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Analysis and Design of Reinforced Concrete Flyover Deck Slab Under IRC Class AA Loading Condition

Saranya P.[1]; Rakshitha S.[2]

[1]Assistant Professor; Department of Civil Engineering, Meenakshi Sundararajan Engineering College Chennai, India
[2]UG Student; Department of Civil Engineering, Meenakshi Sundararajan Engineering College Chennai, India

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Abstract: The Project focuses on the analysis and design of Reinforced concrete deck slab for a flyover bridge. The Deck slab is one of the most important structural components, responsible for directly carrying vehicular loads and transferring them safely to the supporting structural system. The flyover is of 3km length with 150 spans, 20m per span. The manual design of the Deck slab based on code such as IRC: 21-2000 and IS: 456-2000. Here the structural analysis is carried out by using STAAD Pro connection edition software.

Keywords: *Deck Slab; Girder; Working Stress Method; Effective Width Method.*

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I. INTRODUCTION

A.

Flyover can be described as an overpass, a high-level road bridge that spans over a highway interchange or intersection. Flyover is a grade separated structure that connects roads at different levels to reduce the vehicle congestion. This project topic involves analyzing the flyover at Chennai- Anna Salai through the use of STAAD PRO connection edition and manual design methods.

➢ *Objectives*

- Creating model using STAAD pro connection edition.
- Designing the RCC deck slab under IRC class loading.

➢ *Structural Information*

The flyover consists of 150 spans incorporating piers, deck slab, girders and abutments etc. A deck slab thickness of 0.3m and the carriageway width of 7.5m, along with footpath of 0.6m width on either side to accommodate pedestrian traffic. It is supported by longitudinal girders and cross girders. The materials adopted for the design includes M35 grade concrete and Fe415 grade steel.

➢ *Components of Flyover*

- *Deck Slab:*

Deck slab is the part of super structure of bridge which is Constructed over the Girders that transfer the live load of vehicles to the sub structure and substructure further transfer the load to the foundation.

➢ *Longitudinal Girder*

Longitudinal girders are the primary load- carrying members in a bridge deck system, running parallel to the direction of traffic. They receive loads from the deck slab and transfer them to the supports.

➢ *Cross Girders*

Cross girders are the transverse girders placed perpendicular to the longitudinal girders. The play a vital role in distributing loads across the width of the slab and enhancing the overall stability of the bridge system.

II. LITERATURE REVIEW

A comprehensive review of literature is essential for identifying the relevant data, establishing an appropriate methodology and defining the specifications to be adopted in the study. Prior research contributions have been systematically collected from the journals are discussed in the following section.

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- Sweetha D, Nandhini S, Revathee.T.“Analysis and Design of a Flyover using Civil Engineering softwares” IJIRT,(2024): The paper gives us an idea about IRC class A and 70R wheeled & tracked are considered.

- Swathy Padmaja. V, Ramya. T, Gayathri. K, Lakshmi Devi. P. “Analysis and Design of flyover by using Staad pro”, IRJET,(2019) : This Paper focuses on the entire flyover design. And the components consists of Deck slab, Longitudinal girders, foundation .The paper gives us an idea about the IRC class AA loading..

- Bismi M Buhari, Abhijith S, Aparna S, Aparna B Lal, Joseph Samuel, Sarath S, “Design and analysis of flyover”, (2021), IJERT: This paper deals with analytical design of a reinforced concrete deck slab using the effectible width method for the evaluation of bending moment due lo moving loads. The design of longitudinal girdes and cross girdes is performed based on the Courbon’s method , which facilitates the distribution of loads among the parallel girdes. In addition a numerical analysis is conducted using Staad pro to stimulate structural behavior and to obtain critical parameters such as bending moments, shear forces and deflection characteristics under different loading conditions.

- Bharat Jeswani, Dilip Budhlani , “Analysis and design of Bridge components using staad pro”, IJCRT.ORG,(2020): This paper focuses on deign and analyse the T-beam girders on the staad pro.Thismproject looks on the work of analysis and design of bridge deck and girdres on stad pro v8i. And the bridge is subjected ti IRC calss AA tracked loading .It is observed that the behavior of bridge deck and girer under different loading conditions and comparing the results

III. METHODOLOGY

A. Deck Slab:

The Deck slab is subjected to vehicular load, which are initially considered as concentrated load. These loads are dispersed through the slab in both longitudinal (span wise) and transverse (width wise) Thus , the load is effectively distributed over a wider area of the slab. The analysis of the deck slab under concentrated loading conditions can be carried out using the following methods.

- *Effective Width Method*
- *Pigeauds Method*
- *Westergaards Method*

- *Effective Width Method:* Is a widely adopted analytical approach for the design and analysis of reinforced concrete deck slabs subjected to concentrated wheel loads. This method simplifies the complex behavior of slab systems by assuming that the applied load is distributed over an equivalent effective width of the slab rather than acting over the entire deck surface. The primary objectives of this method is to determine the maximum longitudinal bending moment per unit width of the slab:

The effective width

$B_{ef} = \alpha \text{ x } (1 - x/L_{ef}) + b_1$

$L_{ef} = w + 2(h + d)$

B_{ef} = Effective width of the slab

α = A constant that depends on the ratio of the slab length(L) to its width.

x = Distance from the center of gravity of the load to the nearest support.

L_{ef} = Effective span

b_1 = width of the concentration area of the load

w = contact length of the vehicle

- *Pigeaud’s Method:*

It is a widely used analytical approach for determining bending moments in slab panels subjected to concentrated loads. In this method, the bending moment coefficients corresponding to the short span and the long span directions are obtained from the curves developed by M. Pigeaud.These curves are applicable to slab supported on all four edges with restrained corners and subjected to loads distributed over a well defined contact area. For analysis, Poisson’s ratio is considered as $\mu = 0.15$.

$V = l + 2t$

$U = b + 2t$

The bending moment in the shorter span and longer span directions are calculated using the following expressions:

Short span moment=Mb= W (m_1 +0.15 m_2)

Long span moment =Ml= W (m_2 +0.15 m_1)

μ = Poisson’s ratio = 0.15 (as per IRC:112)

m_1, m_2 = moment coefficient from Pigeaud’s curve

B. Girders:

In Bridge structures, loads from vehicular traffic are initially transferred from the deck slab to the substructure elements and subsequently to the supporting substructure components. Although it may appear that a single girder directly resists the load when a vehicle passes over it, the actual load distribution is more complex. The deck slab along with the cross girders, provides connectivity between adjacent longitudinal girders, enabling the effective load sharing among them. This interconnected system ensures that the applied loads are distributed across multiple structural members rather than being carried by a single girder. As the result, the structural components act together to resist external loads efficiently.

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In the present study, a T- Beam bridge configuration, consisting of a deck slab and the longitudinal girders of considered. The distribution of loads among the longitudinal girders is evaluated using the established analytical methods. Several approaches have been proposed for determining the load distribution factors, among which the most widely used methods include :

- Guyon - Massonet Method
- Hendry-Jaegar Method
- Courbon's Method.

IV. LOAD SPECIFICATION

➢ *Dead Load:*

Dead load refers to the self-weight of all permanent structural components of the bridge.

These include the deck slab, wearing coat, railings, parapet, stiffeners and other utilities. It is the primary load considered in structural design and is evaluated at the initial stage of analysis.

➢ *Live Load:*

Live Loads on a flyover consist of moving loads such as vehicles and pedestrians. Since it is not practical to design for a specific vehicle or combination of vehicles, standard loading models are recommended to ensure safety under various traffic conditions.The vehicle loads area categorized in to three types and they are:

- IRC class AA loading
- IRC class A loading
- IRC class B loading

➢ *Impact Loads:*

The Impact load on flyover is due to sudden loads which are caused when the vehicle is moving on the flyover. To consider impact loads on flyover, an impact factor is used.

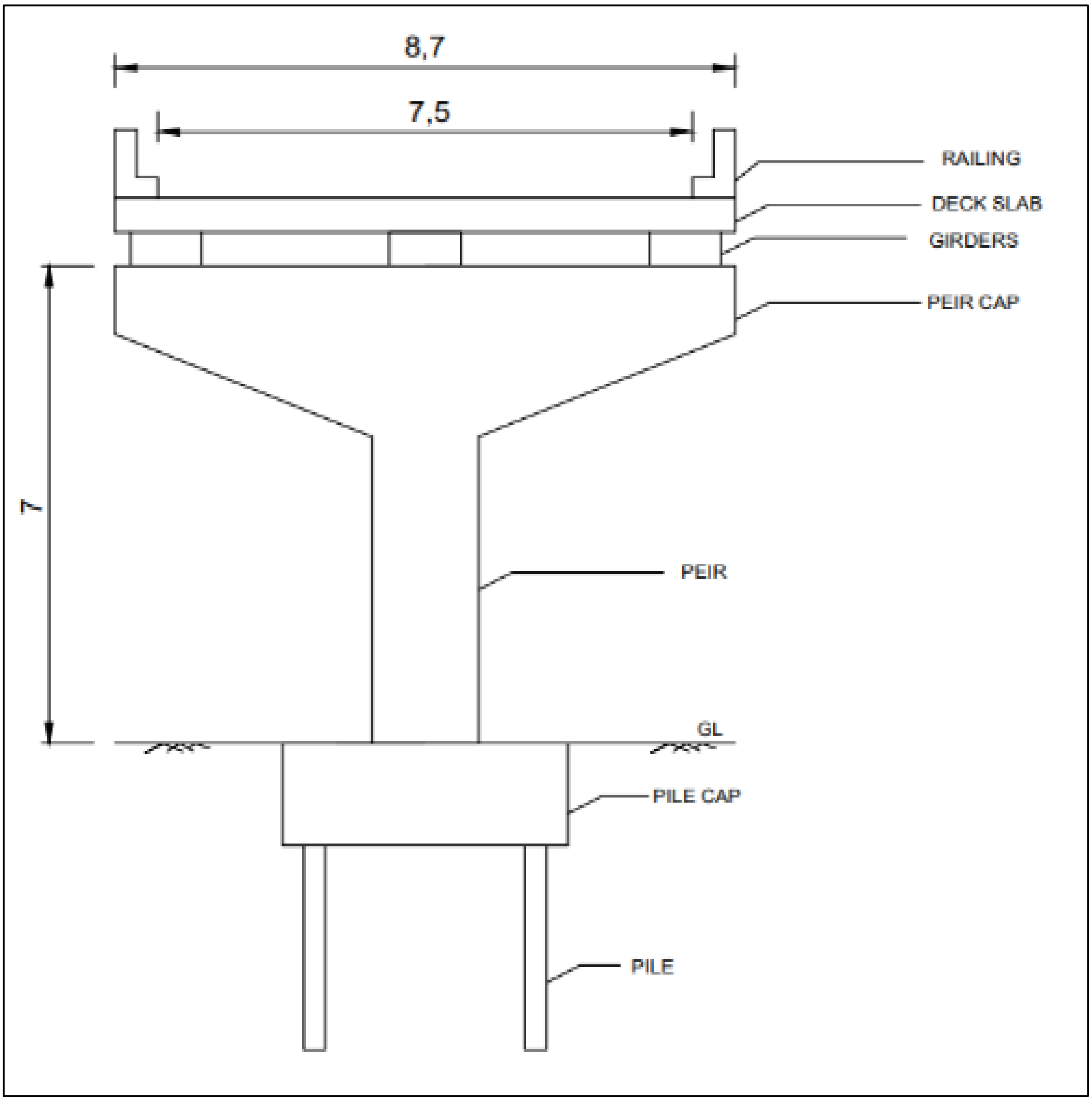

Fig 1 Cross Section of the Flyover

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V. GEOMETRIC DESIGN OF DECK SLAB

The cross-section of the reinforced concrete deck slab has a total width of 8.7 m, including a 7.5 m carriageway for vehicular movement, with remaining width allocated for edge elements such as kerbs.

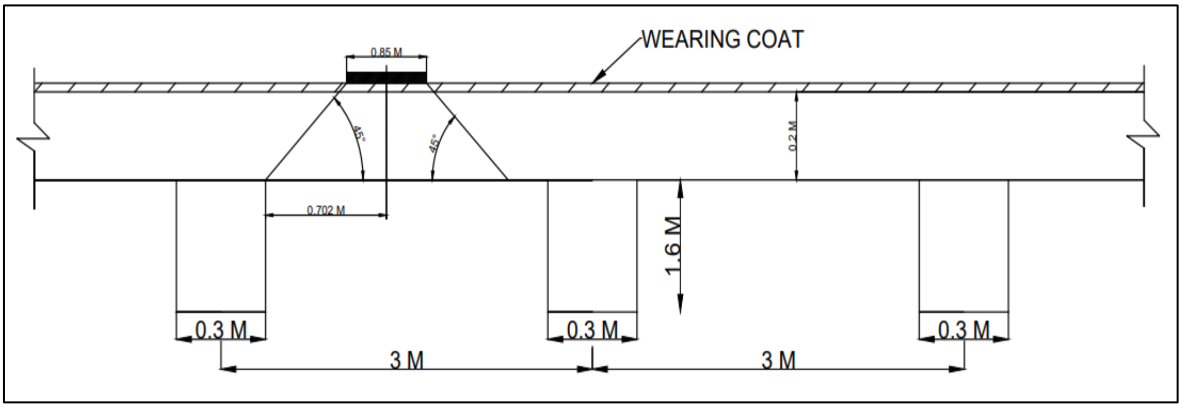

Fig 2 Cross Section of the Deck Slab with Girders

A wearing coat is provided over the slab to ensure smooth riding and proper load distribution. The slab thickness is 0.2 m**,** and the kerb height is approximately 1.0m. The slab is supported by longitudinal girders spaced at 3.0 m center-to-center, with an edge distance of 1.35 m**.** Each girder has dimensions of 0.3 m width and 1.6 m depth. The slab extends beyond the outer girders with an overhang of 0.6 m on either side, ensuring efficient load transfer and structural stability

VI. DESIGN OF DECK SLAB

Width of the carriage way = 7.5m (two lane bridge)

Width of the foot path = 0.6m (either side)

Thickness of wearing coat = 80mm

Span of the slab = 20m

Depth of the slab to be assumed = 0.3m

Span of T – Beam = 20m

No. of Longitudinal girders = 3

c/c of Longitudinal girders = 2.5m

No of cross girders = 6

Spacing between cross girder = 4.0 c/c spacing

Width & depth of Long girder = 300mm, 1.6m

Width & depth of cross girders = 300m, 1.6m

Live Load = IRC class AA loadings

Use M35 grade of concrete, Fe415 grade of steel

- *Dead Load Calculation*

σ_{cbc} = 11.67 N/mm²

σ_{st} = 200 N/mm^2

m = 7.99

n = 0.317

j = 0.894

q = 1.653

Self-weight of deck slab =25× 0.2 = 5 KN/m^2

Self-weight wearing coat =22× 0.08 = 1.76 KN/m^2

Total dead load = 5+1.76 =6.76 KN/m^2

Here K = B/L= 2.5/4.0 = 0.625, 1/k = 1/0.625 = 1.6

Using Pigeaud's curve for slab completely loaded

with uniformly distributed load, will get coefficient

m_1 = 0.625, m_2 = 1.6

- *Shorter Span Moment:*

M_B = W (m_1+0.15m_2) = 3.41KNm x 0.8 = 2.73 kNm

- *Longer Span Moment:*

M_L = W(m_2+0.15m_1) = 1.57KNm x 0.8 = 1.26 kNm

- *Live Load*

u = Tier width + (2 × thickness of the wearing coat)

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v = Tier width + (2 × thickness of the wearing coat)

u = [0.85+2×0.08] = 1.01m *(Fig-3)*

v = [3.60+2×0.08] = 3.76m

u /B = 1.01/2.5 = 0.404

u /L = 1.01/4.0 = 0.94

K = B/L = 2.5/ 4 = 0.625

- *Using Pigeaud's Curve for K = 0.6,*

The moment coefficients are,

$m_1 \times 100 = 8.5$, > , $m_1 = 0.085$

$m_2 \times 100 = 2.5$, > , $m_2 = 0.025$

- *Shorter Span Moment:*

$M_B = W (m_1+0.15m_2)$

= 350(0.085+0.15 × 0.025)=31.06kNm

- *Longer Span Moment*

$M_L = W(m_2+0.15m_1)$

350(0.025+0.15×0.085)=13.21kNm

- *Shear Force*
  Dispersion of wheel load is in the direction of span :

$l_{ef} = w + 2(h + d)$

= 0.85 + 2(0.08 +0.2) = 1.41m

w : Contact length of the vehicle

h : Thickness of the deck slab

d: depth of the slab

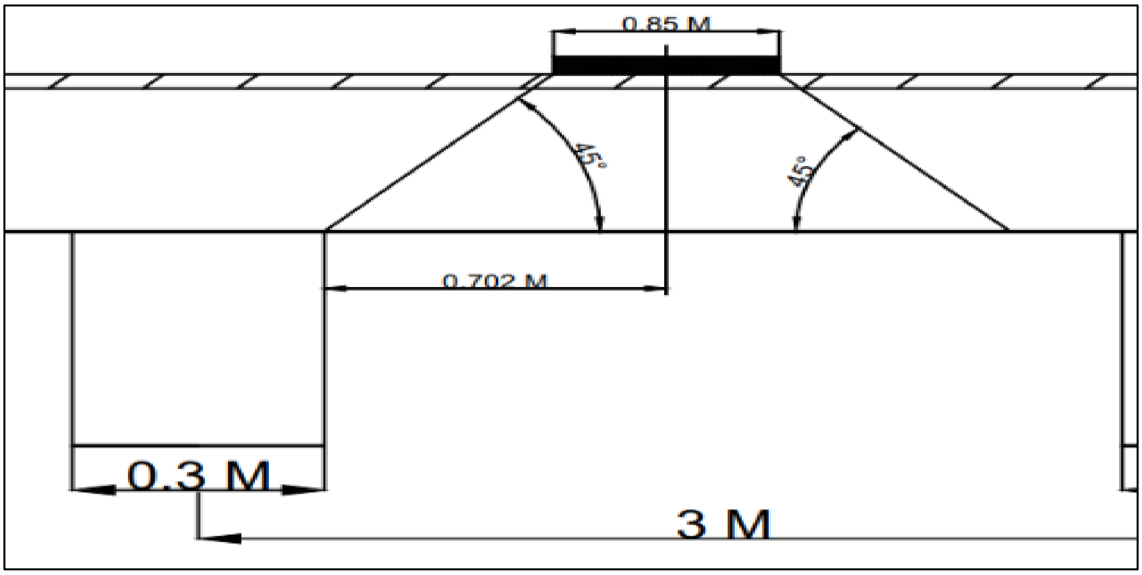

Fig 3 Live Load Acting on the Deck Slab

As per IRC 21:2000, Pg-53, Clause 305.16.2 (Tracked Vehicle)

Effective width of load (b_{ef}) = α× x (1 − x/L) + b_1

= 2.55 × 0.705(1-0.705/2.2) + 3.76= 4.98m

Load per meter width of the slab = 350/4.98 = 70.28KN

Maximum shear force for the slab = 70.28 × 2.2-0.705 /2.2 = 47.76Kn

Maximum shear force with impact load = 1.25 × 47.76 = 59.70KN

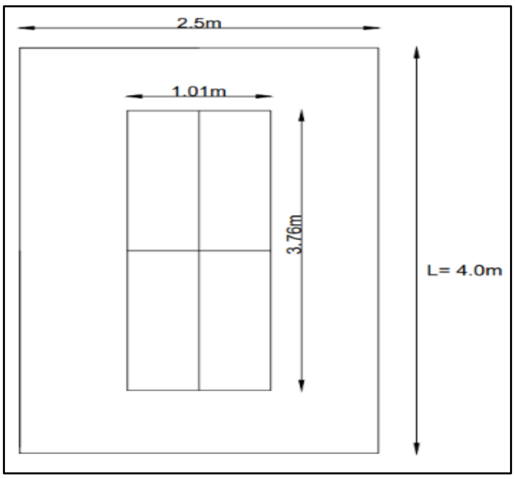

Fig 4 Effective Width and Length of the Flyover

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➢ *Impact Factor*

IRC class AA loading 0.25 for 4m span

M_{BI} = (0.8x 1.25 x 31.06)=31.06kNm

M_{LI} = (0.8 x1.25x 13.21)=13.21kN

$V_d = \frac{wl}{2} = \frac{6.76*2.2}{2}$ = 7.44KN

➢ *Design of Deck Slab*

- *Shorter Span Moment*

M_b = (31.06+2.73) =33.79 kNm

- *Longer Span Moment*

M_l = (13.21+ 1.26) = 14.47kNm

Shear force = (59.70 +7.44) = 67.14kN

The effective depth required for the deck slab is computed as,

D = √ (M /Qb) = √(33.79 x 10^6) / (1.653 x 1000)

= 142.97 ~143 mm

Let us adopt, overall depth be 200mm and d_{req} = 143mm

D = 200mm > d_{req} = 143mm ~150mm

Hence safe

➢ *Design of Reinforcement*

- *Area of Reinforcement Required Along the Shorter Span*

$A_{st} = M_S / \sigma_{st}$ x j x d = 33.79x10^6 / 200x0.894 x 145

= 1303.3mm^2

Using 20mm , Spacing = a_{st} = π /4 x$(20)^2$ = 200mm^2

Spacing = (1000 x 200)/1303.3 = 153.4mm ~150mm

16mm bars of 150mm spacing

for the shorter span

(A_{st} = 1340 mm^2)

- *Area of Reinforcement Required Along the Longer Span*

d = 145 – (20/2 + 16/2) = 127mm ~130mm

$A_{st} = M_L / \sigma_{st}$ x j x d = 14.47x10^6 / 200x0.894 x 130

= 622.5mm^2

Using 16mm , Spacing = a_{st} = π /4 x$(16)^2$ = 200mm^2

Spacing = (1000 x 200)/622.5 = 320mm ~300mm

16mm bars of 300 mm spacing for the Longer span

- *Check for Shear*

✓ *Nominal Shear Stress*

τ_v =(V u/b d) = (67.14× $10^{3)}$ / (1000 × 150)

τ_v = 0.44N/mm

τ_{max} = 2.3 N/mm

For the slab τ_v shall not exceeds half of the τ_{max}

$\tau_{max}/2 > \tau_v$

- *Hence Safe in Shear*

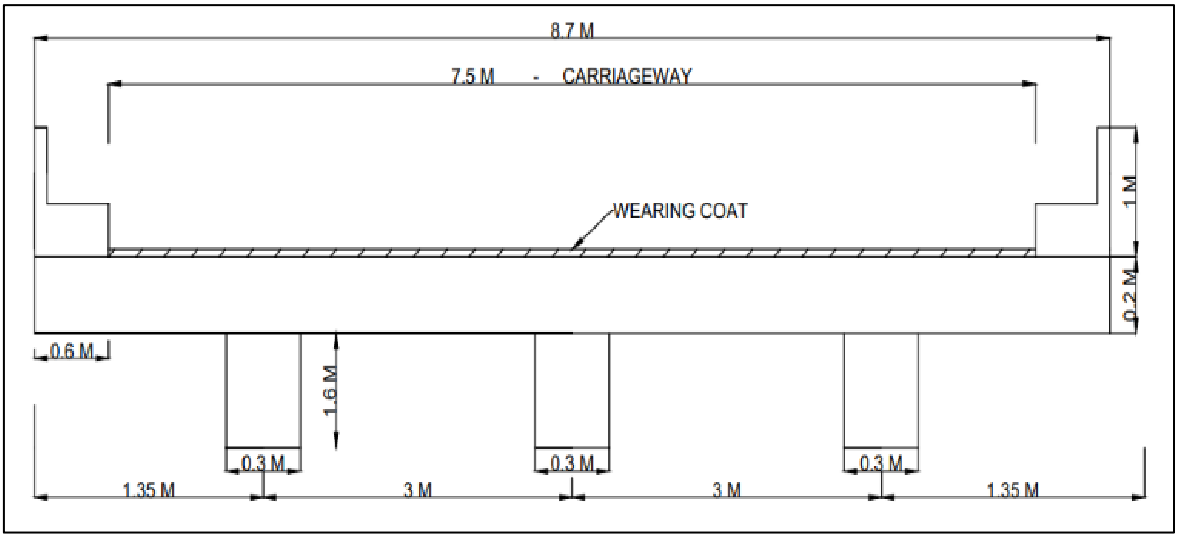

Fig 5 Deck Slab with Girders

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VII. STAAD PRO ANALYSIS

The analysis and design of the deck slab for the flyover are carried out using STAAD.Pro CONNECT Edition. In this project, the deck slab is modeled as a plate element consisting of longitudinal girders and cross girders. The geometry of the model is created based on the given dimensions, with a total slab length of 20 m and width of 8.7 m.

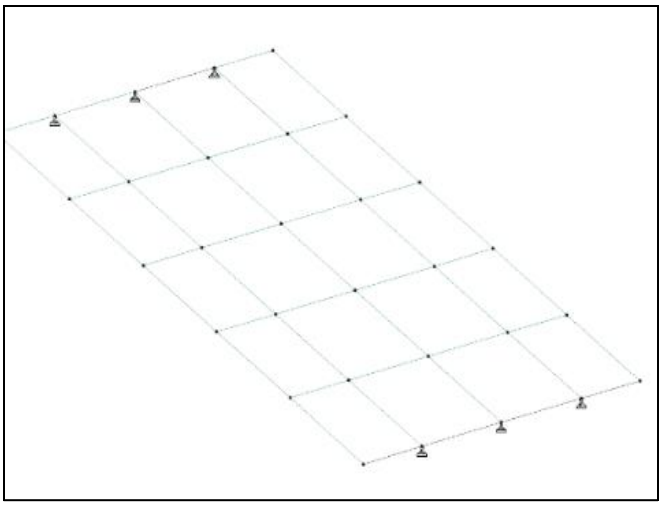

Fig 6 STAAD. Pro Model

Three longitudinal girders are provided at 2.5 m center-to-center spacing, and six cross girders are placed at 4 m intervals along the length.

➢ *Loading Conditions*

The self-weight of bridge in STAAD.PRO is taken as

Table 1 Self Weight

Direction	Factor
y	-1.000

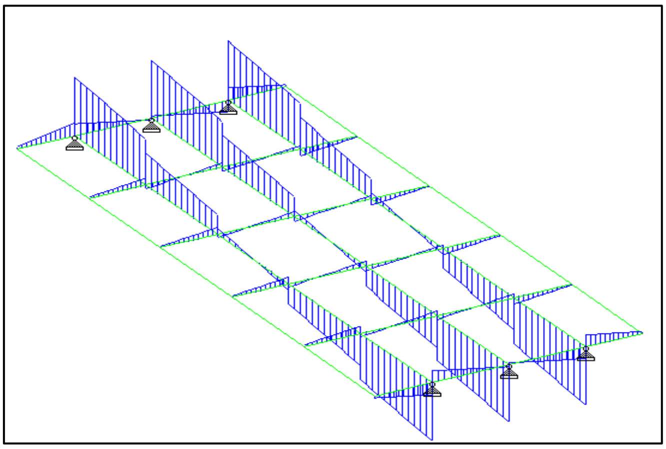

Fig 7 Shear Force Diagram

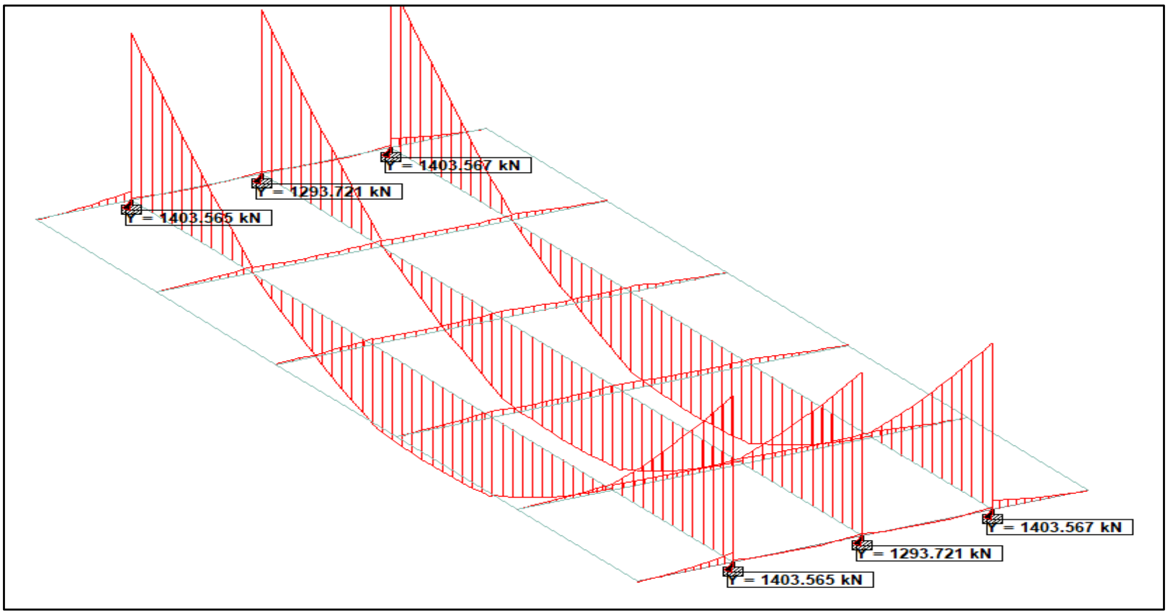

Fig 8 Bending Moment Diagram

➢ *Results of Manual Design*

Table 2 Result of the Manual Design

SI.NO	Type of Loading	Total Load acted (kN /m2)	Shear force (kN)	Shorter span moment(kNm)	Longer span moment(kNm)
1.	Dead Load	6.76 kN /m2	7.44kN	2.73kNm	1.26kNm
2.	Live Load	132 kN /m2	47.76kN	31.06kNm	13.21kNm
3.	Impact factor	25% for span more than 4m			

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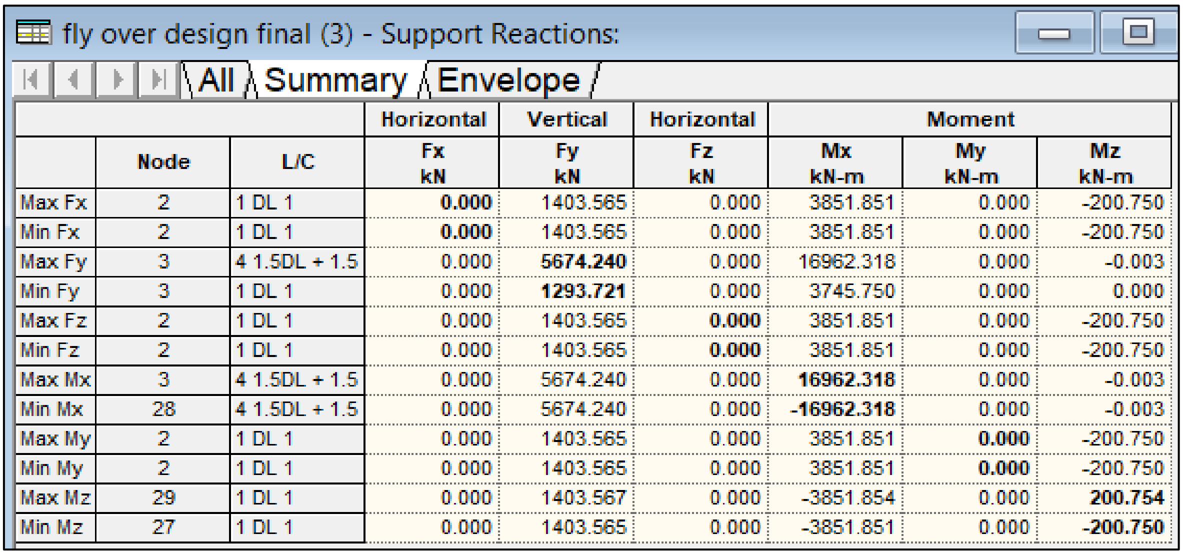
➢ *Results of STAAD Pro*



fly over design final (3) - Support Reactions:

All | Summary | Envelope

			Horizontal	Vertical	Horizontal	Moment		
	Node	L/C	Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
Max Fx	2	1 DL 1	**0.000**	1403.565	0.000	3851.851	0.000	-200.750
Min Fx	2	1 DL 1	**0.000**	1403.565	0.000	3851.851	0.000	-200.750
Max Fy	3	4 1.5DL + 1.5	0.000	**5674.240**	0.000	16962.318	0.000	-0.003
Min Fy	3	1 DL 1	0.000	**1293.721**	0.000	3745.750	0.000	0.000
Max Fz	2	1 DL 1	0.000	1403.565	**0.000**	3851.851	0.000	-200.750
Min Fz	2	1 DL 1	0.000	1403.565	**0.000**	3851.851	0.000	-200.750
Max Mx	3	4 1.5DL + 1.5	0.000	5674.240	0.000	**16962.318**	0.000	-0.003
Min Mx	28	4 1.5DL + 1.5	0.000	5674.240	0.000	**-16962.318**	0.000	-0.003
Max My	2	1 DL 1	0.000	1403.565	0.000	3851.851	**0.000**	-200.750
Min My	2	1 DL 1	0.000	1403.565	0.000	3851.851	**0.000**	-200.750
Max Mz	29	1 DL 1	0.000	1403.567	0.000	-3851.854	0.000	**200.754**
Min Mz	27	1 DL 1	0.000	1403.565	0.000	-3851.851	0.000	**-200.750**

Fig 9 STAAD Pro Results

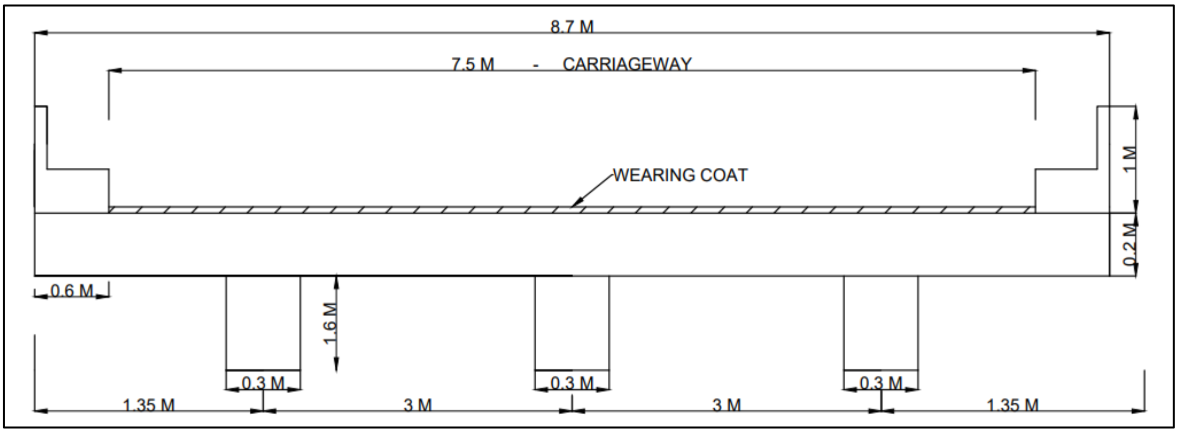


Fig 10 Deck Slab Design

VIII. CONCLUSION

The present study involves the analysis and design of a reinforced concrete deck slab using both analytical and numerical approaches. The manual analysis was carried out using the Effective Width Method and Pigeaud's curve method in accordance with Indian Roads Congress provisions, considering IRC Class AA loading. The design of the deck slab based on these methods was found to be safe and satisfactory, meeting the required design criteria.

In addition, numerical analysis was performed using STAAD.Pro, where the deck slab along with longitudinal and cross girders was modeled using plate elements. The structure was analyzed under relevant loading conditions, and the results indicated that the model is structurally safe, with no significant errors or warnings during analysis. Overall, both methods yielded safe design results.

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