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Comparison of Design Capacity Due to Change in Design Stress Strain Curve of Concrete and Reinforcing Steel

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***Abstract:* -- This paper compares the variation in design capacity of flexural and axially loaded elements due to the difference in the design curves in the IS: 456-2000 and IRC: 112-2011. A bridge deck slab section is selected as a flexural element and a bridge pier column section is selected as an axially loaded element with the uniaxial bending moment. Their design capacities are calculated on the basis of the design curves as per the above codes. An interaction curve for axial compression with uniaxial bending is also plotted in MATLAB for given column section with respect to the design curves of both the code. It concludes that new design curves for concrete and steel increases the flexural design capacity of the section significantly but variation in P-M interaction curve is not significant.**

***Index Terms*: - Design Curves, Design Capacities, Flexural Element, Uniaxial Bending.**

I. INTRODUCTION

In order to arrive at desired target of safety, serviceability, durability and economy in a reliable way Indian Road Congress has adopted IRC:112-2011[1] 'Code of Practice for Concrete Road and Bridges' as new unified concrete bridge standard for both reinforced concrete as well as prestressed concrete replacing the IRC:21-2000[2] 'Plain and reinforced concrete' and IRC:18-2000[3] for 'Post tensioning of bridges' which is based on allowable stress design philosophy and IRC 112:2011 has adopted semi-probabilistic limit state approach. IS: 456-2000[4] 'Plain and reinforced concrete' is the code of practice for general structural use of plain and reinforced concrete that is also based on limit state design.

IRC: 112-2011[1] includes-

Three types of stress strain blocks for concrete i.e.

a. Parabolic-rectangular block (Cl 6.4.2.8 (1-a))

b. Bilinear stress strain block (Annexure A2.9 (i))

c. Rectangular stress strain block (Annexure A2.9 (ii)) and

Two types of stress strain block for design of reinforcing steel i.e.

a. Bilinear simplified stress strain curve (without strain hardening) (Cl 6.2.2)

b. Bilinear idealized stress strain curve (with strain hardening) (Cl 6.2.2)

IS: 456-2000[4] includes-

For concrete

a. Parabolic Rectangular block (Cl. 38.1)

For steel

b. Stress-strain curve (Cl. 38.1)

II. METHEDOLOGY

Although both IS: 456-2000 and IRC: 112-2011 are limit state code but there are some difference in stress strain blocks of concrete and reinforcing steel. This paper compares the effects of variation in curves on the design capacitiy of the flexural element and axially loaded element with uniaxial bending.

A). For comparing the flexural design capacity with respect to different curves singly reinforced section of a bridge deck slab as shown in Fig.1 is taken whose section details are-

Total depth (D) = 700mm,
Width (b) = 1000 mm,
Clear Cover = 50 mm,
Concrete Grade M35,
Steel Grade Fe500,
Diameter of bars = 25mm,

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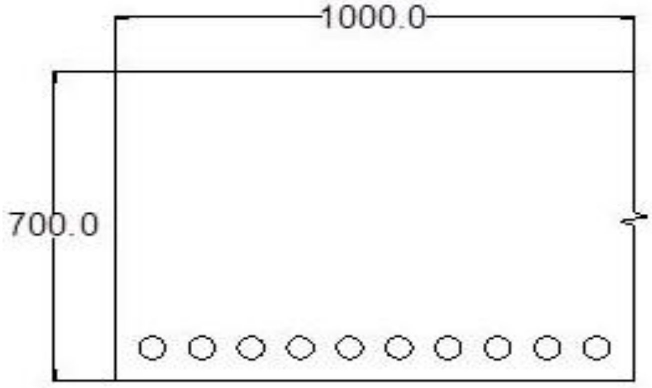

Fig.1 Deck Section (1000 mm. x 750 mm.)

(Reinforcement shown in Fig.1 is representative)

B). For comparing the axial design capacity with respect to different curve a bridge column pier section as shown in Fig.2 is taken whose section details are-

Size of column (mm2) = 1800 x 1500
Diameter of steel bar (mm) = 32
No. of steel bars = 34
Clear cover (mm) = 50

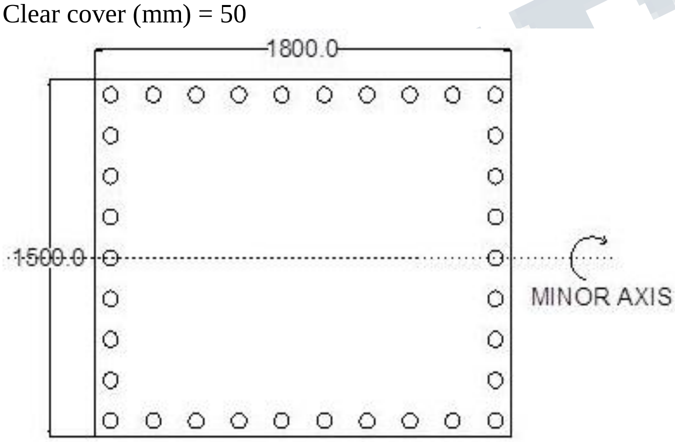

Fig.2 Bridge Pier Column Section (1800mm. x 1500mm

Concrete grade = M60
Steel grade = Fe500

P-M interaction curve (axial load capacity – moment of resistance) of bridge pier section about its minor axis with respect to IRC: 112-2011 is plotted by adopting both simplified as well as idealized stress strain curves for steel with parabolic rectangular stress block for concrete.

P-M interaction curve of pier section about its minor axis is also plotted for stress strain curves given in IS: 456-2000 and both the plots are compared.

III. RESULTS AND DISCUSSIONS

A. Difference between Stress Strain Curves of IS: 456-2000 and IRC: 112-2011

i) For Concrete:

1. Parabolic rectangular stress strain curves of IS: 456 and IRC: 112 are same upto M60 grade of concrete.

2. Bilinear stress strain curve for concrete adopts the $\varepsilon c3$ = 0.0018 whereas parabolic rectangular curve adopts $\varepsilon c2$ = 0.002. But the ultimate strain remains same as $\varepsilon cu2 = \varepsilon cu3$ = 0.0035 in all the curves.

Where,

- $\varepsilon c3$ = strain at which concrete reaches design stress in bilinear stress strain block of concrete.
- $\varepsilon cu3$ = ultimate strain in concrete in bilinear stress strain block of concrete
- $\varepsilon c2$ = strain at which concrete reaches design stress in parabolic rectangular stress strain block of concrete.
- $\varepsilon cu2$ = ultimate strain in concrete in parabolic rectangular stress strain block of concrete.

ii) For Steel Reinforcement:

1. Major difference between design curves for steel reinforcement in IS: 456 and IRC: 112 is former code adopts that ultimate stress in steel will be reached at a strain of fy/(1.15 Es)+0.002 , whereas IRC:112 adopts ultimate stress in steel will be reached at a strain fy/(γ Es).

Where,

fy = yield strain of steel
γm = partial safety factor for steel i.e. 1.15.
Es = modulus of elasticity of steel

2. By lowering the ultimate strain at limit state will increase the balanced neutral axis depth and hence increase the ultimate capacity of the section as shown in table 1.

Table 1. Variation in Limiting depth of balanced section due to the change in Reinforcing Steel Design Curves

		Fe 250	Fe 415	Fe 500	Note
As per IS 456:2000	ε_s min = $(\frac{fy}{1.15\,Es} + 0.002)$	0.0030	0.0038	0.0041	
	$\frac{Xu,lim}{d}$	0.53	0.48	0.45	
As per IRC 112:2011	ε_s min = $\frac{fy}{1.15\,Es}$	0.0010	0.0018	0.0021	For all type of concrete curves
	$\frac{Xu,lim}{d}$	0.76	0.66	0.62	

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B. Effect on Flexural Design Capacity

Maximum moment of resistance deck section is calculated for IS: 456-2000 and IRC: 112-2011 and results are shown in table 2.

Table 2. Ultimate Moment of Resistance of Deck Section with Different Curves

Moment of Resistance (kN-m)			% change (with respect to IS-456:2000)
1.	As per IS:456-2000	1914.298	-
2.	As per IRC:112-2011 (Parabolic-Rectangular Curve)	2367.765	23.68%
3.	As per IRC:112-2011 (Bilinear Curve)	2220.860	16.1%
4.	As per IRC:112-2011 (Rectangular Curve)	2369.798	23.79%
Note: Balanced Moment of resistance for IRC: 112-2011 is calculated with Simplified Bilinear Curve for reinforcing steel.			

C. Effect on Capacity of Column Section Subjected to Axial Load with Uniaxial Bending Moment

Fig.3 shows the comparison of Interaction curves of given column section about minor axis plotted for both the limit state design codes of IS-456:2000 and IRC-112:2011 (parabolic-rectangular stress block for concrete and Simplistic bilinear curve for reinforcing steel). Fig.4 shows the comparision of interaction curves of given column section about minor axis plotted for both the limit state design codes of IS-456:2000 and IRC-112:2011 (parabolic-rectangular stress block for concrete and Idealized bilinear curve for reinforcing steel).

1. Both the comparision plot as shown in Fig.3 and Fig.4 shows that there is not much difference in P-M interaction (axial load capacity – moment of resistance). However P-M curve plotted as per IS-456:2000 is lying inside the P-M curve plotted as per the IRC-112:2011 in both Fig.3 and Fig.4.

2. There is notable difference between design capacities at comparitively higher axial loads.

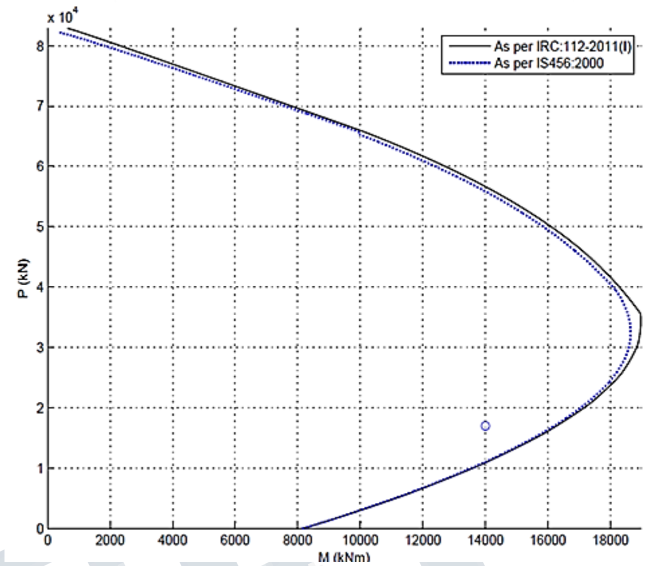

Fig.3, Interaction Curve Plotted for IS-456:2000 and IRC-112:2011 (Parabolic-Rectangular curve for concrete and Simplistic bilinear curve for steel)

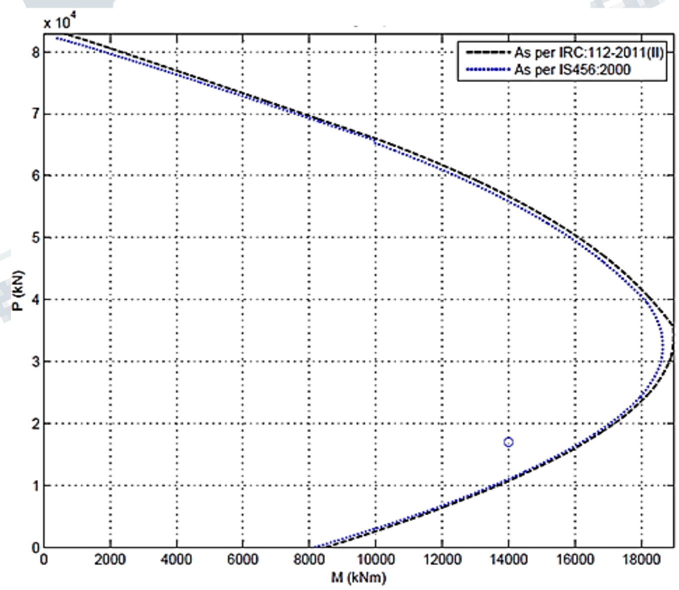

Fig.4, Interaction Curve Plotted for IS-456:2000 and IRC-112:2011 (Parabolic-Rectangular curve for concrete and Idealized bilinear curve for steel)

IV. CONCLUSION

By comparing results drawn out after analyzing the above flexural element and the axially loaded bridge pier section element with uniaxial bending moment following conclusion can be drawn i.e.

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1. Changes in minimum yielding strain of steel causes increases in the neutral axis depth of balanced section thus increasing the ultimate moment capacity of flexural section thus using the material more economically.
2. Interaction curve for axially loaded element with uniaxial bending moment shows that there is not much difference in capacity of section at different P-M (axial load capacity - moment of resistance) combination.
3. At lower axial load capacity both the design curves produces similar results.
4. But at higher axial load there are little differences in P-M curves with IS: 456-2000 slightly lesser than P-M curve of IRC: 112-2011.

REFERENCES

[1] IRC: 112-2011 Code of Practice for Concrete Road Bridges, Indian Road Congress New Delhi

[2] IRC: 21-2000 Standard specification and code of practice for Road bridges, Indian Road Congress New Delhi

[3] IRC: 18-2000 Design Criteria for Prestressed Concrete Road Bridges (Post Tensioned), Indian Road Congress New Delhi

[4] IS: 456-2000 Plain and Reinforced Concrete - Code of Practice, Bureau of Indian Standards, New Delhi.

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