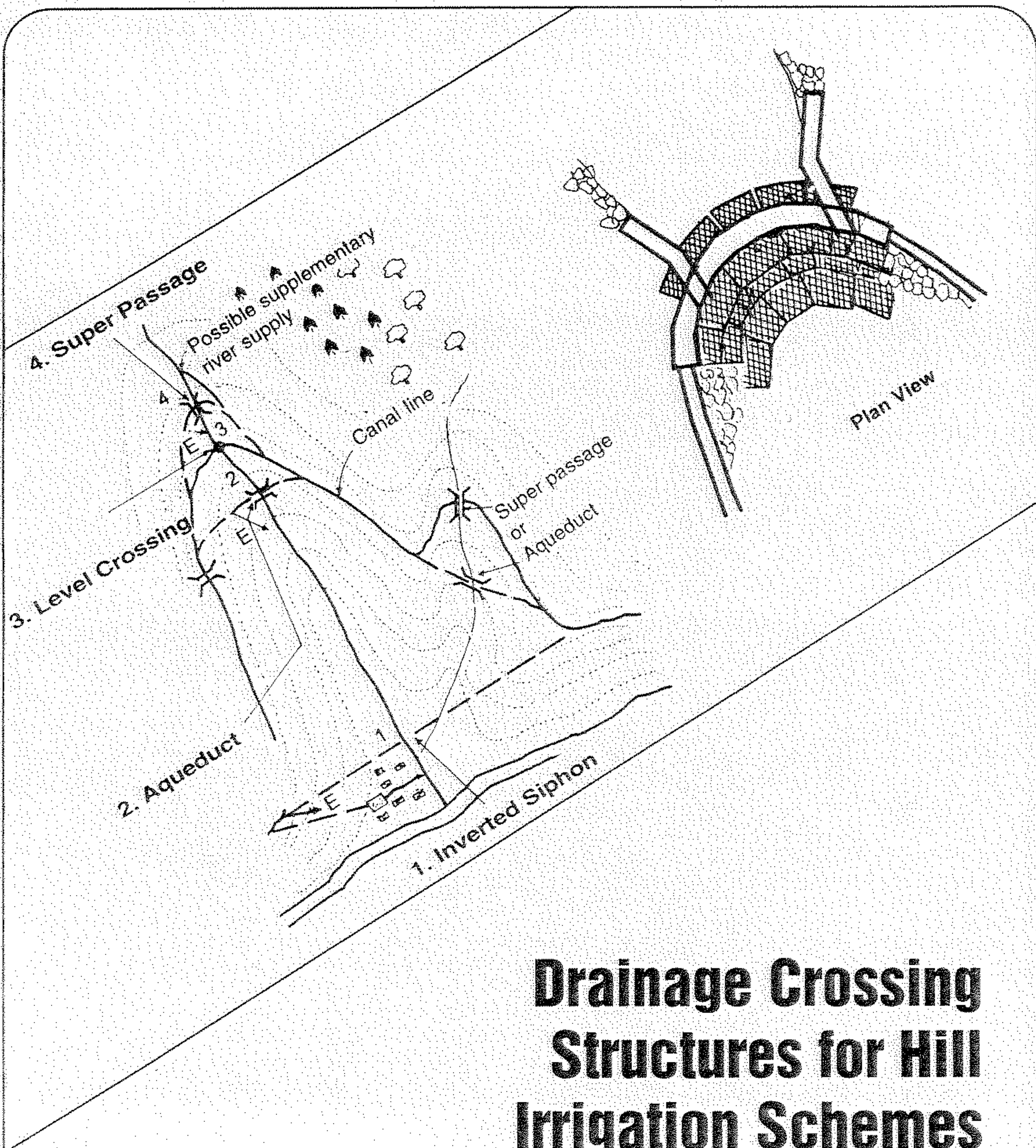
Poverty Alleviation Through Employment Generation in Irrigation Works Programmes

APPROPRIATE DESIGN OF SMALL-SCALE HILL IRRIGATION STRUCTURES



Drainage Crossing Structures for Hill Irrigation Schemes

NEPAL SPECIAL PUBLIC WORKS PROGRAMME
MANUAL NO. 2

Module No 4

DRAINAGE CROSSING STRUCTURES FOR HILL IRRIGATION SCHEMES

List of Figures

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Types of Drainage Crossing Structures

Primary canals of mountain irrigation systems run along contours. These canals often have to cross several drainage gullies. It is usually not necessary to supplement the canal flow by tapping the drainage flow. However, in some cases, part or all of the drainage flow may need to be diverted into the canal. Accordingly, special structures have to be built at drainage crossings to pass the canal either over, under or directly across the drainage stream bed.

A structure that takes the canal water over the drainage gully is called an aqueduct. See Photograph 4A.

A structure that takes the canal water under the drainage gully is called a super passage. See Photograph 4B.

Siphons can also be used to pass the canal under the drainage stream bed, especially when the crossing is wide and deep. Photograph 4C shows a shallow reinforced concrete siphon which are common in the terai areas. In the hills however, deep HDP or hume pipe siphons are more common.

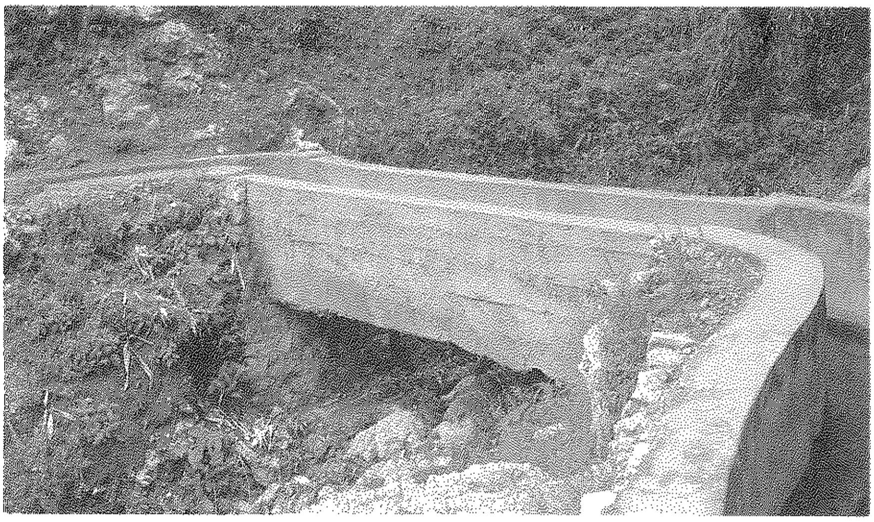
When part or all of the drainage water has to be diverted into the canal, structures called level crossings are required. See Photographs 4D and 4E.

Often, level crossings have to tap all of the drainage flow during lean periods but only part of the drainage flow, allowing excess water to spill over the structure, during monsoon periods.

Level crossings are not satisfactory as permanent solutions across drainage streams that carry frequent large floods because they permit large amounts of sediment to enter the canal during flooding. They can also be easily damaged by unpredictable flood flow in the drainage stream.

A more suitable arrangement to divert drainage flow into the canal would be to build an intake on the drainage stream upstream of the crossing point and to channel the flow into the canal from there.

This is usually an expensive solution, and requires thorough engineering and economic considerations because the benefit by way of increased canal water is often low.



Photograph 4A
Single Span Reinforced Concrete Aqueduct

An aqueduct takes the irrigation canal at the same level over the natural depression of the gully in a conduit (closed or open). The canal water does not come into contact with the drainage water.

Photograph 4B
Super Passage Over a Masonry Lined Canal

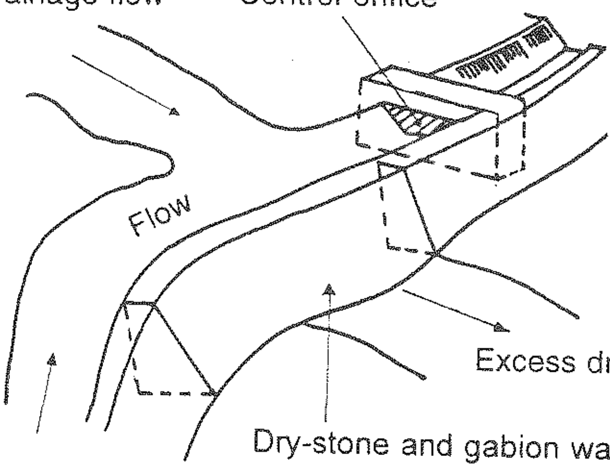
A super passage takes the irrigation canal under the drainage stream at the same natural gradient as the canal. The canal water does not come into contact with the drainage water.

Photograph 4C
Shallow Siphon in Reinforced Concrete

A siphon crossing takes the irrigation canal under the drainage stream in a U-shaped closed conduit (Type 1).

The canal water does not come into contact with the drainage water.

Photograph 4D
Control Orifice at the Downstream End of a Level Crossing to Prevent Excess Drainage Flow Entering the Canal



Level Crossing

In a level crossing the canal and the drainage gully are both at the same level.

Photograph 4E
Dry-Stone Outer Wall of Level Crossing

We have seen the four main types of drainage crossings.

The following pages will now describe the various sub-types, the construction materials that can be used, the design and construction limitations in the hills, and the advantages and disadvantages of the different structure types.

The sections "What Can Go Wrong With..." deal particularly with design and construction limitations. These limitations must be overcome if durable structures are to be built.

Aqueducts

Main Types

SINGLE SPAN →
- Simply Supported
  See Photograph 4F
- Suspended
  See Photograph 4G

MULTI SPAN →
- Continuous Beam
  See Photograph 4H

Ideal Use

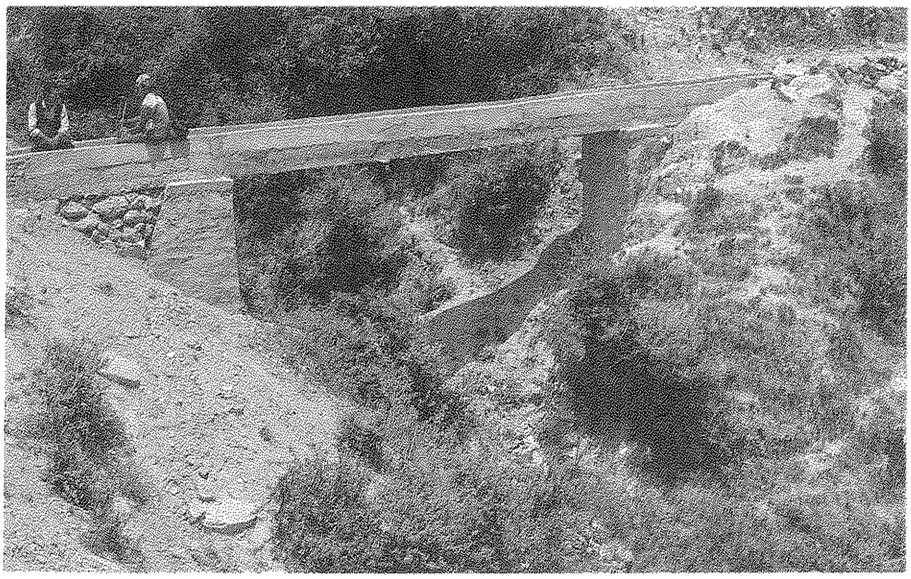
SINGLE SPAN →
- Narrow Deep Gullies
- Wide Shallow Gullies

MULTI SPAN →
- Very Wide Shallow Gullies
  (Moderate floods, no boulder movement)

Design Material Options

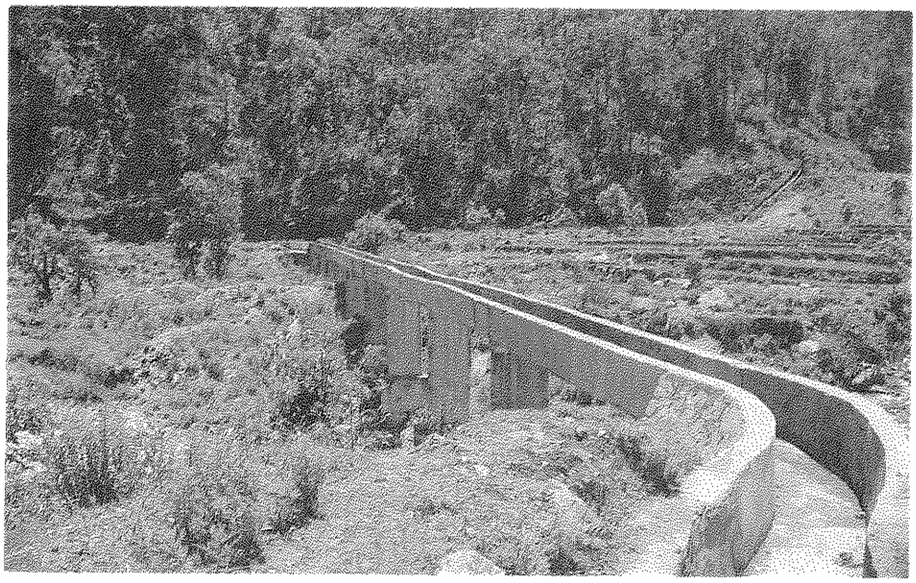
SINGLE SPAN →
- Tree Trunks
  See Photograph 4I
- Galvanised Iron Sheets
  (Supported on timber/steel)
- HDP on Timber Beams
  See Photograph 4J
- HDP on Steel Cables
  See Photograph 4K

MULTI SPAN →
- Concrete (U or T beam)
  See Photograph 4F



Photograph 4F
Reinforced Concrete Single Span Aqueduct Supported on Masonry Abutments

Photograph 4G
Suspended Polythene Pipe Aqueduct:
Span approximately 7 metres



Photograph 4H
Reinforced Concrete Multi-Span Aqueduct

Photograph 4I
Traditional Tree Trunk Aqueduct

If the water carrying capacity of each aqueduct is low then farmers could place two tree trunks parallel to each other

These aqueducts are becoming increasingly difficult to replace because of the shortage of forest products.

Photograph 4J
HDP Pipe Aqueduct Supported With Timber Beams

Polythene pipes can decay quickly when exposed to strong sunlight. It is good practice to put them under the deck (as in the photograph) rather than on the deck.

Photograph 4K
HDP Pipe Aqueduct Suspended on Steel Cable

These are relatively cheaper than more rigid structures such as reinforced concrete. Short spans are not subjected to wind sway. Long spans will need "wind stays" to reduce swaying of the pipe. Loose joints between the end pipes and inlet/outlet masonry structures must be provided to allow for slight movement.

Maximum Allowable Span

SINGLE SPAN SIMPLY SUPPORTED →	6 - 10m
SINGLE SPAN SUSPENDED →	20 - 25 m
MULTI-SPAN	-

Advantages and Disadvantages of Aqueducts

Advantages

- Minimum head loss. Head losses can be easily adjusted with only a marginal increase in cost by varying the area of flow in the conduit.
- Safe against hydrological uncertainties when built well above maximum probable flood level. In deep gullies, the base of abutments will be well above the maximum flood level, hence constitute no erosion hazard.

Disadvantages

- Difficult construction, especially in deep gullies.
- Tend to be used as pedestrian bridges.
- In wide shallow gullies, foundations of abutments and/or piers may be subjected to undermining failure due to erosion at flood times.

Note: Design of various types of aqueducts is described in Chapter 12.6.8 of the PDSP Design Manuals, Part D2.

What Can Go Wrong With Aqueducts?

Problem	Prevention
Timber and timber products used in the construction can deform or rot quickly.	Use seasoned timber. Coat all timber with wood preservatives.
Galvanised sheets may corrode.	Apply anti-rust paint.
HDP pipes can disintegrate if exposed to strong sunlight.	Put pipes below the deck away from sunlight or cover pipes with suitable lightweight materials.
HDP pipe butt joints may start to leak.	Insist on good jointing using correct equipment. Insist on good quality pipes conforming to standard specifications. Insist on a guarantee of durable workmanship from the firm assigned to do the job.
Concrete base slabs and walls can leak.	Insist on strict quality control of construction materials and workmanship. Provide good expansion joints. Cure all concrete well.
Cracks can develop due to uneven foundation settlement or inadequate bearing support.	Do not build foundations very near the edge of hill slopes. Provide sufficient bearing area between foundation and soil beneath. Provide sufficient bearing area between beam/slab and piers.
Reinforcement bars can corrode quickly.	Provide sufficient concrete cover around the steel rods. Avoid kinks in the steel rods.

Problem	Prevention
High flow velocities in the conduit can erode upstream and downstream earthen canals.	Provide adequate transition structures with smooth, contoured surfaces. Provide stone paving beyond transitions: especially down-stream. Key the structure well into existing ground.
Inadequate flow area of aqueduct section can induce backwater effect and possible overtopping of upstream canal bank.	Design aqueduct section allowing for future expansion in command area. Provide sufficient flow area for 'canal banktop level' water to pass without backwater effect. Provide an escape structure before the aqueduct as a safety measure. In the case of an existing aqueduct, increase the flow area by raising aqueduct walls if there is no danger of spilling in the upstream canal, or increase the slope of the downstream canal over a long reach to induce rapid flow in the aqueduct.
Closed conduits can choke.	Design for silt-flushing flow velocities in the conduit. Provide screens to prevent large debris entering conduit.

Level Crossings

Possible Use

SUPPLEMENT CANAL FLOW WITH DRAINAGE STREAM FLOW

Level crossings are not satisfactory permanent solutions for drainage gullies with large and lasting flood flows, because such food flows can bring a lot of sediment into the canal.
They may be considered for use across gullies that are draining spring flows rather than flood flows.
In gullies with large lasting flows a more permanent solution would be to build an intake on the drainage stream, upstream of the crossing point, and to channel the flow into the main canal from there.

Design Material Options

MUD AND STONE
(Local materials)

CEMENT MASONRY & GABION BASKETS

Note: Construction using local materials is preferred because the structure can be rebuilt with minimum delay if damage occurs

Span Restrictions

THE OUTER LENGTH OF THE DRY-STONE OR GABION WALL MUST BE GREATER THAN THE WIDTH OF THE EXISTING DRAINAGE CHANNEL
(See sketch with Photographs 4D and 4E)

SPILL CREST MUST BE SHORT AND LOCATED CENTRALLY TO THE MAIN FLOW CHANNEL

Advantages and Disadvantages of Level Crossings

Advantages

- Easy to repair when locally available materials are used in the construction.
- Also functions as a safety valve to spill excess flood flow entering the intake.

Disadvantages

- Needs frequent maintenance and desilting.
- When orifice control structures are not built, drainage flood flow can enter canal.

Note: Design of level crossings is described in Chapter 12.6.2 of the PDSP Design Manuals, Part D2.

What Can Go Wrong With Level Crossings?

Problem	Prevention
Level crossings are prone to flood damage. Damaged level crossings can interrupt irrigation.	Replace level crossings with other permanent drainage crossing structure types.
Orifice control structures are not completely effective in controlling the entry of flood and sediment into the canal.	Replace level crossings with other permanent drainage crossing structure types.
Level crossings, especially when not used as a supplementary source of water, can be a constant nuisance to the farmers who have to regularly desilt and maintain them.	Replace level crossings with other permanent drainage crossing structure types.

Super Passages

Main Types

BUILT ON NON-EROSIVE ROCK OUTCROPS → NEED LITTLE OR NO STABILISING STRUCTURES
See Figure 4.10

BUILT ON EROSIVE DRAINAGE GULLY BEDS → NEED STABILISING STRUCTURES
See Figure 4.11

Sub-Types Based on Conduit Type

PERMANENTLY COVERED CONDUIT → SUITABLE FOR SHORT SPANS

CONDUIT WITH REMOVABLE COVERS → SUITABLE FOR LONG SPANS

Note: Long spans may get blocked: need provisions for cleaning

Design Material Options

SHORT SPAN →
- HDP Pipes
- Hume Pipes
- Monolithic box sections in concrete
- Masonry sections with fixed concrete cover slabs

LONG SPAN →
- Masonry sections with removable concrete cover
- Concrete box sections with removable concrete cover

Design/Structural Requirements of Super Passage Conduits

- Design for non-silting flow velocity in the super passage.
- Select a sufficiently large conduit diameter to ensure that it flows partly full at design flow capacity, this allows room for future expansion of the command area.
- The inside of the conduit should have a smooth finish to minimise the friction losses.
- Avoid sharp bends.

Advantages and Disadvantages of Super Passages

Advantages

- Minimum head loss. Head losses can be easily adjusted with only a marginal increase in cost by varying the area of flow in the conduit.
- Easy to construct.
- No foundation problems if built on firm rock outcrops.

Disadvantages

- Foundation problems if stabilising structures are inadequate.
- Must be designed with a high margin of safety when drainage stream characteristics are unknown.
- Conduits may become choked with sediment and debris.
- May need diversion of canal to find a suitable crossing point.

What Can Go Wrong With Super Passages?

Problem	Prevention
Excessive narrowing of the waterway can lead to flood water overtopping the sides.	Provide adequate waterway. Do not restrict drainage flow width. Provide sufficiently high wing-walls.
Narrowed waterways lead to very high flow velocity in the narrowed portion resulting in downstream erosion.	Provide adequate waterway. Do not restrict drainage flow width. Provide adequate erosion protection immediately downstream.
Breaching or outflanking can occur when the wing-walls are not properly keyed into the slopes.	Select suitable crossing points which have stable bank slopes and key the wing-walls well. Provide gabion or stone revetments on the inner slopes near the upstream ends of the wing-walls.
Top cover slabs or the wearing surface over the super passage conduit can wear out quickly due to abrasion.	Insist on good quality concrete castings. Insist on good quality masonry for wing-walls.
Top cover slabs tend to move out of place creating gaps allowing debris to get into the canal below.	Cast slabs to correct size and shape, and anchor the slabs well. Provide lifting handles in cover slabs for easy handling during readjustments.
Seepage flows under the structure can cause undermining.	Provide upstream cut-off wall.

Deep Siphons

Note: The term "deep" is used here to differentiate between siphons suitable for hill schemes and those suitable for terai schemes. Deep siphons are common in hill schemes.

Main Types

TYPE 1 → Deep Siphons which at their lowest point pass under the river bed.
See Figure 4.1

TYPE 2 → Deep siphons which at their lowest point pass over a short span bridge.
See Figure 4.2

WARNING

Siphons are likely to choke if the flush-out valve is not operated regularly to clean away silt and sand trapped inside. Depending on the silt content in the canal water, cleaning may be necessary every two to three days. Rainwater intercepted by the canal can bring silt into the siphon during the non-cultivation season and should therefore not be allowed to enter the siphon.

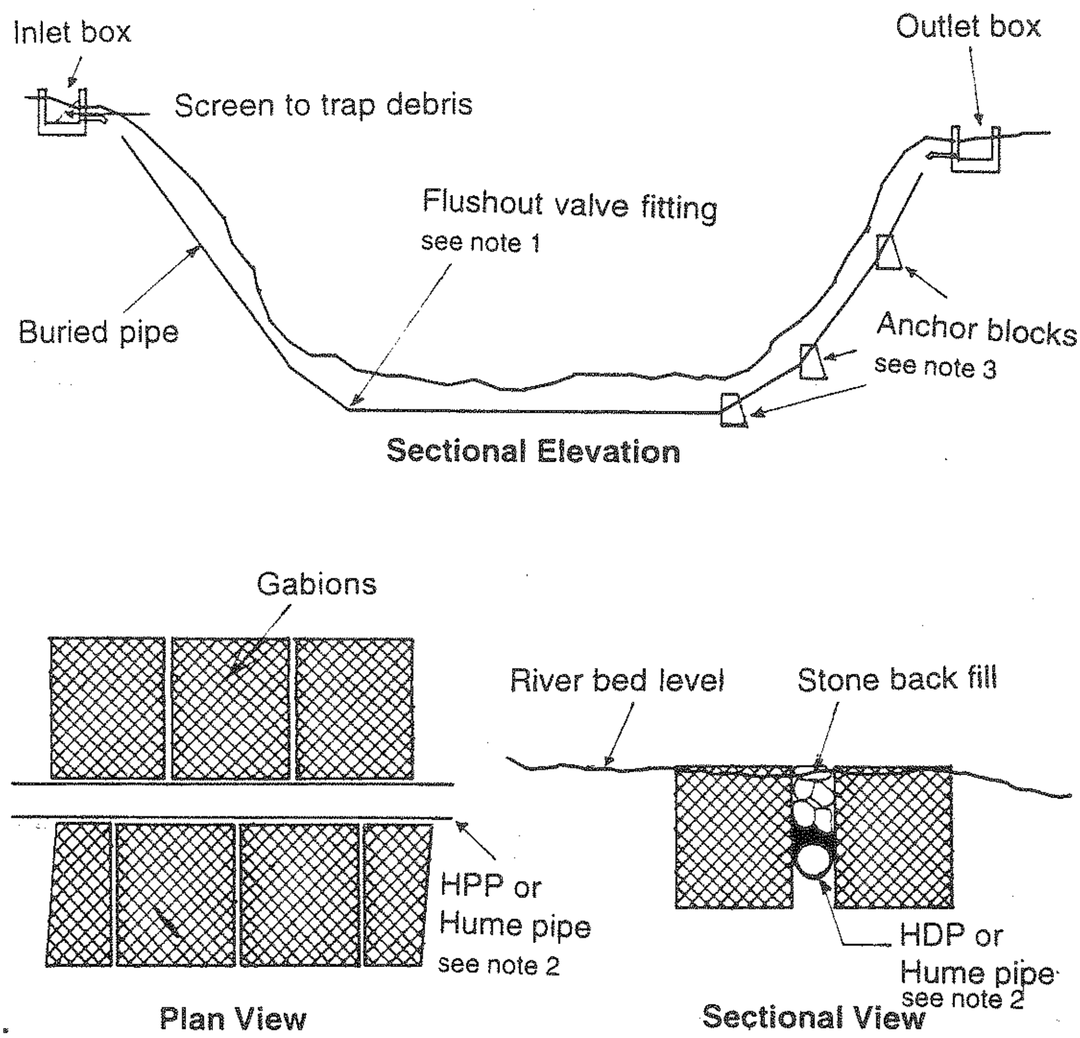
Design Material Options

HDP Pipes → suitable for Types 1 & 2

Hume Pipes → suitable for Type 1

Steel Pipes → suitable for Types 1 & 2

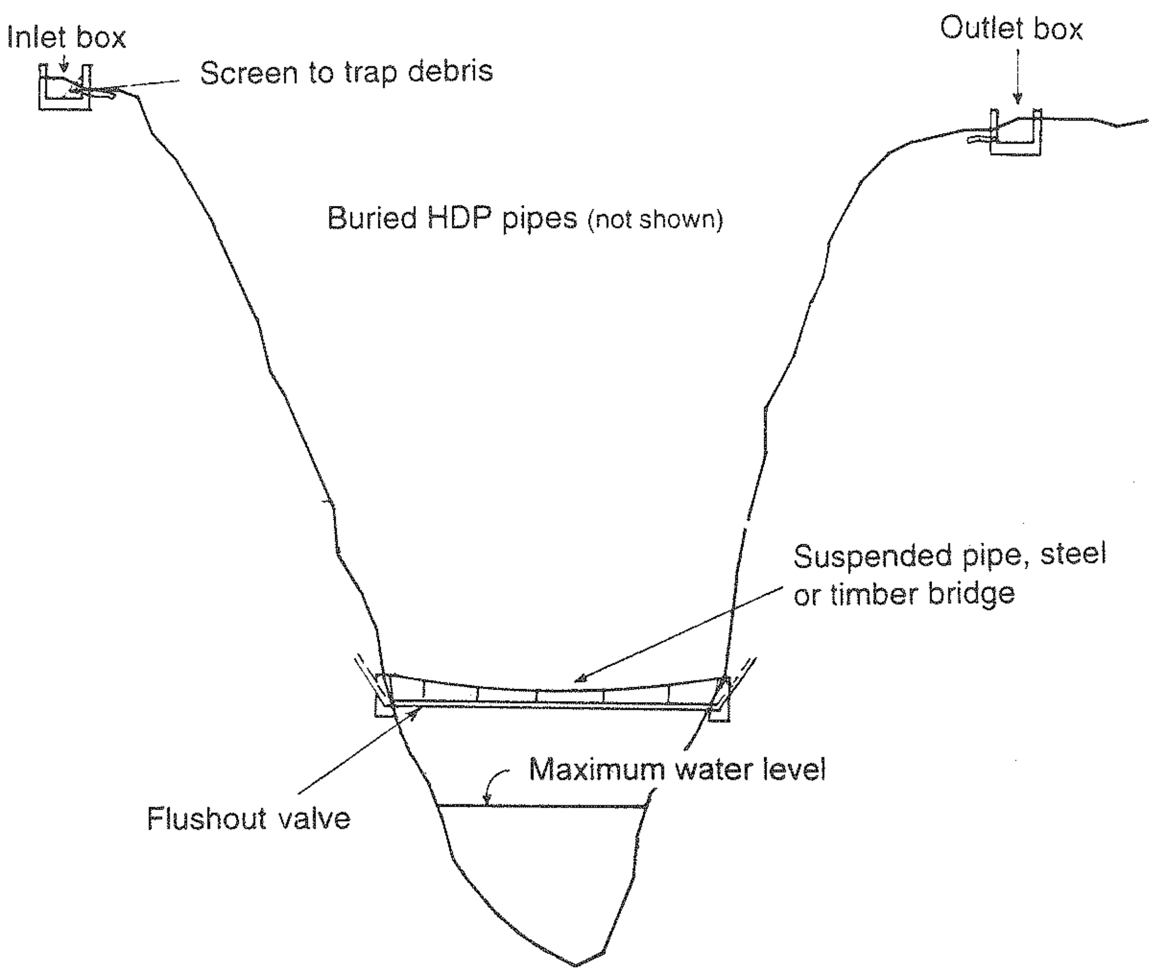
Figure 4.1
Deep Siphon Type 1 Passing Under the River Bed



Note:

1. Flush out valve fittings must be cased inside masonry boxes built below the river bed and protected by gabions.
2. HDP or Hume pipes must be buried below drainage stream bed level to prevent damage by boulders.
3. Anchor blocks must be built near every pipe joint and sharp bends in the pipe line.

Figure 4.2
Deep Siphon Type 2 Passing Over a Short Span Bridge



Note: Steel pipes may be required at the bottom of the valley where the water pressure in the pipe is high.

Advantages and Disadvantages of Deep Siphons

Advantages

- Deep gullies can be crossed without the need for a long diversion.
- Drainage flow does not affect structural safety (in Type 2).

Disadvantages

- Significant head losses.
- Pipe may become choked if silt and sand are not regularly flushed out.
- Unusual flood in the drainage gully can damage the structure (in Type 1).
- If river bed builds up at the crossing point, trapped silt may become difficult or impossible to flush away (in Type 1).

What Can Go Wrong With Deep Siphons?

Problem	Prevention
HDP pipe joints may start to leak.	Insist on good jointing using correct equipment. Insist on good quality pipes conforming to standard specifications. Insist on a guarantee of durable workmanship from the firm assigned to do the job.
HDP pipes/joints may burst.	Select and use the correct class and diameter of HDP pipe according to pressure along the siphon. Use steel pipes at the bottom of the siphon if HDP is inadequate. Insist on factory made HDP "butt" joints with guarantee. Use "flange" joints for in situ connections.
Steel flanges may get stolen.	Case flange joints inside concrete anchor blocks.
Joints at sharp bends may leak/break.	Water in the pipe exerts heavy thrusts on the walls of the pipe. At sharp bends these thrusts are big and have to be provided for. Provide special anchor blocks to withstand these thrusts.
HDP pipes can deform or disintegrate quickly.	Bury pipes below ground.
Hume pipes can leak at joints.	Uneven settlement of heavy concrete hume pipes can strain the joints. Provide rigid bases on compacted foundations to support the hume pipes.

Problem	Prevention
Hume pipes can leak.	If the concrete used for making the hume pipes is porous leaks can develop, especially at the bottom of the siphon where water pressures are high. Use good concrete. Uneven layer of bonding mortar between the hume pipe and collar can lead to leaks. Maintain a uniform layer.
Steel pipes can corrode.	Coat steel pipes with anti-corrosive paint.

Choosing an Appropriate Type of Structure

Five factors need to be considered when selecting cross-drainage works at a given location. These are:

- topography,
- structural stability,
- hydraulic compatibility,
- stability of the drainage stream/gully,
- cost.

Topography

Topography means the shape of the gully, in cross-section and in plan. The shape of the gully cross-section at the proposed crossing point will largely determine the type of structure necessary. See Figure 4.3.

The shape of the gully in plan can also influence the selection of structure type. See Figure 4.4.

Structural Stability

Different cross-drainage structure types have different stability requirements. See Figure 4.5.

Hydraulic Compatibility

Hydraulic compatibility means the availability of adequate hydraulic head to drive the canal flow across the cross-drainage structure.

Compared to aqueducts and super passages, inverted siphons require a large head difference between the inlet and outlet ends of the pipe/s to drive the flow.

See Figures 4.6, 4.7, 4.8, and 4.9 for a sample calculation of the head required (head loss) across a super passage and a siphon for a canal discharge of 200 lps.

A structure type that is suitable on the basis of other factors may not be suitable on the basis of hydraulic compatibility.

Stability of the Drainage Stream/Gully

Generally the safety of any type of cross-drainage structure will be affected by any instability of the gully. Widening gullies can destroy cross-drainage structures such as aqueducts, siphons, level crossings and super passages. Deepening gullies can also destroy structures such as siphons and super passages.

The presence of either of these factors will affect the selection of the site for a cross-drainage structure which, in turn, will affect which type of structure is most suitable.

Cost

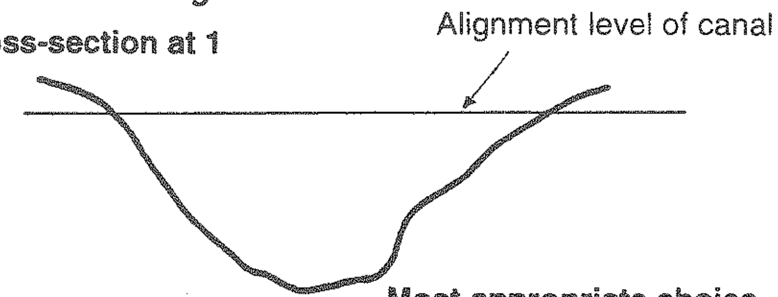
When two or more technically sound alternatives are available for crossing a drainage gully, selection can be made based on the costs of the different alternatives.

The cost of all appertaining works, such as increased length of canal, rock tunnelling, covered canals, etc. must be included when calculating the costs of the different options.

The above five factors must be jointly considered when selecting the type of cross-drainage structure suitable for any given location.

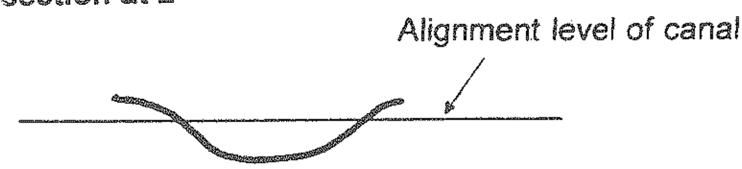
Figure 4.3
The Shape of the Gully Cross-Section will Largely Determine the Type of Cross-Drainage Structure

Gully cross-section at 1



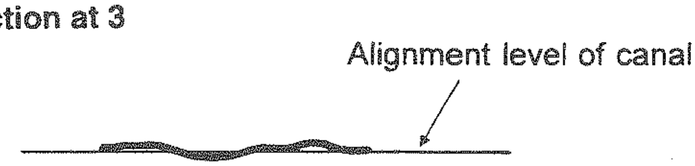
Most appropriate choice based only on the gully cross-section: INVERTED SIPHON

Gully cross-section at 2



Most appropriate choice based only on the gully cross-section: AQUEDUCT

Gully cross-section at 3



Most appropriate choice based only on the gully cross-section: LEVEL CROSSING
suitable only across small streams with infrequent low intensity floods.

Gully cross-section at 4

Most appropriate choice based only on the gully cross-section: SUPER PASSAGE

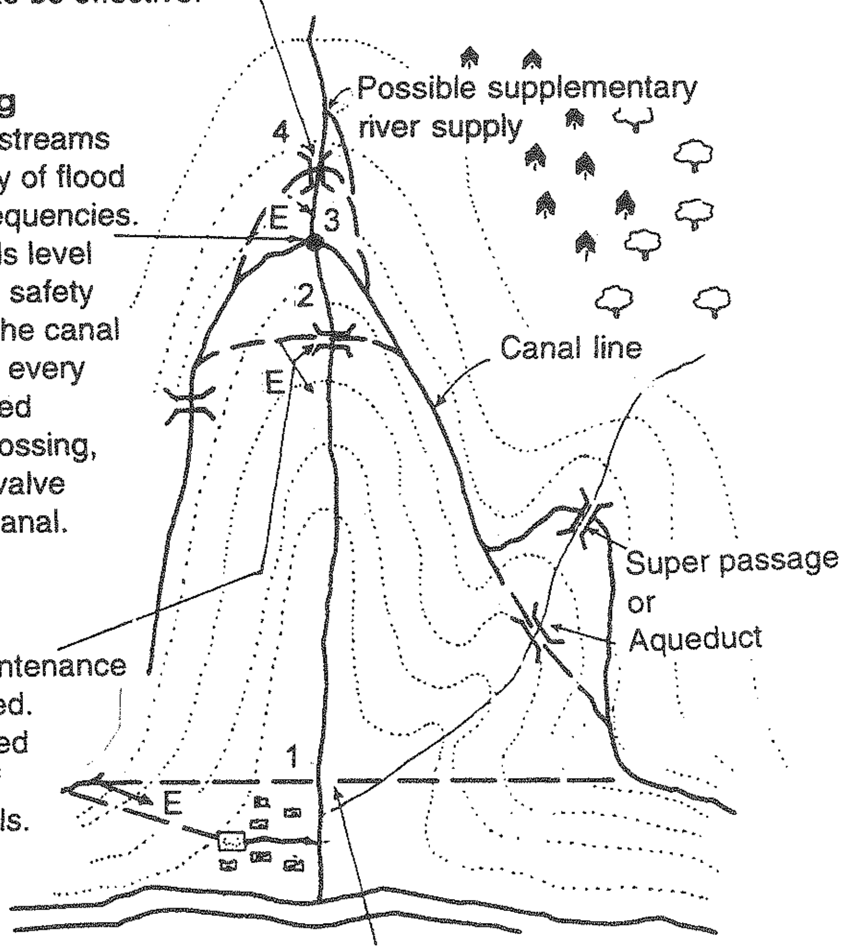
Figure 4.4
The Most Appropriate Type of Structure Depends on the Location

Structure Types Changes as You Move From Location 1 to 4

4. Super Passage
Needs only little maintenance if properly constructed.
Covered conduit must extend several metres beyond the gully banks for the structure to be effective.

3. Level Crossing
Suitable only across streams with very low intensity of flood flow and low flood frequencies.
In some farmer canals level crossings also act as safety valves to safeguard the canal during monsoon. For every level crossing replaced by another type of crossing, an additional safety valve must be built in the canal.

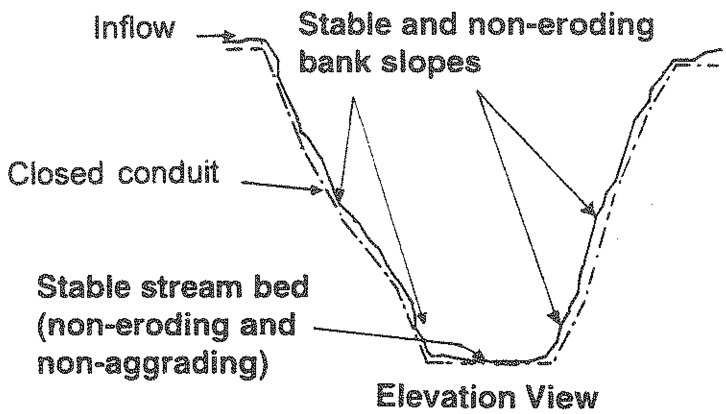
2. Aqueduct
Needs only little maintenance if properly constructed.
Cost can be controlled by suitable choice of construction materials.



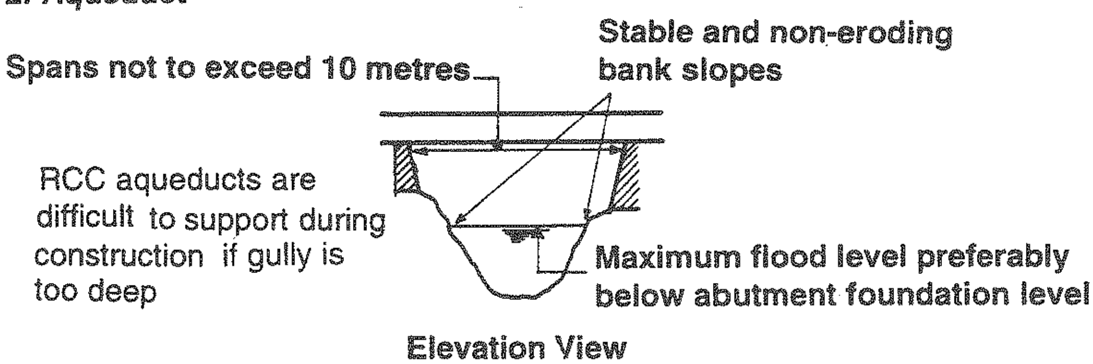
1. Inverted Siphon
A complicated structure requiring a lot of maintenance.
Generally more expensive than other types of structures.

Figure 4.5
Stability and Structural Requirements of Cross-Drainage Structures

1. Inverted siphon



2. Aqueduct



3. Super passage

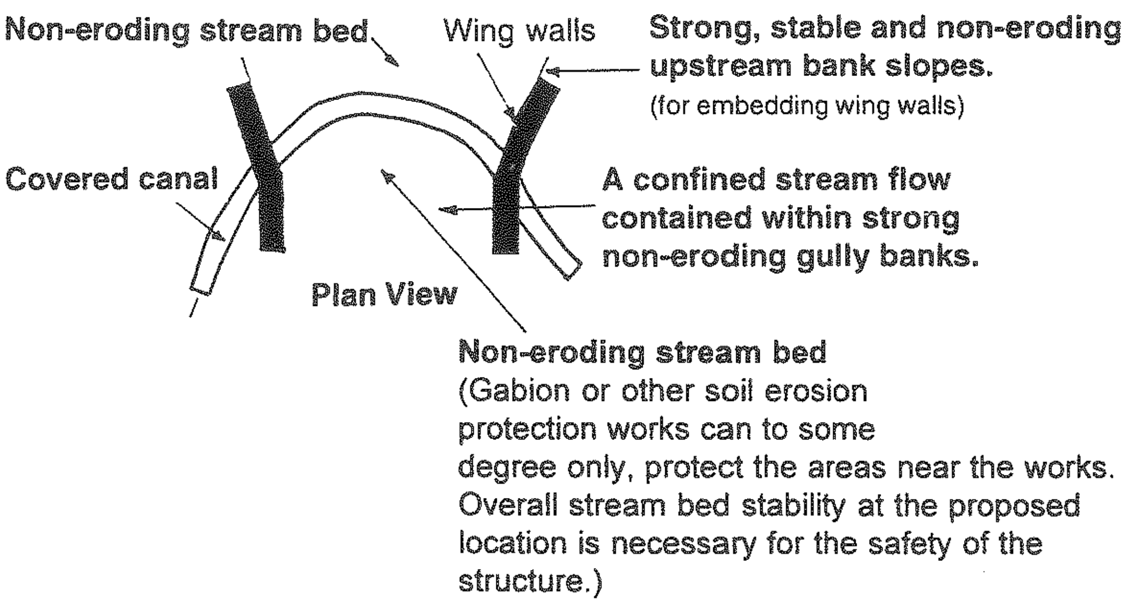


Figure 4.6
Sample Calculation of Head Loss in a Super Passage

Upstream Canal Section	Super Passage Section Length = 7 metres		Downstream Canal Section
Q = 200 lps		Q = 200 lps	Q = 200 lps
BW = 50 cms	**see note 1**	BW = 50 cms	BW = 50 cms
FSD = 37 cms	**see note 2**	FSD = 37 cms	FSD = 37 cms
Side slope = 1:1		Vertical sides	Side slope = 1:1
n = 0.025		n = 0.020	n = 0.025
Bed slope = 1:500			Bed slope = 1:500
Canal velocity = 0.629 mps	**see note 3**	Flume velocity = 1.081 mps	Canal velocity = 0.629 mps
	see note 4	Friction slope = 0.0059	

Total Head Loss = Entrance and Exit Transition Losses
Plus
Friction Loss in Conduit

$$\text{Entrance and Exit Transition Losses} = 1.5\,\frac{\text{Flume velocity}^2 - \text{Canal velocity}^2}{2 \times g}$$

Friction Loss in Conduit = Friction Slope x Length of Conduit
for the above example:
Entrance and Exit Transition Losses = 0.059 m
Friction Loss in Conduit = 0.041 m
Total Loss = 0.100 m

Note 1 A contraction of bed width up to 70% of upstream canal bed width is allowable. In this example no contraction is made in the bed width because high flow velocity in the flume results in large transition head losses and conduit friction losses. (See formula for transition losses and friction losses)

Note 2 It is recommended that flow depth in the canal and the flume are kept equal.

Note 3 Velocity of flow in the flume equals flow rate divided by the area of flow.

Note 4 Friction slope is calculated using the formula:

$$S_f = \frac{V^2 \times n^2}{R^{4/3}}$$

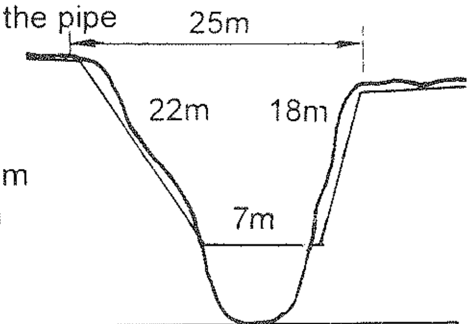
Figure 4.7
Sample Calculation of Head Loss in a Deep Siphon

Upstream Canal Section	Super Passage Section Length = 47 metres	Downstream Canal Section
Q = 200 lps BW = 50 cms FSD = 37 cms Side slope = 1:1 n = 0.025 Bed slope = 1:500 Canal velocity = 0.629 mps	Q = 100 lps (per pipe) **see note 1** HDP Pipe = 2 pieces Diameter = 250 mm **see note 2** Pipe velocity = 2.04 mps **see note 3** Friction loss in pipe = 1.1 m. per 100 m	Q = 200 lps BW = 50 cms FSD = 37 cms Side slope = 1:1 n = 0.025 Bed slope = 1:500 Canal velocity = 0.629 mps

Total Head Loss = Entrance and Exit Transition Losses
Plus
Friction Loss in Conduit
Plus
Bend Losses in the Pipe
Plus
Inlet Trash Rack Loss

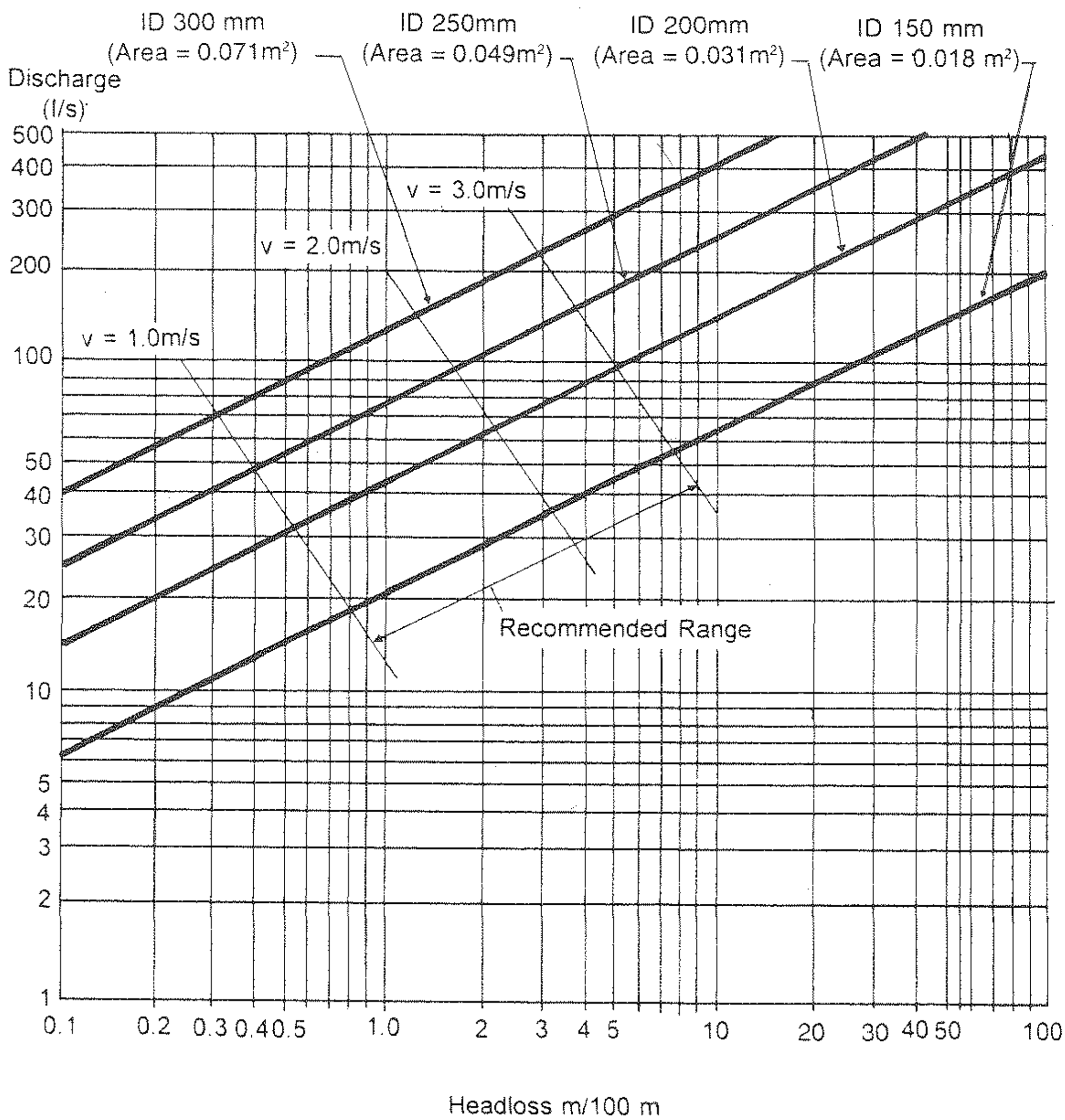
$$\text{Entrance and Exit Transition Losses} = 1.5\frac{\text{Flume velocity}^2 - \text{Canal velocity}^2}{2 \times g}$$

Friction Loss in Conduit = Friction loss per metre x Length of pipe
Bend Losses in the Pipe = 0.1 x velocity head in the pipe
Inlet Trash Rack Loss = 0.05 m (nominal)
for the above example:
Entrance and Exit transition Losses = 0.288 m
Friction Loss in Conduit = 1.1 x 47 / 100 = 0.517 m
Bend Losses in the Pipe = 0.1 x 0.212 = 0.021 m
Inlet Trash Rack Loss = 0.05 m (nominal)
Total Loss = 0.876 m



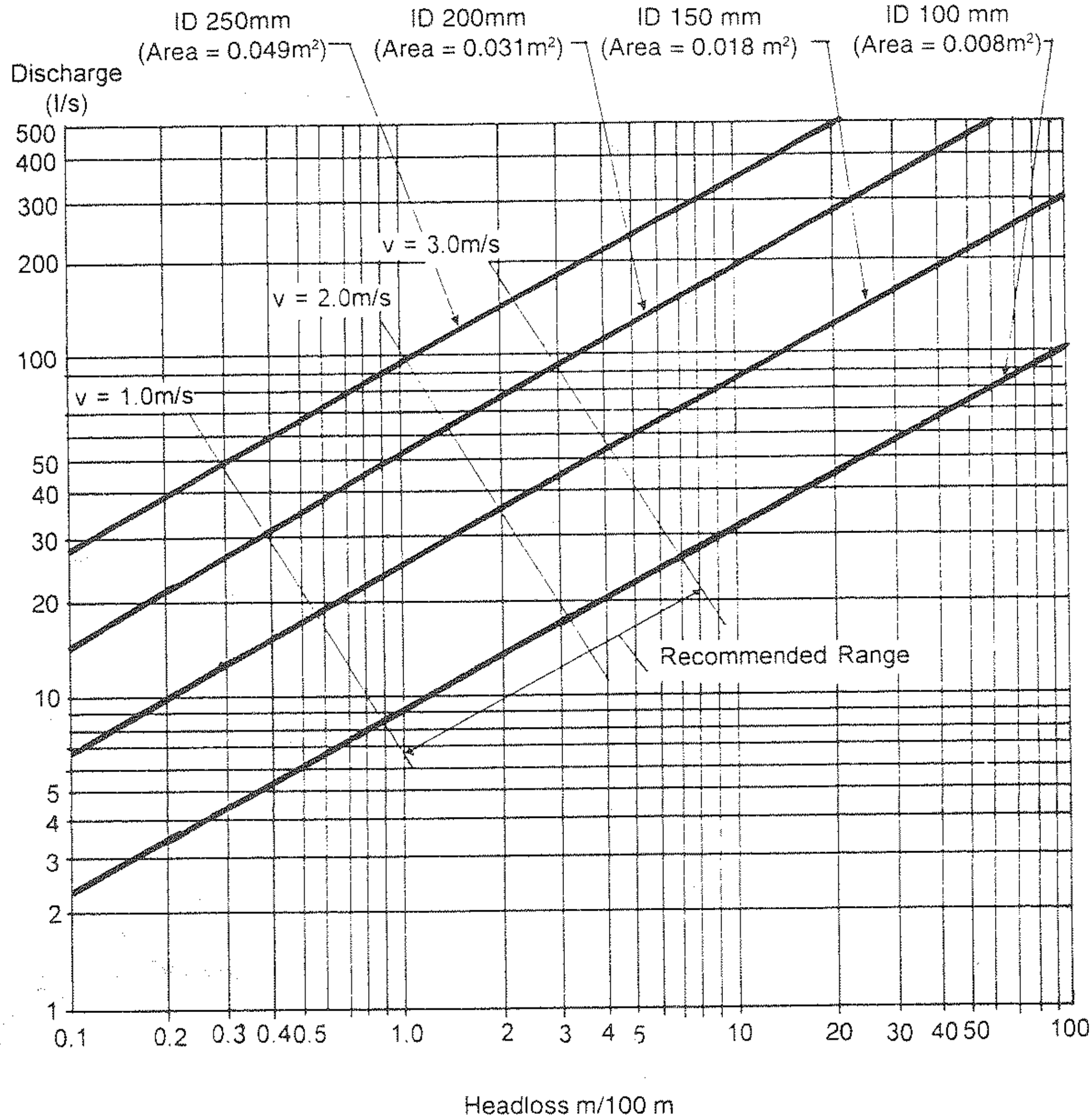
Note 1 Select from easily available pipe sizes.
Note 2 Velocity of flow in the pipe equals flow rate divided by the area of flow. Select pipe size to generate non-silting flow velocity in the pipe. Very high flow velocity in the pipe can cause downstream erosion if adequate downstream transitions are not provided.
Note 3 Use chart to obtain friction loss in the pipe.

Figure 4.8
Nomogram for Determining Head Loss in Concrete Pipes



Note: ID = internal diameter
(k = 0.3 mm)

Figure 4.9
Nomogram for Determining Head Loss in HDP Pipes



Note: ID = internal diameter
(k = 0.003 mm)

Special Safety Considerations for Super Passages, Aqueducts and Siphons

Super Passages

Super Passage Sites Need to be Stable

Super passage sites, particularly for downstream areas, need to be stable and non-erodible, as indicated in Figure 4.10. Erosion of downstream floors, as seen in Photographs 4L and 4M, can lead to undermining failure of super passages.

When downstream floors are not stable and liable to erode quickly, adequate downstream protection must be provided. Gabions are appropriate for providing protection against downstream erosion.

It is not advisable to build super passages on highly erodible ground. However, in the case of an existing structure, problems arising from high erodibility can be minimised using stilling pools. See Figure 4.11.

Flood Flow Over the Super Passage Must be Confined

The path of the drainage flood flow over the super passage should be confined and contained in order to prevent "outflanking". Outflanking can result in undermining failure of unprotected canal segments, and also lead to drainage stream debris collecting in the canal bed. See Photograph 4N.

Flood flows over the super passage can be confined using wing-walls usually built with stone masonry. Wing-walls need to be strong and must be well embedded into the uphill slope to prevent outflanking. Dry-stone revetment protection of the "nose" of wing-walls, as indicated in Figure 4.12, can provide additional safety against outflanking.

Aqueducts

Stable and Firm Bank Slopes are Needed for Building Abutment Piers

In principle, abutment piers need only distribute the load on the aqueduct evenly onto the foundation below. When the bank slopes are stable, abutment piers need not be heavy and big because they only have to bear the load of the aqueduct.

In some exceptional cases the end piers may need to be built as walls to retain the hill slope and to support the aqueduct.

Abutment piers, especially for small span aqueducts in the hills, need not be built up from or below the stream bed level. Instead, they can be founded on stable rock outcrops or firm layers of soil well above the stream water level. See Figure 4.14.

Abutment Piers in Shallow Gullies May Need Special Protection

Undermining of abutment and centre aqueduct piers can occur in wide shallow gullies. The toes of the abutment/centre piers need to be protected with gabions or dry-stone revetments. See Figure 4.13.

The Aqueduct Conduit Must be Well Above the Maximum Probable Flood Level in the Gully

Fast moving floating tree trunks carried by the drainage stream during times of floods can cause impact damage to aqueducts. This can be avoided by locating the aqueduct well above the maximum probable flood level in the drainage stream.

Siphons

Hill irrigation systems generally require deep inverted siphons, as opposed to shallow ones which are more common in the terai areas. Two different options are available for the construction of siphons in deep gullies:

- to bury the conduit below the stream bed (Type1);
- to cross the stream over a short span bridge (Type 2).

Structural safety requirements for both the above types are given below.

Drainage Stream Bed Needs to be Stable for Type 1

Stream bed erosion and "build-up" of the stream bed can affect the buried pipes of a Type 1 siphon. Stream bed erosion can affect buried pipes/conduits by exposing them; making them vulnerable to boulder impact damage and decay by weathering. See Photograph 40. Stream bed build-up, or aggredation, can affect the performance of Type 1 siphons by making regular flushing out of the silt trapped inside the pipe difficult or impossible.

Firm Rock Outcrops or Foundations are Needed to Support the Bridge required for Type 2

Depending on the span and the load on the bridge, adequate stone rock outcrops or firm foundations will be required to support the bridge. A simply supported bridge in timber or steel will require firm foundations for its abutment piers, while a suspended steel bridge will require solid rock on both banks for anchoring its cables.

Bank Slopes Need to be Firm and Stable

Firm bank slopes are needed to enable the pipes of both Types 1 & 2 siphons to be buried and anchored to slopes. Pipes of deep siphons need to be buried or anchored to prevent vibrations which would affect the durability of the pipe and its joints.

Figure 4.10
Super Passage Built on Exposed Non-Eroding Rock Outcrop

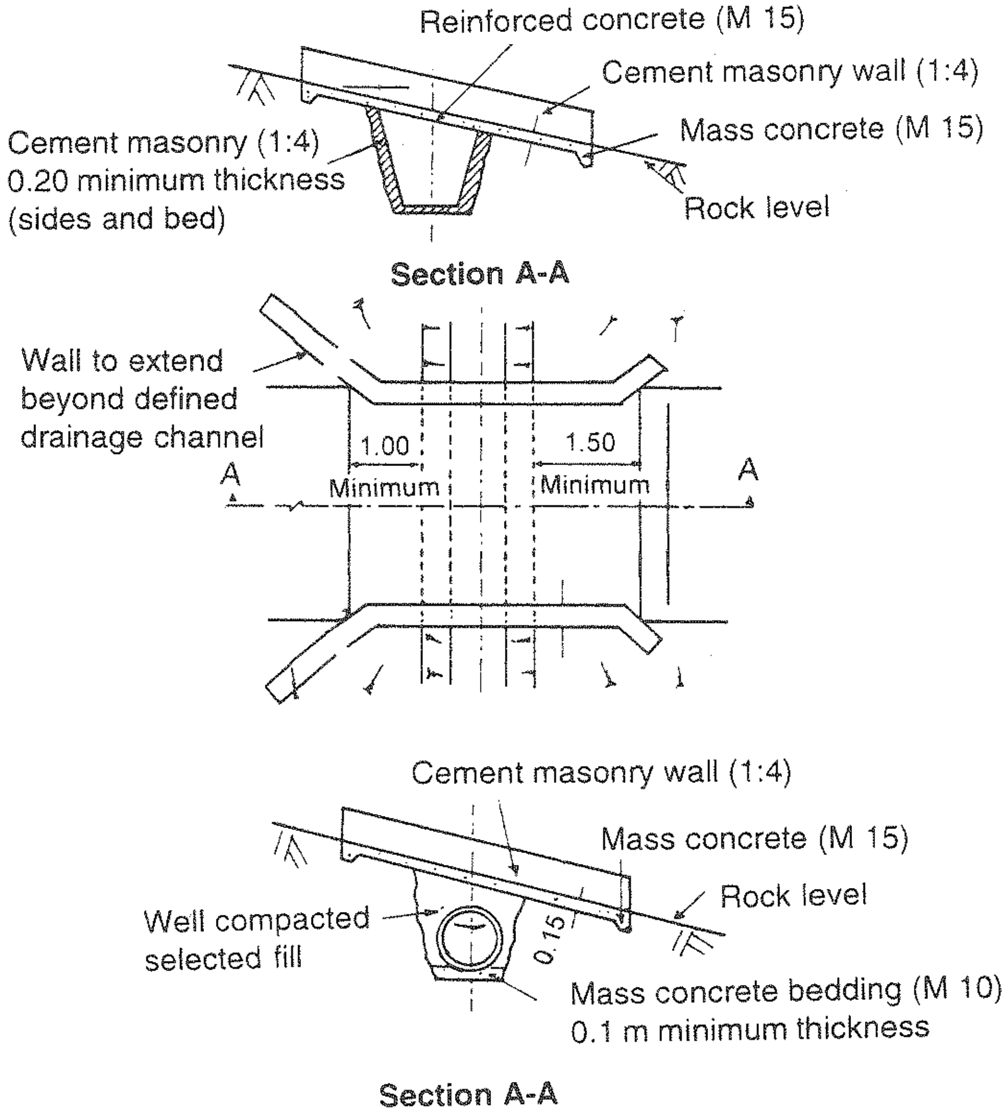
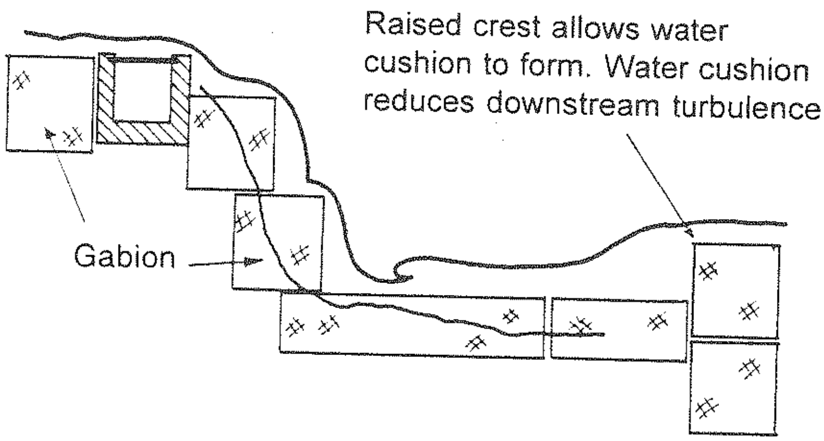
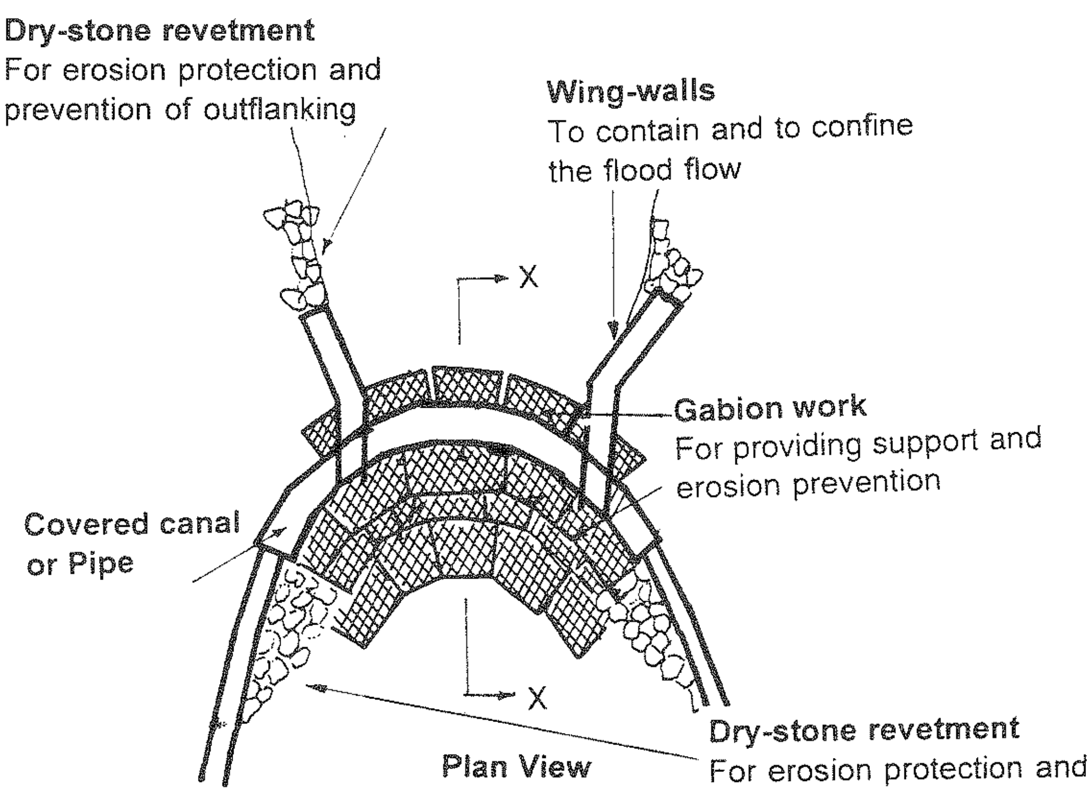


Figure 4.11
Use of Stilling Pools to Minimise Risk of Downstream Erosion

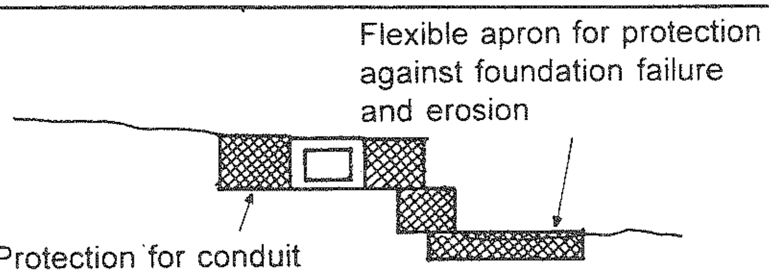


In existing canals where the ground below the super passage is highly erodible, and it is impossible to move the super passage to another site, the risk of further downstream erosion can be minimised by using stilling pools.

Figure 4.12
Structures for Protecting and Stabilising Super Passages

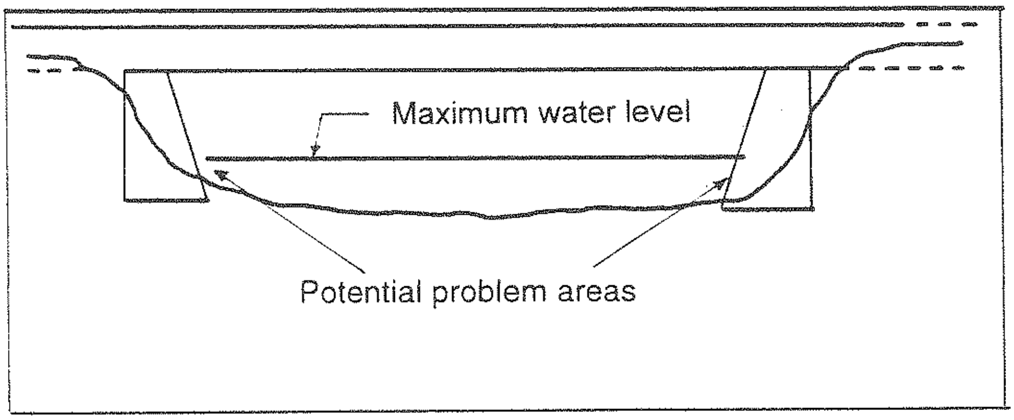


A Super Passage Across an Erodible Drainage Gully



Section X-X

Figure 4.13
Protective Structures for an Aqueduct Across a Shallow Gully



Gabions and/or dry-stone revetments can prevent toe erosion of abutment piers.
Another solution would be to build the foundation of the abutment pier below the maximum possible scour depth and to provide gabion protection.

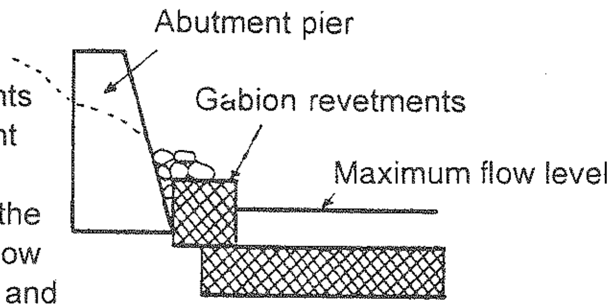
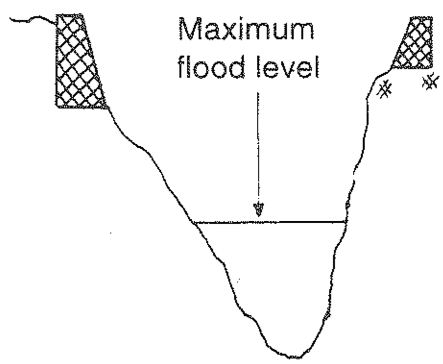


Figure 4.14
Abutment Foundations for an Aqueduct Across a Deep Gully

In deep gullies the abutment foundations need not be built from the stream bed level. They should be built on solid rock outcrops or firm soil strata well above the maximum flood level.



Hydrological Data Required for the Design of Drainage Crossing Structures

The following hydrological data are required for designing cross-drainage structures.

Maximum probable flood flow. Duration of flood flow. Frequency of occurrence of floods.	These affect the safety of super passage conduits, aqueduct piers, buried pipes of siphons and all protective structures built on the stream bed. High intensity floods lasting several hours can destroy structures such as super passages, buried siphons and protective structures.
Maximum flow width.	This dimension controls the span of super passages, and the width of the drainage waterway to be allowed in super passages and shallow aqueducts.
Maximum flow depth.	This dimension controls the safe vertical location of aqueducts as well as the minimum scour depth required for the design of support or protective structures that are built on the stream bed for all types of drainage crossing structures. Maximum flow depth and flow width are also required to estimate maximum flood.

Hydrological Data of Small Drainage Streams/Gullies are Often not Available or are Difficult to Obtain

For small structures across small drainage gullies these data can be estimated from basic field observations such as watermarks, nature of bedload, bed slope and shape, and the condition of the drainage stream bed.

Farmers' observations of the drainage stream can also provide useful clues to help engineers to estimate flood flows.

However, for large expensive drainage crossing works, peak flows estimated using formulae must be verified in the field at least once before finalising designs.

'Rules of Thumb' for Special Cases

When accurate hydrological data for designing cross-drainage structures are not available the following "rules of thumb" are recommended.

Avoid Narrowing the Waterway of the Drainage Stream

This rule is relevant to super passages and aqueducts. When the waterway is constricted, higher flow velocities are created near the constriction leading to downstream erosion and undermining failure. See Photograph 4P.

Foundations of super passages, aqueduct abutments, piers and all other structures built to protect drainage crossings can fail quickly if they come into contact with rapid flowing water. Narrowing the waterway can reduce costs but should only be considered when reliable and accurate hydrological data are available.

Do Not Obstruct the Waterway of the Drainage Stream

This rule is relevant to super passages. Obstructions of the drainage flow can be minimised by building super passages below bed level.

Obstructions may divert the drainage flow into the adjoining canal, especially when wing-walls are not built. See Photograph 4Q.

Provide Adequately High Wing-Walls. Key Wing-Walls Well Into Bank Slopes

This rule is relevant to super passages. When wing-walls of super passages are not well-keyed into the bank slopes flood flow and silt can easily enter the canal. See Photograph 4N.

Provide Dry-Stone Pitching Upstream of Wing-Walls, Abutments and Piers for Additional Protection and for Streamlining the Drainage Flow

This rule is relevant to super passages and aqueducts. The frontal face and the nose of wing-walls, abutments and piers are always subjected to heavy loads from the impact of flowing water and boulders.

Dry-stone armour can reduce the impact forces and prevent breaching.

Stone pitching can also streamline the drainage flow if laid in a correct profile.

Avoid Burying Siphon Conduits Below the Stream Bed

Bed erosion can expose buried siphon conduits making them vulnerable to boulder impact and weathering damage.

Bed aggradation (build-up) can completely cover the silt ejection valves leaving no possibility for silt ejection.

Provide Generous Protection Works Using Local Construction Materials

The safety of a cross-drainage structure depends very much on the strength of the protection works around it. Regular maintenance and repair of these works can increase the lifespan of cross-drainage structures. Instruct users how to maintain and repair such works.

WARNING

Photograph 4L
Eroded Downstream Area Below the Super Passage due to Inadequate Protection

WARNING

Photograph 4M
Eroded Downstream Area Below the Super Passage due to Inadequate Apron

WARNING

Photograph 4N
A Not So Super Super Passage !

High drainage flow intensity over the structure has eroded the base of the gabion protection work. The gabion has moved away from the structure exposing the foundation of the structure to undermining failure. Wing-walls are not well-keyed into the bank slopes; flood and silt can easily enter canal.

WARNING

Photograph 4O
Exposed HDP Pipes of a Siphon

Bed erosion can expose siphon pipes. Exposed pipes are vulnerable to boulder impact and weathering damage.

WARNING

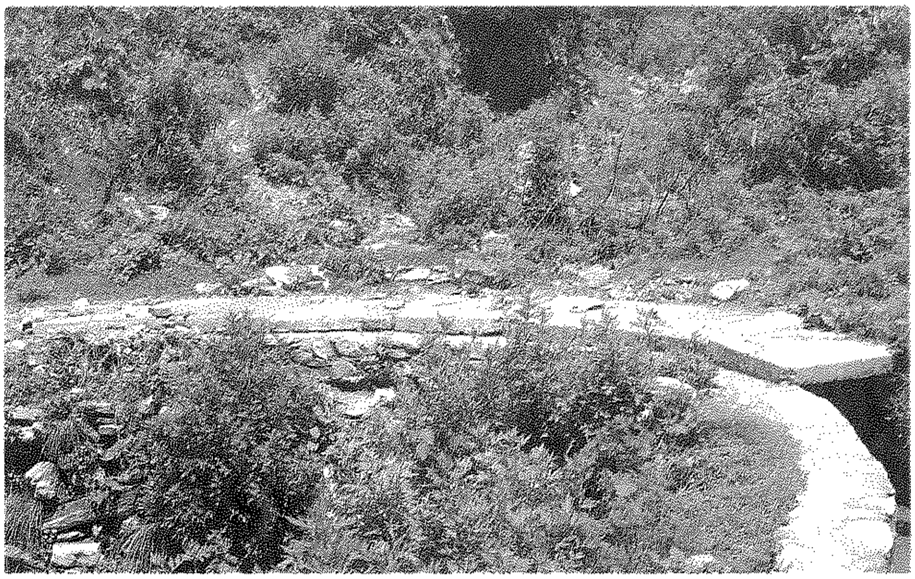
Photograph 4P
Another Not So Super Super Passage !

The natural waterway of the drainage stream has been greatly restricted.

High flow intensity over the narrowed section has eroded and displaced the top cover slab.

Inadequate flow area has caused drainage flow to overspill the walls. Undermining failure is imminent.

WARNING



Photograph 4Q
Obstruction to Flow due to Projecting Canal Cover Slabs

The top cover slab of this super passage has been incorrectly designed and constructed. Slabs have to be well-anchored or placed within seats built in the side walls.

If cover slabs project above the sides they can cause stones and boulders to pile up in front of them causing an obstruction to flow. Drainage flow can divert into the canal because of the obstruction.

The absence of wing-walls also makes it easier for drainage flow to enter the canal.

The Correct Approach to Decision Making in the Field

Decide at the Site

The most suitable type of cross-drainage structure for a given location must be decided at the site and not in the drawing office because only at the site is it possible to confirm the hydrological, topographical and geological conditions required for the safety and proper functioning of the proposed design. Also, when the type of proposed design is known, it is much easier to decide on the measurements to be taken and the observations to be made whilst still at the site. It is advisable to take measurements and observations using the appropriate checklist for the chosen structure. Checklists make it more difficult to forget important data. In cases where more than one type of structure appears to be feasible, exact locations for each structure type must be identified and field data collected using the appropriate checklists. Having all the data to hand will enable quick decisions to be made later when costs for the different options are known.

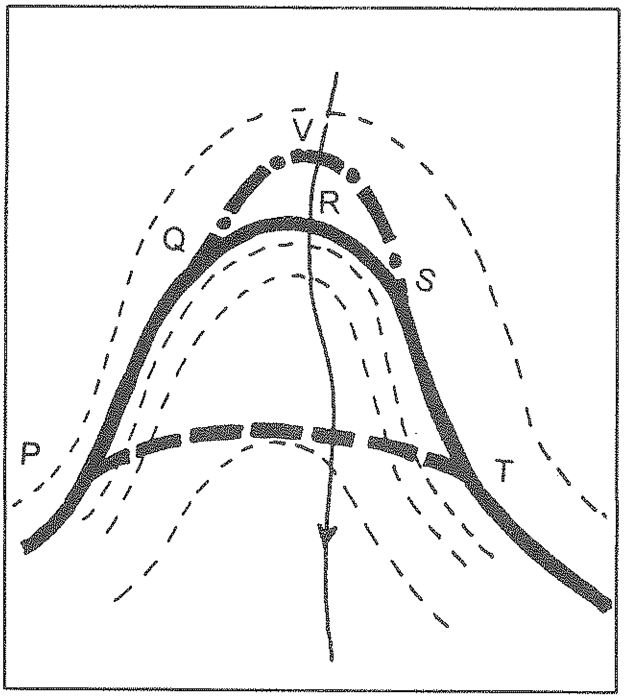
Assess Farmers' Capability to Maintain and Operate the Structure

When choosing between two or more structure type options, or between two or more construction material options for the same type of structure, it is necessary to assess the capability of the farmers to maintain and operate the structure. Farmers do not appreciate the need for constant maintenance and are often unable to maintain the structure when materials used in the construction are not easily available in the village. Little or no maintenance is done during the non-cultivation season. Structures which need year-round maintenance, such as siphons, may become choked because of the lack of maintenance in the non-cultivation season. Structures such as siphons need to be operated according to rigid operational rules: eg. inlet submergence during use, regular silt flushing, etc. The farmers need to be informed about these rules and should be willing and prepared to follow them.

Figure 4.15
A Practical Example of Decision Making in the Field

The Site Condition

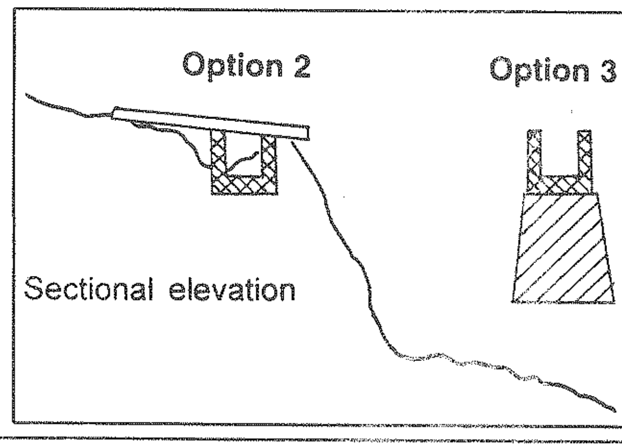
PQRST is an existing farmer-built canal. Because of lack of money to build a "*pukka*" structure the farmers have built a level crossing (see Photographs 4D and 4E,) with stones. During floods the drainage stream carries large quantities of pebbles, sand and silt. There is no need to supplement the canal flow. At P, a large rock outcrop exists a little below the level of the canal. The hill slope at T, is stable.



Note for the Trainer

There are three cases to consider: 1) re-building the level crossing with stronger materials, 2) a super passage at V, 3) an aqueduct.

The level difference between P and T is inadequate for a siphon crossing. Explain to the trainees why option 1 is not the best solution. Explain the structural requirements of option 2, based on assumed topographical, geological and hydrological conditions in the area surrounding canal path QVS. Explain the structural requirements of option 3, based on assumed topographical, geological and hydrological conditions across PT. Work out the appropriate dimensions of the different components of the structure types for options 1 and 2. Assuming both options 2 and 3 to be technically feasible, explain how the choice is made based on cost. Use "to scale" cross-sections and long-sections to obtain dimensions of structure components.



References for Design

Chapter 12.6, "Cross-Drainage Works", of the PDSP Design Manuals describes design procedures for aqueducts, super passages, siphons and level crossings. Sub-sections titled "notes on design" are particularly useful. Chapter 9.3 and Annex T2 of the PDSP Design Manuals deal with theoretical calculations for estimating peak discharge in drainage streams. Most parameters that are required to assess the peak flow in these calculations are very difficult to fix, especially for streams in the hills. In such cases the "rules of thumb" mentioned earlier are recommended for the design of small cross-drainage works.