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Grillage Analysis of Prestressed Concrete Girder Deck Superstructure for NH-16 Bridge Flyover; Part-1

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Abstract: The bridge superstructure flyover built on National Highway route 16 (NH-16) near Benz circle in Vijayawada to act as grade separated highway for vehicles to cross over National Highway route 65 (NH-65) is made of precast and post-tensioned concrete girders. This article is the first part of the two phase study that focuses on the structural analyses of concrete bridge girders. The bridge girders are analyzed for vehicular loads considered as per Indian Roads Congress Specifications. The IRC Class of loads of 70R and Class A and their wheel load configurations are discussed. The bridge girders along with deck are modeled as grillage girder-slab members in Staad Pro analysis software. The bending moments and shear forces are computed for each of the IRC vehicular load configurations and the envelope forces for governing load configuration are presented for each of the girders. Finally, the article summarizes the maximum flexural and shear demands on the bridge girders. The pros and cons of grillage analysis modeling for prestressed girders and the alternate superior options for precise but quick modeling are also recommended.
Keywords: Bridge, Flyover, Analysis, Staad, Girder, Grillage

I. INTRODUCTION

The bridge on NH-16 near Benz Circle in the city of Vijayawada is built as two separate carriageways each of 3-lane post-tensioned concrete girder bridges to cross over the at-grade vehicular traffic on NH-65. A bridge was identified as very necessary here due to the heavy volume of vehicular traffic on both National Highways meeting at this point. The bridge has a total length of about 240 m with an obligatory maximum span of 30m in length. The bridge supports three lanes of traffic with a total carriageway width of 11.5m. The bridge has two crash barriers one at each edge of the carriageway to make the total deck width of 12.5m. The bridge deck is supported by four post-tensioned concrete girders spaced at 3.1 m on center and supporting an overhanging slab of 1.6m. The bridge girders are connected by cross diaphragms one at each support location and one at the midspan. The concrete girders with cross diaphragms are supported on elastomer bearing pads installed on top of reinforced concrete pedestals cast monolithic with pier caps. Figure 1 shows the sectional view of bridge girders and carriageway deck. The girders are rectangular at support locations and taper to become I-shaped along the rest of their length. Figure 2 shows the girder cross section at support location on top of pier caps.

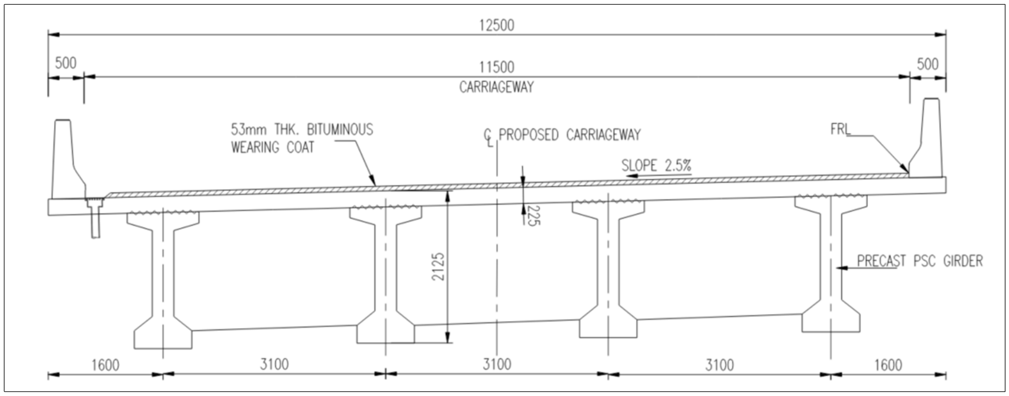

Figure 1 : Cross section layout of the bridge superstructure at midspan location

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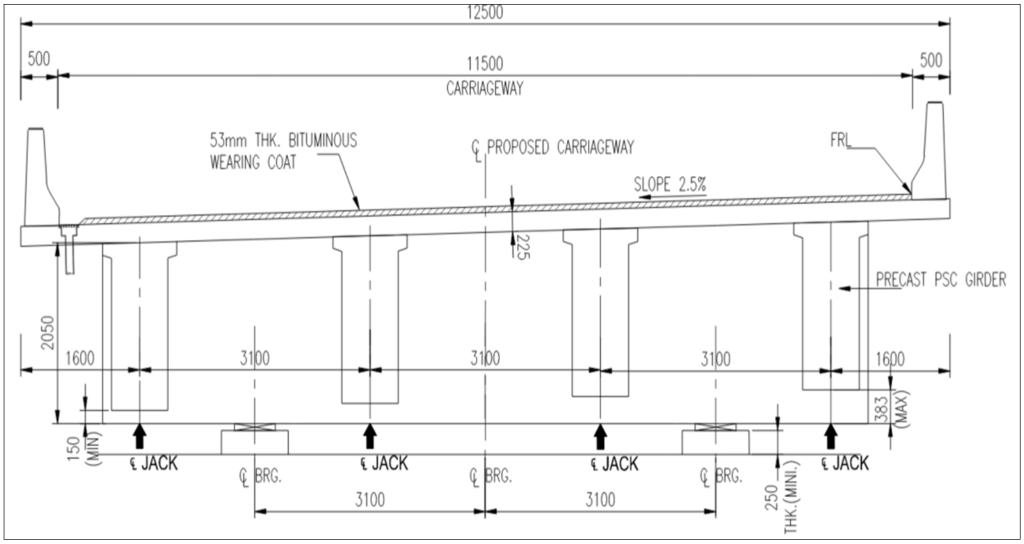


Figure 2 : Cross section layout of the bridge superstructure at support location

The precast girders are 1.9 m tall. The webs of the girders are 300 mm thick, and the bottom flange is 800 mm wide, and the top flange is a meter wide. The top flange thickness tapers from about 250 mm to 150 mm at the edge of the precast flange. Figure 3 shows the geometry of the precast girder at the support section where the webs are wider (800mm) and rectangular while at other sections away from the support where the girder is more standard I shaped. Steel of grade 500 MPa and concrete of grade 45 MPa are used for the design of the girders. The slab is also of M45 grade concrete. The girders are cast at precast plant to avoid challenges associated with cast-in-place construction methods (Jonnalagadda & Vemuri, 2023a). Precast construction combined with prestressing at the plant offers the unique advantage of bringing the members to the site only at the moment of erection thereby significantly minimizing site stacking of materials, expensive formwork, and traffic restrictions (Jonnalagadda & Vemuri, 2023b).

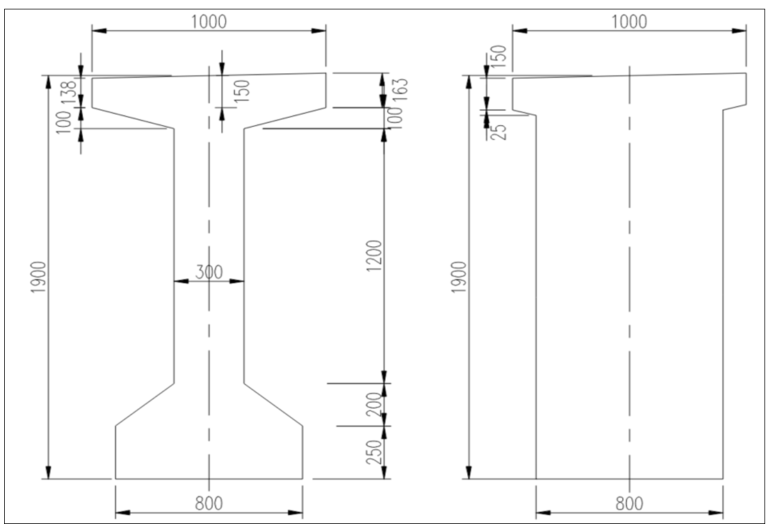


Figure 3: Precast Girder Geometry; At midspan (L), At Support (R)

The layout of the 4 girders along the length is shown in both plan and elevation of the bridge. Figures 4 and 5 show the plan and elevation of the girders with end and intermediate diaphragms. The 30 m spans have center to center of girder as 28.5m as measured bearing seat to bearing seat. The girders are spaced at 3.1m on center along the width of the bridge. The end diaphragms are 750mm wide where as the smaller diaphragm which may also be called as a rib is around 300mm and located at the midspan of the girders. Concrete crash barriers are installed on both edges of the bridge. The location of drainage spouts on the bridge deck are also shown in these figures.

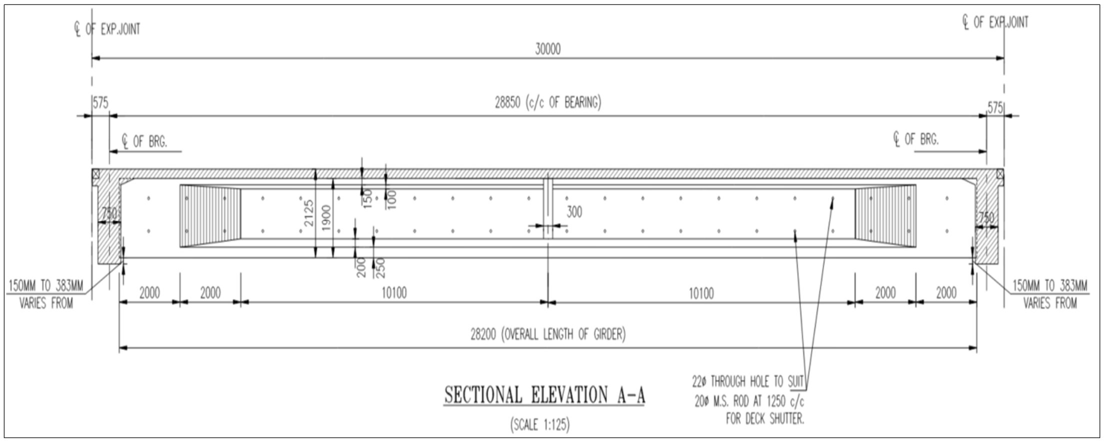


Figure 4: Precast Girder Layout (Elevation)

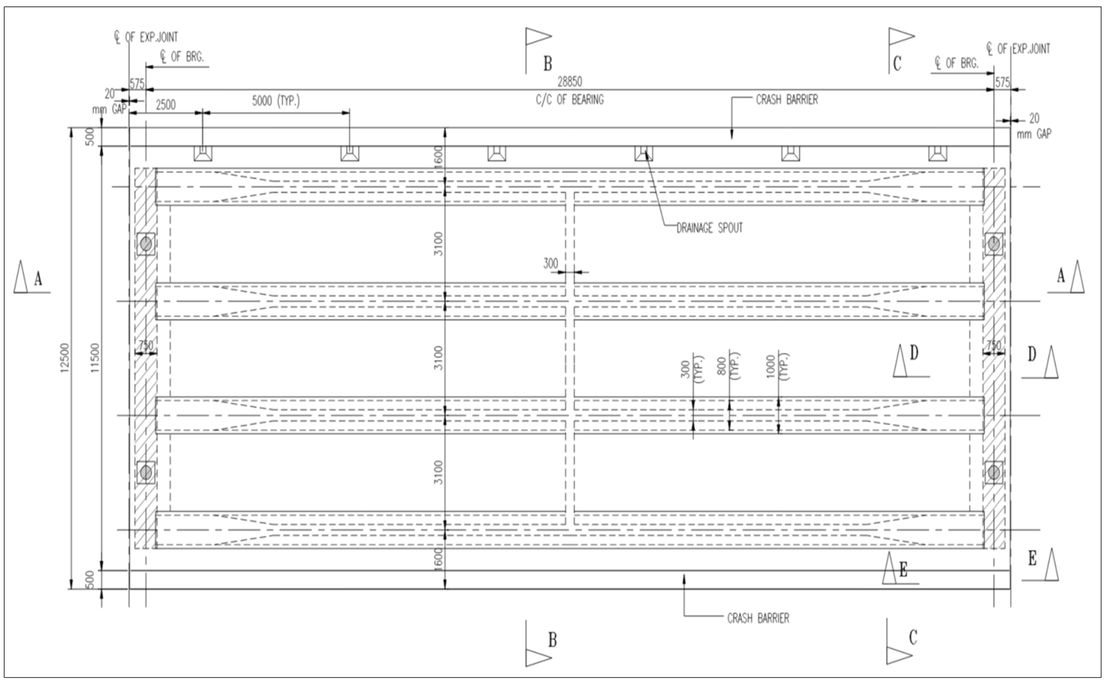


Figure 5: Precast Girder Layout (Plan)

II. ANALYSIS OF SUPERSTRUCTURE GIRDER AND DECK SYSTEM

The analysis and design of the prestressed girders is done as per the guidelines of the Indian codes of standards. The Indian Roads Congress (IRC) specifications and code of practice for road bridges in India (IRC 5 2015, IRC 6 2017, IRC 22 2015, IRC 112 2011, IRC SP:114 2018) along with the specifications of the Bureau of Indian Standards code of practice (IS 456 2000, IS 1893 2016) are referred and followed for the designs. Seismic forces govern the design of this structure over wind due to the urban landscape and low vertical clearance of the bridge deck (Vemuri & Jonnalagadda, 2023a). Also structures subjected to heavy wind loads need different analyses procedures that are more suited to model fluid pressures (Vemuri & Jonnalagadda, 2023b) which is not the case in this bridge. The girders are designed for vehicular forces including gravity, centrifugal and braking forces (Kumar & Ram, 2015). The analysis of the bridge girders is performed using linear member analysis using STAAD structural analysis software; linear member models may not be very accurate in the analysis of members but offer fast and reliable results. The IRC 70R wheeled load and tandem axle load create the worst loading conditions on the bridge girders. The bridge girders are also analyzed for 3 lanes of Class A vehicles. Figure 6 shows the standard configuration of IRC 70R wheeled loading as provided in the standard of IRC 6 (2017)

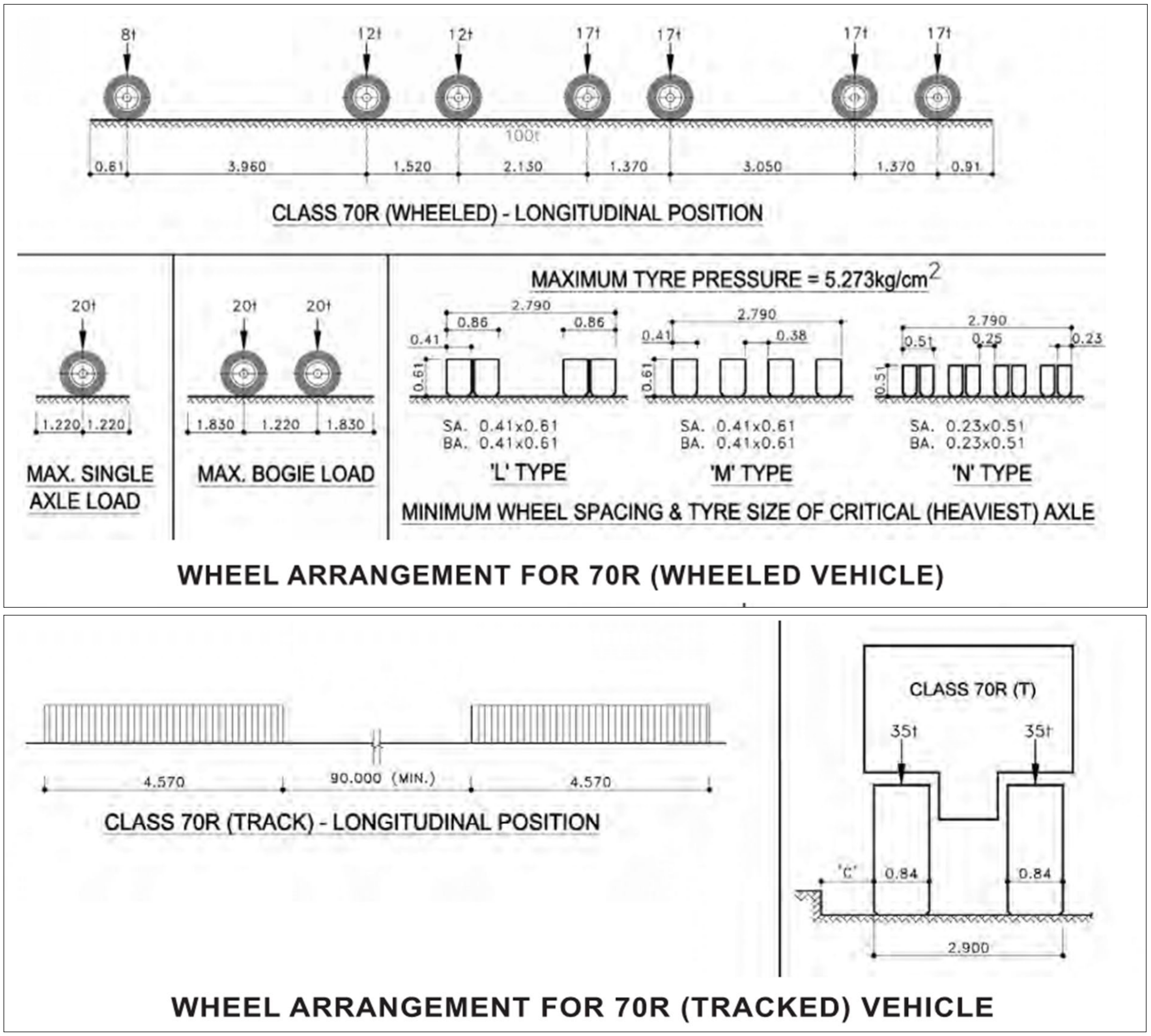


Figure 6: IRC Class 70R wheeled load configurations (IRC 6, 2017)

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. In total, about 100 tons of wheel loads are applied on the bridge over a length of 14.92m. The 70R specifies bogie load checks with heavier point loads using a 20 ton single axle load and a 40 ton tandem axle load with each axle of 20 ton. Staad Pro software is used to perform grillage analysis of the deck and girders to determine bending moment and shear forces in the girders.

A. Grillage Analysis of Girder and Deck

Figure 7 shows the grillage model used. This method of analysis is typically used to design girder and slab system do perform a quick analysis of forces without losing accuracy. In this method of analysis, the girders are assumed as longitudinal grillage members whereas the slab members are used as transverse grillage members. The mesh is discretized as a fine mesh of grillage elements in both orthogonal directions. This method is adopted for girder and slab system because the girders primarily distribute forces in longitudinal direction whereas the deck slab resists forces by transverse spanning action between girders. The 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 carriageway ted maximum transverse flexural and shear demands in the slab. For the interior portions of the slab that are away from , the 40 ton maximum bogie load created the maximum bending and shear forces in transverse direction.

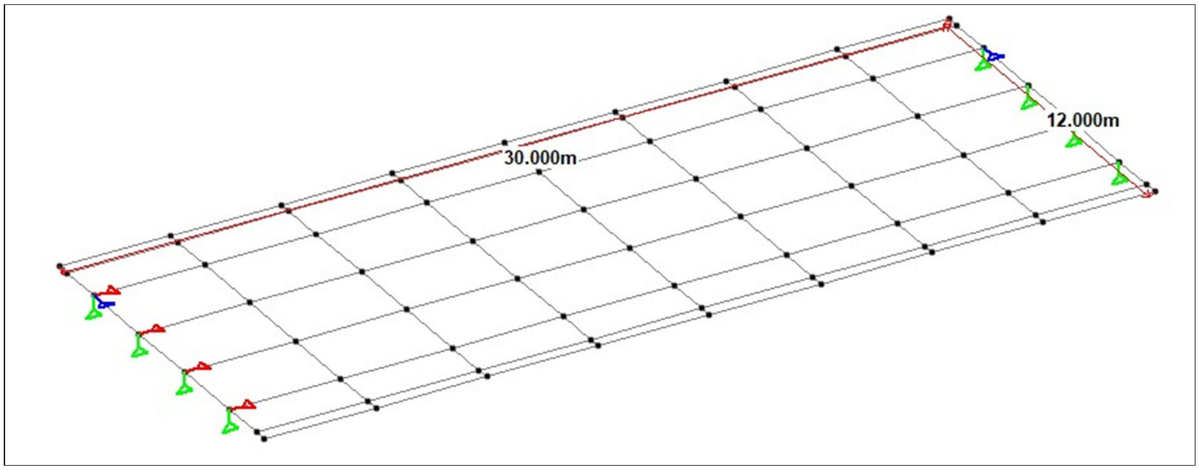
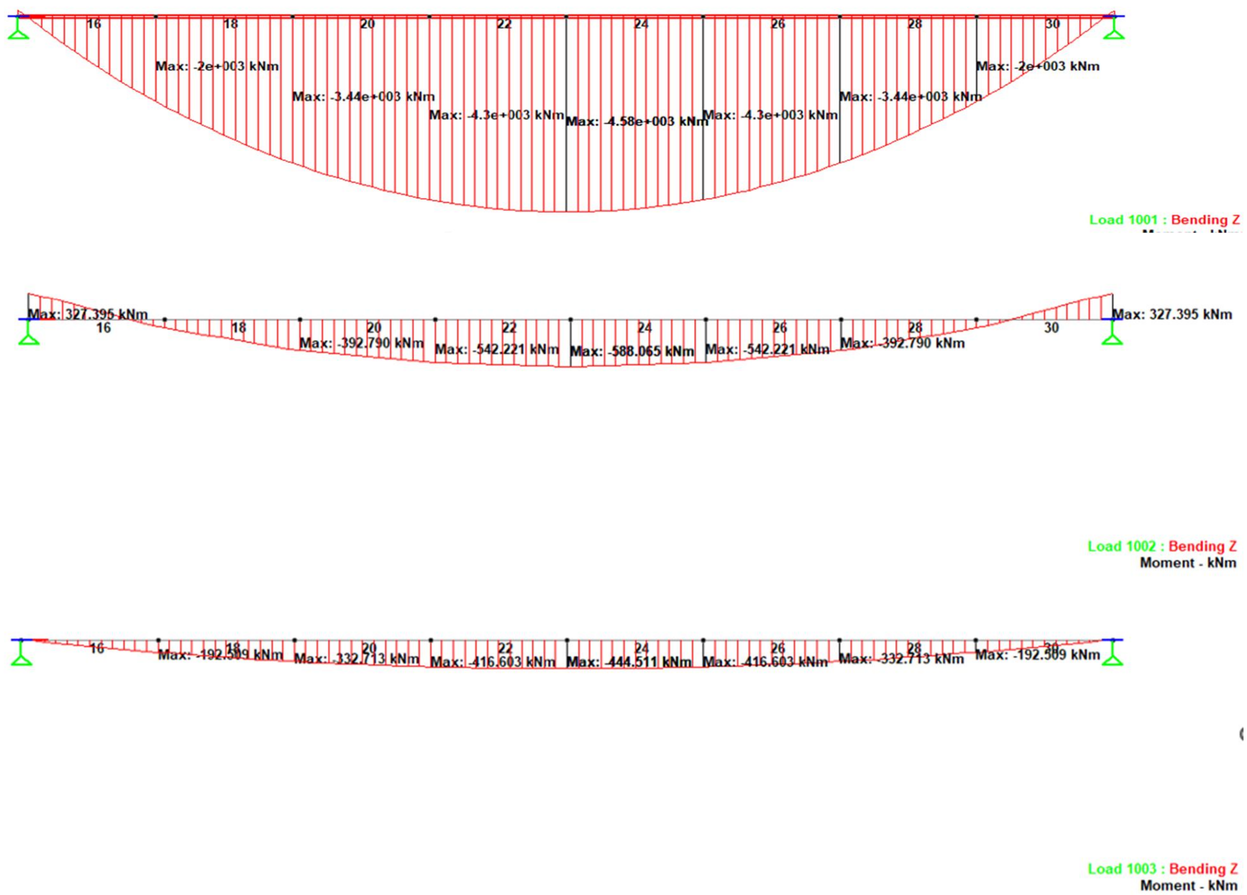


Figure 7: Grillage Model of Girders and Deck (Staad Pro)

III. RESULTS AND DISCUSSION

The results of Structural analysis from grillage model are presented in the following pages. The resulting bending moments and shear forces in one inner girder and one outer girder for dead load and imposed loads are presented in Figures 8 through 11. In these figures, each of the plots correspond to unfactored forces during Dead Load (DL), Super Imposed Dead Load (SIDL), Wearing Coat (WC) and Live Loads (LL) phases. The maximum factored bending moment which happens to be on the outer girders is in the magnitude of 12714 kN-m whereas the maximum shear force on these girders (factored) is 1864 kN.



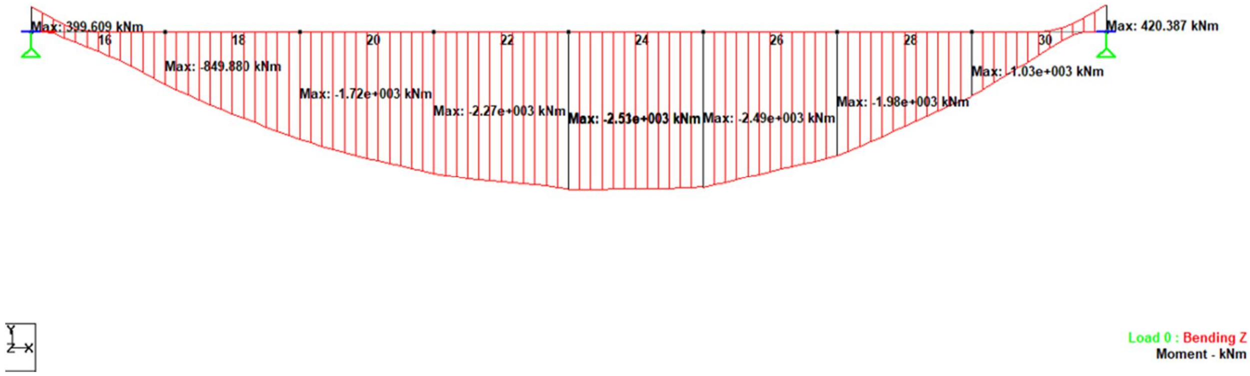


Figure 8: Bending Moment Diagram for Outer Girder (Unfactored); DL, SIDL, WC, LL (Top to Bottom)

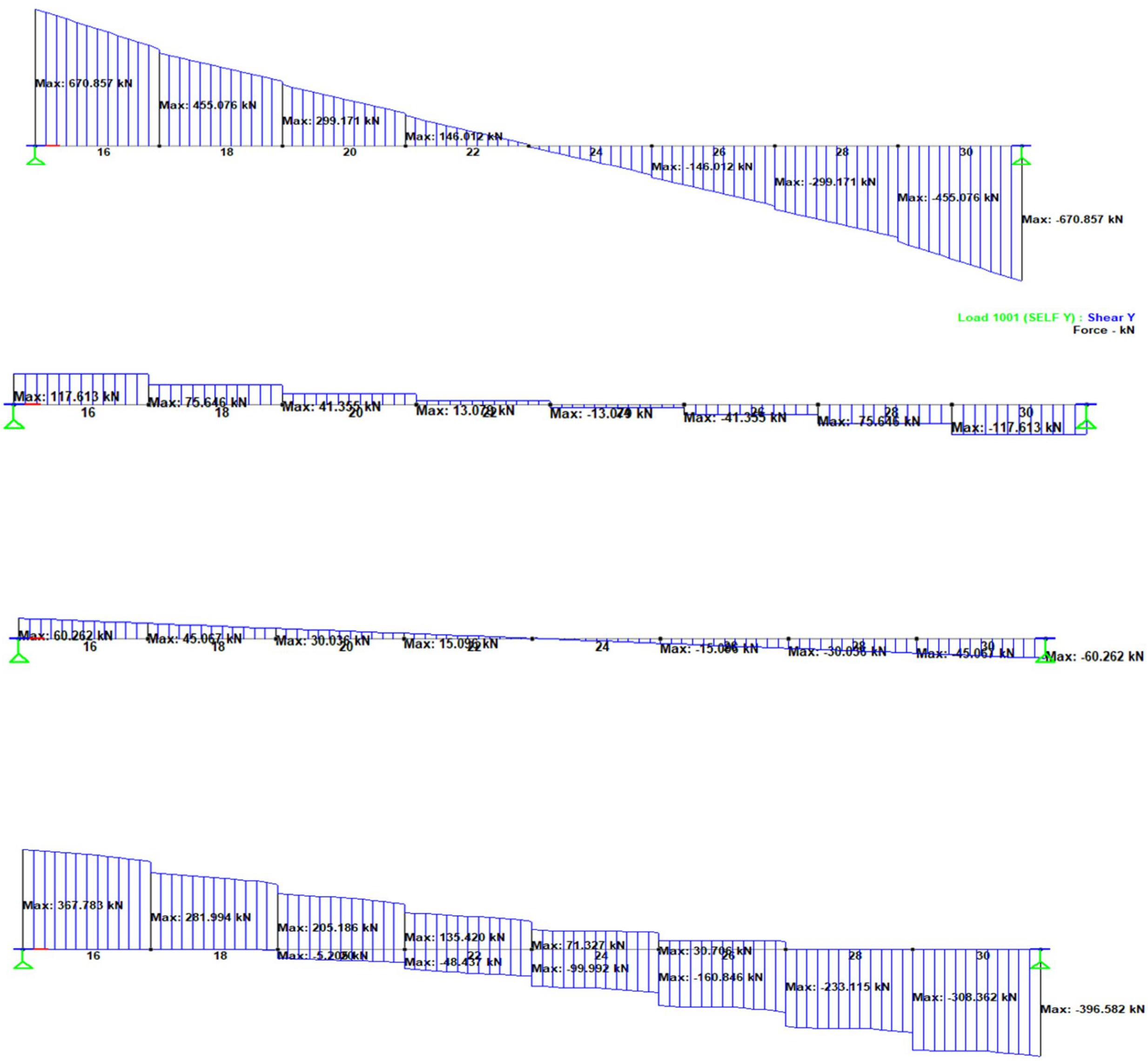


Figure 9: Shear Force Diagram for Outer Girder (Unfactored); DL, SIDL, WC, LL (Top to Bottom)

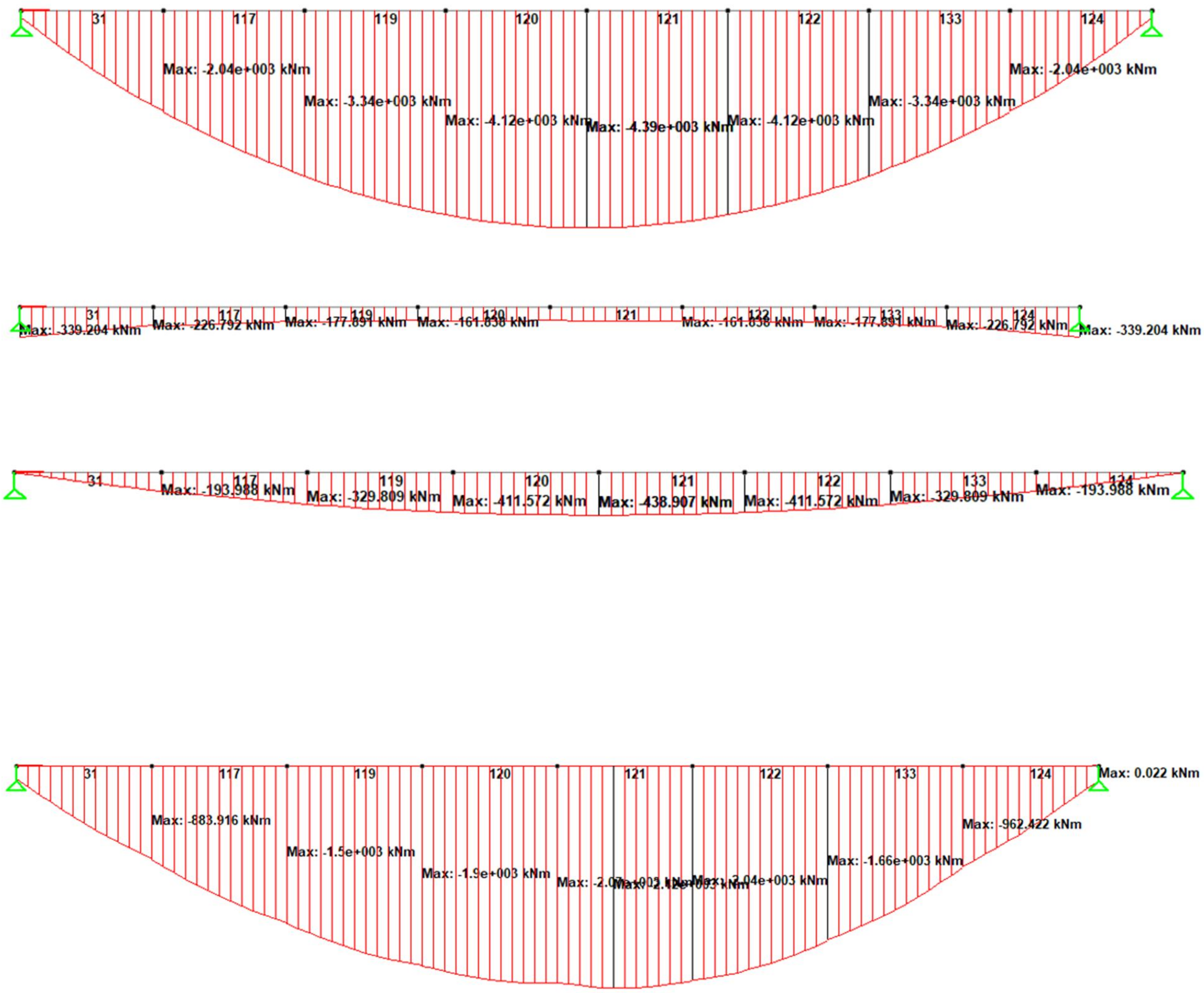
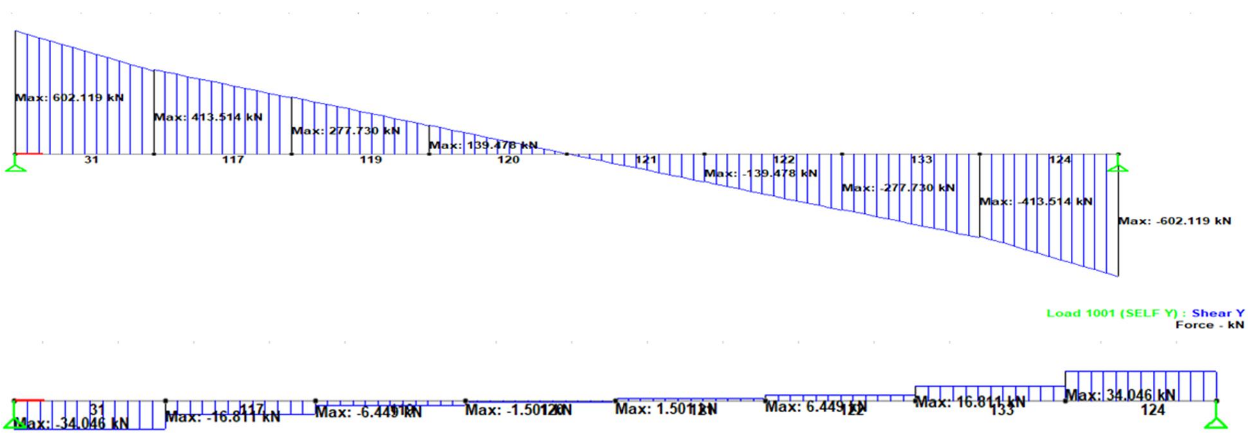


Figure 10: Bending Moment Diagram for Inner Girder (Unfactored); DL, SIDL, WC, LL (Top to Bottom)



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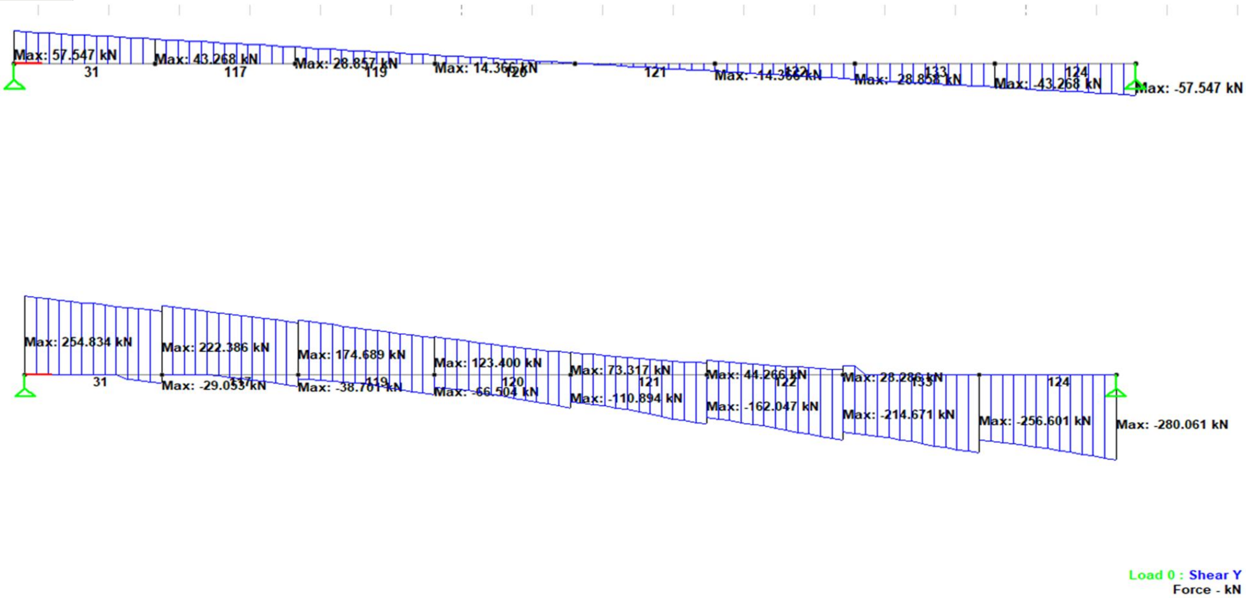

Figure 11 Shear Force Diagram for Inner Girder (Unfactored); DL, SIDL, WC, LL (Top to Bottom)

The Table 1 below gives the summary of unfactored and factored forces for each of the bridge girders due to vehicular (IRC 70R/ Class A configurations) and gravity loads such as self weight, slab super imposed dead loads and wearing coat on top of the bridge surface. The impact factors, the reduction factor for multiple simultaneous presence of trucks in all lanes and the congestion factor are also indicated in the table.

Table 1: Summary of Forces in the Girders

SUMMARY OF GIRDER FORCES

Eff span	=	30 m
Impact factor for class-A vehicle	=	1.125
Impact factor for class-70-R vehicle	=	1.2
Reduction factor	=	0.9
congestion factor	=	1.15

Unfactored BM on Girders

	G-1(kN-M)	G-2(kN-M)	G-3(kN-M)	G-4(kN-M)
D.L	4580	4390	4390	4580
SIDL-WC	588	162	162	588
WC	445	439	439	445
LL	2530	2120	1970	1800
Total	8143.0	7111.0	6961.0	7413.0

Factored BM on Girders

	G-1(kN-M)	G-2(kN-M)	G-3(kN-M)	G-4(kN-M)
D.L	6183.0	5926.5	5926.5	6183.0
SIDL-WC	793.8	218.7	218.7	793.8
WC	778.75	768.25	768.25	778.75
LL	4418.8	3702.7	3440.7	3143.8
Total	12174.4	10616.2	10354.2	10899.4

Unfactored shear on Girders

	G-1(kN)	G-2(kN)	G-3(kN)	G-4(kN)
D.L	671	602	602	671
SIDL-WC	118	34	34	118
WC	60	58	58	60
LL	397	280	290	225
Total	1246.0	974.0	984.0	1074.0

Factored shear on Girders

	G-1(kN)	G-2(kN)	G-3(kN)	G-4(kN)
D.L	905.9	812.7	812.7	905.9
SIDL-WC	159.3	45.9	45.9	159.3
WC	105.0	101.5	101.5	105.0
LL	693.4	489.0	506.5	393.0
Total	1863.5	1449.1	1466.6	1563.1

B. Pros and Cons of Grillage Analysis

The analysis of bridge superstructure in this article is based on grillage analysis of girder-deck systems which is often the preferred method of analyses used by industry bridge engineers to find the force demands in girders and slab (Jonnalagadda, 2016). In this method of analysis, the girders are modeled as longitudinal members, and the slab is modeled as transverse members in a grillage mesh model. The material and geometry properties are assigned for the grillage members based on actual member geometry.

This method of analysis is quick and reasonably accurate as such engineers prefer this method. In grillage analysis, the grillage members in both directions are assumed as 1D members with equivalent inertia and rigidly connected at their intersection. So grillage system is 2D representation of a system using D or line models of members in either direction. Line models are quick and easy to model and run the results, and they are reasonably accurate for engineering and construction purposes (Vemuri & Jonnalagadda, 2023c). The grillage system has another advantage; the force demands in girders and slab are determined with the same model, so separate analyses of girders and slab is not required. This saves time on real projects.

However, some of the disadvantages of grillage analysis include too conservative estimate of force demands on the girders and slab, and an inadequate estimate of torsional forces on the members (Hambly, 1991). In projects that have novel and innovative superstructure girder forms such closed or open box sections (Vineeth et al, 2019), spine and wing beams, beams with troughs for cast-in-place concrete, the grillage analysis can give quite erroneous results. Also novel precast construction methods with adapting construction sequences (Jonnalagadda & Vemuri, 2023c) and high strength materials such as Ultra-High performance concrete (Jonnalagadda & Chava, 2023) that show non-linear deformations beyond elastic range may not offer modeling grillage members without losing accuracy of analyses. Due to inaccurate torsional distribution, skew bridges may not be good candidates for grillage analysis (Raj & Phani, 2017).

Some of the alternatives for grillage analyses include finite element analysis using shell or plate models or combination of plate and shell frame member models. For Structural engineering problems, using Risa 3D® or ETabs® offers facility to model the bridge members as finite element models and optimize the mesh size to achieve accurate measure of force demands on the members. Software specific to bridge member analyses such as Midas® Bridge, Leap® Bridge, Conspan® from Bentley® are available for quick analysis of member forces in girder and slab. Grillage analysis has become an outdated modeling practice with the advent of finite element analysis bases structural analysis software products.

IV. CONCLUSIONS

This study details the analyses and design methods used in the engineering of post tensioned superstructure girders for a 3 lane bridge on NH-16 of India. The article starts with explaining the vehicular loads considered for the design of the bridge in accordance with the Indian standard specifications. The details of Grillage analyses performed in Staad Pro including bending moment and shear force diagrams for inner and outer girders are presented. The summary of factored design load demands is tabulated. Also, the pros and cons of grillage analysis are discussed, and alternate methods of modeling and structural analyses are briefly outlined. The natural follow up for this study will be on the design and detailing of reinforcement in these girders which are planned to be disseminated in a follow-up article.

V. ACKNOWLEDGEMENTS

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