Comparative Study on Analysis and Design of Box Culvert

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Abstract- *Culverts are cross drainage work provided under High embankment in Railway and Roadway. Culverts are required to balance the flood water on both sides of the earth embankment to reduce the flood level on one side thereby decreasing the water head consequently reducing the flood. Culvert are generally classified under three main category (i) Slab Culvert, (ii) Box Culvert and (iii) Pipe Culvert. Box Culvert consists of two horizontal and two vertical slabs which are constructed monolithically. RCC rigid frame box culvert with square and rectangular openings. Box culvert are generally considered if the discharge in a drain or channel crossing is small and for soil having low Safe Bearing Capacity (SBC). Box culverts are economical due to rigidity and monolithic action. The Bottom slab of the culvert serves as raft foundation for box culvert. For small discharges, single celled box culvert is used and for large discharges, multi celled box culvert can be used. This paper deals with the comparative study for design parameters of box culverts based on IRC 21:2000 & IRC 112:2011, like shear design, Flexure Design. The structure is analyzed in STAAD Pro v8i and Cross verified in SAP 2000 v19.*

Keywords- Box culvert, safe bearing capacity, Flexure, shear, raft foundation, IRC 21:2000, IRC 112 :2011.

I. INTRODUCTION

RCC Box Culverts comprising of Top Slab, Base Slab and Stem are casted monolithically to carry Dead Load, Live Load (IRC Class A, IRC Class AA wheeled, IRC Class AA Tracked), Embankment Load, Hydrostatic Pressure, Super Imposed Dead Load (Asphaltic Wearing Coat), Lateral Earth Pressure, Temperature Load, Live Surcharge. They can either be single or multiple celled boxes. The height, width and the number of cells depends on hydraulic requirement and other requirements at site such as Finished Road Level, Nalla Bed Level, and Scour Depth etc. The Length of box culvert should be sufficient enough to accommodate the carriageway, safety kerb and crash barrier. Box Culvertare box Sections rectangular or square cross section culverts are easily adaptable to a wide range of site conditions, including sites that require low profile structures. Due to the angular corners, boxes are not as structurally and hydraulically efficient as other culvert shapes. Box culvert is a structure that consist of two horizontal slab which are parallel to each other and are connected to two vertical slabs monolithically which has rectangular or square openings for waterways or other ways. Box culverts are types of bridges used when the discharge in a drain or channel crossing a road is small, and when the bearing capacity of the soil is low. Culverts are always cheaper than bridges where the discharge opening is less than $15m^2$ and particularly where the road crosses the waterway on relatively high embankment. Box culverts are constructed of reinforced concrete and are either cast-in-place or precast. Most of them are square dimensions; but if not a square, usually have the span length exceeding the opening height. Box culverts may have multiple or single cell openings. They control water flow and drainage for irrigation and municipal services, control storm water, and perform many other services. All the reasons above represent a good motivation to researchers in culvert design method and construction technique. The box culverts are well suited for low stream water bodies, for road crossing of low or medium traffic density, railway crossing of high embankments and sites having low Safe Bearing Capacity (SBC). Box culvert having one opening is termed as 'single celled box culvert and that with more than one opening is termed as 'multi celled box culvert'.Box culvert are economical due to rigidity and monolithic action. The slabs are monolithically connected due to which the bottom slab serves as raft foundation hence minimisingthe pressure on the soil, hence it provided efficient design in sites with low safe bearing capacity (SBC) of soil.

1.1 OBJECTIVES OF THE PRESENT STUDY

In the present study a box culvert of dimension 1x4x4 is model for the fulfilling the following objectives:-

A. Variation of analysis results performed for the same dimension using STAAD Pro and SAP 2000.
B. Variation of design results from two different methodology of design based on IRC 21:2000 and IRC 112:2011.

C. Determination of optimised section based on length by depth of slab ratio and height to thickness of vertical wall ratio based on the new code of practice for highway bridges

II. LITERATURE REVIEW

I. Siva Rama Krishna and Ch. HanumanthaRao (2017) carried out a study to identify behaviour of box culvert with interaction of soil and without interaction of soil. From their study, they concluded that the bending moment values of top slab is increased by 19% in without soil interaction condition when compared to with soil interaction. The bending moment values of side walls is increased by 15% in without soil interaction condition when compared to with soil interaction. The bending moment values of base slab is increased by negligible in without soil interaction condition when compared to with soil interaction. The shear force values of top slab is increased by 27% in without soil interaction condition when compared to with soil interaction. The shear force values of side walls is increased by 31% in without soil interaction condition when compared to with soil interaction.**KriteeChhetri, Rajendra.S, Kavitha.N (2016)**studied on a multi-cell box culvert taking span to height ratio and dynamic vehicular load. They arrived at a conclusion that the change in span to height ratio of the culvert alters the relative stiffness of various members in the culvert and hence affects the internal forces in the members. The results of bending moments have shown considerable variations with the span to height ratio of culverts. Vehicular dynamic analysis has revealed that the maximum bending moment occurs for the dynamic vehicular load case. In case of top slab maximum bending moment is 65% more with dynamic case and in case of side wall maximum bending moment is 85% more with dynamic case. Hence, it can be said that for a multicellular box culvert dynamic vehicular loading analysis is necessary.**MangeshS.Sulke, Ganesh P. Chaudhari, Vishal B. Waghchaure, Swapnil G. Rane (2016)** did a comparative study between design of RCC Box Culvert by analytical method and STAAD Pro. They concluded that moment values calculated by STAAD-Pro program may be greater than moment values calculated by MDM (Moment Distribution Method).**ManmeetsinghSethi (2015)** suggested a design automation for box culverts using web based application.The results obtained from the application testing makes it very clear, that a considerable time of the designers can be saved by using this application. Being a web based application the problem of loss of information is eliminated. Also the communication of information between all the parties involved in construction of box culverts will become very easy. Based on the results, it can be concluded that this application is reliable and can be successfully used in designing the box culverts of different sized with acceptable output. The design moments and steel required generated by this application are very close to the results obtained from manual design and can be successfully used in designing of box culverts used for road construction in India.**Y. Vinod Kumar and Dr. ChavaSrinivas (2015)** studied a box culvert by using computational methods such as Grillage analysis and Finite element method. They concluded that Finite Element Method gives the less value of stresses than grillage and conventional method. Area of reinforcement is decreased in the grillage analysis method. So economical design can be achieved using the result of grillage analysis. Moreover, grillage analysis is easy for modelling of structure.**ShivanandTenagiand R. Shreedhar (2015)** carried out a comparative study of slab culvert design using IRC 112:2011 and IRC 21:2000. For design of the slab culvert using working stress method as per IRC: 21-2000, L/d ratio of 11 to 13 can be adopted, L/d ratio of 13 is most preferable. For design of the slab culvert using limit state method as per IRC: 112-2011, L/d ratio of 18 to 20 can be adopted, L/d ratio of 20 is most preferable. Increase in effective depth with increase in span is found to be lesser for L/d ratio of 20 when compared to L/d ratio of 18 and 19. As thickness of slab increases, the volume of concrete increases and hence dead load increases. Deflections are within the limiting value as mentioned in IRC: 112-2011 but this is not a case for L/d ratio higher than 20. They observed that in slab culvert for L/d ratio of 20, the quantity of concrete saved is up to 30 to 35% using limit state method. In limit state method of design, the utilization capacity of limiting moment will increase with increasing span which is up to 65%. It is observed that the utilization capacity for L/d ratio of 18 & 19 is lesser and for L/d ratio of 21 and 22 it is found to be higher when compared to L/d ratio of 20.**Neha Kolate, Molly Mathew, Snehal Mali (2014)** analysed and designed a box culvert and observed that box culvert for cross drainage works across high embankments has many advantages compared to slab culvert. Box culvert is easy to add length in the event of widening of the road. Box culvert is structurally very strong, rigid & safe. Box culvert does not need any elaborate foundation and can easily be placed over soft foundation by increasing base slab projection to retain base pressure within safe bearing capacity of ground soil. Box culvert of required size can be placed within the embankment at any elevation by varying cushion. This is not possible in case of slab culvert. Box culvert is easy to construct, practically no maintenance, can have multi-cell to match discharge within smaller height of embankment. Small variation in co-efficient of earth pressure has little influence on the design of box culvert particularly without cushion. For culverts without cushion taking effective width corresponding to α for continuous slab shall not be correct. It is likely to provide design moments and shear on lower side hence not safe. For box culvert without cushion braking force is required to be considered particularly for smaller span culverts. For box without cushion having low design moments and shear stress as compared to the box culvert having cushion. So steel required is less in the box with no cushion as compared to with cushion.**SujataShreedhar, R.Shreedhar (2013)** did research ondesign coefficients for single and two-celled box culvert. The study showed that the maximum design forces develop for the following loading conditions:

1. When the top slab supports the dead load and live load and the culvert is empty.
2. When the top slab supports the dead load and live loads and the culvert isrunning full.
3. When the sides of the culvert do not carry the live load and the culvert is running full.

The study showed that the maximum positive moment develop at the centre of top and bottom slab for the condition that the sides of the culvert not carrying the live load and the culvert is running full of water. The maximum negative moments developed at the support sections of the bottom slab for the condition that the culvert is empty and the top slab carries the dead load and live load. The maximum negative moment develop at the centre of vertical wall when the culvert is running full and when uniform lateral pressure due to superimposed dead load acts only. 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. The study shows that the multi-celled box culverts are more economical for larger spans compared to single-cell box culvert as the maximum bending moment and shear force values decreases considerably, thus requiring thinner sections.**KomalS.Kattimani and R.Shreedhar (2013)** studied on some of the design parameters of box culverts like angle of dispersion of live load, effect of co-efficient of earth pressure and depth of cushion provided on top slab of box culverts. From the parametric studies that is by variation of angle of dispersion, co-efficient of earth pressure and cushion depth they concluded that the angle of dispersion increases the intensity of live load but when overall effect of all loads is taken, the moments remain constant. Therefore the angle of dispersion as considered in IRC 6-2000 which is 45^0 can be considered fordesign. The co-efficient of earth pressure has a little influence on the final moments. therefore for safer design the co-efficient of earth pressure can be taken 0.5 which gives higher results than 0.33. By the studies on cushion depth it is feasible to design box type of structure with 0 meter or no cushion which shall be safe for cushion loads which may become a necessity at future date due to change in road profile. From the study it is seen that the moments for no cushion are higher than the moments for a cushion of 5 meters. **B.H.Solanki&Prof.M.D.Vakil (2013)** did a comparative study for shear design using IRC 112:2011 & IRC 21:2000. From the study it was concluded that ultimate shear resisting capacity of the member with shear reinforcement that is V_{Rdmax} is noticeably large compare to WSM, and it is constant as f_{ck} is increased in WSM but increases gradually in LSM by keeping all other parameters same. Shear resisting capacity of the member without shear reinforcement make large difference in LSM compare to WSM, for same cross section, longitudinal reinforcement and grade of steel f_y. Design shear force required for different grade of concrete are almost same in WSM but it decreases as grade of concrete increases in LSM. Inclined reinforcement are more economic compare to vertical one about 50% in LSM,by keeping all other parameters same. **Parisa Haji Abdulrazaghand EsraBayogluFlener (2012)** carried out a the numerical analysis of a long-span deep-corrugated steel box culvert with a span of 14m with soil covers of 0.45m and 1.20m.They concluded that thrusts and bending moments showed that the truck position on the crown has the maximum effect on the 14m-span box culvert with 0.45m and 1.20m covers. This is an important result which will allow for the reduction of amount and time of calculations, especially when the effect of various parameters of a steel structure or soil is going to be studied. Value of thrust does not change significantly along the longitudinal axis of the structure, but the moment increases towards side plates due to a smaller soil cover over the structure. The structure is more sensitive to the change of truck position when the depth of cover is smaller.**Alia Osman Mohamed Ahmed and ElHusseinAlarabi (2012)**discussed about the development of structural design of concrete box culverts. They emerged with the conclusions that the method of analysis of box culverts is different from that for other bridges, since they are analysed and designed as rigid frames with equal bending moments at the end supports. The moment distribution method is used for determination of final moments at joints of the frame. They observed that the results of the analysis of single box culverts using the moment distribution coefficients (Reynolds and Steedman 1994) gave accurate results when compared with analysis using commercially available software (PROKON). The results of analysis using the moment distribution coefficients proposed by Janayni (1986) for both twin and multiple culverts gave acceptable results when compared with analysis using commercially available software (PROKON).**Scott Mitchell Wood (2000)** studied about the internal forces in a reinforced concrete box culvert. He concluded that based on the strain gauge results, axial forces and bending moments in the box culvert are linearly related to the embankment height. The roof pressure does not affect the internal forces. Wall internal forces are affected by the load distribution applied to the wall. With the higher pressure applied at the base of the culvert, the shear force in the bottom of the wall increases greatly. Although the total horizontal design force on the wall of the culvert may be reasonable, a change in the load distribution significantly affects wall shears.**KriteeChhetri, Rajendra.S, Kavitha.N (2016)** studied on a multi-cell box culvert taking span to height ratio and dynamic vehicular load. They arrived at a conclusion that the change in span to height ratio of the culvert alters the relative stiffness of various members in the culvert and hence affects the internal forces in the members. The results of bending moments have shown considerable variations with the span to height ratio of culverts. Vehicular dynamic analysis has revealed that the maximum bending moment occurs for the dynamic vehicular load case. In case of top slab maximum bending moment is 65% more with dynamic case and in case of side wall maximum bending moment is 85% more with dynamic case. 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III. NUMERICAL MODELLING

Numerical modelling is a widely applied technique to tackle complex geological problems by computational simulation. Computer simulations have become a useful tool for the mathematical modelling of many natural systems in engineering. Simulation of a system is represented as the running of the system's model. It can be used to explore into new technology and to estimate the performance of system that are too complex for analytical solution. The numerical modelling had been performed in STAAD Pro V8i and SAP 2000 v18. 6. Models of '1x4x4' box culvert had been chosen for analysis and design. The chosen culvert was first analysed in STAAD Pro V8i and the results were compared with SAP 2000 v18 with the same loads. The following models had been modelled in software based on the L/D ratio and H/B ratio.

TABLE 3.1: LIST OF MODEL BASED ON THE L/D RATIO AND H/B RATIO

RATIO		L/D					
		1/10	1/12	1/14	1/16	1/18	1/20
H/B	1/10	CUL/101	.	.	.	.	.
	1/12	.	CUL/202	.	.	.	.
	1/14	.	.	CUL/303	.	.	.
	1/16	.	.	.	CUL/404	.	.
	1/18	.	.	.	.	CUL/505	.
	1/20	.	.	.	.	.	CUL/606

TABLE 3.2: DIMENSION OF MEMBER

MODEL NO	THICKNESS OF MEMBER (mm)		
	TOP	BOTTOM	SIDE
CUL/101	450	450	450
CUL/202	385	385	385
CUL/303	335	335	335
CUL/404	300	300	300
CUL/505	275	275	275
CUL/606	250	250	250
The dimension here is inclusive of clear cover			

These culverts were idealized using a 1m width section. The following loads had been considered while modeling the box culvert in the software.

3.1 DEAD LOAD:

The dead load carried by the member would consist of the portion of the weight of the structure which is supported wholly or in part by the member including its own weight. The following unit weights of the materials had been used in determining loads, unless the unit weights have been determined by actual weighing of representative samples of the material in question, in which case the actual weights as thus determined has been used.

TABLE 3.3: UNIT WEIGHT OF MATERIAL

	MATERIAL	UNIT WEIGHT (KN/M3)
I	Concrete (asphalt)	22
II	Concrete (cement-reinforced)	25
III	Earth (compacted)	20
IV	Steel (Rolled or Cast)	78
V	Water	10

Hence Range of Dead Load

25 x 0.250 x 1 = 6.250 KN/m
(MODEL-CUL/SP/606&CUL/SAP/606)

25 x 0.275 x 1 = 6.875 KN/m
(MODEL-CUL/SP/505&CUL/SAP/505)

25 x 0.300 x 1 = 7.500 KN/m
(MODEL-CUL/SP/404&CUL/SAP/404)

25 x 0.335 x 1 = 8.375 KN/m
(MODEL-CUL/SP/303&CUL/SAP/303)

25 x 0.385 x 1 = 9.625 KN/m
(MODEL-CUL/SP/202&CUL/SAP/202)

25 x 0.450 x 1 = 11.250 KN/m
(MODEL-CUL/SP/101&CUL/SAP/101)

3.2. SUPERIMPOSED DEAD LOAD (SIDL):

SIDL over the structure would consist of the weight of asphaltic wearing coat over the top slab of the culvert and weight of the earth fill over the top of the culvert.

Thickness of wearing coat = 65mm

Hence SIDL intensity = 22 x 0.065 x 1 = 1.43 KN/m

3.3. EARTH PRESSURE:

The structure to retain earth fills should be proportional to withstand pressure calculated in accordance with Coulomb's theory.

Height of earth retained 'H'= Clear height +Top slab thickness + Bottom slab thickness

H101 = 4 + 0.450 + 0.450 = 4.90m
(MODEL-CUL/SP/101&CUL/SAP/101)

H202 = 4 + 0.385 + 0.385 = 4.77m
(MODEL-CUL/SP/202&CUL/SAP/202)

H303 = 4 + 0.335 + 0.335 = 4.67m
(MODEL-CUL/SP/303&CUL/SAP/303)

H404 = 4 + 0.300 + 0.300 = 4.60m
(MODEL-CUL/SP/404&CUL/SAP/404)

H505 = 4 + 0.275 + 0.275 = 4.55m
(MODEL-CUL/SP/505&CUL/SAP/505)

H606 = 4 + 0.250 + 0.250 = 4.50m
(MODEL-CUL/SP/606&CUL/SAP/606)

"sp" stands for models generated in STAAD PRO & "sap" stands for models generated in SAP 2000

Considered Angle of internal friction for backfill $\Phi = 30^o$

At rest condition,

$$K = \frac{(1-\sin\Phi)}{(1+\sin\Phi)}$$

$K = 0.33$

Earth Pressure at the base of Box	K*Ydry*H101=	32.69	KN/m²
	K*Ydry*H202=	31.82	KN/m²
	K*Ydry*H303=	31.15	KN/m²
	K*Ydry*H404=	30.68	KN/m²
	K*Ydry*H505=	30.35	KN/m²
	K*Ydry*H606=	30.02	KN/m²

3.4. LIVE LOAD SURCHARGE:

Structure had been designed for a live load surcharge equivalent to 1.2m earth fill.

Height of surcharge (Clause 214.1 IRC 6:2014)	hs	= 1.2	m
Live Load Surcharge	K*γdry*hs =	8.00	KN/m²

3.5. WATER PRESSSURE:

In the design of structure, the effects of buoyancy had been considered assuming that the fill behind the abutments has been removed by scour.

Water Pressure γwater*H= 40 kN/m2

3.6. LIVE LOAD:

The design live load would consist of standard wheeled or tracked vehicles or train of vehicles as illustrated in IRC 6 2014. The trailer attached to the driving units had not been considered as detachable.

Within the kerb to kerb width of the carriageway, the standard vehicle or train had been assumed to travel parallel to the length of the culvert and to occupy any positon which would produce maximum stresses provided that the minimum clearances between a vehicle and the roadway face of kerb and between two passing or crossing vehicles.

For each standard vehicle or train, all the axles of a unit of vehicles had been considered as acting simultaneously in a position causing maximum stresses.

Culverts are divided into classes according to the loadings that they are designed to carry.

(I) *IRC CLASS 70R LOADING:* This Loading is to be normally adopted on all roads on which permanent culverts are constructed. Culverts designed for class 70 R loading should be checked for Class A Loading also as under certain conditions, heavier stresses may occur under Class A Loading.

(II) *IRC CLASS AA LOADING:* This Loading is to be adopted within certain municipal limits, in certain existing or contemplated industrial areas, in other specified areas, and along certain specified highways. Culverts designed for Class AA Loading should be checked for Class A Loading also, as under certain conditions, heavier stresses may occur under Class A Loading.

(III) *IRC CLASS A LOADING:* This loading is to be normally adopted on all roads on which permanent culverts are constructed.

3.7. IMPACT:

Provision for impact or dynamic action has been made by an increment of live load by an impact allowance expressed as a fraction or a percentage of applied live load.

CLASS A LOADING

In the members of any culvert designed either for Class A loading, this impact percentage shall be determined from the curve indicated in Figure 4.5., the impact fraction shall be determined from the following equations which are applicable for spans between 3m and 45m.

Impact factor fraction for reinforced concrete bridge or culvert $= \frac{4.5}{6 + L}$.

Where L is length in meters of the span

Impact factor fraction for culvert =

4.5/(6+4.45) = 43.1%

4.5/(6+4.385) = 43.3%

4.5/(6+4.335) = 43.5%

4.5/(6+4.300) = 43.7%

4.5/(6+4.275) = 43.8%

4.5/(6+4.25) = 43.9%

CLASS AA AND CLASS 70 R LOADING

For spans less than 9 m:

For Tracked Vehicles :	25 Percent For Spans Up To 5m Linearly Reducing To 10 Percent For Spans Up To 9m
For Wheeled Vehicles :	25 Percent

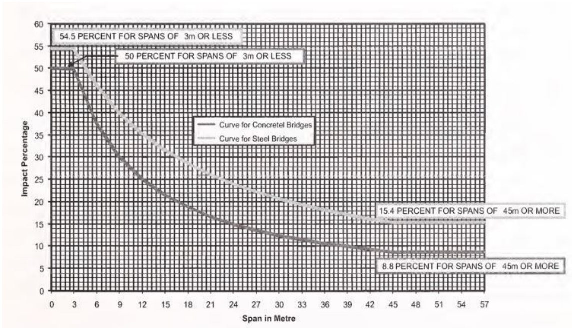
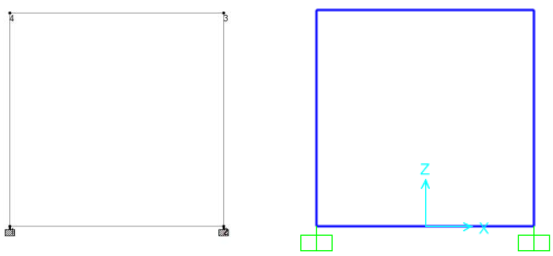


FIGURE 3.5: IMPACT PERCENTAGE FOR HIGHWAY BRIDGES FOR CLASS A LOADING

The models were generated in STAAD Pro and SAP 2000 with the above mentioned dimension and loads. The bottom slab was fixed at ends i.e. node 1 and node 2 for modelling.



(A)STAAD PRO **(B)SAP2000**

FIGURE 3.6: MODEL GENERATED IN STAAD PRO AND SAP 2000

3.8 LOAD COMBINATION

The above load intensity calculation were applied to numerically model and analyse the box culvert, from the analysis result the final 'Design Bending Moment' and 'Design Shear Force' were obtained for design using the critical load case amongst the following load combinations.

TABLE 3.6 LOAD COMBINATION

LOAD CASE NO.	LOAD COMB. (ULS BASIC)
1	DL+SIDL+SIDL(W/O)
2	DL+SIDL+SIDL(W/O)+ EARTH PRESSURE B.S+WATER LOAD
3	DL+SIDL+SIDL(W/O)+EARTH PRESSURE B.S
4	DL+SIDL+SIDL(W/O)+ EARTH PRESSURE B.S + LIVE LOAD SURCHARE
5. A	DL+SIDL+SIDL(W/O)+ EARTH PRESSURE B.S+LIVE LOAD (SAGGING)
5. B	DL+SIDL+SIDL(W/O)+ EARTH PRESSURE B.S+ LIVE LOAD (HOGGING)
6. A	DL+SIDL+SIDL(W/O)+ EARTH PRESSURE B.S+ LIVE LOAD (SAGGING) + LIVE LOAD SURCHARGE+BRAKING LOAD
6. B	DL+SIDL+SIDL(W/O)+ EARTH PRESSURE B.S+ LIVE LOAD (HOGGING) + LIVE LOAD SURCHARGE+BRAKING LOAD

IV. DESIGN PHILOSPHY

4.1 LIMIT STATE METHOD

Equations for flexure

$$\left(\frac{Xu}{d}\right)=\frac{0.87\,fy\,Ast}{0.36\,fck\,bd} \quad 4.1$$

$$\epsilon_{su}= \left(\frac{0.87fy}{Es}+0.002\right) \quad 4.2$$

$$\left(\frac{Xu}{d}\right) =\left(\frac{\epsilon cu}{\epsilon cu+\epsilon su}\right) \quad 4.3$$

$$Mu = T\ (d-0.42Xu) \quad 4.4$$

$$(X_u) = \left(\frac{0.87fyAst}{0.36}fck\ b\right) \quad 4.5$$

$$T = 0.87\ f_y A_{st} \quad 4.6$$

$$Mu=0.87\ fyAst\left[d-0.42\left(0.87\frac{fyAst}{0.36}fck\ bd\right)\right] \quad 4.7$$

$$P=100.\frac{Ast}{bd} \quad 4.8$$

$$D = \sqrt{\frac{Mu}{0.138fck.b}} \quad 4.9$$

$$Mu = 0.87fy\left(\frac{p}{100}\right)\left[1-\left(fy.\frac{p}{fck}.100\right)\right]bd2 \quad 4.10$$

Equations for Shear

$VRdc = [0.12K(80 * \rho l * fck)0.33 + 0.15 * \sigma cp] * bw * d$ 4.11

For Vertical Shear Reinforcement

$VRds = Asw/s * z * fywd * \cot\theta$ 4.12

$VRd,max = \alpha cw * bw * z * v1 * fcd/(\cot\theta + \tan\theta)$ 4.13

$Asw,max * fywd/bw * s \leq 0.5 * \alpha cw * v1 * fcd$ 4.14

For Inclined Shear Reinforcement.

$VRds = Asw/s * z * fywd * (\cot\theta + \cot\alpha l)$ 4.15

$VRd,max = \alpha cw * bw * z * v1 * fcd * (\cot\theta + \cot\alpha l)/(1 + \cot 2\,\theta)$ 4.16

$Asw,max * fywd \,/\, bw * s \leq 0.5 * \alpha cw * v1 * fcd \,/\, \sin\alpha ll$ 4.17

Min. Reinforcement Ratio

$\rho min = 0.072\sqrt{fck}\,/fyk$ 4.18

4.2 WORKING STRESS METHOD

Equations for Flexure

$$n = \left[\frac{1}{\left(1+\frac{\sigma st}{m\sigma cb}\right)}\right] \quad 4.19$$

$$m = \frac{280}{3\sigma cb} \quad 4.20$$

$$j = \left(1-\frac{n}{3}\right) \quad 4.21$$

$$Q = 0.5\sigma cbnj \quad 4.22$$

$$D = \sqrt{\frac{M}{Qb}} \quad 4.23$$

$$Ast = \frac{M}{\sigma st\, jd} \quad 4.24$$

Equations for Shear

$$Tv = \frac{V}{bd} \quad 4.25$$

$$Vs = V - TcbdAsw = (Vs * s)/(\sigma sd\,(\sin\alpha w + \cos\alpha w)) \quad 4.26$$

Pw.min = Asw/b*s = 0.4/0.87*fy ≤ 415 MPa 4.27

V. RESULTS AND DISCUSSION

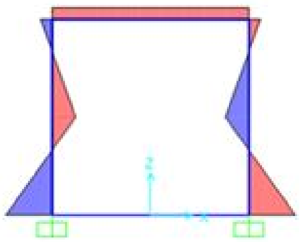


FIGURE 5.1 EARTH PRESSURE BENDING

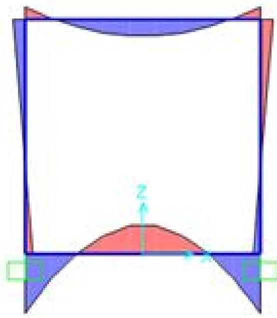


FIGURE 5.2 SELF WEIGHT BENDING MOMENT

BENDING MOMENT	STAAD PRO LHS	STAAD PRO MID	STAAD PRO RHS	SAP 2000 LHS	SAP 2000 MID	SAP 2000 RHS
TOP SLAB	LHS	MID	RHS	LHS	MID	RHS
DISTANCE FROM LEFT END	0	2.225	4.45	0	2.225	4.45
DEAD LOAD + SIDL(W/O WC)	12.377	-15.471	12.377	12.38	-15.13	12.38
WATER LOAD	-8.801	-8.801	-8.801	-8.8	-8.8	-8.8
LIVE LOAD SURCHARGE LOAD	4.401	4.401	4.401	4.4	4.4	4.4
EARTH PRESSURE BOTH SIDE	7.683	7.683	7.683	7.68	7.68	7.68
SIDL(WC)	1.573	-1.967	1.573	1.57	-1.92	1.57
LIVE LOAD HOGGING	43.535	-	43.535	43.53	-	43.53
LIVE LOAD SAGGING	-	-54.419	-	-	-53.21	-

TABLE 5.1 VARIATION IN BENDING MOMENT USING STAAD PRO AND SAP 2000 (TOP SLAB)

SIDE WALL	SAP 200 BOTTOM	SAP 200 MID	SAP 200 TOP	STAAD PRO BOTTOM	STAAD PRO MID	STAAD PRO TOP
DISTANCE FROM TOP	4.45	2.225	0	4.45	2.225	0
DEAD LOAD + SIDL(W/O WC)	-6.19	3.09	12.38	-6.188	3.094	12.377
WATER LOAD	-48.41	20.9	-8.8	-48.406	20.903	-8.801
LIVE LOAD SURCHARGE LOAD	17.6	-8.8	4.4	17.602	-8.801	4.401
EARTH PRESSURE BOTH SIDE	41.02	-17.94	7.68	41.021	-17.939	7.683
SIDL(WC)	-0.79	0.39	1.57	-0.787	0.393	1.573
LIVE LOAD HOGGING	-	37	43.53	-	37.004	43.535
LIVE LOAD SAGGING	-21.77	-15.23	-	-21.767	-15.237	-

TABLE 5.2 VARIATION IN BENDING MOMENT USING STAAD PRO AND SAP 2000 (SIDE WALL)

BOTTOM SLAB	SAP 2000 RHS	SAP 2000 MID	SAP 2000 LHS	STAAD PRO RHS	STAAD PRO MID	STAAD PRO LHS
DISTANCE FROM LEFT END	4.45	2.225	0	4.45	2.225	0
DEAD LOAD + SIDL(W/O WC)	-55.69	26.82	-55.69	-59.449	29.724	-59.449
WATER LOAD	0	0	0	0	0	0
LIVE LOAD SURCHARGE LOAD	0	0	0	0	0	0
EARTH PRESSURE BOTH SIDE	0	0	0	0	0	0
SIDL(WC)	-2.36	1.14	-2.36	-2.36	1.18	-2.36
LIVE LOAD HOGGING	0	31.44	0	0	32.651	0
LIVE LOAD SAGGING	-65.3	-31.44	-65.3	-65.302	-32.65	-65.302

TABLE 5.3 VARIATION IN BENDING MOMENT USING STAAD PRO AND SAP 2000 (BOTTOM SLAB)

TOP SLAB	SAP 2000			STAAD PRO		
	RHS	MID	LHS	RHS	MID	LHS
DISTANCE FROM LEFT END	4.45	2.225	0	4.45	2.225	0
DEAD LOAD + SIDL(W/O WC)	-25.03	0	25.03	-25.031	0	25.031
WATER LOAD	-20.77	-20.77	-20.77	-20.767	-20.767	-20.767
LIVE LOAD SURCHARGE LOAD	14.83	14.83	14.83	14.833	14.833	14.833
EARTH PRESSURE BOTH SIDE	18.96	18.96	18.96	18.964	18.964	18.964
SIDL(WC)	-3.18	0.53	3.18	-3.182	0	3.182
LIVE LOAD	-	70.43	88.04	0	70.438	88.048
	-88.04	-70.43	0	-88.048	-70.438	0

TABLE 5.4 VARIATION IN SHEAR FORCE USING STAAD PRO AND SAP 2000 (TOP SLAB)

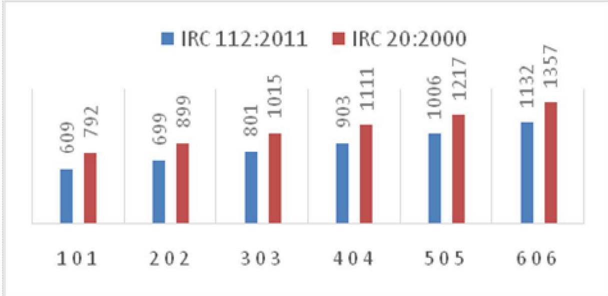
SIDE WALL	SAP 2000			STAAD PRO		
	TOP	MID	BOTTOM	TOP	MID	BOTTOM
DISTANCE FROM BOTTOM	4.45	2.225	0	4.45	2.225	0
DEAD LOAD + SIDL(W/O WC)	-4.17	-4.17	-4.17	-4.17	-4.17	-4.17
WATER LOAD	-20.77	1.483	68.23	-20.767	1.483	68.233
LIVE LOAD SURCHARGE LOAD	14.83	-2.96	-20.77	14.833	-2.967	-20.767
EARTH PRESSURE BOTH SIDE	18.96	-1.71	-57.06	18.964	-1.712	-57.065
SIDL(WC)	3.182	3.182	3.182	3.182	3.182	3.182
LIVE LOAD	14.67	14.67	14.67	14.674	14.674	14.674
	0	0	0	0	0	0

TABLE 5.5 VARIATION IN SHEAR FORCE USING STAAD PRO AND SAP 2000 (SIDE WALL)

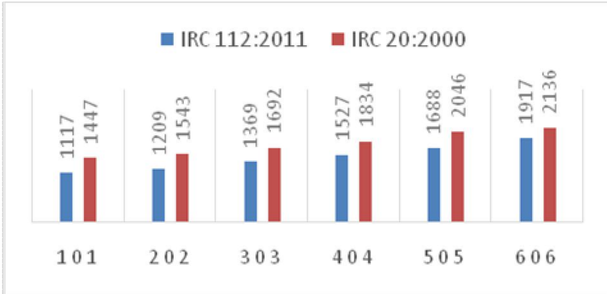
BOTTOM SLAB	STAAD PRO TOP	STAAD PRO MID	STAAD PRO BOTTOM	SAP 2000 TOP	SAP 2000 MID	SAP 2000 BOTTOM
DISTANCE FROM LEFT SIDE	4.45	2.225	0	4.45	2.225	0
DEAD LOAD + SIDL(W/O WC)	80.156	0	-80.156	75.09	0	75.09
WATER LOAD	0	0	0	0	0	0
LIVE LOAD SURCHARGE LOAD	0	0	0	0	0	0
EARTH PRESSURE BOTH SIDE	0	0	0	0	0	0
SIDL(WC)	3.182	0	-3.182	3.182	0	-3.182
LIVE LOAD	0	0	88.05	0	0	88.06
	-88.05	0	0	-88.06	0	0

TABLE 5.6 VARIATION IN SHEAR FORCE USING STAAD PRO AND SAP 2000 (BOTTOM SLAB)

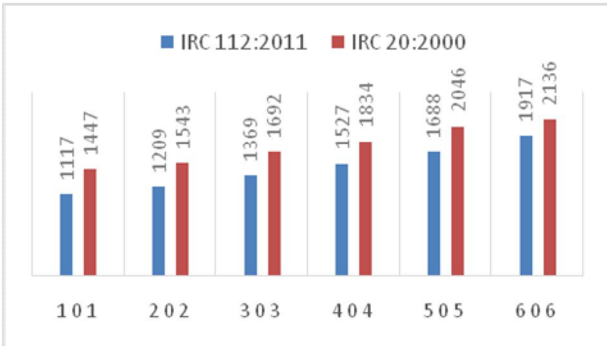
From Table 5.1 to Table 5.6 it is clear that the shear force and bending moment values obtained from the two different software converge with slight variation in values. The sign convention followed in the two software are different hence the values obtained from SAP 2000 were multiplied by a factor of -1 in order to converge with the results obtained from STAAD Pro.



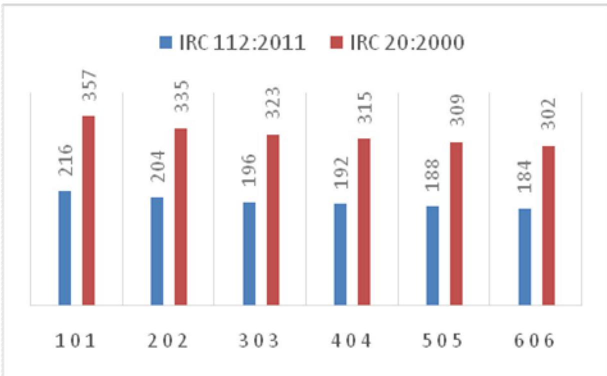
GRAPH 5.1 AREA OF STEEL REQUIRED FOR TOP SLAB OF CULVERT



GRAPH 5.2 AREA OF STEEL REQUIRED FOR BOTTOM SLAB OF CULVERT



GRAPH 5.3 AREA OF STEEL REQUIRED FOR SIDE WALL OF CULVERT



GRAPH 5.4 EFFECTIVE DEPTH REQUIRED FOR TOP SLAB OF CULVERT

GRAPH 5.5 EFFECTIVE DEPTH REQUIRED FOR BOTTOM SLAB OF CULVERT

GRAPH 5.6 EFFECTIVE WIDTH REQUIRED FOR SIDE WALL OF CULVERT

From graph 5.1 to 5.3 it is clear that IRC 112 :2011 reduces the area of tension reinforcement in top slab by 16.5% to 21.3%, in side wall and bottom slab by 10.25% to 22.8%. From the graph 5.4 to 5.6 it is clear that deff required as per IRC 112:2011 decrease by 65%.

The deff required in model 404, 505 and 606 are greater than the deff provided for WSM, hence the design were not performed for these culverts. The culvert 404, 505 and 606 fails in minimum deff requirement as per WSM.

VI. CONCLUSION

i. From Table 5.1 to Table 5.6 it is clear that the shear force and bending moment values obtained from the two different software converge with slight variation in values. The sign convention followed in the two software are different hence the values obtained from SAP 2000 were multiplied by a factor of -1 in order to converge with the results obtained from STAAD Pro.

ii. From graph 5.1 to 5.3 it is clear that IRC 112 :2011 reduces the area of tension reinforcement in top slab by 16.5% to 21.3%, in side wall and bottom slab by 10.25% to 22.8%.

iii. From the graph 5.4 to 5.6 it is clear that deff required as per IRC 112:2011 decrease by 65%.

iv. The deff required in model 404, 505 and 606 are greater than the deff provided for WSM, hence the design were not performed for these culverts. The culvert 404, 505 and 606 fails in minimum deff requirement as per WSM.

v. From the above graphs it is clear that the most economical section in terms of area of reinforcement is culvert 101 and in terms of volume of concrete is culvert 606. Depending on the site requirement and availability of materials the cost optimization can be performed to obtain the optimum solution based on cost for box culvert. Preferably ratio of 1/14 to 1/18 can be preferred

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