Chapter 7 Water Conveying Conduits

After the capacity of the water conduit system is known, the type and size of the supply and drainage conduits have to be determined, which is an iterative process. Various types of conduits are discussed such as open- closed- underground- aboveground conduits, lined- and unlined- earth channels.

The main design formula for conduits is the Strickler/Manning formula. Other considerations are sufficient capacity also for unexpected/infrequent occurrences, social functions of the channels, and diversions from the design because of construction and (neglected) maintenance. A proper selection of the wall roughness coefficient should be made. Water velocities should be within a certain range to prevent erosion and sedimentation.
Evaluation of the wet area is discussed considering hydraulic characteristics, stability of the canal, needed space and steepness of the terrain. Further aspects are freeboard, embankment crest-width and length profile.

What you should know after studying this chapter

1. Types water conveyance conduits: Advantages and disadvantages of under- and aboveground closed- and open conduits, open conduits on supports, lined- / unlined earth channels at ground level, cut- and fill.
2. Strickler/Manning formula, design capacity, consideration social functions, hydraulic irregularities because of construction, neglected maintenance, determination of wall roughness $k_s = 1/n$, applicable water velocities, water levels, gradient, wet section (talus slope 1 vert. : m horiz., bed width / water depth relation n = b/h, combination m and n), freeboard, embankment crest, length profile.

7 Water Conveying Conduits

7.1 Introduction

When it is known for which capacity the water conveyance system has to be dimensioned, the type and dimensions of the conveyance conduits can be established. Conveyance conduits are used to convey the irrigation water from the source (reservoir or river) to the irrigation area, as well as discharging drainage water from the irrigation area to a buffer storage, river, lake sea or dessert. In this chapter is enunciated about the selection of the type and design of these conveyance channels.
In practice this is an iterative process because the type and design of a conveyance conduit affects the efficiency of the supply and discharge systems as well, and influences elapsing peak yields because of the storage in the conveyance system.

7.2 Types of water conveyance conduits

Successively a short overview will be presented of the possibilities, advantages- and disadvantages of some types of water conveyance conduits. The different types of water conveyance conduits are shown schematically in figure 7.1.

- *Underground closed conduits*

  - materials: concrete / steel / synthetic materials
  - free water surface / pressurised
  - advantages: independent of the terrain, water tight, maintenance free, well protected, no occupancy of land
  - disadvantages: construction is troublesome, relatively high costs, sedimentation problems

These type of conduits often are selected in case an open conduit is dangerous or objectionable such as in urban areas or when agricultural land is scarce. Also this type of conduits is used for the supply of water when water is very scarce and the demand fluctuates strongly, complicating economical supply in open conduits.

- *Aboveground closed conduits*

  - materials: concrete / steel / synthetic materials
  - free water surface / pressurised
  - advantages: independent on the terrain, water tight, maintenance free
  - disadvantages: construction is troublesome, relatively high costs, sedimentation problems

This type of conduit is used in the form of aqueducts or as terrain-independent distribution channels.

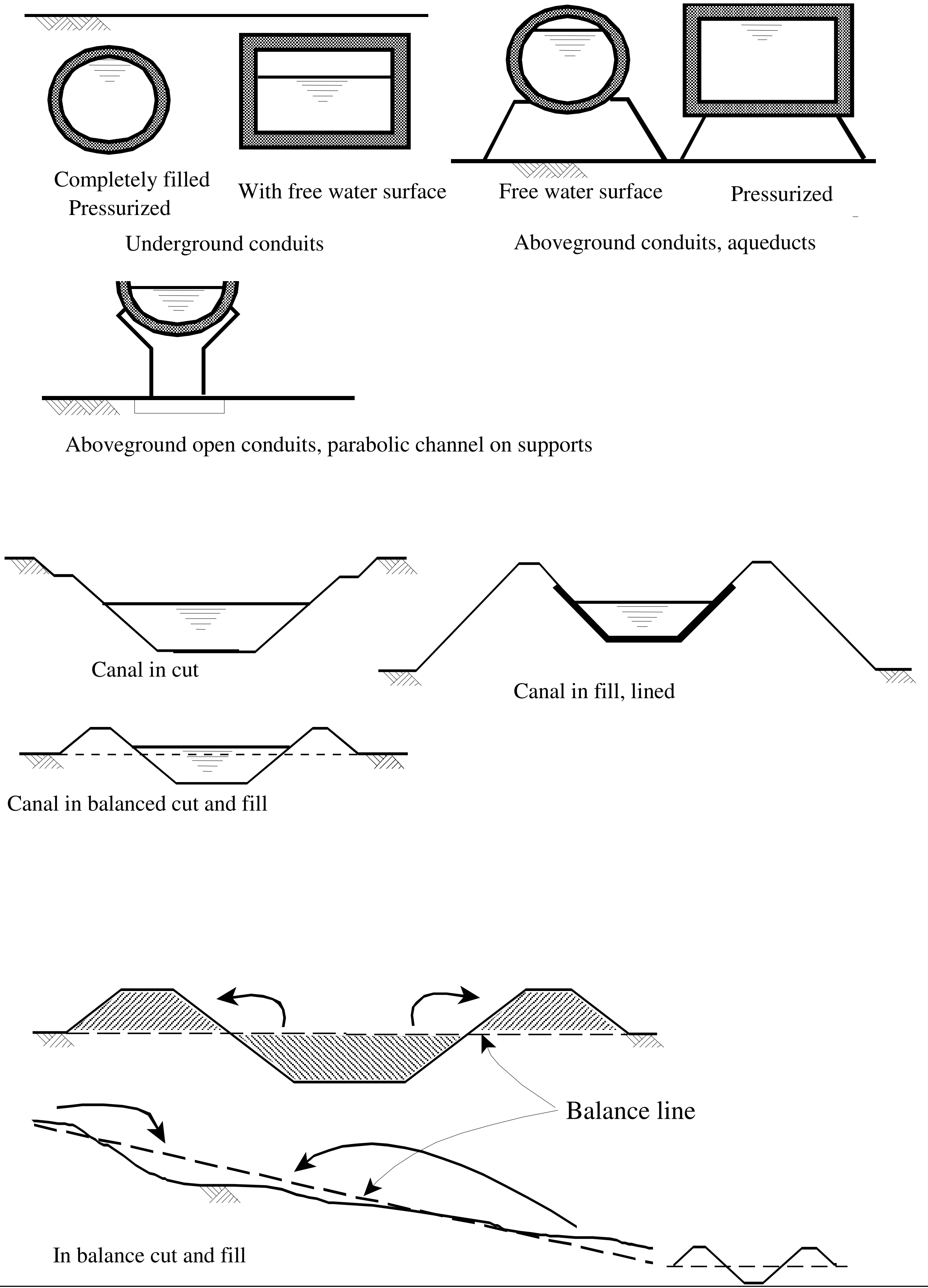

Figure 7.1 Types of conveyance conduits (irrigation and drainage channels)

- *Aboveground closed conduits on supports*

  - materials: concrete / steel
  - free water surface
  - advantages: independent on the terrain, water tight, limited maintenance, prefabrication system possible
  - disadvantages: costs, vulnerable on certain components

This type of conduits appear as aqueduct and as terrain independent distribution conduits.

- *Open earth conduits at ground level*

1. Lined:
   - Earthwork + lining
   - Lining against losses by leakage: concrete, masonry, asphalt, synthetic material, clay
   - Lining against erosion: concrete, masonry, asphalt, gravel/stone
   - Advantages: relatively simple construction, limited maintenance
   - Disadvantages: costs, groundwater, stability

Lined earth conduits often are applied to reduce seepage losses when the local soil is very permeable. Canal in high fills often are lined to prevent weakening of the high embankments. Also in case of no leakage losses protection against erosion may be necessary.

2. Unlined:
   - Earthwork only
   - Advantages: local material only, relatively simple construction, cheap
   - disadvantages: leakage, maintenance costs, limited water velocity resulting in large cross sections, erosion sensitive

Earthworks and the costs of earth canals can be limited by balancing cut and fill, in the cross-sections as well as in the longitudinal profile.

  - Cross section: volume cut = volume fill, which in practice never can be realised for 100 % along the longitudinal profile
  - Longitudinal profile: over the longitudinal profile the shortages have to be filled with soil of the parts with surpluses.

In the following paragraphs the design of open canal cross sections will be dealt with. For tubes with free water level the same principles apply. Pressurised tubes can be designed more simple because of the absence of problems relating to fluctuating water levels.

7.3 Design formulas water conveyance conduits

7.3.1 General consideration

With the design of conduits and canals there is a choice of various friction formulas originating from fluid mechanics. For the dimensioning of closed conduits in general the friction formula of Nikuradse is used. In irrigation practice, where 90% of the water conveyance conduits consist of earthen canals, nearly only the formula of Strickler/Manning is used. One of the reasons is that much is known about the roughness value in the Strickler formula (k_s) and there is an extensively experience with its use.
The most commonly used form of the formula is:

$$v = k_s . R^{\frac{2}{3}} . i^{\frac{1}{2}} \qquad (7.1)$$

When continuity is brought in (Q=v.A), this formula results in:

$$Q = k_s.A.R^{\frac{2}{3}}.i^{\frac{1}{2}} \qquad (7.2)$$

In which:

v	=	average water velocity
k_s	=	Strickler's wall roughness coefficient (= 1/n of Manning)
n	=	Manning's wall roughness coefficient
R	=	hydraulic radius
i	=	gradient of the water (bed) level
Q	=	discharge in the conduit
A	=	surface of the flow section

In the literature Strickler's formula often is indicated as Manning's formula in which k_s is replaced by the equivalent 1/n introduced by Manning, with which Manning introduced an extra coefficient for the modification from the metric to the imperial system. In hydraulics also often Chézy's formula is used: $Q = C.A.(R.i)^{1/2}$, consequently the Chézy-coefficient C equals $k_s.R^{1/6}$.
All these formulas only apply for permanent (not changing in time) and steady (same flow condition at every location along the canal) water flow (so the water level is parallel to the canal bed). In practice the dimensions of the canal are determined for the peak discharge with a permanent and steady flow. For the design of conveyance conduits the following guidelines and notes can be provided:

- The conveyance conduits must have adequate capacity to transport the peak discharge at times of the largest water demand. For discharge conduits applies that they can discharge the design flow, with a certain probability of occurrence, at all times. Nowhere the conveyance conduits should be a bottleneck in the supply- and drainage of the water. This involves that with the design the assumed roughness parameters should not be assumed too optimistic, e.g. for economical reasons.

- Irrigation and drainage canals often form part of daily life of the community in the form of bath-, drinking- and wash water supply (bathing children, washing of domestic cattle). In areas where Bilharzia occurs use of canals should be prevented to the utmost, e.g. by locating the canals far away from the villages. By walking on the talus the k_s value of the canal section can decrease.

- Irregularities at the banks, even far outside the theoretical accepted profile, decrease the k_s enormously, even when the net section is considered! This can occur when the canal is cut or blasted out of a rock slope. Walls and bed have to be finished "smoothly" to reach the design capacity.

- A canal has to be maintained. A once cut canal also changes naturally without use by humans. Plant growth increases the friction, so regularly it has to be cleared. The water transports sand and silt which can deposit, and has to be removed when the canal is dry. Also erosion of the talus can occur, e.g. by seeping out groundwater when the water level subsides, or attack by the flow at some depth. With a proper chosen shape of the section the pace of deterioration (erosion and sedimentation) can be limited so that maintenance remains manageable.
  In the Netherlands the regular mowing of canal vegetation is necessary to keep up the canal capacity.

7.3.2 Determination of the parameters

Usage of Strickler's (or Manning's) formula.

The basic problem is that with a given formula and canal dimensions always only one Q will be found, but that with a given peak discharge Q a large amount of combinations of channel dimensions and materials (determining k_s) are possible.
For each design it is the art to find the most favourable combination to convey the peak discharge.

- *Surface roughness: k_s*

The surface roughness has been approached and computed in many different ways. In the irrigation practice mostly is worked with values known from experience, depending on wall material, surface finishing and type of conduit. In the handbooks overviews can be found, a.o. Ven Te Chow "Open Channel Hydraulics (see table 7.1).

Table 7.1 Roughness coefficient n of Manning (Open Channel Hydraulics, Ven Te Chow)

v = 1/n . $R^{2/3}$. $S^{1/2}$
k_s = 1/n

UNIFORM FLOW

	n		
Type of channel and description	**Minimum**	**Normal**	**Maximum**
C. EXCAVATED OR DREDGED			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
D. NATURAL STREAMS			
D-1. Minor streams (top width at flood stage <100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or flood ways with heavy stand of timber and underbrush	0.075	0.100	0.150

Many used values for earthen channels are (compare with table 7.1):

- Well maintained earthen channels (Q>10 m3/s): $k_s = 50$
- Existing discharge conduits or drains with irregular walls: $k_s = 30$
- Small earthen channels, well maintained $k_s = 30$

- Applicable water velocities

A = Q/v, which means that with a given design discharge Q, a higher water velocity leads to a smaller section A, which may be cheaper. But $v = k_s.R^{2/3}.i^{1/2}$ and to have a large velocity v with a smaller section A (costly causing R to reduce) the gradient I would have to increase strongly. The therefore needed drop in elevation is not always available and forcibly a larger section with a lower velocity has to be designed.

The highest realisable velocity will lead to the cheapest channel section, but the allowable velocity is bound to a maximum. A too high velocity leads to scouring and erosion of the section. Internationally normally the recommended values of the United States Bureau of Reclamation are used as given in table 7.2. This table incorporates the sediment present in the water. Colloid sediments "blocks" the channel walls so that slightly higher velocities are allowed. In literature several prescriptions can be found.

Table 7.2 Permissible water velocities in earthen channels (U.S.B.R.)

Original material excavated for canal	**Velocity, in m per second, after aging, of canals carrying**		
	clear water, no detritus,	**water, bearing colloidal silts**	**water, bearing non-colloidal silts, sands, gravels or fragments**
Fine sand (non-colloidal)............	0,45	0,75	0,45
Sandy loam (non-colloidal)........	0,53	0,75	0,60
Fine loam (non-colloidal)...........	0,60	0,90	0,60
Alluvial silts when non-colloidal.....................................	0,60	1,05	0,60
Ordinary firm loam.....................	0,75	1,05	0,68
Volcanic ash..............................	0,75	1,05	0,60
Fine gravel.................................	1,05	1,50	1,13
Stiff clay (very colloidal)	1,13	1,50	0,90
Graded, loam to cobbles,............ when non-colloidal....................	1,13	1,50	1,50
Alluvial silts when colloidal.......	1,13	1,50	0,90
Graded, silt to cobbles, when colloidal...........................	1,20	1,65	1,50
Coarse gravel (non-colloidal).....	1,20	1,80	1,95
Cobbles and shingles.................	1,50	1,65	1,65
Shales and hardpans	1,80	1,80	1,50

COMPUTATION NEEDED LEVEL IN SERVICE CONDUIT

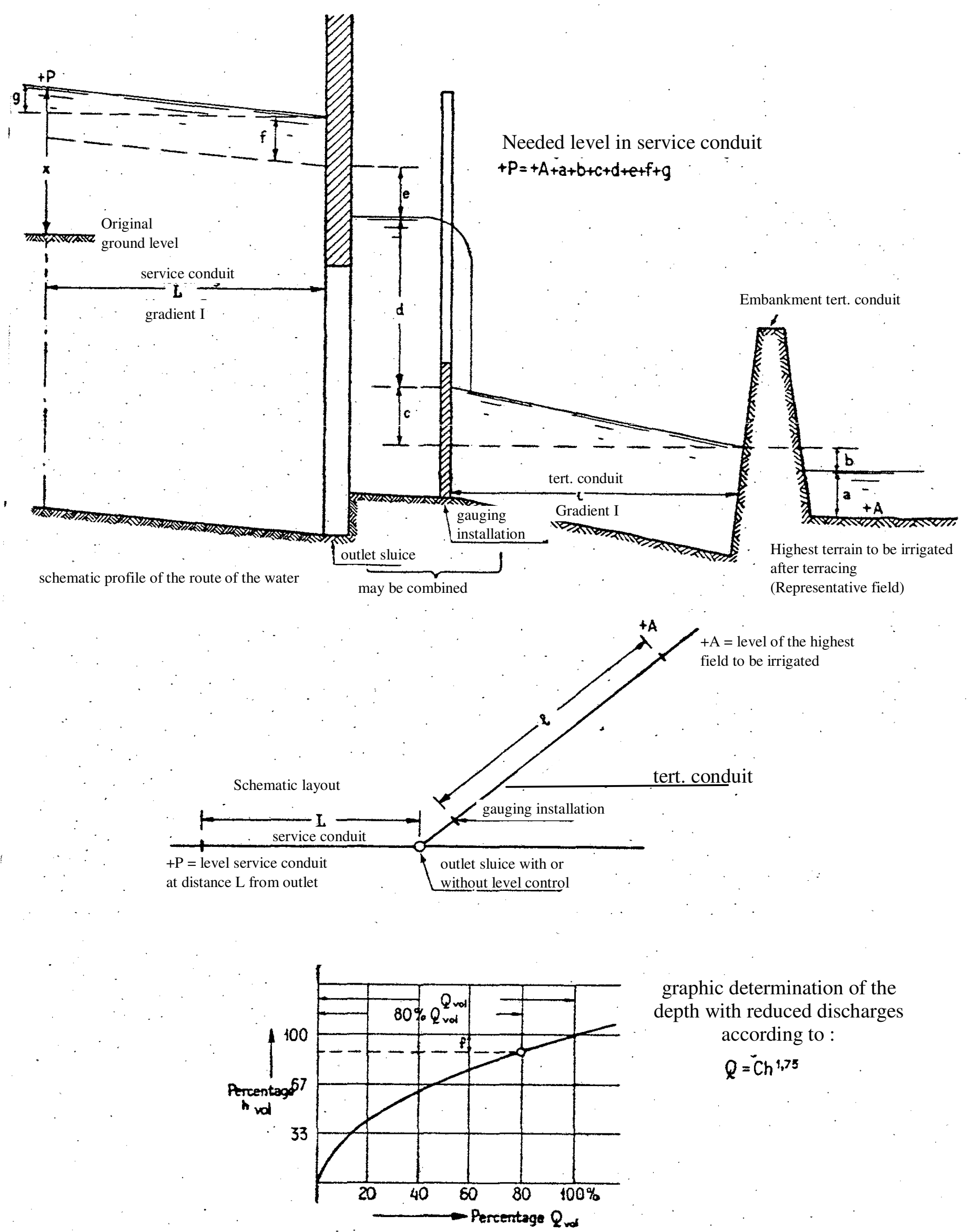

Figure 7.2 Computation of the necessary level in the service conduit

Maximum allowable velocities also can be computed with the shear tension theory (see the chapter "Sedimentation and erosion"). Also with that computation method it has to be known in which type of soil the channel is excavated. Note that according to this theory the water depth affects the allowable velocity, contrary to the recommendations above. When the water contains sediment that could deposit and as such disturb the channel section, then the minimal water velocity has to be so large that the sediment remains in suspension. The costs of dredging of the deposited sediment can mount strongly. This adds extra requirements to the to be designed combination of v, A and i and the relation between channel depth, channel width, bed width and slope of the talus. This problem is dealt with further in the chapter "Sedimentation and Erosion".

For the time being in the following paragraphs is departed from channels without sedimentation hazard.

- <u>Water levels</u>

The levels necessary for the water delivery at the outlets mostly determine the amount of water levels in a channel reach. From these to be computed levels the limits of the possible gradient is found. An example of the determination of a water level is given in figure 7.2.

- <u>The gradient</u>

The gradient I (also i or S) of the channel mostly is fixed because the levels at the begin and at the end of the channel section is fixed within margins.

$$I = \frac{\Delta H}{L} \qquad (7.3)$$

I	=	gradient
)H	=	drop in elevation over the channel section
L	=	length of the channel section

In case very low water velocities are found (with the associated large and expensive channel section with the given Q), with the preliminary design it should be tried to increase)H as much as possible and/or reduce L by short-cutting bends.

Are the velocities too high then:

- Either the channel has to be lined with e.g. concrete, rock etc. to maintain the high water velocities without erosion;
- Or the)H over the channel section should be reduced by constructing drop structures at the beginning, end or within the channel section, to dissipate the surplus of energy.

As primary assumptions for suitable gradients in earthen conduits can be departed from 0.2 m/km (0.2/1000) for very large channels; 1.0 m/km (1/1000) for small field channels. Using these initial values the suitable channel alignments and sections can be found by trial and error.

- <u>The wet section</u>

Talus slope 1 vertical : m horizontal

To limit costs it is tried to make the talus slopes as steep as possible. Steep talus and deep cuts channels give narrow channels of low excavation costs. Steep talus can be dangerous however; a person who has fallen in a channel with talus 1 vert. : 1.5 horiz. will not be able to climb out without help, in particular in case of a fast flow and hard and smooth talus. Therefore deep and steep channels need to have provisions at regular distances to climb out (masonry steps, pieces with extra flat talus), and/or fencing to keep people and animals out.

Further the talus slope is determined by geo-technical properties. Channels cut in rock can have a vertical talus of 1 vert. : 0 horiz., while channels cut in non cohesive silt require a talus of 1 vert. : 4 horiz. or flatter. For large channels a bowl shaped section can be applied with talus according to a broken line e.g. as in figure 7.3.

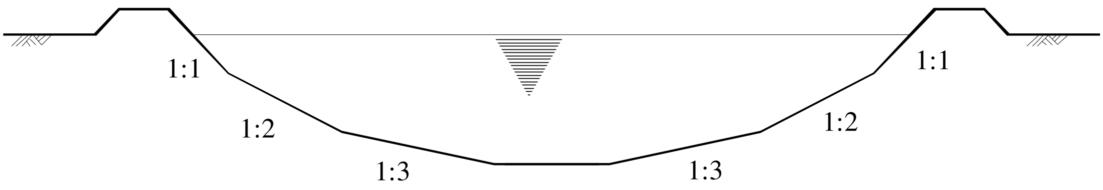

Figure 7.3 Bowl-shaped channel section

Frequently used talus slopes are:

- 1 vert. : 1.0 horiz. small tertiary conduits and drains
- 1 vert. : 1.5 horiz. discharges 1 to 1.5 m^3/s
- 1 vert. : 2.0 horiz. large discharges

These slopes have to be checked for their stability by geo-technical tests or construction of trial-sections.

Bed width / water depth ratio n = b/h

Wide channels require more expropriation costs so that deep narrow channel sections are tried. On the other hand deep channels are more difficult to maintain and are more likely to erode or slip. On Java mostly n = 8 was used for larger channels. In the Punjab and Egypt much larger values are used.

Combination of m and n

Table 7.3 gives as example the design prescriptions for m and n combinations for Java as established by Prof. Haringhuizen.

Table 7.3 Prescribed combinations talus-slope and bed / depth for irrigation channels in Java.

Q [m^3/s]	**m** [1:tgx]	**n** [b:h]
<0,5	1.0	1.0 - 2.0
0,5 - 1	1.5	2 - 2.5
1 - 2	1.5	2.5 - 3.0
2 - 3	1.5	3.0 - 3.5
3 - 4	1.5	3.5 - 4.0
4 - 5	1.5	4.0 - 4.5
5 - 10	1.5	4.5 - 6.0
10 - 15	1.5 - 2.0	6.0 - 7.0
15 - 25	2.0	8.0

In different countries and water boards different descriptions can be found fitting the local condition.

- Freeboard

The crest of the embankment of a canal lies above the theoretical water level at the design discharge. This freeboard varies from 0.20 m with little field channels of less than 0.1 m^3/s, to 1.75 m with the design of the Narmada main channel in India with a design discharge of 1000 m^3/s. The freeboard is particularly important to safely absorb the long-wave effects because of the operation of the sluices, and for buffering in case temporary the volume of water taken in is more than the volume of water let out. Where these effects are small, like with many Dutch buffer channels, a small freeboard will be satisfactory.

- <u>Crest of the embankment</u>

The crest of the embankment often is used also as an inspection- and maintenance road. The minimum width is 0.3 m for pedestrians, 1.0 m for cyclists and 43.5 m for motorised traffic. When the maintenance road will be used also as public road extra width and safety measures will be required.

- <u>The longitudinal profile</u>

The final design is laid down in a longitudinal profile for the following functions:

- To record all consequences of the chosen alignment and the design variables;
- Means to check if all connections of the plots etc. are correct and the required drops are available;
- Means to rapidly verify the hydraulic computations;
- Design drawing to compute the quantities of materials (and excavations) to estimate the costs.
- Tender drawing based on which the contractor can compute a price, and set out and construct the channel in the field.

An example longitudinal profile of a continuous discharge channel without delivery points is given in figure 7.4. An example of a cross section of a secondary channel is given in figure 7.5. The different design parameters are combined in the nomogram for the computation of watercourses (figure 7.6). Also the computer programme "Profile" available at the section LWB is a suitable aid.

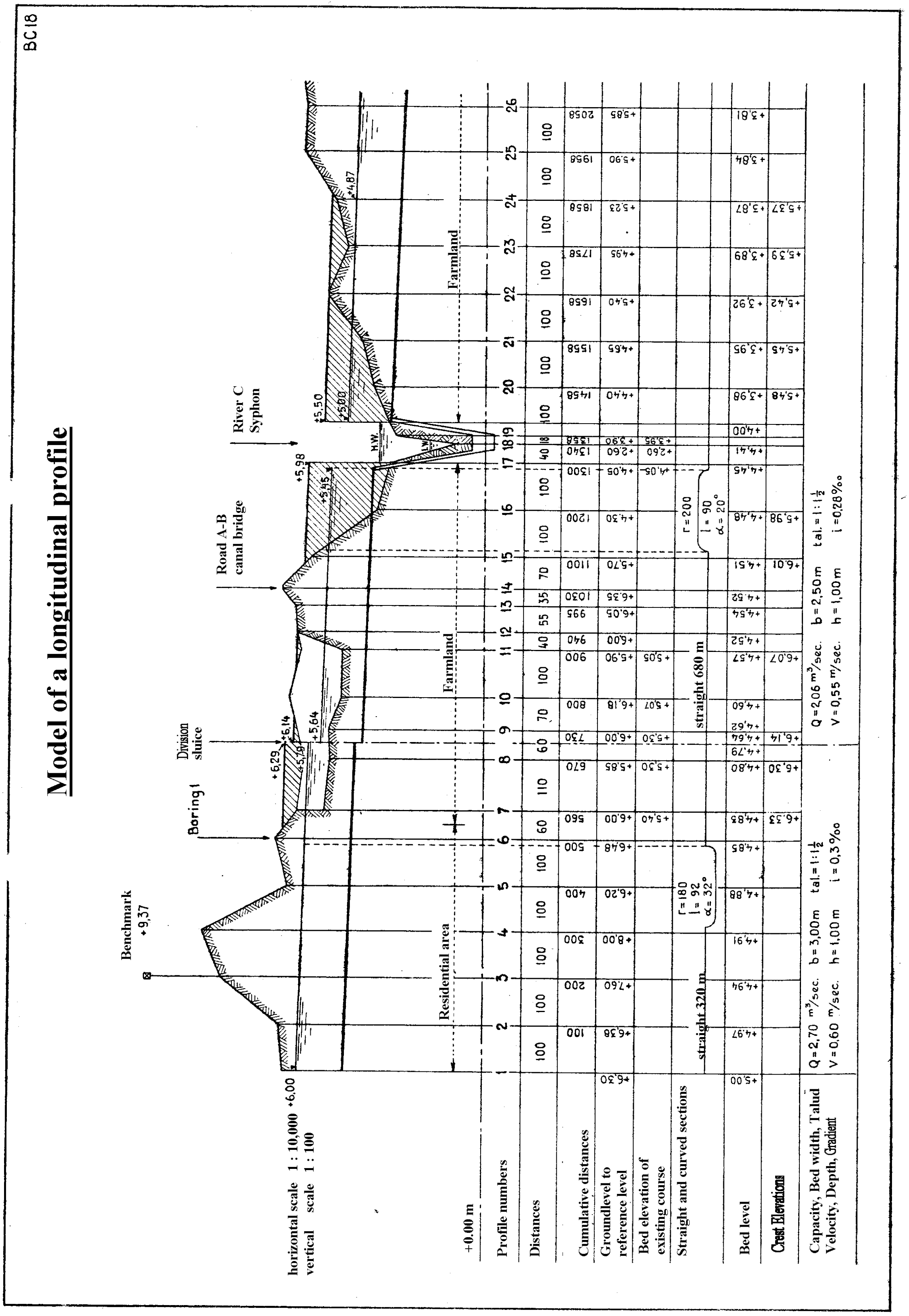

Figure 7.4 Example of a longitudinal profile

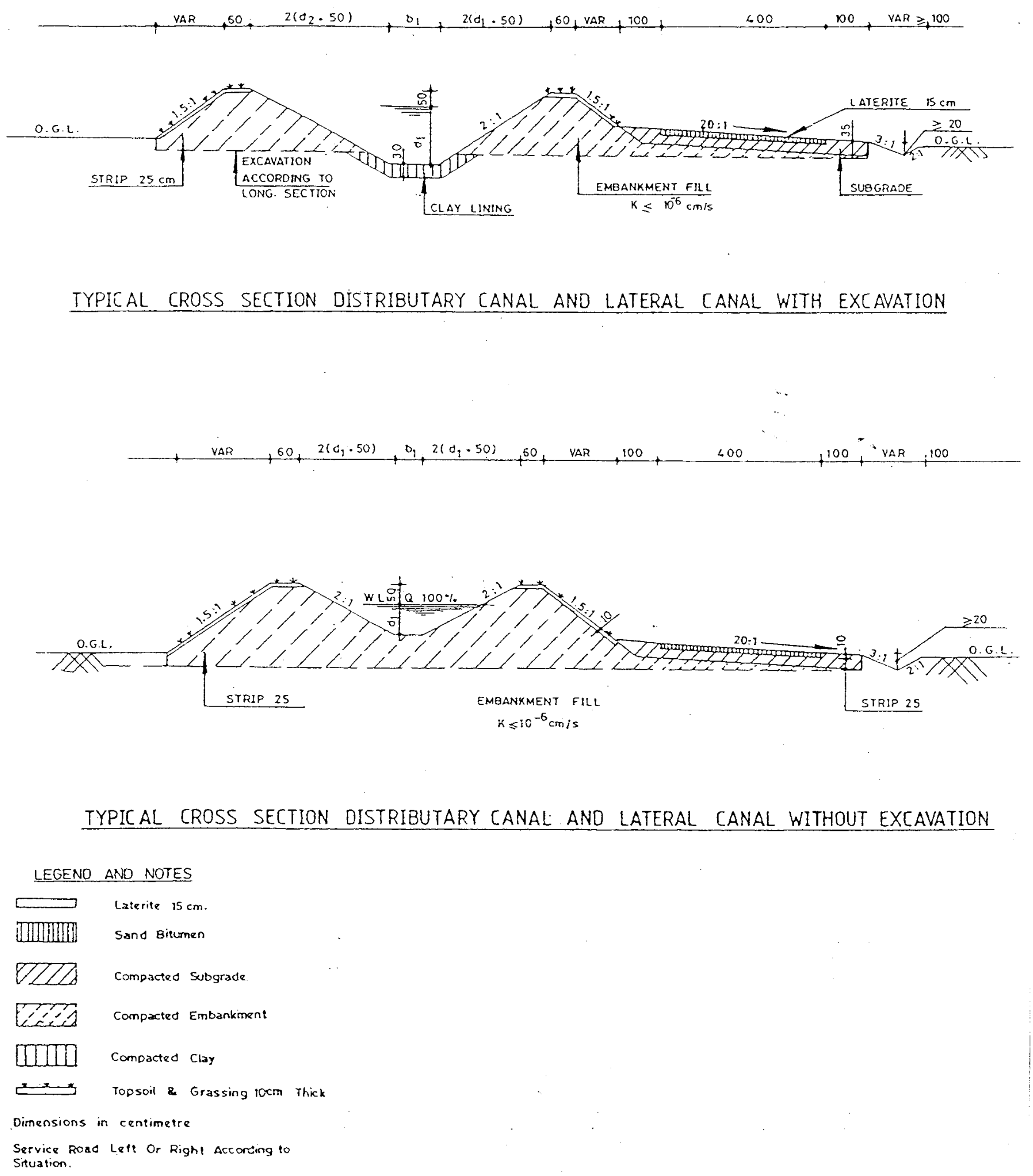

Figure 7.5 Example of a cross section

Figure 7.6 Nomogram for the computation of watercourses