Irrigation and Drainage Engineering

(Soil Water Regime Management)

(ENV-549, A.Y. 2024-25)

4ETCS, Master option

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Platform of Hydraulic Constructions

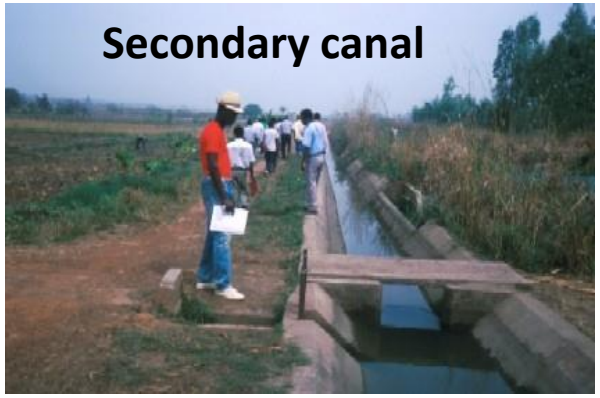
Lecture 4.1. Surface irrigation: water conveyance (linear) structures and engineering

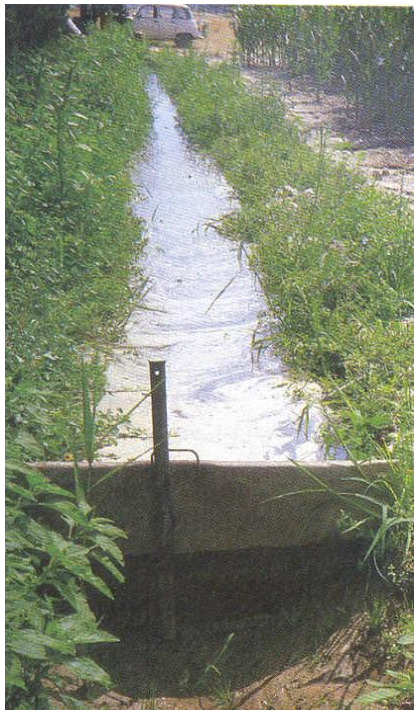
Water conveyance structures for gravity irrigation

Example of water conveyance facilities

Leveling works to ensure proper water distribution

Sometimes pumps and pressure flow to irrigate areas at higher elevation

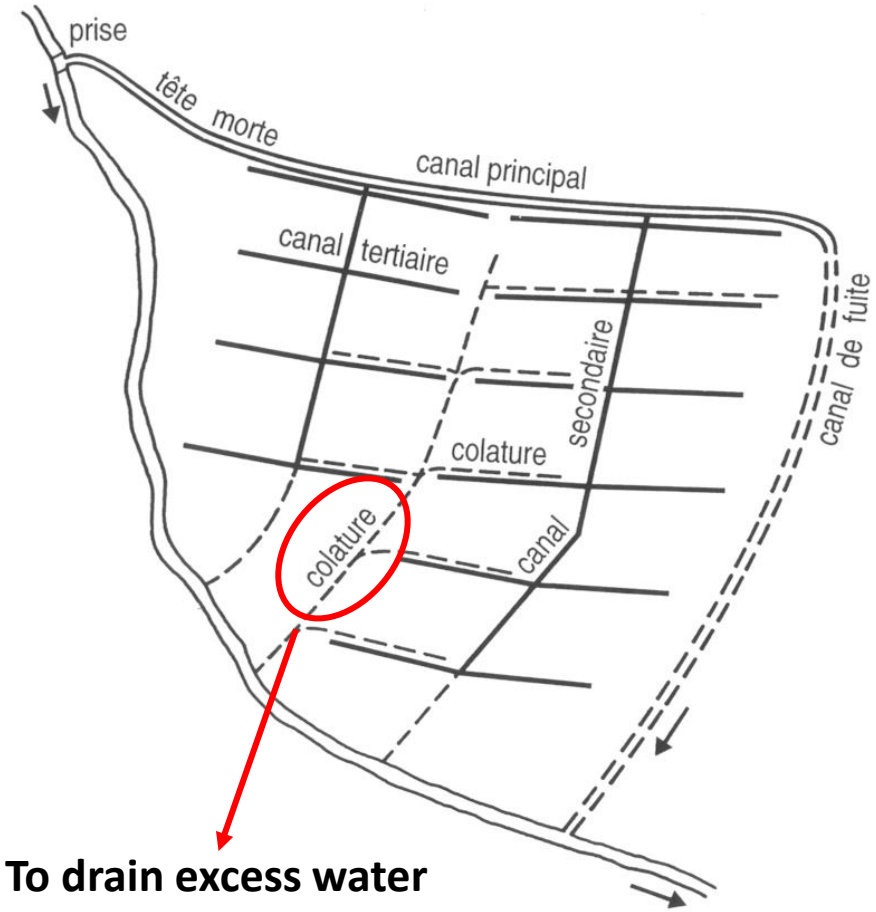




Distribution channel (ditch)

Water conveyance structures for gravity irrigation

Example of water conveyance facilities



To drain excess water

Traffic lanes along a canal

- access to plots
- maintenance and monitoring of canals and structures

Protection dikes

Point structures

- Regulation (gates, valves)
- Distribution (dividers, gates)
- Safety (siphons, draining devices) to prevent overflows

Soil foundation characteristics

Canals without revetment (earthen channels)

- Hydraulic conductivity (losses due to infiltration)
- Soil cohesion (bank slope stabilization)

✓ Soils with wide range of granulometry

Canals with revetment (lined channels)

TO AVOID (IF POSSIBLE)	SOLUTION (IF IMPOSSIBLE)
Light density soil	• Strong compaction
High clay content	• replace the layer • stabilise the surface • use a flexible coating
Unstable zones	• Complete sealing of the canal
Soils with high salinity content	• High-density concrete and special cements • Aboveground structures (aqueducts)

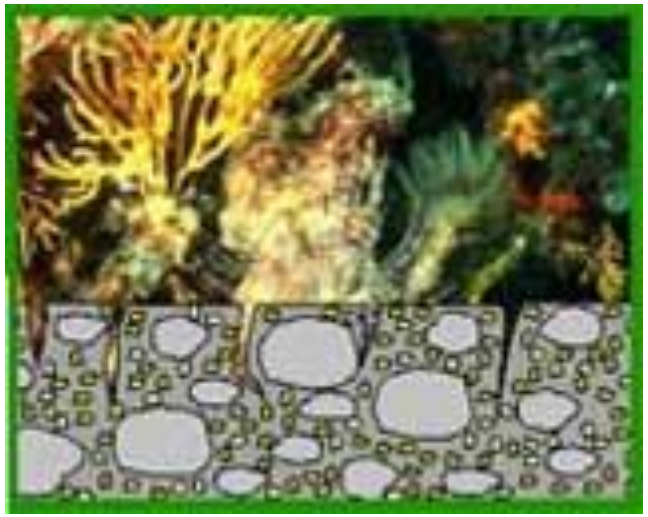
Attack of concrete by soluble substances

Most salts pose a threat to concrete in high concentrations, but particularly sulphates, especially Mg sulphates.

In the presence of salts, very dense concrete and special cements* (low in lime) must be used.

Note: steel is also corroded by sulphates

*Pozzolanic cement: cement containing natural pozzolans (volcanic slag: small particles of pumice) or siliceous fly ash (very fine powdery products from the dusting of combustion gases from thermal power stations).



The porosity of concrete encourages the penetration of salts into the structure, which can dissolve certain minerals in the concrete.

Plan layout of canals

In hilly terrain, the layout of canals and colatures is dictated by the topography.

In regular terrains, the optimum solution is function of:

- ✓ Maximal surface of the districts
- ✓ Admissible length of the plots
- ✓ Plots layout and distribution
- ✓ Soil characteristics
- ✓ Financial aspects, etc.

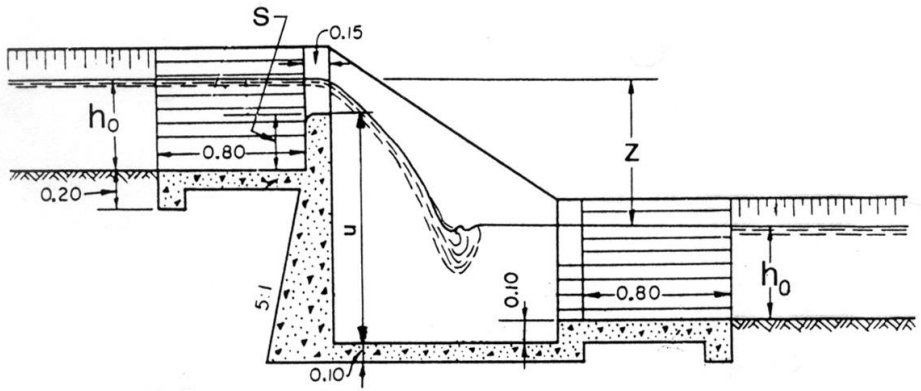
Main canal :

- ✓ generally sized for peak flow conditions
- ✓ usually placed in a dominant position with a gentle slope (0.01-1%)
- ✓ where possible, a balance of cut and fill to regularize
- ✓ gradual change of direction for large channels

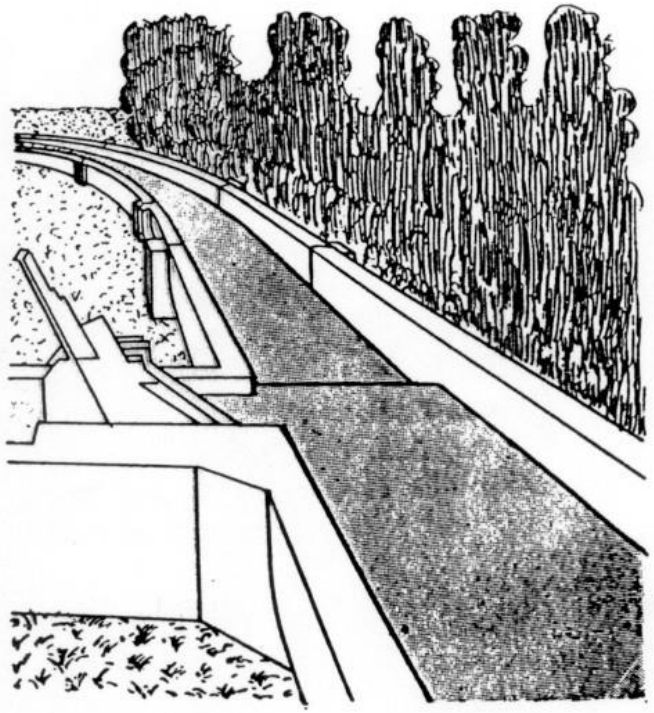
Secondary channels:

- ✓ generally placed on ridge lines
- ✓ often laid on the surface or above the ground
- ✓ sized to carry several handling flows
- ✓ if necessary (slope too steep), waterfalls

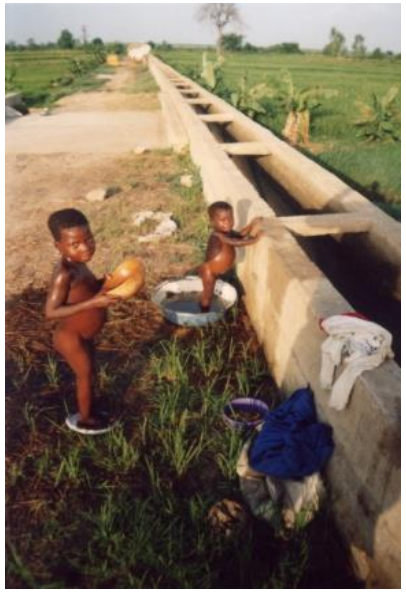
Distribution channels



Waterfall structure



Secondary channels laid on the ground and supported channels



Cross-section profiles

Trapezoidal profile

- earthen canals
- small canals lined on site
- large canals

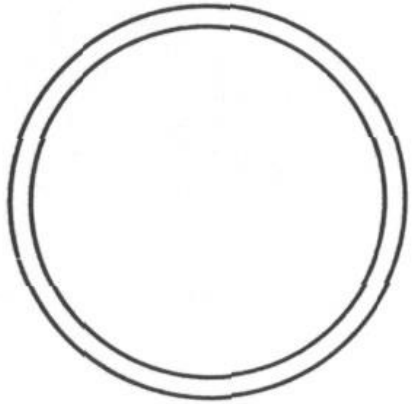
Other profiles

- transport of small flows
- crossing obstacles

profil trapézoïdal

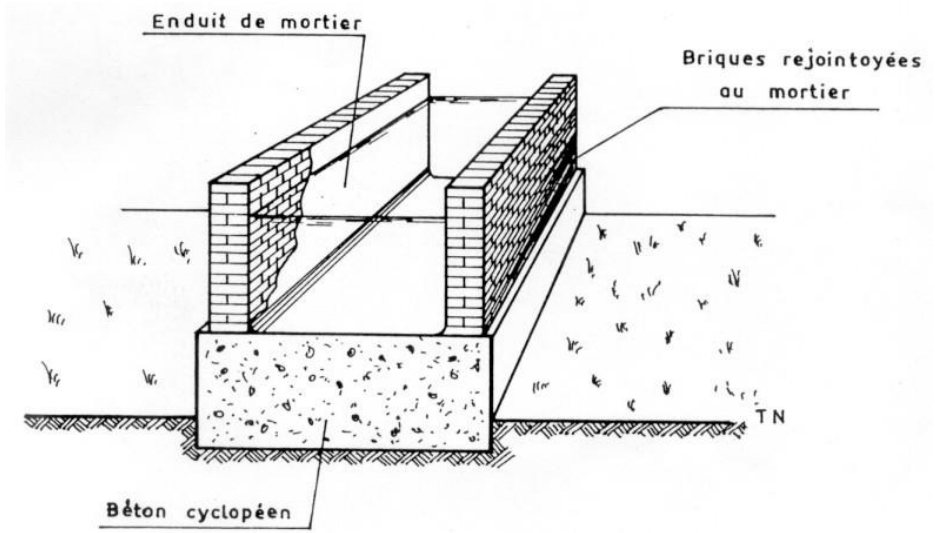
profil rectangulaire

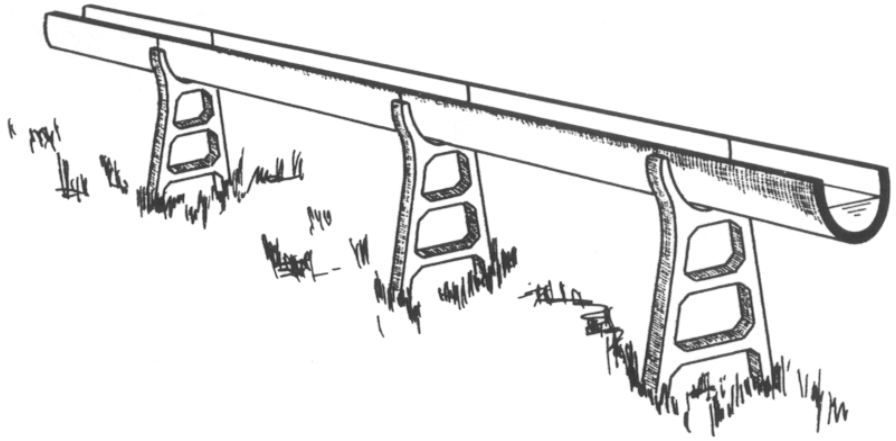
profil semi-circulaire



profil circulaire

Main cross-section profiles of irrigation canals





Rectangular profile

Circular Profile

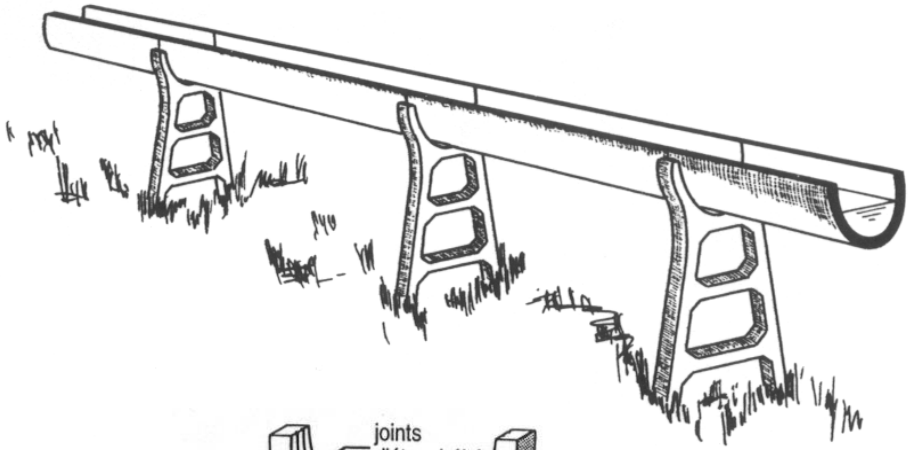
Semi-circular profile

Prefabricated channels

- Variable cross-section (rectangular, circular, semi-circular, semi-oval, triangular, etc.)
- supplied in prefabricated units 5 to 7 m long
- usually in pre-stressed reinforced concrete, but also in steel, plastic, etc.

Ported channels

Channels placed on supports (max. height: 2 to 3 m)

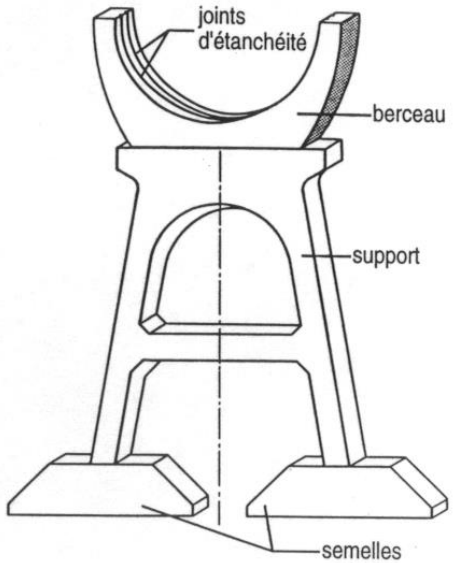


Advantages

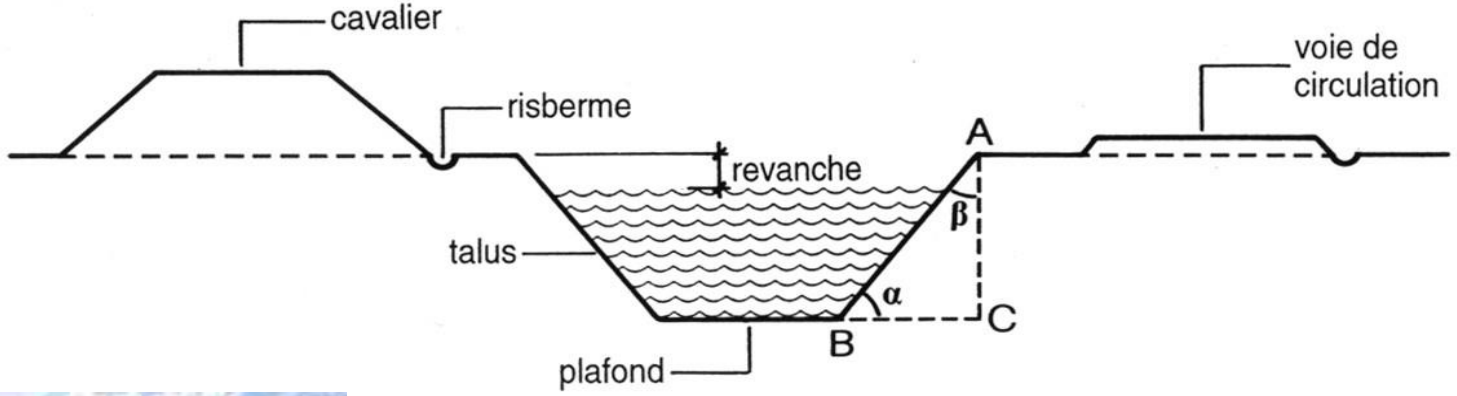
- channels can be sloped, even on flat ground
- small, easily negotiated topographical obstacles
- dominant position of the water
- small footprint
- easy to detect leaks

Disadvantages

- cost
- delicate installation, fragile elements
- crossing traffic lanes

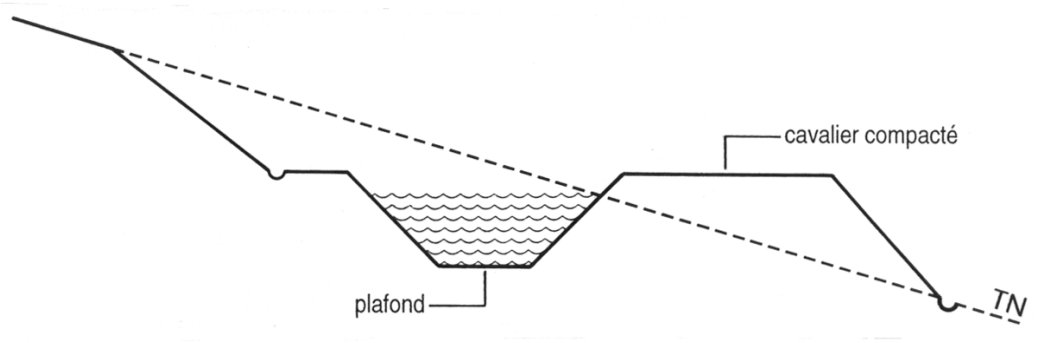


Trapezoidal profile



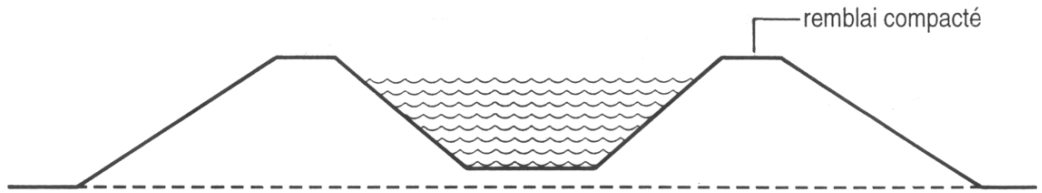
Excavated profile

(typical in flat surfaces)



Mixed profile

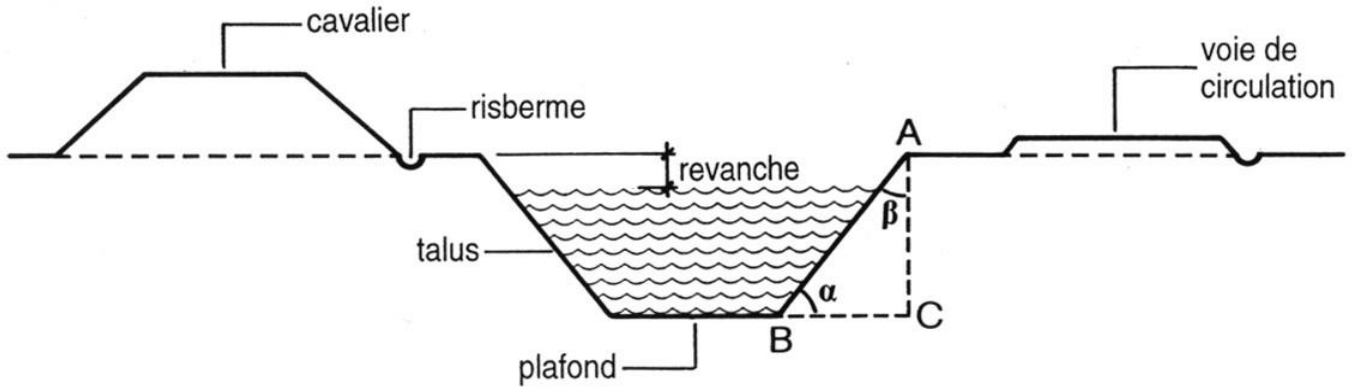
(dike compaction!!)



Embanked profile

(bank stability!!)

Embankment slope of trapezoidal canals



Slope = tg α = AC/BC

Fruit m = 1/tg α = BC/AC

Earthen channels[1] : 1/3 < tg α < 1

Sols à faible cohésion — Sols à bonne cohésion

Lined channels (with concrete revetment):

- ✓small channels: frequently 2/3 or 1
- ✓large channels: 2/3, 2, etc.

Freeboard r

- ✓Earthen channels: 0.3 < r < 1 m
- ✓Lined channels : 0.15 < r < 1 m

The freeboard is a delicate quantity to calculate as it depends on other network infrastructures downstream (e.g., gates), whose operation may induce propagating surface waves

[1] Étude géotechnique préalable: cohésion et angle de frottement interne

Earthen channels

Advantages

- low cost
- achievable with local labour
- materials readily available

Disadvantages

- High leakage losses[1]
- high wall roughness
- high maintenance costs[2]

Empirical formulations

Formule de Ingham (établie en Inde)

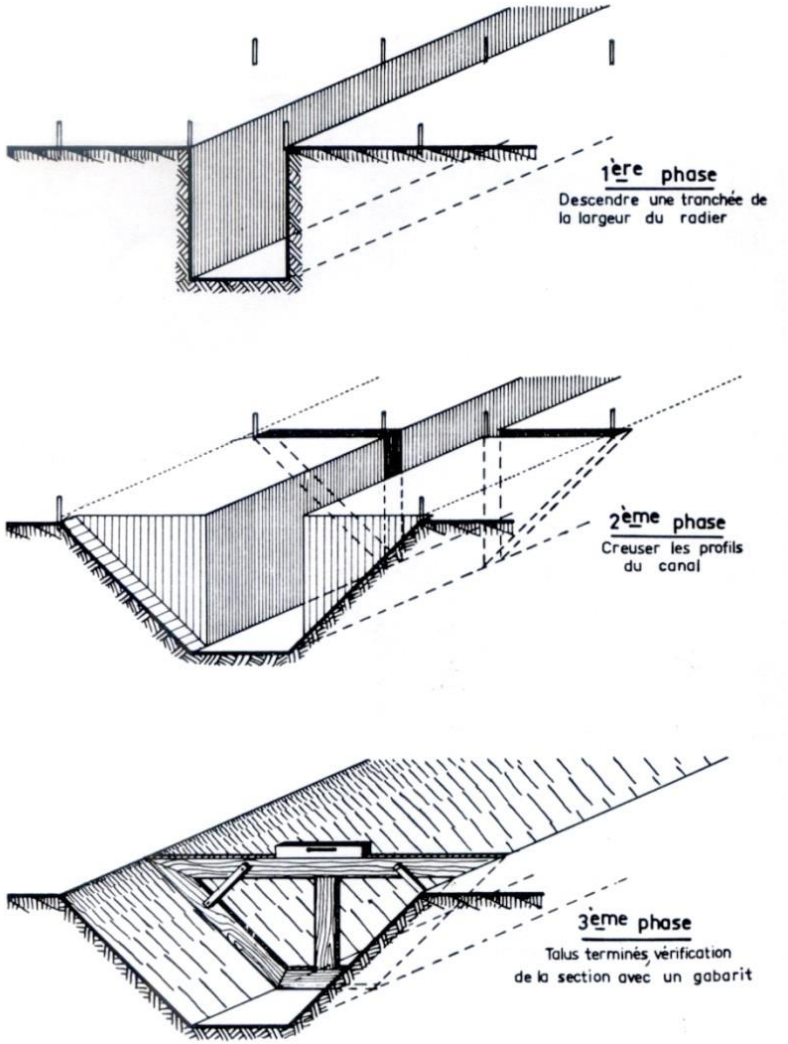
$$Q = 2 \cdot 10^{-6} h^{1/2} W L$$

Formule de Davis et Wilson (USA)

$$Q = \frac{0.45\ C\ \sqrt{h}\ P\ L}{4 \cdot 10^{6} + 3650\sqrt{V}}$$

[1] f(water-soil contact surface, height of water, nature of soil)
[2] annually, approx. 5% of construction costs

Practical realization of an earthen channel



Ameliorations (of earthen channels)

Objectifs

- reduce losses
- increase flow rate
- lower maintenance costs

Types of interventions

- Actions on the mechanical properties of soils (compaction, Proctor test)
- Crack sealing by sedimentation of fine material (silt, bentonite, bentonite-cement, bitumen emulsion, etc.)
  - short-term effectiveness → frequent renewal necessary
  - mainly used as an emergency measure
- Deposition of low-permeability layers
  - deposit of borrowed earth (30 to 60 cm)
  - deposit of earth concrete (approx. 10% cement; 10 to 15 cm thick) (shrinkage cracks!!)

Lining of canals

Quality of lining

- efficiency
- sustainability
- costs

Types of lining

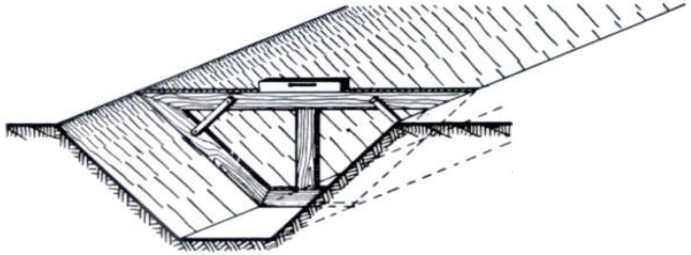
- Hard surfaces
  - ✓masonry
  - ✓bitumen, asphalt
  - ✓concrete
- New materials
- Impermeable membranes

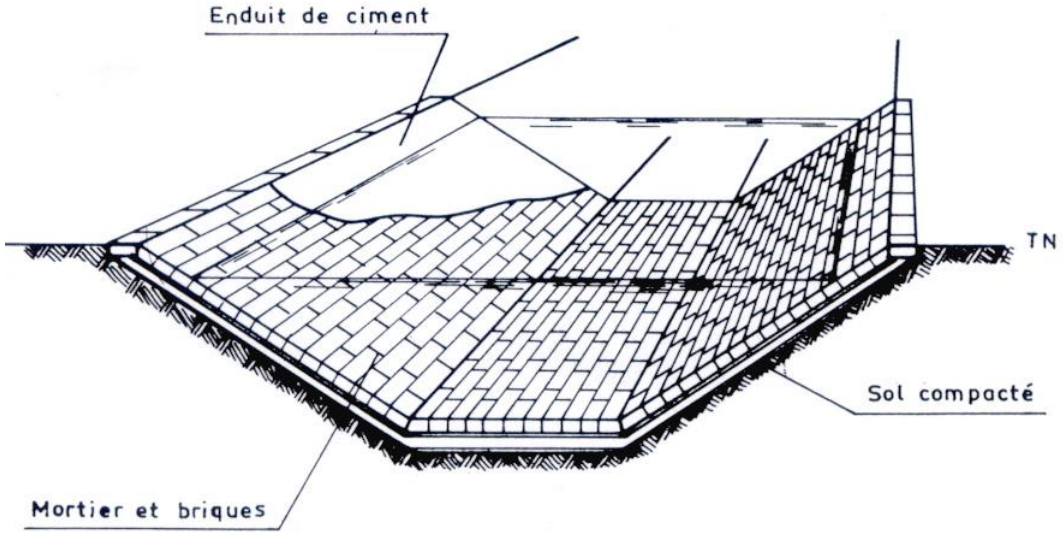
Choice of lining type

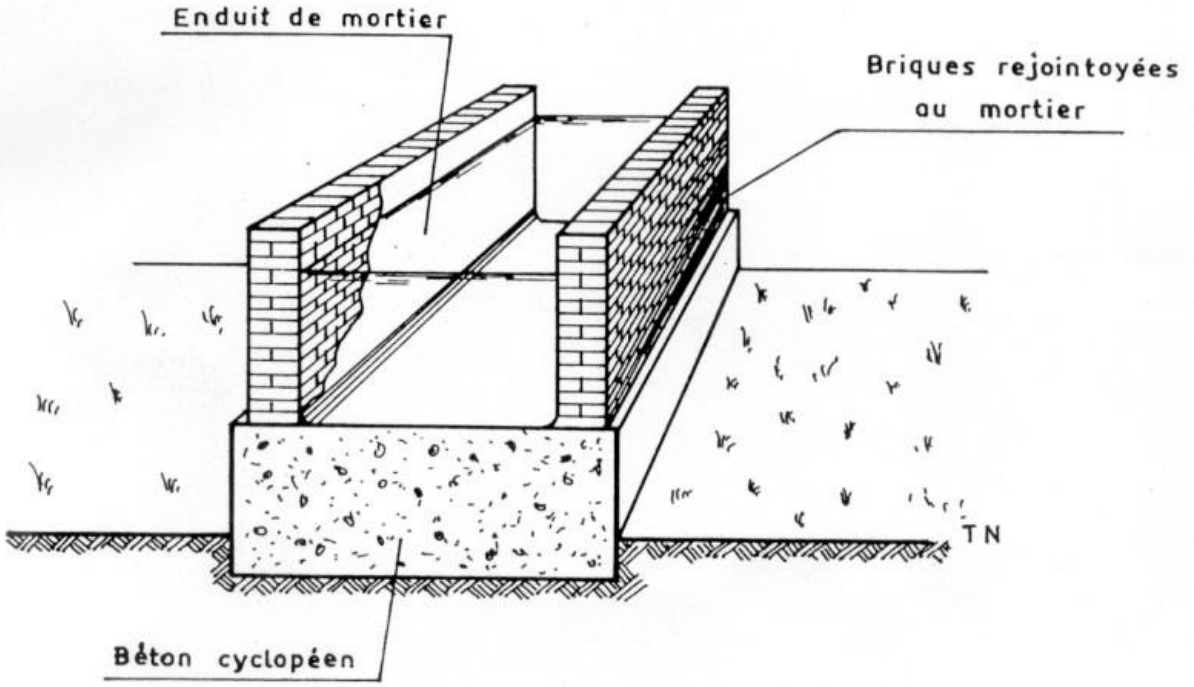
- availability of installation materials and equipment
- channel dimensions
- climatic parameters
- characteristics of the foundation soil

Preliminary actions

- Soil compaction
- Cross-section regularization







Examples of lined masonery channels

Bituminous coatings

Advantages

- good waterproofing (except permeable asphalt)
- flexibility (no joints)
- easy to repair

Disadvantages

- high cost
- risk of creep
- difficult to install
- strength and durability < concrete

Types of bituminous surfacing

- Asphalt mix
  - bitumen (5 - 10%) + aggregates (S and G)
  - permeable (predominantly coarse aggregates)
  - impermeable if porosity is < 4%.

  Used to produce homogeneous coatings of constant thickness

- Bituminous sealants
  - bitumen (12 - 20%) + fine aggregates (S and filler)
  - pasty liquid poured into place without compaction

  Used for coatings on uneven surfaces (low stability!!)

- Prefabricated bituminous screeds

Concrete lining

Advantages

- long service life
- low maintenance
- very resistant

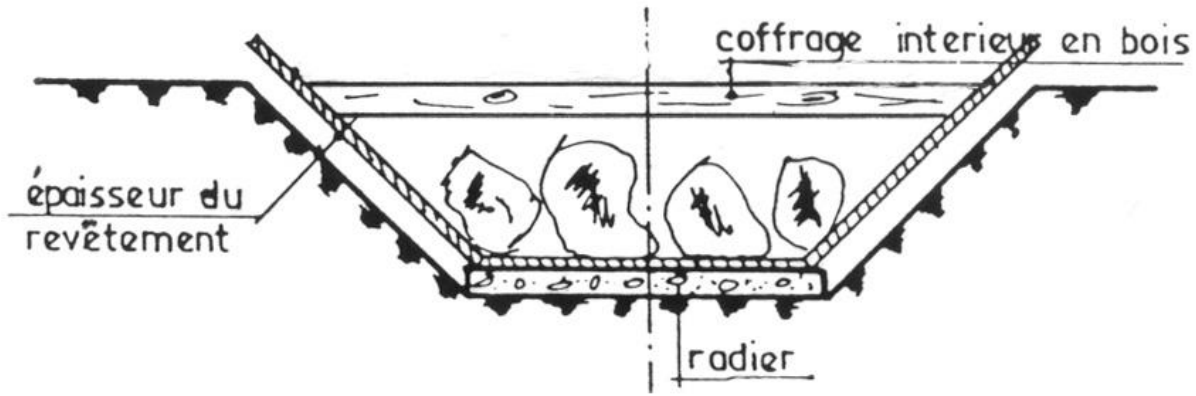
Disadvantages

- coût élevé
- forte rigidité
- sensibilité aux var. de température[1]

Execution

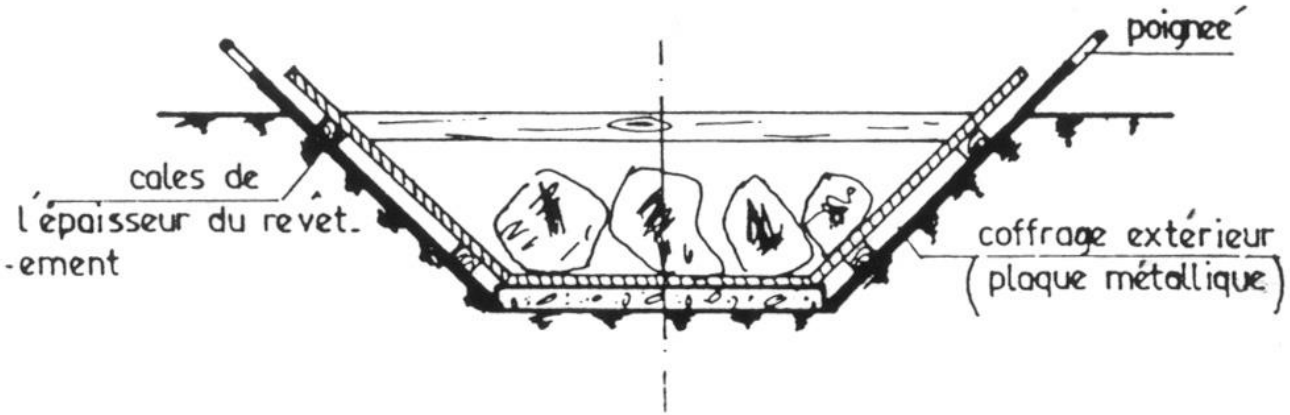
- Cast-in-place concrete
  - With or without reinforcement
  - Implementation
    - ✓ manual
    - ✓ automatic
  - Thickness is function of
    - ✓ importance of the canal
    - ✓ desired tightness
    - ✓ Soil stability
- Prefabricated concrete slabs or tiles

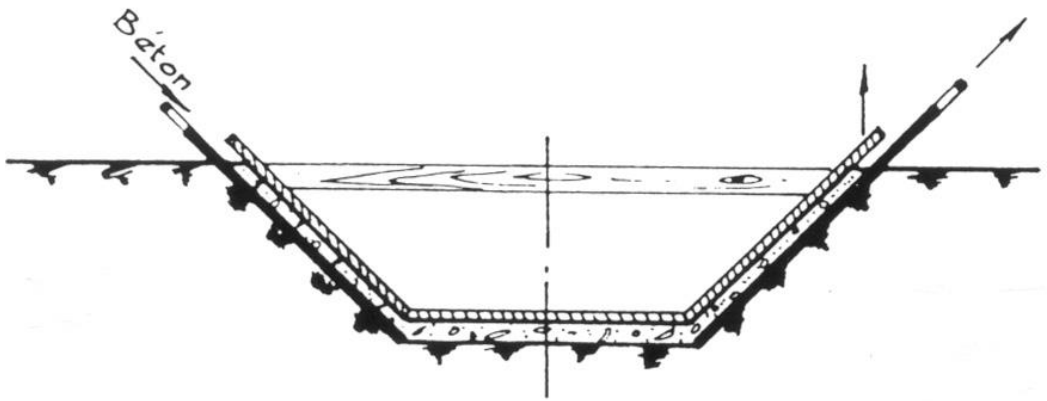
[1] Seals required
- shrinkage (partial sectioning): approx. every 5 m
- expansion (total sectioning): approx. every 15 m



Manual realization of a concrete paving

- Thickness depends on channel size (5-10 to 8-20 cm)
- Wooden formworks or templates
- Concrete can be reinforced or not

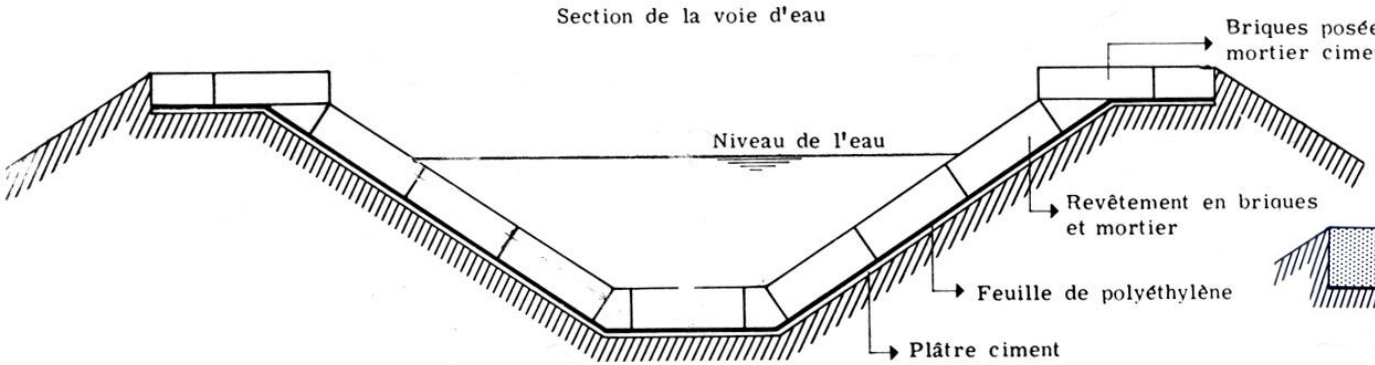


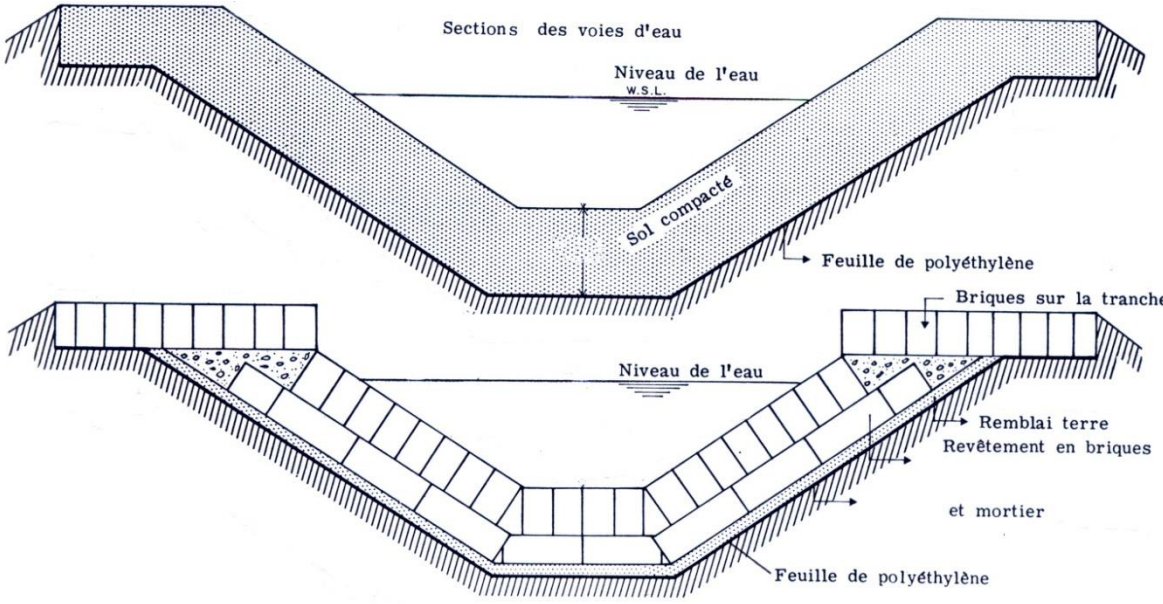


Examples of

canals lined

with concrete





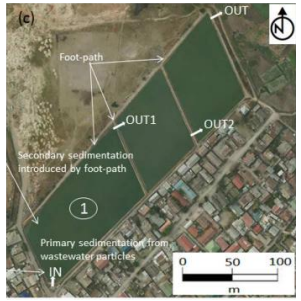
Use of impermeable membranes

- Asphalt sprayed on site (5-8 mm layer)
- Prefabricated asphalt sheets (3-6 mm thick , small sections)
- Plastic membranes (PVC or PE, large rolls): reduces the number of joints.
- Simple application on the bank surface after soil compaction: deterioration (sunlight, erosion, animals…)
- Membranes buried and covered by 20 cm soil: excavation of larger sections, longer duration (15 years)

New material: Biocement

Main idea: similar to the use of brick and cement blocks, but using an innovative, carbon capturing material

Sludge (evt add bacteries)

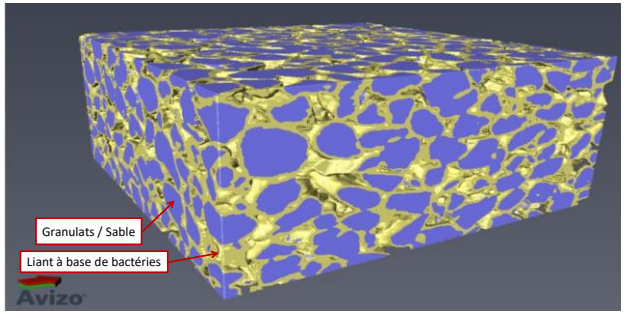


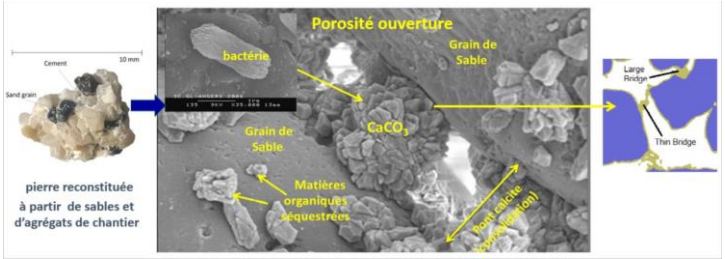
Sand

Calcium ($CaOH_2$)

Water

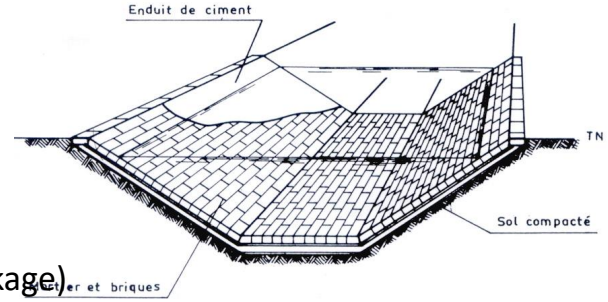
BIO-CEMENT
(Net CO_2 absorbant process)

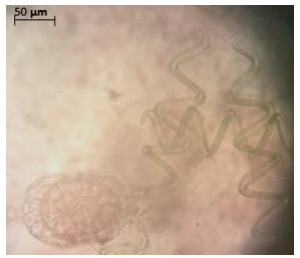




MICP: Microbial-Induced Calcite Precipitation

Efficient use (e.g., reduced leakage)





Improve health (e.g. H-E removal)

Valorisation (e.g. sludge re-use)

Any interest in a Master thesis on the subject?
Please, contact Prof. Perona

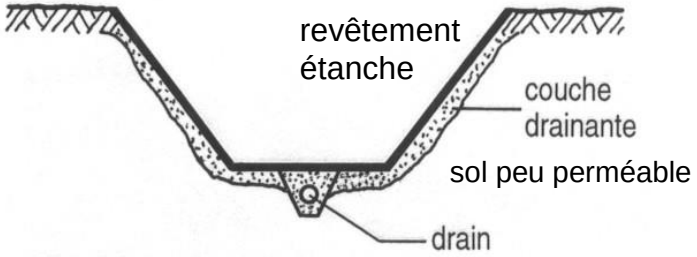
Drainage of irrigation canals

Shallow groundwater can exert hydrostatic pressure on the lined channels

- Channel lifting
- Lining degradation

✓ **poorly permeable foundation soil :**

- **permeable lining if the intrusion of groundwater into the channel is tolerated**
- **waterproof lining + drainage (drainage layer and drains) otherwise**



✓ **Permeable foundation soil:**

- **waterproof coating and drainage**