academicJournals

Vol. 4(7), pp. 224-231, July, 2013
DOI: 10.5897/JCECT12.025
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/JECET

Journal of Civil Engineering Construction Technology

Full Length Research Paper

Integrated hydraulic design approach for cost effective aqueduct trough

Hitendra Chandewar[1], Narendra Kanhe[2]* and Shailendra Rathore[1]

[1]Department of Civil Engineering, Manoharbhai Patel Institute of Engineering and Technology (MIET), Kudwa, Gondia,-441614,Maharashtra, India.
[2]Department of Civil Engineering, Guru Nanak Institute of Engineering and Management, Dahegaon, Kalmeshwar Road, Nagpur- 441501, Maharashtra, India.

Accepted 11 June, 2013

An aqueduct structure is a complex structure as compared to bridge, as it takes canal water across stream and canal traffic over the trough. The water-tightness and free expansions - contractions of trough, canal water load as well as traffic load on the trough involves complex load combinations, for which the superstructure and substructure of it is required to be planned and designed. The object of this research paper is to develop an optimized hydraulic design, by integration of various theories applicable, to provide cost effective aqueduct structure. This integrated hydraulic design for an aqueduct trough aims at minimization of water-way area of moving water, thus, minimizing mass of moving water per unit length of an aqueduct trough, which will result into lesser water load on aqueduct trough which ensures less quantity of construction materials and thus the aqueduct substructure and superstructure is economical. A case study of the executed project is also depicted which shows around 29% saving in concrete quantity by this method.

Key words: Aqueduct, trough, total energy line (TEL), head loss (HL), Integrated hydraulic design.

INTRODUCTION

The flow of water in the aqueduct is considered as an open channel flow. If aqueduct is not optimally designed for hydraulics, it will lead to uneconomical superstructure and substructure. Aqueduct structure is planned, designed and executed through government department with its capital. Without the integrated design approach for aqueducts, design may become unplanned and may make the structure uneconomical as well as hydraulically non functional. This may put unnecessary financial burden on public exchequer.

The review of literature reflected that theories of planning and hydraulic design of all aqueduct components together are not available in books, manuals and codes of practices. The design procedure specially for aqueduct, was not obtained from any of the available sources. While designing aqueduct components, the designer has to use his know-how and a lot of basic theories. The aqueduct trough designed with limited theories may lead to failure of hydraulics of the moving water in the canal and trough, and make the aqueduct structure uneconomical. While going through various literatures available for designs, it was observed that Indian Standards (IS) 7784, part-2/section -1 (1995), Central Design Organization (CDO) manual and number of books such as Larry (2006), Punmia et al. (2009), Garg (1991), and Shrivastava (2005) have given the specific requirements of aqueduct in general. Guidelines of Indian Road Congress (IRC) 6 (11), IRC-78 (11) and IRC -83 (11) and literature in book/handbook of Public Works Department (1983), Raina (1999) are useful for hydraulic and structural aspects of the substructure of aqueduct. IS 7784 part-1: (1993) depicts about the

---

*Corresponding author. E-mail: narendra_mk@hotmail.com. Tel: +91 98233 82851.

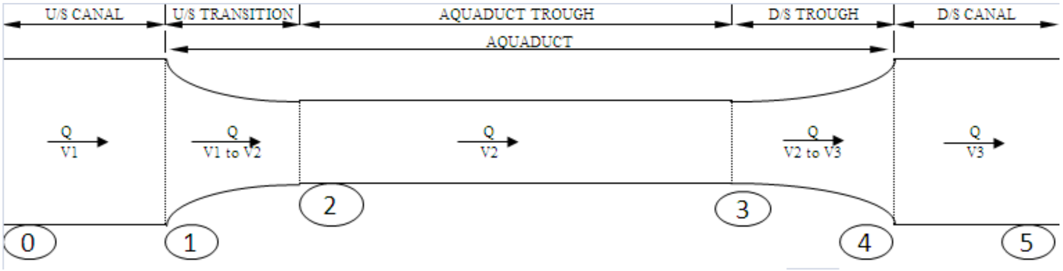


Figure 1. Schematic plan showing the canal and aqueduct.

hydraulics of canal structure which can be referred for aqueduct trough. Sub section 8.6, 8.7 and 8.8 of IS 7784 part-1 mention about the hydraulics of the aqueduct trough.

Theories for open channel flow, total energy line (TEL) etc. have been explained in IS 2912, part-2/section-5, IS 2951, part-1 and in number of books such as Madan (2008), Shrivastava (2005), and Larry (2006). The application of TEL concept for hydraulics of aqueduct trough and adjacent canal is explained in some books such as Modi (2008), and Punmia et al. (2009) in a derived way. For arriving at the cost effective structure of aqueduct trough, an integration of various theories for the hydraulics of upstream canal, trough, downstream canal, field requirements, constraints and economy aspects has been done in this research work. The principal object of this research is to provide cost effective aqueduct structure by using the integration of various hydraulic design theories available. An integrated hydraulic design for an aqueduct trough developed, aims at minimizing the water-way area of moving water, which minimizes mass of moving water per unit length of an aqueduct trough. The minimization of mass of water results into lesser water load on aqueduct trough. Lesser load of water on trough ensures less quantity of construction materials and thus substructure and superstructure cost considerably reduces making the aqueduct structure cost effective.

INTEGRATED HYDRAULIC DESIGN APPROACH

In the present hydraulic design approach, the discharge and the TEL of the moving water in the canal as per planning of the canal segment with allowable head loss (HL) for the aqueduct trough has been kept undisturbed such that the aqueduct trough and the canal on the upstream and downstream will remain effectively functional without damages to the canal and aqueduct. It will not loose design discharge capacity and the command area by gravity. Aqueduct may be made less expensive if canal is flumed to aqueduct trough. Water flows with a uniform velocity in the canal and depth encounters transitions because of fluming of canal to aqueduct trough. The flow characteristics undergo a change. This change is required to be estimated for arriving at the optimum design of aqueduct trough.

Steps for integrated hydraulic design

Study of geometrics of canal and aqueduct components

The study of geometrics of canal and aqueduct components is shown in Figure 1.

Characteristics of flow

The flow in aqueduct and canal is open channel flow, that is, surface of flow open to atmosphere. Free surface makes the open channel flow more complicated to analyze than closed conduit since cross-sectional area depends on flow depth. The adjacent canal is flumed to aqueduct trough. The fluming zone is also called transition zone. Because of fluming, complications arise due to changes in section shape, flow depth, velocity and discharge.

To evaluate the hydraulics in aqueduct, details of geometrics and flow characters of open channel flow in adjacent canal and aqueduct components need to be considered. The characteristics of open channel flow in aqueduct and adjacent canal are given in Table 1. The flow characteristics in various components are as follows.

1) Uniform flow in canal and aqueduct trough

$$dy/d_x = 0,\ dV/d_x = 0,\ dQ/d_x = 0 \qquad (1)$$

Where y is a depth, V is the velocity of flow and Q is the discharge.

2) Non-uniform flow in upstream and downstream transition zone of aqueduct

$$dy/d_x \neq 0,\ dV/d_x \neq 0,\ dQ/d_x = 0 \qquad (2)$$

Table 1. Characteristics of open channel flow in aqueduct and adjacent canal (Figure 1 sections).

Flow and other parameters	Section 1	Section 2	Section 3	Section 4	Section 5
C/S area and bed gradient	Prismatic	Non Prismatic	Prismatic	Non Prismatic	Prismatic
Boundary conditions	Rigid	Rigid	Rigid	Rigid	Rigid
Froude's No.	Sub critical	Sub critical	Sub Critical	Sub Critical	Sub Critical
Discharge	Steady	Steady	Steady	Steady	Steady
Velocity, discharge, depth	Uniform	Non-uniform GVF*	Uniform	Non-uniform GVF*	Uniform
Flow and Reynold's No. (Re)	Turbulent Re > 500	Turbulent Re > 500	Turbulent Re > 500	Turbulent Re > 500	Turbulent Re > 500
Discharge	Q	Q	Q	Q	Q
Velocity	V1	V1 changes to V2	V2	V2 changes to V3	V3 = V1
Head loss	No losses	Kinetic Losses	Friction losses	Kinetic Losses	No Losses

***Gradually varied flow, Total Losses across the aqueduct restricted to canal cut off losses.

3) Steady flow for canal and aqueduct

$$dQ / d_x = 0 \tag{3}$$

4) For Steady non-uniform flow, that is, GVF in upstream transition zone,

$$\text{Energy losses} = HL1 = K1\,(V_2^2 - V_1^2) / 2g \tag{4}$$

Where K1 ranges from 0.1 to 0.3; and 0.2 is considered for aqueduct design.

5) For Steady non-uniform flow, that is, GVF in downstream transition zone,

$$\text{Energy losses} = HL3 = K\,(V_2^2 - V_3^2) / 2g \tag{5}$$

Where K2 ranges from 0.2 to 0.4; and 0.3 is considered for aqueduct design.

6) Steady-uniform flow in aqueduct trough, energy losses shall be.

$$\text{Energy losses} = HL2 = n^2 V_2^2 L / R^{4/3} \tag{6}$$

Where n is Manning's coefficient & R = hydraulic mean depth.

Integration of flow characteristics and equations: The theories for moving water in open channel have been integrated for aqueduct structure. The two basic equations, continuity equation and energy equation, can be used for integration of flow characters in canal and aqueduct.

i) Continuity equation:

$$Q_1 = Q_2 = Q_3 \tag{7}$$

ii) Energy equation (Bernoulli's equation):

$$E = Z_1 + y_1 + V_1^2/2g = Z_2 + y_2 + V_2^2/2g + \text{Losses} = Z_3 + y_3 + V_3^2 / 2g + \text{Losses} \tag{8}$$

Where E denotes total energy, Z denotes potential head, y denotes depth and V denotes velocity

Field requirements and constraints

The following field requirements and constraints are considered for integrated hydraulic design approach:

1) Incoming discharge shall be equal to outgoing discharge. If this condition is not fulfilled, there will be accumulation of canal water on upstream of aqueduct which may make the canal non-functional to some extent as well as there are chances of breaching of canal on upstream of aqueduct.

$Q1 = Q2 = Q3$

2) Velocity in aqueduct trough shall be within 0.9 to 2.5 m/s (IS 7784 part-1: 1993) to keep aqueduct trough self cleansing and non-erodible. The velocity range can be deviated to 0.75 to 2.0 m/s.

$$0.9 \le V2 \le 2.5 \quad \text{or} \quad 0.75 \le V2 \le 2.0 \tag{9}$$

3) Flow depth in transition zone and aqueduct trough shall be same as that of canal flow depth so that the

irrigable command area on downstream side of aqueduct shall not decrease.

$$y1 = y2 = y3 \tag{10}$$

4) The total losses in transition zone and trough shall be within allowable HL in canal cut-off. If the total HL is less than the allowable HL, then the trough size will be more and it will lead to un-economical structure. If the total HL is more than the allowed HL, the irrigable command area on downstream side of aqueduct will decrease and canal water will accumulate on upstream of aqueduct which may make the canal non-functional to some extent, as well as there will be chances of breaching of canal on upstream of aqueduct.

Kinetic HL in upstream + friction HL in aqueduct trough + Kinetic HL in downstream transition ≤ allowable HL in aqueduct, that is, (HL1 + HL2 + HL3) ≤ HLa

$$[0.2\,(V_2^2 - V_1^2) / 2g + n^2 V_2^2 L / R^{4/3} + 0.3\,(V_2^2 - V_3^2) / 2g] \le HLa \tag{11}$$

For aqueduct trough with specified boundary roughness, satisfying some or all the above constraints, there would be infinite combinations of trough gradient and trough width which can be obtained for particular discharge and flow depth. The best combination of the trough gradient and trough width can be taken to obtain optimized water way area.

Objectives of integrated hydraulic design approach

1) To minimize the water way area of moving water in aqueduct trough.
2) The minimized water way area of moving water directly helps to minimize the mass of moving water per unit length of aqueduct trough.
3) Lesser the mass of moving water per unit length of aqueduct trough, lesser will be the water load on the aqueduct trough.
4) Less water load on trough directly helps to minimize the cost of superstructure and hence the cost of substructure. This makes the aqueduct structure cost effective.

Steps for integrated hydraulic design

The basic theories and constraints are integrated in energy equations for open channel flow at various locations of aqueduct. The Bernoulli's TEL equations for open channel flow can be applied at four key locations of aqueduct as shown in Figure 1.

1) At junction of upstream canal and upstream transition wall, that is, Section (1)

E1 = CBL at (1) + FSD at (1) + kinetic energy at (1), that is,

$$E1 = CBL \text{ at } 1 + y1 + V_1^2/2g \tag{12}$$

As CBL at 1, y1 and V1 is available from approved cut-off of canal, hence E1 can be calculated.

2) At junction of upstream transition and aqueduct trough, that is, Section (2),

E2 = CBL at (2) + FSD at (2) + kinetic energy at (2), that is,

$$E2 = CBL \text{ at } (2) + y2 + V_2^2/2g$$

y2 is equal to y1, CBL at (2), and V_2 is not available from approved cut-off of canal and hence not known. E2 is calculated based on E1 and V_2 is calculated assuming base width of trough.

E2 = E1 - kinetic energy HL from Section (1) to (2) = E1 – HL_1

$$E2 = E1 - 0.2\,(V_2^2 - V_1^2) / 2g \tag{13}$$

After calculating E2, CBL at (2) is also worked out to fix the CBL at starting point of trough

$$CBL \text{ at } (2) = E2 - y2 - V_2^2/2g \tag{14}$$

3) At junction of downstream transition and aqueduct trough, that is, Section (3)

E3 = CBL at (3) + FSD at (3) + kinetic energy at (3)
= CBL at (3) + y2 + $V_2^2/2g$

y2 is equal to y1. CBL at (3), and V_2 is not available from approved cut-off of canal and hence not known. E3 is calculated based on E2 and V_2 is calculated assuming base width of trough.

E3 = E2 - friction HL from section (2) to (3) = E2 - HL_2

$$E3 = E2 - n^2 V_2^2 L / R^{4/3} \tag{15}$$

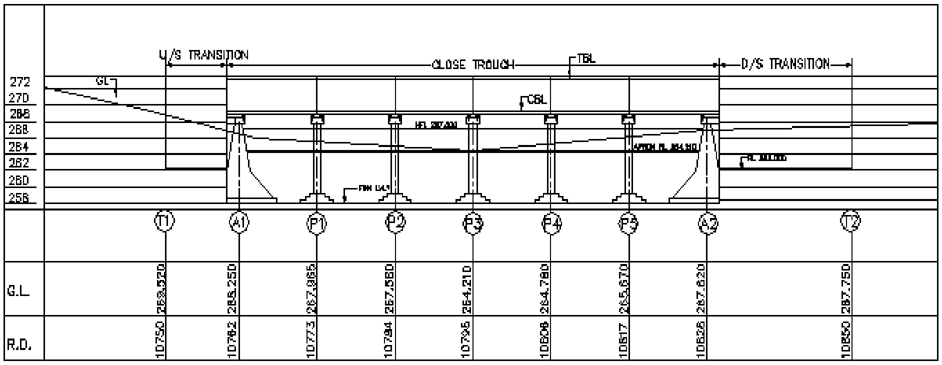
After knowing E3, CBL at (3) is also worked out to fix the CBL at exit point of trough

$$CBL \text{ at } (3) = E3 - y2 - V_2^2/2g \tag{16}$$

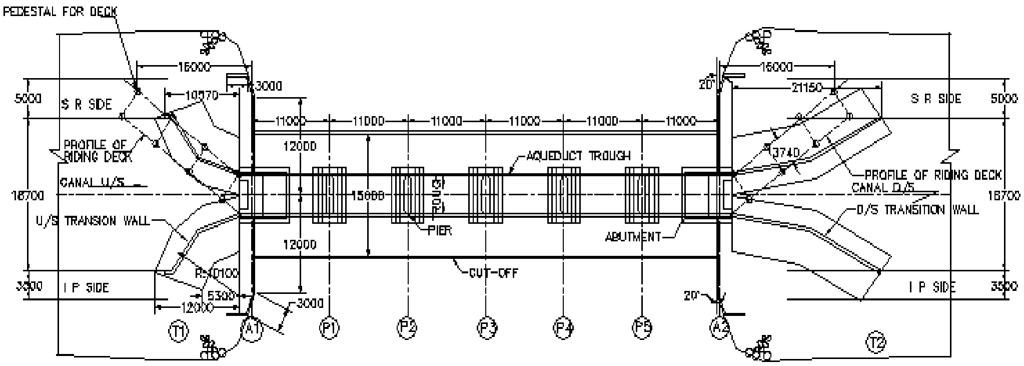
4) At junction of downstream transition and downstream canal, that is, Section (4),

E4 = CBL at (4) + FSD at (4) + kinetic energy at (4)
= CBL at (4) + y3 + $V_3^2/2g$

As y3 is equal to y1, CBL at (4), and V_3 is available from



L/S SHOWING AQUEDUCT DETAILS : GROUND PROFILE, SUB-STRUCTURE, SUPER STRUCTURE



PLAN AT FOUNDATION LEVEL SHOWING SUB-STRUCTURE COMPONENTS

NOTE: ALL DIMENSIONS ARE IN METER UNLESS SPECIFIED
ALL REDUCED LEVEL AND REDUCED DISTANCE ARE IN METER.

Figure 2. General Lay-out of "X" aqueduct on "Y" canal of "Z" Project.

Approved cut-off of canal and hence known. E4 is calculated based on E3 and V_2 is calculated assuming base width of trough.

E4 = E3 - kinetic energy HL from (3) to (4) = E3 - HL3, that is,

$$E4 = E3 - 0.3\,(V_2^2 - V_3^2) / 2g \qquad (17)$$

After knowing E4, CBL at (4) is also worked out.

$$\text{CBL at (4)} = E4 - y3 - V3^2 / 2g \qquad (18)$$

The worked out CBL at (4) is cross checked with CBL at (4) as per cut-off. The worked out CBL at (4) may always not match with CBL at (4) as per approved cut-off; it will only match in case where (HL_1 + HL_2 +HL_3) = HLa (that is, allowable HL at cut-off). Hence, it requires lot of trials of calculations. To avoid un-defined trials, It is suggested to flume the width by some proportion and work out the velocity V_2 for the same, which has been carried out here. After doing this, the energy equations are applied as above to obtain the optimized parameters of aqueduct trough satisfying all field requirements and constraints as mentioned above.

ILLUSTRATION OF INTEGRATED DESIGN APPROACH: A CASE STUDY

A Field example has been illustrated to compare the cost effectiveness of integrated hydraulic design approach as compared to conventional design approach. An aqueduct on same canal already constructed by conventional method and aqueduct recently designed and built by the authors with the integrated design approach, on the same canal of a certain project is taken to work out optimized water way area and for evaluating and comparing the cost effectiveness.

Figure 2 gives the general layout of an aqueduct on a canal of certain project. This has been referred as "X" aqueduct on "Y" canal of a "Z" project. Figure 3 gives hydraulic and geometrical parameters which include details of abutment and pier, cross-sectional elevation of trough and pier, controlling reference levels at trough and transitions for this aqueduct. Figure 4 shows the trough details by conventional method and by integrated hydraulic design method for comparison.

Table 2 presents the integrated hydraulic design output which is obtained for this aqueduct shown in Figure 2. The various canal and trough parameters considered are presented. The programmed output obtained in Table 2

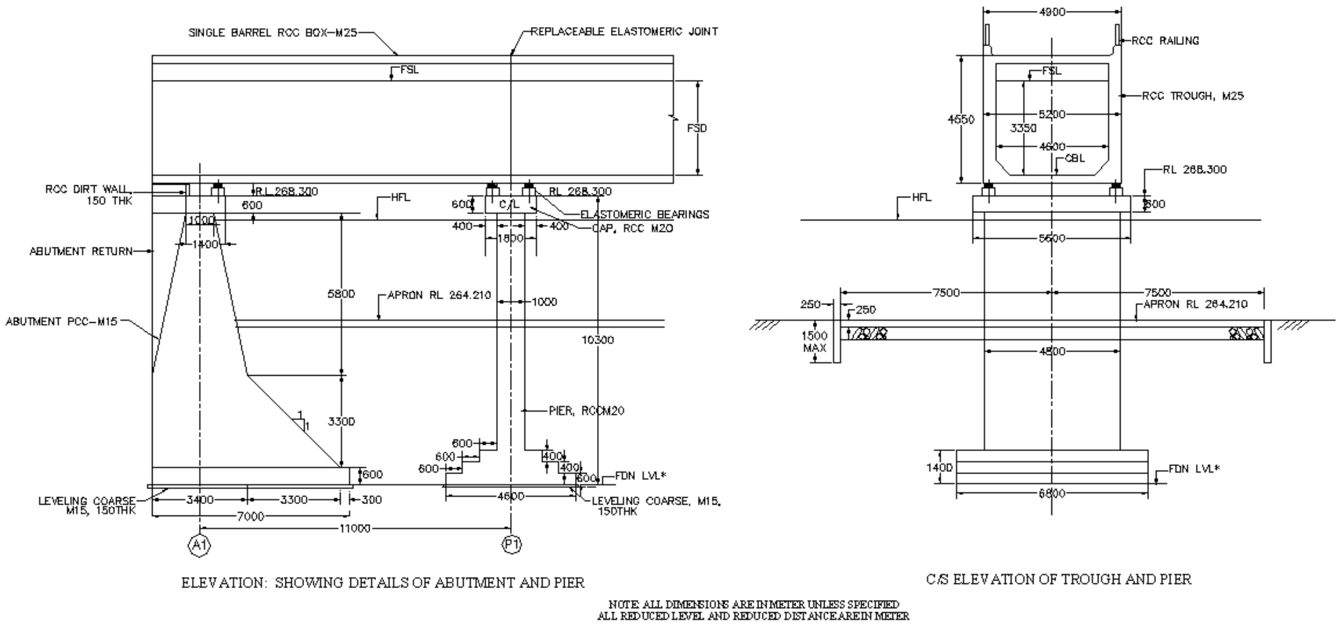
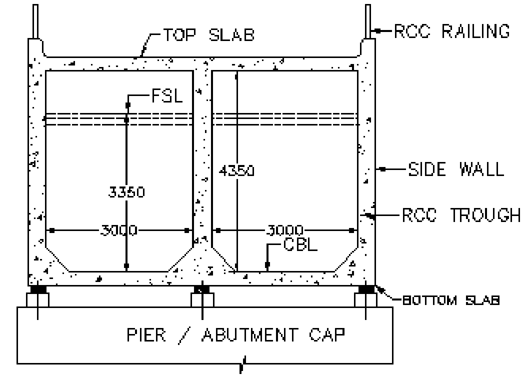
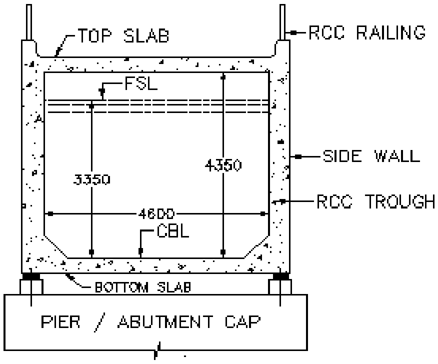


Figure 3. Hydraulic and geometrical parameters of designed aqueduct.



SECTION OF TROUGH
BY CONVENTIONAL METHOD



SECTION OF TROUGH
BY INVENTED METHOD

Figure 4. Comparison of aqueduct trough by conventional method and integrated hydraulic design method.

gives the design dimensions for economical aqueduct trough.

RESULTS AND DISCUSSION

Table 2 presents output of the integrated hydraulic design approach. For various parameters mentioned, the trough hydraulics has been worked out utilizing TEL and HL criteria for the aqueduct under consideration.

Table 2 shows that the higher the fluming ratio, the higher the velocity in trough and hence the higher is the HL. As the fluming ratio decreases, the velocity in the trough decreases and hence the HL decreases and therefore, weight of moving water per meter length of aqueduct reduces. Hence, the designer will have to choose the optimum dimensions for trough considering the fulfillment of both the conditions as $0.9 < V2 < 2.5$ (that is, self cleansing and non-erodible) and $HL < 0.15$ (allowable as per canal cut-off; may vary from structure to structure). The non-fulfillment of either of these conditions will lead to rejection of the design parameters under consideration, as it either lowers the TEL on downstream of trough which will cause the loss in the irrigable command area on downstream side or it will make the trough structure uneconomical. Considering all the above constraints and conditions row number 11 of the programmed output in Table 2 provides the optimum dimensions of aqueduct trough. This can be stated as most feasible and economical design state. Table 3 presents a comparative statement of design when an aqueduct trough is designed by conventional method and by integrated design approach considering all the

Table 2. Integrated hydraulic design programmed output for aqueduct trough: Case study under consideration

S/N	b/B*100	% fluming to base width	Trough Width	Water way Area	Wetted perimeter	Hydrolic mean depth	Trough gradient	Trough gradient	Velocity in trough	Remark on Velocity	Head Loss at entrance of trough	Friction head Loss at trough	Head Loss at exit of trough	Total Head loss in aqueduct	Remark on HL	Weight of water/m	% weight of water reduced /m of trough
	x	%	b=x.B	A	P	R	1/S	S	V_2		h_{L1}	h_{L2}	h_{L3}	H_L		T	%
				sq.m	m	m			m/s		m	m	m	m		ton	
1	50	50	2.65	8.878	9.35	0.949	0.00442	226	3.57	Reject	0.123	0.287	0.185	0.596	Reject	8.88	74
2	55	45	2.92	9.765	9.615	1.016	0.00334	300	3.24	Reject	0.101	0.217	0.151	0.469	Reject	9.77	72
3	60	40	3.18	10.653	9.88	1.078	0.00259	386	2.97	Reject	0.084	0.168	0.126	0.378	Reject	10.65	69
4	65	35	3.45	11.541	10.145	1.138	0.00205	487	2.74	Reject	0.070	0.134	0.106	0.310	Reject	11.54	67
5	70	30	3.71	12.429	10.41	1.194	0.00166	602	2.55	Reject	0.060	0.108	0.090	0.258	Reject	12.43	64
6	75	25	3.98	13.316	10.675	1.247	0.00136	733	2.38	0.9<V2<2.5	0.051	0.089	0.077	0.217	Reject	13.32	62
7	80	20	4.24	14.204	10.94	1.298	0.00114	879	2.23	0.9<V2<2.5	0.044	0.074	0.066	0.185	Reject	14.20	59
8	82	18	4.35	14.559	11.046	1.318	0.00106	943	2.18	0.9<V2<2.5	0.042	0.069	0.063	0.174	Reject	14.56	58
9	84	16	4.45	14.914	11.152	1.337	0.00099	1009	2.12	0.9<V2<2.5	0.040	0.064	0.059	0.163	Reject	14.91	57
10	86	14	4.56	15.269	11.258	1.356	0.00093	1077	2.07	0.9 < V2<2.5	0.038	0.060	0.056	0.154	Reject	15.27	56
11	87	13	4.61	15.447	11.311	1.366	0.00090	1112	2.05	0.9<V2<2.5	0.037	0.058	0.055	0.150	HL < 0.15	15.45	55
12	88	12	4.66	15.624	11.364	1.375	0.00087	1148	2.03	0.9<V2<2.5	0.036	0.057	0.053	0.145	HL < 0.15	15.62	55
13	90	10	4.77	15.980	11.47	1.393	0.00082	1223	1.98	0.9<V2<2.5	0.034	0.053	0.051	0.137	HL < 0.15	15.98	54
14	91	9	4.82	16.157	11.523	1.402	0.00079	1261	1.96	0.9<V2<2.5	0.033	0.052	0.049	0.134	HL < 0.15	16.16	53
15	95	5	5.04	16.867	11.735	1.437	0.00070	1420	1.88	0.9<V2<2.5	0.030	0.046	0.044	0.120	HL < 0.15	16.87	51
16	100	0	5.30	17.755	12	1.480	0.00061	1636	1.78	0.9<V2<2.5	0.026	0.040	0.039	0.105	HL < 0.15	17.76	49

Canal parameters: Discharge (Q) = 31.67 cumecs; Canal bed width (B) = 5.3 m; Full supply depth (D) = 3.35 m; Canal velocity (V1) = 0.789 m/s; Lined/unlined = lined; Side slope H:V (N) = 1.5; Width at full supply level (T) = 15.35 m; Weight of water/Rmt (W) = 34.588 T/m. **Trough parameters:** Length (L) = 65 m; Allowable head loss (H_L) = 0.15 m; Permissible velocity (Vmin) = 0.9 m/s, (Vmx) = 2.5 m/s; Manings; Coefficient (n) = 0.018; No. of barrel (Nb) = 1 No; Rectangular/Trapaz = Rectangular.

Table 3. Comparison for aqueduct trough with conventional and integrated hydraulic design approach (on same canal for project under consideration)

Parameter	Unit	Trough with conventional method	Trough with method specified in this work	Remark
Discharge	Cum./s	31.67	31.67	Same
Full supply depth	m	3.35	3.35	Same
Free board	m	1.00	1.00	Same
Base width	m	3.30 - 2 No.	4.60	Less in B
Trough type	-	RCC Box	RCC Box	Same
Trough: inner size	m	3.00x4.35 twin	4.6x4.35	Less size in B
Trough : no of barrel	No	2	1	Economical
Water way area	Sq. m.	20.10	15.41	Reduced in B
Head loss allowed in aqueduct	m	0.15	0.15	Same

Table 3. Contd.

Actual head loss utilized	m	0.095	0.15	Full utilization of HL in B
Weight of moving water/m length	Tons/m	20.10	15.41	24% saving in B over A
Concrete quantity/m of length	Cu.m.	8.05	5.73	29% saving over conventional

constraints and utilization of TEL and HL as allowed in canal cut-off. It indicates that the integrated hydraulic design approach minimizes the water way area (15.41 tones/m) of moving water in aqueduct trough as compared to the moving water way area in the allied canal (20.41 tones/me), without disturbing the discharge and TEL of the moving water. This leads to minimization of mass of moving water per unit length of the aqueduct trough. Lesser the mass of moving water per unit length of aqueduct trough, lesser be the water load on aqueduct trough. As the water load decreases, the superstructure cost reduces, which results into the lesser cost in the substructure. The reduction in concrete quantity required for improved aqueduct structure as depicted in Table 3 reflects that 29% saving on concrete quantity per meter of length can be achieved in aqueduct structure designed by integrating various available theories, as compared to the conventional one. Thus the integrated hydraulic design of aqueduct leads to most cost effective and feasible aqueduct structure.

REFERENCES

Central Design Organisation (2004). Gate Circle; Government of Maharashtra; ‘Design Process Manual of Gates, Outlets, Canal Structures and Head Works.’

Indian Standard: IS 1893 (Part 1) (2002). ‘Criteria for Earthquake Resistant Design of Structures.

Indian Standard: IS 2912 (Part 2/Sec5) (1992).‘ Liquid Flow Measurement in Open Channels.

Indian Standard: IS 2951 (Part I) (2003). ‘Recommendation for Estimation of Flow of Liquids in Closed Conduits.’

Indian Standard: IS 3370 (Part 1) (2009). ‘Concrete Structures for Storage of Liquids-Code of Practice, General Requirement’.

Indian Standard: IS 4880 (Part VII) (2000). ‘Code of Practice for Design of Tunnels Conveying Water’.

Indian Standard: IS 7331; (2001). ‘Code of Practice for Inspection and Maintenance of Cross Drainage Works’.

Indian Standard: IS 7784 (Part 1) (1993). ‘Design of Cross Drainage Works – Code of Practice: Part-1 General Features’.

Indian Standard: IS 7784 (Part 2/Sec 1) (1995). ‘Design of Cross Drainage Works – Code of Practice: Part-2 Specific Requirements, Section 1: Aqueduct’.

Indian Standard: IS 7784 (Part 2/Sec5) (2000). ‘Design of Cross Drainage Works – Code of Practice: Part-2 Specific Requirements. Section 5: Syphon Aqueduct’.

Indian Standard: IS 800 (2007). ‘Code of Practice General Construction in Steel.

Larry WM (2006). ‘Water Resources Engineering’, John Wiley & Sons Pvt. Ltd, Singapore

Madan MD (2008). ’Open Channel Flow’, Prentice-Hall of India, New Delhi.

Modi PN (2008). ‘Irrigation Water Resources and Water Power Engineering’; Standard Book House, Delhi.

Public Works Departments’ Handbook: Chapter: 18 ‘Hydraulics’ (1983).

Punmia BC, Pande BBL, Ashok KJ, Arun KJ (2009). ‘Irrigation and Water Power Engineering.’ Laxmi Publications(P) Ltd, New Delhi.

Raina VK (1999). ‘Concrete Bridges Handbook’; Galgotia Pub. Pvt. Ltd, New Delhi.