RECENT FAILURES OF LARGE CORRUGATED METAL PIPE SPILLWAYS

Harald W. Van Aller, P.E.
Geotechnical Engineer
Maryland Dam Safety Division

ABSTRACT

Many new stormwater management dams in Maryland have been constructed with large diameter corrugated metal pipe (CMP) spillways. Several of these dams, all "dry" ponds that impound water only during storms, have recently failed by piping of embankment soils along the outside of the conduit or through leaky joints. Random inspections have revealed serious deficiencies in many of the structures. Inadequate construction inspection of critical items has contributed to the failures. Several case histories are discussed.

INTRODUCTION

During the last ten years, more than 400 stormwater management ponds have been designed and built in Maryland with large (48-inches and larger in diameter) pipe conduits. In general, these ponds are low hazard structures less than 30 feet high. As such, they are exempt from Maryland's waterway construction permit requirements if the design is approved by a local Soil Conservation District. Although such local approval requires adherence to minimum design and construction standards that were developed by the USDA Soil Conservation Service, detailed construction inspection by a qualified engineer is often neglected.

Approximately 200 of these ponds have spillways constructed of large diameter corrugated metal (steel) pipe, with some more than eight feet in diameter. In the last two years, the Dam Safety Division has investigated more than a dozen failures of these structures. The failures range in severity from complete failure of the dam and loss of the pool to leaking joints and indications that piping of embankment soils has been initiated.

During the same period of time, about 170 ponds were designed with large diameter reinforced concrete pipe spillways. Only two failures of RCP spillways have been investigated by the Dam Safety Division. One of these had leaking joints that were repaired by injection of hydrophilic grout. The other structure required complete removal and replacement of the spillway conduit.

INSPECTION PROGRAM

The Dam Safety Division recently inspected more than a dozen small dams constructed with CMP spillway conduits. Some of these inspections were conducted with a local CMP manufacturer in order to determine if there are inherent problems with CMP spillways or whether the problems are construction related. In addition, after numerous deficiencies were noted, we enlisted the help of local publics works officials to perform inspections of additional dams. In all, more than 40 new dams with large CMP spillways have been inspected, and more inspections are in progress.

Two complete dam failures were investigated. These resulted in loss of impounded stormwater and severe environmental damage below the dams. Both structures were apparently constructed by installation of the conduits into near vertical trenches cut into the partially completed embankment fill and/or foundation soils. Both failures resulted from loss of embankment soil from along the outside of the conduit by seepage flow, a process termed "piping".

We found that very few installations of large CMP conduits are in accordance with generally accepted criteria for pipes through dams. Many of the problems we observed are most likely due to poor installation, such as:

1. Poor compaction of fill under the haunches of the pipe. Unlike rigid (concrete) pipes which are designed to support external loads with minimal deformation, CMP conduits are flexible, and are designed to deform slightly which allows the surrounding soil to provide most of the support for the embankment fill above the conduit. In practice, it is very difficult to obtain adequate compaction under the haunches of the pipe to provide the necessary support, especially with large diameter pipes. If the contractor is overzealous in his efforts to compact the soil in this zone, there is a possibility that the relatively lightweight pipe will be lifted from the subgrade soils, leaving an open void under the conduit. Inadequate support under the haunches of the pipe will likely result in eventual failure of the conduit. In addition, voids in the fill under the pipe are avenues for seepage flow, increasing the possibility of a piping failure.

2. Pipe was installed in trench with near-vertical sides cut through partially completed embankment fill. Some contractors contend that it is more cost effective to place the majority of embankment fill with large equipment and to cut a trench through the fill and install the pipe. However this can result in poor compaction of the pipe backfill because much of the work is hand labor in a confined area, especially in the haunch area as described above, and thin fill layers are necessitated by the use of lightweight compaction equipment. In addition, there is a potential for transverse cracking of the dam embankment due to differential settlement between the hand placed backfill and embankment fill placed with heavy equipment, increasing the possibility of a piping failure. Also, pipe backfill placed in a trench tends to reduce loads on the pipe by a process known as "arching". While desireable from a structural standpoint for design of the pipe, this phenomenon may result in low soil pressures near the pipe. If the soil pressures are less than the anticipated hydrostatic loading, there is a potential for the pond water to cause serious cracking of the embankment by a process termed "hydraulic fracturing".

3. Watertight joints were not obtained. Our experience indicates that watertight joints are difficult to obtain in the field. This can result from:

   Damaged pipe ends which prevent proper alignment of pipe sections.

Gaskets not installed in joints, wrong type of gaskets used, or gaskets not lubricated properly which causes uneven gasket contact.

Helically corrugated pipe ends not re-rolled to provide concentric channels for proper gasket contact.

Incorrect joint connecting bands installed. "Dimple" or "narrow hugger" bands do not provide the desired level of joint integrity.

Construction inspection was performed on some, but not all, of these structures while they were being built. However, the "inspector" was often a soils technician, with limited dam construction experience, retained by the contractor to simply test the fill for compliance with the project specifications. The inspector was usually not on site full-time, so that certain critical items, such as joint construction, gasket details, compaction of the fill under the haunches of the pipe, etc. were not observed.

Interviews with construction and inspection personnel for some of the projects indicates that there is sometimes a lack of communication between the inspectors and the engineers, often because the inspector worked for another company and was not under the direct supervision of the design engineer. Also, since most of the inspectors were on site to simply "observe and document" construction techniques, the inspector had no control over the project. In one instance, the inspector duly noted in his report that the contractor was installing incorrect gasket materials into the joints. However, this problem was not corrected at the time of construction and several years later the pipe is in the process of failure due to loss of fill material by piping into the leaky joints.

RECOMMENDATIONS

Sowers (1974) observed that the most common failures of dams are those of small reservoirs, in part because the owners of these structures are *"lulled into complacency by the very insignificance of their structures. It is difficult for them to realize the damaging effects of the failure of small reservoirs."* He further states that *"those responsible for design ... of such reservoirs are interested primarily in the [function] of the reservoir rather than with the structure [itself]. They ... are rarely dam designers and builders. Therefore, the smaller dams often are not given the benefit of experienced design, adequate construction supervision ... The consequences are disastrous."* It is obvious that detailed construction inspection by qualified geotechnical engineers is essential for proper construction of small dams.

The construction industry needs to have better trained, full-time construction inspection under the direction of the design engineer. The designer should be a geotechnical engineer experienced in dam design and construction.

In addition to soil compaction specifications, the inspector should be familiar with pipe specifications and should be able to reject deficient installations on the spot. Too often, inspector is under contract only to "observe and document" installation and problems that are documented in daily reports are not forwarded to the engineer until too late to remedy.

Use fly-ash based "controlled low strength material" or "flowable fill" to backfill under the haunches and sides of the pipe. Flowable fill is a low strength material that can be delivered to the job site in a standard ready-mix concrete truck. It can be formulated to have compressive strengths in the range of 30 to 1200 psi. Flowable fill in the range of 30 to 150 psi has characteristics similar to that of compacted fill, and can easily be removed by common excavation techniques at a later date if needed. The material is self-levelling, and is simply poured into an excavation, where it fills the voids under the pipe with no compactive effort. It is recommended that it be placed to a level to at least halfway up the sides of the pipe. Due to the potential for significant shrinkage, it is recommended that the flowable fill be placed in two pours, with sufficient time between then to allow the first pour to cure. The pipe conduit must be anchored to prevent floatation.

Compact the fill that will be under the haunches of the pipe before installing the pipe, and use a special excavator bucket to conform the bottom of the trench to the contour of the conduit. This may reduce the possibility voids under the pipe.

Better inspection during construction to ensure that joints are watertight, from the time the joints are made through completion of filling operations. Since watertight joints are essential for a safe conduit through a dam embankment or its foundation, pressure testing of each joint before continuing with installation may be warranted. This is commonly done for sewer installations.

Improve joint design. Soil Conservation Service pond construction standards in Maryland now requires that pipes with a diameter of 24-inches or more be connected by a 24" long annular corrugated band using rods and lugs. A 12" wide by 3/8" thick closed cell circular neoprene gasket is to be installed on the end of each pipe for a total of 24". Perhaps the use flanged joints instead of connector bands and o-ring gaskets should be considered.

Have pipe manufacturers "match mark" pipe sections. CMP manufacturers in Maryland typically custom fabricate pipe for pond projects in one continuous section which is then cut into lengths that can be shipped to the job site. Since the cuts are not always perpendicular to the pipe axis, misalignment of the joints is inevitable if the same two pieces are not installed adjacent to each other. This is more of a problem with large diameters, since a small cutting error translates to a sizeable alignment error. Match marks will help with alignment of joints in field and result in a greater likelihood of watertight joints.

Eliminate anti-seep collars and use "filter diaphragms" to control seepage and piping along the conduit. It is interesting to note that the two structures that failed completely were built with anti-seep collars which did not prevent loss of soil by piping. It is a common misconception that the collars will prevent seepage along the conduit. Thus, there is a temptation to skimp on compaction of backfill material and to rely on the collars to prevent failure. Properly designed filter diaphragms, on the other hand, will control seepage that may occur along the outside of the conduit. A filter diaphragm is a zone of filter material (sand and gravel) that completely surrounds the pipe. It is generally located near the downstream end of the conduit. (SCS 1985) The filter must be designed in accordance with standard soil mechanics filter criteria. (Talbot 1985, 1990)

CONCLUSIONS

A large number of pond and dam failures can be attributed to problems with the conduit. Since all of the failures that we observed were located along the spillway pipe, consideration should also be given to eliminating conduits through dam embankments and foundations wherever possible, perhaps by utilizing weir structures instead of conduits. If large CMP spillways are to continue to be used in dam construction, new standards need to be developed. These could include: elimination of anti-seep collars and use of filter diaphragms to control seepage that may develop along the outside of the conduits; better joint design to ensure watertightness; shaping the bottom of the trench to precisely fit the circumference of pipe to improve the support of the pipe haunches; and the use of "flowable fill" material for pipe backfill. In addition, installation of pipes in vertical trenches excavated through partially completed dam embankments contribute toward failure potential and the technique should be avoided.

REFERENCES

American Concrete Pipe Association, (1992) "Design Life Seminar, Buried Wastewater and Stormwater Pipelines, Greenbelt, Maryland

Genstar Stone Products Company, (1990) "Ready Mixed Flowable Fill", Hunt Valley, Maryland.

Manzi, Joseph E., (1984) "Construction Inspection: Improving the Benefits Received", Professional Inspection of Construction, edited by Stephen B. Quinn, ASCE, New York, p. 11-19

Martin, Ray E., (1989), "Seepage Control Along Conduits Penetrating Embankment Dams, presented at the 1989 Southeastern Association of State Dam Safety Officials Conference

National Ready Mixed Concrete Association (1989), "CIP 17: Flowable Fill Materials", Silver Spring, Maryland

Shields, David R., (1985) "Geotechnical Inspection for Small Dams: How Small is Too Small?", Hydro Review Magazine, Fall issue.

Sowers, George F., (1974) "Dam Safety Legislation: A Solution or a Problem", Proceedings of Engineering Foundation Conference at New England College, ASCE, New York, p. 65-100

Talbot, J. R. and Ralston, D. C. (1985), "Earth Dam Seepage Control, SCS Experience," Seepage and Leakage from Dams and Impoundments, ASCE Geotechnical Engineering Symposium, edited by R.L. Volpe and W.E. Kelly, New York, p. 44-65.

Talbot, James R., (1990) "SCS Filter Studies, Design Procedures and Experiences with Filter Diaphragms", Association of State Dam Safety Officials Mid-Atlantic Regional Technical Seminar on Seepage in Dam Safety: Evaluation and Remediation, Baltimore, Maryland

USDA Soil Conservation Service, (1992) "MD-378, Standards and Specifications for Ponds", Annapolis, Maryland

USDA Soil Conservation Service, (1985), Technical Release No. 60 (TR-60), Earth Dams and Reservoirs, Washington, DC, p. 6-7 through 6-9

USDA Soil Conservation Service, South National Technical Center, (1985), Technical Note 709, Dimensioning of Filter Drainage Diaphragms for Conduits According to TR-60, Fort Worth, Texas

Van Aller, Harald W., (1990) "Filter Diaphragm Design Considerations", Association of State Dam Safety Officials Mid-Atlantic Regional Technical Seminar on Seepage in Dam Safety: Evaluation and Remediation, Baltimore, Maryland

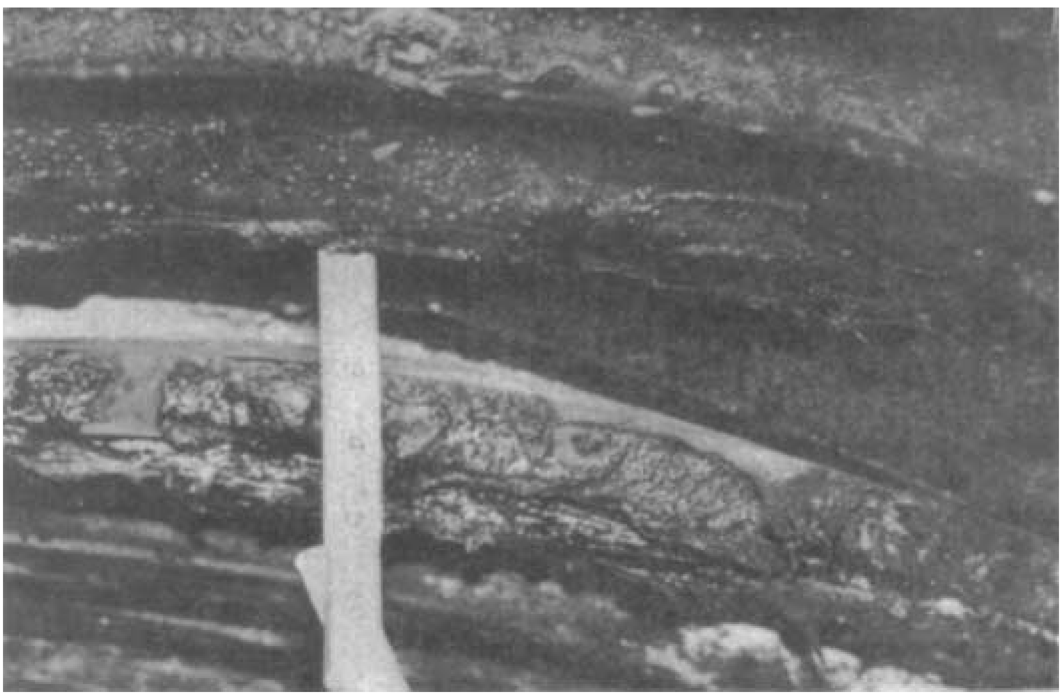
PARTIAL SUMMARY OF CMP PIPE INVESTIGATIONS

Insp. Date	Dam Age	Site Id	Dam Ht	Pipe Dia	Comments
4/93	<1yr	AML	25'	54"	Complete failure and severe environmental damage to creek below dam. Poor compaction; leaky joints; installed in trench cut through partially completed fill. Conduit to be replaced with concrete pipe.
5/89	4yr	LFM	25'	72"	Complete failure and severe environmental damage to trout stream. Poor compaction; installed in trench cut through partially completed fill.
10/90	5yr	SSS	25'	84"	Leaky joints; sinkholes; extensive piping in progress. Breach excavated through dam to alleviate public safety hazard.
2/91	5yr	VHL	15'	72"	Leaky joints; sinkholes in fill due to piping.
10/92	2yr	CST	25'	48"	Deformation of conduit noted to be about 7-inches; leaky joints; missing o-ring gaskets. Embankment was removed, joints were repaired with concrete "collars" and dam was rebuilt.
4/91	4yr	MRN	15'	66"	Wet pond with 6 foot normal pool depth. Leaking joints; piping in progress. Ongoing investigation for repair alternatives. Dam is only access to a housing subdivision, and major utilities (electric, water, sewer, telephone) in the embankment make pipe replacement difficult.
4/91	2yr	BWC	20'	72"	Leaking joints; piping. Sinkhole at upstream end. Pipe replaced.
5/93	3yr	CGY	30'	48"	No gaskets installed during construction. Internal joint rings installed after the fact do not appear watertight.
11/92	6yr	TMR	15'	72"	Leaking joints; wrong connecting bands; pipe ends not re-rolled; piping in progress; pipe damaged by utility contractors after installation.
3/93	3yr	HSM	20'	60"	Leaking joints; repair attempted with mastic but joints not watertight.
2/92	2yr	CVY	20'	54"	Leakage along outsides of five parallel spillway pipe conduits. Repaired by injection of cement grout into voids in embankment.
4/92	3yr	RTP	20'	48"	Leaking joints; excessive deformation. Pipe replaced.
7/93	2yr	MKS	12'	48"	Open joints; large voids under pipe; piping in progress.
5/91	2yr	UP4	20'	72"	Voids and seepage along pipe; settlement profile indicates that pipe was installed in trench through dam.
5/91	<1yr	FOX	15'	66"	Joints separated up to 2". Exposed flat, neoprene gasket leaking. Voids under haunches.
5/93	2yr	SRP	30'	90"	Excellent alignment; nearly all joints appear watertight.
4/91	<2yr	HBC	25'	66"	Voids under haunches; more flow under the pipe than through it; infiltration noted at all joints; deflection of pipe noted at center of dam.

Complete failure of 25 foot high dam for "dry" pond, viewed from the pool area. The structure does not normally impound water. The 72-inch barrel pipe was apparently installed in a vertical trench cut through nearly completed embankment fill. Failure occurred during a storm that filled pool to just below enlarged top of riser.

Detail of above, looking downstream along pipe from riser. Note collapse of 14-foot square anti-seep collar and the near vertical trench wall parallel to pipe in center of picture.

Complete failure of 25 foot high dam as viewed from downstream end of 54-inch pipe. This pipe was apparently installed in a vertical trench cut through partially completed embankment fill. Loss of soil support due to piping of surrounding backfill resulted in collapse of pipe and catastrophic release of flood waters.



Many structures had poor joints, with large gaps between pipe sections that allow embankment soil to wash into the conduit by seepage flow. Sinkholes in fill above such joints indicates severe damage has occurred, and integrity of dam is jeopardized.