Chapter 4
Construction of earth and rockfill dams (Overview)

Phases of Construction

- Evaluation of plans, specifications, basic requirement, and features of the site.
- Planning and scheduling of the job
- Making the site ready
- Building up the structure
- Clean Up

A typical construction sequence for a fill dam is:

Stage 1: Excavate diversion tunnel and build coffer dams. The end of this stage is marked by the milestone of diverting the river through the diversion tunnel.

Stage 2: Strip dam foundation of overburden. Carry out foundation treatment and grouting.

Stage 3. Excavate and haul fill construction materials from their sources and place and compact in the dam embankment. The end of this stage is marked by the milestone of closure of the diversion tunnel to start the storage of water in the dam reservoir. Excavation of the spillway will also be under way during this stage.

Stage 4: Complete outlet works, spillway and all other parts of dam project

RIVER DIVERSION

The **magnitude**, **method** and **cost** of river diversion works will depend upon

- the cross-section of the valley
- the bed material in the river
- the type of dam
- the expected hydrological conditions during the time required for this phase of the work
- and finally upon the consequences of failure of any part of the temporary works.

Possibilities

Cofferdams : Large discharges require cofferdams and different structures of the **diversion system**

An **upstream main cofferdam** serves to retain the anticipated construction floods and to conduct the permanent river discharge and the construction floods to the diversion structures.
A **downstream cofferdam** serves to protect the construction area from inundation by tail water.

The other components of the diversion system may be **channels** and **lateral tunnels** through one of the abutments.

Foundation and Abutment treatment

The preparation of the foundation and abutments for an earth or rock-fill dam is the most difficult and important phase of construction

The degree of foundation preparation depends on the:

- Type of dam
- Height of dam and the consequences of failure
- Topography of the dam site
- Erodibility, strength, permeability, compressibility of the soil or rock in the dam foundation
- Groundwater inflows to excavations
- Climate and river flows

Purpose of foundation and abutment treatment

- to obtain positive control of under seepage
- prepare surfaces to achieve satisfactory contact with overlying compacted fill
- and minimize differential settlements and thereby prevent cracking in the fill

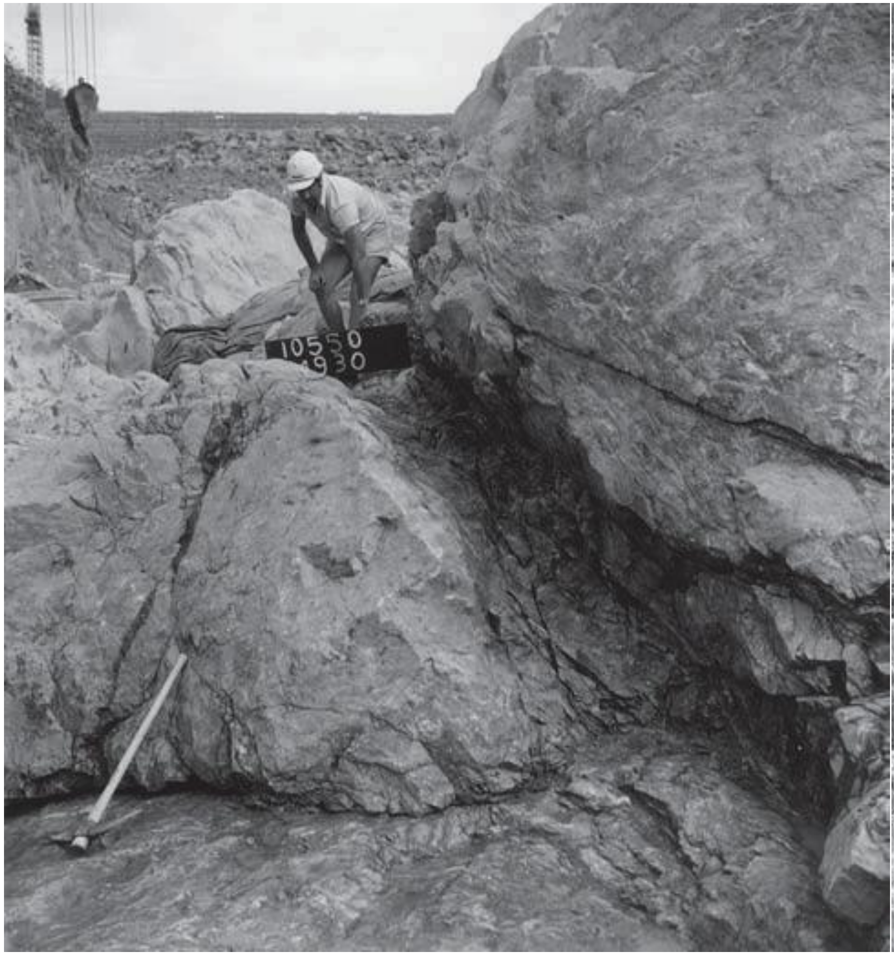
The main activities under the foundation and abutment treatment works are:

- **Stripping** of the foundation and abutments to depths sufficient to remove soft, organic, fractured, weathered, or otherwise undesirable materials;
- Cleaning and adequately **filling of depressions and joints** in rock surfaces
- Rock surfaces are made relatively smooth and uniform by **shaping** and filling
- subsurface cavities are detected and **grouted**
- **cutoffs** extend to suitable impervious materials

FOUNDATION CUTOFF

Cutoff in rock

- Remove rock with **open joints and other fractures** which would otherwise lead to a highly permeable structure.
- Remove rock with **clay infilled joints, roots** etc., which may erode under seepage flows to yield a high permeability rock.
- Carry out **slope modification and treatment**
- Where the exposed rock is susceptible to slaking by wetting and drying (e.g. many shales) or breakdown under trafficking, it should be **covered with a cement-sand grout** (thickness usually 10 mm to 25 mm)
- Remove from the surface **all loose soil and rock**, and debris from grouting (using light equipment and with an air or air-water jet). Hand cleanup may be necessary. The surface may need to be moistened immediately before placing earthfill to maintain the earthfill moisture content.
- If the rock in the floor or the sides of the cutoff trench displays **open joints** or other features which would allow erosion of the earthfill into them, it should be cleaned of loose material and covered by a **cement-sand grout**, pneumatically applied mortar or concrete.



Excavation of sheared zones prior to filling with dental concrete in the cutoff foundation

Application of pneumatically applied mortar on seams in the cutoff foundation

Cutoff in soil

- Remove soil with **open fissures, open joints, roots, root-holes, permeable layers** (e.g. sand and gravel) and other permeable structure (e.g. leached zones in lateritic soils)

- Remove **dispersive soils** if possible

- Carry out **slope modification** (next slide)

- If the soil on the sides of the cutoff trench displays **permeable layers** or features which would allow erosion of the earthfill into them, it should be trimmed and cleaned and covered with a **filter layer or layers** which are designed to control such erosion

- Remove **loose and dry soil** and other **debris** with light equipment, possibly with the aid of an air jet

- The base of the cutoff should be **watered to within 2% dry and 1% wet of optimum water content** and rolled before placing the first layer of fill, to compact any soil loosened by the construction work

SLOPE MODIFICATION AND SEAM TREATMENT FOR EMBANKMENT DAMS

Slope modification

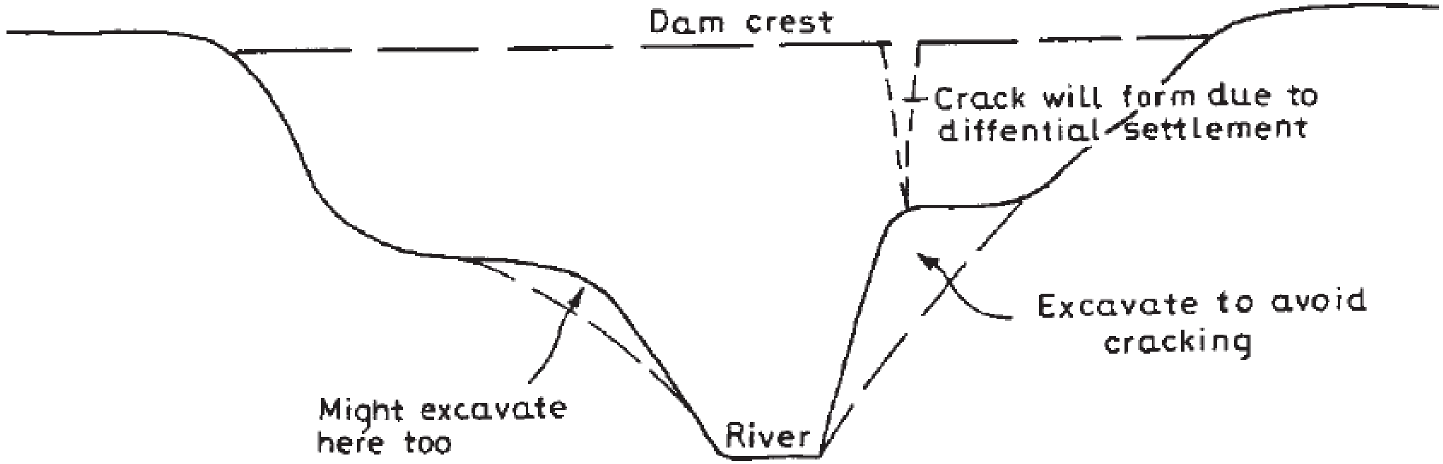
- Excavation of near vertical or overhanging surfaces and/or backfilling with concrete is required

For general foundation:

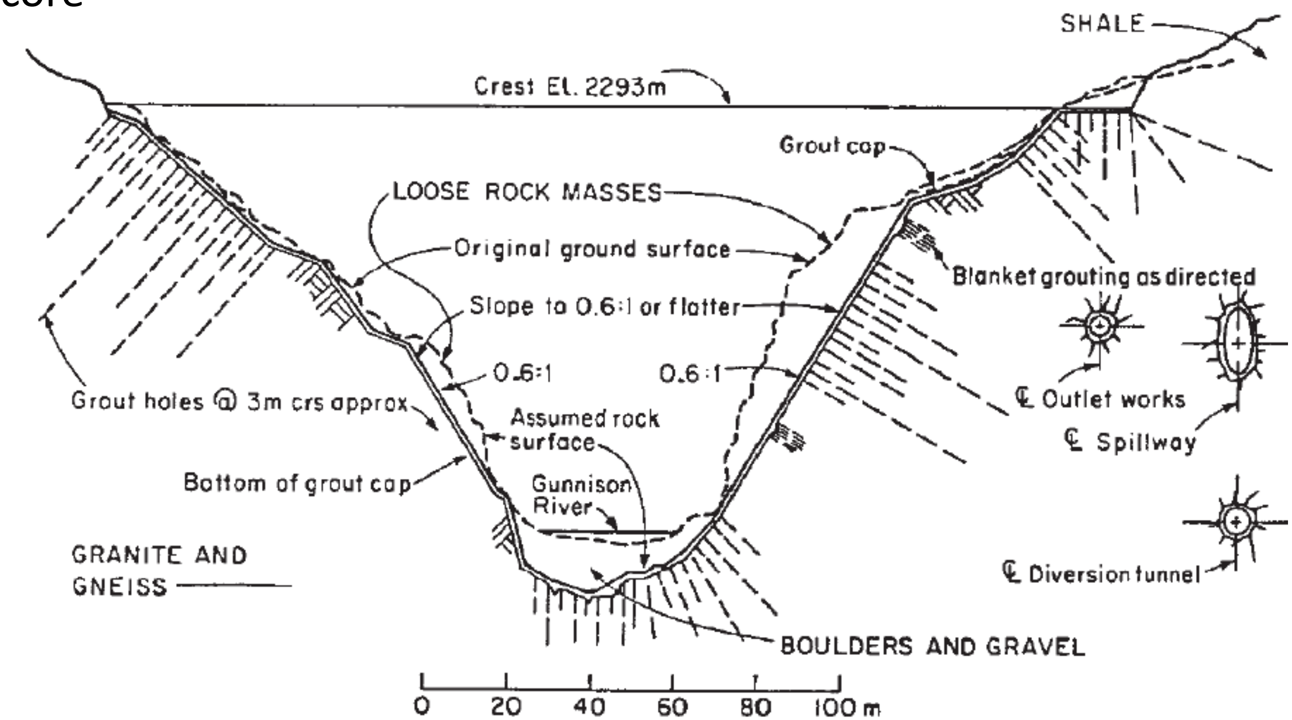
- To **allow compaction of earthfill and avoid cavities** under rockfill due to overhangs in rock in the abutment

For cutoff foundation:

- To **allow compaction of earthfill** to give a low permeability contact between the earthfill and the foundation
- To **limit cracking of the earth core** due to differential settlement over large discontinuities in the abutments



Slope modification in the cutoff foundation to reduce differential settlement and cracking of the earthfill core



Foundation slope correction, Blue Mesa Dam (zoned earthfill dam on the Gunnison River in Colorado)

Seam treatment

It is common practice to require that **seams of clay or extremely weathered rock** which occur in the cutoff foundation **should be excavated and filled with concrete**. This is done to avoid erosion of the seams thus allowing seepage to bypass the earth core and filters.

Thomas (1976) suggests that the **depth of excavation and backfill** should be **2 to 3 times the width of the seam.**

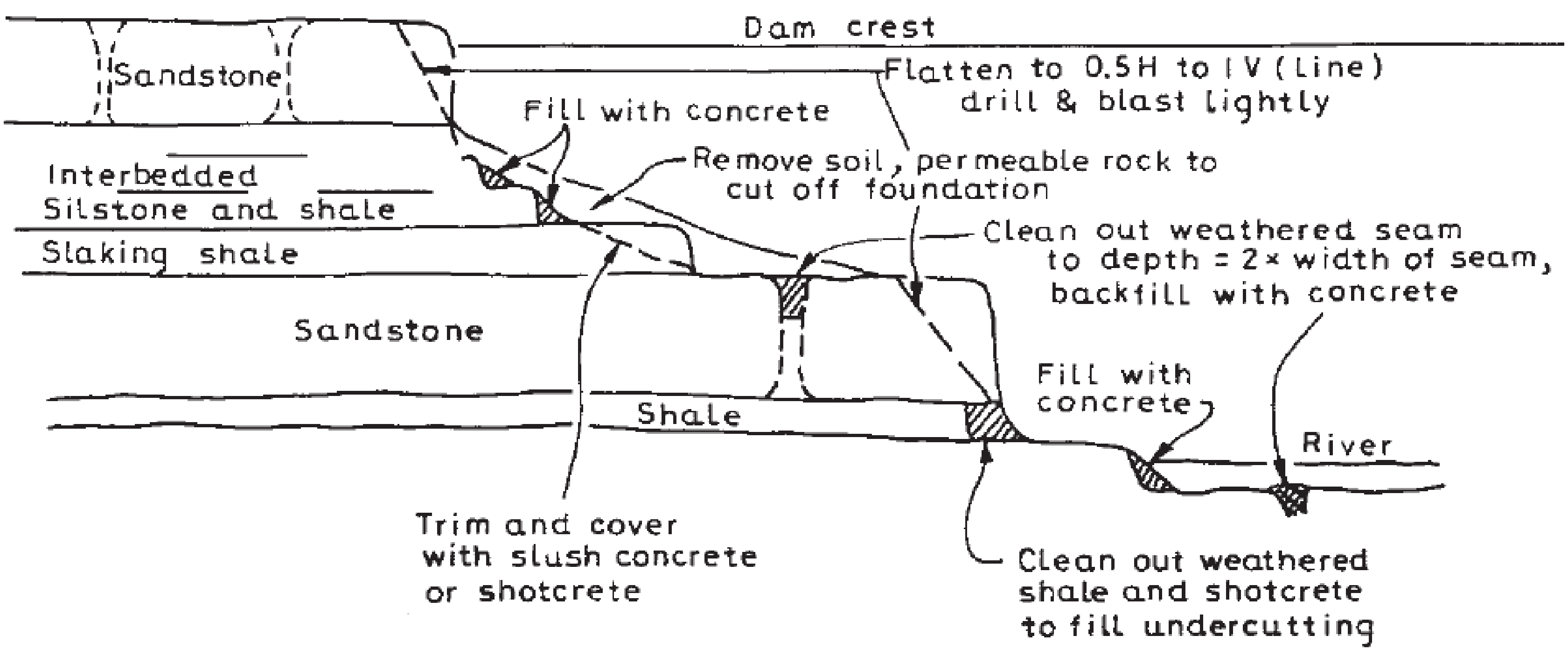
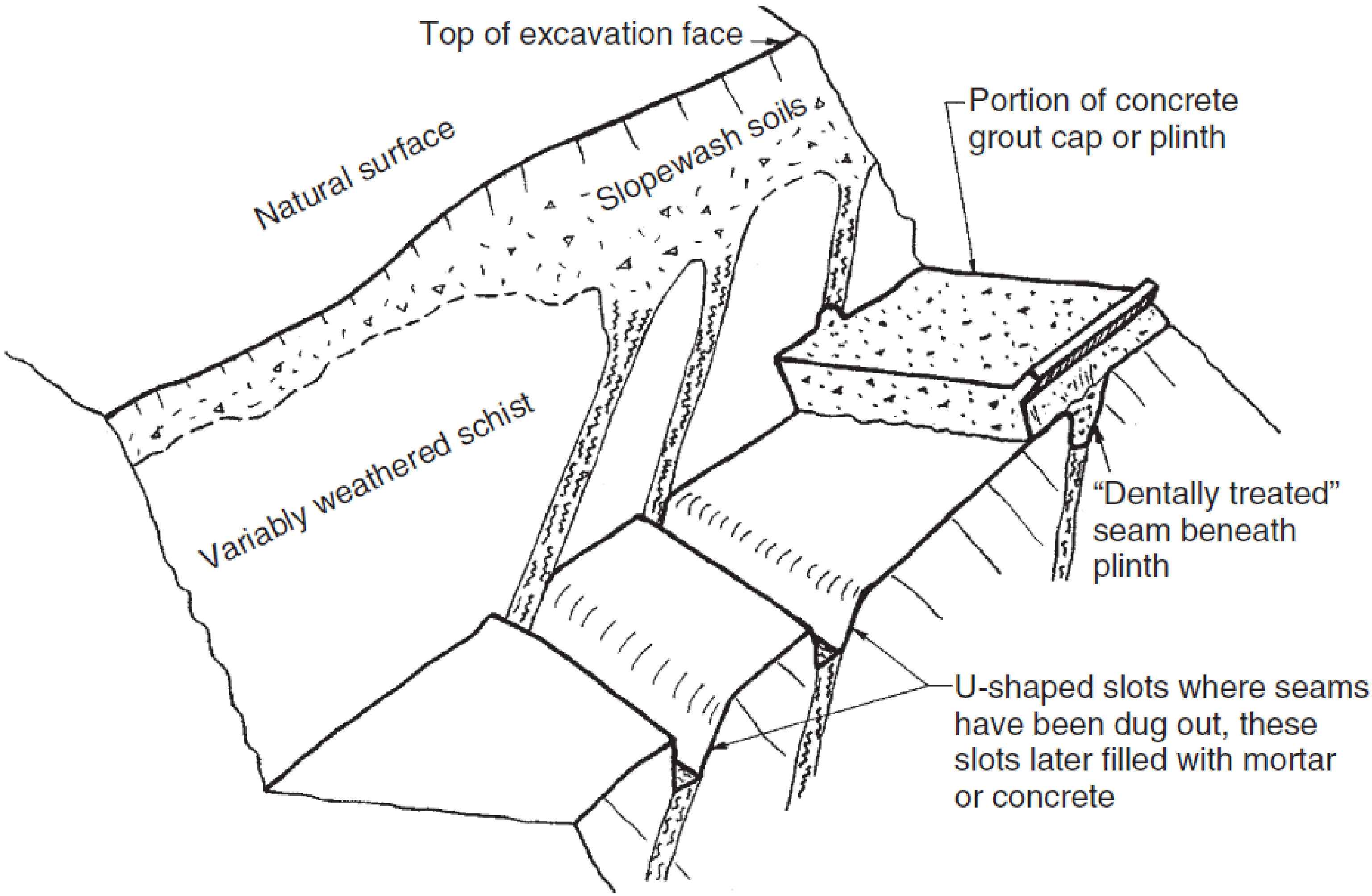


Fig Slope modification and seam treatment in the cutoff foundation for interbedded sandstone and siltstone, near horizontal bedding

Dental concrete, pneumatically applied mortar, and slush concrete

Dental concrete: Dental concrete is used to fill irregularities in the foundation due to joints, bedding, sheared zones, overhangs, or excavated surfaces



Dental treatment of weak seams in the plinth foundation of Kangaroo Creek Dam

EXCAVATING AND QUARRYING OF NATURAL CONSTRUCTION MATERIALS

- The **cohesive materials and rockfill material** are usually excavated or quarried **in dry conditions.**
- There is a **range of equipment** available to excavate, shift and place material in dams. Each type of equipment has been developed to suit particular requirements such as short haul distances or deep and narrow excavations.

PROCESSING OF NATURAL CONSTRUCTION MATERIALS

Processing may involve **removal of oversize or undersize (fines) material, or obtaining a specific size range** for use in a particular zone of the embankment such as a graded filter.

Material blending with sand and gravel

It is occasionally useful to blend cohesive material with sand and gravel to achieve the proper conditions for compaction and performance.

Material blending with clay

The properties of slightly cohesive soil with regard to their use as sealing material can be improved by adding clay. Usually bentonite is added, by adding bentonite the material is made more plastic.

That means that the fill water content can be increased and hence better adjusted to the requirements of appropriate compaction.

Filter materials are treated like concrete aggregates. They are **washed, screened and newly mixed** according to specified gradations

Embankment Construction

The embankment consists of a **series of compacted layers or lifts of suitable material placed on top of each other** until the level of the top of the embankment surface is reached.

The components of embankment construction are:

- Lift Thickness
- Material
- Degree of Compaction

The **thickness** of the lift is limited by the **type and size of compaction equipment** the contractor chooses to use

Material	Group symbol	Layer thickness uncompacted (cm)	Appropriate compactor[1]	Number of passes
Highly plastic clay	CH	15 to 20	SPR	6 to 10
Plastic silt	MH	20 to 25	SPR	4 to 8
Low plastic clay	CL	20 to 30	SPR, VPR	4 to 8
Low plastic silt	ML	20 to 30	SPR, VPR	4 to 6
Clayey sand	SC	20 to 30	SPR, VPR	4 to 8
Silty sand	SM	20 to 30	SPR, VPR	4 to 6
Sand and sand-gravel, poorly graded	SP	30 to 50	VSDR PR	4 to 6 6 to 8
Sand and sand-gravel, well graded	SW	40 to 60	VSDR PR	4 to 6 6 to 8
Clayey gravel	GC	20 to 30	SSDR, VPR, PR	6 to 8
Silty gravel	GM	30 to 40	SSDR, VPR, PR	6 to 8
Gravel, poorly graded	GP	40 to 50	VSDR	4 to 6
Gravel, well graded	GW	50 to 60	VSDR	4 to 6
Rockfill		60 to 150	VSDR	4 to 6

[1]The average weight of all compactors is 100 to 150 kN. The heaviest available compactor should be used. Average operating speed is 5 km/h.
SSDR = Static smooth drum roller
VSDR = Vibratory smooth drum roller
SPR = Static padfoot roller
VPR = Vibratory padfoot roller
PR = Pneumatic tired roller

Table : Standard procedures for compacting construction materials in the field;
(Large field tests are recommended to specify the details).

Smooth drum roller

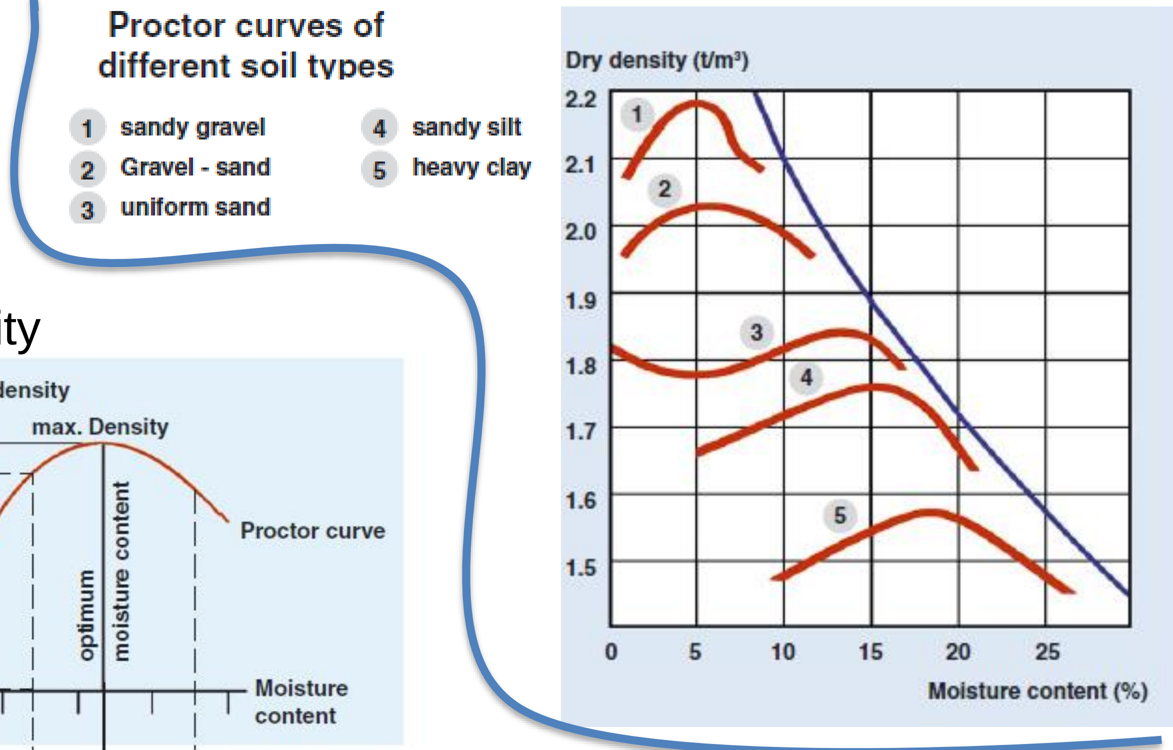
Padfoot roller

Pneumatic tired roller

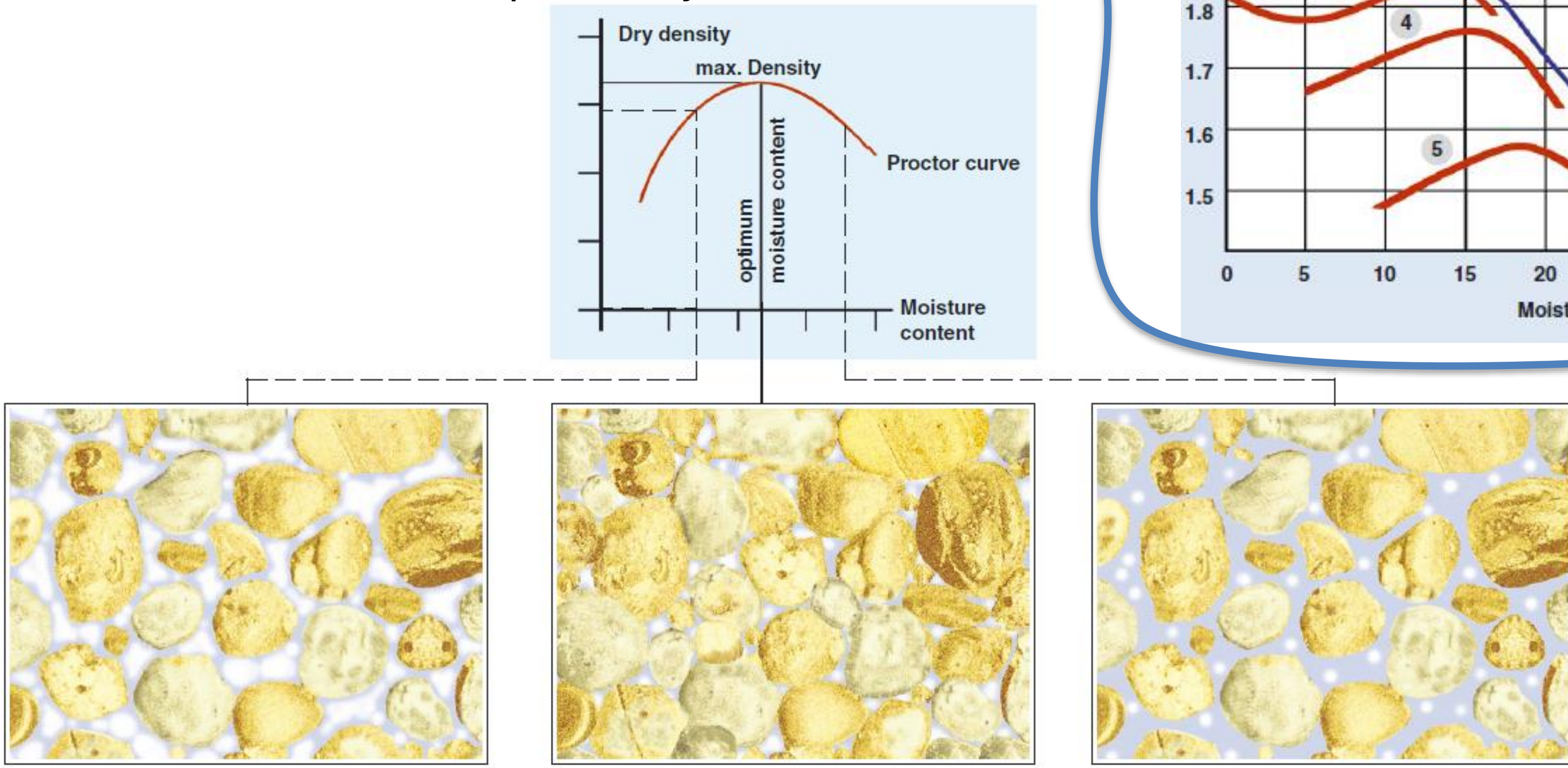
Compaction Fundamentals

- Place loose soil in the field and compact it to make soil strong and attain
  - Maximum shear strength
  - Very little settlement
  - Low hydraulic conductivity
  - soil lowest emin ……highest dry unit weight
- The most important variables affecting **construction of earthfill embankments** are **the distribution of soils, method of placement, water content, and compaction**

- Soils containing fines can be compacted to a specific maximum dry density with a given amount of energy;
- maximum density can be achieved only at a unique water content called **the optimum water content**.
- Maximum dry density and optimum water content are determined in the laboratory by compacting **five or more specimens of a soil at different water contents** using a **test procedure** which utilizes a standard amount of energy called **"standard compactive effort"**
- Most specifications require that the material is to be placed in the embankment at, or near, optimum moisture content and **at least 95% standard compaction** is to be achieved



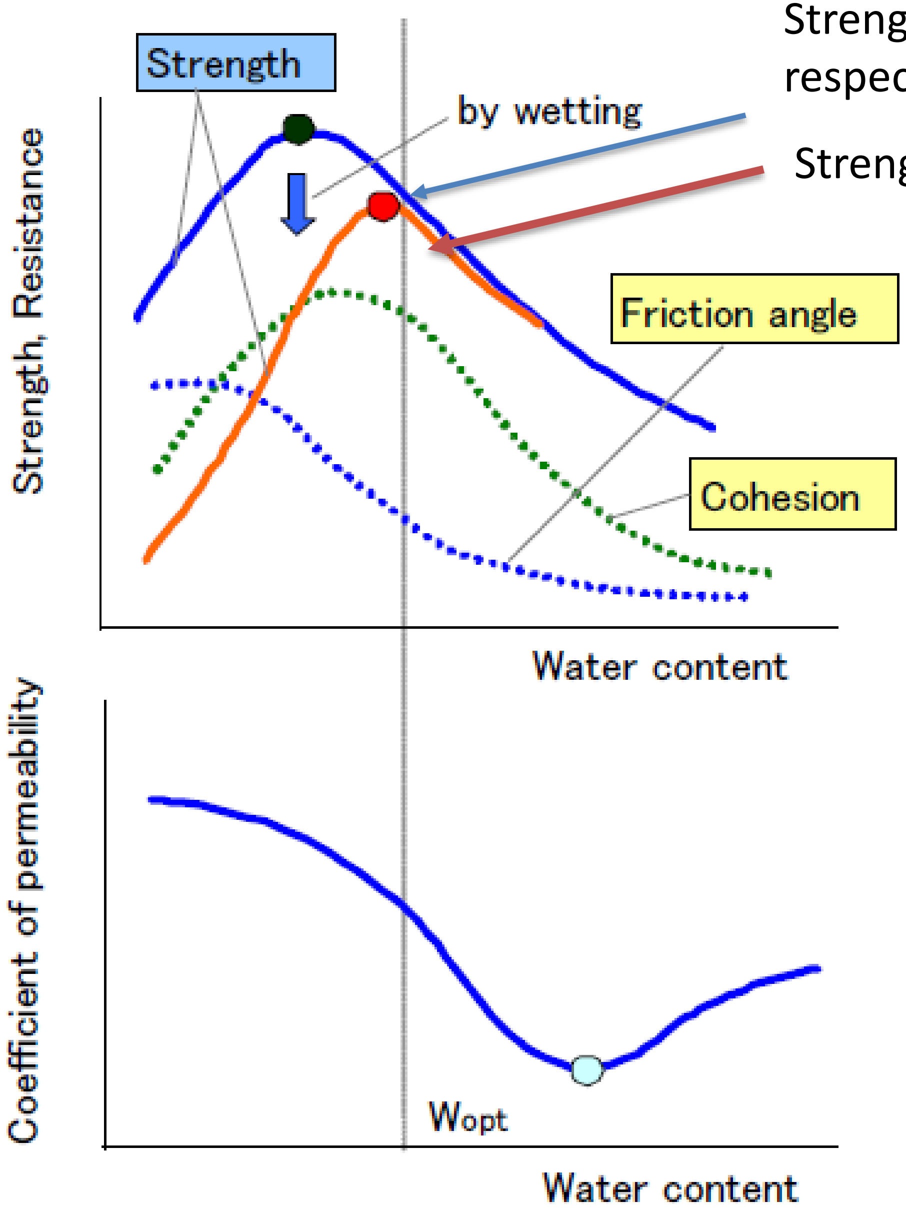
Influence of water on compactability



low moisture content
- high internal friction
- low density

optimum moisture content
- best compactability
- max. density

high moisture content
- high water pressure
- low density



Strength before reservoir filling with respect to moisture content

Strength after reservoir filling (saturation)

Compare the risks of dry side compaction with the wet side compaction

Strength and Permeability of Compacted Soils

Recommended degree of compaction of embankment materials (adapted from USER 1974).

Material	> 5 mm (% by weight)	Minimum (%)[3]	Desirable average (%)[3]	Water content (% ± w_{opt})
Cohesive soils[1]	0 to 25	98	100	0 to + 2
	26 to 50	95	98	0 to + 2
	> 50	93	95	0 to + 2
Non-cohesive soils[2]	Fine sand with 0 to 25	75	90	Very wet
	Medium sand with 0 to 25	70	85	Very wet
	Coarse sand and gravel with 0 to 100	65	80	Very wet

[1]With reference to Standard Proctor density
[2]With reference to relative density
[3]Percent of Standard Proctor and relative density, respectively

Standard proctor for cohesive soils
relative density for non-cohesive soils

The relative density *D* can as well be expressed by:

$$D = \frac{\gamma_{max}(\gamma - \gamma_{min})}{\gamma(\gamma_{max} - \gamma_{min})} \times 100\ (\%)$$

where γ_{max} = unit weights of the soil in most compact state
γ = unit weights of the soil in place
γ_{min} = unit weights of the soil in loosest state

$$\text{Compaction level } (\%) = \frac{\text{Insitu dry unit weight}}{\text{Max. dry unit weight (Proctor)}}\, x\, 100$$

Standard Proctor Specification 95 to 100 percent of MDUW(maximum dry unit weight)

DIMENSIONS, PLACEMENT AND COMPACTION OF FILTERS

The following is offered as a guide to practical minimum widths and also construction methods

a) Filters upstream or downstream of an earth core, when constructed by **end-dumping** off a truck should be at least 2.5 and preferably 3 m wide.

b) If a spreader box such as that shown in Figure below is used, a minimum width of 1.5 m is practicable. The filter material is dumped off the truck into the spreader box, which spreads the filter out of its base as it is pulled along by a small bulldozer.

c) If filter materials are very scarce or high cost, formwork can be used to contain bands of filters as narrow as one meter. Sherard et al. (1963) show an example of such placement. This is very unusual and would only be contemplated in exceptional circumstances.

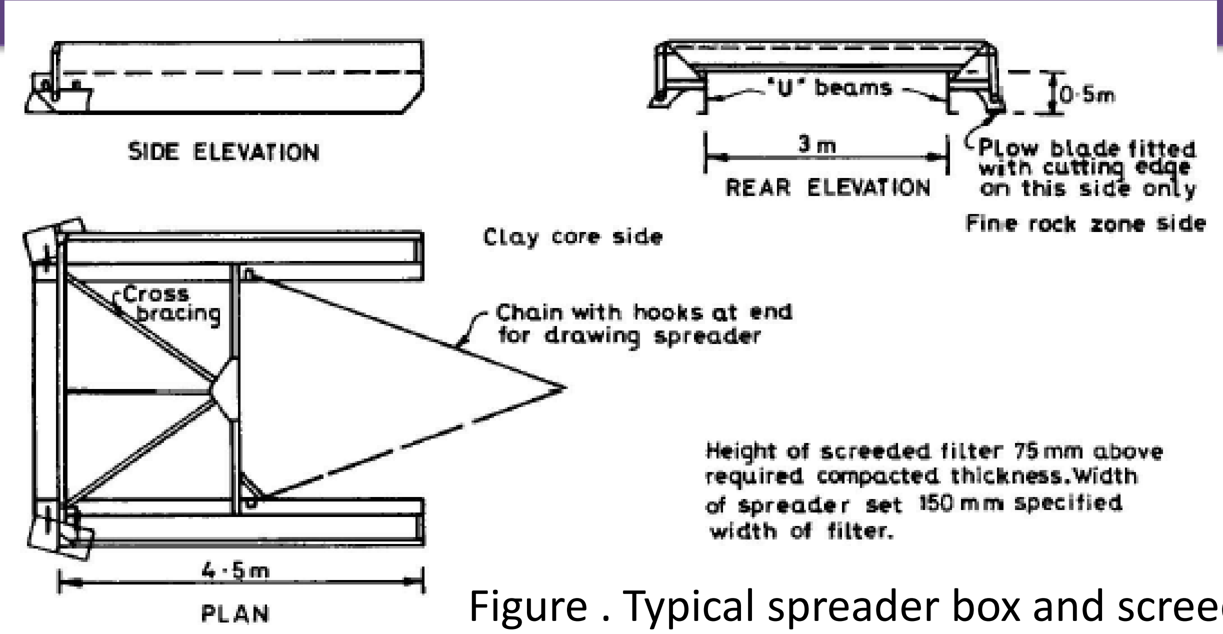


Figure . Typical spreader box and screed

Spreading sand filter material
(usually accomplished by graders or dozers)

spreader box

Trenching

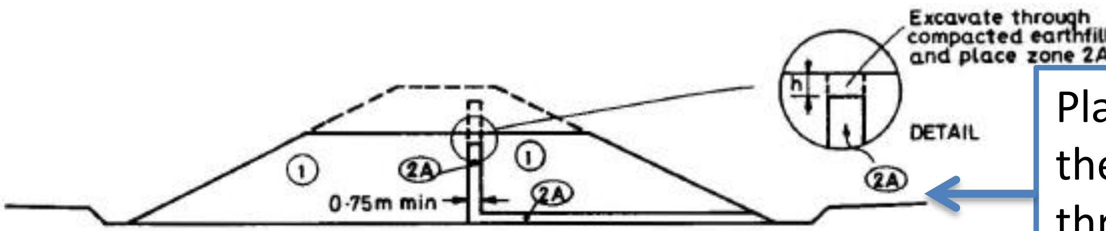


Figure Construction of vertical chimney drain by excavation through earthfill.

Placing the earthflll for up to 2m over the filter layer, and then excavating through the earthflll with a backhoe or excavator to expose the filter

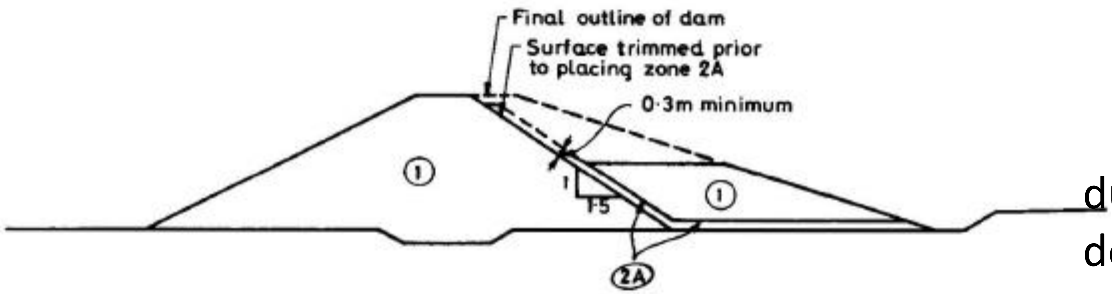


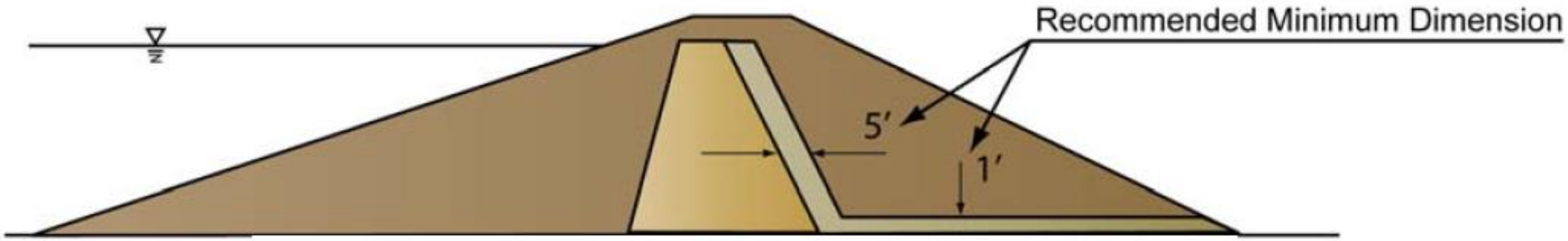
Figure .Construction of inclined chimney drain by placement on downstream slope of earthfill.

dumping the filter on the trimmed downstream slope of the earthfill core

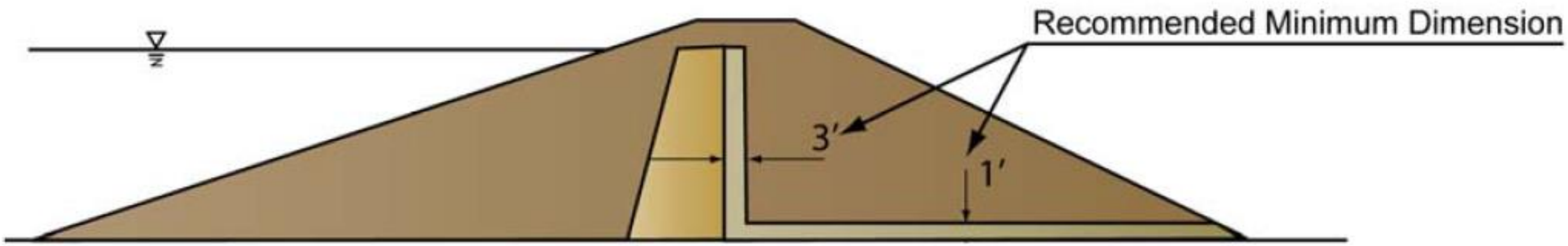
Trenching method – backfilling trench

Minimum recommendations

- Case (a) should be designed with a minimum horizontal dimension of 5 feet and 1 feet as shown
- Case (b) should be designed with a minimum horizontal dimension of 3 feet and 1 feet



a) Inclined chimney place together with adjacent zones



b) Vertical chimney placed together with adjacent zones

Sequence of placement

Filters generally should be placed **ahead of the adjacent earthfill or rockfill zones**. This is desirable because it allows good control of the width of the filter zone compared to the specified width, and reduces the risk of contamination of the filter zone with materials from the adjacent zones, and from water eroding off adjacent areas generally

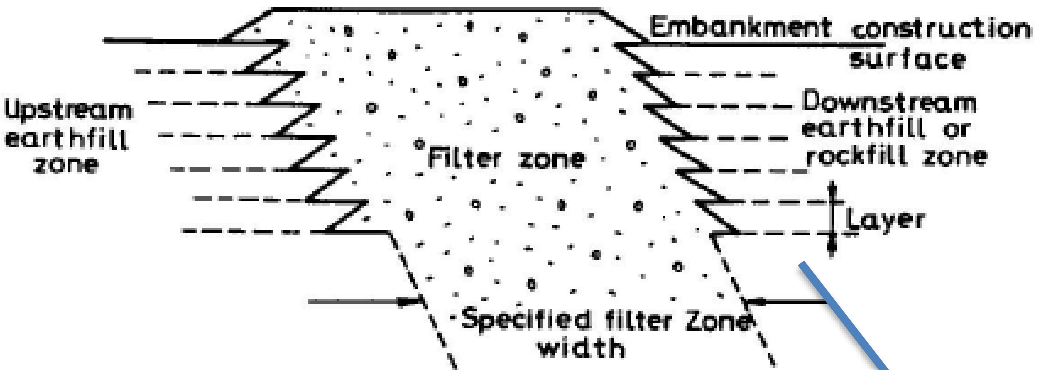
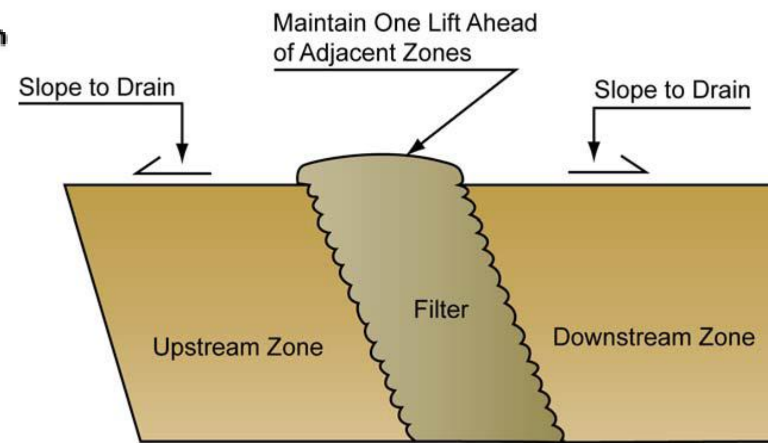


Figure Filter zone placement ahead of other zones – generally desirable.



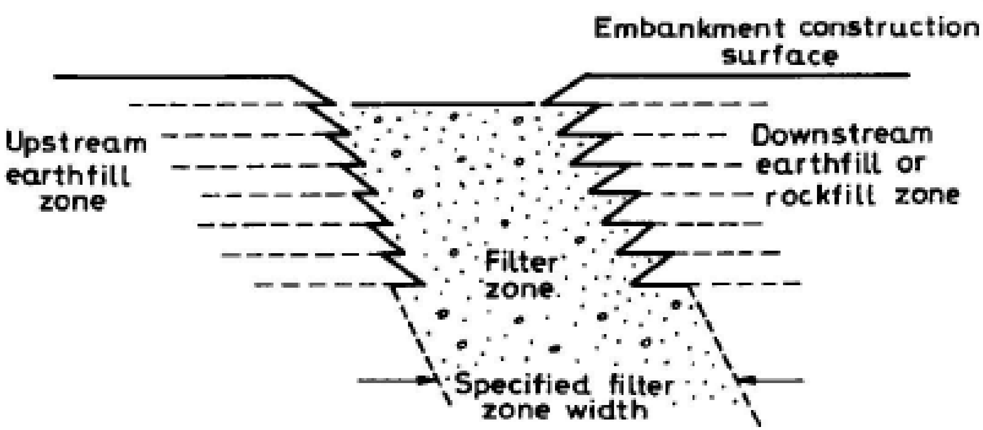


Figure Filter zone following construction of other zones – generally undesirable.

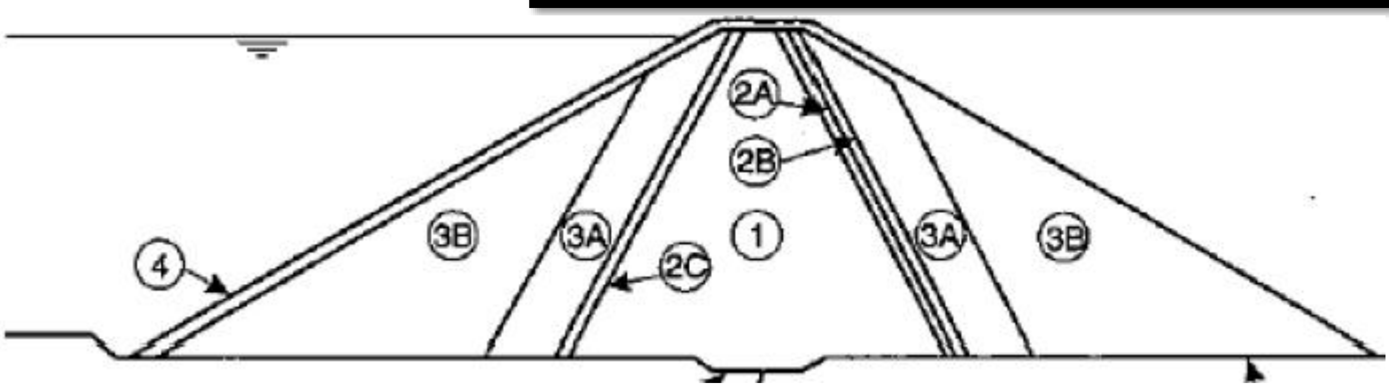
quantity of sand used

Compaction of filters

Filters should be compacted in layers using a vibratory smooth steel drum roller. Filters are usually well graded granular materials and are readily compacted to a dense condition

Table Typical filter compaction specifications.

Authority and dam	Zone	Standards specification	Methods specification
Water Resources Commission of Queensland, Peter Faust Dam (1989)	2A and 2B	AS1289. Density index between 60% and 70%	At least one pass of a suitably smooth drum vibratory roller to give standards specification. Maximum layer thickness 350 mm after compaction
Water Authority of Western Australia, Harris Dam (1989)	2A Chimney drain	AS1289. Density index > 70%	Not given. Maximum thickness 500 mm before compaction
	2A horizontal drain and 2B	Not specified	4 passes of a vibratory roller with static mass between 8 and 12 tonnes, and centrifugal force not less than 240 kN. Maximum thickness 600 mm before compaction
Melbourne and Metropolitan Board of Works, Cardinia Creek Dam (1970)	2A and 2B	Not specified	2 passes of a vibratory roller with static weight not less than 8 tonnes and a centrifugal force not less than 160 kN. Maximum layer thickness 450 mm after compaction
Snowy Mountains Hydroelectric Authority, Talbingo Dam (1967)	2A and 2B	Not specified	4 passes of a vibratory roller with static weight not less than 10 tonnes static weight and a centrifugal force not less than 350 kN. Maximum layer thickness 450 mm after compaction



Rock Fill

i. Dumped Rockfill construction

- the main body of fill is placed by dumping. The initial part of the fill is dumped from clamshell cranes, cableways, or from ramps on the abutments to form a mound or bank. The remainder of the fill is dumped from the top of this mound, allowing the rock to fall down the sloping surface. The combined effect of sliding, tumbling and impact cause the pieces to become tightly wedged together. Not more than 15% fines should be in the dumped rockfill, since they prevent good compaction and make drainage of water difficult.

ii. Rolled Rockfill

- Modern day rockfill dam construction
- It is placed in layers and then rolled by heavy rubber tyred rollers and heavy vibrating rollers. Four to eight passes are required for compaction.
- Optimum rockfill loose lift thicknesses are generally about 18 to 30 inches (0.5 to 0.8 m) with maximum rock sizes limited to two thirds of the lift thickness
- Rockfills for compacted dam structures are generally placed in transitional zones with the most coarse and competent rock placed in the outer shell and finer more weathered rock placed in the interior or adjacent to earthfill filter drain and core materials

iii. Reshaping the Fill

- the dumped rockfill assumes side slopes of the angle of repose. If a flatter slope is required it can be formed by introducing horizontal berms as required

Rock dump loose lift placement in 45 ft (15 m) thickness

Compacted rockfill placement in relatively thin controlled lifts for heavy roller compaction

Concrete face rockfill dam

construction of the face slab

The possible sequence of works associated with the face slab are:

- survey of the upstream face and the shotcrete protection applied to it.

  Due to movements of the embankment during the construction stage and probable bulging, it is necessary to trim the face back to its designed position, in order to enable the slab to be placed correctly and have the required thickness.

- Install the mortal pads along the vertical joints

  To be placed with a high degree of accuracy, because their position dictate the final shape, the thickness of the slab and also its surface specified tolerances. On these pads the cooper water stop will be placed along the full length of each bay

- reinforcing mats.

  Can be transported down the face with the use of a trolley travelling on two rail lines. The reinforcing mats can be placed in the middle of the slab thickness. The work can start from the bottom of the bay and progress up towards the top of the face.

- Casting the slabs consecutively, one after the other

Placement of the mortar pads

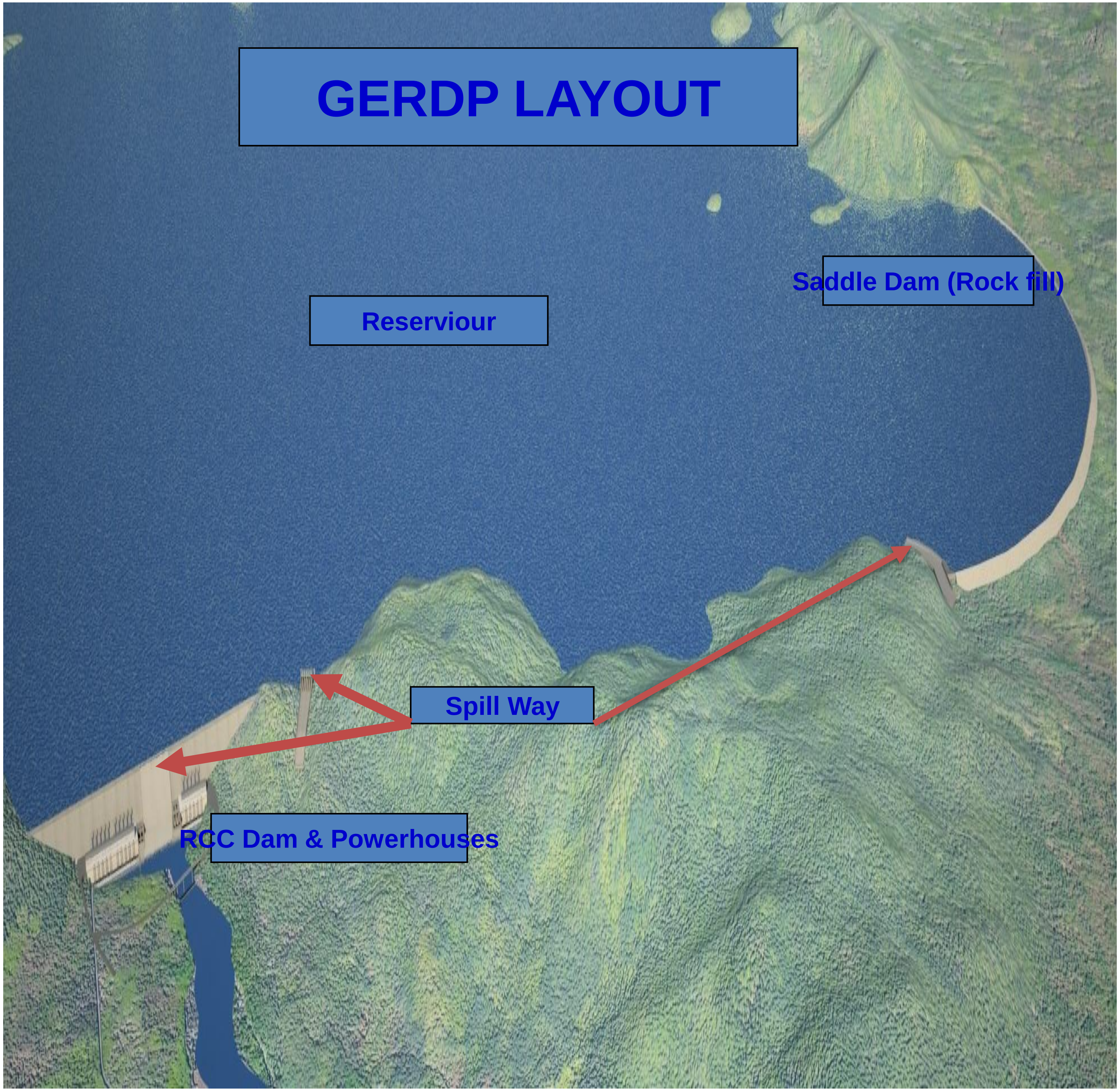
Reinforcement placing trolley

Self climbing slip form with side discharger

Upstream Face Slab Concreting

General view of a completed Dam

GERDP LAYOUT




SADDLE
DAM
SPILLWAY
MAIN DAM
2250 MW
3750 MW
POWER HOUSES

SADDLE DAM