Design and Analysis of Box Culvert and Result Comparison with SAP

Sanskruti Bhagat(1) Raksha Chaudhari(2) Rupali Gade(3) Nutan Patil(4) Divyani Rade(5)

Prof. V. T. Patil(6)

[1,2,3,4,5] Fourth year Student Civil Engineering, Government College of Engineering Jalgaon-425001[MS]India
[6]Assistant professor Civil Engineering, Government College of Engineering Jalgaon-425001[MS]India

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Abstract - *Structure which allows cross drainage of water is known as culvert. A culvert close rectangular reinforced concrete structure which consists of three components top and bottom slab with vertical walls is known as box culvert. Box culvert is made of different material such as RCC and masonry. In a box culvert, pipe solution is inappropriate. It is defaulting buried type of structure. In these large openings are required to provide hydraulic capacity. This structure is designed to take vehicle load pedestrian traffic to cross over and to pass water under a road at natural drainage and river crossing. The reinforcement which is used in a concrete box culvert may be conventional bar reinforcement, welded wire fabric. Yield strength of welded wire fabric is larger than conventional bar reinforcement.*

Key Words: **Culvert, hydraulic capacity, natural drainage, reinforcement, load pedestrian.**

1.INTRODUCTION

Box culvert are subjected to various loads such as active earth pressure, traffic and soil water pressure. Hence, there is need to designed and analyzed box culvert properly to prevent failure. The box culvert which is used in cross drainage work are analyzed for load cases: culvert with full and culvert with empty. But it is analyzed for empty load case. It is monolithic structure which is used in construction of highways and railways project to balance flood on each side of loads. Box culvert which has top and bottom slab are monolithically connected to the vertical walls but in case of slab culvert there is no monolithic connection. This structure is strong safe, stable and very easy to construct and has many advantages when compared to slab culvert or arch culvert. One of the main advantages is that, it is placed at any elevation in the embankment with varying cushions which is not possible for any other type of culvert. Box culvert is placed in such a way that top slab is at road level and there is no need for cushion and it has more than one cell. There are various types of culvert arch culver, slab culvert, pipe culvert but box culvert has many advantages like stability which is better than other type of culverts. The construction process of box culvert is easy and simple and structurally strong. It can be placed at elevation with wearing cushion which is not possible for a slab culvert, arch culvert, pipe culvert and any other type of culvert. Separate foundation is not required.

popular. It is found in various shapes like circular elliptical, pipe arch etc. its shape depends on site condition.

3. Box culverts: In the box culvert there is need to provide large openings to provide adequate water carrying capacity. In box culvert if water is not flowing through the culvert, then these culverts are used by pedestrian or cattle underpass.

4. Cast-In-Place concrete Box culverts: This type of culvert where only used in older days. But now a days various box culverts installations are precast because of various reasons such as lack of time required for and construction.

1.2 Applications of Box Culvert

i. Box culvert has long life span.
ii. Box culvert is generally used for non-perennial streams and where the sub grade soil is weak and depth is not significant.
iii. Box culvert is more economical due to its rigidity and monolithic application.
iv. In these bearings are not needed
v. In this type of culvert separate foundations are not needed.

Dead load and superimposed load are disturbed because bottom slab of culvert act as raft foundation.

2. METHODOLOGY

The culvert which used in cross drainage work is analyzed for the load cases which is given below.

1.Running full condition: In such type of situation Box culvert is subjected to dead load, live load, earth pressure which is coming from outside, lateral pressure due to live load and the water pressure from inside Box. This whole analysis is done through manual calculation and verified through software SAP 2000 in 2D analysis.

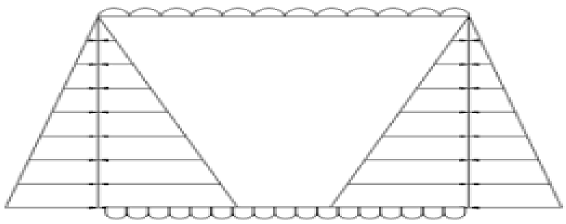

Fig 1: Culvert in Full Condition

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2. Empty condition: In such type of situation box culvert is subjected to dead load, lateral pressure due to live load, live load, earth pressure which is coming from outside,

Fig 2: Culvert in Empty Condition

3. ANALYSIS AND DESIGN OF BOX CULVERT

For calculating the final moments, we need to first calculate the design loads acting on it due to which moments are developed.

Here, we are analyzing a box culvert of clear dimension 4m x 4m for the following data:

Live load = Class AA tracked vehicle

Density of soil = 18KN/m^2

Angle of internal friction of soil = 30^0

Width of bridge deck = 8.7 m

Safe bearing capacity of soil (SBC) = 120 KN/m^2

Grade of Concrete = M 30

Grade of steel = Fe 415

3.1 Dead Load

CLEAR WIDTH	4	m
CLEAR HEIGHT	4	m
SECTION DEPTH	420	mm
CONCRETE DENSITY(ϒ)	25	kN/m³
EFFECTIVE SPAN	4.42	m
EFFECTIVE HEIGHT	4.42	m
(EF SPAN = CL SPAN + S/C DEPTH) Cl.305.4, IRC:21		
SELF WT OF SLAB	B*d*ϒ 10.5	kN/m
TOTAL WT OF SLAB	**46.41**	kN
BASE PRESSURE	TOTAL WT ACTING / BASE SPAN **42**	kN/m

Table 1 : Calculations for Dead Load

(FEM)AB=	**-17.094**	kNm
(FEM)AD=	**0**	kNm
(FEM)DA=	**0**	kNm
(FEM)DC=	**51.283**	kNm

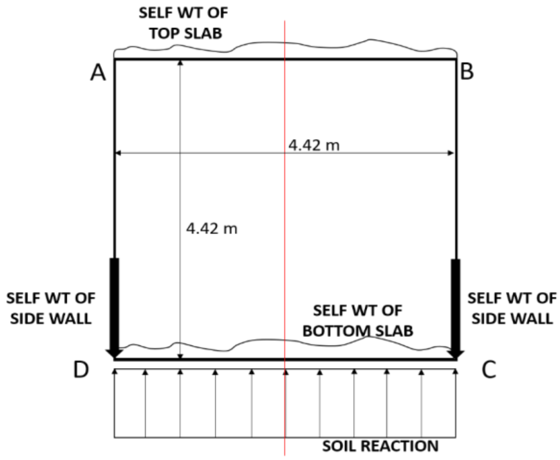

Table 2: Calculations of Fixed end moments

Fig 3: Loading diagram of box culvert

Joint	A		B	
Member	AB	AD	DA	DC
D. F.	0.333	0.667	0.667	0.333
FEM	-17.094	0.000	0.000	51.283
DIST	5.698	11.396	-34.189	-17.094
C. O.	0.000	-17.094	5.698	0.000
DIST	5.698	11.396	-3.799	-1.899
C. O.	0.000	-1.899	5.698	0.000
DIST	0.633	1.266	-3.799	-1.899
C. O.	0.000	-1.899	0.633	0.000
DIST	0.633	1.266	-0.422	-0.211
C. O.	0.000	-0.211	0.633	0.000
DIST	0.070	0.141	-0.422	-0.211
C. O.	0.000	-0.211	0.070	0.000
DIST	0.070	0.141	-0.047	-0.023
C. O.	0.000	-0.023	0.070	0.000
DIST	0.008	0.016	-0.047	-0.023
C. O.	0.000	-0.023	0.008	0.000
DIST	0.008	0.016	-0.005	-0.003
C. O.	0.000	-0.003	0.008	0.000

DIST	0.001	0.002	-0.005	-0.003
C. O.	0.000	-0.003	0.001	0.000
DIST	0.001	0.002	-0.001	0.000
FINAL	**-4.274**	**4.274**	**-29.915**	**29.915**

Table 3: Moment Distribution for DL

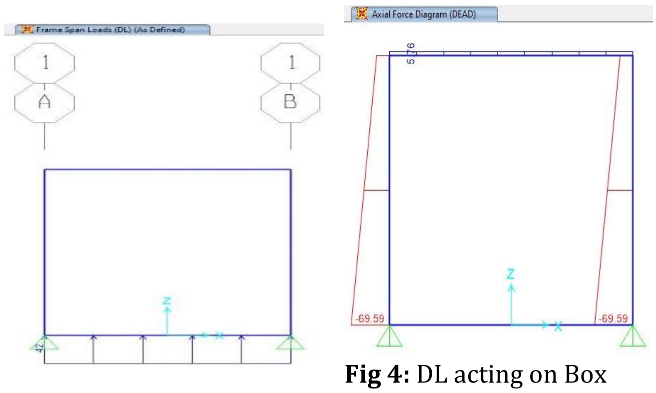

Fig 4: DL acting on Box Culvert &AFD due to DL (KN)

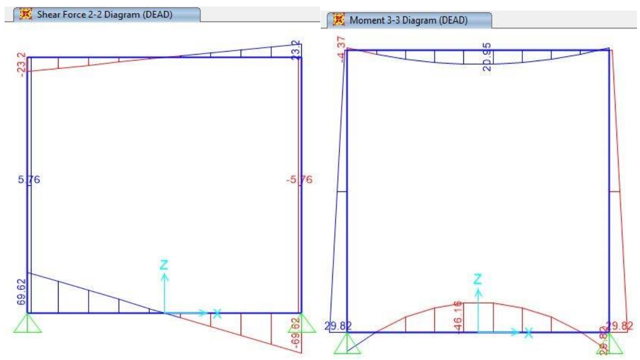

Fig 5: SFD due to DL & BMD due to DL (KN)

3.2 Wearing Coat

WIDTH	4 m
HEIGHT	4 m
SECTION DEPTH	420 mm
ASPHALTIC CONCRETE DENSITY	22 kN/m^3
THICKNESS OF WEARING COURSE	56 mm
EFFECTIVE SPAN	4.42 m
EFFECTIVE HEIGHT	4.42 m
LIVE LOAD SURCHARGE (SU) psu	1.232 kN/m

Table 5: Calculations for Wearing coat

Table 6: Fixed End Moments

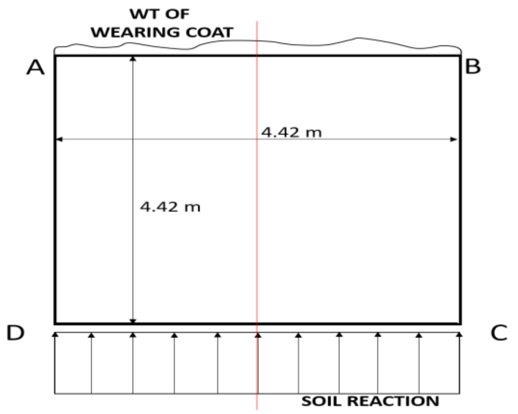

Fig 6: Loading Diagram of WC

Table 7: Moment Distribution for WE

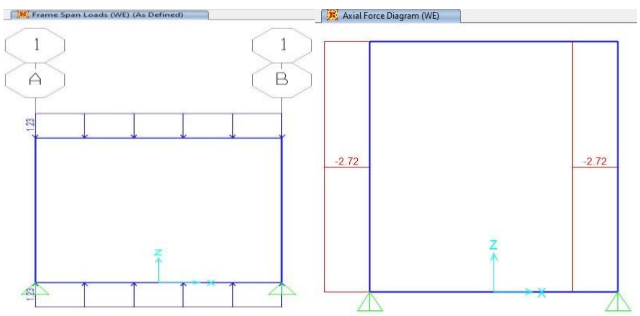

Fig 7: WE acting on Box Culvert & AFD due to WE

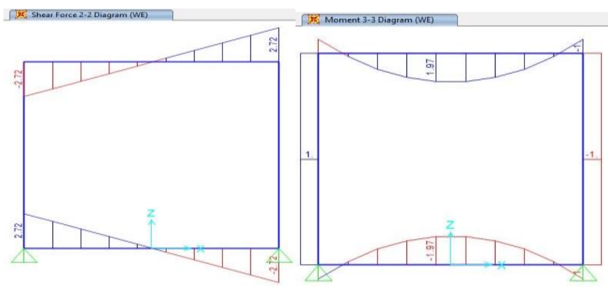

Fig 8: SFD due to WE &BMD due to WE (KNm)

3.3 Live Load

(FEM)AB	-2.006 kNm
(FEM)AD	0.000 kNm
(FEM)DA	0.000 kNm
(FEM)DC	2.006 kNm

Joint	A		B	
Member	AB	AD	DA	DC
D. F.	0.333	0.667	0.667	0.333
FEM	-2.006	0.000	0.000	2.006
DIST	0.669	1.337	-1.337	-0.669
C. O.	0.000	-0.669	0.669	0.000
DIST	0.223	0.446	-0.446	-0.223
C. O.	0.000	-0.223	0.223	0.000
DIST	0.074	0.149	-0.149	-0.074
C. O.	0.000	-0.074	0.074	0.000
DIST	0.025	0.050	-0.050	-0.025
C. O.	0.000	-0.025	0.025	0.000
DIST	0.008	0.017	-0.017	-0.008
C. O.	0.000	-0.008	0.008	0.000
DIST	0.003	0.006	-0.006	-0.003
C. O.	0.000	-0.003	0.003	0.000
DIST	0.001	0.002	-0.002	-0.001
C. O.	0.000	-0.001	0.001	0.000
DIST	0.000	0.001	-0.001	0.000
C. O.	0.000	0.000	0.000	0.000
DIST	0.000	0.000	0.000	0.000
C. O.	0.000	0.000	0.000	0.000
DIST	0.000	0.000	0.000	0.000
FINAL	-1.003	1.003	-1.003	1.003

WIDTH	4	m
HEIGHT	4	m
SECTION DEPTH	420	mm
EFFECTIVE SPAN (l)	4.42	m
EFFECTIVE HEIGHT	4.42	m
THICKNESS OF WEARING	56	mm
TOTAL LOAD	700	kN
TYRE CONTACT AREA	3.6	m
EFFECTIVE LENGTH (Cl.305.16.3, IRC:21-20000000000000)	4.552	m
But le=4.42m as (4.552m>4.42m)		
LOAD ACTING ON CULVERT	679.7	kN
DIST OF CG OF LOAD (a)	2.21	m
LENGTH OF BOX CULVERT	7.5	m

COMBINED LENGTH (b)	8.7 m
b/l RATIO	1.97
α (For Continuous Slab) Cl.B.3.2, IRC:1122011	2.6
EFFECTIVE WIDTH (bef)	(αa(1-(a/l) +b1)
	3.835 m
NET EFFECTIVE WIDTH	5.885 m
INTENSITY OF LL (WLL)	26.13 kN/m^2
IMPACT FACTOR	1.25
ULTIMATE LL	32.66 kN/m^2

Table 9: Calculation for Live Load

(FEM)AB	-53.177 kNm
(FEM)AD	0.000 kNm
(FEM)DA	0.000 kNm
(FEM)DC	53.177 kNm

Table 10 : Fixed End Moment

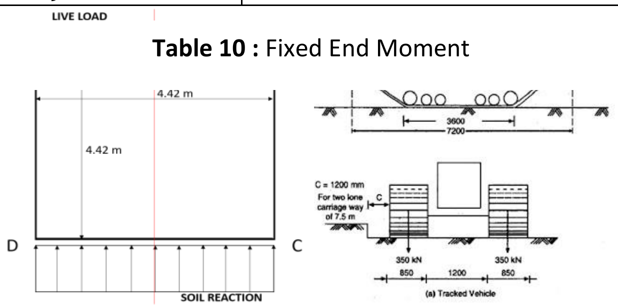

Fig 9 : Loading Diagram of LL

Joint	A		B	
Member	AB	AD	DA	DC
D. F.	0.333	0.667	0.667	0.333
FEM	-53.177	0.000	0.000	53.177
DIST	17.726	35.451	-35.451	-17.726
C. O.	0.000	-17.726	17.726	0.000
DIST	5.909	11.817	-11.817	-5.909
C. O.	0.000	-5.909	5.909	0.000
DIST	1.970	3.939	-3.939	-1.970
C. O.	0.000	-1.970	1.970	0.000
DIST	0.657	1.131	-1.313	-0.657
C. O.	0.000	-0.657	0.657	0.000
DIST	0.219	0.438	-0.438	-0.219
C. O.	0.000	-0.219	0.219	0.333
DIST	0.073	0.416	-0.146	-0.073
C. O.	0.000	-0.073	0.073	0.000
DIST	0.024	0.049	-0.049	-0.024
C. O.	0.000	-0.024	0.024	0.000
DIST	0.008	0.016	-0.016	-0.008
C. O.	0.000	-0.008	0.008	0.000
DIST	0.003	0.005	-0.005	-0.003
C. O.	0.000	-0.003	0.003	0.000
DIST	0.001	0.002	-0.002	-0.001
FINAL	-26.589	26.589	-26.589	26.589

Table 11: Moment Distribution of live load

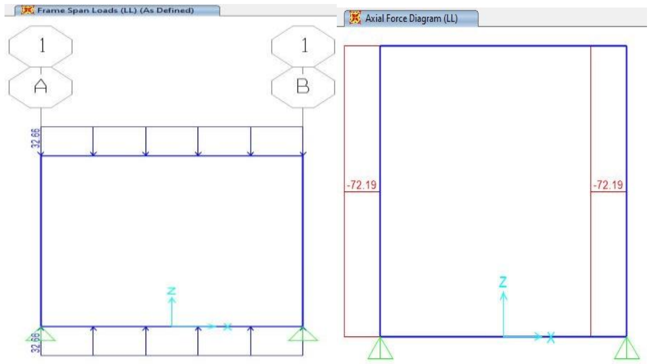

Fig 10 : LL acting on Box Culvert & AFD due to LL (kN)

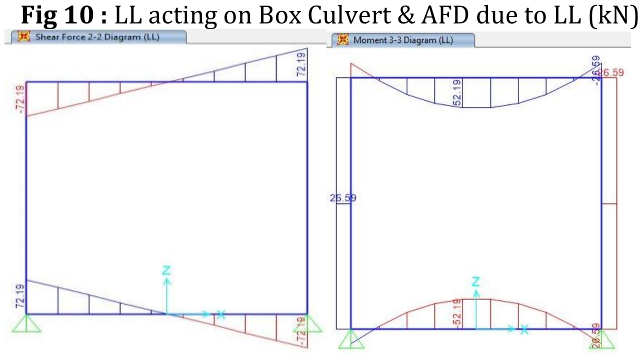

Fig 11 : SFD due to LL (kN)&BMD due to LL(kNm)

3.4 Earth Pressure

WIDTH	4 m
HEIGHT	4 m
SECTION DEPTH	420 mm
SOIL DENSITY	18 kN/m^3
ANGLE OF INT FRICTION	30
COEFF OF EP AT REST(k_o)	0.5
EFFECTIVE SPAN	4.42 m
EFFECTIVE HEIGHT	4.42 m
Ph AT CENTER OF TOP SLAB(h=t/2)	1.89 kN/m^2
Ph AT CENTER OF BOTTOM SLAB (h=EFF HT+t/2)	41.67 kN/m^2

Table 12 : Calculations for EP

(FEM)AB	0.000 kNm
(FEM)AD	28.982 kNm
(FEM)DA	-41.935 kNm
(FEM)DC	0.000 kNm

Table 13 : Fixed End Moments

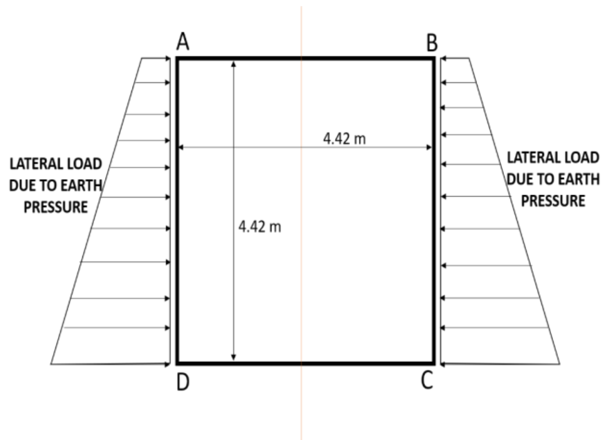

Fig 12 : Loading Diagram of EP

Joint	A		B	
Member	AB	AD	DA	DC
D. F.	0.333	0.667	0.667	0.333
FEM	0.000	28.982	-41.93	0.000
DIST	-9.661	-19.321	27.957	13.978
C. O.	0.000	13.978	-9.661	0.000
DIST	-4.659	-9.319	6.440	3.220
C. O.	0.000	3.220	-4.659	0.000
DIST	-1.073	-2.147	3.106	1.553
C. O.	0.000	1.553	-1.073	0.000
DIST	-0.518	-1.035	0.716	0.358
C. O.	0.000	0.358	-0.518	0.000
DIST	-0.119	-0.239	0.345	0.173
C. O.	0.000	0.173	-0.119	0.000
DIST	-0.058	-0.115	0.080	0.040
C. O.	0.000	0.040	-0.058	0.000
DIST	-0.013	-0.027	0.038	0.019
C. O.	0.000	0.019	-0.013	0.000
DIST	-0.006	-0.013	0.009	0.004
C. O.	0.000	0.004	-0.006	0.000
DIST	-0.001	-0.003	0.004	0.002
C. O.	0.000	0.002	-0.001	0.000
DIST	-0.001	-0.001	0.001	0.000
FINAL	-16.110	16.110	-19.348	19.348

Table 14 : Moment Distribution for EP

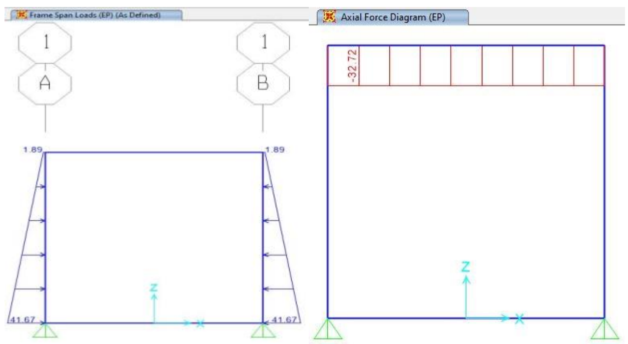

Fig 13 : EP acting on Box Culvert & AFD due to EP (KN)

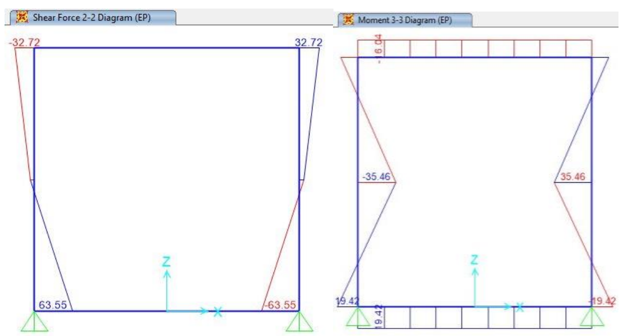

Fig 14 : SFD due to EP (kN) & BMD due to EP (kNm)

3.5 Live Load Surcharged

WIDTH	4	m
HEIGHT	4	m
SECTION DEPTH	420	mm
SOIL DENSITY	18	kN/m^3
ANGLE OF INT FRICTION	30	°
EFFECTIVE SPAN	4.4	m
EFFECTIVE HEIGHT	4.4	m
COEFF OF EP AT REST(k_o)	0.5	
EQUIVALENT HT OF SOIL (heq) (Cl.214.1.1.3, IRC:6)	1.2	m
LIVE LOAD SURCHARGE(SU) psu	11	kN/m^2

Table 15 : Calculations for SU

(FEM)AD	17.583 kNm
(FEM)AB	0 kNm
(FEM)BA	0 kNm
(FEM)BC	-17.583 kNm

Table 16 : Fixed End Moments

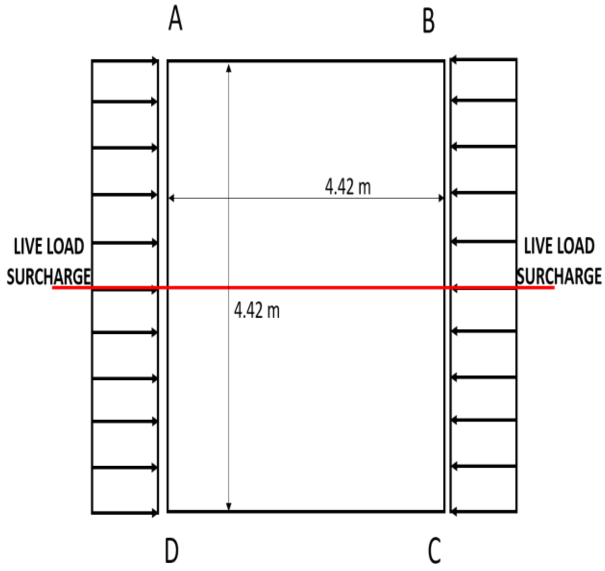

Fig 15 : Loading Diagram of SU

Joint	A		B	
Member	AB	AD	DA	DC
D. F.	0.333	0.667	0.667	0.333
FEM	17.583	0.000	0.000	-17.583
DIST	-5.861	-11.722	11.722	5.861
C. O.	0.000	5.861	-5.861	0.000
DIST	-1.954	-3.907	3.907	1.954
C. O.	0.000	1.954	-1.954	0.000
DIST	-0.651	-1.302	1.302	0.651
C. O.	0.000	0.651	-0.651	0.000
DIST	-0.217	-0.434	0.434	0.217
C. O.	0.000	0.217	-0.217	0.000
DIST	-0.072	-0.145	0.145	0.072
C. O.	0.000	0.072	-0.072	0.000
DIST	-0.024	-0.048	0.048	0.024
C. O.	0.000	0.024	-0.024	0.000
DIST	-0.008	-0.016	0.016	0.008
C. O.	0.000	0.008	-0.008	0.000
DIST	-0.003	-0.005	0.005	0.003
C. O.	0.000	0.003	-0.003	0.000
DIST	-0.001	-0.002	0.002	0.001
C. O.	0.000	0.001	-0.001	0.000
DIST	0.000	-0.001	0.001	0.000
FINAL	8.792	-8.792	8.792	-8.792

Table 17 : Moment Distribution for SU

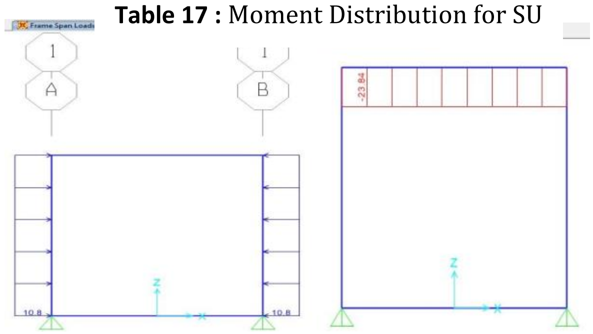

Fig 16 : SU acting on Box Culvert& AFD due to SU (kN)

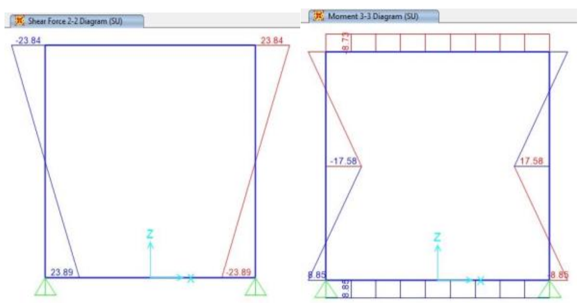

Fig 17 : SFD due to SU (kN) & BMD due to SU (kNm)

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3.6 Load Factor

Partial Safety Factors for Verification of Structural Strength according to Ultimate Limit State as per Table B.2, Annex B, IRC: 6-2016

Table 18 : Partial safety factors

As per above stated partial safety factors, model of basic combination of loads applied to box culvert is generated in software.

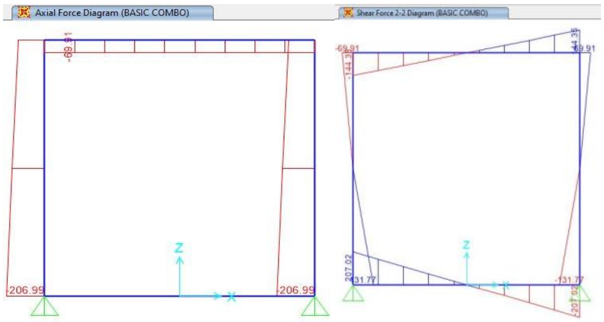

Fig 18 : AFD due to basic combination SFD due to basic combination

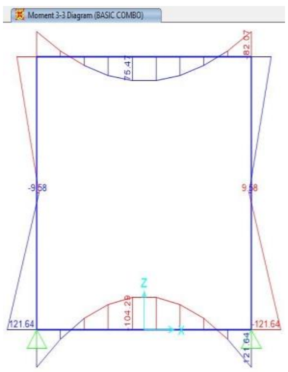

Fig 18 : BMD due to Basic Combination (kNm)

3.7 Design of Box Culvert

Check for effective depth required

$d = \sqrt{M/Qb}$

$= \sqrt{121.64 * 10^6 / 1.2*1000}$

$= 318.38 <$ provide effective depth

Design of top slab

Ast = M / σst *j *d

= $82.07*10^6 / 200*0.9*360$

D = 420-50-20/2

= 360mm

Ast = 1266.51mm^2

Take 20mm bar

Spacing = [(π*20*20/4)/1266.51]*1000

= 248.05mm

Provide 20mm bar @240mm c/c on both faces

Distribution reinforcement

Ast = 0.2% of gross area

= (0.2 *420*1000) / 100

= 840 mm^2.................................... for both faces

Ast on each face = 840 /2

= 420 mm^2

Take 8mm bar

Spacing = [(π*8*8/4)/420]*1000

= 119.67mm

Provide 8mm bar @119mm c/c both faces

Design of bottom slab

Ast = M / σst *j *d

= $121.64*10^6 / 200*0.9*360$

= 1877.16 mm^2

Take 20mm bar

Spacing = [(π*20*20/4)/420]*1000

=160mm

Provide 20mm bar @160mm

Distribution reinforcement

Ast = 0.2% of gross area

= (0.2 *420*1000) / 100

= 840 mm^2.................................... for both faces

Sr. No.	Loads	Basic Combination
1	DL	1.35
2	WE	1.75
3	LL	1.50
4	EP	1.50
5	SU	1.20

Ast on each face = 840 /2

= 420 mm^2

Take 8mm bar

Spacing = [(π*8*8/4)/420]*1000

= 119.67mm

Provide 8mm bar @119mm c/c both faces

Design of side walls

Ast = M / σst *j *d

= $121.64*10^6 / 200*0.9*360$

= 1877.16 mm^2

Take 20mm bar

Spacing = [(π*20*20/4)/420]*1000

=160mm

Provide 20mm bar @160mm

Distribution reinforcement

Ast = 0.2% of gross area
= (0.2 *420*1000) / 100
= 840 mm^2……………………………. for both faces
Ast on each face = 840 /2
= 420 mm^2
Take 8mm bar
Spacing = [(π*8*8/4)/420]*1000
= 119.67mm
Provide 8mm bar @119mm c/c both faces

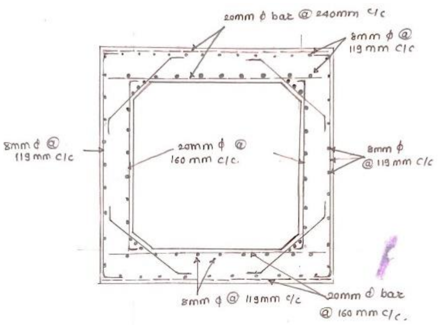

Fig 18 : Designing of Box Culvert

4. CONCLUSIONS

There exist many types of culverts of different types, size and shape but Concrete box culvert are the best when it comes to durability. This type of culvert provides economical satisfaction. It is easy to construct and saves time and money. Moment Distribution method was used for design and analysis of this culvert. One of the advantages of this culvert is that it needs no maintenance.

5. REFERENCES

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