# PHILIPPINE NATIONAL STANDARD

# Design of a Rockfill Dam

DEPARTMENT OF
AGRICULTURE
PHILIPPINES

**Foreword**

The formulation of this national standard was initiated by the Agricultural Machinery Testing and Evaluation Center (AMTEC) under the project entitled "Enhancement of Nutrient and Water Use Efficiency Through Standardization of Engineering Support Systems for Precision Farming" funded by the Philippine Council for Agriculture, Aquaculture and Forestry and Natural Resources Research and Development - Department of Science and Technology (PCAARRD - DOST).

As provided by the Republic Act 10601 also known as the Agricultural and Fisheries Mechanization Law (AFMech Law of 2013), the Bureau of Agriculture and Fisheries Standards (BAFS) is mandated to develop standard specifications and test procedures for agricultural and fisheries machinery and equipment. Consistent with its standards development process, BAFS has endorsed this standard for the approval of the DA Secretary through the Bureau of Agricultural and Fisheries Engineering (BAFE) and to the Bureau of Philippine Standards (BPS) for appropriate numbering and inclusion to the Philippine National Standard (PNS) repository.

This standard has been technically prepared in accordance with BPS Directives Part 3:2003 – Rules for the Structure and Drafting of International Standards.

The word "shall" is used to indicate mandatory requirements to conform to the standard.

The word "should" is used to indicate that among several possibilities one is recommended as particularly suitable without mentioning or excluding others.

**Design of a Rockfill Dam**

## 1    Scope

This standard specifies the minimum design requirements and procedures for the design of a rockfill dam.

## 2    References

The following normative documents contain provisions through which reference in this text constitute provisions in this National Standard:

**PNS/BAFS/PAES 217: 2017**    Determination of Irrigation Water Requirements

**PNS/BAFS/PAES 225: 2017**    Rainwater and Runoff Management - Small Water Impounding System

**United States Bureau of Reclamation Design Standards No.13** – Embankment Dams, Chapter 4: Static Stability Analysis

**United States Bureau of Reclamation Design Standards No.14 –** Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standard, Chapter 3: General Spillway Design Considerations

## 3    Definition

For the purpose of this standard, the following definitions shall apply:

**3.1**
**piping**
internal erosion induced by regressive erosion of particles from downstream and along the upstream line towards an outside environment

**3.2**
**rockfill dam**
dam that relies on rock, either dumped in lifts or compacted in layers, as a major structural element where an impervious membrane is used as the water barrier and can be placed either within the embankment or on the upstream slope

**4        Components of a Rockfill Dam**
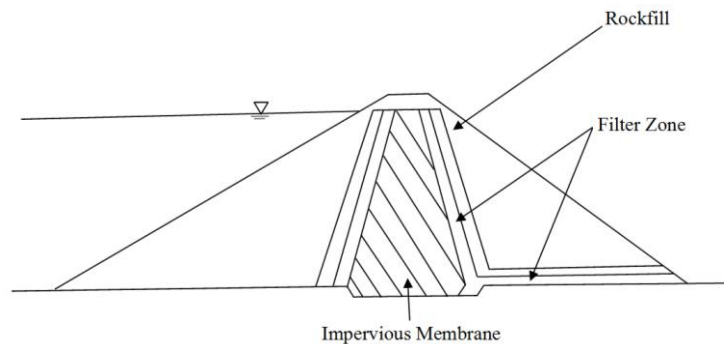


**Figure 1. Rockfill Dam**
SOURCE: Public Works Research Institute

**5        Classification of Rockfill Dams**

**5.1      Based on construction methods**

**5.1.1**  Dumped rockfill dam

**5.1.2**  Compacted rockfill dam

**5.1.3**  Directional blasting rockfill dam

**5.2      Based on the materials of the anti-seepage membrane**

**5.2.1**  Earth-rockfill dam

**5.2.2**  Asphaltic concrete rockfill dam
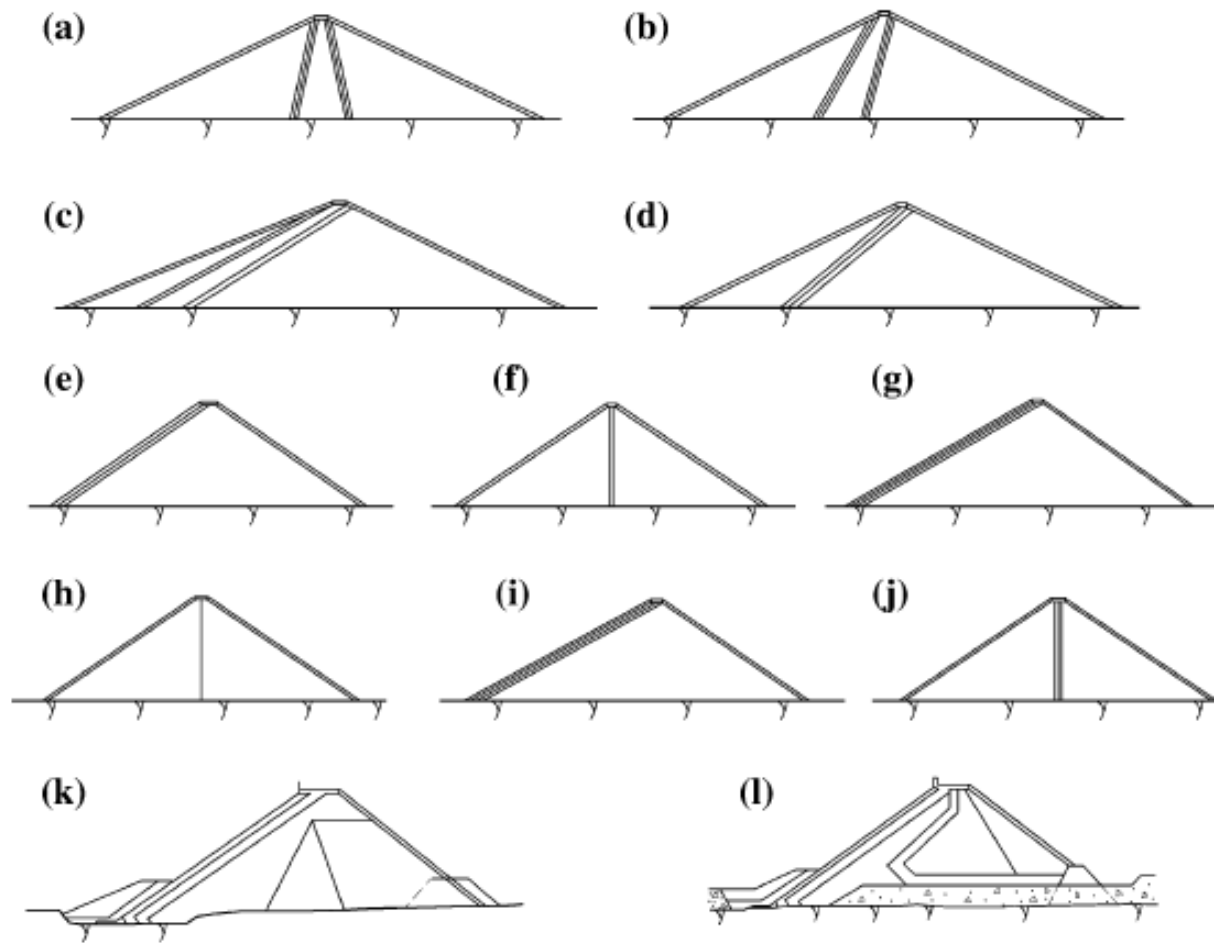
**5.2.3**  Reinforced concrete rockfill dam

**5.2.4**  Wood rockfill dam

**5.3      Based on the location of the anti-seepage membrane**

**5.3.1**  Central core

**5.3.2**  Sloping core

**5.3.3**  Upstream membrane or decked

**Figure 2 –Types of Rockfill Dams**
**(a) central clay core (b) inclined central clay core (c) sloping clay core (d) soil faced (e) sloping concrete core (f) central concrete core (g) sloping asphalt concrete core (h) central asphalt concrete core (i) sloping geomembrane core (j) central geomembrane core (k) concrete-faced (l)**
SOURCE: Chen, Hydraulic Structures, 2015


## 6      Design Criteria

**6.1.**    There shall be no overtopping.

**6.2**     The dam crest shall be high enough allowing for rockfill embankment and foundation settlements and sufficient freeboard.

**6.3**     The velocity of flow of dam face shall be within 5 m/s to 7 m/s with reliable protection measures against scouring.

**6.4**     Seepage shall be kept at minimum to avoid piping of material.

**6.5**     The foundation, abutments, and embankment shall be stable under all situations during construction and operation.

**6.6**     There shall be a rational utilization of rock and soil materials.

**6.7**     There shall be systematic researches on the raw materials and mixing ratios of face slab to improve anti-cracking resistance and anti-seepage resistance and durability.

**6.8**     The downstream slope shall attain good resistance to the scouring of rainfall.

**6.9**     The bedrock foundations should be hard and erosion resistant however, if the foundation consists of river gravels or rock fragments, a positive cutoff to bedrock shall be used.

**6.10**    The foundation shall be selected such that minimum settlement to the rockfill embankment will occur

**6.11**    Filters shall be added where the materials in cracks, faults or deep pits may erode into the rockfill embankment. Otherwise, these materials shall be removed and backfilled with concrete.

**6.12**    The foundation shall be treated using cement grouting beneath the cutoff to prevent underseepage.

**6.13**    All potential pervious zones shall be blanketed with impervious material.

**6.14**    The dam shall be aligned such that minimum membrane exposure is attained.

**6.15**    Cutoff wall should be excavated into the bedrock to ensure the water tightness between the foundation and the membrane.

**6.16**    For a sound rock foundation, a minimum depth and width of 1m cutoff shall be required

**6.17**    The rock material for the embankment shall be hard, durable, able to withstand disintegration from weathering and able to resist excessive breakdown from quarrying, loading, hauling and placing operations.

**6.18**    The upstream and downstream slopes of a dam should be based on the type of impervious membrane and its location


## 7     Dam Foundation

The following depths shall be determined to establish sound dam foundation:

- Stripping
- Core Trench
- Grouting

## 8 Dam Crest Elevation

**8.1** A reservoir operation study shall be conducted to determine the dead storage, live storage and gross storage of the reservoir and their corresponding water level. Details of a simple reservoir operation study is shown in Annex A of PAES 609:2016 – Rainwater and Runoff Management – Small Water Impounding System

**8.2** Flood discharge analysis shall be carried out to determine the peak maximum flood in the reservoir.

**8.3** The determined peak maximum flood shall be subjected to flood routing to determine the surcharge water level. Details of flood routing methods are shown in Annex A of PNS/BAFS/PAES 225:2017 – Rainwater and Runoff Management - Small Water Impounding System

**8.4** The freeboard and safety against overtopping shall be determined at normal water level and at the flood surcharge level.

**8.5** The higher value from both conditions shall be selected as the dam crest elevation.

## 9 Dam Crest Width

**9.1** The dam crest width can be determined using four formulas shown in Table 1.

**Table 1. Determination of Dam Crest Width**

| Method/ Name | Formula |
|---|---|
| USBR | $3.6\,H^{1/3} - 1.5$ |
| Merriman | $0.2\,H + 1.5$ |
| Trantwine | $1.1\,H^{1/2} + 0.6$ |
| JANCOLD | $3.6\,H^{1/3} - 3.0$ |

**9.2** The recommended minimum width of the dam is 4 m.

## 10 Slope

The slope of the dam shall depend mainly on the type of impervious membrane and its location. Table 2 shows the recommended slopes based on the type of materials.

**Table 2. Recommended upstream and downstream slope of various types of rockfill dams**

| Type of Rockfill Dam | Upstream Slope | Downstream Slope |
|---|---|---|
| Central earth-core | 1:1.8 to 1:2 | 1:1.8 to 1:2 |
| Sloping earth-core | 1:2.5 to 1:2.75 | 1:1.6 to 1:2 |
| Concrete-faced compacted by hard rocks | 1:1.3 to 1:1.4 | 1:1.3 to 1:1.4 |
| Concrete-faced compacted by soft rocks and gravel | 1:1.5 to 1:1.7 | 1:1.5 to 1:1.7 |
| Asphaltic concrete-faced | 1:1.6 to 1:1.7 | 1:1.3 to 1:1.4 |

## 11    Zoning

The interior section of a rockfill dam is typically divided into zones depending on the range of variation in the character and gradation of the available material.

**11.1    Impervious Zone** – composed of impervious blanket usually made of cohesive soil or non-cohesive silt and is covered for protection. Materials shall have the required coefficient of permeability with a smaller compressibility after compaction, shall be easy to be compacted, and shall not contain organic substances.  Design details are discussed in United States Bureau of Reclamation Design Standards No.13 – Embankment Dams, Chapter 2: Embankment Design

**11.2    Filter Zone** – composed of semi-pervious materials shown in Table 3.

**Table 3. Filter Criteria (Downstream Semi-Pervious Zone)**

| Protected Material | | Semi-Pervious (Filter) Material (mm) | | | |
|---|---|---|---|---|---|
| Category | Percent Finer than 0.075 mm | $D_5$ Size | $D_{15}$ Size | $D_{60}$ Size | $D_{100}$ Size ($D_{max}$) |
| Fine silts and clays | More than 85% finer | ≥ 0.075 | ≤ 9 $d_{85}$ | ≤ 4.75 or ≤ 20 $D_{10}$ | ≤ 50 |
| Sands, silts, clays, and silty and clayey sands | 40% to 85% finer | ≥ 0.075 | ≤ 0.7 | ≤ 4.75 or ≤ 20 $D_{10}$ | ≤ 50 |
| Silty and clayey sands and gravels | 15% to 40% finer | ≥ 0.075 | $\leq \frac{40-A}{40-15} \times (4d_{85} - 0.7) + 0.7$ | ≤ 4.75 or ≤ 20 $D_{10}$ | ≤ 50 to 150 |
| Sands and gravels | Less than 15% finer | ≥ 0.075 | ≤ 4 $d_{85}$ | ≤ 20 $D_{10}$ | ≤ 50 to 150 |

**11.3    Rockfill Zone or Pervious Zone** – consists of a well-graded mixture of hard and durable particles, and slightly weathered to fresh rock to secure the stability of dam body.

## 12    Available Materials

**12.1**   Site investigations shall be carried out to establish foundation conditions at the dam site and to determine the physical properties of the proposed construction materials from test pits, trench lines and drill holes. Geological investigations, soil physical and mechanical tests shall be conducted.

**12.2**   The volume of available materials from each soil group upstream and downstream of the dam shall be determined.

**12.3**   The soil samples shall be tested for the specific gravity, moisture, grain size, liquid and plastic limits, compaction, permeability, unconfined-undrained triaxial test, confined-undrained triaxial test and consolidation test.

## 13    Stability Analysis

The slip circle method is generally recommended for the stability analysis of embankment dams.

$$Safety\ factor = \frac{c'L + tan\emptyset'(N - U)}{T}$$

where:

| | |
|---|---|
| c' | is the effective cohesion of material on sliding surface of each slice |
| N | is the summation of normal forces along the arc |
| U | is the summation of uplift forces caused by pore water pressure along the arc |
| T | is the algebraic summation of tangential forces along the arc |
| L | is the length of arc of slip circle |
| $\phi'$ | is the effective angle of internal friction |

Details using this method and other recommended methods are discussed and described in United States Bureau of Reclamation Design Standards No.13 – Embankment Dams, Chapter 4: Static Stability Analysis.

## 14    Design of Horizontal Drain

**14.1**   The drain shall be designed such that it can convey seepage water caught by the filter. The volume of leakage shall be computed as follows:

$$Q = K \times Y_o \times L$$

where:

| | |
|---|---|
| Q | is the volume of leakage (m³/day) |
| K | is the coefficient of permeability (m/day) |

$Y_o$     is $\sqrt{d^2 + H^2} - d$; $d = 0.3L_1 + L_2$

L     is the longitudinal length (m)

**14.2**    The acceptable leakage volume is 0.05% of the storage capacity.

**14.3**    The horizontal drain shall have enough perviousness such that it must be covered by sandy filter with the gradation which satisfies the following criteria:

- $F_{15} / B_{15} > 5$
- $F_{15} / B_{85} < 5$
- Gradation curves of filter and base material is desired to be parallel
- Filter material shall not be cohesive and shall not contain silt and clay particles more than 5%

## 15    Design of Outlet, Spillway and Related Appurtenances

Details are discussed and described in United States Bureau of Reclamation Design Standards No.14 – Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standard, Chapter 3: General Spillway Design Considerations

## 16    Bibliography

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**Technical Working Group (TWG) for the Development of Philippine National Standard for Design of a Rockfill Dam**

*Chair*

**Engr. Bonifacio S. Labiano**
National Irrigation Administration

*Members*

**Engr. Felimar M. Torizo**
Board of Agricultural Engineering
Professional Regulation Commission

**Dr. Teresita S. Sandoval**
Bureau of Soils and Water Management
Department of Agriculture

**Dr. Armando N. Espino Jr.**
Central Luzon State University

**Dr. Elmer D. Castillo**
Philippine Society of Agricultural Engineers

**Dr. Roger A. Luyun Jr.**
University of the Philippines Los Baños

**Engr. Francia M. Macalintal**
Philippine Council for Agriculture and Fisheries
Department of Agriculture

*Project Managers*

**Engr. Darwin C. Aranguren**

**Engr. Romulo E. Eusebio**

**Engr. Mary Louise P. Pascual**

**Engr. Fidelina T. Flores**

**Engr. Marie Jehosa B. Reyes**

**Ms. Micah L. Araño**

**Ms. Caroline D. Lat**

**Mr. Gerald S. Trinidad**

University of the Philippines Los Baños –
Agricultural Machinery Testing and Evaluation Center