8

Constructing a Levee

Key Messages

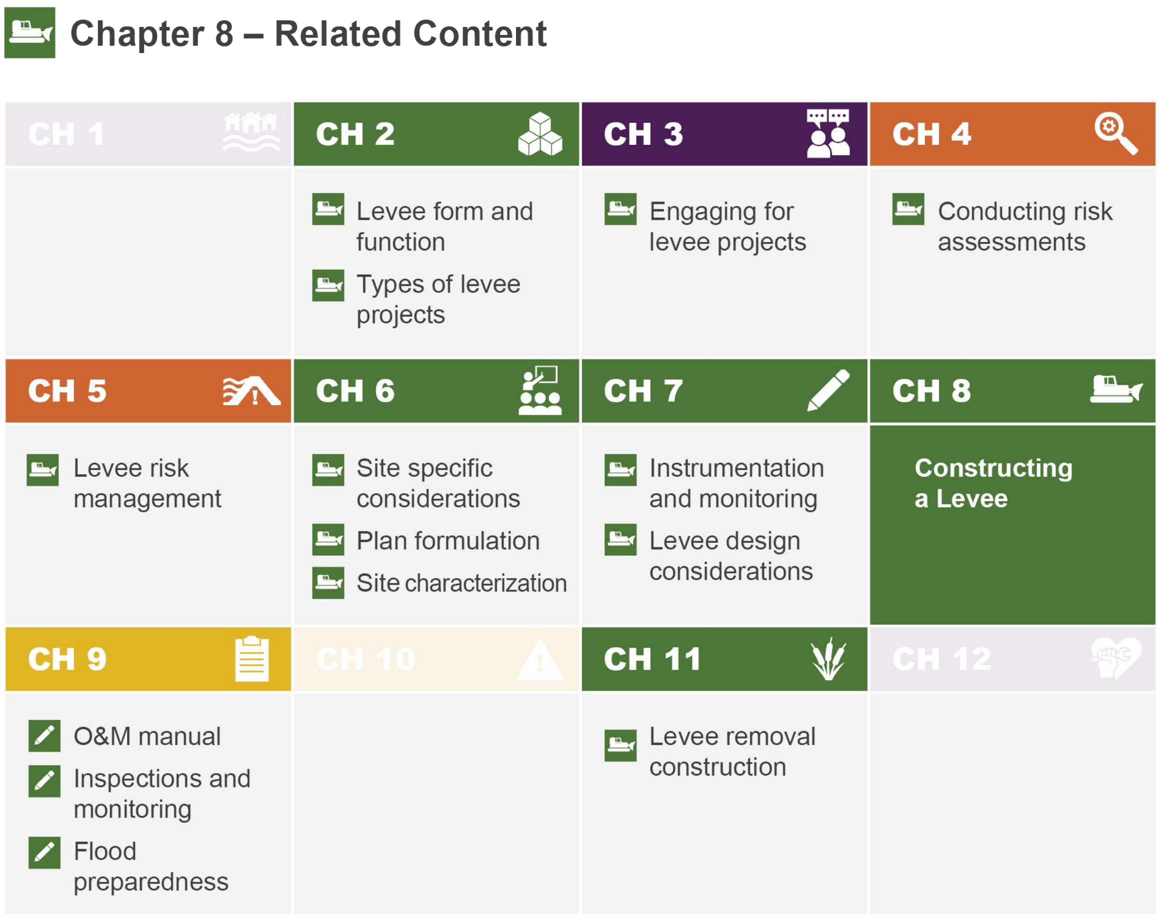
This chapter will enable the reader to:

- **Coordinate.** The coordination of information between levee formulation, design, and construction is vitally important throughout a levee construction project to ensure success.
- **Manage risks.** Flood risk during construction and risks to levee construction (time, quality, cost, safety) should be assessed, communicated, prepared for, and mitigated.
- **Expect variability.** Levee construction projects vary in size and complexity. It is important to understand the procedures and equipment unique to each project feature.
- **Maintain records.** Clear documentation is important to ensure a smooth transition from levee construction to levee operation.


LEVEETOWN, USA

Other chapters within the National Levee Safety Guidelines contain more detailed information on certain topics that have an impact on constructing a levee, as shown in Figure 8-1. Elements of those chapters were considered and referenced in the development of this chapter and should be referred to for additional content.

Figure 8-1: Related Chapter Content



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1 Introduction

The purpose of this chapter is to present the underlying principles, best practices, and situation-specific considerations for constructing levee features. Activities spanning the entire construction lifecycle—preparing for levee construction, constructing the levee, and closing-out construction—are described, emphasizing practices that result in effective levee performance and serviceability. The inherent linkages with project formulation, design, and operation and maintenance (O&M) are addressed early in the chapter to underscore the importance of continuity. Guidance related to managing construction risks, in addition to environmental, cultural, and natural resource impacts, is also covered. The guidance in this chapter is for use by qualified levee designers, constructors, and owners, and these best practices should be applied for the construction of new and existing levee features.

2 Construction Principles and Process

The levee construction phase is vital to ensuring project objectives are met. It involves the physical build of a new levee feature, modification, or rehabilitation of an existing levee feature. Levee construction is often complex, requiring a significant investment of resources (e.g., funds and labor).Levee construction activities, when done improperly, can negatively impact levee performance and **flood risk** to communities, environmental and natural resources, and surrounding critical public infrastructure such as utilities and roadways. It is important for any levee construction project or activity to achieve the following goals:

- Construct the levee project as planned to achieve the intended flood risk reduction benefits, as well as the co-benefits of the levee project.
- Construct the levee project in a cost effective and timely manner.
- Conduct levee construction activities in a manner that minimizes and reduces impacts to environmental, cultural, and natural resources.
- Conduct levee construction activities in a manner to avoid or reduce disruption to local residences, businesses, and industries.

There are many different types of levee construction projects that vary in size and complexity. Each project has a unique set of objectives, constraints, and stakeholders with a vested interest in the project. To achieve the goals of levee construction, it is important to understand the intricate relationship between levee construction activities and the levee project objectives, constraints, and stakeholders involved. The next sections describe key aspects of successful levee construction.

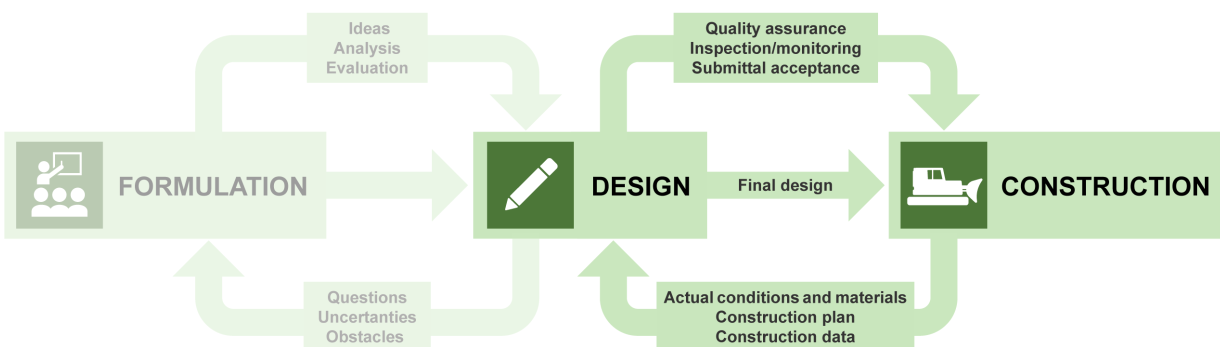
2.1 Relationship Between Formulating a Levee Project, Levee Design, and Levee Construction

The coordination of levee project information between levee formulation, design, and construction ensures a successful project, as follows:

- Formulating the levee project establishes the objectives and constraints of the project using methods described in **Chapter 6**.
- Levee design defines and conveys the levee project scope based on the objectives and constraints using the methods described in this chapter and **Chapter 7**.
- Levee construction involves building the physical structure (e.g., levee, floodwall) based on the project design specifications.

This relationship between levee formulation, design, and construction is shown in Figure 8-2 and emphasizes the relationship between design and construction, including activities and information that is shared between the project phases. Details on these activities are discussed later in this chapter.

Figure 8-2: Relationship Between Levee Project Phases



2.2 Community Engagement During Construction

Engaging community members and impacted stakeholders during construction is beneficial to the project. The engagement increases the likelihood that projects will be widely accepted and helps to create solutions for project constraints that are practical and effective since they draw on local knowledge.

Communication and engagement should be initiated during the levee formulation process and continue throughout levee design and construction (Figure 8-3). Communication during construction should be accurate, timely, and transparent, especially in regard to possible stakeholder disruptions. It is a best practice to understand and take into consideration the unique interests of stakeholders, including but not limited to:

- Adjacent property owners.
- Residents, industries, and business owners of nearby communities.

- Environmental and cultural resources and regulatory agencies.
- Public utility entities (e.g., electrical, water, gas).
- Transportation entities (e.g., road, highway, railroad).

Common questions that stakeholders may ask during construction include:

- Will this project impact or damage my property?
- Will this project disrupt my utilities?
- Will this project disrupt access to my property and/or roads and commute routes?
- Will this project cause damage to the existing levee and increase my flood risk?
- Could this project negatively impact environmental and cultural resources?
- Could this project negatively impact my business or industry?

Refer to **Chapter 3** on best practices for engaging stakeholders and the community for levee projects.

Figure 8-3: Example of Community Engagement

A passing cyclist stops to learn more about improvements to the Sacramento area flood risk reduction system. The displays were part of an April 8, 2016 ceremony where federal, state, and local leaders announced the completion of 22 miles of levee improvements along the American River.

2.3 Types of Levee Construction Projects

Types of levee construction projects can vary in size and complexity; therefore, it is important to understand the different types of projects and the unique considerations for each. The various types of projects include:

- **New levee construction:** Construction of a new levee where no man-made levee features currently exist (Figure 8-4).

- **Levee modification:** An activity that changes the original (e.g., as designed) operation and function of a levee.
  - Example modifications that change the levee function may include raising the levee height or modifying its alignment.
  - Example modifications that change the levee operation may include adding or removing features (e.g., interior drainage, seepage control systems, pipes, gates).

- **Levee rehabilitation:** An activity that restores a levee to its original (e.g., as designed) operation and function. Rehabilitation may be needed due to damage, deterioration, or deficiencies that result in improper levee performance. Rehabilitation is more substantial than normal maintenance and is typically not routine in nature. Examples of levee rehabilitation may include replacement of pipes, pumps, and other significant components; restoration of the levee cross section; and addressing performance issues (e.g., seepage, stability, erosion) that are preventing the levee from functioning as intended.

Figure 8-4: Example of a Levee Construction Project

The Marysville Ring Levee in 2011, with nearly completed portions in the distance, separates the roads and town of Marysville, California, on the left, from the floodplain of the Yuba River on the right.

Table 8-1 shows the typical attributes for the different types of levee construction projects.

Table 8-1: Typical Attributes for Levee Construction Projects

Type of Levee Construction Project	Typical Attributes
New levee construction	• Scope and scale can vary widely depending on the size and types of levee features. • May require multiple constructors with various specialties. • Site condition (access, utilities, foundation conditions) uncertainty may be high.
Levee modification	• Scope and scale can vary widely depending on the degree of modification. • Maintaining the existing levee's flood risk reduction function is typically required during construction. • Site condition (access, utilities, foundation conditions) uncertainty may be lower.
Levee rehabilitation	• Scope and scale can vary widely depending on the degree of rehabilitation. • Less permitting may be required as the work typically occurs within previously permitted areas. • Maintaining the existing levee's flood risk reduction function is typically required during construction.

2.4 Levee Construction Process

For any type of levee construction project, the levee construction process can be divided into three general phases—preparing for levee construction, constructing the levee, and levee construction closeout.

Preparing for levee construction starts during project design and ends when a constructor has been identified. Proper preparation for levee construction will help ensure the success of the project. Some important questions that should be answered during this phase include:

- What is the scope and cost of the levee construction project?
- Are there enough funds available for levee construction?
- How will the levee constructor be selected?
- How will the levee project constraints be addressed during levee construction?

Constructing the levee begins when the levee constructor starts work on the project and ends when construction is near completion. Proper execution of the project scope is vital to ensuring the levee satisfies its intended objectives. Some important questions that should be answered during this phase include:

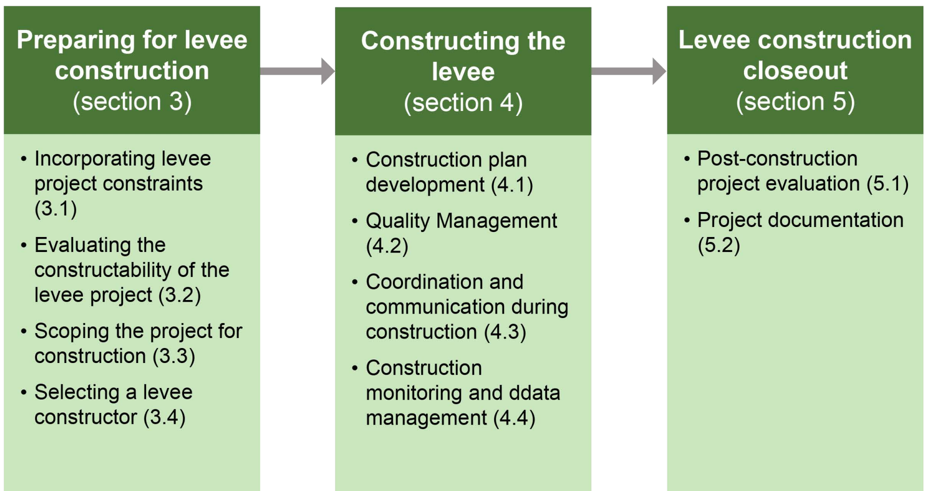
- What type of labor, equipment, and materials is needed for the construction project?
- How will site safety—including public safety—be maintained?
- How will quality be controlled and assured during the construction work?
- How will completed work be maintained during the identified warranty period?

Levee construction closeout is the final phase of the levee construction process. This phase begins when the construction is near completion and ends when the constructed levee is placed into operation. Some important questions that should be answered during this phase include:

- Does the constructed levee meet the intended objectives?
- Has all construction documentation been collected and stored properly for future use?
- Is there sufficient understanding and documentation on how to properly operate and maintain the levee?
- Have all the parties that will be involved in levee management activities been coordinated with and given sufficient information to fulfill their roles?

The levee construction process is summarized in Figure 8-5. The following sections of the chapter will provide best practices on how to successfully implement each phase of the process.

Figure 8-5: Levee Construction Process



3 Preparing for Levee Construction

As stated previously, proper preparation for levee construction will help ensure the success of the project. The main topics that are covered in preparing for construction include:

- Incorporating project constraints into levee construction.
- Ensuring the levee project is constructable.
- Preparing documents for levee construction.
- Selecting a levee constructor.

3.1 Incorporating Levee Project Constraints

There are a variety of levee project constraints that require proper planning to ensure they are addressed and do not negatively impact construction (e.g., costs and schedule). The following is a list of common constraints that should be considered during levee construction:

- Access and right of way
- Borrow areas
- Cultural resources
- Environmental considerations
- Hazardous waste
- Noise, vibration, and lighting

- Permits
- Utilities
- Weather and climate

3.1.1 Access and Right of Way

Access and right-of-way constraints can adversely impact construction due to the inability to access the construction site and/or having insufficient right of way to properly construct the levee. These should be obtained prior to the start of construction.

Recommended access and right-of-way best practices include:

- Proactive traffic management coordination with the local municipality, highway authority, railroads, or regulatory body to minimize delays during construction. See section 4.1.3 for information on managing traffic during construction.
- Development and implementation of a public engagement approach using multiple media approaches (i.e., meetings, websites, call-in numbers) (**Chapter 3**).
- Begin the permitting process as early as possible involving all necessary parties and regulatory agencies, including the acquisition of all necessary access agreements or permits and compliance with any restrictions imposed.
- All areas required for construction activity should be acquired before construction.
- Consider compulsory purchase of access and construction areas as an approach of last resort unless there are long-term maintenance benefits.

Access routes for construction may include over land and by water both to and from the levee construction site, borrow area, and material handling area (Figure 8-6). These typically consist of permanent or temporary routes. Adequate access routes are critical to ensure that construction materials can be delivered on time, and labor and equipment costs are kept within budget. Inadequate access routes can severely affect the overall construction schedule and pose potential safety hazards. Regular maintenance of haul or access roads should be performed during construction to minimize the risk of delivery interruptions during construction.

Figure 8-6: Example of Construction Access

The levee constructor pre-positioned earthern material to fill an old ditch and build seepage berms adjacent to a levee in Greene County, Arkansas. In the background, heavy equipment operators continue to maneuver material for the project; August 2021.

Access routes should:

- Have the ability to withstand construction equipment loads.
- Provide adequate space for the movement and maneuvering of heavy equipment required for construction.
- Provide a safe working environment and ensure the safety of the public.
- Not violate local planning restrictions on noise, vibration, and air quality.
- Not create significant interference to normal traffic flow.
- Have adequate clearance between the roadway and overhead utilities and not endanger buried utilities due to traffic loads.
- Provide access routes to allow for material delivery at points along the length of the entire project.

3.1.2 Borrow Areas

Borrow areas are utilized to provide the earthen material necessary for the levee project. Further discussion on this topic is included in **Chapters 6 and 7**. The levee owner may identify suitable earthen borrow sources to be used during construction or may allow the constructor to identify sources and demonstrate material suitability through the submittal process. Sampling and testing of material in borrow sources is important to avoid delays and increased construction costs. Testing can include test pits that cut down through the soil, to provide representative samples of blended materials, if blending is needed to meet the material requirements. Borrow areas should be capable of providing a minimum of 120% to 150% of the quantity required to construct the project. Selection of suitable borrow areas requires compliance with engineering specifications, as well as environmental, cultural, and water quality laws and regulations.

In general, properly selected and designed borrow areas should satisfy the following:

- Not adversely impact the reliability (i.e., increase the potential for levee underseepage, instability, erosion) of the levee project during and after construction.
- Contain suitable earthen material for the entire levee project.
- Be in compliance with local, state, and federal laws and regulations often related to environmental resources, cultural resources, and water quality.
- Be accessible (i.e., ingress and egress rights are not inundated by flood waters) during the construction of the levee project.
- Have locations and configurations that are optimized to minimize levee project construction costs.

Refer to the United States Army Corps of Engineers (USACE) Engineer Manual (EM) 1110-2-1913 (USACE, 2000a) for best practices regarding the selection and design of borrow areas for levee projects.

3.1.3 Cultural Resources

Cultural resource assessments should be conducted during the formulation stage of a levee project (**Chapter 6**). If significant cultural resources are within the levee project area, the following are common activities that should take place prior to and during construction:

- Secure agreements (may include permits) with federal, state, and cultural or tribal organizations prior to work in the area to ensure any potential damage is mitigated.
- Train construction staff on the cultural resources within the project area and methods that are used to reduce impacts.
- Monitor (part time or full time) and consult with cultural resource experts during construction.

Cultural monitoring may be required, as well as coordination with tribal representatives, throughout the project formulation and construction. Cultural resource issues may affect the levee constructor’s plan and schedule; therefore, proactive communication between all stakeholders should be maintained to minimize work being stopped or significant delays.

3.1.4 Environmental Considerations

Environmental considerations are important for many levee construction projects. Levees are often located in areas with environmentally sensitive area protection and/or with protected and endangered species and associated habitats (Figure 8-7). An environmentally sensitive area often requires restrictions on sound, duration, working days and hours, accessibility of terrains, vibrations, dust, light pollution, and temporary changes of groundwater level. A list of common environmentally sensitive areas include:

- State and national parks
- Wetlands
- Habitat for threatened and endangered species
- Monuments and protected landscapes
- Biodiversity habitats and species
- Polluted areas or areas with hazardous waste
- Forest preservation areas

Permits are often required for levee construction activities in environmentally sensitive areas. Refer to section 3.1.7 for more information on permits for levee construction.

Figure 8-7: Sign for an Environmental Protection Area

Sign indicating a native growth protection area in Snohomish County, Washington.

3.1.5 Hazardous Materials

Unknown hazardous materials are a construction risk. Investigations for hazardous materials (see **Chapters 6 and 7**) should be performed during project formulation and design to characterize and map the materials and develop plans for avoidance or removal and disposal.

All parties should be aware of the nature of hazardous materials and develop appropriate life safety precautions for project personnel working with or near the hazardous materials.

3.1.6 Noise, Vibration, and Lighting Considerations

Levee construction can induce to adverse impacts associated with noise, vibration, and lighting restrictions due to:

- The inherent nature of the construction activity (e.g., excavation, loading, hauling, compaction, rock unloading, and piling installation).
- The fact that water is acoustically ‘hard’ (i.e., sound waves move over water rather than penetrate).
- The close proximity of the public.
- The close proximity to environmentally sensitive areas.

Conflict may arise due to the need to maximize the use of a floating or marine plant and the need to optimize the time windows available for desirable hydraulic conditions, such as tidal conditions in coastal sites. These time windows can occur outside of acceptable working hours, which can lead to an increased number of public complaints.

On some projects, the working hours for noisy operations are defined within the construction documents, although there may be opportunities for extending working hours through coordination with impacted stakeholders. Extensions to working hours may be critical to achieving an effective and efficient construction schedule (particularly on projects that are impacted by tidal conditions). The effect of working hours on the public should be carefully considered and extensions outside acceptable working hours should be avoided as far as practicable. When extended working hours are necessary, affected members of the public should be advised in advance with information regarding duration and the need for the construction work during those times.

In addition to the adjustment of working hours when construction work is taking place, the following measures should be considered:

- Effective noise suppression for all activities, including ensuring all vehicle noise reduction equipment and silencers are fully operational.
- Schedule intrusive activities at less sensitive times within the allowable working day based on needs of the community (including the tourist industry and business). For example, schedule deliveries outside the morning and evening rush hour.
- Consider the effect of noise on the natural environment, such as on birds in the breeding season.

Vibration due to construction activities may have negative impacts on properties of adjacent landowners, residents, and business owners. Where possible, agreement on reasonable vibration damage arrangements should be sought before the project starts. Depending on the project scope, setting, and local regulatory environment this might include agreement on:

- Use of noise meters, parameters to be monitored, and administrative procedures.
- Pre-construction structural monitoring and assessment.
- A vibration monitoring program, if appropriate.

Lighting is essential for many activities to maximize construction working hours, including the use of machinery and to provide suitable working conditions. Lighting can also be used as a deterrent to vandalism. However, light can be a source of annoyance to residents, so it is important to keep site lighting at the minimum brightness necessary for adequate security and safety. The lighting should be located and directed so that it does not intrude on any properties nearby and the use of infrared lighting for security should be considered. Wildlife can also be disturbed by artificial lighting such as sea turtles near beaches.

3.1.7 Permits

Permits are generally required for levee construction. Permits may be required for the use of land, construction activities in environmentally sensitive areas, and transportation of levee construction equipment and materials. Failure to anticipate permitting requirements for the levee construction project can result in adverse impacts to construction schedules and potential legal actions and resulting fines for the constructor or claims to the levee owner. Prior to initiation of construction, a review should be conducted to identify all permits required to construct the levee project. Upon completion of a preliminary set of plans that show the footprint of all levee features with necessary O&M corridors, permit requirements should be identified and permit pre-application discussions should occur with appropriate regulatory authorities.

Permit requirements and responsibilities should be included in the construction documents. Application for permits and licenses should be initiated well in advance to provide adequate time to complete the permit process. Extensive data collection and analyses may be required to accommodate proposed construction activities or acquisition of additional land necessary for construction. If there are any deviations from the original construction documents, relevant regulatory organizations should be contacted to determine how the changes impact requirements for licenses and permits.

More information is provided in the next sections on the aspects of common permits for levee construction.

3.1.7.1 Permits for Use of Land

Proper land acquisition is critical to the success of the construction project and should be planned accordingly. The constructor may determine that lands proposed for levee construction by the levee owner are inadequate to facilitate the preferred construction activities. Constructor preferred routes and lands may be subject to local restrictions. However, the local community may issue temporary permits under special circumstances that include landowner consent, financial reimbursement guarantees, and security bonds.

Temporary permits may be necessary for:

- Rights of way and permission for borrow and temporary material sorting areas.
- Construction of haul roads across floodplains.
- Expansion of rights of way adjacent to levees for increased equipment access.
- Additional lands required for temporary material unloading and storage capabilities.
- Alternative borrow and/or disposal areas not designated in the construction documents that will provide more material or will shorten haul time.

3.1.7.2 Permits for Transportation of Equipment and Material

Levee construction often requires the transportation of construction equipment and materials on public roads, highways, waterways, and railways. This may require permits for construction from local, state, and federal agencies to utilize these public transportation routes. A list of common levee construction activities that may require a permit to transport equipment and materials is provided below:

- Transport of large equipment on specialized carriers.
- Waivers of restrictions that limit vehicle size, wheel weight, and wheel type to use city and rural roadways.
- Cross railway lines and bridges.
- Temporary construction activities or within or adjacent to an existing road or utility.
- Temporary road closures to transport equipment.

3.1.7.3 Permit for Environmental Impacts and Compliance

Levee construction activities should comply with jurisdictional local, state, and federal regulations for air and water quality, as well as restrictions on construction activities in environmentally sensitive areas. Water and air quality requirements may vary with location along a levee alignment depending on the length of the levee project and various jurisdictions the levee project encounters. Permits for construction activities may be required for:

- Operation of equipment that emits fumes.
- Disposal and/or burning of construction debris and vegetation from clearing and grubbing activities.
- Waste material processing such as bio-remediation composting.
- Abstraction of groundwater when dewatering an excavation.
- Discharge of construction wastewater to a natural watercourse or sewer.
- Placement of fill materials into wetland or waterway.
- Storage of fuels/hazardous material.

3.1.8 Utility Considerations

As discussed in **Chapters 6 and 7**, it is common for levee construction projects to encounter utilities, especially in urban areas. Encountering unknown utilities or unexpected utility relocations during construction can cause significant delays and increased costs. Utility surveys should be conducted to identify utilities in the construction area prior to construction. All utilities should be clearly identified in the construction documents so that the levee constructor is well informed of the utilities in the project area. Any additional information obtained during construction on utility locations, relocations, and/or abandonment procedures should be documented during construction and included in the construction closeout activities (section 5).

3.1.9 Weather and Climate Considerations

Levee construction is particularly susceptible to extreme temperature, precipitation, relative humidity, river flow, and tides. These conditions may significantly impact construction timing and operations. Levee construction can be affected by weather and climate conditions in coastal and riverine environments in two ways:

- Restricting work by affecting construction operations.
- Causing flooding, both to the construction site and the leveed area.

Inclement weather may require a temporary suspension of construction activities that could significantly affect the construction schedule (Figure 8-8). Temporary construction features such as haul roads, construction equipment, material unloading, and storage sites could be adversely impacted if not properly designed.

It is important to plan for weather and climate conditions by considering:

- Variability and severity of the weather and climate conditions that could potentially occur.
- Impacts to the flood risk and levee risk during various stages of levee construction due to these conditions.
- Potential construction delays, costs, and adverse impacts if schedule and cost contingencies are not in place.

Planning for weather and climate considerations during levee construction should include:

- The amount of downtime for land-based or water-based construction activities, due to inability to access the site. High water levels can impact the accessibility of land-based activities and low water levels and wave effects can impact the accessibility of water-based activities.
- Whether temporary flood protection measures should be included for the partly completed works. This can entail phasing the work so that partial completion of more robust parts of the permanent work occurs, or to protect/reinforce the more vulnerable parts during times when storms are anticipated.
- Whether it is appropriate to completely shut down construction activity for the season in which most severe weather or flooding occurs.

Figure 8-8: Inclement Weather Impacting Levee Construction

Rain impacts levee construction in Sacramento, California, as construction activities are delayed until drier, more favorable site conditions occur.

Table 8-2 has a list of construction considerations for common weather and climate-related issues.

Table 8-2: Construction Considerations for Weather and Climate-Related Issues

Weather and Climate-Related Issue	Construction Consideration
Construction activities should be avoided during heavy rain seasons or extreme drought conditions.	• Construction documents should clearly identify any expected weather delays before construction commences. Average rain days can often be obtained from the National Weather Service. • Plan for construction activities to occur during months with historically good weather conditions (flood stages, rainfall, and relative humidity).
Riverine and coastal levee (e.g., earthen embankments, floodwalls, and other levee features) construction activities should be avoided during peak flood seasons, high-water events, coastal storms, and hurricane season without appropriate precautions.	• Secure local tidal, weather, and flood stage historical records from local, regional, and national sources. • Detailed construction sequencing may be needed to ensure the levee provides some seasonal flood risk reduction. • Ensure construction of haul roads and material storage facilities are at elevations that are not likely to be impacted by flooding during construction. • Temporary flood protection measures may be constructed if no other options are available, however, this is a costly alternative, which has varying results. • Emergency action planning, including early warning systems, may be needed to minimize flood risk during construction.
Construction activities should be avoided during extreme cold weather.	• Plan for construction activities to occur outside of the months with historically cold weather, especially if there is a risk of ice jam causing river levels to rise. • Concrete work (floodwalls, pump stations, interior drainage systems, etc.) should be avoided during extreme cold weather. If no other options are available, certain construction techniques such as heating elements, variable concrete mix designs, or enclosed pours may be needed. • Plan on placing borrow materials in warm weather, not while in a frozen state or on frozen ground.

More discussion on how to manage flood risks during construction is captured in section 7.

3.2 Evaluating the Constructability of the Project

Evaluating the constructability of the project is an important part of managing risks during construction and should performed during the final design. The constructability of the levee design should be evaluated based on:

- A review of project objectives.
- Funding.

- The construction schedule.
- The experience, capabilities, materials, and equipment of potential levee constructors.

The review should include a detailed understanding of the purpose of the completed project, its operational function, and the construction risk associated with the project. Refer to **Chapter 7** for more information on best practices for conducting constructability reviews. A list of common constructability issues that impact levee construction is shown in Table 8-3 and should be considered when evaluating the constructability of the project.

Table 8-3: Common Constructability Issues and Best Practices for Levees

Constructability Issue	Best Practice
Working around environmentally sensitive areas (e.g., no work in a particular area during the mating season of a threatened or endangered species)	• Identify all sequencing considerations during the planning phase and highlight them in the contract so the constructor has adequate information to sequence the work activities. • Sequence construction in environmentally sensitive or fragile areas based on information contained in environmental documents.
Availability of land for the project	• Ensure proper title is available for purchased land when planning the work. • Some levee projects cover a very large geographic area with multiple construction contracts. This may require the land acquisition be staged and sequenced.
Rate of embankment construction affected by soft foundation conditions	• Consider methods for phasing construction of earthwork on soft soil: – Increase the height in stages, with a period of consolidation between the stages. – Increase the height in one stage, with controlled consolidation of soft soil layers. – Increase the height in one stage, after soil improvement. • Additional measures to minimize delay during phasing of earthwork such as: – Temporary application of extra weight (e.g., pre-load) to accelerate settlements. – Use of vertical drains to accelerate the consolidation process. – Improve stability by using geotextiles, geogrids, or geotubes. – Use of flatter slopes and lower density fill materials to improve foundation stability. – Undercutting or over-excavation of foundation to remove soft or unsuitable materials and replace with suitable embankment.
Flood events occurring during construction	• If there are certain work items that should be sequenced—such as installation of temporary flood protection measures prior to levee excavation—it should be clearly defined in the construction documents. • Consult hydraulic engineers familiar with the project to ensure that sequencing does not create adverse flood conditions.
High groundwater table at the construction site	• Incorporate dewatering systems (e.g., systems that lower the ground water table) into the design and construction documents.

3.3 Scoping the Project for Construction

Defining the scope of the project for construction is accomplished by preparing documents for construction during design. Common documents and their uses in construction are shown in Table 8-4. These documents are typically developed during levee design and prior to the start of construction. It is important to ensure these documents collectively describe the scope of the levee construction project, while incorporating all necessary project constraints.

Table 8-4: Common Documents for Levee Construction

Document	Use in Construction	Source of Best Practice
Project plans and specifications	Defines all of the work including technical requirements.	Chapter 7
Cost estimate and construction schedule	Supports financial planning for the project and provides a baseline to track and control construction costs and progress.	Chapter 7 (Cost estimate) Section 4.1 (Construction schedule)
Geotechnical data report	Source for subsurface and laboratory data information, and provides a baseline for defining existing conditions.	Chapter 7
Basis of design report	Verifies the design intent and supports the evaluation of impacts due to changed conditions during construction.	Chapter 7
Engineering instructions for field personnel	Information and instructions from designers to levee constructors and field personnel performing construction inspections and accepting construction work.	Chapter 7
Construction instrumentation and monitoring	Instructions on how to install and monitor instrumentation, what action limits will apply, and what actions will be necessary to meet the designer's intent.	Chapter 7
Permits	Informs levee construction general conditions, methods, construction schedule, and quality management plan.	Section 3.1.7
Third party agreements	Procedures for minimizing impacts to existing infrastructure, cultural resources, or environmental resources affected by the construction activities.	Section 3.3.1

3.3.1 Third-Party Agreements

Third-party agreements are often required for levee construction. A third-party agreement is typically a legally binding, real estate agreement between the levee owner and a major project stakeholder (e.g., tribes, environmental organizations, railroads, highway agencies, utilities, the off-site borrow pit owner), whose existing infrastructure, cultural resources, or environmental resources are affected by the construction activities.

Examples of third-party agreements are as follows:

- Agreement executed with a railroad providing ‘no-train’ windows on a mainline rail corridor to facilitate construction of a closure structure across the live track. The constructor should be made aware of the scope of their responsibilities to complete the work within the ‘no-train’ window.
- Agreement executed with the owner of an active borrow pit, which would include the location of an off-site borrow source. The constructor should be made aware of any limitations placed on them by the borrow area owner to safely excavate, load, and haul borrow from the borrow area.
- Agreement with local public safety agencies that may include instructions related to the timing of partial demobilization and protection of completed work if flood waters threaten the construction site.
- Agreement may contain requirements for on-site monitoring in environmentally or culturally sensitive areas during significant construction activities (e.g., excavations).

3.4 Selecting a Levee Constructor

Selecting the appropriate levee constructor is an important decision to ensure successful completion of a levee project. Many levee construction projects are publicly financed—either through bonds or taxes—which requires use of procurement methods for constructors that meet the levee owner’s established requirements (Figure 8-9). Levee construction is often characterized by a high degree of mechanization. Constructors are usually highly specialized as this type of construction requires specific types of skills and equipment. The types and number of constructors for a levee construction project depends on the size and complexity of the project. For larger levee construction projects, there may be several smaller constructors (referred to as sub-contractors) managed by a larger constructor (referred to as a general contractor).

Figure 8-9: Levee Construction Performed by a Constructor

Construction of a floodwall requires a levee constructor with specialized skills and equipment; 2017.

It is important to select a levee constructor that can complete the construction in an efficient and cost-effective manner. There are two primary factors that are used to select an appropriate levee constructor:

- Technical merits based on qualification and demonstrated competence.
- Cost merits based on fees, price, work hours, or other cost information.

Table 8-5 provides a list of common criteria used for each factor. The importance (i.e., weighting for decision) of each factor varies depending on the type of project and procurement method. The levee owner should decide whether the technical merit is more important than cost merits, or if technical merit is equally important to cost merits.

A summary of pros and cons of each procurement method to inform levee constructor selection is provided in this section.

Table 8-5: Selection Criteria that Can Be Used for Each Primary Selection Factor

Primary Factor	Selection Criteria
Technical	• Demonstrated competence of similar projects • Qualifications of project personnel • Experience and past performance of the organization • Experience and past performance of assigned individuals • Experience and past performance with the desired delivery system • Capacity to perform the work • Financial strength and bonding capability • Management plan, subcontractor relationships, and technical capabilities • Safety plan and safety record • Quality assurance plan
Cost	• Unit price • Total project bid • Labor rates • Labor hours

3.4.1 Levee Constructor Procurement Process

Various procurement/contracting strategies may be considered by the levee owner, considering factors such as time, capital cost, and project-related risk. For public works projects involving levees, the levee owner should first check with the local regulators having jurisdiction and with applicable contracting codes covering the projects to verify which contracting strategies are permitted. For large projects with multiple distinctly different features, more than one strategy may be considered. The most common of these are set out as follows, with advantages and disadvantages summarized in Table 8-6.

3.4.1.1 Design-Bid-Build

Design-bid-build is the most common project delivery method for public works projects. Separate contracts are awarded to the designer and to the constructor who submits the lowest responsive and responsible bid. The levee owner sometimes retains a construction manager (who can also be the designer) to administer the contract. The levee owner (or representative, who can also be the designer) coordinates with the regulatory permitting agencies.

Construction risks associated with design-bid-build can be minimized by performing comprehensive site investigations, developing robust design details, establishing minimum constructor qualifications or prequalifying constructors, and establishing a strong partnering relationship between the levee owner, designer, and selected constructor. Early constructor involvement during the design phase can also help to minimize risks, as long as such involvement does not preclude constructors from bidding on the work.

3.4.1.2 Construction Manager at Risk

The levee owner selects the construction manager at risk through a competitive request for qualifications process. The construction manager at risk commits to delivering the project within a guaranteed maximum price, based on the version of the construction documents and specifications available at the time of the guaranteed maximum price, plus costs for any other reasonably inferred items or tasks. By giving the levee owner the guaranteed maximum price before bids, the entity assumes the risk of bids coming in higher because they are contractually bound to deliver the project per the plans and specifications (along with any additional allowances), as defined in the guaranteed maximum price.

The construction manager at risk will typically provide professional services and act as a consultant to the levee owner in the final design development and construction phases. Typically, the entity can also provide some of the actual project construction, depending on the availability of bidders and the expertise of the company. In addition to acting in the levee owner's interest, the construction manager at risk needs to manage and control construction costs to avoid exceeding the guaranteed maximum price because, contractually, any costs exceeding that price that are not change orders are the entity’s financial liability.

The levee owner has the option to terminate the construction manager at risk before establishing the guaranteed maximum price if the pricing or scope of services is not acceptable. In that event, the levee owner would then bid the design documents in the open market, the same way it is done with the design-bid-build delivery method.

3.4.1.3 Progressive Design-Build

Progressive design-build is a hybrid between the design-bid-build and construction manager at risk project delivery methods. The levee owner typically selects the design-bid-build entity based only on qualifications, not on price. Construction pricing is then developed as the design progresses. Like design-bid-build, this method can save time in the overall schedule by overlapping the design and construction phases and allowing some design work to begin while site investigations continue to develop the data needed to complete all designs. Progressive design-build’s main features include:

- The design-builder is retained by the levee owner early in the life of the project.
- The design-builder generally is selected primarily on qualifications and their final project cost/price and schedule commitment are not established as part of the selection process.
- The design-builder delivers the project in two distinct phases. Phase 1 includes budget-level design development, pre-construction services, and negotiating a firm contract price (either lump sum or guaranteed maximum price) for phase 2. Phase 2 includes final design, construction, and commissioning.

If for any reason the parties cannot reach agreement on the phase 2 commercial terms, then the levee owner may consider an ‘off-ramp’ option, which will delay project completion. This is a risk factor to be considered in selecting this method.

Table 8-6: Advantages and Disadvantages of Alternate Construction Procurement Strategies

Procurement Strategy	Basis of Constructor Selection	Advantages	Disadvantages
Design-bid-build	• Competitive sealed bid: Low bid of total construction costs. • Best value bid: Technical score and total construction costs.	• Provides levee owner with most pre-construction input into the design. • Potential for lowest pre-construction price.	• Little opportunity for pre-construction collaboration between designer and constructor. • Levee owner has to set aside budget funds for risk factors such as unforeseen conditions and deficiencies in the design documents.
Construction manager at risk	• Best value proposal: Technical source/sum of fees, general condition. • Qualifications based selection: Demonstrated competence and qualifications.	• Commits to delivering the project within a guaranteed maximum price and assumes the risk of total actual costs coming in higher than that price. • Allows opportunity for pre-construction collaboration between the construction manager at risk and their constructor.	• Levee owner has lower pre-construction input. • Levee owner has to set aside budget funds for risk factors such as unforeseen conditions and deficiencies in the design documents.
Progressive design build	• Best value bid: Technical score and total construction costs. • Best value proposal: Technical source/sum of fees, general condition. • Qualifications based selection: Demonstrated competence and qualifications.	• Allows for collaboration between owners, designers, and constructors which can reduce cost and construction risks. • Saves time by overlapping the design and construction phases. • Promotes transparency in costs as each phase tracks project costs and how design changes impact costs and schedule. • Reduces cost as construction risks are managed early in the project leading to less construction cost contingencies.	• Requires significant owner resources to effectively manage. • May not be allowed for some entities due to procurement regulations. • The design-builder is selected without knowledge of the design and construction project cost.

4 Constructing the Levee

Constructing the levee begins when the levee constructor starts work on the project and ends when construction is near completion (Figure 8-10). Proper execution of the levee project is vital to ensuring the levee satisfies its intended objectives (i.e., flood and levee risk reduction benefits, as well as co-benefits), while working within the identified constraints.

The main topics that are covered for the phase of constructing a levee feature include:

- Developing a construction plan.
- Ensuring desired quality of levee construction is achieved.
- Coordinating and communicating during construction.
- Managing construction data.

Figure 8-10: Aerial View of Levee Construction

Aerial view of the Bear River Setback Levee construction in August 2022 in Wheatland, California.

4.1 Construction Plan Development

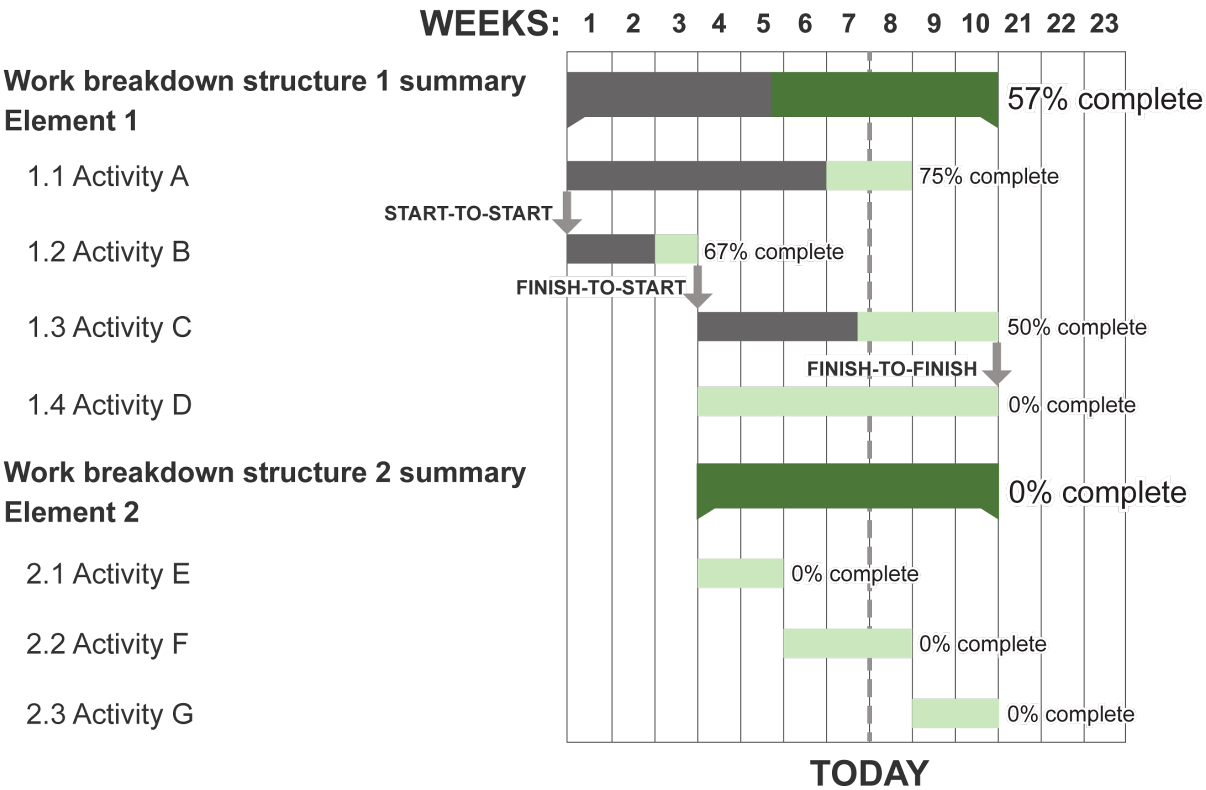
A plan for constructing the levee should be developed to include:

- The selection of appropriate construction labor, equipment, and materials.
- A schedule of construction activities to complete the project on time.
- Procedures for effective management of construction and flood risk.

Labor, material, and equipment should be analyzed and determined based on the levee project requirements defined in the project plans and specifications. The complexity and effort in developing a construction schedule should be commensurate with the size and complexity of the project. Based on the project scope, the following are best practices for developing a construction schedule:

- **Identify the critical path**. This is important in determining the timeline for completion of each project task. The critical path approach identifies the essential construction activities that must be completed in a specific succession on the project.
- **Develop a work breakdown structure**. Breaking down the project into smaller tasks makes it easier to manage and complete on time. Each task should have a defined start and end date.
- **Create a Gantt chart**. A Gantt chart is a graphical representation of the schedule that shows the timeline of the project and the dependencies between tasks. An example Gantt chart is shown in Figure 8-11.
- **Allocate resources**. Assigning resources to each task will help in managing the project efficiently. This will include labor, materials, and equipment.
- **Determine project milestones**. Identifying key milestones in the project will help to track progress and communicate achievements to stakeholders.

Figure 8-11: Example Gantt Chart



If construction activities are not properly sequenced, the levee project may be delayed and costs increased significantly. Material, equipment, and labor availability issues can also delay construction activities. Best practices for resolving common material, equipment, and labor availability issues are provided in Table 8-7.

Table 8-7: Material, Equipment, and Labor Availability Issues and Best Practices

Material, Equipment, and Labor Availability Issues	Best Practice
Availability of necessary materials and resources for the project	• Large projects may be divided into smaller projects to ensure equipment and labor shortages are not encountered. • If possible, projects in the levee should be phased and programmed to avoid extreme peaks in demand for material, equipment, and labor. • Early in the design process, preliminary material quantities should be used to evaluate the local supply chain for delivery and price with a focus on effects of increasing demand with the current supply chain. • Consider pre-ordering particular material prior to the start of construction.
Alternative materials and methods	• The constructor may submit a request for alternatives to a specified method or material to improve project costs, schedule, and/or performance.

To effectively manage risk during construction, it is important to identify potential risks to the project and include procedures to managing these risks in the construction plan. This should include contingency plans in case of delays or unexpected challenges. Best practices for managing risks during construction is discussed in section 7.

Local laws and regulations will often dictate requirements for managing on-site job and public health and safety, environmental impacts, and traffic. This should be included in the construction plan. Failure to manage these effectively can have severe consequences to construction. Best practices for managing health and safety, environment, and traffic during construction is provided in the following sections.

As construction progresses, the construction plan should be regularly reviewed and updated to help identify any issues, and take corrective measures to keep the project on track.

4.1.1 Health and Safety Management

The construction plan should address on-site job and public health and safety management during construction. Levee construction normally involves heavy machinery and exposed working conditions—both have the potential to be hazardous to staff working on site. In addition, levee construction often involves activities near open water that can bring other health and safety risks normally unrelated (or less often related) to machinery or construction work. Waterborne diseases should be considered in health and safety hazard identification, as well as the risk of drowning in adjacent waterways or other water hazards. :

The health and safety management approach should emphasize preventive action to avoid incidents happening in the first place by appropriate staff training (such as in the use of heavy machinery), raising awareness of construction site hazards, and using good construction practices that prevent injury and ill health. A site incident log should be kept, and regular reviews made to monitor the types of incidents that occur. Measures should be instigated to reduce the likelihood of reoccurrence.

Public safety should be maintained at all times. Generally, to provide such protection, the public should be restricted from entering the site by signs, barriers, fences, or other means (Figure 8-12). The warning signs should be placed at prominent locations. For a levee project, this may include restricting access from the water. In urban areas, transient and/or unhoused populations can be particularly difficult to manage during construction. In situations where an unhoused population exists within the construction site, coordination with local governmental authorities should occur and appropriate protocols and procedures followed. Plans to manage underserved populations must be developed during the planning phase (**Chapter 6**), and these plans should be carried through design and construction of the levee project.

All workers and visitors to the site should be trained in the health and safety protocols and be required to adhere to them while on site. Public access to the construction site should be restricted and any visits permitted during construction (e.g., for education or information dissemination purposes) should be carefully controlled.

Figure 8-12: Example of Public Safety During Levee Construction

Safety fencing was installed to protect the general public while levee work was underway along the north bank of the American River, just east of its confluence with the Natomas East Main Drainage Canal in north Sacramento, California; August 2013.

4.1.2 Environmental Management

The equipment, materials, procedures, and schedule-defined construction plan should comply with all environmental permits and cultural restrictions. Common levee construction restrictions include reducing impacts to endangered species, managing unwanted material releases into water bodies, soil erosion control during construction, proper handling of historic artifacts, and reducing impacts of haul routes, noise, and vibrations. See sections 3.1.3 and 3.1.4 for considerations on how to manage environmental and cultural constraints.

For most levees, the construction plan will at least include stormwater pollution prevention approach (sometimes referred to as a stormwater pollution plan), which describes processes to reduce erosion, migration of sediment, and other waste from the site into rivers, lakes, coastal waters, and/or adjacent properties. During and immediately following construction, temporary erosion protection for earthen slopes and sediment control may be required under the project's stormwater pollution prevention approach. The U.S. Environmental Protection Agency provides best practices for developing a stormwater pollution plan with the document *Developing Your Stormwater Pollution Plan, A Guide for Construction Sites* (EPA, 2007). Examples of implementing stormwater pollution measures during construction of a levee project are shown in Figure 8-13.

Figure 8-13: Example of Tempoary Erosion Protection

Workers install straw wattles (left) and silt fences (right) along a new American River levee section in the River Park neighborhood of Sacramento California; November 2014.

4.1.3 Managing Traffic During Construction

It is important to manage traffic because it can cause delays to local residents and create a safety hazard both on and off site. An organized site with well-managed traffic activities—including the storage of construction materials as close as possible to the project site—can provide a positive experience for local residents. Levee construction in urban areas can cause potential traffic tie-ups for residents, trip delays, delayed deliveries to the site, and the loss of access during critical construction times. To minimize these impacts, consider the following:

- Ensure that all drivers are aware of traffic restrictions at and around the site when ordering deliveries.
- Plan the timing of deliveries to avoid vehicles waiting outside the site boundary.
- Load and unload vehicles off the roadway, where possible.
- Designate staging areas where several deliveries are likely to take place over a short period.
- Mitigate construction traffic and their impacts, particularly in the summer.
- Consider allocating a staging area some distance from the site in urban areas, and only calling in deliveries when access to the site is clear.
- Consider the use of in-cab communication systems to maintain control over movements of delivery vehicles.

Construction staff vehicle traffic can negatively impact the public; therefore, the following should be considered:

- Arranging designated parking areas.
- Preventing staff from parking in unsuitable areas and ensuring restrictions are obeyed.
- Implementing a park-and-ride or car-share scheme.

- Avoiding monopolizing public car parking areas, especially those used by high numbers of visitors to the area.

Sometimes construction sites are blamed for disturbance caused by vehicles that are not associated with the site. To avoid this, it may be helpful if site vehicles display some visible identifying marks. While this may not be appropriate for individual deliveries, it can be done for the levee constructor's vehicles.

Some levee projects impacting transportation corridors may require detour and traffic control plans be approved by local transportation agencies. These plans are usually developed in the design phase and included in the plans and specification for implementation by the constructor.

4.1.4 Coastal Construction Considerations

Levees to be constructed along coastal environments or riverine channels affected by tidal changes will require significant constructor planning and timing of all work activities. This especially is true when preparing the foundation and lower portions of a levee that can be inundated daily by tides. This will limit the constructor's effective daily work hours and inspection of the work. Daily flooding of the work may damage completed work; therefore, construction scheduling should be planned based on these tidal effects and rework should be planned in the schedule (Figure 8-14).

Figure 8-14: Example of Coastal Levee Construction

Constructors continue work on a pump station as part of the Hurricane and Storm Damage Risk Reduction System project in New Orleans, Louisiana; April 2016.

4.1.5 Temporary Relocations and Diversions

Establishment and construction of temporary pipe or diversion facilities may be required during levee construction. These often are designed by the constructor, in coordination with local stakeholders and the levee owner, and they should be reviewed by the design engineer to ensure compliance with project requirements.

4.2 Quality Management

Quality management during construction ensures levees are constructed as designed and that they perform reliably over time. The documents for construction should clearly detail the quality management requirements for inspection and acceptance of the construction work as part of a quality management plan. Typical contents of a quality management plan include:

- Purpose and scope of plan:
  - Period pf work covered.
  - Applicability of the plan to proposed construction work.
- Staffing:
  - Responsibilities to implement quality management (Table 8-8).
  - Training and expertise required of the quality management staff.
- Quality surveillance:
  - Frequency and rigor of quality surveillance.
  - Problem solving approaches for deficiencies in construction quality.
  - Deficiency monitoring and tracking (Table 8-9).
- Quality testing:
  - Frequency and rigor of quality testing.
  - Staffing and facilities necessary to implement quality testing.
- Reporting.

The constructor should have arrangements in place to ensure that the specific elements of levee construction are carried out in accordance with the requirements defined in the documents for construction. For example, these elements might include procedures for:

- Drawing plan checking and verification.
- Site/operational activities such as ground clearance and earthwork, as well as compliance with design profiles, site security, and access.
- Selection of equipment and material suppliers.
- Instrument calibration and testing.
- Specialized treatment methods.
- Storage and disposal of waste.

- Corrective actions.

Construction sampling and testing is required to verify contract compliance. Instrument calibration is an important aspect of quality control for which records should be kept. All instruments should be 'in-test' and withdrawn from use if either their calibration has expired, or their measurements become suspect.

The quality management plan should also state a procedure for the resolution of 'rejected' work (or non-compliance) and subsequent corrective actions.

QUALITY CONTROL VERSUS QUALITY ASSURANCE

Quality control is defined as processes used to ensure performance meets agreed-upon customer requirements that are consistent with law, regulations, policies, sound technical criteria, schedules, and budget. Focuses on fulfilling quality requirements of a project, product, service, or process.

Quality assurance is defined as processes employed to assure that quality control activities are being accomplished in line with planned activities and that those quality control activities are effective in producing a product that meets the desired end quality. Focuses on providing confidence that quality requirements of a project, product, service, or process will be fulfilled.

4.2.1 Staffing

The owner, designer, and constructor all play key roles in ensuring that quality management is maintained during levee construction. Table 8-8 identifies the basic quality management staff responsibilities that are critical to the successful completion of a levee meeting good quality practices. Depending on the complexity and size of the project, these responsibilities may be fulfilled by few or multiple personnel. The best practice is to ensure the appropriate level of staffing is provided to fulfill these responsibilities.

Table 8-8: Basic Quality Management Staffing and Responsibilities

Quality Management Staffing	Responsibility
Constructor project manager	• Overall project quality
Construction manager or contract manager (constructor)	• Construction contract quality • Quality compliance submittals • Construction quality manager duties (if/when necessary)
Owner quality manager	• Quality assurance • Quality assurance documentation
Designer	• Quality compliance requirements • Construction quality manager duties (if/when required)
Construction quality manager	• Quality control (including corrective actions) • Quality control documentation • Independent of construction project manager
Testing agency	• Sampling and testing for compliance verification

4.2.2 Corrective Actions

Quality assurance/quality control is necessary to reduce the possibility of construction-related deficiencies that may affect levee performance during and after construction. Failed test results or identified non-conformances should result in corrective actions to resolve the issue. Consequences of failed results may require analysis and a decision based on comparison with the specified requirements, visual examination, and engineering judgment. Corrective actions will depend on acceptability and be very specific to the material location and problem encountered. Corrective action to prevent recurrence is an essential part of quality assurance/quality control. A list of possible construction deficiencies and related consequences to the levee performance for embankments is shown in Table 8-9.

Table 8-9: Possible Construction Deficiencies for Embankments

Deficiency	Potential Consequence
Organic material not stripped from the foundation	• Differential settlements. • Weak embankment/foundation contact layer leading to instability. • Internal erosion caused by throughseepage or underseepage.
Highly organic or excessively wet or dry fill	• Excessive settlements. • Inadequate or weak strength in fill causing instability. • High permeability zones causing instability and/or internal erosion.
Placement of pervious layers extending completely through the levee	• Unimpeded throughseepage, which may lead to internal erosion.
Inadequate compaction of embankment (e.g., lifts too thick, haphazard coverage by compaction equipment, incorrect moisture content)	• Excessive settlements. • Inadequate strength causing instability. • Throughseepage, which may lead to internal erosion.
Inadequate compaction of backfill around structures in the embankment	• Excessive settlements. • Inadequate strength causing instability. • Potential seepage path between the structure and embankment, which may lead to internal erosion.
Inadequate processing of lifts before compaction and/or improper scarification between lifts	• High permeability layers leading to internal erosion. • Weak layers or lift leading to instability.
Seasonal shutdown layers not properly treated or placement in freezing weather	• High permeability layers leading to internal erosion. • Differential settlement of the overlying embankment leading to transverse cracking and subsequent internal erosion.
Cutoff wall gaps and voids	• Concentrated seepage leading to instability and/or internal erosion.

More details can be found in EM 1110-2-1913 (USACE, 2000a).

4.2.3 Testing Entity

To ensure independent verification of the quality of the completed work, using an independent testing laboratory to perform necessary quality control tests is a best practice to implement.[1]

These laboratories should be certified using appropriate laboratory certification standards. Personnel supplied by the independent laboratories should be competent to perform the required tests. The independent laboratory should have their own internal quality management system and supervisory organization, and should maintain a consistent test and report serial numbering format to help facilitate tracking tests and results for each work segment, including certifying test results.

4.2.4 Quality Assurance

A quality assurance approach should be developed to oversee and validate the levee construction quality control plan, including reviewing all quality control test data. The quality assurance program may include a different laboratory to perform independent testing. A reasonable rule of thumb would be to conduct quality assurance testing for approximately 10% to 20% of quality control testing. A higher frequency of quality assurance testing should be anticipated at the beginning of the project to validate the construction quality control testing, and also at times when quality control testing is suspect or problematic.

4.3 Coordination and Communication During Construction

Effective coordination, communication, and sharing of information between the levee owner, designer, and constructor should be maintained throughout levee construction. This is vital to ensuring project requirements are understood and problems that occur during construction are handled properly in a timely manner. The following are best practices to ensure levee project information is effectively coordinated between these phases of a levee project.

- Compliance with local, regional, state, and federal laws and regulations during construction should be maintained. Being out of compliance can cause delays and increases in project costs. The levee owner, designer, and constructor should work together to ensure compliance is met. Construction activities should also be in compliance with mitigation measures defined in project-specific permits (section 3.1.7).
- Documents for construction (section 3.3) should be complete, clearly understood, and free of errors. These documents establish project requirements, a baseline for evaluating conditions during construction, and the roles and responsibilities during construction. Site conditions that differ from the design plans and specifications should be coordinated with levee owners and designers to assess impacts to the levee project.
- All parties involved in levee construction should have access to all relevant construction data and information. This is crucial for efficient construction execution and decision making. Common types of construction data and best practices for managing that data is provided in section 4.4.

[1] American Society for Testing Materials (ASTM) as well as some federal, state, and local agencies establish laboratory certification standards.

- Partnering and conflict resolution should be used to reduce conflict during construction projects. Partnering sessions are often utilized to establish communication channels and methods to advance the project, meeting the ultimate goals of all interested parties. Conflict resolution methods for the levee project are often defined prior to the start of construction in the documents for construction.

ENTITIES INVOLVED IN LEVEE CONSTRUCTION

There are often multiple entities involved in levee construction, dependent on the size and complexity of the levee project. It is important that levee owners, designers, and constructors work together to fulfil their responsibilities.

Levee owners should collaborate to establish project objectives and constraints, levee designers should work together to establish the project scope, and levee constructors should work together to execute the project. All groups should have clear roles and responsibilities established when interfacing with others.

Construction techniques (sometimes referred to as means and methods), sequencing, schedules (including major milestones), personnel qualifications, materials, and equipment should be documented and coordinated to ensure these are appropriate for the levee project. These are commonly documented in submittals, and requirements for submittals are often defined in the design specifications. These submittals provide details on construction implementation plans, including proposed construction techniques, sequencing, schedules, submittal dates, personnel qualifications, and other required information. This documentation, as well as the construction plan, will set the baseline for construction and should be updated as the work progresses.

4.4 Construction Monitoring and Data Management

Construction monitoring and data plays an important role in ensuring the levee design is appropriate for actual site conditions, verifying construction activities are in compliance with plans and specifications, monitoring progress of construction, and informing levee risk management decisions. Construction monitoring and data includes constructor shop drawings and submittals, topographic and/or bathymetric surveys, quality control/assurance test results, and construction inspections. Descriptions of common types of construction data are provided in Table 8-10.

Quality construction data should be maintained throughout the project and the best practices for ensuring quality construction data is discussed in section 4.2. In addition to quality assurance and construction test data, topographic and/or bathymetric surveys are often used in levee construction. These surveys should be timely and accurate (Figure 8-15) to avoid and detect construction problems early. Surveys conducted just prior to commencement of construction activities can provide a clear understanding of the current site conditions, as well as provide a baseline for monitoring progress of construction work. It is a best practice to conduct acceptance (or verification) of topographic surveys to verify the project meets the design intent prior to construction closeout (section 5).

As discussed in **Chapter 7,** a plan for instrumentation and monitoring during construction should be prepared. Site inspections (**Chapter 9**) should be performed to maintain up-to-date knowledge of the construction site and the surrounding area with the objective of discovering any new site conditions that could hinder the project from meeting its objectives. Unforeseen changes during construction could result in complications for the levee project. Site conditions that differ from the design plans and specifications need to be clearly documented and coordinated with levee owners and designers to assess impacts to the levee project.

Table 8-10: Common Data in Levee Construction

Type of Data	Description
Construction administration	Information on administering the construction of the levee including: • Constructor name, contact information, and management staff. • Equipment used for the project. • Types and amount of labor used for the project. • Construction tasks to accomplish the scope of work. • Construction schedule and progress. • Construction budget, costs, and payments. • Change orders, modifications, and variations from the design. • Coordination meetings and correspondence between construction, designer, and owner. • Construction submittal data and information.
Quality assurance and quality control	Data and information related to assuring and controlling quality of the construction work including: • Requirements for inspection and acceptance of construction work. • Quality management staff and testing entity contact information and responsibilities. • Material sampling and testing results. • Calibration record of testing instruments. • Construction topographic and bathymetric surveys.
Accident and safety reporting	Data and information related to monitoring, tracking, and resolving safety issues.
Construction instrumentation data	Data and information related to installing and monitoring instrumentation including thresholds and actions taken when thresholds were exceeded.
Photographs and videos	Photographs and videos taken during construction to document construction conditions and verify compliance with design plans and specifications.
Manual observations	Data and information related to manual observations of construction activities including: • Excavations. • Drilling. • Grouting. • Placement and compaction of fill. • Installation of levee features. • Operation and testing of mechanical and electrical components.
Installation and operation of mechanical and/or electrical components	Data and information related to the installation and operation of mechanical and electrical components. Refer to section 5.2.3 for more information.

For complex levee construction projects, a geographic information system (GIS) may be used to manage construction data. Prior to construction, a baseline GIS is built using design data along with a plan for managing data during construction. This plan often includes procedures for data verification, quality surveillance data collection, backup and disaster recovery, data transfer workflow, and storing the data at construction closeout. During construction, the GIS is updated in real-time to view construction progress and is used to support project decision making.

Refer to section 5.2 for best practices of documenting construction data for future management of the levee.

Figure 8-15: Example Survey Control

A constructor performs a topographic survey at the Wakenda Levee in Carroll County, Missouri. The levee was under repair after it was damaged during the Missouri River flood in 2011; February 2012.

5 Levee Construction Closeout

Levee construction closeout is the final phase of the levee construction process and begins when construction is near completion and ends when the constructed levee is placed into operation. This phase requires ensuring the levee project meets the design intent prior to placing the levee into operation and finalizing the project documentation to support effective levee O&M. The main topics covered for the levee construction closeout include:

- Post-construction project evaluation.
- Construction closeout project documentation.

5.1 Post-Construction Project Evaluation

Evaluation of the finished construction work is a vital step to verify the levee was constructed as intended and provides a baseline for evaluating future levee condition and performance. Post-construction evaluation consists of performing inspections of the finished work, reviewing construction data and instrumentation, and updating the levee risk assessment when necessary.

Refer to **Chapter 5** on best practices for conducting routine and non-routine activities to fulfill levee risk management responsibilities at construction closeout.

5.1.1 Inspection

Detailed observations should be made of all newly constructed or modified levee features to verify the levee was constructed as intended. These observations include vegetation growth, seepage control system performance, embankment stability, settlement, and gate operation. Any deficiencies found during this inspection should be addressed.

In addition to a warranty inspection, a 'first loading' inspection should also be conducted for the newly constructed or modified levee features to observe performance during a flood loading. Refer to **Chapter 9** for procedures on conducting levee inspections.

5.1.2 Risk Assessment

Prior to placing the levee in full operation, a risk assessment should be conducted utilizing the data and information from construction (section 4.4) to establish a baseline and to inform the current risk characterization for the levee. Practices and procedures for conducting risk assessments are discussed in **Chapter 4**. This activity should be planned, funded, and coordinated as part of the levee construction project.

5.2 Project Documentation

Project documentation is important to support the management of the levee and inform any potential future rehabilitation or modification. Project documentation provides a fundamental level of information that will be used to operate and maintain the levee. The rigor of project documentation should be commensurate with the complexity of the project.

More complex projects could include a levee data update in the National Levee Database (NLD), as well as a variety of reports, including:

- Environmental and cultural resources
- Foundation and embankment
- Construction completion
- Design document
- Construction GIS data

Documentation for less complex projects may only include the record drawings, a design document report, and an update of NLD data.

HOW TO UPDATE LEVEE DATA IN THE NATIONAL LEVEE DATABASE

The NLD is the national repository for levee data managed by USACE. Updates to the NLD should occur during construction closeout. If data in the NLD is determined to be inaccurate, an update of that data should be initiated through the following methods:

- Email to nld@usace.army.mil.
- Call 1-877-LEVEEUS.
- Submit new or updated data using the data change request button on the NLD homepage (nld.sec.usace.army.mil).

Local USACE Districts may be contacted directly to update data on levees federally authorized and constructed by USACE.

5.2.1 Construction Completion Report and Record Drawings

For complex levee projects, a construction completion report should be prepared as soon as possible after levee construction is completed. The report should contain design decisions made during construction, modifications, and a summary of project construction issues and resolutions. In addition, the construction completion report should contain information about implementation of the observational methods used during construction.

The report should also include record drawings, documentation of exploration trench conditions and observations, compaction reports, concrete cylinder break data, other construction testing results, and measurements taken during construction to verify compliance with construction documents (e.g., plans and specifications) and acceptability of the construction work. The construction completion report should be maintained with other pertinent documentation for the levee, such as the O&M manual, and be readily accessible for future inspections and risk assessments.

For less complex projects, a construction completion report may not be necessary and only record drawings may be used to reflect how the project was built. Record drawings are corrected design drawings (i.e., design plans) showing the as-constructed conditions and reflects on-site changes made during construction.

5.2.2 Foundation and Embankment Report

For levees that pose a significant threat to life safety and/or are fairly complex, a separate foundation and embankment report should be prepared for the levee construction project.[2]

The report should include a summary of foundation and embankment conditions, issues (and corresponding resolutions) encountered during construction, documentation of exploration trench conditions and observations, final foundation approval reports (if necessary), verification of design assumptions (e.g., shear strengths, hydraulic conductivity values), and records of construction testing.

5.2.3 Operations and Maintenance Manual

The designer, in coordination with the constructor, owner/operator, maintainer, and local regulatory agencies (if applicable), should prepare an O&M manual addressing operation procedures needed to support the function of the levee, as well as the required schedule and scope of maintenance requirements. See **Chapter 9** for best practices in developing an O&M manual.

Information that should be gathered during construction to inform O&M requirements for inclusion in the manual may include:

- Cut sheets and operating instructions on electrical and mechanical equipment, as applicable, including screen shots of instrumentation panels.
- Manufacturer’s instructions on electrical components and control panels.
- Training steps and instructions from the manufacturer for more complex machinery, such as pumps and large flood gates.
- Triggers and operating instructions for floodgate closures.
- Recommended inspection and monitoring frequency (see **Chapter 9**).
- Record drawings including all modifications.
- Lubricants and lubrication type, frequency, and methods.
- Warranties.
- Steel coating types and repairs of steel structures.
- Seal adjustments and replacements.
- Manufacturer’s spare parts storage and replacement instructions.

[2] See USACE Engineering Regulation (ER) 1110-1-1901 (USACE, 2017) for best practices to develop a foundation and embankment report.

6 Levee Features and Construction Considerations

6.1 Embankment

Levee embankments and associated berms are composed of compacted soil, as specified in the documents for construction. Best practices for placement and compaction of the soil is required to ensure the required engineering properties (i.e., strength, permeability, and compressibility) are present in the completed embankment, so the feature will function as intended.

6.1.1 Line and Grade

Survey control during embankment construction is essential to correctly locate embankment components and ensure the constructed embankment alignment and grade are as designed. Field staking and surveys should be performed routinely as with any earth-moving project. Interim surveys are recommended to update progress and document earthwork quantities.

6.1.2 Subgrade Preparation

Generally, levees are founded on soil foundations and the discussion on subgrade preparation and treatment provided in this section applies to soil foundations. Minimum subgrade preparation for levees consist of clearing and grubbing, and most levees will also require some degree of stripping (Figure 8-16).

Clearing consists of complete removal of all objectionable and/or obstructional matter above the ground surface. This includes all trees, fallen timber, brush, vegetation, loose stone, abandoned structures, fencing, and similar debris. The entire foundation area under the levee embankment, berms, and other levee project features should be cleared well ahead of grubbing and stripping.

Grubbing consists of the removal—within the levee foundation area—of all stumps, roots, buried logs, pipes, foundation structures, old pilings, old paving, drains, and other known objectionable matter. Roots or other intrusions over 1.5 inches in diameter within the levee foundation area are typically removed to a depth of at least 3 feet below natural ground surface. Shallow tile drains sometimes found in agricultural areas should also be removed from the levee foundation area.

The constructor should anticipate removal of the root ball, large roots (greater than 1.5 inches in diameter), and the underground portion of stumps to a depth of 3 feet (or more depending on the tree type and size as necessary to remove large roots) where trees and stumps are visible above ground and removed as part of clearing operations. The decision to leave tree roots or stumps in place is generally discouraged. However, in some situations, tree roots or stumps may be left in place after consideration of relative root ball or stump size, submergence and the rate of decay depending on wood species, and performance requirements for the levee.

Figure 8-16: Example Levee Subgrade Preparation

Constructors perform the clearing, grubbing, and stripping operation as part of subgrade preparation for the construction of an approximately 1,800-foot-long setback levee along the right bank of the Sacramento River in Yolo County, California; May 2021.

Typically, the constructor is not required to investigate the entire site for buried objectionable materials that are not already identified or apparent; these features should be identified in the construction documents. Also, any buried debris associated with permitted or unpermitted landfill type deposits require special consideration in the construction documents and are not normally covered by a simple grubbing specification. The sides of all holes and depressions caused by grubbing operations should be flattened to a slope no steeper than 1 vertical to 1 horizontal before backfilling.

Backfill—consisting of material of similar nature to adjoining soils—should be placed in layers up to the existing subgrade and compacted to a density at least equal to that of the adjoining undisturbed material. This will avoid 'soft spots' under the levee and maintain the continuity of the natural blanket.

After foundation clearing and grubbing operations are complete, stripping is commenced. The purpose of stripping is to remove low growing vegetation and organic topsoil. The depth of stripping is determined by local conditions and normally varies from 6 to 12 inches. Of this depth of stripping, 4 to 6 inches is usually adequate to remove the low-lying vegetation and root systems. Additional stripping excavates and preserves the organic rich topsoil for future use.

Stripping is required for subgrade for the levee embankment and may be needed under berms to avoid leaving a weak plane at the berm/foundation contact. All stripped material suitable for use as topsoil should be stockpiled for later use on the slopes of the embankment.

Before placing fill, the exposed subgrade should be inspected as described in the project plans and specifications to ensure an adequate subgrade exists. Unsuitable materials (i.e., soft or organic spots) in the levee foundation at or near the subgrade surface should be removed and replaced with suitable compacted material. Suitable compacted material should be defined in the project specifications. Unsuitable material for embankment construction should be disposed of using proper methods.

Except in special cases where subgrade surfaces are adversely affected by remolding (e.g., soft foundations for instance), the subgrade surface upon or against which fill is to be placed should be thoroughly scarified to a depth of at least 6 inches prior to the placement of the first lift of fill. This helps to ensure good bond between the foundation and fill, as well as eliminates a plane of weakness at the interface.

Dewatering systems may be required during excavation and backfilling to ensure desirable dry conditions exits. The U.S. Department of Defense provides general guidance for the design and construction of dewatering systems (USACE, NAVFAC, and AFCEC, 2004). Generally, a dewatering system is designed to lower the water table a minimum of 5 feet beneath the work surface or excavation to prevent heaving at the base of the excavation, unstable excavation slopes, and lateral or vertical seepage from entering the excavation. A water table depth less than 5 feet may be used in certain situations.

Approval of the subgrade surface (after preparation and treatment) prior to placement of fill should be required for levee projects and pertinent features. Approval should be conducted by trained and experienced personnel. The designers of the levee project should also be involved in the approval of the final subgrade surface to ensure the levee project requirements are met.

Methods to conduct the approval of the final subgrade surface will vary and should be scalable to the complexity of foundation conditions. Visual observations by field personnel through quality assurance activities may be sufficient for simple levee foundation conditions (i.e., alluvial soil foundations, little to no utilities). For complex foundation conditions (i.e., karst foundations, rock foundations with potential for defects and faults, numerous utilities or other human made features), approval of the final foundation surface may be performed using more formal inspections methods. It may be advisable to proof roll the subgrade with a heavy piece of construction equipment to help identify soft/unstable soil conditions.

6.1.3 Inspection Trench

Preparation and inspection of a trench along the embankment alignment is a best practice. Excavation of the inspection trench is performed before the placement of fill, as described in **Chapter 7**. The purpose of the inspection trench is to verify geologic conditions along the alignment are as expected, and no continuous permeable seams or previously unknown utility penetrations cross the alignment at the foundation depth (Figure 8-17).

Figure 8-17: Example Inspection Trench

An inspection trench was excavated under a 1,800-foot-long new setback levee along the right bank of the Sacramento River in Yolo County, California; June 2021.

6.1.4 Embankment Composition and Sources

The documents for construction (including specifications) will specify requirements for embankment soil fill composition. These specifications are selected to ensure the properties of the constructed embankment satisfy assumptions about material strength, permeability, and compressibility made during levee design. Specification will describe the soil materials that may be included in the levee embankment, as well as acceptable placement and compaction procedures.

Two key concepts should be understood with regard to embankment composition. First, soil materials are naturally variable; therefore, the embankment composition will vary. Design analyses should have considered minimum acceptable properties for the specified soil composition. During construction, the limits will not be absolute, and construction personnel should recognize a small percentage of tests may fall below the minimum required by the specification. In these situations, corrective measures in the construction technique or borrow sources may be required to ensure embankment composition meets the required specifications.

A second key concept is that levees will fail at the weakest point. The composition of the levee embankment should not include zones, vertically or laterally, of anomalous or unwanted material, even if the average test results still meet requirements.

An observational approach is necessary to ensure a homogenous embankment—an embankment without anomalous unwanted zones—meets design requirements. Sampling and laboratory testing should be used to confirm field observations and document material properties, but this cannot be a substitute for observation.

6.1.4.1 Off-Site Borrow Sources

Off-site borrow sources may be required which will necessitate hauling fill material, thereby increasing costs and possible environmental impacts. All haul routes should be identified prior to construction. Borrow sources may be investigated and specified during design or may be left to the constructor to identify. Regardless of how the borrow source is identified, the potential soil needs to meet the specifications. Generally, less construction risk is incurred if the borrow sources are specified and confirmed during design (Figure 8-18).

Figure 8-18: Example Borrow Source Excavation

An excavator strips materials from a portion of the Missouri River Levee, along the left bank, in Rock Port, Missouri, that was damaged by erosion during the 2011 flood. Excavated materials are being reused where possible to construct a setback levee further away from the river; February 2012.

6.1.4.2 On-Site Borrow Sources

For levee rehabilitation or improvements, on-site sources of levee fill may be available from existing embankment material. These sources should be identified for re-use during the design phase. The constructor should develop means and methods for re-use of on-site embankment soil material, including the blending of materials.

Use of on-site material should include an assessment to confirm such use will not increase flood risk. Generally, borrow sources requiring excavation within 300 feet of the embankment are not recommended because of the potential to increase seepage risk. This should be assessed during design.

6.1.5 Blending

Mixing or blending of soils to obtain suitable fill material often is not cost effective and can lead to undesirable and inconsistent material. Obtaining borrow material suitable for the levee project without requiring mixing or blending is recommended, where possible.

Using full-face excavation of borrow soil to minimize any soil stratification during placement of embankment fill is a best practice. If mixing or blending is required to adjust soil moisture content, this should be completed and the blended material should be approved before being hauled to the construction site. Blending on the embankment surface is not recommended; however, moisture conditioning may be required.

6.1.6 Compaction

Compaction of soil fill is essential for short- and long-term strength, permeability, and compressibility performance of the embankment. Compaction densifies the fill by removing air voids, increasing strength, and lowering permeability and compressibility. Failure to compact fill will result in excess seepage, long-term settlement, and potential slope stability issues.

The degree of compaction is established during design and denoted in the project specifications. In addition to assuring an acceptable embankment fill, project specifications for a particular material type may also require a compaction method specifying a loose lift thickness, compaction equipment, and number of passes with that equipment.

Evaluation of degree of compaction for fine-grained cohesive soil is measured in the field against a standard, or by using a modified compactive effort, laboratory-determined maximum dry density, and optimum moisture content, in accordance with applicable standards of the American Society for Testing and Materials. The field-achieved dry density and moisture content is measured using sand cone density tests, supplemented with nuclear density testing gages.

A best practice for placement and compaction of fine-grained cohesive fill is to place loose lifts of moisture conditioned soil, and then apply compactive effort. Lift thicknesses are dependent on the soil being compacted and the compaction equipment being used, but generally should not exceed 8 to 12 inches. Moisture conditioning of the soil should be accomplished before placement of the fill lift, during or before excavation from the borrow source. This will help to achieve a more uniform moisture content.

The compactive effort is dependent on the soil type, and a wide range of equipment types are available (Figure 8-19). Finer grained soil generally is better compacted with non-vibratory sheepsfoot or pad rollers, while sands are compacted with smooth-drummed vibratory rollers. Sand or coarse-grained soils—often used for drains and filters—are controlled by degree of compaction or a method requirement (e.g., number for passes of the compactor). Following lift placement, quality control testing should be performed to determine in situ density and moisture content, and then should be compared to the project specification requirements (Figure 8-20).

Figure 8-19: Example of Sheepsfoot and Flat Drum Compactor Equipment

Constructors continued the compaction of the existing foundation area, as part of the subgrade preparation before the construction of a seepage berm with a chimney drain along the right bank of the San Joaquin River in San Joaquin County, California; June 2021.

Figure 8-20: Example Density Testing

Sand cone density and nuclear gage testing was performed on the subgrade of the San Joaquin River. An existing drainage ditch adjacent to the landside levee toe was backfilled and a new drainage pipe was installed; April 2021.

Field observations and testing to verify proper placement procedures should ensure proper fill compaction. As a best practice, test strips (fills) should be constructed early in the process, to establish optimum loose lift thicknesses and required compaction to meet project requirements. Field observations of moisture should be performed. Following lift placement and compaction, the fill should be tested to verify the observations and document the compaction.

In addition to the construction quality control testing, quality assurance tests should be performed to assure acceptability of the completed embankment. The amount of quality assurance testing should be scalable to the scope and potential risk posed by the levee project. Generally, quality assurance tests should be performed to the extent necessary to verify acceptability of the quality control test procedures and results.

6.1.7 Stability During Construction

Placement of new embankment material on relatively weak soils, such as unconsolidated soft clay or organics, will create pore pressure in the foundation soils as water within these soils is squeezed by the embankment loading. These pore pressures effectively will lower the strength of the soil, creating the potential for instability. These concerns should be addressed in the design phase, and a measure to mitigate instability should be developed for implementation during construction.

The best practice to reduce the likelihood of instability is to phase fill placement to allow the pore pressures to dissipate. This can be accomplished by constructing fills over larger areas to reduce the amount of soil placed within a short period. Slopes, temporary or permanent, should not be constructed steeper than specified in the contract documents, and they should be monitored for development of any instability. Additional monitoring may be recommended.

6.1.8 Embankment Slopes

As noted above, the embankment should be constructed in lifts. To construct the side slopes of the levee embankment to final grade, typically the best practice is to overbuild the slope to full lift width and then cut it back to design grade (Figure 8-21).

Figure 8-21: Example Embankment Slopes

Constructors work to scrape the overbuilt levee toe and prepare the levee landside slope on the right bank of the San Joaquin River in San Joaquin County, California; June 2021.

6.1.9 Erosion Control Features

As discussed in **Chapter** 7, erosion control features can be required for different potential erosion sources, including surface runoff during precipitation, riverine or coastal flow, waves, and overtopping. Prevention of erosion of newly completed construction work is important to avoid damage to the levee project and prevent pollution. Refer to section 4.1.2 on storm pollution prevention approaches during construction. This section will primarily focus on the construction of permanent erosion control features.

Armoring/bedding is a commonly used erosion control feature. Armoring/bedding methods can include riprap, concrete slope paving, engineered revetment, and high-performance turf reinforcement mats. Each method requires different construction materials, techniques, and equipment. Construction best practices for each method is discussed below.

For riprap erosion control features, construction quality control of both stone production and riprap placement is essential to ensure design intent is met. An example of constructing a riprap erosion control feature is shown in Figure 8-22. Design of riprap erosion control features are relatively sensitive to the unit weight of stone and should be determined as accurately as possible.

Riprap coming from the various quarries will not be of the same unit weight, so it is important to confirm unit weights for the riprap used during construction. Commonly, design specifications will provide for two limiting gradation curves for the riprap—and any stone gradation as determined from quarry process, stockpile, and in-place field test samples that lies within these limits—should be acceptable for construction. All stones should be contained within the riprap layer thickness to provide maximum resistance against erosive forces.

Oversize stones, even in isolated spots, may result in riprap failure by precluding mutual support and interlock between individual stones. This could cause large voids that expose filter and bedding materials, and create excessive local turbulence that removes smaller size stones. Small amounts of oversize stone should be removed individually and replaced with proper size stones. Refer to EM 1110-2-1601 (USACE, 1994) for best practices for delivery and placement of riprap for erosion control features.

Figure 8-22: Example of Riprap Erosion Control Feature Construction

Workers install riprap erosion protection along a levee in West Sacramento, California; September 2023.

Concrete slope paving can include cast-in-place concrete or articulating concrete blocks. Care consideration should be used when using cast-in-place when significant settlement of the levee is expected. Cast-in-place concrete should have sufficient joints to handle expected differential settlement, or articulating concrete blocks should be used instead. Joint and crack sealing maintenance is often required when cast-in-place concrete is used.

It is also important to consider site conditions during placement of concrete slope paving. Construction earthwork activities may be needed to provide a flat, unvegetated slope to place the concrete slope paving upon. Cast-in-place concrete should only be constructed in dry conditions and allowed to cure prior to exposure to erosive forces. Articulating concrete blocks should be installed by rather small construction crews with a modest amount of equipment. Construction quality control is used to ensure proper materials and construction practices are used as specified by the designer and manufacturer.

High performance turf reinforcement mats utilize synthetic geotextile materials with natural vegetation, such as grasses, to provide an erosion control feature. Traditional installation of a turf reinforcement mat includes placing or grading the embankment or slope to the required lines and grades, seeding the area, then placing and anchoring the mat with any variety of ground anchors. Vegetation (grasses) is then allowed to grow through the mat whereby the turf is reinforced with the geotextile of the mat. Installation of this erosion control feature can be hindered by the ability to establish vegetation—in some situations the use of sod may be required.

Vegetation is also commonly used as an erosion control feature. Vegetation should be designed based on local conditions and regulations, as described in **Chapter 7**. Hydroseeding is commonly used to establish vegetation where climate conditions are favorable. Establishing vegetation from seeds can be problematic in dry areas where the seeds will not germinate for weeks or even months. Provisions may have to be made to verify germination after rainfall in the area (Figure 8-23). Often, construction closeout requires vegetation established before construction is considered complete.

Figure 8-23: Example of Hydroseeding for Erosion Control

Workers make the first of several passes spraying a protective grass mixture on a new American River Levee section in the River Park neighborhood in Sacramento, California. Once sprouted, the mixture is designed to help shield the slopes from erosion; November 2014.

6.1.10 Settlement Control

As discussed in **Chapter 7**, levees often are constructed over areas with highly variable subsurface conditions and various construction techniques may be required to construct levees upon highly compressible foundations. These techniques should be planned in the design phase and implemented in the initial stages of levee construction (Figure 8-24).Construction considerations for various construction techniques are discussed in Table 8-11.

Table 8-11: Construction Considerations for Settlement Control

Settlement Procedure	Construction Considerations
Remove and replace	• Excavation depths and presence of shallow water tables are limiting factors for construction. • Construction monitoring may be required to ensure all unwanted material is removed.
Staged construction	• Settlement plates and piezometer instrumentation are often required to monitor consolidation conditions and inform fill placement rates. • Construction scheduling and fill placement rates may be uncertain depending on conditions during construction. • Staged construction may be combined with prefabricated vertical wick drains to increase rate of consolidation to prevent delays in construction. • Relocating pipes to higher ground or other areas where consolidation and settlement is not expected may be required.
Prefabricated vertical wick drains	• Wick drains can be installed to depths up to 100 feet. • Sand drainage blanket is often installed to provide working platform and drainage for the wick drains. • Special zone or seepage cutoffs may be required to prevent long-term seepage caused by sand drainage blanket and/or wick drains. • Settlement plates and piezometer instrumentation are often required to monitor consolidation conditions and inform fill placement rates.
Preloading and surcharge fills	• Typically uses material not meeting levee fill requirements; it is placed before levee construction and removed before final levee construction. • Where stability conditions allow, surcharge placed to heights in excess of the final levee height may be placed to accelerate the consolidation time needed during construction. • Preconstruction soil testing and investigation is needed to confirm conditions are appropriate for construction.
Soil improvement or amendment	• Construction techniques should be reviewed and approved prior to construction activities. • Rigorous construction quality control and assurance may be needed to ensure acceptable soil improvement or amendment construction activities.

Figure 8-24: Example Wick Drain Installation

Crews install wick drains along a stretch of the levee to remove excess sub-surface water in New Orleans, Louisiana.

6.2 Floodwalls

Floodwalls must be constructed properly to ensure the levee performs as intended. Construction means and methods for floodwalls will depend on the wall type, foundation type (deep or shallow foundation), construction project type, and project constraints. As discussed in **Chapters 2 and 7**, floodwall types include T-, L-, and I-walls, mass gravity walls, and demountable floodwalls.

T-walls, L-walls, and mass gravity walls are typically cast-in-place concrete walls with either shallow foundations (e.g., on soil or rock) or deep foundations (on piles). Demountable floodwalls have either shallow or deep foundations. I-walls are typically driven-in-place cantilever-type sheetpile, sometimes with a concrete cap, but may also be used with soldier piles at regular spacings to stiffen the taller I-walls.

6.2.1 General Floodwall Considerations

The sequence of construction activities (e.g., sequencing of work) is important to successfully construct floodwalls. Construction sequencing is generally done by the constructor (section 4.1), but requirements for construction sequencing may be determined during design to ensure the floodwall is buildable.

Factors when considering construction sequence includes effects of construction on parties other than the constructor to minimize impacts from degradation of an existing floodwall. Construction of the wall project can be affected by the presence of existing features, such as walls and embankments, channels, buildings, roads, railroads, parking lots, utilities, etc. Considerations for construction sequencing should include construction materials or excavated material that is expected to be stored near the workface. Rights of way and available space to work also should be considered.

For construction of a new project or replacement of a floodwall project, all—or a portion of an existing floodwall—may need to be removed. Removal of existing floodwalls or embankments need to be considered in the construction sequence so that flood risk does not increase. In such cases, a plan to manage flood risks during construction should be developed (section 7.2).

When real estate is available, often the best way to manage flood risks is to build the new floodwall parallel with the existing project. This will allow the levee system to remain intact for a majority of the construction duration. If piles (or sheetpiles) are used as part of a temporary flood protection measure, the piles should generally be left in place. Depending on the soil, it will tend to 'ooze' to fill the pile voids, potentially causing displacement of the new project. Timely coordination with utility owners that have penetrations (Figure 8-25) through proposed floodwalls are imperative in maintaining the construction schedule and avoiding cost increases.

Figure 8-25: Example of Excavation of an Abandoned Utility

Levee work is underway along the north bank of the American River in north Sacramento, California. Complicating the work are land easement rights, an inactive railroad line, and an assortment of buried utilities, such as the sewer line shown here; August 2013.

6.2.2 Concrete T-Walls and L-Walls

To ensure design performance, T-walls and L-walls require sufficient foundation preparation, excavation slope stability review, groundwater management as necessary, and appropriate construction means and methods.

6.2.2.1 Foundations

Shallow foundation excavations deeper than 4 feet requires bracing for vertical cuts. This is a safety requirement mandated by the Occupational Safety and Health Administration or applicable local building codes. Bottom of slab excavations should be below the frost line to protect against foundation heaving. Work platforms are recommended for accurate rebar and concrete placement. When working in soft soils below the water table, it is recommended to place 4- to 6-inch concrete working slabs, referred to as stabilization slabs, over a 6-inch gravel layer (Figure 8-26).

Figure 8-26: Example Floodwall Foundation Construction

Constructors continue work on a new concrete floodwall along Morrison Creek in Sacramento, California. The 3,300-foot-long floodwall will extend an existing floodwall, further reducing flood risk in the area; July 2012.

For deep foundations, a variety of pile types are available for the support of floodwall systems, including concrete and steel pipe and H-piles, micropiles, and drilled shafts. The pile selection in the design phase is influenced by the availability of pile types, strength and capacity requirements, soil conditions, installation impacts on adjacent infrastructure (vibrations), corrosion resistance, and cost.

6.2.2.2 Concrete Placement for Floodwalls

The following practices for concrete placement (Figure 8-27) includes:

- Using the correct vibration methods is crucial to avoid honeycombing in the finished concrete.
- Back up concrete sources are recommended to avoid unplanned construction delays and/or cold joints.
- Unplanned cold joints should be properly prepared before additional concrete is placed to allow proper bonding of joints.
- Thermal concerns attributed to thick placements and higher strength concrete mixes are not common in smaller floodwalls. However, temperature sensors can be used to schedule form removal more efficiently.

Proper curing of the floodwall will also be crucial to achieve full strength development of the concrete; a lack of curing can truncate the hydration process. On flat, base surfaces, curing is accomplished by moist curing (ponding) or curing compounds that meet desired specifications. The curing of floodwalls is predominantly accomplished by moist curing, but other methods can be used. Curing is applied after defects, if any, are repaired.

Figure 8-27: Example Concrete Placement for Floodwalls

Concrete is being placed at the base of the western floodwall tie-in in New Orleans, Louisiana. This floodwall will connect the gap between the Seabrook floodgate structure and the hurricane risk reduction system in Orleans Metro; December 2010.

6.2.3 I-Walls

I-walls can be formed with driven, vibrated, or pressed-in sheetpiles. Construction access for I-walls can be as narrow as 15 feet. Construction access can be reduced further if press-in pile equipment is used. The added benefit of a press-in hammer is the elimination of vibration and noise. Sheetpile installation methods are described in EM 1110-2-2502 (USACE, 2022b).

Polyvinyl chloride sheetpiles are sometimes used for sheetpiling in light duty applications. General use of polyvinyl chloride is for earth retaining walls. It has much less strength (by an order of magnitude) and stiffness (by two orders of magnitude) than steel; however, it is more corrosion resistant and less expensive than steel. It cannot be readily driven in as many types of soil as steel. The pile interlocks are not as strong as in steel sheetpiling, therefore provides less robustness and ability to carry overloads. Prior to deciding to use polyvinyl chloride sheetpiling for a floodwall, a risk assessment should be performed to ensure desired levee performance is achieved.

Where greater height of the floodwalls to resist higher flood loading is needed, combo-walls may be used, consisting of steel sheetpiles with structurally connected steel pipe piles at a designed spacing.

To ensure piles are placed and driven to the correct alignment, a guide structure or templates should be used. At least two templates should be used in driving each pile or pair of piles. Templates should also be used to obtain the proper plumbness of the sheetpile wall. Protective shoes to protect the tip are also available so driving through harder soil strata is possible (Figure 8-28).

Figure 8-28: Example Pile Driving

Sheetpile installation takes place at Tanner Pacific in Foster City, California. The city is constructing a 6.5-mile seawall, upgrading the existing levee structure, and increasing the height of the levee; April 2021.

6.2.3.1 Driving Methods for I-Walls (Vibration, Impact, and Press-In)

There are multiple driving methods for I-walls including:

- **Vibratory hammers**: A vibratory hammer can drive piling up to eight times faster than impact hammers, depending on the type of subgrade. Vibratory hammers are widely used because they usually can drive the piles faster, do not damage the top of the pile, and can easily be extracted when necessary. When a hard driving condition is encountered, a vibratory hammer can cause the interlocks to melt. If the penetration rate is 1 foot or less per minute, the use of a vibratory hammer should be discontinued, and an impact hammer should be employed. The selection of the type or size of the hammer should be based on the soil in which the pile is to be driven. The design engineer should be aware of the soil stiffness and possibility of obstructions, which can cause failure or weakening of the sheetpile during driving. Vibrations from driven sheetpile installation may affect and damage existing structures. Work should be performed in a manner that will limit vibrations at the structure nearest to the work being performed to a maximum of 0.5 inch per second. When driving is adjacent to existing infrastructure, vibrations should be limited to 0.25 inch per second. Vibrations at nearby structures should be monitored during construction, and work practices should be adjusted if recorded vibrations exceed allowable levels.

- **Impact hammers**: Types of driving impact hammers traditionally used for sheetpiles include steam, air, or diesel drop, single-action, double-action, or differential-action. The required driving energy range should be specified in foot-pounds, based on manufacturer recommendations and the type of subsurface soil conditions encountered.
- **Press-in hammers**: The equipment jacks the pile into the ground. The system requires reaction piles be driven to anchor the jack and, after being started, the jack uses the driven piles to resist the jacking force. The jack rides along beams attached to the driven piles. The system is free of vibrations that are a concern when driving next to existing infrastructure. Noise levels are also very low and right-of-way requirements are reduced. The production rate is slower than when using the more common vibratory hammer.

Generally, jetting should not be performed on levees. Jetting should only be used to penetrate strata of dense cohesionless soils. Jetting should be performed on both sides of the piling simultaneously and should be discontinued during the last 5- to 10-feet of pile penetration.

6.2.4 Mass Gravity Walls

A mass concrete gravity wall consists of concrete that is often designed without steel reinforcement. There are generally construction methods for mass gravity walls—conventional placed mass concrete and roller compacted concrete.

Conventionally placed mass concrete gravity walls are characterized by construction using materials and techniques employed in the proportioning, mixing, placing, curing, and temperature control of mass concrete (ACI Committee 207, 2022). The cement hydration process of conventional concrete limits the size and rate of concrete placement and necessitates building in monoliths to meet crack control requirements. Construction procedures include batching and mixing, as well as transportation, placement, vibration, cooling, curing, and preparation of horizontal construction joints between lifts. Refer to EM 1110-2-2200 (USACE, 1995) for best practices in constructing conventionally placed mass gravity walls.

Roller compacted concrete walls are characterized by using construction techniques that are similar to those employed for embankment dams. Roller compacted concrete is a relatively dry, lean, zero slump concrete material containing coarse and fine aggregate that is consolidated by external vibration using vibratory rollers, dozers, and other heavy equipment. In the hardened condition, roller compacted concrete has similar properties to conventional concrete.

For effective consolidation, roller compacted concrete must be dry enough to support the weight of the construction equipment, but have a consistency wet enough to permit adequate distribution of the past binder throughout the mass during the mixing and vibration process, thus, achieving the necessary compaction of the roller compacted concrete and prevention of undesirable segregation and voids. The consistency requirements have a direct effect on the mixture proportioning requirements (ACI Committee 207, 2022). Refer to EM 1110-2-2006 (USACE, 2000b) for best practices in constructing roller compacted concrete.

6.2.5 Structural Backfill

The structural backfill material should be adequately compacted to prevent settlement and development of seepage paths. The amount of compaction required will depend on the material used and the purpose of the structure. Strict control of compaction is required when the fill is a cohesive soil. Precautions should be taken to prevent over-compaction, which will cause excessive lateral forces to be applied on the structure. If heavy compaction rollers are used near the wall, their effect on lateral earth pressures on the wall should be considered in the design. Alternatively, the allowable weight of compactors may be restricted by the specifications to control wall pressures. It is a best practice to start compaction at the wall and work away from the wall to minimize excessive compaction-induced locked-in lateral earth pressures.

If backfill is to be placed on both sides of a floodwall; it should be in simultaneous equal lifts on each side. In some situations, the use of clay backfill is unavoidable, and under these circumstances, very strict controls on compaction is required. During winter construction, frozen backfill material should not be allowed under any circumstances.

In some situations where floodwalls are constructed on soft soils, structural backfill can cause settlement and induce forces (e.g., down drag or settlement induced bending moments) on floodwall structural foundation components (e.g., piles). Refer to settlement control in section 6.1.10 on best practices to control settlement.

6.2.6 Levee-Floodwall Combinations

Floodwalls may be constructed on top of levee embankments, new or existing. This is frequently done when limited right of way is available to construct or raise a levee embankment. It may be necessary to allow embankment settlement before constructing the floodwall. Alternatively, the floodwall may be constructed with an overbuild to account for future settlement of the embankment.

6.3 Closure Structures

As discussed in **Chapter 2**, closure structures are used to close gaps in the levee alignment, such as where infrastructure (e.g., a road or railroad) or another water body (natural or human-made) crosses or intersects the alignment. The construction of closure structures presents unique challenges in coordination, management of water, specialized expertise in fabrication of structural and mechanical components, and quality control/testing (Figure 8-29).

Construction and delivery of closure structures to the site can interfere with normal traffic and local businesses and residents. This might have some effect on selecting the closure structure type or size of opening (**Chapter 7**) and the fabrication method. Traffic interruption issues should be properly managed (section 4.1.3) and coordinated (section 4.3). This is especially important for railroad closures. Transportation restrictions might be another key construction issue for larger closure openings. The ability to deliver the closure structure on conventional trucks should be studied. Special permits or road construction may be required for delivery of larger structures, or they may need to be assembled in place.

Construction of waterway closures presents construction challenges with working on or near water and are often impacted by fluctuations of tide and river conditions. If dry conditions are required for the construction of a waterway closure, this may require draining the waterway (if feasible) or require the use of cofferdams. Establishing dry conditions for waterway closures represent a major construction constraint requiring planning months or even years in advance. Refer to section 3.1.9 and 4.1.4 for more considerations on addressing these construction issues.

Figure 8-29: Example Closure Structure Construction

Workers construct a closure structure on the Wood River Levee system in St. Louis, Missouri; April 2012.

Coordination with state or local transportation departments or railroads is required, both to verify requirements and coordinate construction in their rights of way. Shop drawings or other design verification submittals should be submitted by the constructor with sufficient time for review, fabrication, and delivery.

Large closure structures designed and fabricated specifically for the project (e.g., tainter gates, roller gates, miter gates, vertical lift gates, sector gates) will require additional consideration. Properly qualified constructors can perform the closure structure fabrication. The more common practice is to use a fabrication shop that specializes in the fabrication of gates and mechanical components. Regardless, the fabricator's qualifications should be in accordance with the American Institute of Steel Construction certification programs. Constructability of larger closure structures should be considered including deflection, strength, and stability during stages of construction. Refer to EM 1110-2-2107 (USACE, 2022a) for best practices in fabricating closure structures.

Closure structures, both mechanical and electrical components, should be tested in place prior to construction closeout to verify they can be closed when needed. Shop drawings for closure structure components are common submittals and should be reviewed by the designer prior to acceptance for use. These shop drawings are critical for future operation and maintenance activities and should be properly documented during construction closeout (section 5.2).

6.4 Transitions

A levee consists of an arrangement of features along an established alignment, which creates a need to transition between different levee feature types. Transition locations may include:

- Earthen embankment to floodwall (concrete or steel) transitions.
- Earthen embankment or floodwall transition to concrete closure structures.
- Earthen embankment or floodwall tying into existing natural grade.
- Earthen embankment or floodwall tying to other existing infrastructure, such as bridge abutment walls or road embankment fills.
- Encroachments by pipe and culvert systems into earthen embankments.

General construction procedures for embankments, floodwalls, and closures are discussed in other sections of this chapter, whereas the unique aspects of constructing transitions are discussed in this section.

Sheetpiling is commonly extended into the embankment's levee, as shown Figure 8-30. The sheetpile tie-in maintains the height of the levee if settlement, erosion, or scour occurs, and provides protection against the internal erosion that can occur around the transition. One foot of soil over the top of the piling at the transition allows for grass cover. It also reduces the exposure of piling as the surrounding ground settles, making mowing easier.

Figure 8-30: Example Embankment/Floodwall Transition Construction

T-wall to I-wall to embankment transition under construction in New Orleans, Louisiana.

The sheetpile should extend past the concrete cap into the levee. This distance should either be 10 feet wide, equal to or greater than the height of the levee, or as required by evaluation of internal erosion. Design for internal erosion along the contact between the structure and soil is accomplished by lengthening the seepage path or by providing a filter at the exit to arrest soil particle migration. The sheetpile tie-in lengthens the path that soil particles would need to migrate along this contact for internal erosion failure mode.

Often, a short transition concrete-capped sheetpiling I-wall is installed between the embankment and a T-wall. One of the primary concepts in the development of this transition is to arrange details so there will be a minimum amount of differential movement of joints of monoliths in the transition. Where differential movement is anticipated, the sheetpile interlock should fall within the dove tail slip joint. Where differential movement is not anticipated, the sheetpile interlock can be located outside the wall edge. A dove tail slip joint may also be provided to aid in constructability. First, the levee embankment should be placed and compacted. Then, the sheetpile transition should be driven in order to minimize void spaces along the sheetpile.

The I-wall tie-in can be satisfactorily adopted as a transition section between an embankment and a pile-founded floodwall. That is because this type of construction is done after completion of the embankment. A delay in inserting the I-wall tie-in allows for consolidation of the embankment foundation, thus lessening the differential settlement between the embankment end of the transition and the floodwall. Potential ground improvement measures to mitigate for total and differential settlement are described section 6.1.10. The constructed transition may need to be made higher than required to account for settlement over the life of the project.

Settlement of embankments relative to adjacent floodwall sections may require special considerations to accommodate movement. This can be done with joints. The joint widths and waterstops should be selected to accommodate the expected rotation and movement. This may be done with large center bulbs or, in the case of very large movements, surface mounted neoprene sheets. Surface mounted waterstops should only be used as a last resort. They need to have a durable cover in order to protect them from sun, vandalism, or damage. This cover should also allow for movement.

Erosion control features are often required at the transition between embankments and floodwalls to prevent overtopping erosion (Figure 8-31). Refer to EM 1110-2-2502 (USACE, 2022b) for best practices in constructing embankment/floodwall transitions.

When the transition location is between an embankment and natural ground, the contact between the natural ground and the embankment should be prepared similarly to embankment subgrade preparation discussed in section 6.1.2. The contact should not be steeper than 1 vertical to 1 horizontal to avoid embankment cracking. The embankment inspection trench should be extended into the natural ground to ensure proper levee transition connection.

Figure 8-31: Example Levee Transition Connection (Embankment and Floodwall)

Transition of a floodwall and levee tie-in connection in New Orleans, Louisiana; March 2012.

6.5 Seepage Control Features

Seepage control features can include cutoff walls, seepage berms, and landside pressure relief systems. These features require different construction materials, equipment, and procedures. Best practices for construction of common seepage control features are discussed in the following sections.

6.5.1 Seepage Cutoff Walls

Cutoff walls act as a vertical low permeable barrier through existing embankments, or below the embankment or floodwall. They may include open-trench slurry walls, mix-in-place walls, grout walls, and sheetpile walls.

Open-trench slurry walls can include either a low strength soil-bentonite backfill or a higher strength (100 to 300 pounds per square inch) cement-bentonite backfill. In both cases, a narrow trench (24 to 36 inches) is excavated and initially is stabilized by a bentonite-water slurry for the soil bentonite wall, and a bentonite water-cement slurry for the cement bentonite wall. For the soil bentonite wall, a soil bentonite slurry mixture with a concrete slump of 4 to 7 inches is gravity backfilled into the slurry filled trench. The backfill displaces the slurry and forms a low permeable cutoff wall (Figure 8-32). For the cement-bentonite wall, the slurry used to stabilize the trench excavation self-hardens in 24 to 48 hours and forms the cutoff wall.

Figure 8-32: Example Open-Trench Cutoff Wall Construction

(a) Workers install a seepage cutoff wall in an American River Levee near Del Paso Boulevard in Sacramento, California; September 2014. (b) An excavator cleans out excess material from a seepage cutoff wall trench, as part of the Sacramento River Bank Protection project in West Sacramento, California; June 2012.

For mix-in-place cutoff walls (Figure 8-33), either individual elements (panels) or continuous trench mixing systems can be used. For panel construction, the number of panels constructed per shift is selected by the constructor so every panel can be excavated to the full depth and backfilled or mixed as appropriate in one shift. In either panel construction or continuous mixing, complete depths should be achieved and should not be allowed to be left at partial depth at the end of a shift.

Figure 8-33: Example Mix-in-Place Cutoff Wall Construction

A deep soil mixing rig pumps a cement slurry into the floodwall levee's foundation along the east side of the 17th Street Canal in New Orleans, Louisiana. Blades around the augers mix the slurry with the underlying soil to produce stabilized soil columns that will increase the levee's strength; March 2011.

For panel construction or cold joints in continuous trench mixing systems, a minimum overlap for the full cutoff wall depth is specified to ensure continuity of the cutoff wall. If the panels or cold joints are not successfully joined within the identified time frame, an offset adjacent overlapping segment on the waterside typically will need to be constructed to close the potential gap in the cutoff wall.

Crossing of the completed cutoff wall during construction should be allowed only at designated equipment crossings, where metal plates should be placed over the wall as a temporary measure to prevent cracking/collapse of the trench sidewalls.

Equipment and vehicular traffic not related to cutoff wall construction should not be allowed near the cutoff wall trench to avoid surcharge loading on the trench sidewall.

If adopting an open trench cutoff wall, a stability analysis should be completed on the open trench wall configuration. Open trench cutoff wall construction should be logged continuously and monitored during excavation by a qualified geologist or geotechnical engineer to confirm the bottom of the cutoff wall extends into the designated layer to form an adequate cutoff and continuity has been maintained. This should include logging by both the constructor's quality control trench logger and a quality assurance trench logger.

In open-trench cutoff wall construction—when the bottom of the cutoff wall element is reached—the bottom surface should be probed along the trench centerline, using a weighted tape to confirm the target bottom elevation is obtained. If more than a 6-inch-depth of sediment is found on the trench bottom, the trench bottom should be cleaned by successive light passes of an excavation bucket without teeth over the bottom surface, until the bucket returns free of debris or sediments.

For mix-in-place cutoff walls, multiple systems are available and include vertical auger and horizontal cutter wheel systems. Normal depth capacity of these systems ranges up to 150 feet below grade and can inject and mix a combination of bentonite and cementitious material to form a low permeability cutoff wall.

Before construction of a cutoff wall, the constructor should prepare a bench scale wall mix (soil-bentonite-water or soil-bentonite-cement), including varied mix constituents. Testing should be completed on the various mixes, as applicable, for unconfined compressing strength and hydraulic conductivity, and a recommended production mix should be submitted for review and approved by the design engineer. After being approved, this mix will form the basis for the production quality control and quality assurance testing.

As the cutoff walls are installed, a temporary cap should be placed within 24 hours over the top of the wall. The temporary cap should be a minimum 2 feet thick and constructed using embankment fill material placed without compaction effort. After the wall has been allowed to cure for the full period required by the specifications, the temporary cap and the upper 6 inches of wall should be trimmed to expose a clean surface and prepare a foundation for levee embankment or floodwall.

Wall material may be prone to desiccation and cracking when exposed at the surface, even after the wall has cured. The constructor will need to maintain the top of the cutoff wall at a consistent moisture content until covered by a permanent embankment or concrete floodwall. Protection of the cutoff wall will include minimizing the duration hardened cutoff wall materials are exposed, keeping all exposed cutoff wall materials continuously wetted, and applying protective measures, such as wetted burlap coverings or membrane-forming concrete-curing compounds.

During construction, bulk sampling of the cutoff wall slurry/mix should be performed in the excavation trench a minimum of twice per rig shift (i.e., twice per panel). Samples are taken by the constructor quality control personnel and levee owner's quality assurance personnel for applicable testing (Figure 8-34).

Figure 8-34: Example Quality Control Testing of Open Trench Cutoff Wall

Contract workers check the quality of a recently completed seepage cutoff wall near the River Park neighborhood in Sacramento, California; August 2014.

Acceptance criteria should have been developed during preparation of the project specifications and may include consideration of quality control and quality assurance testing, as well as the results of verification coring and downhole data.

To verify in situ competency of the cutoff wall, depending on the type of cutoff wall and as identified in the specifications, verification coring of the completed cutoff walls may be required at a typical spacing of 500 feet along the production wall alignment.

The verification coring, if used, typically will include collecting core samples, downhole televiewers, and falling head/rising head permeability testing. Detailed requirements should be identified in the specifications. Testing frequency and criteria should be established in the specifications.

A detailed description of cutoff wall system construction methods and issues is presented in Specialty Construction Techniques for Dam and Levee Remediation (Bruce, 2013).

6.5.1.1 Grouting and Sheetpiles

Although not as common, both grouting and sheetpiles have been used as seepage control methods. Grouting techniques include jet grouting and conventional pressure grouting. Both systems use combinations of bentonite and cementitious materials to create an in situ low permeability cutoff wall. Steel sheetpiles also can be used to create a cutoff barrier beneath levee embankments and floodwalls.

6.5.2 Seepage Berms

Landside seepage berms generally are constructed using standard earthwork techniques and can be used to control seepage through or under the levee, and at the same time can increase the stability of the levee.

Berms generally include random or general fill that provide only mass stability and move seepage away from the levee. Undesirable materials, such as high plasticity clays and organics, should be excluded from berm materials.

If the berm is drained, drainage layers typically will include filter sand and drain rock. These materials are designed to be filter compatible, and the constructor’s material submittals should be reviewed carefully for compliance with the specifications. Substitutions should be analyzed for filter compatibility before acceptance.

Placement of drainage layers on levee slopes as part of seepage berms (chimney drains) can be especially challenging, as care needs to be taken to avoid intermixing of the materials and maintain continuity of the drainage layer, as the filter, drain rock, and cover soils are placed on the slope of the embankment (Figure 8-35).

Figure 8-35: Example Construction of Landside Berm and Chimney Drain

Constructors continue work on a chimney drain installation as part of the 150-foot-wide drained seepage berm construction along the right bank of the San Joaquin River in San Joaquin County, California; June 2021.

6.5.3 Landside Pressure Relief Systems

As discussed in **Chapter 7**, common types of landside pressure relief systems include blanket drains and toe drains to collect throughseepage (Figure 8-36), and trench drains and relief wells to collect underseepage (Figure 8-37).

Figure 8-36: Throughseepage Pressure Relief Systems

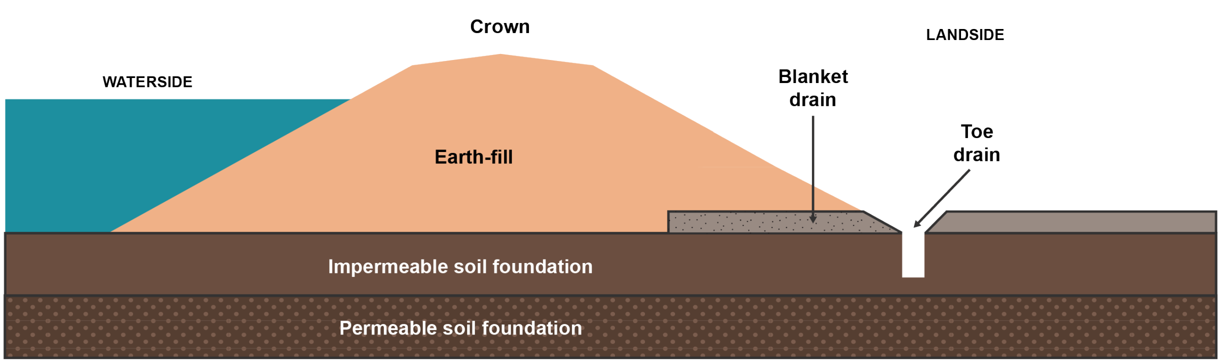
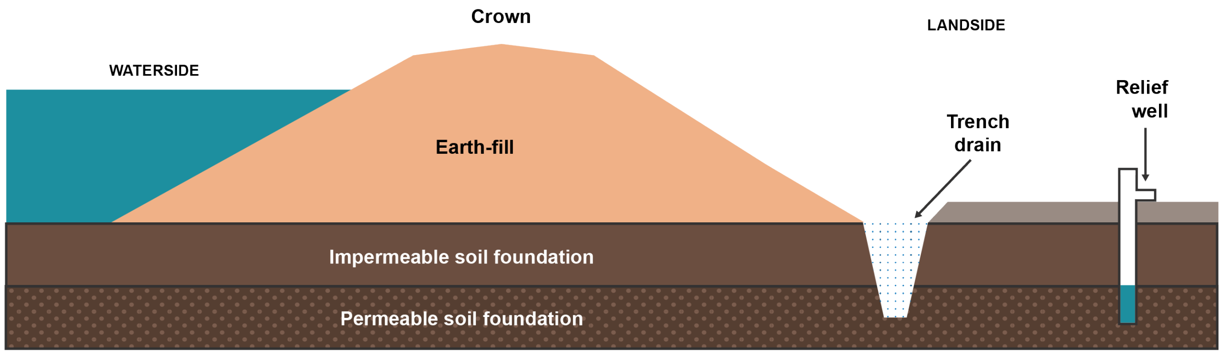


Figure 8-37: Underseepage Pressure Relief Systems



6.5.3.1 Drains

Construction of blanket drains, toe drains, and trench drains requires careful construction procedures to ensure proper materials are placed in the correct location. These drains contain pervious material with a specific particle gradation to ensure proper filtering and drainage. Basic construction procedures include storage (stock piling) of materials, loading of hauling equipment, hauling and dumping, spreading to specified loss lift thickness, wetting, compaction, and horizontal and vertical control. Materials for drains are typically purchased off site and stockpiled on site.

Dust abatement procedures should be used to prevent contamination of fines into the stockpiled material. Drain materials should be wetted prior to handling to facilitate that action, as well as to help minimize segregation. Compaction of drain materials should occur by means of vibratory rollers with the minimum required effort specified that will attain the desired density. For best practices in drain construction, refer to the Federal Emergency Management Agency's (FEMA) Filters for Embankment Dams manual (FEMA, 2011).

6.5.3.2 Relief Wells

Relief wells on the landside of the levee will act to control and relieve seepage pressures under the levee. Construction of relief wells should follow best practices, as outlined in EM 1110-2-1914 (USACE, 1992), and usually are implemented by experienced constructors. The most effective drilling method for any project involving installation of relief wells should be utilized. The method should be selected based on previous experience and consultation with the constructor.

Geology and site conditions, along with well diameter and depth, are major factors that will determine the appropriate drilling method. Relief wells typically vary from 6 to 18 inches in diameter. Boreholes are normally drilled 8 to 12 inches larger than the well diameter to accommodate filter packs. Table 8-12 provides a list of advantages and disadvantages of common drilling methods. Particular care by the constructor should be taken in drilling and the placement of filter pack around the well screen to ensure the well functions as designed (Figure 8-38).

Before installation of relief wells, pilot holes are typically drilled within 5 feet of each well location. These holes are usually sampled continuously or at frequent intervals (less than 3 feet). The purpose of the pilot holes is to verify foundation conditions used for seepage analysis and relief well design. The holes also serve as a check on the design of the relief well filter pack, screen/slot sizes, and screened/blank intervals. Pilot holes can be drilled during the pre-construction engineering and design phase. In this case, information from the pilot holes is included in the subsequent construction documents. Alternatively, pilot holes can be drilled during the construction phase with the final well design performed during well construction. Construction risks (e.g., impacts to schedule and costs) can be greater if pilot holes are drilled during construction due to the uncertainty in conditions.

Once the relief well boring is completed and the tools withdrawn, the boring should be sounded to assure an open hole to the proper depth. All screen and riser to be installed should be laid out. These materials are obtained in standard lengths (e.g., 10 feet) or fabricated in varying lengths. When non-standard lengths are required, it is advantageous to have screen and blank sections pre-fabricated to length by the manufacturer. This is especially important when using stainless screens, due to the difficulty of cutting and welding stainless steel in the field. In either case, all screen and riser must be measured prior to installation to determine its total made-up length. This information should be part of the well construction record. The bottom joint of the well screen should be fitted with a sump or bottom cap.

After installation, all wells should be pump tested to demonstrate the filter pack and screens are allowing flow of water from the wells without loss of foundation fines.

During construction, detailed and accurate observations of all aspects of relief well installation should be documented on site in a timely manner. These records should be included in the project documentation during construction closeout. These records should include information on well material, method of drilling, type, length and size of well screen, and slot size. The filter should be defined as to grain-size characteristics, depth, and thickness. Elevation of the top of the well and the ground surface should be recorded. The depth to granular material, the thickness of that material, and the percent penetration of the well should also be clearly identified. Development data should include the method, the amount of effort, and sand infiltration. The records should show the final sounded depth of the well.

Table 8-12: Advantages and Disadvantages of Relief Well Drilling Method

Common Drilling Method	Advantages	Disadvantages
Cable tool	• Drilling fluid not required. • Borehole remains stable. • Formations with voids can be drilled. • Rigs are simple and economical. • Less well development required compared to standard rotary method.	• Low penetration rates. • Efficiency declines with depth. • Fine-grained formations can be problematic.
Standard (direct) rotary	• High penetration rates. • Ability to maintain open borehole without casing facilitates well and filter pack installation.	• Drilling mud required, can cause plugging, “balling” of bit, etc. • Rigs are large, expensive, and complex with high transportation and daily operating costs. • Requires significant water supply. • Management of drilling fluid requires specialized experience and expertise. • Mud pits in blanket require careful backfilling, compaction, and reseeding.
Reverse rotary	• High penetration rates. • Few or no drilling additives required. • Ability to maintain open borehole without casing facilitates well and filter pack installation. • Less well development required compared to standard rotary.	• Large rig size limits site accessibility. • Requires significant water supply. • Not suited for drilling prolific aquifers and/or materials where loss of circulation is a concern. • Difficult in drilling cobbles or boulders. • Mud pits in blanket require careful backfilling, compaction, and reseeding.
Hollow-stem auguring	• Rigs are simple and economical. • Drilling mud is not required. • Borehole remains stable. • Penetration rates are fast when using bottom plug. • Less well development required compared to standard rotary.	• Augers can smear formation with clays from overlying layers. • Augers must be pulled back while filter material is placed; progress can be slow. • Large augers can get “locked” in saturated sand layers. • Large augers generate a high volume of cuttings.

Figure 8-38: Example Relief Well Construction

Constructors work to install a 95-foot deep relief well for seepage control along the Mississippi River Levee near Vicksburg, Mississippi; September 2011.

6.6 Channels, Floodways, and Controlled Overtopping

6.6.1 Channels and Floodways

As discussed in **Chapter 7**, channels and floodways act as a diversion for riverine floodwater flows to be released into less critical areas. Such diversions may include:

- Diversion of flood water from the river into the leveed area.

- Diversion of water to/from the leveed area to another area or basin, which is either not prone to flooding and/or where other existing drainage facilities can be used to remove the water.
- Removal of water from a detention basin before the water in a basin rises to a level that can cause damage.

Thus, proper sequencing of construction channels and floodways is important in management of risks during construction. When constructing channels and floodways, flows should be managed by diversion, pumping, or sequencing of the construction. One side of the channel is often constructed while providing for diversion of the water on the other side of the channel. After completion of the first side of the channel, flows are diverted to the completed side while completing the opposite side.

Survey control during channel and floodway construction is essential to correctly locate channel and floodway components, as well as to ensure the constructed channel and floodway alignment and grade are as designed. Field staking and surveys should be performed routinely as with any earth-moving project. Interim surveys are recommended to update progress and document earthwork quantities.

Construction of channel erosion control features are similar to that of embankments. Refer to 6.1.9 for best practices in construction of channel erosion control features.

6.6.2 Locations of Controlled Overtopping

Locations of controlled overtopping may include embankments, floodwalls, closure structures, transitions, and erosion protection features. Construction associated with locations of controlled overtopping are similar to the levee features previously discussed in section 6. However, the sequencing of construction for controlled overtopping in relation to the construction of other levee features is a key consideration and should be determined based on effective management of risks during construction (section 7).

6.7 Interior Drainage Systems

Interior drainage system facilities include drainage structures (Figure 8-39) and pump stations (Figure 8-40). Construction practices for these structures are similar to floodwalls, except that large open cuts or braced excavations may be needed, both of which typically require dewatering systems. Testing dewatering systems should be considered in advance of construction to better estimate the dewatering needs to maintain excavations. Braced excavations can be used as temporary flood protection measures when building within the levee alignment. Temporary pumps may be required when the braced excavation blocks the drainage flows. Structures—such as waterway gates constructed in navigation channels—may also require a temporary bypass.

6.7.1 Pipes

It is essential that the construction of pipes associated with interior drainage systems, such as gravity drains or pressurized pipes from pump stations, is performed in a proper manner, as improper construction practices can lead to failure modes that can significantly affect the performance of a levee. Generally, EM 1110-2-2902 (USACE, 2020b) provides the best practices for both the design and construction of pipes for levees. There are several construction considerations involved when work includes the installation of a pipe, including:

- Managing ground water, surface runoff, and/or flooding.
- Pipe installation method.
- Testing and acceptance.
- Construction documentation.

Figure 8-39: Example of Landside Interior Drainage Construction

Excavation and preparation of a trench, followed by installation of a new drainage pipe outside the seepage berm toe, occurs along the right bank of the San Joaquin River in Sacramento, California. An existing drainage ditch adjacent to the landside levee toe is backfilled and a new drainage pipe is being installed; July 2021.

Water management during pipe installations is necessary to prevent schedule delays, increased costs, and lower quality installations. For example, water ponding in the pipe trench can prevent adequate backfill compaction, which may lead to vertical and/or differential settlement between pipe segments.

Excavations which extend below the groundwater table can cause a ‘quick’ condition in the bottom of the trench, which occurs when the upward water pressure reduces the soil’s effective stress, and it begins to behave more like a fluid. This loss of strength creates an inadequate supporting surface for the pipe. The depth of the bottom of the excavation in relationship to the groundwater table, foundation conditions, expected quantity of flow, and size of excavation will dictate the groundwater management method.[3]

[3] The information required for selecting and designing a groundwater control system can be found in Unified Facilities Criteria 3-220-05 (USACE, NAVFAC, and AFCEC, 2004).

Commonly, for the installation of pipes, controlling surface water is typically required for the installation of pipes and may include earthwork/regrading to divert water around the construction site. The installation or replacement of a pipe through a full cross-sectional embankment excavation will typically require temporary flood protection measures (section 7.2).

Pipes may be installed in the foundation beneath a levee by trenching or trenchless methods. Trenched placement involved excavating soil along a path, preparing the excavation to receive a pipe, installing the pipe, and backfilling around the pipe. Although relatively straight forward, the precautions using this method are discussed later in this section. Trenchless methods consist of steerable and non-steerable procedures that produce an overcut, creating an annular space between the excavated soil and the outside of the pipe. These methods often require introduction of water-based lubricants within an annular ‘overcut’ space between the pipe and the soil to facilitate pipe installation and remove drill cuttings. Trenchless methods are more technically challenging, as it requires specialized equipment and skilled workers to monitor drilling pressures and grouting, and to maintain line and grade by controlling the rate of advancement.

For the trenching installation method, the designer should determine if controlled low strength material or soil backfill is desired, since it will impact the trench dimensions. If soil is used, the excavated trench must be wide enough to accommodate the hand-operated equipment used at an angle to compact the soil within the pipe haunches. During new levee embankment construction, it is generally preferred to partially construct the new embankment so that a trench may be cut through uniformly compacted fill. The partially completed embankment should be constructed high enough that the backfill over the pipe is sufficient to protect it from equipment loads once embankment construction resumes. The bottom of the excavated trench should be tested to verify soil and groundwater design assumptions.

There are generally accepted trenching installation restrictions. Excavations for trenching installations must be designed, excavated, and maintained in a stable condition. Seepage into excavations must be controlled to prevent erosion of soils, which may require dewatering. With the exception of trench boxes, deep temporary shoring of pipe trenches through an embankment should be avoided. The soil disturbance associated with vibratory or impact hammers for deep shoring, such as sheetpiling or piles, could damage otherwise acceptable embankments. Also, the removal of sheetpiling can leave gaps in the embankment or foundation. While trench boxes are less likely to disturb embankment soil, they can create lines of disturbance that must be addressed to prevent creating a preferential seepage path.

Figure 8-40: Example Interior Drainage Pump Station

Workers install a new city sump station with 10 lines near the River Park neighborhood in Sacramento, California.; October 2014.

For trenchless methods, there are also several construction installation restrictions to consider. Excavations at entry and exit areas for trenchless installations must also be designed, excavated, and maintained in a stable condition. Trenchless installations are not recommended through earthen embankments or seepage control features. If any seepage control feature is above or beside the proposed trenchless pipe alignment, a review of whether trenchless method is appropriate for the project to ensure the advancement trenchless technique will not impact the seepage control feature. Entry and exit areas must be backfilled with a low permeability cohesive soil placed around the pipe to prevent a preferred seepage path.

Pipe installations, whether trenched or trenchless, have the potential to create preferential seepage paths from the waterside to the landside. Seepage filters are commonly used to address this issue through relieving local pore pressures by allowing the passage of water while preventing the migration of soil particles (internal erosion) when the levee is loaded. FEMA's Filters for Embankment Dams manual (FEMA, 2011) provides best practices to use when constructing filters.

In cases where significant settlement along the pipe alignment is anticipated, the preferred method of mitigation is preloading the foundation to reduce post-construction settlement. Reducing the post-construction settlement reduces stress on the pipe connections and the chance of producing a sag in the pipe alignment that perpetually holds water.

Pipe segments must be joined according to the manufacturer's instructions to better ensure their success and longevity. In general, pipe segments are placed only after pipe supports or cradles have been properly prepared. Pipe placement should begin at the lower elevation and continue uphill, which uses gravity to help home the joints and maintain a seating force.

The effect of the construction loads on the pipe are a function of the depth of soil cover over the top of the pipe. Heavy construction equipment passing over the top of the pipe should be evaluated when necessary. If the soil cover height is at least 3 feet above the top of the pipe, construction equipment can usually pass over the pipe without issue; however, additional analysis may be required. Methods to estimate loads are provided in Chapter 5 of the American Water Works Association M11 manual (Dechant, Bambei and American Water Works Association, 2017), if required.

Acceptance testing formalizes the approval of newly installed or rehabilitated pipes using inspections and field testing so that the pipe owner does not rely solely on the manufacturer's quality assurance/quality control factory testing. The best practice is to perform an inspection of each installed pipe section after the trench has been backfilled but before the embankment is placed. Post installation inspections provide a baseline for subsequent in-service inspections.

The following provides a list of items that should be considered when evaluating installation compliance with documents for construction.

- All pipes and fittings should have a manufacturer's certification stamp stating that the material conforms to the specification and/or guidance governing the manufacture of the particular pipe material.
- Visually inspect all pipe segments and appurtenances upon arrival at the job site to ensure that they were not damaged during transit before accepting the delivery.
- Lift pipes according to the manufacturer's directions (from delivery vehicles and into trenches) to prevent excessive bending stresses or damage to protective coatings.
- Protect pipes from impact damage, such as scratching and cracks, and store on level ground in the manufacturer's packaging. Follow the manufacturer's recommendations for allowable stack heights, supports, and exposure (temperature and ultraviolet).
- Follow manufacturer's guidance for field repair of damaged pipes, if the repair is not expected to affect performance; otherwise, replace the pipe. Defects vary by pipe material, but common defects include fractures and cracks, coating holidays or damage, and surface defects indicating mixing, molding, or other manufacturing deficiencies. Pipe sections with joint damage should be replaced.
- Each joint should be tested hydrostatically to determine whether it exceeds the maximum joint leakage specified by the pipe's applicable American Society for Testing and Materials International standard or other guidance specified in the documents for construction.
- Ensure that pipe segments that are match-marked (i.e., pipe markings indicating the order of installation) are installed in the correct order.
- Backfill should be tested to ensure it meets the requirements specified in the documents for construction.

- Inspect each segment of pipe for: alignment; settlement or sags; excessive joint offsets or separations; buckling, bulging, and deformation; protective coating damage; seal or weld separations; and other damage. Ring deflection that may occur during installation should not exceed the limits in documents for construction. Reinstall segments with installation deficiencies. Repair or replace damaged segments.
- Identified defects on an installed pipe must be assessed by an engineer for potential impacts to levee performance.

Construction reporting and documentation is a valuable reference for future inspections, assessments, and modifications or repairs. As the pipe installation progresses, field documentation must be assembled as part of a post-construction report. Conditions including joint gaps, tears, misalignment, cracks, and deformations must be noted and reviewed by the condition assessor. The post-construction report should include the following items:

- **Manufacturer documentation**: This documentation should include design drawings for pipe joints; design calculations, proof of design testing, and inspection records for pipes and fittings; and, drawings, design calculations, and specifications for appurtenances (such as slide gates, flap gates, valves, pumps, and pre-formed or precast associated structures, such as gatewells, manholes, headwalls).
- **Acceptance testing documentation and inspection reports**: These reports should be developed and include any additional quality assurance/quality control information.
- **Testing and inspection personnel and equipment information**: This should include a statement of the field accuracy achieved for all measurements, including tolerances. The report typically includes a narrative about required field/measurement calibration and provides proof that all calibration procedures were followed when collecting data within the report.
- **Record drawings and field data**: This data should be provided in a digital format, including the pipe's alignment profile and elevations. Tracking equipment, including method or confirmatory procedure, used to capture the data should also be included.
- **Evaluation of installed condition**: This evaluation should be documented, typically including certification that the pipe and backfill were installed consistent with the final approved plans and specifications.

6.7.2 Ancillary Components

As discussed in **Chapter 7**, ancillary components associated with the penetrations may include headwalls and gatewells. Mechanical components may include slide gates or sluice gates, passive flap gates, air vents, and siphon breakers. For construction considerations related to ancillary components, refer to Table 8-13 for references to best practices.

Table 8-13: References to Best Practices for Construction of Ancillary Components

Mechanical Component	Best Practice Reference
Sluice gate	• EM 1110-2-2902 Conduits, Pipes and Culverts Associated with Levees and Dams and Other Civil Works Structures (USACE, 2020b). • EM 1110-2-2107 Design of Hydraulic Steel Structures (USACE, 2022a). • EM 1110-2-6054 Inspection, Evaluation, and Repair of Hydraulic Steel Structures (USACE, 2001). • EM 1110-2-3105 Mechanical and Electrical Design of Pump Stations (USACE, 2020c).
Flap gate	• EM 1110-2-2902 Conduits, Pipes and Culverts Associated with Levees and Dams and Other Civil Works Structures (USACE, 2020b). • EM 1110-2-2107 Design of Hydraulic Steel Structures (USACE, 2022a). • EM 1110-2-6054 Inspection, Evaluation, and Repair of Hydraulic Steel Structures (USACE, 2001). • EM 1110-2-3105 Mechanical and Electrical Design of Pump Stations (USACE, 2020c).
Duckbill check value	• EM 1110-2-2902 Conduits, Pipes and Culverts Associated with Levees and Dams and Other Civil Works Structures (USACE, 2020b).
Air vents and siphon breakers	• EM 1110-2-3105 Mechanical and Electrical Design of Pump Stations (USACE, 2020c).

6.8 Pump Stations

Construction of pump stations can be complex as it requires close coordination with adjacent levee work as well as construction expertise in earthen, drainage systems, electrical, mechanical, and structural components (Figure 8-41). Where pump stations are adjacent to levee embankments or where right-of-way restrictions exist, the stations are typically located at the landside toe of the levee. Vehicle access to pump stations at all flood elevations should be carefully considered when selecting station location, and adequate provisions should be made to permit safe operation of service vehicles bringing in equipment during construction and O&M.

Figure 8-41: Example Construction of a Pump Station

Construction takes place on the pump station along the Chain of Rocks Levee near Granite City, Illinois. The pump station is one feature of the levee system; April 2012.

During construction, the designer should be involved in the review of shop drawings and record drawings, preparation of the O&M manual, and field and shop inspections. The designer should also be consulted when a field change is recommended or required. Considerations for mechanical components of pump stations, as well as commissioning a pump station during construction, can be found in **Chapter 7**.

Commissioning of a pump station involves bringing a recently constructed pump station into proper working order. Commissioning involves the integration of all component mechanisms into a single system (i.e., pump station) through adjustment of settings and other operating parameters. It also involves operational testing to ensure the station is free of defects, either inherent to the design or inadvertently incorporated during facility construction or manufacture of equipment. It is not always possible to foresee all issues during the design phase, and alterations during construction may produce unintended consequences. Commissioning should not be viewed as strictly taking place at the end of construction, but as a process integral to both the design and construction phase of a pump station project.

During construction, the best practices for the commissioning of a pump station involves the following:

- The levee designer should review construction submittals, respond to constructor requests for information, conduct site visits, witness factory testing, and perform preliminary steps for preparation of the O&M manual.
- The designer should review pump equipment shop drawings to ensure construction requirements are met. It also is the best and least costly time to implement any changes to the plans or specifications required due to design deficiencies, equipment changes, or to implement design improvements.
- In addition to procurement and fabrication submittals, informational submittals covering manufacturers' O&M instructions will provide additional operating requirements on equipment which must be vetted for consistency with project operation.
- Shop drawings should be reviewed by the designer to ensure contract specification requirements for fabrication, equipment, materials, and finishes are met. They should be detailed and include all information as described in the specifications. In addition, they should include requirements for manufacturing and assembly drawings that ensure the pump is being built in accordance with contract requirements, industry standards, and best practices.
- The constructor and pump manufacturers should have approved shop drawings on site. It should also be verified that installation instructions including weights of pump components (e.g., shaft, pump impeller, impeller and diffuser bowls, columns, shaft enclosing tubes, bearings), required rigging equipment (e.g., crane, straps, chains, wire cables), and required drawings are on site.
- Submittals from the pump manufacturer should include requirements to have a two-plane dynamic balancing of impeller at rated operating speeds and at 110% of that speed.
- The pump manufacturer should provide shipping information on how to remove and install the pump. They should also provide information on supporting or bracing of the pump enclosing tube, especially at bearing locations if being shipped completely assembled and ready for installation at the construction site. This is to ensure that the construction shaft does not bend, and the bearings are not damaged.
- After reviewing and approving the shop drawings, the next phase is to do a model and/or prototype test for the pumps and factory testing and inspections for other station equipment.
- Submittals for factory testing plans and test reports are key to the process of commissioning a pump station. On large projects, stipulating the constructor maintain an updated schedule for anticipated testing dates may assist in avoiding conflicts and concerns.
- As construction progresses and the constructor begins integrating systems, questions about design intent, functionality, possible issues, or optional ways of implementing items will likely result in constructor requests for information. The response process is

often the early stage of working out issues that will arise in the commissioning process. Maintaining organized records of requests for information resolutions will likely have an impact on O&M documentation or record drawings.

6.9 Instrumentation

As discussed in **Chapter 7**, instrumentation and monitoring is necessary for understanding the levee behavior during construction and validating design assumptions during construction. The installation of an instrument is not a routine task and requires attention to detail. Poor installation of instruments can lead to erroneous data or even adversely affect the levee. Methods of installation depend on the parameter to be monitored, site conditions, and the type of instrument. Successful installation of an instrument requires the labor of qualified personnel. Geotechnical Instrumentation for Monitoring Field Performance (Dunnicliff, 1993, chap. 17) provides a good overview of installation procedures for geotechnical instruments, most of which have applications for embankments. The Bureau of Reclamation Water Measurement Manual discusses requirements for various water flow measurement devices.

If instrumentation installation is required as part of the levee construction, the design documents should include the following items:

- Purpose of each individual instrument.
- Instrumentation system performance criteria.
- Qualifications of the instrumentation installation personnel.
- Quality control and assurance requirements.
- Submittals required.
- Materials (provide a detailed description of all types of instruments included in the contract, including spare parts commonly stocked).
- Factory calibration requirements.
- Pre-installation acceptance tests.
- Verification of instrument function (including raw and reduced data collection retrieval and sample output submittal).
- Installation instructions (providing a detailed step-by-step procedure to install each type of instrument).

Installed instrumentation casings, tubes, and cables should not significantly alter the mechanical properties of the levee features or provide seepage pathways. If significant embankment or foundation deformation is expected, installation of an instrument should prevent damage to elements such as pipes, tubes, and cables. Detailed information on best practices for installing instrumentation is provided in EM 1110-2-1908 (USACE, 2020a). In general, the following are construction considerations for instrumentation:

- Ensure compatibility between the diameter of the borehole and any minimum and maximum diameter requirements of the instrument.
- Establish conventions for instrument naming, field labeling, and borehole logging.

- Ensure instrument components are handled properly prior to installation to avoid damage.
- Perform pre-installation acceptance tests at the project site before an instrument is installed.
- Test the instrumentation after installation to ensure they are functioning correctly.

After completion of the instrument installation, a report should be prepared documenting the pertinent information regarding the instrument's installation. This information should be included in the project documentation at levee construction closeout.

7 Managing Risks During Construction

There are two types of risks that should be managed during construction:

- Construction risk: Cost, schedule, and worker safety and construction quality.
- Flood risk: Flooding of the construction site or leveed area.

Rigor of managing risks during construction should be commensurate with the levee risk. For higher risk levees, managing risk during construction may consist of preparing a risk register, adhering to a construction emergency action plan, tracking risks throughout the construction period, and providing temporary flood protection during construction to maintain the current level of flood risk reduction. For lower risk levees, a less detailed risk register and emergency action plan may be sufficient.

7.1 Construction Risk

Levee construction requires interpreting and complying with governing laws and regulations; gathering considerable resources (e.g., labor, equipment, and materials); and communicating and coordinating with multiple parties (e.g., owner, designer, prime and sub-contractors, suppliers). These factors—in addition to other unknown conditions such as poor site conditions and weather—exposes the constructor, designer, owner, and public to possible loss (i.e., construction risk). All levee construction projects have some degree of construction risk. Identification and management of construction risk is prudent for successful levee construction and occurs when preparing for levee construction.

Levee construction risks may include:

- Unforeseen/unknown environmental (encountering rare or endangered species), cultural (tribal artifacts), or geotechnical conditions (poor foundation soils) affecting the project schedule or requiring costly design changes. Unforeseen conditions may even make a project unbuildable.
- Changes in costs or availability of construction materials.
- Life safety (e.g., excavation and trenching, near or over water work, working around heavy equipment).
- Releases of hazardous or toxic materials to the environment.

- Positive connection of levee embankment to hardened structures (e.g., floodwalls, bridge abutments, natural ground).

Depending on the levee project, construction risks identified either need to be avoided, mitigated, or managed. New levee and modification construction projects with significant financial investment (greater than $5 million) or potential for life loss and significant economic, environmental, infrastructure damages due to poor project performance, should utilize a higher degree of construction risk management. New levee and modification construction projects with no life loss or economic damage may utilize a lesser degree of construction risk management. Generally, repairs including breach and emergency repairs also utilize a lesser degree of construction risk management.

7.1.1 Risk Register

The degree to which construction risks are managed are measured by how much effort is put into the identification of construction risks and the mitigation or avoidance of those risks. For higher degrees of construction risk management, a **risk register** is often used to document all identified construction risks for the project, along with mitigation actions, costs, and responsibilities. The register is a living document created by the full project team and updated as the project progresses. A sample risk register is shown in Table 8-14.

Table 8-14: Sample Risk Register

No.	Risk Description	L	C	R	Risk Mitigation	Residual Risk		
						L	C	R
1	Lack of suitable soil borrow	Med	High	High	Ensure availability of 200% of suitable barrier.	Low	Low	Acceptable
2	Lack of site access	Low	High	Med	Clear property access routes before the contract is awarded.	Low	Low	Acceptable
3	Availability of needed mechanical/ electrical components: gates, valves, and supervisory control and data acquisition	High	High	High	Levee owner preorders necessary items with a long delivery lead time.	Low	Low	Acceptable
4	Changed foundation conditions	Med	High	High	Perform additional geotechnical investigations to reduce data gaps.	Med	Med	Med

No.	Risk Description	L	C	R	Risk Mitigation	Residual Risk		
						L	C	R
5	Worker safety on water construction	Med	High	High	Develop an enhanced project Health and Safety Plan.	Med	Med	Acceptable

Notes to table:
L = Likelihood, C = Consequence, R = Magnitude of Risk

For levee projects that can utilize a lesser degree of construction risk management, a risk register is typically not used and most construction risk are avoided or accepted.

Levee construction may involve work close to or over water. Flooding of the construction site or borrow areas can occur due to high river levels, coastal storm, or tidal events occur during construction. This could damage ongoing work, make the site unpassable, delay work, or change design conditions requiring a construction modification. These risks should be identified and mitigated.

7.1.2 Risk Workshop

Larger, more complex or risky projects may include risk workshops to understand risks and develop mitigation strategies, and to document conclusions in a risk register. These workshops should be attended by the project team members, including the levee owner, design engineer, construction manager, constructor, and sometimes regulators or other entities. Identifying risks, developing and updating the risk register, and assigning actions to mitigate risks are the main functions of the risk workshop.

7.1.3 Test Sections

A test section in construction is an area where specific construction materials, equipment, and/or procedures are evaluated or tested against construction requirements. To minimize construction risk and improve the quality of the levee design, test sections may be used to provide important information on what materials, means, and methods will best deliver the construction project. Test sections are often performed prior to the commencement of the full project so that the information can be utilized appropriately. Test sections are helpful on large projects, where there is a high degree of uncertainty in the levee design, or where unconventional construction materials, means, or methods are being considered.

7.2 Managing Flood Risks During Construction

To mitigate flood risk to leveed areas during construction, temporary flood protection measures should be identified as required, particularly when constructing a levee modification or rehabilitation. Temporary flood protection measures are generally not required for new levee construction.

A plan for temporary flood protection measures should be prepared during project formulation and design, as discussed in **Chapters 6 and 7**. Temporary flood protection measures provided during construction can include physical, temporary flood protection features, and emergency action preparedness and planning. The temporary flood protection measures should be identified in the risk register and highlight risks within the construction site, including life safety, potential economic losses, and environmental risks.

The simplest temporary flood protection measure is to perform the work during a period when high water events are extremely unlikely or will have reduced potential water levels. In many parts of the U.S., high water occurs seasonally, and construction windows can be specified with low likelihood of high water during that time frame. However, coastal and riverine construction affected by tidal changes should be considered in planning the project. Contract documents should clearly state the required construction periods and what work is allowable outside that time frame.

In some situations, physical temporary flood protection measures are necessary. Examples of these measures include earthen berms, water fillable tubes, and/or manufactured waterproof bulkheads. In areas of potentially high consequences, updating or preparing a construction-specific emergency action plan may be appropriate to be prepared in the event a flood occurs during construction. The plan should include known weaknesses, triggering criteria, communication protocols, required actions, and responsible individuals.

8 Summary

Levee construction is a vital step in ensuring objectives of a levee are met. Levee construction occurs when there is physical building of a new levee feature or existing levee feature that is being modified or rehabilitated.

Success of levee construction relies on proper preparation, execution, and closeout of construction activities. All levee construction projects have some degree of construction risk. Identification and management of construction risk is also prudent for successful levee construction.

Key elements of proper preparation for levee construction includes:

- Incorporating levee project constraints into levee construction.
- Ensuring the levee project is constructable.
- Preparing documents for levee construction.
- Selecting a levee constructor.

Key elements of proper execution of levee construction includes:

- Developing a construction plan.
- Ensuring desired quality of levee construction is achieved.
- Coordinating and communicating during construction.
- Managing construction data.

At levee construction closeout, the levee construction project is evaluated to ensure the levee project meets the design intent prior to placing the levee into operation. Any deficiencies noted during this evaluation should be documented and addressed. Finalizing the project documentation at construction closeout is also completed to support effective levee operation and maintenance.

Related content associated with this chapter is included in detail in other chapters of the National Levee Safety Guidelines as described in Table 8-15.

Table 8-15: Related Content

Chapter 8 – Related Content

Chapter	Chapter Title	Related Content
1	Managing Flood Risk	
2	Understanding Levee Fundamentals	• Levee form and function • Types of levee projects
3	Engaging Communities	• Engaging for levee projects
4	Estimating Levee Risk	• Conducting risk assessments
5	Managing Levee Risk	• Levee risk management
6	Formulating a Levee Project	• Site specific considerations • Plan formulation • Site characterization
7	Designing a Levee	• Instrumentation and monitoring • Levee design considerations
8	Constructing a Levee	
9	Operating and Maintaining a Levee	• O&M manual • Inspections and monitoring • Flood preparedness
10	Managing Levee Emergencies	
11	Reconnecting the Floodplain	• Levee removal construction
12	Enhancing Community Resilience	