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Analysis and Design of RCC Box Culvert using Self-Healing Concrete

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***Abstract*— This study focus on the analysis and design of a Reinforced Cement Concrete box culvert comprising self-healing concrete to improve durability and lifelong performance. The box culvert is designed under critical load combinations, including dead load, live load, earth pressure, and hydrostatic pressure in accordance with applicable IRC and IS codes, manual calculations and STAAD.Pro software are used for the structural analysis and design of the box culvert. The self-healing concrete is used to enhanced the strength, durability, and crack resistance of the box culvert. The bacillus subtilis powder is used as a self healing material which mixed with cement as it increase compressive strength of concrete compared to conventional concrete and reduce the risk of corrosion and act as a crack healing material. Although STAAD.Pro cannot directly model self-healing behaviour so its impact is evaluated in term of enhance material performance on the experimental study basis.**

***Index Terms*— Reinforce cement concrete, Dead load, Live load, self- healing concrete.**

I. INTRODUCTION

An RCC box culvert is a unified rigid structure comprising a bottom slab, top slab, side wall, and haunches, with wing walls or headwall provided when required for soil retention. The top slab transfers vehicular live loads, while the bottom slab resists soil pressure and uplift forces. Side walls carry lateral earth and water pressures, ensuring safe load transfer within the system. Design considerations add DD and LL, earth pressure, and hydrostatic pressure analyzed using relevant IS and IRC standards.

Incorporating self-healing concrete further improves durability. Bacillus subtilis powder is added to cement content to promote microcrack healing, minimize leakage, and enhance long-term structural performance. Conventional concrete is the most commonly used material. The tensile strength of concrete is low. Self-healing concrete increases a structure's longevity. It increases the structure's compressive strength by utilizing surface-dwelling bacteria to support the structure. After the development of cracks in the concrete , it starts to lose its distinctive strength, longevity, durability, etc.

An essential component of the study is the use of bacterial powder in concrete since it influences the characteristics of concrete. This study examines the design and analysis of an RCC box culvert using the idea of self-healing concrete. Compressive strength tests at 3, 7, and 28 days are used to ingress the performance of bacterial subtilis powder at 3% and 6% of the cement content in comparison to conventional concrete on the basis of the experiment study compressive strength and crack width is compared between self healing concrete and conventional concrete.

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II. DESIGN OF RCC BOX CULVERT

The RCC box culvert analysis and design follow a methodical approach to ensure structural safety and efficiency of hydraulics. The process begins by selecting the clear internal dimensions based on need of hydraulic. In this study 2.5 m × 2.5 m opening is considered suitable for the design discharge. The vehicular loading is adopted as per IRC provisions, using IRC Class AA tracked load along with M40 grade concrete and Fe415 steel. A centerline frame is assumed, and an initial wall and slab thickness of 300 mm is selected. The frame dimensions corresponding to this thickness work out to 2.8 m × 2.8 m. The culvert is then analyzed for all critical load cases, including DL, LL, earth pressure, and water pressure, and the resulting BM and shear forces are computed using the Moment Distribution Method (MDM). The structural elements are designed based on the most critical results, with checks for depth, shear, and reinforcement detailing as per IS and IRC standards. As per IS 1893-1984 (Clause 6.1.3), seismic loading is not considered necessary for box culverts.

CASE 01: DLWhen there is no internal water pressure, DL & LL act from outside.

$W=\frac{PI}{bef}$

$bef=\alpha x\left[1-\frac{x}{L}\right]+bw$

B = 7.5 m , L= 3.0 m, B/L = 2.5

(From table no.4.1 IRC 21), for B/L , α = 2.6

Taking 80mm as wearing coat.

$bef= 2.60*1.65\left[1-\frac{1.65}{3.1}\right]+0.85+2*0.08$

bef = 2.94 m.

{where, $x=1.2+\frac{0.85}{2}=1.65$

After allowing for overlap ,the net effective width of dispersion for tracks

$=1.2+\frac{0.85}{2}+2.05+\frac{2.94}{2}=5.17m$

Effective width of dispersion is leff = 3.6+2[0.3+0.08] = 4.36m.

The length is greater than actual span available. Therefore the intensity of L.L proportionately reduced, but in case of multiple box culvert:-

For IRC class AA loading, impact factor=25% for 5m span and decreasing linearly to 10% for 9m span.

Total load of two tracks with impact $=\frac{2.8}{4.36}*700*1.25=562KN$

Avg. intensity of load $=\frac{682.33}{4.36X2.8}= 46.02$ KN/m2.

D.L of slab = 14KN/m2.

D.L of top slab = 0.3 * 25 = 7.5KN/m2

Total load on the culvert = D.L + L.L

=14 + 46 = 60 KN/m2.

Therefore, total design load on top slab = 60 + 7.5 = 67.5 KN/m2.

Wt. of each wall = 2.8 * 0.3 * 25 = 21KN/m

Upward soil reaction at base=

$=\frac{60X2.8+2X21}{2.8X1}= 75$ KN/m2.

Lateral Pressure:

Coefficient of Active earth pressure is $Ka=\frac{1-\sin 45}{1+\sin 45}=0.080$

Figure no . 1- Loading

Lateral pressure due to DL and LL = 60 * 0.080 = 4.83 KN/m2.

Lateral pressure owing to soil = Ka r

= 0.08 * 14.12

= 1.13 KN/m2

Lateral intensity at top = 4.83 KN/m2.

Lateral intensity at bottom = 4.83 + 1.13 * 2.8

= 8.00 KN/m2

Moment And Shear Force Calculation

On account of symmetry, it is sufficient to consider half the frame. AEFD for moment distribution. As all members are of uniform thickness and have same dimensions, MI are equal.

Relative Stiffness (K)
KAD =1/4 , KAE = KDF = 1/8
Distribution Factor
DAD = DDA = $\frac{1/4}{\frac{1}{4}+\frac{1}{8}}$= 0.667 (Assuming all joints are fixed)
DAB = DDC = 0.33
Fixed End Moments are :
MFAB = $-\frac{Wl^2}{12}=\frac{-60*2.8^2}{12}$= -39.2 KN.m
MFDC = $\frac{Wl^2}{12}=\frac{-75*2.8^2}{12}$= 49 KN.m
MFAD =$\frac{Pl^2}{12}+\frac{wl}{15}=\frac{4.83*2.8^2}{12}+\frac{2.8*0.5*2.8*3.17}{15}$= 4 KN.m

MFAD =$-\frac{Pl^2}{12}+\frac{wl}{10}=\frac{-4.83*2.8^2}{12}-\frac{2.8^2*0.5*3.17}{10}$ = -4.39 KN.m

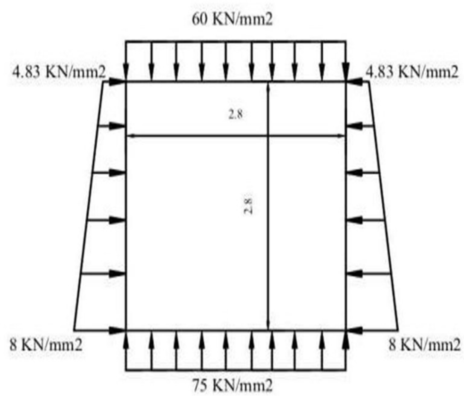

Figure 1. Loading

TABLE I: MOMENT DISTRIBUTION TABLE FOR CASE 1

Joint		D			A	
Member	DC		DA	AD		AB
	0.33		0.67	0.67		0.33
	49		-4.39	4		-39.2
	-14.72		-29.44	23.23		11.61
			11.61	-14.72		
	-3.83		-7.6	9.71		4.85
			4.85	-3.88		
	-1.60		-3.2	2.56		1.28
			1.28	-1.6		
	-0.422		-0.844	1.05		0.528
FINAL MOMENTS	28.4		-28.4	20.93		-20.93

For horizontal slab AB, carrying udl at 60 KN/m2 the vertical reactions at A and B are
$=\frac{1}{2}*60*2.8=84$ KN
Similarly for bottom slab DC, carrying UDL at 75 KN/m2 the vertical reaction at D and C
$=\frac{1}{2}*75*2.8=105$ KN
For vertical member AD, the horizontal reaction hA at A is found by taking moments @ D,

$$-h_A=2.8-20.93-28.42+4.83*\frac{2.8^2}{2}+\frac{3.17*2.8^2}{3*2}=0$$

hA = 5.56 KN
therefore, hD = $\frac{4.83+8}{2}$ *2.8-5.56=12.40 KN"

free B.M at mid point E = $\frac{60*2.8^2}{8}$=58.8KNm
Net BM at E = 58.8-20.93=36.87 KN.m
Free BM at F = $\frac{75*2.8^2}{8}$=73.5 KN.m
Net BM at F = 73.5 – 28.4 = 45.1 KN. m
For vertical member AD, B.M at midspan is $=\frac{4.83*2.8^2}{8}+\frac{3.17*2.8^2}{13.17}$=6.28 KN.m
Net B.M. = $\frac{28.42+20.93}{2}$-6.28=18.39 KN.m

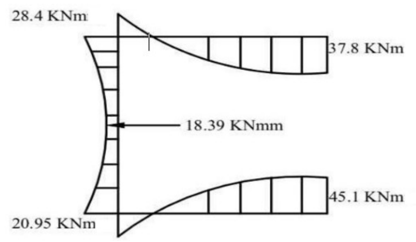

Figure 2. Bending moment

CASE 02: Water pressure act internally , while D.L & L.L act externally.
The water pressure at A is 0 and at D it has peak value.
Wh = 9800*2.8 = 27.44 KN/m2
MFAB = -39.2 KN.m
MFDC = 49 KN.m
MDAD $=\frac{19.44*2.8^2}{12}+\frac{-14.61*2.8^2}{20}$=6.97 KN.m
MDDA $=\frac{19.44*2.8^2}{12}-\frac{14.61*2.8^2}{30}$=-18.42 KN.m
The vertical reaction for slab AB and DC are same as there is no variation in load. The reaction for side wall AD & BC changes

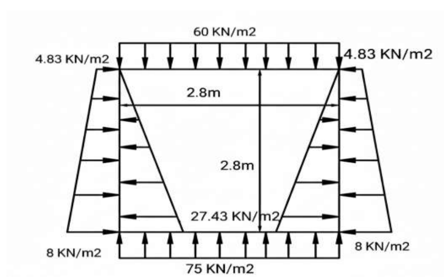

Figure. 3- Loading

TABLE II: MOMENT DISTRIBUTION FOR CASE 2

JOINT		D			A	
MEMBER	DC		DA	AD		AB
	0.33		0.67	0.67		0.33
	49		-18.42	6.97		-39.2
	-10.09		-20.18	21.27		10.63
			10.63	-10.09		
	-3.5		-7	6.64		3.32
			3.32	-3.5		
	-1.09		-2.18	2.31		1.155
			1.155	-1.09		
	-0.39		-0.76	0.7		0.35
FINAL MOMENTS	33.93		-33.93	23.77		-23.77

$-h_A = 2.8 - 23.77 - 33.93 + 4.83*\frac{2.8^2}{2} + \frac{3.17*2.8^2}{3*2} = 0$,hA = 30.40 KN

similarly , $-h_D = \frac{4.83+19.44}{2}*2.8 - 30.40 = 3.57$ KN

Net B.M at mid pt. E = 58.8-23.77 = 35.03 KN.m

Net B.M at mid pt. F = 73.5-33.93 = 39.57 KN.m

For AD,

$$\frac{4.83*2.8^2}{8} + \frac{(19.44-4.83)*2.8^2}{13.17} = 11.89 \text{ KN.m}$$

Net B.M $= \frac{33.93+23.77}{2} - 11.89 = 13.1796$ KN.m

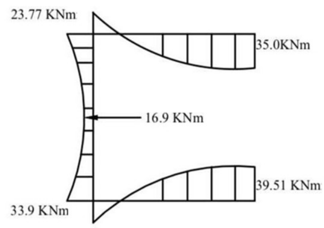

Fig 4. Bending Moment

CASE 03: There is no lateral pressure because of LL and L.L & D.L are acting on top of slab, water pressure from internal.

In this case no consideration is made for lateral effects of L.L on walls. Thus top slab is subjected to 60KN/m2 & bottom slab to 75 KN/m2.

Lateral pressure owing to dead load = 4.67 KN/m2.

Lateral pressure owing to earth is= $\frac{14.12*2.8}{3}$ = 13.17 KN/m2

Total Lateral Pressure at bottom = 4.6+13.17 = 17.77 KN/m2.

In addition to this wall subjected to water pressure of 27.44 KN/m2.

Fixed End Moment are,

MFAB = -39.2 KN/m   MFDC = 49 KN.m

MFAD $= \frac{Pl^2}{12} - \frac{wl}{30} = \frac{4.67*2.8^2}{12} - \frac{14.61*2.8^2}{30} = -0.8$ KN.m

MFDA $= \frac{Pl^2}{12} - \frac{wl}{20} = \frac{4.67*2.8^2}{12} + \frac{19.80*2.8^2}{20} = 2.67$ KN.m

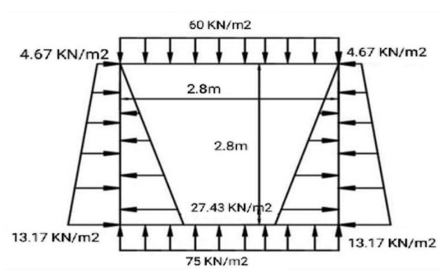

Figure 5. Loading

TABLE III: MOMENT DISTRIBUTION FOR CASE 3

JOINT		D			A	
MEMBER	DC		DA	AD		AB
	0.33		0.67	0.67		0.33
	49		2.67	-0.8		-39.2
	-17.05		-34.1	26.40		13.2
			13.2	-17.05		
	-4.35		-8.71	11.25		5.62
			5.62	-4.35		
	-1.85		-3.70	2.86		1.43
FINAL MOMENTS	25.75		-25.75	18.31		-18.31

Free B.M at mid point E = 58.8 KN.m
Net B.M at point E = 58.8-18.31 = 40.49 KN.m
Free B.M at point F = 73.5 KN.m
Net B.M at point F = 73.5-25.75=47.75 KN.m

For vertical member AD, the S.S B.M = $-\frac{4.67*2.8^2}{8}+\frac{14.61*2.8^2}{13.17}$=2.58 KN.m

The forces, moment and the pressure distribution for this case of loading is given. Let max. hogging B.M occur at distance x below A.

$Mx= 18.31+hAx+\frac{4.67*x^2}{2}-\frac{14.61x^2}{2.8}*\frac{x^2}{2}*(\frac{x}{3})$

For hA,

$= hA*2.8+18.31-25.75+\frac{4.67*2.8^2}{2}-\frac{14.61*2.8^2}{2*3}= 0$

hA = 2.93 KN

Similarly hD,$=\frac{-4.667*2.8^2}{2}+\frac{21.99*2.8}{2}-2.93$

hD= 10.51 KN

$Mx = 18.31+2.93x+\frac{4.67*x^2}{2}-\frac{14.61}{2.8}*\frac{x^2}{2}(\frac{x}{3})$

For max. hogging B.M, we have
γm/γx = 0
18.31+2.93x+4.67*(x2/2)-0.86x3=0
2.93+4.67x-0.86x2*3=0
X = 2.28m
Therefore Max. B.M

$=18.31+2.93*0.4+4.67*\frac{0.4^2}{2}+0.86(0.4)^3$

= 26.93 KN.m

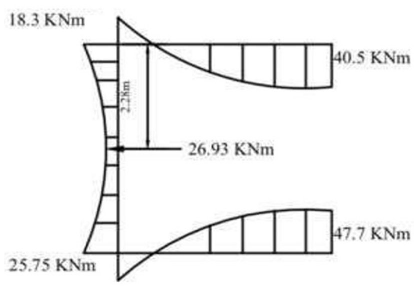

Figure 6. Bending Moment

III. Comparison of Manual Output and STAADPRO Output

TABLE IV: MOMENT AND FORCE OBTAINED ON TOP SLAB

Case no.	B.M (KN.m) at center (Manual analysis)	B.M (KN.m) at center (Staadpro analysis)	B.M (KN.m) at end (manual analysis)	B.M (KN.m) at end (staadpro analysis)	Direct Force (KN) (manual analysis)	Direct Force (KN) (Staadpro analysis
1	37.8	36.072	20.93	22.728	12.4	10.66
2	35.03	32.906	23.77	25.89	3.57	2.86
3	40.49	33.55	18.31	22.24	10.51	8.66

TABLE V: MOMENT AND FORCE OBTAINED ON BOTTOM SLAB

Case no.	B.M (KN.m) at center (Manual analysis)	B.M (KN.m) at center (Staadpro analysis)	B.M (KN.m) at end (manual analysis)	B.M (KN..m) at end (staadpro analysis)	Direct Force (KN) (manual analysis)	Direct Force (KN) (Staadpro analysis
1	45.1	49.00	20.93	24.5	12.4	10.66
2	39.57	34.5	23.77	22.55	3.57	2.68
3	47.75	49.00	18.31	17.5	10.51	8.66

TABLE VI: MOMENT AND FORCE OBTAINED ON SIDE WALL

Case no.	B.M (KN.m) at center (Manual analysis)	B. M (KN.m) at center (Staadpro analysis)	B.M (KN.m) at end (manual an alysis)	B.M (KN.m) at end (staadpro analysis)	Direct Force (KN) (manual analysis)	DirectForce (KN) (Staadpro analysis)
1	18.39	20.6	28.42	22.728	105	99
2	16.96	13.67	33.93	38.4	105	98
3	26.93	26.55	25.75	25.248	105	99

TABLE VII: REINFORCEMENT DETAIL FOR THE BOX CULVERT

Sr no	Member	TYPE OF STEEL	DIA (mm)	SPACING
1	Top Slab	MAIN STEEL	16	200mm C/C
2	Top Slab	DIST. STEEL	10	200mm C/C
3	Bottom Slab	MAIN STEEL	16	200mm C/C
4	Bottom Slab	DIST. STEEL	10	200mm C/C
5	Side wall	MAIN STEEL	12	200mm C/C
6	Side wall	DIST. STEEL	10	200mm C/C
7	Extra r/f top Slab	EXTRA R/F	16	400mm C/C

IV. MIX DESIGN

Under careful supervision, the pumping method will be used to complete the concreting. Crushed angular aggregates with the specific gravities of 2.74 for both coarse and fine aggregates are the aggregates that will be utilized. Cement has the specific gravity of 3.15 and a maximum cement content of 450 kg/m³. The admixture will be a superplasticizer that complies with IS 9103. Fine and coarse aggregates absorb water at rates of 1% and 0.5%, respectively. According to IS 10262:2009 (Table 1, Clause 3.2.1.2, A-3 & B-3), the concrete's target strength is 48.25 N/mm².According to IS 456:2000, the watern cement ratio chosen for M40 grade concrete is 0.40 (Table 5). For aggregates with a size of 20 mm and a slump of 25–50 mm, the maximum amount water content is 186 L. The estimated water content for a 100 mm slump is 197 liters. The adjusted water content is 197 × 0.75 = 147.75 liters because the superplasticizer can lower the water content by up to 25%. As a result, the cement content is determined using w/c = 0.40 as 147.75 / 0.40 = 369.375 kg/m³, which is more than the mix's minimum requirement of 320 kg/m³. Bacillus subtilis powder which is acting as self healing agent mixed with cement is taken as 3% of the volume of the cement.

Mix calculation of the material required in the construction of the box culvert with the Proportion of concrete is 1:2.37:3.027

TABLE VII: MIX DETAIL OF QUANTITY PER CUBIC METER

Cement	369.375 kg/m3
Water	147.75 kg/m3
Fine aggregate	878.52 kg/m3
Coarse aggregate	1118.11 kg/m3
Admixture	6.5 litre
Water cement ratio	0.4
Bacillus subtilis powder	11 kg

TABLE VIII: COMPARISON OF CONVENTIONAL CONCRETE AND SELF HEALING CONCRETE TEST RESULT

Sr.no	PARAMETER	CONVENTIONAL CONCRETE	SELFHEALING CONCRETE
1	Compressive strength (28 days)	40MPa	
2	Initial crack width	0.30 mm	0.30mm
3	Crack width after 28 days	0.3 mm	0.09mm
4	Corrosion risk	High	Low
5	Water absorption	4.8%	3%

V. RESULT AND DISCUSSION

The RCC box culvert is designed and anlysied using manual analysis and STAAD Pro analysis. The effect of self-healing concrete was indirectly incorporated by adopting modified material properties, such as increased compressive strength by 5% based on laboratory test results, because STAAD.Pro is unable to directly simulate the self-healing phenomenon. The validity of the analytical approach was confirmed by the close correlation between the STAAD.Pro results and manual calculations, with variations within 5%.

Significant crack closure and decreased corrosion risk in SHC specimens were confirmed by experimental observations, even though the self-healing mechanism itself was not directly evaluated in STAAD.Pro. The RCC box culvert exhibits decreased cracking potential, and improved durability when these material advantages are taken into account in structural analysis as this reduced the crack width to 70% after 28 days .Overall, the findings show that using self-healing concrete enhances RCC box culverts' structural and serviceability performance. The self-healing action improves long-term durability and service life of RCC Box culvert.

VI. CONCLUSIONS

The design and analysis of a Reinforced Cement Concrete (RCC) box culvert combined with self-healing concrete technology to improve the culvert structural robustness and service life are presented in this paper. I We have contrasted the outcomes of box culverts. Based on the results, we can also draw the conclusion that a box culvert made of a higher grade of concrete can be safer and more resilient under the worst loading conditions and can lower labor costs because the design requires less reinforcement, which will lead to cost-effective construction. In case we use the low-grade concrete in construction and open it to traffic earlier, then it may result in internal microcracking of the top, bottom, and side walls, which may expand with respect to time and loading. Due to this cracking, the reinforcement in the box culvert tends to corrode due to the flowing of water, which may decrease the durability of the culvert.

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