Design and Construction Guidelines for Dams in Texas

Dam Safety Program
Texas Commission on Environmental Quality

RG-473
August 2009

TCEQ

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Dam Safety Program
Field Operations Support Division

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Buddy Garcia, *Chairman*
Larry R. Soward, *Commissioner*
Bryan W. Shaw, Ph.D., *Commissioner*

Mark R. Vickery, P.G., *Executive Director*

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Published and distributed
by the
Texas Commission on Environmental Quality
PO Box 13087
Austin TX 78711-3087

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Chapter 1. Introduction to the Guidelines

1.0 Introduction

These guidelines describe the design and construction requirements for the construction of a proposed dam or the reconstruction, modification, enlargement, rehabilitation, alteration, or repair of an existing dam in Texas. These design and construction requirements include the submission, review, and approval of engineering plans and specifications, inspections, reports, and records.

The guidelines delineate the full extent of a submittal package that would provide the information necessary for the TCEQ to conduct an adequate review of a proposed construction project. Though the guidelines are rather explicit, the engineer may submit alternate designs or utilize unconventional practices if they can be adequately demonstrated to be safe and effective.

These guidelines may be revised and republished at any time. Therefore, when you are preparing a submittal package for a proposed dam construction project, you should specify which version of these guidelines you are using. If we have to revise these guidelines, we will submit the revision to due review by stakeholders and make it available for public comment.

1.1 Regulatory Authority

These guidelines supplement the Texas Administrative Code, Title 30, Part 1, Chapter 299, "Dams and Reservoirs."

1.2 Professional Responsibility and Duty

If you are a licensed professional engineer or working under the guidance of one, we wrote these guidelines for you. We assume that you are familiar with the processes discussed in these guidelines, as well as with the standard engineering software used for stability (including erosion stability) analyses.

In Texas, the design and quality assurance of dam construction projects is considered to be a facet of the practice of engineering and, as such, subject to the Texas Engineering Practice Act, as amended.

1.3 Copies

You can find these guidelines online (for viewing or downloading) at www.tceq.state.tx.us/goto/dams.

1.4 Feedback

Please direct any questions or comments on the content of these guidelines to the coordinator of the Dam Safety Program, Texas Commission on Environmental Quality.

1.5 Applicability

The guidelines described in this document apply to all dams under the jurisdiction of the TCEQ Dam Safety Program. Some dams may also need to meet the requirements of other agencies, such as the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) or the U.S. Army Corps of Engineers (USACE). Construction designs developed to meet the requirements of these agencies will be accepted by the TCEQ as long as their requirements are shown to be at least as conservative as those contained in the present guidelines.

1.6 Definitions

Many of the words and terms used throughout these guidelines are defined in the glossary, “Dam Safety Terms.” According to 30 TAC 299.1(a), dams fall under the jurisdiction of the TCEQ Dam Safety Program if they meet one or more of the following four criteria:

(1) [they] have a height greater than or equal to 25 feet and a maximum storage capacity greater than or equal to 15 acre-feet;

(2) [they] have a height greater than 6 feet and a maximum storage capacity greater than or equal to 50 acre-feet;

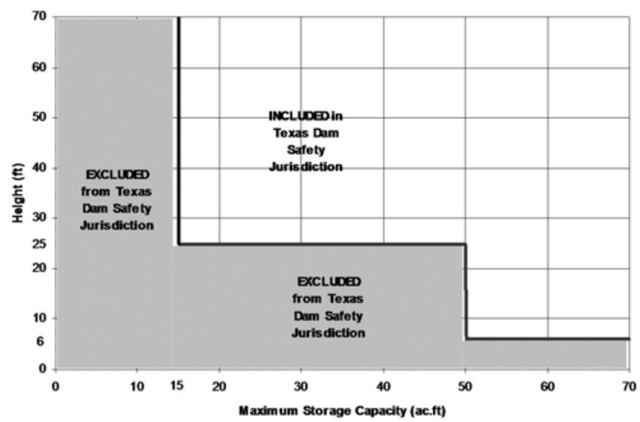
(3) [they] are a high- or significant-hazard dam as defined in §299.14 (relating to Hazard Classification Criteria), regardless of height or maximum storage capacity; or

(4) [they] are used as a pumped storage or terminal storage facility.

1.7 Acknowledgements

These guidelines are based substantially on the work of many agencies and individuals that have contributed greatly to the design and construction of dams in the United States. These agencies and individuals are credited in the Bibliography, at the end of these guidelines.

Figure 1.1. Definition of a Jurisdictional Dam



Chapter 2. Submitting Construction Plans and Specifications

2.0 Introduction

All engineering plans and specifications, inspections, reports, and records for the construction of a proposed dam or the reconstruction, modification, enlargement, rehabilitation, alteration, or repair of an existing dam in Texas must be prepared by, or under the direct supervision of, a professional engineer (licensed in the State of Texas) with direct responsibility for the analysis of the dam.

All applicable proposed construction projects—as defined in 30 TAC 299.21, "Applicability"—must fulfill all construction requirements, including the submission of the engineering plans and specifications to the TCEQ Dam Safety Program, and their review and approval by the program.

Any submittal packages for proposed construction projects that you send to us, the TCEQ, for review and approval must sufficiently document the technical basis for the proposed design(s). Furthermore, this documentation must include the methods used, the key assumptions, and the results and conclusions of any investigations and/or diagnostic work conducted prior to and during the design process.

You should supply the required information regardless of whether the analysis is a stand-alone review of an existing dam, or supports the design of a proposed new dam or the modification of an existing one.

If you are proposing the major rehabilitation of a large dam, you should meet with us before you develop construction plans.

Our requirements as to the preparation of hydrologic and hydraulic analyses, as well as any related breach analyses, are outlined in our most current version of the *Hydrologic and Hydraulic Guidelines for Dams in Texas* (GI-364), which you can find online at www.tceq.state.tx.us/goto/dams.

Two other TCEQ publications that are referred to in these guidelines are also fundamental: *Guidelines for Operation and Maintenance of Dams in Texas* (GI-357) and *Dam Removal Guidelines* (GI-358) These publications are also available at the above Web address.

2.1 Minimum Requirements for Submission

Construction Plans and Specifications

The principal element of the submittal package is the final set of signed and sealed construction plans and specifications.

Supplemental Information

In addition to the construction plans and specifications, you should also include the following supplemental information in the submittal package, depending on the nature of the project.

The supplemental reports that you include in the submittal package must address the requirements and/or considerations outlined in the remaining chapters of these guidelines. The TCEQ forms mentioned below are included in the Appendix. A Submittal Package Checklist is also included in the Appendix, to help you make sure your submittal package is complete.

The submittal package you send in to the TCEQ Dam Safety Program only has to contain one copy of each of the required documents, as delineated below. These documents will be retained in TCEQ records after the construction plans and specifications are approved. If you or the owner need additional approved copies of the construction plans and specifications for your own records or for distribution, the number of additional copies you want should be included in the submittal package.

New Dam or Major Modification Project

A major modification is one that will change the hydraulic or structural design or capabilities of the dam.

- Information Sheet: Proposed New Construction, Modification, Repair, Alteration, or Removal of a Dam (Form TCEQ-20345)
- Hydrologic and Hydraulic (H&H) Evaluation Summary (Form TCEQ-20346)
- Design Report – to assess and report the proper size and hazard classification of the dam, as well as any applicable Federal Emergency Management Agency (FEMA) floodplain issues or requirements
- Geotechnical Report – including stability analyses, if applicable
- Hydrologic and Hydraulic Analyses – if applicable
- Breach Analyses (with inundation mapping) – if applicable; for a dam designed to handle less water than that generated by its required design flood
- Quality Control Plan
- Closure Plan
- Plan for Addressing Possible Emergencies
- Instrumentation and Monitoring Plan – if applicable
- Supplemental Engineering Plans – if applicable, according to 30 TAC 299.22(d)(2)

Additionally, in the case of a large, high-hazard existing dam, the TCEQ Dam Safety Program may require the dam owner to obtain the service of an independent team of professional engineers or other dam experts during the evaluation and design of modifications. This requirement would only apply to dams that have unique or unusually complicated technical issues related to the design of dam safety improvements.

In such a case, the owner would retain a team of two or three independent experts to assist you, the owner's engineer, in the evaluation, design, construction, modification, or operation of the dam. You would have to submit the team members' names, along with their qualifications, to our Dam Safety Program.

The Dam Safety Program will provide the dam owner with names of qualified engineers, if needed.

Major Repair Project

A major repair is one that will NOT change the hydraulic or structural design or capabilities of the dam, but whose scope goes beyond normal maintenance, as defined by our *Guidelines for Operation and Maintenance of Dams in Texas.*

- Information Sheet: Proposed New Construction, Modification, Repair, Alteration, or Removal of a Dam (Form TCEQ-20345)
- Design Report
- Geotechnical Report
- Quality Control Plan
- Plan for Addressing Possible Emergencies
- Supplemental Engineering Plans – if applicable, according to 30 TAC 299.22(d)(2)

Removal or Permanent Breach Project

- Information Sheet: Proposed New Construction, Modification, Repair, Alteration, or Removal of a Dam (Form TCEQ-20345)
- Design Report – to address all considerations outlined in the TCEQ's *Dam Removal Guidelines*
- Hydraulic Analysis – if applicable; for permanent breach projects, for which you need to demonstrate that the proposed breach size(s) can handle at least the peak inflow from the dam's design flood without overtopping the dam

Emergency Repair Project

An emergency repair does NOT require approval prior to commencement, according to 30 TAC 299.45, "Emergency Repair."

- The dam owner must undertake emergency repairs under the supervision of a professional engineer and implement the emergency action plan as soon as possible after the emergency is discovered and evaluated.

- ♦ The dam owner must notify the TCEQ Dam Safety Program coordinator by telephone, e-mail, or fax of the action being taken as soon as the emergency situation allows, but no more than 12 hours after the emergency is discovered and evaluated.
- ♦ The dam owner must have a professional engineer develop plans for permanent repairs as soon as the emergency is over. You, the engineer, must submit the plans for review and approval in accordance with these guidelines.

2.2 Content of Construction Plans and Specifications

The construction plans submitted to the TCEQ Dam Safety Program for review and approval must be 22 x 34 inches in size. (The plans may be reduced to 11 x 17 inches, as long as all details are still clearly legible and you included an accurate scale.) The submittal package must also satisfy all the other requirements outlined in 30 TAC 299.22, “Review and Approval of Construction Plans and Specifications.”

Construction Plans for Proposed Dams

Construction plans for a proposed dam must include:

1. *A Vicinity Map* – which must show the location of the proposed dam and its appurtenant structures with respect to:
   - boundaries of political divisions
   - streams
   - highways
   - railroads
   - pipelines
   - transmission lines
   - utilities
2. *A Topographic Map* – which must have:
   - contour intervals not to exceed five feet
   - the latitude and longitude (in decimal degrees, to six decimal places) of the midpoint of the dam using the NAD 83 conus datum or any future updates
   - a superimposed plan of the dam showing the locations of any:
     - spillways
     - outlet conduits
     - borings and test pits
     - possible borrow areas
     - other structures
3. *A Profile of the Dam* – taken on the long axis of the dam, and showing:
   - the location of the outlet conduit and each spillway
   - the proposed bottom of the core trench
   - elevations of all features
4. *A Profile of Each Spillway* – taken along the long axis.
5. *A Log of All Borings* – showing the classification of materials encountered below the surface, if not provided in a separate geotechnical report (preference is for a separate report).
6. *A Cross-Section of the Dam* – taken at the maximum section, showing complete details and dimensions.
7. *Detailed Sections* – A sufficient number of sections must be included, and with adequate detail to delineate all of the features of structures, including:
   - outlet conduits
   - control works
   - spillways
8. *The Location of All Proposed Permanent Instrumentation* – that will monitor water levels, water and earth pressures, deformations, and/or seepage, which may include:
   - piezometers, observation/monitoring wells, etc.
   - weir plates, flumes, velocity meters, etc.
   - turbidity monitors
   - pressure or load cells
   - strain and stress meters
   - settlement plates
   - inclinometers, tiltmeters, etc.

  - shear strips
  - joint meters
  - thermistors, thermocouples, etc.
  - data acquisition systems
9. *Provisions for a Storm Water Pollution Prevention Plan* – which are the requirements, or design criteria, that the proposed contractor must address, or follow, in developing a Storm Water Pollution Prevention Plan and submitting a Notice of Intent (NOI), if applicable.
10. *Other Design Standards* –which are any standards not covered by the above reports for construction materials, testing, etc.

Construction Plans for Existing Dams

Plans for the reconstruction, modification, enlargement, rehabilitation, alteration, or repair of an existing dam must include (as applicable):

1. *A Vicinity Map* – which must show the location of the proposed dam and its appurtenant structures with respect to:
   - boundaries of political divisions
   - streams
   - highways
   - railroads
   - pipelines
   - transmission lines
   - utilities
2. *A Profile of the Dam* – taken on the long axis of the dam, and showing:
   - the location of the outlet conduit and each spillway
   - the proposed bottom of the core trench
   - elevations of all features
3. *A Log of All Borings* – showing the classification of materials encountered below the surface, if not provided in a separate geotechnical report (preference is for a separate report).
4. *Detailed Sections* – A sufficient number of sections must be included, and with adequate detail to delineate all of the features of structures, including:
   - outlet conduits
   - control works
   - spillways
5. *Provisions for a Storm Water Pollution Prevention Plan* – which are the requirements, or design criteria, that the proposed contractor must address, or follow, in developing a Storm Water Pollution Prevention Plan and submitting a Notice of Intent (NOI), if applicable
6. *Other Design Standards* – which are any standards not covered by the above reports for construction materials, testing, etc.

Specifications

Unless you included or addressed them within construction plans for smaller projects, you must furnish certain other specifications, as follows:

- ♦ A provision that “Plans and specifications will not be substantially changed without either written approval of the executive director before the work is started, or notification of the changes as defined in 30 TAC 299.26, ‘Construction Change Orders.’”
- ♦ Provisions for a professional engineer to observe quality control of the construction, as per 30 TAC 299.4(a)(3).
- ♦ Requirements for the various types of materials used in the proposed construction project (along with references to acceptable standards).
- ♦ Specific requirements for the proper placement and adequate compaction of each fill type, including:
  - the requirements-for both heavy and hand-operated compaction equipment
  - the maximum lift thicknesses for both heavy and hand-operated compaction equipment
  - the requirements for moisture and density
  - the requirements for benched or horizontal placement and compaction
  - the requirement for fill to be free of organic or deleterious material
- ♦ Minimum compressive strength requirement(s) for any cement, slurries, grouts, or structural concrete that is proposed.
- ♦ Testing frequencies or schedule for placed materials (concrete, fill, anchors, pressure

pipe, etc.), incorporating the recommended tests and analyses listed in the Geotechnical Report (see 4.4, “Geotechnical Report Requirements,” in these guidelines).

- All the design specifications necessary to attain proper, quality construction of related components (spill gates, valves, retaining walls, erosion control blankets, slurry walls, anchors, etc.).
- The specified time of completion for the construction project.
- Other specifications not covered by the above items.

2.3 The Review and Approval Process

The TCEQ Dam Safety Program will respond to each submittal package within 30 calendar days of receipt with either a written request for additional information and/or revisions, or with a written approval. Unless there is a large number of plans under review, the Dam Safety Program attempts to complete reviews in two to three weeks. Additionally, we understand that certain critical projects may require urgent attention, and these will be given appropriate priority. The Dam Safety Program will provide acknowledgement of receipt of the submittal package within five working days of receipt. If the Dam Safety Program does not respond to the submittal package within twenty working days of the acknowledgement of receipt, the plans and specifications will be automatically approved.

Water Rights Permits and/or Edwards Aquifer Protection Program Permits

Proposed construction projects that will require you to obtain either (1) a permit to appropriate state waters or (2) approval of an Edwards Aquifer protection plan will not be approved by the TCEQ Dam Safety Program until the required permits or approvals have been issued by the TCEQ Water Rights Program and/or the TCEQ Edwards Aquifer Protection Program.

Securing these permits can be a lengthy process. You should factor adequate time for this into the proposed construction project’s schedule.

Draft Construction Plans

At your request, the TCEQ Dam Safety Program will review and give comments on draft construction plans.

Accountability

The dam owner is responsible for obtaining written approval for construction plans and specifications from the TCEQ Dam Safety Program, prior to beginning construction of a proposed dam, or the reconstruction, modification, enlargement, rehabilitation, alteration, or repair of an existing dam.

Notification of Construction Activities

After the TCEQ Dam Safety Program has issued the written approval for the construction plans and specifications, you may begin construction. The dam owner is responsible for notifying us, or ensuring that you (the project engineer) notify us, within ten working days of the actual start date of construction.

Chapter 3. Determining the Adequacy of the Dam Type

3.0 Introduction

Although a variety of dam types may be suitable for a potential site, a thorough examination of the relevant factors and issues will reveal which type will best achieve an acceptable balance between cost and safety, while still fulfilling the intended purpose of the proposed dam. While there are not many sites where the construction of a safe and functional dam is completely unfeasible from a construction standpoint, the physical characteristics of a particular site may make a potential project too costly. Ultimately, if a proposed dam cannot be built to adequate safety standards, then it should not be constructed.

3.1 Overview of Dam Types

There are many types of dams. Some—such as timber dams and steel dams—are outdated and no longer considered practical, and will not be approved. Following is a brief overview of the most common dam types that are currently being built.

Embankment Dams

Embankment dams include earthfill and rockfill dams. Embankment dams:

- Are the most common (and often most economical) type of dam.
- Utilize materials, usually available locally, that do not require a high degree of processing.
- Have requirements for an adequate foundation that are not as extensive or critical as those for most other dam types.
- Have more potential sites available, especially in Texas.
- Are more susceptible to erosion.
- Require continuous maintenance (including substantial vegetation control).

Concrete Dams

Concrete dams include gravity, arch, buttress, masonry, and roller-compacted concrete (RCC) dams. Concrete dams:

- Are best suited for in-channel overflow structures, as well as narrow gorges.
- Are less susceptible to erosion.
- Rely on the weight of the structure and/or the strength of the bond or anchor at the abutments.
- Require solid impervious strata for an adequate foundation (extensive geotechnical investigation is critical).

Composite Dams

Combining elements of several dam types, composite dams typically utilize an earthen embankment for the non-overflow portion of the dam and concrete for overflow spillways and/or specialized structures (such as hydroelectric facilities, navigation locks, etc.).

Embankment dams with incidental concrete structures (such as conduits, chutes, aprons, retaining walls, slabs, footings, splash-pads, etc.) are not typically considered composite dams.

3.2 Factors Affecting the Selection of a Dam Type

While some proposed dam types may be determined according to a specific intended purpose or function, such as hydroelectric facilities and navigation locks, the majority of proposed dams will have their type determined by the following considerations.

Economic Considerations

The principal consideration in selecting a dam type is economics, into which all other considerations are ultimately translated. Some of the conditions that can result in extensive costs are:

- Site location and accessibility. For some sites, the long distance to adequate construction materials (soils for embankments, rock for embankments and/or riprap, concrete aggregate, etc.) and/or the lack of availability of labor and equipment can result in extensive costs.
- Need for erosion protection. For some sites, unfavorable topography and/or highly erodible soils can result in extensive costs.
- Need for care and diversion of water. For some sites, outlet works constraints and stream flow diversion operations during construction can result in extensive costs.
- Need for geotechnical investigation. For some sites, where the local subsurface conditions are unknown, or for some dams (including most concrete dams of considerable size and/or having a high-hazard classification), a comprehensive geotechnical investigation may be required, and can result in extensive costs.

Geological Considerations

Another consideration in selecting a dam type is the geological characteristics of the dam site.

- The composition of underlying or adjacent geological strata (rock, gravel, silt, sand, clay, etc.) at the site, which determines:
  - The site's ability to adequately support the foundation and anchor abutments of a proposed dam type. If the site does not possess this characteristic, you must assess the degree of improvement that will be needed to ensure sufficient support and anchoring of the foundation and abutments.
  - The site's ability to provide positive cutoff of water percolation beneath or through the foundation and abutments of a proposed dam type. If the site does not possess this characteristic, you must assess the degree of improvement that will be needed to ensure it will provide positive cutoff.
  - The site's general suitability. If the geological strata are not uniform, consisting of both rock and soft material(s), or if dissolvable material such as gypsum is present, you might need to consider and evaluate special improvements.
- The composition of the proposed reservoir bottom, which determines its ability to hold water. If the site does not possess adequate composition, you must assess the degree of improvement that will be needed to ensure it will have positive cutoff of water percolation. You may need to seal it with a layer of impermeable clay or synthetic liner (if practical) or use grout to seal the geological fracture systems.

Location, Topography, and Soil Considerations

Another consideration in selecting a dam type is the physical features of the site.

- The topography and soils characteristics of a site, which determine its suitability for a particular dam type. In Texas, the predominant dam type is an embankment dam, due in part to the topography and available soils across most of the central and eastern portions of the state, where the state is most heavily populated and the need for dams is most critical.
- The physical characteristics of the site that determine its ability to accommodate the proposed spillway size and type. .The spillway size and type are a function of the flood magnitude the dam will be required to pass (see Chapter 7 for a more detailed discussion of spillways). The two most common spillway types are:
  - Overflow spillways. Overflow spillways that are configured as structures atop earthen embankments should consider long-term settling or stability and the potential erosion of any underlying local soils utilized as fill.

- Bypass spillways. Bypass spillways can be used when there is available land acreage (without excessive or sharp bends in spillway alignment). Local features—such as a steep grade, or the presence of highly erodible soils—should be considered when determining the viability of a bypass spillway.

♦ The proximity of the proposed dam and spillways to property lines. The location of a dam, its maximum impoundment area, and its spillway(s) should all be given due consideration when determining the adequacy of a proposed location.

- The maximum reservoir elevations should not cause water to unlawfully back-up or be diverted onto adjacent property (without proper/legal agreements, grants, easements, etc.).
- Spillways should be designed to effectively contain and route discharges back into natural channels prior to crossing adjacent or downstream property lines, thereby preventing undue erosion to such property.
- Dams that have the potential to seep should include an adequate buffer to keep from negatively affecting adjacent or downstream property by creating saturated, boggy conditions; additionally, such dam designs should include seepage collection systems (toe drains, etc.) to effectively route seepage and prevent unstable conditions.

♦ The ecological impact of the proposed dam. The specific dam type may need to accommodate the demands of local wildlife; for example, it may need to provide transit means for migratory aquatic species through or around the dam, requiring the construction of specialized components (see Chapter 5 for a more detailed discussion of environmental issues)

♦ The chemical composition of impounded water and/or local soils. The specific dam type may need to account for, or combat, any detrimental reactivity between the local waters and soils and the materials that compose the dam; for example, the water may be highly acidic or caustic, or high concentration of sulfate ions in the soil may deteriorate concrete.

Chapter 4. Geotechnical Investigation

4.0 Introduction

As briefly discussed in Chapter 3, some potential dam sites may require an extensive geotechnical investigation to properly assess local conditions. This is likely to occur in cases where previous geotechnical documentation does not exist or many unknowns are yet to be determined. Other sites, however, may only require a few borings to verify local conditions that are generally known or well-documented.

Moreover, different types of proposed dams will call for different levels of detail from the geotechnical investigation. For instance, when designing the foundations and abutments for large- and intermediate-sized and high-hazard concrete dams or concrete appurtenant structures, an in-depth comprehensive geotechnical investigation is vital. The foundations and abutments for embankment dams, however, do not typically require geotechnical determinations that are as extensive as those required for concrete dams.

It should be noted here that roughly 70 percent of concrete dam failures have been attributed to geological factors, while nearly 40 percent of embankment dam failures have been attributed to foundation factors.

4.1 The Scope of the Geotechnical Investigation

The scope of a properly prepared geotechnical investigation should be based on the type of dam being proposed or the particular dam rehabilitation or modification being proposed, in conjunction with the geological complexity at the site.

The geotechnical investigation can sometimes extend beyond the design phase of dam improvements, as the construction phase may present unforeseen geological problems. When this occurs, construction is often delayed or halted to allow for additional geotechnical investigation(s) and changes to the original design.

Proposed Dams

For proposed dams, you should conduct an initial investigation to assess the general suitability of the site for a particular dam type and size.

Small Embankment Dams

For many small-sized embankment dams, determining the feasibility may only necessitate a review of commonly available data, including:

- maps (soil survey, topographic, geological, river survey, aerial photography, etc.)
- well and spring data
- geological surveys or investigations
- construction records of nearby structures (highway or railroad cuts, building excavations, soil pits, rock quarries, etc.)
- the presence of adequate soils—including the identification of dispersive soils, collapsible soils (slaking shales, gravelly materials, etc.), sands susceptible to liquefaction, etc.

Concrete Dams and Intermediate and Large Embankment Dams

For concrete dams and intermediate- and large-sized embankment dams, you will likely need a more extensive initial feasibility assessment, with subsurface exploration (numerous and comprehensive borings, fully representative of the site) to evaluate additional considerations, including:

- the depth to bedrock (if applicable)
- the bedrock profile along the axis of the proposed dam
- the classification and integrity of geological strata beneath the proposed dam and appurtenant structure (including

permeability of strata; fractures or seams in rock; and the presence of karstic limestone, gypsum, dispersive soils, etc.)
- the boundaries of soil deposition
- the limits of rock outcrops
- the limits and orientation of geological features such as joints, bedding, sheared zones, etc.
- the geological irregularities (including seismically active fault zones for proposed high- and significant-hazard dams)
- the potential for surface subsistence
- the slide potential of the reservoir rim
- the presence of artesian water conditions
- the potential for landslides at or around the proposed dam and reservoir site

Once the initial geotechnical investigation has been conducted and the feasibility of the proposed dam type and size has been determined, specific geotechnical design considerations can be analyzed for the proposed dam and appurtenances, and the necessity and scope of additional geotechnical investigation(s) can be determined.

If geological problems were identified during the initial investigation, further analyses must be conducted to determine their significance and whether or not they need to be investigated further, or if they can be neglected, removed, and/or treated to an acceptable safety standard with an engineered solution. It is also possible that lab testing may need to be conducted on structural, foundation, and/or fill materials that are found, excavated, or cored on-site, to properly assess the feasibility of a proposed dam design.

Dam Rehabilitation and Modification

For rehabilitation and/or modification projects, geotechnical investigations may or may not be required before the improvements can be designed. This depends on the specific improvements that are being proposed. Additionally, the necessary data may already be available from investigations conducted at the time the dam was originally built, or possibly during past improvements. If an initial geotechnical investigation is warranted, the applicable considerations listed above should be addressed.

Some dam rehabilitation or modification projects require specialized geotechnical investigations to be performed, where specific problems must be analyzed and/or particular considerations must be made for the proposed improvements. Sometimes it is necessary to utilize highly technical geophysical methods, or conduct hydraulic testing within boreholes, in order to properly assess or analyze problematic conditions. In such circumstances, we understand that many or all of the broader considerations listed above may not have any relevance, and that the geotechnical investigations will appropriately have a narrow scope.

4.2 Foundation Examination and Treatment

If geological issues or abnormalities are known to exist at a dam foundation location (valley floor and abutments), or should an initial geotechnical investigation uncover problematic concerns for a foundation, you must determine if an engineered remedy is feasible. If a foundation vulnerability cannot be eliminated or treated to an acceptable safety standard, either the proposed dam should not be built (at the specific location), or the existing dam should be removed or intentionally breached (if a downstream threat exists).

Additionally, many on-channel dams will encounter differing foundation conditions along the length of the dam. Coarse-grained foundation conditions may be present near the centerline of the watercourse, fine-grained foundation conditions along the mild slopes beyond, and rock foundation conditions along steep slopes extending farther to the locations of the dam abutments. Essentially, multiple conditions may be encountered at a potential dam site, presenting a unique set of circumstances and considerations.

Design-Phase Considerations for Foundation Treatments

Properly preparing the dam's foundation (including abutments) is of critical importance when designing a dam. During the design phase, you should make sure that you have not overlooked anything and that all the assumptions you have made up to that point are valid. Even the "unknowns" or "indeterminates" of the overall geological assessment need to be given proper consideration, and allowances should be made for the possibility that such unknown conditions could reveal problems during the construction phase, requiring changes to the foundation design.

Essentially, you need to evaluate worst-case scenarios—including alternate or additional treatments or solutions—during the design phase. If any of these problems surface during construction, they should have already received due consideration. This kind of prior planning can save you considerable time and money by allowing you to avoid lengthy delays during construction, and by ensuring that your initial foundation design can be adapted or altered in response to problems that arise.

Proper treatment of a dam foundation should ensure that it has both (1) sufficient control of seepage waters beneath and around the dam, and (2) adequate structural provisions to prevent its displacement or deformation, whether or not the reservoir is impounding water, and under both dry and saturated conditions.

Foundation Failure Modes

An analysis of potential failure modes may indicate a need to address foundation vulnerabilities, including:

- irregular deformation or settlement leading to cracking
- sliding along weak layers or discontinuities
- piping (internal erosion) of foundation materials
- washout, or erosion of the foundation due to overtopping
- undermining, or erosion of spillway(s)
- liquefaction or seismic deformation

Contributing Factors to Foundation Failures

During an examination of the foundation, some of the more common contributing factors to the foundation failure modes listed above may be revealed, including:

- thin shear zones
- weak, continuous joint sets
- weathered bedrock
- solution features in soluble rock (limestone, gypsum, marble)
- high shrink–swell potential (and associated cracking, infiltration, and possible instability or internal erosion)
- fault zones causing potential sliding
- volcanic rock (erratic capability and concealed or unknown paleo-features)

Common Foundation Problems and Their Treatments

The preferred solution for most foundation problems, usually incurred by the presence of deficient or unsatisfactory materials, is to remove the unwanted material and, if necessary, replace it with suitable material (fill, concrete, grout, etc.).

Sometimes, however, this solution is not cost-effective—sometimes removal of one layer of unsatisfactory material will expose additional or more deficient material. At other times, the solution is simply not feasible. In these cases, an engineered solution is necessary to treat the foundation so that the potential adverse affects are eliminated or minimized to an acceptable standard. Here are some common foundation problems and their respective treatments:

- *Permeable foundation.* This can be alluvial (sandy, silty, or gravelly) foundations or rock foundations with joints, fissures, crevices, permeable strata, fault planes, etc. This condition can result in seepage that causes erosion and/or excessive uplift pressure (both of which are structurally detrimental) or that can be considered an excessive loss from the reservoir (which is an economic or functionality concern, rather than a structural one).
  - Install a filtered drainage system (chimney drains; downstream blanket, finger, or toe drains; drainage holes and/or channels; pressure-relief wells; etc.) to provide a free flow of seepage and dissipation of water pressure without soil loss or disturbance to the foundation structure.
  - Install a means for positive cutoff of seepage. This can take the form of a cutoff trench or wall (to bedrock or impervious strata), a partial cutoff trench or wall (to the depth necessary to satisfactorily limit seepage), grouting of surficial cavities (voids, openings, or seams) in a rock foundation, a grout curtain, a concrete pile curtain, steel sheet piling (with interlocking sections), a slurry trench, etc.
  - Cover permeable foundation material with an impervious material. Depending on the geology of the site, this may include lining the entire reservoir bottom as well.
- *Saturated foundation.* A foundation of this kind can be susceptible to sliding due to low shear strengths associated with saturated fine-grained soils as well as sands containing enough fines to be considered impermeable.
  - Install a drainage system to allow the foundation to be adequately drained during construction. This will increase the shear strength of the foundation (once under full-load conditions of the completed dam).
  - Increase the width of the dam, such as by making the slopes of an embankment dam flatter. This will decrease the normal shear stress along the length of the foundation's potentially critical slide plane.
- *Dry, low-density foundation.* Depending on the compression characteristics of its soils (which are often high-strength soils in their natural state), this kind of foundation can result in significant settlement (including differential settlement) when kept saturated by the presence of a reservoir.
  - If the dry, low-density foundation is thick enough or has a permeable layer beneath it, post-construction settlement can be avoided by allowing the foundation soils to be adequately compressed by pre-wetting them during construction.
- *Highly plastic clay (expansive soil) foundation.* This can result in excessive shrinking and swelling, which may cause damage to the dam's structures and appurtenances.
  - Depending on the severity of the shrink–swell potential, the plastic foundation soil may possibly be treated with hydrated lime (the specific depth of the treatment and the percentage of lime is determined by laboratory testing—for example, the Eades and Grim test). The resultant soil-lime mixture tends to be more granular in texture, which increases its strength and decreases its shrink–swell potential.
  - The design of the dam's structures and appurtenances need to account for the condition, so that potential adverse effects are avoided or controlled.
- *Steep bedrock profile and/or highly compressible foundation deposits.* This can result in differential settlement, which in turn can induce arching and hydraulic fracturing.
  - The foundation area should be excavated so that the sharp grades are eliminated. This will prevent or limit disproportionate stress concentrations and differential settlement.
- *Weak foundation.* This condition can be caused by the presence of cohesionless or dispersive soils, slaking shales, gravelly materials, or clean, saturated sand of very low density. It can result in significant deformation or even shear failure.

- Highly dispersive soils should be avoided altogether.
- If cohesionless or dispersive soils cannot be effectively removed, you have to make provisions for adequate drainage (due to the high susceptibility of erosive piping conditions), such as a downstream engineered filter (an upstream filter may also be necessary for rapid drawdown conditions).

  Alternatively, the upper zone of a dispersive soil foundation can be excavated and treated in bulk (not "in situ") with lime (salt, gypsum, alum, or not more than 8 percent fly-ash have also been successfully used), to help with stabilization and reduce the potential for erosion.

  Strict quality control should be adhered to during the placement and compaction of the treated soil (between 1 and 2 percent moisture content with thinner lifts; compacted with pneumatic tampers; increased frequencies of moisture and density tests), and the material should not be left exposed and allowed to shrink or crack during construction.

  Lastly, dispersive soils should not be used immediately adjacent to structures or rock interfaces (you have to transition with engineered filters).
- In the case of bedrock with slaking shales or other weathered or loose materials, you may have to first remove the top several feet of (disintegrating) bedrock.
- Clean, saturated sand of very low density may behave like a liquid (liquefaction) when subjected to a sudden shock or tremor, and this can lead to severe deformation or failure. Dams should not be built near active faults (earthquake prone areas), unless the deficient soils can be removed.
- Install a filtered drainage system (chimney drains; downstream blanket, finger, or toe drains; drainage holes and/or channels; pressure-relief wells; etc.) to provide a free flow of seepage and dissipation of water pressure without soil loss or disturbance to the foundation structure.

Should all of the above foundation treatments be deemed unnecessary for a proposed embankment dam's foundation, as much as possible of the foundation's overburden material should be removed. *If overburden material cannot be excavated all the way down to bedrock, at a minimum a cutoff trench needs to be excavated along the long axis of the dam's foundation.* The impervious material within the core zones of embankment dams should include the limits of the cutoff trench.

4.3 The Analysis of Available Materials

A thorough geotechnical investigation should include an analysis of the materials found on-site, including specific determinations regarding the available quantities and adequate quality for incorporation into the proposed dam construction project. All qualitative analyses should adhere to accepted standardized testing methods (ASTM, for example). Additionally, the necessary testing should be conducted to verify that the borrow material meets the standards required by the proposed dam improvements. This includes exhaustive efforts to identify cohesionless or dispersive soils, highly plastic soils, or any other potentially problematic material.

4.4 Geotechnical Report Requirements

The final signed and sealed geotechnical report that you submit with plans and specifications for review and approval by the Texas Dam Safety Program must address all of the geotechnical considerations listed above, and include sufficient documentation and/or calculations regarding the *applicable provisions and conclusions* indicated below. The level of detail in the geotechnical report must be commensurate with the dam improvement project it is addressing, with a more detailed and conservative examination being warranted for intermediate- and large-sized dams.

Test Borings (Test Holes, Test Pits, Drill Holes, etc.)

- *Plan-view map.* This map should delineate the dam and reservoir site with test boring locations superimposed. It must be:
  - representative of the site
  - comprehensive with respect to site location(s) and depth(s), and include the entire footprint of the dam, the spillway(s), all appurtenant structures, and any potential borrow area(s)
- *Profile-view map.* This map should show a cross-section of the dam along the centerline with test boring locations and a profile of the foundation.
- *Test boring depths.* Test boring depths should be indicated. Test borings must either:
  - penetrate into competent bedrock (deep enough to demonstrate that the rock is not an isolated layer or lens, and deep enough to confirm the assumed parameters of a subsequent stability analysis), or
  - penetrate to a depth of 1.5 times the height of the dam (whichever is less)
- *Test boring logs.* These logs must indicate:
  - the field soils classifications
  - the water content (percentage) of the soils encountered
  - the density of the soils encountered
  - the full gradation of the soils encountered, including percent fines (passing a No. 200 sieve)
  - the Atterberg limits (liquid limit, plastic limit, plasticity index) of the soils encountered
  - the water level in drilled test borings
  - the depth to bedrock
  - in-situ permeability tests
  - standard penetration tests
- *Summary of boring findings.* This summary shall include the types of rocks present, the weathered condition of rock, fracture systems in rock, and surface water seepage through rocks.

Recommendations

The geotechnical report must include specific detailed recommendations for the proposed dam improvements, including any of the following considerations that may be applicable:

- *Foundation design,* including:
  - the foundation treatments required (with multiple options, if viable)
  - the necessity of concrete footings, concrete piers, drilled shafts, rock anchors, etc., to achieve an acceptable factor(s) of safety for structural stability (as outlined below, in the “Stability Analyses” section)
  - the acceptable construction methods and the criteria for recommended foundation treatment(s)
- *Core requirements* (for a proposed embankment dam), including:
  - the configuration or dimensions
  - the soil permeability requirements
  - the core trench requirements
- *Seepage control requirements,* including:
  - the location, configuration, and dimensions for any filtered drainage system (drainage diaphragms around conduits; chimney, blanket, finger, or toe drains; drainage holes and/or channels; pressure-relief wells; etc.)
  - the configuration, dimensions, and construction techniques for any recommended cutoff trench or wall (to bedrock or impervious strata), partial cutoff trench or wall (to the depth necessary to satisfactorily limit seepage), grouting of surficial cavities (voids, openings, or seams) in rock foundations, grout curtains, concrete pile curtains, steel sheet piling (with interlocking sections), slurry trenches, etc.
  - the omission of anti-seep collars as a viable method of seepage control (for proposed embankment dams)

- *Embankment design requirements* (for proposed embankment dams and/or training levees or berms), including:
  - the configuration for each zone and the requirements for soil types and parameters, if a zoned embankment is recommended
  - minimum slopes
  - minimum crest width and camber
  - expected settlement (required over-design of embankment height)
  - minimum freeboard requirements (to prevent overtopping by wave action) for large-sized dams
  - if cohesionless materials will be placed in the embankment, a minimum density shall be specified (not less than 95 percent of maximum density, as per ASTM D4253)
- *Spillway design,* including:
  - the adequacy of the site to accommodate the proposed spillway (type and location)
  - foundation loads or bearing capacities at the inlet/outlet works (and the resultant buoyancy forces when the inlet/outlet works are empty and the reservoir is full)
  - lateral earth loads at the inlet/outlet works when structures are embedded in the embankment slopes (due to differential heights)
  - conduit bedding requirements
  - requirements to avoid differential settlement along conduits (concrete cradles, concrete encasements, concrete piers, drilled shafts, etc.)
  - the potential for adverse reactivity (acidic, caustic, etc.) between the conduit material and soils and/or water (from the reservoir and/or groundwater)
  - channel and side slopes for open earthen channels
- *Fill requirements and techniques for excavation, placement, and compaction,* including:
  - the necessity and requirements for both heavy and hand-operated compaction equipment (as well as the maximum lift thickness for each)
  - moisture and density requirements
  - soil-dispersion requirements
  - the necessity and requirements for benched or horizontal placement and compaction (including the overbuild and subsequent excavation to achieve the desired slope grade)
- *Erosion-protection requirements* for the embankment crest, slopes, groins, earthen spillways, etc.
- *Groundwater control considerations and recommendations.*
- *Instrumentation recommendations* (for both the construction period and permanent monitoring) for devices that will monitor water levels, water and earth pressures, deformations, seepage, etc., as well as a determinations of critical thresholds for each instrument that should alert the dam owner or operator of a specific condition.
- *Sequence of construction recommendations.*
- *Post-construction monitoring.* If the geotechnical report includes recommendations (including both general requirements and specific design recommendations) that were not accounted for in or incorporated into the dam's final design, the engineer who is submitting the construction plans, specifications, and geotechnical report must provide a written explanation addressing these issues, with sufficient justification for any omissions or alternative designs.

Stability Analyses

For proposed small, low-hazard embankment dams with upstream and downstream slopes flatter than or equal to 3 Horizontal to 1 Vertical, a stability analysis is not required. For all other proposed dams (or applicable dam modifications or additions), stability analyses must be conducted to demonstrate that the specified factors of safety have been met for the following conditions.

In these guidelines, we have not specified particular procedures for conducting stability analyses. Regardless, you should make certain that your procedures have the appropriate parameters and assumptions, and that your analyses are comprehensive, and representative of the various factors (uplift forces, tail water at spillways, drain efficiency, etc.) that are present at your site.

Embankment Dams

- *Stability against sliding* (of foundation)
  - acceptable factor of safety = 1.5
- *Bearing capacity* (of foundation) *vs. overburden stress* (of dam and impoundment)
  - acceptable factor of safety = 3.0
- *Side slope stability* (embankment dams or training berms)
  - acceptable factor of safety for upstream slope (under long-term, steady-state conditions) = 1.5
  - acceptable factor of safety for upstream slope (during rapid drawdown) = 1.2
  - acceptable factor of safety for downstream slope (under long-term, steady-state conditions) = 1.5
  - acceptable factor of safety for upstream and downstream slopes during construction = 1.25
- *Stability against sliding and overturning of other structures* (retaining walls and concrete overflow structures including weirs, chutes, etc.)
  - acceptable factor of safety = 1.5

Concrete Dams

- *Allowable bearing capacity* (of foundation)
  - must not exceed 1/3 of foundation's ultimate bearing capacity
  - must account for eccentric and inclined loadings, as well as other appropriate factors
- *Allowable base pressure* (upon foundation)
  - maximum computed base pressure ≤ allowable bearing capacity for both usual loading conditions (normal pool) and unusual loading conditions (design flood)
  - maximum computed base pressure ≤ 1.33 times the allowable bearing capacity for extreme loading conditions (PMF event)
- *Stability against sliding* (of foundation)
  - acceptable factor of safety for usual loading conditions (normal pool) = 2.0
  - acceptable factor of safety for unusual loading conditions (design flood) = 1.7
  - acceptable factor of safety for extreme loading conditions (PMF event) = 1.3
- *Stability against overturning.* The resultant location of all lateral, vertical, and uplift forces (and related moments) acting about the downstream toe must be:
  - along the base between 1/3 and 2/3 of the base length, for usual loading conditions (normal pool)
  - along the base between 1/4 and 3/4 of the base length, for unusual loading conditions (design flood)
  - within the length of the base, for extreme loading conditions (PMF event)
- *Stability against sliding and overturning of other structures* (retaining walls and concrete overflow structures including weirs, chutes, etc.)
  - acceptable factor of safety = 1.5

Existing Dams

The stability of *existing structures* is sometimes reevaluated due to project modifications, changes in site conditions, or improved knowledge of site data. Since modifications to improve stability are often expensive, each structure should undergo a systematic, phased evaluation process to determine whether remediation is necessary.

To avoid unnecessary modifications, all types of resisting effects, including vertical friction, side friction, or three-dimensional effects, should be considered. It may not be necessary to modify an existing structure that does not satisfy the requirements for new structures, especially when there are no indications of any stability problems.

What is considered an acceptable factor of safety should reflect the differences between new slopes, where stability must be forecast, and *existing slopes,* where information regarding past slope performance is available.

A history free of indication of slope movement provides firm evidence that a slope has been stable under the conditions it has experienced to date. Conversely, signs of significant movement indicate marginally stable or unstable conditions.

In either case, the degree of uncertainty regarding shear strength and piezometric levels can be reduced through back analysis. Therefore, factor-of-safety values that are lower than those required for new slopes can often be justified for existing slopes.

For existing dams, the TCEQ Dam Safety Program will consider factors of safety that are lower than those for new slopes and structures if it is adequately justified through analysis.

Dam Anchors

When *post-tensioned dam anchors* (rock anchors) are proposed for a dam improvement project to achieve required factors of safety for stability, you should adhere to all current construction practices and applications regarding their use, design, and associated testing in accordance with the Post-Tensioning Institute's *Post-Tensioning Manual,* 6th Edition (or most current version).

Seismic Stability Analyses

For dam improvement projects of high- and significant-hazard dams near seismically active fault zones, seismic stability analyses must be conducted. A seismically active fault is one that is recognized by and included in the United States Geological Survey's Quaternary Fault and Fold Database. A seismic stability analysis must include:

- a summary of the faults and fault history in the immediate vicinity and regionally that may affect the dam, including the slide potential around the reservoir's perimeter under earthquake conditions
- overall stability requirements
- a justification and tabulation of all the model input parameters used in analysis (including the rationalization for the selection of an appropriate seismic event)
- a foundation liquefaction potential analysis
- the relative site condition(s) necessitating either dynamic or pseudo-static analysis
  - pseudo-static load coefficient ≥ 0.05
  - acceptable factor of safety ≥ 1.0

Seepage Analysis

For proposed high- and significant-hazard dams that will permanently impound water, a seepage analysis must be performed to demonstrate adequate control of seepage, including:

- a justification and tabulation of all the model input parameters used in analysis
- flow nets of appropriate size and scale
- the acceptable exit seepage gradient

Laboratory Testing and Analyses

Any laboratory tests or analyses that you conduct for the proposed dam improvements must be documented in the geotechnical report, including any of the following for foundation (soils and/or rock) and borrow soils:

- classification
- gradation (particle-size distribution)
- Atterberg limits (liquid limit, plastic limit, plasticity index)
- moisture content
- dry unit weight
- permeability and infiltration
- shear strength (and failure strain)
- unconfined compression
- consolidation (volume change characteristics)
- liquefaction potential
- presence of dispersive soils (crumb tests)
- chemical tests (pH, specific conductance, chloride content, sulfate content, sulfide content, calculation of resistivity, etc.)

4.5 Geotechnical Considerations during Construction

As noted in Section 4.2, geotechnical considerations extend beyond the design phase of a dam improvement project and into the construction phase. Until a contractor is actually “breaking ground,” geotechnical considerations and their respective recommendations are based on data from test borings and test pits, or on other data available at the time. Actual conditions at a proposed dam improvements site may differ significantly from the assumed conditions, which are based on the best available data gathered during the design phase.

Ultimately, when a concrete dam (other than a small, low-hazard structure) is proposed, or when a construction project includes significant foundation treatment(s), a geotechnical professional needs to be involved during the initial phase of construction to verify site conditions and confirm the suitability of the geotechnical design recommendations previously established.

Additionally, throughout the life of the construction project, if a project engineer (or inspectors under the engineer’s supervision) should witness or be informed of something geological in nature that is unusual, unexpected, or suspect, the situation should be adequately documented (photos, samples, etc.) and a geotechnical professional should be consulted to establish its significance and determine whether added precautions and/or possible design changes are required.

For additional details regarding geotechnical matters during construction (changes to proposed material parameters and/or requirements, submission of density test results, retesting of failed densities, etc.), please see Chapter 9, “Project Management and Quality Assurance.”

Chapter 5. Determining Environmental Impact

5.0 Introduction

As is the case with anything made by people, due consideration should always be given to the effects, direct or indirect, that a dam will impose upon the surrounding environment. Though the necessity of a proposed dam may be seen as critical for the welfare of a human population (be it for water supply, flood control, power generation, irrigation, navigation, etc.), it must also be understood that a healthy, sustainable environment is, at the least, just as essential.

This chapter of these guidelines is included as a reference only. The TCEQ Dam Safety Program's review and approval of construction plans and specifications will not be contingent upon the considerations and recommendations in this chapter. Nevertheless, all the pertinent environmental issues should be addressed through the appropriate permitting process, and engineered designs should be consistent with any related requirements. Also, standard engineering principles and dam safety matters should be considered when negotiating permitting issues.

5.1 Preliminary-Phase Planning

Due to the complexity of the environment and its individual ecosystems, it is often a difficult and complicated process to determine in advance the overall impact that a man-made structure, such as a dam, will have upon nature's balance and its ability to sustain itself. Nevertheless, engineers have an undeniable responsibility to ensure that proper consideration is given to the overall environmental impact that a proposed dam may have. If hasty decisions are made, or indirect correlations not given initial due consideration, then sometimes an invaluable, irreplaceable resource may be compromised or lost forever.

In addition, a determination of the overall environmental impact of a proposed dam (or hydraulic modification of an existing dam) may require an assessment of the effects on existing cultural resources, including changes to the floodplain limits established by the Federal Emergency Management Agency (FEMA).

Plant and Wildlife Considerations

Initially, a proposed dam site should be assessed with respect to local plants and wildlife (both land and aquatic), including both permanent and migratory species. Furthermore, if the surrounding environment (including downstream) supports any threatened or endangered species, they need to be identified early on in the preliminary-phase planning, and it needs to be determined whether the dam can exist without affecting these species' ability to survive.

Often, it is an indirect link or association that gets overlooked when speculating on the environmental impact. This is why it is so important to have the benefit of a knowledgeable professional who understands ecosystems and who is familiar with the local flora and fauna of your potential dam site.

Without a clear understanding of the chain reactions (both short- and long-term) that creating a dam and reservoir can engender in an ecosystem, the potential for detrimental impact can easily be overlooked. For instance, it has been documented that the construction of a dam and reservoir at particular sites has resulted in a substantial increase in certain microbial waterborne diseases.

When environmental issues are clearly present at a particular site for a proposed dam, consideration should be given to any other potential dam sites and whether or not these issues can be avoided, or their impact lessened, by changing the proposed dam's location.

In general, a proposed dam can have a detrimental impact on plant and wildlife by effectively reducing habitat and/or food supply, or blocking the means of transit for migratory species. It may be the case that the dam and its surrounding environment can coexist with either no impact or an acceptable degree of impact, but only if certain provisions are accounted for in the dam design, construction practices and procedures, and/or operational requirements.

Cultural-Resource Considerations

During the preliminary-phase planning, an assessment of the potential impact upon existing cultural resources must be given consideration. If a proposed dam, or hydraulic modification of an existing dam, will (directly or indirectly) affect existing cultural resources, these issues will need to be resolved prior to consideration of final design. This may include an analysis of existing data, records, or archives to identify any historical or archaeological sites that could be threatened.

Potential impact to existing cultural resources includes changes to existing FEMA floodplain limits, and engineers should identify and determine the extent of such impacts as early in the planning phase as is feasible. According to FEMA guidelines, existing Flood Hazard Maps have to be revised when related construction projects will alter the FEMA floodplain limits.

Therefore, engineers may need to prepare a corresponding Conditional Letter of Map Revision (CLOMR) and other documents to satisfy FEMA requirements, and these should be completed prior to considering the final design and prior to submitting the proposed construction project to the TCEQ Dam Safety Program for review and approval.

Other Environmental Considerations

Assessing a proposed dam's environmental impact goes beyond immediate ecosystem considerations. Depending on the characteristics of a given site, as well as the proposed size of the project, a dam and the reservoir that it impounds can cause or increase the occurrence of landslides and mudslides along or near the reservoir by creating long-term saturated conditions (which can be compounded by continuously fluctuating water levels).

Catastrophic loss of life can result from either the landslide or mudslide event itself, or from damaging wave-induced events (including overtopping of the dam) if the loss of the land mass is sudden and of significant size.

Although it does not commonly occur, the construction of a dam can also add to a reservoir's hydrostatic load (including periodic fluctuations in a reservoir's water level) affecting the mechanical state of a fault line. This may cause fault activity to initiate or induce potentially deadly earthquakes, as well as increase their frequency and intensity. Depending on the characteristics of the dam itself, more frequent than normal or more severe earthquake activity could also result in damage to the dam, or possibly the dam's failure.

5.2 Dam Design Considerations

If it is deemed that a proposed dam's design will need to account for specific environmental considerations, the extent and configuration of such design requirements or specialized dam components should be based on past-proven methods that are well-documented.

Federal and state wildlife agencies can provide additional expertise and valuable guidance with regard to individual plant and wildlife considerations, and they should be consulted on the design of the dam, including the ability of any specialized components to satisfactorily fulfill their objective.

For instance, provisions for specific fish populations may necessitate the dam design to provide a minimum specified reservoir depth (with associated temperature variations), as well as related spillway withdrawal elevations and locations for operational releases downstream, which would all be necessary to sustain particular fish populations yearlong, including reproductive activity.

Additionally, the dam design might require the use of fish screens to prevent fish from entering spillway conduits or other hydraulic conveyance structures, and/or a fish ladder to provide a means of transit for migratory aquatic species through or around the dam. It should be noted that the use of fish screens across or within open-channel emergency spillways is not recommended, unless proper hydrologic and hydraulic analyses have been conducted that model the dam's ability to pass its requisite design storm with a completely blocked fish screen.

Methods to address some of the more common environmental considerations during the proposed dam's design phase may include:

- mitigation for lost habitat or feeding areas:
  - creation of comparable habitat nearby
  - planting vegetation beneficial to nesting
- provisions for fish habitat, feeding, and nesting:
  - preserving trees and/or anchoring down piles of brush within the limits of the proposed reservoir
  - leaving dense grass and weeds at the proposed reservoir edge

5.3 Construction Practices and Procedures

Although there are specific measures that construction activities must adhere to by law, including Texas General Construction Permits, Storm Water Pollution Prevention Plans (SWP3), etc., there are additional practices and procedures that construction contractors should employ to properly protect the environment, especially when individual sites warrant their inclusion. Some of these precautions may include:

- Erosion control within the site (and not just limiting what is transported off-site):
  - additional silt fencing to protect water bodies
  - upstream siltation ponds (when conditions warrant, such as excessively turbid water)
  - preventing unnecessary traffic by restricting access within the site to areas requiring entry
- Dust control to prevent excessive air pollution (watering unprotected access roads, dry areas, etc.)
- Properly protecting areas for refueling, maintenance, and cleaning of equipment (including containment berms, etc.)
- Controlling or minimizing withdrawals of water for construction activities (especially over a short duration), which would affect wildlife within flowing creeks and streams
- Controlling or minimizing the burning of timber or brush, to prevent excessive air pollution (if necessary, you should utilize a mulching operation)
- Staking off and protecting any trees, shrubs, or grassland areas to be preserved
- Scheduling construction so as to minimize its impact on wildlife (during periods of mating, nesting, migration, etc.)
- Leaving the site free of trash and debris

5.4 Operational Requirements

While some operational requirements might be necessary to adequately sustain plant and wildlife in the reservoir, as well as downstream of the dam, other environmental considerations are related to the routine operation and maintenance of a dam. You need to accord both instances proper planning and execution to avoid negatively affecting the environment. The environmental provisions may include:

- periodic downstream discharges during periods of low flow
- avoiding (or limiting) significant downstream discharges when seasonal migratory routes would be affected downstream
- periodic lowering of the reservoir to control vegetation or repair upstream slopes
- routine inspections of specialized dam components (fish ladders, screens, etc.) to make sure they are working correctly and not in need of repair
- proper selection of any pesticides or herbicides (needed for dam maintenance) to ensure that the application or the subsequent runoff will not pollute local and downstream plant and wildlife

Additional operational requirements may be necessary for a specific dam type, component, appurtenance, and/or site condition. Please consult the agency's *Guidelines for Operation and Maintenance of Dams in Texas* regarding these additional operational requirements.

Chapter 6. The Determination and Design of Dam Components

6.0 Introduction

Once a proposed dam's type (embankment, concrete, or composite) has been determined (see Chapter 3), and geotechnical considerations have established an adequate foundation design (see Section 4.2, "Foundation Examination and Treatment"), the necessary dam components can then be considered.

Certain dam constituents are considered part of the foundation design (the foundation limits include the valley floor and the abutments) and are not covered under this chapter. These constituents include cutoff trenches, grout curtains, slurry trenches, concrete footings, concrete toe walls, concrete aprons, concrete piers, drilled shafts, and rock anchors. These constituents of foundation design are also discussed in Section 4.2, "Foundation Examination and Treatment."

Finally, this chapter discusses the use and design of engineered soil filters and drains; however, it does not cover spillways or other hydraulic conveyance conduits, gates, structures, etc. Please see Chapter 7, "The Determination and Design of Dam Appurtenances," for related guidance.

It is noted that these guidelines do not specify particular design criteria or acceptable codes for structural concrete and steel in dams. Specific guidance and considerations related to the design of concrete and steel structures will be addressed in another publication.

6.1 The Basic Components of Embankment Dams

The most common type of dam in Texas is the embankment dam, which is usually the most economical choice, utilizing locally available materials. Although its requirements for an adequate foundation are not as extensive or critical as for a concrete dam, an embankment dam is nonetheless more susceptible to erosion and requires continuous maintenance, including substantial vegetation control.

Although specific design considerations for determining and sizing the components of a proposed embankment dam are discussed below, practical considerations will often dictate a more conservative approach to the design. Such provisions should be established prior to conducting detailed analyses for sizing other related components, as this could possibly help in avoiding unnecessary costs due to over-design.

For example, functional provisions will often require an embankment dam's upstream and downstream slope to be flatter than empirical methods would otherwise mandate for adequate stability. One common instance is establishing a slope no steeper than 3 Horizontal to 1 Vertical (3H:1V) for slopes that will require routine maintenance, such as mowing. Should other accessibility requirements apply, even flatter slopes than 3H:1V would be necessary. Regardless, the design requirements for an impervious core zone might be considerably less conservative (and less costly) by factoring in a predetermined (much flatter) downstream slope.

Homogeneous Embankment Dams

When sufficient quantities of suitable material exist on-site or are available at a local borrow source, a homogeneous embankment dam can be designed. However, the conditions encountered at most sites dictate that the dam be designed with zones of differing material.

As the name implies, a homogeneous embankment dam is composed entirely of one type of material (excluding surface protection such as topsoil and associated vegetative cover, riprap, etc.). If the dam is intended to permanently impound water (not a detention dam, for instance), the material must be adequately impermeable to prevent substantial leakage from the reservoir.

Even if significant seepage through the embankment can be tolerated from a functional standpoint (reservoir losses deemed acceptable), the material must be impervious enough to maintain a safe phreatic water surface elevation across the embankment width, where the slopes will not slough under saturated conditions and where a rapid drawdown of the reservoir will not result in a slope failure.

For acceptable safety factors regarding such conditions, please see “Stability Analyses” in Section 4.4, “Geotechnical Report Requirements.”

If the calculated safety factors for a given homogeneous embankment design are close to, but outside of, the acceptable limits, it may still be possible to utilize a homogeneous embankment design by incorporating one or more of the following changes or additions into the dam design to increase the factor(s) of safety to within acceptable limits:

- *Filtered drainage system.* A properly designed filtered drainage system (blanket, finger, toe, etc.) may adequately reduce the phreatic water surface elevation across the embankment section (see the “Soil Filter and Drainage System Designs” subsection, below, for specific design criteria).
- *Flatten slopes.* Flattening the upstream slope provides additional stability for rapid drawdown conditions; flattening the downstream slope provides additional stability by reducing the height at which the phreatic water surface elevation emerges on the embankment’s downstream face.
- *Stability berm.* A properly designed stability berm extends the length of the downstream slope (either along the entire downstream toe or where local stability issues may be present). A stability berm works on the same principle as flattening the downstream slope to improve safety factors.

Zoned Embankment Dams

The majority of proposed embankment dam sites do not have sufficient quantities of select impervious material to enable the construction of a homogeneous embankment dam. As a result, site conditions typically dictate a zoned embankment dam design as the most effective and economical use of available materials to safely manage seepage through the dam and provide adequate structural stability.

The importance of an adequate seepage control design cannot be emphasized enough, as history has shown that approximately 50 percent of all embankment dam failures are seepage-related failures that occurred under normal operating conditions.

Core Zone

A zoned embankment dam typically includes (at a minimum) a “core” zone of impervious material with a cross-sectional thickness sufficient to adequately control seepage. The core zone is most often centrally located beneath the embankment crest; however, the core zone may sometimes be offset or located on the upstream side, and it may be vertical or inclined. Additionally, the core zone may consist of earth (typically a clay material with a coefficient of permeability, as defined by Darcy’s Law, of 1×10^{-7} m/s or less), concrete, bituminous concrete, or a slurry trench.

The dimensions established for a core zone (required cross-sectional thickness) are a function of the dam’s design and overall permeability (including the presence of soil filters). The various soils, or combinations thereof, that potentially compose a zoned dam embankment can have significant differences in grain size, gradation, and composition, with a potentially wide range of performance attributes under various loading and saturation conditions.

Ultimately, the core zone should be adequately sized to satisfactorily limit seepage through the dam while maintaining the appropriate structural safety factors outlined in "Stability Analyses," in Section 4.4, "Geotechnical Report Requirements."

As a general guideline for *impervious foundations* and *shallow pervious foundations* with a positive cutoff trench, the cross-sectional thickness of a clay core zone should not be less than the remaining height of the embankment above it for any given elevation. For *deep pervious foundations* without a positive cutoff trench (including deep pervious foundations covered by an impervious foundation with a thickness of 3 feet or less), the cross-sectional thickness of a clay core zone should be at least 2.5 times the height of the dam at its base, or in other words, at the top of the foundation.

A centrally configured core zone should extend vertically above the reservoir's normal pool elevation to a distance determined appropriate by the engineer, while limiting the upper extent of the core zone to within several feet below the embankment crest.

Again, the above guidelines are general rules-of-thumb, intended to be conservative, and detailed engineering analyses can justify less stringent requirements. Lastly, a properly designed core zone (and its impervious material) should incorporate the limits of the dam foundation's key trench.

Upstream Impervious Blankets Tied to Core Zones

Although not necessarily considered part of the core zone, a blanket of impervious material is sometimes placed atop a pervious foundation (including abutments), located upstream of and tying into the impervious core zone, in an effort to increase the percolation path through the pervious foundation while providing free flow of seepage and dissipation of water pressure without soil loss or disturbance to the foundation structure.

Soil Filters and Drains and Core Zones

Even though the core zone is theoretically "impervious," it should not be (and often is not capable of being) the sole component of adequate seepage control. Accordingly, a properly designed zoned embankment dam should also have the necessary engineered soil filters and any associated drainage systems incorporated into its design to safely and effectively route seepage downstream of the core zone (without internal erosion occurring). Some of the more common filtered drainage systems found in zoned embankment dams include types such as chimney, blanket, finger, and toe.

For additional information regarding these specific types of filtered drainage systems and design considerations for each, please consult the following subsection, "Soil Filter and Drainage System Designs."

Shell Zones

A zoned embankment dam is typically equipped with pervious shell zones, most often consisting of random fill (sand, gravel, cobbles, rock, or a combination), located upstream and downstream of the core zone.

While the impervious core zone is the primary means of controlling seepage through the dam, the downstream shell zone also assists by effectively and safely routing seepage that makes its way through the core zone, maintaining a flat enough slope to adequately lower the height at which the phreatic water surface elevation emerges on the embankment's downstream face and ensuring the dam's structural stability.

On the other hand, the upstream shell zone acts to provide stability against a rapid drawdown condition. Although not a rigid guideline due to variation in their composition (including presence of soil filters), downstream shell zones should generally have a cross-sectional thickness roughly three times the height of the dam.

Rockfill and Impermeable "Zones"
Although not typically categorized as a zoned embankment dam, rockfill dams (including dams consisting of rock gabions) are considered such for the purposes of these guidelines.

Ultimately, if the dam is to permanently impound water and the embankment material is rockfill, the dam must be equipped with an impermeable zone—whether it is an internal core zone or a synthetic membrane, a clay or bentonite layer, a concrete cover, etc.—along the face of the upstream slope. When synthetic membranes are used to line a rockfill dam (with a hazard classification other than "low"), leak detection systems with mechanical backup floats should be included in the dam design.

Permeable Downstream Toe "Zones"
In rare instances, a zoned embankment dam may be designed without a core zone and may only differ from a homogeneous embankment dam by virtue of a permeable zone (such as a rockfill zone) along the embankment's downstream toe. Similar to a toe drain, the permeable zone must be capable of reducing the phreatic water surface elevation to an acceptable level where the structure is stable and meets all accepted factors of safety.

When a zoned embankment dam is designed with this configuration, it is also necessary to install an engineered filter between the two zones in order to prevent the migration of fines from the main or upstream portion of the embankment.

Soil Filter and Drainage System Designs

A properly engineered soil filter is a specially designed permeable "zone" that will prevent a piping condition from forming within a dam's embankment or foundation, where internal erosion from seepage through the dam results in a loss of material and eventually an unstable structure, if left unchecked.

Additionally, soil filters and associated drainage systems may be necessary to lower the phreatic water surface elevation across the embankment section in order to meet stability criteria. The requirements for gradation and permeability of a properly engineered soil filter design should be such as to ensure that:

- surrounding soil particles from the embankment or the foundation will not enter the filter and clog it
- the filter has sufficient capacity to handle the total seepage flow rate (required width of filter) and/or to satisfactorily lower the phreatic surface
- the filter has the necessary permeability to sufficiently lower hydrostatic pressure from seepage

The subsequent guidelines are generally-accepted design criteria that should be met to provide adequate stability within the filter, as well as the required permeability between the base material (adjacent to the soil filter) and the soil filter material (sand, gravel, or crushed rock). In the following criteria, the term D_X is used to denote the percent ("X") of total soil particles that are smaller than the particle size diameter ("D"):

- $5 \leq \dfrac{D_{15}\ of\ Filter}{D_{15}\ of\ Base} \leq 40$

  (provided that the filter does not contain more than 5 percent of material finer than 0.074 millimeters in diameter [passing the No. 200 sieve])
- $\dfrac{D_{15}\ of\ Filter}{D_{85}\ of\ Base} \leq 5$
- $\dfrac{D_{85}\ of\ Filter}{Max\ Opening\ of\ Pipe\ Drain} \geq 2$
- Grain size curves for the base material and filter material should be roughly parallel.
- The filter should not include a particle size exceeding 3-inches in diameter.
- When perforated or slotted piping is used within the filter to collect and route seepage, the perforations or slots should run only

along the bottom half of the pipe, with openings that are smaller than D_{50} of the soil filter material (sand, gravel, or crushed rock), and the pipe should not be wrapped with filter cloth, as it will tend to clog at the perforations or slots.

With regard to compaction requirements, a properly constructed soil filter should be sufficiently compacted to prevent consolidation from occurring. Conversely, it should not be over-compacted, where it unduly restricts flow through the filter. The construction project's technical specifications should contain detailed provisions to ensure that the soil filter is installed correctly with the required degree of compaction to prevent consolidation, while still preserving the drainage capacity of the filter's design.

Over-compaction of soil filters does not allow them to function as designed, as it reduces their permeability and increases their potential to crack. For this reason, it is sometimes better to install or construct vertically aligned soil filters by first placing and compacting embankment fill and then trenching the limits of the proposed filter. For large dams or significantly wide soil filters, however, the filter material should be placed in lifts concurrently with the placement of the embankment material.

A few of the previously- mentioned filtered drainage systems and their uses are summarized below:

- ♦ Chimney filter and drain:
  - Located adjacent to the downstream face of the core zone (may be vertical or inclined); often tied into a blanket drain.
  - The vertical extents should extend from the top of the foundation up to at least the reservoir's normal pool elevation at the abutments, with a minimum cover of 2 feet of embankment material.
- ♦ Blanket filter and drain:
  - Located along the base of the downstream slope.
  - With regard to the lateral extents, if a proposed blanket drain will not extend from the downstream toe all the way to the downstream face of the core zone, then at a minimum the blanket drain length should span from the downstream toe to within a specific distance (equal to dam height plus ≈ 5 feet) of the dam's centerline, and/or the blanket drain limits should provide a filter over all foundation material necessary to prevent a piping condition from occurring.
- ♦ Finger filter and drain:
  - Located along the base of the downstream slope, with multiple linear "fingers" aligned roughly perpendicular to the centerline of the dam, and adequately spaced to effectively route seepage.
  - A common design consists of granular media (with or without an internal perforated or slotted pipe) wrapped in geo-fabric to prevent fines from clogging the filter.
- ♦ Toe filter and drain:
  - Located along the base of the downstream toe, with an alignment roughly parallel to the centerline of the dam, and with an adequate number of perpendicular outlets discharging at or beyond the downstream toe.
  - A common design consists of granular media (with or without an internal perforated or slotted pipe) wrapped in geo-fabric to prevent fines from clogging the filter.

Outlet Protection and Drainage Provisions

Consideration also needs to be given for adequate protection at outlets serving filtered drainage systems. Drainage outlets with concrete headwalls and splash pads (of concrete or rock riprap) will reduce the likelihood of erosion problems from active drains.

Outlets should also have protection such as screens, flap valves, etc., to prevent small animals or insects from entering, and they should be marked for easy field identification, such as with permanent staking. This provision should prevent damage to the outlets from a dam's routine maintenance mowing.

Drainage outlets should also be configured to allow for easy measurement of flow, such as leaving 6 inches of clearance beneath the invert of the outlet.

Lastly, care should be taken so that outlets do not discharge onto steep slopes or into inundated areas, and they should have adequate downstream drainage to prevent being buried in sediment. Sometimes it is necessary to construct a drainage or collection ditch downstream of the dam, graded away from the toe to prevent erosion, to route drainage outlet discharges and/or surface runoff.

Geotextiles in Filter Designs

Geotextiles should not be used exclusively as filters, but instead should be properly incorporated into soil filter designs, when appropriate.

This is due to two limitations:

1. Geotextiles are exceptionally vulnerable to tearing caused by sharp or irregularly shaped rocks or rock fragments, or by differential settlement—especially at abutments or wherever the dam height changes abruptly.
2. Geotextiles may easily clog up with migrating sand particles, as geotextiles—when used exclusively—will often lack the ability to adequately support the seepage discharge face. When geotextiles are incorporated into a properly designed soil filter, the soil particles will not move as a result of high gradients when water is passing through the soil.

Transverse Cracking and Filters

In addition to providing engineered soil filters and associated drainage systems downstream of core zones to properly manage seepage, appropriately sized filter zones should also be established upstream and/or downstream of core zones whenever and wherever there is a likelihood for transverse cracking to occur.

Common Drainage Systems for Filters

Some of the above-mentioned components or methods for seepage control are often designed with their respective drainage system outlets tied together.

Also, filtered drainage diaphragms around conduits are often tied into other internal drainage systems, such as toe, finger, or blanket drains. The use of filtered drainage diaphragms around conduits is discussed in greater detail in Chapter 7, "The Determination and Design of Dam Appurtenances."

When tying together common drainage systems, it is important to size the drainage conduits appropriately, with the conduit size progressively increasing as necessary, downstream of junctions and toward the drainage outlet(s).

Surface Protection on Embankment Slopes and Crest

This subsection is intended to provide general guidance for protecting the surfaces of an embankment's slopes (including groin areas) and crest. In this regard, the discussion here is limited to the selection of an appropriate gradation and thickness for a proposed rock riprap layer for a typical 3H:1V slope.

Should any of the following methods of surface protection be intended to handle an overtopping event from a dam's requisite design flood, you will need to submit a detailed analysis together with your construction plans and specifications. This analysis must demonstrate the ability of the surface protection to perform its function without undue erosion occurring. This may include an analysis of expected flow velocities from overtopping events, along with documentation on the scouring velocity limits of a proposed method of surface protection.

Embankment Slope Surface Protection

A number of methods exist to sufficiently protect the vulnerable slopes of an earthen embankment dam. These methods include:

- vegetation (short grass cover, free from any trees, large bushes, etc.)
- rock riprap
- soil cement
- roller-compacted concrete (RCC)
- geotextile fabrics or mats
- reinforced turf mats
- gabions
- articulated concrete blocks
- a combination of the above methods, including bedding requirements

Slope protection should be designed specifically to combat wave-action erosion on the upstream slope along a reservoir's normal pool operating range. The protection should extend to an upper limit a few feet above the crest of the lowest ungated spillway or to the maximum wave run-up distance above the normal pool operating range (per Section 3.3 of *Hydrologic and Hydraulic Guidelines for Dams in Texas*).

In addition to those methods mentioned above, other common means of providing local slope protection include sacrificial berms and retaining walls. Nevertheless, rock riprap is often the most economical and by far the most common choice of upstream slope protection.

Accordingly, it is important that the layer of rock riprap include an adequate bedding material and thickness, as well as appropriately sized rock (gradation and thickness of riprap layer) for a given slope ratio. The following criteria should be used as a general guide to properly sizing rock riprap on a 3H:1V slope:

- For reservoirs with the longest fetch ≤ 2.5 miles:
  - nominal thickness of 30 inches
  - gradation (percentage of rock):
    - 0 to 10 percent < 75 lbs
    - 75 lbs ≤ 50 to 60 percent ≤ 1,250 lbs
    - 40 to 50 percent > 1,250 lbs
    - maximum size of 2,500 lbs
- For reservoirs with the longest fetch > 2.5 miles:
  - nominal thickness of 36 inches
  - gradation (percentage of rock):
    - 0 to 10 percent < 100 lbs
    - 100 lbs ≤ 50 to 60 percent ≤ 2,250 lbs
    - 40 to 50 percent > 2,250 lbs
    - maximum size of 4,500 lbs

The above sizing criteria are intended to be conservative in nature and less stringent criteria may be justified with detailed analyses of wind and wave calculations for sizing rock riprap.

Additionally, the total rock riprap material should not contain more than 5 percent (by weight) sand and rock dust, and the above-mentioned rock size specified for the 0 to 10 percent range(s) should not exceed an amount that will fill the voids in larger rock.

As stated above, bedding requirements are necessary for many slope protection applications, and the use of rock riprap typically warrants gravel bedding that meets filter criteria for both the rock riprap above it and the embankment surface below. Filter cloth is usually used below the gravel bedding as filter criteria often would dictate a second filter zone. In some circumstances, rock riprap can be placed directly on filter cloth if it is done carefully.

Sometimes it is necessary to give additional surface protection consideration(s) for areas that are particularly susceptible to erosion from storm water runoff, such as the upstream and downstream groins, at slope transitions, along steep slopes, at concrete-soil interfaces, along the downstream toe, etc. Nevertheless, sometimes the best option is not necessarily providing slope protection, but instead implementing flatter slopes (or more gradual transitions) at vulnerable areas or even flaring out the groins. This will allow for mowing to be used as vegetation control, while the use of riprap typically requires herbicide for vegetation control.

Lastly, when choosing an appropriate slope protection for a proposed embankment dam, it is essential that maintenance considerations (and related accessibility requirements) be factored into the chosen method of surface protection. For a thorough understanding of the routine maintenance necessary to upkeep an embankment dam, please consult the agency's *Guidelines for Operation and Maintenance of Dams in Texas.*

Crest Surface Protection

The appropriate method of protecting the surface of an embankment's crest depends on the proposed use of the dam and associated accessibility requirements, as well as the erosive potential of the embankment material, itself. For example, if the embankment crest will be used as a routine thoroughfare, it should be designed with an appropriate width to accommodate the anticipated traffic load, as well as any safety requirements that may be applicable (shoulders or emergency lanes, guardrails, etc.).

At a minimum, adequate surface protection of an embankment crest should include or address:

- erosion (including wind- and wave-induced)
- traffic (including livestock or vehicular, as well as any special design considerations for large trucks)
- drainage
- camber
- settlement or consolidation
- cracking potential

6.2 The Basic Components of Concrete Dams

Concrete dams are not as common as embankment dams, but they are the preferred choice for certain sites, including in-channel overflow structures as well as narrow gorges. Because they rely on the weight of the structure and/or the strength of the bond or anchor at the abutments, concrete dams require solid impervious strata for an adequate foundation. This, in turn, necessitates an extensive geotechnical investigation and a detailed foundation design (including required foundation treatments).

Nevertheless, concrete dams are far less susceptible to erosion than embankment dams and do not typically require as much routine maintenance. However, when maintenance, restoration and/or modifications are necessary (to either the dam's main structure or its appurtenances), it is usually more costly.

Overview of Concrete Dam Types and Overall Component Requirements

Gravity Dams

A gravity dam may be solid (more common) or hollow (more economical), it may consist of masonry or more commonly of concrete, and it always requires an impervious foundation of high bearing strength. A proper gravity dam design must account for the tensile forces at the upstream face due to the hydrostatic pressure, and it must effectively handle the compressive forces at the downstream face without the dam sliding, overturning, or crushing the downstream toe.

A roller-compacted concrete (RCC) dam is a specialized type of gravity dam that has become more popular in recent times, due to the fact that it can be built in a short time, with minimal labor, and at a comparatively low cost. Estimates have shown that an RCC dam can sometimes be built at roughly half the cost of a comparable conventional concrete gravity dam and roughly two-thirds the cost of a comparable embankment dam.

An RCC dam consists of a very low-slump, stiff concrete that is spread and compacted in thick lifts (typically not exceeding 12 inches in total thickness after final compaction by a vibratory roller). Additionally, the lifts are usually separated by a thin lift (1/4 to 1/2 inch thick) of high-slump cement-paste mortar that bonds the RCC lifts together and reduces seepage through the dam. Also, the abutments of an RCC dam usually consist of conventional concrete.

Arch Dams

An arch dam may be made of masonry or concrete (more common), and it may consist of one arch or multiple arches that incorporate buttresses between them. The structural stability of the arch dam is dependent on a gravity component (weight of the structure), as well as on the strength of the bond or anchor at the abutments. In contrast to a gravity dam, in which the foundation floor bears the vast majority of the stress(es), the arch dam allows the combined normal (gravitational) and hydrostatic forces to be distributed between the foundation floor and the abutments. Narrow canyons of sturdy rock are best suited as sites for arch dams.

Buttress Dams

A buttress dam is usually made of concrete and typically consists of a vertical wall (flat or curved) supported by strategically spaced buttresses (supports) on the downstream side. As noted above, arch dams utilizing a multiple arch configuration will employ buttresses at the interface(s) between the arches. In contrast to typical gravity dams, buttress dams require a significantly smaller quantity of concrete and are preferred in locations where the foundation floor may not be capable of supporting the size and weight of a gravity dam.

Contraction, Expansion, and Construction Joints

As with many other materials, changes in temperature and moisture will cause concrete to expand and contract. Especially during the initial period after it has been poured, concrete has a tendency to contract, resulting in cracking.

While minor surface cracking is normal and cannot be prevented entirely, detrimental, deep-seated cracks can be minimized or controlled with properly designed joints in the concrete.

For slabs, it is recommended that the maximum joint spacing be 24 to 36 times the thickness of the slab. For concrete panels, it is recommended that the maximum joint spacing along the length not exceed 1.5 times the width.

Contraction Joints

You should plan for an adequate number of contraction joints, strategically placed, to protect critical components from cracking.

Contraction joints within slabs should be equipped with grooves having a minimum depth of 1/4 the thickness of the slab, but not less than 1 inch. Contraction joints may be established by either (1) inserting preformed plastic, hardboard, or other kinds of joint strips into the concrete surface prior to finishing, or (2) saw-cutting joints within 4 to 12 hours after the concrete has been finished.

In order to adequately isolate concrete slabs from columns, slabs should have openings (usually circular or square) formed-out that will not be filled during the slab's concrete pour, with proposed slab contraction joints intersecting at these (formed-out) openings for the columns. When square openings are used at column locations, the configuration of the opening should be rotated 45 degrees so that the contraction joints intersect with the diagonals of the square.

Expansion (or Isolation) Joints

Expansion joints should be included in structural concrete designs to allow independent vertical or horizontal movement at the interface of adjacent slabs, walls, footings, columns, or other structures, preventing cracking due to thermal expansion, differential settlement, non-uniform loading, etc.

Where expansion joints are proposed between slabs, walls, or columns, premolded joint filler material (compressible foam strips, cork board, asphalt-impregnated fiber sheeting, etc.) should be placed between the structures. Additionally, concrete edges should be chamfered along the edges of the structure(s) at expansion joint locations to prevent concrete spalling.

Provisions for rebar should also be incorporated into expansion joint designs. The configuration(s) of the rebar at the expansion joint must allow vertical or horizontal movement. When wire mesh is to be placed within a slab, it should either be discontinued across the length of the joint or have alternate wires cut out.

Construction Joints

Construction joints are usually set at predetermined locations along the interface of successive concrete placements. However, they may be required at unplanned locations when the placement of the concrete is stopped for longer than the initial setting time.

Construction joints are designed to permit movement in slabs or to transfer loads within slabs, and are typically doweled (with rebar) across the length of the construction joint. Care should be taken to ensure that the dowels are carefully lined up and parallel to prevent inducing restraint and associated random cracking at the end of the dowel. Also, keyed construction joints should not be used with slabs that will sustain heavy loads.

Waterstops

Typically consisting of rubber, PVC, or other synthetic material, waterstops are a necessary sealing component to control seepage through a concrete construction or expansion joint. Construction plans should include details indicating the required type and proper configuration, including splicing requirements, for proposed waterstops. Lastly, provisions should be established in the construction plans and/or specifications to ensure that waterstops are protected from oil or grease.

Filters and Drains

Pipe drains should be used as needed to provide relief from any uplift pressure(s) present beneath the downstream toe of a concrete dam (including below concrete aprons). Draining provisions may also be necessary along pervious (soil-like) foundations, as determined through the geotechnical investigation.

Such drainage components could be thought of as part of the foundation design; nonetheless, they are briefly addressed here. Typically consisting of either perforated or slotted pipe or watertight pipe with open joints, and placed on or within bedding material that will also serve as a filter, such drainage systems are vital to the safety of concrete dams.

Additionally, weep holes may be successfully used to alleviate hydrostatic pressure behind concrete walls and beneath concrete aprons. To prevent the loss of soil, it is important that weep hole designs include filters—such as granular media (with or without an internal perforated or slotted pipe)—that are wrapped in geo-fabric, to prevent fines from clogging the filter.

6.3 The Basic Components of Composite Dams

Plans for proposed composite dams should include all of the applicable components listed above for embankment and concrete dams. Additionally, considerations should be made for supplemental components, such as filtered transition zones between embankment sections and concrete sections.

6.4 Retaining Walls and Related Structural Components

Retaining walls and related structural components (such as parapet walls, training walls, wing walls, toe walls, end sills, etc.) are often part of a dam's design, regardless of its particular type.

Retaining walls are typically made from cast-in-place concrete, but they can also be constructed from reinforced masonry blocks, closely spaced driven members, or heavy lumber (such as railroad ties). There are a variety of possible types of retaining walls:

- cantilever
- buttress
- counterfort
- gravity (and semi-gravity)
- soldier pier
- sheet pile
- gabions
- cellular

Retaining walls may be supported at their base with a footing, they may be supported upon drilled shafts, or they may rely on the weight of the wall structure, itself. Additionally, they may have anchors to assist in obtaining required stability.

The choice you make in the type and design of a retaining wall should conform with the findings and recommendations of any geotechnical investigation(s) conducted at the dam site. If necessary, filtered transition zones should be designed between embankment sections and concrete structures. Also, designs should account for the maximum potential discharges adjacent to the structure that may cause scouring erosion, which may undermine or damage the structure.

Parapet walls require additional considerations and design requirements, due to the fact that they are subject to the forces of water on one side (potentially to the full height of the wall, in most cases), with no or minimal earth force on the opposite side to serve as a counterbalance. Accordingly, a parapet wall will likely require wider footings and deeper keys than a typical retaining wall of the same height, or it may even require piles in lieu of or in conjunction with footings.

Concrete retaining walls and related structural components should have an adequate amount of appropriately sized rebar, with a minimum of 2 inches of clearance from the edges of structures.

Additionally, they should have a sufficient number of contraction, expansion, and construction joints, as well as appropriate waterstops (for related guidance, see "Contraction, Expansion, and Construction Joints," above, in Section 6.2, "The Basic Components of Concrete Dams).

Lastly, filters and/or drains (including weep holes) should be incorporated into designs, as required (for related guidance, see "Filters and Drains," above, in Section 6.2).

6.5 Instrumentation Components

When recommended as part of a geotechnical investigation, or when site or downstream conditions warrant it (known problems, unknowns that should be monitored, potential for significant loss of life, etc.), instrumentation components should be included in a dam's design. Some of the more common devices—to monitor water levels, water and earth pressures, deformations, seepage, etc.—are listed below.

- piezometers, monitoring wells, etc.
- weir plates, flumes, velocity meters, etc.
- turbidity monitors
- pressure or load cells
- strain and stress meters
- settlement plates
- inclinometers, tiltmeters, extensometers, etc.
- shear strips
- joint meters
- thermistors, thermocouples, etc.
- data acquisition systems

It is worth noting that piezometers and monitoring wells (the most common instruments for dams), should not be installed in the embankment's core zone, due to the detrimental effects of the drilling operations. However, if an existing zoned embankment dam is suspected to have a high potential for liquefaction, and piezometers are being installed as a result, there may not be an alternative to drilling into the core zone. In this case, a hollow stem auger should be used for the drilling operations to minimize any detrimental impact(s).

A proposed instrumentation plan should include considerations for both the construction period and permanent monitoring (including the frequency and duration of data collection), as well as determinations of critical thresholds for each instrument that should alert the dam operator as to specific conditions. If applicable, the use of instrumentation should be incorporated into Emergency Action Plans (EAPs) and Early Warning Systems (EWSs), with specific courses of action to be taken in the wake of any and all critical instrumentation readings.

Chapter 7. The Determination and Design of Dam Appurtenances

7.0 Introduction

The necessary appurtenances of a proposed dam are typically determined in conjunction with the selection of the dam's type (see Chapter 3). Nevertheless, the specific design for each dam appurtenance often requires geotechnical considerations to be implemented. Accordingly, the dam's foundation design (see Section 4.2, "Foundation Examination and Treatment") and components (see Chapter 6) are often established prior to final appurtenance design.

This chapter primarily includes design considerations for hydraulic conveyance structures that serve a dam (overflow spillways, open-channel spillways, conduit spillways, low-flow conduits, etc.). However, this chapter also discusses conduits within dams that are not hydraulic conveyance structures for the dam itself (such as water distribution lines and other utility conduits).

This chapter does not cover the various configurations and designs of engineered soil filters and drains, although the specific use of filtered drainage diaphragms around conduits is discussed. (Please see Chapter 6 "The Determination and Design of Dam Components," for related guidance on engineered soil filters and drains.)

Please note that the design of all proposed spillways or other related hydraulic appurtenances, including freeboard requirements, must satisfy all the design criteria and considerations that are provided in the agency's most current version of *Hydrologic and Hydraulic Guidelines for Dams in Texas.*

7.1 Spillway Conduits

Spillway conduits usually fulfill the "primary" or "service" spillway requirements, as they are not typically capable of handling the significant flow requirements of "emergency" spillways for on-channel dams. This is mainly due to practical limitations on the required conduit size(s). However, if a proposed dam's drainage area is small enough or enough freeboard is maintained between the reservoir level and the top of the dam, then a conduit may be capable of passing the appropriate design flood flow requirements.

Location Considerations

Spillways should be designed and located so as to route discharges back into natural channels prior to crossing adjacent property lines and without causing undue erosion to adjacent property. Additionally, spillway conduits should not be located at the maximum cross-section of embankment dams (typically the natural alignment of the watercourse for on-channel dams).

Instead, spillway conduits should be offset and aligned (without bends) at an angle to the embankment dam's centerline, with the spillway conduit's outlet roughly coinciding with (and discharging into) the natural watercourse. This provision can often decrease the vulnerability and severity of seepage-related issues along conduits within embankment dams, especially when a filtered drainage diaphragm is not included in the conduit's design.

Drop Inlets

Configurations
The typical spillway conduit design includes a vertically-aligned drop inlet (usually a riser or tower configuration) on the reservoir side, connected to a horizontal conduit that penetrates and traverses the width of the dam and discharges through outlet works on the downstream side of the dam.

Some drop inlets integrate various weir types along their crests. Drop inlet configurations can include a single, ungated inlet, and/or two or more gated or valved inlets (including adjustable low-flow ports), providing flexible spillway capacity and allowing the reservoir to be maintained at multiple elevations. Additionally, locks should be installed on all gated controls, to prevent unauthorized operation.

Properly designed drop inlet conduits should have a diameter that sufficiently exceeds that of the horizontal conduit, so as to prevent damaging vortex action, surging, or pipe vibration. In addition, enlarging the diameter of the drop inlet will allow more flow to be passed under lower head conditions when operating as a weir (not under a submerged condition).

Uncontrolled spillway conduits should not be designed to hold water under pressure when not engaged. For example, spillway conduits that have their uncontrolled inlets near the bottom of the reservoir (at the upstream end of the horizontal conduit) and that have risers on the downstream end with the riser outlet established at the desired elevation to control the reservoir's normal operating level, are considered to be inadequate and should be avoided. This configuration maintains water pressure within the spillway conduit at all times, and this can result in excessive seepage and related piping issues along the conduit.

Inlet Treatment and Protection
Drop inlets should also have adequate inlet treatment and protection, such as anti-vortex collars and trash racks. It is important to sustain converging flow into drop inlets by reducing any vortex action, and this is the justification for utilizing anti-vortex collars. A properly sized trash rack should also be designed to allow smaller debris to pass, while preventing large debris from entering the drop inlet and clogging the outlet conduit or outlet structure.

If the public will have access to the reservoir, adequate safety features(warning signs, safety buoys, etc.) should also be installed around drop inlets.

High-Velocity Considerations
When a proposed spillway is expected to endure conduit velocities exceeding 30 feet per second, or when a proposed spillway conduit's size will exceed 48 inches, special design considerations need to be implemented for the conduit's junction at the transition from the drop inlet to the horizontal conduit, as the high-velocity condition may warrant thrust-blocking provisions. When conduit velocities are anticipated to exceed 50 feet per second, hydraulic modeling should be utilized to ensure the appurtenance's structural integrity under the maximum reservoir level.

Horizontal Spillway Conduits

Although a few considerations have already been mentioned above, this subsection outlines the majority of the design provisions and recommendations for horizontal spillway conduits.

Alignment
Horizontal spillway conduit designs should not typically include bends. Sometimes, however, bends cannot be avoided in the horizontal and/or vertical plane(s), or drop structures are necessary along the conduit's alignment. Bends should be gradual, not sharp, and with adequate thrust-blocking (if necessary) sized for maximum discharge. If a spillway must include a drop structure internal to an embankment

dam, with access-ways, such as manholes, these access-ways should be watertight (bolted manhole covers, for example) to prevent them from being blown off during significant flood events, which could result in erosion damage.

Slope

An appropriate slope should be established for horizontal spillway conduits, with a higher invert elevation at the upstream end, as well as considerations (and any corresponding provisions) for any applicable issues such as cavitation, vacuum breaking or venting, etc.

Size

Typically, the conduit diameter for proposed horizontal spillways should be selected so that under maximum discharge conditions, the cross-sectional area of flow at the pipe outlet will not be more than 75 percent full, permitting ventilation of the conduit from the downstream end. This will avoid complications from air bulking, surging, etc. (siphonic flow conditions). Lastly, horizontal spillway conduits with varying diameters are not considered practical, and these designs should be avoided.

Differential Settlement

When differential settlement within a dam embankment is anticipated or expected (significant enough to be problematic), horizontal spillway conduit designs should include provisions to prevent the potentially damaging effects of differential settlement. These provisions include the use of concrete cradles, concrete encasements, concrete piers, drilled shafts, etc. In addition, an effort should be made to locate horizontal spillway conduits on or near the foundation, to minimize differential settlement adjacent to the conduit.

Low-Flow Spillways and Drains

Drains are a necessary dam appurtenance to lower the reservoir level and/or drain it completely for emergency situations, to perform maintenance, or—in the case of detention dams—to control the rate of release. Low-flow conduits are often necessary to pass flow downstream for environmental considerations, during times of drought, or due to legal requirements with regard to senior water rights and downstream appropriations. Additionally, including a drain in the dam design can assist in maintaining a dewatered condition by passing flows during construction of a dam.

Inlets for low-flow systems and drains are often included in the design of drop inlets. When this is the case, the drop inlet footing may be particularly vulnerable to undermining erosion from the engagement of the low-flow or drain inlet (located at the bottom of the structure) and the associated high velocity of the flow as it is drawn into the drop inlet structure. Accordingly, provisions—such as extending the low-flow system's or drain's inlet location an adequate distance upstream of the drop inlet structure via a conduit—should be included to address the potential damaging effects. Lastly, inlet protection should be included to prevent conduits from clogging.

As stated previously, conduits should not be designed to hold water under pressure when not engaged, and this includes low-flow systems and drains. Thus, gates or valves that will act as the primary controls should be located on the upstream end of the low-flow systems and drains, and they should be equipped with locks to prevent unauthorized operation. Also, air venting provisions downstream of a gate or valve may be necessary to prevent cavitation for high head conditions in low-flow systems.

It is also critical to ensure that dam designs provide accessibility to drain valves during flood events. When drain valves are incorporated into drop inlets, walkways, bridges, etc., should be provided to allow access to the drain valves should an emergency situation require it.

Culvert Spillways
A culvert spillway should not be used as a primary, or service, spillway of an on-channel dam. Culvert spillway configurations are horizontal conduits that are not connected to a drop inlet, have uncontrolled inlets and outlets, and are essentially a straight conduit placed through the dam embankment (with minimal slope).

Unless the dam has a very small drainage area and/or plenty of available freeboard, culvert spillways are usually incapable of passing any significant flow (not enough driving head), and this could possibly result in premature engagement of the emergency spillway(s) and/or an overtopping event. Additionally, culvert spillways often discharge along the downstream face or groins, resulting in undue erosion issues.

Siphons as Spillways, Drains, and Low-Flow Conduits
A siphon configuration can sometimes be used to fulfill primary or service spillway design requirements. A siphon arrangement can also perform the function of a drain or low-flow system. Because siphons operate at their full discharge capacities with minimal driving head-conditions at their inlets, and because siphons do not typically contain moving parts, they are well-suited for particular applications. However, siphon configurations can also be problematic and/or limited in other regards, including:

- The siphon conduit and/or breaker vents can get clogged with leaves and other debris.
- Siphon inlets and vents are vulnerable to ice forming within them and freezing up, preventing operation of the siphon.
- The operational nature of a siphon (all-or-nothing discharge frequency) can result in drastic oscillations of discharging flow, with the resulting downstream surges becoming problematic in some circumstances.
- The nature of a siphon can result in intense operational vibration, and accordingly additional provisions must be incorporated to properly anchor the siphon to resist movement detrimental to the appurtenance.
- Multiple siphons are often necessary to counteract the above “drastic oscillations of discharging flow.” To adequately balance the reservoir’s inflows and outflows, the breaker vents of the multiple siphons are staged at predetermined reservoir levels.

Spillway Conduit Materials

Spillway conduits may consist of various materials, including reinforced concrete pipe (RCP), steel pipe, ductile iron (DI) pipe, cast iron (CI) pipe, polyvinyl chlorinated (PVC) pipe, and high-density polyethylene (HDPE) pipe. Because replacement of a spillway conduit within an embankment dam can be difficult, costly, and potentially damaging to the structure (due to the depth and extent of excavation), it is important that the material chosen be as permanent as possible. Iron and steel conduits are sometimes galvanized, lined with bituminous coating, or given some other rust-resistant treatment; these conduit materials should only be used in small-sized, low-hazard dams.

As long as the selected pipe is watertight (including joints sealed with waterstops and/or rubber gaskets) and capable of withstanding the maximum potential pressure, as well as the dam design’s external loads, it is acceptable. However, corrugated metal pipe (CMP) is not considered an acceptable spillway conduit material for use in dams, and accordingly, designs that incorporate CMP will not be approved. In the recent past, a considerable number of embankment dams in Texas have either failed or needed expensive spillway replacements due to the advanced deterioration of CMP (often prior to reaching the CMP’s “design life”).

It is also important to consider potential adverse reactivity between conduit materials and surrounding soils and water. For example, the proposed conduit’s concrete type or mix may be particularly vulnerable to sulfate ions, cathodic protection of the metal conduits may be required, highly acidic or caustic water may warrant additional considerations, etc.

Anti-Seep Collars

Anti-seep (cutoff) collars should not be used in designs for horizontal spillway conduits. For related information regarding the discontinued use of anti-seep collars, please consult the following sources (publications of the Natural Resources Conservation Service [NRCS]): *Supplement to Technical Note 709* (1989), Chapter 26 of Part 633 of the *National Engineering Handbook* (1994), and Chapter 45 of Part 628 of the *National Engineering Handbook* (2007). It has become accepted practice in dam construction to use filtered drainage diaphragms in lieu of anti-seep collars.

Filtered Drainage Diaphragms

A filtered drainage diaphragm is an engineered soil filter (with a drainage system) for controlling potential seepage. Essentially, it is a specially designed permeable "zone" around horizontal spillway conduits that will prevent a piping condition from forming within a dam's embankment, where internal erosion from seepage through the dam results in a loss of embankment material and eventually an unstable structure if left unchecked.

As stated in the above section on anti-seep collars, filtered drainage diaphragms, or similar filter drain systems, should be included in proposed horizontal conduit designs for embankment dams, to adequately control potential seepage flow along the outside edge(s) of the conduit(s). However, if an embankment dam design already contains a chimney filter downstream of the impermeable zone, the chimney filter will effectively serve the purpose of a filtered drainage diaphragm around a conduit.

Given that embankment dam failures (and accidents) occur more often at the location of conduit penetrations than at any other location on the dam, it would seem appropriate to assume that *seepage related causes* are often involved. Conditions that can lead to adjacent soils becoming internally eroded (piping condition), resulting in weak areas within the dam embankment (such as voids, sinkholes, etc.) and eventually a possible dam failure, may include the following:

- Deterioration or defects in a conduit wall.
- Poor compaction of soils adjacent to a conduit (during construction).
- Leakage or separation at conduit joints (possibly the result of poor construction, post-construction differential settlement, faulty or deteriorated seals, etc.).
- The hydraulic fracture of surrounding fill due to the presence of the conduit (which often creates differential settlement because the soil columns on each side of the conduit compress more than the soil column above the conduit; a new embankment dam is particularly susceptible to this condition once it first fills to its normal pool elevation).

Although individual conditions may warrant more stringent criteria, it is recommended that filtered drainage diaphragms be designed with locations, configurations, and minimum dimensions in accordance with the following guidelines:

- Located downstream as far as possible while maintaining a minimum cover of 2 feet of embankment material.
- Usually aligned vertically, but may be inclined (typically when parallel to an inclined core zone).
- Horizontal extents beyond conduit:
  - *Rigid conduits.* The diaphragm should extend laterally (perpendicular to conduit alignment) a length of 3 times the conduit's diameter (or height) beyond the outer limits of and to each side of the conduit.
  - *Flexible conduits.* The diaphragm should extend laterally (perpendicular to conduit alignment) a length of 2 times the conduit's diameter (or height) beyond the

outer limits of and to each side of the conduit.

- Vertical extents above conduit:
  - *Rigid conduits.* The diaphragm should extend vertically a length of 3 times the conduit's diameter (or height) above the outer limits of the conduit, if possible.
  - *Flexible conduits.* The diaphragm should extend vertically a length of 2 times the conduit's diameter (or height) above the outer limits of the conduit, if possible.
  - When the above conditions cannot be met—at a minimum, the diaphragm should extend to the reservoir's normal pool elevation at the abutments with a minimum cover of 2 feet of embankment material.
- Vertical extents below conduit:
  - When foundations have low compressibility (conduit settlement ratios are ≥ 0.7), the diaphragm should extend at least 1 foot beneath the bottom of the conduit's installation trench, but not more than 2 feet or down to unweathered bedrock.
  - When foundations are compressible (conduit settlement ratios are < 0.7), the diaphragm should extend a length of 1.5 times the conduit's diameter (or height) below the outer limits of the conduit, or down to unweathered bedrock.
- Minimum thicknesses:
  - 2 feet for small-sized, low-hazard dams.
  - 3 feet for all others.
  - For multiple zone filters, no zone should be less than 1 foot.
- The filter's drainage system outlet is often tied into downstream toe and/or finger drain outlet(s).

With regard to other considerations or provisions for engineered soil filters, soil filter outlets (and outlet protection) and *filter permeability requirements* to provide adequate stability within the filter (between the adjacent soil, fill, or base material and the soil filter material), please see "Soil Filter and Drainage System Designs." in Section 6.1, "The Basic Components of Embankment Dams." For more specific guidance or additional design and construction provisions regarding the use of filtered drainage diaphragms around conduits, please consult Chapter 45 of Part 628 of the *National Engineering Handbook* (NRCS, 2007).

Other Conduit-Type Appurtenances

There are many functions other than spillways that conduit-type appurtenances within a dam may perform, including bypass conduits, raw water intake lines, penstocks for hydroelectric facilities, electrical conduits, etc. Due consideration must be given to each of these particular types of conduits when designing a proposed dam, and many of the same (above-noted) concerns for spillway conduits must also be exhausted.

As with spillway conduits, other conduit-type appurtenances must be watertight and capable of withstanding the maximum potential pressure, as well as the dam design's external loads (including maximum vehicular traffic loads). Also, any conduits that are buried and traverse the width of embankment dams, and especially those that must operate under pressure, should have appropriate seepage-control features, such as filtered drainage diaphragms (which can be designed for multiple conduit penetrations).

Valves should also be located at each end of buried conduits, allowing cutoff of flow beneath a dam. Additionally, they should have sufficient cover and adequate thrust blocking where appropriate. Lastly, such specialized conduit-type appurtenances might necessitate the use of instrumentation to detect leaks, loss of and/or excessive pressure, faulty automated valves, etc., as well as any related controls to prevent damage to the dam.

7.2 Unconfined Spillways

Unconfined spillway designs are often used for both primary, or service, spillways and for emergency spillways. For the purposes of this text, unconfined spillways are considered to be anything other than conduit spillways. They may be overflow spillways, open-channel spillways, or a combination of the two.

Overflow Spillways

Overflow spillways are equipped with various weir configurations (crest, profile, and alignment) at the control section (spillway crest), including:

- broad-crested weirs
- sharp-crested weirs
- ogee-crested weirs
- rectangular weirs
- v-notch weirs
- trapezoidal weirs
- labyrinth weirs
- piano-key (P.K.) weirs
- duckbill weirs
- a combination of the above

For some in-channel dams, the entire length of the dam may function as an overflow spillway. Additionally, overflow spillways may be controlled or uncontrolled; may discharge directly downstream into a watercourse, with or without energy dissipation structures; or may discharge into downstream chutes, discharge channels, or other conveyance structures, which may or may not be equipped with energy dissipation structures.

When overflow spillways discharge into open-channel conveyance structures, they should include the considerations for open channels that are mentioned in the following section. Lastly, overflow spillways that are equipped with gates should have locks to prevent unauthorized operation.

Open-Channel Spillways

Open-channel spillways can include approach and discharge channels for overflow spillways (including the "chute" configuration atop a dam) or they may have a "bypass" configuration, where flow is conveyed around one or both of the dam's abutments and back into the natural channel downstream. Additionally, open-channel spillways may be controlled or uncontrolled, they may serve as primary spillways or as emergency spillways, or they may be configured to serve both primary and emergency spillway functions (multiple-staged channels).

When determining the layout of spillway discharge channels, they should be designed and located so as to route discharges back into natural channels prior to crossing adjacent property lines and without causing undue erosion to adjacent property.

"Chute" Configuration: Layout, Alignment, and Slope

The "chute" configuration is one of the most common designs, and it is often used atop both embankment and concrete dams. Chute designs are basically open-channel spillways equipped with a control section that traverses the crest of the dam, and they are typically designed with a discharge channel section; however, approach channel sections are not always included. Additionally, retaining walls or slope paving are typically located along the lateral edges of a chute spillway to contain the flow.

When chute spillways consist of a concrete lining or apron atop an embankment dam's face and crest, they should have adequate toe walls along both the upstream and downstream edges of the chute to prevent undermining erosion from damaging the structure. Also, when slope paving is used along the lateral edges of a chute spillway, toe walls should also be included (essentially, toe walls should line the entire perimeter of the chute spillway when this is the case).

For downstream discharge channel sections of chute spillways serving embankment dams, it is important to incorporate weep holes or pressure-relief wells or valves to prevent hydrostatic buildup beneath the layer of concrete. Properly designed weep holes should include necessary filters to prevent the loss of soil such as granular media (with or without an internal perforated pipe) wrapped in geo-fabric to prevent fines from clogging the filter or other filtering provisions.

In general, to ensure satisfactory hydraulic performance, chute spillway designs should not contain abrupt slope changes, including sharp convex curves that will result in separation of the flow from the channel floor or sharp concave curves that will cause damaging dynamic forces upon the channel floor. Drastic converging or diverging sections should similarly be avoided.

Discharge channel sections that continue beyond the dam's downstream toe should include the considerations for open channels that are mentioned in the following subsection on "bypass" configurations.

"Bypass" Configuration: Layout, Alignment, and Slope

The most common type of emergency or auxiliary spillway for embankment dams is the "bypass" configuration (also referred to as a "side channel" spillway), which is typically a wide earthen open-channel with a trapezoidal cross-section that circumvents the dam. Nevertheless, these open earthen channels are sometimes lined with concrete, riprap or other erosion-resistant material.

When designing such a spillway channel, it is important that sharp bends, steep slopes, and constrictions (drastically converging sections) be avoided, and that the alignment of the downstream discharge channel be located sufficiently beyond the dam's downstream toe, so as not to cause undue erosion.

Near the upstream end of earthen bypass spillways, the control section should be established with a straight alignment and with a flat slope for at least 30 feet before descending down into the discharge channel. As per *Hydrologic and Hydraulic Guidelines for Dams in Texas,* the discharge channel should be configured such that critical flow will occur as far downstream as reasonably possible so as to maximize the length of any erosion path back to the reservoir.

If an approach channel is included upstream of a bypass spillway's control section, its alignment should be in line with the control section; however, gradual or tangential bends are acceptable if the approach channel is located a sufficient distance prior to the control section, in order to prevent excessive approach velocities.

If necessary, training berms should be incorporated into a channel design to protect the downstream toe from erosion and to prevent spillway releases from breaching discharge channels. These training berms should be designed with similar requirements for embankment sections of dams, with side slopes of 3 Horizontal to 1 Vertical (3H:1V) or flatter. Additionally, if berms will reside on foundations vulnerable to either undermining or piping conditions, they should be designed with key trenches, as well as core zones of impervious material that incorporate the limits of the key trench.

Engagement Frequency and Erosion Resistance

Open-channel spillways are often composed of earth (with a vegetative cover), but they can be lined with concrete, RCC, soil cement, cement-stabilized sand, riprap, gabions, etc. Regardless, the exposed material that lines the channel must be capable of withstanding the effects of scouring erosion caused by maximum potential discharges from the dam's design flood.

With specific regard to open-channel emergency spillways, these should typically be designed so as not to engage during frequent floods, and they are often sized to engage only during storms more intense than a 100-year flood event. When this is the case, erosion damage can typically be expected within the emergency spillway (especially when composed of earthen material with a vegetative cover); however, a stability analysis should be conducted on the open-channel emergency spillway design to ensure that erosion will not occur too rapidly, head-cutting all the way to the spillway's control section.

If necessary, adjustments to the spillway design, including the addition of energy dissipation or erosion cutoff structures (see the following subsection), elongating the discharge channel, and/or flattening its slope(s), should be incorporated to prevent or control head-cutting erosion that could compromise the dam.

Energy Dissipaters and Erosion Cutoff Structures

Sometimes it is necessary to include energy dissipation and/or erosion cutoff structures in open-channel spillways, to prevent erosion damage from high-velocity flows. These may include baffled aprons or chute blocks along the downstream face(s) of chute spillways.

For discharge channels with a significant enough slope, and especially earthen discharge channels, it may be necessary to install erosion cutoff structures to decrease discharge velocities and control head-cutting erosion that could compromise the dam. Energy dissipation structures at the terminal ends of open-channel spillways are briefly discussed in Section 7.4, ”Spillway Outlet Structures.”

7.3 Spill Gates and Other Controls

The guidance presented within this section is general in nature, intended to provide basic design considerations and outline common problems that should be considered when designing or rehabilitating spill gates and other controls. Specific guidance and considerations related to the design of spill gates and other controls, including the concrete and steel structures that support them, will be addressed in a future publication.

Spill Gates

Spill gates (flood gates, crest gates, etc.) are typically used in conjunction with overflow spillways, but they may also be used as control devices in large conduits or open channels. Incorporating spill gates into a dam's spillway design allows a flexibility of operation unattainable with ungated spillways, such as increasing reservoir storage or releasing significant discharges downstream on demand. However, the use of spill gates also brings increased safety risks, especially when used on spillways for earthen dams, where an operational failure of the spill gates may result in overtopping of the dam's embankment.

For flood control dams, the use of spill gates allows for controlled releases to be made in anticipation of increased inflow. For non-flood control dams, the operation of the gates is based on the safety of the dam and preservation of the reservoir.

Regardless, failure of both automatically and manually operated spill gates, including the unexpected lowering of spill gates, as well as the inability to operate spill gates, may result in catastrophic consequences both upstream (especially on recreational reservoirs) and downstream (flood wave). Accordingly, gated spillways should only be used in situations where the potential consequences of spill gate malfunction (including dam failure) are less serious, or when elevated flood elevations in the reservoir would require an ungated alternative that is not acceptable from either a structural or economic perspective.

This guidance document is not intended to be comprehensive with regard to the many spill gate types, configurations, designs, and operational requirements. The considerations outlined below are broad in nature and are intended to establish baseline parameters for spill gate designs, as well as raise awareness of common spill gate problems and issues that may affect the overall design.

Dams may be equipped with a variety of spill gate types, including the following:

- radial (tainter) gates
- vertical lift gates (includes fixed wheel, tractor, stoney, and sluice gate types)

- ♦ hinged crest gates (includes flap, Bascule, and Pelican gate types)
- ♦ roller gates
- ♦ wicket gates
- ♦ drum gates
- ♦ bear-trap gates
- ♦ inflatable rubber gates

The first three in the above list (radial, vertical lift, and hinged crest) are the most commonly used in dam design, and accordingly, the following sections attempt to provide general guidance, considerations, and vulnerabilities particular to each of these three types.

Regardless, there are some issues that are common to many or all of the above spill gate configurations, and all designs should contain the following components or features:

- ♦ For significant- and high-hazard dams:
  - redundant gate controls (in at least two locations; including remotely operated controls)
  - alternative power supply; also, primary and backup power conduits should be routed separately
- ♦ Provisions to prevent or combat long-term corrosion issues (one of the most serious issues as spill gates age), including designs that do not have areas where water can collect.
- ♦ Provisions to prevent damaging gate vibration that may result from instability initiated by vortices, sill seal leakage, or hydraulic jump formation near the lip of the spill gate.

All designs should also address the following concerns:

- ♦ Possible loss-of-storage issues from a spill gate malfunction.
- ♦ Possible siltation issues and associated impact on spill gates.
- ♦ Possible complications from areas prone to debris damage during flood events.

Radial Gates

Radial gates are the most commonly utilized spill gates on overflow spillways, due to the fact that they are the most simple, most reliable, and, often, least expensive design. Additionally, there has been a great deal of experience regarding their use, and, subsequently, an abundance of documentation and guidance on adequate designs is available.

The following design considerations should be integrated into a radial gate design:

- ♦ The gate structure should be capable of resisting any and all external forces that may counteract the raising or lowering of the gates.
  - Side wheels should be included (on each side), when necessary.
  - The angle between the gate's upstream face and the spillway's flowline should be maximized, so that the likelihood of damaging vibrations (resulting from gate seal problems and associated instability) is minimized when the gates are slightly opened.
  - The trunnion should be located above the water pressure's center of force to avoid damaging vibrations
- ♦ There should be provisions for stoplogs and associated grooves or slots for maintenance or repair, or should an emergency situation warrant their use (gate stuck open or failing to operate).
- ♦ When gates are designed to be overtopped (or if overtopping potential exists):
  - Non-overtopping side shields should be provided on both ends of the gate to prevent overflowing nappe from impinging on gate arms, causing potential damage from pulsating forces.
  - Ventilation provisions should be included at the nappe region to prevent or control potentially unstable conditions.
  - Large radial gates should not be designed for overtopping conditions.
- ♦ Regarding gate seals: stiff bar seals should be installed across the bottom of the gate and music-note rubbing seals along the vertical sides.
- ♦ For areas where substantial debris accumulation occurs upstream of the gates, movable flaps are sometimes installed along

the top of the gates to allow passage of debris. Such radial gates should also be designed with a shaped overflow crest, due to the fact that movable flap hinges sometimes require continual maintenance to ensure that they function properly when needed.
- For orifice type gates, all edges of the gate (top, bottom, and sides) should have adequate seals.

Vertical Lift Gates

Vertical lift gates are well equipped to handle situations where a reservoir is subject to extreme pool fluctuations, as their design allows them to be lifted entirely out of the water. They do not require complex prestressing system designs, and once installed do not require maintenance to be conducted "in-place."

On the other hand, vertical lift gate designs include guides or slots, and their presence causes flow disturbance, making vertical-lift gates less efficient in passing flow than some of the other gate types. For this reason, the upstream sides of vertical-lift gates are often equipped with seals and skin plates to minimize the disruption of flow caused by gate slots. Additionally, the presence of gate slots can sometimes initiate cavitation conditions and collect debris.

The following additional considerations should be incorporated into a vertical lift gate design:
- They usually require rollers to counteract water pressure and allow operation of the gates; however, for small dams or for small sluice gates, a slide-action configuration (without rollers) may be sufficient.
- They require accurate alignment of guides (and any associated rollers) for satisfactory operation.
- They require particular gate lip designs for consistently reliable closure under full flow conditions.
- Regarding gate seal types: stiff bar seals should be installed across the bottom of the gate and music-note rubbing seals along the vertical sides. For vertical lift gates on conduit spillways, two music-note rubbing seals should also be installed along the top of the gate to avoid damaging vibration that results from leakage at the top of the conduit when opening the gate.

Hinged Crest Gates

Hinged crest gates can often be beneficial when precise control of a reservoir's water surface elevation is necessary, as long as the maximum operating head will be relatively small. They are also typically well-equipped at passing debris over the gates, and can be advantageous when a large amount of debris accumulates in the reservoir. Nevertheless, due to substantial lifting loads associated with their operation, hinged crest gates are generally limited with respect to gate height.

The following considerations should be integrated into a hinged crest gate design:
- Splitters are usually required along the gate crest to allow venting of the cavity below the nappe and prevent potential damage from vibrations.
- Continuous seals are typically required along the bottom of the gate, and rubbing seals are usually necessary along the vertical sides.

Hoisting Equipment

Hoisting equipment is required to operate spill gates and is usually configured with cable hoists or hydraulic cylinders. However, some innovative designs allow the gates to be controlled by utilizing water pressure from the head of water provided by the upstream reservoir (bear-trap gates, for example); these unique cases are not addressed in these guidelines.

For some gate types or specific situations, only one hoisting configuration can be utilized. When operating a top-sealing radial gate in a conduit spillway, for instance, only hydraulic cylinders can be used. For vertical lift gates operating at the bottom of a tall control shaft, cable hoists are best suited to handle the lifting.

When it is expected that spill gates will be subject to frequent vibrations, the selected hoist system is often hydraulic cylinders, as their design provides additional dampening to the vibrating forces on the gate. Hydraulic cylinders are also capable of providing substantially larger lifting forces than cable hoists. Lastly, hydraulic cylinders can provide both lifting and pushing forces when configured with double-acting cylinders, while cable hoists are only capable of lifting.

Because cable hoists only supply the force necessary to raise spill gates, it is necessary that the spill gates be massive enough to close under their own weight. For vertical lift gates that are configured in tall towers, this presents a problem where damaging vibrations can occur due to the rate of gate closure into a high-velocity flow combined with the elasticity of a long cable. In these situations, it is necessary to equip the hoist system with a braking mechanism to control the rate of gate closure.

Often, gantry cranes or mobile cranes are utilized to fulfill cable hoisting requirements for spill gates, as well as for trash racks and bulkheads. Due to the fact that cranes can handle only one gate at a time, it is not advisable or safe to have only one crane-type cable hoist for multiple gates. When extreme or flash floods occur, having only one crane-type cable hoist for multiple gates results in operations that are too slow. Additionally, gates cannot be operated if the sole hoisting apparatus malfunctions, and this can pose a serious problem during an emergency.

Gate-Operation Plans

Owners of proposed significant- and high-hazard dams that will utilize spill gates on spillways are required to develop gate-operation plans before completion of construction. The owner is not required to submit the plan to the TCEQ Dam Safety Program.

A suitable gate-operation plan should outline the overall strategy for handling significant and extreme flood events (including coordination with upstream and/or downstream dam owners and affected populations), as well as the operator's specific responsibilities. If stream gauge data (upstream and downstream) or the rate of the reservoir's rise and fall will be utilized to determine spill gate operations, detailed procedures for this should be established and documented in the gate-operation plan.

Additionally, gate-operation plans should establish a maintenance schedule (including detailed inspections to identify and treat any corrosion) for the actual gates, and also for gate slots, gate rivets, gate seals, hoisting equipment, etc.

Spill gates should also be routinely inspected for local subsidence, erosion of moving gate parts by friction, erosion due to cavitation and energy dissipation, and obstruction of gates by bed load. For gates not routinely used, gate-operation plans should establish minimum frequencies to test or operate them to ensure that they will not lock up should an emergency require their use.

Lastly, gate-operation plans will be considered an appendix to the dam owner's Emergency Action Plan (EAP) and should establish procedures for emergencies, including the conditions necessary for operators to initiate specific emergency actions (spill gate malfunction, loss of either primary or alternative power, etc.) or other related components of an EAP.

Other Controls

Flashboards and stoplogs are sometimes used to increase the height of an uncontrolled spillway crest, essentially raising the level of the reservoir. Flashboards and stoplogs should only be used when they will not raise reservoir levels above those permitted in a corresponding water right, or when they will not affect a dam's ability to safely handle its requisite design flood.

If necessary, flashboards and stoplogs must be removed before expected flood events, or they should be designed so that they can be removed while engaged (during flood events). Alternatively, some flashboards are designed to fall out of position at designated reservoir levels, or to fail if overtopped. If an undesirable amount or damaging quantity of flow will result from a sudden release of water, flashboards should not be designed to fall out of position or fail from overtopping.

If flashboards and stoplogs are designed to be removed prior to or during flood events, and a dam operator fails to do so, the dam owner's liability will increase extensively should any detrimental impact result. As such, dams and reservoirs with drainage basins that are highly susceptible to flash flooding should not incorporate their use.

7.4 Spillway Outlet Structures

Outlet structures are essential dam appurtenances to handle discharges from spillways, and they should be included in every dam design. Depending on the type of spillway and flow characteristics, outlet structures may be simple (layer of riprap, for instance) or elaborate (large concrete structures). In addition to serving spillways, outlet structures often act as a common terminal structure, where discharges from drainage structures (toe, finger, chimney, and blanket drains; filtered drainage diaphragms; etc.) and/or low-flow drain systems empty into them.

As previously stated in this document, spillway outlets (and any associated discharge channels) should be designed and located so as to route discharges back into natural channels prior to crossing adjacent property lines, thereby preventing undue erosion to adjacent property.

Impact Basins, Stilling Basins, and Plunge Pools

When spillway discharges or other conduit releases are not conveyed directly into a flowing watercourse capable of dissipating the energy, and high-velocity discharges may otherwise result in damaging erosion to the dam's toe or other adjacent structure(s), it is necessary to include outlet structures such as impact basins, stilling basins, or plunge pools in the dam design.

Outlet structures should have designs that accommodate the maximum dynamic forces and turbulence that can reasonably be expected from discharging flows. In particular, concrete outlet structures should be capable of resisting sliding action and rigorous vibrations, and this may necessitate foundation designs that incorporate piers, anchors, toe walls, etc. When needed to prevent scouring action downstream of or adjacent to a concrete outlet structure, riprap or other erosion protection should also be incorporated.

While some outlet structures designs require a pool of water to properly dissipate energy and handle hydraulic jumps, outlet structures that serve spillway conduits should not have conduit outlets located below the normal pool levels of the outlet basins. If a conduit outlet is constantly submerged, incipient problems (such as seepage along the conduit) will likely not be detected during routine inspections. When necessary, downstream grading should be used to prevent this condition.

End Sills and Deflector Buckets

When unconfined spillway discharges are conveyed directly into a flowing watercourse capable of dissipating the energy, the spillway should typically employ features such as end sills (or end lips) or deflector buckets, to project the discharging flow a safe distance away from the terminal end of the spillway to prevent any undermining erosion. If necessary, erosion protection, such as riprap, might be necessary immediately downstream of the terminal end of the spillway to combat any scouring effects.

7.5 Specialized Appurtenances

There are many specialized appurtenances—such as fish ladders (also termed “fish passes” or “fish steps”), fish screens, navigation locks, turbines or powerhouses for hydroelectric power, and sluiceways (used in gravity dams to reduce the accumulation of silt)—that, due to their specific design considerations, are beyond the scope of this document.

Nevertheless, most of these appurtenances include conduit components or unconfined, open-channel components. Therefore, the general considerations outlined in this chapter should be applied to the related components of each specialized appurtenance that is proposed, and any necessary provisions should be included in the proposed dam design.

7.6 Non-Appurtenance Conduits

When a dam has internal conduits—such as water distribution lines, wastewater lines, or other utility conduits—that are not appurtenances directly serving the dam (their specific function is not related to the dam or reservoir), care should be taken so that their operation, or possible malfunction, will not have a detrimental impact on the structure of the dam or the dam’s ability to function as intended. They should be designed to be watertight and capable of withstanding the maximum potential pressure.

Additionally, their locations should be accessible for any required maintenance and repair without causing a major disturbance (excessively deep excavation, demolition, etc.) to the dam structure. Nevertheless, such buried conduits must have sufficient cover to handle a dam’s maximum external loads, including vehicular traffic.

For general considerations and requirements for non-appurtenance conduits that are buried and traverse the width of embankment dams, and especially those that must operate under pressure, please consult “Other Conduit-Type Appurtenances,” in Section 7.1, “Spillway Conduits,” above.

Chapter 8. Rehabilitation of Existing Dams

8.0 Introduction

This chapter primarily includes design considerations for the rehabilitation of existing embankment dams. Some dam rehabilitation projects are initiated when normal maintenance becomes excessive or the dam's structural integrity is threatened, while other projects are initiated to replace or restore damaged components or appurtenances. In some instances, a failed or breached dam may need major restoration, or emergency repairs may be in need of permanent solutions.

It is also important to carefully consider situations where a dam has major structural problems, as it may be more cost-effective (in the long term) to replace the dam than to rehabilitate it, especially in the case of historically perpetual or recurring problems. Lastly, rehabilitation of an existing dam may be necessary to modernize the structure in accordance with current standards and requirements.

When a dam requires rehabilitation, the specific improvements should be designed in accordance with these guidelines—including dam foundation treatments (Chap. 4), dam components (Chap. 6), and dam appurtenances (Chap. 7). When reevaluating the stability of an existing structure due to project modifications, changes in site conditions, or new site data, you should consult "Existing Dams," in the subsection "Stability Analyses," in Section 4.4, "Geotechnical Report Requirements," for related guidance.

8.1 Conduit Rehabilitation

Replacement

Before being able to determine the appropriate or most cost-effective solution for replacing a conduit, you should diagnose the extent of damage to the existing conduit. If large enough to provide access, the conduit can be entered and inspected firsthand, as long as confined-space precautions are taken during the inspection. Some submerged conduits may require a diver to inspect them (if the reservoir is not to be lowered or drained).

However, many conduits are too small to allow human access and firsthand visual inspections, and for these, other means—such as a Styrofoam pig (which detects conduit irregularities) or a closed-circuit television (CCTV) camera crawler (small robotic buggy with a camera mounted on it)—may be necessary to verify the extent of damage (offset joints, voids, stress cracking, seepage, protrusions, obstructions, etc.).

The replacement method should be carefully considered based on the diagnostic findings. Additionally, either the partial or full demolition of inlet, outlet, or other structures may be required for specific conduit replacement methods, and these associated impacts should be factored into the decision.

Open Cut

When an open cut into an earthen embankment is required to remove and replace an existing conduit, it typically involves significant disturbance of the embankment structure. This is especially the case for open-cut replacements of conduit spillways, as these are typically located at or near the dam's foundation, necessitating extensive excavation of embankment material.

The open-cut conduit replacement method can further be characterized as follows:

- Allows changes in conduit size to accommodate an increased discharge capacity.
- Often involves increased costs and longer construction time (more impact to reservoir operations) than some of the other viable techniques. However, for small embankment dams (where the extent of the excavation will not be as substantial) open-cut replacement may be the most cost-effective option.
- May require new inlet or outlet works to accommodate the new conduit.
- May require construction of a cofferdam within the impoundment to maintain a dewatered condition if the reservoir cannot be lowered to a sufficient depth to conduct the work (or should the conduit replacement necessitate demolition, repair, or replacement of an associated intake structure).
- Involves increased risk (for construction activities, as well as for downstream hazards), as compared to other methods.
- Excavations that traverse the width of embankments involve an increased risk of future hydraulic fracture due to arching within the replaced embankment material; to reduce differential strain, the excavated side slopes should be as flat as possible.
- If differential settlement issues are anticipated, should include provisions (such as the use of concrete cradles, concrete encasements, concrete piers, or drilled shafts) for addressing future damage to the new conduit. This is especially the case when differential settlement issues contributed to the original malfunction of the conduit being replaced.
- Commonly entails the construction of a filtered drainage diaphragm around the downstream portion of the new conduit (see "Filtered Drainage Diaphragms" in Section 7.1, "Spillway Conduits," for guidance on the design and use of filtered drainage diaphragms around conduits).

Slip Lining

Replacing a conduit via the slip-lining method involves pulling or pushing a smaller-diameter conduit through the damaged conduit, and then sealing the resulting annular region between the two conduits with grout. When slip lining a horizontal conduit that is connected to a riser, a concrete or grout plug must first be placed in the local annular region at the junction of the horizontal conduit and riser before the remainder of the annular region can be sealed with grout.

The technique for sealing with grout also involves provisions for venting—whereby the annular region is temporarily threaded from the downstream end of the horizontal conduit along its top edge and to its full length with a venting conduit (that is small enough to fit)—to prevent air pockets from being trapped. Grout is then pumped into the annular region from the downstream end of the existing conduit, until the venting pipe returns grout.

The slip-lining conduit replacement method can further be characterized as follows:

- Excavation is minimized.
- Limited (or negligible) reservoir lowering is often required.
- Often is quicker and cheaper than other methods.
- Generally is limited to straight conduits.
- Results in a decrease in the conduit's discharge capacity (due to the smaller diameter of the new, slip-lined conduit).
- Requires a new slip-lined conduit to handle all internal and external loads (assumes the existing conduit continues to deteriorate and is incapable of providing structural support).
- Should not be used when significant seepage exists along the exterior of the conduit to be

replaced and downstream of the core zone or filter zone (drainage diaphragm or chimney filter), unless an adequate filtered drainage diaphragm is being proposed to handle the seepage (see “Filtered Drainage Diaphragms” in Section 7.1, “Spillway Conduits,” for guidance on the use and design of filtered drainage diaphragms around conduits).

- A new slip-lined conduit may need to be filled with water and may require the use of spacers to keep it from floating to the top of the damaged conduit under the fluid pressure of the grout, as this would prevent a thorough encasement in grout (this is more common with lighter plastic pipe, such as HDPE and PVC).
- Should only be executed by experienced contractors.

Conduits that are significantly dilapidated (especially when there is evidence of eroded embankment material adjacent to the conduit) are not capable of being adequately sealed with the slip-lining method, and other conduit replacement techniques should be considered.

Boring and Horizontal Directional Drilling

Boring (such as microtunneling, pipe jacking, etc.) or horizontal directional drilling typically should not be utilized for conduit installation or replacement within the main section of embankment dams. Although these methods are beneficial because they do not require trenching into the dam embankment for the entire length of the conduit, they are strongly discouraged due to the problems with achieving a watertight seal around the bored conduit, as well as due to the overall disturbance to the embankment structure itself.

Nevertheless, boring or horizontal directional drilling are feasible techniques for conduits that will be located at the abutments or at the foundations of embankment dams, when an experienced and competent contractor is executing the work and strict quality control is being provided.

Repair

Grouting around Conduits

When internal erosion from a piping condition has produced voids along a conduit’s exterior, with uncontrolled seepage occurring along the length of the conduit, it may be possible to reduce the flow to an acceptable level by injecting grout into the voids. Grouting applications may also be utilized to seal leaking or displaced conduit joints.

If a conduit is large enough to provide access, grouting may be applied from inside the conduit (this is especially effective when combined with geophysical methods to identify void locations). Otherwise, grouting operations must be combined with drilling operations and initiated at the embankment’s surface.

Regardless of the specific method of applying the grout, repairs that include grouting around a conduit also require a filtered drainage diaphragm to be installed around the conduit, downstream of the grouting limits, to prevent additional internal erosion (see “Filtered Drainage Diaphragms” in Section 7.1, “Spillway Conduits,” for guidance on the use and design of filtered drainage diaphragms around conduits). It should be noted that grouting around conduits is seldom capable of providing a long-term solution and is typically only able to slow the deterioration.

As with many of the previously mentioned conduit replacement techniques, pressure grouting should only be performed by experienced contractors. If a high degree of quality control is not exercised, pressure grouting can result in the hydraulic fracturing of embankment soils. Many cases of hydraulic fracture due to pressure grouting have been documented, sometimes even with substantial oversight and monitoring of applied grouting pressures.

Additionally, when applying pressure grouting within fine-grained embankment zones, drilling fluids (including water and bentonite) should not be used if possible, as these pumped liquids have the potential to quickly exceed the adjacent overburden pressure, resulting in immediate hydraulic fracture. Here, auger drilling should be used instead of methods that require drilling fluid.

When applying grout from the surface of the dam embankment through drilled holes, it is imperative that the reservoir elevation be lowered, unless the proposed grouting is located far enough on the downstream slope that the projected phreatic water surface (internal to the dam embankment) is not intercepted. Also, when grouting along a substantial length of an existing conduit (other than treating individual voids), drilling and grouting should progress from downstream toward the reservoir. In addition, for significantly large voids that require a large volume of grout to be filled, you should drill secondary holes and apply additional grout, if possible.

Hydraulic Sealants and Conduits

When conduit problems—such as open, displaced, or offset joints, or the cracking of the conduit material—are not significantly advanced to warrant replacement, but enough to warrant repair, the most cost-effective solution may be to seal the affected area(s) with a quality sealant. Nevertheless, this repair method requires the conduit in need of repair to be large enough to allow access.

In selecting a sealant, it is important to choose a product that will serve the intended application. There are many sealants available in today's market, including a variety of epoxies and chemical grouts. Some require dry conditions during application and curing, while some hydraulic sealants, such as hydraulic epoxies, are capable of being applied in a submerged or saturated condition. (Third-generation hydraulic epoxies, or newer, are preferred due to their non-toxic properties, as well as their long shelf life, as they do not crystallize over time).

Abandonment

In some situations, repair or replacement of a conduit is not a viable option due to physical constraints, because of the structural harm from excavating into the embankment, or because it is extremely cost-ineffective. The best option may be to abandon the conduit, fill it with grout, and install a new conduit at an alternate location. As with the slip-lining conduit replacement method, the proper technique for abandoning an existing conduit and filling it with grout should address venting provisions to prevent air pockets from being trapped (see the "Slip Lining" subsection, above).

Also, if there is significant seepage along the exterior of the conduit to be abandoned and downstream of the core or filter zone (drainage diaphragm or chimney filter), then an adequate filtered drainage diaphragm may be necessary to handle the seepage (for guidance on the use and design of filtered drainage diaphragms around conduits, see "Filtered Drainage Diaphragms," in Section 7.1, "Spillway Conduits").

8.2 Embankment Slope Repair and Stabilization

Small-scale slope repairs, including shallow-seated slides, are often conducted as part of an embankment dam's routine operation and maintenance plan (for related guidance, see *Guidelines for Operation and Maintenance of Dams in Texas*). However, when an embankment's side slopes are suffering damage from deep-seated slides, numerous small slides, or persistent recurring slides, it may be necessary to initiate a construction project for substantial repairs to stabilize the embankment.

Methods to address slope repair may include reworking the area and adding select fill, shoring up affected areas, constructing retaining walls, applying rock riprap (sometimes with grout), applying a soil enhancement (lime, fiber-grids, etc.), or flattening embankment slopes. Some of these methods may be more effective as short-term stop-gap measures or emergency repair solutions, and permanent solutions should always be implemented whenever there are safety issues. Additionally, if an embankment has suffered damage such as a sinkhole, then diagnostic efforts should initially take place to identify the cause of the problem before a permanent solution may be implemented.

When proposing to remediate a slide on an embankment slope by reworking the area and placing select fill, care should be taken to over-excavate the slide area and properly incorporate the select fill by scarifying, placing, and compacting it in horizontal lifts of an appropriate thickness.

8.3 Raising an Embankment

Sometimes it is necessary to raise an existing dam embankment to address the issue of hydraulic inadequacy, and such proposed improvements are typically conducted in conjunction with spillway modifications to provide additional discharge capacity. Other times, dam embankments are raised for the exclusive purpose of increasing the storage volume of the reservoir (to accommodate increased water demand, loss of existing storage due to siltation, etc.).

When proposing to raise the height of a dam, it should initially be confirmed that any existing or proposed development will not be negatively affected, such as by an increase in the extent of flooding upstream and adjacent to the dam. Additionally, raising the height of a dam may require corresponding improvements to earthen spillway channels, including raising the height of training berms or addressing issues of erosion stability within the channel. The necessity of such provisions may result from an increase in both the depth and velocity of the spillway's discharge.

A dam embankment's crest is typically raised by providing additional fill, by constructing a parapet wall atop the crest, by adding roller-compacted concrete (RCC), or by a combination of the three.

Additional Fill

When an embankment dam is raised by adding fill to increase the height, it is important to integrate the added fill properly, including any necessary improvements to the upstream and downstream slopes. Unless the existing slopes are flatter than they need to be (to provide adequate structural stability), increasing the height of an embankment dam via additional fill will require an increased footprint for the dam to maintain the existing slopes.

Most often, the grade of the upstream slope is maintained up to the newly established crest elevation, and the downstream slope is modified accordingly. Crest widths should be established to provide adequate structural stability, and excessively steep slopes should be avoided at the edges of the crest where it transitions to the upstream and downstream slopes.

Also, the portion(s) of the existing embankment to receive additional fill should be appropriately scarified (at least 6 inches); the additional fill should be placed and compacted in benched horizontal lifts, including "overbuild" beyond the desired slope (which is necessary to provide stability and to safely conduct future maintenance operations); and any necessary blading should then be made to establish the final desired slope.

When additional fill is used to raise a dam embankment's height, it is also important to consider the added load on the foundation, as well as on structures internal to the embankment, and verify their structural soundness. It is possible that stability issues with the dam may need to be addressed. Also, the added hydrostatic load from any increases in the reservoir's normal pool operating elevation should be taken into consideration along with the extra load from the added embankment material.

Parapet Walls
When compared to the configuration of typical retaining walls, parapet walls require additional considerations and design requirements due to the fact that they are subject to the forces of water on one side (potentially to the full height of the wall, in most cases), with no or minimal earth force on the opposite side to serve as counterbalance. For additional guidance, please see Section 6.4, “Retaining Walls and Related Structural Components.”

Roller-Compacted Concrete (RCC)
In some instances, roller-compacted concrete can be effectively used to raise an embankment dam’s height. This option will allow the added segment to have steep slopes, and this may be an especially viable solution when either the dam’s existing slopes cannot be made steeper (due to safety or stability issues) to allow properly sloped transitions, or when the dam’s footprint cannot be enlarged to accommodate slope improvements. For related guidance on the use of RCC, please see “Overview of Concrete Dam Types and Overall Component Requirements” in Section 6.2, “The Basic Components of Concrete Dams.”

8.4 Overtopping Protection

When an embankment dam is in need of modification to address the issue of hydraulic inadequacy, one option might be to add overtopping protection to the embankment’s crest and downstream slope to safely pass the dam’s requisite design flood. Due to physical constraints, sometimes spillway capacity cannot be increased, an embankment cannot be raised, or a reservoir’s normal storage volume cannot be reduced (to increase storm surcharge capacity), and the addition of overtopping protection will be the most cost-effective option to upgrade the dam to safely pass its requisite design storm.

Should any of the following methods of surface protection be proposed to handle an overtopping event from a dam’s requisite design flood, detailed analyses that demonstrate the surface protection’s ability to do its job without engendering undue erosion will need to be submitted with the construction plans and specifications. This may include an analysis of expected flow velocities from overtopping events, along with documentation on the scouring velocity limits of a proposed surface protection.

A number of viable methods exist to protect the vulnerable slopes of an earthen embankment dam from an overtopping event, including:

- rock riprap
- soil cement
- roller-compacted concrete (RCC)
- geotextile fabrics or mats
- reinforced turf mats
- articulated concrete blocks
- gabions
- a combination of the above methods, including bedding requirements

For other considerations that may possibly be applicable, please see “Surface Protection on Embankment Slopes and Crest” in Section 6.1, “The Basic Components of Embankment Dams.”

8.5 Breaching an Embankment

When a dam embankment’s structure has been compromised, sometimes the safest immediate course-of-action is to perform a controlled breach of the structure in an effort to quickly lower the reservoir and limit the dam’s impounding capability. Whether due to damage from an overtopping event or from a prolonged period of maintenance neglect, or possibly the result of precautionary measures to protect downstream population and property from a hydraulically inadequate spillway capacity, a controlled breach should only be performed under the direct supervision of a professional engineer.

Additionally, controlled cuts into a dam's embankment should not be made along the maximum section, but instead should be made near the abutments. The cuts made into the dam embankment should be of sufficient number and/or size to prevent the dam from impounding water during its requisite design storm and possibly creating hazardous conditions for downstream population and property. Lastly, dams that are intentionally breached or partially breached, which are to be maintained for any significant period of time in a breached or partially breached condition (not conducted as an emergency action), should have adequate sedimentation controls installed downstream.

If it is subsequently decided that a dam is to be removed, then all the requirements and considerations presented in the agency's most current version of the *Dam Removal Guidelines* should be addressed.

Chapter 9. Project Management and Quality Assurance

9.0 Introduction

This chapter includes the minimum requirements and recommended provisions to ensure proper management of dam construction projects, including adequate quality control. Additionally, it establishes the protocol for communication with the TCEQ Dam Safety Program during the life of the construction project, as well as the conditions required for project completion and final acceptance by the State of Texas. Finally, it includes time frames for TCEQ reviews and approvals.

9.1 Notifications, Change Orders, and Record Drawings

Once final construction plans and specifications have been approved by the TCEQ Dam Safety Program, the dam owner's engineer will receive a written approval letter. As stated in Chapter 299, "Dams and Reservoirs," of Title 30 of the Texas Administrative Code (30 TAC 299.22[a][4]), "The owner shall not allow construction of a proposed dam or the reconstruction, modification, enlargement, rehabilitation, alteration, or repair of an existing dam to be commenced before the executive director's review of the final construction plans, specifications, and other engineering reports and the owner receives written approval of the final construction plans and specifications. The owner shall provide a copy of the executive director's written approval to the contractor before commencing construction."

Notifications

Start of Construction

Within ten working days after the construction project has officially commenced (mobilization initiated), or before significant construction effort has begun, the dam owner must have the engineer provide written correspondence to the TCEQ's executive director with the following information, in accordance with 30 TAC 299.24(a):

(1) the actual start date;
(2) the contractor's name and address; and
(3) the name and telephone number of the professional engineer or inspector that will be on-site during construction.

Progress Reports

For all high- and significant-hazard dams, once the construction project is under way, the TCEQ Dam Safety Program must receive on a monthly basis due notification of completed construction activities. These monthly progress reports shall include the following, according to 30 TAC 299.24(b):

(1) the work accomplished during the month;
(2) the percent of the contract time used;
(3) the percentage of completion of the project on the date of the report;
(4) a description of problem areas encountered during construction;
(5) the dates of the reporting period; and
(6) any changes in the contact information.

Closure of Dam

Prior to beginning closure of a dam, the dam owner must furnish due notification to the TCEQ Dam Safety Program. According to 30 TAC 299.27:

(a) The owner shall have a professional engineer submit a written request to close the dam to the executive director for approval before beginning closure of the dam. The request must include:
   (1) a copy of the owner's emergency action plan (for significant and high hazard dams); and
   (2) documentation that all parts of the proposed plan for closure of the dam, as submitted with the construction plans, have been met.

(b) The owner may begin closure of the dam after receiving written approval from the executive director.

(c) The owner shall notify the executive director in writing that the gate operation plan has been completed with the request for closure of the dam (if applicable).

The TCEQ Dam Safety Program will review the closure request and respond within 3 working days after receipt, provided all the required material is included with the request.

Deliberate Impoundment

Prior to beginning deliberate impoundment, the dam owner must furnish due notification to the TCEQ Dam Safety Program. According to 30 TAC 299.28:

(a) The owner of a dam and reservoir designed to impound more than 1,000 acre-feet at normal storage capacity shall submit a written request to the executive director to begin deliberate impoundment of water, as defined in §299.2 (17). The owner shall submit a letter from the owner's professional engineer stating that the dam is substantially complete.

(b) The owner may begin deliberate impoundment after receiving written approval from the executive director.

The TCEQ Dam Safety Program will review the deliberate impoundment request and respond within 3 working days after receipt, provided all the required material is included with the request.

Completion of Construction

Once the dam construction project has reached final completion status, the following notification must be furnished in accordance with 30 TAC 299.29:

(a) The owner shall have the professional engineer of record submit written notification, which is sealed, signed, and dated, to the executive director within 45 calendar days after the work is substantially completed on the construction of a proposed dam or the reconstruction, modification, enlargement, rehabilitation, alteration, or repair of an existing dam. This notification may be submitted separately from the record drawings.

(b) The owner's professional engineer shall state that, to the best of the professional engineer's knowledge, the construction or reconstruction, modification, enlargement, rehabilitation, alteration, or repair was completed in substantial compliance with the approved plans and specifications and any approved construction change orders.

(c) For projects excepted under §299.5. Exception, the owner shall notify the executive director in writing that construction or reconstruction, modification, enlargement, rehabilitation, alteration, or repair was completed.

A copy of the Engineer's Notification of Completion (Form TCEQ-20347) is included in the Appendix of these guidelines.

Changes to Supplemental Engineering Plans

If supplemental engineering plans were included in the construction project's initial submittal package or subsequently required by the executive director per 30 TAC 299.22(d)(2)—including quality control and assurance plans, plans for closure of the dam, or plans for addressing possible emergencies—and were reviewed and approved by the TCEQ Dam Safety Program in conjunction with construction plan approval, these supplemental engineering plans must be adhered to for the full duration of the construction project.

Should any changes be necessary to these plans (such as changes regarding on-site inspection personnel, designated testing laboratories, types and frequencies of tests to be conducted, provisions or sequences for closure of the dam, or emergency management officials to be notified), due notification must be given to the TCEQ Dam Safety Program and the related revised plan(s), or amended portions thereof, must be submitted to the TCEQ Dam Safety Program for review and approval prior to implementing the proposed change(s). The TCEQ Dam Safety Program will respond within 24 hours after receipt, provided that all the required material is included with the request.

Change Orders

When a construction project will necessitate modifications to the approved construction plans and specifications, a change order must accompany the revision, in accordance with the following provisions of 30 TAC 299.26:

(a) The owner shall submit any proposed changes to the approved construction plans and specifications to the executive director for review and approval as a construction change order as defined in §299.1 (13). The construction change order shall be signed, sealed, and dated by a professional engineer.

(b) The owner shall submit a construction change order before work starts on the proposed changes, if possible. If there is an emergency requiring immediate action, a construction change order may be submitted after the work is performed. However, the owner or the owner's professional engineer shall inform the executive director by telephone or electronic mail of the action being taken as soon as the situation allows, but no later than 24 hours after becoming aware of the emergency or the need for a change order. If the time needed for an approval of a change order will require that the construction be halted, the work may be performed once the construction change order is signed, sealed, and dated by the owner's professional engineer and submitted for review. However, if the construction change order is not approved, the owner shall be responsible for having any work performed or modified to reflect the approved construction change order, as needed.

(c) The executive director shall review a construction change order [in accordance with the design and construction practices outlined in these guidelines].

(d) The executive director may request that the owner submit a construction change order if, during construction, the executive director finds that changes to the construction plans and specifications are necessary to ensure the integrity of the dam.

(e) If the proposed construction change order would result in a change in the permitted water rights, the owner shall submit an application for an amendment of the water right permit.

Review Timeframes

Submitted change orders will be reviewed as soon as possible. If a submitted change order does not involve a design change or addition, approval will be granted within 3 working days. However, when a submitted change order does involve a design change or addition, the review may take as long as 20 working days from receipt, after which either written approval will be granted, or a written request for additional information and/or revisions will be furnished. Unless there is a large number of change orders under review, the TCEQ Dam Safety Program attempts to complete reviews in one to two weeks.

Record Drawings

After all phases of construction have been successfully concluded, the dam owner shall furnish record (as-built) drawings to the TCEQ

Dam Safety Program, in accordance with 30 TAC 299.30:

(a) Within six months after final completion of construction, the owner shall submit to the executive director a complete set of record drawings of the project for filing with permanent records. These record drawings must show all revisions made during construction, including the permanent reference mark(s), as per §299.31; be sealed, signed, and dated by the professional engineer; and be identified as final record drawings.

(b) If no changes were made during construction, the owner may submit in writing a statement, which is signed, sealed, and dated by the professional engineer, that no changes were made during construction.

In accordance with 30 TAC 299.23(c), the dam owner shall also record and incorporate into the final record drawings:

(1) final bottom width and elevations of core and cutoff
(2) trenches;
(3) structural excavations;
(4) documentation of permanent sheet piles or bearing piles; and
(5) documentation of foundation grouting, de-watering problems, or observations during the construction period of any instruments installed to measure movements, stresses, and pore pressure.

Final Acceptance of Construction Project

Once the TCEQ Dam Safety Program has received both the engineer's notification of completion, as well as acceptable record drawings for a finished construction project, the TCEQ will provide the dam owner with written notification of the project's acceptance. It should be noted that a construction project cannot be considered complete until a state engineer with the TCEQ Dam Safety Program has approved the project in writing.

9.2 Inspections

Once a construction project has commenced, the dam owner must establish provisions for a professional engineer to oversee quality control of construction, in accordance with 30 TAC 299.4(a)(3). Additionally, 299.25 makes the following stipulations related to construction inspections by both the owner's professional engineer and the TCEQ Dam Safety Program:

(a) The owner shall have a professional engineer, or a qualified inspector, provided the inspector is under the direct supervision of the owner's professional engineer, conduct inspections of the construction work to determine if the work is in compliance with approved construction plans, specifications, and accepted engineering practices.

(b) The executive director may make periodic inspections of the construction to determine if the dam is in compliance with approved construction plans and specifications. If the executive director's inspection reveals that the dam is not being constructed according to the approved construction plans and specifications, the executive director shall notify the owner by telephone within 24 hours and in writing within five days after the inspection of the deficiency items or violations noted. The executive director shall direct the owner to take the necessary action to bring the project into compliance with the approved plans and specifications within 30 days after being notified.

(c) The owner, at the owner's expense, shall submit documentation of the work or tests performed or sufficient information to enable the executive director to determine if conformity with approved plans and specifications is accomplished.

Responsibilities of Qualified Inspectors and Professional Engineers

The professional engineer retained by the dam owner must report directly to the owner. If the owner's professional engineer elects to have a qualified inspector conduct inspections of the construction work to provide quality control on the project and ensure the work is conducted in accordance with the approved construction plans and specifications, that same professional engineer must understand that he or she is ultimately responsible for the inspector's performance.

If the dam owner elects to have a qualified inspector conduct the inspections, then the dam owner must ensure the required supervision of a professional engineer, and the professional engineer must fully understand his or her responsibility.

If it should come to the attention of the supervising professional engineer that the inspector is not adequately performing the required duties or has displayed unsatisfactory behavior with regard to quality control, the supervising professional engineer should see to it that immediate action is taken to rectify the situation.

Additionally, the supervising professional engineer should still make site visits to personally monitor and document the critical stages of construction during the life of the project (for a new dam, these site visits will likely be more frequent in the early stages of construction).

It is up to the owner's professional engineer to determine which events are critical, and it may be necessary to have the project's geotechnical engineer on-site for key stages, especially when unexpected conditions are discovered that differ from those documented in the geotechnical report.

During construction, events deemed critical by the owner's professional engineer may include foundation treatments, completion of the final prepared foundation, the initial placement of core material, major concrete pours, large-gate installations, instrumentation installations, anchor installations, large open-cuts into embankments, spillway conduit slip-linings, borings or tunneling, seal-grouting, and slurry trench installations.

The professional engineer should also make inspections of environmentally sensitive features that could be affected by the construction.

9.3 Testing

As outlined in 30 TAC 299.23(b), "The owner shall furnish copies of the construction test results for high- and significant-hazard dams to the executive director for review at least once a month during the construction period to document compliance with the approved plans and specifications and the requirements in this chapter. The test results to be submitted must include . . .:

(1) soil moisture-density test results;
(2) soil dispersion test results; and
(3) concrete trial batch design test and compression test results."

For dam construction projects (high- and significant-hazard dams, as indicated above) that are required to submit monthly test results to the TCEQ Dam Safety Program, these test results must be in accordance with and reflective of the testing methods and frequency established in the approved construction specifications (see Section 2.2, "Content of Construction Plans and Specifications," for related requirements).

The TCEQ Dam Safety Program must be provided with retest results for all failed tests or documentation that any and all deficient work has been corrected. When a failed density or moisture test for compacted soil requires reworking of the soil and subsequent retesting to be conducted, all retesting shall be conducted on the same lift and within a 5-foot proximity of the initial failed test to be considered valid.

Appendix. Submittal Forms

TCEQ DAM SAFETY

Submittal Package Checklist for Proposed Construction Projects

Note: If you include a copy of this checklist with your submittal package, please designate items that are Not Applicable with "N/A" next to the item's check box.

Overview of Submittal Package: Construction Plans and Specifications

- ☐ Signed and sealed by a licensed Texas professional engineer
- ☐ Final version (not stamped "Preliminary," "For Review Only," etc.), unless being submitted for draft review
- ☐ Complete set (all indexed Plan Sheets accounted for, all necessary Specification Sections included, any referenced Addendums provided, etc.)
- ☐ Plan Sheets include scale, north arrow, and stationing
- ☐ New/Proposed Dam or Major Modification Construction Project:
  - ☐ Information Sheet (Form TCEQ-20345)
  - ☐ Hydrologic and Hydraulic (H&H) Evaluation Summary (Form TCEQ-20346)
  - ☐ Design Report—to assess the proper size and hazard classification of the dam, as well as any applicable Federal Emergency Management Agency (FEMA) floodplain requirements
  - ☐ Geotechnical Report—including stability analyses, if applicable
  - ☐ Hydrologic and Hydraulic Analyses—if applicable
  - ☐ Breach Analyses (with inundation mapping)—if applicable; for dams proposing to pass less than the required design flood
  - ☐ Quality Control Plan
  - ☐ Closure Plan
  - ☐ Plan for Addressing Possible Emergencies
  - ☐ Instrumentation and Monitoring Plan—if applicable
  - ☐ Supplemental Engineering Plans—if applicable, per 30 TAC 299.22(d)(2)
- ☐ Major Repair Project:
  - ☐ Information Sheet: Proposed New Construction, Modification, Repair, Alteration, or Removal of a Dam(Form TCEQ-20345)
  - ☐ Design Report
  - ☐ Geotechnical Report

- ☐ Quality Control Plan
- ☐ Plan for Addressing Possible Emergencies
- ☐ Supplemental Engineering Plan—if applicable, per 30 TAC 299.22(d)(2)

- ☐ Dam Removal Project:
  - ☐ Information Sheet: Proposed New Construction, Modification, Repair, Alteration, or Removal of a Dam (Form TCEQ-20345)
  - ☐ Design Report—to address all considerations outlined in the agency's *Dam Removal Guidelines*
  - ☐ Hydraulic Analysis—if applicable; for permanent breach projects where it needs to be demonstrated that the proposed breach size(s) can handle at least the peak inflow from the dam's design flood without overtopping the dam

Content of Construction Plans

- ☐ Vicinity map of site depicting local streams, highways, railroads, utilities, etc.
- ☐ Topographic map of site with contour intervals not exceeding five feet, with plan view of dam and appurtenances superimposed, and with latitude and longitude of dam's center point (NAD 83 conus datum)
- ☐ Profile(s) of the dam and each spillway along the long axis
- ☐ Cross-section of the dam at maximum section
- ☐ Necessary details and/or sections for structures and appurtenances (control works, spillways, etc.)
- ☐ Location(s) defined for borrow area(s) and stockpiled topsoil, clay, riprap, etc.
- ☐ Location(s) and detail(s) for all necessary instrumentation (piezometers, monitoring wells, staff gauges, pressure cells or transducers, settlement plates, inclinometers, slope indicators, data acquisition systems, etc.—if applicable)
- ☐ Plan for care and diversion of the water (including sedimentation and pollution control—SWP3 provisions); may be included in specifications in lieu of plans
- ☐ Plan for dewatering the foundation(s) and borrow area(s); may be included in specifications in lieu of plans
- ☐ Plan for restoration and/or reseeding of disturbed areas; may be included in specifications in lieu of plans
- ☐ Provision that "Plans and Specifications shall not be substantially or materially altered without prior written approval of the TCEQ's executive director"; may be included in specifications in lieu of plans

Design Considerations

- ☐ Need for seepage control under the dam (cutoff trench, slurry trench, grout curtain, sheet pilings, etc.), through or around the dam (toe drain, drainage blanket, chimney drain, etc.), along conduits (filter diaphragm), and adjacent to concrete structures (relief drains)
- ☐ Exclusion of anti-seep collars as an acceptable method of seepage control along conduits
- ☐ Exclusion of corrugated metal pipe (CMP) as an acceptable conduit material
- ☐ Need for a reservoir drain and/or a low-flow conduit
- ☐ Need for conduit protection (including trash racks on inlets, screens on drain outlets, etc.)
- ☐ Need for venting provisions and/or cavitation protection
- ☐ Need for thrust-blocking on pressure conduits
- ☐ Adequate freeboard (including consideration for wave run-up along the longest reservoir fetch)
- ☐ Protection from wave-action erosion
- ☐ Protection from erosion at or downstream of conduit or channel outlets (concrete headwalls, riprap-lined plunge pools, stilling basins, hydraulic jump basins, energy dissipaters, baffle blocks, etc.)
- ☐ Protection from crest erosion (when vehicular traffic is expected on the crest)
- ☐ Protection from erosion of the downstream toe (as well as from the possibility of tailwater conditions)
- ☐ Erosion stability in earthen spillways (adequate grades for design velocities and the need for erosion control)
- ☐ Need for instrumentation
- ☐ Need for security measures (fencing, gates, locks, lights, cameras, etc.)
- ☐ Proposed scope of work (and/or owner's submitted corrective action plan) addresses deficiencies documented in past TCEQ inspection reports
- ☐ Proposed plan for first reservoir filling (for new dams with a significant- or high-hazard classification)—to include the responsibility and duties of each party while the reservoir is filling, as well as a requirement to obtain written approval of a state engineer from the TCEQ Dam Safety Program prior to the initiation of deliberate impoundment

If a Geotechnical Report is not required for a proposed construction project, then additional design considerations may include those listed under Geotechnical Report (below).

Content of Construction Specifications

(in the case of smaller projects, may be included within Construction Plans)

- ☐ Compatibility with submitted Plans (no conflicting standards, procedures, etc.)
- ☐ Requirements for the various types of materials to be used in the construction project
- ☐ Requirements for installation and workmanship of materials (with reference to acceptable standards)
- ☐ Proper compaction of fill:
  - ☐ Necessity of and requirements for both heavy and hand-operated compaction equipment
  - ☐ Maximum lift thicknesses for heavy compaction equipment and for hand-operated compaction equipment (to be required around concrete structures, beneath conduits, etc.)
  - ☐ Moisture and density requirements
  - ☐ Requirements for horizontal (or "benched") placement and compaction
  - ☐ Requirement for fill to be free of organic or deleterious material
- ☐ Minimum requirements for compressive strength for any cement, slurries, grouts, or structural concrete that is proposed
- ☐ Procedures and techniques for any proposed pressure-grouting in the scope of the work (filling or sealing around slip-lined conduits, conduits to be abandoned, grout curtains, subsurface voids, etc.)
- ☐ Testing frequencies for placed materials (concrete, fill, etc.)
- ☐ Time of completion for the construction project

Geotechnical Report

(if required for the scope of the work in the Plans)

- ☐ Geology of the construction project site and vicinity
- ☐ Test boring (test pit) logs that are representative of the site and comprehensive with respect to site location(s) and depth(s)
- ☐ Results of field and lab tests on structural, foundation, and fill materials
- ☐ Seepage analyses (through or under embankment(s), along conduits, etc.); for new dams with a significant- or high-hazard classification that will permanently impound water
- ☐ Stability analyses of embankments, spillways, retaining walls, etc.; for new dams (and applicable modifications or additions to existing dams) *except* small low-hazard dams with upstream and downstream slopes flatter than or equal to 3 Horizontal to 1 Vertical
- ☐ Presence of dispersive soils, collapsible soils (slaking shales, gravelly materials, etc.), sands susceptible to liquefaction, etc.
- ☐ Shrink and swell potential of site soils
- ☐ Seismic potential

- ☐ Recommendations for:
    - ☐ Foundation and/or abutment adequacy and any necessary preparation and treatment (including concrete footings, concrete piers, drilled shafts, rock anchors, etc.)
    - ☐ Necessity and (if required) configuration (with dimensions) and soil permeability of the embankment core and the core trench
    - ☐ Necessity and (if required) method(s) to control anticipated seepage
    - ☐ Minimum slopes for earthfill and rockfill embankments and/or training levees or berms
    - ☐ Minimum crest width
    - ☐ Expected settlement to occur and account for in over-design of the height(s) of the embankment(s)
    - ☐ Moisture-density and strength requirements of fill
    - ☐ Soil dispersion requirements
    - ☐ Erosion protection (embankment crest, slopes, and groins)
    - ☐ Groundwater control
    - ☐ Sequence of the construction

Texas Dam Safety Program, MC 174
Field Operations Support Division, Office of Compliance and Enforcement
Texas Commission on Environmental Quality
P.O. Box 13087
Austin, TX 78711

INFORMATION SHEET: EXISTING DAM

(PLEASE PRINT OR TYPE)

Reference 30 Texas Administrative Code, Chapter 299, Dams and Reservoirs

SECTION 1: OWNER INFORMATION

Owner's Name ______________________ Title ______________________

Organization ______________________

______________________ ______________________

(Signature of Owner) *(Date)*

Owner's Address ______________________

City ____________ State ____________ Zip Code ____________

Phone Number ( ) ____________ Emergency Contact Phone ( ) ____________

Fax Number ( ) ____________ E-mail ____________

Owner Code *(Please check one)*: ❑ Federal (F) ❑ Local Government (L) ❑ Utility (U) ❑ Private (P) ❑ State (S)
❑ Other (O) please specify: ______________________

Year Built ____________ Year Modified ____________

Dam and Reservoir Use *(Please check one)*: ❑ Augmentation ❑ Diversion ❑ Domestic ❑ Erosion Control
❑ Evaporation ❑ Flood Control ❑ Fire Control ❑ Fish ❑ Hydroelectric ❑ Industrial
❑ Irrigation ❑ Mining ❑ Municipal ❑ Pollution Control ❑ Recreation ❑ Stock Water
❑ Settling Ponds ❑ Tailings ❑ Waste Disposal ❑ Other, please specify: ____________

Engineering Firm ______________________

Project Engineer ____________ Texas P.E. License Number ____________

Engineering Firm Address ______________________

City ____________ State ____________ Zip Code ____________

Phone ( ) ____________ Fax ( ) ____________

E-mail ______________________

SECTION 2: GENERAL INFORMATION

Name of Dam ______________________

Other Name(s) of Dam ______________________

Reservoir Name ______________________

Location ____________ Latitude ____________ Longitude ____________

County ____________ Stream Name ____________

River Basin ____________ Topographic Map No. ____________

Distance & Direction from Nearest City or Town ______________________

Last Inspection Date ____________ Inspected by (name of company or agency) ____________

TX Number ____________ Water Rights Number ____________

Date of Emergency Action Plan (EAP), if one exists ______________________

Describe the current operating condition of dam ______________________

____

If you have questions on how to fill out this form or about the Dam Safety Program, please contact us at 512-239-5195.
Individuals are entitled to request and review their personal information that the agency gathers on its forms. They may also have any errors in their information corrected. To review such information, contact us at 512-239-3282.

SECTION 3: INFORMATION ON DAM

Classification

Size Classification: ❑ Large ❑ Medium ❑ Small
Hazard Classification: ❑ High ❑ Significant ❑ Low
Number of People at Risk ________________ Study Year ____________________

Type of Dam: ❑ Concrete ❑ Gravity ❑ Earthfill ❑ Rockfill ❑ Masonry ❑ Other (specify) __________________

Dam Structure (dimensions to nearest tenth of foot, volume to nearest acre-foot or cubic yard, areas to nearest acre):

Spillway Height ________________ ft *(natural surface of ground to bottom of emergency spillway at longitudinal centerline)*

Embankment Height ____________ ft *(natural surface of ground to crest of dam at centerline)*

Structural Height _______________ ft *(bottom of cutoff trench to crest of dam at centerline)*

Length of Dam _________________ ft Crest Width ____________________________________ ft

Normal Pool Elevation ______________________ ft-MSL Principal Spillway Elevation ___________________ ft-MSL

Emergency Spillway Elevation _________________ ft-MSL Top of Dam Elevation _______________________ ft-MSL

Embankment Volume _______________________________ cu yd

Maximum Impoundment Capacity ____________________ ac-ft *(at top of dam)*

Normal Reservoir Capacity ___________________________ ac-ft *(at normal or conservation pool)*

Reservoir Surface Area _______________________________ acres *(at normal or conservation pool)*

Outlet

Outlet Diameter: ___________________ ❑ in ❑ ft *(check one)*

Type: _____________________________

Principal Spillway

Type: ❑ Natural ❑ Riprap ❑ Concrete ❑ CMP ❑ RCP ❑ Other

Width (Diam.): ____________________ ft Capacity: _____________________ cfs

Emergency Spillway

Type: ❑ Natural ❑ Riprap ❑ Concrete ❑ CMP ❑ RCP ❑ Other

Width (Diam.): ____________________ ft Capacity: _____________________ cfs

Total Spillway Capacity: ____ cfs (crest of the dam)

SECTION 4: HYDROLOGIC INFORMATION

Required Hydrologic Criteria (% PMF) _____________ % PMF Passing ________________________________

PMF Study Year ________________________________

Drainage Area: _________________________________ acres, or __________________________________ sq mi

Curve Number (AMC III condition) ________________

Time of Concentration __________________________ hr

Peak Discharge _________________________________ cfs

Peak Stage ____________________________________ ft-MSL

Storm Duration Causing Peak Stage ________________ hr

Texas Dam Safety Program, MC 174
Field Operations Support Division, Office of Compliance and Enforcement
Texas Commission on Environmental Quality
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Austin, TX 78711

INFORMATION SHEET: PROPOSED NEW CONSTRUCTION, MODIFICATION, REPAIR, ALTERATION, OR REMOVAL OF A DAM

(PLEASE PRINT OR TYPE)

Reference 30 Texas Administrative Code, Chapter 299, Dams and Reservoirs

PLEASE CHECK ONE: ❑ New ❑ Modification ❑ Repair ❑ Removal ❑ Alteration

SECTION 1: OWNER INFORMATION

Owner's Name ______________________ Title ______________________

Organization ______________________

I have authorized the submittal of the final construction plans and specifications to the TCEQ Dam Safety Program according to 30 TAC Chapter 299.

______________________ ______________

(Signature of Owner) *(Date)*

Owner's Address ______________________

City ______________ State ______________ Zip Code ______________

Phone Number ( ) ______________ Emergency Contact Phone ( ) ______________

Fax Number ( ) ______________ E-mail ______________

Owner Code *(Please check one)*: ❑ Federal (F) ❑ Local Government (L) ❑ Utility (U) ❑ Private (P) ❑ State (S)
❑ Other (O) please specify: ______________

Dam and Reservoir Use *(Please check one)*: ❑ Augmentation ❑ Diversion ❑ Domestic ❑ Erosion Control
❑ Evaporation ❑ Flood Control ❑ Fire Control ❑ Fish ❑ Hydroelectric ❑ Industrial
❑ Irrigation ❑ Mining ❑ Municipal ❑ Pollution Control ❑ Recreation ❑ Stock Water
❑ Settling Ponds ❑ Tailings ❑ Waste Disposal ❑ Other, please specify: ______________

Engineering Firm ______________________

Project Engineer ______________ Texas P.E. License Number ______________

Engineering Firm Address ______________________

City ______________ State ______________ Zip Code ______________

Phone ( ) ______________ Fax ( ) ______________

E-mail ______________________

SECTION 2: GENERAL INFORMATION

Name of Dam ______________________

Other Name(s) of Dam ______________________

Reservoir Name ______________________

Location ______________ Latitude ______________ Longitude ______________

County ______________ Stream Name ______________

River Basin ______________ Topographic Map No. ______________

Distance and Direction from Nearest City or Town ______________

TX Number ______________ Water Rights Number ______________

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SECTION 3: INFORMATION ON DAM

Classification

Size Classification: ❑ Large ❑ Medium ❑ Small

Hazard Classification: ❑ High ❑ Significant ❑ Low

Number of People at Risk ________________ Study Year ____________________

Type of Dam: ❑ Concrete ❑ Gravity ❑ Earthfill ❑ Rockfill ❑ Masonry ❑ Other (specify) __________________

Dam Structure (dimensions to nearest tenth of foot, volume to nearest acre-foot or cubic yard, areas to nearest acre):

Spillway Height ________________ ft *(natural surface of ground to bottom of emergency spillway at longitudinal centerline)*

Embankment Height ____________ ft *(natural surface of ground to crest of dam at centerline)*

Structural Height _______________ ft *(bottom of cutoff trench to crest of dam at centerline)*

Length of Dam _________________ ft Crest Width ____________________________________ ft

Normal Pool Elevation ______________________ ft-MSL Principal Spillway Elevation ___________________ ft-MSL

Emergency Spillway Elevation _________________ ft-MSL Top of Dam Elevation _______________________ ft-MSL

Embankment Volume ______________________________ cu yd

Maximum Impoundment Capacity ____________________ ac-ft *(at top of dam)*

Normal Reservoir Capacity ___________________________ ac-ft *(at normal or conservation pool)*

Reservoir Surface Area ______________________________ acres *(at normal or conservation pool)*

Outlet

Outlet Diameter: ___________________ ❑ in ❑ ft *(check one)*

Type: _____________________________

Principal Spillway

Type: ❑ Natural ❑ Riprap ❑ Concrete ❑ CMP ❑ RCP ❑ Other

Width (Diam.): ____________________ ft Capacity: _____________________ cfs

Emergency Spillway

Type: ❑ Natural ❑ Riprap ❑ Concrete ❑ CMP ❑ RCP ❑ Other

Width (Diam.): ____________________ ft Capacity: _____________________ cfs

Total Spillway Capacity: ____ cfs (crest of the dam)

SECTION 4: HYDROLOGIC INFORMATION

Required Hydrologic Criteria (% PMF) _____________ % PMF Passing ________________________________

PMF Study Year ________________________________

Drainage Area: ________________________________ acres, or __________________________________ sq mi

Curve Number (AMC III condition) _______________

Time of Concentration __________________________ hr

Peak Discharge ________________________________ cfs

Peak Stage ___________________________________ ft-MSL

Storm Duration Causing Peak Stage _______________ hr

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Austin, TX 78711

HYDROLOGIC AND HYDRAULIC (H&H) EVALUATION SUMMARY

(Please complete **all** sections, unless otherwise specified)

Name of Dam: ____________________

TCEQ Dam Safety Project No.: ____________________

County: ____________________

Year to Build: ____________________

Maximum Record Precipitation (in): ____________________

Record Area (county or city): ____________________

Duration (hr): ____________________

Date of Record (MM/DD/YY): ____________________

Source Ref. (FEMA, National Weather Service, etc.): ____________________

Downstream Dam Toe ____________ (ft-MSL)

Normal Pool ____________ (ft-MSL)

Principal Spillway ____________ (ft-MSL)

Emergency Spillway ____________ (ft-MSL)

Top of Dam ____________ (ft-MSL)

Normal Reservoir Capacity ____________ (ac-ft)

Maximum Reservoir Capacity ____________ (ac-ft)

Reservoir Surface Area ____________ (ac)

Drainage Area ____________ (ac)

Outlet Diameter or Cross-Section ____________ (in)

Storm Duration	Peak Inflow (cfs)	Peak Outflow (cfs)	Peak Stage (ft-MSL)	% PMF Passing	Comments (if needed)
1 hr					
2 hr					
3 hr					
6 hr					
12 hr					
24 hr					
48 hr					
72 hr					

To the best of my knowledge, I certify the above data are correct. I will supply the hydrologic and hydraulic reports to the Texas Commission on Environmental Quality upon request.

____
(Signature)

(P. E. Seal)

____
(Date)

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Texas Commission on Environmental Quality
P.O. Box 13087
Austin, TX 78711

ENGINEER'S NOTIFICATION OF COMPLETION

(PLEASE PRINT OR TYPE)

PLEASE CHECK ONE: ❑ New ❑ Modification ❑ Repair ❑ Removal ❑ Alteration

TX Number ______________________ County ______________________

Adjudication Number ______________________ Permit Number ______________________

Name of Dam/Project ____

Owner:

Name ____

Address ____

City ______________________ State __________ Zip Code __________

Phone (   ) ______________________ Emergency Contact Phone (   ) __________

Fax (   ) ______________________ E-mail ______________________

Engineering Firm:

Firm Name ____

Project Engineer ______________________ TX P.E. License No __________

Firm Address ____

City ______________________ State __________ Zip Code __________

Phone (   ) ______________________ Fax (   ) ______________________

E-mail ____

The project was completed on ____________, 20_____. To the best of my knowledge, the project was constructed in substantial conformance with plans, specifications, and change orders filed with and approved by the Texas Commission on Environmental Quality.

____
(Signature)

(P. E. Seal)

____
(Date)

If you have questions on how to fill out this form or about the Dam Safety Program, please contact us at 512-239-5195.
Individuals are entitled to request and review their personal information that the agency gathers on its forms. They may also have any errors in their information corrected. To review such information, contact us at 512-239-3282.

Dam Safety Terms

Most of the definitions printed here were taken verbatim from 30 TAC 299.

accepted engineering practices The application of design and analysis methods that are commonly used by professional engineers in their field of expertise and are well documented in published design manuals, codes of practice, text books, and engineering journals.

alteration Any change to a dam or appurtenant structures that affects the integrity, safety, and operation of the dam.

appurtenant structures The outlet works and controls, spillways and controls, gates, valves, siphons, access structures, bridges, berms, drains, hydroelectric facilities, instrumentation, and other structures related to the operation of a dam.

breach An excavation or opening, either controlled or a result of a failure of the dam, through a dam or spillway that is capable of draining the reservoir down to the approximate original topography so the dam will no longer impound water, or partially draining the reservoir to lower impounding capacity.

breach analysis The determination of the most likely uncontrolled release of water from a dam (magnitude, duration, and location), using accepted engineering practice, to evaluate downstream hazard potential.

closure of dam The commencement of placing material within the closure section of the dam.

closure section The section of the dam left open during construction of a proposed dam in order to pass floodwaters through the dam without endangering the dam.

commence construction An actual, visible activity beyond planning or land acquisition that initiates the beginning of the actual construction of a dam in the manner specified in the approved construction plans and specifications for that dam; the action must be performed in good faith with the intent to continue with the construction through completion.

conceptual design A design that presents a location and proposed plan of the dam and appurtenant structures and elevations of all pertinent features of the dam.

conduit settlement ratio The ratio of the settlement estimated beneath a conduit divided by the settlement estimated to the side of a conduit.

construction Building a proposed dam and appurtenant structures, capable of storing water.

construction change order A document recommended by the owner's professional engineer and signed by the owner's contractor and the owner that authorizes a significant addition, deletion, or revision of the approved construction plans and specifications that has a material impact on the safety and integrity of the dam.

dam Any barrier or barriers, with any appurtenant structures, constructed for the purpose of either permanently or temporarily impounding water.

dam failure A breach and uncontrolled release of the reservoir.

deficient dam A dam that fails to meet the requirements of Chapter 299 and poses a significant threat to human life or property.

deliberate impoundment The intentional impoundment of water in the reservoir.

design flood The flood used in the design and evaluation of a dam and appurtenant structures, particularly for determining the size of spillways, outlet works, and the effective crest of the dam.

detention dam A dam that is normally dry and has an ungated outlet structure that is designed to completely drain the water impounded during a flood within five days.

drawdown The change in surface elevation of the reservoir due to a withdrawal of water from the reservoir.

effective crest of the dam The elevation of the lowest point on the crest (top) of the dam, excluding spillways.

emergency action plan (EAP) A written document prepared by the owner or the owner's professional engineer describing a detailed plan to prevent or lessen the effects of a failure of the dam or appurtenant structures.

emergency repairs Any repairs, considered to be temporary in nature, necessary to preserve the integrity of the dam and prevent a possible failure of the dam.

emergency spillway An auxiliary spillway designed to pass large, but infrequent, volume of flood flows, with a crest elevation higher than the principal spillway or normal operating level.

engineer of record The professional engineer who obtains construction plan and specification approval from the TCEQ Dam Safety Program.

engineering inspection Inspection performed by a professional engineer, or under the supervision of a professional engineer, to evaluate the safety and integrity of the dam and appurtenant structures to determine if the dam and appurtenant structures meet applicable rules and accepted engineering practices, including a field inspection and review of records for design, construction, and performance.

enlargement Any change in, or addition to, an existing dam or reservoir that raises, or may raise, the normal storage capacity of the reservoir impounded by the dam.

existing dam Any dam under construction or completed as of the effective date of these rules.

fetch The straight-line distance across a reservoir subject to wind forces.

fines Finely crushed or powdered material (as ore); especially : material finer than the minimum for any specified grade or passing through a screen on which the coarser material is retained.

fish ladder An appurtenant structure on or around a dam to facilitate some fish species' natural upstream migration. A fish ladder typically consists of a series of relatively short steps with water cascading down them at a depth and velocity that will allow the fish to swim upstream by leaping up the steps; also referred to as "fish passes" or "fish steps."

hazard classification A measure of the potential for loss of life, property damage, or economic impact in the area downstream of the dam in the event of a failure or malfunction of the dam or appurtenant structures; the hazard classification does not represent the physical condition of the dam.

height of dam The difference in elevation between the natural bed of the watercourse or the lowest point on the toe of the dam, whichever is lower, and the effective crest of the dam.

inundation map Map delineating the area that would be flooded by a particular flood event, or a dam failure.

maintenance Those tasks that are generally recurring and are necessary in keeping the dam and appurtenant structures in a sound condition, free from defect or damage that could hinder the dam's functions as designed, including adjacent areas that also could affect the function and operation of the dam.

maintenance inspection Visual inspection of the dam and appurtenant structures by the owner or owner's representative to detect apparent signs of deterioration, other deficiencies, or any other areas of concern.

maximum normal operating level The highest water surface elevation within the range of planned operating levels for the reservoir, above which floodwaters would be released.

maximum storage capacity The volume, in acre-feet, of the impoundment created by the dam at the effective crest of the dam; only water that can be stored above natural ground level or that could be released by a failure of the dam is considered in assessing the storage volume; the maximum storage capacity may decrease over time due to sedimentation or increase if the reservoir is dredged.

minimum freeboard The difference in elevation between the effective crest of the dam and the maximum water surface elevation resulting from routing the design flood appropriate for the dam.

modification Any structural alteration of a dam, the spillways, the outlet works, or other appurtenant structures that could influence or affect the integrity, safety, and operation of the dam.

music-note rubbing seal A gate seal whose cross-section is shaped like a music note (the bulb-portion of the seal may be solid or hollow); also referred to as a “J-bulb” seal.

normal storage capacity The volume, in acre-feet, of the impoundment created by the dam at the lowest uncontrolled spillway crest elevation, or at the maximum elevation of the reservoir under normal (non-flooding) operating conditions.

outlet A conduit or pipe controlled by a gate or valve, or a siphon, that is used to release impounded water from the reservoir.

piping The progressive removal of soil particles from a dam by percolating water, leading to development of channels or flow paths.

population at risk The number of people present in an area that would be flooded by a particular flood event, or a dam failure.

principal spillway The primary or initial spillway engaged during a rainfall runoff event that is designed to pass normal flows.

probable maximum flood (PMF) The flood magnitude that may be expected from the most critical combination of meteorological and hydrologic conditions that are reasonably possible for a given watershed.

probable maximum precipitation (PMP) The theoretically greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year.

professional engineer An individual licensed by the Texas Board of Professional Engineers to engage in the practice of engineering in the State of Texas, with expertise in the investigation, design, construction, repair, and maintenance of dams.

proposed dam Any dam not yet under construction.

pumped storage dam A rectangular or circular embankment used to store water pumped from another source.

reconstruction Removal and replacement of an existing dam or appurtenant structures.

rehabilitation The completion of all work necessary to extend the service life of a dam and meet the safety and performance standards of these guidelines.

removal The complete elimination of a dam, the appurtenant structures, and the reservoir to the extent that no water can be impounded by the dam or reservoir and the approximate original topography of the dam and reservoir is restored.

repairs Any work done on a dam that may affect the integrity, safety, and operation of the dam.

reservoir A body of water impounded by a dam.

safe manner Operated and maintained in sound condition, free from defect or damage that could hinder the dam’s functions as designed.

seal To affix a professional engineer’s seal to each sheet of construction plans or to an engineering report or [other] required document.

spillway An appurtenant structure that conducts outflow from a reservoir.

stability analysis The analytical procedure of determining the most critical factor of safety.

substantially complete A dam under construction that is complete except for minor correction of items identified in the final construction inspection and that can be operated in a safe manner to the dam’s full functional capability.

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