still maintaining cost considerations of the owner. Data acquisition systems were utilized during all pressure testing and grouting operations. The system collected information in real-time and provided insight to the engineer and contractor during all phases of the operation. The results were uploaded to a file transfer system nightly for the engineers and owner, allowing review while on- or offsite.
During the early stages of the project, the grouting was monitored closely for injection rate and to determine the most suitable grout mix for the successful completion of the project. While utilizing the GIN method it is important to note that it is preferable to utilize a single thick mix to complete the grouting. This differs from other grouting approaches that utilize a mix-thickening sequence that starts with a thin, flowable mix and thickens to a much more viscous grout mix with less flowable characteristics. The geology at the Cedar Creek Dam site varied from porous gravel zones to less permeable sand layers to bedded shales/sandstones. It was difficult to determine prior to grouting how thin or thick the mix should be for optimal treatment. To assist in the decision, a suite of grout mixes was submitted for approval on the project with varying viscosities. All grout mixes were balanced and stable mixes, yielding a bleed of less than 3%.

The grouting operation was initially completed with the thinnest mix, A-mix, to make sure small fractures and low porosity zones were not missed as a result of the mix thickness. The A-mix produced positive results and consistently established the GIN value set in the project specifications. The data was monitored continuously with the iGrout system and submitted daily for review. A small, less critical section of the grout curtain was selected for treatment of all four hole series to be completed for analysis and to determine if any adjustments to the grouting program were necessary. The initial grouting utilized a high threshold for grout take before intermittent grouting was employed. Stopping of a stage that encountered back pressure was not practiced due to fear of losing a stage, or inadequate treatment of the groutable zone. The results of the completed section were graphed for analysis (Figures 9 & 10).

![Figure 9. Grout takes by series during early grouting.](image)

The grout takes are presented as the grout volume per foot of borehole. The results indicated that grout takes reduced from primary to secondary, however, the change was not significant enough to leave the grouting program unchanged. The project team
reviewed the data and procedures and adjusted the grouting approach to limit “excessive” grouting and provide a more targeted grout curtain. The first adjustment was thickening the mix from the thinnest mix to a medium viscosity mix. The early phases of grouting and pressure testing indicated that the grout zone could be grouted with a medium viscosity mix. The initial pressure testing indicated levels of high permeability with Lugeon values of 20 or greater. A Lugeon is defined as: 1 Lugeon = 1 L/m/bar at a test pressure of 10 bars (Bruce 2003). The Lugeon value of 10 or greater warrants grouting for seepage mitigation (Houlsby 1990). The second adjustment was a more rigid intermittent grouting program with a lower injection quantity. After the program changes, the geotechnical contractor monitored the data and plotted it regularly to evaluate the effectiveness of the changes.

![Figure 10. Bar chart demonstrating grout takes by series following changes to grout program.](chart.png)

The updated grout analysis indicated a very steady reduction in grout take by order of hole series. The grout take per linear foot was reduced by 50% from A-line primary to the final B-line secondary series and grout takes decreased considerably for each series. The results provided the project team with a high level of confidence in the effectiveness of the grouting program. To confirm the analysis of the data, verification holes were drilled along the centerline of the grout curtain, in between the rows, and pressure tested to evaluate the post-treatment permeability.

The verification test required the drilling of a hole in the center of the grout curtain in an area where all four series were completed. It should be noted that coring was specifically eliminated due to the nature of grouted gravel zones and the recovery of such material. The hole was drilled into the grout zone and terminated prior to exiting the bottom of the grout curtain. The packer was inflated at the top of the grout zone for a water pressure test. The geotechnical contractor calculated the pressure utilized for the test by taking the...
maximum pressure on the grout curtain at maximum pool height and multiplying it by 2. The results of the verification test indicated a Lugeon value of less than 5. The results indicated a low Lugeon value, or very tight zone, that is difficult to grout. The low Lugeon values indicated that additional series of holes would not be required.

**Phase 2**

**Drainage Trench Installation.** Following the completion of the grout curtain, a collector trench drain was installed through permeable sands downstream of the dam embankment. The trench consists of two short legs and one long leg forming a “Y.” The total length of the trench is 1,300 feet, which includes 3 weir monitors within a collector drain for measurement of seepage through the grout curtain and embankment along the left abutment. The trench was installed into a permeable sand layer to allow transport of water into the trench drain and collection in a controlled manner. The vaults and weir design were established based on the design goals for a total seepage of 20 to 40 gpm.

Installation of the collector drain (Figure 11) took approximately 4 weeks from start to finish. The excavation was partially completed in a running sand that created some difficulty with maintaining an open excavation. A combination of dewatering and trench boxes were utilized for the completion of the work. The collector drain was composed of SDR-135 PVC perforated pipe that was surrounded by 1 inch crushed limestone number 4 stone aggregate, wrapped in a geotextile filter fabric, and placed on a clean filter sand to allow for the flow of water into the pipe. Once the pipe was installed, a vault was formed and poured to allow the placement of vibrating-wire weir monitors.

![Figure 11. Trench collector installation August 2014.](image)

**DATA ACQUISITION (DAQ)**

The geotechnical contractor employed a proprietary DAQ system to monitor all pressure testing and grouting operations in real-time. The grout technician simultaneously
controlled up to 3 water pressure testing or grouting operations from a single computer screen. The system automatically computed target pressures for each grouting stage based on the project specifications, and recorded various monitoring parameters, including injection pressure, flow rate, and volume. The utilization of iGrout allowed for real-time observation of all pressure testing and grouting operations. The data were used for grouting analysis to determine the grouting effectiveness and to allow for on-the-fly decision making regarding the proper completion of each stage. The data were displayed on a desktop computer screen for a grout technician (Figure 12) and engineer to monitor progress. In addition, pressure testing and grouting plots (Figure 13) were created and submitted daily for each stage. The water testing and grouting data were synced with a CAD interface and plotted automatically to produce updated “as-built” drawings.

Figure 12. iGrout Technician at Cedar Creek Dam.
CONCLUSIONS

The project achieved the goals set forth in the project specifications. The GIN methodology proved effective for this geology, however, it should be noted that success was not achieved blindly; it required constant evaluation and targeted modifications to the approach based on information gained during construction. The data acquisition systems enabled the project team to evaluate the effectiveness of the grouting program and modify when necessary. The recorded information provided the opportunity for the proper interpretation of the ground conditions. Throughout the entire project, a high level of communication between the owner, engineer, and contractor ensured that any changes were agreed upon, and that the time required to implement the changes was minimal.

The post-treatment seepage results indicate that the system is effective. Observations of the left groin indicate that the surface conditions are significantly improved, and areas with standing water at the start of construction are now dry. Initial seepage observations of the drainage collection lines indicated flows of about 30 gpm, which agrees closely with the seepage quantity predicted during design. The weir and instrumentation will be used to automatically monitor seepage on a daily basis, and trends will be developed to relate seepage levels to the reservoir level.
REFERENCES


USGS National Geologic Map Database Catalog, 2013