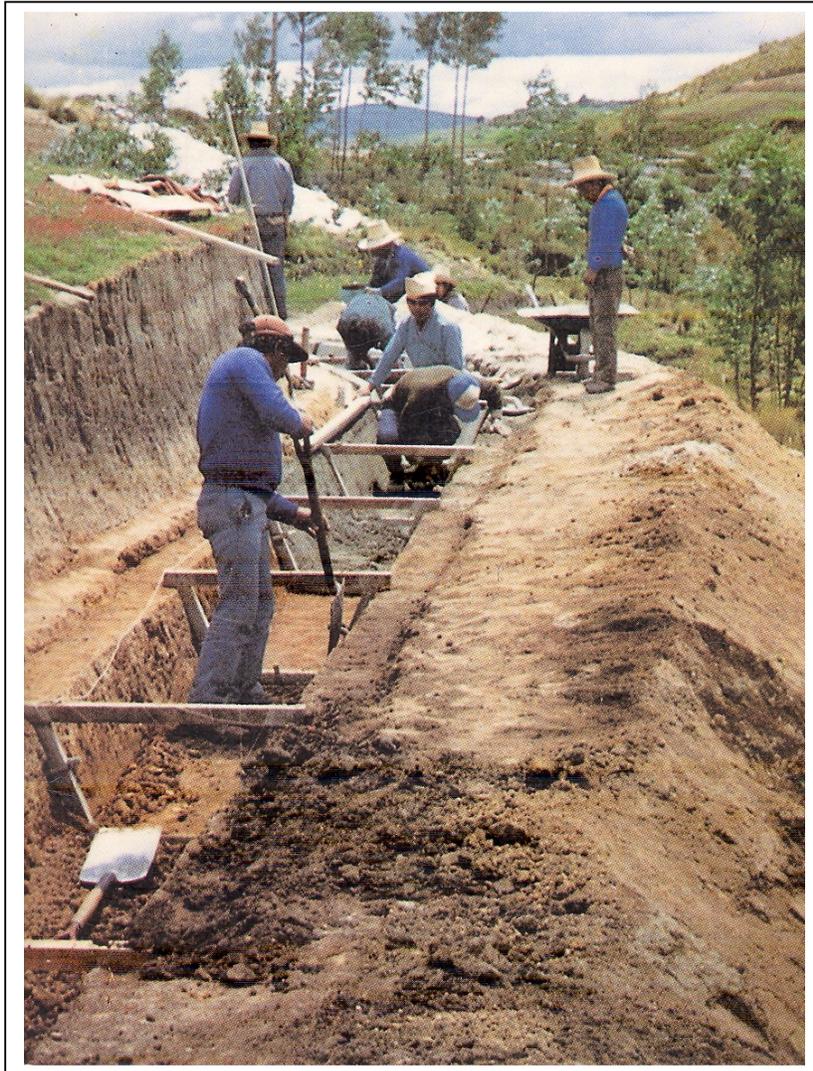# LAYOUT AND LINING OF
CANALS

Appropriate technology for micro hydroelectric power schemes

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LAYOUT AND LINING OF
CANALS
Appropriate technology for micro hydroelectric power schemes

INTRODUCTION

The use of small hydroelectric plants is an alternative for the development of thousands of isolated areas without any hope of being connected to the national electricity grid.

However, some important difficulties need to be overcome if the plants are to be a valid alternative, such as costs, the availability of equipment, technology, training on the maintenance and repairs of facilities, and so on.

Costs are naturally related to the availability of a local and appropriate technology. In an effort to make the use of Micro Hydroelectric Power Schemes a viable alternative for poor rural sectors, on this occasion ITDG is publishing an interesting canal construction method referred to as the *“CERCHAS” [WOODEN FRAMES] METHOD*.

ITDG has used this method to build canals in micro hydroelectric power schemes implemented in various parts of the country, reducing costs by 50% on materials and 30% on manpower, compared to the traditional formwork method.

This handbook is written in a simple language and contains guidelines for applying the above mentioned method, from the layout and excavation work to the lining and curing of the mix, guaranteeing the quality of the finished work.

The use of this handbook is not limited to hydro power, as we believe its dissemination could be of help to other fields such as irrigation.

The IT-PERU Hydro Power Programme believes this publication will be a valuable contribution to the efficient use of water for the benefit of rural people.

Intermediate Technology
(Soluciones Prácticas)

LAYOUT AND CONSTRUCTION OF CANALS

CANALS

A canal is an open-air waterway along which water flows unassisted.

The two main characteristics of every canal are:
- Geometric characteristics and
- Hydraulic characteristics

These are illustrated below.

Geometric characteristics (Fig. 1)

b = inner border

B = Canal bed

B$^{'}$ = Top base of the canal

b' = outer border

h = Depth of the canal

ø = Angle of the canal slope

A' = Cross-cut section of the canal (it can be rectangular, circular, trapezoidal or triangular)

Hydraulic characteristics (Fig. 2)

Q = Water flow (litres/second)

V = Water velocity (m/second)

A = Area of the cross-section of the mass of water conveyed by the canal (m^2). Its shape will depend on the cross-section of the canal

S = Slope or inclination of the canal bed, expressed in percentage terms or in so much per thousand

d = Water stress or depth

R = Hydraulic radius. $R = A/P$

P = Wet perimeter, the sum of two banks and the canal bed which are in contact with the water

n = Rugosity coefficient. Its value depends on the material the canal is made of (earth, concrete, stone, etc.).

Types of canal: (Fig. 3)

The most commonly excavated canals are rectangular, trapezoidal, circular and triangular, though this depends on the cross-section.
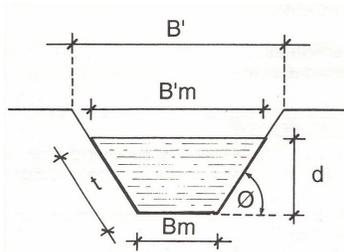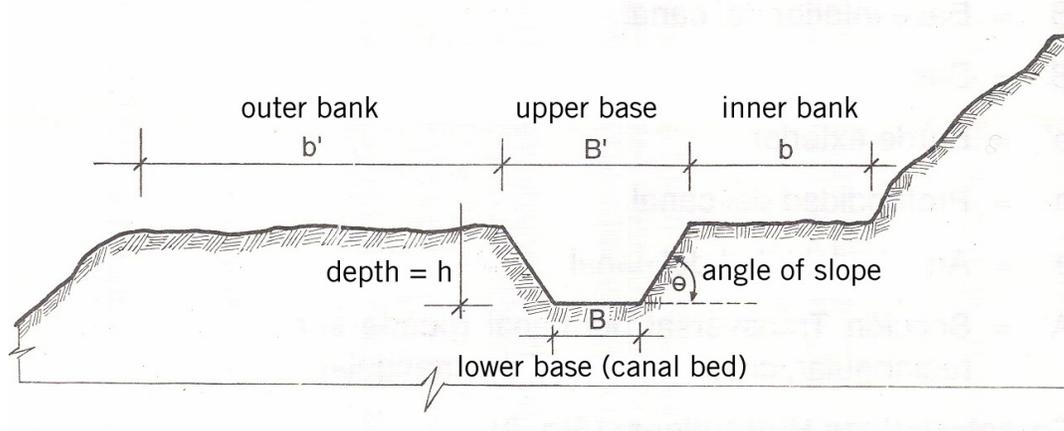
Fig.1

$$A = \frac{(B'm + Bm)\, d}{2} \qquad\qquad p = Bm + 2t$$

Fig.2

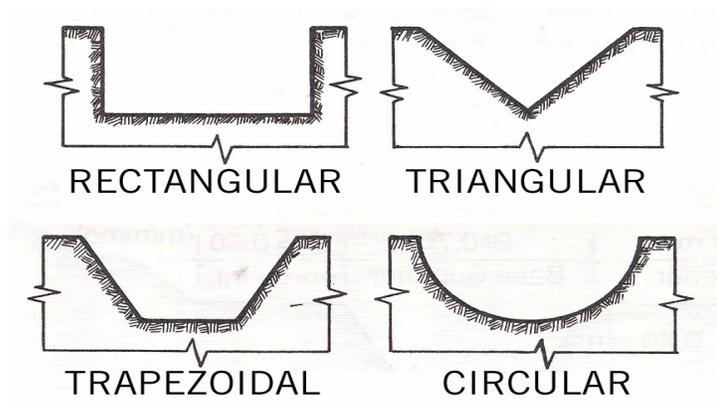RECTANGULAR   TRIANGULAR

TRAPEZOIDAL   CIRCULAR

Fig. 3

The layout and staking out of a trapezoidal canal

The layout of a canal takes place after the platform is built, in accordance with technical requirements.

Procedure

a) Assess the geometric characteristics, as specified in the project.

b) Make drawings of the centre line of the canal, both for a straight section and for a bend.

c) Draw the canal bed and the top base of the canal, deciding whether or not it will be lined with concrete.

d) Stake out measurements according to the specifications (see below).

Verify the geometric characteristics of the canal, specifying the measurements and details that appear in Figure 4.
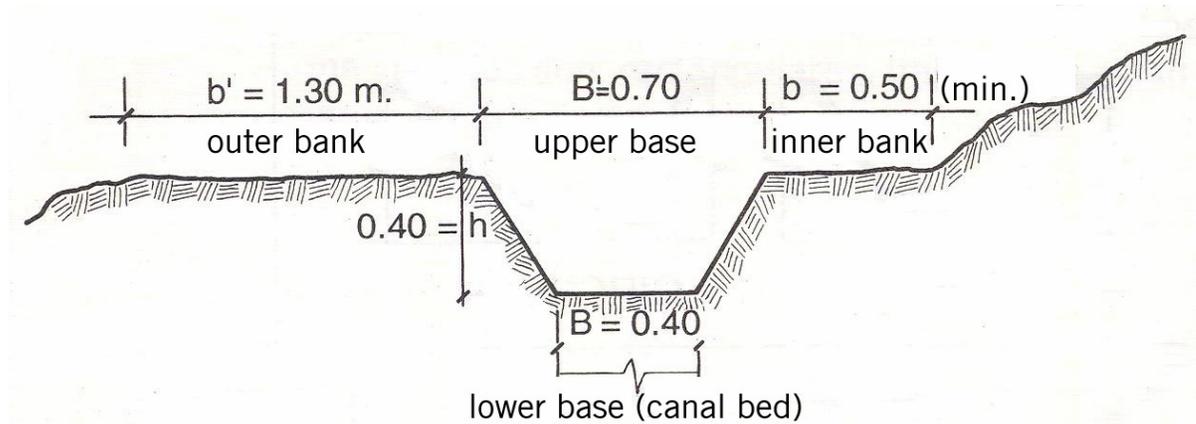

Fig. 4

Layout of the centre of the canal

The centre is an imaginary line drawn along the middle of the bases and parallel to their borders (Fig. 5).

The layout of the centre line involves two stages: a straight section and a bend.
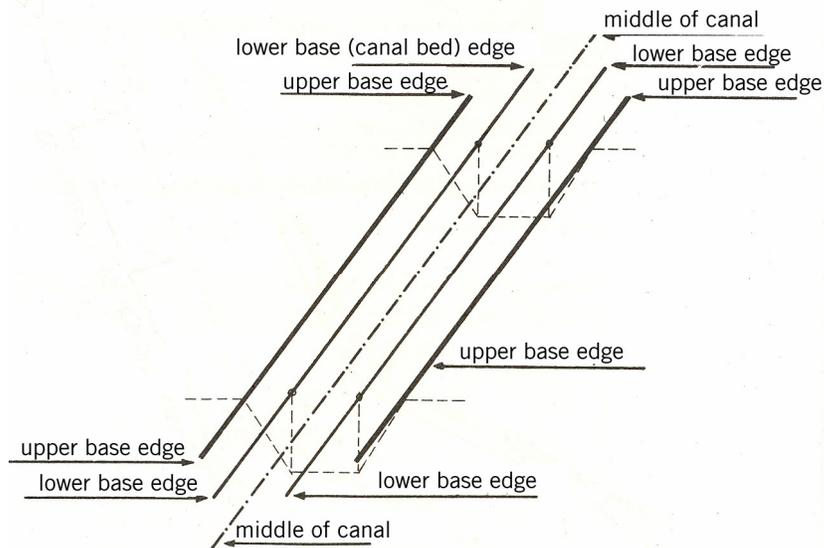
5

lower base (canal bed) edge

upper base edge

middle of canal

lower base edge

upper base edge

upper base edge

upper base edge

lower base edge

lower base edge

middle of canal

Fig. 5

a) Straight section (Fig. 6)

- Put stakes in place every 5m along the platform (bank) and at a distance of $X = B'/2 + b$ at the foot of the platform bank.

- Place a taught rope on the heads of the end stakes, trying to ensure that there are the same number of stakes on the left and on the right of the rope. Then mark them with gypsum, lime or ashes so that they intersect continuously at every change of direction (points of intersection = PI).
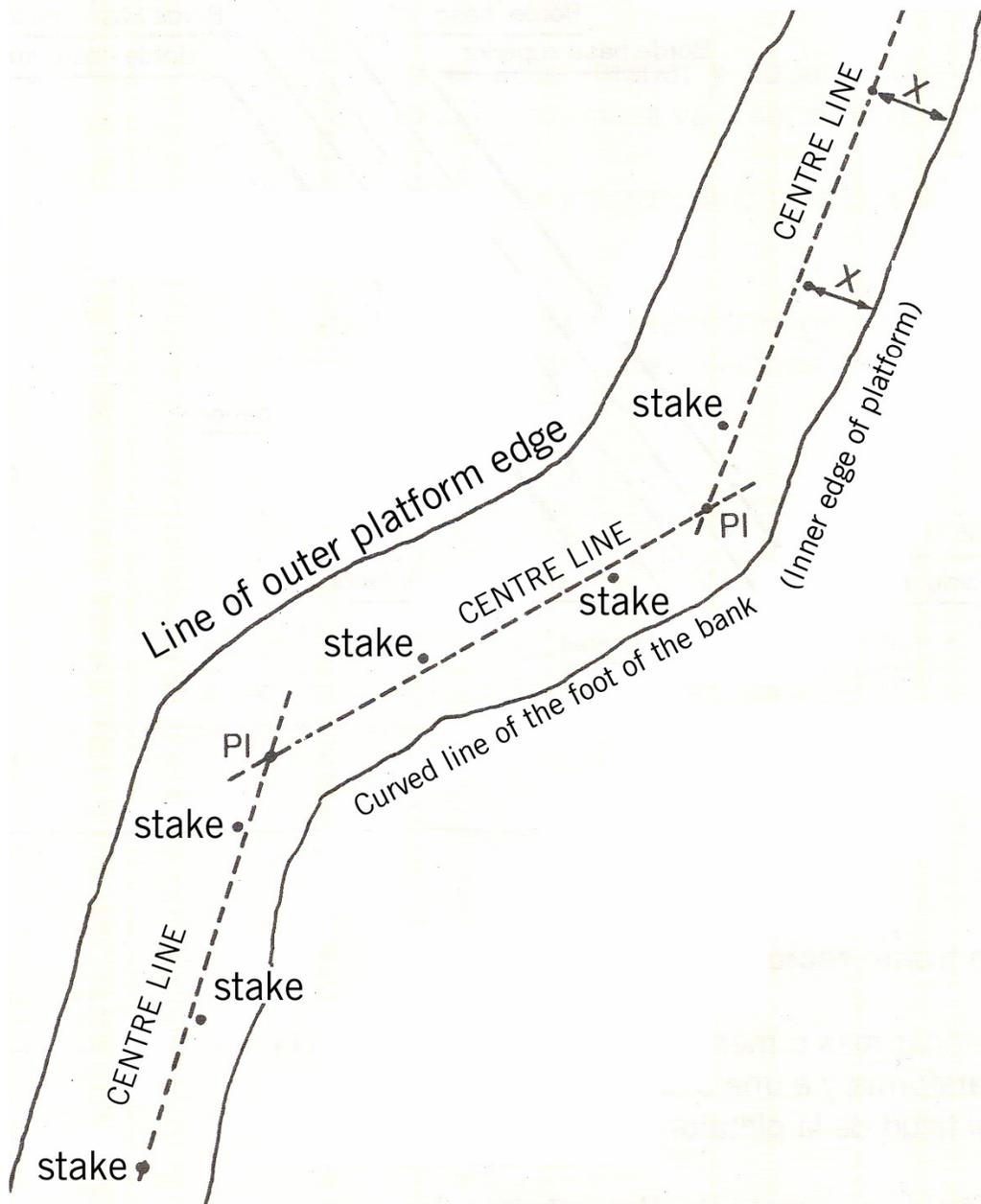
Line of outer platform edge

stake

CENTRE LINE

CENTRE LINE

stake

PI

stake

(Inner edge of platform)

Curved line of the foot of the bank

X

X

PI

stake

stake

CENTRE LINE

stake

stake

Fig. 6

b)   Curved section (Figs. 7 & 8)

This consists of determining the curves of the canal. The criterion is to obtain a smooth and symmetrical curve so that the water flows as smoothly as it does in the straight section.

Steps:

1. Take a distance "L" from the PI towards the left and the right, determining points **a** and **b**.
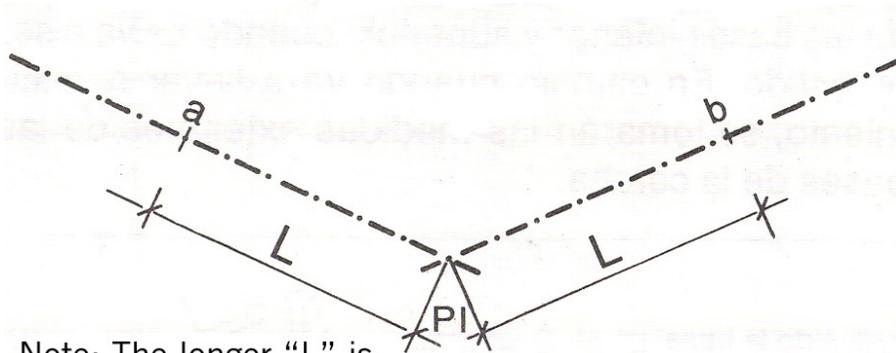
Note: The longer "L" is, the smoother the curve

Fig. 7

2. Determine points **c, d, e**, placing a taught rope between **a** and **b**. Then take distance "m" perpendicular to the PI with the rope. Points **c, d, e** are then located at:

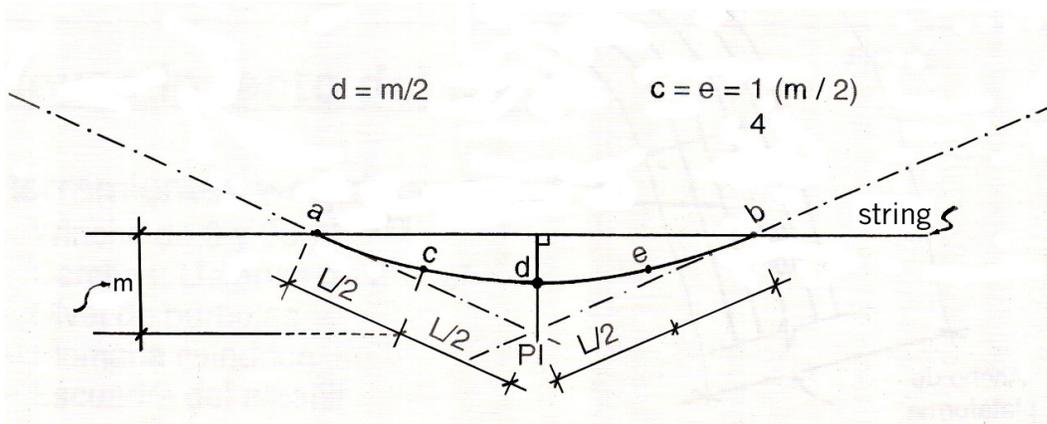$$D = m/2 \quad c = e = \frac{1}{4} \frac{(m)}{(2)}$$

Fig. 8

8

- Next, with a rope and five people placed at each point, join **a, c, d, e, b**, obtaining a smooth and symmetrical curve.

It is possible to place stakes at each point instead of people.

Outline the borders of the canal bases (Fig. 9)

Once the centre line of the canal is obtained on a straight section and on a curved section, the measurements of the canal bed and the top base are shared half and half when the canal is not lined. If the canal will be lined, then the outside measurements of the wooden frames must be taken.
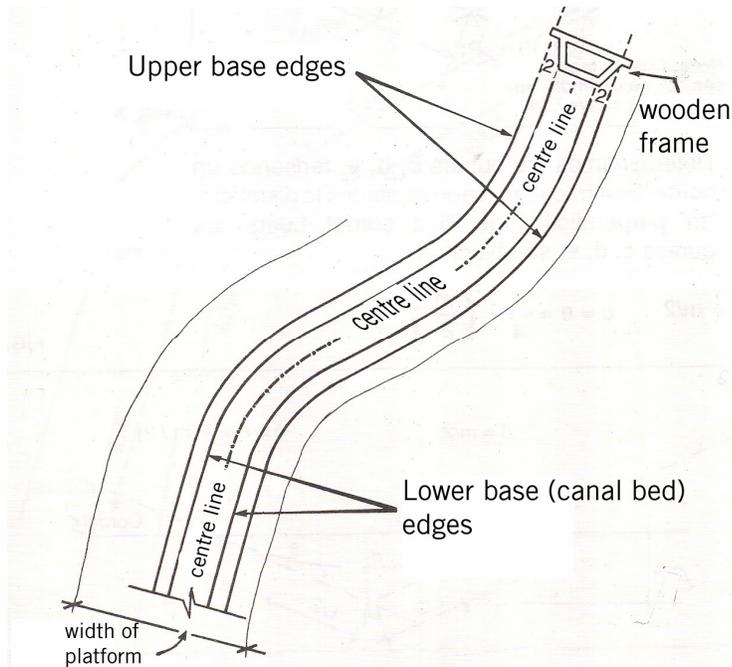

Fig. 9

Excavation of the canal ditch

This consists of digging out the required trapezoidal section. The excavation must begin in the middle and work towards the width of the canal bed to the specified depth (Fig. 10). Then dig out the banks, without going beyond the width of the top base.

The slope at the bottom of the canal must be constantly verified with a mete stick or a level hose.
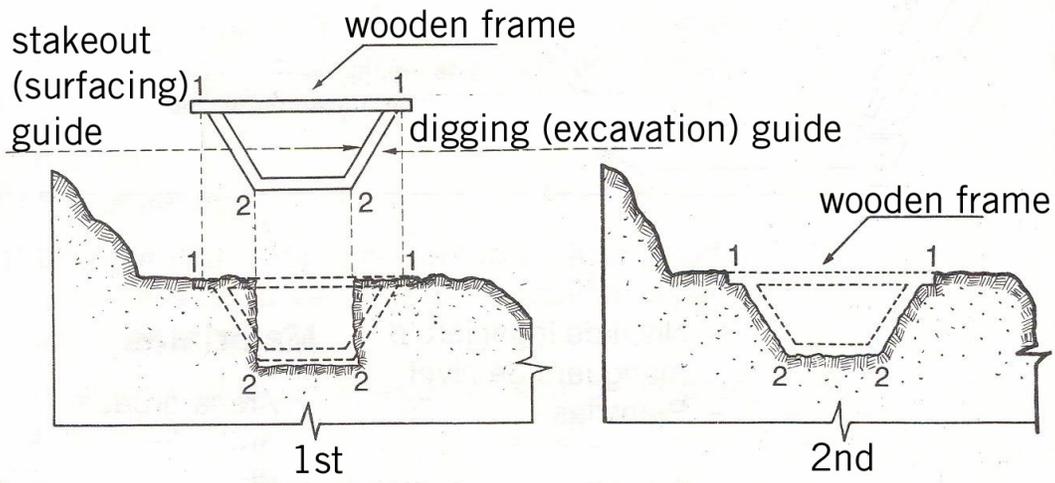
9

Fig. 10

Lining a Canal

Tools and equipment required

- 3 and 30m measuring tapes
- Wooden frames: 2" x 2" slats
- Spirit level
- Cylindrical plumb bob
- Framing square
- Rope
- Mete stick or level hose
- Templates
- 2" nails
- A pick
- A straight shovel
- A spade
- A 3 to 4 lb. sledge hammer
- A concrete tin
- A pasting tool
- A cement spreader
- A trowel
- An Oregon pine ruler
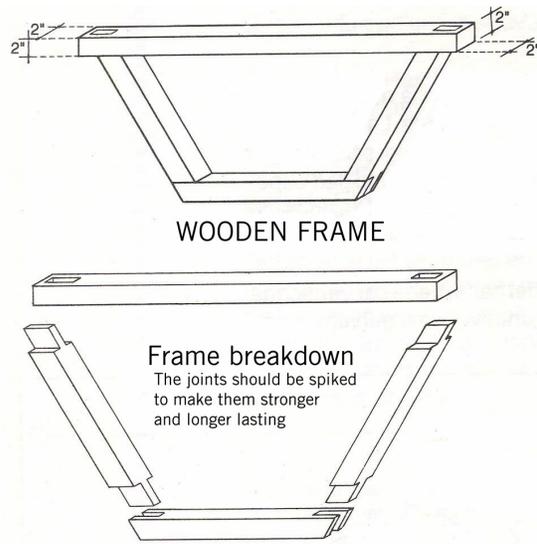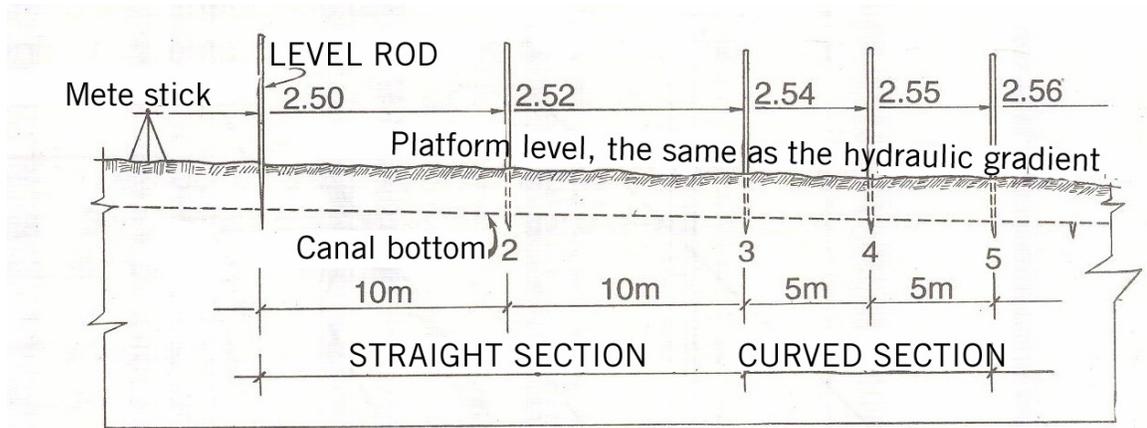- 1 ½" x 3" x 3.00 m
- 1 ½" x 3• x 1.50 m

WOODEN FRAME

Frame breakdown
The joints should be spiked
to make them stronger
and longer lasting

Fig. 11

Materials
- Thick sand
- Fine sand
- ½ to ¾" stones
- Cement
- No. 16 wire
- Wooden stakes

Slope: 2/1000 (two per thousand), which means that every
10 m horizontally there is a difference in elevation of 2 cm and every
5m horizontally there is a difference in elevation of 1 cm.

Fig. 12

Lining the Canal

This consists of placing a layer of concrete (Concrete compressive strength, f'_c:
175 kg/cm^2) on the bottom and side walls of the canal, forming a uniform
thickness and a polished finish. Level the finished work to the thickness
determined by the wooden frame.

Procedure:

a) **Fill with rubble** every 10m on a straight section and every 5m or so
on a curved section, taking the design slope into account.
Use a mete stick to achieve more precision.

b) **Fitting the wooden frames**. The guide frames or master frames will
be placed in each template, properly aligned, squared and plumbed
with respect to the centre line of the canal, fixing them with stakes
and No. 16 wire hammered into both banks. Subsequently, the
construction worker will fit intermediate wooden frames every 2.50m
in straight sections, checking the required slope with a level hose.

(0.5cm difference in elevation). Each one will be aligned, squared, plumbed
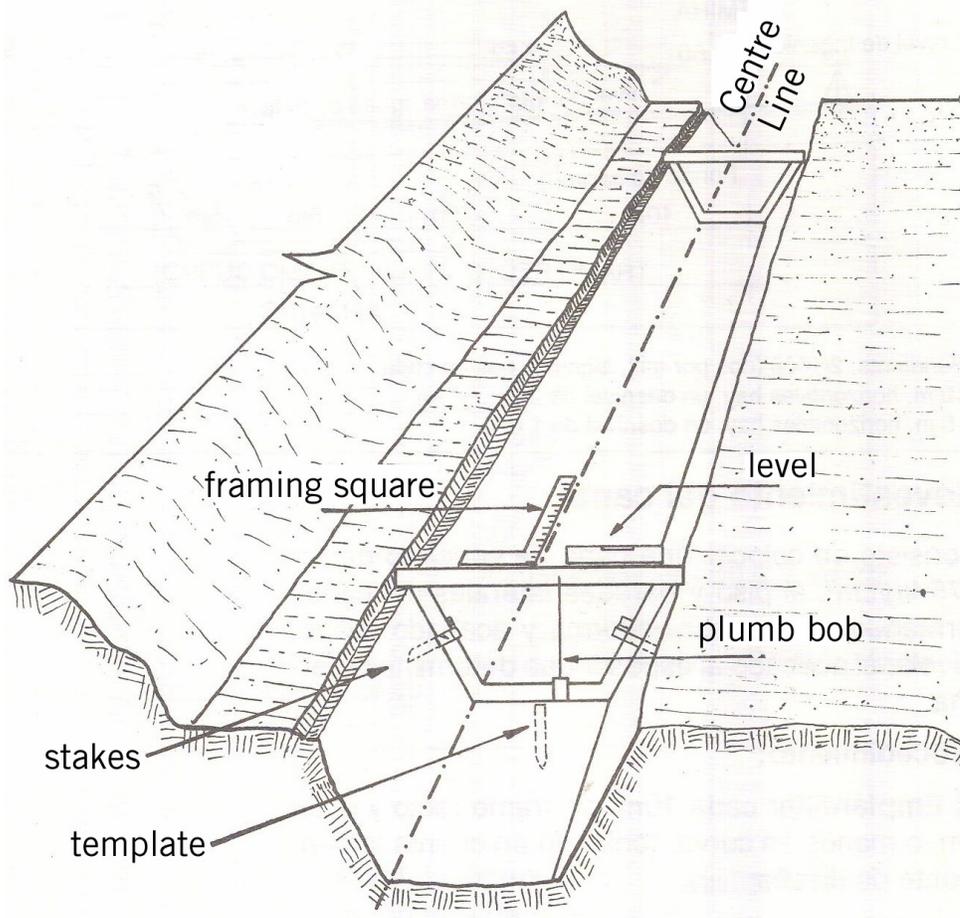and fixed.

Fig. 13

c) Lining

Preparation of the mix: In volume, $f_c':175$ kg/cm^2 is equivalent to mixing one bag of cement, 2 wheelbarrows of sand and 3 wheelbarrows of stones (each wheelbarrow = 1 cubic foot).

After these dry materials have been mixed and turned at least three times, add a quantity of water, which in litres must not be more than half the total weight of the cement (1 kg = 1 litre).

Then put mortar on the banks, compacting it with the ruler.   The hammered stakes must be removed before the final finish.

Next, sprinkle cement with fine sand 1:3 and use a pasting tool to give it a polished and waterproof finish.

Once the banks are completed, follow the same procedure for the canal bed.

When finishing the borders, make sure they are aligned, to which end a ruler or rope should be used between one wooden frame and the next.

d) Removing the wooden frames

These are usually removed after 24 hours (in cold climates). So that they are easier to remove, a layer of petroleum or burnt oil should be spread on them before lining the canal; this will also help to keep them clean and in good condition. When removing the wooden frames, care should be taken to prevent the outside borders from deteriorating.

e) Curing the lined canal

Fresh concrete should lose its dampness slowly so that it hardens to the desired resilience, to which end it must be cured by filling the lined boxes to the brim with water for at least 10 days.

This is easy to do, placing turf at the ends so that the water fills the lined boxes. Excess water can be eliminated through a provisional overflow pipe upstream.

In this way, the water route can be followed and the slope verified.
The curing must be done carefully as it is very important.
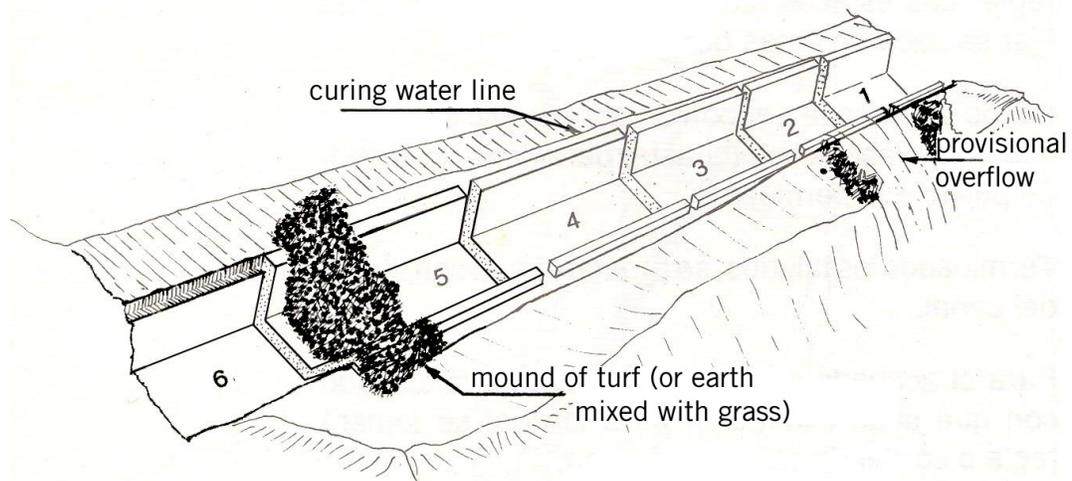
f) Filling in the expansion joints

The expansion joints will be determined by the spaces left by the wooden frames when they are removed, every 2.50m in straight sections and variable on a curved section. This will allow the concrete to expand or contract depending on the temperature, thus preventing the boxes from cracking.
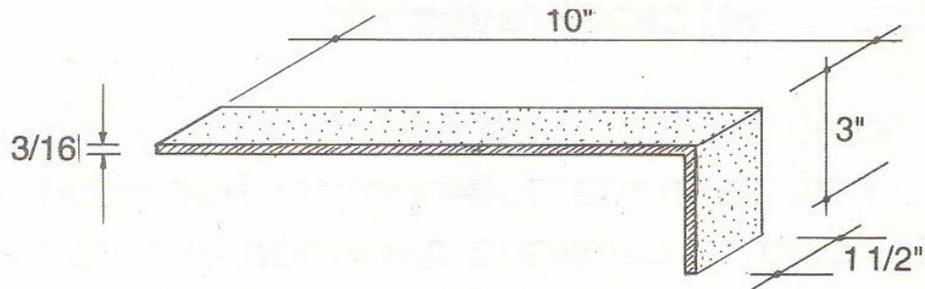
ANGULAR PALLET
PT   1½ " x 3/16

Fig. 15

These steps should be followed when filling in the joints :

a.   Use the angular pallet to remove any strange elements from the joints. The size of the pallet will depend on the thickness of the joint.

b.   Use the angular pallet to compact the natural soil of the joint. The pallet is useful for two purposes: cleaning and compacting.

c.   Prime the inner surface of the joint with a tar and kerosene solution in a proportion of 1 to 3, so that it has the viscosity of malleable paint. It should be applied with a paint brush.

d.   Place a mixture of hot tar and fine sand in a proportion of 1 tin of tar to 4 tins of sand. Begin by heating the tar, then add the sand gradually, stirring constantly until it has the consistency of black sugar.

This mixture should be applied to the banks first and then to the bottom in layers, compacting it with the same angular pallet. Try not to extend beyond the level of the canal lining.

LAYOUT AND OPENING OF THE CANAL PLATFORM

The platform is like a wide highway – normally consistantly sloping - on which the canal is built.

Characteristics of the platform

a)   Width: a

b)   Length: L

c)   Slope: S
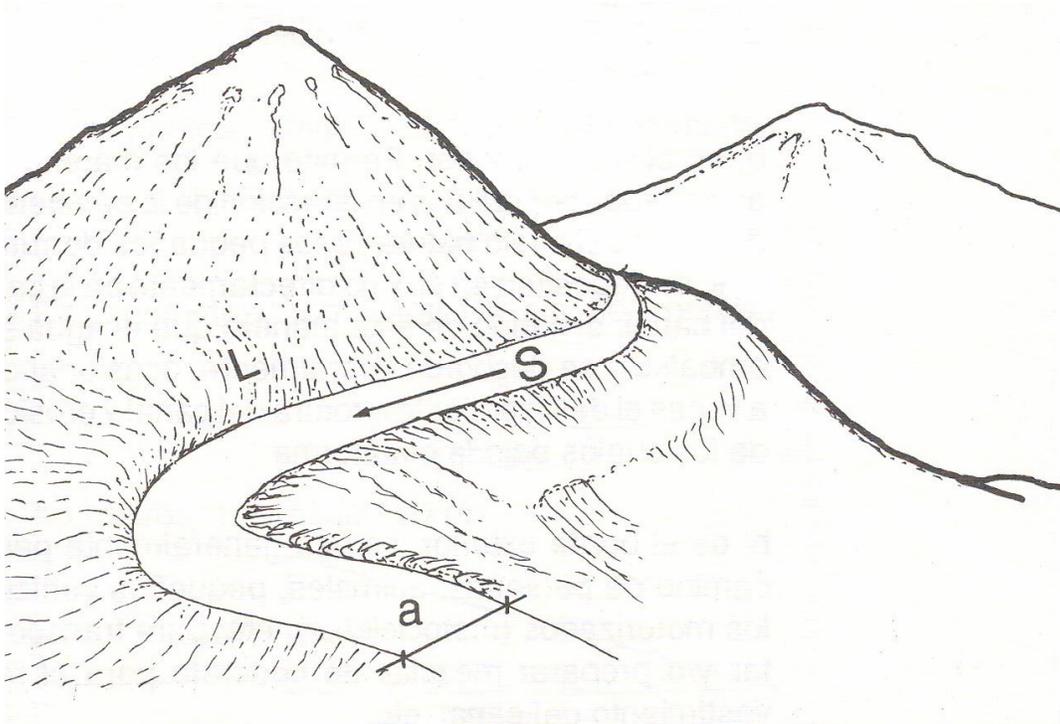
Fig. 16

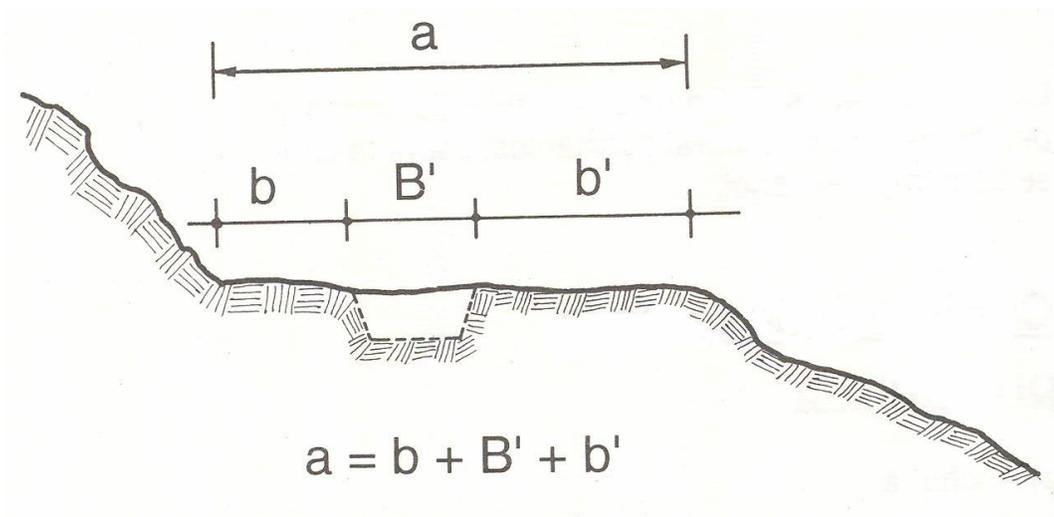Width "a" is determined by the geometrical characteristics of the canal:

$$a = b + B' + b'$$

Fig. 17

Recommendations:

b   =   50 cm (minimum)

b'   =   120 cm (minimum)

B'   =   Depends on the previously designed section of the canal

b is the inner border, where slope run-off material is deposited rather than directly into the canal channel. The channel is thus prevented from overflowing its banks, causing the canal to slide or break and eroding the soil beneath the platform.

b' is the outer border, usually used as a pathway for people, animals, small motor vehicles (motorcycles) etc. to transport and/or prepare concrete mixes for lining the canal, etc.

Example: If the platform base of a trapezoidal section of canal is 0.90m, the width of the platform must be no less than:

A = 0.50 + 0.90 + 1.20 = 2.60m

The length of the platform is usually determined from the intake weir to the forebay tank.

The gradient of the platform must coincide with the canal slope throughout its entire length.The slope is graded in percent or in parts per thousand.

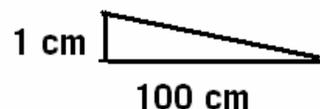Gradient is calculated by dividing the difference in elevation between two points and the horizontal distance between them.

Example: Say the platform will be drawn with a 1 percent slope, then the difference in elevation will be:
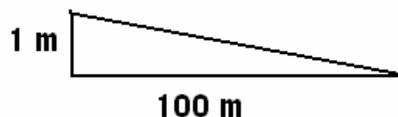
a) In millimetres: 1mm every 100mm horizontally.

1 mm
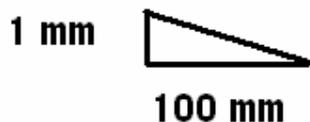
100 mm

b) In centimetres: 1 cm every 100 cm horizontally.

1 cm

100 cm

c) In metres: 1 m every 100 m

1 m

100 m

Example 2: If the platform slope is 4 per thousand, there will be a difference in elevation of:

a)   4 mm every 1000 mm horizontally

4 mm

1000 mm

b)   In centimetres: 4 cm every 1000 cm horizontally

4 cm

1000 cm
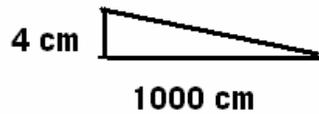
c)   In metres: 4m every 1000 metres horizontally

4 m

1000 m
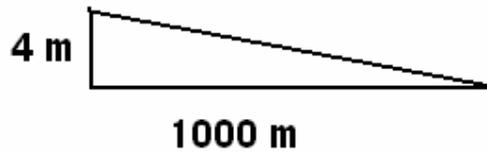
Equivalence between the slope and fractions or decimal numbers

Example:

2 percent   = $\dfrac{2}{100}$ =   0.02

1.5 percent = $\dfrac{1.5}{100}$ =   0.015

2 per thousand = $\dfrac{2}{1000}$ =   0.002

3.5 per thousand = $\dfrac{3.5}{1000}$ =   0.0035

etc-

In practice, these equivalents can be used to identify the correct difference in elevation when drawing the platform.

Examples:

a)   Every 20 m horizontally with a 1.5% slope, it would be enough to multiply:

20m x 0.015 = 0.30 m.

b)   Every 10 m horizontally with a 2% slope, multiply:

10m x 0.02 = 0.20m

c)   Every 20m horizontally with a 2 per thousand slope:

20m x 0.002 = 0.04m.

d)   Every 5m with a 4 per thousand slope:

5m x 0.004 = 0.02m

e)   Every 2.50m with a 2 per thousand slope

2.50m x 0.002 = 0.005

and so on.

Other characteristics of the platform are determined by the type of soil (geological characteristics). It is likely that limey, clayey, stony or rocky soil will be found all along the platform; not all banks will be stable, some will be damp and will need to be drained. In all cases, the platform must be free of all organic matter, fill and it must be stable at all times.

Requirements for the platform layout

a) Conduct a survey of the area, from the intake weir to the forebay tank.
b) Verify the plans of the intake weir with the headrace channel, the settling basin, the conveyance ditch, etc.   The levels of each of these must be consistent, in accordance with the slope established in each case.

c) Have the proper basic instruments and equipment available:
-       Mete stick
-       Tripod
-       Level rods
-       20 to 30m measuring tapes
-       Stakes
-       Machetes
-       3 to 4 lb sledge hammers

- Picks
- Shovels
- Paint
- ¼" paint brush

d) Staff members
- Topographer
- Measuring technician
- Rodman
- Stake man
- Brush cutter
- Auxiliary staff

e) Determining the initial level of the platform

- Select a place with sufficient visibility near the intake weir in which to place the level station
- Fit the level rod in the river bed opposite the catchment area and take the corresponding reading
- The initial level of the platform is the difference between the first reading taken in the previous step and the highest level of the headrace channel

f) Layout of the platform

The layout of the platform consists of a number of stakes placed in the ground between the intake weir and the forebay tank.
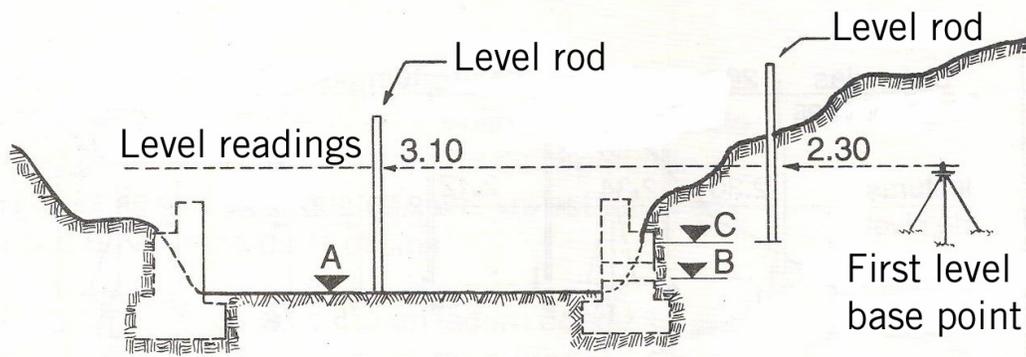
A = Level of the river bed
B = Level of the bottom of the catchment area
C = Highest level of the headrace channel
For example, if it is assumed that in the corresponding plan the levels are A = 3,100 m.a.s.l (metres above see level).; B = 3,100.30 m.a.s.l. and C = 3,100.80 m.a.s.l, then calculate the difference in elevation between A and C (0.80m).
Make a note of the 1st reading (3.10m), then the reading for the initial level of the platform (3.10 – 0.80 = 2.30m).

Fig. 18

Stakes are placed every 20m (horizontally) on a straight section, and every 10m on a curved section (a bend).

Once the first stake has been placed at the initial platform level, take the corresponding reading and put the next stakes in place consecutively, taking respective readings according to the distance and the canal design slope.

Figure 19 shows the outline of the platform. Here the slope gradient is 2 per thousand.

1 = the stake in the initial platform level and the first reading is 2.30m,

4 = the stake with the last reading from station I (2.42m) and the first reading from station II (2.20m). This stake is called the **changing point**

The readings are noted in sequence from each point of the level station, as shown in table 1.

Layout of the platform, MHPP canal
Slope gradient: 2 per thousand
Date: 02.01.92.
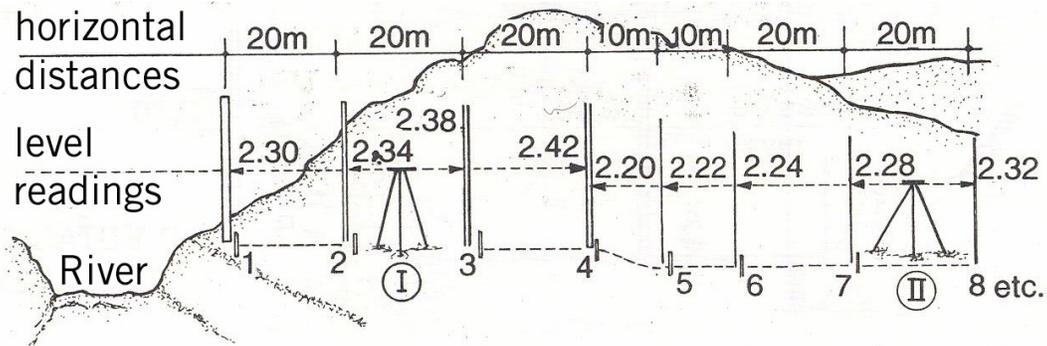
I, II… = level stations   **Fig. 19**
1   = 1st stake
4   = stake with the last reading from the 1st station, also called *changing point*

TABLE 1

Stake No.	Horizontal distance	Reading to be noted	Observations
01	0+00	2.30	Initial reading at initial level
02	0+20	2.34	Correct reading
03	0+40	2.38	Correct reading
04	0+60	2.42	Correct reading
Change	--	2.20	Reading from the stake at the

			changing point from the station II bend
05	0+70	2.22	Bend
06	0+80	2.24	Bend
07	0+100	2.28	Rocky material
08	0+120	2.32	Rocky material
Etc.			

Opening the Platform

To open the platform a breadth of land of uniform width and slope gradient must be achieved, taking the outer border of the platform as a reference. That is to say, drawing an imaginary line joining the stakes placed along the outline of the platform.

This usually involves cutting into a hillside using tools, equipment and machinery, depending on the soil type.

The canal will be built into this platform. Its entire length must therefore be cleared of all organic matter or debris that could affect the stability of the platform and the canal.
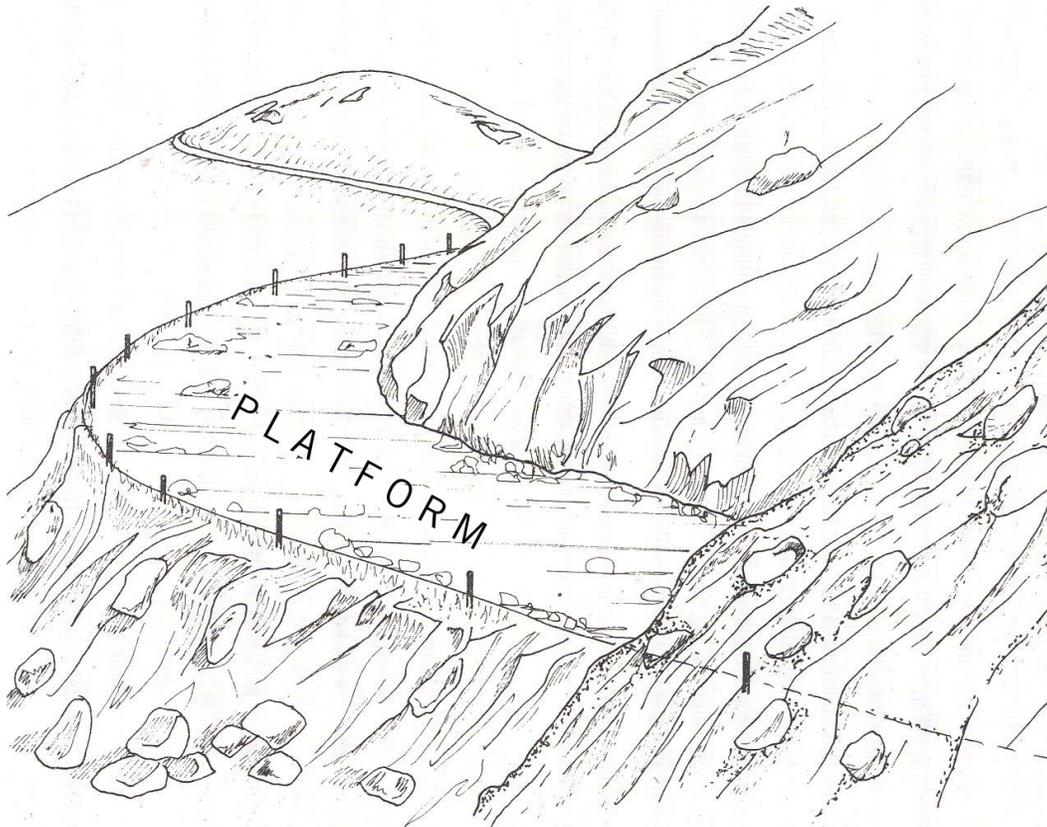

Fig. 20

Dosage of concrete mixes

Concrete is a mixture of cement, aggregates and water.

Examples of aggregates are *'hormigón'*, sand, stones, and slag from furnaces.

'Hormigón' is a mixture of stones and natural sand found in quarries. Stones from river quarries are round and stones from hill quarries are angular. The sand may be thick or fine and both kinds of stones are of variable sizes.
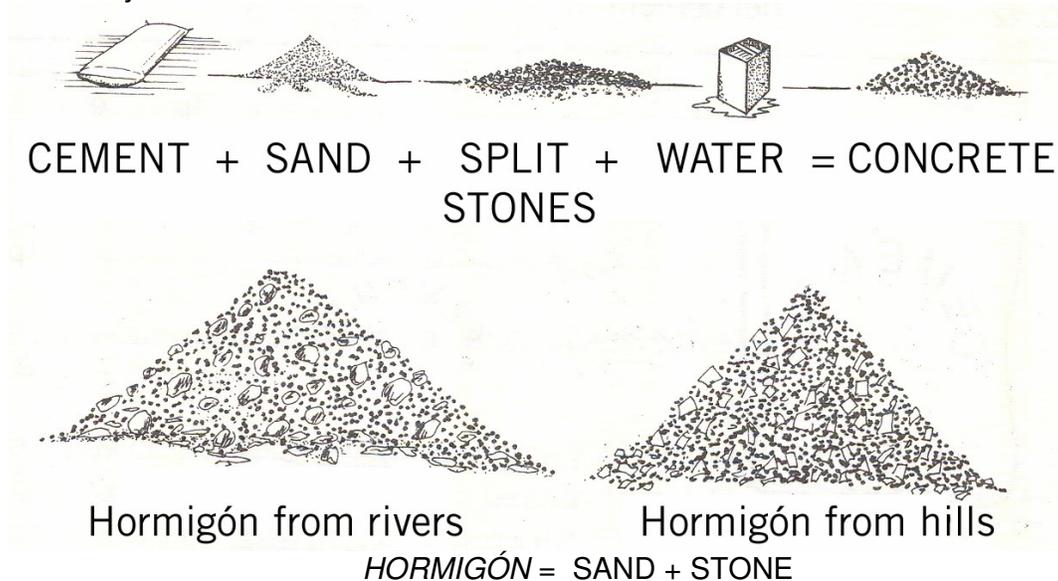

CEMENT + SAND + SPLIT STONES + WATER = CONCRETE

Hormigón from rivers   Hormigón from hills

HORMIGÓN = SAND + STONE

Fig. 21

To obtain the right concrete mix – and thus the desired type and resilience of concrete -, it is important to blend the correct proportions of aggregates (cement, sand and water).

There are two methods of doing this: 1) by weight, and 2) by volume, of the concrete components. In both cases the aggregates should be free of organic matter and have the recommended or specified hardness and size. The water must be clean, fresh and free of organic matter, salts, acids, etc. The cement must be fresh and in good condition.

The most advisable way to prepare the mix is by weight, as it is economical and the results are good. However, your dosage plant must have large-capacity scales, mixers, transport equipment, cement silos and aggregates classified by diameters.

Preparing the mix by volume is a reasonable alternative to weighing, whereby the weight of each component is converted to volume based on volumetric weights of the aggregates and the cement.
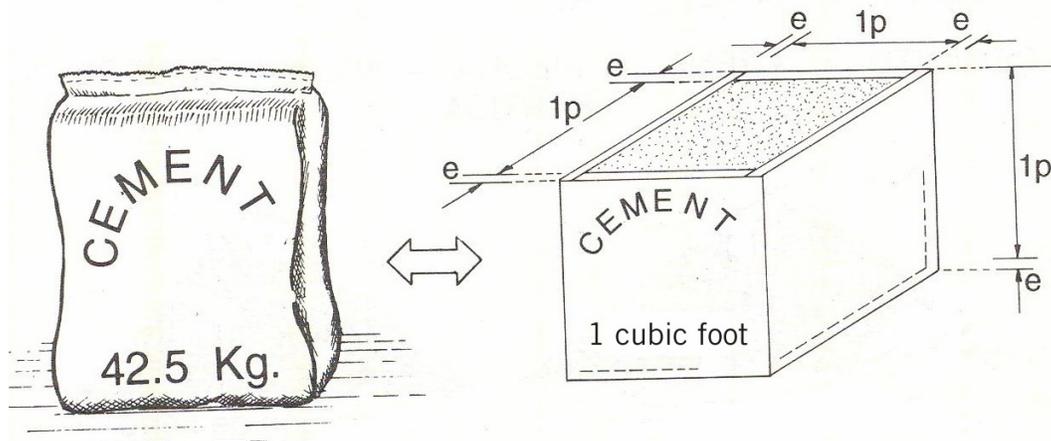
1 cubic foot = inside measurement
e = thickness of the wood

Fig. 22

In this country *[Peru]*, cement is sold in 42.5 kg bags, a volume equivalent of 1 cubic foot.

The proportions by volume are expressed as a single unit for all aggregates except water.

The data shown in the following table were carefully calculated from dosage by weight. Nevertheless, it is worth pointing out that good concrete does not only depend on the required proportions but on other parameters as well, as is explained below.

Proportions vary according to resilience and compression (f'_c). Resilience will depend on the type of work undertaken. Typical concrete values are 140, 175, or 210 kg/cm^2 of f'_c; some projects may require more resilient concrete.

Table 1

F'c	Proportion of cement and aggregates concrete : sand : stones	Water (litres/bag)
140	1 : 2 : 4	28
175	1 : 2 : 3	25
210	1 : 2 : 2	22

This means that in order to obtain 140 kg/cm^2 of concrete, the mixture must consist of:

1 bag of cement, 2 bags of sand and 4 bags of split stones (if a bag is used as a measuring unit), plus 28 litres of water.

If a tin is used as a measuring unit then the mix should consist of 1 tin of cement, 2 tins of sand and 4 tins of split stones. However, the water varies depending on its equivalence.

For lining canals using the wooden frame method, the concrete used is $f_c' = 175$ kg/cm^2 2 inches thick, equivalent to 5 cm. Therefore the crushed stone is 1 : 2 : 3,

The wheelbarrow used for the works must be calibrated to find out how many cubic feet it can hold.

A wheelbarrow usually holds 1 level cubic foot. For $f_c' = 2.10$ kg/cm^2, for example, the following should be used:

1 bag of cement, 2 wheelbarrows of sand and 2 wheelbarrows of crushed stones. Bear in mind that the material in the wheelbarrow must be level.

So that it reaches the f_c' design resilience, good concrete not only depends on the dosage but also on other factors that should not be neglected, such as:

-        The water/cement ratio, by weight
-        Mixing
-        Transport
-        Laying
-        Consolidation
-        Curing

The water/cement ratios w/c for each of these doses are:

Table 2

f'c	w/c
140	0.66
175	0.59
210	0.51

If the w/c ratio is altered, that is if more water than necessary is added, the concrete will be less resilient and the structure could fail as it may not be strong enough to support the compression stress.

A mixer should preferably be used for the concrete mix, as the mixing time - no more than 1.5 minutes - and the order in which the aggregates, cement and water are added, are both important.

When a mixer is not used and the mix is prepared manually, it is recommended that the correct proportions of dry aggregates and dry cement are mixed at least

three times until a uniform colour is obtained. Then spread the mixture and mix with water, trying to prevent the water from dripping.

The concrete can be transported horizontally or vertically: horizontally over longer distance and vertically to different levels or floors. Special transporting equipment is required which must not transmit any vibration to the concrete before it is laid, as the stones will separate from the fresh concrete.

The concrete should not be laid from heights that modify the homogeneity of the fresh concrete.

The consolidation of the concrete consists of vibrating the fresh concrete when it is being laid, in order to make it more resilient to external (outdoor) agents. Concrete vibrators are used in every type of structure.

When transporting the lining it is advisable minimise the distance from mixing area to application area. It is best to prepare the mixture on site. When placing the concrete on the banks and at the bottom of the canal, it should be compacted with a masonry tool to consolidate it properly.

The concrete is cured so that it slowly loses the water in the mix, reducing dampness. Curing helps to obtain the desired resilience, as well as making the concrete waterproof and durable. Curing is obtained by covering the concrete with water within 12 to 18 hours of its being laid, and leaving it for at least 14 days. Much depends on the climate, temperature, and other factors.