Design of Irrigation Canal

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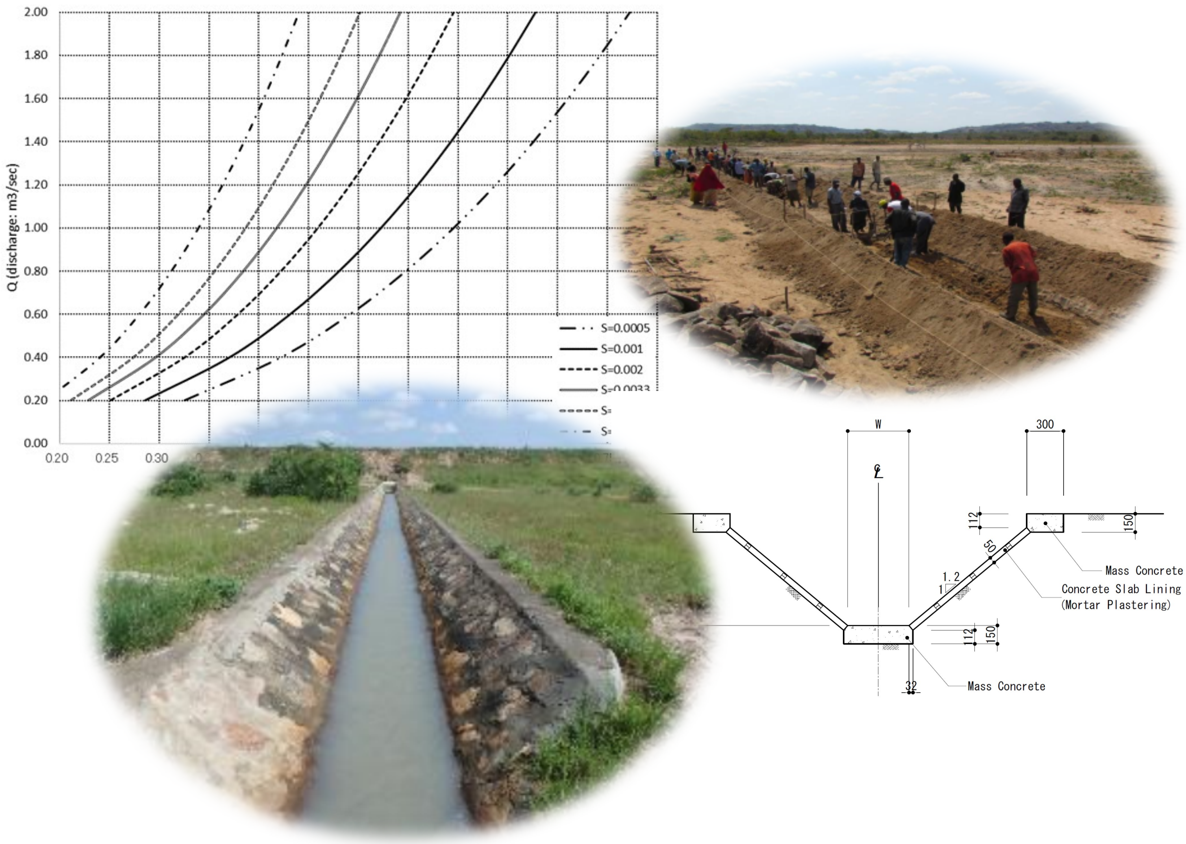


Table of Contents

1. Introduction

1.1 Background

The promotion of irrigation project becomes the urgent matter as a policy to plan improvement of the farm productivity in Tanzania. However, a great variety of irrigation facilities exist because the standard guidance about the design of canals and related structures is not arranged.

On the other hand, the staff of Zonal Irrigation Office and District taking the role that is important to the promotion of the irrigation project largely is in hard situation; lack the number of engineer or insufficient accumulation of technical know-how, so improvement of these circumstance is necessary.

1.2 Objective

Problems related to the existing irrigation facilities in selected area from the viewpoint of policy system and technical aspect are to be grasped and clarified through survey and collection of data. Objective of this manual is to support smooth enforcement of designing of irrigation canal by LGA supported by ZIO and NIC using the flowchart for selecting the canal type and calculation charts for decision of canal cross-section, etc.

On the occasion of the development of the manual, the following points are noted.

- Arranging the problem of existing irrigation facilities and the cause of issue on every stage of investigation, plan, design, construction and maintenance respectively, standard design manual of irrigation canal should be made included the measures corresponding to these problem.
- Confirming the capacity of technical staff and material/tools which can be obtained locally by execution of survey in cooperation with Counter Part engineer, this standard design considers Tanzanian situation.

1.3 Scope of the manual

This manual covers standard design of the open canals such as lining canal mainly. Especially, the method for decision of canal cross-section using calculation chart based on the direct calculation method will be described. In addition, division structure and drop structure are attached as incidental structure.

The scope of irrigation canal is as Table 1-1 in next page. Because this manual relatively intends for the small canal of the scale as it is listed, larger scale irrigation facilities more than this range needs original detailed design separately.

Table 1-1 Scope of application

Item	Scope of application	Remark
Canal system	Open canal	Open canal generally has advantages compared with other water conveying facilities.
Design discharge	0.2 – 2.0 m^3/sec	Intending for small irrigation scheme less than about 500ha of beneficial area, main canal and secondary canal can be applied.

When there is no explanation in particular, the technical standard and the standard numerical value described in this manual shall be quoted from “Land Improvement Project Plan Design Standard, Design, Canal Works”, as Japanese Design Standard (hereinafter called as JDS) or from small scale irrigation design manual and CGL.

1.4 Relation to relevant Guidelines and manuals

The Guidelines consist of the main part and reference materials. The former shows the process of the procedure for Formulation, Construction, O&M and training. The latter collects a series of technical standard to supplement the main body.

The standard design manual improves the ability of Zonal Irrigation Offices and Districts staff by being made as Technical Guidance in the Comprehensive Guidelines. (Figure 1-1)

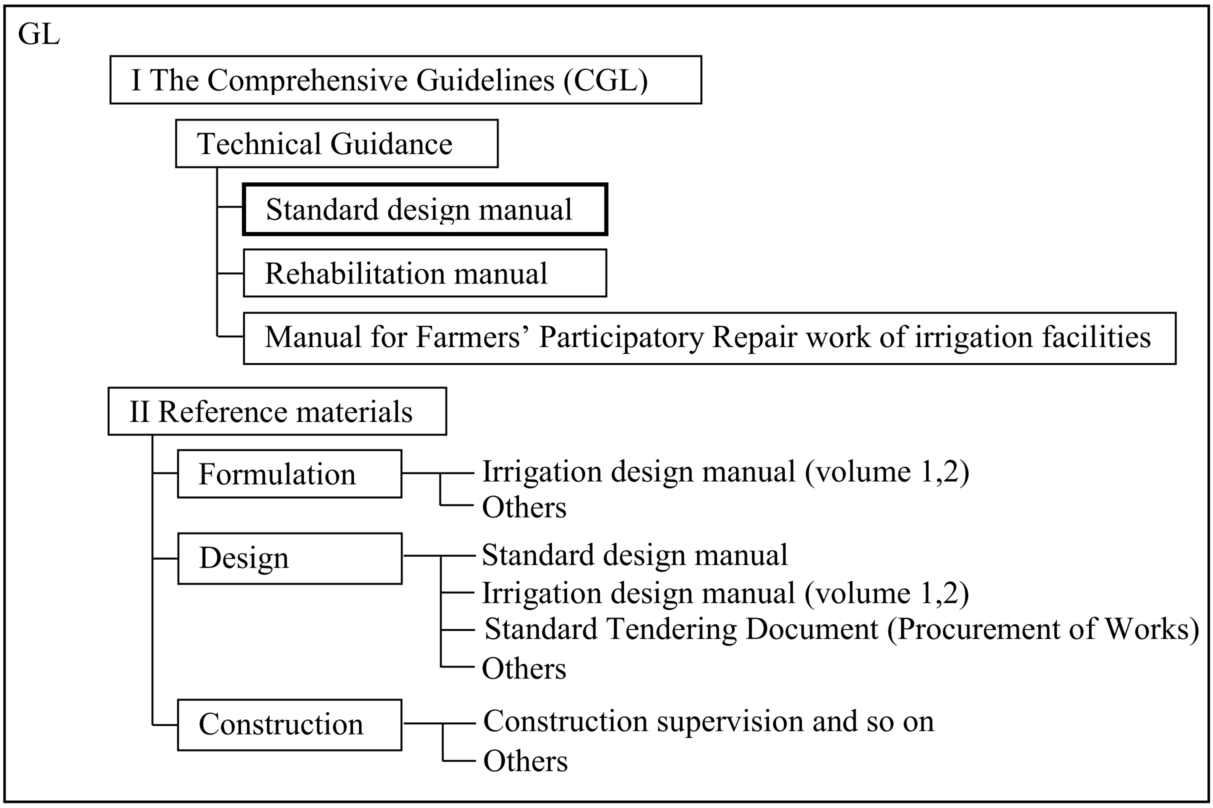


Figure 1-1 Relation to relevant guidelines

2. Summary of the design for open canals

2.1 Procedure for decision of canal cross-section

Procedure for decision of canal cross-section shall be as shown in Figure 2-1.

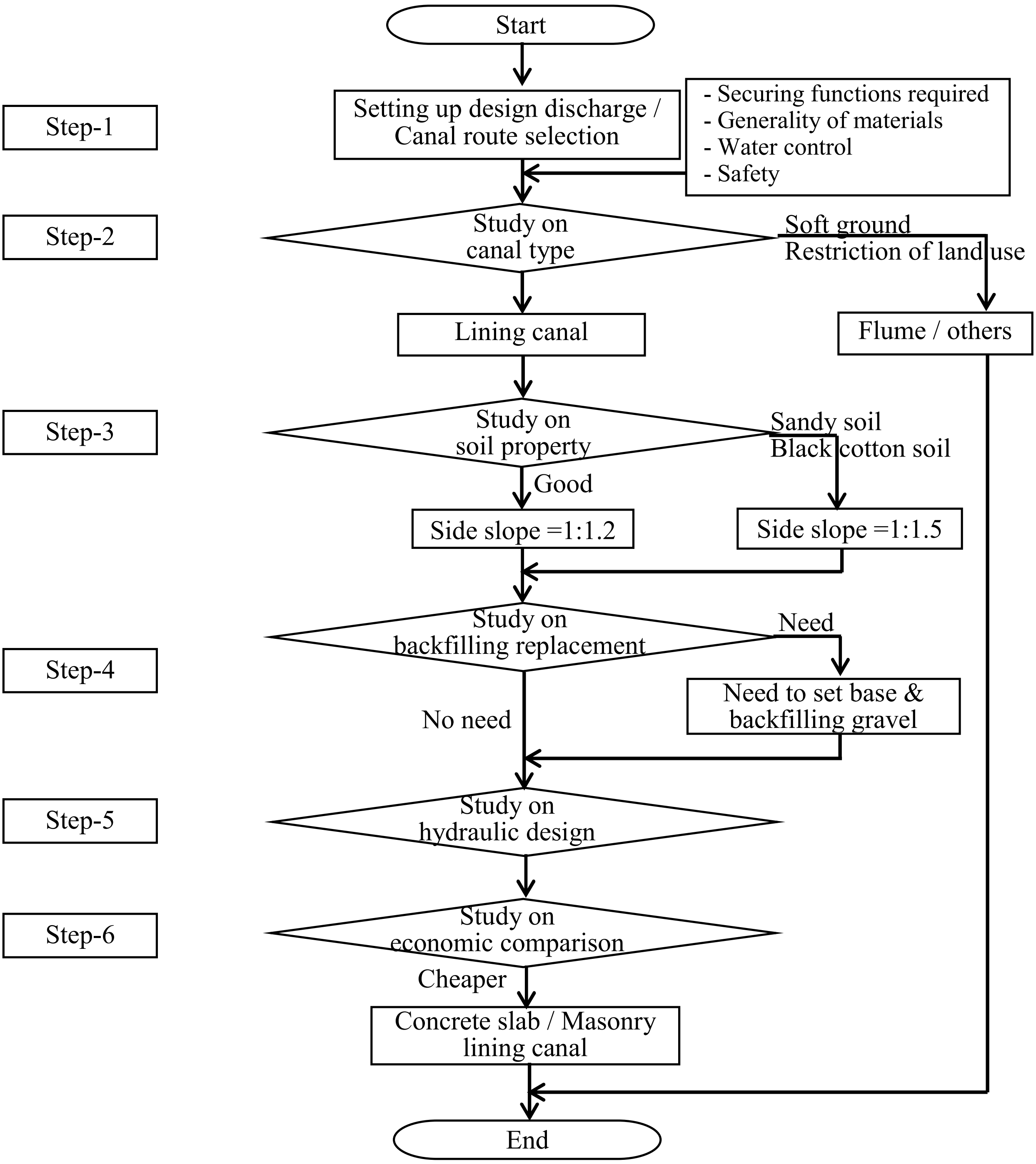


Figure 2-1 Procedure for decision of canal cross-section

2.2 Examination item in each step

Step-1 Setting up design discharge / canal route selection

For the design discharge of the irrigation canal, the planned maximum discharge for each season and irrigation water system defined in the irrigation plan is generally used. For example, design discharge shall be calculated based on CGL: Comprehensive Guidelines, or it may be determined using another technical documents or in reference to the example of other scheme.

< For details, refer to 3.1 >

The canal route should be examined taking into consideration of maintenance, operation and economic efficiency after reviewing result of the field survey. Moreover, main canal should be located at the higher level of the land surface.

< For details, refer to 3.2 >

Step-2 Study on canal type

In the selection of canal type, several factor such as design discharge, securing functions required, generality of materials, etc. should be considered comprehensively. Moreover, irrigation facilities should be designed and constructed to show high performance during the service period. As a result of examination, masonry lining canals and concrete slab lining canals are selected as the most suitable canal type in Tanzania.

< For details, refer to 3.3 >

Step-3 Study on soil property

The soil property should be determined using easy method described in the CGL. The side slope of lining canal shall be decided based on the soil property because there is a difference in stability of the slope or resistance for scouring against water flow. In this manual, the side slope of lining canal is proposed as follows.

Normal (cohesive) soil	1:1.2
Sandy soil	1:1.5
Black cotton soil	1:1.5

< For details, refer to 3.4 >

Step-4 Study on backfilling replacement

In case of soft ground such as black cotton soil or high groundwater level, the irrigation canal possibly deteriorates with differential settlement due to expansion of the soil or uplift pressure of groundwater, replacement of backfilling using gravel, sand soil or morrum is proposed while weep hole or under drain is effective as a counter measure.

< For details, refer to 3.4.5 >

Step-5 Study on hydraulic design

This manual is introducing a simple design method of canal cross-section settling for small scale irrigation schemes by using “Calculation Chart” as attached in Annex-1.

After getting Q (discharge), S (canal slope), m (side slope) and assuming the canal type such as concrete slab lining, masonry lining, you can simply design the cross-section of canals using the chart.

< For details, refer to 3.5 >

Step-6 Study on economic comparison

Since the coefficient of roughness between concrete slab and masonry differ, the cross-section of each canal changes even if the discharge is the same. So, after setting the cross-section of both lining canal using calculation chart, economic comparison should be executed.

< For details, refer to 3.7 >

The most suitable cross-section of irrigation canal shall be decided based on this flow chart mentioned above. Several calculation chart for cross-section settling of concrete slab lining canal, masonry lining canal and flume are attached in Annex-1.

Moreover, actual construction plan shall be examined using drawings of standard design for irrigation canal attached in Annex-2.

Table 2-1 Classification of open canal

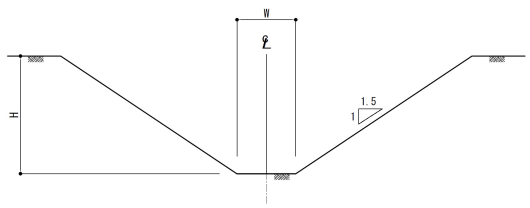
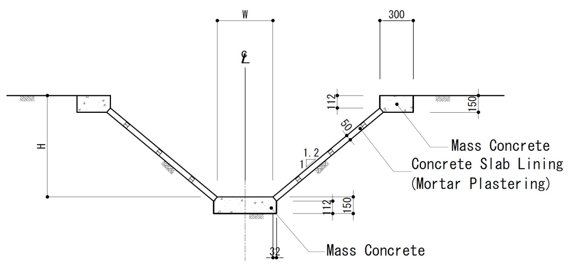
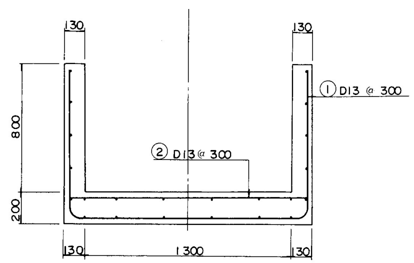
Item	Unlined canal	Lining canal	Retaining wall canal
Outline	Canals where the natural ground is simply excavated or dikes, and canals where inner flow portions are protected by turf, stabilizer or granular fill.	Canal where concrete slabs, masonry and concrete are used for a pavement material. These materials have higher resistance against corrosion than other materials, and is adaptable to comparatively large velocity.	Canals where the wall body is independent from the canal base, and the retaining wall itself acts a role for maintaining stability against earth pressure from behind, groundwater pressure, etc.
Application	Applied to irrigation and drainage canals.	Applied to irrigation canal generally in Tanzania. Superior to retaining wall canal in economy.	Applied to irrigation canal having an advantage in structural durability, conveyance efficiency and its suitability for large-sized canal system.
Materials	Clay or clay loam soil used for both irrigation and drainage canal.	Concrete slabs, masonry, plain concrete and reinforced concrete.	Masonry, concrete slab, plain concrete, reinforced concrete
Side slope	1:1.0 (consolidated gravelly clay) to 1:2.0 (gravel-mixed sandy loam)	More than 1:1.0 determined through considering soil character, canal size, construction method, maintenance, etc.	Less than 1:1.0, and flumes have rectangular cross-section
Points of attention	In cases of soft ground or large-sized canals, it is often difficult to maintain slope stability, and careful studies are required for adopting gentler side slopes or other bank protection methods.	In cases of unsuitable soil such as where slopes are not stable, designs shall be performed on necessity of replacing banking, conditions of groundwater, etc.	The construction cost shall be expensive rather than other method. Therefore, it is desirable to carry out a comparison study on ease of work, cost efficiency.
Cross-section			

	
Photo-1 Unlined canal (Igongwa, Misunguwi, Mwanza)	Photo-2 Masonry lining canal (Chomachankora, Igunga, Tabora)
	
Photo-3 Masonry lining canal (Ulyanyama, Sikonge, Tabora)	Photo-4 Concrete slab lining (Msagali, Mpwapwa, Central)
	
Photo-5 Concrete lining (With RBC) canal (Nyida, Shinanga, Mwanza)	Photo-6 Concrete retaining wall canal (Msufini, Mvomero, Morogoro)

Figure 2-2 Open canal in Tanzania

3. Detailed description of the components

3.1 Design discharge

Design discharge means the planned maximum discharge in the irrigation plan for each season and irrigation water system, or the planned maximum discharge in the drainage plan. While the size of canal is expressed in the design discharge, other discharges shall be studied as well in determining cross sections, structures, water level control, etc.

3.1.1 Irrigation canal

For the design discharge of the irrigation canal, the planned maximum discharge for each season and irrigation water system defined in the irrigation plan is generally used. However, when diversion of discharge not in accordance with the plan can occur in upstream sections, or when it is possible that the inflow of flood water is unavoidable due to topological restrictions, the design discharge can be obtained by adding the planned diversion discharge or inflow flood water volume.

Generally, the design discharge shall be determined after completing comparative studies for the overall facility costs covering possible new construction of wasteways/spillways for each section and improvement plan of discharging rivers.

Also, since it is often that planning conditions of the irrigated areas change over time during each phase of planning, design, and construction, periodical confirmations of determining factors for irrigation volume (e.g. water requirement rate, cultivation system, irrigated acreage, diversion points, irrigation methods, etc.) are necessary.

Calculation example of design discharge in CGL is as follows.

Calculation Form of Gross Unit Water Requirement (Unit: mm/month)

		Dry season						Rainy season					
Crop to be irrigated													
Name of the Month		1st Jul	2nd Aug	3rd Sep	4th Oct	5th Nov	6th Dec	1st Jan	2nd Feb	3rd Mar	4th Apr	5th May	6th Jun
Net unit water requirement (mm/month)	Table-1												
Gross unit water requirement (GWR) (l/sec/ha)	NWR/E /8.64/ D*												

*D :number of days by the month,

Figure 3-1 Calculation form of GWR: Gross unit Water Requirement
(quoted from Vol 1, Sec 3 in CGL: Comprehensive Guide Line)

Table-1 Net Unit Water Requirement (NWR) in each Region (1/2)

Unit: mm/month

Region	Crop	Soil Type	Dry Season						Rainy Season					
			Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Arusha	Paddy	Sandy Loam	637	460	502	501	-	-	686	465	484	358	390	-
		Clay Loam	432	310	352	346	-	-	481	325	329	208	235	-
		Clay	289	220	262	253	-	-	338	241	236	118	142	-
	Maize		90	112	194	191	144	-	45	124	165	58	75	-
	Bean & Veg		90	112	169	172	-	-	49	111	149	66	72	-
Kilimanjaro	Paddy	Sandy Loam	633	461	507	512	-	-	736	506	540	403	406	-
		Clay Loam	428	311	357	357	-	-	531	366	385	253	251	-
		Clay	285	221	267	264	-	-	388	282	292	163	158	-

Table-2 Irrigation Efficiency by Scheme Condition

Proposed canal condition Farmers' experience	Lined -	Unlined Sufficient	 Poor
Irrigation efficiency	0.40	0.30	0.25

Figure 3-2 Parameter for calculation of GWR)

< Calculation example >

1. Place Arusha
2. Crop Paddy (Clay Loam)
3. Irrigation efficiency 0.40 (Lined)

Table 3-1 Result of discharge calculation

Mon	Dry season						Rainy season					
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
NWR	432	310	352	346	-	-	481	241	236	118	142	-
GWR	4.03	2.89	3.40	3.23	-	-	4.49	2.49	2.20	1.14	1.33	-

- NWR (Net Unit Water Requirement): mm/month
- GWR = NWR / E (Irrigation efficiency) / 8.64 / D (number of days by the month): ℓ/sec/ha
- Design discharge may be decided using maximum GWR as 4.49 ℓ/sec/ha

3.1.2 Drainage canal

The design discharge of the drainage canal shall be the planned maximum discharge defined in the drainage plan. While the flow exceeding the design discharge is not expected in the normal irrigation canal, the drainage runoff with frequency exceeding the planned probability is possible. Therefore, thoughtful considerations shall be given for the flow equal to or exceeding design discharge.

Also, although there is generally no change in catchment area of the drainage plan, runoff data may vary as hydrological conditions, land use category, site social environment, and other items change. Therefore, it is necessary to check these items throughout each phase of planning, design, and construction, and to advance the project while implementing necessary response measures.

3.2 Canal route selection

The canal route shall be selected in a way that it assures the design discharge and designed water level that are determined based on the irrigation and drainage plan, and that it shall be able to accommodate assumed canal types.

In doing so, the route shall be selected with consideration of the canal structure selected for water conveying facilities, the layout of various facilities, and their structural systems as well. Also, in canal route selection, problems with social implications, such as site acquisition and changes in irrigation and drainage practices, may arise. Thus a rigorous comparative study shall be conducted on map drawings beforehand.

The following are general points to be considered for canal route selection.

- For the irrigation canal, the route selection shall be made with consideration that the canal, in principle, can irrigate by gravity to the benefited area, and that the available water head at the intake point will be utilized as much as possible.

- Canal route selection shall be made so that the drainage canal shall, in principal, run through the section of lowest elevation within the project area.

- Items including spillways, waste-weir, and turnouts in irrigation canals shall be located in appropriate locations after a thorough investigation of matters such as conditions of rivers and project area in connection with these facilities, and after coordination with relevant organizations and bodies.

- When the irrigation canal system is very long or it mainly irrigates upland fields, the necessity and possibility of establishing regulating reservoirs shall also be studied because benefits including effective utilization of water and rationalization of water distribution management can be expected by having intervening regulating reservoirs.

- Agricultural water use has multilateral functions as a region's service water system including domestic water, water for purification of water quality, groundwater stabilization, landscape/eco-system conservation water, fire protection water.

- In case of a modification or shifting of canals, those points mentioned above shall be fully considered in the design as well. In addition, great efforts are needed to ensure that this project conforms to other regional development projects by studying them carefully.

3.3 Classification of open canal

3.3.1 Type of open canal

Figure 3-3 shows a structural classification of open canals.

- Open canals
  - Unlined
    - Unlined canals
    - Covered canals (turf, granular fill)
  - Lining
    - Masonry lining canals
    - Concrete slab lining canals
    - Concrete lining canals
    - Reinforced concrete lining canals
  - Retaining wall
    - Masonry retaining wall canals
    - Concrete block retaining wall canals
    - Concrete retaining wall canals
    - Flumes

Figure 3-3 Classification of open canals

3.3.2 Unlined canal

(1) Outline of applications

Unlined canals consist of unlined and protected canals. The former are canals where the natural ground is simply excavated or dikes are filled up on the natural ground, and the latter are canals where inner flow portions are protected by turf, stabilizer or granular fill, etc.

Unlined canal
(Chomachankora, Igunga, Tabora)

Unlined canals are generally applied to irrigation canals and drainage canals. It is favorable to make up a safe and cost efficient design through sufficient studies on alignment of the canal, longitudinal slope, cross-section, so that the canal should be a structure where mechanical stability is secured and where scouring and erosion are not developed by water flow.

(2) Cross-sections of canals

Cross-sections of canals differ depending on the respective canal size, but generally in cases of canals where quantity of flow is small, bottom width/depth ratio of around 2:1 is adopted, and where quantity of flow is large, the ratio of up to around 8:1 is applied.

Inner side slopes of canals often take values of around 1:1.5 to 1:2.5, and in cases where soil character is especially of good quality and the canal size is small, inner side slopes shall be able to be steeper within a range where no trouble occurs on the slope stability.

On the other hand, in cases of soft ground or large-sized canals, it is often difficult to maintain slope stability, and careful studies are required for adopting gentler side slopes or other bank protection methods, after grasping accurate geological features by soil tests.

Canal size, purposes, site conditions shall be considered for determining cross-sections of canals including side slope of the canal. Table 3-2 shows general values for side slope by soil character.

Table 3-2 Side slopes of unlined canals

Nature of soils	Side slope
Hard rock	1:0.3
Weathered rock with cracks	1:0.5
Hard plane of clayey gravelly soil	1:0.5 – 1:1.0
Consolidated gravelly clay	1:1.0 – 1:1.5
Sand-mixed clayey loam	1:1.5 – 1:2.0
Gravel-mixed sandy loam	1:2.0
Sandy loam, soft clay	1:3.0

(Quoted from JSD)

3.3.3 Lining canal

(1) Outline for applications

Lining canal is a canal where concrete slabs, masonry, plain concrete and reinforced concrete are used for a pavement material. These materials have higher resistance against corrosion than other generally used materials, and is adaptable to comparatively large velocity.

Masonry lining canal
(Inara, Sikonge, Tabora)

Since stability of canals of this type depends basically on the stability of the foundation ground, the lining thickness generally requires only the bare minimum. However, where the groundwater level is high and amount of spring water is large, or the foundation ground is unsuitable and the canal is structurally unstable and consequently, it is desirable to discuss on structures or to select other construction method.

(2) Basement of linings

i. Banking

For basement of banking parts, surface soils shall be peeled away, garbage, etc. shall be removed, and proper materials shall be filled back, so that the linings and the filling materials should come into intimate contact with each other.

ii. Cutting

In cases where some or all parts of the lining canal is placed after excavating the foundation ground, the ground shall be properly treated through a judgment whether the ground is appropriate or not.

In cases of unsuitable soil such as where slopes are not stable, designs shall be performed through overall discussions on necessity of replacing banking, conditions of groundwater, range of the unsuitable ground, and presence/absence of banking materials, etc.

(3) Side slope

Side slope of lining canals shall be determined through considering soil character, canal size, construction method, maintenance, etc. In general cases, the values of grade fall into a range of 1:1 to 1:1.5.

Stability side slopes of the canals performed by earth works, and the side slope shall be determined considering nature of soil, canal size, construction method, extent of compaction, distinction of cut or fill, slope height, rapid draw down of water level, etc., so that earth pressure, which can lessen the slope stability, should not act on.

Masonry lining canal
(Buhekela, Igunga, Tabora)

3.3.4 Retaining wall canal

(1) Outline for applications

A retaining wall canal is a type of canals where the wall body is independent from the canal base, and the retaining wall itself maintains stability against earth pressure from behind, groundwater pressure, inner water pressure, etc., and is often adopted for wide canals such as drainage canals.

This type has an advantage in its suitability for large-sized canals. From an aspect of construction works, this type enables partial construction and is employed in cases where works in the canal portion, such as repair works are required.

(2) Type of canal

i. Stone masonry canals

Revetments of these type of canal are formed by laying up cobble stones, rag-stones, etc. Generally, they are often used for canals with broad width. In cases of irrigation canals, many of them are of the type where water tightness and durability are planned to improve by applying wet masonry walls, or others, considering flow velocity or canal functions, etc.

Masonry retaining wall canal
(Msagali, Mpwapwa, Central)

ii. Gravity type retaining wall canals

Gravity type retaining wall canals are generally of plain concrete structures that act as earth retaining structures as well, and are often used for drainage canals and combination canals for drainage and irrigation, where wall heights are less than 2 m.

Meanwhile, semi-gravity type retaining wall canals reduce the concrete volume, comparing with those of gravity type, and instead steel bar reinforcement is provided at points where tensile stress is developed.

iii. Flumes

A flume is a canal of such type where the canal sidewall and bottom slab form a single-piece structure and support together loads such as water pressure or others. A flume is generally used as a reinforced concrete rectangular cross-sectioned canal. Sidewalls of flumes should preferably be vertical.

Flume (Lusu, Nzega, Tabora)

For rectangular cross-sections, hydraulically the most effective ratio of bottom width and water depth is 2:1, but the most effective cross-section is not always superior from structural and economical points of view. Therefore, for decision of the cross-section, it is desirable to carry out a comparison study on safety, ease of work, cost efficiency, with sufficient considerations for characteristics of the flume and the site conditions, etc.

iv. Precasted reinforced concrete flumes

Precasted reinforced concrete flumes are canals where unit bodies, produced at factories or the like, or factory-produced members, either of which is manufactured basing on specified design characteristics, are connected or combined by concrete materials, etc.

Generally, the smaller the canal size is, the more ease of works can be obtained, and this type is adopted when it is economically advantageous. In area where yearly number of workable days is small, this type is often used to shorten construction period.

3.3.5 Points to be considered for selection of canal type

In the selection of canal type, several factor such as design discharge, securing functions required, generality of materials, etc. should be considered comprehensively. Moreover, irrigation facilities should be designed and constructed to show high performance during the service period.

Based on following reason, lining canal is selected as the most suitable canal type in Tanzania except under special condition such as soft ground, restriction of land use, and so on.

- There is much construction example in the country.
- It is not necessary to consider influence of the earth pressure from back soil by inclining canal sidewall because active earth pressure does not act and only examining the measures to prevent scouring of the side slope with the running water is needed.
- Superior to other construction method in economy.
- Materials such as natural stone or concrete slabs are available easily.
- Considerable degree of durability can be secured if appropriate construction is undertaken.

3.4 Evaluation of the soil property

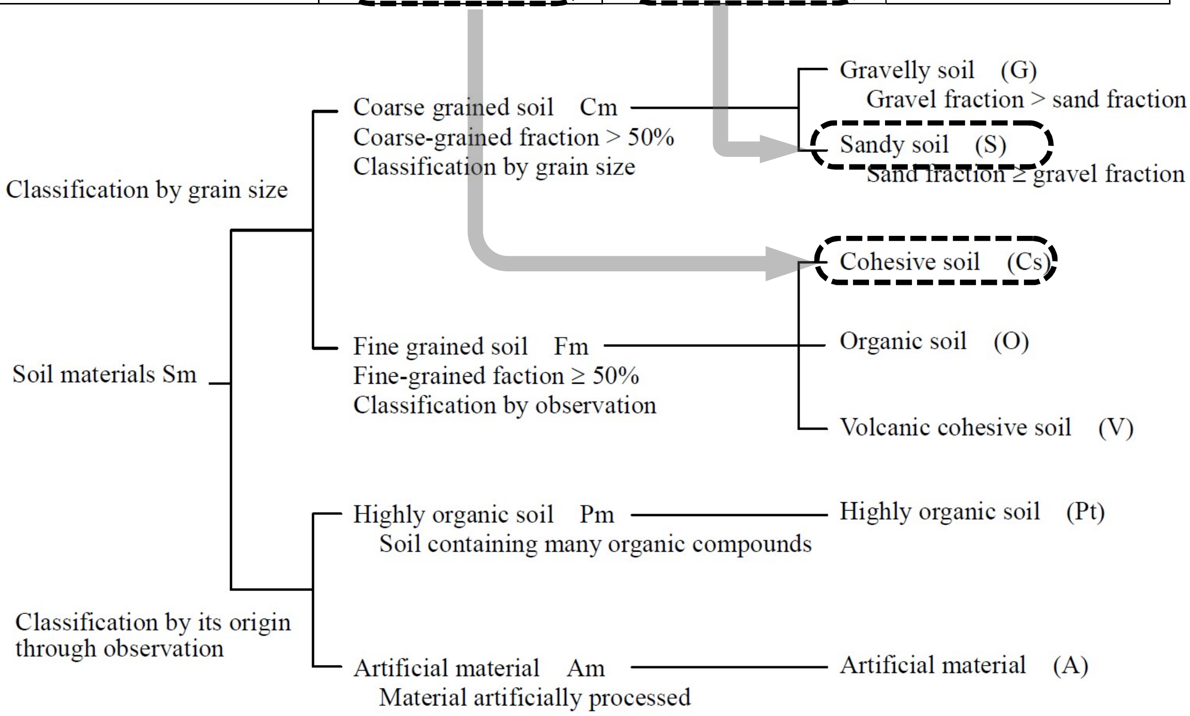
3.4.1 Classification of soil materials

Those soil materials composed of grain sizes less than 75 mm excluding rock fractions are classified into major classifications mainly by observations. According to percentage content (percent by mass,) of coarse-grained fraction or fine-grained fraction, content amount of gravel faction or sand fraction and so on, soil type shall be divided.

The percentage contents in Figure 3-4 are component fractions of 75 μm to 75 mm for coarse-grained fraction, less than 75 μm for fine-grained fraction, 75 μm to 2 mm for sand fraction, and 2 to 75 mm for gravel fraction.

Here, when coarse grained fraction occupies above 50% and sand fraction is more than gravel fraction, “sandy soil” shall be selected as representative soil type. Similarly, when fine grained fraction occupies above 50% without organic or volcanic ingredient, “cohesive soil” shall be selected.

Classification-1	Fine-grained fraction	Coarse grained fraction	
Grain size	less than 75μm	up to 2mm	up to 75mm
Classification-2	-	Sand fraction	Gravel fraction
Representative soil type	Cohesive soil	Sandy soil	Gravelly soil



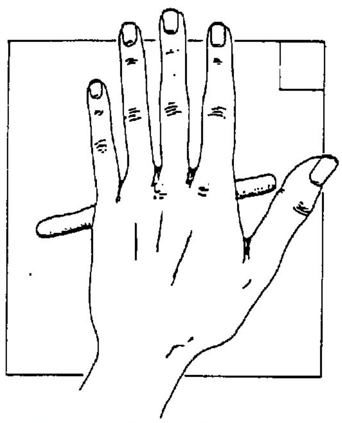
Note: Percentage content(%) indicates the percent by mass for the soil material.

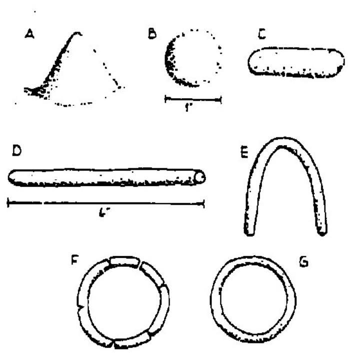
Figure 3-4 Engineering classification system for soil materials

3.4.2 Confirmation of soil property

Easy method for confirmation of soil property is as shown in Figure 3-5. The property of the soil can be estimated by utilizing this method.

1) **Visit the survey together with village chairperson and villagers.**
   Visit the proposed area and choose typical soil in the area with the consultation of the village chairperson and villagers.
2) **Sampling of the soil**
   Gather a soil sample from the soil surface (sample should be about 10 x 10 x 10 cm).
3) **Knead the soil with water.**
   Add some water to the soil sample so it is moist but not wet. Knead it well. Pebbles should be removed.
4) **Try to create ring shapes with the soil sample and choose the most advanced shape that can be made.**





A: Soil can only be shaped into a cone. No other shapes hold together.
B: Soil can be formed into a circle, but not a rod shape.
C: Soil can be formed into a stout rod shape.
D: A thin rod (about 6 mm diameter) can be formed but not bent.
E: Thin rod can be bent without breaking
F: Circle can be formed with some breaks.
G: Complete circle with no breaks can be formed.

5) **Evaluate the soil texture**
   According to the result of 4), <u>circleoneofthedetailedsoiltexturetypes</u> and choose a general soil texture type by conversion of the detailed soil texture type.

Detailed soil texture type			conversion	General soil texture type	
Shape A	Sand	☐	if you choose Shape A →	Sand ☐	Sandy soil
Shape B	Loamy sand	☐	if you choose Shape B or C →	Sandy Loam ☐	Sandy soil
Shape C	Silty Loam	☐			
Shape D	Loam	☐	if you choose Shape D or E →	Clay Loam ☐	Cohesive soil
Shape E	Clay Loam	☐			
Shape F	Light Clay	☐	if you choose Shape F or G →	Clay ☐	Cohesive soil
Shape G	Heavy Clay	☐			

In this manual, "Sand" and "Sandy Loam" evaluated in CGL shall be handled as "Sandy soil". Similarly, "Clay Loam" and "Clay" shall be handled as "Cohesive soil".

Figure 3-5 Easy method for confirmation of soil property
(quoted from Vol 1, Sec 3 in Comprehensive Guidelines)

Note: Black cotton soil (Vertisols: Name of Soil Orders in Soil Taxonomy)

The central concept of Vertisols is that of soils that have a high content (>30%) of expanding clay known as montmorillonite and that have at some time of the year deep wide cracks. They shrink when drying and swell when they become wetter. The shrinking and swelling of Vertisols can damage buildings and roads, leading to extensive subsidence.

Therefore, a form to reduce influence by the expansion of the soil as much as possible is desirable in the setting of the canal cross-section and the replacement of backfilling and basement with gravel shall be necessary as a counter measure.

3.4.3 The side slope of lining canal

The side slope of lining canal should be decided so that it cannot be scoured or washed out by water flow. In addition, water loss such as leakage from the canal section have to be reduced as much as possible to supply irrigation water to the beneficial area certainly.

In this manual, the side slope of lining canal is proposed as follows.

Table 3-3 Side slope of lining canal

Soil type	Side slope	Remark
Cohesive (Normal) soil	1:1.2	
Sandy soil	1:1.5	
Black cotton soil	1:1.5	With backfilling and base gravel

The reason of decision is as follows.

(1) Little influence of "Active Earth Pressure"

It is not necessary to consider influence of the earth pressure from back soil by inclining canal sidewall because active earth pressure does not act.

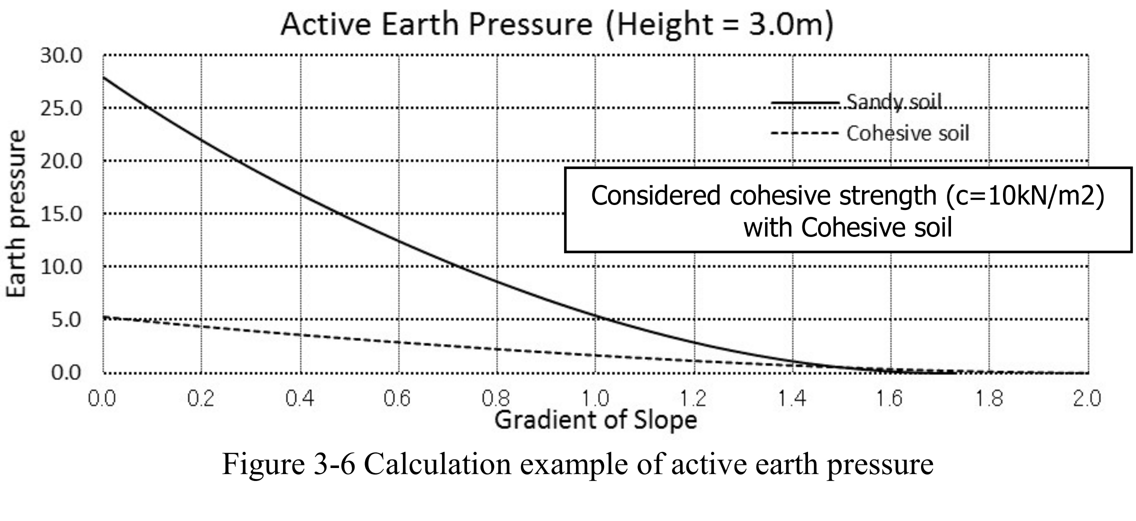


Figure 3-6 Calculation example of active earth pressure

(2) Current situation of canal construction in Tanzania

There is much construction example in the country. Moreover, as for the serious problem was not supposed in the site survey was executed from 18th, Jan to 18th, Feb, 2016.

The survey result is as shown blow.

Table 3-4 Representative cross section of canal according to the scheme

Scheme	District	Zone	W	H	m	Classification	Const. year
Igongwa	Misungwi	Mwanza	1,00	0.70	1.20	Unlined	1997
Bukigi	Mleba	Mwanza	1.30	0.60	1.25	Masonry lining	2006
Itilima	Kishapu	Mwanza	1.00	1.00	1.20	Unlined	2003
Nyida	Shinyanga	Mwqanza	0.4	0.7	1.20	Con. lining (BRC)	2017
Buhekela	Igunga	Tabora	0.60	1.00	1.20	Masonry lining	2003
Chomachankora	Igunga	Tabora	1.50	1.30	1.20	Masonry lining	1994
(Mwamapuli)	Igunga	Tabora	1.50	1.25	1.20	Concrete slab lining	1986
Lusu	Nzega	Tabora	1.20	0.80	0.00	Flume	1996
Ulyanyama	Sikonge	Tabora	0.80	0.50	1.20	Masonry lining	2007
(Inara)	Sikonge	Tabora	0.45	0.70	1.20	Masonry lining	2015
(Chalinze)	Dodoma	Central	0.70	0.85	1.00	Concrete slab lining	2012
Bahi-sokoni	Bahi	Central	0.50	1.00	1.00	Masonry lining	2012
Msagali	Mpwapwa	Central	0.70	0.70	0.00	Masonry	2003
			0.60	0.70	1.20	Concrete slab lining	2013
Msufini	Mvomero	Morogoro	0.50	0.80	0.80	Conc. retaining wall	2013
Kimbande	Nyasa	Mtwara	0.60	0.90	0.50	Masonry lining	2008

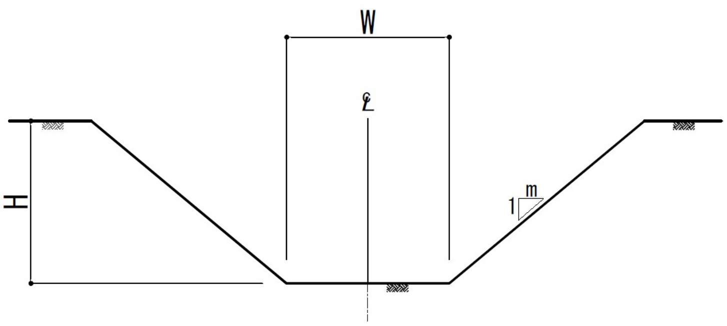


Figure 3-7 Cross-section model

(3) Japanese criteria for lining canal

Since stability of lining canal depends on stability of side slopes and side slope as a standard shall be determined in the range of 1:1.0 to 1:1.5 at Japanese criteria.

(4) Japanese criteria for unlined canal

Referring to Table 3-2, side slopes of unlined canals, “Normal soil” as “Consolidated gravelly clay” and “Sandy soil” as “Sandy mixed clayey loam”, can be employed.

(5) Japanese criteria for earth work

The gradient of slop in earth work referring to Table 3-5 (cutting) and Table 3-6 (banking) is established as rather stable shape after earth work. So, the gradient value of sandy soil (not dense) and cohesive soil can be handled for a reference.

i. Cutting

Natural ground often shows non-uniformity with reasons including that soil property significantly differs depending on the extent of weathering and cracking, cutting height, state of spring water, conditions of stratification, water content, etc.

Therefore, for designing gradient of slopes, investigations should be carried out in advance for site conditions, state of existing slopes, and then design specifications including cutting heights or gradient of slope should be determined referring to Table 3-5.

Table 3-5 Standard side cutting slope

Soil property of natural ground		Cutting height	Gradient
Hard rock			1:0.3 – 1:0.8
Soft rock			1:0.5 – 1:1.2
Sand	Not dense and gradation distribution is bad		1:1.5 -
Sandy soil	Dense (tight)	5m or less	1:0.8 – 1:1.0
		5 – 10m	1:1.0 – 1:1.2
	Not dense (loose)	5m or less	1:1.0 – 1:1.2
		5 – 10m	1:1.2 – 1:1.5
Pebbly soil, Gravel or rock-hump mixed sandy soil	Dense or gradation distribution is good	10m or less	1:0.8 – 1:1.0
		10 – 15m	1:1.0 – 1:1.2
	Not dense or gradation distribution is bad	10m or less	1:1.0 – 1:1.2
		10 – 15m	1:1.2 – 1:1.5
Cohesive soil		10m or less	1:0.8 – 1:1.2
Rock-lump or cobble stone mixed cohesive soil		5m or less	1:1.0 – 1:1.2
		5 – 10m	1:1.2 – 1:1.5

(Quoted from JSD)

ii. Banking (Embankment)

For lining canals where stability of structures heavily depends on the banking conditions, it is required to fill up good quality soil and compact it sufficiently so that rainwater should not enter into the backside of linings.

Gradients of banking slopes cannot be defined easily as they depend on the site topography, banking materials, banking methods, slope protection methods, etc. Design specifications, for including banking heights or gradients of banking slopes should be determined referring to Table 3-6.

Table 3-6 Standard side banking slope

Banking material	Banking height	Gradient	Notes
Sand with good gradation, pebble, and fine-grain mixed pebble	5m or less	1:1.5 – 1:1.8	Applied to the banking whose base ground provides sufficient bearing capacity that will not be affected by water exposure.
	5 – 10m	1:1.8 – 1:2.0	
Sand with bad gradation	10m or less	1:1.8 – 1:2.0	
Rock lump (including muck)	10m or less	1:1.5 – 1:1.8	
	10 -20m	1:1.8 – 1:2.0	
Sandy soil, hard viscous soil, hard clay	5m or less	1:1.5 – 1:1.8	
	5 – 10m	1:1.8 – 1:2.0	
Volcanic cohesive soil	5m or less	1:1.8 – 1:2.0	

(Quoted from JSD)

3.4.4 Study on backfilling replacement

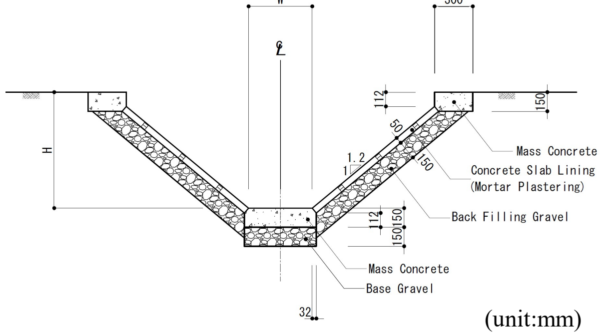
On the basis of foundation ground conditions that have been grasped through soil investigations, safety of the canal structures should be studied so that an appropriate design should be performed. When unfavorable ground exists in the foundation of the canal, it is normally preferable to make a plan avoiding such a site.

However, if it is inevitable to make such a plan due to various conditions including cost efficiency of the alignment of the canal or ease of works, suitable soil stabilization works or foundation works should be selected, so that the design should be executed to take countermeasures for preventing differential settlement and others.

In canal construction, however, changes in the foundation ground are often realized in the site working stage, and therefore supplement investigations should be executed for such occurrences, and it is required to cope with quickly basing on the investigation results.

In case of soft ground such as black cotton soil or high groundwater level, the irrigation canal possibly floats or deteriorates with differential settlement due to uplift pressure of groundwater. Moreover, when groundwater moves to the canal inside, hollowing out by a particle of the soil from backfilling and foundation of the canal may lead to structural collapse at last.

In consideration of the situation mentioned above, replacement of backfilling and basement using gravel, sandy soil or morrum is proposed while weep hole or under drain is effective as a counter measure. In addition, the thickness of the gravel layer should be set at least 15 cm so that abnormal pressure to act by groundwater shall be absorbed.



(unit:mm)

Figure 3-8 Model of backfilling

3.5 Hydraulic design by normal calculation

3.5.1 Discharge in canal

In hydraulic design of the canal, the following equation shall be used generally.

$Q = A \cdot v$

Q: Discharge (m^3/s)
A: Cross-sectional area of flow (m^2)
v: Mean velocity (m/s)

3.5.2 Mean velocity formula for open channel system

The mean velocity of uniform flow in the open channel system is calculated by the Manning's equation. The relation of each element is as shown in Figure 3-9 and 3-10.

$v = 1/n \cdot R^{2/3} \cdot S^{1/2}$

v: Mean velocity (m/s)
n: Coefficient of roughness
R: Hydraulic mean depth (m)   R = Cross-sectional area (A) / Wetted perimeter (P)
S: Canal slope

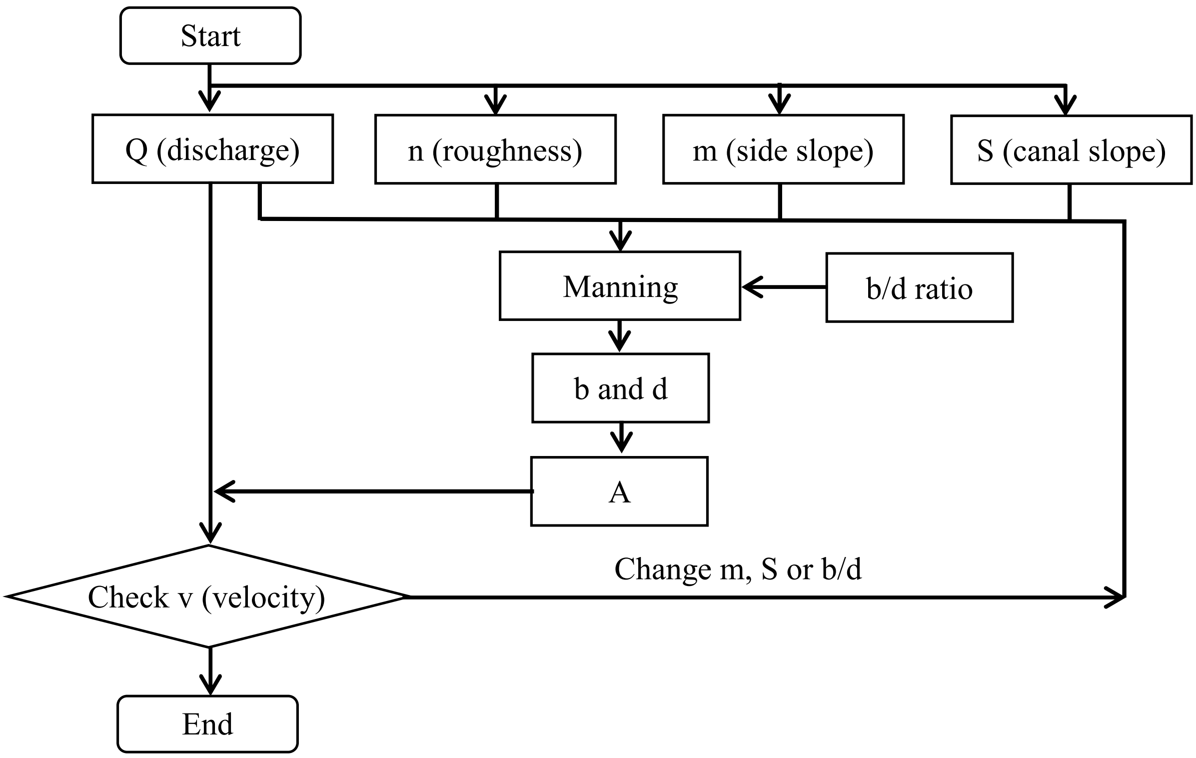


Figure 3-9 Flowchart for canal design calculations

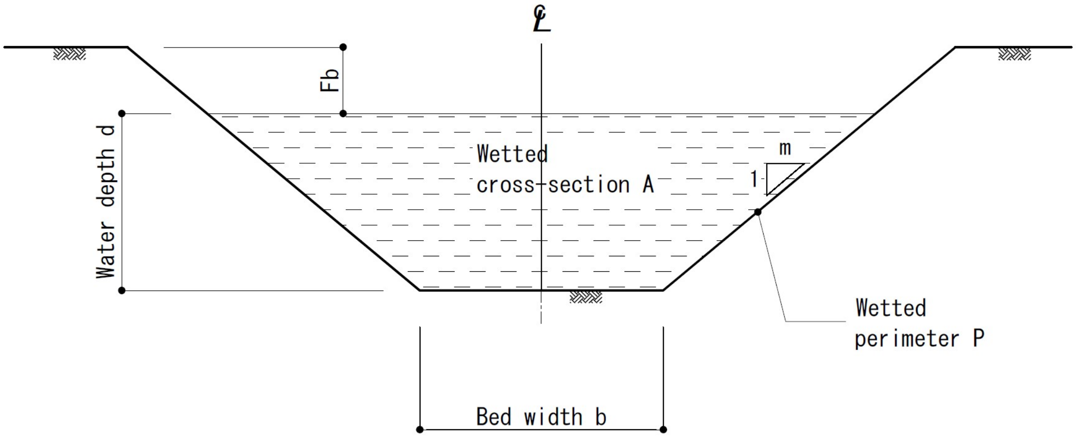


Figure 3-10 Canal parameters

The steeper the side slope, the faster the water will flow and the greater the discharge will be. Velocity increases with an increase in side slope or longitudinal slope. It therefore follows that a canal with a steeper side slope but with the same cross-section can discharge more water than a canal with a smaller side slope.

3.5.3 Selection of coefficient of roughness

The applicability of the Manning's equation depends on whether selection of coefficient of roughness is appropriate. Therefore, determination of coefficient of roughness requires careful consideration because the result varies depending on numerous factors including surface roughness, grass vegetation, curvature of the canal, cross-sectional shape, velocity, hydraulic mean depth, sediment deposition and scour, suspended substance, future maintenance and operation conditions of the canal, etc.

Generally, if canals constructed by the same materials are compared to each other, the coefficient of roughness tends to be larger when the velocity is extremely small, or when the hydraulic mean depth is small. Although commonly used coefficient of roughness are listed in Table 3-7, standard values are being typically used in design.

Also, in canal, since the smoothness of the inside wall surface are gradually lost due to wear, scour, sediment from flowing water actions, or due to overgrowth of water weeds, stains and rusts on the surface generated by suspended solid, thoughtful considerations shall be provided in design for these items.

The standard values in Table 3-7 are used, taking these factors considered to be common items into considerations as well. Specifically, when the degree of roughness degradation is not considered to be common, the minimum or maximum value can be selected.

Table 3-7 Values for coefficient of roughness

< Canals constructed by excavation or dredging >

Material of canal and its condition	Coefficient of roughness		
	Minimum value	Standard value	Maximum value
Earth, straight and uniform			
1. No weed (immediately after completion of the canal)	0.016	0.018	0.020
2. No weed (after the canal has been exposed to weather)	0.018	0.022	0.025
3. Gravels (no weed)	0.022	0.025	0.030
4. Few weeds with short grasses	0.022	0.027	0.033

(Quoted from JSD)

< Lining, retaining wall canals >

Material of canal and its condition	Coefficient of roughness		
	Minimum value	Standard value	Maximum value
Concrete (cast-in-place flume, culverts, etc.)	0.012	0.015	0.016
Concrete (reinforced concrete pipe)	0.011	0.013	0.014
Concrete(metal trowel finishing)	0.011	0.015	0.015
Concrete slab masonry	0.014	0.016	0.017
Cement (mortar)	0.011	0.013	0.014
Masonry (rubble stone mortar masonry)	0.017	0.025	0.030
Masonry (rubble stone cavity wall)	0.023	0.032	0.035
Vegetation coverage (sodding)	0.030	0.040	0.050

(Quoted from JSD,JRA)

< Natural flow canals >

Material of canal and its condition	Coefficient of roughness		
	Minimum value	Standard value	Maximum value
Small canals in plain area			
1. No weed and straight. No fracture or deep water spot when the high-water level is reached	0.025	0.030	0.033
2. No weed, but meandering. Some shoals and deep water spots	0.033	0.040	0.045
3. Weeds and deep spots in mild flow sections	0.050	0.070	0.080
4. Section with thick vegetation of weed. Many deep water spots and trees	0.075	0.100	0.115
Canal in mountainous land, no plant. River banks are steep.			
1. River bed is covered by cobble stones and gravels	0.030	0.040	0.050
2. River bed is covered by large cobble stones	0.040	0.050	0.070

(Quoted from JSD)

Table 3-8 Values for coefficient of roughness (FAO)

Type of surface	Range of roughness
Pipes, precast and lined canal	
Metal, wood, plastic, cement, precast concrete etc.	0.010 – 0.015
Concrete canal and canal structures	0.012 – 0.016
Rough concrete lining	0.017 – 0.025
Masonry	0.025 – 0.035
Corrugated pipe structures	0.023 – 0.025
Earthen canals, straight and uniform	
Clean, recently completed	0.016 – 0.020
Clean, after weathering	0.018 – 0.025
With short grass, few weeds	0.022 – 0.027
Earthen canals, winding and sluggish	
No vegetation	0.023 – 0.030
Grass, some weeds	0.025 – 0.033
Dense weeds or aquatic plants in deep canal	0.030 – 0.040
Canals, not maintained, weeds and brush uncut	
Dense weeds as high as flow depth	0.050 – 0.120
Clean bottom, brush on sides	0.040 – 0.080

Note: Since there is not much difference in values of coefficient of roughness between Japanese Standard Design and FAO, JSD value can be employed.

3.5.4 Composite coefficient of roughness

When the Manning's equation is applied to the cross section of canal which coefficient of roughness at the wetted perimeter varies depending on spot locations, the velocity shall be obtained by calculating the composite coefficient of roughness for the entire wetted perimeter. (Figure 3-11 and Table 3-9)

$$n_i = \{\frac{1}{\sum p_i}(p_1 \cdot n_1^{3/2} + p_2 \cdot n_2^{3/2} \cdots + p_5 \cdot n_5^{3/2})\}^{2/3}.$$

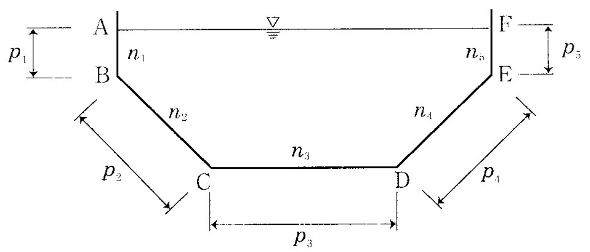


Figure 3-11 Wetted perimeter diagram

Table 3-9 Composite coefficient of roughness

Wetted perimeter	Coefficient of roughness	Length of wetted perimeter
AB	n_1	p_1
BC	n_2	p_2
CD	n_3	p_3
DE	n_4	p_4
EF	n_5	p_5
Total	n_i	Σp_i

(Quoted from JSD)

3.5.5 Minimum allowable velocity

Object discharges in studying the minimum allowable velocity are as shown in Table 3-10.

Table 3-10 Object discharges in studying the minimum allowable velocity

Type of canal	Object discharges
Irrigation canal	Most frequent discharge (the discharge which occurs most times in the pentad mean discharge unit throughout the water conveyance period of the canal)
Drainage canal	Discharge to study the low water revetment, etc. (1-year or 2-year probability discharge)

(Quoted from JSD)

It is appropriate that the minimum allowable velocity would not be below the velocity under the object discharge flow condition. However, when the velocity is below the minimum allowable velocity out of necessity, the structure and management system that are capable of maintaining drainage function of the canal shall be provided.

Also, the minimum allowable flow velocities shall follow values provided in Table 3-11.

Table 3-11 Minimum allowable flow velocities

Condition of canal	Minimum allowable velocity
Canal where concerns regarding deposition of floating sediment do exist.	0.45 - 0.90 m/s
Canal where concerns regarding overgrowth of water weed do exist.	0.70 m/s

(Quoted from JSD)

Note: The minimum allowable velocity shall be determined by the grain size of floating sediment.

3.5.6 Maximum allowable velocity

Object discharges in studying the maximum allowable velocity are as shown in Table 3-12.

Table 3-12 Object discharges in studying the maximum allowable velocity

Type of canal	Object discharges
Irrigation canal	Planned maximum flow discharge
Drainage canal	Discharge to study the low water revetment, etc. (1-year or 2-year probability discharge) season

(Quoted from JSD)

The maximum allowable velocity is a value determined mainly by structural durability of the material of the canal structure against scour and wear. This velocity involves uncertainties because it significantly varies depending on the material constituting the canal. Therefore, judgments have to be exercised based on experiences and other case examples.

Based on materials and thickness of the members of the canal and the inside surface of the canal structure, those values shown in Table 3-13 are considered as approximate limiting values.

Table 3-13 Maximum allowable velocity

Type of material	Maximum allowable velocity (m/s)	Classification	Maximum allowable velocity (m/s)
Sandy soil	0.45	Thick concrete (approximately 18 cm)	3.00
Sandy loam	0.60	Thin concrete (approximately 10 cm)	1.50
Loam	0.70	Asphalt	1.00
Clayey loam	0.90	Block cavity wall (buttress pier less than 30 cm)	1.50
Clay	1.00	Block cavity wall (buttress pier 30 cm or larger)	2.00
Sandy clay	1.20	Block mortar masonry	2.50
Soft rock	2.00	Reinforced concrete pipe	3.00
Semi-hard rock	2.50	Steel pipe, ductile cast iron pipe	5.00
Hard rock	3.00	Reinforced concrete secondary product canal	3.00

(Quoted from JSD)

3.5.7 Freeboard

The freeboard deals with unanticipated events that a canal may encounter such as water surface vibration, and its size shall be assessed by the discharge. The basic equations for canal freeboard calculation by cross section shapes and types of canal are as follows.

< Non-lining canals and lining canals >

$Fb = 0.05\ d + \beta \cdot hv + hw$

Fb: Freeboard (m)

d: Water depth corresponding to design discharge (m)

hv: Velocity head (m) = $v^2 / 2g$

β: Conversion factor from velocity head to static head, ranging 0.5 - 1.0

Note: When there are gates and/or screens that can block the canal completely, it is possible to have an upraise of water surface by 50 to 100 % of the velocity head in the upstream side of these structures depending on their operation mode.
Moreover, 50 % of the velocity head shall be allotted to deal with unanticipated situations and other events for canals where factors for water surface upraise due to velocity head is not particularly expected.

hw: Freeboard for water surface vibration (m) = 0.05 - 0.15m

Note: The flow in a canal generates wave movement due to structures (gates, drops, chutes, pumping stations, etc.), wind, etc. Therefore, 5 to 15 cm shall be added as freeboard specifically for the water surface vibration

< Retaining wall canals: flumes, retaining wall canals, box culverts, etc.>

$Fb = 0.07\ d + \beta \cdot hv + hw$

3.5.8 Hydraulically effective cross-sections

When a flow area "A" is given, a canal cross-section with the shortest length of wetted perimeter "P" is capable for the largest quantity of flow. Such a cross-section is called the most hydraulically effective cross-section, and it is generally accepted that cross-sections close to the most effective cross-section are usually most cost effective as well.

The most hydraulically effective cross-sections for trapezoid and rectangular cross-sections are obtained through following equations.

$b = 2\,d \cdot \tan(\theta/2)$

d: Water depth (m)
b: Bed width (m)
θ: Angle between sidewall and horizontal plane (°)
m: Side slope

K: $(Q \cdot n) / (S^{1/2} \cdot b^{8/3})$

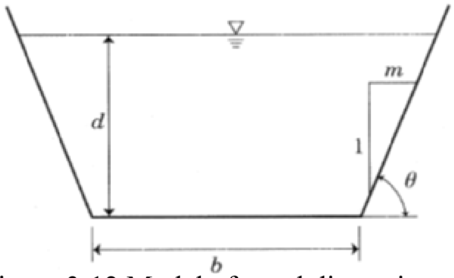


Figure 3-12 Model of canal dimension (quoted from JSD)

Here, "K" is the parameter that is obtained by transformation of Manning's equation and it is necessary to calculate the cross-section based on the direct calculation method for the depth of uniform flow.

The most hydraulically effective cross-sections for each side slope "m" in canals of trapezoid and rectangular cross-section are as shown in Table 3-14.

Table 3-14 The most hydraulically effective cross-sections and dimensions

m	0.0	0.3	0.5	1.00	1.20	1.25	1.50	2.00
θ	90	73.30	63.43	45.00	39.81	38.66	33.69	26.57
d/b	0.500	0.672	0.809	1.207	1.381	1.425	1.651	2.118
K	0.198	0.396	0.622	1.903	2.851	3.141	5.058	11.445

< Calculation example >

(1) Test condition

The test condition is as follows;

Q (discharge) = 0.80 m^3/sec
S (canal slope) = 1 / 1000 = 0.001
n (coefficient of roughness) = 0.016 (concrete slab lining)
m (side slope) = 1.20 (1:1.20)

When each element is determined as shown above, the parameter "d/b" and "K" shall be set as follows on the basis of Table 3-14.

$d/b = 1.381$

$K = (Q \cdot n) / (S^{1/2} \cdot b^{8/3}) = 2.851$

Here, "b" is obtained by transformation of the equation written above.

$b = (1 / 2.851)^{3/8} \times (Q \times n / S^{1/2})^{3/8}$

(2) Calculation

$b = (1 / 2.851)^{3/8} \times (0.80 \times 0.016 / 0.001^{1/2})^{3/8}$
$= 0.481 = 0.48$ m

$d = 0.48 \times 1.381$
$= 0.663 = 0.66$ m

$A = (0.481 + 0.664 \times 1.20) \times 0.664$
$= 0.848 = 0.85$ m^2

$v = Q / A$
$= 0.80 / 0.85$
$= 0.941 = 0.94$ m/sec

$Fb = 0.05\, d + \beta \cdot hv + hw$
$= (0.05 \times 0.664) + (0.5 \times 0.941^2 / 19.6) + 0.10$
$= 0.033 + 0.023 + 0.10$
$= 0.156 = 0.16$ m

Height of canal = d + Fb
$= 0.664 + 0.156$
$= 0.82$ m

3.6 Hydraulic design using the proposed chart

3.6.1 General

This Manual is introducing a simple design method of canal cross-section settling for small scale irrigation schemes by using “Calculation Chart” as attached in Annex-1. After getting Q (discharge), S (canal slope), m (side slope) and assuming the canal type such as concrete slab lining, masonry lining, you can simply design the cross-section of canals using the chart.

The contents of Annex-1 is as follows.

Table 3-15 Contents of “Calculation Chart for Cross-section Settling”

Item	Side slope	Curve name	Result to be provided	Chart No.
Concrete Lining Canal	1:1.2	Q – b	b (Bed width)	C-1
		Q – v	v (Velocity of flow)	C-2
		Q – H	H (Height of canal)	C-3
	1:1.5	Q – b	b (Bed width)	C-4
		Q – v	v (Velocity of flow)	C-5
		Q – H	H (Height of canal)	C-6
Concrete Slab Lining Canal	1 : 1.2	Q – b	b (Bed width)	CS – 1
		Q – v	v (Velocity of flow)	CS – 2
		Q – H	H (Height of canal)	CS – 3
	1 : 1.5	Q – b	b (Bed width)	C S- 4
		Q – v	v (Velocity of flow)	C S– 5
		Q – H	H (Height of canal)	C S– 6
Masonry Lining Canal	1 : 1.2	Q – b	b (Bed width)	M – 1
		Q – v	v (Velocity of flow)	M – 2
		Q – H	H (Height of canal)	M – 3
	1 : 1.5	Q – b	b (Bed width)	M – 4
		Q – v	v (Velocity of flow)	M – 5
		Q – H	H (Height of canal)	M – 6
<Reference>				
Unlined Canal	1 : 1.2	Q – b	b (Bed width)	U – 1
		Q – v	v (Velocity of flow)	U – 2
		Q – H	H (Height of canal)	U – 3
	1 : 1.5	Q – b	b (Bed width)	U – 4
		Q – v	v (Velocity of flow)	U – 5
		Q – H	H (Height of canal)	U – 6
Flume (Rectangular cross-section)	-	Q – b	b (Bed width)	F – 1
		Q – v	v (Velocity of flow)	F – 2
		Q – H	H (Height of canal)	F – 3

The setting condition for calcullation is as follows.

Table 3-16 Setting condition

Item			Setting value	Remark
Coefficient of roughness	Concrete Slab Lining Canal		0.016	
	Masonry Lining Canal		0.025	
Minimum allowable velocity			0.50 m/sec	
Maximum allowable velocity			2.50 m/sec	
Freeboard (Fb = 0.05 d + β • hv + hw)		β	0.5	As minimum value in the range
		hw	0.10 m	As average value in the range

Note: 1. When obtained b using Q – b curve, the parameter of “d (Water depth)” shall be obtained from “d/b” ratio automatically. (Table 3-14, P.28)

2. Freeboard shall be calculated after obtained both of “d (Water depth)” and “v (Velocity of flow)”. Moreover, “H (Height of canal)” means “d (Water depth)” + Freeboard.

3.6.2 How to use the chart

How to use the “Calculation Chart” is as follows;

Step-1

Set the “Q” (discharge) in vertical axis of the chart after selecting the line of S (canal slope).

(1) “b” (Bed width) shall be decided using “Q – b curve” as Chart No. “C-1”.

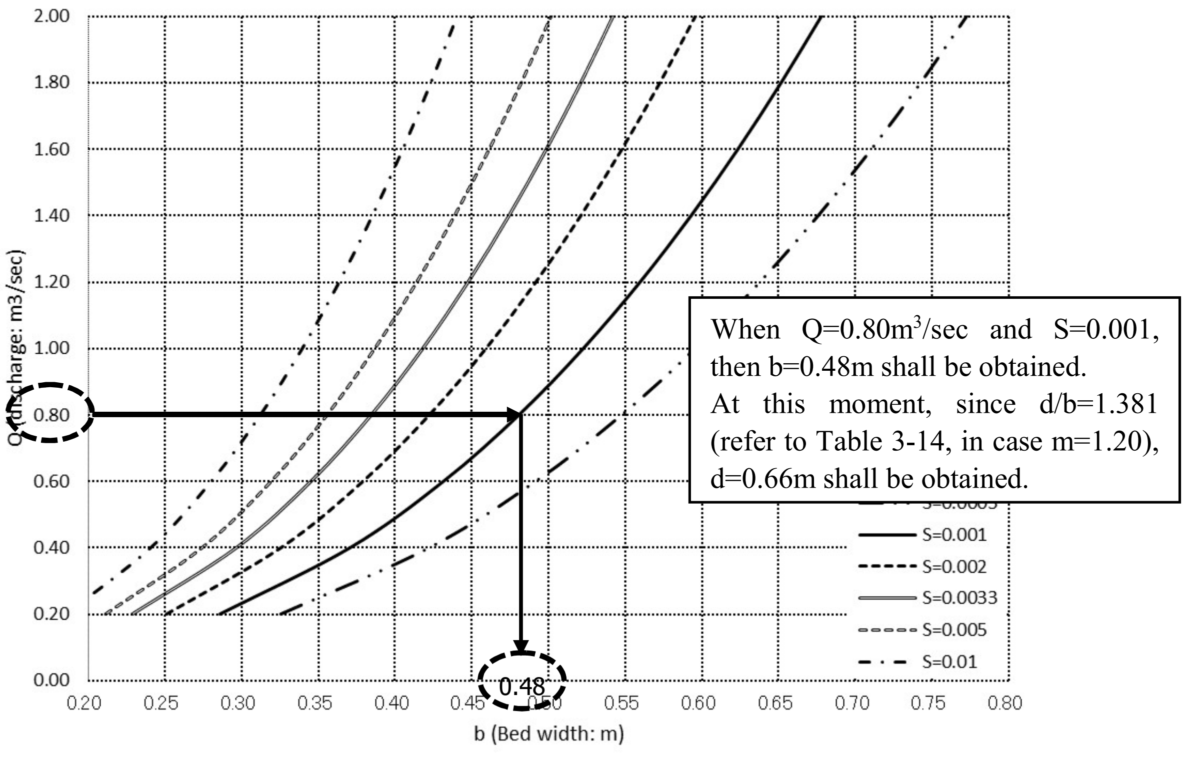


Figure 3-13 Example of Q – b curve

(2) "v" (Velocity of flow) shall be decided using "Q – v curve" as Chart No. "C-2".

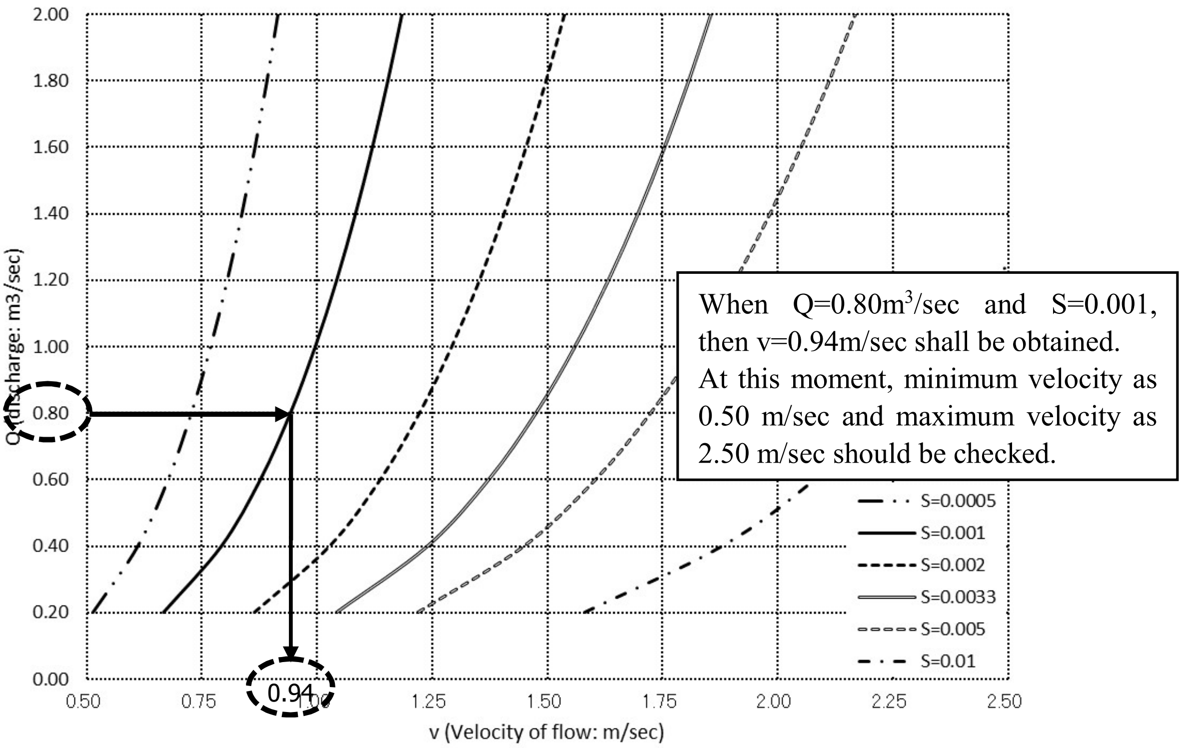
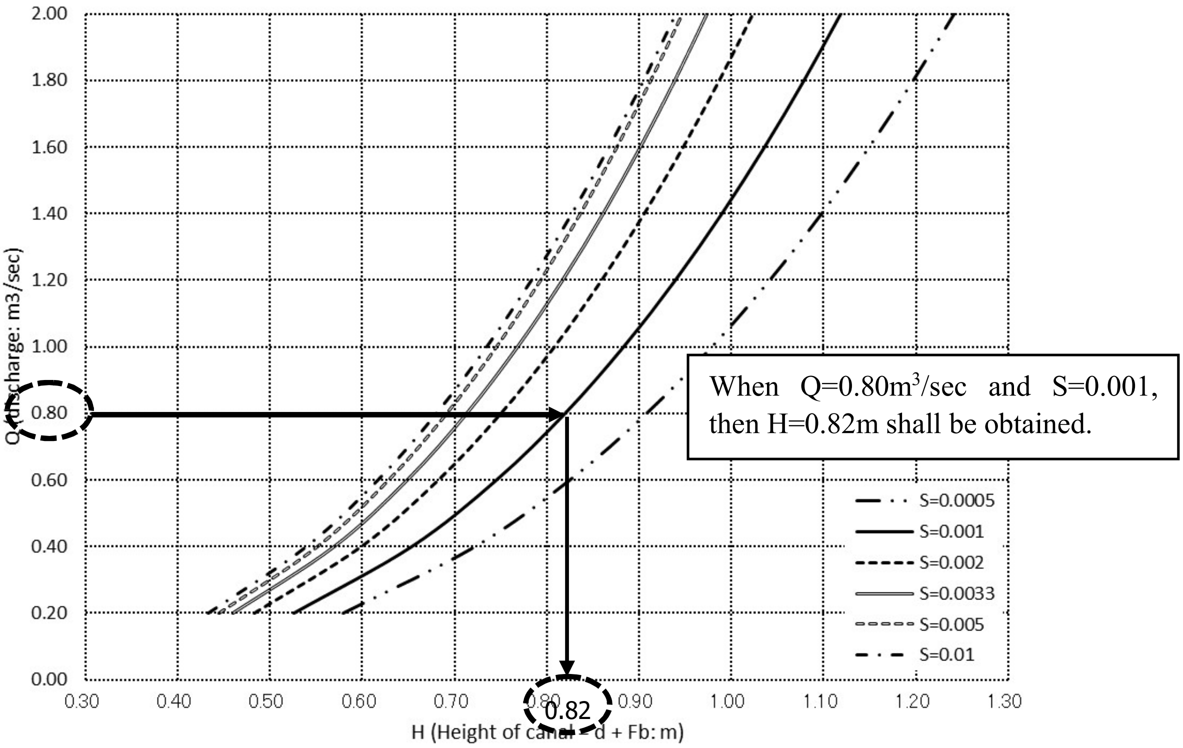


Figure 3-14 Example of Q – v curve

(3) "H" (Height of canal) shall be decided using "Q – H curve" as Chart No. "C-3".



Step-2

Read the value of "b" (Bed width) in horizontal axis at the point to intersect.

An example of how to use "Concrete Slab Lining Canal (Side Slope = 1:1.2)" is as follows. (Test condition is same as normal calculation mentioned above)

Figure 3-15 Example of Q – H curve

The cross-section as a result of above procedure is as follows.

b (Bed width) = 0.48 m (from Q – b curve)

d (Water depth) = 0.48 × 1.381 (d/b ration) = 0.66 m

H (Height of canal) = 0.82 m (from Q – H curve)

Fb = 0.82 – 0.66 = 0.16 m

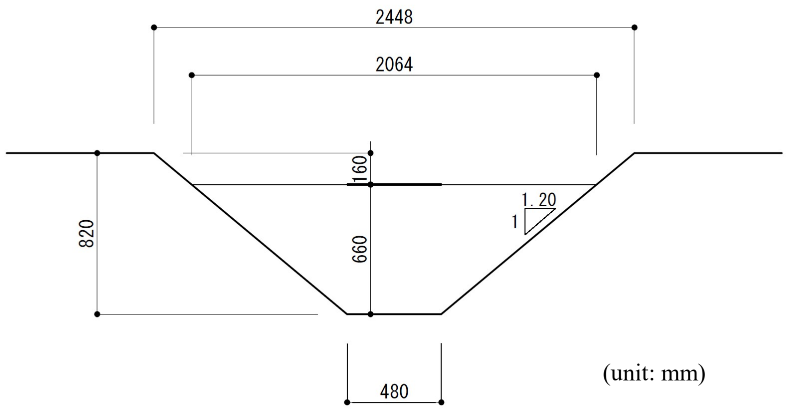


Figure 3-16 Decided cross-section

For reference, accuracy confirmation of a demanded result by normal calculation described at "(2) Calculation, P.29" is as follows;

Table 3-17 Summary of the calculation

Item	Calculation chart (A)	Normal calculation (B)	Accuracy (A/B)
b (Bed width)	0.48	0.48	100.0 %
v (Velocity of flow)	0.94	0.94	100.0 %
H (Height of canal)	0.82	0.82	100.0 %

As shown in Table 3-17, the result of each calculation factors are same, and the validity of the calculation chart shall be proved.

3.7 Economic comparison

3.7.1 The need of the economic comparison

After study on hydraulic design, the economic comparison is necessary because there are two type of lining canal; concrete slab and masonry. Since the coefficient of roughness between those types differ, the cross-section of each canal changes even if the discharge is the same.

So, after setting the cross-section of both lining canal using calculation chart, economic comparison should be executed.

3.7.2 Procedure of the comparison

The comparison is carried out as follows;

Step-1 Setting the cross-section

Test condition is same as an example described at 3.6.2.

Q (discharge) = 0.80 m^3/sec
S (canal slope) = 1 / 1000 = 0.001
m = 1.2 (1:1.2)

Each factor of cross-section shall be obtained using calculation chart "Masonry Lining Canal (Side Slope = 1:1.2): Chart No. M-1, M-2, M-3" in Annex-1.

The result of each item is as Table 3-18.

Table 3-18 Decided cross-section

Item	Concrete slab lining	Masonry lining
b (Bed width)	0.48 m	0.57 m
v (Velocity of flow)	0.94 m/sec	0.63 m/sec
H (Height of canal)	0.82 m	0.94 m
W (Width of canal)	2.45 m	2.83 m
SL (Side slope length: both side)	2.56 m	2.94 m

Step-2 Estimation of the unit cost. (Please calculate based on your local condition.)

Since the construction costs, material costs vary largely for each area in Tanzania and it is difficult to estimate the accurate unit cost as a standard. However, the construction cost should be calculated as usually and it is necessary to keep the execution of economical and effective project in mind.

Moreover, when the estimation of unit cost is carried out, not only material cost but also labor cost and transportation cost, etc. should be considered.

The example of the cost estimation sheet is as shown in Table 3-19.

Table 3-19 Summary of the cost estimation

Item	Concrete slab lining	Masonry lining
Earth work (cutting)		
Treatment of foundation		
Mass concrete		
Concrete slab lining		-
Masonry lining	-	
Total		

Finally, concrete slab or masonry lining canal will be selected as a suitable structure.

4. Incidental structure

4.1 Division structure

4.1.1 General

When installing division structures, it is necessary to plan with prescribed functions based on the irrigation network studied in designing the canal system, scrap-and-build plan for division structures, and the diversion plan and its arrangement of route system which consider the local irrigation custom and the will of the community.

Accordingly, before designing a facility, design consideration points based on the canal system must be confirmed; for example, water supply plan, water management system, type of division structure considering the canal type, scale, and the number of facilities.

To select the installation location, the following matters should be considered from the view point of maintenance, management and structural design.

- The location shall be on the good ground.
- The location shall be near the irrigated area and convenient for the maintenance and management of the division structures.
- High banking or deep cutting shall be avoided as much as possible.
- The location where there is no possibility of the occurrence of disaster.
- The location at which construction can be executed easily.
- The location where water flow is stabilized.
- The location where necessary head can be ensured

4.1.2 Selection of type of division structure

Proper type of division structure shall be selected in accordance with the water management system, water level and discharge control system, and canal type.

An indication of selecting the type of division structure is a diversion ratio which is a ratio of branch canal discharge to main canal discharge. When the diversion ratio is almost equal to or more than 20 %, selection of a dividing wall distributor, jet flow distributor, or a cylindrical proportional distributor shall be considered, and when the diversion ratio is less than 20 %, selection of a gate offtake regulator or a constant head orifice offtake regulator shall be considered.

When discharge from a division structure needs to be measured, type of division structure and a discharge measurement method that match the combination shall be selected. As shown in Fig 4-1, when a diversion pipe shall be mounted directly to the side wall of the main canal so as to divert water to the diversion canal, inflow loss shall be taken into consideration.

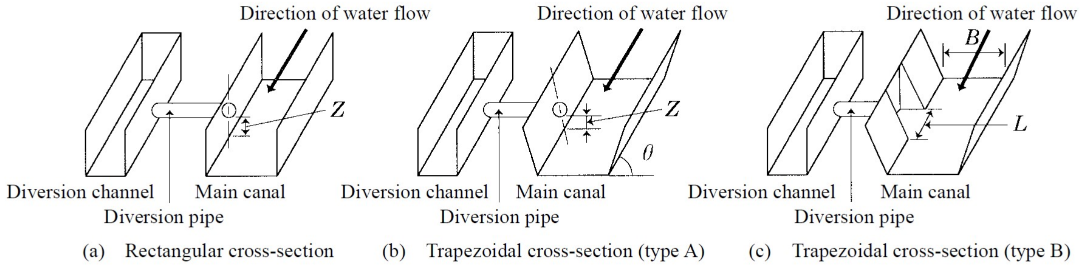


Figure 4-1 Shape of sluice-pipe type division structure

(quoted from JSD)

4.1.3 Consideration points for designing division structures

- The structure shall be rigid, accurate, and durable.
- The costs of facility, maintenance and management shall be inexpensive.
- Division structures shall not cause hydraulic state of upstream and downstream to change significantly.
- Although division structures are basically designed based on the design discharge, the amount of discharge, such as most frequent discharge, minimum discharge shall be considered according to the functions and purpose of each division structure.
- Head loss for diversion shall be minimized and easily regulated from the view point of maintenance and management.
- The diversion type shall be united as much as possible so as to save labor for water management and equalize diversion accuracy.

4.2 Drop structure

4.2.1 General

In the design of the canal system, when an excess head is present in spite of the appropriate distribution of the longitudinal slope of the canal and the appropriate selection of route, drops or chutes are installed in the canal so as to adjust the head, ensure the safety of the canal, and make the best use of functions of the entire canal system.

Generally, locations and types of drops or chutes are selected according to topographic features and other locational conditions. It is desirable that drops or chutes be stable and do not inhibit functions of the canal and be planned and designed by fully considering the economic efficiency.

In some cases, drops and chutes may vibrate due to impact resulting from the adjustment of high heads; therefore, bearing capacity to withstand the impact as well as safety must be ensured. Also, when drops and chutes are planned in the urban area and its vicinity, noise, vibration, and splash must be considered and studied.

4.2.2 Selection of installation location

It is desirable that the following matters be considered when selecting a location to install drop structures.

- A location in which drop structures can blend in with the surrounding topography, such as a location where there is a topographical level difference, should be selected.
- A location on the base ground, which has bearing capacity to withstand impact of water flow as well as the drop structures dead weight, should be selected.
- Drop structures shall be linear as long as possible and shall not be an asymmetric structure so as to avoid generating unfavorable waves to the water flow. Therefore, it is desirable that the section of the canal be selected in which both the upstream canal and the downstream canal are in a straight line.
- In most cases, drop structures create vibration and noise due to falling water. Accordingly, when installing a large-scale drop structures, it is desirable that installation near a residential district be avoided in considering the effect on the surrounding communal environment.

4.2.3 Water-cushion type drop structures

The water-cushion type drop structures consist of an inlet canal which is normally a transition section from an upstream canal, outfall, water cushion section for energy dissipation, and an outlet canal for a downstream canal.

In this type of drop structures, vertical steps are made just below the outfall and energy is dissipated by the impact resulting from falling water clashing into a water cushion and disturbance in the water cushion.

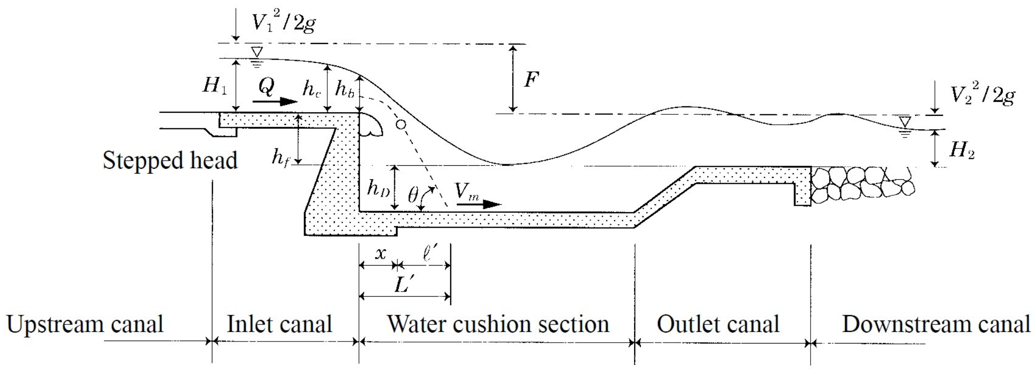


Figure 4-2 Example of water cushion type drop structures

(quoted from JSD)