भारतीय मानक

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भाग 2 विशिष्ट अपेक्षाएँ

अनुभाग 5 साइफन एक्वोडक्ट

(पहला पुनरीक्षण)

Indian Standard

CODE OF PRACTICE FOR DESIGN OF CROSS DRAINAGE WORKS

PART 2 SPECIFIC REQUIREMENTS

Section 5 Syphon Aqueducts

(First Revision)

ICS 93.160

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Cross Drainage Works Sectional Committee, WRD 17

FOREWORD

This Indian Standard (Part 2/Sec 5) (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Cross Drainage Works Sectional Committee had been approved by the Water Resources Division Council.

IS 7784 has been published in two parts. Part 1 of this standard covers general requirements of the design of cross drainage works. Part 2 covers specific requirements and has been published in the following five sections:

Section 1 Aqueducts
Section 2 Superpassages
Section 3 Canal syphons
Section 4 Level crossings
Section 5 Syphon aqueducts

This standard (Part 2/Sec 5) covers specific design requirements for syphon aqueducts.

This standard was first published in the year 1980. This revision was taken up in view of the revision of Part 1 of the standard, which lays down general requirements for design of cross drainage works. As modifications have been effected in Part 1 of the standard, this revision is intended to modify the provisions of this standard so as to align the same with Part 1.

There is no ISO standard on the subject. This standard has been prepared based on indigenous manufacturers' data/practices pravalent in the field in India.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

CODE OF PRACTICE FOR DESIGN OF CROSS DRAINAGE WORKS

PART 2 SPECIFIC REQUIREMENTS

Section 5 Syphon Aqueducts

(First Revision)

1 SCOPE

This standard (Part 2/Sec 5) lays down specific design requirements for syphon aqueducts.

2 REFERENCES

The following standards contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
456 : 1978	Code of practice for plain and reinforced concrete (*third revision*)
4410(Part 15/Sec 5): 1992	Glossary of terms relating to river valley projects : Part 15 Canal structure, Sec 5 Cross drainage work (*first revision*)
7784(Part 1) : 1993	Code of practice for design of cross drainage works : Part 1 General features (*first revision*)
10751 : 1994	Planning and design of guide banks for alluvial river — Guidelines (*first revision*)

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 4410 (Part 15/Sec 5) shall apply.

4 DATA FOR DESIGN

For the design of syphon aqueduct, data given in IS 7784 (Part 1) shall be made available. In addition, value of '*n*' for the design of drainage channel shall be known.

5 GENERAL DESIGN CONSIDERATION

5.1 Shape

5.1.1 For designing syphon aqueduct, circular, square, rectangular, horse shoe shape, single or multi cell barrels can be adopted.

5.1.2 Precast RCC pipes may be economical for syphoning small drainage discharges. For large drainage discharges, circular, square, rectangular or horse shoe shaped barrels are suitable Rectangular section may be preferable due to ease of construction and maintenance.

5.2 Materials

5.2.1 For the construction of the syphon barrels, prestressed concrete, RCC or masonry or a combination of these may be used depending upon the availability of materials, labour and relative economy.

6 TYPES OF SYPHON AQUEDUCTS

6.1 Syphon aqueducts may be classified into the following two types:

a) Barrel type, using barrel for drainage waterways, and
b) Trough type, using trough section for carrier channel waterways.

6.2 In barrel type of syphon aqueducts, the entire carrier channel portion may be taken as it is over the barrel or it may be flumed to a rectangular or trapezoidal section to reduce the length of barrels (*see* Fig 1A, IB and 1C).

6.3 In trough type of syphon aqueducts, carrier channel Water is taken across drainage channel through a trough supported on barrels or on piers/abutments raised from the drainage bed (*see* Fig. ID, IE and IF). Bottom of the trough of carrier channel is lower than HFL of drainage channel. An impervious floor, if necessary, with protection against surface and sub-surface flow may be provided in drainage bed.

6.4 It is preferable to regrade the exit of drainage channel or stream to allow the water to flow without restraint if it is economically feasible. When it is not feasible, the bed may be regraded to a suitable slope. The type of syphon aqueduct to be adopted shall be decided on the basis of relative economy and restraints of carrier channel design.

7 LAYOUT

7.1 General

7.1.1 The layout of syphon aqueduct shall be so fixed that the drainage channel crosses the carrier channel preferably at right angles.

7.2 Barrel

7.2.1 The floor level of barrels shall be fixed in relation to the drainage bed level at the syphon aqueduct site. The future retrogression and regrading of drainage channel depending on outfall conditions may also be considered. The floor level is combination with ventway shall be judiciously fixed below the existing drainage bed in such a manner that a water seal of 1.5 times the change in velocity head, with a minimum of 150 mm, should be provided over the crown of barrels at start to prevent air entering the barrel.

7.2.2 At the outlet end of the syphon, the top of the barrel may be kept slightly depressed below the normal downstream flood level in the drainage channel. The amount of this depression may be equal to the difference in the velocity head at the exit end of the barrel and that in the drainage channel on the downstream side.

7.2.3 In case of barrel of R.C.C box type or R.C.C. slab with masonry walls, a minimum cushion of 300 mm may be provided with the precaution that heavy vehicles do not ply over the barrels unless the cover is suitably increased and the structure is properly designed. In case of R.C.C. pipes and circular barrels, a minimum cushion of 900 mm should be provided. This will protect the pipes and barrels against damage by the movement of construction equipment over them. This cover also permits any future regrading of the carrier channel.

7.2.4 At the site of syphon aqueduct the drainage bed is generally depressed and provided with PUCCA floor (Fig. 1E). On the upstream side, the drainage bed may be joined to the PUCCA floor by a vertical drop (when drop is of the order of 1 m or less) or by a glacis of 3:1 (when drop is more then 1 m). The downstream rising slope should not be steeper than 5:1.

7.2.5 Depending upon the bed level of carrier channel and HFL of drainage channel, the barrels under the carrier channel bed portion are generally lower than the barrels at the entry and exit. This difference is negotiated with the provision of sloping length of barrels under carrier channel banks. The upward inclination of the barrel shall start from a point at least 1.0 m away from the end of the carrier channel bed width on either side.

7.2.6 The length of barrels should be fixed on the consideration of economics of increasing barrel length with respect to reduction in length of wing walls of drainage channel and height of breast wall and practical and economical depth of cut off under barrels for safe exit gradient. However the length should be sufficient to accommodate the width of service road.

7.3 Drainage Wings

7.3.1 The length of drainage wings shall be adjusted so as to contain the slopes of carrier channel embankments. The wings shall be provided straight or in a smooth curve giving a minimum splay of 2:1 on upstream and 3:1 on downstream. If necessary, return wall may be provided thereafter. The top of wings shall be kept at least 300 mm higher than the HFL of the drainage channel.

7.3.2 The wing wall sections shall be checked for carrier channel full and drainage channel dry condition, considering backfill as saturated. No passive resistance shall be considered from drainage channel side.

7.3.3 If the foundation of wing wall requires to be taken deeper than 1.5m from consideration of scour, a concrete cut-off of required depth shall be provided along the upstream face of the wing wall.

7.4 Trough

7.4.1 In the case of trough type syphon aqueduct, both carrier channel transitions and drainage wings shall be provided.

7.5 Carrier Channel Section and its Fluming

7.5.1 *Carrier Channel Section*

The carrier channel embankment adjoining the syphon aqueduct should have adequate provisions to avoid possibility of any breach and to minimize seepage. The outer slope of bank should have a clear cover of 600 to 900 mm over the designed phreatic line often referred to as hydraulic gradient, (*see* IS 7894 for details). High banks (say, more than 6 m height above ground level) should be checked for slope stability and normal provisions of filter and rock toe should be made. In cases where HFL in the drainage channel is substantially higher than bed of the carrier channel, the bank of the carrier channel should be checked for the condition when drainage channel is in high floods and the carrier channel is dry.

7.5.2 *Fluming*

Fluming ratio shall be adopted as given in IS 7784 (Part 1) keeping in view the permissible head loss in the carrier channel, and whether the carrier channel is lined or unlined.

7.5.3 *Transitions*

The flumed portion of the trough shall be joined with the normal section with proper transitions to minimize head loss at entry and exit. The loss of head in transitions shall be calculated in accordance with IS 7784 (Part 1). The transitions should correspond to a minimum splay of 2 : 1 on the upstream side and 3:1 on the downstream side. It should be ensured that the flow follows the boundaries of the wings.

7.6 Joints

7.6.1 In case of RCC barrels, joints with water stops shall be provided across and along the barrel length. The maximum spacing of these joints in either direction shall be 20 m. A gap of 10 to 15 mm with water stops at all the joints across and along the barrel should be provided. The position and details of joints shall be in accordance with the provisions of IS 7784 (Part 1). In case of multi-barrel syphons, units of 3 or 4 barrels can be adopted side by side with longitudinal joints between the units having water stops all around. Water stops shall also be provided at the junction of RCC barrels with transition walls.

7.6.2 In case of syphon barrels resting on compressible soils, collars encircling the plain joint (*see* Fig. 2) shall be provided. This will protect the water stop from vertical shear due to excessive settlement. The width and thickness of collars shall not be less than 300 mm. In case of syphons of multiple barrels of more than one unit, the collars shall be designed to be flexible.

7.7 A typical layout of barrels of syphon aqueduct is shown in Fig. 3.

8 LIMITING VELOCITY AND LOSS OF HEAD

8.1 Limiting Velocity

The vertical slope on approaches should not be steeper than 1 in 3 on the entry side and 1 in 4 on the exit side. The minimum permissible velocity allowed in the drainage channel may be derived from Table 1. However, the velocity in the barrels shall not exceed the maximum permissible velocity given in IS 7784 (Part 1).

Table 1 Minimum Permisible Mean Velocities for Loose Granular Bed Material

Material	Diameter of Particle 'd' mm	Minimum Mean Velocity in Case of Depth (h = 1m) V_1 m/s
(1)	(2)	(3)
Very coarse gravel	200-150	3.9-3.3
	150-100	3.3-2.7
Coarse gravel	100-75	2.7-2.4
	75-50	2.4-1.9
	50-25	1.9-1.4
	25-15	1.4-1.2
	15-10	1.2-1.0
	10-5	1.0-0.8
Cobble	5-2	0.8-0.6
Coarse sand	2-0.5	0.6-0.4
Fine sand	0.5-0.1	0.4-0.25
Very fine sand	0.1-0.02	0.25-0.20
Silt	0.02-.002	.0.20-0.15

Correction coefficients formula :

$V-av_1$ where V refers to the permissible minimum mean velocity.

Depth, m	*Correction Coefficient, a*
0.3	0.80
0.6	0.90
1.0	1.00
1.5	1.10
2.0	1.15
2.5	1.20
3.0	1.25

8.2 Loss of Head

The loss of head at the entry, at the exit and in the barrel due to friction and due to elbow and joints shall be calculated in accordance with IS 7784 (Part 1). The water way shall be so adjusted that the afflux does not exceed the limits of submergence tolerances of the environments.

9 DESIGN OF BARREL TYPE SYPHON AQUEDUCT

9.0 The main considerations for design of syphon barrels are the following:

a) It should be safe against uplift,

b) It should be strong to resist internal and external forces,

c) It should be safe against subsurface flow, and

d) It should be safe against surface flow.

9.1 Safety Against Uplift

9.1.1 The barrels shall have enough load to resist upward buoyancy force tending to lift it. The barrels underneath carrier channel bed are critical for checking against uplift. The safety of barrels should be checked for the following three conditions:

a) Carrier channel at full supply level and drainage barrels empty,

b) The drainage channel at designed flood level and carrier channel empty, and

c) Carrier channel is suddenly closed and drainage barrel is empty thereby causing two-thirds of the head corresponding to carrier channel full supply level to act. Lesser percentage of head up to one-third of total head may be considered in case the carrier channel section is made of relatively permeable material.

The minimum factor of safety against uplift should be 1.2 in all the three conditions.

NOTE — Full hydrostatic head from carrier channel full supply level to the drainage barrel foundation should be taken for checking the stability.

9.1.2 The bottom slab of barrel may be suitably projected beyond its side walls to take advantage of the weight of the earth wedge over the projection in counteracting the uplift forces.

9.1.3 If the weight is taken to counteract uplift in design computation, the earth cushion over the barrels should not be allowed to fall below the corresponding design depth. In such cases the carrier channel bed should be adequately protected against erosion by providing a suitable protective cover over the earth extending 20 m upstream and downstream of the syphon. Lean concrete/random rubble masonry over the barrel as additional weight may be provided.

9.2 Safety against Internal and External Forces

9.2.1 *General*

The barrels should be designed strong enough for the dead load of the structure, earth and water loads, earth and water pressures, soil reaction and uplift pressure and live load, if any. The combination of loads which will result in maximum stresses shall be carefully considered.

Due to the diference in loading, the length of barrels of major structures can be divided into two portions, one under carrier channel bed and the other under carrier channel banks for economical design.

9.2.2 *Transverse Analysis*

The barrels for the purpose of transverse analysis shall be treated as a box. The box shall be analyzed by any standard method for the following conditions and loadings to determine the worst moments, shear and thrust at any section:

Condition - I Carrier channel at full supply level and barrels dry (for loading *see* **9.2.2.1**).

Condition - II Carrier channel dry and the drainage channel at designed HFL (including afflux) (for loading *see* **9.2.2.2**).

9.2.2.1 Loading and forces under condition-I are as given below:

a) Barrel under carrier channel bed portion

1) The bottom slab will be subjected to the upward soil reaction due to entire vertical loads. The soil reaction can be assumed to be uniformly distributed. Uplift pressure due to subsoil water level, if any, shall also be considered;

2) The top slab will be subjected to downward loads due to carrier channel water load, self weight of slab and weight of earth and lining, etc, over top slab;
3) The end walls will be subjected to submerged earth pressure and water pressure corresponding to carrier channel full supply level; and
4) The intermediate or partition walls in case of multicell barrel will be subjected to direct compression due to vertical downward loads. These walls are not subject to any significant lateral pressure when all the barrel openings are running. However, these walls will also be checked for the condition when one barrel is dewatered for repairs and adjoining barrel is filled with water and silted up to half the height of the barrel.

b) Barrel under carrier channel bank portion

The different members will be subjected to the loads as enumerated above except that the carrier channel water load will be replaced by earth load. The saturation level for the earthfill may be properly accounted for with appropriate hydraulic gradient - line from F.S.L. of the carrier channel with regard to type of soil comprising the banks. Additional live load on service road, if any, shall also be considered.

9.2.2.2 Loading and forces under condition-II are as given below:

a) Barrel under carrier channel bed portion :
   1) The bottom slab will be subjected to upward load as for condition-I [*see* **9.2.2.1**(a), (l)].
   2) The top slab will be subjected to upward pressure corresponding to HFL in the drainage channel and downward loads of carrier channel lining, earth filling and self weight.
   3) The intermediate walls will be subjected to direct tension due to net upward pressure on top slab.
   4) The end walls will be subjected to water pressure corresponding to HFL from inside and saturated earth pressure from outside.

b) Barrel under carrier channel bank portion due to the predominant effect of bank load the different members in this condition will be subjected to loads similar in nature but lesser in magnitude as compared to condition-I [*see* **9.2.2.1**(b)]. As such, normally, analysis for condition II in bank portions is not required.

9.2.2.3 In case of two or more monoliths each consisting of 3 or 4 barrels, the side wall of each monolith at joints shall be subjected to water pressure in the joint corresponding to HFL or no water pressure in the joint.

9.2.2.4 Adequate reinforcement corresponding to worst moments and forces at different sections shall be provided.

9.2.3 When RCC pipes are used in place of barrels, they shall rest on cement concrete cradle of M 15 grade (*see* IS 456), which shall be suitably increased at joints. Standard joints shall be used and these shall be properly grouted to make them water tight. At bends, anchor blocks shall be provided to receive the end of pipes.

Generally RCC pipes may be provided up to 3 cumecs discharge and minimum diameter of pipe shall be 0.9 m.

9.2.4 *Longitudinal Analysis*

9.2.4.1 Longitudinal analysis shall be made in cases where loose soil or various types of soils are met with at the completed final level of foundation.

9.2.4.2 In case the socket and spigot arrangement of collars is provided, the vertical displacement of one unit will cause extra loads and stresses on the other unit due to the restraining effect of the collar. For analysis of these loads the barrels in longitudinal direction shall be considered as beams resting on elastic foundations. The analysis should be carried out according to the principles given by M. Hetenyi ('Beams on elastic foundation', M/s Cushing Malloy, USA) or any other standard method of analysis.

9.2.4.3 The restraining force of collar can be determined by evaluating the defection of the two units at the joint. The collar shall be designed for the cantilever moment due to this force.

9.2.4.4 The bending moment in the barrel in longitudinal direction due to superimposed loads as well as collar reaction shall be calculated as per standard expressions for different loading conditions given by M. Hetenyi and the required reinforcement shall be provided, subject to a minimum nominal reinforcement in accordance with IS 456.

9.3 Safety Against Sub Surface Flow

9.3.1 *Cut-offs*

The depths of cut-off shall be calculated from scour and exit gradient considerations.

9.3.1.1 The normal scour depth shall be computed for the drainage channel in accordance with IS 7784 (Part 1). Depth of cut off below the entrance and exit ends of barrels may be provided along the width of the barrels and along the river or the drainage channel wings up to 1.25 to 1.5 times the normal scour depths below HFL based on the site conditions. In case of rocks, the cut off shall be taken minimum 1.0 m from the sill of the barrel into the fresh rock. The width of concrete cut off shall not be less than 0.3 m.

9.3.1.2 Depth of cut off shall be checked for safe exist gradient in accordance with Khosla's theory for two dimensional flow. In syphons of carrying capacity over 20 cumecs the effect of 3 - dimensional seepage flow on exit gradient shall be considered. For this, electrical analogy model testing should be carried out and cut offs at the end of the barrels should be provided accordingly. The safe value of exit gradient for different types of soil generally adopted can be as follows:

Clay	1 in 4
Shingle	1 in 4 to 5
Coarse sand	1 in 5 to 6
Fine sand	1 in 6 to 7

9.3.1.3 The vertical cut off shall also be provided under river or drainage channel wings. However, the depth of cut off may be suitably reduced under wings depending upon the length of wings, but should be adequate from scour considerations.

9.3.2 Ribs at suitable spacings may be provided to increase the seepage path.

9.3.3 *Filter*

A suitable filter under open jointed cement concrete blocks or rubble should be provided along the cutoff that is u/s of upstream cut-off and d/s of downstream cut-off. The length of filter to be provided should be 1.5 times the, scour depth (below drainage bed). Typical arrangement shown in Fig. 3 may be adopted. The filter should be designed in accordance with standard criteria conforming to IS 8237.

9.3.3.1 The safety of filter should also be checked against heave in accordance with the method suggested by Terzaghi.

9.4 Scour shall be considered at entry and exit of syphon barrels in accordance with IS 7784 (Part 1) and launching appron adequate to provide a cover of 0.6 to 0.9 m over the entire slope of the scour shall be provided.

10 DESIGN OF TROUGH TYPE SYPHON AQUEDUCT

The basic design features of this type shall be the same as those of aqueducts [*see* IS 7784 (Part 2/Sec 1)]. However, the carrier channel trough in this type should be designed so as to provide the dead load of the trough at least 1.2 times the upward thrust acting on it when the drainage channel is in high floods and the carrier channel is dry. If it is not so, the trough shall be suitably anchored to the piers. The floor of the syphon aqueduct shall be suitably designed for the uplift pressures acting on it, according to conditions given in **9.2.2**.

11 ADDITIONAL PROVISIONS

11.1 The outer slopes of carrier channel banks and drainage channel slope should be protected in the vicinity of syphon aqueduct by pitching. For large size drainage channel, properly designed guide banks should be provided.

11.2 In major syphon aqueducts stop-log grooves in the barrels at the upstream and downstream ends may be provided by extending the partition walls to facilitate isolating one or more barrels for annual repairs and maintenance. Stability of barrels shall be suitably ensured in this case.

11.3 A retaining wall should be constructed over the barrels to retain the carrier channel banks slopes over the barrels. If constructed in reinforced cement concrete, this walls (breast wall) should be constructed monolithically with the top slab of the barrels. Adequate anchorage of reinforcement as well as reinforcement for proper transference of loads and moments to the top slab shall be provided. The effect of live load, wherever applicable shall also be considered in the design of this wall. At the junction of this wall with barrel, a haunch of suitable size shall be provided.

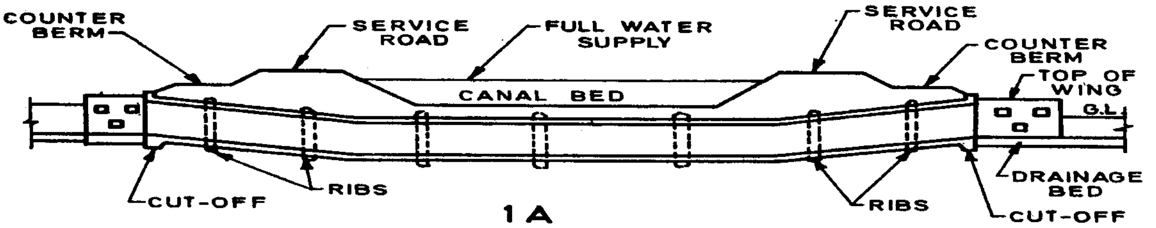
11.4 The design of the wings, both for carrier channel and the drainage channel, shall be carried out for earth and water pressures calculated according to standard practice. The effect of live load and surcharged effect, if any, shall be taken into account while designing the wings. Wing walls shall be checked for earthquake conditions also, in seismic zones.

11.4.1 Weep holes shall be provided in the drainage wings above low water level at spacing of 2.5 m c/c bothways in staggered fashion. Filters shall be provided at the rear end of weep holes to prevent movement of the backfill material.

11.5 In case of barrels, the top slab at entry of drainage may be given a smooth curve shape to reduce afflux.

11.6 In case of streams in bouldery region, provision of wearing coat in the floors of the barrel may be necessary.

11.7 In case of multibarrels, intermediate partition walls need to be provided with suitable cut and ease water. The minimum thickness of the R.C.C. walls shall be 200 mm. Reinforcement in these walls shall be anchored with the slabs. In case of RCC walls, suitable haunches in square or rectangular barrels with haunch reinforcement shall also be provided.



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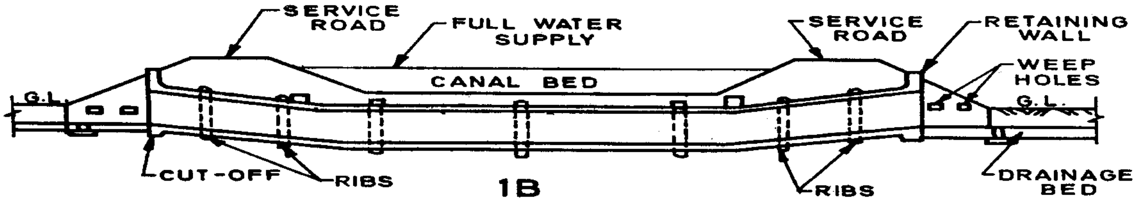

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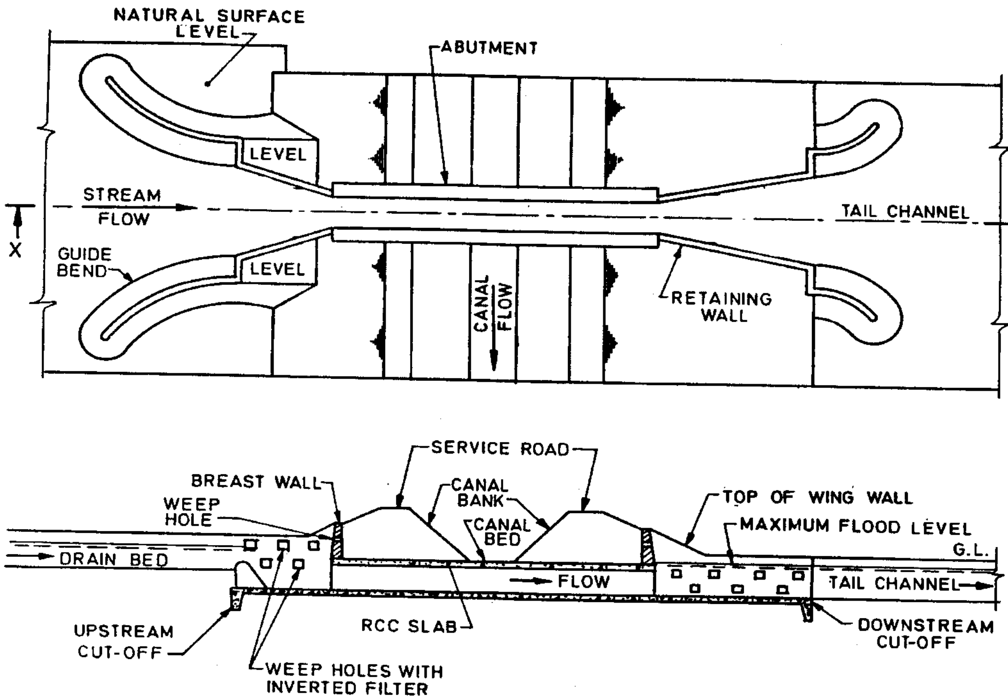

SECTION XX

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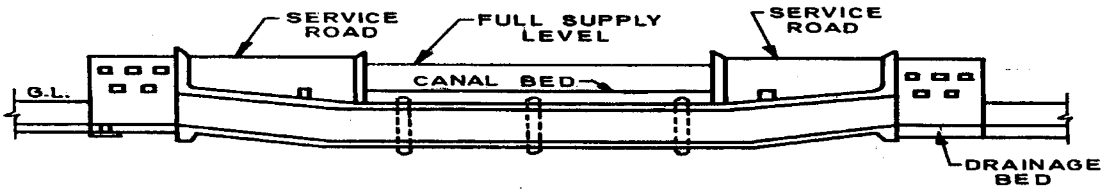

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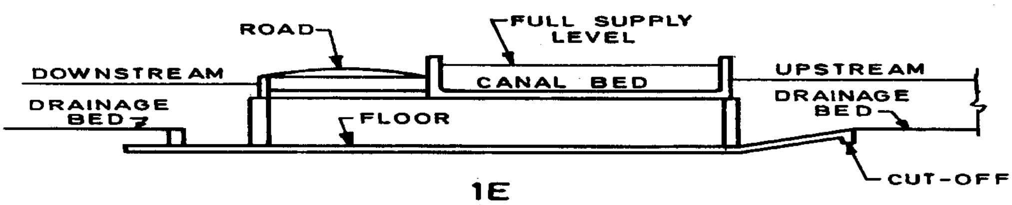

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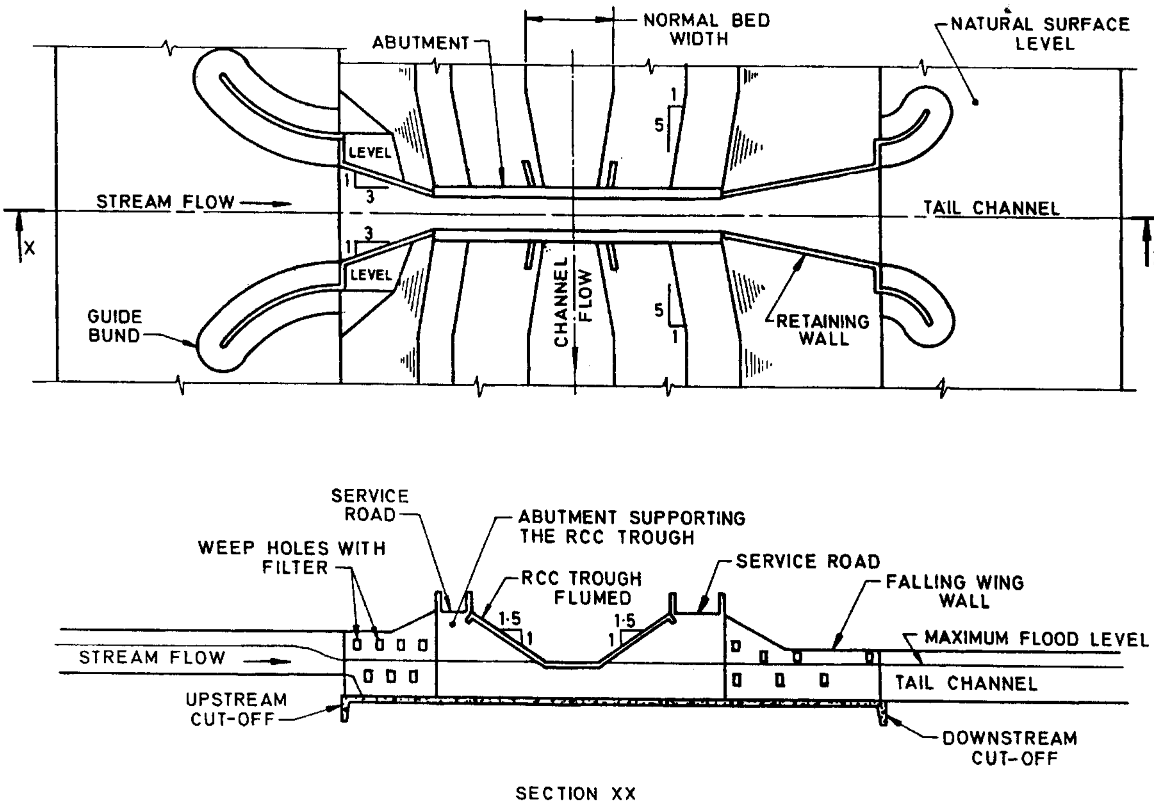

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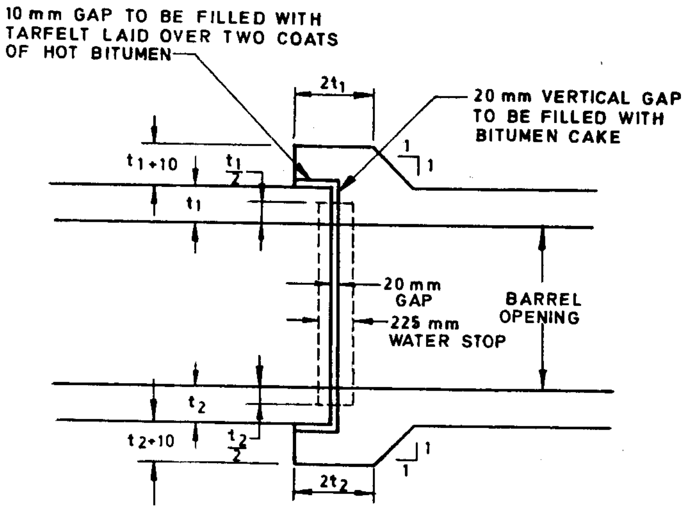
FIG. 1 TYPES OF SYPHON AQUEDUCTS



All dimensions in millimetres.

t_1 = Thickness of top slab, and

t_2 = Thickness of bottom slab.

FIG. 2 DETAILS OF COLLAR

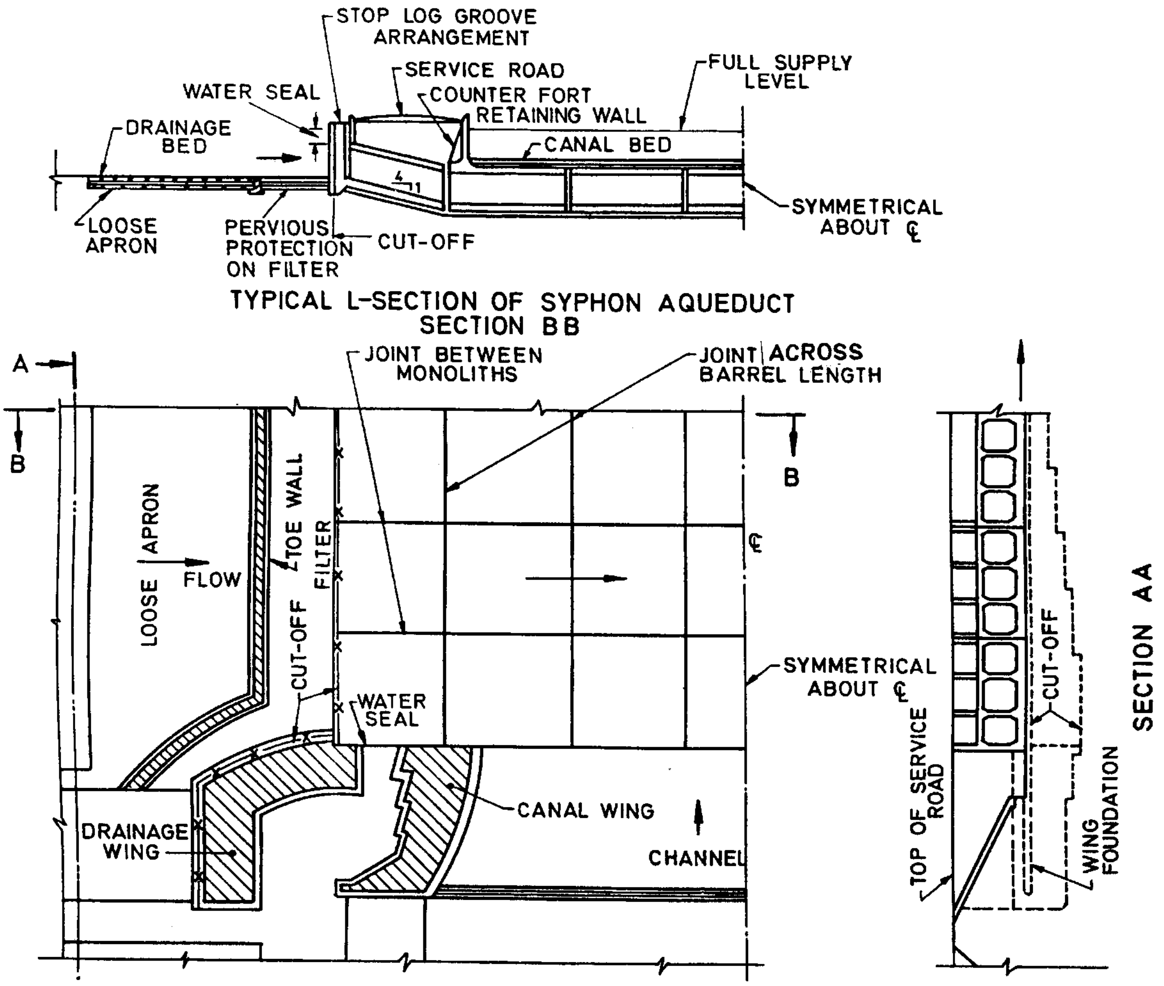


FIG. 3 DETAILS OF SYPHON AQUEDUCTS

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Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Handbook' and 'Standards: Monthly Additions'.

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Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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