COST ANALYSIS FOR BRIDGE AND CULVERT

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Abstract

A bridge is commonly constructed at the intersection of a road and either a canal or a drain. Alternatively, a culvert may be constructed at the same intersection, providing that the canal is not navigable. In this paper, a cost comparison between culvert and bridge is presented. Several factors are included in the comparison.

Design data are presented for both bridges and culverts. Computer program is designed and used to estimate the cost of each. Multiple regression analysis is performed to relate the dependent parameter, cost, to different factors. The concept of using reference bridge and reference culvert is introduced. Dimensionless relationships for both structures are presented and compared to show the limit at which the bridge is cheaper than the culvert and vice versa.

Introduction

When a road crosses a canal or drain, either a bridge or culvert may be a good solution. However, a civil engineer is always seeking for a decision; which one is more economic?. The decision is not an easy task. It depends on several criteria. For example, if the canal is navigable, bridge is a must and it is a unique decision. On the other hand, if the canal or the drain is small and is not navigable, a culvert is an easy structure. When the canal or drain gets bigger, the dimensions of culvert vent increases, thereby emphasizing the use of a bridge. In this situation, a comparison between a bridge and a culvert must be done from an economic point of view.

The factors affecting the choice are many. In case of bridge, the main factor is the height of bridge abutment (i.e. the difference between the road level and the bed level of canal or drain). Other factors are, the span of bridge and the road width. On the other hand, in case of culvert, the water area is the main factor in determining the clear dimensions of culvert vent (i.e. the clear span and clear height of vent). Also, the number of vents is of great importance. Still the difference between the road level and bed level is a secondary factor responsible for increasing the weight of fill above the culvert and thereby affecting the thickness of culvert wall.

Bearing capacity of soil is another main factor. Soil investigation shows that culvert is preferred when the bearing capacity of soil is low. It is well known that stress distributions under culvert are almost, differently from bridge case, where the stress distribution under the abutment is not uniform.

Yassin (1988) presented a procedure for the economic sizing of box culverts. He formulated a set of 13 accurate dimensionless equations for the estimation of the cost of 13 different box culvert sizes ranging from 1.0 m*1.0 m and up to 3.0 m *3.0 m. Relationships presented were able to deal with culverts of not only one vent but also several vents. However, the cost of wing walls was not included. The paper was concentrating on culvert as a highway drainage structure. Bridge was not included in the paper.

The paper presented herein, concentrates on the cost comparison of both culvert and bridge, providing that both are convenient. Considering few assumptions, the results allow for the designer engineer to decide which one is more economic, the culvert or the bridge.

Components of Bridge and Culvert

For bridge, the components are the superstructure (slab, cross girders, main girders), substructure (i.e. abutment), wing walls (type, length and thickness). On the other hand, for culvert, the components are the clear dimensions of box culvert vent, l, h, number of vents, thickness of wall culvert, and wing walls (type, length and thickness). Hence, the bridge factors are:

1- H = height between road level and bed level of canal or drain
2- S = bridge span and W = bridge width
3- Soil bearing capacity at site
4- Length of wing walls and their type.

Meanwhile, the culvert factors are:

1- H = height between road level and bed level of canal or drain
2- Clear dimension of culvert vent, l is the width and h is the height
3- W = road width
4- Length of wing walls and their type

Assumptions

For the present paper, the following assumptions are considered:

1- The wing walls are of box type for both bridge and culvert.
2- The bearing capacity of soil is: $\sigma = 1.0$ kg/cm^2.
3- For culvert, only one vent is considered.
4- The live load considered in design of bridge is 60 ton lorry and a surcharge of 600kg/m^2 is considered in the design of different components of both structures
6- The data of soil properties are: $\gamma_{soil} = 1.8$ t/m^3 and $\phi = 30^o$
7- The compressive strength of reinforced concrete is, $f_{cu} = 325$ Kg/cm^2 and the strength of high tensile steel is; $f_s = 1600$ Kg/cm^2. The Quantity of Portland cement is 400 Kg/m^3.
8- The price list for different components of bridge and culvert according to market price of 2003 is given in Table (1).

Table (1) The price list for different components of bridge and culvert according to market price of 2003

bridge		culvert	
component	price	component	price
RC superstructure	620 LE/m^3		
RC walls	480 LE/m^3	RC walls	480 LE/m^3
RC floor	380 LE/m^3	RC floor	380 LE/m^3
PC floor	185 LE/m^3	PC floor	185 LE/m^3

General Layouts of Bridge and Culvert

The general Layouts of both bridge and culvert are shown in Fig. 1 and 2, respectively.

Computer Program

A computer program is designed to perform several procedures for the design of different components of the bridge. The output of the program gives:

1- Straining actions
2- Stress distribution
3- Stability calculation against sliding and overturning
4- Complete structural design for different components
5- Cost of bridge

Another computer program is designed to perform several procedures for the design of different components of the culvert. The output of the program gives:

1. Straining actions
2. Stress distribution
3. Complete structural design for different components
4. Cost of culvert

For bridges, several values of H, the difference between the road level and bed levels, are considered. These values are, H = 4, 4.5, 5, 5.5, 6, 6.5 m. For each value of H, all bridge components are estimated and consequently, the cost is determined based on the price list shown in Table (1). Also, different road widths, W = 6, 8, 10 m, and different span values, S = 6, 8, 10 m, are considered.

On the other hand for culverts, same height values; H = 4, 4.5, 5, 5.5, 6, 6.5 m and same road widths, W = 6, 8, 10 m are considered. Moreover, several dimensions of span, l, and height, h, of clear vent; (l=3, h =3,) & (l=2, h=3) & (l=3, h=2,) & (l=2, h=2) are used.

Estimated Cost of Bridges and Culverts

Characteristics of bridges and culverts as well as their estimated costs are summarized in Table (2). Costs of 54 different bridges and costs of 72 different culverts are tabulated.

Table (2) Estimated cost of bridges and culvers

Bridge characteristics					Culvert characteristics					
series	W	S	H	Cost*1000	series	W	H	l	h	Cost*1000
	m	m	m	L.E.		m	m	m	m	L.E.
1	6	10	6.5	261.15	1	6	6.5	2	2.00	107.07
2	8	10	6.5	296.79	2	6	6	2	2.00	104.68
3	10	10	6.5	331.80	3	6	5.5	2	2.00	102.38
4	6	8	6.5	246.71	4	6	5	2	2.00	100.15
5	8	8	6.5	275.87	5	6	4.5	2	2.00	98.00
6	10	8	6.5	304.50	6	6	4	2	2.00	95.90
7	6	6	6.5	221.52	7	8	6.5	2	2.00	110.91
8	8	6	6.5	244.28	8	8	6	2	2.00	108.53
9	10	6	6.5	266.81	9	8	5.5	2	2.00	106.22
10	6.00	10.00	6.00	233.56	10	8	5	2	2.00	104.00
11	8.00	10.00	6.00	267.09	11	8	4.5	2	2.00	101.84
12	10	10	6	300.29	12	8	4	2	2.00	99.74
13	6	8	6	221.78	13	10	6.5	2	2.00	114.75
14	8.00	8.00	6.00	249.04	14	10	6	2	2.00	112.37
15	10.00	8.00	6.00	276.14	15	10	5.5	2	2.00	110.07
16	6	6	6	199.76	16	10	5	2	2.00	107.84
17	8	6	6	221.05	17	10	4.5	2	2.00	105.68
18	10	6	6	242.33	18	10	4	2	2.00	103.58
19	6	10	5.5	204.96	19	6	6.5	2	3.00	125.65
20	8	10	5.5	236.53	20	6	6	2	3.00	121.94
21	10	10	5.5	267.92	21	6	5.5	2	3.00	118.30
22	6	8	5.5	195.93	22	6	5	2	3.00	114.74
23	8	8	5.5	221.50	23	6	4.5	2	3.00	111.24
24	10	8	5.5	247.08	24	6	4	2	3.00	107.79
25	6	6	5.5	177.20	25	8	6.5	2	3.00	132.34
26	8	6	5.5	197.24	26	8	6	2	3.00	128.62
27	10	6	5.5	217.28	27	8	5.5	2	3.00	124.99
28	6	10	5	178.25	28	8	5	2	3.00	121.42
29	8	10	5	205.05	29	8	4.5	2	3.00	117.92
30	10	10	5	233.72	30	8	4	2	3.00	114.47
31	6	8	5	168.99	31	10	6.5	2	3.00	139.02
32	8	8	5	192.38	32	10	6	2	3.00	135.31
33	10	8	5	215.76	33	10	5.5	2	3.00	131.67

34	6	6	5	153.86	34	10	5	2	3.00	128.11
35	8	6	5	172.10	35	10	4.5	2	3.00	124.61
36	10	6	5	190.34	36	10	4	2	3.00	121.16
37	6	10	4.5	137.23	37	6	6.5	3	3.00	128.37
38	8	10	4.5	161.32	38	6	6	3	3.00	124.17
39	10	10	4.5	185.42	39	6	5.5	3	3.00	120.06
40	6	8	4.5	124.55	40	6	5	3	3.00	116.01
41	8	8	4.5	143.13	41	6	4.5	3	3.00	112.03
42	10	8	4.5	161.72	42	6	4	3	3.00	108.10
43	6	6	4.5	114.77	43	8	6.5	3	3.00	136.01
44	8	6	4.5	129.38	44	8	6	3	3.00	131.82
45	10	6	4.5	144.00	45	8	5.5	3	3.00	127.70
46	6	10	4	104.19	46	8	5	3	3.00	123.66
47	8	10	4	123.74	47	8	4.5	3	3.00	119.68
48	10	10	4	143.29	48	8	4	3	3.00	115.75
49	6	8	4	99.43	49	10	6.5	3	3.00	143.66
50	8	8	4	115.33	50	10	6	3	3.00	139.46
51	10	8	4	131.23	51	10	5.5	3	3.00	135.35
52	6	6	4	94.95	52	10	5	3	3.00	131.30
53	8	6	4	107.83	53	10	4.5	3	3.00	127.32
54	10	6	4	120.70	54	10	4	3	3.00	123.39
					55	6	6.5	3	2.00	122.09
					56	6	6	3	2.00	118.38
					57	6	5.5	3	2.00	114.75
					58	6	5	3	2.00	111.20
					59	6	4.5	3	2.00	107.71
W = road width					60	6	4	3	2.00	104.28
					61	8	6.5	3	2.00	128.59
S = span of bridge					62	8	6	3	2.00	124.88
					63	8	5.5	3	2.00	121.25
H = road level - bed level					64	8	5	3	2.00	117.70
					65	8	4.5	3	2.00	114.21
l = width of culvert internal vent					66	8	4	3	2.00	110.78
h = height of culvert internal height					67	10	6.5	3	2.00	135.09
					68	10	6	3	2.00	131.38
					69	10	5.5	3	2.00	127.75
					70	10	5	3	2.00	124.20
					71	10	4.5	3	2.00	120.71
					72	10	4	3	2.00	117.28

When the characteristics of bridges and their costs are analyzed, the bridge cost is considered as a dependent parameter, while the three independent parameters are W, S, and H. However, when the characteristics of culverts and their costs are analyzed, the culvert cost is also considered as a dependent parameter, while the four independent parameters are W, H, l and h.

For purpose of presenting nondimensional relationships, a concept of reference bridge as well as reference culvert is introduced. Both the reference bridge and the reference culvert are selected from Table (2) so that their costs are identical.

The reference bridge is defined herein, as the bridge of the following characteristics:

Road width, $W_{ref)b}$ = 6.0 m,
Span vent, $S_{ref)b}$ = 6.0 m,
Height of road level above bed, $H_{ref)b}$ = 4.0 m
and the bridge cost, $cost_{ref)b} = 94.95*10^3$ LE

The reference culvert is also defined as the culvert of the following characteristics:

Road width, $W_{ref)c}$ = 6.0 m,
Height of road level above bed, $H_{ref)c}$ = 4.0 m,
Width of clear vent, $l_{ref)c}$ = 2.0 m
Height of clear vent, $h_{ref)c}$ = 2.0 m
and the culvert cost, $cost_{ref)c} = 95.9*10^3$ LE

Nondimensional Relationships for the Cost Ratios of Bridges and Culvert

The characteristics of bridge and their cost are redefined relative to the characteristics of the reference bridge as following:

$W_{r)b} = W_b/W_{ref)b}$.
$S_{r)b} = S_b/S_{ref)b}$,
$H_{r)b} = H_b/H_{ref)b}$
$cost_{r)b} = cost_b/cost_{ref)b}$.

To relate the dependent parameter, $cost_{r)b}$, to the independent parameters; $W_{r)b}$, $S_{r)b}$, and $H_{r)b}$, a multiple regression analysis is performed. The following equation represents nondimensional form of the bridge cost ratio:

$$Y = a(X1)^b (X2)^c (X3)^d \quad (1)$$

Results of regression analysis give the coefficient values shown in Table (3)

Table (3) Coefficient values of the bridge cost ratio, equation (1)

Dependent parameter	Independent parameters		
Y	X1	X2	X3
$Cost_{r)b}$	$W_{r)b}$	$S_{r)b}$	$H_{r)b}$
coefficients			
a	b	c	d
1.0	0.4725	0.35457	1.79314

Therefore, equation (1) can be written in the following form:

$$Cost_{r)b} = 1.0\ [W_{r)b}]^{0.4725}\ [S_{r)b}]^{0.35457}\ [H_{r)b}]^{1.79314} \qquad (2)$$

Equation (2) represents a nondimensional form can be applied to estimate the cost ratio of an existing bridge relative to that of the reference bridge.

Meanwhile, the characteristics of culvert and their cost are redefined relative to the characteristics of the reference culvert as following:

$W_{r)c} = W_c/W_{ref)c}$,
$H_{r)c} = H_c/H_{ref}$,
$l_{r)c} = l_c/l_{ref)c}$,
$h_{r)c} = h_c/h_{ref)c}$
$cost_{r)c} = cost_c/cost_{ref)c}$.

To relate the dependent parameter, $cost_{r)c}$, to the independent parameters; $W_{r)c}$, $S_{r)c}$, and $H_{r)c}$, a multiple regression analysis is performed. The following equation represents nondimensional form of the culvert cost ratio:

$$Y = a(X1)^b\ (X2)^c\ (X3)^d\ (X4)^e \qquad (3)$$

Results of regression analysis give the coefficient values shown in Table (4)

Table (4) Coefficient values of the culvert cost ratio, equation (3)

Dependent parameter	Independent parameters			
Y	X1	X2	X3	X4
$Cost_{r)c}$	$W_{r)c}$	$H_{r)c}$	$l_{r)c}$	$h_{r)c}$
coefficients				
a	B	c	d	e
0.99	0.20138	0.2893	0.1802	0.256

Therefore, equation (3) can be written in the form:

$$Cost_{r)c} = 0.99\ [W_{r)c}]^{0.20138}\ [H_{r)c}]^{0.2893}\ [l_{r)c}]^{0.1802} [h_{r)c}]^{0.256} \qquad (4)$$

Equation (4) represents a nondimensional form can be applied to estimate the cost ratio of an existing culvert relative to that of the reference culvert.

Equation (2) and equation (4) are presented graphically in Figure (3). To focus on a narrow range of data, Figure (4) is presented.

The effect of H_r on the cost ratio, $cost_r$, for both bridge and culvert is shown Fig. 4. For bridge, the rate of change is steeper than that for culvert. The trend is logic where increasing H for bridge, leads to increase height and thickness of not only abutment but also wing walls. For culvert, H is just a fill height above culvert. The result of regression analysis shows that for bridge, the power, m, of H_r is 1.79314 while it is 0.28934 in case of culvert.

The effect of span of bridge, S, on the “bridge to culvert cost ratio” is shown in Fig. 5 The change in span from 6 m to 10 m leads to a change of ratio from 1.0 to 1.2, from 1.65 to 2.0 and from 2 to 2.4 for three sets of data as shown in Fig. 5

On the other hand, the effect of road width, W is shown in Fig. 6. The “bridge to culvert cost ratio” changes from 1.0 at W =6 m to 1.15 at W =10m. The trend is opposite when the bridge to culvert ratio is related to the change of clear vent dimension of culvert. For dimensions, l*s = 2*2 m, the bridge to culvert ratio is 1.0, while it becomes 0.9 and 0.82 for culvert dimensions, l*s = 2.5*2.5 m, l*s = 3*3 m, respectively. The trend means that the two culverts are more expensive than the corresponding bridges.

Dividing equation (2) by equation (4) gives the following equation:

$$\frac{Cost_{r)b}}{Cost_{r)c}} = \frac{[W_{r)b}]^{0.4725}}{[W_{r)c}]^{0.20138}} * \frac{[H_{r)b}]^{1.79314}}{[H_{r)c}]^{0.2893}} * \frac{[S_{r)b}]^{0.35457}}{[l_{r)c}]^{0.1802}} * \frac{1}{\underset{6}{[h_{r)c}]}^{0.25}} \qquad (5)$$

As mentioned before, the costs of both reference bridge and reference culvert are the same. Therefore:

$$\frac{Cost_{r)b}}{Cost_{r)c}} = \frac{Cost_b}{Cost_c} \qquad (6)$$

This means that:

$$\frac{Cost_b}{Cost_c} = \frac{[W_{r)b}]^{0.4725}}{[W_{r)c}]^{0.20138}} * \frac{[H_{r)b}]^{1.79314}}{[H_{r)c}]^{0.2893}} * \frac{[S_{r)b}]^{0.35457}}{[l_{r)c}]^{0.1802}} * \frac{1}{[h_{r)c}]^{0.256}} \qquad (7)$$

For the same width, W, and same height, H, in both bridge and culvert, equation (7) may take the following form:

$$Cost_b/(Cost_c=0.055(W)^{0.27112}(H)^{1.50384}(S_b)^{0.35457}(l_c)^{-0.1802}(h_c)^{-0.256} \qquad (8)$$

<u>Example 1</u>

At certain location, a bridge has the following characteristics:

road width, W=10 m, span, S =10 m, road height above bed , H =6 m.

Estimate the cost of construction?.

The first step is to estimate the relative values:
$W_{r)b}$=10/6=1.6667, $S_{r)b}$=10/6=1.6667, $H_{r)b}$=6/4=1.5
Applying equation (2), to estimate the relative cost of bridge
$Cost_{r)b} = 1.0\ [1.6667]^{0.4725}\ [1.6667]^{0.35457}\ [1.5]^{1.79314} = 3.157$
This value means that the existing bridge costs 3.157 times that of the reference bridge. It is known that, $cost_{r)b} = cost_b/cost_{ref)b}$
but the reference bridge cost, $cost_{ref)b} = 95*10^3$ LE
then, the bridge cost is $cost_b = 3.157*95*10^3$ LE $= 300*10^3$ LE

Example 2:

The above data of bridge given in Example 1 is to be compared with a culvert of the following characteristics:
road width, W=10 m, road height, H =6 m,
width of internal vent, l =3, height of internal vent, h=3 m,
Estimate the "bridge to culvert cost ratio".
In example 1, the cost of bridge is estimated. The same procedures can be repeated to estimate the cost of culvert as following;
$W_{r)c}$ =1.667, $H_{r)c}$ =1.5, $l_{r)c}$=3/2=1.5, $h_{r)c}$=3/2=1.5.
Then equation (4) can be applied to estimate $cost_{r)c}$
$Cost_{r)c} = 0.99\ [1.6667]^{0.20138}\ [1.5]^{0.2893}\ [1.5]^{0.1802}[1.5]^{0.256} = 1.487$
This means that the culvert of the mentioned characteristics costs 1.487 times that of reference culvert. It is known that, $cost_{r)c} = cost_c/cost_{ref)c}$ but $cost_{ref)c} = 95*10^3$ LE
then, the culvert cost is $cost_c = 1.487*95*10^3$LE $= 141.3*10^3$ LE
Now the bridge to culvert cost ratio can be estimated:
$Cost_b/cost_c = 300*10^3 / 141.3*10^3 = 2.123$
This means that the cost of the mentioned bridge is 2.123 times that of the mentioned culvert. The result can be alternatively, obtained by using equation (8) as following:
$Cost_b/(Cost_c=0.055(W)^{0.27112}(H)^{1.50384}(S_b)^{0.35457}(l_c)^{-0.1802}(h_c)^{-0.256}$
In this equation the road width and road height of bridge are equal to their corresponding values of culvert. Their values are 10 m, 6 m, respectively. While the other two values l_c , h_c in the last equation are those of culvert. All values in this equation must be absolute not relative.
$Cost_b/(Cost_c=0.055(10)^{0.27112}(6)^{1.50384}(10)^{0.35457}(3)^{-0.1802}(3)^{-0.256} = 2.128$
Almost the same value is obtained.

Conclusion

Estimated costs of 54 bridges and 72 culverts are presented in this paper. Multiple regression analysis is performed. A nondimensional relationship, equation (2), is presented to estimate the bridge cost ratio. However, another nondimensional relationship, equation (4), can be applied to estimate the culvert cost ratio. Equation (8) can be applied to estimate the "bridge to culvert cost ratio". If the ratio is less than one, the bridge is cheaper. However, if the ratio is greater than one, the culvert is cheaper. Two examples are presented to explain the procedures of estimating the cost t of either a bridge or a culvert.

It is shown that the culvert maximum cost ratio is almost 1.5, while for bridge, the values of cost ratio lie between 1.5 and 3.5. Curves, also show that for H_r <1.2 or H< 4.8 m, it is difficult to decide which is one cheaper, bridge or culvert. On the other hand for H_r >1.2 or H> 4.8 m, curves and relationships, show that the culvert is cheaper than the bridge.

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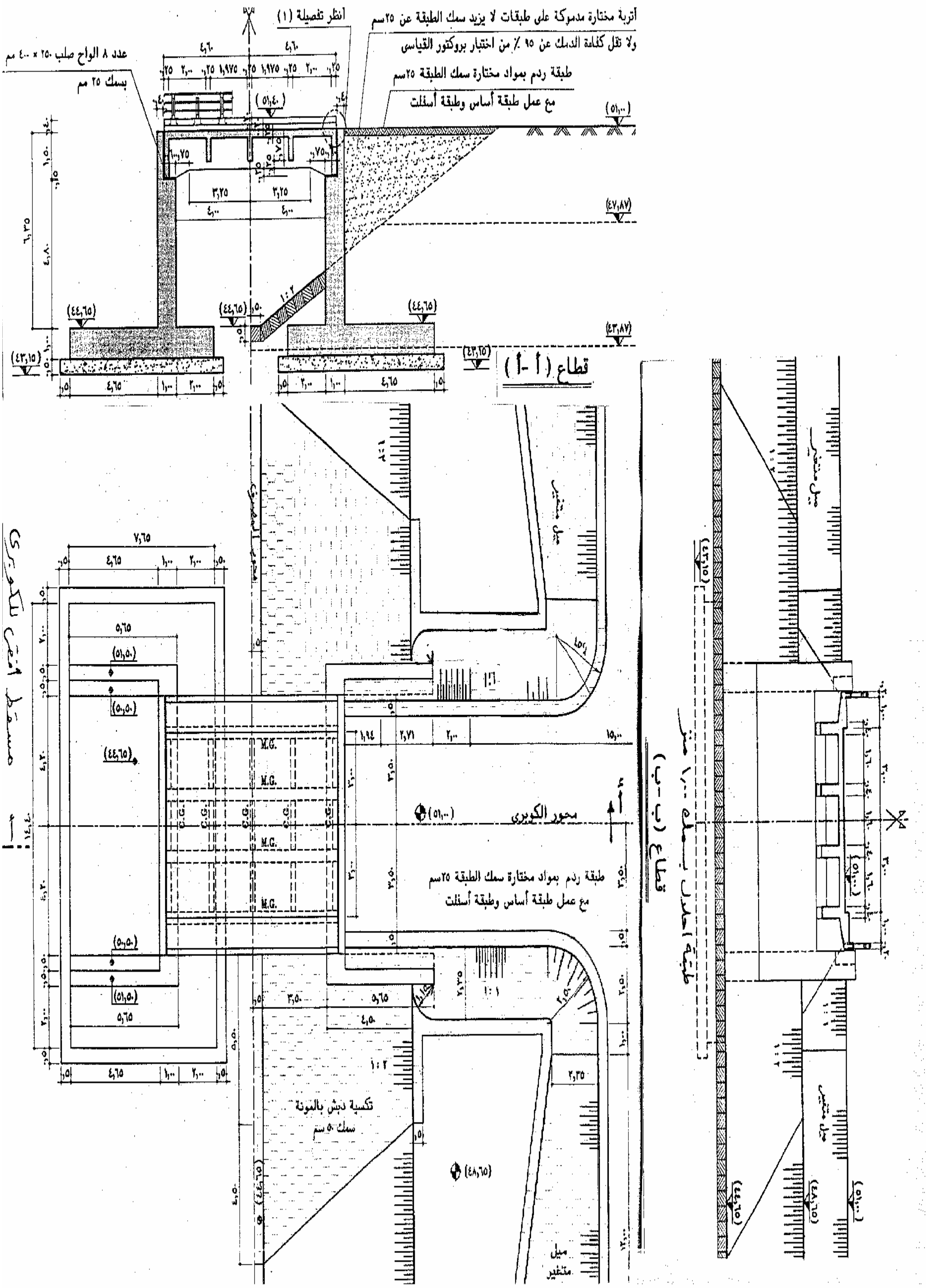

Fig. 1 plan and elevation of bridge

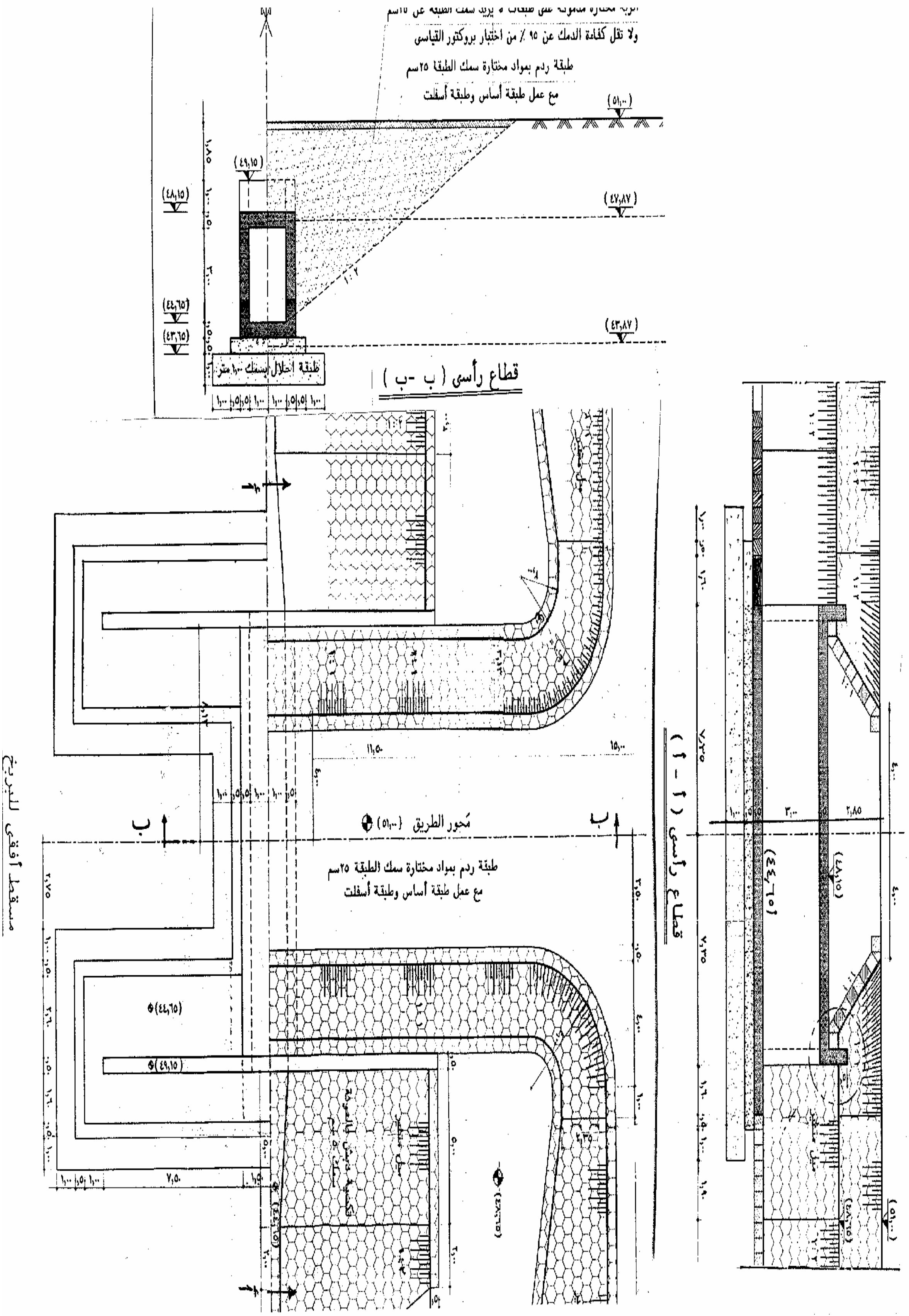

Fig. 2 plan and elevation of bridge

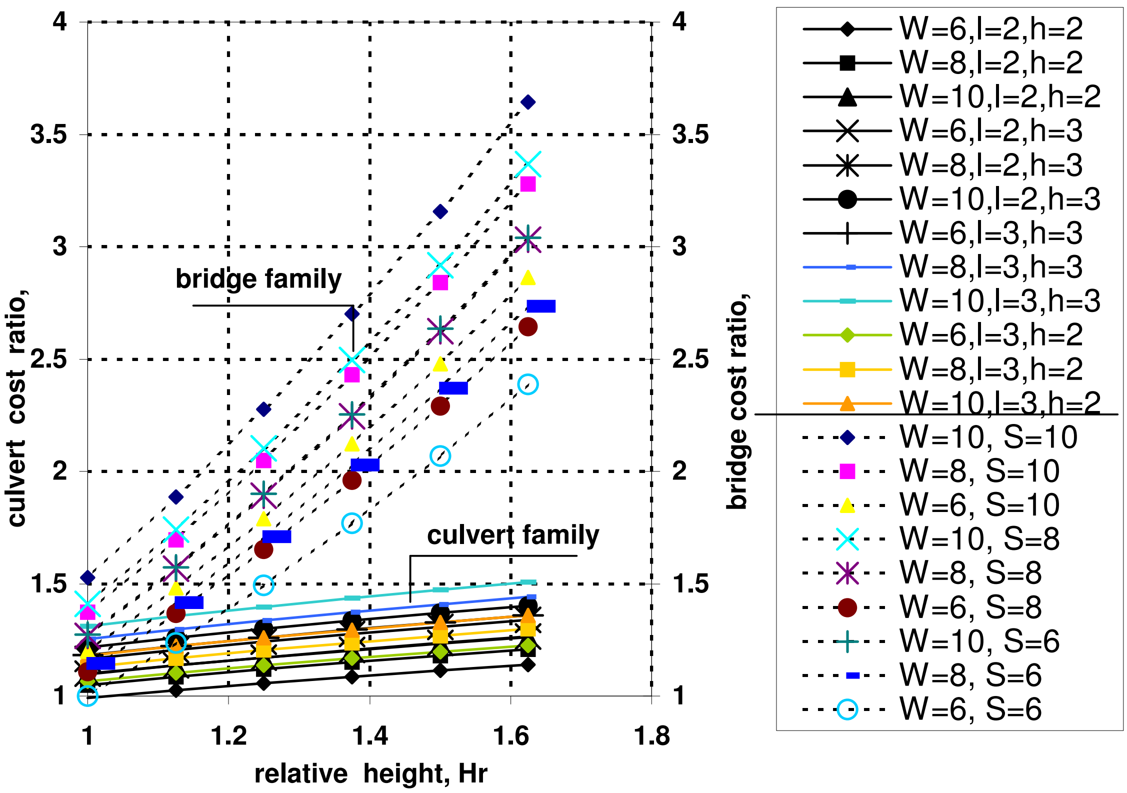

Fig. 3 Graphical representation of Eq. 2 and Eq. 4

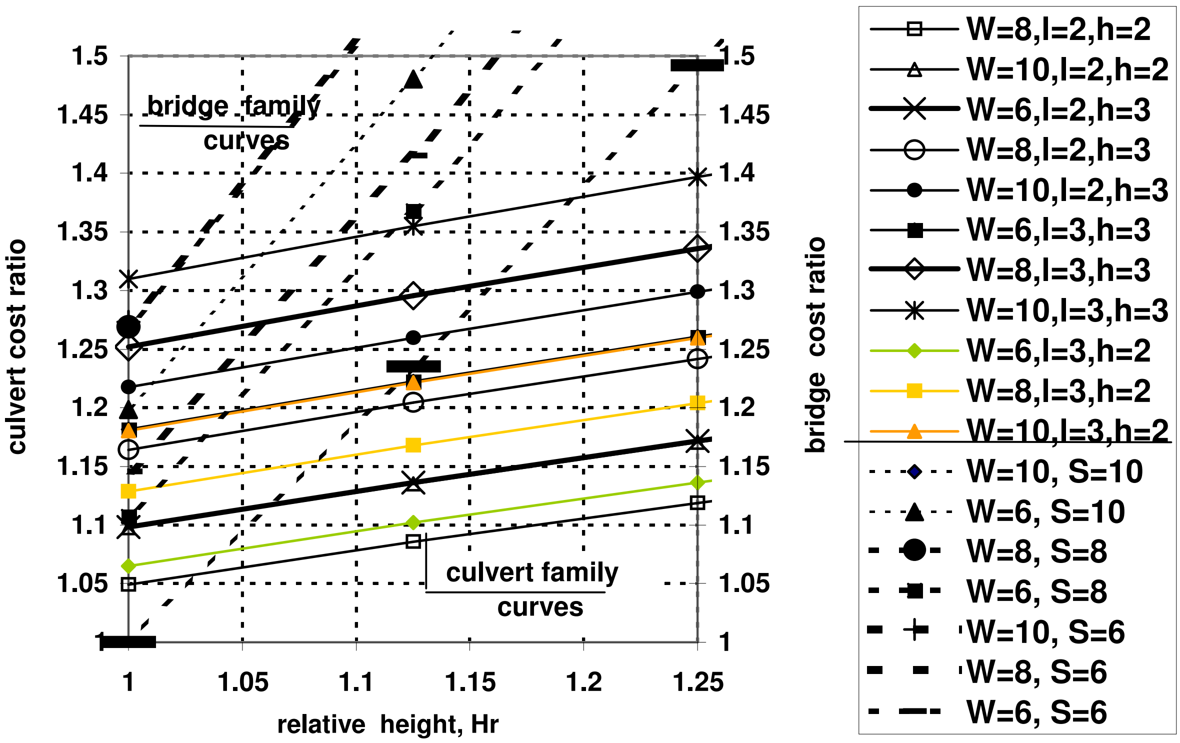

Fig. 4

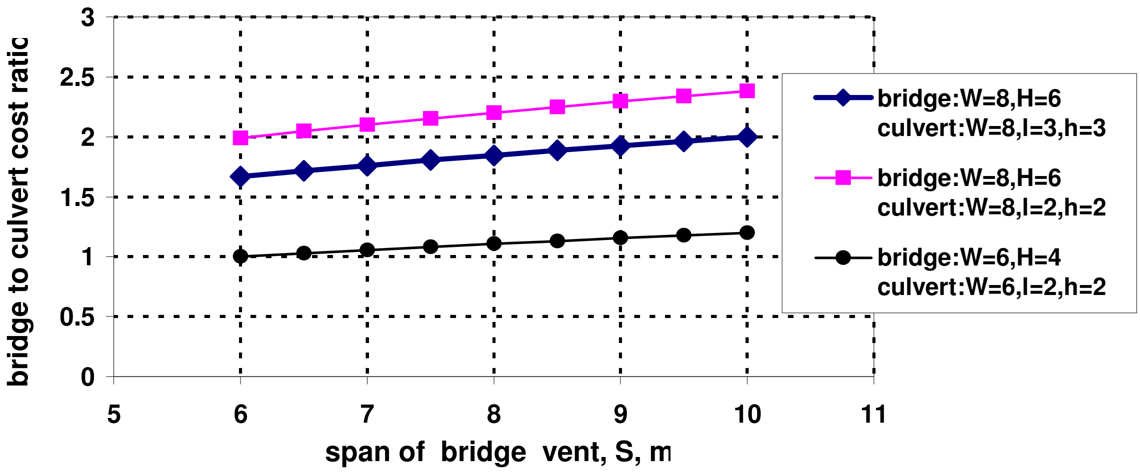

Fig. 5

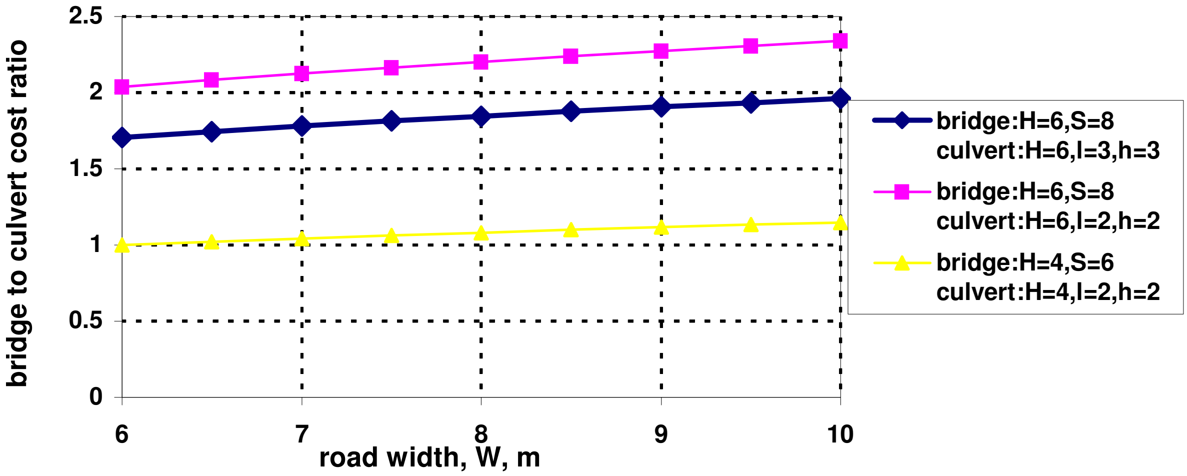

Fig. 6

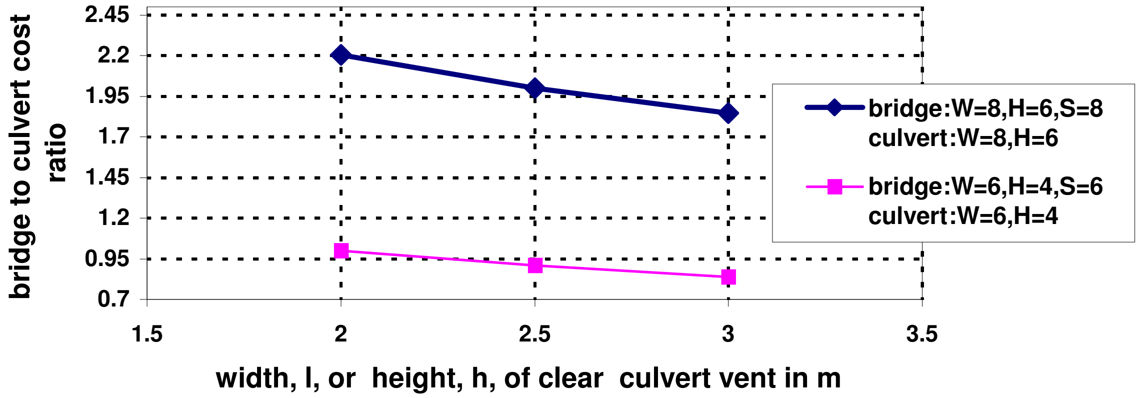

Fig. 7