OCHOCO DAM DRAIN REHABILITATION

Mark Pabst - Bureau of Reclamation

Introduction

Ochoco Dam is an earthfill structure that is located six miles east of Prineville in central Oregon. The dam was built between 1917 to 1921 by the Veterans Farm Administration. Responsibility for safety of the dam was transferred to the Bureau of Reclamation in 1948. Ochoco Reservoir is an essential component of the Ochoco Irrigation District which supplies water for such crops as mint, garlic, alfalfa and others. The reservoir also provides flood protection and recreation benefits. Ochoco Lake State Park boating and camping facilities also utilize the reservoir.

Because of ongoing seepage related concerns with the dam since construction in 1917, several modifications have been made to the structure. The most recent modification, rehabilitation of the right abutment drains is the subject of this paper.

Description and History of the Dam

Ochoco Dam was originally constructed utilizing hydraulic fill techniques. Material was sluiced from the right and left abutments, with coarser material placed in the upstream and downstream shells and finer material puddled on either side of the centerline. In 1949 and 1994 the dam was raised to it's current structural height of 152 ft. The dam has a volume of approximately 1 million CY. The spillway is a concrete chute overflow structure excavated through fan deposits on the left abutment. The outlet works conduit was constructed along a pre-existing canal alignment. Embankment material was then sluiced over the structure. Control comes from an intake and gate tower built at the upstream toe of the dam.

Immediately after initial filling, seepage flows estimated at 40 cfs were seen coming through the right abutment. Material was sluiced into the reservoir on the right abutment and the seepage rate was cut in half. In 1949 an earth blanket was constructed on the upstream right abutment (along with other work described later) which reduced the seepage rate to 12 cfs. In the 1980's several sinkholes were noted on the upstream right abutment, near the intake tower, and in front of the spillway crest. In 1989 a piezometer adjacent to the OW conduit, near the centerline of the dam, showed erratic behavior which was not related to reservoir operation. This behavior is thought to be related to piping into the foundation. Concurrently, several yards of material were found having piped into the outlet works conduit. At this time the reservoir was restricted and in 1991 a second emergency blanket (geomembrane) was placed on the right abutment. Continued poor performance was seen in 1992 and 1993 and the reservoir was evacuated in late 1993.

Geology at the site consists of a massive landslide making up the right abutment, alluvium at the maximum section, and an alluvial fan on the left abutment. The landslide and fan form a constriction in the valley and must have been attractive to the original builders in that it minimized the volume of embankment fill needed to close the valley. At the maximum section the alluvium is divided by a low permeability lacustrine layer which causes the lower alluvium to have artesian characteristics. Bedrock, a vitrified tuff, exists several hundred feet deep below the original stream channel and is exposed on the left abutment downstream from the dam.
**Modifications**

The first modification to Ochoco Dam was done in 1949 when Reclamation inherited the structure. The dam was raised nine feet by placing fill on the downstream slope for increased flood storage. The new fill consisted of a pervious zone placed on the face of the dam which was then covered by shell material. Prior to placement of the overlay, butt joint drain tile was installed at the toe of the dam (East Drain). Upon re-filling, seepage continued to issue from the right abutment and a second drain system was installed (West Drain).

Due to erratic instrument readings in 1989 and sinkhole exposure on the upstream right abutment, the reservoir was restricted by approximately 20 ft. and a geomembrane liner was added as an emergency precaution to increase the seepage path through the right abutment.

Continued poor performance was observed from 1990 to 1993 and a major modification was undertaken in 1994. That modification replaced all of the seepage related features of the structure by excavating an upstream trench and placing a filter/drain system and new impervious upstream core. Seepage collected by the upstream drain was transferred to the downstream channel by a gravel drain constructed through a temporary breach in the dam. The plan and section for the dam showing these modifications is shown on Figure 1.

Upon re-filling in 1995 a sinkhole developed through the new upstream core. The material in the vicinity of the sinkhole was subsequently removed and replaced with engineered fill. The cause of the sink was investigated and found to be associated with a loss of the filter material into an isolated pocket of coarse open work boulders undetected in the upstream face of the original dam.

In order to address hydrologic deficiencies the spillway was rehabilitated in 1996. The rehabilitation consisted of rebuilding the crest, raising the walls, adding a stilling basin and rebuilding the return channel to the creek.

In 1997 cracks were repaired in the outlet works conduit, a minor repair was made to the East Drain, and diversion capability was added to the East and West Drains.

Due to continued poor performance of the East and West Drains, as described below, they were extensively rehabilitated in 1998, which is the subject of this paper.

**Existing Right Abutment Drains**

During the 1949 modification, the downstream face and toe of the dam were stripped. A toe drain consisting of concrete bell and spigot pipe was laid with loose joints at the toe of the stripped slope. A coarse gravel envelope surrounded the pipe. Due to its location, this drain has become known as the East Drain. The downstream earthfill overlay was then placed.

The following year a drain field was constructed on the right abutment. For this drain, shallow trenches were excavated, coarse gravel envelope placed, and concrete bell and spigot pipe laid, similar to the East Drain. The pipe for this drain was of higher quality than that used for the East Drain. This downstream drain was subsequently referred to as the West Drain. In addition to this drain, an open pit was excavated downstream of the drains on the right abutment and an overflow structure was constructed which was connected to one of the legs of the West Drain. Because of high groundwater on this abutment, water filled the pit at higher reservoir levels. Water from this pond was used for irrigation and livestock. It has been commonly referred to as the Dam Tender’s Pond. This feature and the original drain layout are shown on Figure 2.

The original outfall for both the East and West Drains was into the irrigation canal. As part
of the dam safety program in 1985 it was recommended that the flow from the East and West Drains be measured. Subsequently diversion pipes were added across the canal and into a weir box. The flow for each drain was measured in the weir box and the outfall from that box progressed downslope to an energy dissipation structure. That structure consisted of a 90° upward bend in the steel outfall pipe which was embedded in concrete. The discharge was directed into the air where it fell back onto the concrete and flowed to the creek. During maximum flow the jet rose about six feet above ground.

During the modification in 1994, some construction equipment traffic probably led to a break in the East Drain in 1997. That break was repaired in that year and a repair was also made to the West Drain overflow structure. In 1998 the repair to the overflow structure failed and the water in the Dam Tender's Pond was lost. Both of these incidents led to abnormal instrument readings which caused Reclamation to institute 24-hour surveillance of the dam. After video examination of the West Drain and performance review, the facility was returned to normal operations. In May of 1998 a transfer inspection (transfer from construction back to O&M) was performed for the entire facility. During that inspection sand and gravel was found in the weir box and drain pipe. This condition was considered unacceptable and a specification was prepared to rehabilitate the East and West Drains.

**Drain Rehabilitation - Design**

Rehabilitation of the drains was limited by existing facilities, flow in the drains, and work with a nearly full reservoir. Based on analysis of post 1994 instrumentation data, it was known that the West drain was not optimally located to intercept flow. Because the entire West Drain was going to be removed a new alignment was selected to optimize flow interception. Since the primary flow path on the right abutment is from right to left, three legs of the new West Drain were oriented upstream-downstream. The alignment for the East Drain was fixed by the existing alignment and deviating from it would require excavation of a large part of the dam. The new East and West Drains are shown in plan view on Figure 3. It was also desired to reuse the outfall crossing at the canal, the weir box, and the downslope outfall and energy dissipation structure (IW-2) which were built in 1998. This arrangement is shown in Figure 4.

All new drains were high density doubled walled polyethylene (HDPE) corrugated pipe. This material was selected for it’s strength, which is required both during construction and after. Both slotted and solid pipe were specified to have smooth interior walls for increased flow capacity and ease of video camera access. The pipe segments ranged in size from 10 to 18-inches. Some segments of the East Drain could not be removed by excavation so inner sleeves were inserted into these pipes. The inner sleeves consisted of 8-inch-dia. slotted HDPE pipe. The inner sleeves were added to provide additional support to the existing pipe, to prevent collapse and to filter out coarse sand size material and larger.

Since access to the existing drains had caused difficulty in the past, it was desired to have access to all drain segments once the work was completed. This was done by two methods; cleanouts and inspection wells (IW). A cleanout consists of turning the drain pipe through a minimum 30-ft. radius until it daylights. A protective pipe with locking lid is then installed at the ground surface. A typical cleanout is shown on Figure 5. Inspection wells are used as a junction of drains and or outfalls and made of 8-ft. dia. concrete pipe. Inspection wells were especially useful in gaining access to bends in the East Drain as shown on Figure 3 (IW-3, 4, and 5). Typically flow measurement capability was incorporated into an inspection well along with a
sediment trap. For this work the bottom of the sediment trap was painted white to aid in the observation of sediment. Since IW-4 and 5 were installed along the drain line, they were placed on, and surrounded by, filter material so the well would not act as a dam and backup water into the embankment. At the last inspection well (IW-3) an underground dam was built to force all flow through the well. This inspection well is built at the downstream toe of the dam and could be easily accessed, should problems arise.

Based on foundation inspections in 1994, it was known that foundation conditions could range from open work to high fines content areas. The right abutment foundation is composed of a chaotic mixture of boulders, cobbles, gravel, sand, and silt. Gradation of the minus 3-inch fraction is shown on Figure 6. Note that none of the six gradations indicate open work in the foundation. Included on the plot is a line in which internal instability can be judged. The line is the ratio $4D_6_{85}/D_{15,F}$. As an approximation, soils with gradation segments flatter than this line may be internally unstable. Since insufficient medium to coarse sand size material is present in most of the six samples it would be expected that material smaller than medium sand will move through the gravel fraction.

The original drains do not meet filter criteria as evidenced by material seen in the drain pipes and weir boxes, although they do collect a large amount of seepage. The Figure 6 gradations were regraded on the No. 4 sieve as per standard practice and the limits are shown on Figure 7. The foundation material classifies as a Category 2 material. Utilizing standard filter criteria as shown on Figure 8, a $D_{15,F}$ would be 0.7mm. The ASTM specified gradation of C33 concrete sand would meet this requirement.

There was concern that placing concrete sand over the open work portions of the foundation would cause it to act as a barrier and the quantity of intercepted flow could be less than what is collected now, an undesirable condition. From Darcy's Law ($Q=kiA$), the ability to intercept seepage for this case is a function of permeability and surface area (gradient is constant). If a filter material with a permeability (orders of magnitude) less than existing conditions, the surface area would have to be larger (by orders of magnitude), which is not economically feasible. For this reason a coarser filter was selected, as shown on Figure 7. The coarseness of the filter was established by taking four to eight times the interpreted lower limit of the unstable fraction of the base material (ex. $8 \times 0.6 = 4.8$mm). Although some fines may move into this filter, it is anticipated that the largest fraction of the base material will redistribute and become internally stable at the filter contact.

In order to achieve maximum permeability and to minimize segregation, a uniformly graded material was selected as shown on Figure 7. Additionally in order to maximize efficiency of the drain, a two stage system was used. The next stage, which surrounds the drain pipe was selected as a uniformly graded gravel and is also shown on Figure 7. The filter material, placed against the foundation, was termed the outer envelope (P-gravel) and the drain material surrounding the pipe was termed the inner envelope (Q-gravel).

**Drain Rehabilitation - Construction**

To intercept the East Drain at two changes in alignment, large excavations were made for IW-4 and 5. In order to minimize the excavation size, and cost, a tie-back wall was presented in the specification, as shown on Figure 9. Reception of bids showed the price for the wall to be much greater than that estimated by Reclamation. Although Reclamation contacted wall subcontractors during estimate preparation, details in the specification later caused the price to
escalate. Upon award of contract, the contractor requested a change removing the wall and replacing it with open excavation. The contractor was motivated by cost sharing from Reclamation's Value Engineering program and elimination of a sub-contractor which could slow up the work. Design slopes and safety requirements were negotiated with the contractor and open excavation was allowed. Depth of the right most drain was about 14 ft. deeper than expected. Review of 1949 construction photos showed the toe of the dam on the far right side of the dam was placed at the top of a gully, and the East Drain was placed in this gully. The deeper excavation was problematic in that the excavation already had steep side slopes and minimum work area in the invert. To accommodate the greater depth the axis of IW-5 was moved left and the size of the excavation enlarged.

Video examinations were made of all existing East and West Drains prior to excavation. The examination was made with a video camera mounted to a motorized tracked vehicle. The camera had limited ability to view left and right and up and down. The camera was supplied and operated by a subcontractor that specializes in inspection of sewer lines. Purpose of the video examination was to document the condition of drain that was to be removed and to evaluate the condition of the drain to remain. During examination of the existing East Drain in the vicinity of IW-4 a drain segment was discovered that was originally unknown. This video examination had the added benefit of giving Reclamation good lead time to prepare a modification to address the newly found drain segment.

During construction field personnel referred to the filter as pea gravel and some confusion arose on which material was NOT to be placed against the foundation. Later the filter and drain materials were referred to P and Q-gravel respectively. The onsite 'rule' for placement was defined as 'no Q-gravel against the foundation'. This was more straight forward than verbose descriptions of 'inner' and 'outer' envelopes.

Weir plates were intended for the inspection wells. A concrete wall was formed into the bottom of the IW to which the plate was mounted. As the wall backs up water for the weir it also raises the water level in the foundation. This water level caused increased seepage in the adjacent OW conduit. Because material has been transported into the conduit in the past, increased seepage was undesirable. For this reason the weir walls in IW-3 and 4 were removed, and the water level lowered.

Video examination was also made of the completed drains as required by the specification. Initial video examination did show the accumulation of some material which came from construction activity. Although care was taken to keep the drain pipes clean during construction some material was introduced into the pipes. The contaminated drain segments were cleaned with a water spray and another video examination was made to verify their cleanliness.

**Drain Rehabilitation - Instrumentation**

The flow measured by the existing East-West weirs was known to be inaccurate because of flow over the top of the weir plate (under-sized plates). In 1994 and 1997 flowmeters were installed in IW-1 and IW-2. These flowmeters consisted of a magnetic ring that is placed against the inner wall of the pipe in which the flow measurement is desired. This type of flowmeter is typically used in municipal and industrial applications. During several years of operation an oscillation was noticed in the flow readings. These oscillations would range over about one quarter of the mean flow and would take several minutes to complete. Reclamation was unable
to correct this behavior and found it unacceptable for a measurement device. Consequently during this work the flowmeters were removed and replaced with flumes. This required some structural work to the East-West weir box.

Some previous instrumentation and the instruments added for this work are automated. The automation consists of the instrument, data logger, phone access, and an Hydromet uplink. The data logger can be accessed by phone and the Hydromet uplink. As desired, engineers call into the data logger and retrieve stored data from the memory. Independent of this storage, the data logger continuously transmits data via the Hydromet to Reclamation's Boise office. There the incoming data is continuously compared to acceptable performance bounds. Data that falls outside the bound sets off an alarm. The alarm consists of electronic mail sent out to a predefined list of contacts and an automated voice messaging system calls a previously defined phone list. These data are also continuously posted to one of Reclamation's websites.

**Drain Rehabilitation - Performance**

Flow is now more balanced through the cross canal pipes and East-West flume box. No material has been seen in any of the sediment traps or drains. All flow has been clear and the ground surface is completely dry.

The groundwater level has been lowered 5 to 7 ft on the right abutment. As a result of this lowered groundwater level the Dam Tender's Pond is now dry. Although the groundwater level is lower, no appreciable increase in flow rate has been seen. This may be a function of the inaccurate readings that were previously collected.

All instrumentation, including the automation system is in good working order. Flow measurements are now uniform and the data are reliable.

**Conclusions and Recommendations**

The original drain pipes have either been replaced with structurally sound material or liners have been added for increased integrity giving greater confidence in future performance. The compete drain system is now fully accessible from both inspection wells and cleanouts. Video inspection can be made of any segment.

Collected data is now robust and compliant with the alarm system.

Specifications should require water jet washing of all newly constructed drains followed by video inspection for integrity and cleanliness.

A coarse filter system has been designed and built which performs without evidence of material movement. If a coarse filter satisfying filter criteria with the coarse pervious foundation material and not satisfying filter criteria with the finer material is desired in areas of higher gradient or on more critical work, laboratory filter testing and/or model testing of the foundation and drain is recommended.

Coarse filters should only be considered for use against broadly graded base material under low gradient. Coarse filters should NOT be considered for use against uniformly graded fine grained base material or Category 1 soils.
Figure 1 - General Plan and Section of Ochoco Dam
Figure 2 - Plan View, Existing East and West Drains
Figure 3 - Plan View, New East and West Drains
Figure 4 - Plan View, East/West Weir Box and IW-2

Figure 5 - Typical Drain Cleanout
GRAIN SIZE DISTRIBUTION
SIEVE ANALYSIS
SIZE IN INCHES
7/16 1/4 1/8 1/32 1/64 1/128 1/256
12 24 48 1/8 1/16 1/32 1/64
U.S. STANDARD SIEVE OPENING IN INCHES
2" 1 1/2" 3/4" 1/4" 1/8" 1/16" 1/32" 1/64"
U.S. STANDARD SIEVE NUMBERS
#10 #16 #40 #80 #100 #200 1 W.HR 4 W.HR 15 W.HR
TIME READINGS
4 H.R. 9 H.R. 15 H.R.

PARTICLE SIZE IN MILLIMETERS
BOULDERS COBBLES GRAVEL SAND FINES
C F C M F

Figure 6 - Gradation of Base Soils

Figure 7 - Gradation of P and Q Gravels
U.S. Standard Sieve Opening in inches

U.S. Standard Sieve Numbers

Filter Criteria

Category 1 (Fine silts and clays)
- Filtering: D_{15F} \leq 0.9 \times D_{5B}
- Drainage: D_{15F} \geq 0.1mm

Category 2 (Silts, clays, and silty and clayey sands)
- Filtering: D_{15F} \leq 0.7mm
- Drainage: D_{15F} \geq 0.1mm

Category 3 (Silty and clayey sands and gravels)
- Filtering: D_{15F} \leq 0.7mm \times \left(4 \times 0.1 - 0.7mm\right)
- Drainage: D_{15F} \geq 0.1mm

Category 4 (Sands and gravels)
- Filtering: D_{15F} \leq 4 \times D_{5B}
- Drainage: D_{15F} \geq 5 \times D_{5B}

*For D_{5B} \geq 20mm, the ratio of D_{5B}/D_{15F} is limited in accordance with table 2.

1. For all gap-graded and all internally unstable, broadly-graded soils, category designation 1, 2, 3, and 4 is determined from a gradation curve of the base soil which has been adjusted to 100 percent passing the No. 4 (4.75mm) sieve.
2. For all soils containing particles larger than the No. 4 (4.75mm) sieve, including gap-graded and internally unstable broadly-graded soils, category designation 1, 2, and 3 is determined from a gradation curve of the base soil which has been adjusted to 100 percent passing the No. 4 (4.75mm) sieve.
3. For all soils not gap-graded and not internally unstable broadly graded, category 4 designation is determined from a gradation curve of the natural grain-size distribution of the base soil.
4. Filter criteria is applied to the base soil gradation (natural or regraded) used to determine the category of the base soil.

Figure 8 - Filter Criteria Summary

Figure 9 - Plan View, Tie Back Wall