Special Series: What the Heck Should Be in My Spec?

Part 1: Earthwork Considerations

A thorough set of technical specifications for any 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 helps reduce risks for construction claims. There are many considerations for technical specifications that are unique for dam construction projects. In this special series we will present some of the key topics that are distinctive and important for dam specifications through a series of 3 articles:

1. Earthwork Considerations
2. Dewatering and Diversion – Writing "team effort" specifications.
3. The Devil is in the Details – specification tips to make your construction project move ahead smoothly

Purpose of Technical Specifications

Technical specifications, along with the design drawings, are the guiding documents which enable the project to be constructed according to the intent of the design engineer. They provide a roadmap of sorts for the appropriate procedures and processes to be used to achieve the desired end result. Technical specifications, when properly tailored specifically to the project for which they were written, will provide an enveloping description of how the works shown on the construction drawings are to be assembled and any special considerations and conditions which are not readily shown on the drawings. The technical specifications serve the purpose of explaining the drawings, and ensure that a detailed set of instructions are documented for the purpose of implementing dam construction projects in accordance with the current state of practice for civil engineering work involving dams.

It is oftentimes true that both design engineers and contractors will devote the vast majority of their attention to the development and understanding of the detailed construction drawings for a project, while the technical specifications are seemingly relegated to a lesser position of importance. However, construction contracts are almost invariably written stating that, in the event of inconsistency or disagreement between the drawings and specifications, the written specifications take precedence over the drawings. For this reason alone, it is imperative that the technical specifications be written specifically and accurately for the project at hand, and be unambiguous in their content and meaning. The use of broadly-based, standard earthwork specifications which may be based on other forms of heavy civil construction, such as highways or support of structures, may result in rejection by the regulatory agency having jurisdiction, conflicts during construction, or worse yet, a constructed project which utilizes inappropriate construction techniques and methodologies rather than the original intentions of the designer.

This first article of the series will focus on specifications requirements common for earth materials in dam construction.

Filter Placement

Filters and drains are placed in embankment dams to provide for the safe transmission of seepage water through the dam and out the downstream side. As such, they are placed on the downstream side of the impervious portion of the dam, which is constructed of fine grained soils and is referred to as the core. Filters are used to protect the core from movement of soil particles due to seepage forces, while providing some measure of drainage ability. Drains are designed for the removal of water, so must be relatively free-flowing and designed to prevent the migration of granular filter particles into the drain. Design and construction considerations of filters were discussed in Issue 1, Volume 1 of this Technical Note publication (March 2013).

Four primary items are generally specified in contract documents that relate to construction of filter and drainage zones:

1. In-place material gradation, including material quality and durability specifications;
2. Moisture (wetting requirements) – generally requiring the addition of water to the material during handling and prior to compaction;
3. Compaction effort (number of passes with specified equipment) for a method specification or % compaction/relative density for an end-result specification (see discussion later in this article concerning method and end-result specifications); and
4. Geometry (alignment, width, and vertical continuity).

Filters used to protect the core are generally specified to be constructed of sand-sized materials. Gradations should be designed in accordance with current dam practice to provide for both filtration of the base soil and for drainage of collected water. To accomplish this, more uniformly graded sand is preferable to broadly graded materials. In practice, commercially available concrete sand produced in accordance with ASTM C33 is applicable in most cases for protection of a fine-grained base soil. However, this information should always be verified by analysis.

Aggregate quality and durability are other requirements which should be specified for granular filter materials, and those in ASTM C33 are applicable for filters, as well. Specifications for filter sands typically require that filter aggregates shall be "sound, strong, durable, clean, and minimally affected by chemical alteration and physical breakdown, meeting durability requirements for concrete sand." These requirements can be verified by use of the various testing methods for friability, clay lumps, soundness, and impact resistance listed in ASTM C33.

To ensure permeability and the self-healing nature of filters, the presence of fines (-#200 sieve size materials) in filter sand should always be limited to no more than about 3-4% at the source, and the presence of plastic fines should be prohibited altogether. Typical practice requires that particle breakdown during handling and compaction should result in no more than about 5% fines in place. This limit on break down is generally achievable with the typical durability and compaction requirements discussed herein.

Filter and drain materials are not particularly amenable to conventional earthwork compaction density control. Typical filter sand materials do not exhibit the "standard" compaction curve shape, with a clear maximum dry density at specific optimum moisture content. Rather, these materials exhibit their maximum dry densities when compacted either completely dry or nearly saturated. Drain materials, usually uniform gravels, are not influenced in their compactability by the presence of water, and are not suitable for conventional compaction testing or conventional field density testing.

Conventional end-result compaction specifications (e.g., percent compaction specifications such as ASTM D698) are sometimes used for filter and drain materials, but they can be difficult to apply in the field. End-result compaction specifications based on relative density requirements (e.g., ASTM D4254) are also sometimes used, but the relative density test is notoriously difficult to apply in the field. Consequently, method specifications are often used for filter and drain materials. The difference between method and end-results compaction specifications are discussed in a subsequent section of this article.

Photo 1. Placement of a 3-stage filter showing use of hand-held plywood shield to limit cross contamination.

For most applications, the desired degree of compaction of filter and drain materials is such that sufficient strength is attained and settlement is limited. In locations subject to seismic loading, it is also necessary that filter materials be sufficiently dense to avoid the potential for liquefaction if saturated. All of these requirements can be met by compacting to around 70% relative density (ASTM D4254), which is not particularly difficult to accomplish. Overcompaction beyond this point should be avoided, as this can lead to excessive particle breakage and increased fines content, which can negatively affect permeability and the desired self-healing nature of filters.

In general, it is easier to use a method specification for filter and drain materials, in which a minimum size and weight of compaction equipment, and a minimum compaction effort (e.g. number of passes with the required equipment), are specified. In addition to the compaction equipment and effort, it is also recommended that the placement specification for the filter include wetting the material both during handling, which may help prevent segregation, and prior to compaction. Compaction is most effectively achieved when water is added to the filter material as it is placed to produce a moisture content near saturation. This can be effectively accomplished with a water bar mounted on the compactor or by applying water with a water truck or hose just in advance of the compactor. The filter material should not be oversaturated in locations where the water cannot readily flow away during compaction. Vibratory compaction equipment, such as smooth drum vibratory rollers, should be specified for compacting granular filter and drain materials in order to achieve uniform, complete compaction.

Construction of filters and drains within dams generally requires that the designed width and alignment of these features conform to the types and methods of construction to be used. As a practical issue, alignments of filters and drains should be kept as reasonably straight as possible across the width of the dam section to ensure that continuity of those features is maintained, and thicknesses/widths of filters and drains should be specified to match up with the types of construction equipment to be used. Maintaining alignment, width and vertical continuity of filter and drain zones is of vital importance, and should be covered in detail within the specifications.

Placement specifications should be written to provide for accurate surveys of filter and drain locations during construction, so that these locations are reasonably certain during fill placement operations. The correct geometry must be maintained at all times to ensure vertical continuity of filter and drain zones. Accurate and precise placement of filter material, in lifts of limited thickness, can help prevent the development of “Christmas tree” shaped filter zones within the embankment, thus minimizing the expense of placing excess filter material while ensuring that the design width of the filter is maintained. Some degree of variation in the filter boundaries will occur despite the best efforts of the contractor and specified widths should be sufficient to maintain continuity with an expected variation in these boundaries.

To prevent the potential for contamination of filter and drain zones, placement and compaction of materials in those zones should be advanced one lift thickness ahead of materials in surrounding core and shell zones, to ensure that surface drainage is away from the filter/drain. Also, traffic of construction equipment across the filter and drain zones should be eliminated or very carefully controlled to prevent contamination of the surface. Those areas where traffic over the filter/drain zone is allowed require special treatment to remove contaminated granular materials before the next lift is placed.

Core Placement

Specifications for low permeability core materials generally need to consider the following:

1. Minimum fines content and plasticity
2. Moisture requirements
3. Compaction requirements
4. Special compaction
5. Protection from drying or overwetting

Embankment core sections are generally constructed of the most fine-grained, highest fines content soils available on or near site, although there are some exceptions which may arise due to unworkable materials. Specifications should require that core materials possess a certain minimum content of fines (minus #200 sieve size fraction). It is also desirable that the fines maintain a required minimum plasticity, as measured by Atterberg limits; however, in some locations soils with plastic fines may not be available. Embankment cores can be successfully constructed with soils with very low or non-plastic fines, but precautions such as wider cores, more robust filters, and material test pads are appropriate in these cases. There is no absolute limit on any of these criteria, but the goal is to obtain a relatively watertight core which maintains some measure of flexibility under loading. Core sections can be constructed with a broad range of material; ranging from material comprised of nearly all fines to material containing as little as 20-30%. The amount of preferred fines will depend on the plasticity and coarseness of the remaining material gradation. Generally, clay materials of low to moderate plasticity are preferred, as they are quite impermeable and maintain good workability characteristics. Sandy clay soils and clayey sands can also provide a very desirable core section, of both high strength and impermeability. However, as noted above silty sands, silty sands and gravels, and even low plasticity silts can potentially be used with appropriate precautions.

Problems of workability can arise if fine grained materials having liquid limits in excess of 50% (CH and MH soils) are allowed.

Moisture contents for compacted core material should be specified over the range at which optimal compaction can be best achieved, while still maintaining satisfactory plasticity of the fill. For clay materials, this will generally be between 2% below and 2% above optimum moisture content, as defined by ASTM D698. For silty, lower plasticity materials, somewhat lower moisture content is desirable, in the range of 3% below to 1% above optimum moisture, per ASTM D698.

Compaction requirements for fine-grained embankment fill materials such as clay core materials are almost universally defined by end-result based specifications rather than method specifications, due to the well-established relationship between moisture content and compacted density under a given compaction effort, and the relatively straight forward means by which the state of compaction is measured. Generally, compaction specifications will be defined by requiring 95% of standard Proctor maximum dry density (relative compaction), as measured by ASTM D698. Under some conditions, such as fill under rigid structures, greater density and resistance to settlement may be desirable, and a higher percentage of relative compaction, such as 98%, may be specified. Alternatively, modified Proctor (ASTM D1557) standards may be used for structural support fill, in which case the required percentage of compaction should be decreased a few points, to 95%. Control of embankment core material using modified Proctor is not commonly used for embankments, due to the shifting of the lower moisture contents required to achieve the higher modified Proctor densities, which has an undesirable effect on core ductility. In addition, experience has shown that the greater compactive effort required to achieve modified Proctor compaction is not generally required for acceptable embankment performance.

In addition to the required density and moisture content, acceptable compaction equipment and methodology should be specified. For core materials, this would appropriately involve the kneading action of sheepsfoot or pad foot rollers for mass fill areas. Use of a sheepsfoot or pad foot roller will result in a more homogeneous fill which is compacted from the bottom up, leaving a rough surface for the next layer to adhere to, with less tendency to produce laminations in the fill.

In all cases, the specifications should require that placement and compaction of core materials be done in the longitudinal direction parallel to the dam axis rather than across the axis, to avoid the potential for non-uniform fill materials or laminations creating preferential seepage paths through the embankment. Each succeeding lift must be well-bonded with the preceding lift by ensuring the proper fill placement moisture content, and, where necessary, scarifying the preceding lift to prevent slick surfaces which may cause laminations in the fill. Core fill placement specifications also typically require that fill placement shall advance relatively evenly along the length of the core zone, to help prevent the potential for transverse shear surfaces or poorly compacted zones within the fill.

Photo 2. Core Compaction. *Note compacting in paths parallel to dam axis and the hand tamper in photo that will be used to compact zone immediately next to wall.*

Almost invariably, there will be areas within the core section, such as at contacts with outlet conduits or other structures and at the contact areas with rock foundations and abutments, where the equipment used for compacting the mass fill areas is not suitable. These areas are referred to as special compaction areas, and should be addressed with their own specification. Compacted density requirements should not be compromised in these areas, but it may be desirable to maintain soil moisture contents on the wet side of optimum to ensure the plasticity of the fill, so that it readily deforms to the shape of the surface contacted. Rubber-tired compaction equipment, such as heavy front-end loaders, should be used where possible in these areas, rather than sheepsfoot rollers, to avoid damaging foundation and abutment surfaces and to permit compaction of soils directly against structures. Smaller, hand-operated compaction equipment may be necessary in more confined areas, but their use should be minimized as much as possible, and lift thicknesses should be reduced accordingly to allow for full effectiveness and uniformity of the compactive effort.

The specifications should also provide for protecting the placed core material from excessive drying, overwetting, and freezing. Any areas that are allowed to dry excessively should be scarified, watered and recompacted to ensure that subsequent lifts can bond adequately. Similarly, if the core zone is exposed to excessive rainfall or ponding of water on the surface, it may be necessary to scarify the wet material and allow it to air dry to an acceptable moisture content prior to recompaction, or, in some cases, completely strip the overwet material prior to proceeding with subsequent fill placement. The specifications should also address preventing the incorporation of frozen materials within the embankment, and the protection of placed fills from freezing.

Method Specifications versus End-Result Specifications

For earthwork projects, specifications may be written to require either a specific methodology to achieve a desired result (“method specification”) or to require a certain specific outcome which is verified by testing (“end-result specification”).

A method specification may be appropriate if limited material is being placed, or if testing of materials is difficult or too time-consuming for real-time test results. A typical usage of a method specification would be to control the placement and compaction of granular materials, such as would be used for filters and drains within dams. Since these types of materials do not exhibit the type of moisture/density compaction behavior typical of fine-grained soils, test procedures developed for fine-grained soils are not generally applicable, and the types of tests which have been developed to determine placed densities can be somewhat problematic. Method specifications are, therefore, often more appropriate for controlling the placement of these materials. A method specification would typically specify a required type and amount of effort to be expended to achieve the desired result, without necessarily testing for the result.

Method specifications are usually verified by requiring the contractor to perform a scaled test pad using proposed source materials and equipment. The test pad places the material in accordance with the proposed method specification. Testing of the in-place compacted materials including gradation (for particle breakdown) and in-place density are performed to confirm the method specification achieves the desired results.

Photo 3. Test Pad for Granular Filter Materials

Below is an example excerpt from a specification for placement and compaction of a sand filter. It is not all encompassing, and only provides an example portion of typical requirements, and would be tailored for project specific requirements by the design engineer.

"Place, spread, and compact Zone 2 material parallel to the embankment axis and in such a manner as to avoid cross contamination of adjacent zones…Place and spread Zone 2 material in level, continuous, approximately horizontal lifts that do not exceed 12 inches in thickness before compaction….Thoroughly wet Zone 2 material at the time of compaction in such a manner as to achieve uniform moisture throughout the lift…compact each lift on Zone 2 with 4 coverage's, as is defined in these specifications, of an approved 20-ton smooth drum vibratory roller, or with the number of passes based on the test pad program result…"

End-result (or QC-based) specifications are more typically and effectively used to control the compacted density of fine-grained, especially cohesive, embankment materials. Verification of the desired outcome is obtained by QA/QC testing of the completed product against a required minimum standard, such as a percentage of standard Proctor maximum dry density within a range of acceptable moisture contents. This is the most common type of earthwork control specification for clay and silt core materials where in-place density testing can be readily performed with real-time results using nuclear density testing gauges.

Below is an example excerpt from a specification for placement and compaction of a core material. It is not all encompassing, only provides an example portion of typical requirements, and would be tailored for project specific requirements by the design engineer. It does not present associated requirements including, but perhaps not limited to, protection from cold and wet weather, limits on exposure time of unworked surfaces, discing of clumps, scarifying for adequate tie-in of layers, special compaction at contacts, etc.

"Place, spread and compact Zone 1 material parallel to the embankment axis… Place and spread Zone 1 material in level, continuous, approximately horizontal lifts that do not exceed 8 inches in thickness before compaction…compaction water content of Zone 1 shall be between minus 1 and plus 3 of the optimum water content in accordance with ASTM D698… moisture conditioning shall be performed in the borrow area or at the stockpile to the extent possible…Zone 1 material shall be compacted to at least 98 percent of the maximum dry density (unit weight) as determined by ASTM D698.

References

FEMA (2011), Filters for Embankment Dams - Best Practices for Design and Construction (FEMA).

Montana Department of Natural Resources (2010), *Chimney Filter/Drain Design and Construction Considerations (Technical Note 4)*

New Mexico Office of the State Engineer (2008), *Technical Specifications for Dams*

Montana Department of Natural Resources (2012), *Specification Requirements for Dams (Technical Note 8)*

American Society for Testing and Materials (ASTM), various reference standards

FEMA (2005), *Technical Manual: Conduits Through Embankment Dams (FEMA 484)*

Colorado Division of Water Resources (2007), *Rules and Regulations for Dam Safety and Dam Construction*

Specification Guidance Documents

U.S. Dept. of the Interior, Bureau of Reclamation (Reclamation, 1987), *Design of Small Dams, Third Ed.*

U.S. Dept. of the Interior, Bureau of Reclamation (Reclamation, 1998), *Earth Manual, Third Ed.*

U.S. Army Corps of Engineers (USACE, 2003), *Engineering Regulations, ER 1110-1-8155.*

U.S. Natural Resources Conservation Service (NRCS, 2001), *National Engineering Handbook, Part 642: National Standard Construction Specifications, Chapter 2*

Construction Specifications Institute (CSI)

New Mexico Office of the State Engineer (2008), *Technical Specifications for Dams*

Montana Department of Natural Resources (2012), *Specification Requirements for Dams (Technical Note 8)*