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# Analysis and Design of Superstructure of Bridge Built Through Engineering College Premises

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***Abstract: The earlier publication from the authors focused on "The bridge through the college" which highlights how contracts and agreements signed many decades ago have to still be respected and fulfilled. A public highway planned to originally be laid on top of a filled-out irrigation canal passing through the campus of a college that commenced in 1977 was later replaced with an elevated bridge that was completed in 2023 and is now open to the public. The first part of the two-stage manuscript elaborated on the conception of the bridge, the general layout, geometry, and construction of this reinforced concrete girder bridge. The challenges associated in the process of engineering and construction as well as the opportunities missed were discussed. The second part of this study details the analysis process of the girders, the static and dynamic bridge loads considered, the code specifications and guidelines followed. The results of the analyses present the strength and service level member forces the bridge girders and slab are subjected to, and the design governing load combination envelopes. The study presents the superstructure girder designs, slab designs and the design methodology followed overall.***
***Keywords: Analysis, Design, Staad, Girder, Slab, Infrastructure, Sustainability, Resilience.***

## I. INTRODUCTION

In this two part study, the original first part focused on the conception of the bridge, its need and function [1]. The general layout of the bridge, the geometry of the members and the detailed method and sequence of construction were presented elaborately. The challenges associated in the construction of the bridge and the missed opportunities for incorporating sustainability and resilience were also discussed in detail. To quickly refresh the readers about the background of this structure, this bridge has a total length of about 409 m including the embankment and approaches out of which the elevated reinforced concrete bridge portion has 12 spans of each about 17m long. The bridge supports two lanes of traffic with a carriageway width of 7.5m. The deck has two pedestrian footpaths each about 1.75m, one on each side of the carriageway and carrying a crash barrier to make the total deck width 12m. The bridge deck is supported by four reinforced concrete girders spaced at 3m on center and supporting an overhand slab of 1.5m on edge girders. The bridge girders are simply supported with expansion joints provided in the topping slab over the piers. The reinforced concrete girders are supported on elastomer bearing pads installed on top of reinforced concrete pedestals cast monolithic on top of hammer head pier caps. The circular piers transfer the loads from the deck and girder through the pier caps to the isolated pad footings. Figure 1 shows the sectional view of superstructure and substructure arrangements of the bridge members.

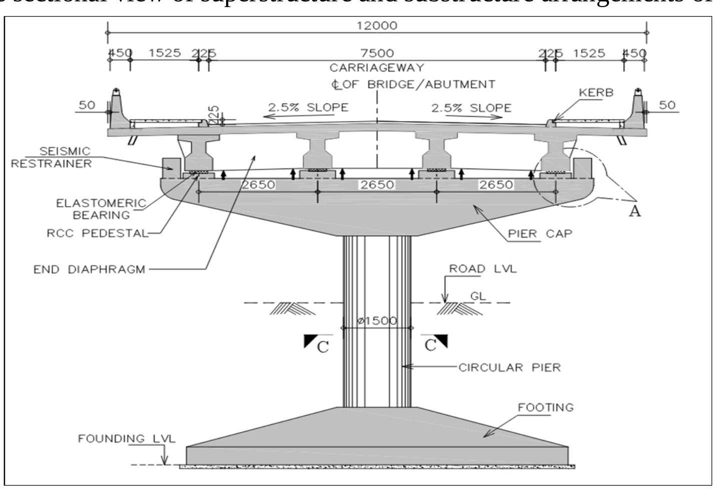


Figure 1 : Cross section layout of the bridge

The bridge girders are designed as reinforced concrete members. The girders are precast at site and erected on the pedestals on top of pier caps. Precast construction eliminated some of the challenges associated with stacking of materials, delays in work and labor problems [2]. The girders span between the pier caps as simply supported members. The girders are erected with interface shear reinforcement stirrups projecting put of their tops. The slab reinforcement is arranged on site and the girder interface ties are connected to the main slab reinforcement to ensure composite behavior of the girder and slab during service life of the bridge. The deck slab is designed to be 8" thick and it is cast once girders erection and slab steel arrangement is complete for every two spans. The deck slab had to be heavily supported with temporary field formwork to enable its casting. However, using precast panels for construction of deck slab could have improved the design efficiency of the slab system because this eliminates need for temporary but expensive formwork while also adding the precast panel strength to composite slab strength at service stage [3].

## II. STRUCTURAL ANALYSIS OF THE BRIDGE GIRDERS AND SLAB

This section presents the analysis and design of the bridge members conducted in line with the statutory specifications and standards. The Indian Roads Congress (IRC) documents the specifications and code of practice for road bridges in India [4, 5, 6, 7, 8]; these specifications along with Bureau of Indian Standards code of practice [9, 10, 11, 12, 13] for the design of reinforced concrete structures and relevant international codes are referenced in the design of the bridge members. The methods documented in standard textbooks for the analysis and design of bridge superstructure elements are referenced as well [14]. This work only presented gravity analysis because the lateral analysis due to seismic forces did not govern any member geometry or reinforcement. The bridge is a low profile structure with maximum ground to roof clearance of about 6m. As such wind on the structure is not governing the lateral forces on this structure [15]. Seismic forces are higher than wind forces for this structure [16]. However, gravity loads, and gravity forces govern the design, and the resulting designs are checked for sufficiency against seismic forces. Seismic restrainers are provided on top of each pier cap to resist the seismic lateral force and transfer it to ground through piers and foundations. The seismic restrainers also help keep the girders in place without being displaced in the event of a major earthquake. The analysis of the bridge girders is performed using linear member analysis using STAAD structural analysis software. It is understood and documented in research studies in the past [17] that linear member models may not be very accurate in the analysis of members but offer fast and reliable results. This method of analysis was performed keeping in mind the little around time available for submitting designs for this bridge. IRC:6 specifies the code of practice for "Loads and Load Combinations" to be applied in the analysis and design of bridge girders. Class 70R, Class AA, Class A vehicles are specified by IRC 6 are typically applied for the analysis of bridge girders for all permanent bridges in India. In general, the IRC 70R wheeled load and tandem axle load create the worst loading conditions on bridge girders. However, Class AA and Class A loading are also analyzed to verify that the load demands or stress conditions due to these loads do not exceed those created by Class 70R loading which is possible for certain bridge geometries and span conditions especially in the transverse design of slab.

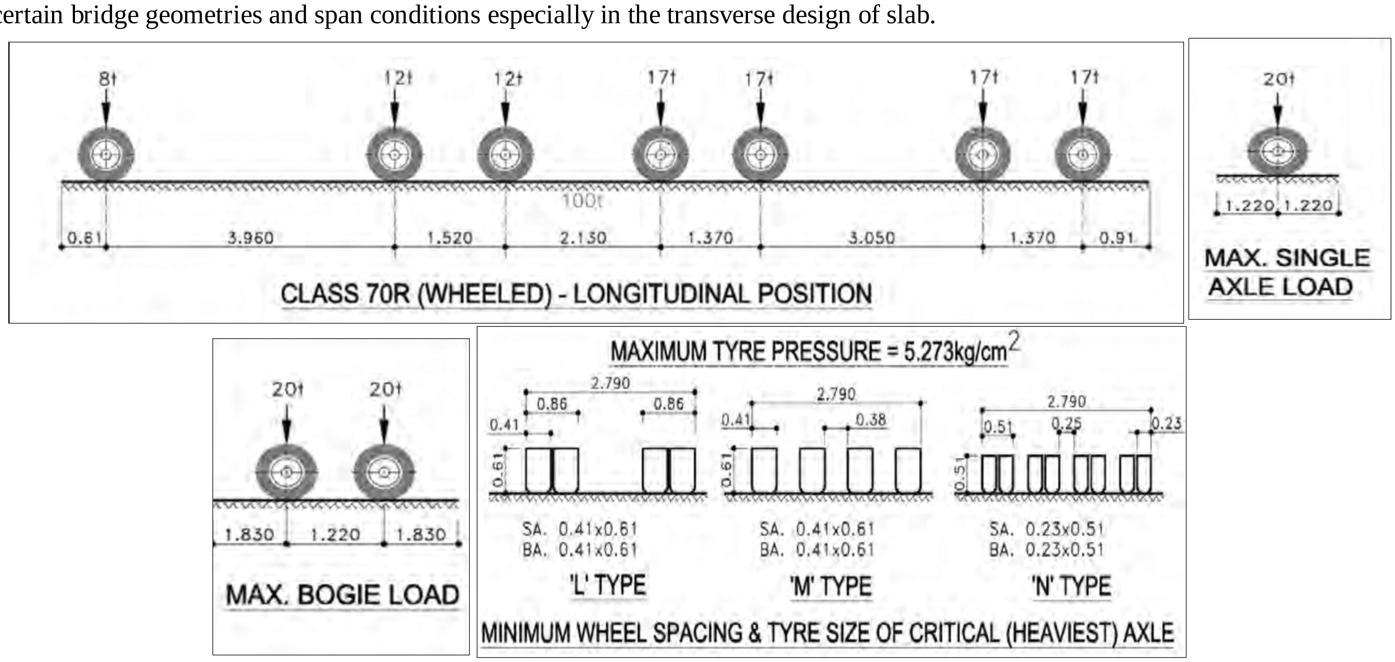


Figure 2: IRC Class 70R wheeled load configurations (IRC 6, 2017)

Figure 2 shows the IRC class 70R wheeled load configuration applied for the analysis of the bridge girders. The edge of the wheel loads is kept at 1.2m from the edge of the kerb for analyzing the bridge girders for these loads. The IRC 70R wheeled load configuration has 7 axle loads with loads ranging from 8 ton to 17 tons. A total of 100 tons of load is applied on the bridge over a length of 14.92m. The 70R also requires checks with localized heavier point loads using a 20 ton single axle load and a 40 ton tandem axle load with each axle of 20 ton.

For this bridge, even though there are only two lanes of traffic currently, there are 1.5m wide pedestrian footpaths at both ends of the deck. The total width of both footpaths is considered as one additional traffic lane, and the bridge is analyzed and designed for three lanes of traffic instead of two. This is done for two reasons; first there is a future potential for this bridge to be turned into a 3-lane vehicular bridge in the event of such demand. In such case, both footpaths can be converted into one additional vehicular lane without need for repair or retrofit of the bridge. Second, the IRC vehicular load intensity is much higher than pedestrian load, so the current 3-lane design is conservatively over designed for pedestrian loads.

Grillage deck analysis has been performed to determine the moment and shear demands on girders and slab. Staad Pro software is used to perform this analysis. Figure 3 shows the grillage model of bridge slab and girders as modeled in Staad Pro. The Staad analysis showed that class 70R wheeled loads in 2 lanes and a single class A wheeled load in the 3rd lane created the maximum longitudinal flexural and shear demands on the girders whereas the class A eccentric lane load with just 150 mm clearance from the edge of the carriage way on the outer lane created maximum transverse flexural and shear demands in the slab. Within the slab, the Class 70R, 40 ton maximum bogie load created the maximum positive and negative flexure and shear forces in the transverse direction.

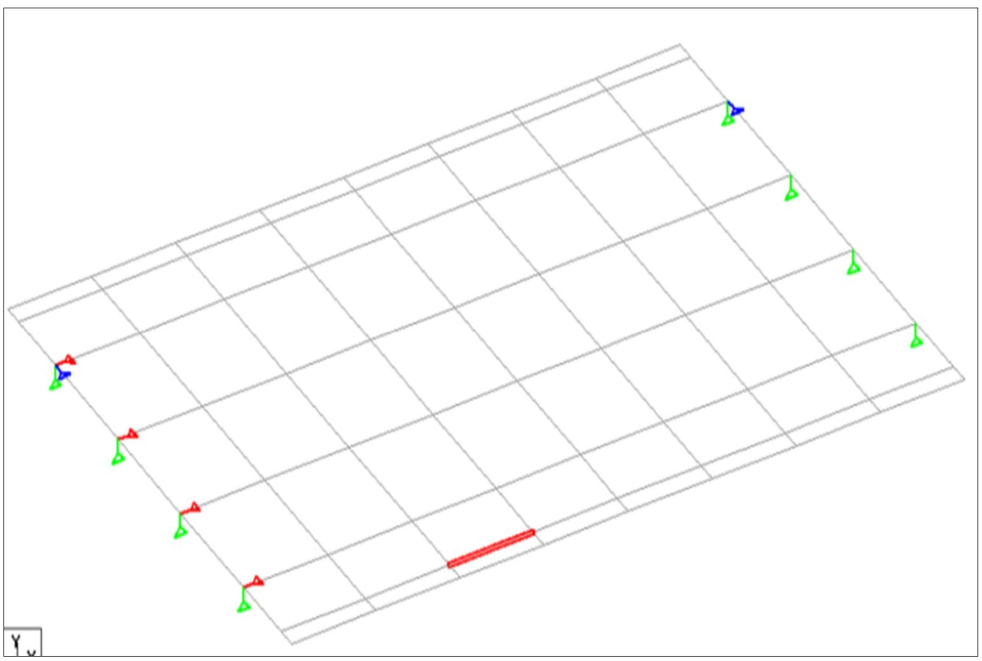

Figure 3: Staad Pro Grillage Model of Girders and Deck

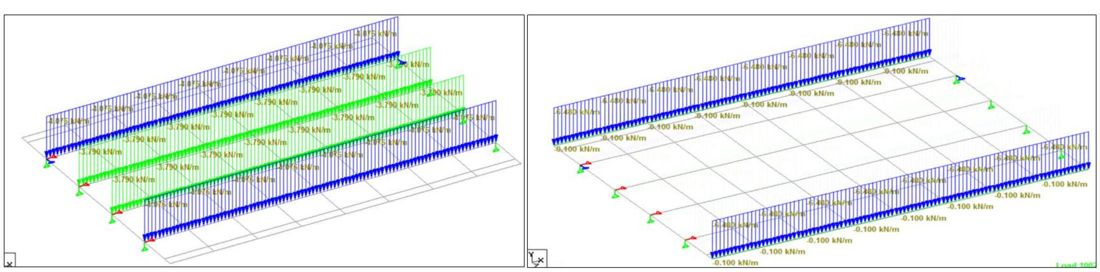

Figure 4: Wearing Coat Load (L), Crash Barrier Load (R)

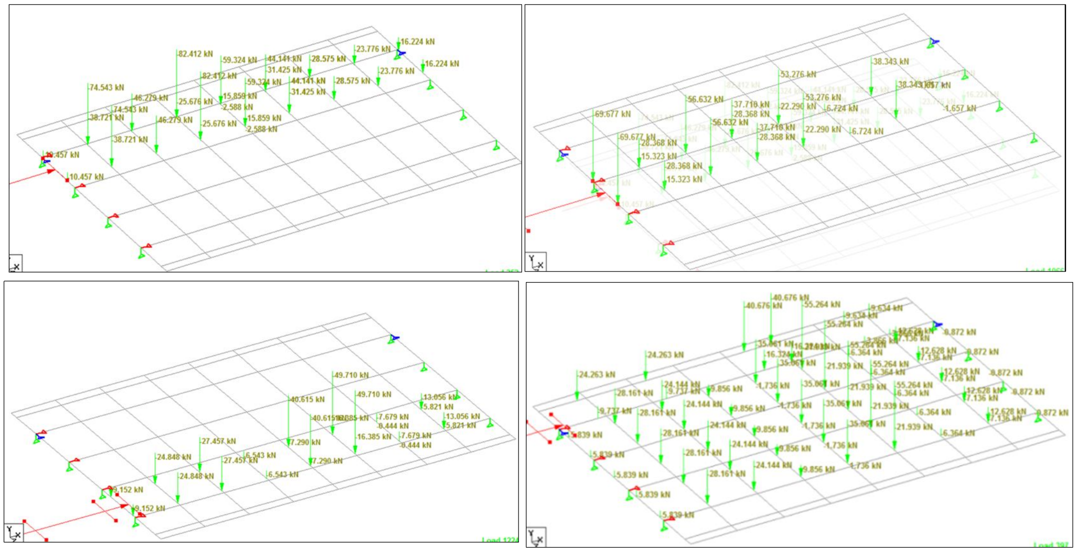

Figure 5: Live Load Models- One Lane Class 70R Wheel Load (TL, TR), One Lane Class A Edge Lane (BL), Three Lanes of Class A (BR)

Detailed analyses have been performed in Staad Pro using the above shown load scenarios in Figure 5. Both lane loads and the additional lane load (in lieu of pedestrian load) have been used to apply vehicular live loads The resulting bending moments and shear forces in each of the girders for worst case scenario (also called 'envelope' of loads) are presented in Figure 6 through Figure 9.

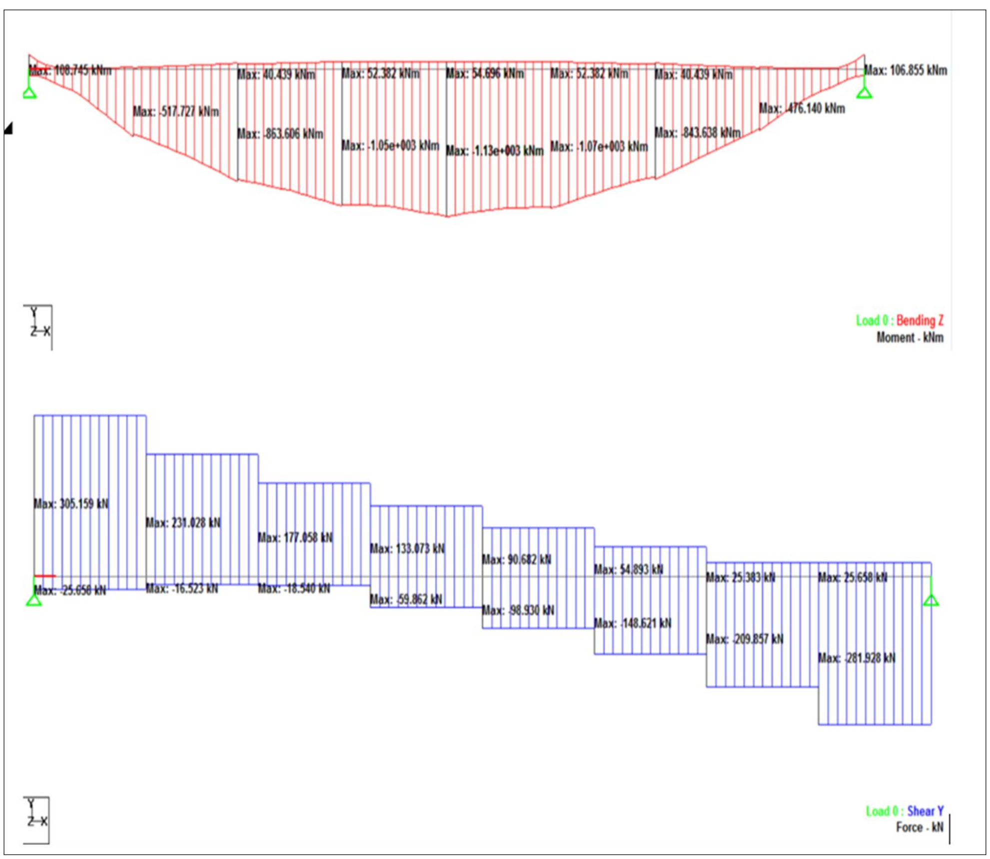


Figure 6: Bending Moment & Shear Force in Girder-1

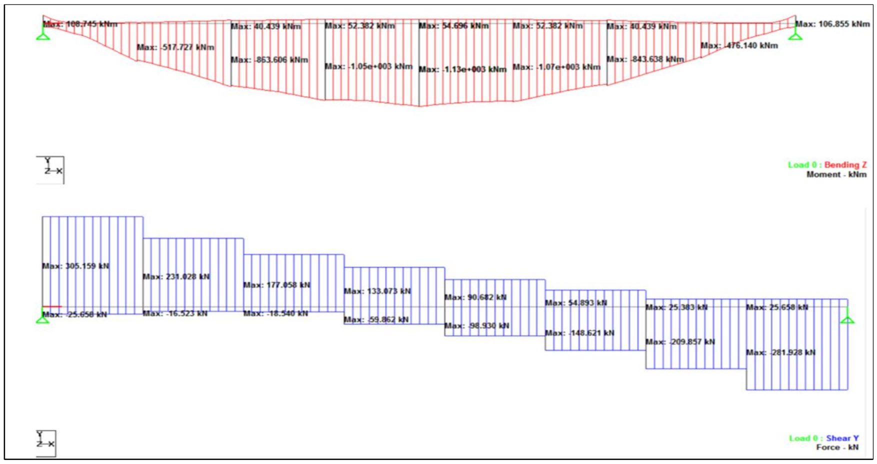


Figure 7: Bending Moment & Shear Force in Girder-2

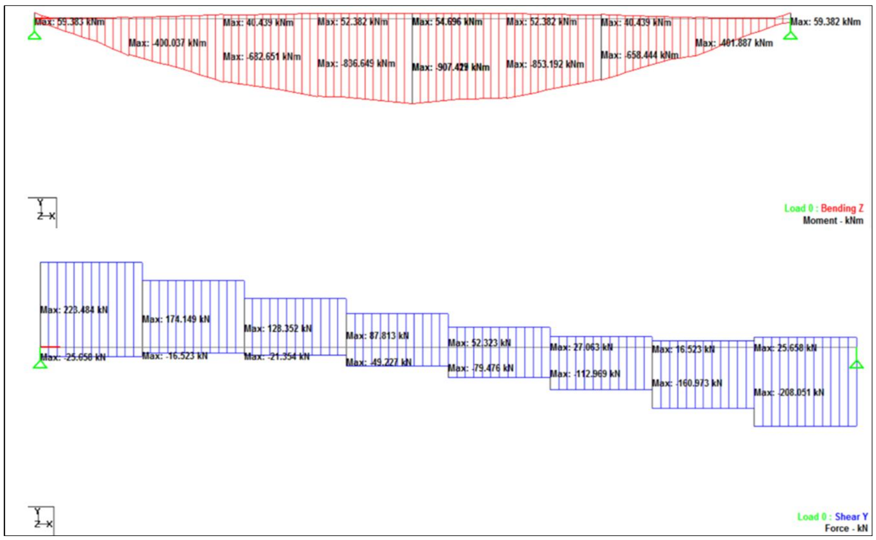


Figure 8: Bending Moment & Shear Force in Girder-3

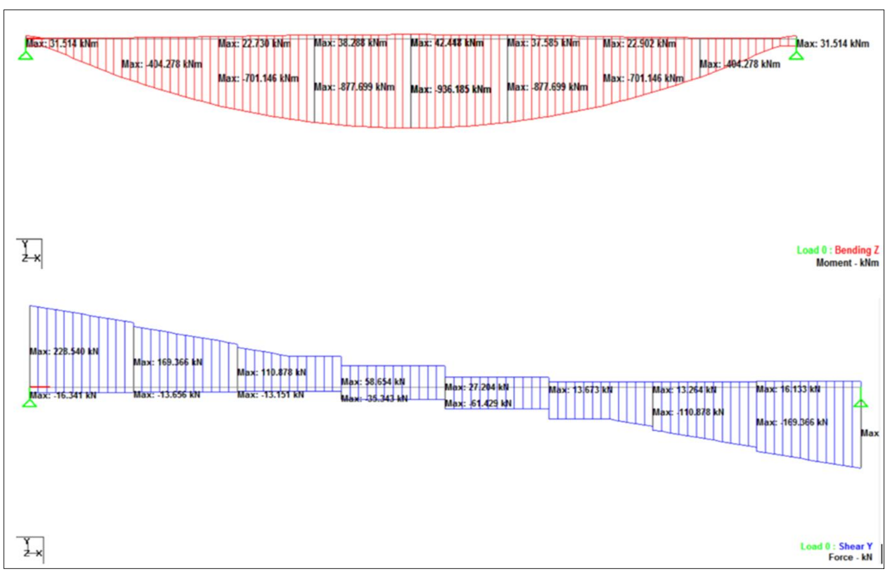


Figure 9: Bending Moment & Shear Force in Girder-4

The dynamic impact factor due to moving vehicular loads is taken as 1.2. The IRC allows for reduction of lane load due to less likelihood of multiple presence of vehicles on all lanes at the same time. This reduction factor is taken as 0.9. Table 1 summarizes the factored bending moments and shear forces on each of the girders for self-weight, dead loads, and live loads due to different load classes of 70R and Class A combinations. G1 through G4 represent the girders. Finally, the bending moments and shear forces are highest in girder G1 which is the outer (edge) girder. This is intuitive because the load tributary on this girder is the highest. The maximum design bending moment is 4483 kN-m, and the maximum design shear force is 1152 kN.

Table 1: Factored Bending Moments (L) and Shear Forces (R) in Girders

| | G-1(kN-M) | G-2(kN-M) | G-3(kN-M) | G-4(kN-M) |
|---|---|---|---|---|
| **D.L** | 1263.9 | 1059.8 | 1059.8 | 1263.9 |
| **SIDL-WC** | 373.6 | 73.8 | 73.8 | 373.6 |
| **WC** | 235.62 | 227.5 | 227.5 | 235.62 |
| **LL** | | | | |
| **Class-A 3 lane** | 2055.1 | 1566.6 | 1496.2 | 1138.4 |
| **class-70-R** | 2584.2 | 1743.8 | 434.1 | 59.6 |
| **class-A+70-R** | | | | |
| claas-A(edge) | 1771.2 | 372.9 | 42.9 | 5.4 |
| 70-R | 552.2 | 2096.8 | 1690.7 | 268.6 |
| **70-R+class-A** | | | | |
| 70-R(edge) | 2584.2 | 1743.8 | 434.1 | 59.6 |
| class-A | 25.2 | 183.5 | 796.8 | 1155.9 |
| **Total** | 4482.4 | 3830.8 | 3094.6 | 3088.6 |

| | G-1(kN) | G-2(kN) | G-3(kN) | G-4(kN) |
|---|---|---|---|---|
| **D.L** | 308.5 | 250.1 | 250.1 | 308.5 |
| **SIDL-WC** | 92.1 | -34.6 | -34.6 | 92.1 |
| **WC** | 57.9 | 54.9 | 54.9 | 57.9 |
| **LL** | | | | |
| **Class-A 3 lane** | 488.5 | 338.4 | 378.3 | 254.3 |
| **class-70-R** | 693.4 | 424.8 | 61.3 | 30.6 |
| **class-A+70-R** | | | | |
| claas-A(edge) | 514.1 | 39.4 | 15.2 | 9.6 |
| 70-R | 82.9 | 568.5 | 416.4 | 19.3 |
| **70-R+class-A** | | | | |
| 70-R(edge) | 609.6 | 424.8 | 61.3 | 30.6 |
| class-A | 13.1 | 25.5 | 209.7 | 285.6 |
| **Total** | 1151.9 | 878.4 | 702.0 | 774.7 |

Followed by the longitudinal analysis to find the highest load demands and stresses on the composite girders during erection stage, composite topping condition (when topping slab is poured) and final service condition, a transverse analysis is performed to check the load demands on the composite concrete slab. The transverse analysis of the slab gave the maximum flexure and shear on the slab for maximum positive moment in the midspan of the slab between girders and the maximum negative moments in the slab on top of the girders as well as at the face of the girder for cantilever slab overhangs at the edges of the deck.

## III. DESIGN OF THE BRIDGE GIRDERS AND SLAB

As shown in Figure 10, the precast girders are 1m deep and the depth is arrived based on an span to deflection of 17. The girders stems are 325mm thick which is set based on shear sufficiency of the section. The bottom flange is 625 mm wide whereas the top flange is 925mm wide. The top flange thickness tapers from 200mm to 150 mm at the edge of the precast flange. Figure 9 also shows the reinforcement scheme in the precast girder. The girders are designed for a bending moment of 4483 kN-m and a maximum shear demand of 1152 kN. Steel of grade 500 MPa and concrete of grade 35 MPa are used for the design of the girders. 32 mm diameter steel is used in the girders as primary reinforcement and 12 mm steel is used for shear stirrups. In total, 18 bars of 32mm size are used for primary reinforcement in the girders. The moment capacity of the girders is 6265 kN-m with a utilization ratio of 0.72 (moment demand to capacity ratio, should be less than unity). The shear stirrups are spaced at a distance of 200 mm in 2 legs. The crack width in the girders is calculated and is limited to 0.03 mm.

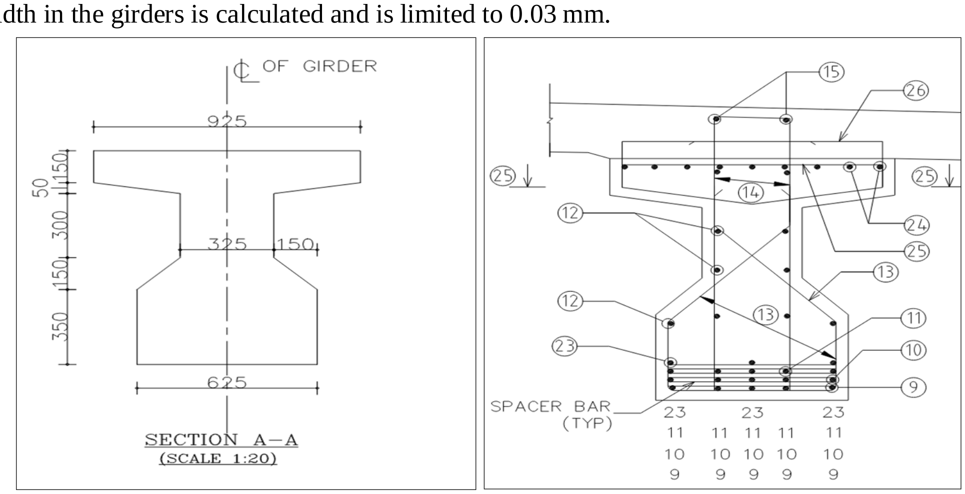


Figure 10: Precast Girder Geometry (L) and Reinforcement (R)

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The deck slab is analyzed in the transverse direction as a slab continous on the girders. The deck is analyzed for maximum bending moments and shear forces in the transverse direction as one way slab spanning between girders. The girders act as continous supports on top of which the slab spans. Figure 11 shows the bending moment envelope in the deck slab continuously spanning on top of girders in the transverse direction (along the width of the bridge). The maximum negative bending moment in the slab is 65 kN-m which occurs on the top the slab at the outer most girder due to overhanging lane load. The maximum positive bending moment in the slab occurs at mid span of the slab between girders and is about 36 kN-m.

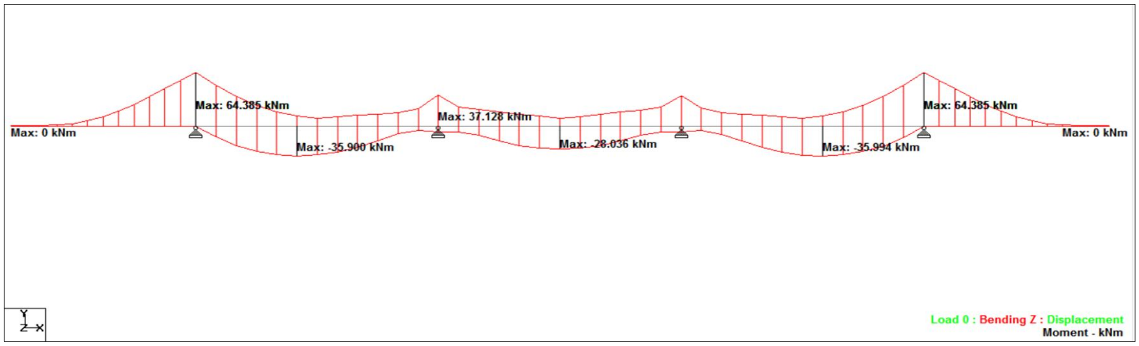


Figure 11: Bending Moment envelope in the Deck Slab (Transverse Direction/Width of the Slab)

The main reinforcement in the slab which runs in transverse direction in the deck slab (parallel the width of the bridge) is composed of 16mm size bars spaced at 150mm on centers at the top of the deck slab (negative bending regions) and of 12mm bars spaced at 110mm on centers at the bottom of the deck slab (positive bending regions). The outer most cantilever portion of the slab has slightly lower moment demands, so 10mm size bars are used in the deck slab in the cantilever overhang regions. The overall reinforcement details of the deck slab are presented in Figures 12 and 13.

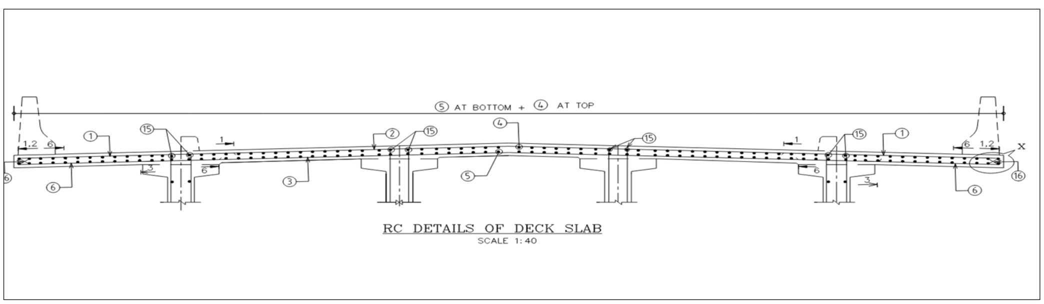


Figure 12: Reinforcement Details of Deck Slab (C/S of bridge deck)

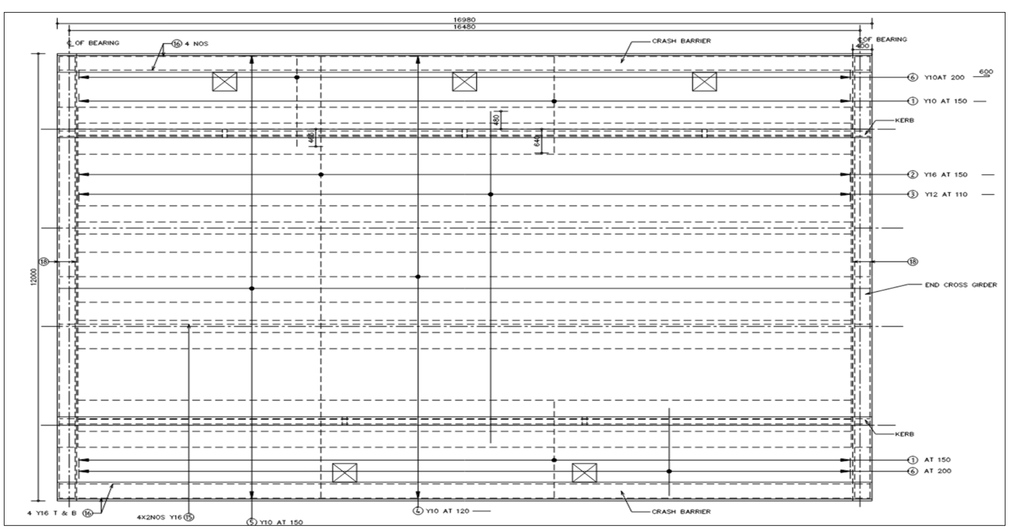


Figure 13: Plan of Deck Reinforcement

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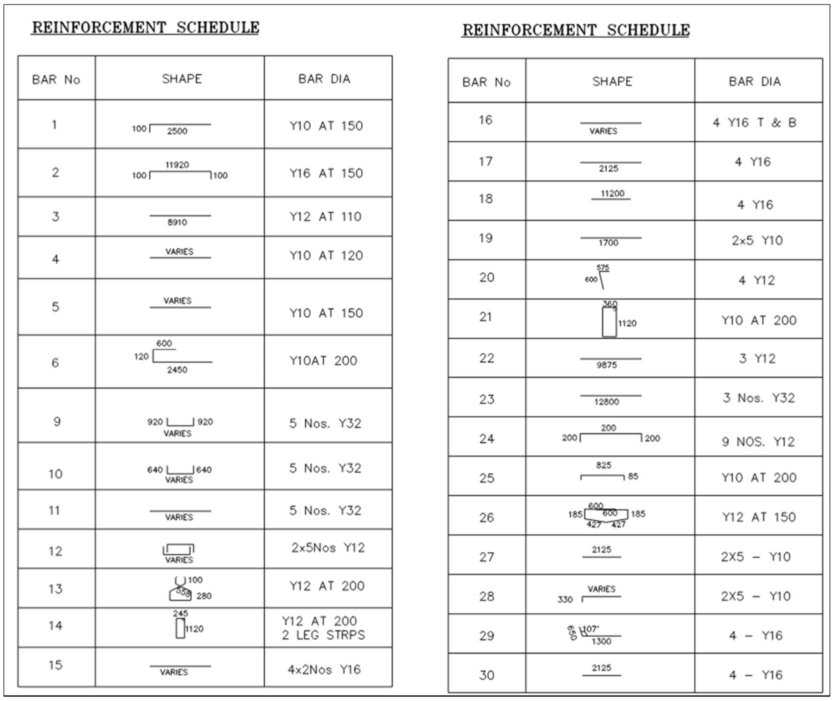
Figure 14 shows the schedule of reinforcement for the members in this bridge. This figure should be referred to while reading the reinforcement details shown in Figures 10 through 13.



REINFORCEMENT SCHEDULE

| BAR No | SHAPE | BAR DIA |
|---|---|---|
| 1 | 100 2500 | Y10 AT 150 |
| 2 | 100 11920 100 | Y16 AT 150 |
| 3 | 8910 | Y12 AT 110 |
| 4 | VARIES | Y10 AT 120 |
| 5 | VARIES | Y10 AT 150 |
| 6 | 120 600 2450 | Y10AT 200 |
| 9 | 920 VARIES 920 | 5 Nos. Y32 |
| 10 | 640 VARIES 640 | 5 Nos. Y32 |
| 11 | VARIES | 5 Nos. Y32 |
| 12 | VARIES | 2x5Nos Y12 |
| 13 | 100 280 | Y12 AT 200 |
| 14 | 245 1120 | Y12 AT 200<br>2 LEG STRPS |
| 15 | VARIES | 4x2Nos Y16 |

REINFORCEMENT SCHEDULE

| BAR No | SHAPE | BAR DIA |
|---|---|---|
| 16 | VARIES | 4 Y16 T & B |
| 17 | 2125 | 4 Y16 |
| 18 | 11200 | 4 Y16 |
| 19 | 1700 | 2x5 Y10 |
| 20 | 600 575 | 4 Y12 |
| 21 | 360 1120 | Y10 AT 200 |
| 22 | 9875 | 3 Y12 |
| 23 | 12800 | 3 Nos. Y32 |
| 24 | 200 200 200 | 9 NOS. Y12 |
| 25 | 825 85 | Y10 AT 200 |
| 26 | 185 600 600 185 427 427 | Y12 AT 150 |
| 27 | 2125 | 2X5 – Y10 |
| 28 | 330 VARIES | 2X5 – Y10 |
| 29 | 650 107° 1300 | 4 – Y16 |
| 30 | 2125 | 4 – Y16 |

Figure 14: Reinforcement Schedule (dimensions in mm)

## IV. CONCLUSIONS

This paper presents the details of the analysis and design of the bridge to cross the premises of VR Siddhartha Engineering college in Kanuru mandal on the outer skirts of Vijayawada city. The paper presents the vehicular loads considered for the design of the bridge in accordance with the IRC specifications and the analyses performed in longitudinal and lateral direction in Staad Pro as well as using calculations in excel spreadsheets. The design and reinforcement details of the girders and the deck slab are presented. The bridge is designed for typical loads and typical methods. A missed opportunity is to design the girders as prestressed concrete members which would make the bridge more durable and reduce maintenance issues pertaining to cracking and spalling [18]. Similarly using Ultra-High-Performance concrete (UHPC) for bridge joints is another missed opportunity to improve durability of bridge joints and reduce maintenance costs [19]. These simple designs and material adaptations could have significantly enhanced the efficiency and performance of the bridge [20] and made it more robust while contributing to sustainable and resilient infrastructure practices [21].

## V. ACKNOWLEDGEMENTS

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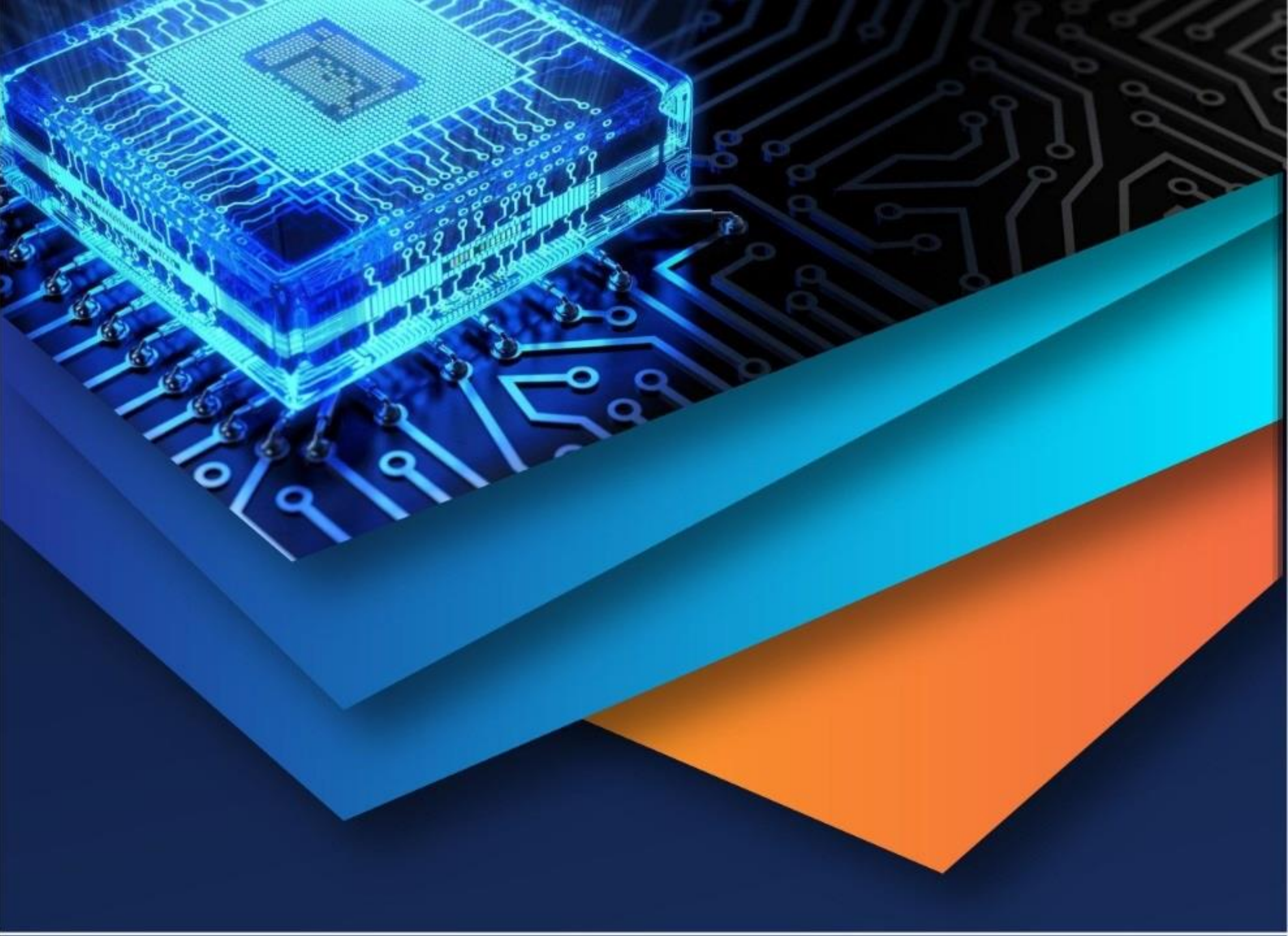


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