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DESIGN OF BOX CULVERT WITH AND WITHOUT CUSHION LOADING & HYDROLOGICAL STUDY

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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.

Key Words: *Reinforced cement concrete box culvert, hydraulics calculation, cushion loading, earth pressure, subgrade reaction, sidl, structural design, theoretical calculation, staad pro etc.*

1.INTRODUCTION

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.

In order to adopt uniform standards and to assist the field engineers in providing cross drainage works, type designs and estimates of culverts of probable spans and heights for rural roads are given. These designs are based on relevant IRC codes and guidelines. This Chapter generally deals with culverts, small bridges and minor bridges for rural roads, having height from foundation to road top up to 8 m and spans up to 10 m. Information and details of causeways and submersible bridges are also given.

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.

It is monolithic structure having parts are top slab, bottom slab and vertical walls and wing walls. Culverts are provided to allow water to pass through the embankment and follow natural course of flow and road passes and culverts are also provided to balance the water level on both sides of embankment during floods, such culverts are termed as balancers. 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.

STAAD .Pro 2008 is a suite of proprietary computer programs of Research Engineers, a Bentley Solutions Center. Although every effort has been made to ensure the correctness of these programs, REI will not accept responsibility for any mistake, error or misrepresentation in or as a result of the usage of these programs. STAAD.Pro is a general purpose structural analysis and design program with applications primarily in the building industry - commercial buildings, bridges and highway structures, industrial structures, chemical plant structures

Box culverts are economical for the reasons mentioned below:

- The box is a rigid frame structure and both the horizontal and vertical members are made of a solid slab, which is very simple in construction.
- In case of high embankments, an ordinary bridge will require very heavy abutments that will not only be expensive but also transfer heavy loads to the foundations.
- The box type of structure is suitable for non-perennial steams where scour depth is not significant but subgrade soil is weak.

- The dead 1oad and superimposed 1oad are distributed almost uniformly over a wider area as the bottom slab serves as a raft foundation. Thus reducing pressure on soil.

1.1 Literature Review

1. **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.[1]

2. **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.[2]

3. **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.[3]

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.[4]

5.

2. Methodology

Hydrological Study

For survey, following points are required to be prepared:

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

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- 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).

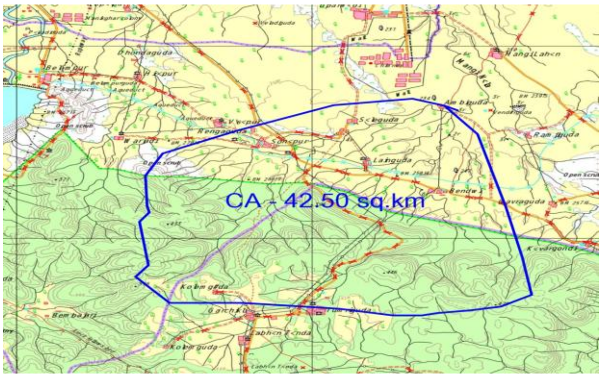


Figure 1 .Catchment Area

3.1.1. Hydraulics Calculations

Where,

- 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)

1. Discharge calculation: (As per Clause. 4.2 IRC:SP:13-2004)

   Discharge by Dickne's Formula (Q) $= C * M^{3/4}$

   $= 14 * (42.50)^{3/4}$

   $= 233.034\ m^3/sec$

2. Velocity (V) $= (R^{2/3}+S^{1/3}) / n$

   $= (2.150^{2/3} + 0.0030^{1/3}) / 0.033$

   $= 2.78$ m/sec

3. Linear waterway required (L) = Wetted area at HFL / Max. flood depth = 84.47/3.82 = 21.10 m
4. Provide Linear waterway > Linear waterway is required

   24 > 21.10 m………Hence ok

5. Therefore 3 x 8 m Box size to be provide.

Table 1 Praposals

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 Ht.	3.730 m	0
3	HFL to Soffit difference	0.9 m	0.9 m
4	Raft thickness	0.700 m	0.550 m
5	Top slab	0.500 m	0.550 m
6	Side wall	0.700 m	0.450 m
7	Intermediate Wall	0.450 m	0.400 m
8	Haunch's	0.450 x 0.450 m	0.450 x 0.450 m

Figure 2 Drawing For With Cushion Box Culvert

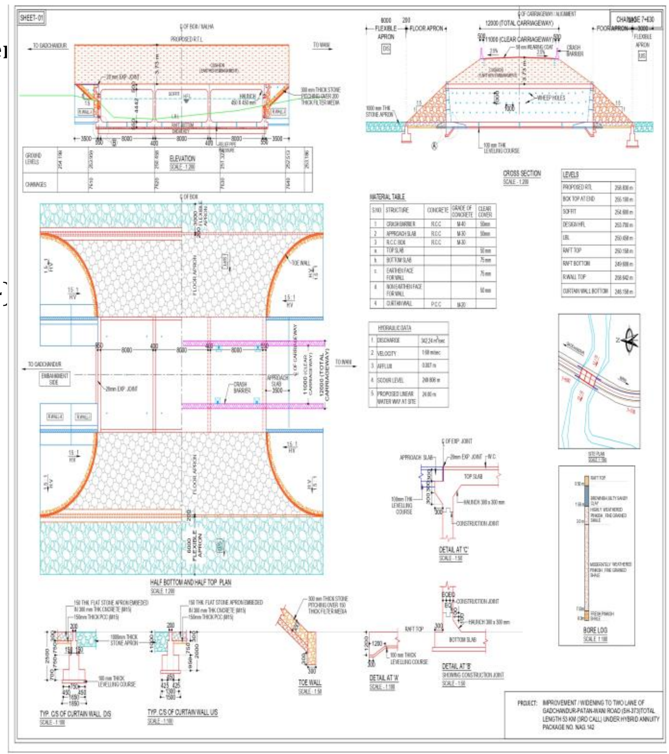
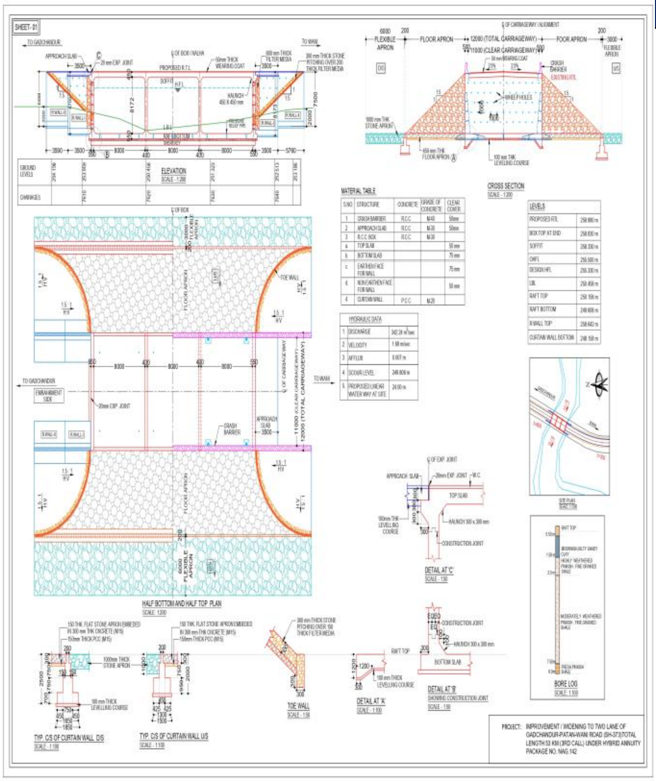


Figure 3 Drawing For Without Cushion Box Culvert



2. 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

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
(for both cases)

Wt of crash barrier (Width*height*density of concrete)= 0.5 *1.1*25 = 13.75 KN/m
(for without cushion) = 13.75/12 = 1.15 KN/m2

Wt of crash barrier (Width*height*density of concrete)= 0.5 *1.1*25 = 13.75 KN/m
(for without cushion) = 13.75/12 = 1.15 KN/m2

Ht of fill = 3.730 * 20 = 74.60 KN/m
(for with cushion) = 13.74+74.60 = 88.35 KN/m = 88.35/12 = 7.360 KN/m2

Table 2 Earth pressure at rest: (Cushion load)

Height from top	Intensity of Earth pressure (Ka*y*H)	
(m)	(KN/m2)	
3.830	0.5 x 20 x 3.830	38.300
4.280	0.5 x 20 x 4.280	42.550
4.730	0.5 x 20 x 4.730	47.050
5.438	0.5 x 20 x 5.438	51.697
6.147	0.5 x 20 x 6.147	56.340
6.855	0.5 x 20 x 6.855	60.989
7.564	0.5 x 20 x 7.564	65.635
8.272	0.5 x 20 x 8.272	70.282
8.722	0.5 x 20 x 8.722	74.928
9.172	0.5 x 20 x 9.172	79.574

Table 3 **Earth pressure at rest: (Without Cushion load)**

Height from top	Intensity of Earth pressure(Ka*y*H)	
(m)	(KN/m2)	
0.250	0.5 x 20 x 0.255	2.500
0.550	0.5 x 20 x 0.550	5.500
1.000	0.5 x 20 x 1.000	10.000
1.708	0.5 x 20 x 1.708	17.085
2.417	0.5 x 20 x 2.417	24.170
3.125	0.5 x 20 x 3.125	31.250
3.834	0.5 x 20 x 3.834	38.340
4.542	0.5 x 20 x 4.542	45.420
4.992	0.5 x 20 x 4.992	49.920
5.292	0.5 x 20 x 5.292	52.920

Live load surcharge

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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

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

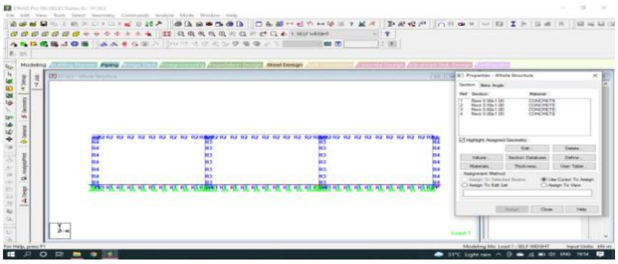

Figure 4 **Staad Model & Properties**

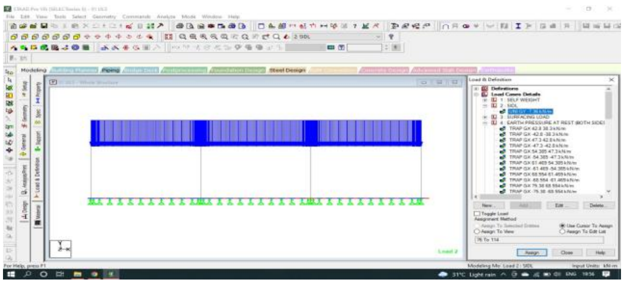

Figure 5 **Super Imposed Dead Load**

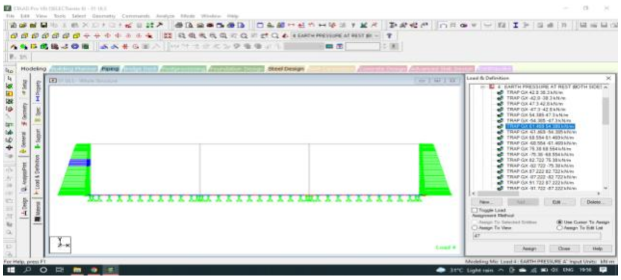

Figure 6 **Earth Pressure**

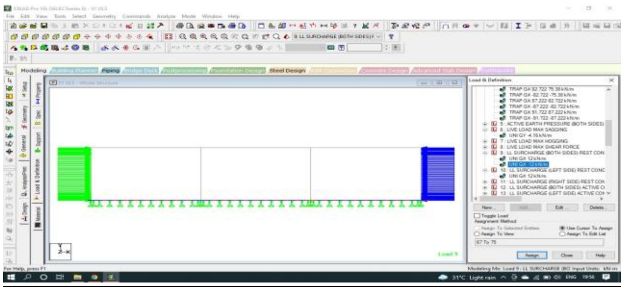

Figure 7 Live load surcharge

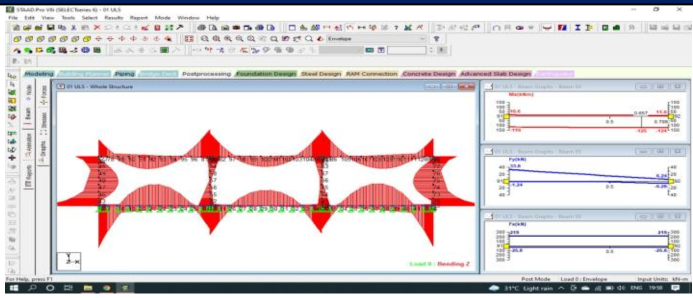

Figure 8 Bending Moment

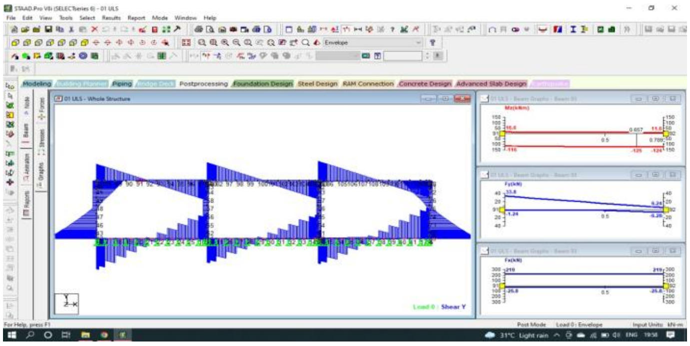

Figure 9 Shear Force

3. STAAD RESULTS

Bending Moment Comparision

Member	Case	Section	Bending Moment (KN/m) With cushion	Bending Moment (KN/m) Without cushion
Top Slab	Sagging	Mid Span	124	266
		Curtailment	111	165
		deffective	9	5
		Haunch End	13	8
	Hogging	Face of Support	242	397
		Haunch End	172	275
		deffective	67	91
		Curtailment	7	5
		Mid Span	12	14
Side Wall	Sagging	Mid Span	93	48
		Curtailment	93	39
		deffective	110	10
		Haunch End	40	10
	Hogging	Face of Support	320	210

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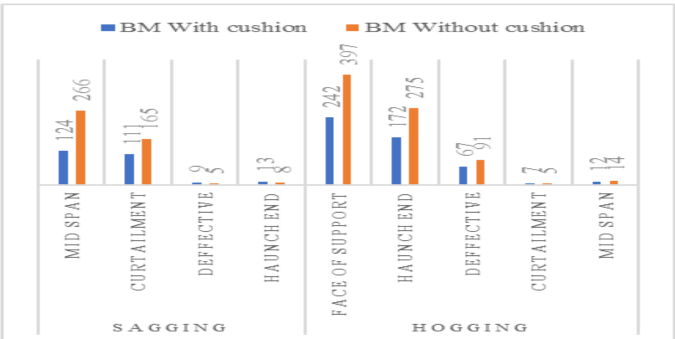
		Haunch End	112	144
		deffective	117	144
		Curtailment	143	99
		Mid Span	147	83

Inner Wall	Sagging	Mid Span	17	3
		Curtailment	40	10
		deffective	64	10
		Haunch End	40	17
	Hogging	Face of Support	87	78
		Haunch End	13	65
		deffective	20	44
		Curtailment	13	44
		Mid Span	6	25

Bottom Slab	Sagging	Mid Span	216	282
		Curtailment	182	255
		deffective	112	5
		Haunch End	16	11
	Hogging	Face of Support	423	353
		Haunch End	258	227
		deffective	59	44
		Curtailment	50	10
		Mid Span	41	16

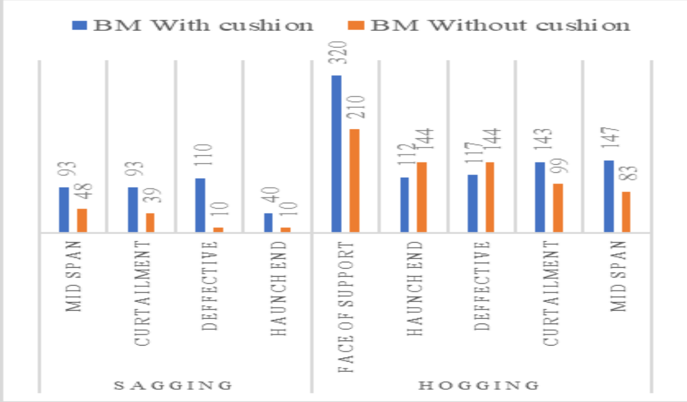
Top Slab



B.M (KN/m) Top Slab

➢ Observations : - For Without cushion case, vehicle load is directly coming on top slab, hence B.M & S.F. is more or Reinforcement requirement for top slab is greater than reinfent requirement of top slab of with cushion case.

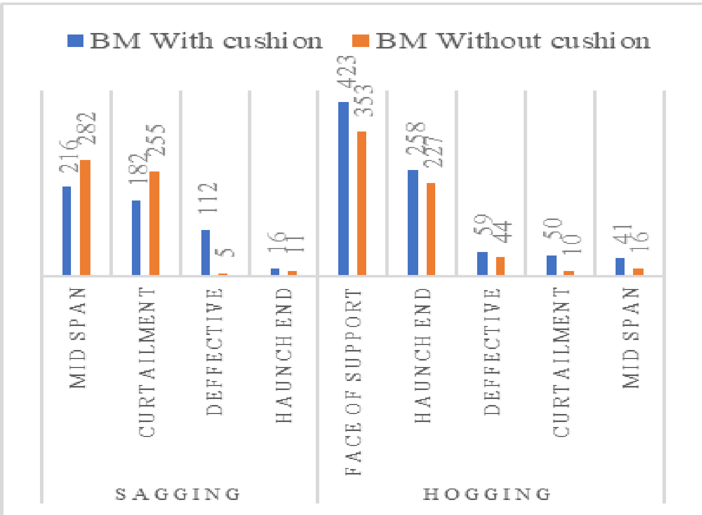
Side wall



B.M. (KN/m) Side wall

➢ Observations : - For With cushion case, earth fill load on box culvert causes more downward pressure. Which is transferred wall to the base slab, Hence outer wall requires more bending or reinforcement than reinforcement required for without cushion case.

Bottom Slab



B. M. (KN/m) bottom Slab

➢ Observations : - For With cushion case, earth fill load on box culvert causes more downward pressure. Which is transferred wall to the base slab, Hence Intermediate wall requires more bending or reinforcement than reinforcement required for without cushion case.

4. Design Top Slab, Raft, Side Wall, Intermediate Wall for cushion load.

Depth of top slab (D1) = 700 mm,
Depth of raft (D2) = 750 mm
Thickness of outer wall (T1) = 750 mm
Thickness of inner wall (T2) = 600 mm
Width of the member (b) = 1000 mm

ULS Capacity Check (Top Slab Sagging)

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Top slab

bottom main bar = 16mm @ 180mm c/c

Extra bar = 10mm @ 180mm c/c

Ast provided = ($\pi/4 * 16^2 * 180$) + ($\pi/4 * 10^2 * 180$) = 1553 mm2

Xumax /d = εcu2/(εcu2+εud) = 0.0035 /(0.0035+0.00405) = 0.4636

Xumax = 0.4636*492=228mm

Xu = 0.87 fyk Ast / 0.36 fck b = 0.87 * 500*1553/0.36*35*1000 = 54mm

Xu < Xumax,…………………………….Hence ok

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

= 266/0.87*500*(492-0.416*54) =1302 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 =311 mm2

Provide distribution steel = 10mm @ 200mm c/c

Ast provided = ($\pi/4 * 10^2 * 200$) = 393 mm2

311 < 393mm…………………………..Hence ok

Check of Shear Reinforcement Requirement

(IRC 112 / clause 10.3.2 (2), (5))

VED = 17 (kN)

β = 1

βVED = 17 (kN)

d = 492mm

bw = 1000mm

k= Min [1 + √200/d , 2]

= 1.638

Asl = 1553 mm2

ρ1 = Min [Asl/bw d , 0.02]

= Min [1553/1000 * 492 , 0.02]

= 0.003

νmin = 0.031 k3/2 fck1/2

= 0.031 *1.673/2 *35/2

= 0.384

VRdc =Max [(0.12 k (80 ρ1 fck)0.33 + 0.15 σcp) bw d ,

(νmin +0.15σcp) bw d]

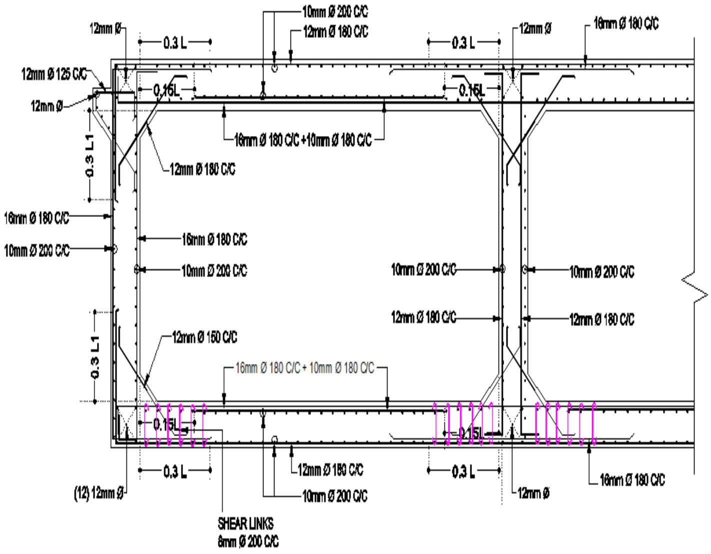
=Max [(0.12 k (80 * 0.003 * 35)0.33 + 0.15 *0) 1000* 492 ,

(νmin +0.15*0)1000*492]

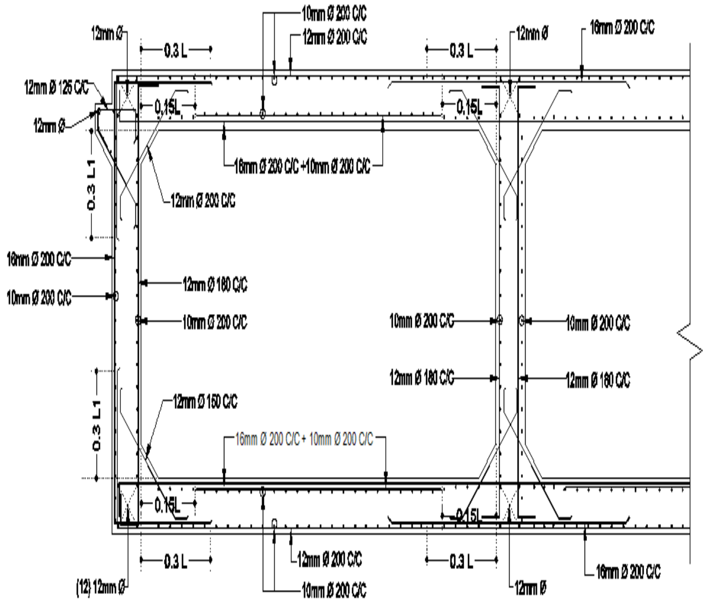
= 198 Kn

βVED < VRdc

17 (kN) < 198 kN …… No Shear Reinforcement Required



With Cushion Reinforcement Details



Without Cushion Reinforcement Details

- ➢ lap shall be staggered and not more than 50% bars shall be lapped at any time.
- ➢ hook for 10 times diameter of stirrups.

3. CONCLUSIONS

- 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.
- The maximum negative moment develop at the centre of vertical wall, top slab, bottom slab (raft) when the culvert is running full.
- The maximum positive moment develop at the corners of vertical wall, top slab, bottom slab (raft) when the culvert is running full.
- The maximum shear forces develop at the corners of top and bottom slab when the culvert is running full and the top slab carries the dead and live load,
- With cushion box Wall , slab, Raft slab thickness is more as compare to without cushion box culvert.
- Without cushion load box culvert is more economical .
- For Without cushion case, vehicle load is directly coming on top slab, hence Reinforcement requirement for top slab is greater than reinforcement requirement of top slab of with cushion case.
- For With cushion case, earth fill load on box culvert causes more downward pressure. Which is transferred to the base slab, Hence Base slab requires more bending reinforcement than reinforcement required for without cushion case.

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