Chapter 4: Operation and maintenance (O&M)

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Chapter 4 - Context

Chapter 4 discusses the operation and maintenance of levees. It examines the challenges a maintainer may face and suggests preventive measures and repair techniques. Key inputs from other chapters:

- Chapter 3 "forms, functions and failure mechanisms of levees"
- Chapter 5 "visual inspection methods to identify and assess levee issues"
- Chapter 9 "insights into maintaining the levee’s intended design"

Key outputs to other chapters:

- routine operations ⇒ Chapters 5 and 9
- maintenance procedures ⇒ Chapters 5, 6 and 9

Note: The reader should revisit Chapters 2 and 3 throughout the levee life cycle for a reminder of important issues.
4.1 Applying Asset Management Principles to O&M

- Levee management life cycle
- Organisation of O&M
- Importance of the O&M Manual

Figure 4.1 Levee life cycle diagram
4.1 Applying Asset Management Principles to O&M (continued)

- Activities and practices of asset management
- General approaches to O&M
- Scope of O&M and Chapter 4
4.2 Operations

- Operating to keep water out of the leveed area
- Operating to get water out of the leveed area
- Operating to keep the levee standing
Table 4.3  Operational activities that may be required to keep water out of a levedd area

<table>
<thead>
<tr>
<th>Type of structure</th>
<th>Operational activities</th>
</tr>
</thead>
</table>
| *Stop logs*       | • transporting materials to the closure  
|                   | • stacking logs on top of each other to close the physical opening in the levee  
|                   | • covering the structure with plastic sheeting  
|                   | • patrolling the closure if logs are made of valuable material that may be stolen. |
| *Flap gates*      | None. A flap gate operates passively. It has a one-way door that closes to keep rising water level fluctuations from flowing through a flood defence. It keeps water out of the levedd area by closing when the water pressure differential is high enough to hold the gate closed. |
| *Slide gates*     | Slide gates allow interior drainage to flow from the levedd area out through the flood defence and keep flood waters from inundating the levedd area when water levels are high. They give the levee owner and maintainer close control over how much water is allowed to enter or leave the levedd area. Operational activities may include:  
|                   | • adjusting the gates (manually or automatically) up and down along the track  
|                   | • regularly removing any debris that accumulates in the intake structure.  
|                   | See Section 4.14 for more information on maintenance of closure structures. |
4.3 Maintenance

- Limits of maintenance
- Consequences of postponing maintenance
- Issues with earthen levees
Structure of Maintenance Sub-Sections

All maintenance-related sub-sections address the following topics:

• What maintenance issues you are likely to see, what they look like, and why they are problematic
• How you can prevent these issues from happening
• How you can repair these issues if they happen
• How you can know when repairs are beyond O&M
Topics Discussed in the Maintenance Section of the ILH

- Encroachments
- Vegetation Management
- Burrowing Animals
- Erosion
- Depressions
- Settlement
- Seepage

- Instability
- Cracking
- Slope/bank protection
- Closure Structures
- Pipes
- Transitions
- Floodwalls
4.4 Encroachments

- Why encroachments occur on levees
- Why encroachments need to be controlled
- 7 elements of an effective encroachment control program
- Repairs of encroachment issues
- When repairs are beyond O&M
Reinforcing the levee to allow for permitting encroachments

Figure 4.12  Levee along a river – historical house on the riverside of the levee, the Netherlands

Figure 4.13  Possible levee reinforcements to accommodate a pipe

Option 1: Berm with pipe outside zone of influence (grey area)

Option 2: Berm with pipe inside zone of influence (grey area), but with sheet piling
4.5 Vegetation Management

- Protecting the levee from external erosion
- Maintaining adequate access and visibility
- Preventing the development of vegetation-induced damage or defects
Summary of potential deterioration mechanisms associated with woody vegetation

<table>
<thead>
<tr>
<th>Deterioration process</th>
<th>Role of woody vegetation</th>
<th>Potential levee damage mechanisms affected (see Chapter 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blowover/overtopping</td>
<td>The overturning or blowover of a large tree may remove a large section of a levee or adorning ground during a flood event. If on the waterside, the resulting pit may leave the levee susceptible to scour.</td>
<td>External erosion, slope instability, and internal erosion (caused by through-seepage, underwater-seepage, and piping)</td>
</tr>
<tr>
<td>Root penetration</td>
<td>Roots, especially when decayed, may alter soil permeability or concentrate seepage along root paths.</td>
<td>External erosion and internal erosion (caused by through-seepage, underwater-seepage, and piping)</td>
</tr>
<tr>
<td>Woody vegetation weight and wind loading</td>
<td>The adverse effects of woody vegetation weight and wind loading is transferred to a levee slope.</td>
<td>Slope instability (slip surfaces may be deeper than extent of root penetration)</td>
</tr>
<tr>
<td>Scour flows</td>
<td>Woody vegetation may cause concentrations or eddies in waterside or overtopping flows.</td>
<td>External erosion</td>
</tr>
<tr>
<td>Burrowing</td>
<td>Woody vegetation may attract burrowing animals into a levee.</td>
<td>Internal erosion</td>
</tr>
<tr>
<td>Discouraging adequate growth of grass and turf</td>
<td>Woody vegetation may prevent adequate growth of grass and turf by blocking sunlight, absorbing nutrients and moisture or releasing chemicals that act as herbicides, resulting in bare, exposed soil on levee surfaces.</td>
<td>External erosion</td>
</tr>
<tr>
<td>Damage to the revetment</td>
<td>If the revetment was not designed for vegetation, the growth of roots and stems may move and loosen the stones, or rigid levee protection elements such as asphalt, grouted stone, or concrete slabs, thus affecting the revetment’s interlocking characteristics.</td>
<td>External erosion</td>
</tr>
</tbody>
</table>
4.6 Burrowing Animals

One method that is used in France to prevent levee damage from burrowing animals.

*Figure 4.33* Metal mesh on the surface of the levee (courtesy Symadrem)
4.7 Erosion and Bank Caving

Box 4.35  Effects of erosion on a levee slope, Park Creek, New York, USA

On Park Creek deposits have concentrated the river flow close to the levee. Because the flow is more intense on the outside of the curve, the portion of levee in that area was heavily eroded during the 2006 flood (Figure 4.34). Once the grass cover was removed from the levee and the unprotected earthen material was exposed, erosion progressed very quickly. This site was repaired by armouring the toe of the levee. No damage was done to the levee during the largest flooding event on record in September 2011.

Figure 4.34  The effects of erosion on a levee slope at Park Creek, New York, USA
### 4.9 Settlement and Subsidence

#### Table 4.16 Settlement: causes and preventive measures

<table>
<thead>
<tr>
<th>Observations</th>
<th>Preventive measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seepage-related</strong></td>
<td>• if a boil is identified, a ring dike could be placed around it to keep fine particles from piping, preventing settlement if caught early enough</td>
</tr>
<tr>
<td>Loss of excessive amounts of material as a result of boils</td>
<td>• every effort should be made to control seepage runoff so that the loss of material does not lead to settlement</td>
</tr>
<tr>
<td>Decreased crest elevation</td>
<td>• if excessive amounts of material have already been lost in an area of the levee because of a boil, consider installing a cut-off wall (see Chapter 9)</td>
</tr>
<tr>
<td>Movement of material under and through the levee due to seepage can cause settlement</td>
<td>See Section 3.2.2.9 on cut-offs for permeable foundations, Section 6.7.2.1 on seepage berms and Section 6.7.3.1 on additional techniques for flood-fighting boils.</td>
</tr>
</tbody>
</table>
4.11 Instability

Recognizing slope instability

Figure 4.43 Cross-sectional diagram of a slide in the levee
## 4.12 Cracking

### Table 4.19 Characteristics of desiccation and structural cracks

<table>
<thead>
<tr>
<th>Type of cracks</th>
<th>Typical level of concern</th>
<th>Characteristics</th>
<th>Why they are a concern</th>
</tr>
</thead>
</table>
| Desiccation cracks      | Low                      | • vary in size by material type  
• appearance of the crack varies based on the moisture content (may exhibit a blocky pattern common in very dry or desiccated clayey levee surfaces)  
• generally parallel to the crest, although they may be parallel or perpendicular  
• generally narrow and shallow and extend 0.3 m to 0.5 m into embankment and/or adjacent riverbank  
• normally close during wet periods  
• typically smaller than structural cracks, but more extensive over levee surface. | • extended dry periods may induce larger and deeper cracks into levee  
• repeated wetting and drying fatigues the embankment soils, reducing embankment shear strength and possibly resulting in a shallow slope (slough) slide  
• material or debris may enter the crack when it is open and keep the crack from closing properly when it is wet. |
| Structural cracks        | High                     | • may run parallel or perpendicular to the levee crest  
• may result from embankment movement or duress, such as settlement, sliding and/or soil-bearing type failures. | • may appear as small displacement cracks and grow substantially depending on the mechanism for movement or duress  
• should be brought to the attention of a geotechnical engineer for evaluation of foundation conditions. |

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### 4.13 Levee Slope and Bank Protection

#### Table 4.22 Stone and concrete methods of levee slope and bank protection

<table>
<thead>
<tr>
<th>Method</th>
<th>What it is and where it could be used</th>
<th>Maintenance needs</th>
</tr>
</thead>
</table>
| Rip-rap (courtesy USACE)                    | Rip-rap is carefully placed or dumped natural stone, typically in two layers. The stability of rip-rap depends on the selected stone size. To ensure stability of the rip-rap slope the toe should either extend below bed level or contain additional stone that can be released if further channel erosion occurs. The size of the stone should be chosen with consideration for its stability and the likelihood of it washing out, given the prevailing wave and current conditions. Rip-rap is used on levee slopes/banks, straight or meandering rivers and coastal locations. Rip-rap can be used to cover and reinforce pre-existing revetments. | - rip-rap should require little maintenance except inspection and monitoring for movement, loss of rocks, a change in rock size (especially after cold events), or toe erosion  
- saplings or vegetation growing between the rip-rap stone should be removed to avoid unduly displacing the rip-rap in the future. Note that one of the benefits of the rip-rap is that some damage or displacement may be allowed for in the design and may be tolerable. |
| Rip-rap grouted with asphalt or colloidal concrete (courtesy Rijkswaterstaat) | The stability of rip-rap can be increased by penetrating the stones with asphalt                                                                                                                                                      | - grouted rip-rap needs little maintenance                                                                                                                                                                      |
4.14 Closure Structures

• Types of closures
• Preventing closure structure failures
• Examples of: trial closure policies, why it is important to have trials, a competition for the fastest closure structure installation
• Maintenance methods and repairing closure structures
• Determining when repairs are beyond maintenance
4.14 Closure Structures:

Text box example (Box 4.47)

- Annual closure exercise competitive event
- 6 closures including two sandbag closures and four aluminium panels
- BEFORE: 1996 flood event, 40 men were required for 5.5 hours to install one of the sandbag closures
- AFTER: three men (an equipment operator and two labourers) in less than 12 minutes
4.15 Culverts and Discharge Pipe Systems

Part 1: Culverts and discharge pipes
• Why culverts and discharge pipes are a concern
• Maintenance – avoiding internal erosion
• Maintenance – avoiding external erosion
• Maintenance – avoiding levee instability
• Repairing culverts and discharge pipes
• Maintenance of culverts and discharge pipes system components

Part 2: Utility pipe and line systems
• Why utility pipes and line systems are a concern
• Maintenance of utility pipes and lines
• Repair of utility pipes
• Determining when repairs are beyond O&M
4.15 Pipes: Text box example (Box 4.49)

**Box 4.49**  
**Pipe failure causing a sinkhole in the levee crest on the Jeffersonville/Clarksville levee system, Indiana, USA**

On the Jeffersonville/Clarksville levee located in Indiana, two 1.8 m diameter corrugated metal pipes collapsed in 1996 beneath the 10.7 m tall levee embankment. This section of levee is within the jurisdiction of the USACE Louisville District. The pipes were 50 years old. Had the pipes failed during a flood event, the resulting sinkhole (Figure 4.56) might have caused the levee to fail due to internal erosion or an overtopping breach. To repair the levee, the entire levee section was cut open and the pipes were replaced.

This experience inspired the Louisville District to create an inspection program to ensure that flood control system pipes passing through the levee are not threatening the levee’s integrity. Inspections are done by physically entering the pipes or by remote video inspection.

**Figure 4.56**  
**Sinkhole created when two 1.8 m diameter corrugated metal pipes collapsed under a levee in Indiana, USA**
4.16 Levee Transitions

- Why transitions are a well-known weak point in the levee
- Deciding whether a transition zone is problematic
- Preventing internal and external erosion at transitions by maintenance
- Repairing erosion at transition zones
- Determining when repairs are beyond maintenance
Figures 4.61 and 4.62 illustrate two types of transitions.

**Figure 4.61**
Transition from flood wall to levee (Rushford, Minnesota, USA)

**Figure 4.62**
Levee tying into high round (Halstad, Minnesota, USA)
4.17 Flood Walls

- Preventing flood wall deterioration
- Repairing common flood wall problems
- Determining when repairs are beyond maintenance
<table>
<thead>
<tr>
<th>Observations</th>
<th>Potential impact on levee</th>
<th>Preventive measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion of cement paste on floodwall surfaces (exposes more durable aggregates beneath, resulting in a roughened or textured surface)</td>
<td>No immediate impact, but can induce scaling, spalling and micro-cracking (spalling is the deterioration of concrete by flaking and crumbling)</td>
<td>Consider applying protective coatings, by spraying or painting, to retard this process (horizontal surfaces may otherwise retain moisture, accelerate the freeze/thaw processes in colder climates and affect vertical expansion joints)</td>
</tr>
</tbody>
</table>
A free electronic version of the handbook can be downloaded at [www.ciria.org/ilh](http://www.ciria.org/ilh).

The Levee Coalition, a group in the US that comprises of organizations with an interest in levees, sponsored a series of webinars on the ILH. The entire webinar schedule, recorded webinars for all the chapters and registration information for upcoming webinars can be found on ASDSO's website at [http://www.damsafety.org/news/?p=e7c72c98-d7e6-456a-86bb-5f339de32bac](http://www.damsafety.org/news/?p=e7c72c98-d7e6-456a-86bb-5f339de32bac).
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