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A COMPARATIVE STUDY ON THE DESIGN OF REINFORCED CONCRETE BRIDGE DECKS USING IRC 21 AND IRC 112

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ABSTRACT: In India, reinforced concrete (RC) road bridges were designed according to the Indian Roads Congress code IRC: 21-2000 which is based on the working stress method. In the recent years,IRC: 112-2011 and lately IRC: 112-2020 which follow the limit state method, are being used.This has led to significant change in the design procedure.

The objective of the present study was to compare designs of slab deck and girder and slab deck for the bending moments and shear forces, due to dead load and live load (Class AA tracked vehicle as per IRC: 6-2017) using IRC: 21-2000 and IRC: 112-2020 (subsequently referred to as IRC:21 and IRC:112, respectively). First, a literature review on the analysis anddesign of RC bridge decks was conducted. Next, manual analyses and designs of the selected types of decks for certain spans were done. Finite element models were developed for the selected bridges deck to compare the results of analysis from manual calculations and softwareanalyses. A parametric study was carried for several spans of each type of deck and to comparethe designs based on IRC: 21 and IRC: 112.

From the study, it was observed that IRC: 112 leads to economical designs of slab deck and girder and slab deck, in terms of flexural and shear reinforcement. The software analyses gave higher values of moment compared to manual analyses.

Key words: slab deck

1. INTRODUCTION

In India, reinforced concrete (RC) road bridges were designed according to the Indian Roads Congress code IRC: 21-2000 (subsequently referred to as IRC: 21) which followed the working stress method. In the recent years IRC: 112-2011 and lately IRC: 112-2020 (subsequently referred to as IRC: 112) are being used, which are based on the limit states method. This has led to a significant shift in the design procedure. In general, the design for flexure of a slab or girder based on the limit states method is expected to be more economical than the design based on the working stress method. However, the detailing requirements specified in IRC:112 are more stringent than those in IRC:21.

In the present project, a study is undertaken to compare the designs of two basic types of bridge decks using IRC:112 and IRC:21.

IRC: 21-2000

Basis of Design

- Strength of Reinforced concrete members can be assessed by commonly employing: E = 200 GPa, modular ratio m is taken as given in table 9 of the code and ignoring the tensile strength of concrete.
- Minimum cover for any reinforcement bar shall be 40mm or can be taken as 50 mm when members are exposed to severe conditions (table 5). For factory made precast above values may be reduced by 5mm.
- Diameter of bars in the slabs shall be limited to depth/10 and of shear in web beams (thickness of web)/8. Maximum shall be 40 mm, not less than 8mm for secondary reinforcement and 12mm for longitudinal reinforcement in columns.
- Distance between parallel bars shall not be less than the greatest of
  1. Diameter of the bar - if diameters are equal
  2. Diameter of largest bar - if diameters are unequal
  3. 10 mm more than the nominal size of the coarse aggregate used in concrete

In this approach, service, loads are used in design and strength of materials is not fully utilized. Calculation of stresses acting on the members is based on elastic theory whose values are limited to certain extent

Shear

The design shear stress at any cross section of the beams or slabs of uniform depth is given as

$$\tau = \frac{V}{bd}$$

In case of beams or slabs of varying depth the equation of shear stress is given as

$$\tau = \frac{V - \frac{M\tan\beta}{d}}{bd}$$

Positive when the bending moment (M) and effective depth (d) increases in the opposite direction and vice versa.

Shear in the beam τ should not exceed τ_{max}, else redesign the member. While designing the member for shear the permissible shear stress in the concrete is considered and designed for remaining stresses. When members subjected to axial force then the permissible stress in the concrete is increased by a factor δ

$$\delta = 1 + \frac{5P}{A_g \times f_{ck}} \quad \leq \quad 1.5$$

P = axial compressive force in N; A_g =gross area of the concrete section in mm^2; f_{ck}= characteristic compressive strength of concrete.

When τ exceeds τ_c, shear reinforcement shall be provided in any of the following

a. Vertical stirrups
b. Bent-up bars along with the stirrups and
c. Inclined stirrups

If τ is less than τ_c then, Minimum shear reinforcement; $f_y \leq 415$ MPa.

$$P_w = \frac{A_{sw}}{b.s} = \frac{0.4}{0.87 \times f_y}$$

Torsion

Torsional reinforcement is not calculated for torsion alone, instead the total longitudinal reinforcement is determined for an imaginary bending moment which is a function of actual bending moment and torsion, similarly web reinforcement is determined for an imaginary sheara function of actual shear and torsion. Sections less than the effective depth d from the face of the support are taken as critical sections and designed for the same torsion computed at a distance d (effective depth).

Equivalent shear V_e = V+ V_t

Torsional shear for rectangular and flanged beams

$$V_t = 1.6 \times \frac{T}{b}$$

F or box sections

$$V_t = \frac{T \times D}{2 \times A_o}$$

Longitudinal reinforcement shall be designed to resist equivalent bending moment (M_e)

$$M_e = M + M_t$$

M = bending moment at the cross section,

$$M_t = \frac{T(1+\frac{D}{b})}{1.7}$$

D = overall depth, b = breadth of beam or b_w in case of flanged beams or width of soffit in case of box sections.

If M_t exceeds M, then longitudinal reinforcement shall be provided on the flexural compression face to with stand the moment of $M_{e2} = M_t$- M, acting in the opposite sense to M.

Beams and Slabs

Minimum of three longitudinal girders are provided for bridges having beam and slab type super structure, except for single lane bridges and pedestrian bridges. Cross girders should be monolithic with the deck slab at the bearing and at intermediate locations they are provided depending on requirement. Thickness of cross girder should not be less than the minimum web thickness of the main longitudinal girder. Effective depth of the beam when haunches are provided is no portion of the haunch lying below a plane which makes a slope of 1:3 shall be considered as adding to the effective depth. And for moment in this slab the variation of moment of inertia in the span shall be considered

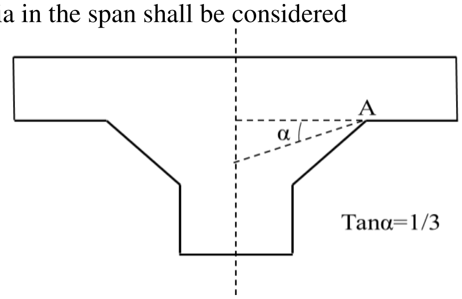

Fig :effective depth when haunches are provided

Compression reinforcement:

a. Slabs: When the percentage of reinforcement in compression face of slab exceeds 1 %, links for a depth of 200mm should be provided of at least 6mm or one quarter the size of the largest compression bar through the of the slab.

b. Beams: If in beam, all the main or part of longitudinal bars are required to resist the compression then links or ties of at least one quarter of size of largest compression bar should provide at maximum spacing of 12 times the size of the smallest compression bar.

Shrinkage and Temperature reinforcement

All reinforced faces either fully exposed or lying within a depth of 500 mm below the level ofperennial submergence under water, soil or soil water system shall be reinforced in both the directions in a plane parallel tom the surface of consideration with maximum spacing of 300 mm maximum and 250mm^2

of steel per metre in each direction for all grades of reinforcement. Main reinforcement provided near the surface for other purpose can be considered as effectivein providing reinforcement for shrinkage and temperature.

Longitudinal Beams

For longitudinal beams connected together by cross girders, deck slab, diaphragms or soffit slab, the bending moment distribution between longitudinal girders can be calculated as

a. If there are only two longitudinal girders with no soffit slab, then the reactions on longitudinal are found by assuming the deck slab unyielding

b. Distributing the loads between longitudinal girders by using Courbon's method, strictly within its limitation i.e., when effective width of deck is less than half the span and when the stiffness of cross girder is very much greater than that of longitudinal girders

c. Distributing the loads between longitudinal by rational method of grid analysis like method of harmonic analysis as given by Hendry and Jaeger or Morice and Little's version of the isotropic plate theory of Guyon and Massonet, etc.,

Effective width for compression flanges of beams of solid webs and hollow box sections

$$b_e = b_w + 1/5\ l_o \quad (\text{T}-\text{beams})$$

$$b_e = b_w + 1/10\ l_o \quad (\text{L}-\text{beams})$$

For effective stress transfer the junction of web and flange is splayed to form an angle of greaterthan 110^o

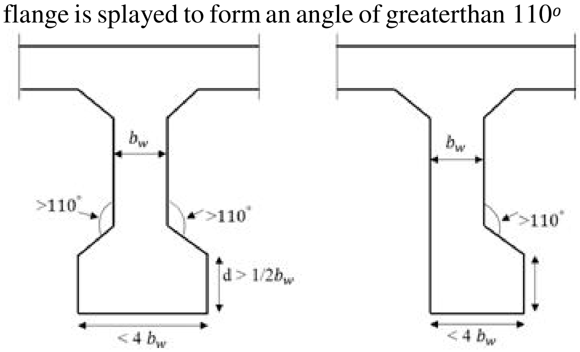

Fig: splaying the junction of web and flange

Deck slabs

The width of the slab that is effective in resisting the bending moment due to concentrated loadis given

Solid slab spanning in one direction

$$b_{ef} = \alpha_o \left(1 - \frac{a}{l_o}\right) + b_1$$

Solid cantilever slab

$$B_{ef} = 1.2\ a + b_1$$

Where,

a = distance of centre of gravity of concentrated load from the nearer support

b_1 = breadth of concentration area of the load $(b + 2 \times t_{wc} + 2 \times t_{sf})$

IRC: 112-2020

Basis of Design

Reliability aspect: Degree of reliability in this defined as the acceptably low level of failure in meeting the expected requirements in specified time. Different approximate methods are followed to achieve desirable reliability.

- Known statistical parameters describing properties of materials and actions.
- Deterministic models of structural behaviour.
- Internal practices and past experiences of acceptable/ unacceptable performances.
- Partial factors for actions and resistance models based on calibration and rationalisation of existing international practices.

Limit state Philosophy of Design: Limit beyond which the structure cannot perform its intended function satisfactorily in future in terms of safety and serviceability. Two basic limit groups of limit states are considered.

1. Ultimate limit states (ULS)

a. Limit state of equilibrium: Bridge as a whole or an individual component shall not become unstable when subjected to various design combinations

b. Limit state of Strength: When subjected to various load combinations bridge or any of its components shall not lose its capacity to sustain by undergoing excessive deformation, transformation into mechanism, rupture, crushing or buckling.

2. Serviceability limit states (SLS)

a. Limit state of internal stress
b. Limit state of crack control
c. Limit state of deformation
d. Limit state of vibration
e. Limit state of fatigue

Limit state of collapse: Flexure

Parabolic rectangular stress block is considered and for design of section the following relation may be used

$$\sigma_c = f_{cd} \left[1 - \left(1 - \frac{\varepsilon_c}{\varepsilon_{c2}}\right)^n\right]; \qquad 0 \leq \varepsilon_c \leq \varepsilon_{c2}$$

$$\sigma_c = f_{cd} \qquad ; \quad \varepsilon_{c2} \leq \varepsilon_c \leq \varepsilon_{cu2}$$

Up to grade M60

n = 2 ; C_{cZ} = 0.002 ; C_{cuZ} = 0.0035

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Simplified equivalent stress block: The parabolic rectangular stress block is of general validity for all design situations, however simplified equivalent stress block such as rectangular or bilinear may be used for design purposes where the net results are sufficiently accurate

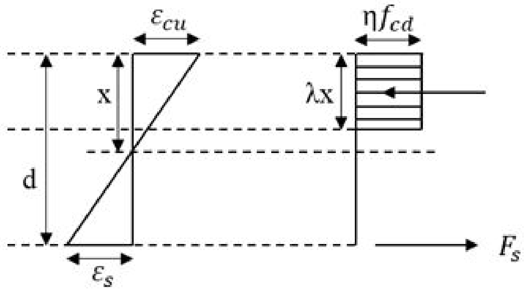

Fig : simplified equivalent stress block

Considering a rectangular shape with width B and effective depth d, then net compressive force is given by (for $f_{ck} \leq 60$ Mpa)

$$C = \lambda \times x \times 0.45 \times f_{ck} \times B$$

which should be equal to $0.36 f_{ck} \times x \times B$, therefore form this we get that λ = 0.8. And to the moment resistance of the section, we can find out by

$$M = 0.8 \times x \times B \times 0.445 \times f_{ck} \times (d - 0.5 \times 0.8 \times x)$$

Classification of action

Permanent actions - G

a. Permanent action
   (i) Self Weight/Dead load
   (ii) Backfill Weight
   (iii) Earth pressure
   (iv) Prestressing force
   (v) Secondary effects

b. Variable gravity loads treated as permanent loads

(i) Superimposed dead load

(ii) Surface and wearing coat

(iii) Snow load

c. Quasi-Permanent loads

Variable actions – Q

a. vehicular
   (i) Vehicular live load
   (ii) Impact factor due to vehicular gravity load
   (iii) Longitudinal forces
   (iv) Centrifugal force
   (v) Pedestrian load/Foot path load
   (vi) Earth pressure surcharge effect due to live load

b. Loads of Environment origin
   (i) Temperature effects due to restraints to free structural deformation
   (ii) Effect of thermal gradient in the structure
   (iii) Wind load

c. hydraulic actions
   (i) Buoyancy effect
   (ii) Water current forces
   (iii) Wave pressures

Accidental actions :

a. Impact of external bodies
b. Seismic hazards

The actions mentioned above, act on bridge in different combinations at different times with magnitude of loads varying from time to time. Therefore, there are large number of loading conditions to which bridge structure is exposed. In practice the limit states is carried out for limited combinations which are likely to occur in its design service life. Depending on the duration and frequency of occurrence of load combinations, four design situations are considered.

A. Persistent design situation
B. Transient design situation
C. Accident design situation
D. Seismic design situation

Shear

Shear failure is likely to occur near the supports of decks because of the maximum shear force at the supports develop due to applied live loads. The ultimate shear strength of the RC slab or girder depends on various factors like percentage of reinforcement, grade of concrete and depth of slab. In recognition of the criteria that slabs fail at loads corresponding to a nominal shear stress higher than that applicable for beams of usual proportions, IRC 112 has incorporated a factor K that depends on the effective depth of the slab.

$$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$$

According to IRC 112, the design shear resistance of the member without shear reinforcement $V_{Rd\,c}$ is given by

$$V_{Rd\,c} = [0.12K(80\rho_1 f_{ck})^{0.33} + 0.15\sigma_{cp}]b_w d$$

$$\rho_1 = \frac{A_{st}}{b_w d} \leq 0.02$$

A_{st} = Area of longitudinal reinforcement

b_w = width of the member in slab and width of rib in beams

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d = effective depth of the member

In case of RC slab decks, ultimate shear strength being high, failure due to shear is not possibleand in general shear reinforcement is not provided in slab. If the shear stress exceeds shear strength, then depth of the slab is increased.

For member with vertical shear reinforcement, the shear resistance, V_{Rd} is smaller value of

$$V_{Rd\,s} = \frac{A_{sw}}{s} z f_{ywd} \cot\theta$$

$$V_{Rd\,max} = \alpha_{cw} b_w z v_1 \frac{f_{cd}}{\cot\theta + \tan\theta}$$

For beams, minimum shear reinforcement ratio (ρ_{min}) shall be

$$\rho_{min} = \frac{0.072\sqrt{f_{ck}}}{f_{yk}}$$

IRC 112 also mentions about the interface shear, that is the shear stress induced between the interfaces of concrete placed at different times. This shear is resisted by friction at the interface and by the reinforcement placed across the shear plane.

$$\mathbf{V_{Edi}} \le V_{Rdi}$$

Where,

V_{Edi} (interface shear stress) = βV_{Ed} / Z.b_i

β ratio of longitudinal force in the new concrete and the total longitudinal force

V transverse shear force

Z lever arm

b_i width of the interface

Resisting capacity of the section

$V_{Rdi} = \mu\sigma_n + \rho f[\mu \sin\alpha + \cos\alpha] \le 0.5 v f_{cd}$

Detailing

Flexural reinforcement: In case of slab decks and girder slab decks, the effective cross-sectionalarea of longitudinal tensile reinforcement neither be less than required to control cracking nor

$A_{s,n}$ given by

$$A_{s,min} = 0.26 \times \frac{f_{ctm}}{f_{yk}} \times b_i d$$

the above value shall be less than $0.0013 b_i$d

b_i mean width of tension zone

f_{ctm} mean value of axial tensile strength of concrete

d effective depth

- The maximum tensile reinforcement shall not exceed $0.025A_c$ at sections other than laps and total of tension and compression reinforcement should not be greater than $0.04A_c$ at the section.
- Secondary transverse reinforcement of at least 20 percent should be provided in one- way slabs.
- Maximum spacing of main reinforcement in one-way slab and reinforcement of two- way slab in both directions should be lesser of 2 time the total depth of slab or 250 mm
- Maximum spacing of secondary reinforcement in one-way slab shall be lesser of 3 timesthe total depth of slab or 400 mm.

Shear reinforcement: Shear reinforcement can be provided in a combination of links, bent-up bars or shear assemblies in the form of cages or ladder. At least 50 percent of shear reinforcement provided shall be links.

The shear reinforcement ratio is given by

$$\rho_w = \frac{A_{sw}}{s\, b_w \sin\alpha}$$

A area of shear reinforcement

S spacing of the shear reinforcement

b_w width of the member

α angle between shear reinforcement and longitudinal axis

The minimum spacing of shear reinforcement should be maximum of

- d_g + 10 mm
- 40 mm
- 2 times diameter of shear reinforcement

The maximum clear distance of stirrups ($S_{L\,max}$) shall not be greater than

0.75 d (1 + cotα) ≤ 600 mm and

0.6 d (1 + cotα) for bent-up bars.

2. MANUAL ANALYSIS AND DESIGN OF SLAB DECKS

Problem statement

Carriage way	Two lane (7.5 m wide)
Width of the bridge	9.5 m
Width of bearing	400 mm
Wearing Coat	56 mm
Footpath	1 m footpath provided on each side
Clear span	5 m
Grade of Concrete	M30
Steel	Fe415 HYSD bars
Loading	Single IRC Class AA tracked vehicle

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Assumed slab thickness = 450 mm
Clear cover = 40 mm
Effective depth = 450 - 40 – 10 = 400 mm (assuming 20 mm diameter bars are used as primary reinforcement)
Effective span = 5+0.4 = 5.4 m
Cross section of the bridge is shown below

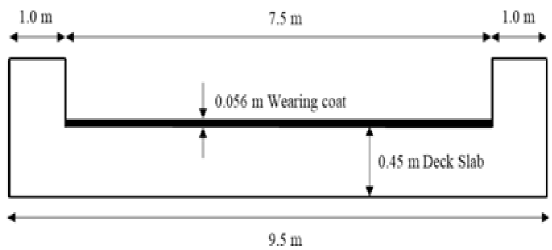

Fig : cross section of the deck

<u>Dead load Bending moment per metre width of slab:</u>
Dead load due to slab = 0.45×24 = 10.5 kN/m^2
Dead load due to wearing coat = 0.056×22 = 1.2 kN/m^2
Total load = 10.48+1.232 = 12.0 kN/m^2
Bending moment due to dead load = 12.032×5.4^2/8 = 43.8 kN-m/m

<u>Live Load Bending moment:</u>
Impact factor is 25% for 5 m span and decreasing linearly to 10% for 9 m span, So for 5.4 mspan the impact factor will be = 25 – 15×0.4/4 =23.5%
Class AA tracked vehicle is placed symmetrically on the span Effective length of the load = 3.6 + 2× (0.45+0.056) = 4.612 m
Effective width of the load = 3.6 + 2× (0.45+0.056) = 4.612 m
Effective width of slab
B = 9.5 m ; L = 5.4 m ; B/L = 9.5/5.4 = 1.76
From IRC 21, B/L = 1.76, K = 2.94

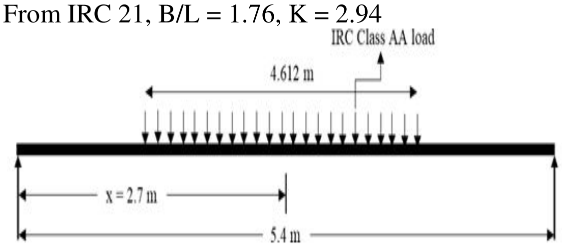

Fig : position of load for maximum bending moment

x= 2.7 m ; b_w = 0.85 + 2×0.056 = 0.962 m

b_e = 2.94×2.7× (1-2.7/5.4) +0.92 = 4.889 m
The tracked vehicle is placed close to the kerb with the required minimum clearance as shown in the figure below

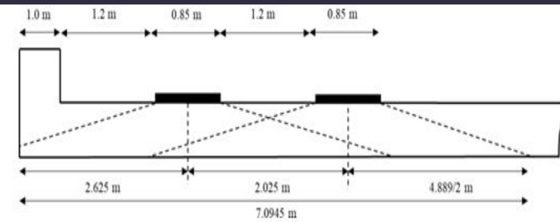

Fig: effective width for IRC class AA tracked vehicle

Effective width for both tracks = 2625 + 2050 + 4889/2 = 7094.5 mm (after allowing theoverlap)
Total load of two tracks after including impact = 1.235×700 = 864.5 kN
Average intensity of load = 864.5/(4.612×7.0945) = 26.5 kN/m^2
Maximum bending moment due to live load

$$= \left(\frac{26.5\times 4.612}{2}\right)\times 2.7 - \left(\frac{26.5\times 4.612}{2}\right)\times \frac{4.612}{4} = 95 \text{ kN-m}$$

Design bending moment = 43.85 + 95 = 140 kN-m

<u>Shear due to live load</u>
For maximum shear at support, the IRC Class AA tracked vehicle is arranged as shown in the figure below

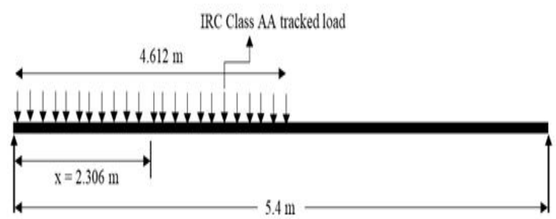

Fig : Position of load for maximum shear

Effective width of dispersion

$$b_e = 2.94\times\frac{4.612}{2}\times\left(1-\frac{4.612}{2\times 5.4}\right) + 0.962 = 4.846 \text{ m}$$

Width of dispersion = 2625 + 2050 + 4846.5/2 = 7098.25 mm
Average intensity of load == 26.4 kN/m^2
Maximum shear force due to live load == 70 kN
Maximum shear force due to dead load = 12.032×5.4/2 = 32.5 kN

Design shear force = 32.5 + 70 = 102.5 kN

Design of slab using IRC: 21
Design bending moment = 140 KN-m
M30 Grade of concrete is considered and Fe415 HYSD bars
σ_{cbc} = 10 N/mm^2 ; σ_{st} = 230 N/mm^2 ; modular ratio m = 280/(3×10) = 9.33
Consider diameter of the longitudinal bar = 20 mm
Overall depth = 450 mm

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Effective depth provided = 400 mm

Limiting depth

$$d_{req} = \sqrt{\frac{M}{Qb}}$$

$$Q = 0.5 \times \sigma_{cbc} \times k_b \times j_b$$

$$k_b = \frac{m \times \sigma_{cbc}}{m \times \sigma_{cbc} + \sigma_{st}} = \frac{93.33}{93.33+230} = 0.288$$

$$j_b = 1 - k_b/3 = 1 - 0.288/3 = 0.903$$

$$Q = 0.5 \times 10 \times 0.903 \times 0.288 = 1.301$$

d_r = 328.04 mm < 400 mm (ok)

For knowing the area of steel required

Considering the allowable stress in steel as 200 N/mm^2

$$k_b = \frac{m \times \sigma_{cbc}}{m \times \sigma_{cbc} + \sigma_{st}} = \frac{93.33}{93.33+200} = 0.318$$

$$j_b = 1 - k_b/3 = 1 - 0.318/3 = 0.894$$

$$A_{st} = \frac{140 \times 10^6}{200 \times 0.894 \times 400} = 1957.5 \text{ mm}^2$$

$$A_{st} = 1957.5 \text{ mm}^2$$

Spacing of the bar required= 161 mm (say 150 mm)

Check for shear force:

$$r = \frac{V}{bd} = \frac{107 \times 1000}{1000 \times 400} = 0.26 \text{ N/mm}^2$$

$$\% \text{ of steel} = \frac{100 \times 1944.44}{1000 \times 400} = 0.5\%$$

r_c = 0.31 N/mm^2 for M30 and 0.5% steel from IRC 21 (table 12B)

$r < r_c$ hence safe in shear

Design of slab using IRC: 112

Total design Ultimate moment = 1.75×4.5 + 1.35×38.3 + 1.5×95 = 202 kN-m

<u>Design of slab deck:</u>

M30 grade concrete and Fe415 HYSD bars

Depth required for a singly reinforced section is given by

$$d_{req} = \sqrt{\frac{M}{Qb}} = \sqrt{\frac{202 \times 10^{\wedge}6}{0.138 \times 30 \times 1000}} = 220.72 \text{ mm} < 400 \text{ mm (Ok)}$$

Q = 0.36× f_{ck} × k × (1-0.42 × k)

K = 0.48

Q = 0.36 × f_{ck} × 0.48 × (1-0.42×0.48) = 0.138f_{ck}

The area of steel required is calculated using first equilibrium equation.

$$C = T$$

$$0.36 \times f_{ck} \times B \times x_u = 0.87 \times f_y \times A_{st}$$

For knowing the depth of neutral axis, use second equilibrium equation

M= 0.36× f_{ck} ×B× x_u × (d-0.42× x_u)

$$201.7 \times 10^6 = 0.36 \times 30 \times 1000 \times x_u \times (400 - x_u)$$

$$x_u^2 - 400x_u + 18675.92 = 0$$

$$x_u = 54 \text{ mm}$$

Substitute in the equilibrium equation ,

0.36×30×1000×54 = 0.87×415× A_{st}

A_{st} = 1615.47 mm^2

Using 20 mm diameter bars main reinforcement, the spacing is given by

S =194.37 mm (say 180 mm)

Maximum spacing = min (2×400, 250) = 250 > 180 (ok)

A_{st} provided is 1744.4 mm^2

Minimum area of steel required is =720.12mm^2 <1744.4mm^2 (0k)

The distribution reinforcement should be designed to resist a moment computed as Transverse moment = 0.3× M_{uL} + 0.2× M_{uD}

M_{uL} = 1.5×95 = 142.5 kN-m

M_{uD} = 1.35×43.85 = 59.2 kN-m

Transverse moment = 0.3×142.5 + 0.2×59.2 = 55 kN-m

Area of distribution bars = (1615.47/201.7) ×55 = 440.5 mm^2

Provide 12 mm diameter bars at a spacing of 230 mm

<u>Check for ultimate shear strength:</u>

Design Ultimate shear force = 1.35× V_d + 1.5×V_L = 1.35×32.485+1.5×70 = 148.85 kN

$V_{Rd,}$ = 0.12×1.7×(80 × 0.00436 × 30)$^{0.33}$ × 1000 × 400

= 177.08 kN > 148.85 kN (hence safe)

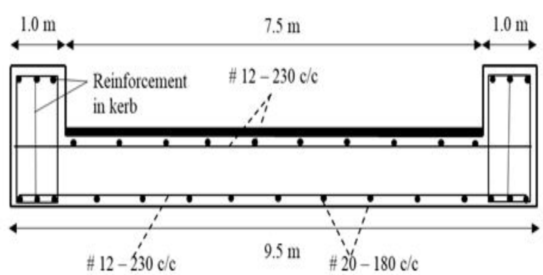

Fig : Reinforcement detailing (cross section)

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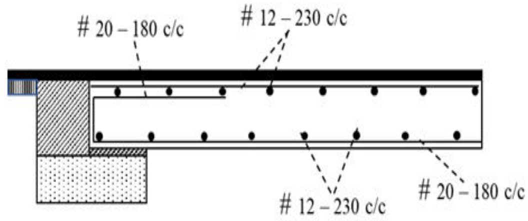


Fig : Reinforcement detailing (longitudinal view)

3. COMPUTATIONAL MODEL

BRIDGE DATA

The Slab deck and Girder and slab deck analysed in the previous two chapters, were modelled using SAP 2000 to compare the forces calculated manually and using the computational models. The basic data of the two models considered are given below for ready reference.

Slab Deck

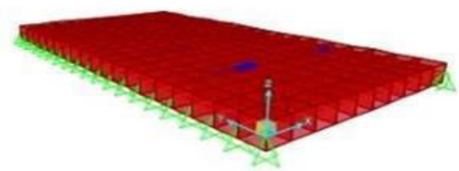
Attributes	Information
Type	Slab deck
Clear Span	5 m
Carriage way	Two lane (7.5 m wide)
Footpath	1.0 m (on one side)
Total width	9.5 m
Wearing coat	56 mm
Grade of concrete	M30
Grade of Steel	Fe415 HYSD bars
Loading	Single lane IRC Class AA tracked vehicle

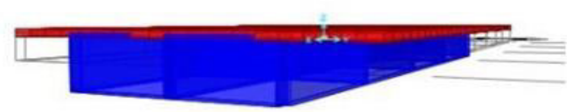
Girder and Slab Deck

Attributes	Information
Type	Girder Slab deck
Clear Span	16 m
Carriage way	Two lane (7.5 m wide)
Footpath	No Footpath is provided
Total width	8.7 m
Wearing coat	80 mm
Kerb	(0.6 × 0.3) m
Grade of concrete	M30
Grade of Steel	Fe415 HYSD bars
Loading	Single lane IRC Class AA tracked vehicle

Deck Models

The decks were modelled using two dimensional plate elements. The live load due to Class AA tracked wheel vehicle was idealised as a linear multi step static loading.





Grinder and slab deck

Fig: extruded view of computational models

LOADS

Dead load (DL)

The self-weight of the deck were considered in the models. The superimposed dead loads due to wearing course and kerb were assigned separately as uniformly distributed loads.

Live load (LL)

L/d	4.00	5.00	6.00	7.00	8.00	9.00	10.00
12.00	333.33	416.67	500.00	583.33	666.67	750.00	833.33
13.00	307.69	384.62	461.54	538.46	615.38	692.31	769.23
14.00	285.71	357.14	428.57	500.00	571.43	642.86	714.29
15.00	266.67	333.33	400.00	466.67	533.33	600.00	666.67
16.00	250.00	312.50	375.00	437.50	500.00	562.50	625.00
17.00	235.29	294.12	352.94	411.76	470.59	529.41	588.24
18.00	222.22	277.78	333.33	388.89	444.44	500.00	555.56
19.00	210.53	263.16	315.79	368.42	421.05	473.68	526.32
20.00	200.00	250.00	300.00	350.00	400.00	450.00	500.00

Class AA tracked wheel load was placed on the deck following the recommendations of IRC 6-2000, satisfying the minimum edge clearance and minimum inter-vehicular spacing. The live load on the footpath was neglected.

Preliminary Analysis

The results of slab deck and girder slab deck using

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manual methods and computational models are presented below.

Slab deck

Table : bending moment values of slab deck

Bending Moment	Dead Load	Live Load
Manual method	43.85	95.00
Computational model	54.13	109.64

Girder Slab Deck

Table 5-2 Bending moment values of girders

Bending Moment	Load	Dead Load	Live Load
Morrice and Little Method	Outer Girder	866.67	1237.36
	Inner Girder	852.27	939.41
Courbons method	Outer Girder	1171.60	1512.53
	Inner Girder	1171.60	911.16
Computational model	Outer Girder	932.00	1963.25
	Inner Girder	920.00	1411.16

It is evident from the above results that for the considered live load, the software analysis gives higher values compared to the manual analysis. However this needs to be verified for other cases of live load.

4. PARAMETRIC STUDY

Slab Deck

The slab culvert of spans 4 m to 10 m were analysed for IRC loadings as per IRC: 21 – 2000 and IRC: 112 – 2020 i.e., Working stress and Limit State methods for L/d ratios of 12 to 20. Class AA tracked vehicle was considered as the live load acting on the slab deck.

The below table shows the assumed values of effective depth for different spans for the analysis purpose, and these are checked whether they are getting satisfied for that particular span considered using IRC: 21 and IRC: 112.

TABLE : Assumed Effective Depth {mm}

After analysing the spans for the above assumed depths using IRC: 21, shorter spans (4 to 6 m) with depths for L/d ratios 12, 13, 14 are getting satisfied. Longer spans (7 to 10 m) with L/d ratio 12 to 17 are being satisfied. Compared to IRC: 21, all the spans with L/d ratio 12 to 20 are adequate while using IRC: 112Considering the above outcome of effective depths using IRC: 21 and IRC: 112. An appropriate depth (figure 6-1) was chosen for a particular span. The adequacy of depth chosen is checked for bending moment and shear capacity. The slab has been designed for the chosen depth and the results are as shown below

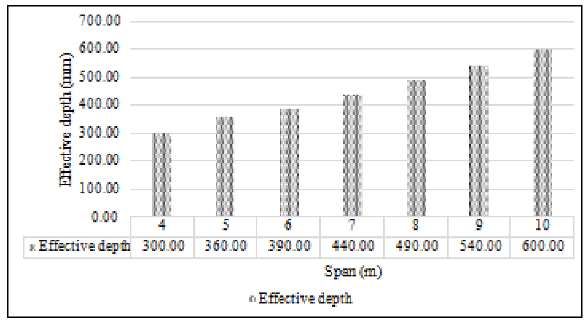

Fig: Assumed Effective depth

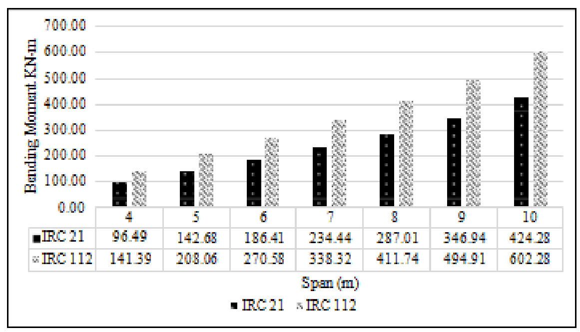

Fig: Design Bending Moment

The analysis for Bending moment using both the IRC codes is similar but while designing, IRC: 112 considers various partial factors for moments due to dead loads and live load. Therefore, the design moments using IRC: 21 and IRC: 112 varies as shown above after considering the appropriate partial factors mentioned in the code.

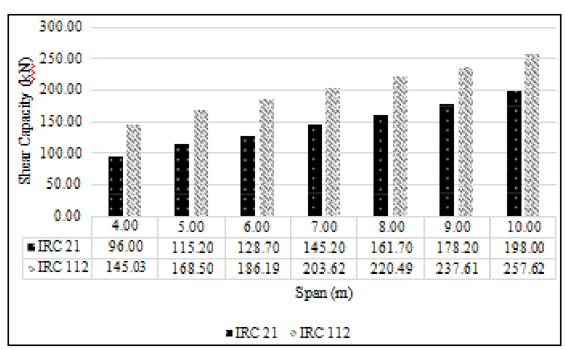

Fig : shear capacity

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The design shear force of IRC: 112 differs from IRC: 21 because of the partial factors considered in IRC: 112

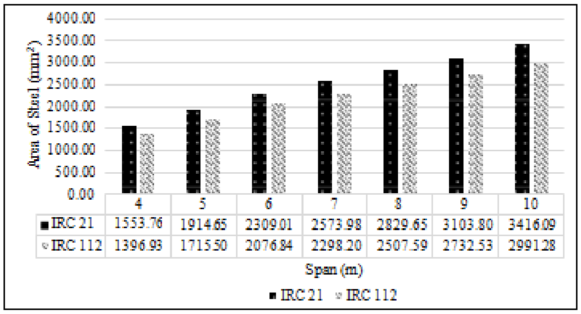

Fig :Area of steel required

Table : Area of main flexural reinforcement required in slab deck

Area of steel required			Reduction % of steel
Span	IRC 21	IRC 112	
4.00	1553.76	1396.93	10.09
5.00	1914.65	1715.50	10.40
6.00	2309.01	2076.84	10.05
7.00	2573.98	2298.20	10.71
8.00	2829.65	2507.59	11.38
9.00	3103.80	2732.53	11.96
10.00	3416.09	2991.28	12.44

Comparing the area of steel required using IRC: 21 and IRC: 112, the area of steel obtained using IRC: 112 is less than the area of steel obtained using IRC: 21 keeping the effective depth to be same. It can be observed that as the span is increasing, the difference in the area of steel required between IRC: 21 and IRC: 112 is also increasing

Girder Slab Deck

The Girder slab decks of spans 16 m to 22 m were analysed for IRC loadings as per IRC: 21 –2000 and IRC: 112 – 2020 i.e., Working stress and Limit State methods. Class AA tracked vehicle is considered to be acting on the deck following the norms from IRC 6.

Three main girders are provided at 2.5 m centre to centre for all the spans. The depth of the longitudinal girders is assumed be at a rate of 100 mm per metre of span. An interior slab panelis considered and designed to be a two-way slab as it supported on all of its sides by longitudinal and cross girders. The depth of the interior slab panel for all the spans is assumed to be same. The depth of the cross girder is considered to be equal to the depth of the main girder to simply the computations.

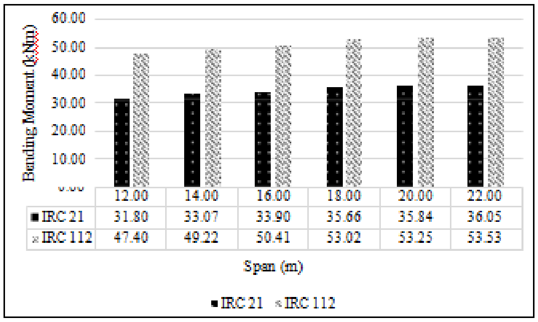

Fig: short span bending moment in slab

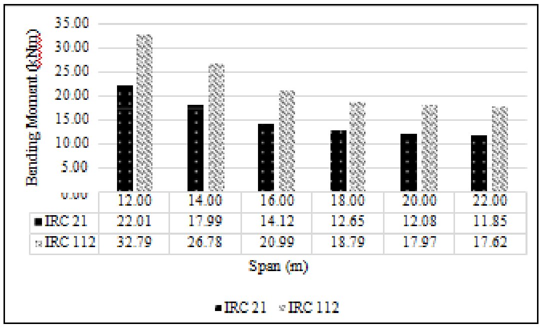

Fig : long span bending moment in slab

The bending moments for short span and long span are varying using IRC: 21 and IRC: 112 because of partial factors considered in IRC: 112. Since the slab panels are designed as two- way action, the shorter span moments are higher than the longer span moments. Area of steel required is calculated for the maximum moment and is presented in the figure below

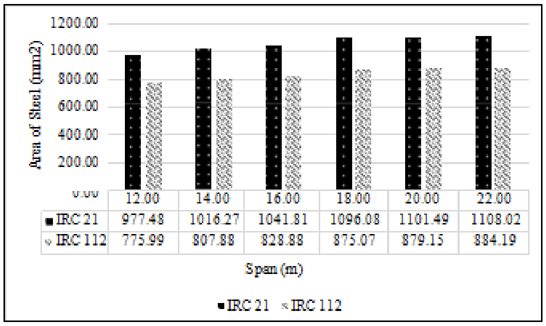

Fig : area of steel required (slab

Since the thickness of all the spans in the slab is assumed to be the same, the bending momentand area

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of steel required is not varying much in between the spans. The difference between area of steel required using IRC: 21 and IRC: 112 is significant. IRC: 112 gives lesser area ofsteel compared to IRC:21

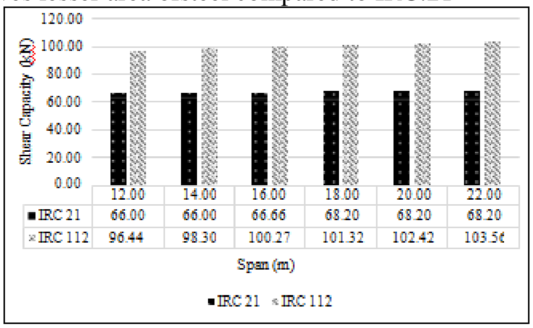

Fig : shear capacity of slab

The increase in shear capacity for different spans using both the codes individually is marginal. The shear capacity for a particular span is more using IRC: 112 when compared to IRC: 21

Longitudinal Girders:

The longitudinal girders were analysed using courbons method for Class AA tracked loading placed on the slab deck following the norms of IRC 6 for clearence and gap between the lanes.The results of analysis are presented below

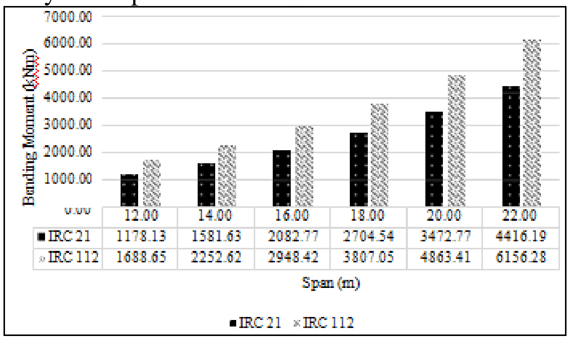

Fig : bending moment of inner girder

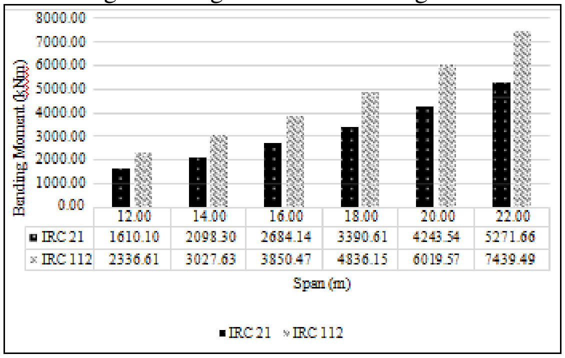

Fig : bending moment of outer girder

The bending moments in the outer girder is more compared to the inner girder for all the spans. This is because the load is placed nearer to the outer girder on the slab deck according to IRC 6. The area of steel required for the outer girder is calculated

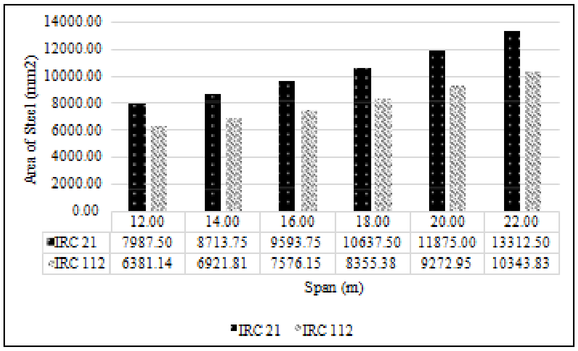

Fig : area of steel required in outer girder

The area of steel required using IRC: 21 is higher compared to IRC: 112. The increase in the area of steel for IRC: 21 is more than that of IRC: 112 as the span is increasing. Area requiredfor inner girder also follows the same trend as shown in the outer girder.

Table :Area of steel required in outer girder

Outer Girder Area of steel			**Reduction % of steel**
Span	**IRC 21**	**IRC 112**	
12.00	7987.50	6381.14	20.11
14.00	8713.75	6921.81	20.56
16.00	9593.75	7576.15	21.03
18.00	10637.50	8355.38	21.45
20.00	11875.00	9272.95	21.91
22.00	13312.50	10343.83	22.30

The Reduction in percentage of steel required is increasing as the span is increasing.

The shear capacity of the outer girder is computed using both IRC 21 and IRC 112 as presentedas shown

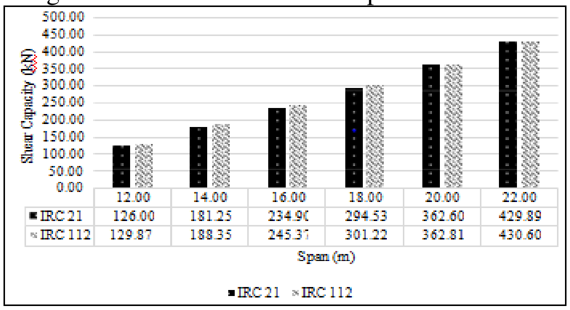

Fig : shear capacity

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The shear capacity is computed using both the codes with different percentage of steel required(refer figure 6-11). The difference in the shear capacity is marginal using IRC 21 and IRC 112

5. CONCLUSIONS

SLAB DECK

1. For design of slab culvert using IRC: 21, L/d ratio between 12-14 can be adopted for all the span, based on allowable flexural capacity.
2. For design of slab culvert using IRC: 112, L/d ratio between 18-20 can be adoptedfor all the span, based on ultimate flexural capacity. However, the selected depth needs to be checked to satisfy deflection requirement.
3. When compared with IRC: 21, IRC: 112 gives economic design as the percentage of steel required in IRC: 112 is less than that of IRC: 21.
4. Reduction in percentage of steel using IRC: 21 and IRC: 112 is about 10 to 12 % and it is increasing as the span is increasing

GIRDER SLAB DECK

1. Design of Girders as per provisions of IRC: 112 leads to an economical design.
2. The shear capacity of the girder is computed using IRC: 21 and IRC: 112 with different percentage of steel. The shear capacity of the girder is almost same usingboth the codes.
3. The reduction in the percentage of steel in the longitudinal girders using IRC: 21 and IRC: 112 is about 20 to 22% and it is increasing as the span is increasing from20 to 22.

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