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PROPOSING ‘L/d’ RATIO OF SLAB CULVERT FOR LIMIT STATE METHOD BY USING IRC: 112-2011 AND COMPARISON WITH WORKING STRESS METHOD

Sharanabasava G.[1], Anilkumar S. Katageri[1]

[1] RYMEC, Dept. of Civil Engineering, Ballari, Karnataka, INDIA
e-mail: anilkumarkatageri@gmail.com

ABSTRACT: A bridge is a structure built to span physical obstacles such as a body of water, valley or road for the passage. In India, RC road bridges are designed and constructed according to Indian Road Congress guidelines as per IRC: 21-2000 code in which working stress method is used. Recently Indian Road Congress has introduced another code IRC: 112-2011 for design of bridges. More research in bridge design using limit state method has to be carried to enlighten the recently introduced IRC-112 code.

In regards to this, present study has been performed to know how design of IRC-112 differs from IRC-21 and attempt is made to study undefined parameters of IRC: 112-2011 such as span to effective depth (L/d) ratio. It is observed that L/d ratio for slab culvert is 20. Quantity of materials required in limit state method is compared with quantity of material required in working stress method. On comparison for slab culvert, steel can be saved up to 5 to 10% and quantity of concrete can be saved up to 33 to 44% using limit state method. It can be concluded that concrete and steel can be saved by adopting limit state method in design of bridge in comparison to working stress method.

KEYWORDS: IRC: 21-2000; IRC: 112-2011; Limit state method; L/d ratio; Slab culvert; Working stress method.

1 INTRODUCTION

Good and efficient transportation is one of the important systems of networking for any nation. The backbone of any countries economy consists of its assets of constructed facilities, such as highways, bridges. Bridge is a structure providing passage over an obstacle without closing the way beneath. Bridges are constructed using timber, reinforced concrete, steel, prestressed concrete and composite materials. Reinforced concrete bridges of beam form can be designed using working stress method and also by limit state method.

There are many codes used around the world and most of countries have their own code depending on the nature and the surrounding circumstances, such as the effect of earthquakes and heavy snowfall, etc. The road bridges are designed in our country as per Indian Road Congress (IRC) guidelines. Till now RCC road bridges are designed by using IRC: 21-2000 code and prestress bridges are designed as per IRC: 18-2000 in which working stress method is used. Indian road congress has introduced a single code IRC-112 recently for both prestress and RCC bridges, in which there is no proper guidelines for considering depth criteria for bridges. Due to lack of proper guidelines trial and error should be carried out in fixing depth. To avoid this, present study has been performed to develop span to depth (L/d) ratio for RC slab culvert, through which depth can be adopted.

Parameter study

L/d ratio for the R.C.C. slab culvert is developed for Limit state method. Slab culvert is designed for proposed L/d ratio by limit state method as per IRC: 112-2011 code specifications. Later comparison has been made on quantity of materials (concrete and steel) required for slab culvert by limit state method as per IRC: 112-2011 code and working stress method as per IRC: 21-2000 code specifications. Parameters are studied for IRC Class AA trucked live load and materials used in the design are Concrete- M25 and Steel-Fe 415.

2 SLAB CULVERT

2.1 Methodology for slab culvert

- Analysis part in limit state method remains same as in working stress method except for calculating dead load bending moment where factor of safety 1.5 is considered.
- The effective depth (d) of the balanced section is calculated for limit state method and working stress method for different spans starting form 3 m to 8 m, so that we can know the L/d ratio of the balanced section for limit state method.
- To define L/d ratio for under-reinforced section of the slab culvert for limit state method, maximum bending moment (M_u) and limiting moment of resisting ($M_{u\ lim}$) is calculated for different spans with assumed L/d ratio which is less than that of L/d ratio of balanced section.
- The above procedure is continued by assuming different L/d ratio.
- L/d ratio is developed for under reinforced section, by comparing different L/d ratio based on different parameters like deflection, crack width, percentage steel and effective depth for different spans.
- A further attempt is made to compare limit state method IRC-112:2011 for proposed L/d ratio with working stress method IRC-21:2000 for quantity of the materials required in slab culvert.
- Properties of the slab culvert:

Effective span of bridge = 5 m

Width of bridge = 12 m
Wearing coarse =56 mm
Effective cover = 50 mm
Let 'd' be effective depth of slab in meter.

2.2 Design of slab culvert for balanced section

Effective depth is calculated for balanced section of slab culvert, in limit state method by equating limiting moment to maximum bending moment, so that we can know the L/d ratio for balanced section. Effective depth is calculated in working stress method by equating moment of resistance to maximum bending moment.

Then comparison is made between limit state and working stress method for balanced section of the slab culvert which are tabulated in Table 2.1.

Table 2.1 Comparison of Limit state and Working stress method

Span L (m)	Limit state method					Working stress method			
	d (mm)	L/d	A_{st} (mm²)	p_t %	Concrete (m³)	d (mm)	A_{st} (mm²)	P_t %	Concrete (m³)
3	125	24	1660.7	1.329	6.30	205.4	1345	0.655	9.19
4	165	24.24	2192.1	1.329	10.32	271.8	1780	0.655	15.45
5	195	25.64	2590.6	1.329	14.70	329.3	2163	0.655	22.76
6	225	26.67	2989.2	1.329	19.80	380.4	2492	0.655	30.99
7	255	27.45	3387.8	1.329	25.62	430	2817	0.655	40.32
8	280	28.57	3719.9	1.329	31.68	478	3131	0.655	50.69

L/d ratio in limit state method for spans 3 m, 4 m, 5 m, 6 m, 7 m, and 8 m are 24, 24.24, 25.64, 26.67, 27.45, 28.57 respectively. Average L/d ratio for slab culvert of the balanced section is 26. It is observe red that percentage of steel remains constant for both, in working stress method it is 0.655 and in limit state method it is 1.329. It shows that maximum permissible percentage steel in limit state method for slab is 1.329% of cross sectional area. Percentage tension reinforcement required in limit state is double than that of working stress method. Huge volume of concrete required in working stress method as compare with limit state method.

2.3 L/D ratio for the slab culvert of the under-reinforced section

To developed an efficient L/d ratio for under reinforced section of the slab culvert for limit state method, different parameters like crack width, percentage steel, moments, deflection and effective depth are calculated for different spans like 3 m, 4 m, 5 m, 6 m, 7 m and 8 m. An efficient L/d ratio can be obtained on comparing the above parameters with different L/d ratios 18, 19, 20, 21 and 22 which are less than that of L/d ratio of balanced section, which are tabulated in Table 2.2 to 2.6. In slabs shear is not predominate one, so it is not considered in comparison of L/d ratio.

Table 2.2 Effective depths for different span with different L/d ratio

L (m)	Eff. depth for bal. sec in mm	Effective depth in mm				
		L/d 18	L/d 19	L/d 20	L/d 21	L/d 22
3	125	170	160	150	145	140
4	165	225	215	200	190	190
5	195	280	265	250	240	230
6	225	335	315	300	290	275
7	255	390	370	350	335	320
8	280	445	425	400	385	365

Table 2.3 Steel for different span with different L/d ratio

L (m)	steel in %				
	L/d 18	L/d 19	L/d 20	L/d 21	L/d 22
3	0.56	0.64	0.78	0.83	0.90
4	0.71	0.75	0.89	1.01	1.1
5	0.69	0.74	0.83	0.91	1
6	0.65	0.70	0.77	0.88	0.92
7	0.62	0.65	0.73	0.8	0.9
8	0.6	0.61	0.70	0.76	0.83
Ave	0.64	0.68	0.78	0.86	0.95

Table 2.4 Deflections for different span with different L/d ratio

Span L (m)	Deflection in mm				
	L/d 18	L/d 19	L/d 20	L/d 21	L/d 22
3	1.77	1.98	2.33	2.51	2.71
4	3.15	3.46	4.18	4.72	4.72
5	3.92	4.42	5.1	5.62	6.24
6	4.26	4.92	5.52	6.01	6.86
7	4.35	4.91	5.86	6.4	7.2
8	4.3	4.75	5.74	6.37	7.26

Table 2.5 Crack width for different span with different L/d ratio

Span L (m)	Crack width in mm				
	L/d 18	L/d 19	L/d 20	L/d 21	L/d 22
3	0.126	0.122	0.117	0.115	0.112
4	0.152	0.147	0.14	0.136	0.136
5	0.178	0.171	0.164	0.159	0.154
6	0.204	0.194	0.187	0.183	0.176
7	0.229	0.22	0.211	0.204	0.197
8	0.255	0.246	0.234	0.227	0.218

Table 2.6 Moments for different spans with different L/d ratio

L/d 18		L/d 19		L/d 20		L/d 21		L/d 22	
M_u	$M_{u\ lim}$	M_u	$M_{u\ lim}$	M_u	$M_{u\ lim}$	M_u	$M_{u\ lim}$	M_u	$M_{u\ lim}$
48	101	48.5	89.7	50.7	78.8	50.4	73.65	50.158	68.67
102.5	177.4	101.6	161.9	101.4	140.2	100.7	126.45	100.7	126.46
155.2	274.7	151.7	246	149.8	218.9	148	201.77	146.97	185.3
211	393.2	205.6	347.6	201.8	315.3	199.7	294.6	196.78	264.9
273.5	532.8	265.9	479.6	262.2	429.2	258.1	393.12	22.57	347.6
345.4	693.4	335.8	632.8	331.7	560.5	326.2	519.2	319	466.69

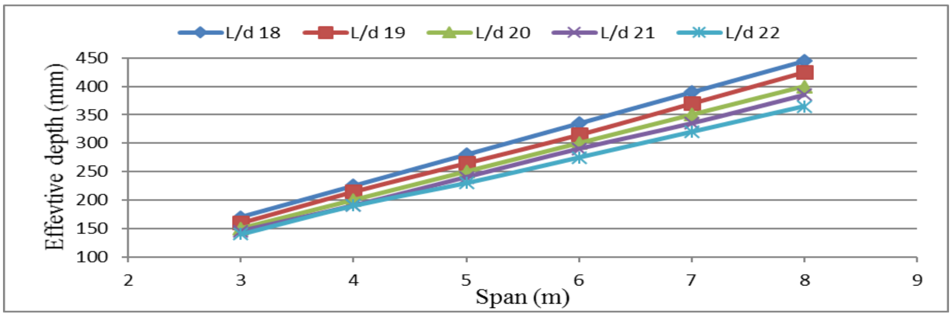

Figure 2.1 Effective depth with respective to span, for different L/d ratio

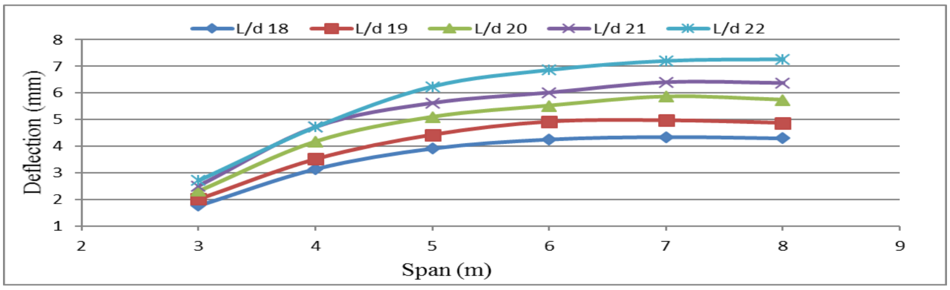

Figure 2.2 Deflection with respective to span, for different L/d ratio

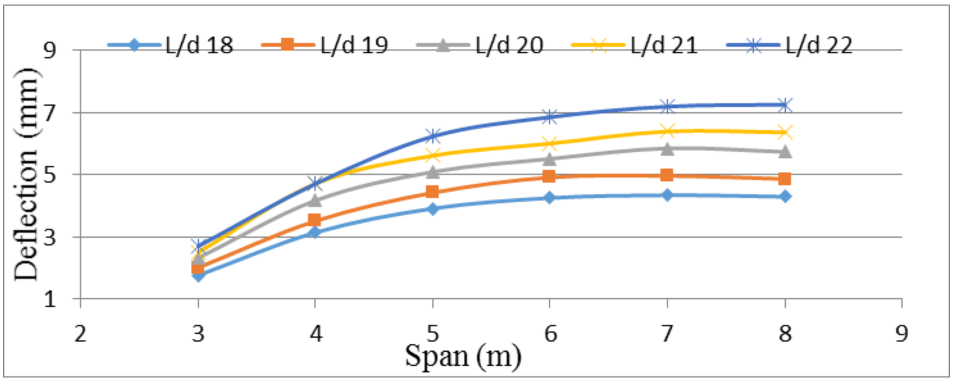

Figure 2.3 Deflection with respective to span, for different L/d ratio

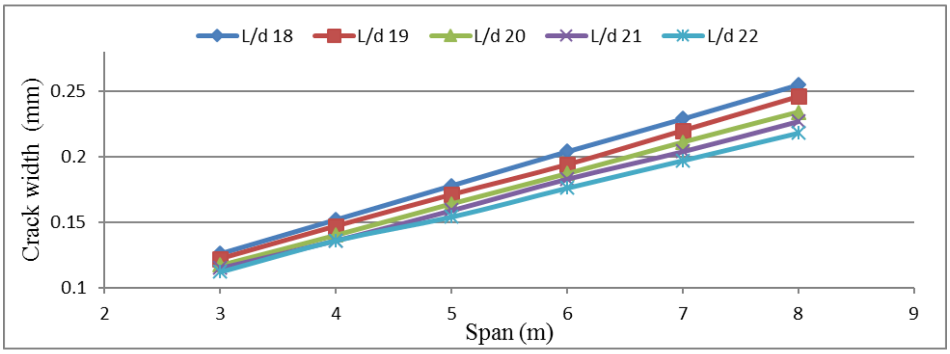

Figure 2.4 Crack width with respective to span, for different L/d ratio

Effective depth is an important parameter as all other parameters like moment carrying capacity, max bending moment, deflection, crack width, shear force, percentage of tensile reinforcement depends on it. Fig 2.1 shows the variation of effective depth with respect to span, the effective depth increases as span increases this is because effective depth is proportional to span of the bridge and the effective depth increases with decreasing L/d ratio. Minimum overall depth should be 200 mm as per IRC 112:2011 code specification. Fig 2.2 shows the variation of Percentage steel with respect to span, it is observed that Percentage steel required for 3 m span is lesser than 4 m span, because span of bridge is smaller than the effective length of load. After 4 m span it will decrease with increasing span for all the cases of L/d ratio this is because with increasing span average intensity will decrease. Percentage of the steel increases with increasing L/d ratios. Max percentage steel is 1.329% of cross sectional area which is for balanced section. Fig 2.3 shows the variation of deflection with respect to span for different L/d ratio, deflection will increase with increasing span up to certain point after that it will slight decrease with increasing span, this is true for all L/d ratio and deflection increase with increasing L/d ratio. Fig 2.4 shows the variation of crack width with respect to span for different L/d ratio. Crack width will decrease with increasing L/d ratio and linearly increase with increasing span. Table 2.6 Show the results for Mu and Mu lim for different spans with different L/d ratio, it is observed that the Mu and Mu lim increase with increasing span and it is decreasing with increasing L/d ratio, this because the depth of the slab is proportional to the limiting moment and design moments of the section.

From Tables 2.2 to 2.6 we can conclude that the L/d ratio of 20 is efficient because of following reasons.

- Increasing 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. Especially in slabs, thickness plays an important role because increasing a centimeter thickness of slab increases volume that will increase dead load. So thickness should be in such a way that it is minimum and it should satisfy serviceability criteria. As per IRC: 112-2011 code minimum overall depth should be 200 mm, this criteria is satisfied by L/d ratio of 20 for the different spans.

- It is observed that the Percentage of tension reinforcement for L/d 20 is found to be less than that of L/d ratio of 21 and 22. For balanced section with L/d ratio of 20 the maximum Percentage of tension reinforcement is found to be 1.329% which is more than the under reinforced section i.e 0.89% (for 4 m span) and which also satisfy the code requirement.
- Deflections are within the limiting value as mentioned in IRC-112, this is not a case for L/d ratio higher than 20. For L/d ratio higher than 20, deflection criteria is not satisfying for 4 m to 7 m spans. For L/d ratio of 20 the maximum deflection is found to be 5.86 mm for 7 m span.
- Crack widths are within limit.
- It is observed that the limiting moment will utilize by 50%. This utilization capacity will increase with increasing in span which is up to 65%. It is observed that the utilization capacity in L/d ratio of 18 and 19 is lesser and for L/d ratio of 21 and 22 it is found to be higher when compared to L/d ratio 20.

2.4 Design of slab culvert for under-reinforced section

Slab culvert is designed by working stress as per IRC-21:2000 and limit state method as per IRC-112:2011 specification. For design same properties are considered in limit state and working stress method. Depth criteria is considered in limit state method is based on L/d ratio 20 and in working stress method is based on 100 mm per meter length of span. Analysis and

Design by working stress method [4]

For different spans 3 to 8 m, valves of effective depth, area of steel, max bending moment and shear force are tabulated in Table 2.7 and 2.8.

Table 2.7 Flexure parameters for slab culvert by working stress method

Span L (m)	d (m)	L_{eff} (m)	W kN/m^2	BM_{DL} (kN-m)	Red intensity (kN/m^2)	BM_{LL} (kN-m)	Total BM (kN-m)	req depth deff (m)	A_{st} (mm^2)	P_t
3	0.25	3.25	9.5	12.54	31.74	37.43	49.98	0.213	1110.6	0.444
4	0.35	4.35	12	28.38	31.46	74.30	102.69	0.306	1630.0	0.466
5	0.45	5.4	14.5	52.85	27.25	97.73	150.59	0.370	1859.1	0.413

6	0.55	6.4	17	87.04	24.84	120.3	207.34	0.434	2094.4	0.381
7	0.65	7.4	19.5	133.4	22.15	137.1	270.59	0.496	2312.8	0.356
8	0.75	8.4	22	194.0	19.86	151.5	345.56	0.560	2559.7	0.341

Table 2.8 Shear parameters for slab culvert by working stress method

Span L (m)	L_{eff} (m)	W (kN/m^2)	V_{DL} (kN)	Reduce intensity (kN/m^2)	V_{LL} (kN)	Total shear V_{LL} (kN)	τ_v	τ_c
3	3.25	9.50	15.44	29.57	42.92	58.36	0.233	0.26
4	4.35	12.00	26.10	30.09	65.36	91.46	0.255	0.275
5	5.40	14.50	39.15	27.61	73.33	112.48	0.250	0.330
6	6.40	17.00	54.40	24.69	74.75	129.15	0.235	0.2406
7	7.40	19.50	72.15	22.60	75.62	147.77	0.227	0.237
8	8.40	22.00	92.40	20.71	75.22	167.62	0.223	0.2354

Design by limit state method [4]

For different spans 3 to 8 m, valves are tabulated in Table 2.9 to 2.11 for L/d ratio 20.

Table 2.9 Flexural parameters of slab culvert by limit state method

L (m)	d (m)	L_{eff} (m)	W kN/m^2	BM_{DL} (kN-m)	Inten - sity kN/m^2	BM_{DL} (kN-m)	Total BM (kN-m)	$M_{u\ lim}$ (kN-m)	A_{st} (mm^2)	Pt
3	0.15	3.15	10.50	13.02	30.330	37.62	50.642	79.98	1170	0.78
4	0.20	4.20	12.38	27.29	33.617	74.13	101.41	142.2	1796	0.90
5	0.25	5.25	14.25	49.10	30.172	100.63	149.72	222.1	2096	0.84
6	0.30	6.30	16.13	80.00	26.963	121.76	201.75	319.9	2325	0.78
7	0.35	7.35	18.00	121.55	24.478	140.65	262.20	435.4	2569	0.73
8	0.40	8.40	19.88	175.30	22.250	156.34	331.63	568.8	2830	0.71

Table 2.10 Shear parameters of slab culvert by limit state method

L (m)	L_{eff} (m)	W (kN/m^2)	V_{DL} (kN)	Reduce intensity (kN/m^2)	V_{LL} (kN)	Total shear V_U (kN)	$V_{R\ cd}$ (kN)	
							K	$V_{R\ cd}$ (kN)
3	3.15	10.50	16.54	30.33	43.31	59.85	2.155	234.11
4	4.20	12.38	25.99	33.62	70.60	96.58	2.000	312.15
5	5.25	14.25	37.41	30.09	76.47	113.87	1.894	379.49
6	6.30	16.13	50.79	26.88	77.06	127.86	1.816	445.91
7	7.35	18.00	66.15	24.44	76.42	142.57	1.756	511.64
8	8.40	19.88	83.48	22.25	74.45	157.92	1.707	576.81

Table 2.11 Serviceability parameters of slab culvert by limit state method

L (m)	D (mm)	L_{eff} (mm)	Average intensity (kN/m^2)	I (mm^4)	E (N/mm^2)	Deflection (mm)	Crack width (mm)
3	200	3150	30.300	666666667	25000	-2.33	0.117
4	250	4200	33.617	1302083333	25000	-4.18	0.140
5	300	5250	30.172	2250000000	25000	-5.10	0.164
6	350	6300	26.963	3572916667	25000	-5.52	0.187
7	400	7400	24.478	5333333333	25000	-5.86	0.211
8	450	8400	22.250	7593750000	25000	-5.74	0.234

2.5 Comparison of limit state and working stress method for under-reinforced section of slab culvert

Comparison between the limit state method IRC-112:2011 for proposed L/d ratio i.e 20 with working stress method IRC-21:2000 for quantity of the materials i.e concrete and steel required in slab culvert.

Table 2.12 Limit state and working stress method for under reinforced section of slab culvert

L	Limit state method				Working stress method			
	d (mm)	A_{st} (mm²)	p_t	Concrete (m³)	d (mm)	A_{st} (mm²)	p_t	Concrete (m³)
3	150	1170	0.780	7.200	250	1110	0.444	10.8
4	200	1796	0.898	12.000	350	1630	0.466	19.2
5	250	2096	0.838	18.000	450	1887	0.419	30.0
6	300	2325	0.775	25.200	550	2095	0.381	43.2
7	350	2569	0.734	33.600	650	2312	0.356	58.8
8	400	2830	0.708	43.200	750	2560	0.341	76.8

- Result shows that the percentage of tension reinforcement required in limit state method is almost double than that of working stress method and also there is a need of huge volume of concrete in working stress method as compare to limit state method.

Table 2.13 Reduction of steel

Span L (m)	Steel
3	5.13
4	9.24
5	9.97
6	9.89
7	10.00
8	9.54

Table 2.14 Reduction of concrete

Span L (m)	Concrete
3	33.3
4	37.5
5	40.0
6	41.7
7	42.9
8	43.8

- By using working stress method the quantity of steel usage will reduce than that of limit state method because of large volume of concrete. Steel reduced in working stress method is 5 to 10% than that of limit state method. Maximum steel reduced is 10.04% for 7 m span.
- By using limit state method the quantity of concrete usage will reduce than that of working stress method because of smaller cross section of slab in limit state method. Concrete reduced in limit state method is 33.5 to 43.5%. Reduction of concrete increases with increasing span, which is maximum for 8 m span i.e. 43.5%.

3 CONCLUSIONS

Based on above, the following conclusions can be drawn

1. For design of the slab culvert using limit state method as per IRC: 112-2011, L/d ratio of 18 to 21 can be adopted, L/d ratio of 20 is most preferable.
2. It is observed that in slab culvert for L/d ratio 20, huge quantity of concrete can be saved up to 33 to 44% using limit state method.

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