WATER OPERATION AND MAINTENANCE BULLETIN

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UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Reclamation personnel and water user groups in operating and maintaining project facilities.

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Cover photograph: *Pipe being covered with granular envelope material.*

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UNITED STATES DEPARTMENT OF THE INTERIOR Bureau of Reclamation

WATER OPERATION AND MAINTENANCE BULLETIN
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SUBSURFACE DRAINAGE OF IRRIGATED LAND

by Glen D. Sanders[1]

Introduction

Operating and maintaining an irrigation project presents many challenges. Among those is the challenge of keeping the irrigable lands irrigable. Water logging and salinization can reduce the irrigable land base if drainage is not provided. Nearly all Bureau of Reclamation (Reclamation) sponsored projects have experienced drainage problems. Thousands of miles of subsurface drains have been constructed, and more drains are needed. Reclamation has the technical capability to assist the water users with their drainage problems. However, the extent of engineering services provided by Reclamation is dependent upon the contractual arrangements. This assistance can be at any level requested—data collection, analysis, design, specification preparation, construction oversight, or maintenance support.

This discussion is intended to present updated information on materials, construction, and maintenance methods that we have found to be most effective.

Materials

Clay and Concrete Pipe

Until about 1970, most pipe drains were constructed of vitrified clay or unreinforced concrete. Both are classified as “rigid” pipe. The pipe is either perforated or laid with "open joints". Some designs called for simple butt-end joints, and they seldom remained in alignment during construction. If they did, subsequent minor shifts in the soil would move them out of alignment. Most of the rigid pipe were bell-and-spigot or tongue-and-groove pipe. If properly constructed, these are satisfactory joints. Open joints are made by providing a 1/8-inch gap between each piece of pipe to allow water entry. The gap width is controlled by molded lugs or wood spacers glued to the pipe ends.

Plastic Pipe

Corrugated high-density polyethylene (HDPE) pipe has become the pipe of choice for most subsurface drain designers. The pipe is lightweight for easy handling, has adequate strength for burial in most applications, and is flexible, allowing installation on limited curvilinear alignments. The pipe is produced in sizes from 3 inch to 42 inch and can be perforated or solid wall. Sizes 6, 4, and 3 inch are typically shipped in rolls of 100 feet, several hundred feet, and several thousand feet, respectively. Size 8 inch and larger are typically shipped in straight 20-foot lengths.

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HDPE is flexible pipe and, as such, derives much of its load bearing strength from the soil or envelope material surrounding the pipe. It is important to consider this aspect during both the design and construction of HDPE drain lines. With most construction techniques, corrugated HDPE is subject to stretch during installation. A small percentage of stretch is acceptable, but anything above 5 percent is unacceptable because the pipe begins to lose strength, and, at 10 percent stretch, structural failure is probable. Figure 1 shows the shape that the pipe takes as a result of stretch failure. The crease is typically on the bottom of the pipe, and the pipe does not appear to have failed if one uncovers and examines the top of the pipe in place. Reclamation has developed Standard Specifications No. M-20 for Corrugated Polyethylene and Polyvinyl-Chloride Drainage Pipe. The standards are based on American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO) specifications but, in some instances, are more stringent.

Figure 1.—Pipe failed due to stretch.

Corrugated polyvinyl chloride (PVC) pipe is not currently manufactured in the United States but has been in the past and still is in many parts of the world. PVC pipe is a satisfactory product if it meets the requirements of the M-20 Standard Specifications.

Asbestos-Cement Pipe

Asbestos-cement (AC) pipe was just gaining popularity when asbestos was found to be a health hazard. It is no longer used but may be encountered during maintenance of old drains. AC pipe sections are typically 20 feet long and joined with a rubber collar. Since AC pipe is nonfriable and is in a wet environment, it should not pose a health risk to workers performing routine maintenance. If sections of the pipe are removed from the ground, they may become hazardous waste and subject to Federal health and safety regulations.

Envelope

Discussions as to whether to use a sand/gravel (granular) envelope, a synthetic (geotextile) envelope, or no envelope at all are ongoing. The Natural Resource Conservation Service (NRCS) (formerly Soil Conservation Service) has developed criteria for all three applications. These criteria can be found in the NRCS Drainage Handbook. The American Society of Civil Engineers (1998) defined four functions of a drain envelope.

(1) To prevent excessive movement of soil particles into the drain

(2) To improve drain hydraulic performance by providing material in the immediate vicinity of the drain which is more permeable than the surrounding soil

(3) To provide a structural bedding for the drain to protect and improve the strength of the pipe

(4) To stabilize the soil in which the drain is being placed

Reclamation specifies granular envelopes (figure 2) for all pipe drains because properly designed granular envelopes satisfy all four of the functions. Thin synthetic filters (figure 3), while less costly initially, satisfy only the first of the four functions. The drain may fail due to clogging of the filter, water bypassing the drain rather than entering the pipe, or crushing of

Figure 2.—Pipe being covered with granular envelope material.

Figure 3.—Pipe with thin filter sock.

the pipe due to improper bedding. If the drain fails, it is more costly in the long run. Once installed and operating, granular envelopes have a life expectancy in excess of 50 years. Drains with a granular envelope constructed on the Huntley Project near Billings, Montana, have operated for nearly 90 years with no indication of envelope deterioration. Design criteria for granular envelopes can be found in Reclamation's Drainage Manual (1993). Figure 4 shows typical gradations for four soil types and an "A" Zone which fits all four cases. R.J. Winger, Jr. published "A Simple Method for Selecting Gravel Envelope for Agricultural Pipe Drains" in Bulletin No. 88.

Granular envelopes can be either crushed or rounded material. Both have been used with good success on Reclamation drains. However, contractors at times have problems getting crushed material placed evenly and without segregation. The recommendation is to use rounded material if available; otherwise, use crushed material and take a little additional care in placement of the envelope.

Synthetic envelopes are not recommended, even by proponents, for installation in saturated plastic soils (McGill University, 1992) because they are subject to smearing and clogging by soil particles. Clogging results from entrance velocities that are too high, causing soil particles to move into the filter and become trapped (Stuyt, 1992 and Willardson, 1979). Once the filter is clogged, the drain is useless and cannot be repaired. Entrance velocities are inversely proportional to the entrance area which, for bare pipe or thin synthetic filters, is generally assumed to be the open area of the pipe perforations. With a granular filter, the entrance area is the outside surface of the envelope, which is several orders of magnitude greater than the area of pipe perforations.

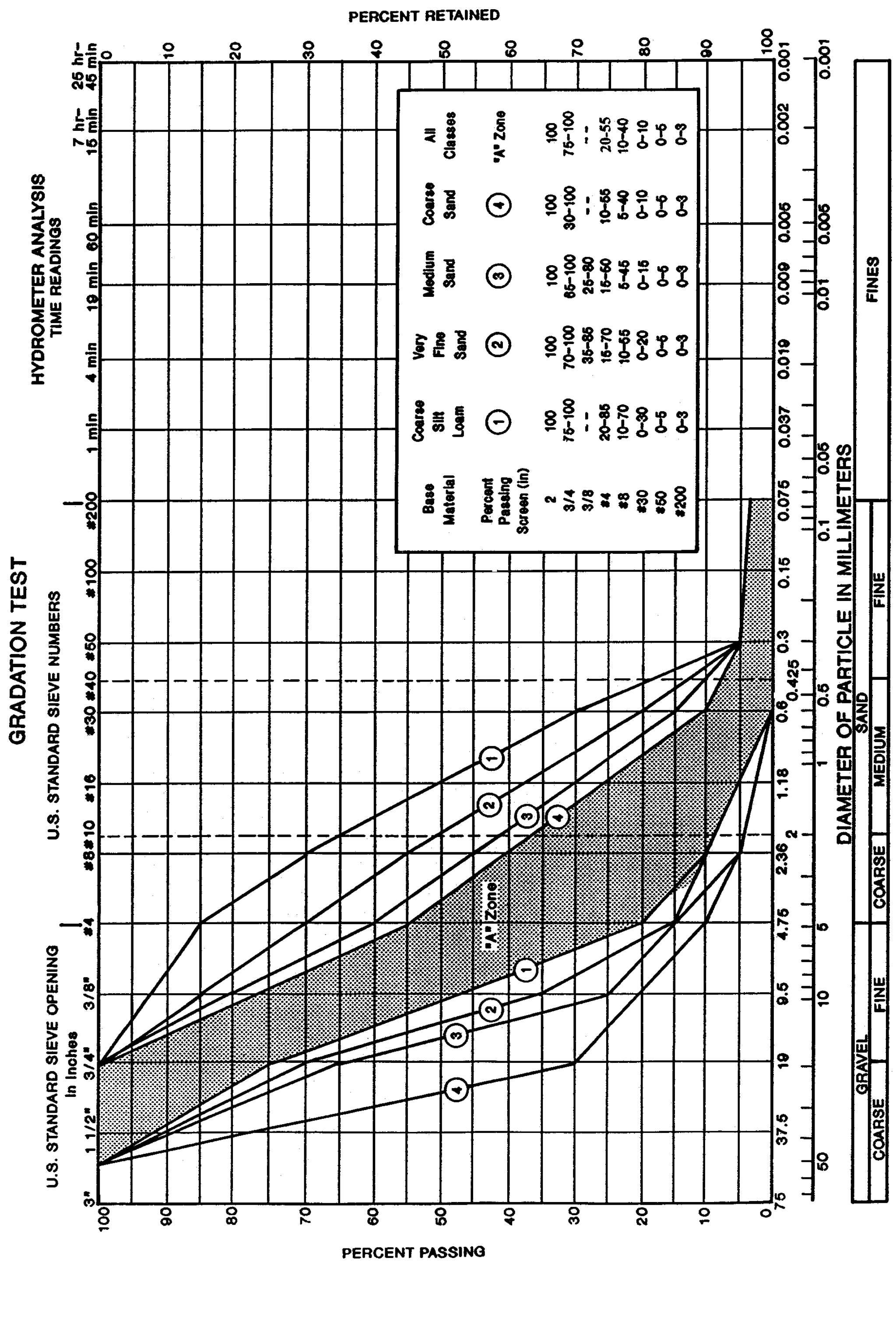

Figure 4.—Diagram showing "A" zone for envelope material.

In applications where excessive hydraulic gradients may occur, such as on toe drains for dams, two-stage filters may by used to ensure more secure filtering action. Two-stage granular filters are difficult to construct and have not been entirely satisfactory. Recently, Reclamation has tested a two-stage filter composed of a granular filter surrounding plastic pipe with a fabric sock to restrain the fine granular envelope from entering the pipe. Although further testing is planned, this arrangement appears to meet the two-stage filter criteria while simplifying construction. In agricultural drains, there is no need for two-stage filters.

Manholes

Although drains can function very well without manholes, they are usually provided at sharp angles in the drain alignment and at junction points of two or more drains. With concrete and clay pipe, the manholes were needed to connect pipe junctions and to make changes in pipe size or direction. With flexible pipe, the number of manholes is reduced to those needed as access points for monitoring and maintenance of the drains. Since they are a nuisance to farming operations, Reclamation has reduced the number considerably, leaving only those that are the most important, and even those are designed so that the top section can be removed if and when the drain has proven to be trouble free, as most do in time.

Manholes are typically constructed of 3- to 4-foot-diameter reinforced concrete pipe set on end. A larger area base is used to gain stability. The top is made so that the entire lid can be removed with machinery for maintenance or an access plug large enough for a person to look through or enter can be removed by hand. A lock arrangement to prohibit unauthorized access to the manhole should also be installed.

Outlets

Outlet structures are used to control erosion and to maintain a stable drain. They are usually made of a 20-foot length of corrugated metal pipe (CMP) compacted in place and may include rip rap protection at the outfall.

Construction Methods

Subsurface drains are usually installed by backhoe or by continuous trenching machines. Large plow machines have been developed to install corrugated drain pipe and are used extensively in areas where shallow, closely spaced drains are desirable.

Backhoe

Drains are often constructed by excavating a trench with a backhoe, laying the pipe and envelope in the bottom, and backfilling. This process is referred to as "open trench" construction. Reclamation highly recommends use of a trench box for open trench construction. Besides safety considerations, better control of the envelope material within a box generally results in a better end product (figures 5 and 6). Dewatering is not required but is generally recommended if the water table is more than a few inches above the bottom of the trench.

Figure 5.—Open trench without box, gravel uncontrolled.

Trenching Machines

Continuous trenching machines equipped with laser plane grade control and a boot for placing the pipe and a granular envelope in the trench typically provide the most reliable installation. The trencher excavates the trench, lays the pipe within a granular envelope, and sometimes backfills the trench in one operation. Trenching machines use three different methods of excavating the trench. The trenching machines are wheel trenchers (figure 7), ladder trenchers (figure 8), and chain trenchers, sometimes referred to as "high speed trenchers" (figure 9). Each method has advantages and disadvantages that relate to the geology or soil makeup where the trench is being dug. Dewatering is seldom needed for trencher installed drains because the pipe and envelope are placed within seconds of the trench being opened. Partial or complete back-filling takes place before a great amount of water can enter the trench. Figure 10 shows a typical boot arrangement where the pipe exits through the round chute while envelope material is fed through the surrounding opening. Partial backfilling is important to accomplish within a short time because the plastic pipe may float off grade if water enters the trench faster than it can enter the pipe openings.

Figure 6.—Open trench with box, envelope material controlled.

Figure 7.—Wheel trencher.

Figure 8.—Ladder trencher.

Figure 9.—Chain trencher.

Figure 10.—Trencher boot arrangement.

Plows

Reclamation does not recommend plow machines for drain installation. Plow drain installation costs are generally less than costs for trenchers or backhoes. However, pipe size and depth of installation are much more restrictive, and plows have not been successful in installing pipe drains with granular envelopes (figure 11).

Grade Control

Grade control is critical in the construction of pipe drains. The drains depend on gravity flow to move water and minor amounts of sediment through the pipe. In most cases, the slope is between 0.1 and 0.5 feet per hundred feet, leaving little room for error. Most contractors have adopted the use of laser planes for grade control. A revolving laser sender generates a plane of laser light over the work area. With open trench methods, hand held receivers are placed on the pipe to check grade. With trenchers, receivers mounted on the trenching machine follow the plane as the trencher moves across the field. The receivers send commands to the hydraulic system to raise or lower the digger and the boot to keep the drain on grade. In figure 12, the sending unit is mounted on the tripod in the foreground, and the two masts at center and rear of the machine contain the receivers.

Figure 11.—Drain plow.

Figure 12.—Laser plane system.

Operation and Maintenance

General

Pipe drainage systems require maintenance just as do dams and distribution systems. Fortunately, drains usually require a less intensive effort, but they are expensive and should not be neglected. In a technical paper prepared for the American Society of Civil Engineers in 1985, Messrs. Sanders and Crooks (1985) presented a practical approach to pipe drain maintenance. They discussed methods that worked well for them and some methods that did not work as well. The paper is available to districts from Reclamation's Technical Service Center upon request. Dolven (1967) presented a guide for "Operation and Maintenance Standards for Irrigation Project Drainage Systems," in Bulletin No. 62, and, although it is somewhat dated, overall we found it to be very informative, and the criteria is applicable to modern drainage systems.

Monitoring the Water Table

Monitoring the water table is an important part of maintaining the irrigable land base of an irrigation district. Good records provide a heads-up when drainage is needed. The district may be directly involved in financing the construction of drainage facilities or may simply be a facilitator assisting the landowner in other ways. Whatever the district's involvement, it is in the their best interest to avoid losing their land base to high water tables. Good records are also the best legal defense against damage claims for a wide variety of ground water related problems that get blamed on the district simply because they are there and are managing a water system that can have an effect on ground water.

The simplest way to monitor the water table is by taking direct measurements of observation wells. Many districts have a grid of observation wells in place and read them at least twice a year. More frequent readings are needed where the water table is at depths where problems may occur.

Monitoring Drains

Monitoring existing drain systems provides a data base for planning drain maintenance and is often used as a tool to adjust design factors to better fit local conditions. Many pipe drains function for decades with no maintenance, but in most cases, when problems do occur, they are much easier to deal with if they are identified early.

A well-planned monitoring program includes keeping records of flows in manholes and outlets, recording any submerged flow conditions in manholes, observing signs of roots or debris in manholes, recording the depth of sediment in manholes, and observing depressions or sink holes that may develop along the drain line or around manholes as shown in figure 13. Fortunately, the manholes are most accessible during the nonirrigation season when personnel typically have the most time to do the monitoring.

Figure 13.—Sink hole at manhole caused by improper pipe connection.

Some of the more common problems that occur include clogging by roots, clogging by sediment, clogging by iron ocher, failed pipe sections, and failed envelope. Lidster (1980) discussed iron ochre problems and solutions in Bulletin No. 113.

Cleaning

Clogged or partially clogged drains can be cleaned with a high-pressure hydraulic drain cleaner. The spray nozzle shown in figure 14 provides up to 2,000 pounds per square inch of water pressure. The forward facing jet cuts through roots or other blockages that it encounters in the pipe. The rear-facing jets propel the hose along the drain and clean the pipe of obstructions both while moving in and while being dragged out.

Figure 14.—High-pressure spray nozzle.

Repairs

When only a few feet of drain need repair, the excavation methods are similar to open trench construction. A broken or crushed pipe, a breach of the envelope material, or a misaligned joint may be the source of sediment in the drain or a persistent sink hole along the drain. Nearly any other problem requires reconstruction of the entire drain or segment of drain.

If rigid pipe is broken or out of alignment, it may be possible to use plastic pipe one standard size smaller to bridge the gap. This is done by inserting the plastic pipe into the existing pipe for several feet in both directions away from the trouble spot. This should be done only if records show that the smaller diameter pipe will have adequate capacity to carry the normal maximum flow in the drain. If the drain often carries flows near the capacity of the original pipe, the repair pipe size should be equal to the original pipe. Connections can be made by using universal drain pipe connectors available at many plumbing supply businesses.

Regardless of type of repair being accomplished, the job should always be finished by providing a granular envelope entirely around the repaired section. Unless the section of drain is in sealed pipe, the envelope gradation should be as close as practicable to the original envelope. The original envelope was probably designed to be compatible with the native soils. If it is obvious that the original envelope was not compatible, a gradation taken from figure 4 will work. A generous supply of envelope material should be used, taking care to get at least 3 to 4 inches of envelope on the bottom side of the pipe.

Safety

Safety is a major concern in subsurface drain maintenance. Each manhole is a confined space as defined by OSHA 29 CFR 1910.146. Manholes on Reclamation drains have tested positive for toxic gases, explosive atmosphere, and insufficient oxygen to support life. Any manhole that has been closed for even a few hours should be ventilated by forcing at least 20 volumes of air through the manhole before entry is permitted. When entry is made, all confined space regulations should be followed.

Caving of trenches is an extreme hazard when repairing pipe drains. The soils are usually saturated and lack normal soil mechanical strength because they were disturbed during initial construction.

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BUZZARD BE-GONE, The Wire Barrier for Messy Birds

It is not unusual to see buzzards circling overhead during a site visit at a large dam. At Choke Canyon Dam, these large birds used to relax atop the fences and handrails surrounding the hoist deck for the spillway to gain an easy view of carrion in the landscape below. Reservoir operation personnel got tired of cleaning up after the birds, so they devised a prevention strategy.

Figure 1.—Wire barrier above fencing at Choke Canyon Dam.

Using No. 4 steel reinforcement bars, wire, and hose clamps, the crew attached wire above the top rail of the fence. The steel reinforcement bars are attached to vertical fence posts with hose clamps. The wire, 14 gauge or smaller, is then clamped to the reinforcement bar at the desired height, and the wire barrier is complete. The wire is less than a foot above the fence, and when buzzards try to land on the fence, they come in contact with the nearly invisible wire, feel the obstruction, and take off before leaving their usual mess.

Norman Kuenstler, Reservoir Superintendent at Choke Canyon Dam, and his crew have attached the wire barriers above chain link fences and handrails around the hoist deck and adjacent service bridge. The wire barriers appear to be doing their job in keeping buzzards and other large birds from creating a maintenance problem that could corrode nearby metalwork. No one claimed credit for this innovation, but it does the trick.

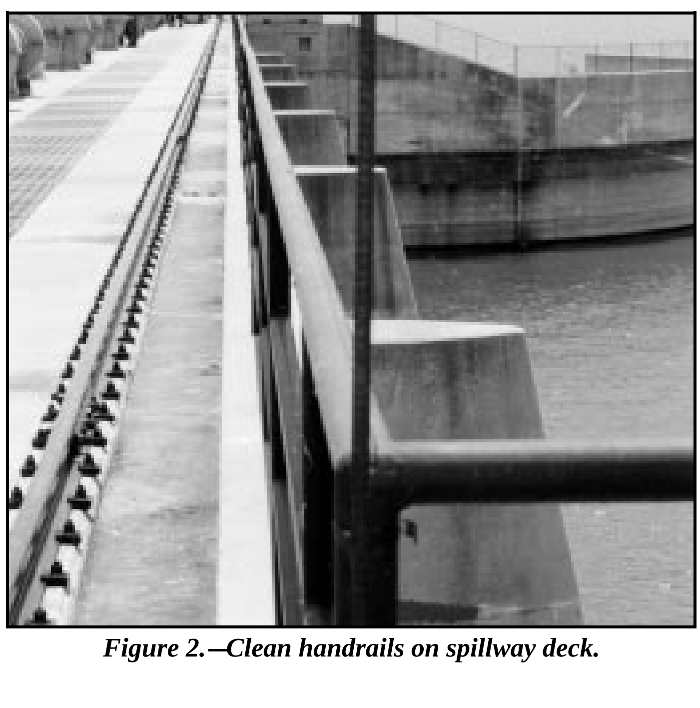

Figure 2.—Clean handrails on spillway deck.

RADIAL GATE TRUNNION LUBRICATION

by Rod Rodriguez[1]

Introduction

The following discussion concerns lubrication of radial gate trunnions. Topics covered include: factors affecting trunnion lubrication, lubrication regime, lubricant properties, lubricant selection, frequency of lubrication, and general suggestions for lubrication. Although some of the material presented is general in nature, much is derived from the radial gate failure at Folsom Dam. The information presented in this article was included, in a different format, in Corps of Engineers (Corps), Engineering Manual EM-1110-2-1424 Lubricant and Hydraulic Fluids. The engineering manual was prepared under a joint effort between the Bureau of Reclamation's (Reclamation) Denver Office and the Corps. The manual contains information concerning lubrication of mechanical equipment specific to Reclamation and Corps facilities such as powerplants, pumping plants, and dams. The manual is available only through the internet and can be accessed via the Corps' internet site at http:/www.hnd.usace.army.mil/. Once at the site, click on "TECHINFO," then click on "Engineering Manuals (EM x-x-x)" to obtain the publication menu.

Factors Affecting Trunnion Lubrication

Various factors affect the lubrication requirements for trunnions—among these are load, speed, and friction.

Load

Radial gate trunnions operate under high loads and extremely slow speeds. The load on the trunnion is the water level pressure plus a portion of the gate weight. Typical design loading on radial gate trunnions is 2,000 to 3,000 pounds per square inch (psi) for leaded tin bronze bearing surfaces and 4,000 to 5,000 psi for aluminum bronze.

Speed

Relatively speaking, a trunnion pin rotates at extremely slow speeds. The radial trunnion pins at Folsom Dam rotate at 0.002 revolutions per minute. The slow operating speed dictates the type of lubrication regime applicable to trunnions. These regimes are addressed below.

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Friction

Trunnion friction is especially critical at high water levels and low gate openings but lessens as the gate is opened and the reservoir level drops. Typical design coefficients of friction are 0.3 for grease-lubricated trunnion bearings and 0.15 for self-lubricated trunnion bushings.

Lubrication Regime

Two grease lubrication regimes are applicable to trunnions operating under high load, slow speed conditions—hydrostatic lubrication and boundary lubrication.

Hydrostatic Lubrication

Hydrostatic lubrication may be used when bearing surface velocities are extremely slow or zero. Under hydrostatic lubrication, pressurized grease produces a thick film that physically separates the bearing surfaces. Trunnion friction can be reduced approximately 40 percent if the grease film can be maintained during operation by an automatic greasing system.

Boundary Lubrication

Boundary lubrication occurs when bearing surfaces are separated by a lubricant film of molecular thickness causing momentary dry-contact between asperities (microscopic peaks) in the metal surfaces. In trunnions, friction is caused by contact of bushing and pin surfaces asperities. When boundary lubrication occurs, friction becomes independent of film viscosity and is reduced through additives. Surface active additives, such as fatty esters in the grease oil, are the most effective. These lubricity agents form a chemically bonded thin film on the bronze and steel surfaces that reduce the metal-to-metal contact and friction.

Lubricant Properties

The following list identifies the desirable lubricant properties for trunnions. These properties and other criteria are shown in table 1 at the end of this discussion.

Lubricity

Low breakaway (static), running (kinetic) friction, and no stick-slip friction (sliding surfaces momentarily stick and then slide) are necessary for smooth gate and valve operation. The grease should possess good "lubricity" for low startup and running torque. Lubricity additives, such as oleic acid, are surface-active chemicals in the oil or grease that form a chemically bonded thin film on the bushing and pin to reduce the amount of metal-to-metal contact and friction.

Anti-Rust

Rust on a trunnion pin thickens with time, reduces bearing clearance, absorbs the oil from grease, prevents film formation, causes high friction, and abrades bronze bushing material. Since rust expands to about 8 times the volume of the iron from which it is formed, it is very important for a grease to inhibit rust.

Low Corrosion of Leaded Bronze

Grease degradation products, such as organic acids and chemically active sulfur and chlorine compounds used in gear oils, can corrode leaded bronze bushings. Some light tarnishing is acceptable, but excessive corrosion is indicated by stains, black streaks, pits, and formation of green copper sulfate from sulfuric acid.

Scuff Preventer

Scuffing causes serious damage to surfaces such as metal transfer, melting, and tearing. Anti-scuffing additives form a protective surface film that is activated by the heat of friction. If used in a trunnion grease, sulfur concentrations must be low to prevent chemical corrosion of sliding surfaces.

Resists Water Washout

Resistance to water washout is especially important when trunnions are submerged.

Pumpability and Flow

Grease should be nonhardening and flow into the load-bearing clearances of the trunnion. A grease should easily pump and flow through piping and tubing. The grease should retain its NLGI grade over long periods during any temperature fluctuations.

Adherence to Metal

Tackiness agents provide this characteristic.

Long Life

Grease oxidation will occur over long periods at dam environment temperatures. Symptoms of oxidation are discoloration, hardening, and bronze corrosion. An effective oxidation inhibitor will increase longevity.

Low Oil Separation

Oil separation or "bleeding" from the gelling agent should be minimized during inactivity and storage. Excessive bleeding lowers the oil-to-thickener ratio which hardens the remaining grease. Some separation, especially under pressure, is desirable for the oil and its additives to flow into the molecular clearances between pin and bushing for boundary lubrication.

Lubricant Selection

Grease for trunnions should be selected for high-load and slow-speed applications (boundary lubrication). Other considerations include frequency of operation, trunnion friction, temperature range, condition of bearing surfaces (rust, scuffing, etc.), whether the trunnions are exposed to sunlight or submerged, and contaminants such as moisture and debris. During the warranty period, greases recommended by equipment manufacturers should be used. If another grease is desired, testing of a number of greases by a qualified lubricant expert (tribologist) to the exacting conditions of your equipment will determine the optimum grease. However, testing can be expensive and is not necessary unless highly unusual conditions exist. Suitable greases can often be identified by consulting other facilities, such as those operated by Reclamation, Corps of Engineers, BC Hydro, TVA etc., using similar equipment under similar conditions.

Environmental considerations are also important. There is a growing awareness concerning the damage caused by indiscriminate use and disposal of lubricants. Many environmentally acceptable greases are currently being marketed. Lubricant suppliers are readily available to recommend acceptable grease products. To make the best selection, the supplier must be advised of all operating conditions, including normal and abnormal. Suppliers also possess equivalent lubricant charts to compare different brand name products.

Grease Selection Based on Boundary Lubrication

Grease should be selected based on its performance specifically for boundary lubrication whether for manual lubrication or the automatic greasing system. Manual hydrostatic lubrication on stationary equipment under load reduces trunnion friction for the next operation, but as the pin rotates, the lubricant film thins until pure boundary lubrication results. With rust on the trunnion pins, the preferred method of trunnion lubrication is hydrostatic lubrication during gate operation using an automatic greasing system. However, automatic systems are not impervious to breakdown, and boundary lubrication will result without continuous greasing.

Recommended Greases—A "Lessons Learned" Approach

A spillway radial gate failure at Folsom Dam in 1995 led to an investigation and the testing of greases for trunnions. Table 1 lists desirable grease properties for the Folsom Dam trunnion bearings. Details of the investigation may be found in the report, *Folsom Dam Spillway Gate 3 Failure Investigation Trunnion Fixture Test*, prepared by Reclamation's Mid Pacific Regional Office, July 1997. The properties compiled for the trunnions at Folsom Dam are applicable to trunnions in general. Table 1 shows the purpose of grease property, base oils for grease, grease gelling (thickening) agents, additives, ASTM grease tests, and desired results for the properties.

Self-Lubricating Bearings

When new equipment is purchased or existing bushings are replaced, self-lubricated bushings are recommended. The trunnion bushings for the failed gate at Folsom Dam were replaced with self-lubricated bushings. Modern gates such as the clamshell gate are specified exclusively with self-lubricated trunnion bushings.

Solid Lubricants

Molybdenum Disulfide (MSO_2) and Polytetraflouroethylene (PTFE or Teflon)

The Folsom Dam radial gate failure investigation recommended that MSO_2 and PTFE not be used in greases for radial gate trunnions at Folsom. The lowest friction coefficients were achieved with greases that did not have these solid additives. Furthermore, addition of MSO_2 to greases has been shown to reduce the grease's ability to prevent corrosion.

Graphite

Although not a part of the Folsom Dam radial gate failure investigation, graphite is not recommended as an additive for lubricating trunnions because it has been identified as promoting galvanic corrosion.

Frequency of Lubrication

Frequency of lubrication depends on many factors such as frequency of operation, trunnion friction, temperature, condition of bearing surfaces (rust, pitting, etc.), whether or not the equipment is submerged, replacement of grease lost to leakage or oxidation, and the need to flush out moisture or other contaminants. Following are two examples of different lubrication frequencies based on design factors and gate operating conditions.

Folsom Experience

The Folsom Dam spillway radial gate investigation suggests that, in general, if the allowable gate trunnion friction used in the structural design of a gate is at least 0.5 and the bearing is well protected from its given environment, the Reclamation standard of lubricating radial gates twice a year is adequate. The Folsom investigation revealed that no trunnion friction was factored into the failed gate design. Furthermore, the trunnion pins were rusted, scuffed, and had inadequate protection from rain and spray. Based on these factors, a reasonable trunnion lubrication schedule for this gate would be to grease once a month when the lake level is below the gates; grease once a week when the lake level is above the gate sill; and employ automatic greasing while the gate is in motion. Frequent grease applications can remove moisture from trunnion surfaces and decelerate the rust progress.

Corps of Engineers Survey

A survey of frequencies for lubricating gate and culvert valve trunnions at locks and dams was conducted at Corps facilities. The frequency varied from weekly to twice a year, indicating that there was no set frequency of lubrication. Aside from recommendations for new equipment, lubrication frequencies tend to become site specific based on operating experience and the factors and conditions noted above.

General Suggestions for Radial Gates Based on the Folsom Investigation

Some of the recommendations made for Folsom Dam, such as the automatic greasing system and the lubricant type, were due in part to rust of the trunnion pins and bushings. Other radial gates may be affected by different conditions such as local climate, frequency of gate operation, the designed allowable trunnion friction, and the lubrication system. The following suggestions may be used to determine the requirements for trunnions at other radial gates:

- If exposed to water, air, and abrasive dust and debris, install weather protection seals on the edges of the trunnions to protect the bearing. Seals will protect against rusting of the pin while protecting the grease from oxidation and contamination.

- Determine the allowable trunnion friction. An allowable friction coefficient below 0.3 would be considered low.

- Carefully review the design of the trunnion assembly and lubrication system.

- Review the frequency of gate operations.

- Inspect the trunnions using some of the techniques listed below to determine the presence of rust and to estimate the existing trunnion friction. These techniques have been established as a result of the investigation; however, their effectiveness or feasibility has not been extensively determined and may depend on local conditions. If corrosion is suspected, determine trunnion friction. Friction coefficients above design value may require a change of lubricants and/or lubrication frequency. Techniques are:

    - Send used grease which is pumped out of the trunnions to a laboratory to test for contaminants such as rust.

    - Measure the gate's hoist motor current as an indication of possible increased trunnion friction.

    - Attach strain gauges to the gate arms to measure induced stresses caused by trunnion friction.

    - Attach a laser and target to the gate structure to measure deflections caused by trunnion friction.

    - Fabricate probes that can access the trunnion pin through the lubrication ports to determine the presence of rust.

Review the Type of Lubricant in Use

Consider the lubricant specification recommended for the Folsom Dam trunnions.

Use New Pins

Previously rusted steel is prone to rapid rusting; therefore, if the existing pins are rusted, use new steel pins.

Table 1.—Desirable grease properties for the Folsom Dam trunnion bearings
(Reference: "Lubricating Grease Guide," NLGI 4th edition, 1996)

	Examples of composition					ASTM test		
			Additives					
Purpose of grease property[a]	Base oil	Gelling agent	Type	%	Chemical	Number	Desired result	Maximum
Lubricity, that is, low static and kinetic friction for bronze on steel	Mineral or synthetic including polyol ester, jojoba oil, vegetable oils	Lithium or calcium soaps, or polyurea	Lubricity (reduction of friction)	2.5	Fatty materials, oleic acid, oleyl amine, jojoba oil	D99-95 Pin-on-Disk apparatus applicable	Coefficient of static friction, fs, (breakaway), 0.08, (b) Coefficient of kinetic friction at 0.2 inch/min, fk, 0.10	fs,0.10, (b) fk, 0.12
Prevent rusting of steel	Mineral or synthetic	Calcium, lithium, or aluminum complex soaps, or calcium sulfonates, or polyurea	Rust inhibitors, calcium sulfonate	0.2 to 3	Metal sulfonates, amines	D1743-94	Pass - no rusting of steel after 48 hours in aerated water	Pass
Low corrosion of leaded bronze (Cu 83, Sn 8, Pb 8%)	Mineral or synthetic	Lithium or calcium sulfonate and soaps, or polyurea	Corrosion inhibitors, metal deactivators	0.2 to 3	Metal sulfonates, phosphites	D4048 (copper strip)	1 to 1B	4C
Prevent scuffing of steel vs. bronze	Mineral or synthetic	Lithium or calcium soaps, or polyurea	Anti-scuff (EP)	1 to 2	Sulfur and phosphorous compounds, sulfurized fats, ZDDP	D99-95, bronze pin vs. steel disk	No scuffing, that is, transfer of bronze to steel. "EP" film formation	No scuffing
Resists washout by water	Mineral or synthetic	Polyurea or calcium hydroxystearate	—	—	—	D1264-93	0 washout	1.9%
Does not "harden" in pipes	Mineral or synthetic	Lithium or calcium soaps or polyurea	—	—	—		No change in consistency with aging	No change
Easy to pump and distribute through tubing and grooves in bronze bushing	Mineral or synthetic, ISO 100 to 150	Polyurea, lithium or calcium soaps	—	—	—	a. D217	a. NLGI 1 or 1.5, cone penetration 340 to 275 b. Pumps through 25' to 1/4" copper tubing	NLGI2
Adherence to metal and retention in areas of real contact of trunnion	Mineral or synthetic	Lithium or calcium soaps or polyurea	Tackiness agent		Polymers, iso-butylene or polyethelene	None	Slightly tacky between metals	Slightly tacky
Long life, oxidation stable	Mineral or synthetic	Polyurea	Oxidation inhibitors		Amines, phenols, sulfur compounds	D942-90	Pass, also no acid formation, odor, or discoloration.	Pass
Low bleeding, oil does not separate from grease excessively	Mineral or synthetic	Lithium or calcium soaps or polyurea	High-viscosity base oil	-	-	D-1742-94 and Federal test	Limited "bleeding" of oil, less than 0.1%	1.6% in 24 hours, 3% in 48 hours

[a] Applied to low carbon (SAE1045) steel pin 32-inch diameter rotating in trunnion bronze bushing at 0.2 inches per minute and 1.8 million pounds load. Dam site environment—temperature range 30 to 125 °F, wet, long periods of no sliding under load.

[b] Only known bench test with Pin (bronze pad)-on-Disk (1045 steel) tribometer, at Herguth Laboratories, P.O. Box B, Vallejo, California 94590; run at 50 N (11.2 pounds of force) load, 0.2 inch per minute sliding velocity, and room temperature.

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Mission

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