2: Understanding Levee Fundamentals

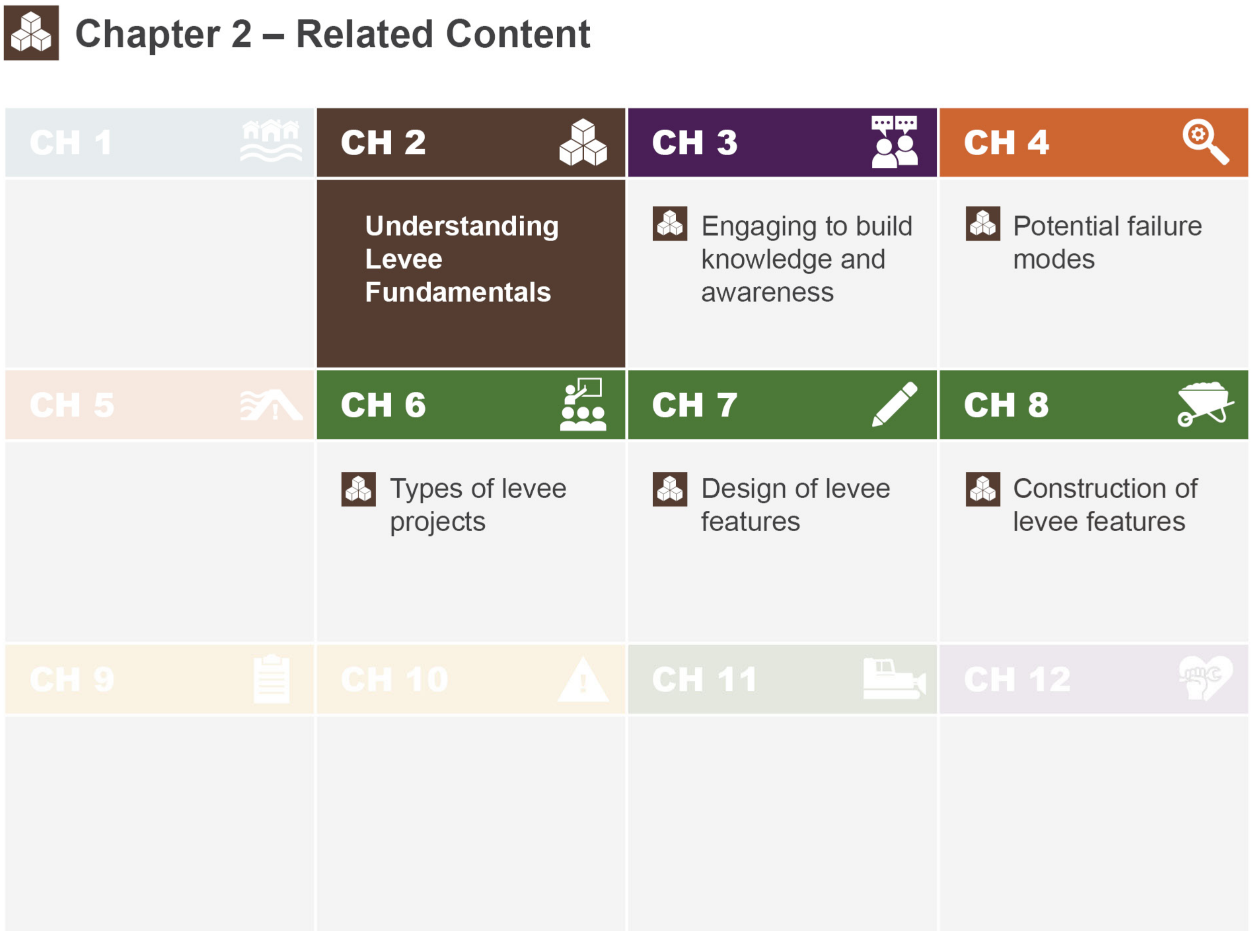
KEY THEMES

This chapter will enable the reader to:

- **Know levee terminology.** A levee is a human-made barrier with the primary purpose to provide flood risk reduction to a portion of the floodplain and does not constitute a barrier across a watercourse.
- **Understand levee function.** The function of a levee is to exclude floodwater from a defined area, channel water away from a defined area, or control the release of water into a defined area.
- **Understand levee features.** Levees are composed of various features that are spatially arranged to meet its intended function.
- **Understand ways levees can breach.** A levee breach could develop in different ways; therefore, it is important to understand why and how a breach may occur.

Other chapters within the National Levee Safety Guidelines contain more detailed information on certain topics that have an impact on understanding levee fundamentals, as shown in Figure 2-1. Elements of those chapters were considered and referenced in the development of this chapter and should be referred to for additional content.

Figure 2-1: Related Chapter Content



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1 Introduction

The purpose of this chapter is to introduce the basic concepts and terminology associated with a levee, which provides the necessary foundation for information presented in the remaining chapters.

Two main types of levees are discussed in this chapter–those that reduce flood risk from riverine hazards and those that reduce risk from coastal hazards. The various features that comprise these levees are described and illustrated, with examples showing how they are arranged along a selected alignment into a spatial form to create a leveed area.

In addition, different potential failure mechanisms that lead to breach and inundation of the leveed area are presented, which is an essential concept for understanding the role of levees in flood risk management.

2 Levee Basics

2.1 What is a Levee?

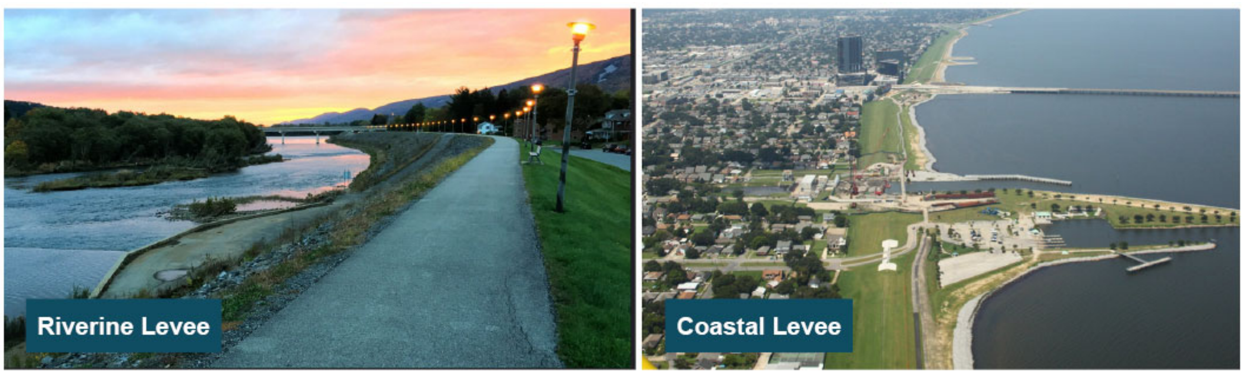
A levee system or just 'levee' for short, is a human-made barrier with the primary purpose of reducing the frequency of flooding to a portion of the floodplain. Basic characteristics of a levee include the following:

- Typically constructed along a watercourse (not across a watercourse like a dam), such as rivers, tributaries, coastlines, canals, or other waterways.
- Designed to exclude flooding from limited range of flood events. Levees do not eliminate the risk of flooding.
- Usually subjected to flood loading of a limited duration (days or weeks); however, some levees are continuously loaded.
- Typically comprised either of earthen embankments, concrete floodwalls or a combination of both.
- Can have other features such as pedestrian gates, traffic closures, and pump stations.
- Will usually tie into high ground (elevated land that is taller than the floodplain and less likely to flood) on either end, but some levees do exist that are open-ended.
- Could be designed to be compatible with a designed channel or canal.
- May be linked to or comprised of other engineered structures that are integral to the levee system performance but were not designed specifically for a flood risk reduction purpose, such as roadway, railroad, or canal embankments.
- May be linked to dam-related structures and coastal barriers, which can also be integral to a levee system or can function like a levee.

The term ‘levee’ does not include a stand-alone roadway or railroad embankment; a canal or channel constructed completely within natural ground without an embankment or retaining wall to constrain the flow of water; or shoreline or riverbank erosion projects.

Levees can be broadly categorized as either riverine or coastal based on the primary source of the hazard and resulting floodwaters being excluded and their environmental setting. Natural features (i.e., foreshore dunes, barrier islands, mangroves) and engineered structures such as jetties, spur dikes, and groins, often support the function of the levee system, typically by attenuating the flood loading, but are not considered to be a part of the levee. Figure 2-2 illustrates both riverine and coastal levees.

Figure 2-2: Typical Riverine and Coastal Levees



A levee generally goes through various stages throughout its life (**Chapter 4**), referred to as the levee lifecycle. This lifecycle consists of project formulation, design, construction, operation and maintenance, modifications, and levee removal (if needed). Certain activities, such as emergency preparedness and response, and community engagement occur at all stages of the lifecycle.

2.2 Levee Projects

Levee-related activities necessitating any aspect of planning, design, or construction should be considered levee projects. There are five different types of levee projects that are discussed in greater detail in subsequent chapters. These projects are shown in Figure 2-3 below.

Figure 2-3: Levee Projects

- **New:** Building a new levee as part of a flood risk reduction strategy.

- **Repair:** Restoring a levee to its original (e.g., as intended in design) operation and function after isolated damage has occurred and a structure's functionality has been reduced. Repair can also be thought of as normal maintenance and routine in nature.
- **Rehabilitation:** Restoring a levee to its original operation and function due to extensive deterioration or deficiencies from design/construction. Rehabilitation is more substantial than normal maintenance and repair and is not routine in nature.
- **Modification:** An activity that changes the original operation and function of a levee. It includes raising a levee, modifying its alignment, or changing features. Modification is not routine in nature.
- **Removal:** An intentional activity that effectively eliminates the flood risk reduction benefits provided by a levee. Removal is a form of modification and is not routine in nature.

3 Levee Function

3.1 Levees Role in Reducing Flooding

Levees are just one element of a community's flood risk management strategy, which may include non-structural and structural measures, as discussed in **Chapter 1**. As a structural measure, levees can have one to three primary functions:

- **Exclude water**: Levees reduce the risk of inundation of an area by keeping floodwaters out of the leveed area (riverine and coastal). They may also manage stormwater in the leveed area when storm drainage systems are closed off from natural gravity drainage during floods.
- **Divert water**: Levees direct floodwater, storm surge, and wave run-up either downstream (riverine only) or into a non-leveed area to avoid inundation of the leveed area (riverine and coastal).
- **Controlled release**: Levees can be designed or operated to release water in a designated area in order to remove a portion of flow upstream, which within a watercourse reduces flood loading downstream (riverine only).

In addition to flood risk reduction, levees often serve as sites for riverine habitat corridors, regional trails, recreational parks, transportation corridors, and other public amenities. These supplemental benefits can be vitally important to those living and working nearby and to those visiting the region. When designed with the multi-purpose use in mind, levees provide important social, economic, agricultural, recreational, and environmental benefits. However, care should be exercised to ensure other uses of the levee do not take priority over the flood risk reduction function or compromise levee performance.

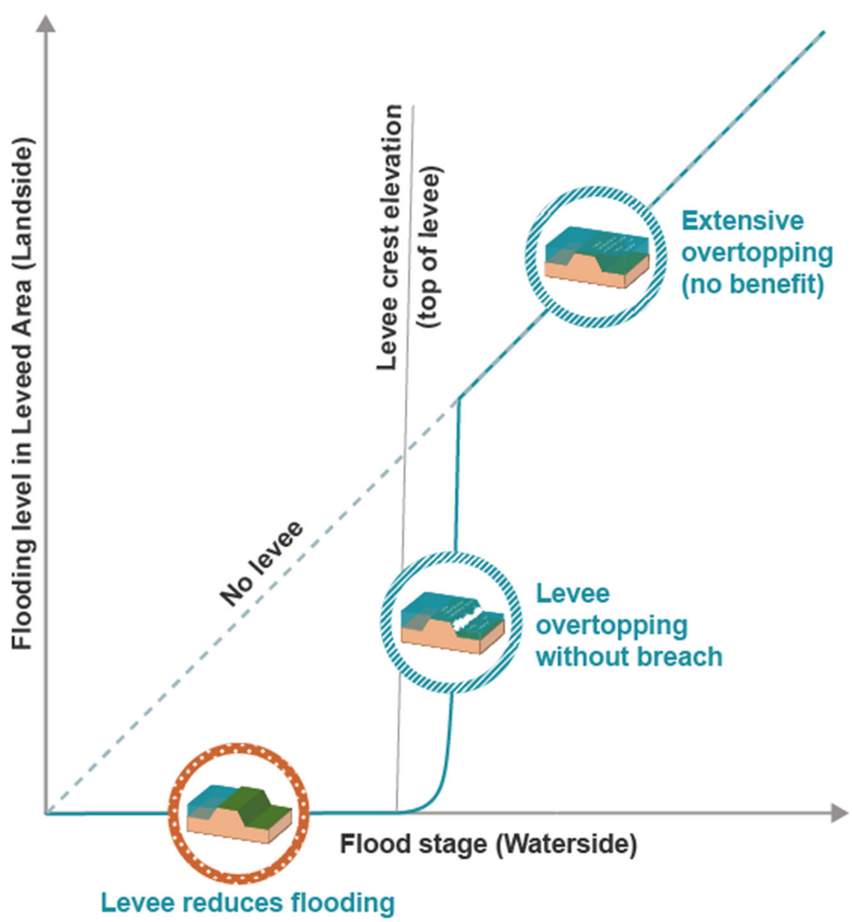
The function of levees in reducing flooding in the leveed area is illustrated in Figure 2-4, which portrays flood stage on the waterside of the levee versus flooding elevation in the leveed area (landside). When there is no levee (dashed line), the flooding elevation in the leveed area is equal to the flood stage on the waterside. The introduction of a levee and the resulting flood risk reduction is depicted as a solid line. The solid line traces the flooding on the waterside of the levee from the levee toe to the levee crest and beyond. Following the line from left to right illustrates that there is no flooding in the leveed area for flood stages on the waterside of the levee up to the levee crest elevation when the levee performs as intended. As water exceeds and overtops the crest of the levee, the levee continues to provide some benefits during overtopping, until a point where there is so much water in the leveed area that the levee no longer provides any flood risk reduction benefits (solid line meets and follows dashed line).

Figure 2-4 illustrates a levee that is functioning as intended by providing flood risk reduction benefits including:

- Excludes flood waters from the leveed area for flood levels up to the levee crest.
- Allows time for orderly evacuation of individuals within the leveed area.

This figure is a simplification to illustrate the general function of levees to exclude floodwaters. It should be recognized that levees transform the floodplain, **Chapter 5**.

Figure 2-4: Function of Levees in Reducing Flooding



The intended level of flood risk reduction can vary significantly for different levees. For some communities, a shorter levee providing less flood risk reduction combined with zoning restrictions and evacuation planning for larger events may be a preferred strategy, while other communities may opt for higher levees as their strategy to achieve the same overall flood risk reduction.

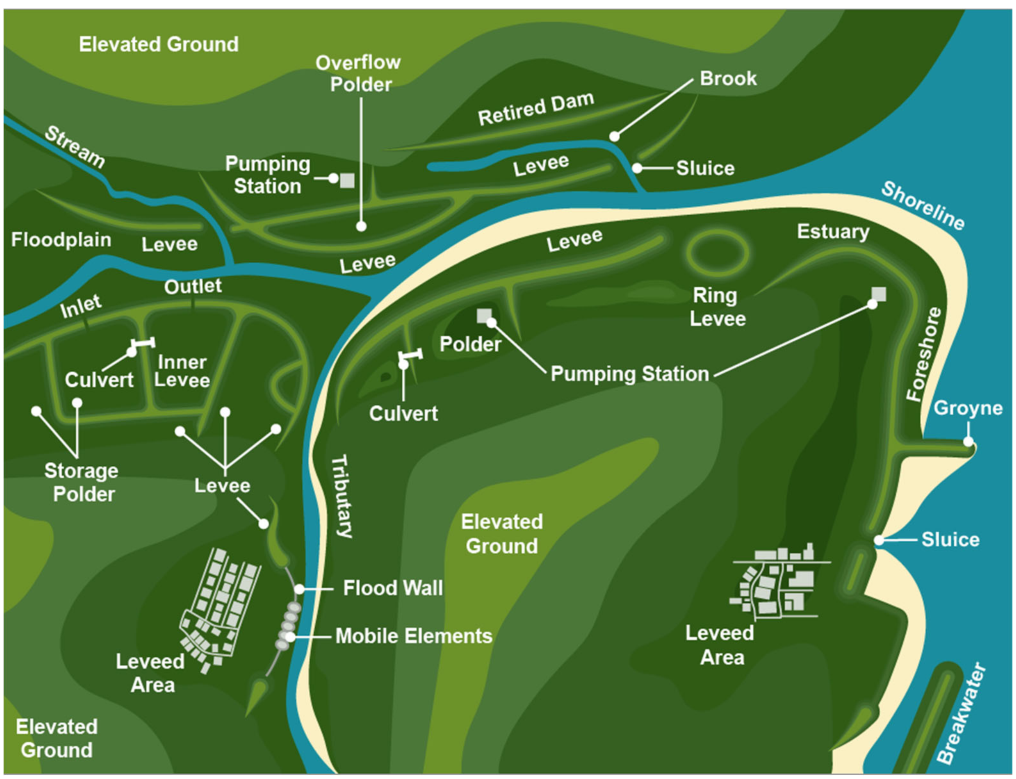
Flood awareness and emergency preparedness play an important role in flood risk management for individuals and communities behind levees. Involved, informed individuals and communities behind levees will be better prepared to take meaningful actions to reduce risks to loss of life (e.g., practicing emergency action plans, warnings, and evacuations) or property (e.g., flood-proofing, purchasing flood insurance, or elevating structures). See **Chapters 1, 10, and 12** for additional details.

3.2 Configuration of Levees

The overall levee configuration is primarily based on the level of flood risk reduction that the levee is intended to provide and its environmental setting; however, other natural and human-made factors influence the configuration (e.g., right-of-way constraints), as discussed in **Chapter 6**.

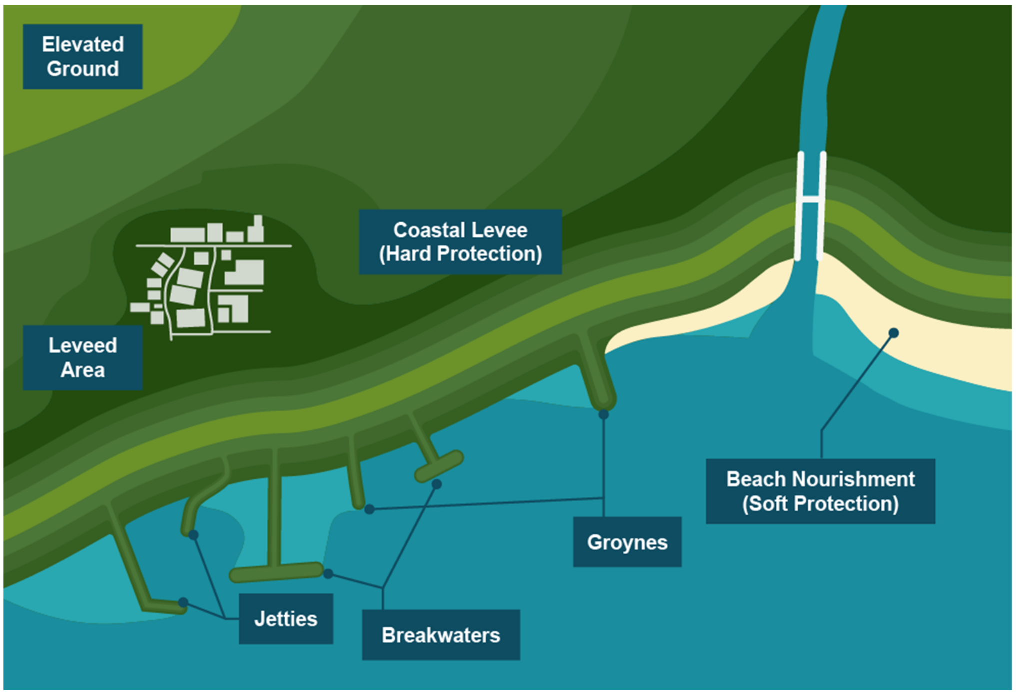
In a riverine environment (Figure 2-5), levees are generally placed parallel to a river channel in order to help pass floodwater downstream. Levees may be constructed along both banks of a watercourse, often set back from the channel to provide added storage capacity during high water. Under normal, non-flood conditions, secondary use of this area may be allowed for farming operations, recreation, or other approved uses. Because levees are expected to overtop for floods greater than the designed level of risk reduction, the levee may include location(s) with a lower crest for intentional overtopping to control and understand where flooding will first occur.

Figure 2-5: Typical River Levee



In a coastal environment, Figure 2-6, levees are typically aligned with the coastline and, therefore, are generally situated perpendicular to the incoming flow from the sea. Levees function to temporarily retain storm surge and moderate wave overtopping. Coastal systems may also include other human-made or natural structures such as offshore breakwaters, groins, mangroves, and dunes to reduce erosive forces on the beaches and levees. Coastal areas may also be subject to flooding due to the rise in sea level during a storm event causing backwater flooding of drainage features that flow to the sea. To prevent this, levees may be needed along these drainage features.

Figure 2-6: Typical Coastal Levee



Levees that are built landward of existing levees, usually because the existing levee has experienced distress or is in some way being endangered, are typically referred to as setback levees, Figure 2-7. When the existing levee is removed, setback levees can promote floodplain restoration by giving space for riparian and aquatic habitats in the floodplain (**Chapter 11**). Setback levees are generally loaded less frequently than levees positioned directly adjacent to main river channels.

Figure 2-7: Typical Setback Levee

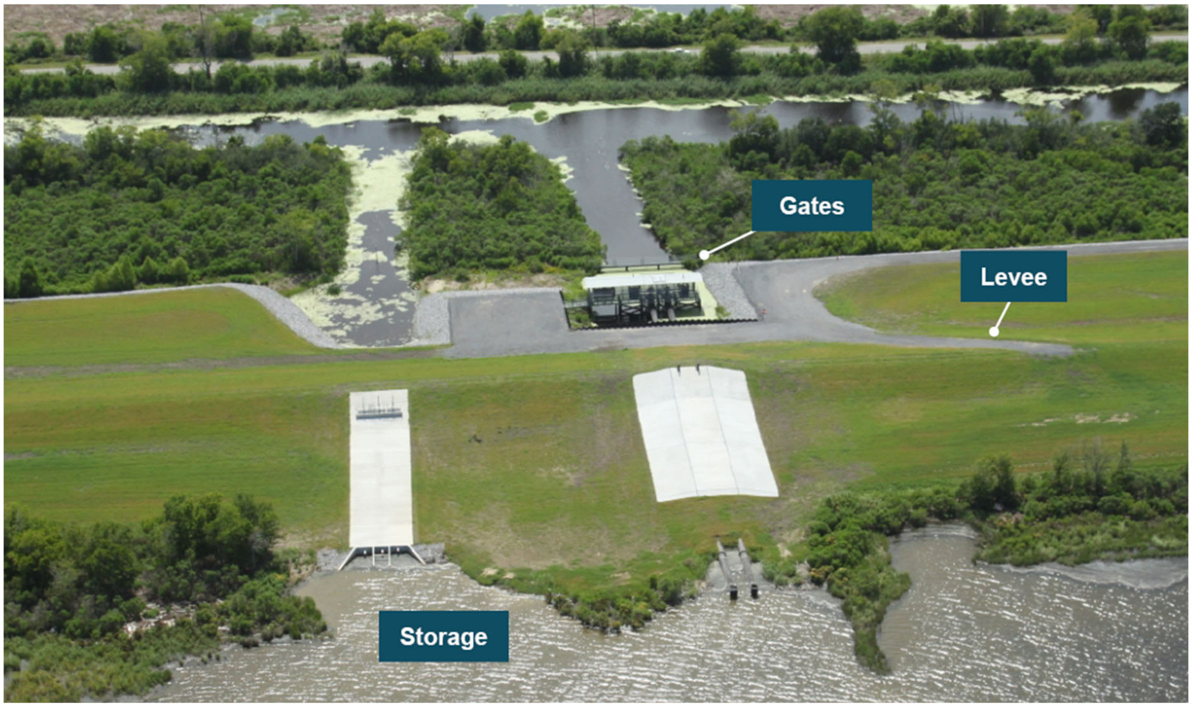
Levees typically tie to (abut) natural high ground in order to exclude floodwaters from a leveed area. Where it is not feasible to abut natural high ground, a ring levee (Figure 2-8) may be constructed to enclose a leveed area, to help reduce the risk of flooding to isolated, vulnerable infrastructure.

Figure 2-8: Typical Ring Levee

Offline storage areas (Figure 2-9) are often created to complement the use of levees, floodways, natural structures, and topography. Such storage areas are normally empty for long periods of time and are only used during flood events, providing for secondary uses and benefits, including public access, recreation, and opportunities for environmental habitat.

Levees often work together with dams to manage floods and in these cases, the infrastructure, where they coexist within a watershed, should be considered as one integrated system. Dams attenuate and regulate flood flows while levees exclude flood water from the leveed area.

Figure 2-9: Offline Storage Area



4 Levee Features

A levee may be composed of multiple features acting as a physical barrier to prevent floodwater from entering the leveed area. Utilizing complementary structures beyond the levee structure may be necessary for activities that promote proper functionality. Examples of related activities include managing interior stormwater within the leveed area or reducing the loading on the primary feature (floodways). Features can be thought of as the major elements or building blocks that comprise the levee system. The form of the levee is the spatial arrangement of features to provide flood risk reduction within the leveed area.

Table 2-1 presents the typical levee features and some key types. There are a limited number of features and variations of feature types, but there are numerous ways they can be formed into an arrangement to create a levee. The sections that follow illustrate some of the various levee features and their typical types that provide benefits to the leveed area.

Table 2-1: Features

Feature	Types	Function
Embankment	Zoned, homogeneous	Exclude water from leveed area.
Floodwall	I-wall, T-wall, L-wall, mass gravity, demountable	Exclude water from leveed area.
Closure structure	Roller and slide gate, swing gate, stoplog, sector gate, vertical lift gate, sandbag	Exclude water from leveed area.

Feature	Types	Function
Transition	Embankment/hard structure, embankment/high-ground, embankment/revetment	Exclude water from leveed area.
Seepage control systems	Cutoff wall, relief well, seepage berm	Exclude water from leveed area.
Channels and floodways	Natural, concrete lined, armored	Manage floodwater outside the leveed area.
Interior drainage systems	Canals, pipes	Manage primarily surface water inside the leveed area.
Pump stations	"-"	Manage primarily surface water inside the leveed area.
Instrumentation	Settlement cells, staff gages, piezometers, inclinometers	Provide operational and performance data.

4.1 Embankment

An earthen embankment is the most typical feature associated with a levee, and for many levees it can be the primary (or even only) physical feature. However, they often work in concert with other features which support the function of excluding floodwaters (e.g., a floodwall along the water course or relief wells for seepage control). Supporting features are sometimes required to ensure this integrity, such as erosion protection, stability berms and seepage control features.

Embankments are common features incorporated into both riverine and coastal levees. However, their geometric configuration and the components incorporated into an embankment typically differ based on the environment (see Figure 2-10 and Figure 2-12) they are situated in and the loading to which they are subjected to due to the hazard.

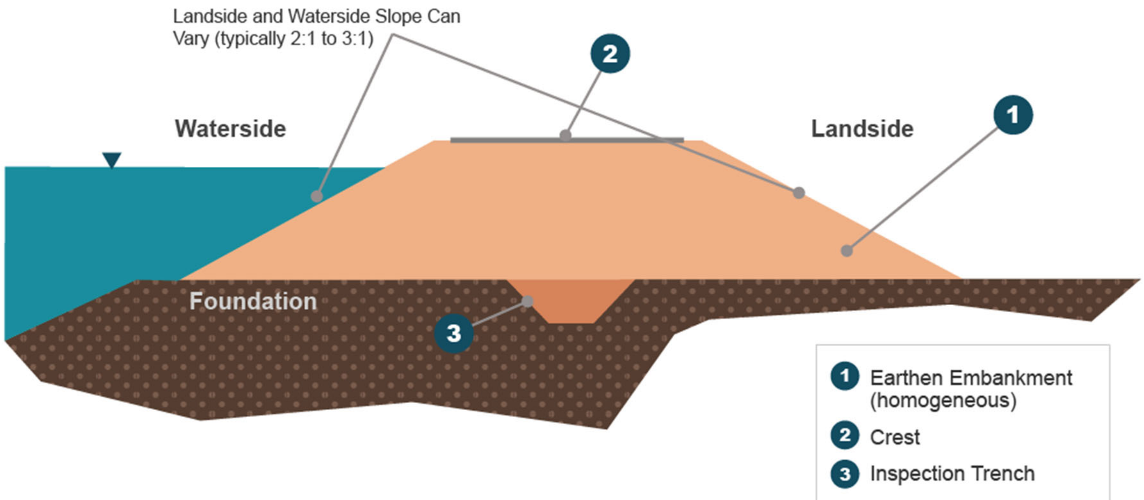
The function of an embankment is to act as a barrier to restrict the intrusion of floodwaters into the leveed area. The embankment must be designed and constructed to function under the required flood loading without loss of its structural integrity and stability. Its successful integration as a levee feature needs to consider potential failure mechanisms that could compromise its ability to function as designed. The performance of the embankment must consider the performance of the underlying embankment foundation when subjected to the flood load, because the performance of the levee is greatly impacted by the conditions below the levee. Embankment design considerations are presented in more detail in **Chapter 7**.

A number of embankment types may be developed to meet unique functional requirements, such as:

- Characteristics and duration of flood loading.
- Components incorporated into the levee.
- Geomorphic and geologic setting.
- Locally available materials.
- Construction access.
- Right of way.

The most common type of embankment levee is a homogeneous earthen (i.e., one soil type) compacted embankment as shown in Figure 2-10. Common geometric characteristics include a 10-15-foot-wide crest and 3:1 sides slopes for riverine levees and flatter slopes for coastal levees (typically 5:1 or greater on the waterside).

Figure 2-10: Typical Homogeneous Embankment



Several factors impact the geometry of the embankment, including the allowable steepness of the waterside and landside slopes, and often the minimum levee crest width. The steepness of the embankment slopes depends on the evaluation of the stability of the levee, which is influenced by the loading, foundation conditions, and type of soil used in the embankment. The width of the embankment crest may be established based upon the anticipated or predicted stability of the embankment, seepage considerations, accessibility needs (e.g., vehicular access, provisions for bike paths, or other recreational elements) or by regulatory minimum requirements. The crest may consist of simple grass cover, gravel, pavement, or other surface cover based on the expected allowable use. Provisions to incorporate roads and/or ramps for vehicular access to the levee crest may be needed and stairways or ramps for pedestrian access may also be included. An exploration or inspection trench is typically constructed into the foundation below all earthen embankments to provide direct visual observation of the subsurface foundation conditions continuously along the alignment of the levee. See **Chapters 7 and 8** for more details.

A slight variation to the homogeneous earthen levee embankment shown in Figure 2-10 is the zoned earthen embankment shown in Figure 2-11. The central portion of the embankment is constructed with a less pervious soil type to address potential seepage issues. Note that the location of this less pervious zone is beneath the levee crest but may be shifted towards either the waterside or landside slopes, as necessary.

This schematic also shows scour protection on the waterside slope, which is typically riprap or some other hard armored surface. Such treatment is required when the flow velocities under the flood event are substantially high, undermining the stability of a simple grassed waterside embankment slope.

Figure 2-11: Typical Zoned Embankment

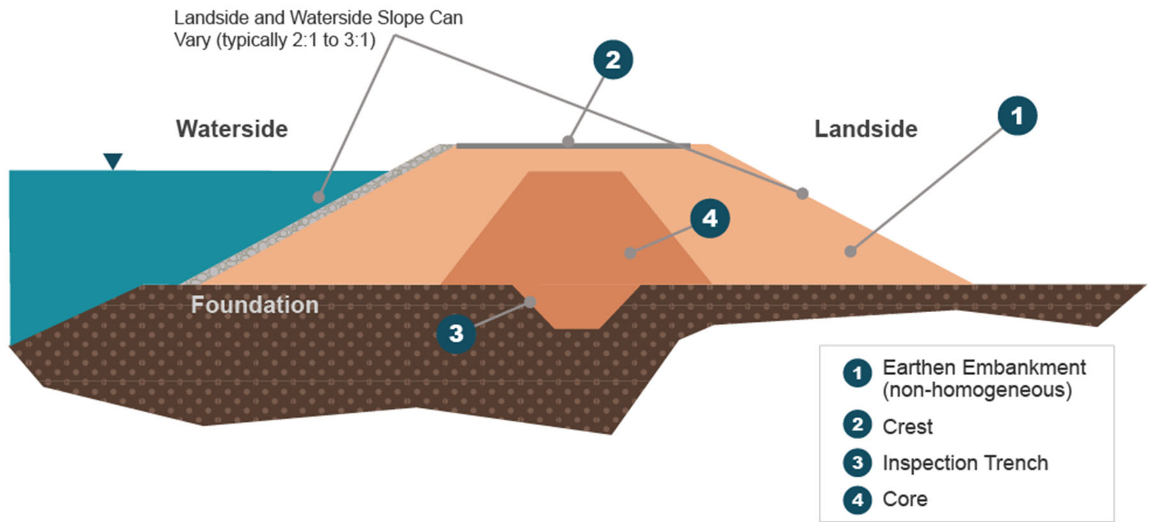
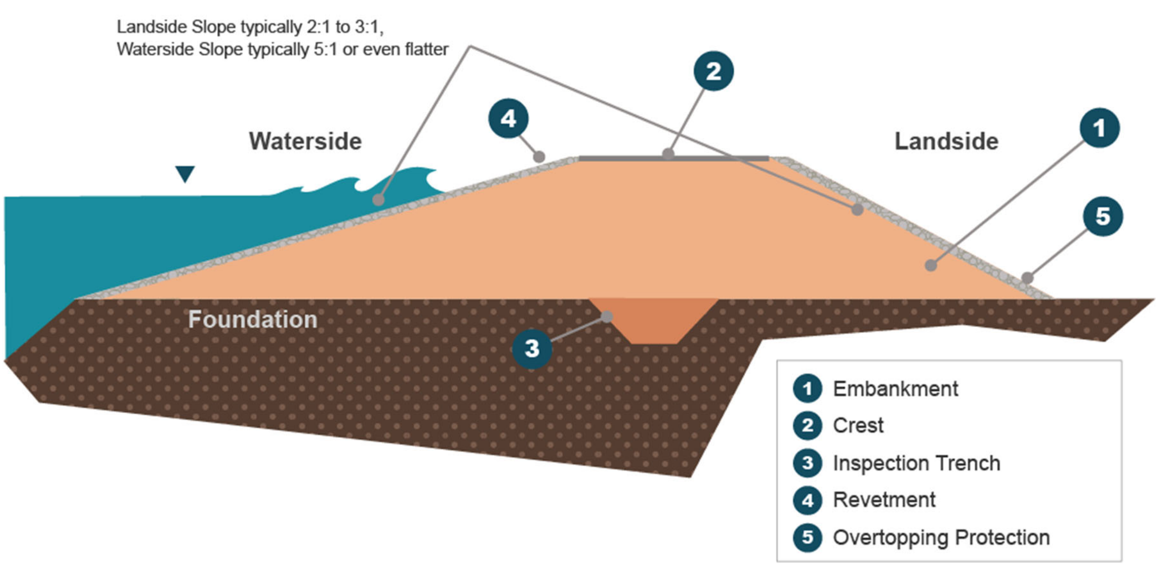


Figure 2-12 shows a coastal levee embankment and some additional components that may be incorporated due to unique coastal hazards. For coastal levees, the loading is primarily attributed to storm surge (often combined with tidal effects and high winds) resulting in higher water levels and wind/wave action. There are a wide variety of options for the materials used to construct the embankment as well as surface treatments of the waterside embankment slope and crest. The geometry of the waterside slope is generally flatter and can incorporate revetments to minimize the impact of wave action. Due to potential for wave overtopping, it is also possible that scour protection may be required on the landside.

Figure 2-12: Typical Coastal Embankment



Structures such as groins and revetments may be incorporated as vital elements to attenuate storm surge and/or wave action loading on the levee. Natural features such as marshes or mangroves, sand bars, or barrier islands, can also reduce loading impacts. While these elements are potentially vital to levee performance, they are not considered levee features.

4.2 Floodwalls

Floodwalls are commonly used where earthen levees are not considered a viable alternative, typically either due to limited real estate space for the levee's alignment or a need to tie into other structural features. They are commonly used in both riverine and coastal levee systems.

The function of a floodwall is to act as a barrier to restrict the intrusion of floodwaters into the leveed area. As with the earthen embankment, the floodwall must be able to function under the required flood loading without compromising its structural integrity and stability. The performance of the floodwall should consider the underlying foundation (typically soils) and support of the structure using either a deep or shallow foundation system. These considerations are described in more detail in **Chapter 7**.

There are a variety of floodwall types (T, L and I walls) that consist of a stem that protrudes above the ground surface to act as the barrier to the intrusion of floodwater into the leveed area. The stem consists of a linear arrangement of discrete sections or monoliths typically constructed with reinforced concrete. T and L walls also incorporate a reinforced concrete base within foundation soils to provide stability. The type of wall selected is based on the type of loading, the foundation conditions, and the foundation system required to resist that loading (Figure 2-13). In most floodwalls, a cutoff is typically provided to control underseepage because the distance between the flood loading and the landside floodwall toe where underseepage may surface is typically very short. A component often incorporated, particularly for coastal levees, is a concrete 'splash' pad to protect against overtopping wave action. This can be accommodated by exposing the base on the landside or providing a separate component as depicted in the illustrations. These components can also be incorporated as a buttress on the landside of the floodwall as shown in Figure 2-14, Figure 2-15, and Figure 2-16 which can function to aid in either stability or seepage control.

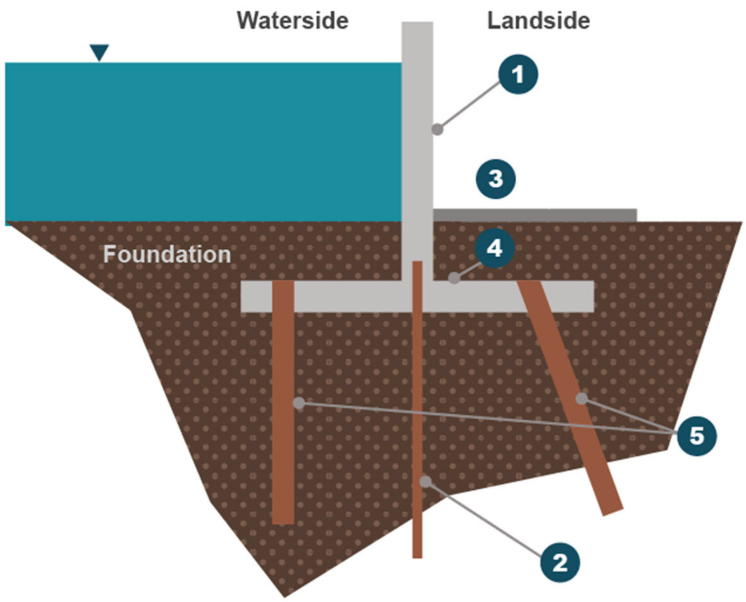
Two other types of floodwalls are mass gravity floodwalls, which are typically constructed of un-reinforced concrete, and demountable floodwalls, which are described and illustrated in Figure 2-17 and Figure 2-18.

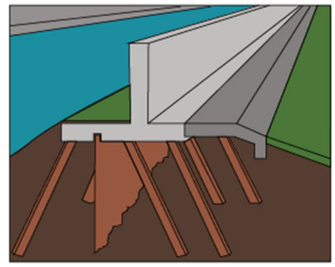
Figure 2-13: Examples of Floodwalls

4.2.1 T Wall

The designation as a T wall originates from the shape of the stem and base (Figure 2-14). The stem is structurally connected to a reinforced concrete base. The base serves as the foundation of the floodwall, acting as a cap for deep foundation elements (steel pile sections, sheet pile, and/or drilled shafts) or simply acting as a shallow foundation bearing on the underlying foundation soils without a deep foundation.

Figure 2-14: Typical T Wall

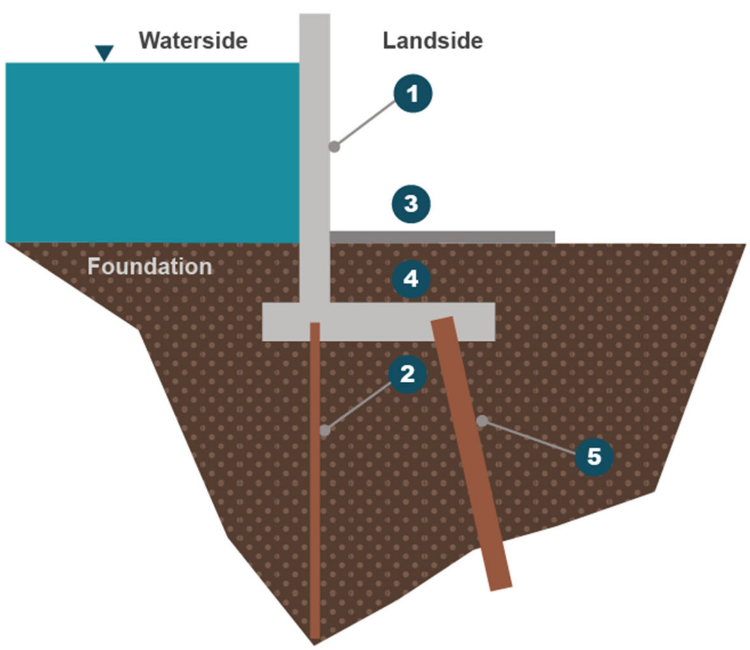




4.2.2 L Wall

The designation as a L wall originates from the shape of the stem and base (Figure 2-15). The stem is structurally connected to a reinforced concrete base. The base serves as the foundation of the floodwall, acting as a cap for deep foundation elements (steel pile sections, sheet pile, and/or drilled shafts) or simply acting as a shallow foundation bearing on the underlying foundation soils without a deep foundation.

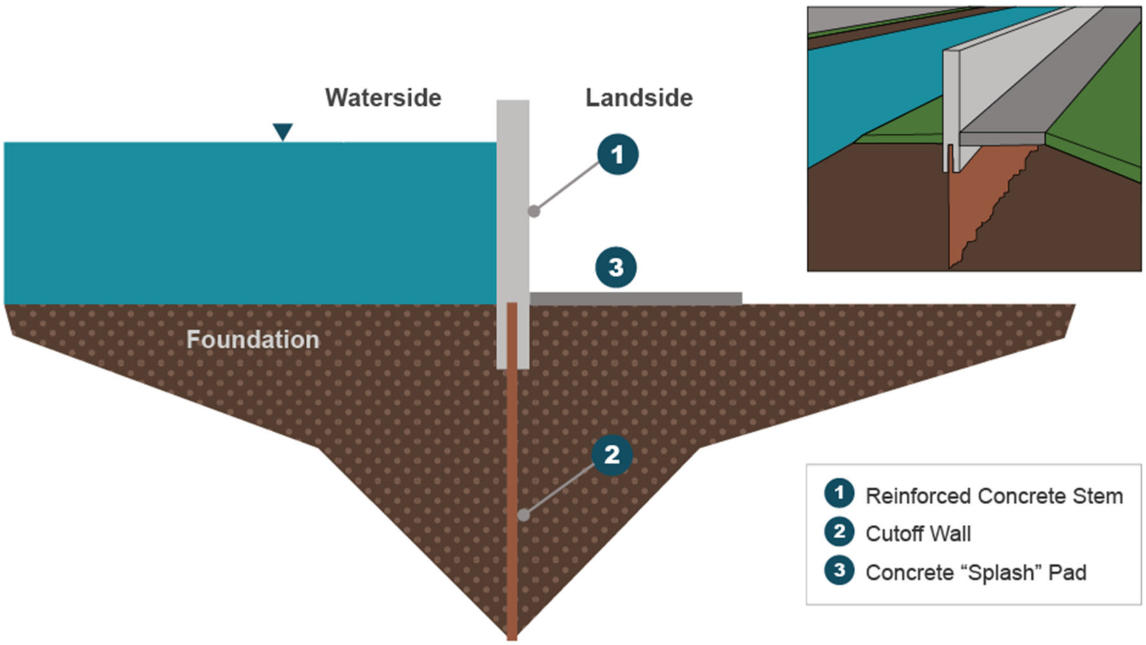
Figure 2-15: Typical L Wall



4.2.3 I Wall

An I-wall has no base and is essentially a vertical structural element consisting of the stem, which is commonly supported by a sheet pile cutoff (Figure 2-16). The use of I-walls is primarily for very short walls or for transition elements.

Figure 2-16: Typical I Wall



4.2.4 Mass Gravity

Mass concrete gravity structures (Figure 2-17 and Figure 2-18), often found in coastal environments, are unreinforced structures where the flood loading is resisted by the shear mass of the structure, and the mass of the structure acts as the barrier to exclude floodwater from the leveed area. A unique element of this type of feature is the geometric design of the waterside face, which is often tailored to deflect the incoming waves.

Figure 2-17: Typical Mass Gravity Wall

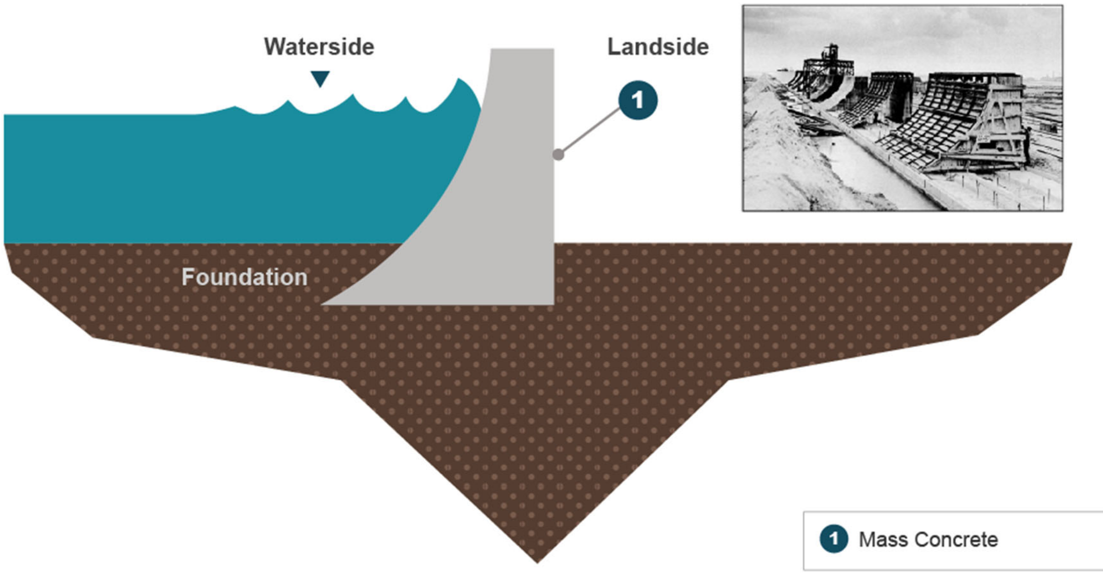
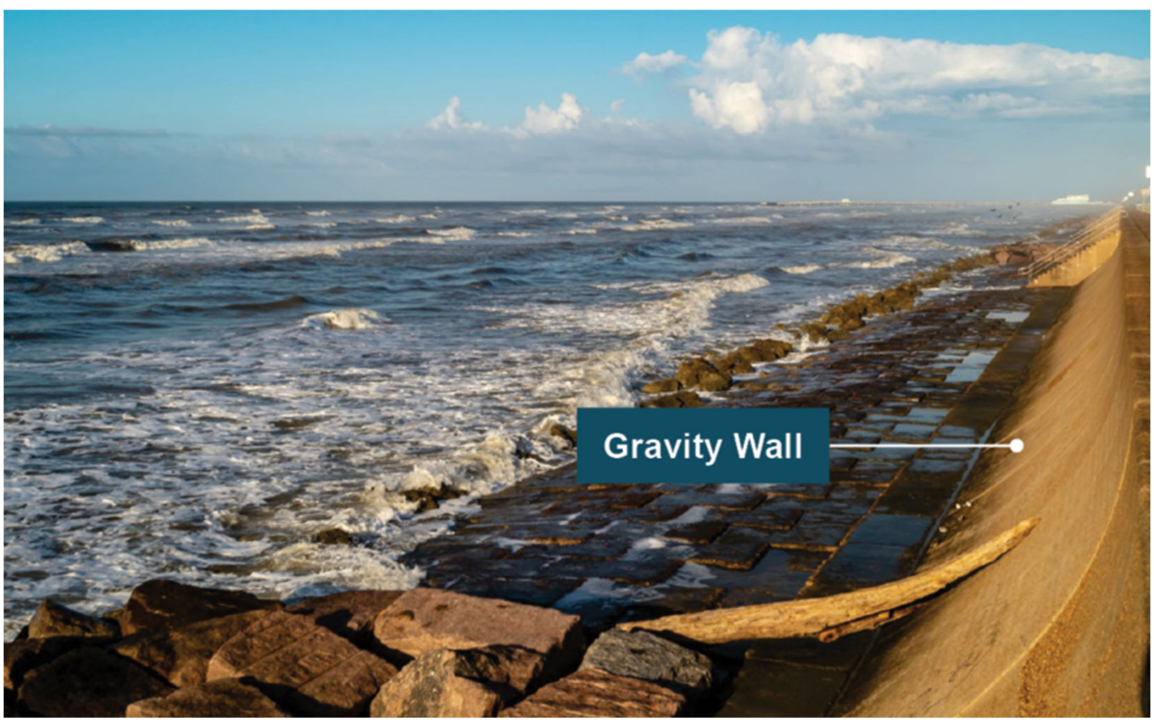


Figure 2-18: Example of Mass Gravity Wall



4.2.5 Demountable

In certain situations where a permanent structure is undesirable because of aesthetics, accessibility, or required vertical clearances during non-flooding conditions, a demountable floodwall system (Figure 2-19) may be employed. Key considerations for demountable walls include the ability to safely store the components and having sufficient time and trained personnel to reliably deploy the system prior to a flood. Typical demountable floodwalls use a series of posts that are embedded into a reinforced concrete sill that extends along the levee alignment. Spans between the posts are filled with panels or stoplogs that mechanically interlock with the posts. Additional structural supports may be required to support the lateral flood loading. Many of these structures are functionally similar to closure structures, which are also only deployed prior to a flood. The key difference between demountable floodwalls and closure structures is the size of the opening. Closure structures typically have a limited opening length along the alignment of the levee to accommodate the required access corridor. The opening length of a demountable floodwall can extend considerably further along the levee alignment.

Figure 2-19: Typical Demountable Walls

4.3 Closure Structures

Closure structures are required where access at-grade across or through the alignment of a levee is needed during non-flood periods. This may be where roadways, railways, walkways, waterways (including both navigable and non-navigable types), and runways transect the alignment of a levee. Closure structures addressed in this section do not include gates, valves, or other controls for pipes, and other penetrations through a levee that are meant to convey channelized water flow. Those types of structures are detailed in section 4.7.

During non-flood periods, access typically remains open. When flood conditions are forecasted, the opening must be closed on a temporary basis to restrict the intrusion of floodwaters into the leveed area. When closed, the structure essentially acts as a floodwall or embankment; therefore, many of the key concepts and considerations are identical or similar to those previously discussed.

Closure structures can be broadly classified based on:

- Whether they transect the levee over a land course (e.g., roadways, railways, walkways) or water course (when the watercourse closure is part of the levee system).
- Whether the opening is automated, mechanical/structural, or requires human assembly (slats, sandbags, earthen fill).

The selection of a specific type of closure typically depends on two primary factors: first, the physical constraints associated deploying/installing or removing the structure that is used to close the opening, and second, the operational constraints (i.e., warning time before deployment is required and time/resources required to deploy the system). Additional details are provided in **Chapter 7**.

4.3.1 Roller and Slide Gate Closure

Roller/slide gate closure structures (moveable transect over land) move on wheels or casters that travel on a set of tracks on its foundation to slide the gate in and out of position (Figure 2-20). They frequently require a mechanical system (e.g., a cable winch) to move the gate. These gates can often be deployed rapidly and may be incorporated into levees that transition into either floodwalls or levees on the flanks of the opening (Figure 2-21). The tracks are attached to a sill bearing on a foundation system to structurally support the entire closure system. The performance requirements, and thus design and construction of the foundation system, is nearly identical to that for supporting a floodwall and could be either a deep or shallow foundation system. However, a key, unique component consideration for closures is providing a mechanism to seal the gate when its deployed. The frame of the closure structure typically consists of end supports that tie in and transition to the levee features on either side of the levee, which could be either earthen embankments or floodwalls. Some closures require an overhead trolley gate in which the gate is deployed using an overhead hoist system instead of moving on rollers and tracks.

Figure 2-20: Typical Roller/Slide Gate

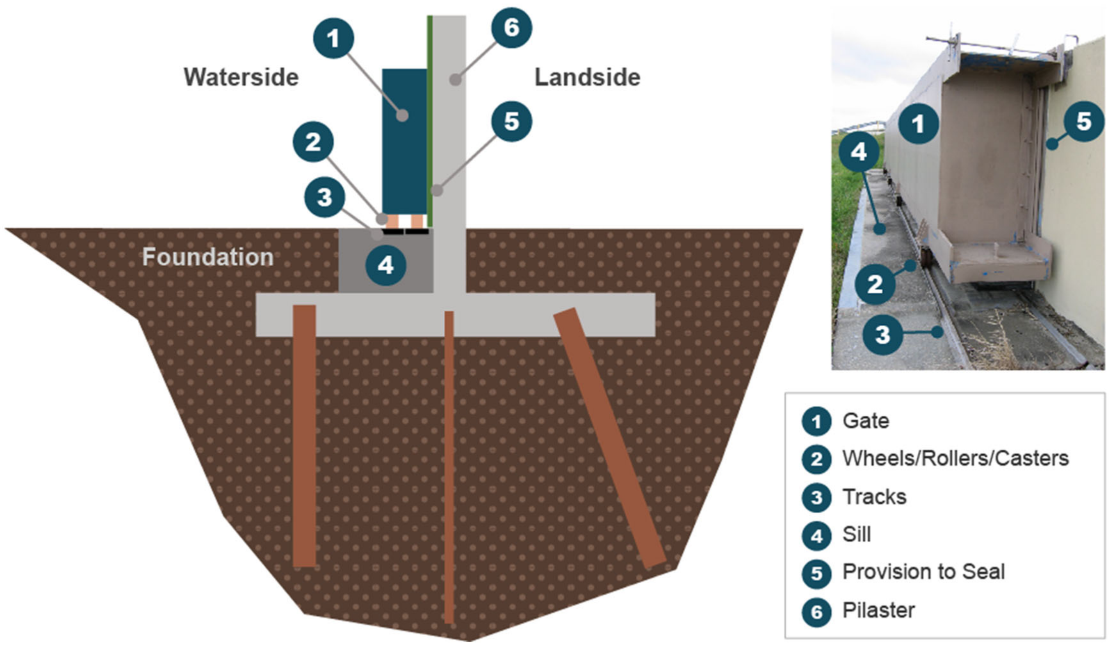
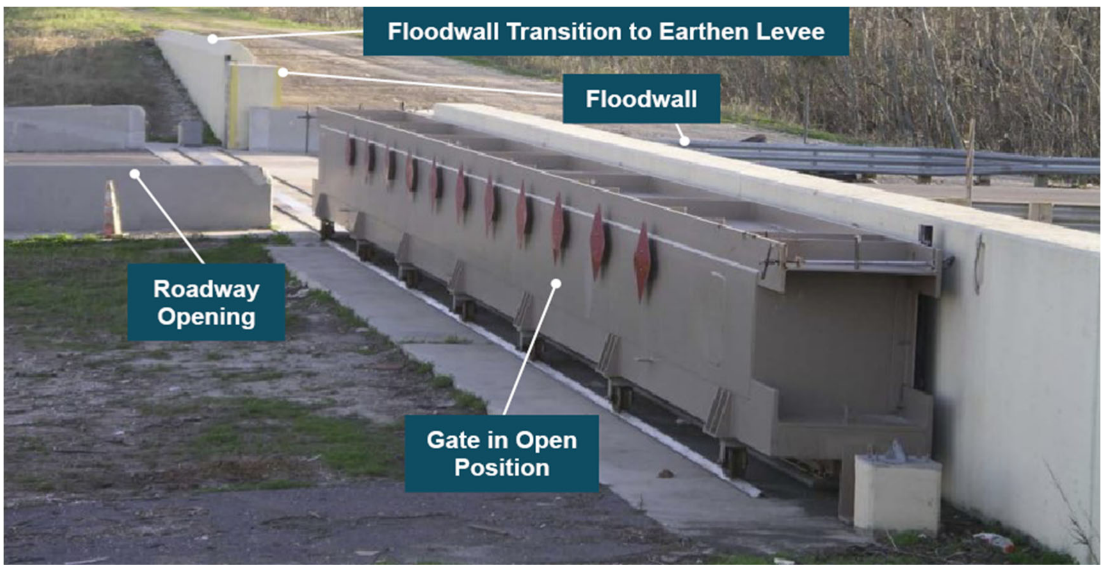


Figure 2-21: Roller/Slide Gate Details



4.3.2 Swing Gate Closure

A swing gate closure (Figure 2-22, Figure 2-23, and Figure 2-24) is similar to a roller/slide gate with the exception that it rotates in and out of place using a set of hinges that attach the gate to the structure (pilaster). They may require a cable winch to physically move the gate and a reliable means to seal the gate when deployed.

Figure 2-22:Typical Swing Gate

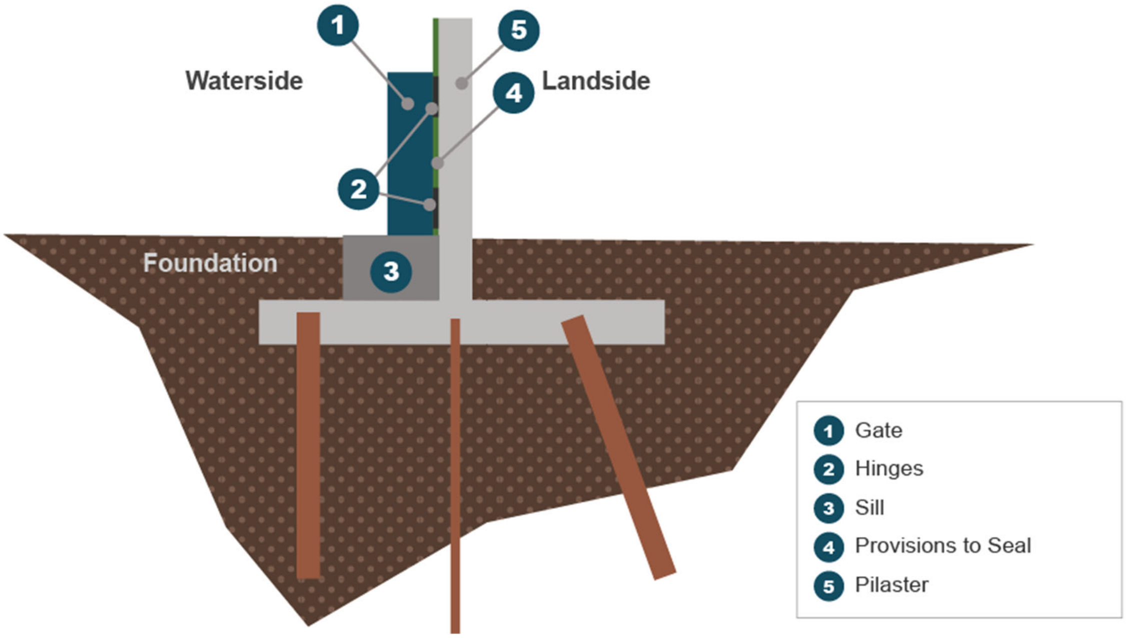


Figure 2-23: Swing Gate Details

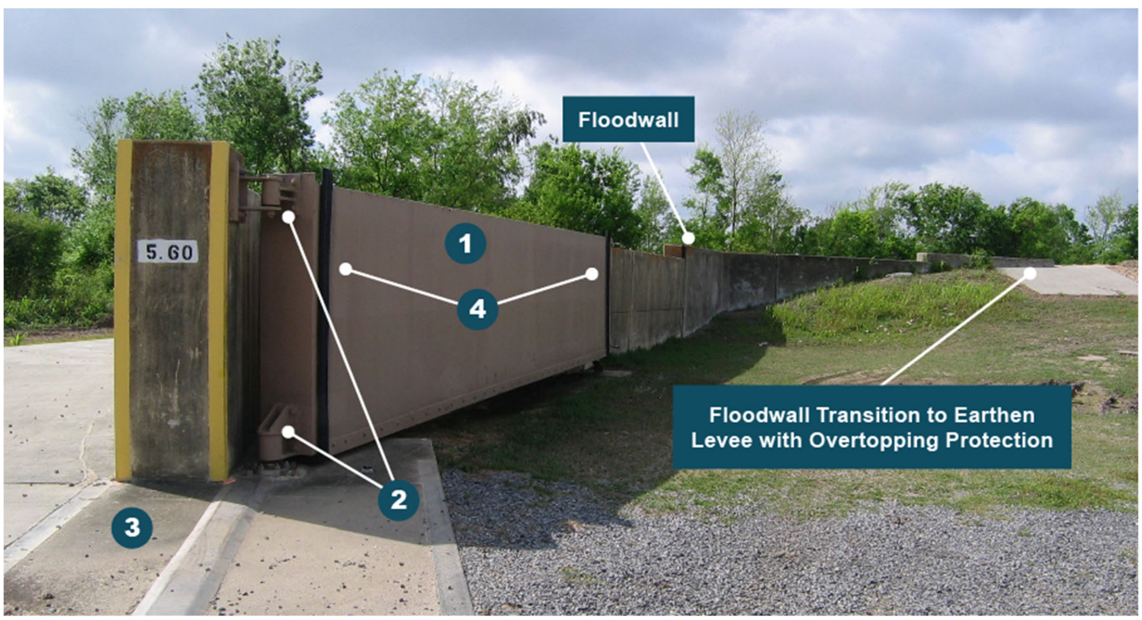
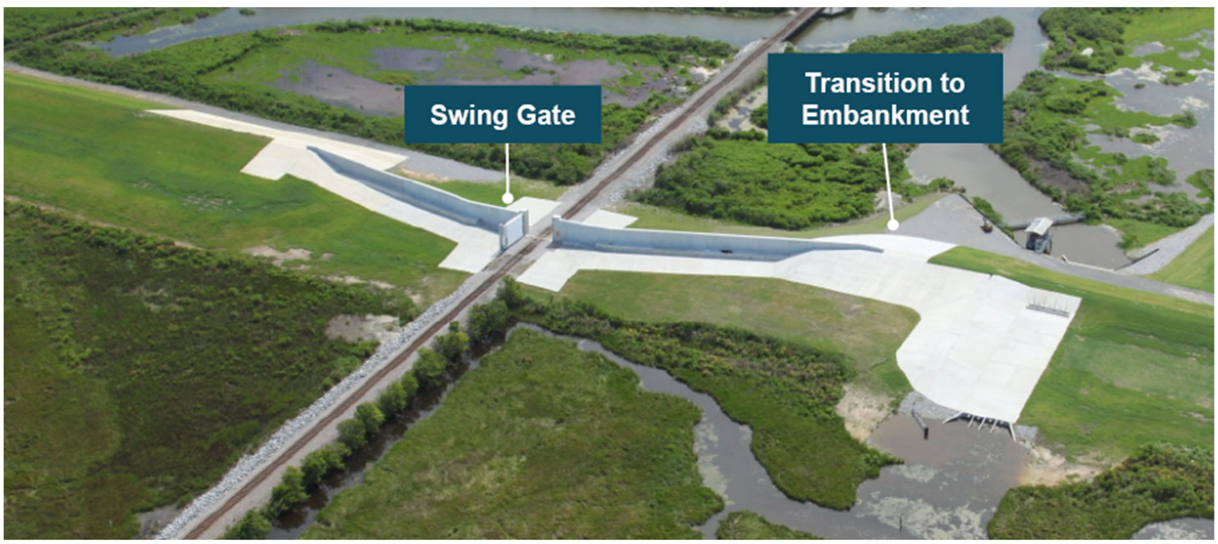


Figure 2-24: Example Swing Gate



4.3.3 Stoplog Closure

A stoplog closure structure (Figure 2-25 and Figure 2-26) is similar to a demountable floodwall. Discrete structural beams or panels are put into place across the opening. Intermediate columnar post supports and bracings are required for larger openings, depending on the specific structural requirements and constraints (e.g., maximum allowable unsupported length of the stoplogs/panels).

As with all non-moveable structures, they are potentially less costly to construct and maintain, but may take significantly longer to deploy resulting in higher operational costs. Often, they are the only viable option for very long openings along the levee alignment or preferred to provide a narrow opening, such as a single-track railroad.

Similar evaluations are made for foundation support, with the added consideration of connection and embedment of the posts into the sill, the potential need for additional strut supports, and attention to watertight seals of the panels or stoplogs.

Figure 2-25: Typical Stoplog Closure

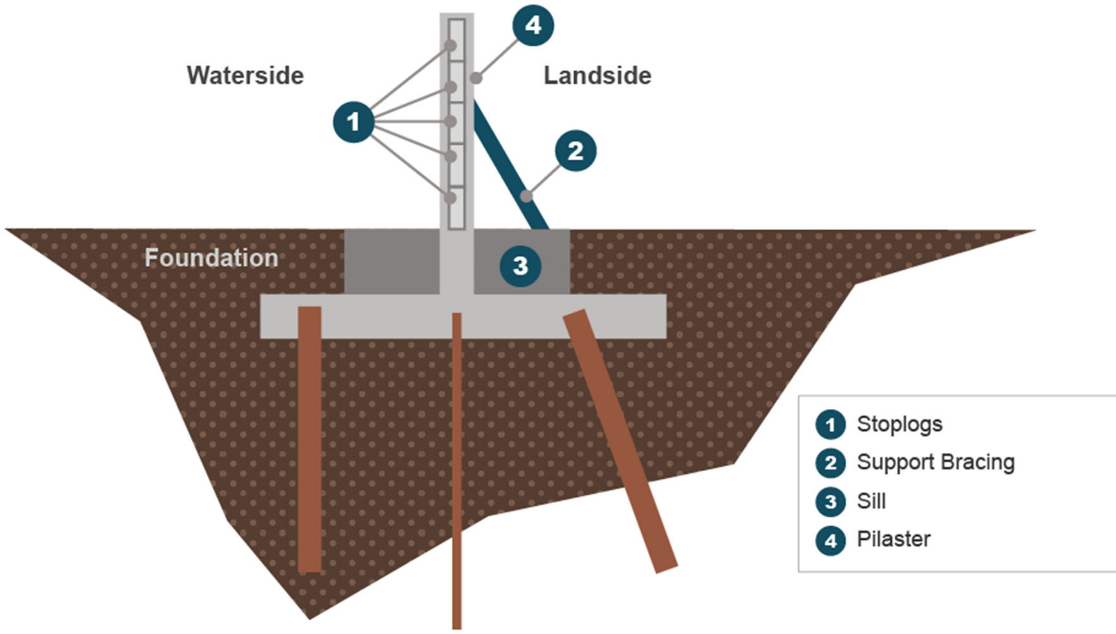


Figure 2-26: Example Stoplog Closures

4.3.4 Closure Across Waterways

Closures across waterways have a similar function to other types of levee closures. They allow water from tributaries, canals, and other waterways to flow uninterrupted across the levee under normal conditions but prevent flood waters from entering the leveed area during storms. Common types include sector gates, miter gates, and lift gates (Figure 2-27 and Figure 2-28). These closures are often used in coastal levees where creeks and rivers discharge into the ocean to prevent storm surge from traveling up the river and into the leveed area. Closures across waterways may require pump stations. When the gates are closed and the flow cannot discharge naturally, water needs to be pumped over the levee. Therefore, a typical operation includes closing the gates and activating pumps for interior drainage.

Figure 2-27: Sector Gate

Figure 2-28: Vertical Lift Gate

4.3.5 Sandbag Closure

Sandbags may also be deployed to achieve closures (Figure 2-29). While they are less expensive and may be viable to deploy for relatively short openings, the necessary lateral footprint and number of sandbags required can make them infeasible for openings with heights greater than 3 to 4 feet (see **Chapter 10** for deployment details). They are also often less reliable and more prone to physical damage. Successful deployment relies on careful, often time consuming, manual placement. They are typically not favored for modern closures unless there are no other viable alternatives. Other soil/rock container systems may be used in-lieu of sandbags, and while uncommon, compacted soil has been used to close openings at closures.

Figure 2-29: Typical Sandbag Closure

4.4 Transitions Between Different Types of Features

A levee consists of an arrangement of features along an established alignment, which creates a need to transition between different feature types. Several types of transitions between different features are illustrated in Figure 2-30.

If not designed and constructed properly, transitions can become a vulnerable point of the levee due to the intrinsic dissimilarity of the structures, such as their material types. Different features will likely respond differently during and after construction. For example, a floodwall and embankment may impose different loads on the foundation which will cause the transition to be prone to issues due to differential settlement. Foundation treatments such as surcharging or preloading are often implemented to address these concerns. Often, the transition must be more robust than the individual features being joined, with careful consideration of how they overlap and are incorporated within the transition section. Issues due to differences in geometry can arise if not carefully evaluated and addressed in the design. For example, flow concentrations where floodwalls tie into earthen embankments can cause erosion of soils.

Figure 2-30: Typical Types of Transitions

4.5 Seepage Controls

The differential water elevations between the waterside and landside of the levee and the associated seepage could cause issues with structure integrity and stability of the feature. Seepage through or under the levee could produce water flow that exits at some point on the landside of the levee, which may require collection with filters and drains, and ultimately be conveyed and discharged with interior drainage. The movement of water under or through a levee from high energy to low energy can result in erosion of foundation or embankment soils. To mitigate these effects, seepage controls may be employed.

Seepage controls provide a mechanism to reduce, collect, filter and/or discharge seepage through the levee or its foundation. They may be used as individual features or used in combinations to mitigate potential seepage issues for levees and may address potential issues through either diversion or interception of the water flow.

4.5.1 Cutoff Walls

Cutoffs (Figure 2-31) divert seepage below the cutoff, extending the seepage path length to reduce the amount of energy within the flow of water and reduce the force with which it exits on the landside of the levee. Sheet pile cutoffs were previously discussed in section 4.2, but cutoffs can also be constructed through, below and riverside of earthen embankments (Figure 2-32) by excavating the soils and filling the excavation with a material that has lower permeability (soil-bentonite, cement-bentonite, or soil-cement-bentonite). Careful consideration is needed to determine the necessary depth of cutoff, as discussed in **Chapter 7**.

Figure 2-31: Typical Cutoff Wall

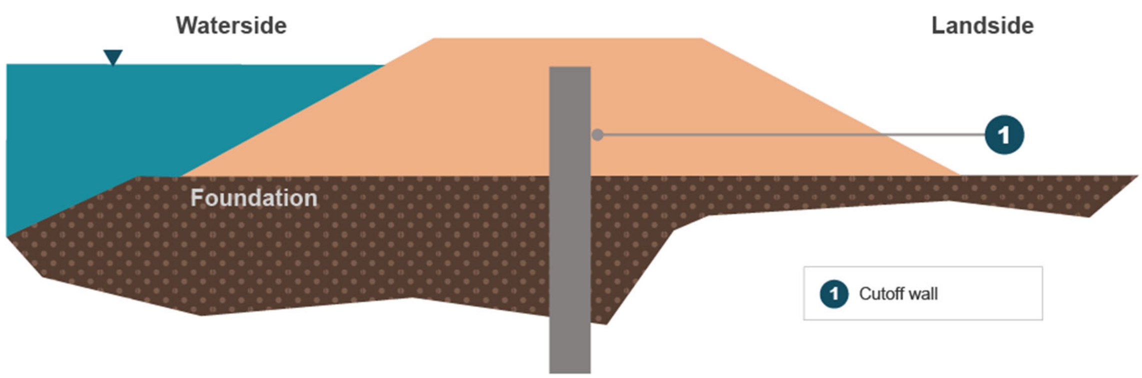
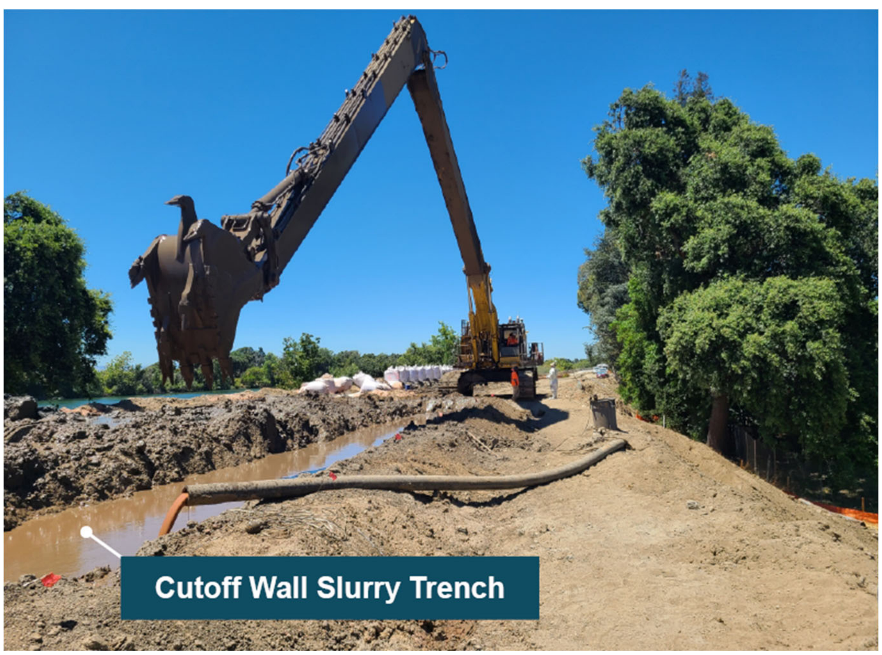


Figure 2-32: Cutoff Wall Under Construction



4.5.2 Seepage and Stability Berms

Seepage berms and stability berms have similar appearance because they consist of prisms of soil immediately to the landside of an earthen embankment (some stability berms may be constructed waterside). And while both provide some level of stability and seepage improvement, seepage berms are primarily intended to counter underseepage and high uplift pressures in the levee foundation, whereas stability berms are meant to provide predominantly counterbalancing weight to prevent slope instability and address through-seepage issues. Seepage berms can be constructed from either impervious or pervious soils, depending on the specific seepage issue that needs to be addressed based on the site-specific foundation conditions. Seepage berms lengthen the seepage path such that seepage water emerges further from the levee toe where it is less likely to cause damage to the levee. An example of a seepage berm is shown in Figure 2-33 and Figure 2-34.

Figure 2-33: Typical Seepage Berm

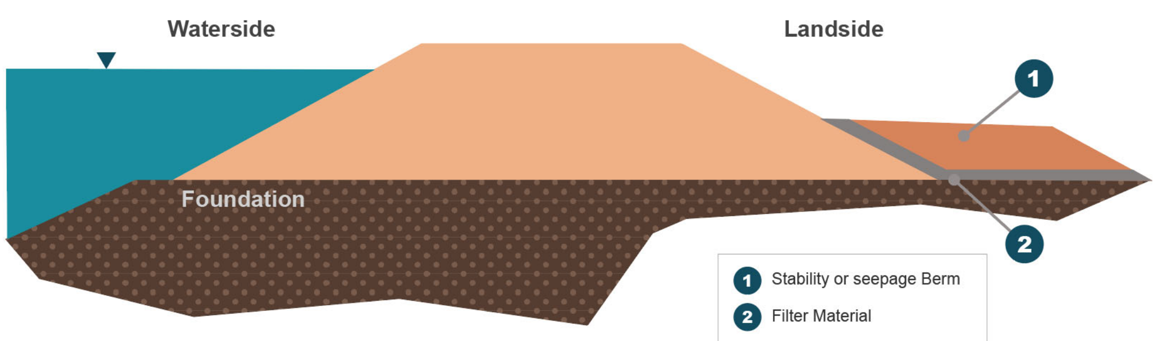
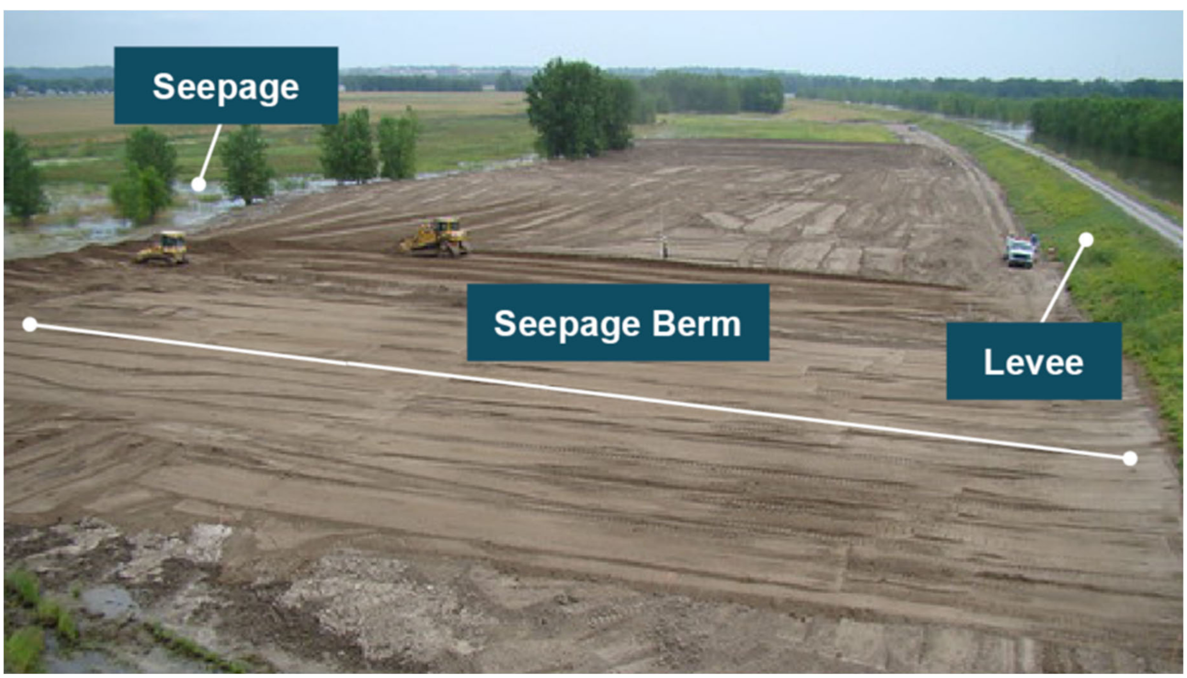


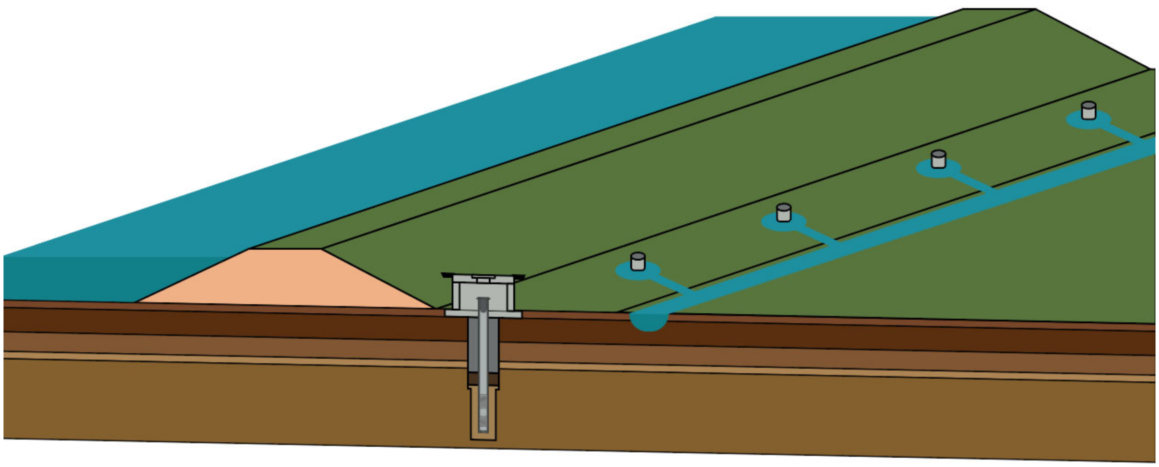
Figure 2-34: Image of Seepage Berm



4.5.3 Relief Wells

Relief wells (Figure 2-35) are installed along the landside toe of levees to reduce uplift pressure which may otherwise cause sand boils and internal erosion of foundation materials. Wells accomplish this by intercepting and providing properly filtered, controlled outlets for seepage. Relief well systems are often used where space for landside berms is limited.

Figure 2-35: Typical Relief Well



A relief well system usually requires less space and right-of-way acquisition/access compared with berms. However, wells require periodic maintenance and frequently suffer loss in efficiency with time, due to clogging of well screens by muddy surface waters, bacteria growth, or mineral build-up. Relief well systems also require a means for collecting, conveying, and disposing of the discharge from the wells (Figure 2-36).

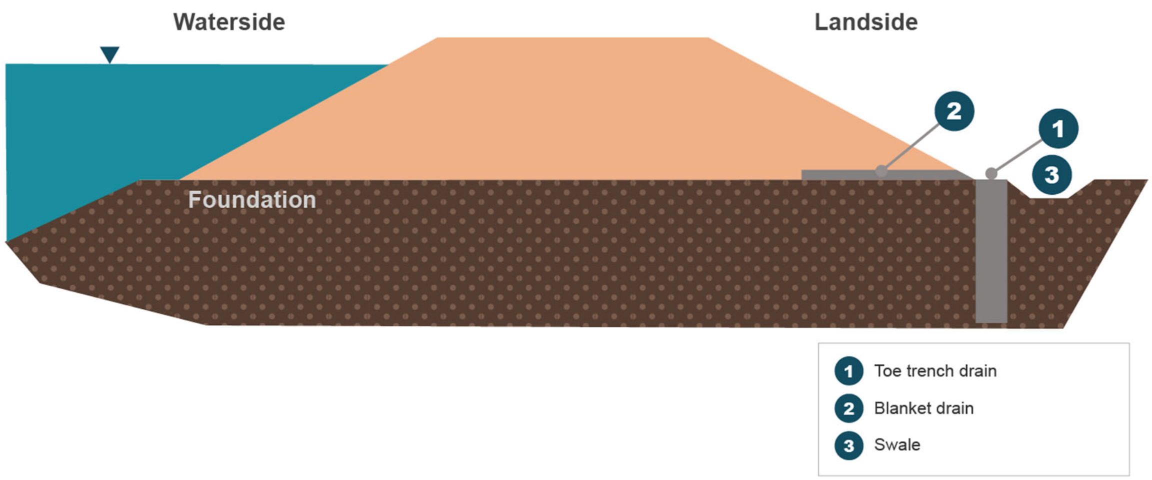
Relief wells may also be installed around structures such as pump stations and drainage structures to reduce uplift pressures and improve stability of the features.

Figure 2-36: Example of Relief Well

4.5.4 Trench and Blanket Drains

Trench drains and/or blanket drains (Figure 2-37) may be installed near the landside toe (termed toe drains) where there is little to no impervious material, and there is a need to intercept, filter, and convey seepage in a controlled manner. In some cases, a trench drain can be constructed towards the waterside below the levee if there is a need to intercept seepage closer to the waterside. A blanket drain would then convey the intercepted seepage through the foundation to the landside. These systems also require means for collecting, conveying and disposing of the collected seepage.

Figure 2-37: Typical Trench and Blanket Drain



4.6 Channels and Floodways

Channels and floodways act as diversion for floodwater flows to be released into less critical areas. Figure 2-38 shows a typical floodway scenario. These features are similar to spillways for dams and function to remove a portion of flood waters and lessen the load on the levee. They consist of controlled overflow sections, which allow flow to bypass a river and be diverted into a channel and ultimately a floodway to provide an area where the consequences of flooding are deemed an adequate trade-off for reduced flood risk to a levee.

Releases can either be controlled with gates that must be operated, or uncontrolled, meaning that flows initiate once they reach a specific elevation on the overflow structure. Fuse gates may also be incorporated to control the release. Fuse gates act as a barrier to flows until the water level reaches a critical height, at which point they 'wash away' allowing a larger release opening to accommodate higher bypass discharges.

While floodways are almost always natural, channels can be natural, concrete lined, or armored to prevent erosion or loss of foundation material in the channel. Figure 2-39 shows an armored and a concrete lined channel.

Figure 2-38: Typical Floodway Channel

Figure 2-39: Examples of Channel Erosion Control

4.7 Interior Drainage Systems and Pump Stations

Levees should not impede stormwater collection and drainage within the leveed area. During non-flood periods, interior drainage systems allow interior stormwater to flow out of the leveed area under gravity drainage through pipes. These pipes create penetrations through the levee. It is important to ensure such pipes are regularly inspected to prevent them from introducing a weak point in the levee (**Chapter 9**).

To prevent floodwater from entering the leveed area through these drainage systems, various controls can be employed that can be closed during floods. Because interior stormwater cannot be discharged through the pipes when the controls are closed, pump stations must be employed to remove the water from within the leveed area. This may be accomplished through the use of pressurized pipes or making provisions for a sufficient ponding area to allow stormwater to collect within the leveed area without inducing damages to improved property.

Figure 2-40 shows a diagram for the essential function of an interior drainage system and pumping. The diagram shows schematically the key elements of the system, which is to (1) allow interior storm drainage to flow out through pipes that extend from the landside to the waterside of the levee; (2) provide outlet control so that stormwater can flow out from the leveed area during non-flood periods, and be closed to prevent floodwater flows into the leveed area during floods; and (3) provide the energy and means to remove interior stormwater that can no longer flow out when the interior drainage controls are closed. Interior stormwater is diverted to an area near the pumping station (interior ponding area) to be removed by the pumping system. Figure 2-41 shows details of a typical interior drainage system.

Figure 2-40: Essential Function of Interior Drainage System

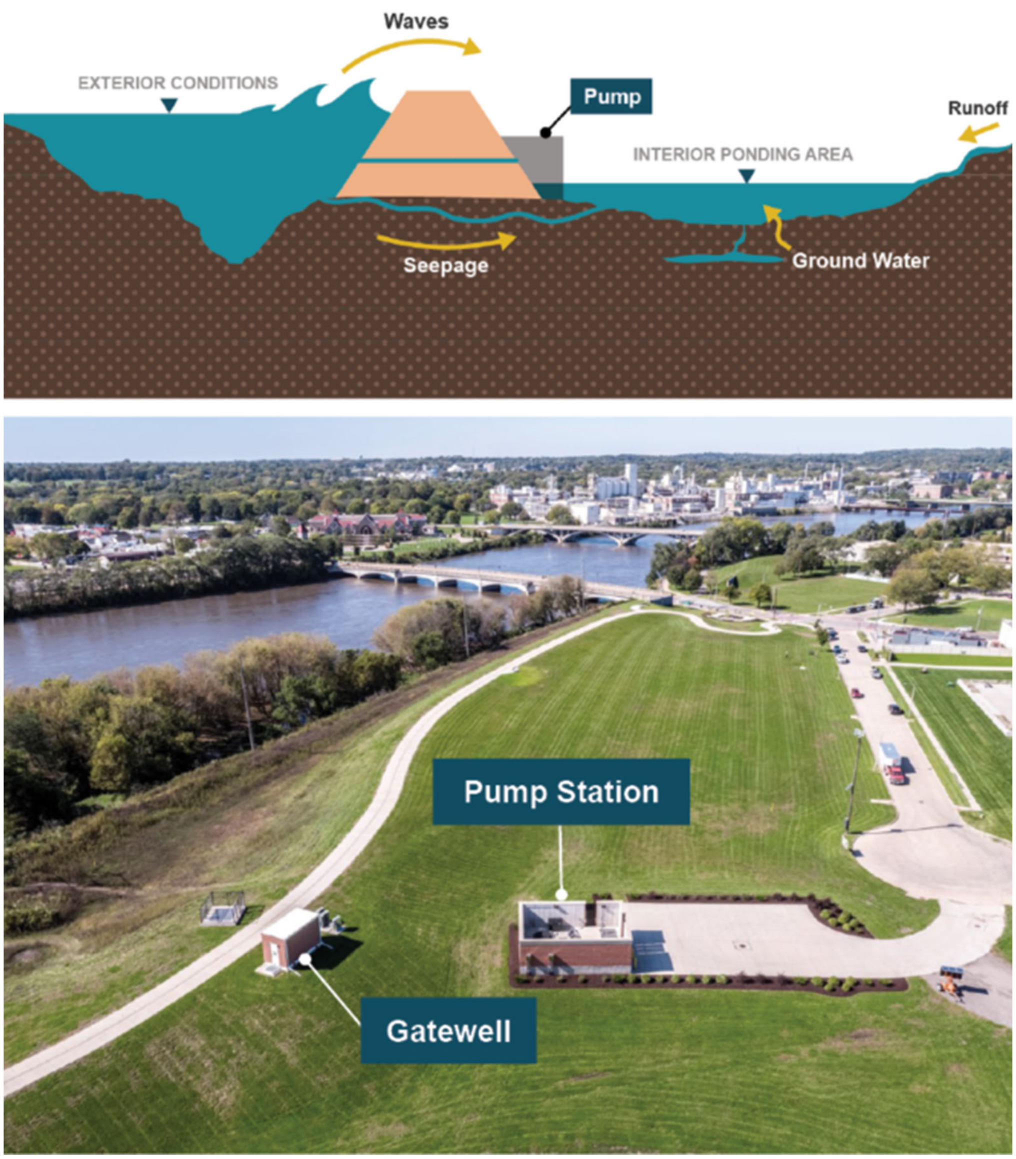
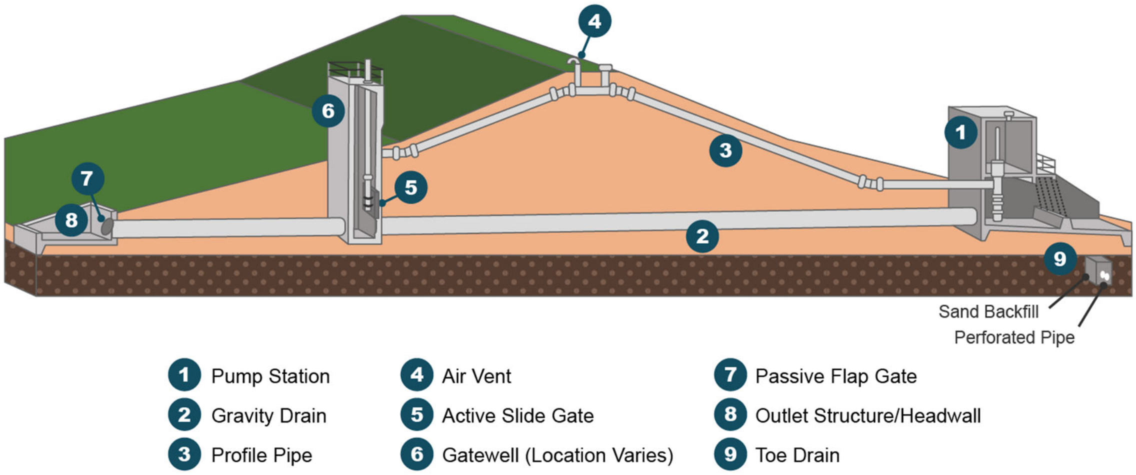
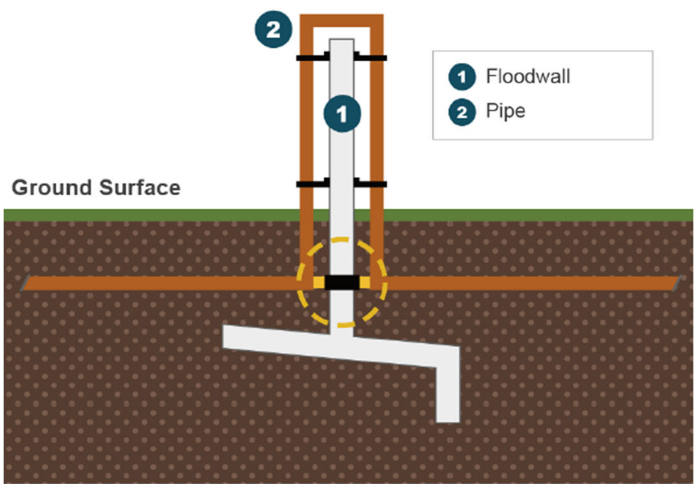


Figure 2-41: Typical Interior Drainage System



As shown in Figure 2-42, when interior drainage is required through a floodwall, the preferred path to route the pipe is over the floodwall or through the floodwall foundation. Figure 2-43 shows some of the more common gates used for interior drainage systems. The gates are either manually operated (sluice gate) or designed to remain closed until a certain pressure builds up behind the gate, at which point it opens (flap gate and duckbill). Once the pressure relieves the gate closes.

Figure 2-42: Detail of Pipe Passing Floodwall



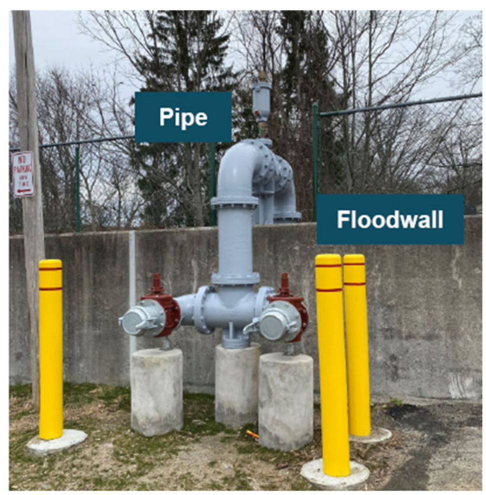
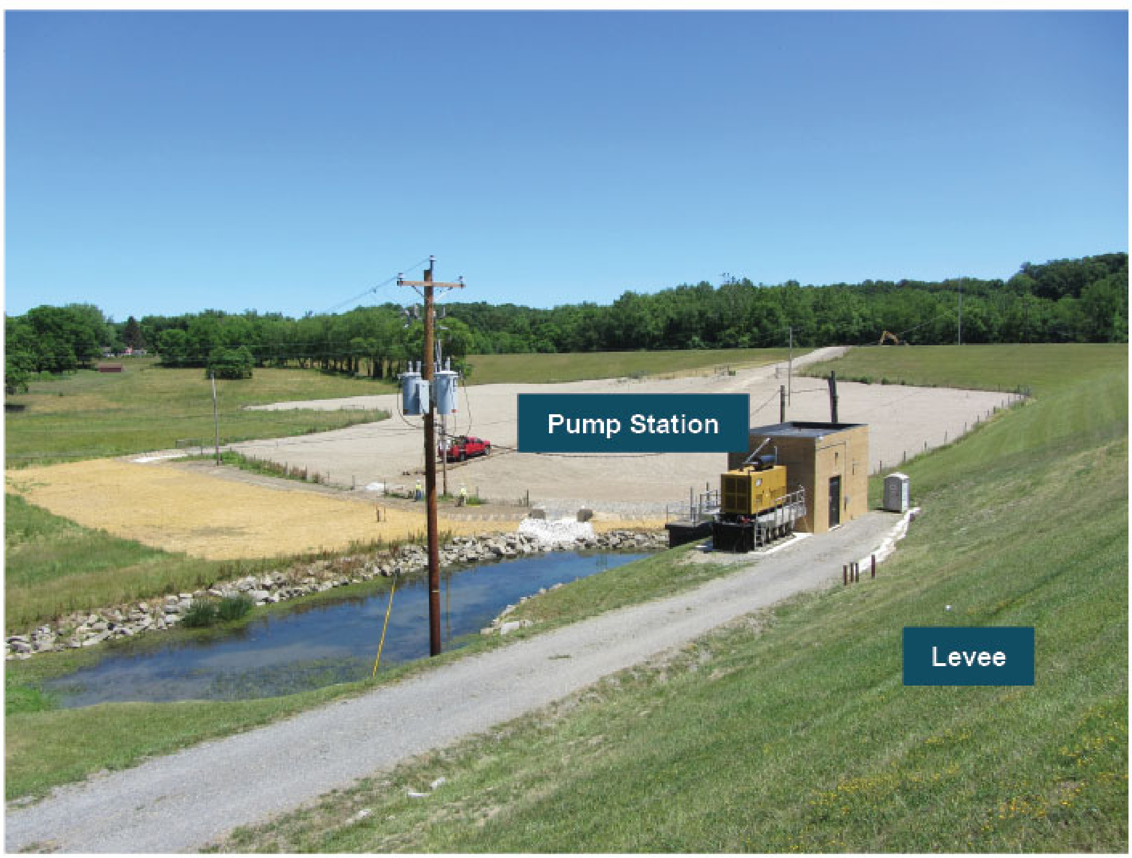


Figure 2-43: Typical Gates for Interior Drainage Systems

Figure 2-44 shows a pumping station example. The scale and configuration of pumping stations can vary tremendously based on the pumping rates required. Regardless of the scale of the system, the key components consist of (1) an area to collect the diverted interior storm drainage (ponding area); (2) the pumps to create sufficient energy and capacity to remove the stormwater out from the leveed area, and (3) pipes to discharge the pumped water out from the leveed area.

Figure 2-44: Typical Pump Stations



4.8 Instrumentation

A number of different instruments and technologies can be used for levee monitoring. Instrumentation may provide an indication of conditions on a relatively discrete portion of the levee or provide an understanding of the levee conditions on a broader scale. Instrumentation can broadly be classified according to the parameter it is used to detect and measure, which generally falls into one of the following three main categories:

- Hydraulic head (pore water pressure)
- Seepage
- Displacements (vertical and lateral)

Instrumentation can provide useful performance and operational data. A variety of instruments can be used to monitor performance including; observation wells, piezometers, weirs, staff gages, displacement gages, settlement cells, and inclinometers. Some instrumentation examples are shown in Figure 2-45.

Observation wells are the simplest device for measuring water pressures in soils. Piezometers are used to measure the pore pressures (head) in levees and their foundations under both unconfined and confined conditions. The elevation of the water in both wells and peizometers can be determined manually by using a water level indicator, or the readings can be automated by installing a pressure transducer in the standpipe.

Direct measurement of seepage through a levee or its foundation can be a challenge if the seepage path is not known or if the seepage water cannot be collected and directed to a measurement location. When the opportunity exists to channel seepage water into a ditch or channel, weirs or flumes installed in the ditch or channel can be used to quantify the seepage flow. Water levels at weirs or flumes can be read visually using staff gages or using instruments.

A number of methods and types of instrumentation are available to measure settlement and vertical displacements. The methods vary depending on what type of displacement is to be measured, and what sort of measurement methods are feasible. The simplest form of displacement measurement (apart from just a qualitative visual observation) is the total displacement at the ground surface of a fixed location or marker, determined by surveying. Other traditional methods can be used to provide the relative displacement of a location compared to a specific reference point, but these methods generally require installation of instrumentation within the body of the levee.

Besides surveying monuments to determine lateral displacements, inclinometers are the primary method to monitor for lateral displacements at levees. Inclinometers can monitor for lateral displacements or offsets within the body of a levee embankment and/or within its foundation. For structures such as floodwalls, inclinometer casings can be installed in the backfill adjacent to the structure, or within the concrete flood wall itself. Also, tiltmeters can be installed on floodwalls to infer the lateral displacement from rotation of the face.

Figure 2-45: Typical Levee Instrumentation

5 Levee Breach

Levee breach, or sometimes referred to as levee failure, is the formation of a gap in the levee system through which water may flow uncontrolled into the adjacent levee area. A breach may occur prior to water reaching the top of the levee or subsequent to overtopping. Levee breaches may occur due to an unknown defect or the malfunction or mis-operation of a levee feature. If is important to be aware of some of the common breach mechanisms of a levee so they can be identified and mitigated to ensure successful levee performance. The following sections describe levee breach scenarios and breach mechanisms, commonly referred to as potential failure modes.

5.1 Levee Breach Scenarios

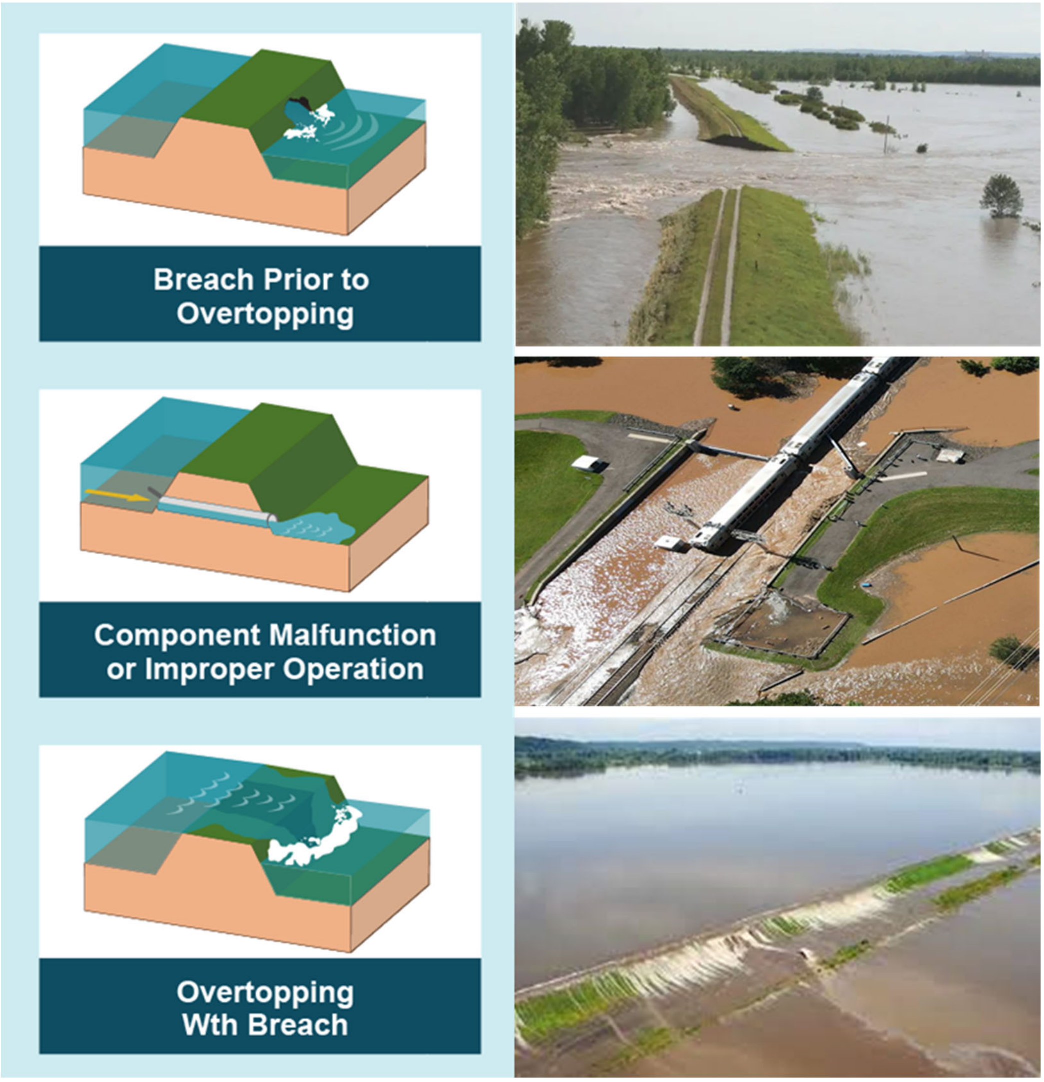
Levee breach scenarios include the following, also illustrated in Figure 2-46:

Breach prior to overtopping: In this scenario, the levee breaches, and floodwaters flow uncontrolled into the leveed area before the levee is overtopped.

Malfunction or improper operation: In this scenario, a levee feature either malfunctions or does not properly operate. These failures can result in an uncontrolled release of floodwater into the leveed area or can lead to more constricted and constrained inundation.

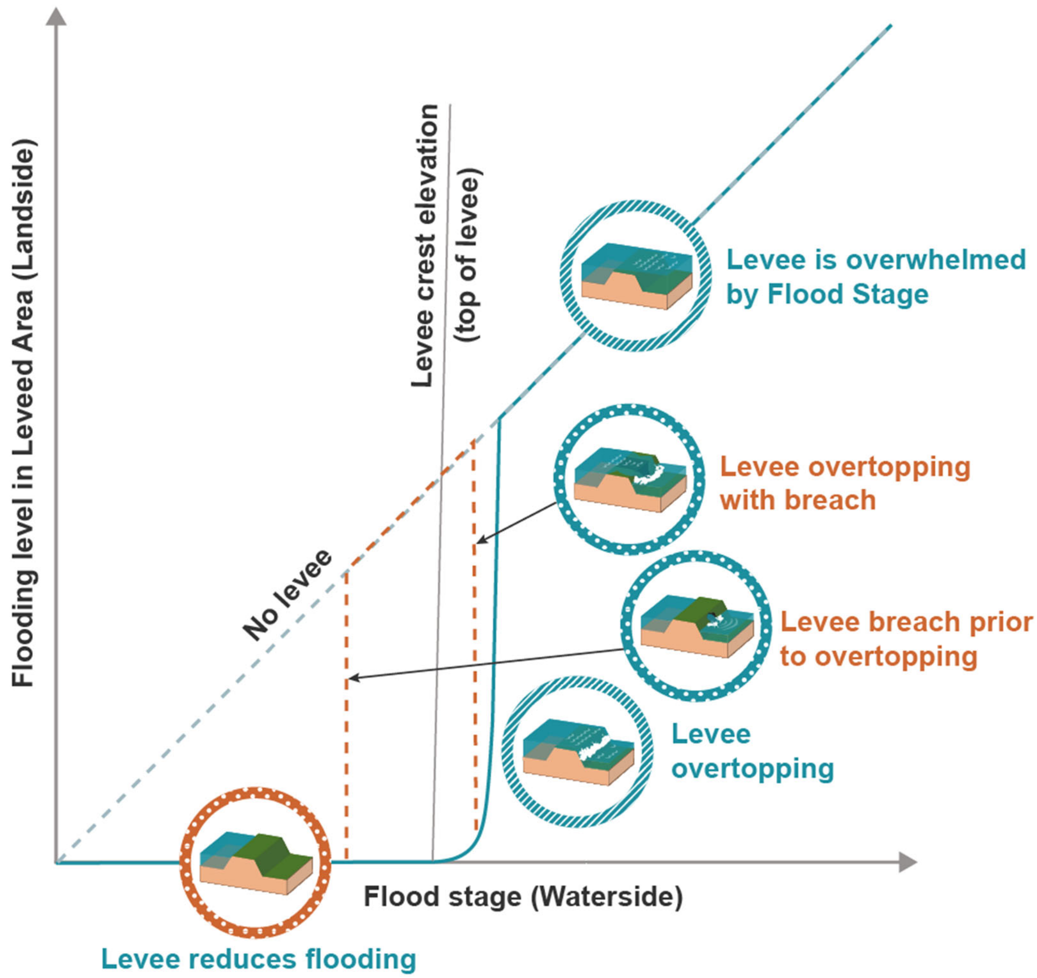
Overtopping with breach: This scenario occurs when water overtops the levee, and the flows cause erosion sufficient to breach the levee with rapid inundation of the leveed area.

Figure 2-46: Levee Breach Scenarios



Using the same concept as Figure 2-4, Figure 2-47 illustrates how the leveed area (landside) could be flooded with each of these breach scenarios. The solid blue line illustrates the levee functioning as intended, including inundation resulting from overtopping of the levee without breach. The orange dashed lines illustrate the levee breach prior to and from overtopping.

Figure 2-47: Graphical Representation of Levee Breach Scenarios



5.2 Levee Potential Failure Modes

These guidelines describe five general categories of potential failure modes considered most common to levees. These include breach from overtopping, external erosion, internal erosion, instability, and malfunction or improper operation of a feature, which are illustrated in Figure 2-48 and Figure 2-49, followed by a description.

5.2.1 Breach from Overtopping

Breach from overtopping is typically the result of progressive erosion of the landward slope from the flow over the levee. Overtopping may cause concentrated flows that, with sufficient velocity, can erode rills and channels on the landside embankment or of a floodwall toe. With time, this can either cause landside embankment slope or floodwall instability or progressive erosion through the levee embankment. Overtopping without breach is not considered a levee failure.

5.2.2 Breach Prior to Overtopping

Breach prior to overtopping is typically the result of sudden progression of one or a combination of external erosion, internal erosion or instability as described below.

External erosion occurs when water flow or wave action causes loss of surface protection (vegetative, riprap, mat armoring, or fabrics) that results in undercutting the levee toe or loss of the levee prism. Once exposed, riverine or coastal forces can progressively and catastrophically continue to erode the levee, leading to levee instability and breach.

Internal erosion occurs when seepage exits on the landside levee face or foundation at or beyond the levee toe with sufficient force to erode and carry soil particles from within the levee foundation or embankment prism. This can occur through one of several mechanisms such as concentrated leak erosion, backward erosion piping, suffusion, and soil contact erosion. Specifics of these mechanisms are extensively studied and described in technical literature, including best practices for dam and levee risk analysis.

Instability of the levee includes slope stability failures (slides), or excessive settlement due to foundation issues. This can lead to loss of the crest and during a flood, result in overtopping and breach at the location of the instability. Instability also includes sliding or overturning failure of structural elements such as floodwalls.

5.2.3 Malfunction or Improper Operation of a Feature

This potential failure mode includes inability to deploy removable flood risk reduction features, operate closure gates or walls, component of a closure fails, pump does not operate, or installation of a closure does not occur in time for the structure to properly exclude floodwaters. This typically leads to inundation of the leveed area prior to overtopping.

Figure 2-48: Typical Embankment Potential Failure Modes

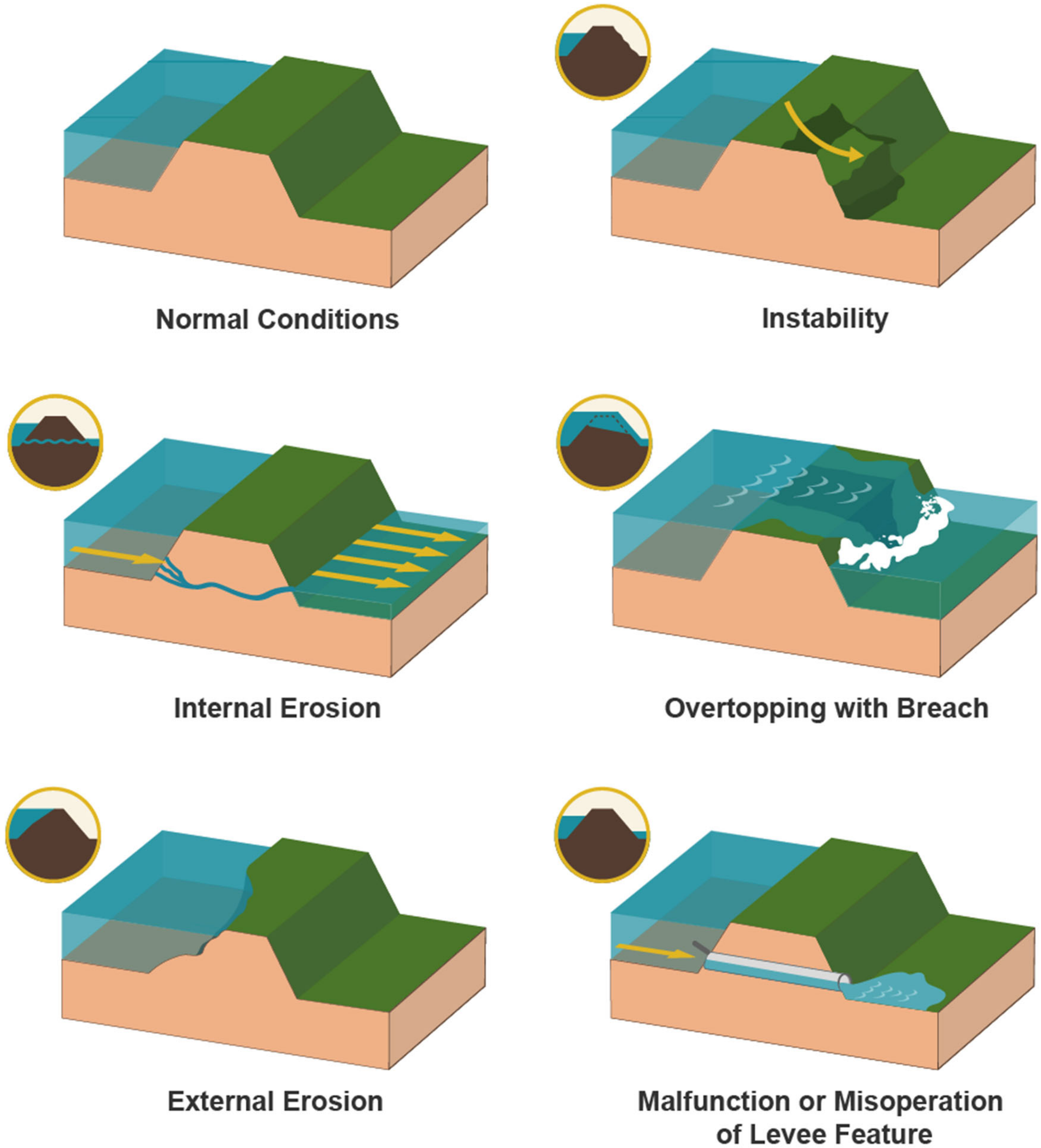
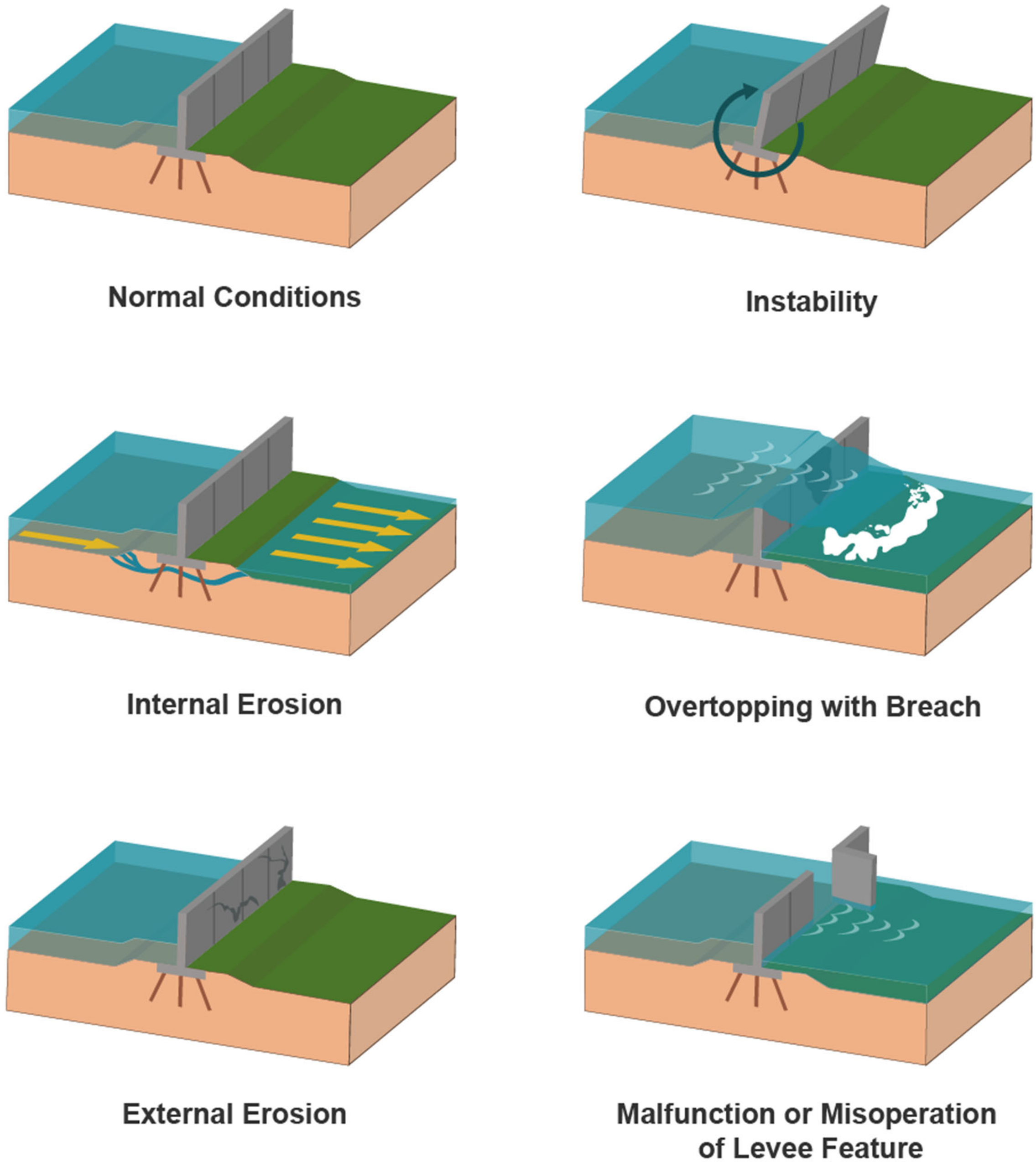


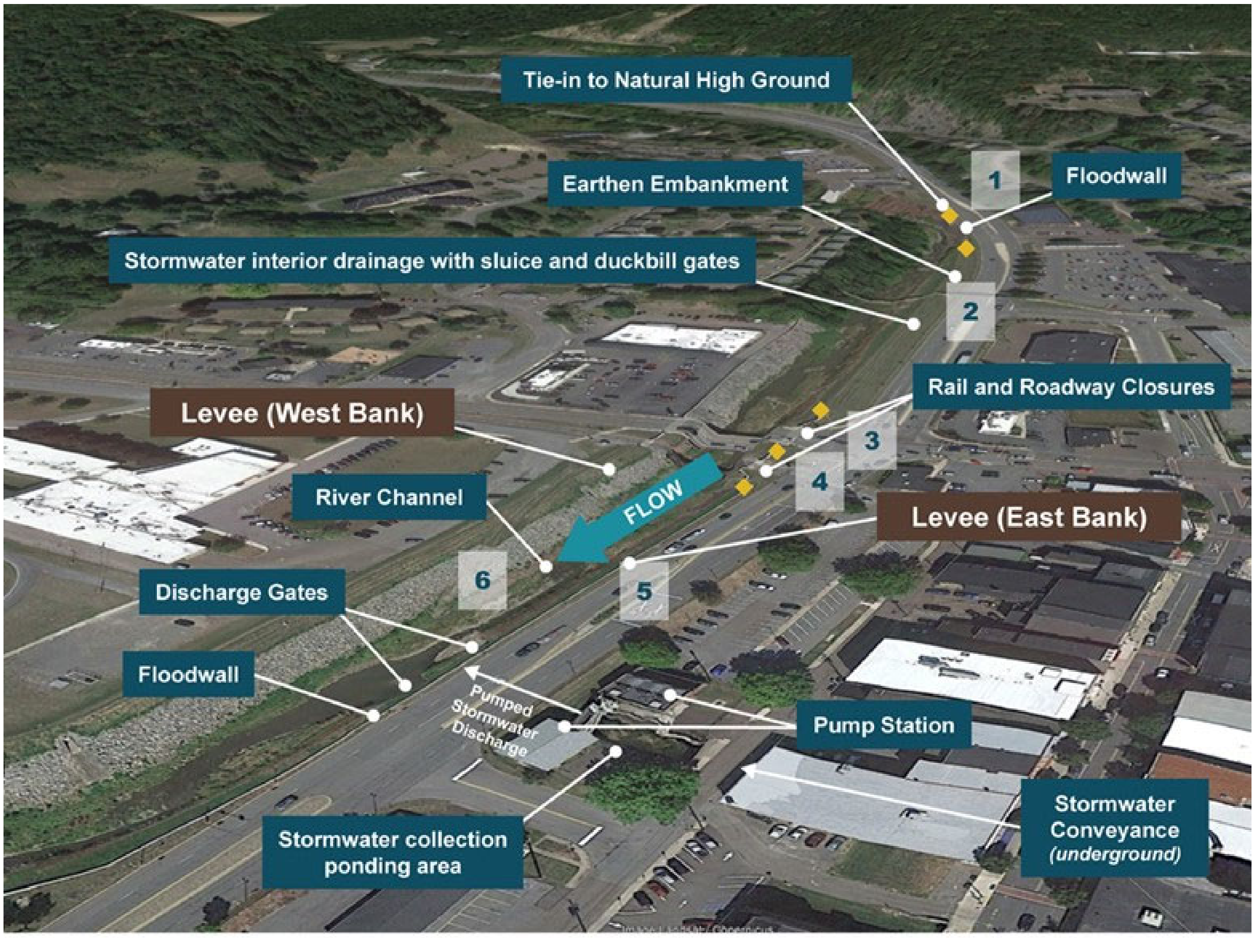
Figure 2-49: Typical Floodwall Potential Failure Modes



6 Example of Levee System

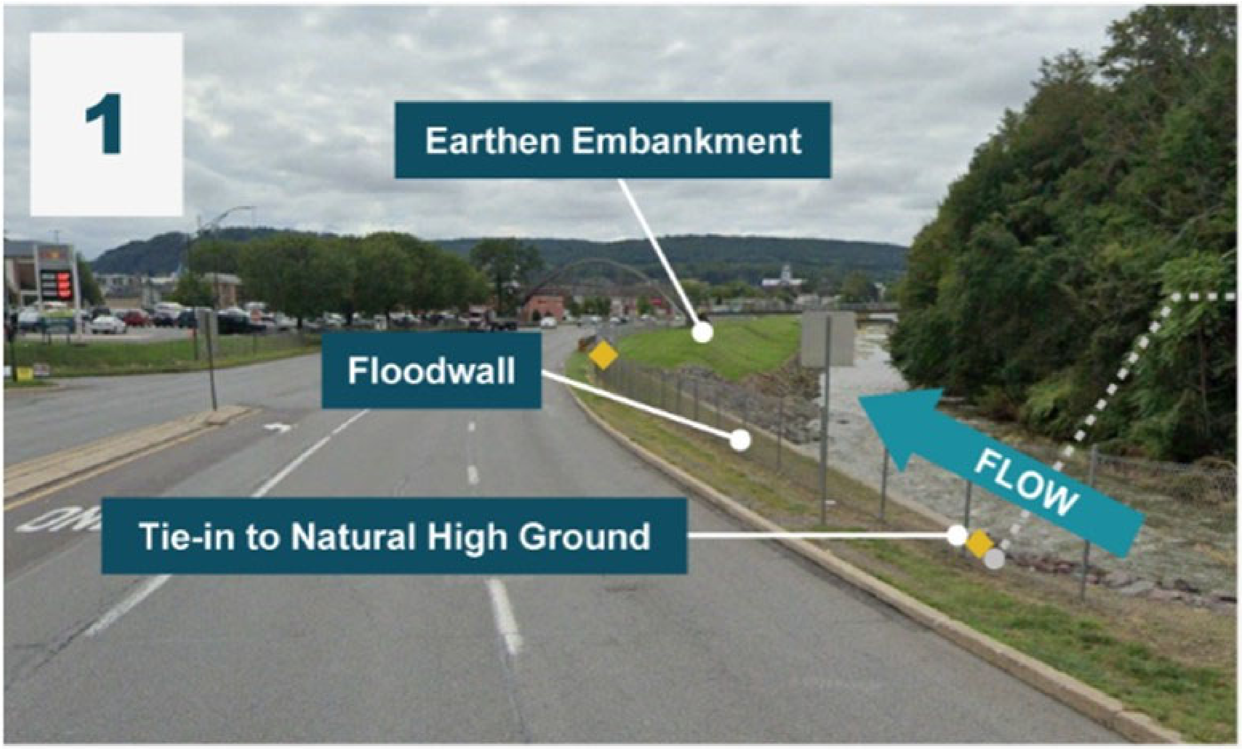
To illustrate how levee form and function coincide to achieve the intended flood risk management objective of a levee system, the following material describes a real levee example with a discussion pertaining to individual features. Figure 2-50 displays a portion of a riverine levee system in a semi-urban area in central Pennsylvania. The levee extends from the north to the south along either side of the Mahoning Creek, which is a natural drainage feature in a watershed north of the Susquehanna River (West Branch). For the purposes of this example, the focus will be the levee on the east bank.

Figure 2-50: Example of Features Along a Riverine Levee System



Area 1: The east bank levee begins at the northern terminus with a short length of low-profile floodwall that ties into natural high ground (Figure 2-51). A floodwall was used in this area due to the limited right-of-way available between the creek bank and adjacent roadway (State Route PA-54). The tie-in of the floodwall with natural high ground represents a transition between two different features. Erosion protection in the form of large diameter stone (riprap) was placed around the wall at the high ground contact.

Figure 2-51: Example of Floodwall and Tie-In to High Ground



Area 2: On the landside portion of the levee, there are a variety of interior drainage features to manage stormwater within the leveed area (Figure 2-52). Catch basins along the curb line of the roadway and inlets within swales on the land side of the levee capture surface runoff into stormwater collection pipes. During non-flood periods, control structures (gates) are open and allow the stormwater to drain into the creek by gravity.

Figure 2-52: Example of Interior Drainage Systems

During floods, these controls are closed to keep floodwater from backing into the stormwater collection system and entering the leveed area. The gravity discharge is bypassed with the control structures, and stormwater that collects within the leveed area is conveyed to areas where it can be temporarily ponded with provisions to pump out of the leveed area and into the waterside (in this case the creek).

Areas 3 and 4: The earthen embankment continues south to the intersection with a transportation corridor consisting of a major roadway (US Route 11) and railway (SEDA-COG Joint Rail Authority). The earthen embankment transitions into a floodwall and two stoplog closure structures extending across the roadway and railway (Figure 2-53 and Figure 2-54). During the 2011 flooding, sandbags were used to transition from the earthen embankment to the closure structures (Figure 2-54). Stormwater is ponded on the landside of the closures, and a mobile pumping station is used to divert the stormwater from within the leveed area back into the creek.

Figure 2-53: Example of Embankment Tie-In to Floodwall

Figure 2-54: Example of Railway and Roadway Closures

Areas 5 and 6: The railway closure transitions into a floodwall to the south, dictated by the limited footprint between the adjacent roadway (PA-54) that runs parallel to the creek and levee

(Figure 2-55). Further south along PA-54 lies the main interior drainage ponding area to which a large portion of the stormwater within the leveed area is conveyed (Figure 2-56).

Gates control the discharge of the interior drainage from culverts extending under the roadway, which can be released under gravity drainage into the creek during non-flood periods or discharged using the pumping station during flooding events.

Note that the levee continues beyond what has been shown in this example.

Figure 2-55: Example of Floodwall

Figure 2-56: Example of Interior Drainage System

7 Summary

Related content associated with this chapter is included in detail in other chapters of the National Levee Safety Guidelines as described in Table 2-2 below.

Table 2-2: Related Content

Chapter 2 – Related Content

Chapter	Chapter Title	Related Content
1	Managing Flood Risk	
2	**Understanding Levee Fundamentals**	
3	**Engaging Communities**	• Engaging to build knowledge and awareness
4	**Estimating Levee Risk**	• Potential failure modes
5	Managing Levee Risk	
6	**Formulating a Levee Project**	• Types of levee projects
7	**Designing a Levee**	• Design of levee features
8	**Constructing a Levee**	• Construction of levee features
9	Operating & Maintaining a Levee	
10	Managing Levee Emergencies	
11	Reconnecting the Floodplain	
12	Enhancing Community Resilience	