Analysis and Design of Box Culvert: A Manual Approach

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Abstract— *Box culverts are the monolithic structure made to pass across a roadway, railway lines etc. Embankments are used to balance the flood water on both sides. Box takes various types of loads generated by water, traffic, cushion, soil etc. This work deals with complete design of box culvert manually and study the design parameters such as effect of earth pressure, depth of cushion at the top slab of culvert, factor such as braking force, Impact load, Live load, Dispersal of load through tracked or wheeled vehicle, effective width etc. In this work, study of culvert with and without cushion analyzed for different classes of IRC loadings and conclusions made on the basis of bending moments and shear forces with and without cushioning cases. This paper provides full discussion of provisions provided by Indian Standards, their justifications and considerations are taken into the account for design purpose.*

Keywords— Box culvert, Cushioning, Loading class, Moment calculations, Percent reinforcement, Pressure cases, Side walls, Top slab.

I. INTRODUCTION

Box culverts are low rise bridge or structure which is used to discharge water in the proper channel in crossing of railway, flyover, roads etc. and is used where the bearing capacity of soil is low. Culverts are always economical than bridge where the discharge in the opening is 18 m2 it depends on the number of cells which is generally used where roadway crosses the high embankment. Box culverts are generally cast in situ in India, but in other countries the box culverts are preferred due to low cost and economically with having fast workmanship. The box is just name given for its shape, can be found in various types of shapes and also it can be act as minor bridge when the number of cells increases and span greater than 6m in length. Its height depends on span. It can control all water coming from irrigation, surface water, river and canals they control all the storm water and flood water during rainy season.

Box culverts which have four corners are monolithically jointed. In other cases the box will be of three sides means which has bottom slab (Raft) and vertical walls. Top slab needed to be made otherwise precast slab also available in market we cannot joint it monolithically. Cushioning is very important in every box culvert which decided by road profile and bearing capacity of soil available at site.

II. TYPES OF BOX CULVERTS

1) **According to the Classification by Materials**
   - 1.1) Concrete
   - 1.2) Steel
   - 1.3) Aluminum
   - 1.4) Plastic
   - 1.5) High density Polyethylene
   - 1.6) Timber
2) **According to the Classification by Shape**
   - 2.1) Box culvert
   - 2.2) Pipe culvert
   - 2.3) Pipe arch culvert
   - 2.4) Bridge culvert
   - 2.5) Arch culvert
3) **According to the Classification by Loading as per IRC**
   - 3.1) IRC-CLASS-70 R
   - 3.2) IRC-CLASS-A
   - 3.3) IRC-CLASS-B

3.1) IRC-CLASS-70 R: - It is a loading which used by the municipality which includes industrial areas along with major highways, bridges culverts etc. For military heavy loads vehicles, the bridge, culverts designed for Class-A and also for Class-B. It should be checked for Class-A loading because there will be heavy stresses created under Class-A loadings. As per IRC 6, the value for Class 70 R provided is 350 KN for tracked vehicle.
3.2) IRC-CLASS-A: - This loading is preferred on each and every roads on which permanent structures are made

such as bridges, culverts etc. As per IRC 6, the value for Class A provided is 114 KN for wheeled vehicle.

3.3) IRC-CLASS-B: - This loading is preferred on each and every road on which temporary structures are made and for bridges the different materials are used respect to situations. As per IRC 6, the value for Class B provided is 68 KN for wheeled vehicle.

III. CASES TO BE SOLVED & PARAMETERS USED

For this work, total six cases are taken for analysis and design. For that each case is numbered as Case A, Case B, etc. Description for Without Cushion and With Cushion cases are mentioned in table 1.

Table.1:- Types of cases used with description as per loading class

Cushion Type	Cases	Description
Without Cushion	CASE A	350 KN of Tracked vehicle using Class-70(R)
	CASE B	114 KN of Wheeled vehicle is using Class-A
	CASE C	68 KN of Wheeled vehicle is using Class-B
With Cushion	CASE D	350 KN of Tracked vehicle using Class-70(R)
	CASE E	114 KN of Wheeled vehicle is using Class-A
	CASE F	68 KN of Wheeled vehicle is using Class-B

For this work, parametric values taken for analysis and designing of box culvert. Description for both Without Cushion and With Cushion cases are mentioned in table 2.

Table.2:- Parameters used for designing

Parameters	Values
Clear span	3m
Clear height	3m
Top slab thickness	0.3m
Bottom slab thickness	0.35m
Side wall thickness	0.35m
Unit weight of concrete	25 KN/m^3
Unit weight of earth	18kN/m^3
Unit weight of water	10kN/m^3
Coefficient of earth pressure at rest	0.5
Types of cushioning	With/Without
Thickness of wearing coat	0.070m
Carriageway	8 lane divided
Concrete grade	M 25
Steel grade	Fe 500
Esc(concrete)	8.33Mpa
Esc(steel)	200 Mpa
Cushion depth	3.5m
Modular ratio	10
n (for depth of neutral axis)	0.294
j (for effective depth)	0.902
k (for moment of resistance)	1.105

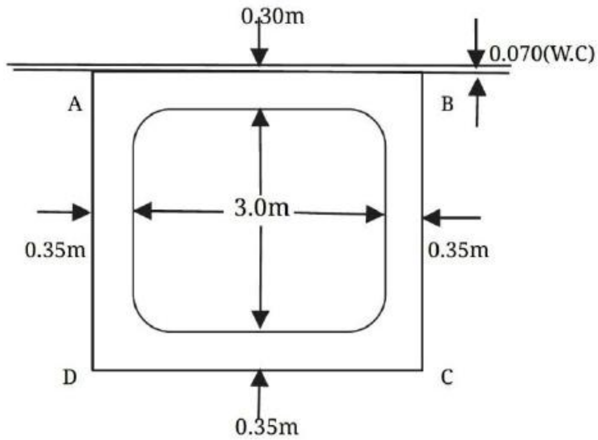

Fig.1: Box culvert without cushion

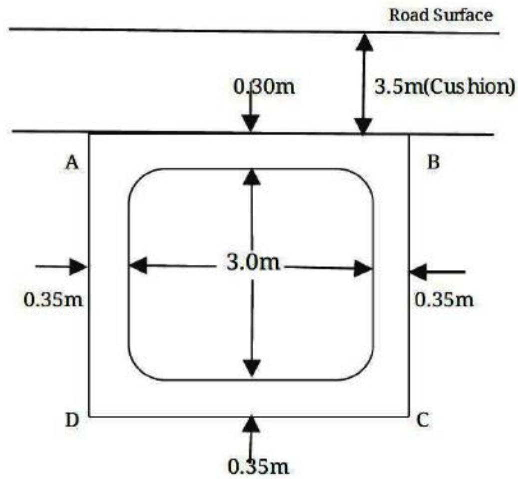

Fig.2: Box culvert with cushion

IV. METHODOLOGY AND PROBLEM SOLVING APPROACH STEPS

1) Design steps without cushion:-

1.1) Silent Features
1.2) Load Calculations
    1.2.1) Top slab
    1.2.2) Bottom slab
    1.2.3) Total load
1.3) Moment Calculations
    1.3.1) Top Slab
    1.3.2) Bottom Slab
    1.3.3) Side Walls
1.4) Distribution Factors

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1.5) Moment Distribution
- 1.5.1) Fixed end moment due to dead load
- 1.5.2) Fixed end moment due to live load
- 1.5.3) Fixed end moment due to total load

1.6) Braking Force
- 1.6.1) Load: 70 R (T)
- 1.6.2) Moment due to Braking Force

1.7) Design of Section
- 1.7.1) Top Slab
- 1.7.2) Bottom slab
- 1.7.3) Side Walls

2) Design steps with cushion:-

2.1) Silent Features

2.2) Load Calculations
- 2.2.1) Top slab
- 2.2.2) Bottom slab
- 2.2.3) Total load

2.3) Moment Calculations
- 2.3.1) Top Slab
- 2.3.2) Bottom Slab
- 2.3.3) Side Walls

2.4) Distribution Factors

2.5) Moment Distribution
- 2.5.1) Fixed end moment due to dead load
- 2.5.2) Fixed end moment due to live load
- 2.5.3) Fixed end moment due to total load

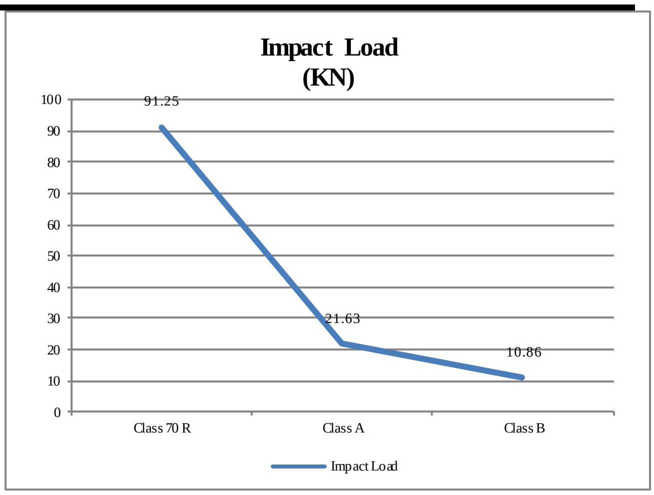
2.6) Design of Section
- 2.6.1) Top Slab
- 2.6.2) Bottom slab
- 2.6.3) Side Walls

V. RESULT AND DISCUSSIONS

1) Impact load

Table 3:- Values of Impact Loads

Non Cushion	Class 70-(R) Loading	Class A Loading	Class B Loading
	91.25kN	21.63kN	10.86kN

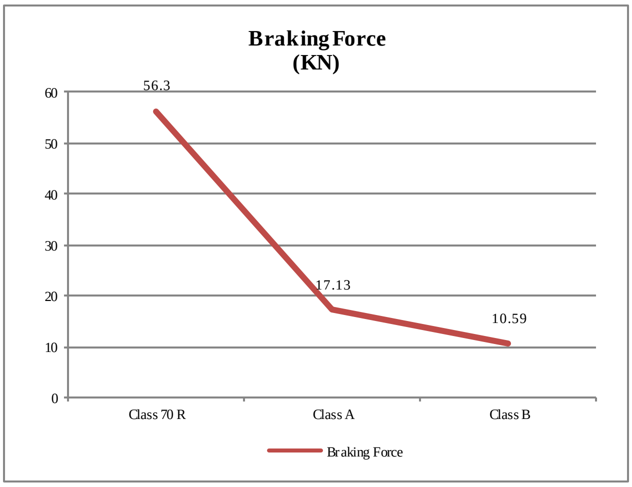


Graph 1:- Graphical representation of values of Impact Load

2) Braking force

Table 4:-Values of Braking Forces

Non Cushion	Class 70-(R) Loading	Class A Loading	Class B Loading
	54.52kN	17.13kN	10.59kN



Graph 2:- Graphical representation of values of Braking Forces

3) Bending moment of structure

Without-Cushioning:

Table 5:-Values of Bending Moments (Without-Cushion)

Item	Location	Members	Classes 70-(R)	A	B
Bending Moments (kN.m)	Support	M_{AB},M_{BA},M_{AD},M_{DC}	103.74	41.04	29.69
		M_{DC},M_{CD},M_{DA},M_{CB}	70.94	43.26	38.58
	Mid	M_{AB},M_{B}	85.54	25.9	16.91

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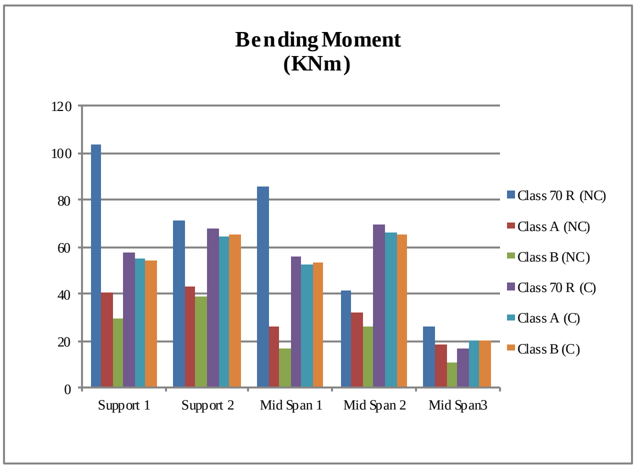
	Span	A		2	
		M_{DC},M_{CD}	41.75	32.21	26.38
		M_{AD},M_{DA}	26.12	18.26	10.54

With Cushioning:

Table 6:-Values of Bending Moments (With-Cushion)

Item	**Location**	**Members**	**Classes**		
			70-(R)	**A**	**B**
Bending Moments (kN.m)	**Support**	M_{AB},M_{BA},M_{AD},M_{DC}	57.67	55.03	54.56
		M_{DC},M_{CD},M_{DA},M_{CB}	67.54	64.63	65.22
	Mid Span	M_{AB},M_{BA}	56.15	52.78	53.50
		M_{DC},M_{CD}	69.43	66.40	64.90
		M_{AD},M_{DA}	17.23	20.01	19.95



Graph 3:- Graphical representation of values of Bending Moments (Without and With Cushion)

4) Shear force of structure

Without Cushioning:

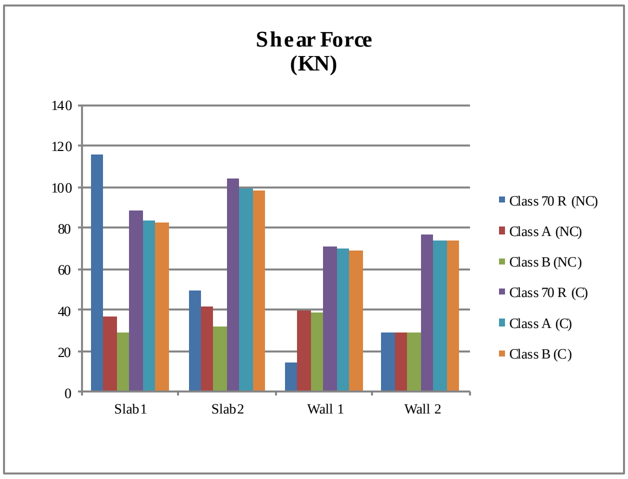
Table 7:-Values of Shear Forces (Without-Cushion)

Item	**Location**	**Members**	**Classes**		
			70-(R)	**A**	**B**
Shear Force (kN)	At d_{eff} from support for slab	A&B	115.8	37.35	24.43
		D&C	49.45	42.14	37.51
	At d_{eff} from top slab for wall	A&B	40.18	39.89	39.31
	At d_{eff} from bottom slab for wall	D&C	29.61	29.69	28.69

With Cushioning:

Table 8:-Values of Shear Force (With Cushion)

Item	**Location**	**Members**	**Classes**		
			70-(R)	**A**	**B**
Shear Force (kN)	At d_{eff} from support for slab	A&B	88.26	83.49	82.61
		D&C	104.36	99.46	98.52
	At d_{eff} from top slab for wall	A&B	71.74	70.16	69.26
	At d_{eff} from bottom slab for wall	D&C	77.21	74.23	73.54



Graph 4:- Graphical representation of values of Shear Force (Without and With Cushion)

5) Steel percentage

Without -Cushioning load:

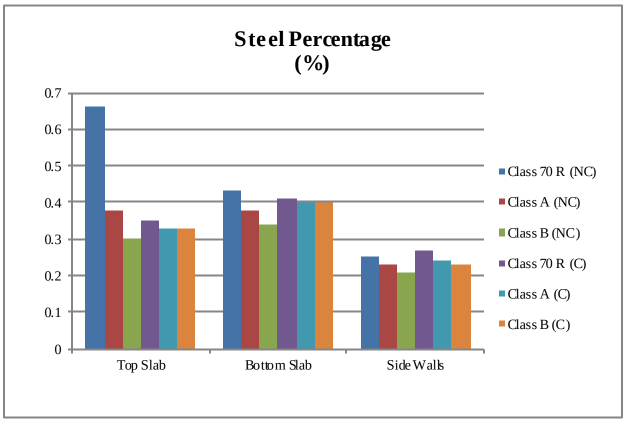
Table 9:-Values of Steel Percent (Without-Cushion)

Classes	**Top slab**	**Bottom slab**	**Side wall**
70-(R) loading	0.63	0.43	0.25
A-loading	0.38	0.38	0.23
B-loading	0.30	0.34	0.21

With Cushioning load:

Table 10:-Values of Steel Percent (With Cushion)

Classes	Top Slab	Bottom Slab	Side Wall
70-(R) loading	0.35	0.41	0.27
A-loading	0.33	0.40	0.24
B-loading	0.33	0.40	0.23



Graph 5:- Graphical representation of values of Steel Percent (Without and With Cushion)

VI. CONCLUSIONS AND RECOMMENDATIONS

1. By using manual calculations as per IRC rules, the design and analysis of box has thoroughly done. By using the manual calculation, we can easily find out the data which is beneficial.
2. Small variations in coefficient of earth pressure observed have very small influence on design of box culverts without cushioning. It is easy to judge the variations observed in percent as per different classes of loading.
3. When Cushioning is not used, Impact Values are observed as 91.25 KN, 21.63 KN & 10.86 KN for Class 70 R, Class A & for Class B respectively. Values of Braking Forces seem to be 56.30 KN, 17.13 KN & 10.59 KN for Class 70 R, Class A & for Class B respectively.
4. For box culvert which is without cushion braking force is required to consider for small spans. It is easy to widen the box length when required.
5. Comparing different loading cases, class 70 R loading gives maximum B. M. at support with and without cushioning cases. Least values are observed in Class B for the same. Again, mid span moment values are greater in 70 R class loading comparing to least values observed in Class B loading.
6. At upstream and downstream there will be apron floor that should be provided with level to be maintained and also haunches should be provided at edge of box.
7. The total deformations of box full without cushion condition are more than box full with cushion conditions. The normal stress, maximum principle stress and equivalent stress are without cushion is more than with cushion.
8. For Shear force values, class 70 R loading gives maximum values for top slab, bottom slab and side walls for non cushion cases. Comparing shear force values for cushion cases, again Class 70 R shows maximum values. Class B shows minimum shear force values for both cushion and non cushion cases in top slab, bottom slab and side walls.

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