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Comparative Evaluation of Crack Width for Reinforced Concrete Bridge Deck

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Abstract: ***Cracking in reinforced concrete bridge decks is a massively concern in the India. Many concrete bridge decks, inobservant to the age of construction, have shown different levels and patterns of cracking. Not only does cracking of bridge decks weaken the bridge infrastructure, but also allows the inflow of corrosive agents into the reinforcement.***
In this study, the crack width evaluation of RC bridge deck of span of 5 m. and 9 m. is based on equations given by IRS Concrete Bridge Code 1997 for different cases like- the effect of depth variation, reinforcement diameter, clear cover, variation in live load moment, spacing of tension reinforcement and different no. of tension reinforcement bar to constant width for the same cross-section.
This study concluded that crack width increases with increase in clear cover, variation in live load moment and spacing of tension reinforcement while it decreases with increase in reinforcement diameter, depth of the bridge deck and number of reinforced bars and percentage change evaluation of different parameter of 5m and 9m span bridge deck.
Keyword: Crack Width, Cracking, Bridge Deck Slab, Crack Spacing.

I. INTRODUCTION

Generally, crack width of cracks that develop during the loading of a member should satisfy the serviceability criteria. The crack width of RC bridge deck is evaluated when loading occurs at the tension or compression face of an RC bridge deck. Due to low tensile strength, cracks occur in the RC bridge deck. Control of cracking is important for obtaining long-term durability for concrete structures, especially for those that are subjected to aggressive environments.

When the crack width is increasing, the service life of the structure will be decreasing by allowing more rapid penetration of chlorides to reach the reinforcement causing corrosion. Various factors such as high humidity, repeated loads, and gases with chemicals may cause corrosion of reinforcement and spalling of concrete. Cracking in reinforced concrete structures affects structural performance including stiffness, energy absorption, capacity etc., Consequently, there is an interest in the control of cracking by IRS bridge code. In some cases, shrinkage crack also may occur, we can reduce those cracks by adding extra reinforcement in reinforced concrete.

The crack width is one of the important factors to the design of reinforced concrete structures. Currently, estimations of the crack width in the deck slab of bridges given by IRS Bridge code of practice are based on either theoretical or empirical approaches. Cracking in reinforced concrete structures is unavoidable due to the low tensile strength of concrete. Wider cracks may not only destroy the aesthetics of the structure, but also expose steel reinforcement to the environment leading to corrosion. To control the crack width at the member surface, designers may use the guidelines prescribed in various bridge codes.

II. DESIGN CRACK WIDTH

Crack width calculation is one of the serviceability requirements in the structural concrete elements. The occurrence of cracks in reinforced concrete elements is expected under service loads, due to the low tensile strength of concrete. Excessive crack width may reduce the service life of the structure by permitting more rapid penetration of corrosive factors such as high humidity, repeated saturation with moisture, vapor, salt-water spray and gases with chemicals, to reach the reinforcement.

The crack width of a flexural RC member is calculated to satisfy a limit state of serviceability. Among pre-stressed concrete members, there is cracking under service loads. The crack width is calculated for the cracks due to bending which occur at the bottom or top surfaces of a flexural RC member.

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A. Method and Formula of Calculation

According to IRS Concrete bridge code for the crack width calculation formula for bridge deck section is –

$$\text{Design crack width} = \frac{3a_{cr}\varepsilon_m}{1+2(a_{cr}-c_{nom})/(h-d_c)} \qquad \text{(A)}$$

a_{cr} is distance from crack considered to the surface of nearest longitudinal bar

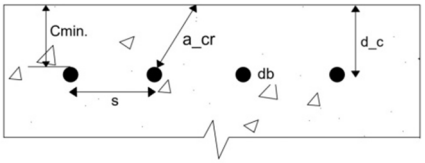

Figure 1 Cross-section of Slab Base

$$a_{cr} = \left[\sqrt{\left(\frac{s}{2}\right)^2 + (c_{eff.})^2}\right] - \frac{d_b}{2} \qquad \text{(B)}$$

d_b = diameter of longitudinal bar

$c_{eff.}$ = effective cover = $C_{min} + d_b/2$

s = centre-to-centre spacing of longitudinal bars.

c_{nom} is required nominal cover to tensile reinforcement

d_c is depth of concrete in compression

h is overall depth of section

ε_m is calculated strain, where cracking is considered

$$\varepsilon_m = \varepsilon_1 - \left[\frac{3.8 b_t h(a'-d_c)}{\varepsilon_s A_s (h-d_c)}\right]\left[1-\frac{M_q}{M_g}\right]10^{-9} \qquad \text{(C)}$$

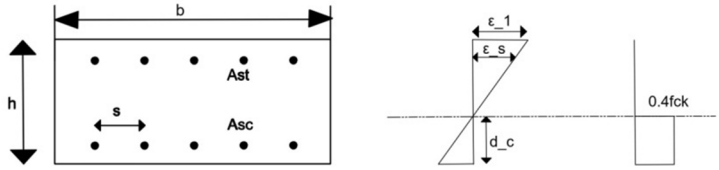

Figure 2 Strain and Stress Diagram for Slab Section of Bridge Deck

ε_1 is calculated strain at the level where cracking is being considered, ignore stiffening effect of concrete in tension

b_t is width of section at level of centroid of tension steel

a' is distance from compression face to the point at which crack width is calculated

M_g is moment at section considered due to permanents loads

M_q is moment at section considered due to live loads

ε_s is calculated strain in tension reinforcement, ignore stiffening effect of concrete in tension

A_s is area of tension reinforcement where design moment and tension resisting moment are not normal to each other.

$$A_s = \sum (A_t \cos^4 \alpha_1) \qquad \text{(D)}$$

A_t is area of reinforcement in particular direction

α_1 is angle between axis of design moment and tension resisting moment

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III. CALCULATION OF CRACK WIDTH

In present study, for calculation of crack width for bridge deck as per IRS bridge code 1997. Considering RC two way bridge design of two bridge deck, one is 5 m. (short) and other 9 m. (long) length of bridge deck for moderate environment condition. This is designed for IRC class AA loading. Width of the deck is 9.5 m., clear cover as per environment condition is 25 mm., the grade of concrete is M30 and grade of steel is Fe-415.

Cut the section of 1 m. x 1 m. of both (5m. and 9m) of the span of bridge deck, where crack is considered and finally calculate the crack width.

A. Structural Detailing

Table 1: Structural detail of model

General detail	5 m. bridge deck	8 m. bridge deck
Structure	Bridge deck structure	Bridge deck structure
Types of bridge	RC Two way bridge	RC Two way bridge
Environment	Moderate	Moderate
Length of deck	5 m.	9 m.
Width of deck	9.5 m.	9.5 m.
Depth of deck (h)	450 mm.	800 mm.
Type of loading	IRC Class AA	IRC Class AA
Clear cover	25 mm.	25 mm.
Grade of concrete	M30	M30
Grade of steel	Fe-415	Fe-415
Moment due to dead load (M_g)	60 KN-M	220 KN-M
Moment due to live load (M_q)	90 KN-M	200 KN-M
Dia. Of tension R/f bar	25 mm.	25 mm.
Dia. of compression R/f bar	20 mm.	20 mm.
Effective cover	25 + 25/2 = 37.5 mm.	25 + 25/2 = 37.5 mm.
Effective depth of bridge deck (d)	450 – 37.5 = 412.5 mm.	800 – 37.5 = 762.5 mm.
Area of tension R/f of section (A_{st})	$5 \times \frac{\pi}{4} \times 25^2 = 2455\ mm^2$	$8 \times \frac{\pi}{4} \times 25^2 = 3927\ mm^2$
Area of compression R/f of section (A_{sc})	$5 \times \frac{\pi}{4} \times 20^2 = 1571\ mm^2$	$6 \times \frac{\pi}{4} \times 20^2 = 1885\ mm^2$
Reinforcement detail	Provide 5 no. of 25 mm. bar @180mm c/c spacing at tension face and 5 no. of 20 mm. dia. Bar @200mm c/c spacing at compression face.	Provide 8 no. of 25 mm. bar @120mm c/c spacing at tension face and 6 no. of 20 mm. dia. Bar @150mm c/c spacing at compression face .

Now calculate the crack width of bridge deck for both of the span of 5m and 9m with the help of structural detail show in table-1. The design crack width for moderate environment conditions is calculated with above formula. Specifies the range of crack width in order to magnitude and sturdiness of the structural element is not affected. The limiting value of design crack width are less or equal to 0.2 mm for moderate environment conditions and 0.1 mm take for severe and extreme environment condition. The determined value of parameters and crack width for 5m and 9m span bridge deck is present in table-2.

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Table 2 : Determined value of parameters for crack width formula –

Parameter detail	5 m. bridge deck	8 m. bridge deck
a_{cr}	85 mm	58.25 mm
d_c	130.23 mm	231.06 mm
I_{cr}, Moment of inertia of crack section-	3.94×10^9 mm^4	2.22×10^{10} mm^4
ε_s	8.24×10^{-4}	7.73×10^{-4}
ε_1	9.33×10^{-4}	8.27×10^{-4}
ε_m	9.33×10^{-4}	7.35×10^{-4}
W_{cr}	0.1730 mm	0.1150 mm

From above table-2, determined the value of crack width is 0.1730 mm for 5 m and 0.1150 mm for 8 m bridge deck slab. Now the crack width evaluation of RC bridge deck of span of 5 m. and 9 m. for different cases like- the effect of depth variation, reinforcement diameter, clear cover, variation in live load moment, spacing of tension reinforcement and different no. of tension reinforcement bar to constant width for the same cross-section. The result of percentage change evaluation for crack width is represent with variations in different parameter of 5m and 9m span bridge deck.

IV. RESULT AND DISCUSSION

In present work, Considering RC two way bridge design of two bridge deck, one is 5 m. (short) and other 9 m. (long) length of bridge deck. Calculate the crack width of individual span with the help of IRS concrete bridge code 1997 and compare both of the results on the basis of percentage change. The results are obtained after calculation, which has been discussed in this chapter.
The crack width of RC bridge deck for different parameter variation. The graphical representation is generated for combined results of the bridge deck. Which represents, when the parameter of bridge deck is change, then crack width of deck is increased or decreased.
The combined graphical result for different cases of 5m and 9m span of bridge deck is-

1) *Case 1:* When variation in depth of deck up to 5% to 10% in both (positive and negative) direction, then change in crack width is-

Table 3 Variation in Depth of Deck and Crack width for 5 m and 9 m span

Variation in depth of deck in (%)	Crack width for 5m span (mm.)	Crack width for 9m span (mm.)
H (-5%)	$W_{cr} = 0.1824\ mm.$	$W_{cr} = 0.1239\ mm.$
H (+5%)	$W_{cr} = 0.1650\ mm.$	$W_{cr} = 0.1070\ mm.$
H (-10%)	$W_{cr} = 0.1936\ mm.$	$W_{cr} = 0.1332\ mm.$
H (+10%)	$W_{cr} = 0.1577\ mm$	$W_{cr} = 0.0996\ mm$

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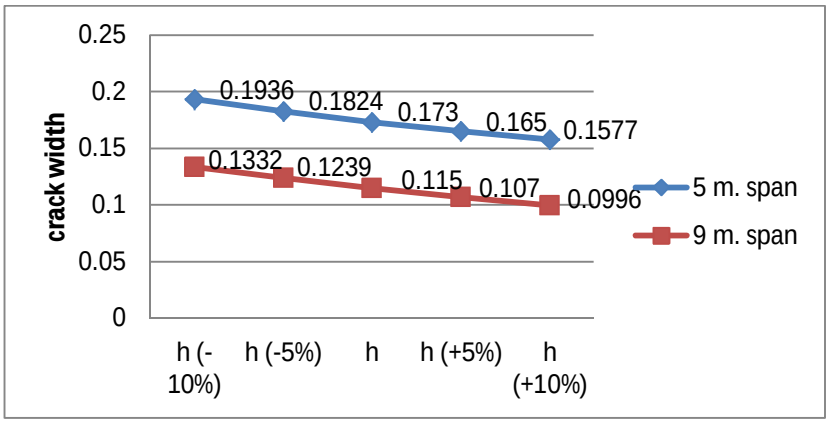

Figure 3 Graph B/w Crack Width and Variation in Depth for 5m. and 9m. Span

The variations in depth of bridge deck for presentation of analysis of crack width evaluation are shown in figure 3. This figure 3 observed that the depth of 5m.and 9 m. span is increase or decrease to 5%, then crack width change up to 4-6% and 6-8% respectively. If depth of both of the span is change up to 10%, then crack width change up to 8-11% for 5m. and 13-15% for 8m. span.

2) Case 2: When change in diameter of tension reinforcement (d_b) of deck for 20 mm., 32 mm., 36 mm. and 40 mm. bar, then change in crack width is-

Table 4 Variation in Crack Width, When Use Different diameter of bar for 5 m. and 9 m span

Different Diameter of Tension Reinforcement (mm.)	Crack Width for 5 m Span (mm.)	Crack Width for 9 m Span (mm.)
d_b = 20 mm	W_{cr} = 0.2674 mm.	W_{cr} = 0.1843 mm.
d_b = 32 mm	W_{cr} = 0.1076 mm.	W_{cr} = 0.0663 mm.
d_b= 36 mm	W_{cr} = 0.0858 mm.	W_{cr} = 0.0504 mm.
d_b= 40 mm	W_{cr} = 0.0703 mm	W_{cr} = 0.0400 mm

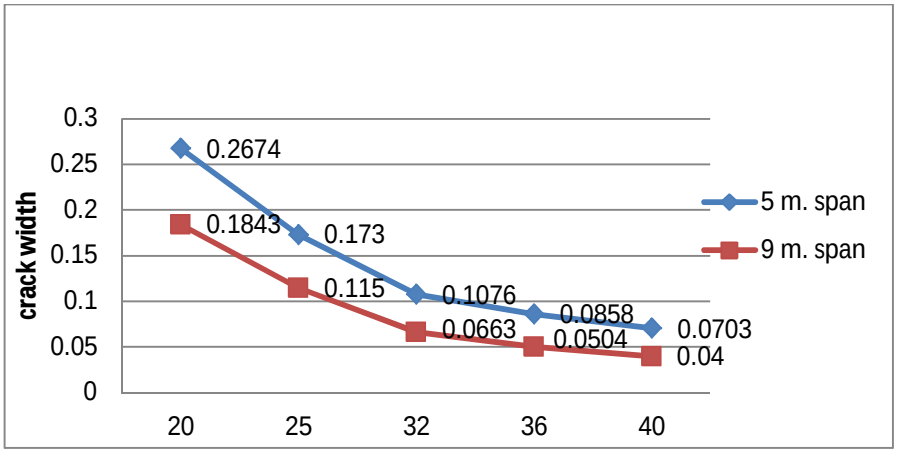

Figure 4 Chart B/w Design Crack Width and Different Dia. of Tension R/f of 5 m. and 9m. Span

For analysis of crack width evaluation the change in diameter of the reinforcement effect are shown in figure 4, it is observed that when the diameter of reinforcement bar is increases in the deck, then the crack width of bridge deck reduced. In the span of 5 m. and 9 m., the reinforced diameter of bar increases up to 15 mm, then the crack width is reduces up to 65%.

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3) *Case 3:* Crack width value for different clear cover (C_{nom}.), When clear cover of deck in increasing order is 30 mm., 35 mm., 40 mm. and 45 mm., then change in crack width is-

Table 5 Variation in Crack Width, When Increase the Value of Clear Cover of 5 m. and 9 m span

For Different Clear Cover (mm.)	Crack Width for 5 m Span (mm.)	Crack Width for 9 m Span (mm.)
C_{nom} = 30 mm	W_{cr} = 0.1859 mm.	W_{cr} = 0.1241 mm.
C_{nom} = 35 mm	W_{cr} = 0.1996 mm.	W_{cr} = 0.1335 mm.
C_{nom} = 40 mm	W_{cr} = 0.2143 mm.	W_{cr} = 0.1438 mm.
C_{nom} = 45 mm	W_{cr} = 0.2316 mm	W_{cr} = 0.1555 mm

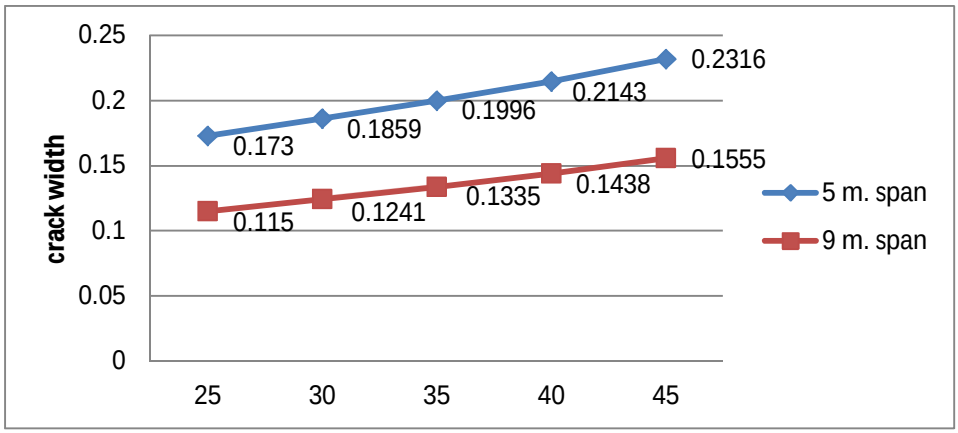

Figure 5 Chart B/w Crack Width and Different Clear Cover for 5m. and 9m. Span

The analysis of crack width evaluation is present in fig. 5, it present the change in value of crack width for different clear cover values. This figure 5 conclude that when the value of clear cover of the deck is increases, then the value of crack width also increases. If the clear cover of 5 m. and 9 m. span bridge deck is increase up to 20 mm., then the crack width is increases up to 30%.

4) *Case 4:* When variation in live load moment (M_q) of deck upto 5% to 10% in both (positive and negative) direction, then change in crack width is-

Table 6 Variation in Live Load Moment and Crack width for 5 m and 9 m. span

Variation in Live Load Moment (%)	Crack Width for 5 m Span (mm.)	Crack Width for 9 m Span (mm.)
M_q (-10%)	W_{cr} = 0.1626 mm.	W_{cr} = 0.0926 mm.
M_q (-5%)	W_{cr} = 0.1680 mm.	W_{cr} = 0.1041 mm.
M_q (+5%)	W_{cr} = 0.1782 mm.	W_{cr} = 0.1250 mm.
M_q(+10%)	W_{cr} = 0.1836 mm	W_{cr} = 0.1353 mm

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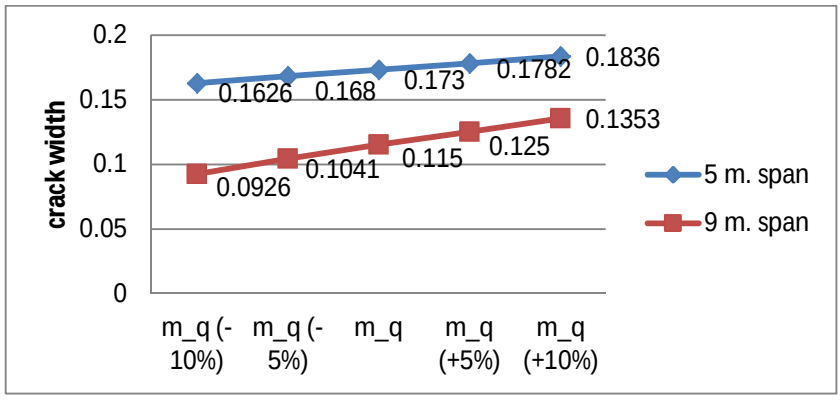

Figure 6 Chart B/w Crack Width and Different Value of Live Load for 5m. and 9m. Span

The analysis of crack width evaluation is present on fig. 6, it shows the change in crack width of bridge deck due to variation in live load moments . From the figure 6, it is observed that the value of live load moment for 5 m. and 9 m. span is increase or decreases to 5 %, then the crack width change up to 2.5-3% and 8-10% respectively. If the value of moment for both span is increase or decrease to 10%, then crack width change up to 5-6% and 15-20% respectively.

5) Case 5: When variation in centre to centre spacing of tension R/f up to 5% to 10% in both (positive and negative) direction, then change in crack width is-

Table 7 Variation in Spacing of Tension Reinforcement and Crack width for 5 m. and 9 m span

Variation in Spacing of Tension Reinforcement (%)	Crack Width for 5 m Span (mm.)	Crack Width for 9 m Span (mm.)
S (-10%)	W_{cr} = 0.1623 *mm.*	W_{cr} = 0.1068 *mm.*
S (-5%)	W_{cr} = 0.1677 *mm.*	W_{cr} = 0.1109 *mm.*
S (+5%)	W_{cr} = 0.1781 *mm.*	W_{cr} = 0.1191 *mm.*
S (+10%)	W_{cr} = 0.1830 *mm*	W_{cr} = 0.1227 *mm*

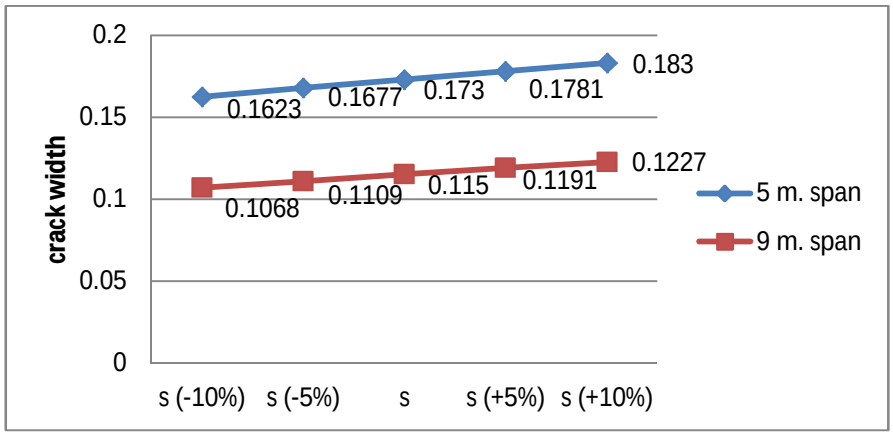

Figure 7 Chart B/w Crack Width and Variation in c/c Spacing of Tension R/f for 5m. and 9m. Span

The effect of tension reinforcement spacing variations shows in fig. 7, it present the change in crack width due to change tension reinforcement spacing . This figure 7 is observed that the spacing of 5m.and 9 m. span is increase or decrease to 5%, then crack width change up to 3-4% for both of the span. If spacing of both of the span is change up to 10%, then crack width change up to 5-7% for 5m. and 6-8% for 9m. span.

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6) Case 6: Effect of no. of bar to constant width – Crack width value for use more number of bar in tension zone in constant unit width, then change in crack width is-

Table 8 Variation in Crack Width, When Use Different No. of Tension Reinforcement bar for 5 m and 9 m. span

Different No. of Tension Reinforcement Bar	Crack Width for 5 m Span (mm.)	Crack Width for 9 m Span (mm.)
5 bar (180 mm.c/c)	W_{cr} = 0.1730 mm.	W_{cr} = 0.2516 mm.
6 bar (170 mm.c/c)	W_{cr} = 0.1397 mm.	W_{cr} = 0.2030 mm.
7 bar (150 mm.c/c)	W_{cr} = 0.1114 mm.	W_{cr} = 0.1562 mm.
8 bar (120 mm.c/c)	W_{cr} = 0.0861 mm.	W_{cr} = 0.1150 mm.
9 bar (100 mm.c/c)	W_{cr} = 0.0693 mm	W_{cr} = 0.0893 mm

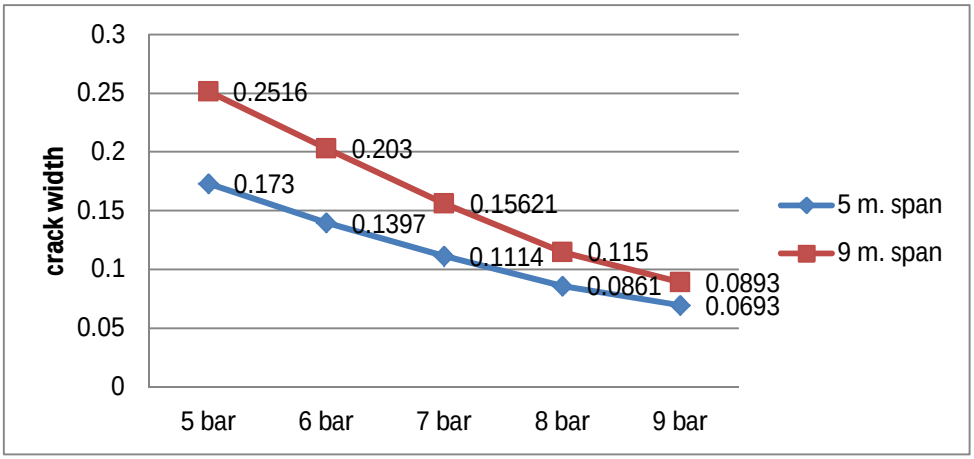

Figure 8 Chart B/w Crack Width and Different No. of Tension Reinforcement Bar for 5m. and 9m.Span

The fig. 8 is shows comparative study for analysis of crack width for the effect of increase number of the reinforcement bar on the bridge deck, it is observed that when the number of reinforcement bar is increases in the deck, then the crack width of bridge deck reduced.

V. CONCLUSION

This study explains the behavior of the crack width of RC bridge deck for different cases from change in parameters, which the following conclusion can be drawn, based on the result:

A. The analysis shows that the depth of bridge deck is increases then crack width of the section is decreases. The depth of 5m.and 9 m. span is increase or decrease to 5%, then crack width change up to 4-6% and 6-8% respectively. If depth of both of the span is change up to 10%, then crack width change up to 8-11% for 5m. and 13-15% for 8m. span.

B. When the diameter of reinforcement bar is increases in the deck, then the crack width of bridge deck reduced. In the span of 5 m. and 9 m., the reinforced diameter of bar increases up to 15 mm, then the crack width is reduces up to 65%.

C. When the value of clear cover of the deck is increases, then the value of crack width also increases. If the clear cover of 5 m. and 9 m. span bridge deck is increase up to 20 mm., then the crack width is increases up to 30%.

D. If the value of live load moment of the bridge deck is increases, then the crack width is also increased. The value of live load moment for 5 m. and 9 m. span is increase or decreases to 5 %, then the crack width change up to 2.5-3% and 8-10% respectively. If the value of moment for both span is increase or decrease to 10%, then crack width change up to 5-6% and 15-20% respectively.

E. In RC bridge deck, the spacing of the reinforcement is decreases or no. of reinforcement bar is increases, then the crack width of bridge deck is reduced.

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F. From this study the results of this concluded that the crack width of RC bridge deck is depends on the parameter. For quick reduction in crack width- increasing diameter of reinforcement bar or increase the no. of reinforcement bar is most appropriate and short span are more in number is useful for design crack width.

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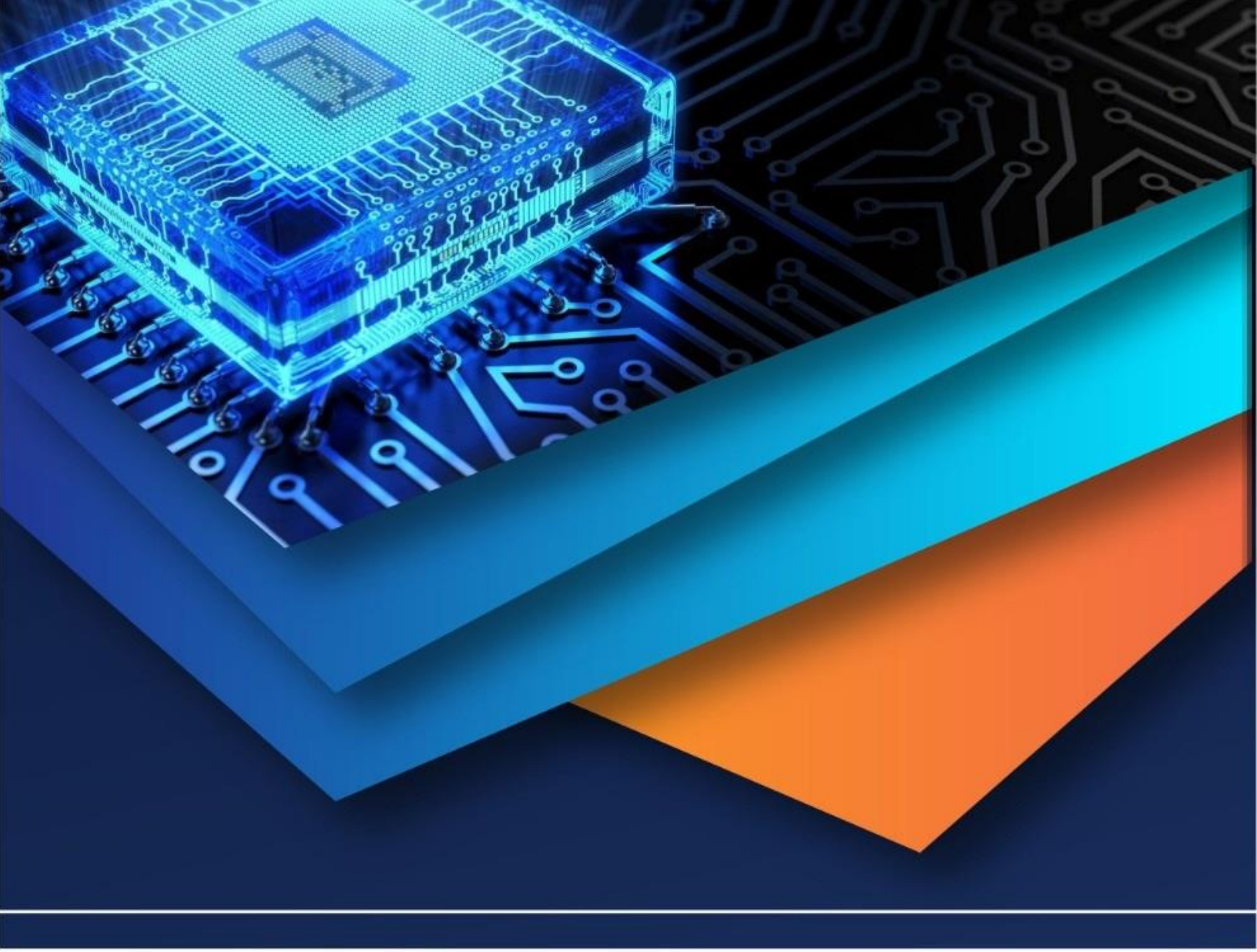

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