

**NEW MEXICO OFFICE OF THE STATE ENGINEER**  
**Dam Safety Bureau**  
**Technical Specifications for Dams**  
**August 15, 2008**

Documentation requirements are cited in the Rules and Regulations Governing Dam Design, Construction and Dam Safety, which were filed with the New Mexico Record Center as Title 19, Chapter 25, Part 12 of the New Mexico Administrative Code (19.25.12 NMAC). Technical Specifications shall be prepared in accordance with Subsection E of 19.25.12.11 NMAC. The design life of a dam is much longer than the record retention period of most engineering firms and the memories of most design engineers. Therefore, the Office of the State Engineer (OSE) requires that the technical specifications be organized, well written, and entirely consistent with the construction drawings and any other documentation filed for the dam.

All projects involving the proposed construction of new dams, proposed alterations or repairs to existing dams, and the proposed removal of dams in New Mexico require technical specifications to facilitate successful completion of the project. The technical specifications must be certified by the responsible engineer overseeing design of the project in accordance with Subsection B of 19.25.12.12.B NMAC. Correctly written technical specifications enable a project to be completed according to the original intent of the design engineer responsible for the project. The technical specifications also ensure that a detailed set of instructions are documented for the purpose of implementing dam construction projects in accordance with the current state of the practice for civil engineering work involving dams.

This document is organized as follows:

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Discussions pertinent to the above listed topics are provided below.

***A. Internal Peer Review of Specifications by Engineers and Regulatory Agency Role***

The prevailing philosophy concerning specifications writing appears to be that it is a relatively uncomplicated assignment that can be based on existing specifications from previously completed dam construction projects and therefore minimal time and effort is allocated towards internal reviews of specifications packages prior to submitting them to regulatory agencies. However, it is often the case that each construction project is unique unto itself and this requires that specifications be thoroughly evaluated prior to submitting them to the respective regulatory authorities to ensure that specifications are fully relevant and that they address all aspects of the project at hand.

For many projects construction contracts are written such that specifications take precedence over the construction drawings. This can result in problematic issues in that generally design engineers devote significant effort towards the development of suitable drawings unique to the site that may not be fully appreciated or sufficiently addressed in the specifications package if an appropriate level of internal peer review has not taken place. Therefore, it is essential that both the engineer responsible for the overall design of the project and the engineer responsible for drafting the specifications package communicate frequently to ensure that issues pertinent to proper implementation of the specifications during the construction process can be successfully addressed.

Inevitably, the consequences of an engineering firm not allocating an appropriate level of effort to the preparation of specifications, in conjunction with a comprehensive and detailed internal peer review, is rejection of the specifications by the approving regulatory agency. It must be emphasized herein that the regulatory authority, whether it be the OSE Dam Safety Bureau or another state or federal agency, does not operate in the same capacity as the engineering firm hired by the owner of the dam. That is, regulatory agencies review proposed projects for completeness and to ensure that compliance with statutes and that established standards for the most current state of the practice are being implemented.

In summary, well written, coherent specifications that are project specific to a particular construction project involving a dam are essential to ensuring that cost overruns and change orders are alleviated and to diminish the potential for improper construction of critical design elements whose failure or misoperation could result in the need for expensive repairs.

***B. Inappropriate Use of “Standard” Specifications***

The use of “*Standard*” specifications from local, state, federal or other government agencies is *not* allowed for construction projects involving dams. However, it is recognized that minor extractions from standard specifications may be acceptable on a limited basis provided that the extractions are thoroughly scrutinized to ensure they are applicable to and meet the intended purpose of the proposed dam construction project. Incorporating a standard specification from a previous project into a new specifications package is only appropriate if the meaning and relevance of the extracted sections are found to be satisfactory for the current project, are clear and concise with no potential for misinterpretation, and are equally pertinent to the proposed project.

It is often the case that standard specifications from the State of New Mexico Department of Transportation (DOT) are cited for use in the technical provisions of specifications for construction projects involving embankment dams. More often than not, this practice is inappropriate because the purpose served by an embankment dam versus a roadway fill is significantly different given that loading scenarios for a dam involve potentially long term hydrostatic and seepage forces, whereas highway fills are not subject to this type of loading. Another frequent source of standard specifications that are improperly cited and applied are various Public Works specifications that, with possibly the exception of the upfront specifications documents such as bidding and contract documents, contracting conditions, and general requirements, have little or no relevance to construction projects involving dams.

Furthermore, the OSE Dam Safety Bureau will not accept a specifications package that cites a reference standard that is not already included within the specifications package. An example is citing a Department of Public Works standard without enclosing the standard in the specifications package, or enclosing a reference standard which in turn cites another standard that has not been enclosed in the specifications package. Specification packages submitted as such are unacceptable and will be rejected for review by the OSE Dam Safety Bureau.

In summary, standard specifications adopted entirely for use within the technical specifications and the inclusion of specifications not relevant to dam construction projects is unacceptable. Technical specifications for projects submitted to the OSE Dam Safety Bureau must be specifically adapted for dams.

### ***C. Consistency of Specifications Package with Project Construction Drawings***

Design Report Submittal Packages received by the OSE Dam Safety Bureau commonly consist of a design report narrative organized into sequential sections describing the project and the various analyses performed, engineering certifications, computations and assumptions used in the analyses, a project specifications package, a set of construction drawings, and at times, assorted reference materials. With few exceptions, a significant number of the comments generated by the OSE Dam Safety Bureau during a “*typical*” review of a design report submittal address discrepancies between the technical provisions of the specifications package and the construction drawings. The majority of the discrepancies relate to instances where portions of the specifications package are included as “*notes*” in the construction drawings. Examples of common discrepancies include, but are not limited to:

1. Inconsistent relative compaction standards and moisture content (e.g., citing Standard Proctor on the drawings but Modified Proctor in the specifications).
2. Inconsistent requirements for uncompacted lift thicknesses.
3. Inconsistent requirements concerning foundation preparation.
4. Inconsistent requirements concerning Quality Assurance \ Quality Control testing and test frequencies.
5. Inconsistent elevation datum.

Similar to the discussion under Section A, an internal peer review by the consulting engineering firm's staff must be performed prior to transmitting a design submittal package to the OSE Dam Safety Bureau. A thorough internal peer review will alleviate many of the discrepancies that would otherwise remain in the design report, the specifications package, and the construction drawings.

Another issue concerning consistency between the specifications package and the construction drawings involves "constructability" of the project. That is, whether or not the features or details shown on the drawings can actually be constructed, placed, or installed at the locations shown on a particular drawings sheet or detail and whether or not the specifications package adequately addresses such issues. It is imperative that the specifications package provides sufficient detail with regard to any specific type of equipment, methodology, or procedure that may be required to meet the overall project objective.

#### ***D. Specifying the Appropriate Compaction Standard***

The selection of a compaction standard to be included in specifications involving earthen dam construction needs to be based on the engineering properties and strength parameters of the embankment fill available for embankment construction, and the foundation materials upon which the dam will be founded. As described by McCook (2007), the engineering properties of soil to be used as fill material will depend on the compacted dry density and the corresponding moisture content of the compacted soil. Many small to medium size embankments can generally be satisfactorily constructed and expected to perform well by using a specified in-place dry density corresponding to 95 percent of the maximum dry density as determined by the Standard Proctor Compaction Test (ASTM D 698), and depending on the plasticity characteristics of the soil, moisture contents ranging between plus and minus two percent or zero to four percent wet of optimum moisture content.

The consensus within the civil engineering community is that over compacting embankment soils at too low a water content impairs the performance of the dam, in that elasticity or flexibility of the fill is diminished. This can lead to unacceptable settlement and cracking under static loading conditions and perhaps excessive cracking and deformation under seismic (dynamic) loading conditions.

Specifying a more rigorous compaction standard such as the Modified Proctor (ASTM D1557) must be justified. It is recognized that a higher shear strength and generally more impervious fill is attained from a more rigorous compaction standard. However, the increase in strength comes with the consequence of having a less elastic fill that is more susceptible to cracking and deformation which in turn could lead to increased seepage and possibly hydraulic fracturing of the dam. If the foundation material at the site is highly compressible beneath a section of the embankment or beneath the entire embankment, it becomes even more important that the embankment is flexible and to ensure that the embankment fill material is placed wet of optimum. If the Modified Proctor compaction standard is justified for a project, then it may be more appropriate to specify that the in-place dry density of the fill material adhere to 90 to 93 percent relative compaction and a moisture content range that ensures embankment flexibility.

### **E. Quality Assurance / Quality Control**

Locations to be inspected and tested on an embankment fill can and should be provided under “*Quality Assurance / Quality Control*” in the Earthwork Section of the Specifications Package. Field density tests must be performed:

1. In areas where the degree of compaction is suspected to be inadequate.
2. In areas where embankment operations are concentrated.
3. For every 2,000 cubic yards of embankment when no doubtful or concentrated areas occur.
4. For representative tests of every 30,000 cubic yards of earthfill placed. Representative tests include gradation, Atterberg limits, specific gravity, and Proctor density curves.
5. For the locations of all embedded instruments.
6. At least one test during each shift involving the placement of earth materials.

Possible locations where inadequate compaction may occur are:

1. The junction between areas of mechanical tamping and rolled earthfill along abutments, cut-off walls, and outlet works head walls and conduits.
2. Areas where rollers turn during rolling operations.
3. Areas where too thick a layer is being compacted.
4. Areas where improper water content is present (too dry or too wet of optimum moisture content).
5. Areas where less than the specified number of roller passes were made and areas where dirt-clogged rollers are being used for compaction.
6. Areas where over-sized rock is present in the fill.
7. Areas where materials have been placed in a frozen or partially frozen condition, or at near freezing conditions.
8. Areas that have been compacted by rollers that have possibly lost part of their ballast.
9. Areas containing material differing substantially from what was intended as embankment fill.

Special attention is required for areas along conduits and concrete structures that are located in the embankment. The major issues to be addressed are outlined below and are based on Sections 5.3.1 and 5.3.2 of the document by the Federal Emergency Management Agency titled “Technical Manual: Conduits through Embankment Dams” (FEMA 484 / September 2005).

1. Specify suitable backfill material to be placed against conduits and concrete structures with special consideration given to:
  - (a) Gradation requirements including a gradation table, maximum allowable particle size, and the minimum percentage passing the minus 200 sieve.
  - (b) Supporting calculations to verify that filter compatibility criteria have been satisfied, that is, the migration of fines (embankment piping) is satisfactorily addressed.
  - (c) Plasticity requirements for backfilling around a conduit or concrete structure through distinct embankment zones.

2. Provide appropriate measures and standards to address the compaction of backfill material against conduits and concrete structures with special consideration given to:
  - (a) The minimum compressive strength to be attained by a concrete structure prior to backfilling against it (usually specified as the 7-day compressive strength or some percentage of the 28-day compressive strength ( $f'_c$ )).
  - (b) Clearly stated moisture range requirements referenced to the optimum moisture content (OMC) of the backfill material. Usually in the range of 1 to 3 percent wet of OMC where OMC is determined by a Standard Proctor (ASTM D698) compaction test. The compacted unit weight of the backfill against the conduit or concrete structure must be similar to that required for the surrounding embankment soil.
  - (c) Not allowing the placement of angular particles against the conduit.
  - (d) Backfill permeability to ensure that no layers of material with permeabilities higher than in the adjacent earthfill extend in an upstream and downstream direction along the conduit.
  - (e) Slopes required for ramping against and the compaction of backfill along a conduit or concrete structure.
  - (f) Alleviating the potential for lateral movement by maintaining approximately the same backfill elevations along both sides of the conduit.
  - (g) Frequent scarification and moisture conditioning of backfill in highly trafficked areas to eliminate smooth surfaces between lifts and the formation of cracks.

#### ***F. Specifying Appropriate Compaction Equipment***

The specification must identify the type of compaction equipment to be used by the contractor. The most common types of heavy equipment utilized for embankment dam construction are self-propelled and tow-behind, tamping sheepsfoot rollers, rubber-tired (pneumatic) rollers, and smooth drum vibratory rollers. A discussion concerning rollers follows below.

##### **Sheepsfoot Rollers**

Sheepsfoot rollers are most suited for the compaction of cohesive, fine-grained materials, ranging from clays to plastic silts. Soil compaction imparted by sheepsfoot rollers is a result of the kneading action of the roller as it moves across the fill with the roller essentially compacting from the bottom of the embankment lift up. In general, the lift is adequately compacted after a certain number of passes by the sheepsfoot roller with the roller “walking” out of the fill after compaction of the entire lift thickness has occurred.

Advantages associated with the use of sheepsfoot rollers are:

1. Kneads or works the soil as it compacts (promotes mixing of the soil and thus a more uniform or homogeneous lift).
2. Leaves a rough surface for the next lift to adhere to (promotes bonding of subsequent lifts).
3. Mobility, especially for self-propelled models.

4. Has less of a tendency to produce laminations (smooth surfaces within a lift that are less conducive to bonding with subsequent soil layers and more likely to act a potential seepage path).

Conversely, the disadvantages of sheepsfoot rollers are:

1. Not appropriate for final lift and difficult to use for overly wet clays.
2. Cannot be used for initial lift on rock or adjacent to abutments or structures.

The primary factors affecting the compactive effort of sheepsfoot rollers are static weight of the roller, the size (cross sectional area of the foot), the length of the shank, and the operating speed of the roller.

#### **Rubber-tired (Pneumatic) Rollers**

Rubber-tired (pneumatic) rollers are suited for soil-rock mixtures such as gravelly clays, cohesive soils such as clays and silty clays, and granular soils such as sands, gravel, and cobbles. Pneumatic rollers compact an embankment soil lift from the top of the lift down (opposite to sheepsfoot rollers).

The advantages associated with pneumatic rollers are:

1. High compactive effort and broader range of use (both cohesive and granular soils).
2. Promotes a “squeezing” action and is suitable for compaction of initial lift onto foundations comprised of rock.
3. Is good for “proof” rolling (determining where soft or yielding areas occur).

Conversely, the disadvantages of pneumatic rollers are:

1. Leaves a smooth surface and thus does not optimize the potential for bonding with subsequent lifts and increases the potential for laminations within the lift to occur.
2. Difficulty in compacting clays and silts on the wet side of the optimum moisture content.
3. Slow and not very mobile.

The primary factors affecting the compactive effort of pneumatic rollers are static weight, tire pressure, and the operating speed of the roller.

#### **Smooth-drum Vibratory Rollers**

Smooth-drum vibratory rollers are most suited for imparting compactive effort to non-cohesive materials such as sand, gravel, and rock, and similar to pneumatic rollers compacts from the top of the lift downward.

The advantages associated with the smooth-drum vibratory rollers are:

1. Vibratory action is well suited for imparting compactive effort to granular materials.
2. Mobility.

Conversely, the disadvantages of smooth-drum vibratory rollers are:

1. Use is limited to granular materials.
2. Tends to laminate “borderline” soils such as clayey sands and clayey gravels.
3. Leaves a smooth and loose surface.
4. Requires a slow operating speed.

The primary factors affecting the compactive effort of smooth-drum vibratory rollers are static weight, vibration frequency, and the operating speed of the roller.

In summary, specifying a particular type of roller involves matching the roller to the material type, the desired compactive effort and method of compaction, and fill placement water contents. Publications from Ingersoll-Rand and Caterpillar are available for detailed information concerning specifications, statistics and properties of the various rollers.

### ***G. Elements Common to a “Typical” Earthwork Specifications Package***

The following is meant to serve as an example of a basic outline of elements common to an Earthworks section embedded within a comprehensive specifications package. Similar outlines depicting elements common to concrete, metal and steel works, conduits, and other items appurtenant to the dam would also be expected as part of a complete specifications package submittal.

**PART 1 – GENERAL:** Provide a short narrative of general requirements to be fulfilled by the Contractor.

- 1.1 Related Sections: Provide an alphabetized listing of Sections, A through E, etc.
- 1.2 References: Provide an Alpha/Numeric sequential list of ASTM or other standards applicable to project.
- 1.3 Definitions: Provide an alphabetized listing of all major terms essential to understanding the project.
- 1.4 Submittals: Provide an alphabetized listing of all data, reports, and information pertinent to the project, from manufacturers, materials testing facilities, etc.
- 1.5 Quality Assurance: Provide an alphabetized listing of all major requirements, qualifications, applicable ASTM Standards, earthwork test frequency, etc.
- 1.6 Standard Abbreviations: Provide an alphabetized listing of all abbreviations pertinent to this section of the specifications package.
- 1.7 Testing Services: Provide an alphabetized listing of all laboratory testing facilities, conditions of acceptance of such facilities, procedures for test specimen compliance with Contract Documents and specifically noted deviations.
- 1.8 Sequencing and Scheduling: Provide a listing of scheduling requirements with resident/supervising construction engineer and regulatory authorities.
- 1.9 State Engineer Authority: Provide the following statement recognizing state engineer authority – “All construction shall be performed in strict accordance with the accepted plans and specifications. Representatives of the state engineer shall have full authority to

perform inspections during construction and shall have full power to act pursuant to the law and in accordance with Title 19, Chapter 25, Part 12, Dam Design, Construction and Dam Safety of the New Mexico Administrative Code if plans and specifications are not followed.”

## **PART 2 - PRODUCTS**

- 2.1 Embankment Fill: Provide an alphabetized listing of all details specific to embankment fill, e.g., plasticity, gradation, soil classifications, free of deleterious materials, designated borrow source areas, moisture conditioning requirements, maximum particle size, etc.
- 2.2 Structural Fill: Provide narrative on what constitutes structural fill, soil classification, gradation, plasticity requirements, etc.
- 2.3 Filter and Drain Sand: Provide narrative and gradation table for filter and drain material.
- 2.4 Suitable and Unsuitable Soils: Provide narrative and list of acceptable and unacceptable soils for embankment construction; include details concerning soil classifications, moisture contents, maximum particle size, etc.
- 2.5 Miscellaneous: Provide an alphabetized listing of specialty materials - geotextile fabric, etc. and applicability to the project.
- 2.6 Compaction Equipment: Provide details specific to the type of equipment and specifications for the equipment to be used on the site for the various embankment zones including equipment for specialty compaction near transitions areas, outlet conduits, pipe cradles, etc.

## **PART 3 – EXECUTION**

- 3.1 Examination: Provide narrative details related to verification of conditions (foundation conditions, scarification, etc.) and specifics related to the appropriate use and locations where the various equipment types are to be used.
- 3.2 Preparation: Provide details specific to the preparation of all foundation materials including but not limited to: proof-rolling, excavations, acceptable moisture, conformance with lines, grades, and cross sections shown on plans, freeze protection, etc.
- 3.3 Embankment Fill: Provide details specific to loose lift thickness, applicable compaction standard, percent relative compaction and moisture content range, etc.
- 3.4 Filter and Drain Sand Placement: Provide details specific to loose lift thickness, applicable method specification, application of water for densification, contamination issues, removal of deleterious material, etc.
- 3.5 Structure Backfill: Provide details specific to loose lift thickness, placement of backfill against recently poured concrete structures, applicable compaction standard or method specification, moisture content, etc.
- 3.6 Field Quality Control: Provide specific information concerning scheduling of compaction or subgrade tests, proof rolling, the acquisition of samples from embankment material to evaluate if material meets specification requirements, including gradations, in-place density, and moisture content.
- 3.7 Quality Assurance: Provide details specific to test frequency and the need for verification of nuclear gage test results with sand-cone tests.
- 3.8 Tolerances: Provide information concerning conformance of final elevations, slopes, etc., with an established tolerance from the grades shown on the Drawings.

- 3.9 Cleaning: Provide details related to the disposal of all trash, debris, excess materials, foreign objects, etc., and the smoothing and grading of ground surfaces to eliminate ruts and erosion.
- 3.10 Protection and Maintenance: Provide details related to winterizing the project, protection against erosion, etc.

**H. *Common Reference Standards included in Specifications Packages and Geotechnical Investigations for Embankment Dam Design and Construction***

The following serves as partial list of American Society of Testing Materials (ASTM) standards applicable to construction and geotechnical investigations for earthen dams. Depending on the particular circumstance, it is not expected that each and every test on the list will be included for any given project or that other tests by ASTM, USBR, and others will not also be applicable. The list is provided to summarize the more common tests specified for earthen embankment dams.

1. ASTM D 421: Practice for Dry Preparation of Soil Samples for Particle Size Analysis
2. ASTM D 422: Method for Particle-Size Analysis of Soils
3. ASTM D 698: Test Methods for Moisture-Density Relations of Soils and Soil Aggregate (Standard Proctor)
4. ASTM D 854: Test Method for Specific Gravity of Soils
5. ASTM D 1140: Test Method for Amount of Material in Soils Finer than the No. 200 Sieve
6. ASTM D 1556: Test Method for Density of Soil In-Place by the Sand-Cone Method
7. ASTM D 1557: Test Methods for Moisture-Density Relations of Soils and Soil Aggregate (Modified Proctor)
8. ASTM D 1586: Penetration Test Method and Split-Barrel Sampling of Soils.
9. ASTM D 2216: Method for Laboratory Determination of Moisture Content of Soil, Rock, and Soil-Aggregate Mixtures
10. ASTM D 2434: Test Method for Permeability of Granular Soils (Constant Head)
11. ASTM D 2487: Test Method for Description and Identification of Soils
12. ASTM D 2922: Test Method for Density of Soil and Soil-Aggregate In-Place by Nuclear Methods
13. ASTM D 3017: Test Method for Moisture Content of Soil and Soil-Aggregate In-Place by Nuclear Methods
14. ASTM D 4220: Practices for Preserving and Transporting Soil Samples
15. ASTM D 4221: Test Method for Dispersive Characteristics of Clay Soil by Double Hydrometer
16. ASTM D 4318: Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
17. ASTM D 4253: Test Method for Maximum Index Density of Soils Using a Vibratory Table
18. ASTM D 4254: Test Method for Minimum Index Density of Soils and Calculation of Relative Density
19. ASTM D 4546: Test Method for One-Dimensional Swell or Settlement Potential of Cohesive Soils

20. ASTM D 4644: Slake Durability of Shales and Similar Weak Rocks
21. ASTM D 4647: Test Method for Identification and Classification of Dispersive Clay Soils by the Pinhole Test
22. ASTM D 4718: Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles
23. ASTM D 4767: Test Method for Consolidated Undrained Triaxial Compression Tests of Cohesive Soils
24. ASTM D 4829: Test Method for Expansion Index of Soils
25. ASTM D 5080: Test Method for Rapid Determination of Soil Density (3-Point Compaction Test)
26. ASTM D 5084: Test Method for Permeability of Fine Grained Soils (Falling Head)
27. ASTM D 5333: Test Method for the Measurement of Collapse Potential of Soils

### **I. *Examples of Reference Sources for Embankment Dam Specifications***

There are numerous references available that discuss the specifics of what to include in a specifications package for the construction of earthen dams. Some of these include:

1. *Earth Manual*, Third Edition 1998, by the United States Department of the Interior, Bureau of Reclamation (USBR).
2. *Engineering Regulations*, ER 1110-1-8155, October 2003, Department of the Army, U.S. Army Corps of Engineer (USACE).
3. *Design of Small Dams*, Third Edition 1987, United States Department of the Interior, Bureau of Reclamation (USBR).

Additional information related to previous construction projects involving earthen dams and the associated technical specifications is available on the worldwide web (internet) and can be accessed through various search engines.

### **J. *References***

1. *American Society of Testing Materials*, various reference standards.
2. FEMA (2005), *Technical Manual: Conduits through Embankment Dams (FEMA 484)*
3. McCook, D.K. (2007): *Twenty Questions You Should Ask Yourself Before You Approve That Design*, ASDSO Dam Safety 2007 Annual Conference, Austin, Texas.
4. OSE (2005), *Rules and Regulations Governing Dam Design, Construction, and Dam Safety*, Title 19, Chapter 25, Part 12 New Mexico Administrative Code