TECHNICAL MEMO

Prepared By: Water Resources Management Division (WRMD)
Date: October 2023
Re: Erosion Control

Background

This memo is part of a series of documents on dam emergency interventions, and its focus is to provide guidance on erosion control. Erosion occurs when soil particles are transported from one place to another by the action of water. Erosion is a significant concern in earthen dams as it can develop into a breach and eventually cause a dam failure. Failure of a dam poses a significant flood risk to the downstream development and can lead to loss of life and costly damage to infrastructure.

Modes of failure

1. *Overtopping*

One type of failure is overtopping. An earthen dam is not designed for overtopping and is therefore susceptible to erosion and slope stability failure. Overtopping occurs when water spills over the dam due to waves generated by winds, landslides, high water levels or a combination of these. The high water level can be due to the malfunctioning of outlets, insufficient spillway capacity and runoff from a storm or heavy rainfall. (Nigatu, Sigtryggsdottir, Lia, & Jabir, 2017)

The uncontrolled flow of water over the earthen dam results in channel erosion over the crest and downstream face of the dam. The erosion process differs for cohesive [clay] and non-cohesive [sand] embankments and depends on slope gradient and flow rate. For non-cohesive soil, there is progressive surface erosion, while for cohesive soil, there is headcut erosion, as illustrated in the pictures for Figure 1. (Wu, et al., 2011) Headcut erosion starts at the downstream slope and moves upward. The dam base is more prone to erosion due to the high momentum of the runoff at the bottom. (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

During the overtopping of a cohesive embankment, flow produces sheet and rill erosion. Sheet erosion occurs when surface flow removes exposed surface soil. As the surface flow becomes more concentrated, it creates rivulets and grooves known as rills. (Erosion Prevention and Sediment Control Planning and Design Manual, 2020) As the rate of flow increases, the rills turn into a master rill and finally to a cascade flow which is a significant headcut on the downstream slope. Breaching occurs and there is a mass failure of the sidewall and the crest is washed out. (Wu, et al., 2011) The pictures in Figure 1 depict the breaching of a cohesive embankment.

Figure 1: Stages of the erosion process that lead to the breaching of the earthen dam. (Wu, et al., 2011)

2. *Undermining of spillway conduit system*

The conduit system is the primary spillway (outlet) of many dams, and it allows normal streams and small floods to flow through the embankment, as shown in the picture below.

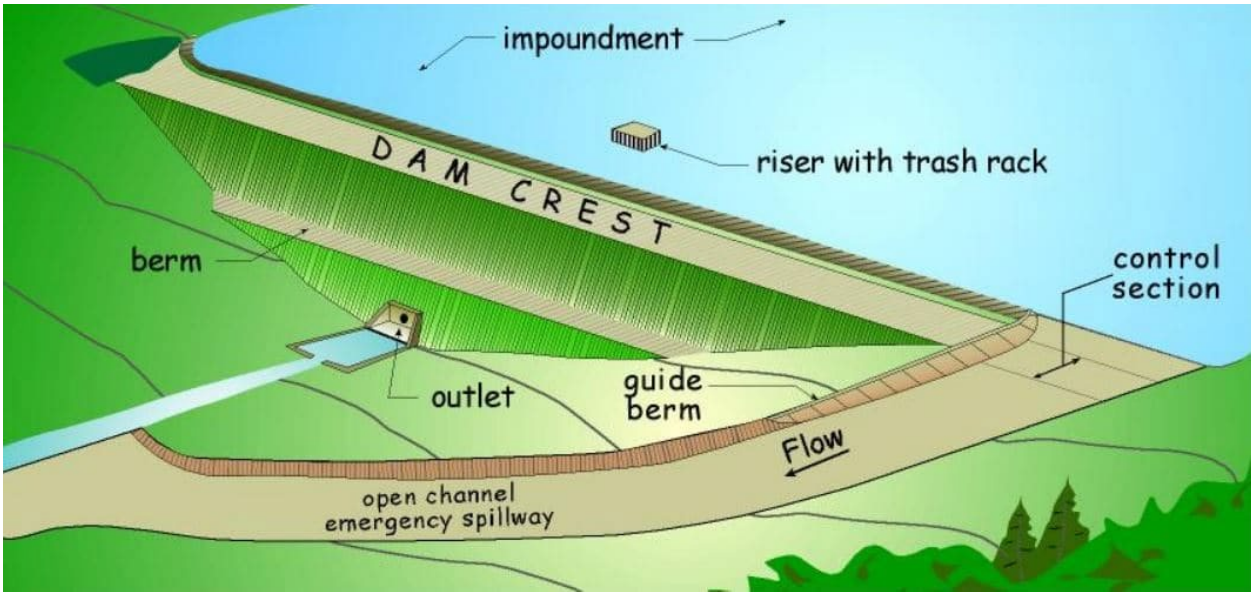

Figure 2: Dam with conduit system as the primary spillway (Open Channel Spillway, n.d.)

Undermining is when foundation material surrounding the conduit system is removed and is a significant concern for earthen dams. It occurs as a result of erosion due to the absence of adequate energy dissipation or erosion protection at the outlet. Undermining can cause misalignment, separated joint and pipe deterioration. The undermining is visible at the outlet and can extend into the embankment. As erosion continues, undermining can result in displacement and collapse of pipes and cause sloughing and sliding, which affects the dam's stability. It can lead to the complete failure of the conduit system and, eventually, the dam. (Spillway Conduit System Problems, n.d.)

3. *Erosion of earthen open channel spillway*

Open channels are used for both emergency and principal spillways. Its purpose as the main spillway is to pass normal flow, where as an emergency spillway is to operate during a large flood. High-velocity flow along the channel can lead to erosion. The eroded area allows more water to flow out of the reservoir, leading to a lower lake and higher stream water levels. (Open Channel Spillway, n.d.)

4. *Erosion at the toe of the downstream slope*

The downstream toe of a dam often has little erosion protection and is therefore susceptible to erosion. Erosion at the toe can occur when water backs up due to a blockage in the channel caused by debris. Beavers also can cause river obstruction by building a dam. As water backs up to the downstream toe, it erodes the exposed soil. If the obstruction is not cleared, the water level increases, and so does the erosion.

Erosional Control Methods

Erosion control methods can help prevent dam failure due to erosion. For erosion from overtopping, the conventional practice is to stabilize exposed soils with vegetation, and it is effective for low rate surface flow. However, seeding does not impart immediate erosion protection. The seeds take time to develop and establish their root system to produce an erosion-resistant layer. If the slope needs instant erosion protection, it is vital to implement other methods.

Some other erosion control methods are sodding, temporary matting, plastic sheeting and riprap lining with geotextile filter fabrics. These methods are also effective in preventing erosion along the earthen open channel spillway.

Water flows through the conduit at high velocity and causes erosion at the outlet. Outlet erosion control structures need to be implemented to dissipate the energy and provide erosion protection. Outlet erosion protection includes:

1. Riprap lined basin (see Figure 3) - The layer of rock produces a rough surface dissipating the energy of the water. Geotextile filter fabric can be placed beneath the stone to prevent underlying soil from being washed away. The riprap lined basin is the simplest, quickest and less expensive outlet protection.

Figure 3: Riprap lined basin

2. Stilling basin (see Figure 4) - A stilling basin reduces the flow velocity by using an energy dissipater such as chute blocks and baffle piers within the structures. The purpose of the endsill is to create a tailwater to reduce the flow velocity. (Outlet Erosion Control Structures, n.d.)

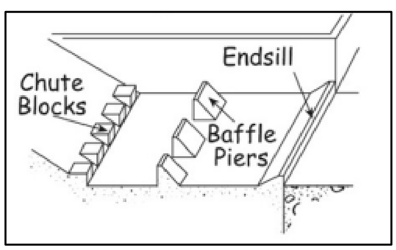

Figure 4: Stilling basin (Outlet Erosion Control Structures, n.d.)

3. Headwall/Endwall (see Figure 5) - The purpose of the headwall is to prevent undermining and is typically made of concrete. A strong foundation ensures a stable headwall. (Outlet Erosion Control Structures, n.d.)

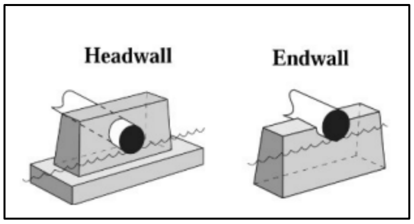

Figure 5: Headwall/Endwall (Outlet Erosion Control Structures, n.d.)

4. Impact basin (see Figure 6) - The vertical hanging baffle is the energy dissipater. Water coming out of the pipe strikes the wall and is directed upstream in vertical eddies. (Outlet Erosion Control Structures, n.d.)

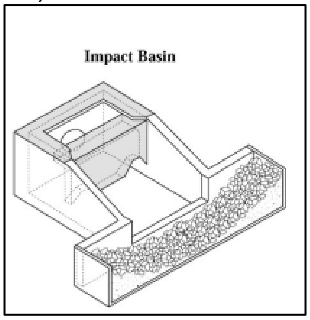

Figure 6: Impact basin (Outlet Erosion Control Structures, n.d.)

5. Plunge pool (see Figure 7) - As the water flows into the plunge pool, energy is dissipated. A riprap lining is also used to prevent erosion of the pool area. (Outlet Erosion Control Structures, n.d.)

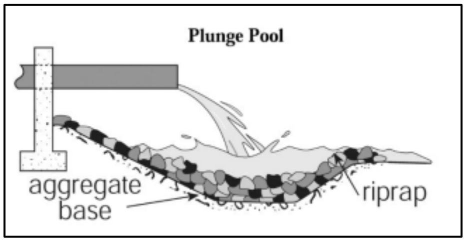

Figure 7: Plunge pool (Outlet Erosion Control Structures, n.d.)

The stilling basin, headwall/endwall and impact basin are long term and permanent solution to outlet erosion.

Runoff control methods can also be implemented along the channel to decrease runoff velocities and prevent sediment transport to nearby waterbodies. The runoff control method can be grass-lined swale with check dams as shown in Figure 8. (Erosion Prevention and Sediment Control Planning and Design Manual, 2020).


Figure 8: Grass-lined swale with check dams (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

Erosion controls must be implemented near the toe when the channel often experiences water back up. As illustrated in Figure 9, a gabion basket lining prevents exposure of soil to water. Therefore, it helps against erosion and provides stability to the slope.


Figure 9: Gabion basket protecting channel against erosion (Channel Lining, 2021)

The following section provides a detailed description of the methods that provide immediate erosion protection.

Vegetation - Sod

A well-maintained vegetation cover (see Figure 10) can prevent erosion and decrease the number of muskrats. The roots hold the soil particle together and create an erosion-resistant layer. (Ground Cover, n.d.) Sodding establishes an immediate cover imparting erosion protection and stabilizing the slope. (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

Figure 10: Sod Installation (Sod Installation Costs, n.d.)

Advantages (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

- Imparts immediate and effective protection.
- Aesthetically pleasing.
- Provides a high-density vegetation compared to a recently seeded area.

Disadvantages (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

- More costly compared to seeding.
- May not be readily available throughout the year.
- Requires sufficient time to establish root system.

Design Criteria (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

- Use weed-free, uniform thickness and dense root mat sod.
- Prepare and grade the surface and apply fertilizer based on the supplier's recommendation (Abstain from using phosphorus fertilizer).
- Work fertilizer and lime into a 1-2 inches soil depth and smooth the surface.
- Staple sod when placed onto a 3:1 or steeper slope.

Matting

Matting is a blanket like material used to provide cover to slopes or channels and is available in rolls (see Figure 11). Some examples of mats include jute, glass fiber, woven paper and vegetative mat. The selection of the blanket depends on the site condition and availability in the local market. (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

Figure 11: Erosion control blanket (Short Term Erosion Control Blanket, 2021)

Advantages (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

- Protect against surface runoff.
- Hold moistures that promote vegetative growth.
- Instant protection.
- Easy to install.
- Reduce runoff velocity and protects the slope.

Disadvantages (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

- Proper installation is vital for the matting to be effective. It requires ground contact to prevent runoff under the blanket.
- The soil surface must be properly graded.
- Labor intensive.

Design criteria (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

- Suitable for 2:1 slope or steeper.
- Matting should be in complete contact with the ground.
- The surface must be smooth with no debris.
- The mat must overlap lengthwise and crosswise for a minimum of 4 inches (100 mm).
- The matting must be fixed in a trench at the crest as shown in the Figure 12.
- At the bottom, the mat must extend two feet (0.6 metres) beyond the toe.
- Figure 12 illustrates the detailed matting installation.

Table 1 summarizes the type of mat for different inclines.

Table 1: The matting type for different slopes (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

Matting Type	Slope
Straw	3:1 or less
Straw-Coconut	2:1 or less
Coconut	1:1 or less
Jute	3:1 or less
Excelsior	2:1 or less

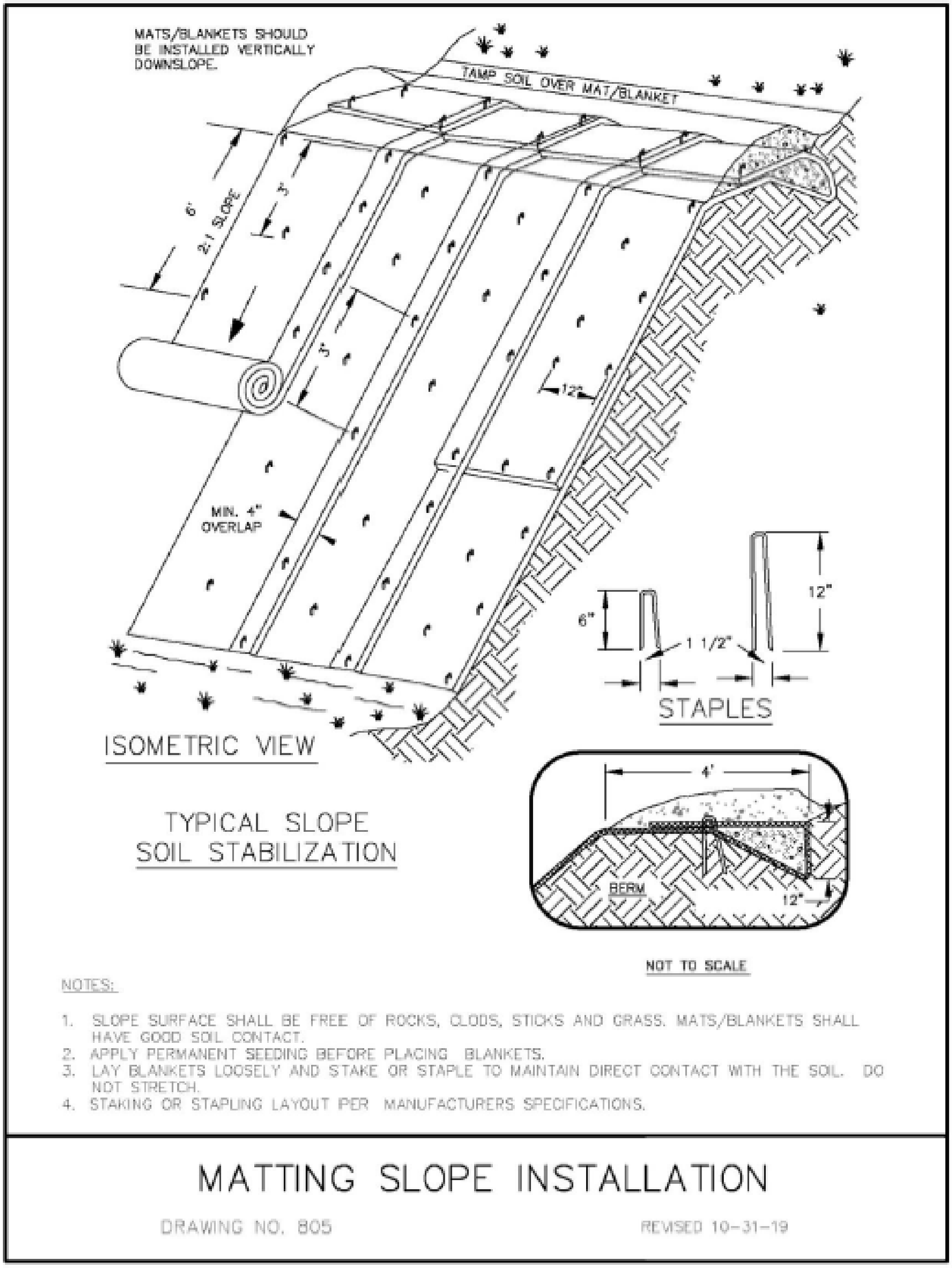

Figure 12: Matting slope installation drawing (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

Plastic Sheeting

Plastic sheeting (see Figure 13) is used to protect the slope from erosion. However, it generates high-velocity runoff and transfers the erosion problems downstream. It is recommended to use other alternatives when possible. (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

Figure 13: Plastic sheeting over a slope (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

Advantages (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

- Provide instant erosion protection.
- Fast and easy to install.

Disadvantages (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

- Produces high-velocity runoff.
- Ultraviolet radiation damages plastic.
- Wind can blow away the plastic if not correctly installed.
- Plastic damages vegetation and prevents plant growth.

Design Criteria (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

- Avoid using plastic for steep and unstable slopes.
- At the crest, the sheet must be fixed in a 6-inch by 6-inch (150 mm by 150 mm) trench.
- A gravel berm or riprap must be installed at the toe to reduce runoff velocity.
- The plastic must be anchored at 10-foot (3.0 metre) grid spacing.
- The plastic sheets must overlap for at least 1 to 2 feet (0.3 to 0.6 metres) and must be taped.

Geotextile Filter Fabric with Riprap

The geotextile filter fabric allows water to flow through it and prevent the erosion of underlying soil. It must be used in conjunction with riprap lining (see Figure 14). (Erosion and Sedimentation Control - Handbook for construction site)

Figure 14: Riprap lining for an embankment (Erosion and Sedimentation Control - Handbook for construction site)

<u>Advantages</u> (Erosion and Sedimentation Control - Handbook for construction site)

- The geotextile filter fabric allows some lateral seepage.
- Provides instant protection.
- Low-cost when rock is readily available.
- The rough surface reduces the run-off velocity.
- It can be installed during the winter months.

<u>Disadvantages</u> (Erosion and Sedimentation Control - Handbook for construction site)

- Expensive if rocks need to be transported.
- Should be used on a slope not steeper than 2:1.

<u>Design Criteria</u> (Erosion and Sedimentation Control - Handbook for construction site)

- Consult a soil engineer or manufacturer representative to select a geotextile design.
- The fabric should overlap at least 1 foot (0.3 metres).
- Fabric must not stretch, but there must not be folds or wrinkles. Care must be taken to lay or roll the material.
- Anchor the fabric using pins or trenching.
- Avoid dropping rocks from a height greater than 1.0 metre.
- The riprap thickness must be greater than 1.5 times the maximum rock size and not less than 300 mm.

<u>Outlet Protection – Riprap lined basin</u>

The outlet protection aims to convert pipe flow into channel flow, reducing scour and preventing erosion and embankment slippage. It reduces flow velocity and therefore lowers the risk of downstream erosion. The simplest outlet protection consists of riprap-lined basin (see Figure 15). (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)

Figure 15: Riprap outlet protection (Storm Water Management BMP Handbook, 2005)

Advantages (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)
- Low cost and easy to install.
- Reduce flow velocity.
- Prevent scouring and streambed erosion.

Disadvantages (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)
- The rock outlet may need regular maintenance.

Design Criteria (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)
- The apron should be made of concrete, gabion or riprap. Filter fabrics may also be required.
- It should slope downstream.
- The sidewall should be 300 mm higher than the tail water.
- The apron should be maintained regularly.

The table below illustrates the size of apron and rock diameter required for different pipe size.

Table 2: Rock diameter and apron dimension for different pipe size (Storm Water Management BMP Handbook, 2005)

Pipe Size (inches)	Average Rock Diameter (inches)	Apron width (feet)	Apron length for high flow (feet)
8	3	2-3	5-7
12	5	3-4	8-12
18	8	4-6	12-18
24	10	6-8	18-22
30	12	8-10	22-28
36	14	10-12	28-32
42	16	12-14	32-38
48	20	14-16	38-44

Toe Protection – Gabion Basket Lining

A gabion basket is a basket made of wire and filled with rock (see Figure 16). It is built along a waterway as erosion control and provides stability to the slope. A geotextile filter is generally required at the bottom. (Erosion and Sedimentation Control - Handbook for construction site)

Figure 16: Gabion Basket (Common Uses for Gabion Stone, 2019)

Advantages: (Erosion and Sedimentation Control - Handbook for construction site)
1. Require little maintenance.
2. Long lifespan (30-50 years).
3. It can be built for various lengths, heights and shapes.
4. Aesthetically pleasing when established with vegetation.

Disadvantages: (Erosion and Sedimentation Control - Handbook for construction site)
1. The wire rusts if left ungalvanized.
2. The gabion must be anchored deep enough to prevent scouring.

Design Criteria: (Erosion Prevention and Sediment Control Planning and Design Manual, 2020)
1. An experienced soil engineer must design the gabion basket lining.
2. The site must be cleared of debris and graded as required.
3. The gabion must be filled uniformly with rocks larger than the mesh. Hand filling is preferred.
4. When the height of the basket is greater than 0.3 m, fill the rocks to the 0.3 m mark and tie the connecting wires to the opposite side of the basket to prevent deformation.
5. Once the gabion basket is built, backfill any open spaces with the slope. Exposed soil must be protected with a vegetative lining to prevent erosion.

Recommendation

The methods outlined are not accurately described for each site as the soil, topographic and climatic conditions vary from site to site. They are just general guidelines that can be put into practice with the consultation of professional engineers to ensure the best outcome.

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