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Comparative Study of Live Load Condition on RCC Girder Span Bridge using IRC and AASHTO

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Abstract—*This study summarizes the comparative design of a single-span T-Beam Reinforced Concrete Girder under Indian Road Congress IRC: 112 – 2011 and AASHTO (American Association of State Highway and Transportation Officials) LRFD Bridge Design Specification. This study addresses the differences in calculation procedure with live load condition and the resulting design. This study comprises of evaluating the limit state method of IRC and AASHTO. The main objective of this study is to study the similarities and differences of design procedure between the IRC and AASHTO. It consists of design procedure of IRC and AASHTO for the same loading criteria. For this study, Dead Load, Vehicular Live Load, Impact Load along with live load combination is considered. T-Beam girder of 20 m span length with 2 lane of carriage way width is considered. STAAD Pro is utilized for analysis purpose and design is done manually with help of excel sheets. This study discusses the calculation procedure for flexure design and shear design. After the end of study, conclusions will be made that up to what extents similarities between both standards.*

1. INTRODUCTION

One of the most important steps in the process of designing a bridge is to determine the most appropriate live load representing to a high certainty, the expected normal traffic loads that might go over the bridge. These expected live loads vary from a country to country, depending upon many parameters such as degree of locality, the volume of traffic, the nature of the expected major traffic passing over the bridge. In India, IRC: 6 standards is referred for load considerations while designing bridge, while In United States, load considerations is inbuilt in the AASHTO code only. Bridge design practices vary extensively throughout the world. Many codes are currently dealing with limit state method. In India, IRC has published new code IRC: 112 – 2011 that combines specifications for both RCC & Prestress Concrete Bridges. In United States, bridge engineers use AASHTO Code for design of highway bridges. The goal of this study is to finding the similarities and differences between IRC: 112 and AASHTO-LRFD. The need of this study is to evaluate Indian Road Congress IRC: 112(2011) which are amalgamated IRC: 21(2000) and IRC: 18(2000).

2. DEAD LOAD CONSIDERATION

2.1 As per IRC: 6(2014) – Clause 203

The dead load carried by a girder or member shall consist of the portion of the weight of the superstructure which is supported wholly or in part by the girder or member including its own weight. The following unit weights of materials shall be used to determining loads, unless the unit weights have been determined by actual weighing of representative samples of the materials in question, in which case the actual weights as thus determined shall be used.

Table 1: Unit Weights as per IRC

Sr. No.	Materials	Weight (t/m³)
1	Concrete (Asphalt)	2.2
2	Concrete (Cement-Reinforced)	2.5

2.2 As per AASHTO – Clause 3.5.1

Dead load shall include the weight of all components of the structure and utilities attached thereto, earth cover, wearing surface, future overlays, and planned widening. In the absence of more precise information, the unit weights, specified in following table, may be used for dead loads.

Table 2 Unit Weights as per AASHTO

Sr. No.	Materials	Weight (kcf)
1	Concrete (Normal Weight with $5.0 < f'c \leq 15.0$ ksi)	$0.140 + 0.001 f'c$

3. LIVE LOAD CONSIDERATION

3.1 As per IRC: 6(2014) – Clause 204

3.1.1 IRC Class A Wheeled Loading[1]

This loading is to be normally adopted on all roads on which permanent bridges and culverts are constructed.

[1] Notes are considered as per IRC: 6 – 2014

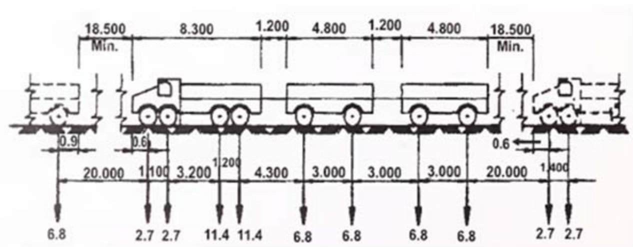

Fig. 1 IRC Class A Wheeled Loading

3.1.2 IRC Class 70R Wheeled Loading[2]

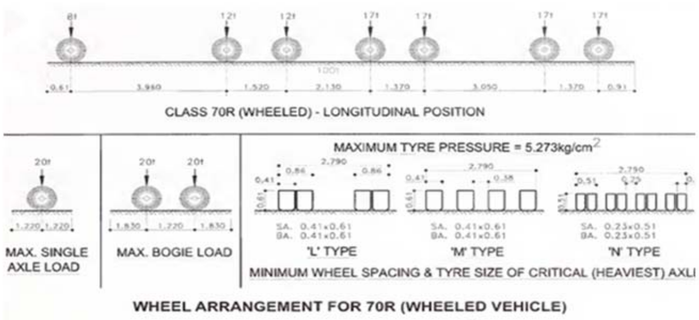

Fig. 2 IRC Class 70R Wheeled Loading

This loading is to be normally adopted on all roads on which permanent bridges and culverts are constructed. Bridges 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.

3.2 As per AASHTO – Clause 3.6.1.2

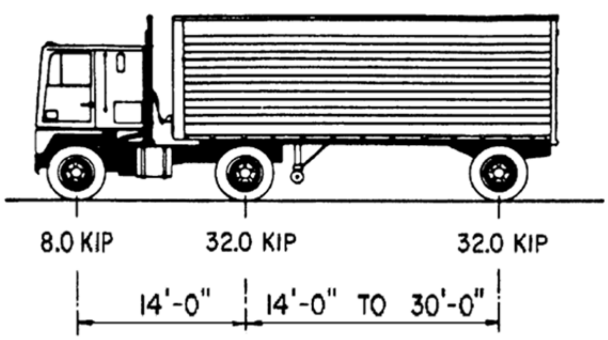

Fig. 3 Design Truck for AASHTO Loading

3.2.1 Design Truck

The Weights and spacing's of axles and wheels for the design truck shall be specified in Fig. 3. A dynamic allowance shall be considered. The spacing between the two 32.0 kip axles shall be varied between 14.0 ft and 30.0 ft to produce extreme force effect.

3.2.2 Design Lane Load

The design lane load shall consist of a load of 0.64 klf uniformly distributed in the longitudinal direction. Transversely, the design lane load shall be assumed to be uniformly distributed over a 10.0 ft width. The force effects from design lane load shall not be subject to a dynamic load allowance.

4. IMPACT LOAD

4.1 As per IRC: 6(2014) – Clause 208

4.1.1 IRC Class A Wheeled Loading

The impact fraction shall be determined from the following equations which are applicable for spans between 3 m and 45 m, for beyond 45 m refer Fig. 4.

$$For\ RCC\ Bridge, \qquad Impact\ Factor\ I = \frac{4.5}{6 + L}$$

$$For\ Steel\ Bridge, \qquad Impact\ Factor\ I = \frac{9}{13.5 + L}$$

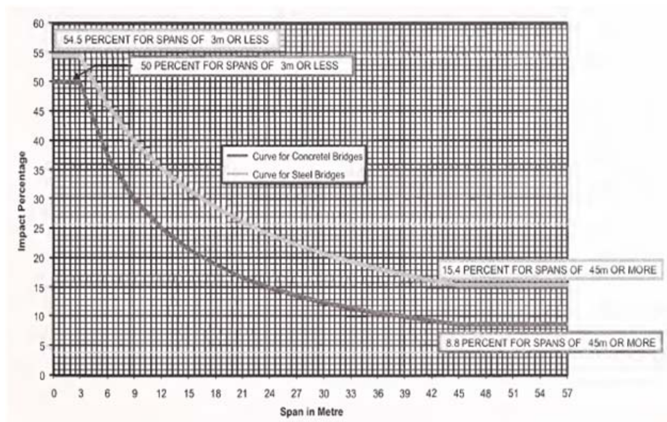

Fig. 4 Impact Fraction Graph

4.1.2 IRC Class 70R Wheeled Loading

Table 3: Impact Fraction for Class 70R Wheeled Loading

For Span 9 m or more	
RCC Bridge	
Wheeled Vehicle	25 percent up to a span of 12 m and in accordance with the curve in Fig. 5 for spans in excess of 12 m.

4.2 As per AASHTO – Clause 3.6.2

The static effects of the design truck or tandem, other than centrifugal and braking forces, shall be increased by the percentage specified in following table.

[2] Notes are considered as per IRC: 6 – 2014

Table 4 Dynamic Impact Allowance as per AASHTO

Component	IM
Deck Joints – All Limit States	75 %
Other Components	
1. Fatigue and Fracture Limit State	15 %
2. All Other Limit States	33 %

5. LIVE LOAD COMBINATIONS

5.1 As per IRC: 6 (2014) – Clause 208

Carriage Way Width	Nos. of Lanes	Live Load Combination
5.3 m and Above but Less than 9.6 m	2	One lane of Class 70R or Two lanes of Class A

5.2 As per AASHTO

In AASHTO, there are not such combinations of live load as specified in IRC code for different design vehicle, because, In AASHTO, there is one design truck HL93, which has to run for all numbers of lanes for design purpose.

6. LOAD COMBINATIONS

6.1 As per IRC: 6(2014) – Annex B – Table 3.1, 3.2, and 3.3

For this case study, the governing load combinations are summarized as follows;

For Ultimate Limit States	1.35 DC + 1.75 DW + 1.50 (LL+IM)
For Serviceability Limit States	1.00 (DC + DW) + 1.00 (LL+IM)

6.2 As per AASHTO – Table 3.4.1-1 and 3.4.1.1-2

For this case study, the governing load combinations are summarized as follows;

Strength I	1.25 DC + 1.50 DW + 1.75 (LL + IM)
Service II	1.00 (DC + DW) + 1.30 (LL + IM)
Extreme I	1.25 DC + 1.50 DW + 1.00 (LL + IM)
Fatigue I	1.50 (LL + IM)

6.2 Data

1	Overall Span of Bridge	20.560 m
2	Effective Span of Bridge	20.000 m
3	Clear Carriage Way Width	7.500 m
4	Total Width	8.250 m
5	Depth of Slab	0.400 m
6	Depth of Girder	2.000 m
7	Width of Girder	0.325 m
8	Width of Kerb	0.375 m
9	Depth of Kerb	0.550 m
10	Centre to Centre Distance Between Longitudinal Girders	2.500 m
11	Centre to Centre Distance Between Cross Girders	4.000 m
12	Numbers of Longitudinal Girders	3 Nos.
13	Numbers of Cross Girders	6 Nos.
14	Grade of Concrete	M 35
15	Grade of Steel	Fe 500
16	Using Main Steel Bars of Diameter	32 mm
17	Using Vertical Stirrups of Diameter	12 mm
18	Live Load Considered	
	IRC Class A Wheeled Loading – For 2 Lanes	
	IRC Class 70R Wheeled Loading – For 1 Lane	
	AASHTO HL-93 Loading Plus Lane Loading – For All Lanes	
19	Impact Factor	
	For IRC Class A Wheeled Loading	1.173
	For IRC Class 70R Wheeled Loading	1.173
	For AASHTO Hl-93 Loading	1.330
20	Governing Load Combination Considered	
	For IRC:	
	1.35 DC + 1.75 DW + 1.50 (LL + IM)	
	For AASHTO:	
	1.25 DC + 1.50 DW + 1.75 (LL + IM)	

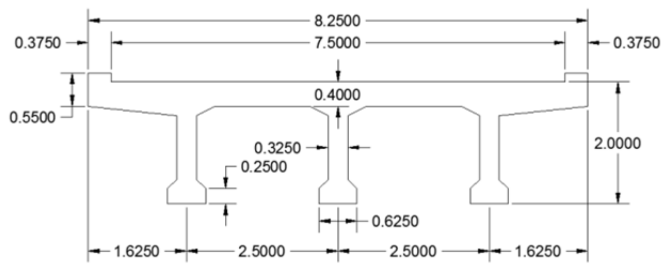

Fig. 5 Cross Section of RCC T Girder Bridge

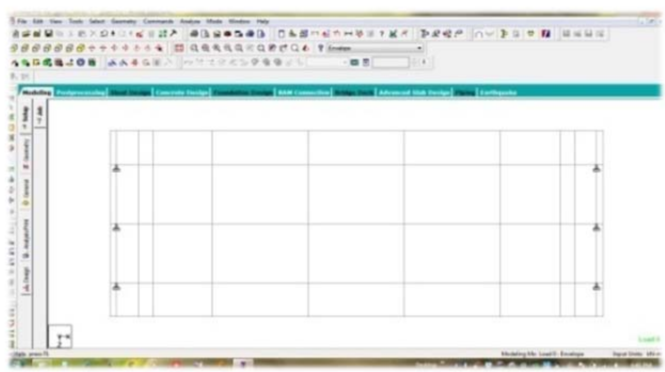

Fig. 6 Snapshot of STAAD Model - RCC T Girder

7. STAAD ANALYSIS SUMMARY

7.1 OUTER GIRDER

Table 5 Outer Girder - Bending and Shear Summary

BENDING MOMENT (kN-m)			
		Center	1/4th
1	DC	2586.00	1943.00
2	DW	217.00	162.81
3	70R	1447.00	1077.93
4	A	1193.00	987.02
	Max(3,4)	1447.00	1077.93
5	HL 93K + LL	1366.47	968.84

SHEAR FORCE (kN)						
		Center	3/8th	1/4th	1/8th	Support
1	DC	0.00	142.02	250.64	458.69	525.10
2	DW	0.00	13.11	21.91	32.60	42.50
3	70R	127.00	135.11	208.78	243.94	306.76
4	A	94.70	126.42	194.22	222.18	282.22
	Max(3,4)	127.00	135.11	208.78	243.94	306.76
5	HL 93K + LL	74.77	137.01	152.55	194.54	251.77

7.2 INNER GIRDER

Table 6 Inner Girder - Bending and Shear Summary

BENDING MOMENT (kN-m)			
		Center	1/4th
1	DC	2574.00	1925.80
2	DW	217.00	161.51
3	70R	1339.23	978.08
4	A	1021.73	945.05
	Max(3,4)	1339.23	978.08
5	HL 93K + LL	1322.40	962.65

SHEAR FORCE (kN)						
		Center	3/8th	1/4th	1/8th	Support
1	DC	0.00	142.02	250.64	389.69	503.94
2	DW	0.00	12.01	20.80	32.12	41.59
3	70R	121.00	123.85	206.87	216.64	266.87
4	A	70.20	122.42	148.47	212.56	266.54
	Max(3,4)	121.00	123.85	206.87	216.64	266.87
5	HL 93K + LL	62.39	144.06	144.06	191.12	240.95

7.3 IRC Load Combination

7.3.1 For IRC Live Load

Table 7 IRC Load Combo - IRC Live Load

1.35 DC + 1.75 DW + 1.50 (LL + IM)					
OUTER GIRDER					
B.M. (kN-m)		S.F. (kN)			
@ Center	@ 1/4th Span	@ Support	@ 1/4th Span	@ 3/8th Span	@ Center
6041.350	4524.855	1243.400	689.880	417.335	190.500
INNER GIRDER					
B.M. (kN-m)		S.F. (kN)			
@ Center	@ 1/4th Span	@ Support	@ 1/4th Span	@ 3/8th Span	@ Center
5863.150	4349.590	1153.405	685.075	398.515	181.500

7.3.2 For AASHTO Live Load

Table 8 IRC Load Combo - AASHTO Live Load

1.35 DC + 1.75 DW + 1.50 (LL + IM)					
OUTER GIRDER					
B.M. (kN-m)		S.F. (kN)			
@ Center	@ 1/4th Span	@ Support	@ 1/4th Span	@ 3/8th Span	@ Center
5920.555	4361.220	1160.915	605.535	420.185	112.155
INNER GIRDER					
B.M. (kN-m)		S.F. (kN)			
@ Center	@ 1/4th Span	@ Support	@ 1/4th Span	@ 3/8th Span	@ Center
5838.250	4326.445	1114.525	590.860	428.830	93.585

7.4 AASHTO Load Combination

7.4.1 For IRC Live Load

Table 9 AASHTO Load Combo - IRC Live Load

1.25 DC + 1.50 DW + 1.75 (LL + IM)					
OUTER GIRDER					
B.M. (kN-m)		S.F. (kN)			
@ Center	@ 1/4th Span	@ Support	@ 1/4th Span	@ 3/8th Span	@ Center
6090.250	4559.338	1256.950	711.535	433.633	222.250
INNER GIRDER					
B.M. (kN-m)		S.F. (kN)			
@ Center	@ 1/4th Span	@ Support	@ 1/4th Span	@ 3/8th Span	@ Center
5901.653	4384.600	1187.143	708.193	413.928	211.750

7.4.2 For AASHTO Live Load

Table 10 AASHTO Load Combo - AASHTO Live Load

1.25 DC + 1.50 DW + 1.75 (LL + IM)					
OUTER GIRDER					
B.M. (kN-m)		S.F. (kN)			
@ Center	@ 1/4th Span	@ Support	@ 1/4th Span	@ 3/8th Span	@ Center
5949.323	4368.430	1160.718	613.133	436.958	130.848
INNER GIRDER					
B.M. (kN-m)		S.F. (kN)			
@ Center	@ 1/4th Span	@ Support	@ 1/4th Span	@ 3/8th Span	@ Center
5872.200	4357.598	1141.783	598.275	449.295	109.183

8. DESIGN SUMMARY

8.1 Flexure Design

For IRC design, considering 32 mm diameter of bar as main steel reinforcement, and for AASHTO design, considered 10 size of bar whose equivalent metric size is 32.26 mm.

8.1.1 IRC Load Combination

Table 11 Outer Girder Summary - IRC Load Combo

AREA OF MAIN STEEL PROVIDED (mm^2)				
	IRC LIVE LOAD		AASHTO LIVE LOAD	
DESIGN	Center	1/4th Span	Center	1/4th Span
IRC	9646.1	6430.7	8842.2	6430.7
AASHTO	8985.4	6534.8	8985.4	6534.8

Table 12 Inner Girder Summary - IRC Load Combo

AREA OF MAIN STEEL PROVIDED (mm²)				
	IRC LIVE LOAD		AASHTO LIVE LOAD	
DESIGN	Center	1/4th Span	Center	1/4th Span
IRC	8842.2	6430.7	8842.2	6430.7
AASHTO	8985.4	6534.8	8985.4	6534.8

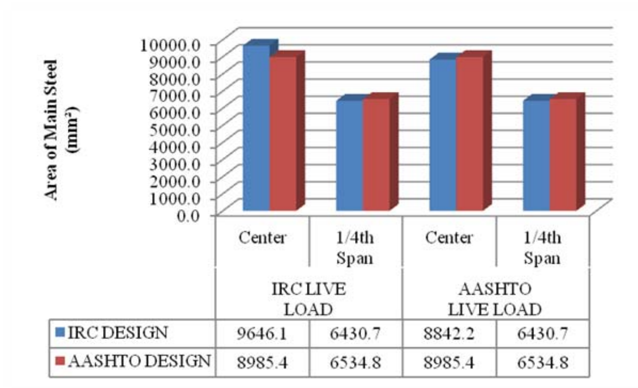

Fig. 7 Outer Girder Summary - IRC Load Combo

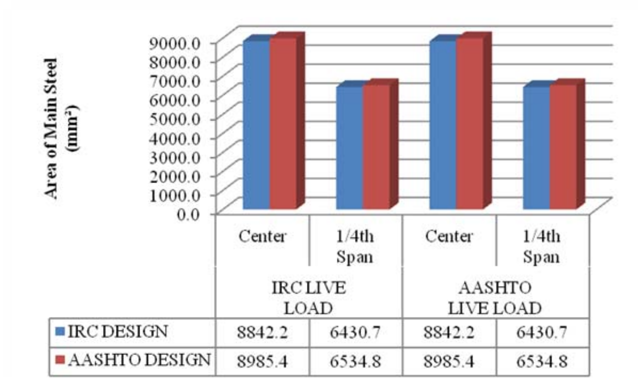

Fig. 8 Inner Girder Summary - IRC Load Combo

8.1.2 AASHTO Load Combination

Table 13 Outer Girder Summary - AASHTO Load Combo

AREA OF MAIN STEEL PROVIDED (mm²)				
	IRC LIVE LOAD		AASHTO LIVE LOAD	
DESIGN	Center	1/4th Span	Center	1/4th Span
IRC	9646.1	6430.7	8842.2	6430.7
AASHTO	8985.4	6534.8	8985.4	6534.8

Table 14 Inner Girder Summary - AASHTO Load Combo

AREA OF MAIN STEEL PROVIDED (mm²)				
	IRC LIVE LOAD		AASHTO LIVE LOAD	
DESIGN	Center	1/4th Span	Center	1/4th Span
IRC	8842.2	6430.7	8842.2	6430.7
AASHTO	8985.4	6534.8	8985.4	6534.8

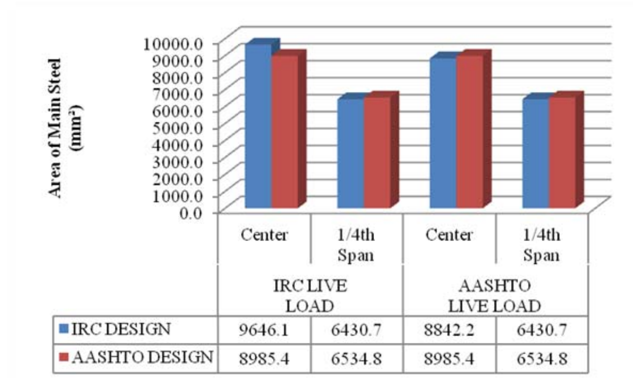

Fig. 9 Outer Girder Summary - AASHTO Load Combo

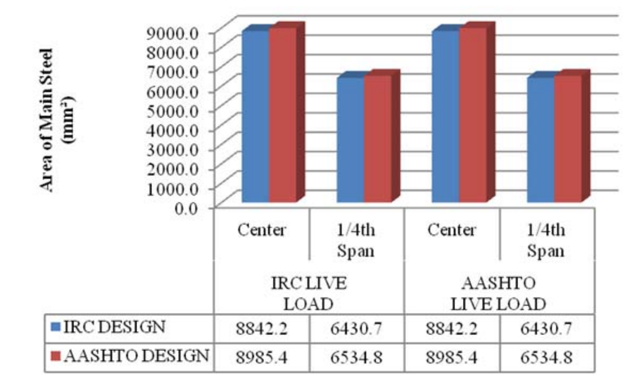

Fig. 10 Inner Girder Summary - AASHTO Load Combo

8.2 Shear Design

For IRC design, considering 12 mm diameter of bar as vertical stirrups, and for AASHTO design, considered 4 size of bar whose equivalent metric size is 12.70 mm.

8.2.1 IRC Design

Table 15 Design Summary for Both Load Combo

SHEAR REINFORCEMENT PROVIDED					
	@ Support	@ 1/8th Span	@ 1/4th Span	@ 3/8th Span	@ Center
Asw/s (mm²/mm)	1.508	0.905	0.905	0.905	0.905
MINIMUM SHEAR REINFORCEMENT REQUIRED					
	@ Support	@ 1/8th Span	@ 1/4th Span	@ 3/8th Span	@ Center
Asw/s (mm²/mm)	0.594	0.309	0.309	0.309	0.309

8.2.2 AASHTO DESIGN

Table 16 Design Summary for Both Load Combo

SHEAR REINFORCEMENT PROVIDED					
	@ Support	@ 1/8th Span	@ 1/4th Span	@ 3/8th Span	@ Center
Asw/s (mm²/mm)	0.831	0.498	0.498	0.415	0.415
MINIMUM SHEAR REINFORCEMENT REQUIRED					
	@ Support	@ 1/8th Span	@ 1/4th Span	@ 3/8th Span	@ Center
Asw/s (mm²/mm)	0.613	0.319	0.319	0.319	0.319

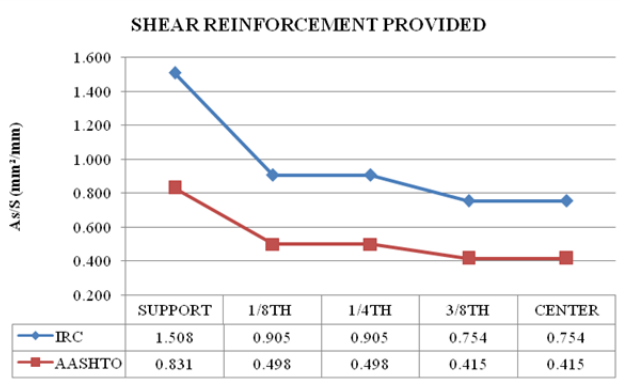

Fig. 11: Shear Reinforcement Provided - For Both Combo

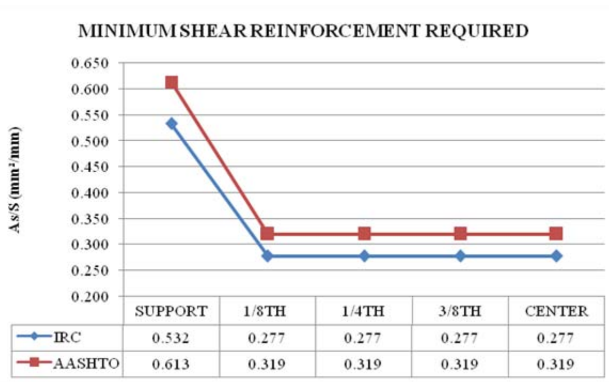

Fig. 12: Minimum Shear Reinforcement Required

9. CONCLUSION

1. From Load Combinations, both codes have its own limit states which have different partial safety factors for loading. Thus, for criteria of this case study, the load combination stipulated above clearly indicates that AASHTO load combination will govern compare to IRC load combination due to safety factor for Live Load is more in AASHTO.
2. From Table 5 and Table 6, the bending and shear values is higher for IRC live load compare to AASHTO live load. Also, AASHTO gives equal distribution of bending and shear values to all girders compare to IRC. This is because, while calculating distribution factors for IRC live loads, the C.G. of wheel load lies towards the first lane. That is the reason, outer girder has to resist more bending and shear values.
3. From Fig. 4, Table 3: Impact Fraction for Class 70R Wheeled Loading and Table 4 the impact fraction as per AASHTO is more and independent of span while as per IRC impact fraction is dependent on span and decreases as span increases.
4. Even though higher safety factors for Dead Load and SIDL in IRC compare to AASHTO, From Table 7 and Table 9, the bending and shear values are less for IRC load combinations, and from Table 8 and Table 10, the bending and shear values are more for AASHTO load combinations, this is due to higher factors for Live load in AASHTO compare to IRC.
5. From Fig. 7 and Fig. 8, Fig. 9 and Fig. 10, the area of steel provided is almost same for both IRC design and AASHTO design. There is hardly a difference of 1 bar is less provided in AASHTO Design for Outer girder. And for a same numbers of bars the area of steel provided varies due to for AASHTO design, 32.26 mm size of bar use while for IRC, 32 mm size of bar used.
6. From Fig. 11, the provided area of transverse reinforcement is much higher in IRC design compare to AASHTO.
7. From Fig. 12, the requirement of minimum shear reinforcement is quite less for IRC compare to AASHTO. This is due to the equations provided for minimum shear reinforcement in both codes is quite different.
8. From all above conclusion and as per referred materials, the new code IRC: 112 – 2011 are lined up with relevant international standards and design practice such as AASHTO – LRFD.
9. Still both codes have different design philosophy and design procedures but at last gives nearly similar results.

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Unit Conversions

Quantity		US Unit			SI Unit
Length	1	in	=	25.4	mm
	1	ft	=	0.304	m
Area	1	in²	=	645.2	mm²
	1	ft²	=	0.092	m²
Area/Unit Length	1	in²/in	=	25.4	mm²/mm
	1	ft²/ft	=	0.304	m²/m
Mass	1	lbm	=	0.454	kg
	1	lbm	=	4.448	N
Unit Weight	1	kcf	=	157.1	kN/m³
Force	1	kip	=	4.448	kN
Moment	1	kip-ft	=	1.356	kN-m
Force/Unit Length	1	kip/ft	=	14.59	kN/m
Pressure	1	ksi	=	6.895	Mpa