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Hydrological Study and Design of Box Culvert with Comparative Study with and without Cushion Loading

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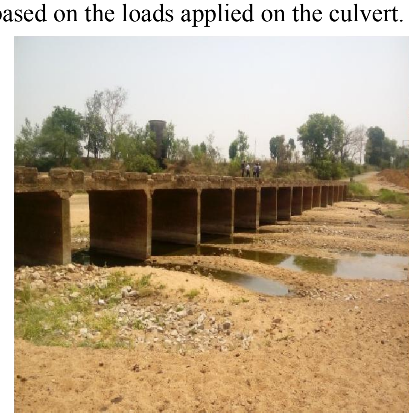
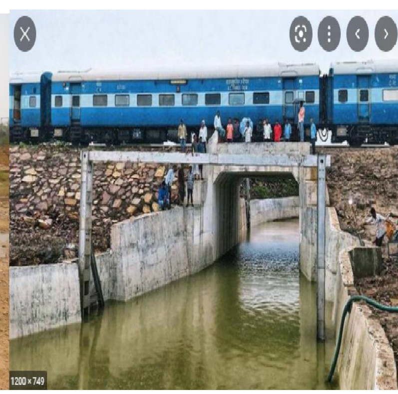
Abstract: *The hydrology and hydraulic calculations has been carried out for the proposed box culvert to justify the waterway required for the river crossing the alignment. Structural analysis is a process to analyse a structural system in order to predict the responses of the real structure under the action of expected loading and external environment during the service life of the structure. The present work reflects on the analysis and design of bridges which are the main source of human life which helps to travel from place to place. The modeling and analysis of bridge is carried out by using the software Staad-pro software. The bridge we designed is box culvert bridge. The design loads are considered as per IRC 6. Box culvert is designed by using Staad-pro and results are compared manually.*

Keywords: Reinforced cement concrete box culvert, hydraulics calculation, cushion loading, earth pressure, structural design, theoretical calculation, STAAD PRO etc.

I. Introduction

Box culverts are the structures constructed below highways and railways to provide access to the natural drainage across them. They are also constructed sometimes to provide the access to the animals to cross the road which is known as animals crossing, vehicular under pass (VUP) & railway under pass (RUB). The opening of the of the culvert section is designed based on the loads applied on the culvert.





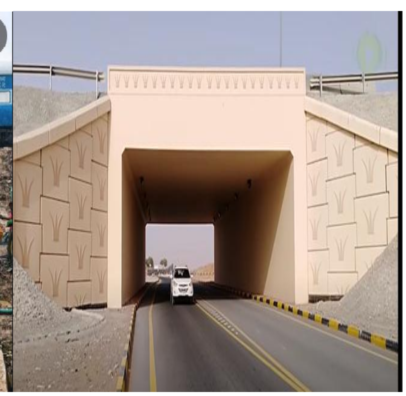


Fig 1:- Box Culvert **Fig 2:- Railway Over Bridge** **Fig 3:- Vehicular Underpass**

Culverts are the structures constructed across the drainages below the highway and railways for easy access for animals and humans. The dimensions of culvert are designed based on waterway. Thickness is adopted based on loads acting on culvert and span of culvert.

The topography of the land across the country varies widely and conditions may be dissimilar even within the same State, depending on the annual rainfall and nature of terrain. The hill streams are flashy in nature, which need tall substructures to span them. The natural streams in plains and rolling terrains are usually wide and need longer superstructures with relatively shorter substructures. The man made drains both for irrigation and industrial use could be low cost structures such as pipe culverts. Since the catchment area varies widely, it is suggested to estimate discharge of a natural stream by direct measurement. If it is not possible to measure, some of the empirical formulae (like, Dicken's and Inglis) listed in IRC:SP: 13 may be referred to fix the waterway. In the plains of north-eastern States, the CD works may be expected to carry a very heavy discharge necessitating deeper foundations and/or adoption of longer span lengths.

A box culvert can have more than single cell and can be placed such that the top slab is almost at road level and there is no cushion. A box can also be placed within the embankment where top slab is few meters below the road surface and such boxes are termed with cushion.

Box culvert rest where safe bearing pressure (SBP) of soil is less, such as soft soil, sand not in hard rock. Therefore geotechnical investigation report are required at the time of design of structure Cut-off walls shall run continuously from outer wall to outer wall and shall rest only on elastic medium no part of it shall rest on hard strata.

II. Review Of Literature

[1]. Ajay R. Polra, Pro. P. Chandresha, Dr. K.B Parikh (2017), had done the analysis and comparison by using design consideration in mind of box coefficient of earth pressure, cushion, width or angle of dispersion and load case for design. The result is without cushion or with cushion and angle of dispersion is zero there will be maximum live load greater stresses are created without cushion.

[2]. RajendraThakaiet all (2016) , have carried out the analytical study of the box girder bridge for rectangular and trapezoidal cross-section. The model is analyzed using the software SAP 2000 which is economically accessible for the finite element analysis. The model is studied for the combination of loads i.e. dead load and live load taken from IRC 70R loading for zero eccentricity for continuous and simply supported span. In this paper, the work is done for the bending moment and longitudinal bending stress in both the top and the bottom flanges. Some of the assumptions which are made during the analysis are:

The vehicular loads taken are from class 70R wheeled vehicle having seven axles given in IRC. The box girder used in this paper is of rectangular and trapezoidal section of single celled box girder bridges. The study can be concluded by the following conclusions:

- Rise in the depth of the box girder increases the bending moment but decreases the bending stress in both the top and the bottom flange.
- Between the rectangular and the trapezoidal cross section, the bending moment is highest in trapezoidal section under the combination of loads (DL+LL). Thus, from the result obtained, it can be said that the rectangular section is stiffer than the trapezoidal section.

[3]. Ketan Kishor Sahu, Shraddha Sharma (2015), had study by using software hydraulic parameters, graphs, charts, tables are showing variations in test result for different ratio which are aspect bending moment, shear force, discharge capacity, loads etc are find out. Result is declared on the basis of the software analysis tables for hydraulic parameter, bending moment for bottom slab, side walls and top slab are shown in tables for different aspect ratio of cell.

[4]. M. Bilal Khan, M. Parvez Alam (2015), This paper includes the hydraulic design which the catchment area, maximum HFL, longitudinal area, cross section, velocity observation and estimation of discharge by rational method empirical formula (dickens formula), critical depth and height of jump also decides the area and length of apron. The culvert are designed by manual calculations which gives size and shape of box according to discharge and depth of scour deciding the jump is undular jump and required to be made of 2m×2m box culvert.

[5]. Neha Kolate et al (2014), have carried out an analytical study on design of RCC box culvert. In this study, they have given a brief idea about a box culvert and usefulness of the box culvert in reducing the flood level. In this paper, the box of 3mX3m with and without cushion of 5m has been taken. Different load cases are calculated and are checked for shear for the box culvert. The results of analysis and design have discovered that RCC box culvert has many advantages over slab culvert for cross drainage work across high embankment. In box culvert it’s easy to add length for widening of road and is structurally rigid and safe. The examination and analysis revealed that box does not need any elaborate foundation, it’s easy to construct, requires no maintenance and small variation in coefficient of earth pressure has little influence on the design of box without cushion.

[6]. Sujata Shreedhar, R. Shreedhar (2013), had find out the coefficients for moment, shear and thrust of single and two cell box culvert by using Staad Pro software. The result is the design of box culvert includes the information regarding the effect

different ratio L/H=1.0, L/H=1.25 etc. Also moments and loads are found out

[7]. B.N Sinha and R.P Sharma (2009), have worked with box culverts made of RCC without and with the cushion. In this study, design of RCC box culvert has been done manually and by computer method. RCC box culverts are modeled and analyzed using STAAD Pro. The structural design involves consideration of load cases like box empty, full, surcharge load etc. and factors like live load, effective width, impact force, coefficient of earth pressure. Relevant IRC codes are referred in this paper. The designs are done to withstand maximum bending moment and shear force. Effective width in case of box culvert plays an important role without cushion as the live load becomes the main load on the top slab and effective width should withstand this load. Impact of live load, shear stress, distribution reinforcement, load cases have also been discussed in this paper. It has been concluded that the box culvert have more advantages than slab culvert, easy to add length for widening of roads. Box culvert is structurally strong, rigid and safe and does not need any elaborate foundation.

III. Objective

1. To study the parameter needed for Hydrological study.
2. To study the behavior of box culvert with cushion and without cushion loading.
3. For analysis, the box model is subjected to Dead loads, SIDL, Earth pressures, Surcharge loads on the side walls, and Live Loads.
4. To study the effect of different load combination which will produce worst effect for safe structural design.
5. To study the steel & concrete quantity require for both cases cushion and without cushion.

IV. Purposes

1. To study the effect of cushion over structural.
2. Culvert is a structure which is built over some physical obstacle such as a body of water, valley, or road, and its purpose is to provide crossing over that obstacle. It is built to be strong enough to safely support its own weight as well as the weight of anything that should pass over it.To save human life and buildings
3. They easily accommodate both pedestrian and vehicular traffic.
4. To compare with & without cushion loading box culvert.

V. Methodology

5.1. Hydrological Study

For survey, following points are required to be prepared:

Right angle crossing (Proposed location of bridge is 0 degree skew angle)

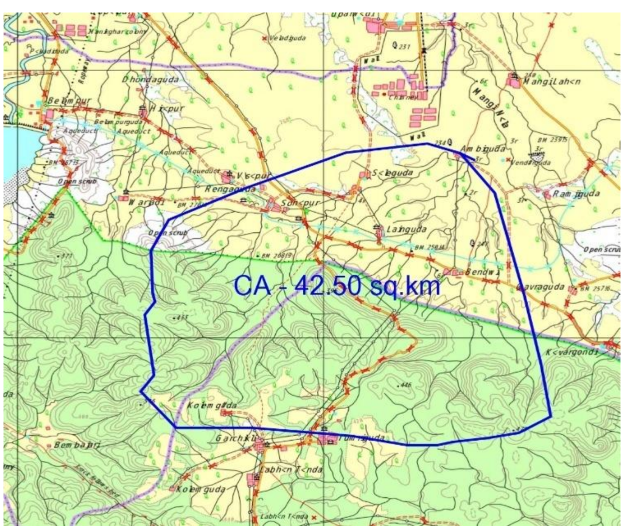


Fig 4: Catchment Area

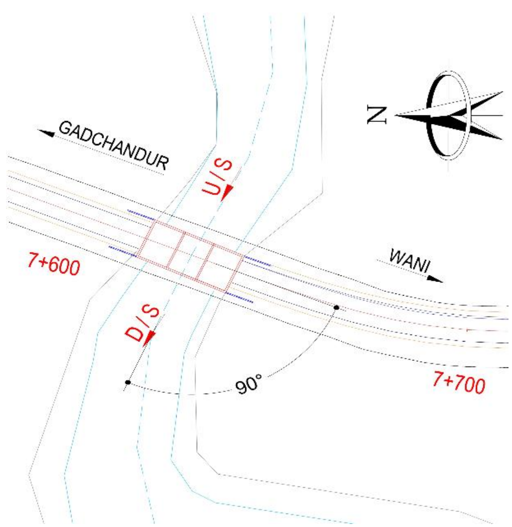


Fig 5: Bridge Site Plan

Check soil strata available at a site is sand & also we check direction of water flow.
Lowest Bed Level: Measuring lowest level of water and mark on cross section.
Highest Flood Level: The high flood level should be ascertained by intelligent local observation, supplemented by local inquiry, and mark on cross section.(LBL to HFL diff. is 3.4m)
Catchment Area: Marking the watershed on "topo" (G.T.) sheet & it is found in the Survey of India.(42.5 Sq km).

5.2 Hydraulics Calculations

Nallah L-section = Bed slope (S) = 0.0030
Catchment area in sq km. (M) = 42 sq.km
Annual reinfall is 60-120 cm (C) = 11-14 (As per Clause.4.2 IRC:SP:13-2004)
Mean Depth (R) = 2.150 m
Rugosity coefficients (n) = 0.033 (As per IRC:SP:13-2004)
Discharge calculation: (As per Clause. 4.2 IRC:SP:13-2004)
Discharge by Dickne's Formula (Q) = C * M 3/4
= 14 * (42.50) 3/4
= 233.034 m3/sec
Velocity (V) = (R 2/3+S 1/3) / n
= (2.150 2/3 + 0.0030 1/3) / 0.033
= 2.78 m/sec
Linear waterway required (L) = Wetted area at HFL / Max. flood depth= 84.47/3.82 = 21.10 m
Provide Linear waterway > Linear waterway is required
24 > 21.10 m,……………………………Hence ok
Therefore 3 x 8 m Box size to be provide.

5.3. Proposal Finalization and Preparation of Drawing

Proposal Finalization as per hydraulics study of box which is (Nos x L) ,3x 8m size of box to be provided. Preparation of drawings shown in fig.1 & fig.2

Sr. No.	Description	Cushion Box Culvert (L x B x H)	Without Cushion Box Culvert (L x B x H)
1.	Size of box	3 x 8 x 4.442 m	3 x 8 x 4.442 m
2.	Cushion height	3.730 m	0
3.	HFL to Soffit difference	0.9 m	0.9 m
4.	Raft thickness	0.900	0.600
5.	Top slab	0.800	0.550
6.	Side wall	0.800	0.450
7.	Intermediate Wall	0.700	0.400

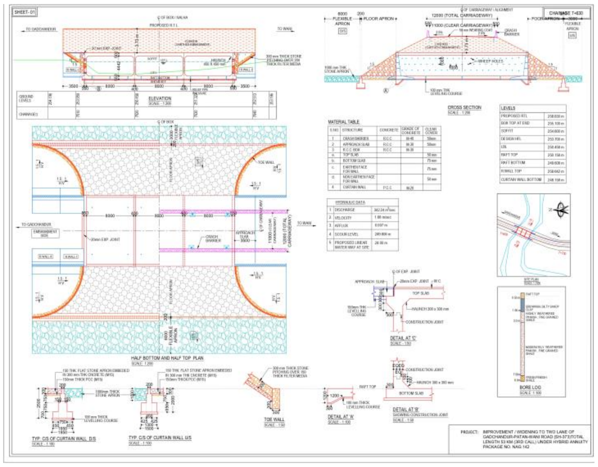


Fig 6: With Cushion Box Culvert

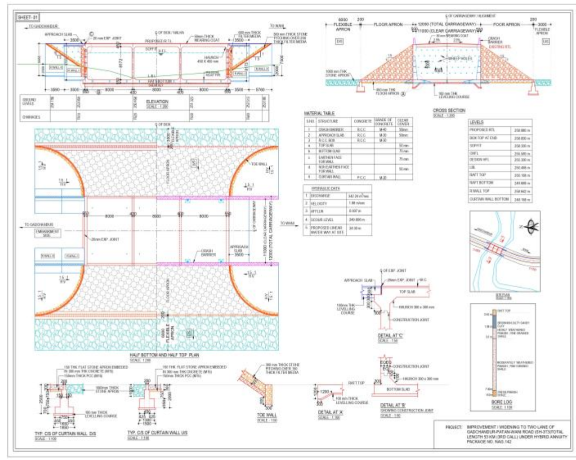


Fig 7: Without Cushion Box Culvert

5.4 Loading Calculations:

Density of concrete = 25 KN/m3
Density of soil = 20 KN/m3
Density of water = 10 KN/m3
Density of wearing coat = 22 KN/m3
Angle of internal friction (in degree) = 30
Coefficient of earth pressure at rest = 0.500
Coefficient of active earth pressure = 0.279
Coefficient of passive earth pressure = 0.400

DEAD LOAD- Self weight of the structure has been calculated directly in STAAD file by the comment "SELFWEIGHT - 1".

SUPER IMPOSED DEAD LOAD-

Load (UDL) on top slab due to W.C (thick.*density of WC)= 0.065*22 = **1.43 kN/m**

Wt of crash barrier (Width *height*density of concrete) = 0.5 *1.1*25 = **13.75 KN/m**

EARTH PRESSURE

Total height c/c of top slab to raft = 3.717 m
Height of overburden = 3.730 m

Earth Pressure at Rest

Height from top		Intensity of Earth pressure(Ka*y*H)		
(m)		(KN/m2)		
3.905	3.905	0.5 x 20 x 3.905	=	39.050
4.255	4.255	0.5 x 20 x 4.255	=	42.550
4.705	4.705	0.5 x 20 x 4.705	=	47.050
5.170	5.170	0.5 x 20 x 5.170	=	51.697
5.634	5.634	0.5 x 20 x 5.634	=	56.343
6.099	6.099	0.5 x 20 x 6.099	=	60.989
6.564	6.564	0.5 x 20 x 6.564	=	65.635
7.028	7.028	0.5 x 20 x 7.028	=	70.282

7.493	7.493	0.5 x 20 x 7.493	=	74.928
7.957	7.957	0.5 x 20 x 7.957	=	79.574
8.422	8.422	0.5 x 20 x 8.422	=	84.220
8.872	8.872	0.5 x 20 x 8.872	=	88.720
9.247	9.247	0.5 x 20 x 9.247	=	92.470

Active Earth Pressure

Height from top (m)		Intensity of Earth pressure (KN/m2)		
3.905	3.905	0.2794 x 20 x 3.905	=	21.822
4.255	4.255	0.2794 x 20 x 4.255	=	23.777
4.705	4.705	0.2794 x 20 x 4.705	=	26.292
5.170	5.170	0.2794 x 20 x 5.170	=	28.888
5.634	5.634	0.2794 x 20 x 5.634	=	31.485
6.099	6.099	0.2794 x 20 x 6.099	=	34.081
6.564	6.564	0.2794 x 20 x 6.564	=	36.677
7.028	7.028	0.2794 x 20 x 7.028	=	39.274
7.493	7.493	0.2794 x 20 x 7.493	=	41.870
7.957	7.957	0.2794 x 20 x 7.957	=	44.466
8.422	8.422	0.2794 x 20 x 8.422	=	47.063
8.872	8.872	0.2794 x 20 x 8.872	=	49.577
9.247	9.247	0.2794 x 20 x 9.247	=	51.673

Live Load Surcharge

Uniform Intensity of loading (for Rest condition) = Coefficient of earth pressure at rest * Equivalent height * Density of soil =1.2*0.5*20 = 12.0 KN/m2

Uniform Intensity of loading (for Active condition) = Coefficient of earth pressure at active * Equivalent height * Density of soil =1.2*0.279*20 = 6.71 KN/m2

CUSHION LOAD = (3.730M * 20)/12 = 15.56 kN/m

BRAKING LOAD

Carriageway Live Load = 100 t
Width of the box = 12 m
Braking Load = 0.2*100 = 20 t
Applied on one points = 20 * 9.81/12 = 16.35 KN /m

LIVE LOADING **(Refer: Clause 204.1.3, Fig.2, IRC : 6-2014)**

Effective width of tyres and load distribution for different vehicular loadings:

Effective span (I0) = 8.68 m
Total Width of Box culvert (b) = 12.0 m
Width/Effective Span ratio,b/ I0 = 1.38

As per Cl. B3.2 of IRC:112-2011(Page-278), for continous slab, α = 2.47

Loading	Intensity of Load (t/m2)
70R - Axle 'l'	2.325
Class A	0.363

Live load max sagging , max hogging, max shear force is 23.25 KN/m2

VI. RESULTS

With Cushion Load (B.M & Sf)

Member	Case	Section	Bending Moment (KN/m)			Shear Force (KN)
			ULS	SLS (Rare)	SLS (QP)	ULS
Top Slab	Sagging	Mid Span	440	412	100	8
		Curtailment	343	305	218	3
		deffective	377	215	96	3
		Haunch End	50	42	36	1
	Hogging	Face of Support	353	200	115	198
		Haunch End	288	253	202	188
		deffective	40	35	30	76
		Curtailment	31	20	10	50
		Mid Span	30	8	8	20
Side Wall	Sagging	Mid Span	47	41	47	6
		Curtailment	40	40	40	6
		deffective	16	16	0	6
		Haunch End	11	19	0	6
	Hogging	Face of Support	430	400	154	189
		Haunch End	405	371	131	166
		deffective	299	135	105	126
		Curtailment	162	113	84	75
		Mid Span	147	108	73	31
Intermediate Wall	Sagging	Mid Span	1	1	0	2
		Curtailment	12	10	1	4
		Haunch End	25	20	1	6
		deffective	34	27	2	6
	Hogging	Face of Support	61	54	0	8
		deffective	45	30	0	2
		Haunch End	35	23	0	2
		Curtailment	19	13	0	1
		Mid Span	4	3	1	1
Bottom Slab	Sagging	Mid Span	580	412	100	9
		Curtailment	443	305	218	10
		deffective	477	215	96	1
		Haunch End	150	42	36	2
	Hogging	Face of Support	553	200	115	254
		Haunch End	388	253	202	251

		deffective	140	53	30	199
		Curtailment	53	20	10	120
		Mid Span	53	8	8	53

Without Cushion Load (B.M & SF)

Member	Case	Section	Bending Moment (KN/m)			Shear Force (KN)
			ULS	SLS (Rare)	SLS (QP)	ULS
Top Slab	Sagging	Mid Span	280	260	99	6
		Curtailment	250	220	92	2
		deffective	201	150	70	2
		Haunch End	50	35	28	2
	Hogging	Face of Support	285	234	105	120
		Haunch End	241	220	99	115
		deffective	30	24	22	60
		Curtailment	24	14	10	40
		Mid Span	15	8	8	125
Side Wall	Sagging	Mid Span	40	35	30	4
		Curtailment	34	30	25	4
		deffective	12	10	0	4
		Haunch End	9	9	0	4
	Hogging	Face of Support	285	270	199	159
		Haunch End	280	265	106	120
		deffective	282	250	99	101
		Curtailment	150	140	70	60
		Mid Span	99	50	60	20
Intermediate Wall	Sagging	Mid Span	1	1	0	2
		Curtailment	12	10	1	4
		Haunch End	25	20	1	6
		deffective	34	27	2	6
	Hogging	Face of Support	61	54	0	8
		deffective	45	30	0	2
		Haunch End	35	23	0	2
		Curtailment	19	13	0	1
		Mid Span	4	3	1	1

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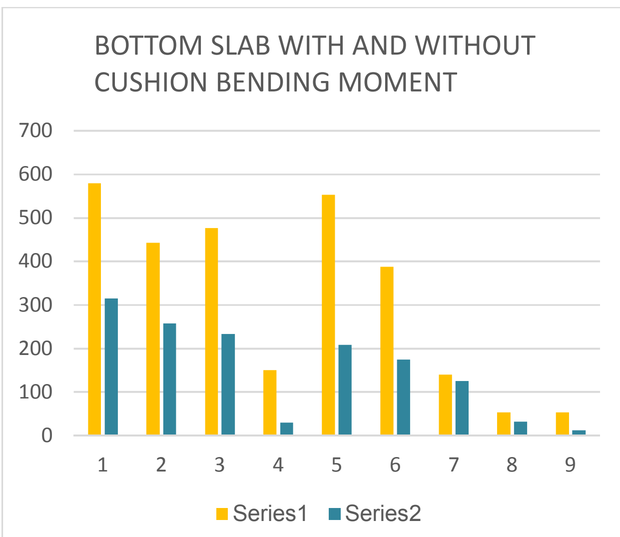
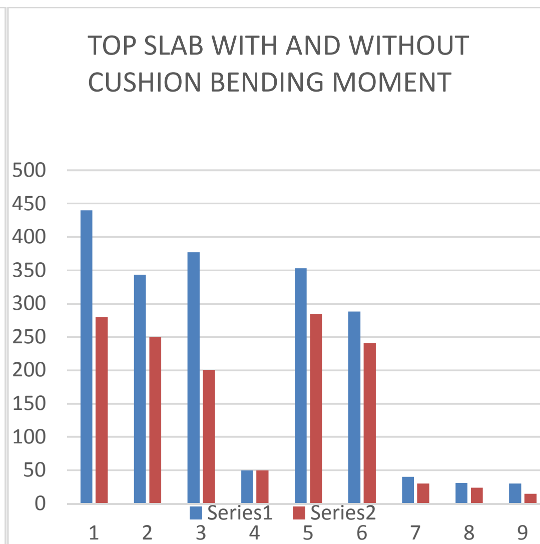
Bottom Slab	Sagging	Mid Span	315	285	125	5
		Curtailment	258	220	100	5
		deffective	234	201	88	1
		Haunch End	30	28	10	2
	Hogging	Face of Support	208	184	99	156
		Haunch End	175	160	125	130
		deffective	125	99	60	70
		Curtailment	32	24	20	51
		Mid Span	12	8	5	160





VII. MODOLING AND LOAD APPLICATIONS:

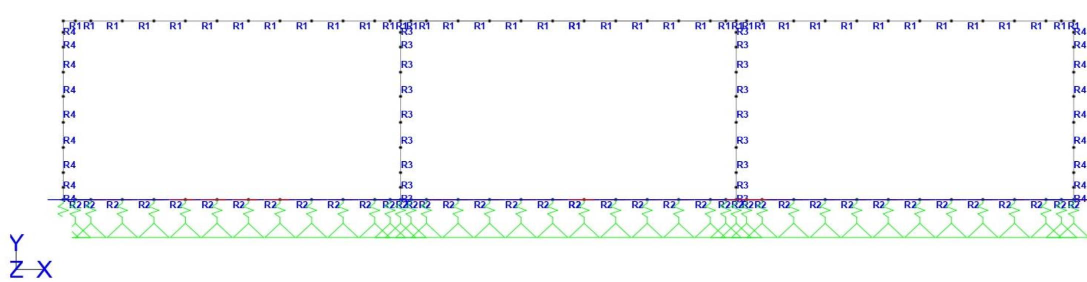


Figure 8: Model

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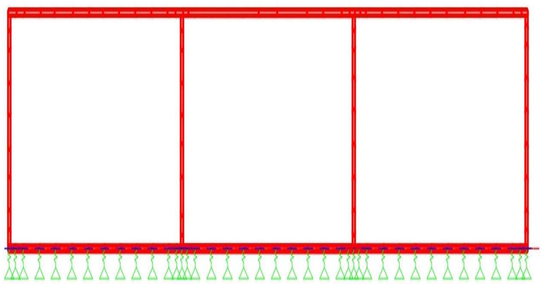


Fig 9 :- Self Weight

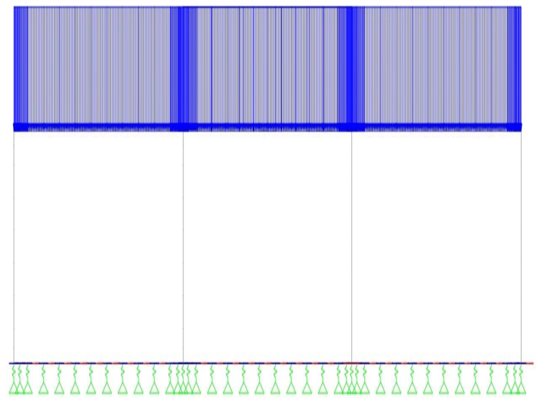
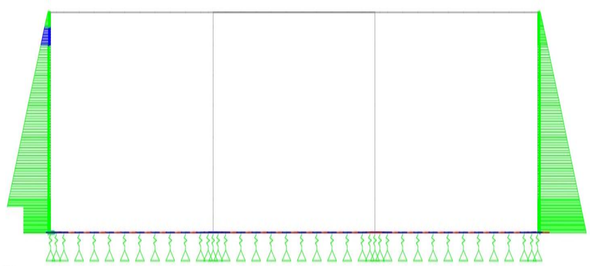
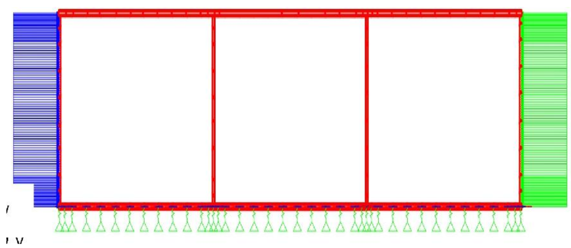


Fig 10 :- Super Imposed Dead Load





Fig

11 :- Earth Pressure

Fig 12 :- Live Load Surcharge

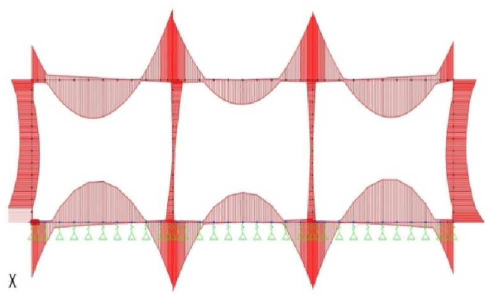


Fig 13: Bending Moment

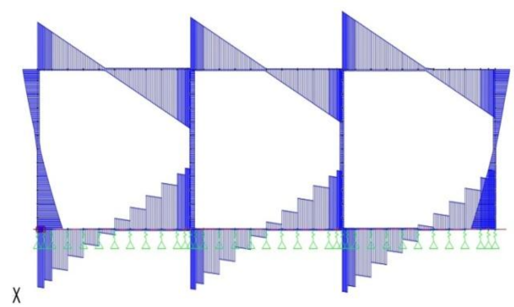


Fig 14: Shear Force

Design Top Slab, Raft, Side Wall, Intermediate Wall

Depth of top slab (D1) = 700 mm,

Depth of raft (D2) = 750 mm

Thickness of outer wall (T1) = 750 mm

Thickness of outer wall (T2) = 600 mm

Width of the member (b) = 1000 mm

3.1 Top Slab Sagging

Top slab bottom main bar = 16mm @ 150mm c/c

Extra bar = 10mm @ 150mm c/c

Ast provided = $(\pi/4 * 16^2 * 150) + (\pi/4 * 10^2 * 150) = 1864\ mm^2$

$X_{umax}/d = \varepsilon_{cu2}/(\varepsilon_{cu2}+\varepsilon_{ud}) = 0.0035/(0.0035+0.00405) = 0.4636$

$X_{umax} = 0.4636*642 = 298mm$

$X_u = 0.87\ f_{yk}A_{st} / 0.36\ f_{ck}\ b = 0.87 * 500*1864/0.36*35*1000 = 64mm$

$X_u < X_{umax}$,……………………………..Hence ok

Ast,cal = M/0.87*fyk*(d'-0.416*xu)

= 280/0.87*500*(642-0.416*64) =1046 mm2

Ast Calc. <Ast Provided,……….Hence ok

Distribution steel at bottom of top slab: (Refer IRC:112 clause 16.6.1.1)

Distribution Reinforcement : At Least 20% of the main Reinforcement =268 mm2

Provide distribution steel = 10mm @ 150mm c/c

Ast provided = (л/4 *102 * 150) = 525 mm2

268 < 525mm…………………………….Hence ok

Safe Bearing Capacity Calculations

A. SBC FOR CUSHION LOAD.

SR NO	STRUCTURSL ELEMENTS	NO	L	W	H	VOLUMN	DENSITY	LOAD
			m	m	m	m3	t/m3	t
1	TOP SLAB	1	26.7	12	0.9	288.36	2.5	640.80
2	BOTTOM SLAB	2	26.7	12	0.9	576.72	2.5	1441.80
3	OUTER WALL	2	12	0.8	4.442	85.2864	2.5	213.22
4	INNER WALL	2	12	0.7	4.442	74.6256	2.5	186.56
5	HAUNCH	12	0.45	12	0.45	14.58	2.5	36.45
6	WEARING COAT	1	26.7	11	0.065	19.0905	2.2	42.00
7	CRASH BARRIER	2	26.7	0.5	1.1	29.37	2.5	73.43
8	CUSHION LOAD	1	26.7	1	3.73	99.591	2.0	199.18
9	LIVE LOAD	1	23.25			23.25		
						TOTAL LOAD		2833.44

TOTAL LOAD / AREA	=	2833.44 / 320.4
SBC	=	8.840

SBC 8.840 < 10 t/m2………**Hence ok**

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B. SBC FOR WITHOUT CUSHION LOAD.

SR NO	STRUCTURSL ELEMENTS	NO	L	W	H	VOLUMN	DENSITY	LOAD
			m	m	m	m3	t/m3	t
1	TOP SLAB	1	26.7	12	0.55	176.22	2.5	440.55
2	BOTTOM SLAB	2	26.7	12	0.6	384.48	2.5	961.20
3	OUTER WALL	2	12	0.45	4.442	47.9736	2.5	119.93
4	INNER WALL	2	12	0.4	4.442	42.6432	2.5	106.61
5	HAUNCH	12	0.45	12	0.45	14.58	2.5	36.45
6	WEARING COAT	1	26.7	11	0.065	19.0905	2.2	42.00
7	CRASH BARRIER	2	26.7	0.5	1.1	29.37	2.5	73.43
8	CUSHION LOAD							
9	LIVE LOAD	1	23.25			23.25		
						TOTAL LOAD		1780.17

$$\frac{\text{TOTAL LOAD}}{\text{AREA}} = \frac{1780.17}{320.4} \text{ t}$$

SBC = 5.556 t/m2

SBC 5.56 < 10 t/m2…………. **Hence ok**

VII. Conclusion

- In this paper hydraulics calculation are done.
- As per IRC SP : 13 required HFL to Soffit clearance is 0.9m, Hence both cases applicable. Where clearance is 0.9 m maintained there available Cushion height is 3.730 m.
- If clearance is 0.9 m not maintained then box culvert height will increase.
- With cushion loading box Wall, slab, Raft slab thickness is more as compare to without cushion loading box culvert.
- Without cushion load box culvert is more economical.
- Safe baring capacity of box culvert is 8.840 t/m2 which is less than10 t/m2 , so the Box type structure is suitable for less available safe bearing capacity of soil at site

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