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A COMPARATIVE STUDY ON DESIGN CAPACITY OF A DECK SLAB USING IRC 112-2011 AND AASHTO LRFD

Justin Johnson[1] and R.K.Tripathi [2]

[1,2] Department of Civil Engineering, National Institute of Technology Raipur
e-mail: [1]jobsjust09@gmail.com, [2] rktripathi.ce@nitrr.ac.in

ABSTRACT: AASHTO LRFD is a standard for design of bridge structures, which has been used by many countries due to its rational results. IRC 112-2011 is a recently launched standard for the design of concrete bridge structures based on the limit state approach. By designing a deck slab with both the standards, a comparison can be drawn on the basis of strength and economy of the section. This study intends to compare the design capacity of the slab deck using IRC 112-2011 and AASHTO LRFD. In this study a two lane deck slab of 8.7m wide has been considered. The analysis has been done in STAAD Beava software. It has been concluded that the section designed with AASHTO LRFD will have more strength than with IRC 112-2011.

KEYWORDS: AASHTO LRFD, IRC 112-2011, Limit State Design, Slab Deck

1. INTRODUCTION

Till last decade, the bridges in India were designed as per working stress design philosophy. With the introduction of IRC 112-2011, which is based on limit state design philosophy, the IRC has made IRC 21 as obsolete. This has called for a major shift in the design of bridge structures from working stress method to limit state method. Major developed countries are using limit state design philosophy for the design of their structural elements. The limit state approach would result in lesser area of concrete and reinforcement compared to that designed using working stress method. AASHTO LRFD being a limit state approach, is used by many developing countries as a general code for the design of bridge structures. It provides more rational approach to design. It is based on the probabilistic approach to establish an adequate margin of safety based on variability of anticipated actions and reactions.

In this study a deck slab has been used to compare the design capacity. The slab deck bridges are economical for spans up to 10m. As the span increases, thickness of the slab increases which ultimately result in higher dead load. The formwork required for the construction of slab deck is simpler compared to other type of deck slabs. The reinforcement distribution in a slab deck is evenly distributed and the concrete is easier to be placed in slab deck, thereby reducing the cost of finish and quicker method of construction. All these factors have contributed to make a slab deck a popular choice for culverts. In this study a slab deck of 8.7 m wide carrying a two lane traffic spanning between 8m to 12m has been considered for the analysis. A plate model has been used to model the deck slab in STAAD Beava software. Live load models from each standard have been analysed in the software and the load generating maximum straining effects has been utilised for the design consideration.

The loads under consideration included the dead load, live load from the vehicular movement and the superimposed dead load.

The slab has been designed as per the basic load combination in IRC 112-2011 and as per Strength 1 condition for AASHTO LRFD. The strength 1 condition is mainly used for load combination relating to normal vehicular load without wind load. The minimum depth and area of reinforcement required as per each code have been obtained and tabulated.

2. SLAB DECK MODEL

As per the IRC 6-2016, the minimum width for a two lane carriageway is 7.5 m. As per AASHTO LRFD, the width of a notional lane is an integer valve when the effective carriage way is divided by 12ft. Hence a slab of 7.5m wide slab with kerbs of .6m wide on both sides have been considered in the model. A finite element plate model has been used to model the deck slab. A convergence study has been performed to find out the optimum mesh size.

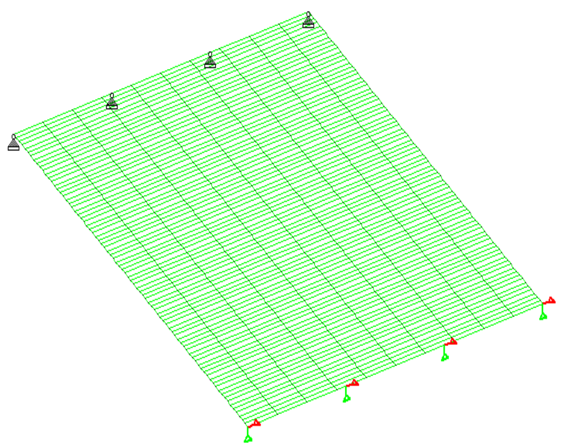

Figure 1. Deck slab model

3. LIVE LOAD MODELS

3.1 Live load per IRC 6-2016

Live load models are vehicular models that are used in analysing the vehicular effect on the bridge deck. The live load models represent the nature and size of the vehicles of a region. Different international standards specify a unique and exclusive live load models. Following are the vehicular load models considered as per IRC 6-2016.

3.1.1 Class 70R tracked and wheeled loading

The class 70 R tracked is a military vehicle of weighing 70 tonnes. The nose to tail spacing of the vehicles is restricted to a minimum of 90m. The vehicle is assumed to occupy two lanes and no other vehicles are allowed in these lanes. The minimum clearance of the vehicle with the nearest kerb is assumed to be a minimum of 1.2m.

The class 70 R wheeled vehicle is a seven axle vehicle weighing 100 tonne in total. The nose tail spacing and other conditions of the class 70R tacked vehicles are said to be applicable to the wheeled vehicle.

3.1.2 Class A loading

This class of loading consists of a wheeled vehicle of 8 axles which are assumed to occupy a single lane of road. These vehicles are more pronounced where the width of the carriage way is in between 5.3 and 7.5m. The deck analysed with Class 70R should also be checked with Class A loading.

3.1.3 Class AA wheeled and tracked loading

Class AA wheeled loading consists of axle loading of 20 tonnes, spaced 1.2m apart. The nose to tail spacing should be more than 90m. The vehicle is assumed to occupy two lanes and no other vehicle is allowed to ply over the same lanes.

3.2 Live load models as per AASHTO LRFD

AASHTO LRFD live loading is commonly known as HL-93 loading where H stands for highway and L stands for loading, developed in 1993. This is a hypothetical live load model proposed by AASHTO LRFD for the analysis of bridges with a maximum design period of 75 years. Reason for proposing this live load model is to prescribe a set of loads such that it produces extreme load effect approximately same as that produced by the exclusion vehicles. HL-93 loading consists of three basic live loads: design truck, design tandem and design lane.

3.2.1 Design truck

It is commonly called as HS-20-44 where H stands for highway, S for semitrailer, 20 ton (325 kN) weight of the tractor (1st two axles) and was proposed in 1994. HS20-44 indicates a vehicle with a front tractor axle weighing 4 kips (35kN), a rear tractor axle weighing 16 kips (145kN), and a semitrailer axle weighing 16 kips (145kN).The two rear axles have a variable spacing that ranges from 4.3 to 9 meter in order to induce a maximum positive moment in a span.

3.2.2 Design lane

It consists of uniformly distributed load of 9.3kN/m and is assumed to occupy 3 meter width in the transverse direction.

3.2.3 Design tandem

It consists of two axles weighing 12 tons (110kN) each spaced at 1.2 meter.

4. LIVE LOAD ANALYSIS OF THE SLAB DECK

The deck slab has been analysed with the live load models of the respective standards. For the design comparison, the load model giving the highest straining effect shall be considered for the respective standard.

Table 1. The live load bending moment

Span(m)	Class 70 R (kNm/m)	Class AA (kNm/m)	Class A (kNm/m)	AASHTO LRFD (kNm/m)
8	221.79	238.04	149.47	182.90
9	239.64	252.3	157.73	231.70
10	248.74	272.33	168.36	235.63
11	265.45	283.5	187.74	239.38
12	273.81	299.21	209.38	243.04

The basic load combination takes into account the effect due to live load, dead load and superimposed dead load. The following equation enunciates the basic load combination at ULS, adopted as per IRC 112-2011.

$$M_u = (1.5M_{ll} + 1.75M_{wl} + 1.35M_{dl}) \quad (1)$$

Where M_u is the ultimate moment

M_{ll} is the live load moment

M_w is the dead load bending

M_{dl} is the superimposed dead load.

The AASHTO LRFD code specifies strength 1 load combination, which takes into consideration the basic loads and without considering the wind load. The following formula states the strength 1 limit state at ULS:

$$M_u = \eta * (\gamma_{DC}(M_{DC} + M_{DC1}) + \gamma_{DW} M_{DW} + \gamma_{LL}(M_{LL+IM})) \qquad (2)$$
$$\eta = \eta_D * \eta_R * \eta_L \geq .95$$

Where M_{dc} = moment due to dead load
M_{dw}= moment due to wearing coarse
M_{LL+IM} = moment due to vehicular load

5. CALCULATION OF STRENGTH OF RECTANGULAR SECTION AS PER IRC 112-2011

For calculation of strength of a rectangular section following two conditions are to be satisfied

1) Stress strain compatibility: The stress at a point in the member would correspond to strain at that point.
2) Equilibrium – Internal force effects must match the external force effects.

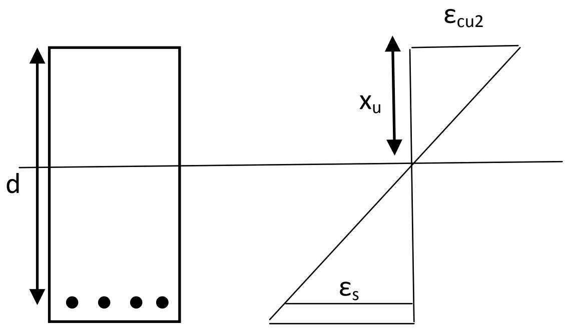

Figure 2. Strain distribution as per IRC 112-2011

To ensure ductile behaviour, the neutral axis depth should not be greater than

$$x_{lim} = \frac{\in_{cu}}{\in_{cu} + \in_{yd}} * d; \qquad (3)$$

Where $\in_{cu} = .0035$ and $\in_{yd} = \frac{f_{yd}}{E_s}$

To find neutral axis depth the following formulae can be used

$$\beta_1 f_{cd} bx(d - \beta_2 x) = M_{ED} \qquad (4)$$

Where β_1=.41597 and β_2=.80952 $f_{CD} = \frac{.67 f_{ck}}{1.5}$

The lever arm z =d-.416x and hence the area of steel required $A_s = \frac{M_{ED}}{.87 * f_y * z}$

The following are the provisions in the IRC 112-2011, for the design of flexural sections.

1. Secondary transverse reinforcement should be minimum of 20% of the primary reinforcement.
2. Negative reinforcement should be able to resist at least 25% of the external moment generated.

6. CALCULATION OF STRENGTH OF RECTANGULAR SECTION AS PER AASHTO LRFD

For calculation of strength of a concrete member as per AAASHTO LRFD, the following provisions will have to be taken care off;

1. The maximum unusable strain at extreme compression in concrete is .003
2. Sections are compression controlled when the tensile strain in steel is equal to or less than the compression controlled strain limit at the time when concrete reaches its assumed strain limit of .003
3. Sections are tension controlled when the net tensile strain in steel is greater than .005 just as the concrete in compression reaches a strain limit of .003.

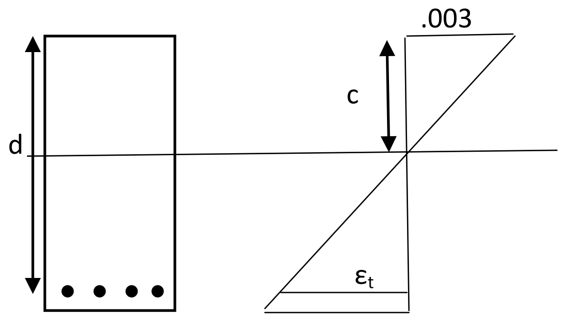

Figure 3. Strain distribution as per AASHTO LRFD

For a rectangular stress distribution the concrete compressive stress block is of .85 f_c' over a zone bounded by edges of the cross section and a straight line located at a distance of a=βc, where c is the depth of neutral axis from the extreme compression fibre and β is taken as .85 for concrete of strength up-to 4 ksi.

The factored flexural resistance M_r=φ*M_n. In case of tension controlled section the value of φ is taken as .9.

7. COMPARISON OF THE DESIGN PROVISION AS PER IRC 112-2011 AND AASHTO LRFD

The strain distribution diagrams from both of the code has been analysed and limiting depth of neutral axis for a balanced section has been found out. Following table represents the limiting depth of neutral axis for different grade of steel.

Table 2. Depth of neutral axis as per IRC 112-2011 and AASHTO LRFD

Grade of steel	$\left(\frac{x_u}{d}\right)_{\text{lim}}$ as per IRC	$\left(\frac{x_u}{d}\right)_{\text{lim}}$ as per AASHTO LRFD
Fe 415	.66	.59
Fe 500	.62	.54
Fe 550	.59	.52
Fe 600	.57	.50

By taking stress distribution diagram given in IRC 112-2011 and AASHTO LRFD, moment of resistance of a balanced section as well as the area of reinforcement have been computed. The following table gives the moment of resistance of a balanced section of depth 762.5mm, as per the provisions of IRC 112-2011.

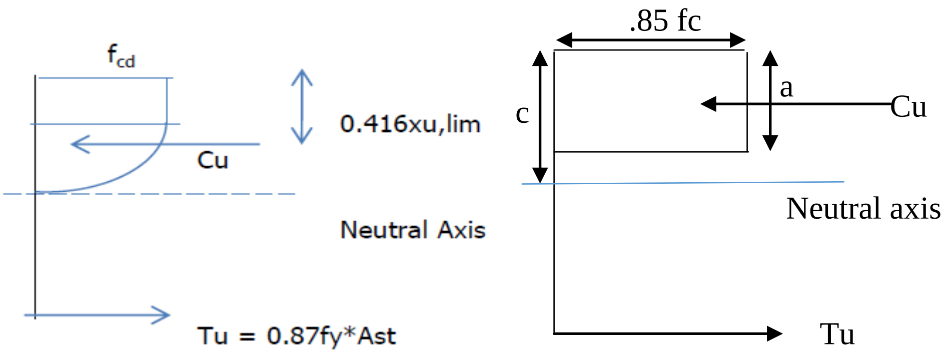

Figure 4. Stress diagram as per IRC 112-2011 and AASHTO LRFD

Table 3. Limiting area of reinforcement and moment of resistance of the section as per IRC 112-2011

Grade of steel	$\left(\frac{x_u}{d}\right)_{\text{lim}}$	Moment of resistance (kNm)	Limiting area of reinforcement (mm^2)
Fe 415	.66	3006.41	15061.12
Fe 500	.62	2888.99	11743.11
Fe 550	.59	2795.43	10159.00
Fe 600	.57	2730.45	8996.14

Table 4. Limiting area of reinforcement and moment of resistance of the section as per AASHTO LRFD

Grade of steel	$\left(\frac{x_u}{d}\right)_{\text{lim}}$	Moment of resistance (kNm)	Limiting area of reinforcement (mm^2)
Fe 415	.59	4456.64	18797.19
Fe 500	.54	4194.64	14279.49
Fe 550	.52	4083.85	12500.56
Fe 600	.50	3969.62	11018.13

Design of deck slab as per IRC 112-2011 and AASHTO LRFD

A slab deck of 8.7m wide having a depth of 800mm has been considered for the analysis. Deck slabs of spans varying from 8m to 12m are considered for the design. STAAD Pro software have been used for the design of the deck slab. The vehicular loads as per the IRC 6-2016 and AASHTO LRFD has been considered for the analysis. The live load analysis result has been tabulated in table 1. The results of the analysis have been used to find the factored moment of the section using the load combinations defined in IRC 112-2011 and AASHTO LRFD.

The following are the provisions in the IRC 112-2011, for the design of flexural sections.

1. The secondary transverse reinforcement should be minimum of 20% of the primary reinforcement.
2. The negative reinforcement should be able to resist at least 25% of the external moment generated.
3. The section has to be checked for shear as per the provisions and the reinforcement are provided as per IRC 112-2011

The following are the provisions in the AASHTO LRFD, for the design of flexural sections

1. The temperature and shrinkage reinforcement shall be provided at the top of the slab satisfying the following criteria

$$A_s \geq \frac{1.3 * bh}{2(b+h)f_y} \tag{5}$$

   where.11<As<.6
2. For primary reinforcement parallel to the traffic, the distribution reinforcement shall be of the following percentage as primary reinforcement.

$$A_{st} = \frac{100}{\sqrt{S}} \leq 50\% \tag{6}$$

3. As per AASHTO LRFD, the slab deck need not checked for the shear.

The quantity of reinforcement required when a slab deck designed with AASHTO LRFD and IRC 112-2011 have been tabulated in Table 5 and 6 respectively. The following tables show the results of the design calculations.

Table 5. Minimum depth of section and reinforcement required for a section when designed as per AASHTO LRFD

Span(m)	Required depth of section (AASHTO LRFD) mm^2	Required area of reinforcement (AASHTO LRFD) mm^2
8	235.62	4153
9	246.48	4628
10	251.72	5657
11	257.44	6215
12	263.64	6748

Table 6. Minimum depth of section and reinforcement required for a section when designed as per IRC 112-2011

Span	Required depth of section (IRC 112-2011) mm	Required area of reinforcement (IRC 112-2011) mm^2
8	326.2	5480
9	341.0	6186
10	358.68	6977
11	375.18	7635
12	394.23	8558

8. RESULTS AND CONCLUSIONS

1. The depth of the neutral axis of balanced section when designed using IRC 112-2011 will be more than 10% higher than when designed using AASHTO LRFD.
2. The section designed as per the provisions of AASHTO LRFD will be having higher moment of resistance than that designed as per AASHTO LRFD.
3. The limiting area of reinforcement for section designed as per the AASHTO LRFD will be more than the area of reinforcement designed as per IRC 112-2011.
4. The vehicular loading as per the AASHTO LRFD would generate lesser straining effects as compared to that with vehicles defined under IRC 6-2016.
5. The depth required for a section when designed as per IRC 112-2011 would be more than when designed as per AASHTO LRFD.
6. The area of steel required for a section will be more when designed as per IRC 112-2011 than by AASHTO LRFD.
7. The serviceability criteria of AASHTO LRFD mandates to have a deck

section of higher thickness than the thickness obtained from ultimate limit state. This along with the higher moment of resistance of the section might be the possible reason to neglect the shear reinforcement in a section when designed as per AASHTO LRFD.

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