

Annex 2

How to construct a canal

A2.1 INTRODUCTION

Annex 2 describes the technical aspects of canal construction. However, attention should also be paid to social aspects of canal construction, as it is important to involve farmers in the project from the very beginning of the designing of an irrigation scheme. Designers and authorities responsible should be in close contact with the farmers in order to identify their needs and to form consensus for the proposed project design. Only when farmer participation is well developed should construction of the system be carried out, and that construction must be done in close cooperation with them. At the same time, farmers should be brought to realize that the system needs to be maintained, and that they are responsible for this. Again, this can only be possible when farmers are participating in every stage of the project from the first beginnings right through to the first water delivery.

A2.2 CANAL ALIGNMENT

A2.2.1 Layout

With regard to the layout of a canal system, reference can be made to Section 7.4 of this manual.

One additional general remark can be made here. That is that the main canal of a system will be laid along the high edge of the irrigable area in order for the largest possible area to be commanded for irrigation. In most cases, the canal will closely follow the land contours, losing only enough elevation to maintain the slope needed for suitable flow velocity. The land commanded by the main canal will be subdivided into irrigation units of about 10 ha each.

From the main canal, secondary canals will be laid out to each irrigation unit, following the line of highest elevation in each unit so as to maximize the area served by each secondary canal.

Tertiary canals, or field channels, will then be laid out from the secondaries to deliver water throughout the unit.

A2.2.2 Bed slope

On flat sloping, non-undulating lands, canals will generally have the same slope as the terrain. In steeply sloping lands, canals will be given a slope which is less than the terrain to avoid high flow velocities. In such cases, drop structures will have to be installed to connect the canal sections. See also Section 5.6.2 of this manual.

When a canal crosses a depression or a gully, it cannot follow the terrain and should be constructed in fill, and if a ridge in the terrain has to be crossed the canal will have to be constructed in cut. See Figures A2.1 and A2.2 in Section A2.2.3.

Whatever the slope of the canal, abrupt changes in the slope should be avoided. If the bed slope changes suddenly the flow velocity in the canal will also change, and such a change in flow velocity can cause erosion or may lead to siltation in the canal bed.

A2.2.3 Bed elevation

Depending on local circumstances, canals can be built in fill or in cut. A typical cross-section of a canal in fill is shown in Figure A2.1, and in cut in Figure A2.2.

FIGURE A2.1
Cross-section of a canal in fill

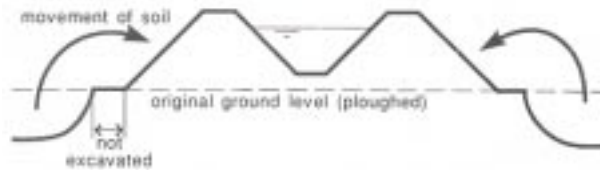
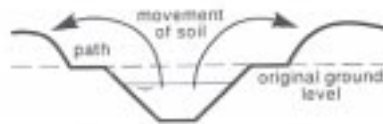


FIGURE A2.2
Cross-section of a canal in cut



There are three factors that play a role in deciding the level of the canal bed.

The first factor is that the slope of a canal should be as constant as possible. Abrupt changes in slope should be avoided. This may result in canal sections having to be constructed in cut or in fill, depending on topography.

Another factor is that the volume of cut should preferably equal the volume of fill when constructing the canal (See Figure A2.3).

FIGURE A2.3
Cross-section of a canal with balance between cut and fill



When the elevation of a canal bed is so high that the volume of fill is larger than the volume of cut, soil has to be brought from elsewhere. This may result in high construction cost. Also, if a canal is to be constructed in cut, the excavated soil is to be spread out over the fields or it should be used elsewhere, which also increases the cost of canal construction. Construction costs are usually at a minimum when there is a balance between the volumes of cut and fill.

The third factor to take into account when determining the bed level of a canal is the water level in the canal. The water level in field channels should be about 0.10 m higher than

the level of the fields to be irrigated from those canals, and the water level in a secondary canal which supplies a field channel should be about 0.05 m higher than the design level in the field channel. This is because of the loss in water level at the canal offtake.

The bed elevation and water level at the downstream end of a tertiary canal is determined as the first step, assuring at least 0.10 m difference between the water level in the canal and the field level. Going upstream, it should be checked that the water level in the field channel all along the channel is at least 0.10 m higher than the fields. Further upstream, the water level in the secondary canal can also be determined, taking into account the 0.05 m loss at the canal off-takes.

A2.3 DESIGN AND CONSTRUCTION OF A CANAL EMBANKMENT

As has been discussed, canals may be constructed in cut or in fill depending on local circumstances.

Canals in fill are constructed above ground level by building embankments with soil brought from other locations or scraped from the adjacent field. For small canals, sometimes only one large embankment is constructed, and then the canal cross-section is excavated in the middle.

See Figure A2.4.

FIGURE A2.4
Canal in fill



A.2.3.1 Design of an embankment

Before an embankment is to be constructed, its elevation and its width have to be calculated.

The elevation of the top of the embankment (ETE) can be calculated as follows:

- For a canal with a bed elevation higher than the field (See Figure A2.5-A)

$$ETE = h + \text{bed elevation}$$

- For a canal with a bed which is lower than the field (See Figure A2.5-B)

$$ETE = h - \text{bed elevation}$$

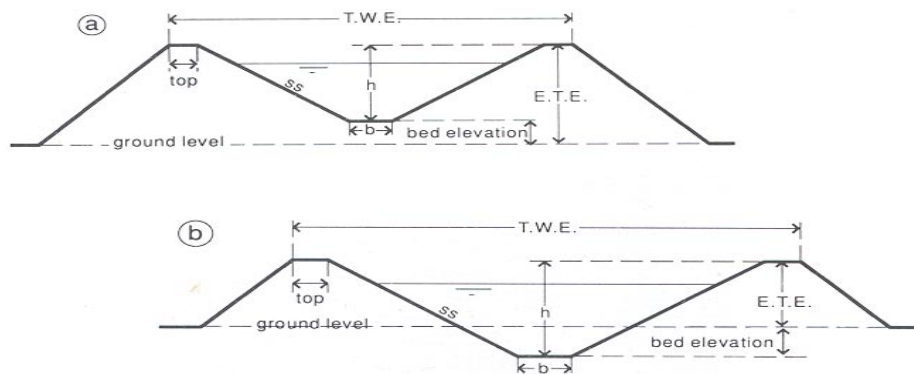
in which: ETE is the Elevation of the Top of the Embankment in metres; h is the Height of the canal cross-section (relative to bed elevation) in metres; and Bed elevation is the elevation of the canal bed in relation to the adjacent field, in metres.

The top width of the embankment (TWE) (See Figure A2.5) can be calculated using:

$$TWE = b + (2 \times (h / ss)) + (2 \times \text{top})$$

in which: TWE is the Top Width of the Embankment (the distance at the top between the two outer edges of the embankments, in m; b is the Bed width in m; h is the height of the cross-section (relative to bed elevation) in m; ss is the side slope of the cross-section; and top is the width of the top of the canal bank in m.

FIGURE A2.5
Elevation and width of a canal embankment



EXERCISE A2.1

Question 1: What should be the elevation of the top of an embankment, given the following (See Figure A2.7-A):

- Height of the cross-section of the canal to be excavated in the embankment is 0.70 m;
- Elevation of the bed of the canal to be constructed will be 0.20 m lower than the field.

Answer: For a canal with a bed which is *lower* than the field, use: $ETE = h - \text{bed elevation}$.
 $h = 0.70$ m; bed elevation = 0.20 m below ground level.
Hence $ETE = 0.70 - 0.20 = 0.50$ m.

The canal embankment should be 0.50 m above the original field level.

Question 2: What should be the top width of the embankment (See Figure A2.6), given:

- The bed width of the canal to be constructed is 0.30 m;
- The height of the cross-section is 0.70 m;
- The side slope of the cross-section is 1:1.5 or 1/1.5;
- The canal banks will be used as a path and should have a minimum width of 0.40 m.

Answer: Use the formula: $TWE = b + (2 \times h/ss) + (2 \times \text{top})$, where $b = 0.30$ m;
 $h = 0.70$ m; $ss = 1/1.5$; and $\text{top} = 0.40$ m.

$$TWE = 0.30 + (2 \times 0.70 / (1/1.5)) + (2 \times 0.40) \\ = 0.30 + (2 \times 1.05) + (2 \times 0.40) = 3.20. \quad TWE = 3.20 \text{ m.}$$

The canal embankment to be constructed has a top width of 3.20 m.

Soil used for building an embankment should have a good texture. Clay-rich soil is to be preferred, if available. Soil containing weeds, plant stubble or roots must not be used for construction as it is difficult to compact properly, and when the plant material rots it leaves small

holes that allow water to seep through the banks. If any of the plants sprout in the channel this will increase the maintenance need.

The fill section should be constructed in layers of 5 to 10 cm thick, and should be compacted moist by tamping and rolling. Moistening is done by sprinkling each layer.

A.2.3.2 Construction of an embankment

The following steps can be used as guidance for the construction of an embankment.

Step 1 *Based on the canal layout, locate the alignment of the canal and plough a strip in the terrain where the embankment is planned*

A strip in the field is ploughed to clear all vegetation and roots. The material removed can be used to dress the sides and top of the completed embankment before planting grass. The width of the strip should be larger than the total width of the future canal embankment.

FIGURE A2.6
Determination of elevation and width of an embankment

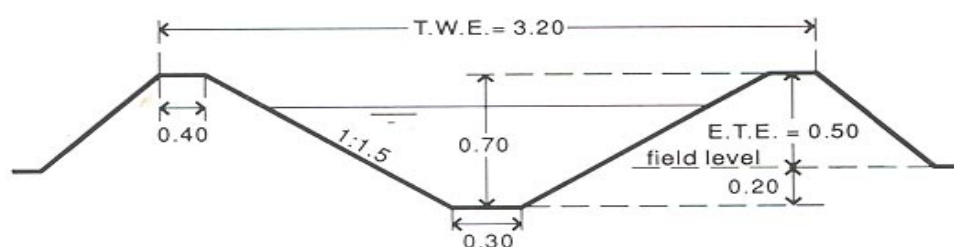
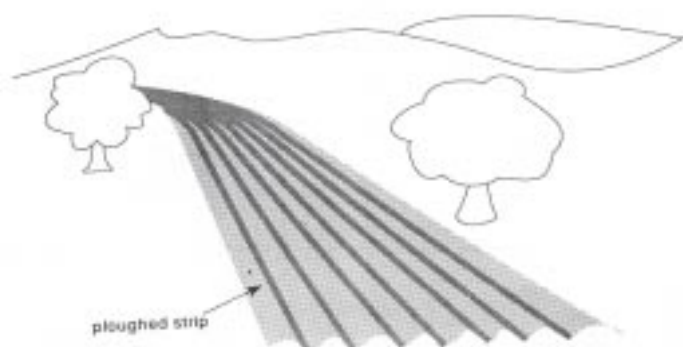


FIGURE A2.7-A
Ploughing the field as preparation of embankment construction

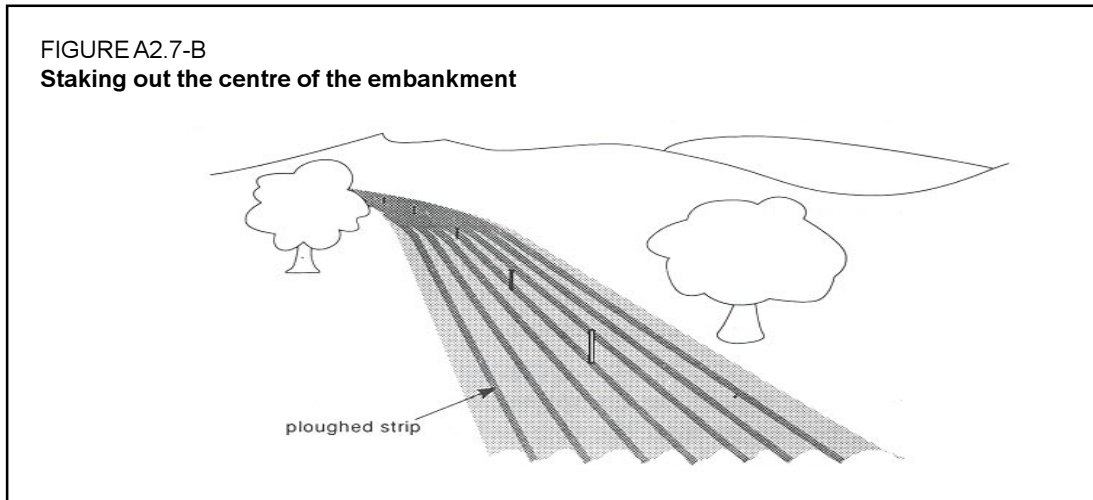


Step 2 *Hammer pegs in the soil every 50 m in a line to mark the centre line of the embankment and its final level.*

The top of each peg should indicate the top level of the embankment at that point.

Mark the centre line of the embankment in between these points with boning rods every 10 m. (See Figure A2.7-B, and also Training Manual 2, Section 6.1.2)

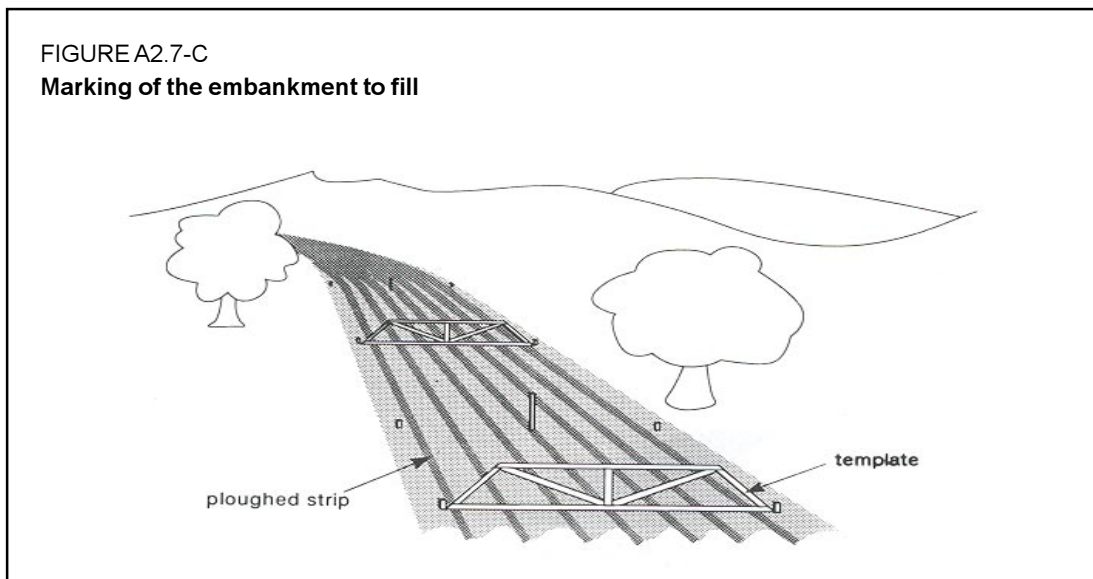
FIGURE A2.7-B
Staking out the centre of the embankment



Step 3 Every 10 m, mark the outer line of the body of the embankment to be constructed

The top level of the embankment has been marked in Step 2. The outside slope of the embankment must be stable and depends on the material which is used. As a rule of thumb, a slope of 1:2 [1 vertical to 2 horizontal] may be taken. Marking for the outside line of the embankment can be done by using a template, which can be made from sticks, bamboo or other material. See Figure A2.7-C.

FIGURE A2.7-C
Marking of the embankment to fill



Step 4 Construct the embankment

The embankment is constructed by adding soil in 5 cm thick layers, with each layer compacted moist. See Figure A2.7-D.

Figure A2.8 shows an embankment under construction. Mark the width of the embankment at the foot.

FIGURE A2.7-D
Construction of the embankment

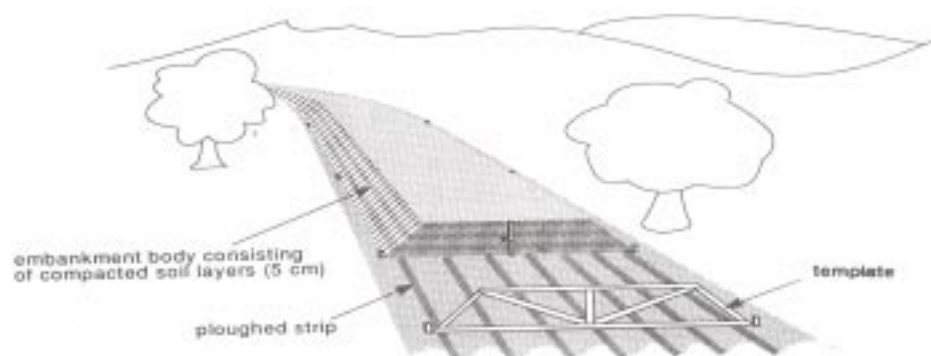


FIGURE A2.8
Embankment under construction



A2.4 CONSTRUCTION OF A CANAL - AN EXAMPLE

Small irrigation canals are either dug in the original soil or they are excavated in an embankment, constructed as described in the previous section. In the former case the soil is generally well compacted and stable, while in the latter case the embankment may not be very stable even after elaborate compaction during construction. Therefore it is good practice to wait at least one rainy season before excavation of a canal in an embankment can start, having thus allowed the soil in the embankment to fully settle down.

In this section the procedure for canal construction is presented. As an example the section of the embankment which was determined in Section A2.3 will be used. The embankment has been constructed and has been allowed to settle. The elevation and size of the embankments has been checked, and is according to the specification.

NOTE 1 Larger canals in fill or partly in fill are usually constructed by bringing up soil from two sides. The two canal banks are then re-shaped to conform to the designed cross-section of the canal.

NOTE 2 The construction of small canals in cut is identical to the construction of small canals in fill, assuming that the latter is excavated in an embankment.

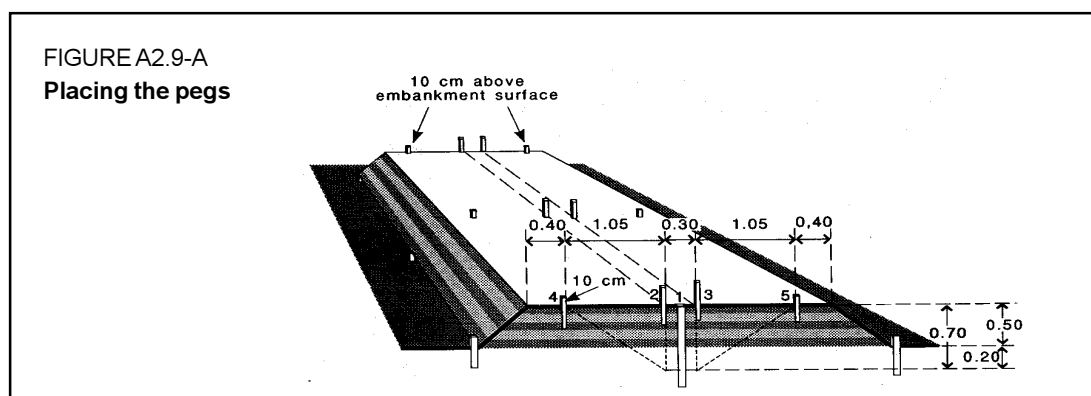
NOTE 3 Canals should be built continuously from one end, not as scattered small sections. This results in uniform construction, and makes supervision easier.

Before the canal is constructed, all plant growth, rubbish, stones and other debris should be removed from the site.

The procedure for constructing a canal is given in steps. The dimensions of the canal are as follows (See Figure A2.9-A):

- Height of the cross-section: $h = 0.70$ m
- Bed width: $b = 0.30$ m
- Side slope: $ss = 1/1.5$ or $1:1.5$
- Top width of canal banks: $top = 0.40$ m

Step 1 *Mark the cross-section with pegs.* (Figure A2.9-A)

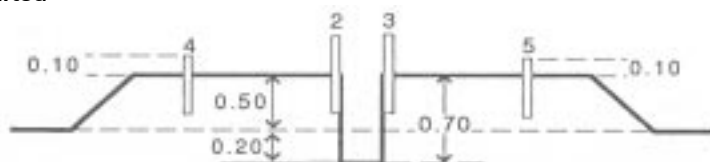


- Hammer a peg in the centre line of the canal, which is usually done during the embankment construction period. This is Peg 1.
- Measure the bed width: 0.15 m to each side of Peg 1. Place Pegs 2 and 3 perpendicular to the centre line of the canal.

- Calculate the width of the inner side of the canal bank by dividing the height of the cross-section by the side slope. In this case, $w = h / ss = 0.7 / (1/1.5) = 1.05$ m.
- Measure 1.05 m from Peg 2 and from Peg 3, and drive Pegs 4 and 5 firmly into the soil, because later they will serve as reference pegs. Fix the level of these pegs in relation to the top of the embankment, by, for instance, putting a mark at 0.10 m above the design top of the embankment. The difference in level between the marks at Pegs 4 and 5 and the canal bed is then 0.80 m (height of the cross-section + 0.10 m).
- For a canal in cut, measure a path of 0.50 m next to Pegs 4 and 5, marking the points with Pegs 6 and 7. As earth is excavated it should be placed outside of these pegs so that the earth will not fall back into the excavated canal section.

Step 2 *Excavate a trench*

FIGURE A2.9-B
Excavation is started



- Remove Peg 1. Excavate the soil between Pegs 2 and 3 until approximately 0.1 - 0.15 m above the final bed level.
- Deposit the excavated earth at the foot of the embankment, or outside of Pegs 6 and 7 in the case of a canal in cut. The deposited soil may be spread out over the adjacent fields later. (Figure A2.9-B)

Step 3 *Excavate the cross-section*

FIGURE A2.9-C
Excavation nearly completed



- Remove Pegs 2 and 3, and excavate a rough canal cross-section approximately 0.1 - 0.15 m above the final section. Final trimming and finishing should be done by checking the final canal section carefully. (Figure A2.9-C)

Figure A2.10 shows a canal under construction. Step 3 is almost finished.

Step 4 *Check the cross-section of the canal*

- Hold a solid frame (template) against Pegs 4 and 5, and check the bed and the side slopes at the same time, remembering that the marks on Pegs 4 and 5 are 0.10 m higher than the design top of the canal banks. Any over-excavation or slide in side slope should be carefully filled and compacted, as for the embankment in Section A.2.3.2.
- The canal should be checked at intervals of 10 metres. (Figure A2.9-D)

FIGURE A2.9-D
Bed level and side slopes are checked

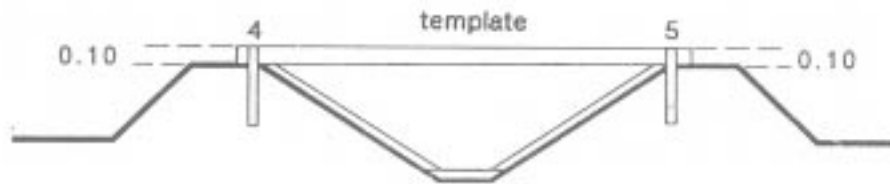


FIGURE A2.10
Canal construction at step 3



A2.5 ENLARGING THE CAPACITY OF AN EXISTING CANAL

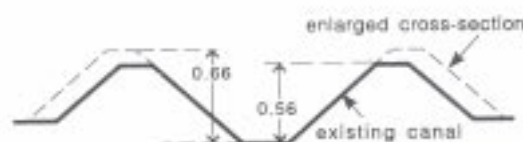
It may be necessary in existing irrigation schemes that some canal sections have to be enlarged in order to give these canals a larger capacity. This can be done by increasing the maximum allowed water depth, either by raising the banks or by deepening the bed. It is also possible to enlarge the bed width (See also Annex 1). Examples of enlarging capacities by these three methods are given in the following sections.

A2.5.1 Enlarging canal capacity by raising the canal banks

The procedure to follow for enlarging a canal capacity by raising the banks will be given for the canal discussed in Annex 1, Section A1.3.1, based on the following assumptions (See figure A2.11):

- capacity before enlargement: 56 l/s
- capacity after enlargement: 80 l/s
- height of the cross-section before enlargement: 0.56 m
- height of the cross-section after enlargement: 0.66 m
- Bed width: 0.30 m

FIGURE A2.11
Cross-section before and after enlargement



Step 1 Construct a template for the existing cross-section

A template of plywood is made with the dimensions of the actual cross-section: bed width, b_{old} , top width, a , of the cross-section, and embankment height, h . See Figure A2.12-A.

FIGURE A2.12-A
Template for canal cross-section

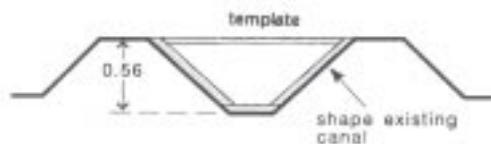
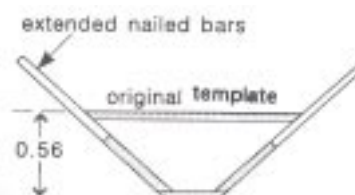


FIGURE A2.12-B
Template with bars

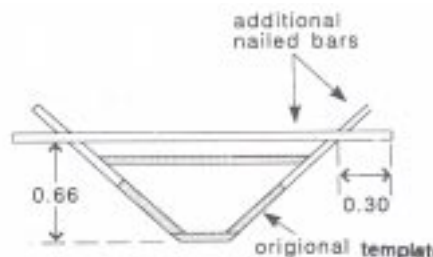


Mark the elevation from the canal bed so that the height of the canal cross-section can always be checked. The sides of the template has bars nailed to it which are long enough to mark the height of the new embankments. See Figure A2.12-B.

Step 2 Adapt this template for the new enlarged cross-section

Another bar is nailed on the template, parallel to the bed at a height of 0.66 m, which is the new height of the embankments. The same bar indicates the widths of the crests of the banks, here 0.30 m. See Figure A2.12-C.

FIGURE A2.12-C
Template gives the size of the new cross-section of the canal



Step 3 Excavate the canal embankments partially

The canal embankments are partially excavated to have better contact between old and new embankments, as in Figure A2.12-D. In the middle of the embankments, a deeper trench is excavated in order to avoid seepage between the old and new soil.

Step 4 Fill the embankments, layer by layer, and compact moist; check the new cross-section regularly using the template.

FIGURE A2.12-D
Partially excavated embankments



FIGURE A2.12-E
Filling the new embankment and checking the cross-section



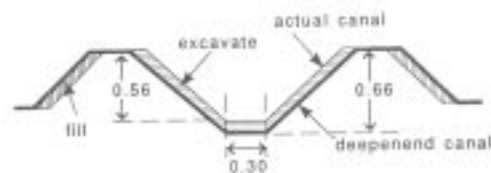
The new embankments are built up with moist soil. The filling of the embankments is done layer by layer, with each layer compacted moist. The new cross-section can be regularly checked with the template. Attention should be paid to the width of the crests of the embankments. They should be at least 0.30 m wide, and more if they will be used as paths. (Figure A2.12-E)

A2.5.2 Enlarging canal capacity by deepening the bed

Instead of raising the embankment of a canal, its bed can be deepened to increase water depth. As an example, the procedure is given for the same canal as was discussed above, in Section A2.5.1. See Figure A2.13.

- Step 1** See Step 1 in Section A2.5.1.
Step 2 See Step 2 in Section A2.5.1.
Step 3 *Excavate the bed and sides of the canal and check the cross-section regularly.*

FIGURE A2.13
Actual and deepened canal

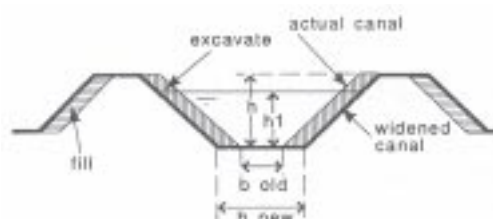


The sides and bed of the canal are excavated until the template fits. The excavated soil can be used as fill for the embankments. See Figure A2.13.

A2.5.3 Enlarging a canal capacity by enlarging the bed width

A canal's capacity may also be enlarged by widening the bed width. In this case the height of the canal banks remain the same, and only the sides of the cross-section are to be excavated. The same procedure as described above can be followed, by using a template for a wider canal. See Figure A2.14.

FIGURE A2.14
Actual and widened canal



Annex 3

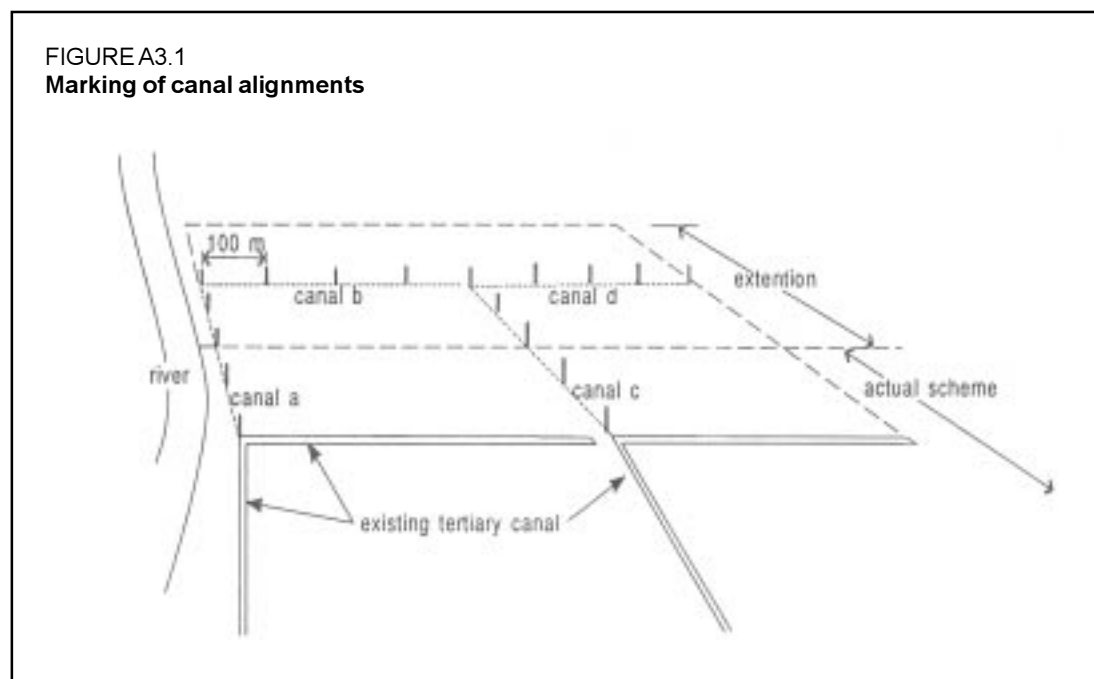
How to determine the slope of a canal alignment

Annex 3 describes a method for determining the slope of a new canal alignment. Reference is made to the extension of the irrigation scheme that was discussed in Chapter 7.

In Figure 50, canals a and b, and c and d are the proposed new canals. The slope of the terrain where canal b is planned will be determined here as an example. See Figure A3.1. The procedure is given in the following steps.

Step 1 *Mark in the field the centre line of the proposed canal, marking at regular intervals of say 50 or 100 m*

See Figure A3.1, in which the canal alignments of the extension in Figure 50 are marked.



Step 2 *Measure the elevations of the marked points and calculate the differences*

Calculation of the difference in elevation between distant points is described in Training Manual 2: *Elements of Topographic Surveying*.

The following data have been obtained by the field survey for canal alignment b:

- difference in elevation between point 1 and point 2: 0.16 m
- difference in elevation between point 2 and point 3: 0.12 m
- difference in elevation between point 3 and point 4: 0.13 m

Step 3 *Determine the average slope between the marks*

For determination of the average slope, the differences in elevation are divided by the distance between the two marks concerned. As a formula:

$$s_i = \text{difference in elevation}_i / \text{distance}_i$$

where: s_i is the average slope of the terrain between points 1 and 2; *difference in elevation_i* is difference in elevation between points 1 and 2, in metres; *distance_i* is the distance between points 1 and 2, in metres.

The following average slopes have been calculated for canal alignment b:

- Average slope between points 1 and 2: $s_1 = 0.16 / 100 = 0.0016$
- Average slope between points 2 and 3: $s_2 = 0.12 / 100 = 0.0012$
- Average slope between points 3 and 4: $s_3 = 0.13 / 100 = 0.0013$

Step 4 *Determine the average slope of the field where canal alignment b is projected*

The average slope of (future) canal b is determined by adding up the different average slopes of the sections and by dividing this sum by the number of measurements. In this example, three measurements were made, thus

$$\text{Average slope of canal alignment b: } S_b = (s_1 + s_2 + s_3) / 3$$

$$S_b = (0.0016 + 0.0012 + 0.0013) / 3 = 0.0014$$

Step 5 *Check whether the average slope of the canal alignment is within the range 0.0005 (0.05%) and 0.0015 (0.15%)*

The slope of the alignment calculated (0.14 %) is within the range of 0.05 to 0.15%, and so in this case the canal can be given the same slope as the terrain. If the calculated slope falls outside of this range, an irrigation engineer should be contacted for advice.