Abdelhafid University Center Bousouf - Mila
2024-2025 Semester 1

Hydraulic works

– Lesson 4 –

Chapter 04 : *Sizing of dam components and definition of the template*

Teaching staff			
Name	**Grade**	**Institute**	**E-mail address**
Boumessenegh Amel	MCB	Science and Technology	a.boumesseneegh@centre-univ-mila.dz

Students concerned			
Institute	**Department**	**Year**	**Speciality**
Science and Technology	GC and hydraulics	Year 3 license	Urban hydraulics

Course Objective 4

This chapter aims to provide students with the theoretical and practical knowledge necessary to:

- Understand the fundamental principles of sizing the different constituent elements of a dam (body, foundations, spillways, water intake, etc.);
- Apply calculation methods to determine the optimal dimensions of the dam components based on hydrological, geotechnical and structural constraints;
- Define the template of the dam, i.e. its general shape and typical profiles, according to the type of dam (gravity, arch, embankment) and the site conditions;
- Integrate safety, stability and operational considerations into the design process;
- Master the use of technical diagrams and standard profiles to illustrate the sizing of the different parts of the structure.

Introduction

Earth dams are structures, more than half of whose volume is formed by fine materials preventing footprint areas, built from natural materials.

The term "earth" therefore covers a whole range of materials from very fine pure clay to very coarse elements.

In some cases, even easily compactable weathered rocks are used, such as laterites, schists and soft sandstones , etc.

The volumes required for the construction of an earth dam are generally significant: 5 to 15 times more than for a concrete dam of the gravity type likely to be built on the same site.
Nb: Laterite (from the Latin later , brick) is a **red or brown** rock , which is formed by the alteration of rocks in tropical climates .

4.1-Dam sealing organs and sizing:

A waterproofing device is provided in an earth dam when the materials constituting the embankment are not sufficiently impermeable to prevent large losses of water by infiltration. There are several types of waterproofing devices, those made of local materials and others of artificial materials

a) Compacted clay core

The core is constructed of compacted clay, centered vertically in the middle of the dam or inclined upstream.

Its thickness is fixed according to the height of the dam (Figure 4-1)

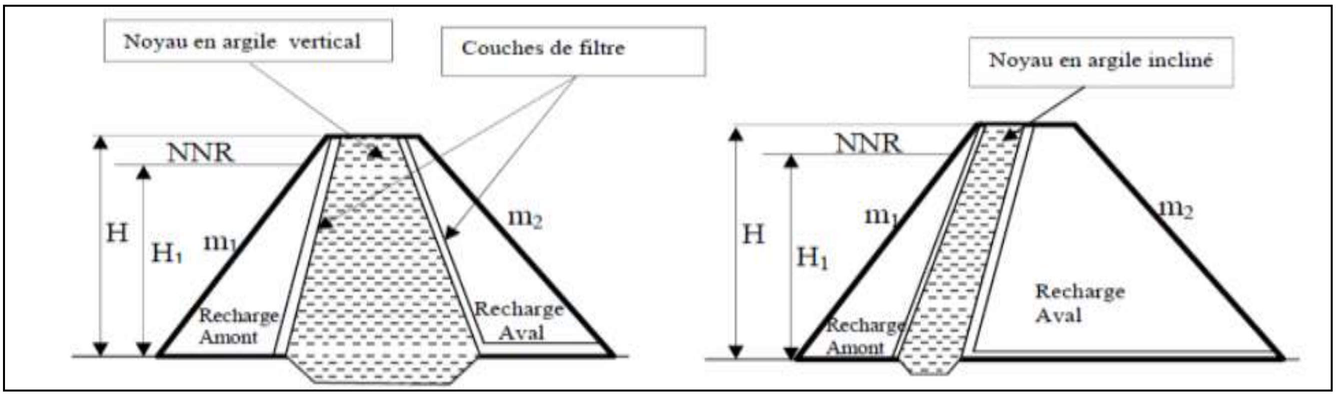


Figure 4-1: Vertical and inclined clay core

The core must have a minimum thickness. $Ep_{min} = 1/6 * H_b \geq 2.0$ m.

$B_n = 6 + c.\ H_b$ (c: coefficient depending on the quality of the material).

We must also check the inequality. $0.8.\ H_b \leq B_n \leq 1.2.\ H_b$

b) Internal diaphragm

If materials are not available clay to create a core ensuring waterproofing, we can use the solution diaphragm which is generally executed in the form of a diaphragm wall reinforced concrete or clay concrete. (Figure 4-2)

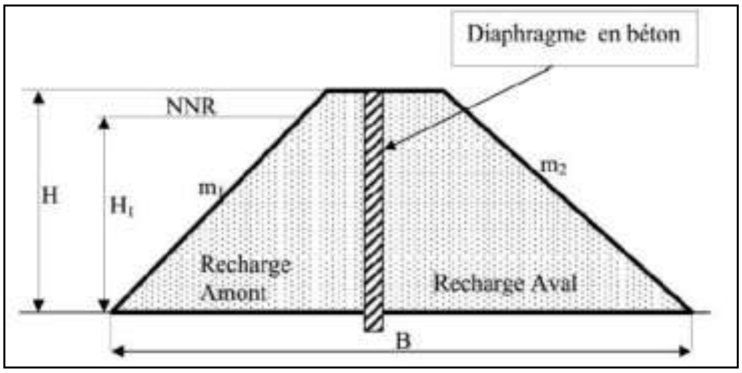
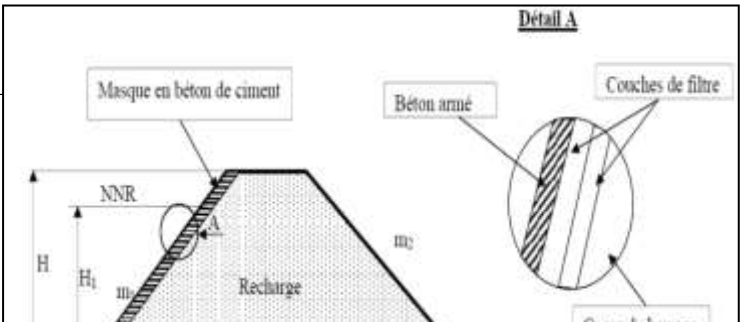


Figure 4-2: Internal diaphragm dam

c) Upstream mask

The upstream mask, which constitutes the waterproofing element, is traditionally made of cement concrete, bituminous concrete or geomembrane. It has a reduced thickness, which allows it to accommodate deformations of the support mass.

- **Cement concrete mask**



This is the oldest type of mask and which is practically abandoned because of its rigidity which accommodates very damage from deformations of the supporting mass. In general, it is made up of prefabricated slabs or cast on site with expansion joints that mitigate the effect deformations of the concrete. (Figure 4.3.).

Figure 4.3- Upstream mask in cement concrete

Reinforced concrete mask

- **Bituminous concrete mask**

The bituminous concrete mask is made using bitumen and is very effective in that it is more watertight than those made of cement concrete. Its flexibility allows it to easily follow the movements of the embankment without suffer significant damage. This type of mask also has the advantage of being economical and easily repairable. (Figure 4.4.).

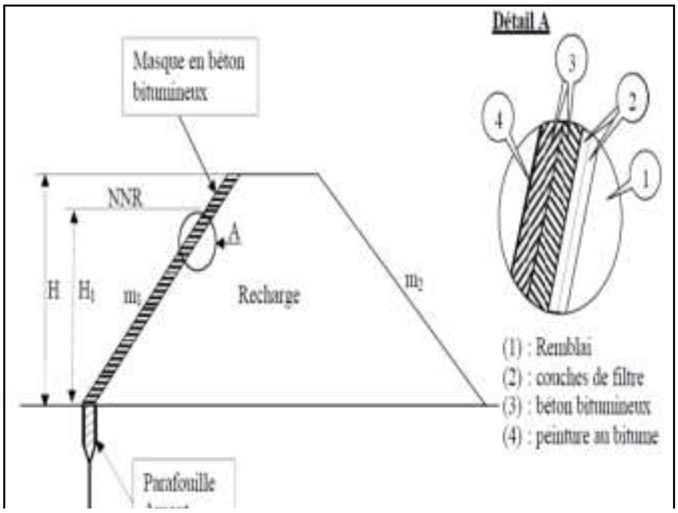
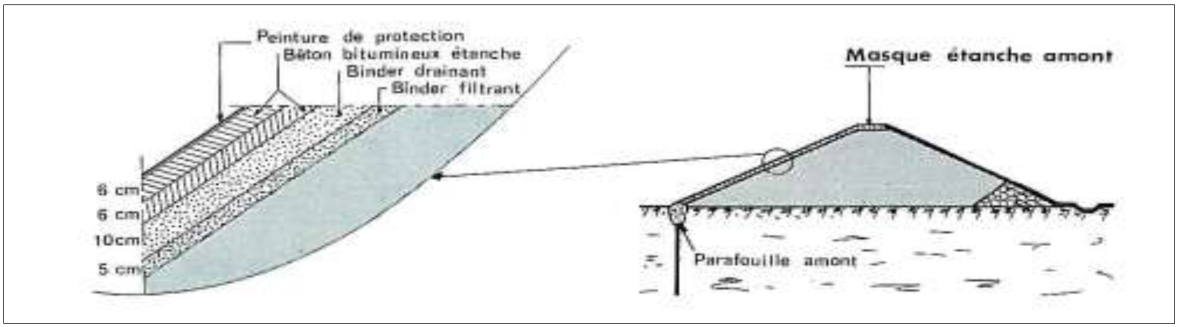


Figure 4.4. Masque amont en béton bitun

But it has the disadvantage of not

not withstand climatic hazards well, which accelerate its aging.



Upstream mask in bituminous concrete

- **Soft membrane mask**

The soft membrane mask is a relatively recent waterproofing process . It has the advantage of being very simple to to achieve and be physically and chemically resistant, although with the disadvantage to be sensitive to shocks and punching. For the production of this type of mask products, the most used are: butyl rubber, plastics, products etc. (Figure 4.5.).

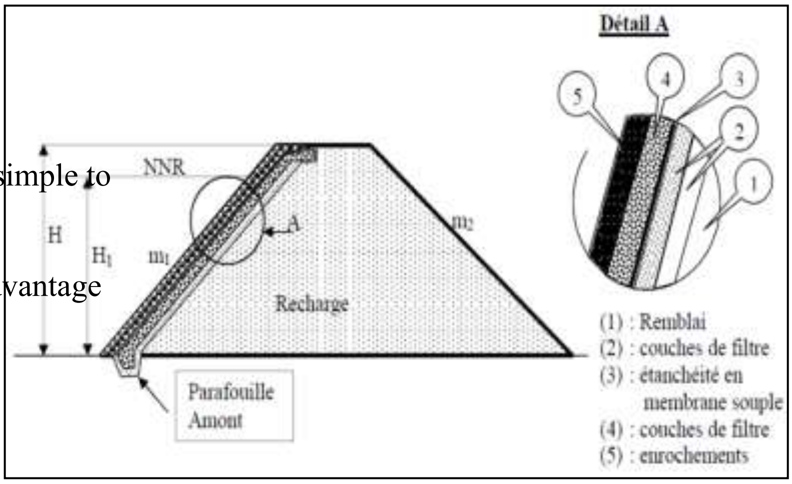


Figure 4.5- Masque en membrane souple

- **Steel mask:**

Steel is a technically nearly perfect material for an upstream mask. The disadvantage is usually a question of cost.

- **Earth mask:**

Using compacted clay soil, we can achieve a suitable waterproofing, with thicknesses that are characteristics of the permeability of the material available.

4.2- Waterproofing of earth dam foundations

To prevent infiltration along the contact line between the **dam** and its **foundation** . In the case where the **foundations** are permeable, their treatment is essential to make them watertight. This treatment depends on the nature of the materials constituting them and their depths.

4.2.1 Sealing key

It is a trench filled with materials ensuring the waterproofing of the massif, which must intersect the permeable layer and be anchored in the impermeable substratum Figure 4.6 .

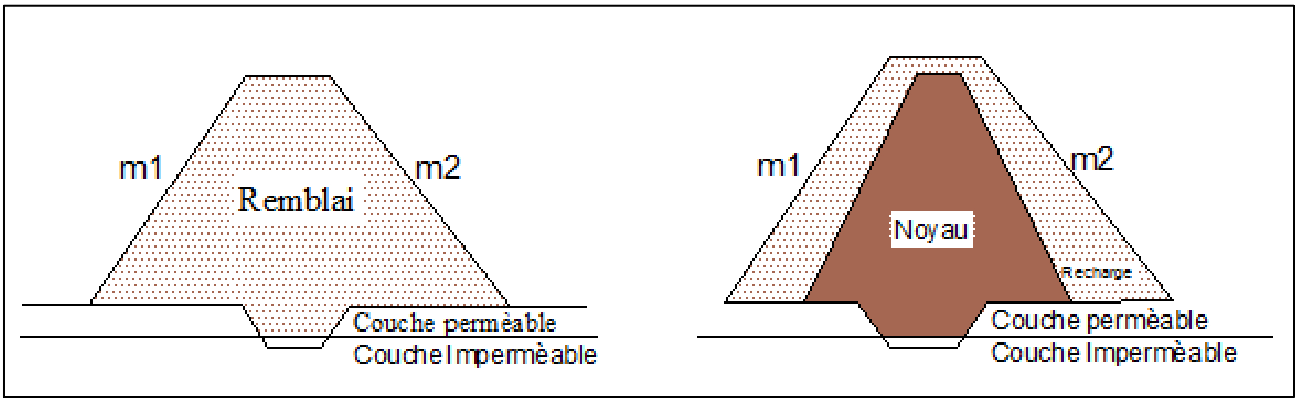


Figure 4.6. Sealing key.

4.2.2 Diaphragm wall

A diaphragm wall is called a vertical screen. built from the surface of the foundations by excavation. A **A diaphragm wall** is a reinforced concrete wall cast into the ground. The principle is to dig a trench , kept constantly full of mud during excavation, and then pour concrete into it. fig . 4.7.

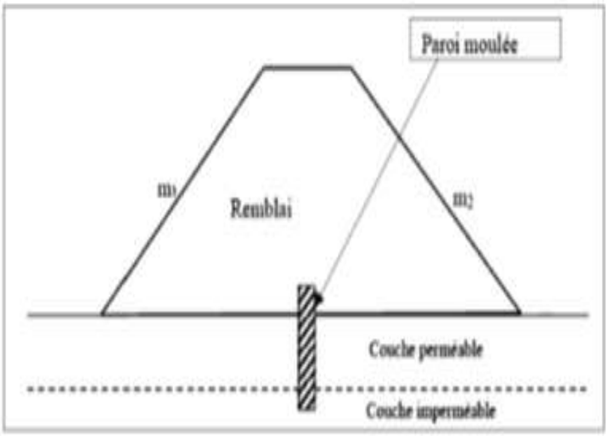


Figure 4.7. Diaphragm wall.

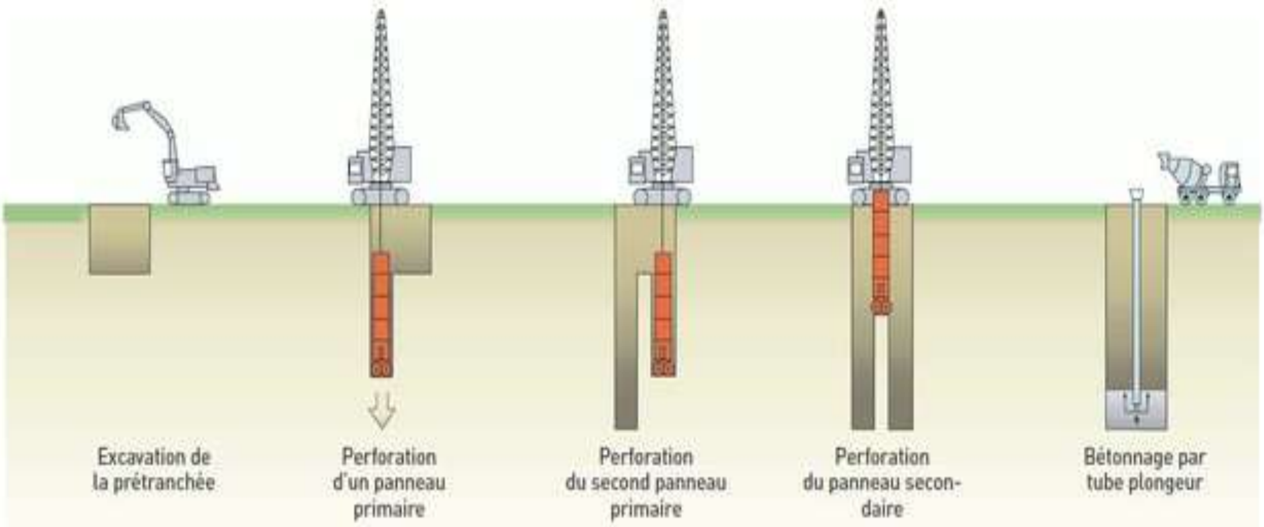


Schéma de réalisation d'une paroi moulée en béton.

NB: Injection is a process for sealing voids using liquid products which solidify over time.

4.2.3 Treatment of foundations by injection

The injection consists of penetrating into a more or less permeable medium a material pumpable called injection grout.

The injection is usually carried out by drilling carried out in the environment to be treated and often to improve its resistance mechanical and reduce its permeability. Fig.4.8

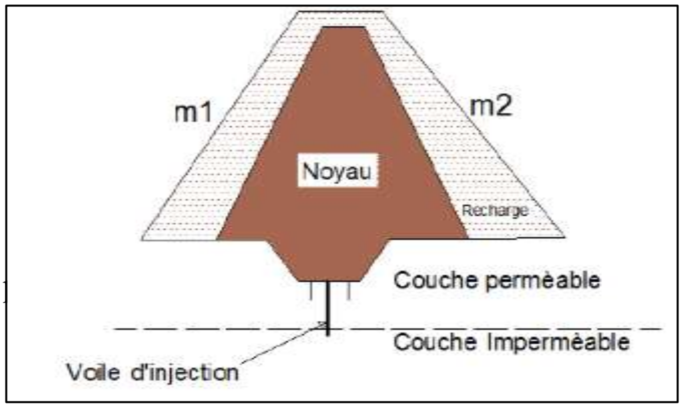
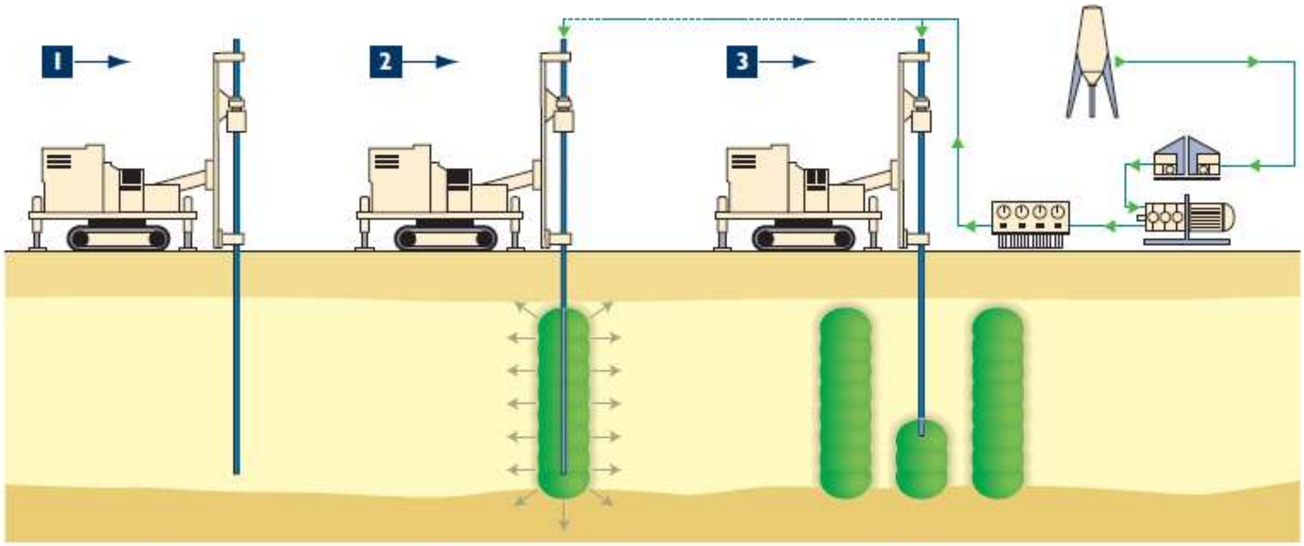


Figure 4.8. Injection veil.



1 Mise en place du tube d'injection

En fonction de la nature du sol ou du type de projet, le tube est mis en place soit par forage, soit par battage.

2 Compactage Horizontal Statique

Le mortier, préparé dans une centrale adéquate, est injecté sous pression dans le sol grâce à une pompe spéciale. En procédant par paliers successifs montants ou descendants, on réalise une inclusion constituée d'une succession d'injections de mortier constituant une colonne.

3 Compactage par colonnes alternées

Afin d'assurer une répartition homogène du compactage, on commence par un maillage primaire assez large. Ensuite, des colonnes secondaires en intermaille permettent d'arriver au compactage optimal.

4.2.4 Upstream sealing mat

A horizontal upstream waterproof mat can replace the vertical screen . Its role is to reduce the leaks and the risks of foxes , extending upstream THE infiltration lines . In order to achieve good waterproofing ; clay materials are added synthetic polymers and bentonite .

Figure 4.9.

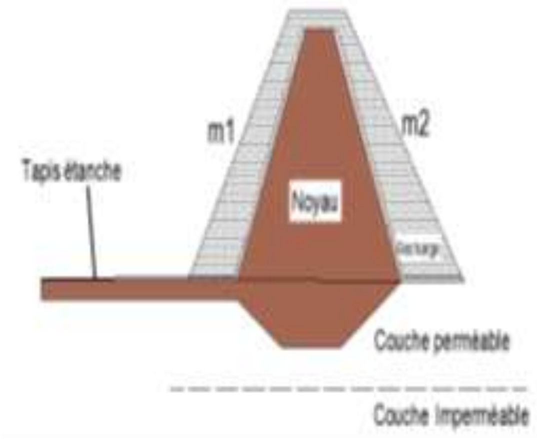


Figure 4.9. Waterproof upstream mat

Bentonite.

4.3- Drainage organs in earth dams and sizing:

- ***Water protection devices***

The presence of a hydraulic load upstream of the embankment causes water infiltration into the dam and its foundations. Despite the attention paid to the planned waterproofing system, this infiltration can be detrimental to the stability of the structure. To remedy this, a drainage system is provided, often associated with filters.

Today, there are two complementary ways to counteract its action:

- Either by reducing the amount of water that passes through the structure and foundation, i.e. by reinforcing the waterproofing.
- Either by drainage, channeling the water to the parts of these structures where its effects will be the least harmful.

4.3.1 The filters

Soil area placed downstream of the core to prevent internal erosion, i.e., to prevent the migration of soil particles. This is the most important area from a safety point of view.

Filters are made of sand and gravel whose grains are insoluble and do not change in the presence of water. In recent years, granular filters have increasingly been replaced by geotextiles, which are very economical and easy-to-use industrial products.

4.3.1.1. The role of filters is very important

The role of filters is very important in the operation of an earth dam, particularly in terms of the safety of the structure, so they can play many complementary functions to each other, sometimes the filters can play the role of drains especially in small dams.

Their roles include:

- Stored between two layers with different grain sizes, they prevent the fine grains of the first layer from being carried by infiltration water through the large diameter materials.

- Stored on either side of a waterproofing core or under a waterproofing screen, they act as drainage layers by evacuating infiltration water downstream of the dam.

- Inserted between a dam mass and its foundation, if it is clayey, it contributes greatly to activating its consolidation thanks to its draining role which reduces internal pressures.

The filters are made of sand and gravel.

4.3.1.2 Composition of filters

Filters are made of sand and gravel whose grains are insoluble and do not change in the presence of water. In recent years, granular filters have increasingly been replaced by geotextiles, which are very economical and easy-to-use industrial products.

To be effective, filters must not clog or deteriorate due to the entrainment of their own grains. They must perform the role for which they are intended, namely to prevent fine particles from the base material from being entrained through the voids in the permeable layers.

4.3.1.3 Filter sizing:

The basic parameters of these rules are the granulometric characteristics of the materials.

Di represents the diameter of the particle in the filter (the coarser material) for which there is a percentage di% by weight of smaller particles (L. Delliou , 2003). Similarly, di is the corresponding parameter for the base material (the finer material to be protected). (Terzaghi) proposes two criteria for sizing filters:

- $D15 > 4\ d15$ permeability condition.
- $D15 < 4\ d85$ blocking condition.

A formulation almost equivalent to that of Terzaghi was proposed by Sherard in 1963, replacing the numerical coefficient 4 by 5. (Lautrin , 2002)

- Permeability condition $D15/d15 > 5$.
- Condition of non-training of fines $d85 > D15/5$.

These two conditions are met in the following formulation:

5d85>D15>5d15

Most often for small dams, a sufficiently permeable drainage material can be chosen which directly satisfies this double condition: the installation of a filter is then unnecessary.

Furthermore, to ensure the internal stability of the filtering or draining material, the uniformity condition must be checked: $2<D_{60}/D_{10}< 8$.

Sometimes, we are forced to interpose, between the embankment and the drain, of very different permeability and granulometry, a filter layer, taking care to check the filter rules at each interface. D_x Dimensions of the filter grains taken from the granulometric curve with x% as ordinates

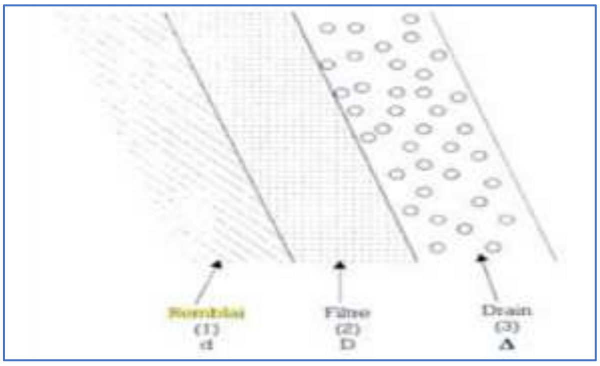


Figure 4.10: Filter meeting TERZAGHI conditions

$5\, d_{85} < D_{15} < 5\, d_{15}$ 5

$D_{85} < \Delta_{15} < 5\, D_{15}$

d : for the embankment

D: for the filter

Δ : for the drain

4.3.1.4 Filter thickness:

The thickness of the filter must not be less than 25 cm to take into account the settlements that occur throughout the embankment. This thickness must always be greater than or equal to 50 D15.

If the filter layer is used to drain seepage water, its drainage capacity must be greater than the flow rate through the embankment and can be verified using Darcy's law.

4.3.2 The drains

The drain is a highly permeable organ incorporated into the earth dam. It is generally made of gravel and rockfill with characteristics of non-alteration in contact with water and resistant to large compressions.

4.3.2.1 Role of drains

Drains in earth dams have a multitude of very important functions.

- ✓ Intercept the infiltration water and evacuate it downstream of the dam.
- ✓ Lower the saturation line and avoid resurgences on the downstream slope
- ✓ Lower the saturation line, to keep a large part of the embankment unsaturated in order to preserve the geotechnical characteristics of the material used.
- ✓ The presence of the drain in an earth dam serves to minimize the leakage flow on the structure.
- ✓ It also serves to decompress the foundation and therefore to minimize interstitial pressures.

4.3.2.2. Different types of drainage and their sizing

There are several types of drainage systems which differ from each other in their construction forms, their location in the dam and the role for which they were designed.

a) Drainage prism:

It is planned when there is a presence of water downstream of the dam with a variation in the level fig.4.11.

Some definitions:

The core : vertical or inclined part ensuring the watertightness of the dam located in the center of the embankment.

Recharges (upstream or downstream): parts constructed with frictional soils , preferably permeable, which provide resistance and support the core.

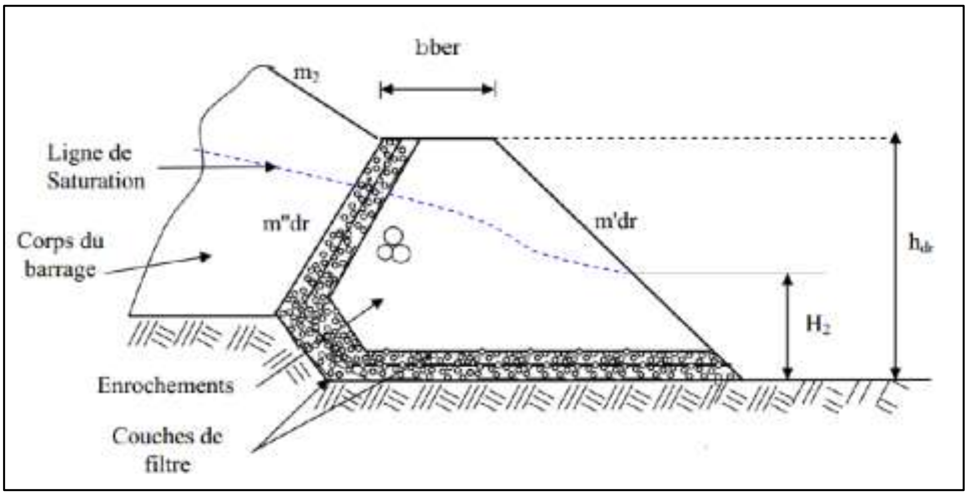
Drains : often thin areas of high permeability, capable of collecting leaks, thus reducing interstitial pressures.

Filters : often thin areas whose grain size, intermediate between that of the neighboring parts, opposes the migration of particles under the action of flows. They fight against internal erosion. (Fox phenomenon)

Rip-rap : a surface layer of rock placed on a thinner embankment, protecting it from waves, currents, etc.

chimney drain : It is so named because it is arranged almost vertically downstream of the core (or located towards the center of a homogeneous embankment). Its thickness is around 3 m for construction reasons.

The downstream drainage mat : It covers approximately half of the foundation downstream from the core and carries leaks to the downstream foot. Its thickness is at least 50 cm.



Legend :
b_{berm} : width of the berm
hdr : drainage prism height
m' dr and m" dr : slope of the downstream and upstream slo
of the drainage prism
m_2 : slope of the downstream embankment of the dam
H_2 : water height downstream
the dam

Fig.4.11: Downstream drainage prism

- **Prism sizing:**

- The width of the berm (b_{berm}) is also fixed according to the equipment used for its construction

ber ≥3.00 meters

- For small dams this width may be smaller for economic reasons.

ber =0.5 to 2.00 meters

- The height of the drainage prism (h_{dr}) is fixed if the downstream water level is known precisely.

$$h_{dr} = H_2 + (0.5 \text{ to } 1.00 \text{ meters})$$

In the case where the presence of water downstream is unlikely, we can fix the height of the drainage prism according to the following expression:

$$h_{dr} = (0.15\ 0.18)H$$

H: Total height of the dam;

- The slope of the downstream slope: The downstream slope of the drainage prism depends on the characteristics of the rockfill and therefore on its stability to sliding and wave effects. It is generally set as follows:

$m'dr$ =(1.00 to 1.50). m 1

m 1: Upstream slope of the dam.

- The slope of the upstream embankment: it is closely linked to the saturation line and therefore to the stability of the embankment, but it also plays a very important role in quantifying the infiltration flow. Usually it is fixed as follows:

$m''\ dr$ =(1.25 to 2.00). m 1

m 1: Upstream slope of the dam.

b) **The internal carpet drain:**

It is a drainage strip placed in the part downstream of the massif and in contact with its found This type of drainage ensures the drainage of the massi and its foundation and it has the advantage of fold the saturation line inside the massif.

Its realization is very easy but its repair in case of damage is impossible. (Figure. 4.12).

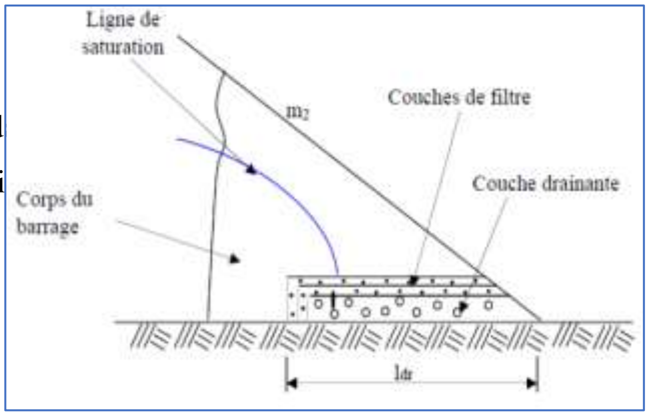


Figure 4.12: The internal carpet drain

The thickness of the internal carpet drain is chosen to be able to evacuate the infiltration flow through the massif and its foundation without overflow.

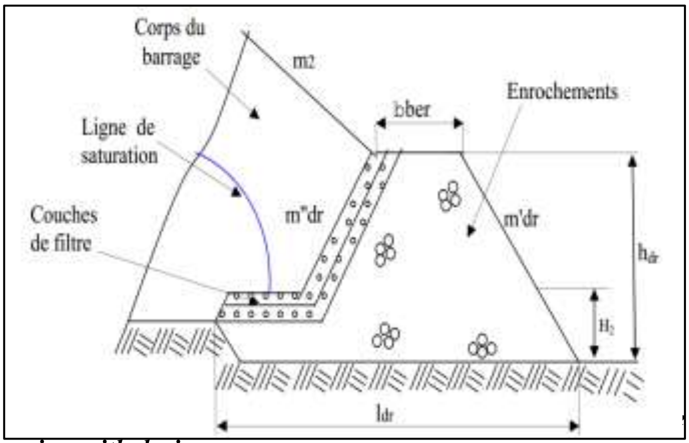
- The length of the internal carpet drain is usually taken equal to (1/4 to 1/3) of the dam footprint.

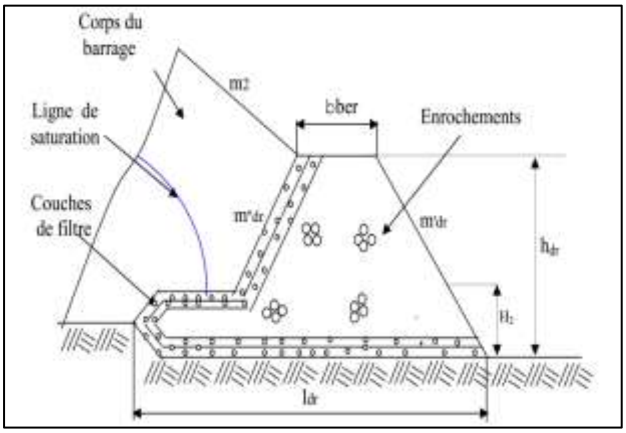
This length will be the subject of a detailed study with the development of a calculation program and the proposal of a simple method for its determination.

c) **Drainage prism with internal carpet drain**

Most often, and for reasons of safety of the structure, the two variants of the drainage prism and the internal carpet are combined. Thus the drainage prism is extended inside the massif by an internal carpet drain. There are two variants depending on whether the foundations are permeable or not (fig.4.12-4.13).

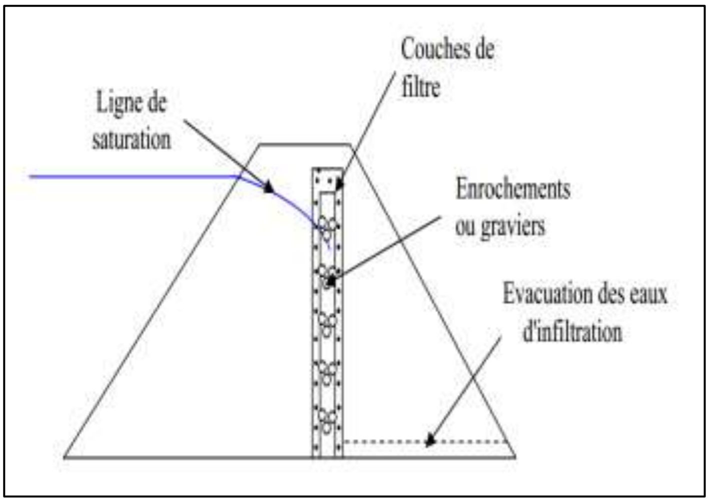
The length of the internal carpet drain is usually taken as 1/4 to 1/3 of the dam footprint.





prism with drain
internal on impermeable foundations internal on permeable foundations.

d) **Vertical drain**



When there is a high risk of anisotropy, the only valid solution is the projection of a vertical drainage in the form of a strip rock or gravel protected from and on the other hand by transition filters (fig.4.14) Percolation water carried downstream from the dam by a network of drain pipes or by drain-filter mat if it is also necessary to drain the foundations.

The minimum width of such drainage is 1.00 m and its ideal position is downstream of the dam axis The top of the drain is leveled at the normal level of the plane water (NNE).

Fig.4.14 : The vertical drain

Construction of a vertical drain with 0-5 mm sand

e) **Use of geotextiles as filters or drains**

Geotextiles are sheets of flexible, strong, and permeable fibers. There are several products, each of which can perform one or more functions (filter, drain, puncture protection).

In a dam, geotextiles are most often used to help drain percolating water by acting as a protective filter for a draining granular material.

Réalisation de filtres en géotextile protégeant un drain horizontal.

4.4 Study of infiltrations through the body of the dam

- General information

The infiltrations that occur through the body of the dam, and its foundations must be considered from two different aspects, on the one hand they reduce the stored volume, on the other hand they can compromise the stability of the structure under the influence of foxes; which is a process of underground regressive erosion and the water infiltrating under a certain pressure allows the appearance of paths through the dike or the foundation with entrainment of fine particles and filtration pressures.

The infiltrations must make it possible to determine the following elements:

- The saturation line of the dam massif;
- The leak rate;
- The pressure of pore water in the massif.
- The submerged area of the body of the dike
- A protective device

4-4-1- Study of infiltrations

- Sizing of the drainage prism

$H_P = (15 \text{ to } 20)\% \; H_b$

$L_p = (2 \text{ to } 2.5 \text{ m})$.

Sizing the filter mat

- **Length:**

$$L_{carpet} = (1/3)\, L$$

L_{mat} : length of the filter mat drain (m).

L: the dam's footprint.

- Thickness :

For construction reasons, the thickness of the carpet must be at least 30cm and must be such that the drainage capacity of the carpet is equal to twice the flow rate crossing the dam (the dike).

3.6- Study of infiltration through the earth dam

The flow of water into the dam body and its foundation threatens the stability of the hydraulic structure, which can suffer internal or external erosion. These actions cause very serious and irreversible damage.

a) Saturation line equation

The saturation line delimits the wet part of the dam and the part saturated with water . The method for drawing this line was proposed by Kozeny who showed that for an undrained homogeneous earth dam, the saturation line is similar to a parabola in its middle part. (Figure

17).

The equation of the saturation line is written as follows: $y^2 - y_0^2 - 2xy_0 = 0$

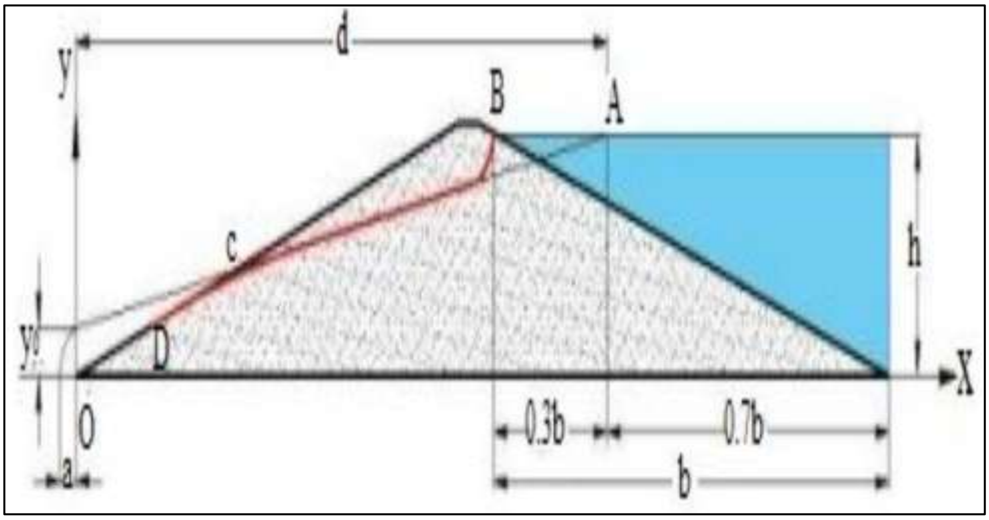


Figure 3.4: Saturation line in an earth dam

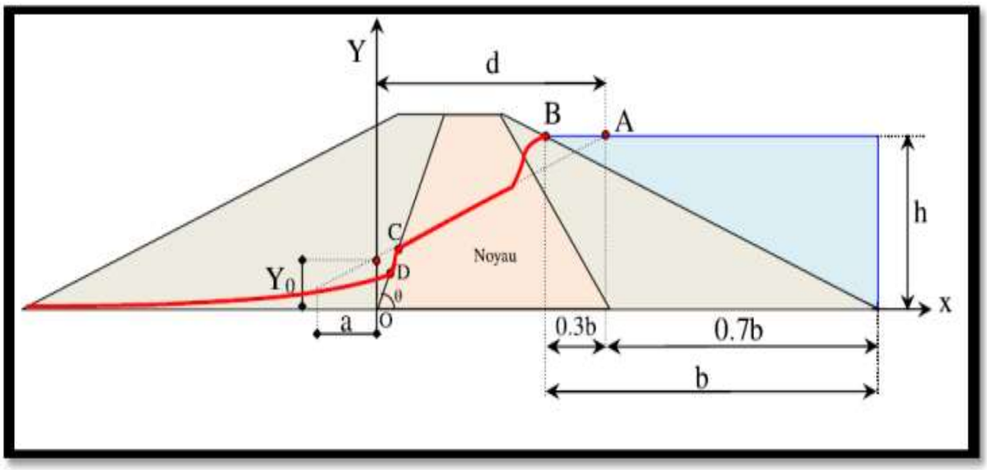
With :$y_0 = \sqrt{H^2 + d^2} - d$

d : being the width at the base of the basin reduced by “0.7b”. And “b” being the horizontal projection of the wetted part of the upstream facing. The parabola intersects the upstream water body at “A ” located at a horizontal distance from this facing “AB=0.3b”

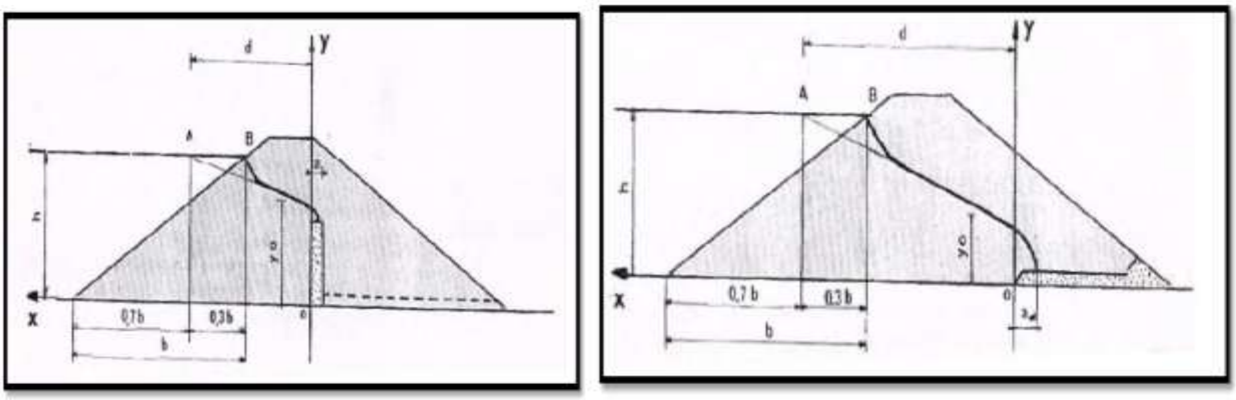
To obtain the saturation line from the Koseny parabola , we connect it to point “B” of the upstream water body by a curve normal to the upstream face at “B” and tangent to the parabola.

Downstream, the saturation line ends at a point “D” approximately located at 2/3 of “OC” theoretically such that:

$$\mathbf{OD} = \sqrt{h^2 + d^2} - \sqrt{d^2 - h^2 cot^2\ \theta}$$



Case of the dike with a core on impermeable foundations.



Case of a horizontal drain   *Case of a vertical drain*

Figure 4.6 Plot of the saturation line of a drain dam

b) Leakage rate

Once the saturation line has been located, it is always interesting to know the infiltration rate. Several methods can be used, but all assume that the position of the saturation line is known.

The leakage flow rate is given by:

$$Q_{Fuit} = Q_d + Q_F$$

With

Qd: Leakage rate through the dike; $Qd = k_1\sqrt{H_1^2 + d^2}$-d

Qf : Leakage rate through the foundation.

$$Q_F = K_2 T + \frac{H_1 - h}{s_p}$$

H_1 : Height of the normal level of the reservoir (m)

d : distance between the two sections, the y axis and the water level (m)

$K_{1.2}$: permeability (m/s)

h : height determined graphically

Sp : average thickness of the anchor

T: thickness of the permeable base

Criteria	Terms	Objectives
Filtered Particle retention fines	$\frac{D_{15\ filtre}}{D_{85\ sol\ migrateur}} \le 5$ $\frac{D_{15\ filtre}}{D_{50\ sol\ migrateur}} \le 25$	• **Prevent the passage of particles from the migratory soil** • **Avoid clogging of the filter by fine particles**
Drain Permeability (drainage)	$\frac{D_{15\ filtre}}{D_{15\ sol\ migrateur}} \ge 5$	• **Ensure the greatest permeability possible filter** • **Reduce hydraulic pressures in the filters** • **Ensure filter stability**

Useful links

- https://youtu.be/65Ee-4RC_bY
- https://youtu.be/tIno0da06Pc

References

- ABRAMSON, L., LEE, T., SHARMA, S. & BOYCE, G. 2002. Slope Stability and Stabilization Methods .: John Wiley & Sons, New York.
- Bouslah , S (2022) Educational handout Badji hydraulic works mokhtar-annaba university university badji mokhtar-annaba
- De Cesar , G; De Almeida, Manso. PF (2019) Course handout “Hydraulic works and hydroelectric development ”. EPFL
- Vischer, DL; Hager, W. H. (1998) Dam Hydraulics . John Wiley & Sons, Ltd, Chichester, UK.
- DEGOUTTE, G. & FRY, J. 2002. Small dams : guidelines for design, construction and monitoring .
- BONNET, F. 1920. Dam course. Paris, Technical Education Bookstore.

- BONELLI, S. 2001. Hydraulic embankment structures: a cross-sectional look at the action of water. Water-agriculture-territory engineering, p. 49-p. 58.
- BERTHAUD, Y., DE BUHAN, P. & SCHMITT, N. 2018. Aide-mémoire - Soil mechanics - 3rd ed: Mechanical aspects of soils and structures, Dunod.