

# Western Dam Engineering Technical Note

A QUARTERLY PUBLICATION FOR WESTERN DAM ENGINEERS

In this issue of the **Western Dam Engineering Technical Note**, we present the first in a series of articles on performing **soil characterization**, an article presenting methodologies for in place **conduit repairs**, and the final article for the technical project specification series presenting general **“specification tips”** to help your job run smoothly. This quarterly technical note is meant as an educational resource for civil engineers who practice primarily in rural areas of the western United States. This publication focuses on technical articles specific to the design, inspection, safety, and construction of small dams. It provides general information. The reader is encouraged to use the references cited and engage other technical experts as appropriate.

## GOOD TO KNOW

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## Soil Characterization – Here’s the Dirt (Part 1)



### Introduction

Soil characterization can be a dirty job. So dirty that it makes jobs on Mike Rowe’s *Dirty Jobs* TV show look clean by comparison. There’s the obvious dirt involved with drilling and soil sample collection in the field, then it gets even dirtier in the laboratory where soil gets scooped, mixed, wetted, baked, squeezed, and shaken in an effort to discover its properties. Perhaps the “dirtiest” (i.e., not clean or straightforward) aspect of soils characterization happens in the engineer’s office where the usually challenging task of characterizing soil properties and utilizing the results begins. But the trail of dirt actually begins long before drill rigs mobilize and samples get shuttled to the laboratory.

The need for site-specific soil characterization is usually justified with a **trigger event** such as:

- Dam hazard reclassification
- Owner’s decision to significantly modify the dam
- Flooding or a seismic event that puts an unprecedented or extreme loading on the dam
- Periodic dam inspection that identifies a dam safety deficiency.

The trigger event can lead to a dam safety evaluation or other study, which in turn may trigger geotechnical investigation, analyses, and dam modification. Soil characterization is a critical step in the dam modification process – it is the culmination and *product* of data review, use of empirical correlations,

and/or geotechnical investigation, and it is the *basis* of analyses and design.

For a Dam Owner or small engineering firm with limited dam design experience, trying to understand soil characterization can seem daunting. This article helps the reader through the soil characterization labyrinth by presenting the fundamentals of soil characterization pertinent to dam design and providing some key resources that can be useful. So let’s dig in and get dirty!

### The Challenge of Soil Characterization

Failure to develop meaningful, representative soil parameters can result in faulty analyses and design, unacceptable dam safety risks, and wasted money. The acronym **GIGO** (Garbage In - Garbage Out) captures it well: the outcome of geotechnical analyses, design, and construction will only be as good as the input soil parameters upon which they are based.

Soil characterization is usually an inexact process, requires considerable experience and judgment, and sometimes resembles more of an art than a science. To the unenlightened, dirt is...well, just plain ol’ dirt. But to the geotechnical engineer and enlightened Dam Owner, dirt is anything but, considering the following:

There are many types of soils used as engineering materials, each with different properties and behavior

There are a plethora of soil characterization tools to choose from – investigation methods, laboratory tests, equations, correlations, “index” properties, classification systems, and soil behavior models

Unlike other engineering materials with uniform or isotropic composition / behavior such as steel or concrete, soil is a 3-phase material (solid particles, water, and air) with potential for complex physical interactions among the three constituents and under various loadings

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## The Soil Characterization Process

The key steps in the soil characterization process leading to dam modification are outlined as follows:

1. Identify required soil properties to characterize an identified dam deficiency
2. Level One Soils Characterization – Paper Study (utilization of existing data, correlations, and graphical tools)
3. Level Two Soils Characterization - Site Investigation (subsurface investigation, field testing, laboratory testing)
4. Developing input parameters for analyses and design

In the following paragraphs, we'll take a more detailed look at each of these soil characterization steps.

### Identifying Required Soil Properties

A trigger event (see above) usually establishes the need for further evaluation, investigation and/or analysis, which in turn governs which soil properties are required. For example, repair or modification became necessary for some dams that experienced excessive seepage and slope failure during the record-setting flooding along Colorado's Front Range in the fall of 2013. Assuming flattening or buttressing the downstream slope and/or adding an internal filter zone is selected as the design remedy, the key required soil properties necessary for design would then be strength, gradation, and hydraulic properties (permeability). Or, erosive properties of a soil may be required for design and repair of an emergency spillway that experienced severe erosion during the flooding.

It's very important to check applicable state rules, regulations, and/or guidelines that provide specific requirements for dam modification / construction, analyses and design. These will guide the engineer's determination of the required soil properties.

Some of the key soil properties requiring characterization that are most common to dam modifications are:

**Shear Strength** – ability of soil to resist failure (rupture or sliding) under loading

**Permeability** – ability of water to seep or flow through void spaces in soil or through fractures and joints in rock

**Compressibility** – susceptibility to volume change under loading; can include immediate settlement, consolidation, shrink/swell, and collapse

**Protective Filters\*** – used to direct flow and prevent migration of fines or piping between various zones and foundations of embankment dams *\*Although not a soil property, soil characterization is a key component of filter design*

**Erosion Resistance** – ability of a soil to resist erosive seepage or water flow; includes internal erosion and surface erosion

**Dispersibility** – susceptibility of soil (typically clay) particles to break apart or disperse when wetted due to an unstable soil structure

**Compaction Characteristics** – the degree to which a soil can densify through mechanical compaction methods

Table 1 at the end of this article provides a summary of key considerations, test methods, and required sample types for characterizing the soil properties listed above. There are of course numerous other soil parameters that may come into play for various dam rehabilitation projects (bearing capacity, lateral earth pressures, cyclic or seismic characteristics, etc.). However, the intent of this article is to discuss a few of the most common parameters.

### Level One Soils Characterization

Depending on the availability and quality of existing soils data, Level One soils characterization may be all that is necessary (or affordable) for most low hazard, low cost structures. Level One typically involves review of existing data and use of correlations, and may also include use of graphical tools such as subsurface profiles or cross sections.

### Existing Soils Information Review

Before spending money on a new geotechnical investigation, available documents should be researched and reviewed for pertinent soil

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characterization information. Documentation such as previous geotechnical reports, dam safety inspection reports, design studies, risk analyses, etc. may be available from sources such as the Dam Owner and/or Operator, state regulatory agency files, and/or the public domain. All possible existing information should be exploited to the full extent before dirtying a drill rig.

## **Empirical Soil Correlations**

Empirical soil correlations are a relatively quick and inexpensive means of soil characterization, but do have some limitations (see below). By definition, “empirical” means *relying upon or gained from experiment or observation* and are therefore those correlations that (a) have been developed by investigators and researchers utilizing a large body of soil data and knowledge from a broad spectrum of projects and site conditions, and (b) are commonly developed using site-specific data and case histories. Empirical correlations can take the form of equations, data plots, or rules of thumb.

[Chapter 4, Figure 4-14 of the NRCS Engineering Field Manual](#) provides a qualitative summary comparing soil type (USCS<sup>1</sup> soil classifications) and various performance parameters such as strength, compressibility, permeability, and construction workability.

Common examples of more quantitative empirical correlations include:

- SPT blow counts to: relative density, shear strength, or liquefaction potential
- Effective grain size ( $D_{10}$ ) to: permeability
- Shear wave velocity to: density
- Dry unit weight to: collapse potential
- Plasticity index to: erosion resistance or liquefaction potential

Specific references that provide typical ranges of soils properties and correlations were presented in the November 2013 issue of the *Western Dam Engineering* newsletter in an article titled “[Embankment Dam Slope Stability 101](#)”. Caution must always be exercised when using generalized empirical correlations and published

typical values because: (a) site-specific conditions may be unique, (b) soil properties may be different in the horizontal and vertical directions (anisotropy); (c) soil properties may change over time by chemical, environmental, or man-made processes, and (d) there may be uncertainty associated with spatial soil variability (e.g., under-compacted lifts in a dam, zones of higher permeability in a dam foundation, etc.). Adjustments and calibrations to a generalized correlation may be necessary.

Additionally, certain parameters such as strength may be more critical than others, warranting site-specific testing (Level Two) coupled with correlation data.

## **Utilizing Graphical Tools**

A useful tool for a broad-view correlation of multiple soil properties is to develop dam and foundation cross sections and/or profiles, as appropriate, with existing data such as test hole stick logs and field / laboratory data plotted. This allows the engineer to identify specific locations and/or depth intervals where: (a) specific soil parameters may be divergent from data at other areas, and (b) there are sparse or missing data, thereby helping to evaluate data uncertainty and representativeness. In the latter case, barring additional data collection, more conservative soil input parameters for analyses and design may be warranted.

## **Level Two Soils Characterization**

If there is insufficient existing soil data to perform Level One characterization, Level Two may be necessary. Additionally, Level Two is generally necessary for modifications to significant and high hazard dams to satisfy applicable dam safety regulations, and as part of standard practice. The components of Level Two are discussed below.

## **Subsurface Investigation**

Subsurface investigations should be strategically planned to obtain the required soil properties with sufficient sample quantity and at critical locations to be statistically representative and to satisfy analyses and design requirements. All soil sources anticipated to be involved with or affected by construction should be investigated and sampled for characterization purposes, such as different zones and depths within

<sup>1</sup> Unified Soil Classification System

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the embankment dam, the dam foundation, and potential borrow sources.



## Geotechnical drilling for a new reservoir feasibility study.

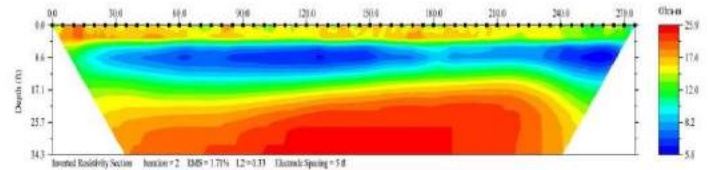
Geotechnical investigation is a vast field with numerous exploration methods, standards, and a multitude of publications on the subject. Key guidance and a list of important references on the subject were provided in the April 2014 edition of the *Western Dam Engineering* newsletter in an article titled [“Poking the Bear: Drilling and Sampling for Embankment Dams”](#).

## Field Testing

Standard or specialized field testing techniques performed during a geotechnical investigation can provide valuable information on soil properties and subsurface conditions. There are intrusive methods such as standard penetration testing (SPT) that indirectly measures soil density/consistency as “blow counts”, downhole packer water pressure testing that measures hydraulic conductivity, pressuremeter testing to measure in-place strength of stronger materials, and cone penetrometer testing (CPT) that measures a variety of soil properties.

There are also non-intrusive geophysical techniques such as electrical resistivity imaging (ERI) and seismic refraction (SR) surveying. The ERI method can help delineate layers of fine-grained and coarse-grained soils, saturated or unsaturated conditions, and seepage pathways through an embankment or foundation. Seismic refraction surveying measures shear wave velocity through a soil, which has been widely used to correlate soil type, density, and stratification. SR surveying is particularly useful for

determining the contact between embankment and bedrock foundation. These are the most common types of field testing methods, although there are numerous others. Several references are provided below that offer good discussion on various field testing methods.



ERI plot, showing different soil layers with depth; red/orange/yellow layers typically represent coarse grained and/or unsaturated soil; green/blue layers typically represent finer grained and/or saturated soil.

## Laboratory Testing

A typical laboratory testing program of soils recovered during subsurface exploration consists of a combination of index and engineering property tests. Common index tests include moisture content, unit weight, Atterberg limits (soil plasticity), grain size distribution, visual classification, and organic content. Some less common index tests that may be appropriate depending on the soils types include soil salinity, sodium content, and dispersion. Data generated from index tests provide an inexpensive way to assess soil consistency and variability among samples, general engineering behavior, and aid in selecting samples for engineering property tests.

Engineering property tests are usually more costly and time consuming than index tests, and test samples should be carefully selected for representativeness and to ensure that the highest quality samples are being tested. Common engineering property tests include direct or indirect measurements of soil consolidation, shear strength, hydraulic conductivity (permeability), compaction characteristics (maximum dry density and optimum moisture content), and erosion characteristics.

An example of an index test providing information on general engineering behavior is as follows: a sample with high plasticity, as measured from Atterberg limit tests, may indicate high compressibility, low hydraulic conductivity, and/or high swell potential. [Chapter 4, Figure 4-14 of the NRCS Engineering Field Manual](#)

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provides a good reference for this type of information. Table 1 below also summarizes testing methods and associated design considerations for various index properties.

Different sample types, volumes, and preparation methods are required for different types of laboratory tests. For example, most index property tests can be performed using disturbed samples (commonly obtained using split spoon or modified California samplers, or by hand from an auger flight, spoil pile or test pit). Conversely, if testing of in-situ properties is desired, engineering property testing such as triaxial shear strength, consolidation, collapse, and permeability tests require relatively undisturbed samples, such as obtained from thin-walled samplers. There are exceptions; for example, strength or permeability tests are often performed on remolded samples to enable modeling compacted embankment fill.



Assortment of soil testing equipment: (a) Atterberg Limits, (b) Sieve Analysis. (c) Consolidation. (d) Triaxial Shear

Care should be taken to avoid sample disturbance when handling and transporting samples intended for in-situ properties testing from the field to the laboratory. Sample disturbance can significantly affect test results, possibly resulting in mis-characterization of a soil, especially for loose or weaker soils.

Laboratory tests, along with the results of field observation and testing, can also be used to identify the properties of special or problematic soils or adverse ground conditions. These can include

collapsible soils, dispersive soils, organic soils and peat, expansive soils, slaking shales and degradable soils, sensitive clays, and ground susceptible to fissures.

## Soil Classification & Description

Soil classification is the grouping of a soil into a category, typically using an established system such as the USCS. Soil description is the systematic, precise, and complete naming of individual soils. The soil's classification and description, as typically provided on a test hole log, should include as a minimum:

- ✓ Apparent consistency (stiffness for fine-grained soils or density for coarse-grained soils)
- ✓ Water content condition adjective (e.g., dry, moist, wet, saturated)
- ✓ Color (e.g., red color can indicate weathered soil, green can indicate organic content)
- ✓ Plasticity adjective for cohesive soils (e.g., medium plasticity)
- ✓ Minor and MAIN (capitalized) soil types (e.g., clayey GRAVEL [GC])
- ✓ USCS Group name and symbol (e.g., GC, GM, GW, GP, SC, SM, SW, SP, ML, CL, SP-SM, etc.)
- ✓ Inclusions (e.g., trace amounts of other soil types, organic content)
- ✓ Geologic name, or embankment zone, if known

Field engineer's or geologists make their best determination of the soil classification at the time of drilling and sampling. Final boring or test pit logs are typically checked and adjustments made as necessary based on the results of the laboratory testing. Here is a typical example of a soil description that may be found on a test hole log:

“medium-dense, moist, red-brown, silty SAND (SM), trace fine gravel to coarse sand (Alluvium)”

Soil descriptions should be provided for each main strata or zone of soil identified in the foundation and embankment. Standard methodology for visual soil classification is provided in ASTM D 2488 – Standard Practice for Description and Identification of Soils

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(Visual-Manual Procedure). There are several references that can be used as guides for field explorations, such as references [4], [8], and [9].

## Developing Input Parameters for Analyses and Design

Ultimately, the process of soil characterization culminates with geotechnical analyses and design. Common geotechnical analyses and design categories include: slope stability, seepage, settlement, liquefaction, estimating required depth of foundation overexcavation, filter-drain design, developing compaction requirements, and erosion potential of earthcut spillways. Geotechnical analyses typically require adoption of a soil behavior model, complete with relevant, representative, and usually conservative soil properties as input parameters.

To develop representative and conservative input parameters, it is helpful to tabulate the soil property data and compute vital statistics (e.g., maximum, minimum, and average standard deviation values). Additionally, the upper-bound, lower-bound, and regression curves can be plotted on a graph. Data points that appear anomalous to the body of data should be evaluated for possible exclusion, lest an excessively high or low anomalous, non-representative data point skew the body of data.

A common practice in selecting an input parameter for modeling that balances both conservativeness and representativeness is to select a value where two-thirds of the data are greater than the selected value, and one-third are lower (or vice-versa, depending on the parameter). This approach is typically used in selecting a friction angle for slope stability modeling. For analyses where a more conservative input parameter is desired, such as seepage analyses (e.g., to account for potentially higher-permeability seepage pathways through a foundation or embankment) a hydraulic conductivity value closer to the maximum, or upper bound envelope from the data set may be desired. Selection of input parameters for soil modeling and design should always be performed by an experienced engineer.

If there is considerable uncertainty about how a selected input parameter models long-term performance, or if there is a limited amount of data, a sensitivity analyses may be appropriate, where

multiple model runs are performed using a range of input parameters. This approach helps to evaluate how sensitive soil behavior and performance are to input parameters, and facilitates selection of performance-driven input parameters.

## Planning and Documenting Soil Characterization

The planning and process of soil characterization should be documented in the work plan, geotechnical investigation report, and design documents in sufficient detail to allow Dam Owners, state regulators, and other reviewers to independently evaluate whether soil characterization will be/has been performed in accordance with the industry standard of care, applicable regulations and is sufficient for the complexity of the given project. This article is intended to assist the reviewer in this capacity, and can be used as a guide to assess if the key aspects of soil characterization discussed above have been addressed, as applicable.

## Closing

In the next Tech Note edition, we'll present in greater detail the process of model input parameter development for slope stability analysis, settlement analysis, filter design, and seepage analysis.

## Useful References

- [1] ASTM D 2488 – 00, *Standard Practice for Description and Identification of Soils* (Visual-Manual Procedure), ASTM International (2000)
- [2] [Design of Small Dams](#), United States Department of the Interior, Bureau of Reclamation, 1987 (Third Edition)
- [3] [Earth Manual, Part 1](#), U.S. Department of the Interior, Bureau of Reclamation, 1998 (Third Edition)
- [4] [EM 1110-1-1802, Geophysical Exploration for Engineering and Environmental Investigations](#), Department of the Army, U.S. Army Corps of Engineers, 31 August 1995
- [5] [EM 1110-1-1804, Geotechnical Investigations](#), U.S. Army Corps of Engineers, January 2001
- [6] [FHWA NHI-06-088, Soils and Foundations, Reference Manual – Volume 1](#), U.S. Department of Transportation, Federal Highway Administration, December 2006
- [7] [Manual on Estimating Soil Properties for Foundation Design](#), EPRI EL-6800, Electric Power Research Institute (EPRI), August 1990.
- [8] [Engineering Field Manual, Chapter 4 - Elementary Soil Engineering](#), U.S. Dept of Agriculture, Natural Resources Conservation Service (NRCS), July 1984 (Fourth Printing)
- [9] [Engineering Geology Field Manual](#), U.S. Dept of Interior, Bureau of Reclamation, 2001, (Second Edition)

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## Technical Note

**Table 1 – Summary of Characterization, Test Methods, and Sample Types for Key Soil Properties**

Soil Property / Design Aspect	Characterization and Design Considerations	Key Testing Methods	Sample Type for Laboratory Testing
Shear Strength ( $\phi$ – friction angle) (c- cohesion)	Influenced by soil type, in-situ dry unit weight, degree of saturation, pore water pressure, degree of compaction, plasticity, cementation, seismic loading, weathering. Consists of frictional and cohesion components Estimated from in situ field tests, gradation data, density, Atterberg limits, and drained and undrained strengths from lab tests. Strength considerations for slope stability analyses are discussed in Vol. 1, Issue 3 (Nov 2013) newsletter.	<u>In Situ (Field)</u> : standard penetration test, vane shear test, cone penetration test, pocket penetrometer <u>Laboratory</u> : direct shear (DS), triaxial shear (TS), unconfined compression (UC) tests	<u>Undisturbed<sup>1</sup></u> sample needed for DS, TS, or UC tests. <u>Remolded<sup>2</sup></u> sample used for testing proposed new embankment fill.
Permeability (k)	Influenced by soil type, fines content, degree of compaction, cracking; and joints, fractures and weathering in rock. For analyses & design often need embankment, foundation, and filter material “k” values. Anisotropy: horizontal “k” can be up to 1000 times greater than vertical “k”.	<u>In Situ</u> : pressure (packer) test, constant/falling/rising head tests, pump tests <u>Laboratory</u> : Falling head, constant head, and back pressure permeability tests performed in triaxial cell.	<u>Undisturbed<sup>1</sup></u> or <u>remolded<sup>2</sup></u> sample used for back pressure permeability test, falling / constant head tests.
Protective Filters	Gradation data and permeability estimates needed for base and filter materials. Filter design discussed in Vol. 1, Issue 1 (March 2013) newsletter.	<u>Laboratory</u> : sieve analysis, hydrometer (to estimate fines fraction); see above for lab permeability test methods	<u>Disturbed or undisturbed sample</u> : Sieve analysis. See above for permeability test.
Compressibility -settlement -consolidation -shrink/swell -collapse	Influenced by soil type, plasticity, loading, consolidation history, degree of compaction, in-situ unit weight, cementation. Embankment fill typically experiences immediate settlement, consolidation (squeezing out of pore water), and secondary compression Shrink/swell – largely dependent on soil plasticity and clay content; fat clays are of concern. Collapse susceptibility w/wetting – foundation deposits with dry unit weight approximately < 95 pcf, low moisture content, above water table.	<u>In Situ</u> : settlement plates; test fill measurement for proposed fill <u>Laboratory</u> : consolidation, sieve analysis, Atterberg limits, dry unit weight, permeability, collapse potential	<u>Undisturbed sample</u> : dry unit weight, consolidation, collapse potential, permeability. <u>Disturbed or undisturbed sample</u> : sieve analysis, Atterberg Limits.
Erosion -Internal erosion (IE) -Surface erosion (SE)	IE and SE influenced by soil type, in-situ dry unit weight, gradation, degree of compaction, plasticity, cementation, weathering. IE also influenced by embankment defects such as internal cracking, under-compacted soil adjacent to penetrations or lifts, dispersive soils, gap grading, and inadequate/no filter. Potential for IE also relates to the soil’s dispersibility (see below)	<u>In Situ</u> : VJT (SE) <u>Laboratory, direct erosion tests</u> : EFA, SERF, HET, RETA. <u>Laboratory, indirect tests for evaluating IE likelihood and erosion resistance</u> : sieve analysis, Atterberg limits, dry unit weight	<u>Undisturbed sample</u> : EFA, SERF, HET, RETA, dry unit weight <u>Disturbed or undisturbed sample</u> : sieve analysis, Atterberg Limits.
Dispersibility	Typically montmorillonitic or illitic clays, high in sodium, low to medium in dissolved salts, and are easily erodible. Avoid using, selectively place, treat with lime, protect from drying/cracking, and/or provide a robust filter for dispersive soils.	<u>Laboratory</u> : Double hydrometer, pinhole, crumb test. <i>Note that all three tests are usually required</i>	<u>Remolded sample</u> : crumb test, pinhole test. <u>Disturbed or Undisturbed sample</u> : double hydrometer
Compaction Characteristics	Compaction increases strength and reduces permeability, compressibility, and erodibility.	<u>Field</u> : test fill <u>Laboratory</u> : Standard Proctor Compaction	Disturbed sample.

<sup>1</sup> Relatively undisturbed samples commonly obtained from thin-wall (e.g. Shelby) tube or modified California samplers.

<sup>2</sup> Remolded (or reconstituted) samples can be created using soil from either undisturbed or disturbed<sup>3</sup> samples.

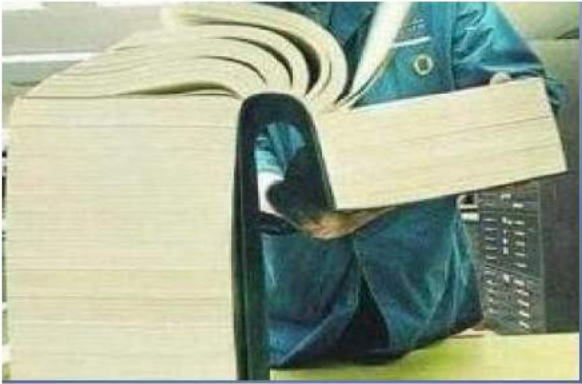
<sup>3</sup> Disturbed bag or bucket samples commonly obtained from split spoon sample, test pit spoil, or auger cuttings



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### Special Series: What the Heck Should Be in My Spec? Part 3: The Devil is in the Details – Specification Tips to Help Your Job Run Smoothly



A thorough set of technical specifications for a dam construction project helps ensure the owner and regulator that the desired product is attained, provides the contractor with a clear understanding of requirements for bidding and project execution, and helps reduce risks for construction claims. There are many considerations for technical specifications that are unique for dam construction projects.

Previous installments of this specifications special series discussed earthwork considerations ([Part 1](#) of the series) and team-effort specifications ([Part 2](#)). This third and final installment considers various details that are important to ensure a smooth-running project.

#### The Project Team

As discussed in the previous issue, all dam construction projects will require the assembly of a project team. This team will consist of the owner (or sponsor) of the dam, the design/construction engineer, the contractor and subcontractors, manufacturers and suppliers of materials, any governmental regulatory agencies having jurisdiction over the project, and organizations that may have provided portions of the project funding. In all cases, the various responsibilities of these entities should be clearly defined within the specifications to the maximum extent possible, so that confusion and overlapping responsibilities can be avoided. Some of these entities will be more intimately involved with the day-to-day project

operations than others, but the roles of all must be considered and clearly defined within the specifications package.

#### The Role of Regulatory Agencies

Regulators are often viewed as an obstacle to overcome. However, the Dam Safety regulator can be everyone's ally. The regulator provides an objective third party review of the project specifications, with no financial incentive to guide their comments. Often they have the benefit of having seen what works and doesn't work for similar projects, and can provide meaningful suggestions based on that experience. The regulator should be consulted in the early phases of the design and plans development. All too often engineers miss the real needs of a given project as perceived by the regulator, requiring re-submittals that are time consuming for all parties.

However, with regard to specifications, it is most beneficial to provide the regulator and other reviewers a complete set of specifications that are not too far from bid-ready. Specifications should not be submitted to the regulator for review until the design is well developed (80-90% level). On that same note, the designer should not spend time on the specifications until the design is well developed. The development of bid-ready specifications is typically a dynamic process for the designer. It is easy to accidentally leave in a spec for a material you thought you were going to use, but decided at the 95% design level to delete. A thorough regulatory review commonly catches these and other oversights that can snag a project. The result will be a much more comprehensive review of all components, particularly how they all tie together.

In addition to state dam safety agencies, other state and federal entities having jurisdiction over environmental issues, such as water quality, wetlands, threatened and endangered species, etc., must be consulted and informed of the plan, with appropriate permits obtained well in advance of construction. The specifications should clearly spell out the roles and functions of the various regulatory agencies involved, so that the contractor understands the working relationships required and knows what to expect. Any responsibilities the contractor has regarding permit compliance, monitoring, testing, and reporting should also be specified.

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### **Keep Specifications Tight and Relevant**

Technical specifications should be written and tailored specifically to the conditions expected to be encountered on the project, and should avoid the inclusion of unnecessary sections that are not pertinent to the project at hand. It may seem that the inclusion of every possible specification from 40 years of design practice would help cover any potential situation encountered during construction, but this would create a specification package so voluminous as to virtually guarantee that none of it would be comprehended or even read.

Including unnecessary specification sections that are not relevant to the particular project just because they are part of a standard specification package, can make the project requirements confusing to the contractor. This results in higher bid prices to account for the uncertainty created. Worse yet, the requirements stated in unnecessary specification sections may actually contradict those of relevant sections, thus creating the potential for claims during construction. Similarly, vague specifications create uncertainty in the mind of the contractor, leading to high bid prices and/or construction claims.

For dam projects, engineers should be careful to ensure that the requirements of the specifications, specifically regarding earthwork provisions, are consistent with locally available natural materials. It makes little sense to carefully describe the use of a particular type of material if it is not available in sufficient quantities nearby. Material specifications should be kept flexible enough to allow for some variability in the types of materials suitable for construction. In general, it will prove to be less expensive to use materials available on site that are suitable for construction than to import materials from off site.

### **Use of Standard Specifications**

While the use of standard, prewritten specifications not specifically tailored to the particular dam project is generally discouraged, it may be useful at times to utilize minor extractions from standard specifications where applicable. Any standard specifications so used should be included within the published specifications for the project and not merely attached by reference. This allows both the contractor and construction inspector to readily refer to the specification in the

field, and reduces the risk of unintentional noncompliance with the requirements of the specification. Care should be taken that any standard specifications included in the bid package are relevant to the work at hand and do not conflict with the requirements of proper dam construction practices. For example, the use of department of transportation or public utility type specifications for earthwork construction on dams may not be applicable, appropriate, or acceptable to regulatory agencies.

The major federal agencies who maintain a role in the design, construction and operation of dams in the United States, such as the Bureau of Reclamation, U.S. Army Corps of Engineers, and the Natural Resources Conservation Service, have all developed what might be referred to as standard specifications for dam construction, and these should be consulted first among standard specifications for use in a specifications package. A listing of references on standard specifications available from these entities is included at the end of this article. These may provide a useful starting point for the design engineer to modify for the project-specific requirements.

Each of the federal agencies listed above employs a somewhat different approach to specification writing, so, if one of those standards is used, it is important to be consistent with the way that standard was developed, or extract the information into the format being used for your project. The NRCS standard specifications, for example, are based on “parent” specifications which cover a wide range of general requirements and possible materials and processes for each technical specification section that are written as general requirements applicable for all projects. Each specification section then requires a project-specific “Items of Work and Construction Details” or a “Special Provisions” subsection to be included at the end to narrow down from the standard spec to specifically what materials and processes are required or allowed for the particular project. This format of incorporating a concise listing of project specific requirements in one section at the end of the standard specification is important when using this “parent spec format”. The more common approach in private practice is to develop a specification package written tailored to the given project in its entirety.

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### **Include a Clear, Detailed Summary of Work**

A Summary of Work should be placed in an obvious location near the front of the specifications package to describe to the project team what the project is about and the steps necessary to complete it. The Summary of Work is the engineer's opportunity to describe and explain, in straightforward, non-technical terms, the various work elements and how they are to be constructed. Each of the work items described within the summary should include a reference to pertinent items of the technical specifications and the bid schedule where that work item is covered. Each technical specification section then provides a detailed technical description of the work items covered under that specification.

### **Pricing Considerations and Use in Bid Schedules**

The specification package must include a discussion of the methodology to be utilized in measurement and payment for the required items of work, and this will carry over to the bid schedule. This may be a separate section of the specs that is usually included in Division 1: General Requirements or a subsection of each technical specification section that describes the methodology for that particular item of work. Either way, it should include a clear, detailed description of how the work is to be measured and what is included in payment for each bid item.

Two methods are commonly used to specify how the contractor is to develop his bid price: (1) lump sum pricing, and (2) unit pricing. Lump sum pricing is appropriate for work items where the contractor is largely in control of the specifics of the work item, such as contractor-developed river diversion plans, cofferdams, site dewatering and unwatering, development of contractor work areas, mobilization costs (usually some maximum allowance), site fencing and security, etc. Unit pricing is appropriate where specific quantities are required and can be estimated but may vary, such as earthwork material quantities, concrete quantities, reinforcing steel, manufactured materials, etc.

A useful rule of thumb is that unit pricing methodology should always be used for anything that can be measured. This provides a basis for determining cost should quantities not be as expected, and helps shift the risk for cost overruns into a more shared territory.

As a general rule, contractors do not bid lump sum items low, because they need to protect themselves from the possibility that the work will be much more involved, and thus more costly, than anticipated. Unit pricing helps define the actual expected cost of a specific bid item, allowing for fair compensation when adjustments are needed.

Specifications or other contract documents should also be clear that quantity overruns resulting from contractor means and methods rather than unanticipated site conditions will not be compensated. For example, overexcavation of foundation materials which is done for the convenience of the contractor and not as a matter of necessity to establish an acceptable work surface as required by the specifications will not be compensated either in the amount of overexcavation yardage or in the quantity of compacted fill materials or concrete materials needed to replace the materials removed by the overexcavation. The point is to place the burden for intelligent contractor means and methods where it belongs, directly on the contractor.

### **Project Completion Schedules and the Use of Liquidated Damages and Incentives**

Contract documents should provide for a firm but reasonable period of time for the contractor to complete the work, which allows for likely weather delays, seasonal shutdowns, anticipated delays in the acquisition of manufactured materials, etc. This schedule is often heavily influenced, as it should be, by the desires and/or needs of the project owner. However, those in a position to dictate the schedule need to remain cognizant of the corollary that among the three desirable attributes of any construction project (high quality, low cost, rapid completion), only two are attainable. Therefore, the schedule must be reasonable to provide any realistic certainty that high quality and low cost can be achieved. If schedule really is a critical issue for the projects, the use of liquidated damages is sometimes offset with the use of performance incentives to compensate the contractor for accomplished work ahead of schedule.

To ensure that the contractor puts forth a diligent effort to complete the job within the specified time frame, liquidated damage provisions are often included within the specifications. These provide for financial penalties to the contractor if the project is not completed within the required time frame and/or if

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intermediate completion milestones are not met. Contractors generally understand this provision and are willing to work within it if it is reasonable. However, contractors will tend to be leery of liquidated damage provisions if they perceive that they may be unfair or rigidly enforced despite mitigating circumstances. This will inevitably drive up prices bid for the work.

To provide the appearance of fairness, completion schedules should allow realistic time frames to complete tasks, and the actual dollar amount of the late penalty should be roughly equivalent to the actual damages incurred by the owner if the task/project is late in being completed. A contractor that is making a good, diligent effort to complete the project according to the schedule should not be subject to financial penalties for things beyond his control, as this will likely raise the overall price of the project.

On larger, more complex jobs, or where certain elements of the construction must be completed within a specific time frame, a baseline schedule for the completion of individual project tasks (milestones) should be established. This will help ensure that the contractor completes those items on time and continues to make acceptable progress. The milestone and baseline schedule requirements should be clearly identified within the specifications, and the contractor should be required to develop and submit a detailed construction schedule for the review and approval of the engineer. The schedule should define when each of the critical construction tasks is to be initiated, what the duration of the task is, and when the task is to be completed.

### Use of Specification Checklists

The preparation of a specifications package requires the assembly of a large volume of information and requirements into a single document, making it easy to forget or overlook something. The use of an appropriate checklist prepared in advance can help prevent this problem, by at least requiring the consideration of the items on the list. State regulatory dam safety agencies may have such a checklist suggested and available for use by the engineer. A link to Colorado's recently completed "Project Review Guide" is provided in the reference section. Also, recent FEMA grant funding has been used to develop a dam specifications review tool, which is scheduled for

release in late 2014. Further information will be provided in a future technical note issue.

### Provisions for Project Construction Meetings and Schedules

A schedule that defines a frequency for required meetings should be laid out within the specifications. Each construction project should kick off with a Preconstruction Meeting involving the owner, engineer, contractor, key subcontractors, and regulator. The principal features of work should be reviewed and any questions regarding the Contract and work site should be addressed. If the project is particularly specialized, involves high risk activities for workers or the safety of the dam could be compromised during construction, a construction risk meeting should be a part of the Preconstruction Meeting(s). Topics in the risk meeting should include reviewing approaches to high risk components, mitigating measures, and emergency response procedures.



**Encourage effective communication between engineer, owner, and contractor**

Regular project construction meetings involving the core project team members (owner, contractor, key subcontractors, engineer) are vital to ensure that the project runs smoothly. These will typically be held as often as weekly, at or near the same time each week, so that developing or impending problems are quickly identified and addressed. Input from all participants should be encouraged. Documentation (minutes) of these meetings is important to track the timely resolution of problems. Minutes are also useful in the

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event these discussions need to be referred to later (i.e., in the unfortunate case of dispute).

In addition to these regular meetings, it may be desirable to define a meeting schedule at the initiation of each new major work item of the project, so that specific requirements of that work item can be presented and discussed.

### **Anticipating Delays in the Delivery of Specified Materials or Products**

Engineers need to be aware that specified pre-manufactured items, such as gates, valves, operators and other mechanical systems may not be readily available on the desired timeline during construction. To help overcome this problem, standard off-the-shelf items should be used in the design whenever possible, rather than special-production items. In any event, engineers should attempt to identify the availability of required/specified manufactured items early, and allow for long-lead items in the project and submittal schedules. Experience indicates, for example, that the delay between order and delivery of larger gate systems can be several months. Therefore, provisions should be made to require the ordering of these materials early in the construction project to ensure their availability when needed. As an alternate plan, the owner may wish to procure long lead items in advance of the project to be provided to the Contractor.

### **Frequency/Location of Quality Control Testing of Earth Fills**

Quality Assurance and Quality Control (QA/QC) testing considerations for dam construction could easily fill a separate article and are dependent on the level of complexity of the project, confidence in the contractor, and variability of available materials. QC refers to the primary testing being conducted to validate the quality of the completed work. QA refers to testing performed to validate another party's test results (i.e. an owner doing spot check test to verify contractor supplied testing). The assignment of responsibility for QC testing was discussed in the second article of this series.

The type, frequency and location of testing on an embankment fill should be described under "QA/QC" in the Earthwork section of the specifications, stating who is responsible to perform the testing. This should

be described even if the owner/engineer is performing the testing to notify the contractor of the testing plan. This section provides a brief discussion of some key considerations in selecting testing frequency for earthfill materials commonly used in dam construction. Numerous other QA/QC requirements typical of dam construction are not covered. These may include foundation preparation inspections, rebar inspections, concrete testing, grouting, etc.

### **Low Permeability Core Materials**

Representative tests to verify specified earthfill properties, such as gradation, Atterberg limits, specific gravity, and Proctor density curves, should be performed during borrow area development or in the stockpile area prior to fill placement. Frequency of this testing may depend on the variability of the borrow source materials, but in general should be on the order of one test for every 10% of total required volume, with the exception of Proctor tests. A sufficient number of Proctor density curves should be obtained to represent the range of material available. Periodic one-point Proctor tests should be performed throughout material placement to verify the appropriate representative curve is being used for QC comparison.

Frequency of compaction testing for critical earthfills, such as those being placed for low permeability cores, should be at least one per 2 to 5% of the total volume (e.g., if 20,000 cy total are being placed, a test every 500 cy) or at least one per day, per area of placement. Additional testing may be warranted (1) in areas where the degree of compaction is suspected of being inadequate; (2) in areas where small working areas lead to rapid fill placement; and (3) in areas requiring special compaction techniques.

### **Granular Materials**

Compaction testing of granular materials (e.g., sand filters) is generally not performed during placement and instead QA/QC consists of visual inspection of the method-based compaction procedures (visual confirmation of number of passes of the specified equipment). Gradation testing is the most important for granular materials, and one test should be performed for every 2 to 5% of total placement volume for filter/drain materials and less frequently for shell and bedding materials. Testing should be

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done both at the source and after placement to evaluate particle breakdown. QC of large diameter (i.e. > 12-inch) materials, such as rockfill and riprap, is generally limited to visual inspection.

Many regulatory agencies require a “Construction Observation Plan” as part of the pre-construction submittals for review and approval. Consistency should be maintained between the project specifications and the Construction Observation Plan to avoid confusion among the project team.

### Seasonal Shutdown Considerations

Cold weather placement of earthfill materials is undesirable as it can lead to frost, heave, voids, difficult moisture control, lenses that may lead to seepage, and an overall weakened mass. A limited amount of cold weather earthfill placement may be unavoidable. In these cases provisions may include soil heaters, blankets, 24-hour work schedules to keep fill “alive” and avoid frost buildup, more intensive QA/QC, and removal of any fills negatively impacted by weather.

Any dam construction project that will require more than one construction season to complete to avoid adverse weather conditions will need to have specification provisions for shutdown of the site to protect the work that has already been completed. It will generally be left to the discretion of the engineer to decide when the seasonal shutdown is necessary, based on conditions experienced at the site. In cold weather climates, this will involve protecting the work from the effects of freezing temperatures and excess moisture in the form of snow. Exposure of compacted earth materials can lead to the formation of frost and ice lenses within the material, altering its density and structure to an unacceptable state.

Specifications should require that all placed and compacted fill materials, at least those within the impervious zone(s) of the dam, be protected from freezing by the placement of sacrificial loose soil materials to a depth sufficient to insulate the fill from freezing. Surfaces should be sloped to drain to prevent rainfall and snowmelt from saturating placed soils. Exposed filters and drains should be capped with fine-grained sacrificial materials (usually separated with geotextile), to be removed when construction resumes. Concrete work must be protected from

freezing temperatures during the initial curing period, and so may require the use of blankets and/or heaters, or accelerants in the mix, during cold weather leading up to winter shutdown.



**Poor weather can often mean lower quality and higher cost.**

Maintaining river diversions and necessary dewatering of the worksite can be problematic during seasonal shutdowns, and these issues should be considered and discussed within the specifications. The specifications should also discuss what provisions are required to verify and validate the adequacy of previously completed work at the re-initiation of construction at the end of the shutdown period.

### Contractor Qualifications

For many construction projects, it is difficult to anticipate what contractors might bid on the job and just what their qualifications are, let alone who the winning contractor might be in an open-bidding scenario. Since dam construction projects tend to be unique in their requirements and challenges versus other heavy civil construction, having a contractor who is experienced in dam construction is nearly always advantageous, if not crucial, for success.

Requirements for contractor qualifications should be incorporated in the bidding package to ensure they demonstrate familiarity and experience with dam construction upon bidding. This includes minimum required qualifications for the general contractor as well their proposed key subcontractors (i.e. grouting, blasting, and manufacturers assigned to design certain components). Qualification requirements should include the key staff (Superintendent, Construction Engineer) and not just the overall company. In some

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cases it may be desirable to prequalify contractors in order to prevent the problems associated with inexperience. This will largely depend on the complexity of the construction project and the ability of the owner's engineer to provide consistent oversight of the project during construction. This is particularly important if several items are being left to the contractor's design and means/methods as mentioned in the last issue of this series, "Team Effort Specifications."



### Require Experienced Personnel to Construct Your Job

In cases where value selection of contractors is allowable (i.e., no requirement to select the "low-bid" contractor on cost basis alone), it may be desirable to utilize project award criteria that consider both the price and established contractor qualifications to get both the best price and the best qualified contractor for a given project. This increases your chances of successful completion.

Beware of contractors with a significant claim history! While not all claims can be avoided, a pattern of repeated claims against the owner and/or engineer should send up a large red flag regarding that contractor's business methods. In any event, the purpose of pre-qualifying contractors should not be to reduce the number of bidders on a particular job, but to ensure that those who do bid are capable of constructing it.

### Common Specification Pitfalls

Poorly written specifications, the use of specifications not tailored to dam construction, or many of the other concerns discussed above may result in:

Lengthy schedule delays for design review by state regulatory agencies

Poor quality construction that may influence long-term performance  
Costly change orders  
Post construction claims and litigation  
Delays that impact the use of the reservoir for the upcoming season  
Team conflict  
Unanticipated expenses for the dam owner for additional materials and inspections (i.e. unhappy dam owners)  
In a worst case scenario, construction of a dam that incorporates unsafe elements, resulting in undesirable and unnecessary risks to lives and property downstream and loss of the water resource until deficiencies are corrected.

### Useful References

The following references provide additional tips on specification requirements for dam construction.

- [1] [New Mexico Office of the State Engineer \(2008\), Technical Specifications for Dams.](#)
- [2] [Montana Department of Natural Resources \(2012\), Specification Requirements for Dams \(Technical Note 8\).](#)
- [3] [Colorado Division of Water Resources \(2007\), Rules and Regulations for Dam Safety and Dam Construction](#)
- [4] [Colorado Division of Water Resources \(2014\), Project Review Guide.](#)
- [5] [U.S. Dept. of the Interior, Bureau of Reclamation \(1987\), Design of Small Dams, 3<sup>rd</sup> Ed.](#)
- [6] [U.S. Dept. of the Interior, Bureau of Reclamation \(1998\), Earth Manual, 3<sup>rd</sup> Ed.](#)
- [7] [U.S. Dept. of the Interior, Bureau of Reclamation \(1988\), Concrete Manual, 8<sup>th</sup> Ed.](#)
- [8] [U.S. Army Corps of Engineers \(2003\), Engineering Regulations, ER 1110-1-8155.](#)
- [9] [U.S. Dept. of Agriculture, Natural Resources Conservation Service \(2001\), National Engineering Handbook, Part 642: National Standard Construction Specifications, Chapter 2.](#)
- [10] [Construction Specifications Institute, Master Guide Specifications.](#)

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### You Con-du-it; How to Fix a Leaky Pipe

#### Introduction

A key component in operation and risk management of small to medium sized embankment dams is the outlet conduit(s) that provide the means to control the reservoir level. Maintenance of conduits through embankment dams is essential to the overall reliability of the dam facility. Conduit deterioration such as joint offsets, cracks, and voids behind the conduit develop for a variety of reasons. This deterioration can lead to the inability to operate the conduit or to excessive seepage into, out of, or along the conduit, which could endanger the integrity of the entire dam embankment. This article presents investigation techniques and common methods for in-place outlet pipe repairs that

can extend the life of the outlet conduit and possibly provide an alternative to conduit abandonment or replacement.

#### Outlet Conduit Inspections

Typically, dam safety organizations and embankment dam owners will conduct a variety of inspections throughout the service life of a conduit. Regulatory requirements, dam hazard classification, conduit condition, and access dictate both the scope and frequency of the conduit inspections.

Dam inspections, and therefore outlet conduit inspections, generally fall into four different categories: formal, intermediate, routine, and emergency. For additional detail regarding each type of outlet conduit inspection, refer to Table 1 below.

**Table 1: Types of Outlet Conduit Inspections**

Type of Inspection	Frequency Interval	Inspection Team	Inspection Scope
Formal <sup>1</sup>	4-6 yrs - High Hazard 10 yrs - Low Hazard  Often performed in conjunction with formal inspection of entire dam facility.	Owner Representative Qualified Engineer Regulatory Agency Rep	<ul style="list-style-type: none"> <li>- Prepare inspection plan &amp; checklist<sup>2</sup></li> <li>- Review all available data (design reports, drawings, instrumentation data, current and historic operating data)</li> <li>- Check operability of all mechanical equipment associated with the outlet works, through its full range of operation</li> <li>- Perform external conduit inspection</li> <li>- Perform internal conduit inspection</li> <li>- Document findings in inspection log<sup>4</sup></li> <li>- Develop inspection report<sup>5</sup></li> </ul>
Intermediate <sup>1</sup>	1 yr – High/Sig Hazard 3-5 yrs – Low Hazard	Owner Representative Qualified Engineer Regulatory Agency Rep <sup>6</sup>	<ul style="list-style-type: none"> <li>- Prepare inspection plan &amp; checklist<sup>2</sup></li> <li>- Review current operating and instrumentation data</li> <li>- Perform external conduit inspection</li> <li>- Check operability of critical mechanical equipment for outlet works</li> <li>- Perform internal conduit inspection<sup>3</sup></li> <li>- Document findings in inspection log<sup>4</sup></li> <li>- Develop inspection report<sup>5</sup></li> </ul>
Routine <sup>1</sup>	Conducted in conjunction with other routine inspections of the dam facility	Owner Representative	<ul style="list-style-type: none"> <li>- Prepare inspection plan &amp; checklist<sup>2</sup></li> <li>- Perform external conduit inspection</li> <li>- Perform internal conduit inspection<sup>3</sup></li> <li>- Document findings in inspection log<sup>4</sup></li> <li>- Develop inspection report<sup>5</sup></li> </ul>
Emergency <sup>1</sup>	Conducted when an immediate dam safety concern is present or an adverse loading condition has occurred	Owner Representative Qualified Engineer Regulatory Agency Rep <sup>6</sup>	<ul style="list-style-type: none"> <li>- Perform external conduit inspection</li> <li>- Perform internal conduit inspection<sup>3</sup></li> <li>- Document findings in inspection log<sup>4</sup></li> <li>- Develop inspection report<sup>5</sup></li> </ul>

<sup>1</sup> More detailed information regarding inspections can be found in *Technical Manual: Conduits through Embankment Dams*, produced by the Federal Emergency Management Agency (FEMA 2005).

<sup>2</sup> Develop a detailed inspection plan & checklist to identify the features to be inspected and the objectives of the inspection.

<sup>3</sup> Based on the results of the external inspection, state or federal requirements, and general facility maintenance, an internal visual inspection may be warranted.

<sup>4</sup> It is good practice to maintain an inspection log documenting the historic inspections and their associated findings for reference during future inspections.

<sup>5</sup> After an inspection has been completed, an inspection report should be developed documenting the findings and any recommendations for repairs.

<sup>6</sup> As a courtesy, an invitation is typically extended to the regulatory agency but the presence of the regulatory agency is not required.



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Conduit inspections are conducted in one of two ways; exterior conduit inspections and interior conduit inspections. Methods for inspecting the various features of a conduit mainly depend on accessibility. Exterior inspections are obviously the most cost-efficient, but rely primarily on secondary indicators of conduit performance and condition. Interior inspections can be difficult to conduct and sometimes require special equipment. For this reason, exterior inspections are typically used as a good screening tool for justifying more costly, but more definitive interior inspections. The following sections describe exterior inspections and interior inspections in more detail.



**Photo 1:** Sinkhole around a spillway riser<sup>2</sup>

### Exterior Inspections

Exterior inspection of the areas above and surrounding the conduit can provide clues about the condition of the conduit. Depressions, sinkholes, or cavities noted along the outlet conduit alignment on the surface of the embankment are indications that internal erosion or backward erosion piping is likely occurring. Seepage areas may also be indicated by changes in vegetative color or excessive vegetative growth on the embankment dam surface. Cloudy discharge or sediment deposits at toe drains or conduit outlets are other external indicators of potential internal erosion issues of the embankment along or into the conduit. Unexplained outlet discharge unrelated to outlet operation or known leakage past the outlet gate is also an indication of potentially deteriorating conditions. If any of these indicators is observed during an exterior inspection, photographs should be taken and the areas monitored for continued changes. These exterior indicators warrant an inspection of the conduit's interior if one has not been recently completed.

<sup>2</sup> FEMA *Technical Manual: Conduits Through Embankment Dams*

### Interior Inspections

In attempting to inspect the interior of any conduit, accessibility must be considered. Typical accessibility issues include access to the outlet, unwatering the conduit and stilling basin, poor air quality, or small diameter conduits. Confined space permitting, lockout/tagout safety procedures, and stand-by emergency response personnel are all generally required for man-entry into any accessible conduits. If the conduit cannot be unwatered, then special services such as closed circuit television (CCTV), remotely operated vehicles (ROVs), or divers should be used. As a general rule of thumb, dive inspections are 3 to 5 times more expensive than ROV inspections. Should divers be selected to perform an inspection, it is important that they are certified by the Association of Diving Contractors International. Similar to a typical man-entry inspection, a pre-dive inspection plan should be developed and the objectives of the inspection clearly defined prior to the dive, because underwater communication can be difficult with the diver once underwater.

Conduit diameters smaller than 36 inches are generally inaccessible for man-entry and require the use of CCTV or ROVs. An ROV unit typically consists of a video unit, a power source for propulsion, vehicle controllers, and a display monitor. ROVs can be obtained for both dry and underwater conduit inspections. ROVs are capable of providing real-time viewing, continuous video for re-viewing, spot photography, and surveying for spatial reference during re-viewing (typically determined by the length of cable discharged into the conduit with the ROV unit).



**Photo 2:** ROV entering a conduit for inspection.

If unwatering of the conduit is not possible and the cost of diving is prohibitive, an ROV or CCTV unit can

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be used. While ROVs or CCTVs can compensate for the inherent limitations of underwater dive inspections (depth, temperature, altitude, time, etc.) extreme caution is advised when using an ROV for inspection. The ROV operator should be qualified, experienced, and knowledgeable of the potential hazards involved. The primary concern when using an ROV for inspection is that the ROV can become entangled or get stuck in a small-diameter conduit, causing an obstruction. Retrieving ROV units can be difficult and expensive work, so care should be taken prior to the inspection to develop a retrieval plan for the ROV unit. Often, a steel umbilical cable is connected to the unit prior to deployment to assist in retrieval.

In contrast to ROVs, CCTV can be utilized. CCTV units are typically manually operated, mounted onto an external carrier, and pushed into the conduit using a rod to direct the mounted CCTV. Historically, it has been difficult to obtain real time video or images captured by the CCTV but with the advent of mobile technology, cameras that allow for some mobile viewing and control have become commercially available.

In terms of costs, ROV units are typically rented at rates ranging from \$1,000/day to \$3,000/day, depending on the sophistication of the unit. ROV units can usually be rented directly and the unit shipped or picked up for use. For the reasons previously listed, it is recommended that experienced and certified personnel be used to operate ROV units whenever possible. The cost for a small crew to mobilize, operate the ROV unit, and demobilize depends on the travel required for the crew but usually ranges between \$1,500 and \$3,000. Most inspections can be conducted in one working day with two days spent traveling to and from the site. In contrast to ROV units, CCTV units are typically purchased by the dam owner and assembled on site. With minimal maintenance, CCTV units can be re-used for future inspections and are a cost-effective solution for many dam owners of small to intermediate sized dams.

One CCTV device that has been used successfully for years by members of the Colorado Dam Safety Branch is a sled-mounted camera attached to a metal push pipe with couplers to extend the sled in 6-foot lengths as necessary. Originally designed by Jim Norfleet in the 1990s and recently modernized by Jason Ward, the sled unit can be constructed for about the cost of a

single ROV rental. Details of the sled are provided as an attachment to the PDF of this Tech Note issue and a photo is shown below.



**Photo 3:** Manually operated CCTV sled.<sup>3</sup>

Common issues with CCTV units include difficulty in obtaining real-time images, lack of spatial reference, and the potential for getting the unit stuck and causing an obstruction. In addition, when inspecting longer conduits or those with bends, CCTV can be problematic and ROV units are typically used instead. Even if man-entry is not an option, the conduits would preferably be unwatered prior to inspection, because particles floating within the water often reflect back during the lighted camera inspection and prevent full view of joints and damage around the conduit.

In addition, both ROV and CCTV inspections should be monitored by a qualified engineer. When viewed continuously during the inspection, qualified inspectors can spot locations where additional time and video angles are warranted. Modern ROV equipment includes pan and zoom capabilities that can be used to get the most from the inspection. Without adequate oversight, untrained technicians can unknowingly move past areas of interest too quickly and diminish the value of the inspection.

If the conduit is accessible for man-entry, the inspection should be documented using photographs or video equipment and whenever possible, the interior of the conduit should be pressure washed prior to the inspection. Locations of all damaged or questionable areas should be documented using

<sup>3</sup> Photo courtesy of [www.water.state.co.us](http://www.water.state.co.us)

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measuring tape and in concrete conduits, locations of cracks along the conduit should be documented using a crack map, or similar reporting method, to track the development of new cracks during future inspections. The continuity of cracks can be investigated using a geologist's pick to tap on the concrete and listen for variations in pitch that give clues as to the condition of the concrete. In pre-cast conduits, the joints in the conduit should be checked for separation due to settlement along the conduit alignment or issues with construction during assembly of the conduit sections. In conduits accessible for man-entry, joint meters can be installed to monitor the opening and closing of the joints that might be of concern.

Other common defects observed during interior conduit inspections include deterioration or corrosion, obstructions, joint offsets and separations, defective joints, voided encasements, heaving, and cavitation damage. Sediment accumulation within the pipe, especially a concentrated build-up, is usually a sign of a defect along the pipe. Cavitation damage generally occurs immediately downstream of mechanical control equipment, such as gates or valves in the outlet works, where pressure flow changes to free flow. Cavitation damage is usually characterized as an erosion issue that begins with pitting and progresses into large cavities. Proper venting is the best method for preventing cavitation damage. The [July 2013 issue of the Western Dam Engineering Technical Note](#) can be referenced for information on proper ventilation for outlet works and common indications of cavitation during inspections. Repair methods for some of the defects listed will be covered in more detail in the following sections.

### **Different Types of Conduits and Common Issues Associated with Them**

A variety of materials has been used to construct conduits through embankment dams during the past 100 years. For the purposes of this article, conduits constructed of concrete, plastic, and metal will be reviewed, as they are the most common conduit materials used in small to medium sized dams. This section presents some common defects with each of these materials and a few potential repair alternatives. All repairs presented below require complete unwatering and isolation of the conduit from the reservoir.

### **Precast Concrete Conduits**

Reinforced concrete pressure pipe (RCPP) and reinforced concrete pipe (RCP) are two types of conduits that have historically been used in many small to intermediate sized embankment dams. One of the primary advantages of precast concrete conduits is that they are relatively inexpensive and can be purchased in standard lengths. RCP/RCPP conduits are connected using a bell and spigot type of connection and can be constructed to accommodate some expected settlement along the conduit alignment due to the flexibility provided at each joint location. However, leaks are prone to develop at RCP/RCPP joint locations because the reinforcement is not continuous at the joints and there is potential for exceeding the joint extensibility through poor construction techniques or settlement along the conduit alignment.

Other common issues to look for during inspections of RCP/RCPP conduits are cracks in the conduit and spalled concrete. Cracks in the conduit typically occur at the transition immediately downstream of the control structure due to differential settlement. Spalling often occurs in precast concrete pipe at the joint locations where there is unequal displacement of the joint in the crown and invert or spring line. It should be noted that a well prepared subgrade, continuously positive slope, and good quality control during construction can go a long way toward preventing these joint offsets and other associated issues. Whenever possible, a concrete cradle should be used beneath pre-cast conduits to ensure support underneath the conduit haunches. Unfortunately, however, these more modern practices have not always been followed in the past, leading to long-term degradation of existing precast concrete conduits.

### **Spalled Concrete**

Methods to repair spalled concrete within concrete conduits are similar to that of typical concrete structures. The surface must first be prepared by removing the deteriorated concrete down to sound material. Reinforcing steel exposed for more than one-third of its circumference should be completely exposed to provide clearance around the reinforcement for the repair material.

The final prepared surface should be free of all loose aggregate, spalled concrete, and dirt, leaving the aggregate of the remaining concrete partially exposed

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to achieve a good bond between the existing and new material. For most small to intermediate sized conduits, the conduit thickness isn't sufficient to develop reinforcement, so dowels typically are not used. All surfaces to be covered with fresh concrete should be moistened to saturated surface dry condition and all standing water removed, leaving the surface damp immediately prior to receiving concrete. A high strength, 3/8-inch concrete mix is usually prescribed for the repairs (pre-mixed Sika product or similar).



**Photo 4:** Spalled concrete inside a conduit.<sup>2</sup>

### *Joint Offsets and Cracked Concrete*

Since RCPP conduits are typically made up of short sections of pipe connected by gasketed bell and spigot type connections, the joint locations are a common place for deterioration or poor construction practices to manifest. First, the cracks or joint offsets should be thoroughly cleaned of any embankment material and cleared of all loose or spalled concrete. For larger cracks, offsets, or failed joints, grout injection helps to fill any voids that may have developed behind the conduit due to localized erosion at the crack or joint locations.



**Photo 5:** Crack in precast concrete conduit.

For this method of repair, the opening should be temporarily sealed, creating a bulkhead, so that grout can be injected behind the conduit. Non-shrink grout can be applied from the interior of the conduit to develop the bulkhead and grout injection ports can be installed through the grout, around the circumference of the crack, at a spacing that will allow the grout to fill any voids that may have developed. Generally, grout injection behind the conduit should be completed so that the injection pressures do not exceed about half the lateral earth pressure of the embankment at the location of the crack.



**Photo 6:** Grouted joint offset with grout port installed for injection grouting behind conduit.

For large cracks, redundancy may be desired and a mechanical repair can be implemented by installing a seal around the inside of the conduit after injection grouting has been completed. A mechanical seal should span the original crack to overlap sound concrete (typically 6-9 inches on either side of the crack). Various products are available to create this seal (Link-Pipe Grouting Sleeve , EPDM rubber seal,

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etc.). Many common mechanical repairs consist of a rubber seal with a stainless steel band that helps to compress the rubber seal against the conduit by expanding the band once in place. It is important that any mechanical repairs implemented within the conduit be tapered at the ends to minimize flow obstruction. Because seepage can sometimes extend away from the conduit, it is important that repairs like these are monitored by regular exterior and interior inspections to ensure no new signs of internal erosion, backwards piping, or seepage into or along the conduit develop.



**Photo 7:** Link-Pipe Grouting Sleeve after installation over cracked conduit.

### Metal Conduits

The most common metal pipe used today in constructing conduits through embankment dams is steel. Steel pipes are typically used as liners in RCIP conduits. These conduits are typically delivered to the job site with the interior painted from the factory and the exterior bare steel. The pipe is typically set into place and the joints welded together. The factory-applied coating along the interior of the conduit stops about six inches short on either side of the joints (to allow space for welding) and has to be painted in the field after assembly. A reinforced concrete encasement is cast-in-place after the conduit has been water tested and accepted for use.



**Photo 8:** Sandblasted steel surface in preparation for applying new epoxy coating at joints.

### Corrosion

A common maintenance issue for steel liner encased conduits is deterioration of the coating system and corrosion of the conduit. Because the joints are painted in the field, the coating at joint locations often deteriorates faster than other portions of the pipe. For that reason, proper care and quality control is critical during construction. Remediation of the liner coating system typically includes sandblasting the interior of the liner to expose the bare steel and applying two coats of high solids epoxy paint (typically ~7 mils per coat).

### Voided Encasements

Another common issue in steel liner encased conduits is voids within the concrete encasement due to poor consolidation of the concrete. This issue is most prevalent in encasements that are constructed monolithically (no horizontal construction joints). In these cases, consolidation beneath the steel liner can be difficult during construction. Voids behind the steel liner are usually detected during a conduit inspection from visual confirmation of seepage at the downstream end of the encasement or the sound of water moving behind the conduit.

Sinkholes, depressions, or cavities on the surface of the embankment, along the conduit alignment, can indicate piping and the potential for voids within the encasement. Because of the presence of the welded steel liner, seepage into the conduit is typically not an issue. Repairs to voided encasements are generally made by injecting grout behind the steel liner. Pressure grouting behind the steel liner is done via

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primary injection ports that are drilled and installed along the invert, spring line, and crown of the voided encasement to ensure that the grout can travel and vent as necessary. Secondary grout ports can be added at intermediate locations if communication between the primary grout ports is not confirmed (air or grout return). Grout pressures should be monitored during injection and each port grouted until project criteria for grout refusal is met or grout return is achieved at the next grout port location.

Communication between the voids in the encasement and the surrounding embankment could exist; therefore, pressures should be limited to prevent fracturing the embankment behind the encasement.

In the past, many small and intermediate sized embankment dams were constructed with conduits made of Corrugated Metal Pipe (CMP). CMP has a typical service life of about 25 to 50 years, but depending on the metal's reaction with certain soils and water conditions, cases have been documented where CMP has deteriorated in less than 7 years after construction. The current state of practice is not to repair severely deteriorated CMP but to replace it with another conduit system. Describing methods for replacing CMP conduits is outside of the scope of this article but the [March 2013 issue of the Western Dam Engineering Technical Note](#) can be referenced for information on slip lining existing conduits.



**Photo 9:** Injection grouting voided encasement behind steel liner.

## Plastic

Historically, when compared with steel or concrete, plastic pipe has not been commonly used as the primary material in outlet conduits. FEMA (2007) describes the uses of plastic pipe in embankment dams. Plastic pipe is more typically used in small-diameter toe drain systems. Plastic pipe, however, has been used in lining rehabilitation of existing conduits. Plastic conduits are generally considered to have a shorter service life than RCPP conduits (approximately 50 to 100 years). However, in environments where the water or soil may cause premature degradation of concrete and steel, plastic conduits may be a favorable alternative. Lining rehabilitation with plastic pipe is typically accomplished by one of two methods, slip lining (typically using HDPE) or cured-in-place pipe (CIPP) liners. Slip lining is completed by installing a smaller, "carrier pipe" into a larger "host pipe," grouting the annular space between the two pipes, and sealing the ends. Preventing collapse of the interior carrier pipe during grouting of the annulus is critical to the success of a lining rehabilitation project. Pressures should be monitored during grouting and, in some cases, the carrier pipe filled with water to provide additional resistance to collapse.



**Photo 10:** Grouting HDPE liner pipe.<sup>3</sup>

A CIPP liner is a resin-saturated felt tube made of polyester, which produces a jointless, seamless, pipe-within-a-pipe. A CIPP liner is either inverted or pulled into the host pipe, cured-in-place using pressurized steam or hot water, and serves as the new carrier pipe. Although these rehabilitation methods may also require draining of the reservoir, they are typically lower cost alternatives to cut and cover methods for full replacement. Renovation of existing conduits by

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installing a liner is outside the scope of this article, but the [March 2013 issue of the Western Dam Engineering Technical Note](#) can be referenced for information on slip lining existing conduits.

FEMA's technical manuals provide detailed discussion of parameters that should be considered during the slip lining design process.

[FEMA - Conduits through Embankment Dams](#)

[FEMA - Plastic Pipe Used in Embankment Dams](#)

### Conclusion

For a variety of reasons, joint offsets, cracks, liner deterioration, and voids are common issues that must be addressed during the service life of a conduit. With careful planning, design, and construction quality control, existing outlet pipe repairs can be successfully implemented and the service life of an outlet structure extended. As an alternative to conduit abandonment or rehabilitation, this article presents some repair methods that can be considered for typical localized defects of various types of conduits commonly associated with small dams. The repairs discussed in this article should be carefully considered for each specific project before implementation, and final design should be prepared by an experienced dam engineer.

### Useful References

The following is a list of design references that should be used during design:

- [1] [FEMA \(2005\), \*Technical Manual: Conduits through Embankment Dams\*, FEMA 484, Federal Emergency Management Agency, September 2005.](#)
- [2] [NRCS \(2005\), \*Structural Design of Flexible Conduits\*, NRCS, 2005.](#)
- [3] [FEMA \(2007\), \*Plastic Pipe Used in Embankment Dams\*, FEMA, 2007.](#)
- [4] [AWWA \(2004\), \*Steel Water Pipe: A Guide for Design and Installation\*, AWWA, M11, 2004.](#)
- [5] [Amstutz \(1970\), \*Buckling of Pressure Shafts and Tunnel Linings\*, Amstutz, Ing. Ernst, 1970.](#)