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Evaluation of performance of RCC-T girder bridge by varying girder configuration and span length

Sadiksha Kandel[1], **Rajan Suwal**[1], **Subash Bastola**[1*]

[1] *Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Lalitpur, Nepal*
**Corresponding email: kandelsadiksa54@gmail.com*

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Abstract

Reinforced Concrete-T girder bridges are generally constructed in Nepal because of their suitability and adaptability to medium span range from 10 m to 25 m. The behavior and performance of such bridge depends on variations of parameters. Therefore, there is need of parametric study to understand how these different parameters influence the behavior (stress and deflection) that helps to identify the possible weaknesses. Parametric studies analyze stress and strain distribution, assess the dynamic performance that helps to determine material efficiency, costs, and durability which contribute to bridge lifespan. This research mention parametric variation by considering changes of span length and number of girders. The motive behind this study is to find out the behavior of bridge (stress and deflection) by varying the span length and number of girders, also to determine impact of dynamic load on bridge and to calculate how number of girders will affect economy and behavior of bridge. The study was conducted by following static and dynamic analysis using FEM software CSiBridge V24.2.0 along with economic implication implementing MCDA approach on python. Dead load, Live load IRC Class A vehicular load was used to perform static and dynamic analysis. The findings of this study shows that under equivalent deflection, compressive stress is higher in three-girder system while tensile stress dominates in two-girder system suggesting that two-girder system performs better structurally and it is economical by reducing cost from 7.5% to 5.9% at shorter span and three-girder performs better at longer span with being the most economical choice by reducing cost up to 4.68%. Along with it, Dynamic Amplification Factor (DAF) was also determined to know how much structure gets amplified. The result stated that both stress and deflection gets more amplified when bridge is subjected to dynamic load and compressive stress seems to be more amplified compared to tensile stress and deflection.

Keywords: *RCC T-girder bridges, Parametric study, Dynamic Amplification Factor, Cost optimization, Finite Element Analysis*

1. Introduction

A bridge is a structure that can withstand all kinds of load, including its own weight with vertical load: pedestrian and vehicle load. Beyond these, it must endure lateral loads such as seismic activity, wind pressure, and other forces like hydrodynamic effects and temperature fluctuation (Gaur & Pal, 2019). So, this structure must be strong enough to sustain and adapt to the ever-changing demands imposed upon it. The structure is constructed to provide a passage through the obstacles without blocking the way beneath it (Hemalatha et al., 2021). The physical obstacles can be road, railway, river, valleys, and canals, aqueducts (Ajay et al., 2017). This structure facilitates the movement of traffic in the most effective way over obstacles, connecting the routes across the country, and helps to mobilize the resources resulting in economic growth of the country by providing a way to the development of infrastructures (San, 2022). Various types of bridge are constructed depending on the requirement of the site in addition to fulfill the need and motive of construction taking account of economic aspect (San, 2022), (Bhandari et al., 2024). The development of infrastructure demands cost effectiveness and structural effectiveness in developing countries like Nepal (Bhandari et al., 2024). RCC T-girder bridges (reinforced concrete), due to their versatility and adaptability to medium spans (10 m to 25 m) are most commonly adopted and serve as a fundamental component of modern transportation networks (Shreedhar & Mamadapur, 2012). The T shape is due to the monolithic cast of the deck with girder. Due to flexibility of RCC -T girder, such bridge is generally constructed in Nepal. Past data have shown the significance of RCC -T girder bridges in Nepal (Suwal & Jamarkattel, 2023). Therefore, parametric study is essential. Parametric study imparts the importance of various parameters such as material, geometrical and load to obtain safe, reliable, and optimized output. Parametric study provides a foundation in the design and optimization of bridge structure by analyzing systematically how variations in design parameter changes the structural response and performance (Huang et al., 2008). Similarly, (Gaur & Pal, 2019) performed a parametric study on RC deck slab-bridge with varying thickness by varying the span length with the objective of obtaining the variation of stress in slab, variation of bending moment and shear force in girder and concluded that stress increases with span length and thickness. So, parametric study helps engineers to design bridge that results optimization, design flexibility, safety, reliability and durability. These factors contribute to provide cost effective solution with effective structural performance. Hence, a comprehensive understanding of various parameters of bridge plays a pivotal role in ensuring the sustainability of the structure (Mansour et al., 2024), (PM & Sekhar, 2015).

Parametric study preceded by adopting the analysis process. The analysis provides a way to optimize the bridge based on different parameters and imparts the knowledge on how different component of bridge acts to generate the response in terms of stress and deformation. The responses are generated based on load consideration, load combination, design strategy, method of construction of bridge for the ultimate strength and serviceability of the structure (Shaikh & Nallasivam, 2023), (Bruno et al., 2009). The analysis of structures is generally followed by the motive of the project, mainly includes static and dynamic analysis. Static analysis addresses the permanent load such as dead load and vehicular load which is time independent load while dynamic analysis is time dependent load such as seismic activity, wind pressure, moving load which requires position, magnitude and direction of mass with respect to time (Nunia & Rahman, 2020), (Jia, 2024), (Gupta & Verma, 2019). Most of the research are based on dynamic analysis using seismic activity and wind forces. This research is mainly focused on static and dynamic analysis taking account of moving load focusing on bridge vehicle interaction. (Jia, 2024) also performed a static analysis and optimization using mathematical and genetic algorithm, using different load condition on a simply supported bridge to minimize the weight of structure while meeting strength and deformation criteria which shows the improvement in material utilization rate by more than 15 percentage with increase in stiffness and strength. Similarly, (Jain & Singh, 2020) investigated the dynamic analysis on RC bridges under seismic excitation using response spectrum and found that I girder model is the optimized model. Likewise, other researcher also performed a study on dynamic analysis to find out the behavior and response of structure (Iordan, Mihaela, and Marian 2024) performed dynamic analysis on railway bridges subjected to high-speed traffic to determine the dynamic behavior and the results have shown that the resonance increases with increase in speed and dynamic amplification factor of displacement seems maximum at mid span than of forces. (Arunrao & Hamane, 2022) performed a dynamic analysis to determine the cost effective and efficient girder system between PSC T and box girder for different span length. (Nguyen et al., 2019) also state the behavior of short skew bridge under high moving load through dynamic analysis and determined the ratio of response of dynamic analysis to static analysis which is called as Dynamic Amplification Factor (DAF), the result have shown that DAF decreases with rise in span length but increases with speed. (Manasa et al., 2022) investigated dynamic analysis of existing RC bridge taking account of earthquake forces. Seismic analysis is conducted to find out the time period, base shear, displacements.

Additionally, (Ulape & Shiyekar, 2023) presented a dynamic amplification factor for Highway Bridge under moving load for different loading. The result has shown that DAF is varied for different loading condition, it increases with increase in speed. This analysis contributes to effective and optimized model. Hence, several research were also performed to analyze the cost-effective model. Similarly, (Kale et al., 2014) presented cost optimization of RCC-T girder bridge using Matlab Software with Sequential Unconstrained Minimization Technique, to obtain low cost and results have shown that cost of girder decreases with increase in girder depth. Similarly, (Uzairuddin et al., 2021) performed optimization of RCC T girder, bridge using Matlab based on cost of concrete and steel and the findings have demonstrated that cost depends upon the grade of material used, section properties of superstructure and also on span length. The analysis of such structure is performed using FEM. These tools generate the bridge model precise to the real-world problem in a more effective, constructive and innovative cost saving design (Jia, 2024), (Gupta & Verma, 2019). FEM modeling and analysis simulate the real-world scenario cases and provide more optimized solution in accordance with the design code. The use of FEM increases significantly as it allows engineers to build model and analyze complex structures more accurately, simulating stress, deformation and dynamic behavior under various loads to a more optimized, effective and accurate, economical assessments and designs (Cakebread, 2010).

1.1 Need of the Study

RCC-T girder bridges are generally constructed in Nepal due to the suitability of the terrain condition and also provide a cost- effective solution as Nepal is a developing country. Therefore, the popularity of the RCC-T girder bridge has risen (Bhandari et al., 2024). The research is mainly focused on rural areas where traffic volume appears to be less compared to urban areas favored by the construction of intermediate-lane-type bridges. The study has been carried out to incorporate improved structural performance of RCC-T girder bridges in those areas by varying the number of girders and span length while addressing the economic constraints, design flexibility and safety enhancement. Based on numerous literature review reveals a dearth of research on RCC-T girder bridges that examines the effect of various parameters like number of girders and evaluates their impact on bridge responses, including stress and displacement. Additionally, economic implication of superstructure of bridge remains underexplored. So, this study was aimed to be carried out by performing static and dynamic analysis of a superstructure components of RCC-T girder, bridge using moving load considering various parameters (span length and number of girder) to determine the behavior of two and three girder configuration and also economic feasibility. Hence, a comprehensive understanding of these factors is essential for evaluating the bridge's dynamic performance and assessing how changes in these parameters affect its response. The motive of this study is mentioned below:

- To find out the trend chart of bridge's response in terms of deflection and stress by varying span length and number of girders.
- To determine the impact of dynamic load on bridge at constant and varying speed.
- To calculate how number of girders will affect economy under similar bridge response while varying span length.

2. Materials and Methods

2.1Methodology

Various steps were followed to achieve the expected results, first the study of literature review was done, selection of bridge, parametric study then FEM was followed to perform analysis and the results were determined.

2.2 Data and Materials

The required data for both three and two-girder configuration has been collected from respective government bodies to carry out the research. The sectional properties and material properties are based on the design approved by authority. In order to carry out the comparison, the sectional properties and material properties of superstructure of bridge kept constant while depth and spacing between the girders were varied. FEM was used to perform design and analysis. To analyze the cost, the volume of concrete required and the weight of reinforcement were calculated for different configuration of bridge. M25 grade concrete and Fe415 grade steel used as material properties for both configuration of bridge.

2.3 Bridge Description

The analysis was carried out for the number of spans. To have a real-world perspective, the study was made as real as possible following the real bridge design method. The data and information related to the bridge were collected from department of Roads, Ministry of Federal Affairs and General Administration Department of Local Infrastructure (DoLI) Local Roads Bridge Programme (LRBP). To conduct the study, Khajura bridge was selected as this bridge is intermediate lane type situated in Sonbarsa-Pratapur-Athailahi road, Nawalparasi West. The bridge is RCC-T girder with four simple supports at the pier caps with 20 m span.

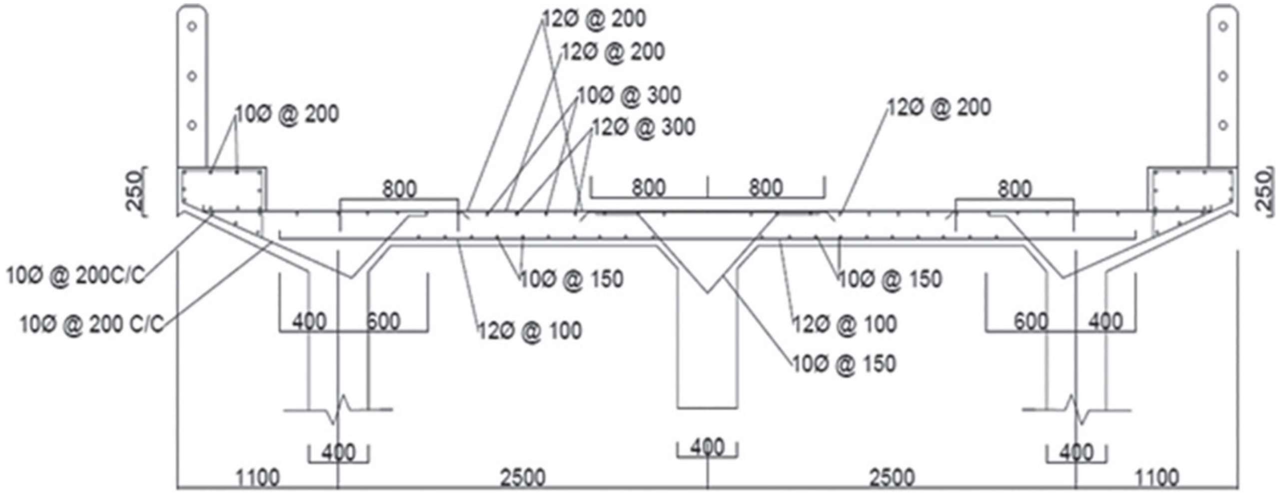


Figure 1: Cross-Section of Superstructure

Table 1: Geometry of bridge

Parameter	Value
Type of bridge	RCC-T girder
Total length of bridge	82.55 m
Effective span	20 m
Number of spans	4
Type of lane	Intermediate lane
Foothpath width	0.45 m
Kerb width	0.15 m
Width of carriageway	6 m
Total width of deck slab	7.2 m
Number of longitudinal girders	3
Spacing of longitudinal girder	2.5 m
Overall depth of longitudinal girder	1.7 m
Number of cross girders	5
Spacing of cross girder	5 m
Depth of cross girder	1.4 m
Thickness of deck slab	0.22 m
Fillet size (horizontal and vertical)	0.15 m×0.15 m
Elastomeric bearing size	0.4 m×0.25 m×0.06 m
Number of piers	3
Width of pier cap	1.7 m
Depth of pier cap	1.6 m
Height of pier wall	4.4 m
Diameter of pier column	1.7 m
Longitudinal reinforcement on pier	49nos of 25 mm dia@100 mm
Transverse reinforcement on pier	12 mm dia@120mm c/c

2.4 Parametric Study

The Parametric study was performed to obtain the response of structure subjected to variance in configuration of bridge by altering the number of girders for all span length. The study was conducted focusing on the superstructure of bridge for three and two-girders configuration for a 15 m, 17.5 m, 20 m, 22.5 m and 25 m single span bridge. The geometrical parameters such as depth of slab, width of longitudinal girder, width of cross girder, number of cross girders, material properties: grade of concrete, grade of steel, and vehicular load kept constant for both girders type but the only variable was depth of longitudinal girder and spacing between girders. The principle of this analysis is to have the same deflection for both configurations and on the basis of that benchmark, variance in response of bridge was analyzed to optimize the section also taking account of cost. Depth of girder for both configuration and for all spans has been finalized by a solving numerical calculation based on same deflection criteria by performing hit and trial method using FEM software CSiBridge on the basis of IRC code which is shown in Table 4. The cantilever portion of slab was designed using effective width method, the design of restrained slab was done by following Piegaud's method. Then, the design was checked using FEM software CsiBridge following limit state method. Using static loadcase (DL+IRC Class A) the deflection of both girder configuration was made equal. Then the design of bridge was finalized using CSiBridge software and the response of bridge was obtained in terms of stress. The research was carried out by comparing three and two type of girder configuration. The parameters for three-girder and two-girder configuration is shown below in Table 2 and 3.

The deck slab was designed for two-girder configuration on MS Excel by performing numerical calculation and later used in FEM to validate the model. The sectional properties of two-girder configuration are the same as of three-girder while maintaining the variations in span length of cantilever slab and spacing between main longitudinal girders.

The Principle of this study is based on same deflection principle for both girder system,

$\Delta 2 = \Delta 3$,

$(\frac{5w_2 l^4}{384EI_2})$2 girder $=$ $(\frac{5w_3 l^4}{384EI_3})$ 3 girder, all other parameters were same except the depth of girder

For 2 girder, load per girder is distributed by w/2 whereas for 3 girder, load is distributed by w/3,

The moment of inertia I is given by,

$$I_f = \frac{b_f t_f^3}{12} + A_f(y_f - \overline{y})^2$$

$$I_W = \frac{t_w h_w^3}{12} + A_w(\overline{y} - y_f)^2$$

Total moment of inertia $(I_{XX}) = I_f + I_{w,}$

By following the above approach, the depth was determined by performing hit and trial method based on IRC code IS456-2000.

For cantilever slab, effective width was calculated as per IRC 21-2000

$b_{eff} = 1.2a + b_{1,}$

Where,

b_{eff} = the effective width

a = Distance of centre of gravity of concentrated load from the face of cantilever support

b_1 = Breadth of concentrated area of load

For restrained slab spanning in two direction, Pigeaud's method was used,

$$u = \sqrt{((x + 2D)^2 + H^2)}$$

$$v = \sqrt{((y + 2D)^2 + H^2)}$$

Where,

L = Long span length

B = Short span length

u, v = Dimensions of the load spread after allowing for dispersion through the deck slab

x = Wheel dimension measured parallel to span (L or B)

D = thickness of the wearing surface

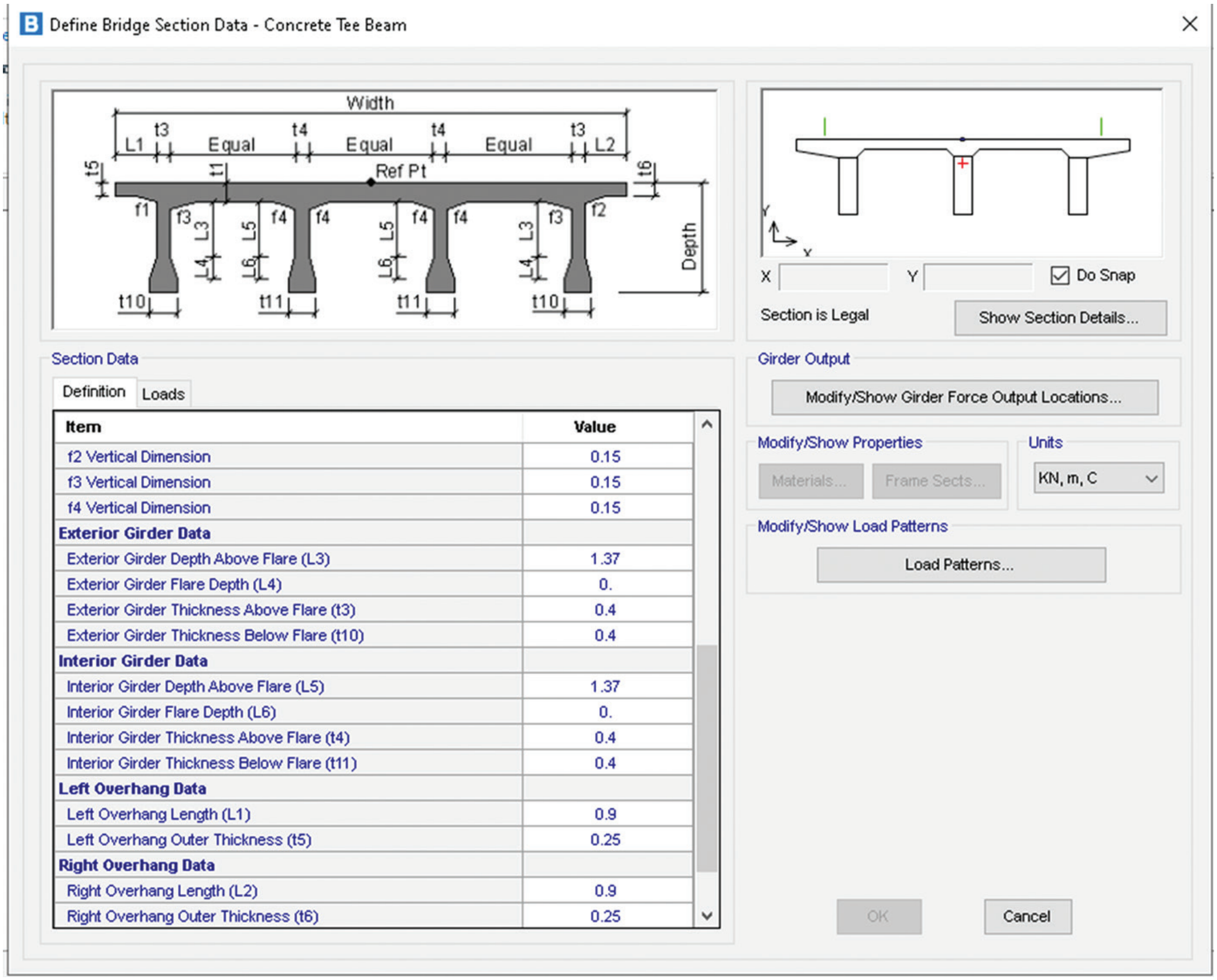
H = Depth of the slab

The bending moments are computed as,

$M_1 = (m_1 + \mu m_2)W$

$M_2 = (m_2 + \mu m_1)W$

Where, W= Load from the wheel under consideration



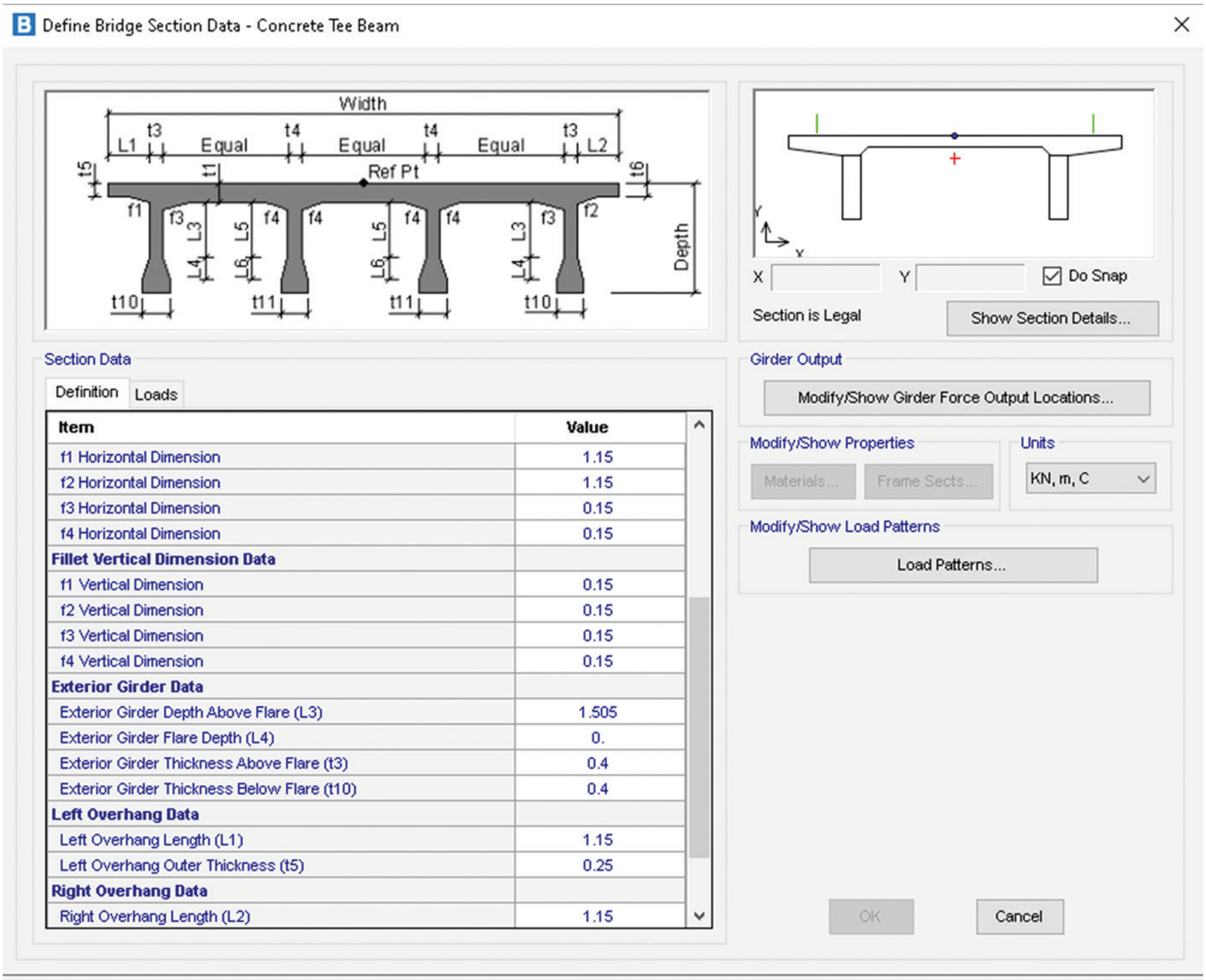
X Y ☑ Do Snap

Section is Legal

Units: KN, m, C

Item	Value
f2 Vertical Dimension	0.15
f3 Vertical Dimension	0.15
f4 Vertical Dimension	0.15
Exterior Girder Data	
Exterior Girder Depth Above Flare (L3)	1.37
Exterior Girder Flare Depth (L4)	0.
Exterior Girder Thickness Above Flare (t3)	0.4
Exterior Girder Thickness Below Flare (t10)	0.4
Interior Girder Data	
Interior Girder Depth Above Flare (L5)	1.37
Interior Girder Flare Depth (L6)	0.
Interior Girder Thickness Above Flare (t4)	0.4
Interior Girder Thickness Below Flare (t11)	0.4
Left Overhang Data	
Left Overhang Length (L1)	0.9
Left Overhang Outer Thickness (t5)	0.25
Right Overhang Data	
Right Overhang Length (L2)	0.9
Right Overhang Outer Thickness (t6)	0.25

Figure 2: Components of RCC-T Girder Bridge for Three-Girder Configuration



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Section is Legal

Units: KN, m, C

Item	Value
f1 Horizontal Dimension	1.15
f2 Horizontal Dimension	1.15
f3 Horizontal Dimension	0.15
f4 Horizontal Dimension	0.15
Fillet Vertical Dimension Data	
f1 Vertical Dimension	0.15
f2 Vertical Dimension	0.15
f3 Vertical Dimension	0.15
f4 Vertical Dimension	0.15
Exterior Girder Data	
Exterior Girder Depth Above Flare (L3)	1.505
Exterior Girder Flare Depth (L4)	0.
Exterior Girder Thickness Above Flare (t3)	0.4
Exterior Girder Thickness Below Flare (t10)	0.4
Left Overhang Data	
Left Overhang Length (L1)	1.15
Left Overhang Outer Thickness (t5)	0.25
Right Overhang Data	
Right Overhang Length (L2)	1.15

Figure 3: Components of RCC-T Girder Bridge for Two-Girder Configuration

Table 2: Geometrical Parameters of Superstructure of Bridge for Three Girders Configuration

Parameter	Value
Total width of bridge	7.2 m
Width of carriageway	6 m
Thickness of deck slab	220 mm
Spans	4
Fillet size	0.15 m*0.15 m
Spacing between girders	2.5 m
Number of girders	3
Width of longitudinal girder	450 mm
Elastomeric bearing size	0.4 m×0.25 m×0.06 m

Table 3: Geometrical Parameters for Two Girders Configuration

Parameter	Value
Thickness of deck slab	0.22 m
Cantilever span	1.35 m
Spacing between girders	4.5 m

Table 4: The calculated depth of both girder system for all span length

Depth Span (m)	Three-girder	Two-girder
15	1.22 m	1.34 m
17.5	1.4 m	1.525 m
20	1.59 m	1.725 m
22.5	1.85 m	1.98 m
25	1.92 m	2.07 m

2.4.1 Loadcase

Both girders' configurations were designed based on the limit state method following IRC code. Such as IRC: 06-2017 is given for load (dead and live load) and load combination, IRC 112-2020 for concrete road bridges, IRC: 83-2018 part 2 for elastomeric bearings also IS 456:2000. The dead load is due to permanent elements that are used to construct the bridge labeled as self-weight. The superimposed load is due to the gravity load of the bridge's non-structural component which stays for long term but may vary during the lifespan of bridge (Ajay et al., 2017). IRC Class A vehicular load is used as a live load. The load cases are defined as per the requirement of analysis. The analysis is categorized as linear and nonlinear, here we performed linear analysis. For the static analysis, the dead load, superimposed dead load were defined as linear static and live load as linear multi-static load. Similarly, for dynamic analysis, the analysis was performed incorporating the direct integration method.

2.5 Finite Element Modeling

FEM software CSiBridge V24.2.0 was adopted for modeling the bridge. CSiBridge is a specialized design and analysis software engineering of a bridge system. This FEM software provides an advanced object-based modeling environment is combined with tailored controls and features to create a user- friendly, effective, efficient and practical computational tool for bridge engineering. This software combines automated designs with analytical processes to optimize bridge component resizing including rebar size adjustment. The modeling of a bridge was conducted by construction of a layout line where the span of a bridge was mentioned then material, M25 grade concrete and Fe415 grade steel was assigned to it. Using component tab, the deck slab with longitudinal girder was model as a 4 noded shell element which shows monolithically cast. The cross girder was modeled as a solid object. The rigid link was used to connect deck slab, longitudinal girder and cross girders. Elastomeric bearing was modeled as a linear link element in vertical, transverse, and rotational direction to connect superstructure and substructure. The pier cap was modeled as a beam element using non-prismatic section, whereas pier shaft was modeled as a column element using section designer. The bent was designed using pier cap and pier shaft then fixed foundation spring was created. The loads were assigned using load tab, the dead load such as weight of railing, weight of kerb, weight of wearing course, was assigned as a line and area load. For live load IRC Class A vehicle load was adopted, the live load was updated using modified bridge live load in load pattern tab where speed of vehicle, lane path and duration of loading can be updated. The bridge was designed as a simply supported beam. For the analysis, the modeling of the bridge was updated to an area object model because the elements were only defined earlier, and to have a detailed representative, accurate result of bridge. The discretization of element was shown below in Figure 6.

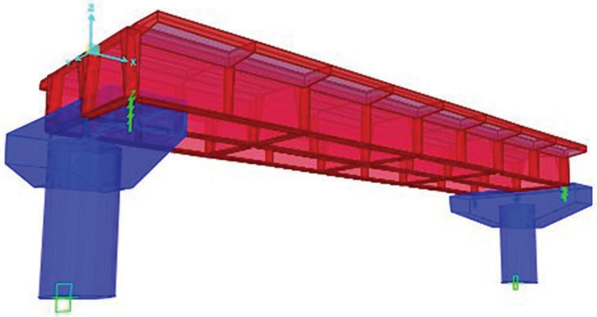


Figure 4: Modeling of Three-Girder Bridge

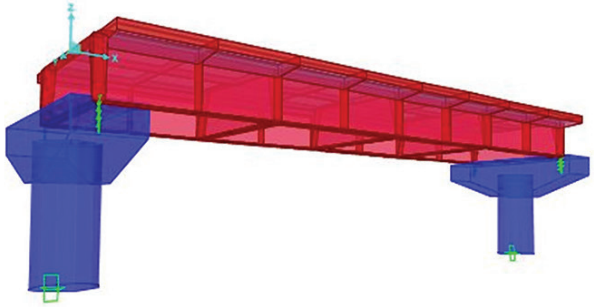
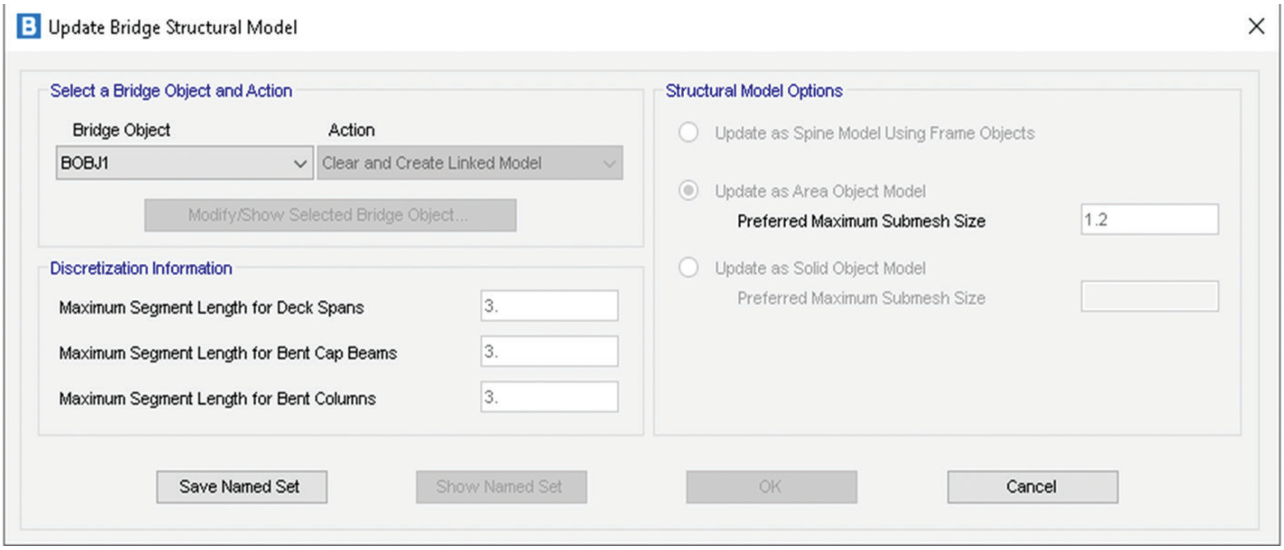


Figure 5: Modeling of Two-Girder Bridge



Bridge Object: BOBJ1

Action: Clear and Create Linked Model

Discretization Information

Maximum Segment Length for Deck Spans: 3.

Maximum Segment Length for Bent Cap Beams: 3.

Maximum Segment Length for Bent Columns: 3.

○ Update as Spine Model Using Frame Objects

● Update as Area Object Model

Preferred Maximum Submesh Size: 1.2

○ Update as Solid Object Model

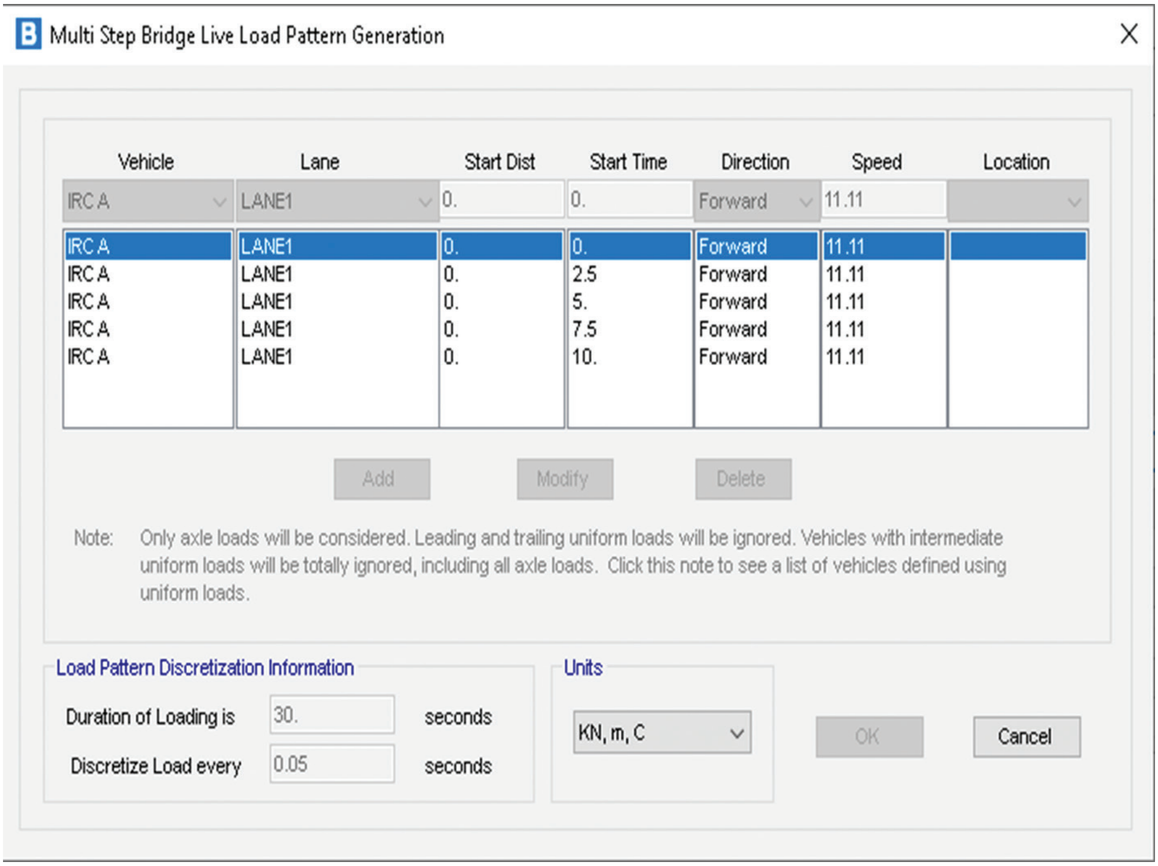
Preferred Maximum Submesh Size:

Figure 6: Discretization of Element

2.6 Analysis

The structure gets deflected more because of its own weight over a period of time. That is why static load case need to consider during analysis. The static analysis was performed under permanent load, which is time-independent. The response of bridge in terms of vertical deflection and stresses was obtained by performing static analysis. The modal analysis was performed before conducting dynamic analysis. The time period and natural frequency of structure obtained without the application of external load which is based on purely inherent structure only. This analysis was performed to calculate the time step to carry out dynamic analysis.

Moving vehicle as per IRC, Class A load was used to perform dynamic analysis. This analysis indicates a time-dependent load which induces responses that fluctuate with the time. Since the nature of the response is dynamic, the criticality of this load should be considered during the analysis of bridge to have an effective and efficient output. In this research, the dynamic analysis was performed using two cases. The first case is by keeping the speed of vehicle constant at 40 Km/hr for a given time period. The interval of time is kept at 2.5 sec starting from zero to ten sec (0 to 10). The second case is varying the speed of vehicle from 40 km/hr to 120 Km/hr at an interval of 20 Km/hr for (0 to 10) sec at an interval of 2.5 sec. The process is mentioned in figure below for both constant and varying speed. The result of above analysis was mentioned in the result section. Also, Dynamic Amplification Factor which is the ratio of maximum dynamic response to maximum static response was determined in order to see the vehicle induced effects on both bridge system. This helps to understand that how much structure gets amplified when subjected to this kind of dynamic load.



Multi Step Bridge Live Load Pattern Generation

Vehicle	Lane	Start Dist	Start Time	Direction	Speed	Location
IRC A	LANE1	0.	0.	Forward	11.11	
IRC A	LANE1	0.	0.	Forward	11.11	
IRC A	LANE1	0.	2.5	Forward	11.11	
IRC A	LANE1	0.	5.	Forward	11.11	
IRC A	LANE1	0.	7.5	Forward	11.11	
IRC A	LANE1	0.	10.	Forward	11.11	

Note: Only axle loads will be considered. Leading and trailing uniform loads will be ignored. Vehicles with intermediate uniform loads will be totally ignored, including all axle loads. Click this note to see a list of vehicles defined using uniform loads.

Load Pattern Discretization Information

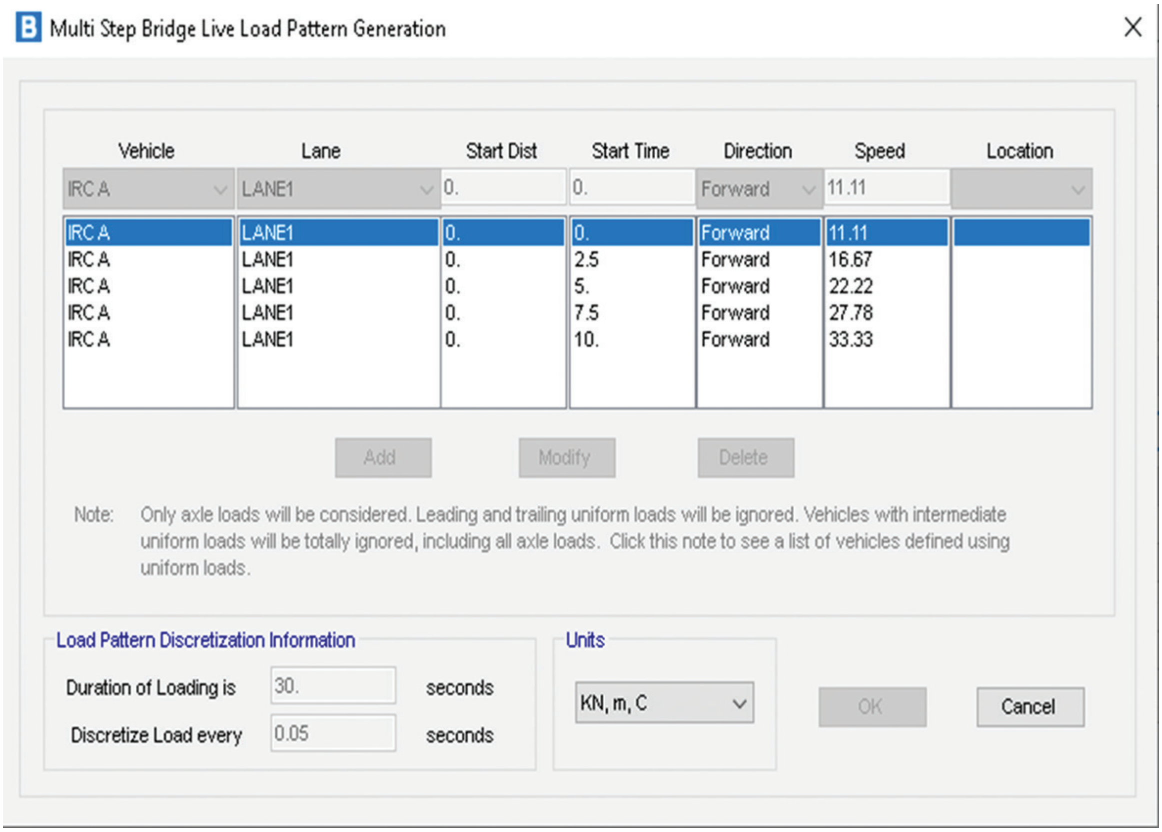
Duration of Loading is 30. seconds

Discretize Load every 0.05 seconds

Units

KN, m, C

Figure 7: Load Discretization Based on Time Interval (Constant Speed)



Multi Step Bridge Live Load Pattern Generation

Vehicle	Lane	Start Dist	Start Time	Direction	Speed	Location
IRC A	LANE1	0.	0.	Forward	11.11	
IRC A	LANE1	0.	2.5	Forward	16.67	
IRC A	LANE1	0.	5.	Forward	22.22	
IRC A	LANE1	0.	7.5	Forward	27.78	
IRC A	LANE1	0.	10.	Forward	33.33	

Note: Only axle loads will be considered. Leading and trailing uniform loads will be ignored. Vehicles with intermediate uniform loads will be totally ignored, including all axle loads. Click this note to see a list of vehicles defined using uniform loads.

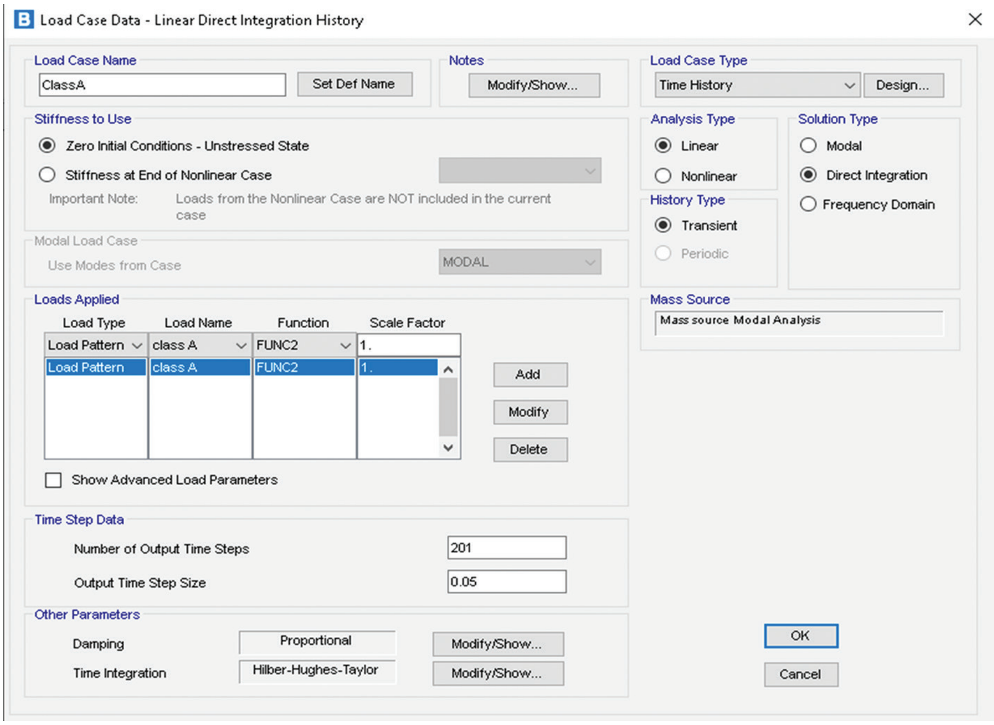
Load Pattern Discretization Information

Duration of Loading is 30. seconds

Discretize Load every 0.05 seconds

Units: KN, m, C

Figure 8: Load Discretization Based on Time Interval (Varying Speed)



Load Case Data - Linear Direct Integration History

Load Case Name: ClassA

Load Case Type: Time History

Stiffness to Use

● Zero Initial Conditions - Unstressed State

○ Stiffness at End of Nonlinear Case

Important Note: Loads from the Nonlinear Case are NOT included in the current case

Modal Load Case

Use Modes from Case: MODAL

Analysis Type: ● Linear ○ Nonlinear

History Type: ● Transient ○ Periodic

Solution Type: ○ Modal ● Direct Integration ○ Frequency Domain

Mass Source: Mass source Modal Analysis

Loads Applied

Load Type	Load Name	Function	Scale Factor
Load Pattern	class A	FUNC2	1.

☐ Show Advanced Load Parameters

Time Step Data

Number of Output Time Steps: 201

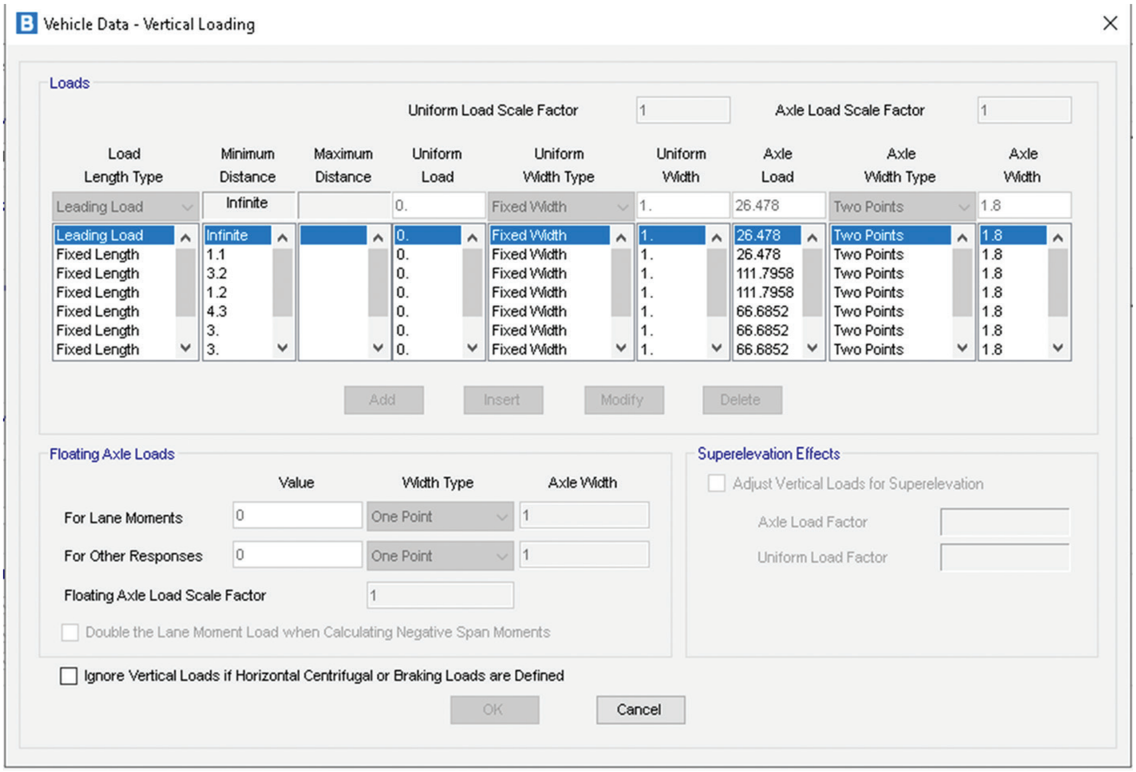
Output Time Step Size: 0.05

Other Parameters

Damping: Proportional

Time Integration: Hilber-Hughes-Taylor

Figure 9: Time History Loadcase



Vehicle Data - Vertical Loading

Loads

Uniform Load Scale Factor: 1

Axle Load Scale Factor: 1

Load Length Type	Minimum Distance	Maximum Distance	Uniform Load	Uniform Width Type	Uniform Width	Axle Load	Axle Width Type	Axle Width
Leading Load	Infinite		0.	Fixed Width	1.	26.478	Two Points	1.8
Leading Load	Infinite		0.	Fixed Width	1.	26.478	Two Points	1.8
Fixed Length	1.1		0.	Fixed Width	1.	26.478	Two Points	1.8
Fixed Length	3.2		0.	Fixed Width	1.	111.7958	Two Points	1.8
Fixed Length	1.2		0.	Fixed Width	1.	111.7958	Two Points	1.8
Fixed Length	4.3		0.	Fixed Width	1.	66.6852	Two Points	1.8
Fixed Length	3.		0.	Fixed Width	1.	66.6852	Two Points	1.8
Fixed Length	3.		0.	Fixed Width	1.	66.6852	Two Points	1.8

Floating Axle Loads

	Value	Width Type	Axle Width
For Lane Moments	0	One Point	1
For Other Responses	0	One Point	1

Floating Axle Load Scale Factor: 1

☐ Double the Lane Moment Load when Calculating Negative Span Moments

Superelevation Effects

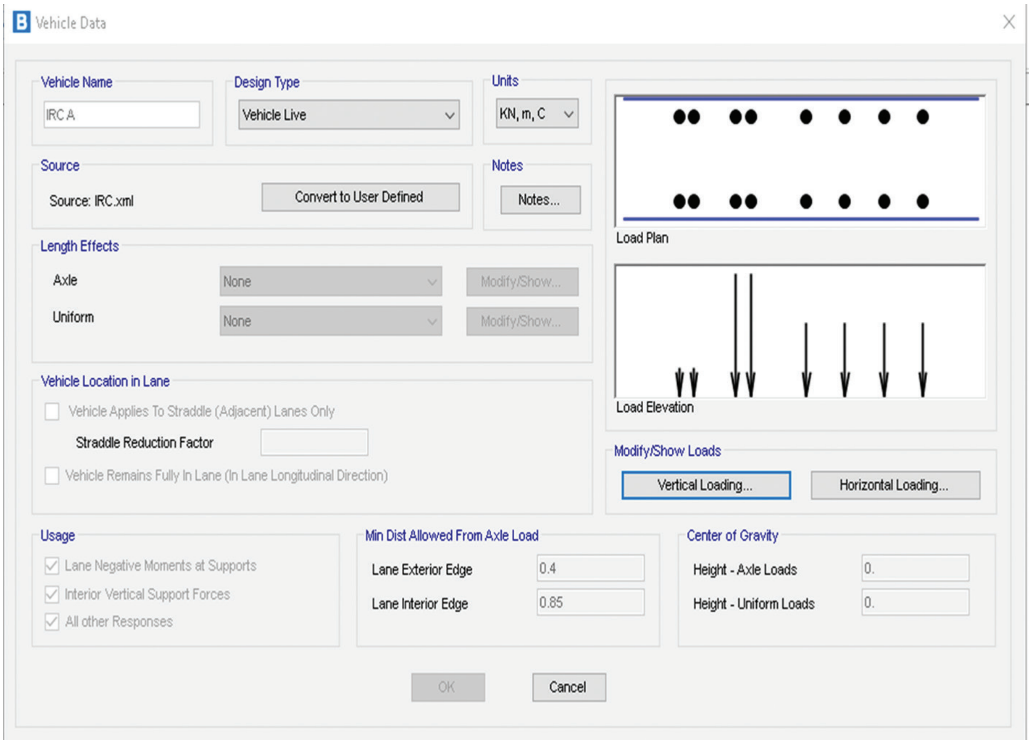
☐ Adjust Vertical Loads for Superelevation

Axle Load Factor

Uniform Load Factor

☐ Ignore Vertical Loads if Horizontal Centrifugal or Braking Loads are Defined

Figure 10: Vehicle Wheel Load



Vehicle Data

Vehicle Name: IRC A

Design Type: Vehicle Live

Units: KN, m, C

Source

Source: IRC.xml

Length Effects

Axle: None

Uniform: None

Vehicle Location in Lane

☐ Vehicle Applies To Straddle (Adjacent) Lanes Only

Straddle Reduction Factor

☐ Vehicle Remains Fully In Lane (In Lane Longitudinal Direction)

Usage

☑ Lane Negative Moments at Supports

☑ Interior Vertical Support Forces

☑ All other Responses

Min Dist Allowed From Axle Load

Lane Exterior Edge: 0.4

Lane Interior Edge: 0.85

Center of Gravity

Height - Axle Loads: 0.

Height - Uniform Loads: 0.

Figure 11: Axle Wheel Load Configuration

The overall performance of both girder system has been identified using python-based algorithm. Libraries like pandas help manage tabular data, making it easy to manipulate datasets and extract relevant information. Using Python's numerical libraries like numpy and scipy, help us to perform essential calculations such load distribution, stress-strain analysis, Deflection and bending moments, cost estimation based on material volume. The MCDA approach was conducted based on weighted sum model where the problem was identified, as the problem of this analysis is comparison of two and three-girder system. Decision making criteria were identified which were cost, static compressive and tensile stress, dynamic amplification factor based on deflection, compressive stress and tensile stress. Then, weights were assigned to each criterion and normalized them from 0 to 1 to ensure fair comparison. Each normalized criteria were multiplied by its weights, then all criteria were summed to calculate score. Result was obtained in forms of plot of graph.

The procedure to use MCDA in this study is given below:

- Define the decision problem: Here, Comparison of two and three girders
- Identify and define Criteria: Cost, Stress(tensile and compressive) dynamic amplification factor based on deflection, stress (tensile and compressive)
- Assign weights to criteria (a weighted sum model): Weights are assigned to each criteria based on priorities of response. Since, this study considers cost as an important governing factor so a 50% weightage was given then remaining 50% was distributed to all other component, 20% was given to compressive stress as compressive stress tends to be more amplified when subjected to transient load than tensile stress and deflection. Then 10% is given to tensile stress and 5% given to DAF based on deflection and stress (tensile and compressive).
- Normalize the criteria: Convert all criteria to a comparable scale which this study has mentioned earlier. $X_{\text{normalize}} = \frac{X - X_{minimum}}{X_{maximum} - X_{minimum}}$, X represent the decision making criteria.
- Weighted scores were computed for both girder system and compared the result by plotting the graph.

3. Results and Discussion

3.1 Results

3.1.1 Static Analysis: The result of static analysis is given below in table format.

Table 5: Static Deflection

Span (m)	Three-girder	Two-girder
15	0.01307 m	0.01308 m
17.5	0.01644 m	0.01647 m
20	0.01976 m	0.01982 m
22.5	0.02128 m	0.02183 m
25	0.02879 m	0.02883 m

The Table 5 stated that deflection is equal up to third digit which is our principle of performing the analysis to compare both girder configuration. The deflection is also within permissible limit as specified by IS 456:2000 code for dead load case which is Span/250.

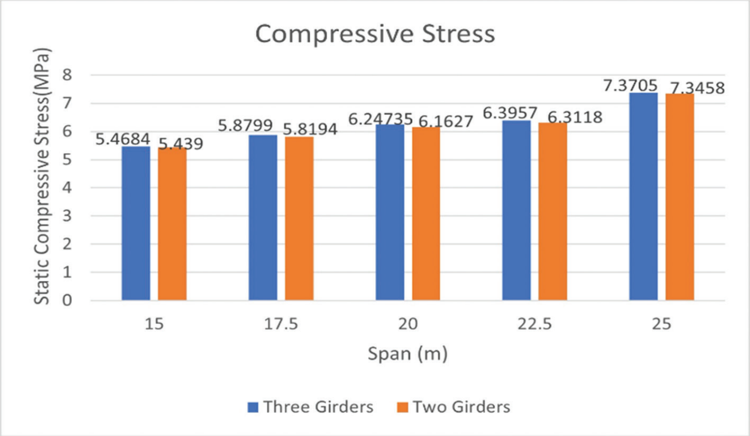


Figure 12: Static Compressive Stress

Based on same deflection condition, the compressive stress in three-girder seems to be higher than two-girder configuration while tensile stress is higher in two-girder configuration.

3.1.2 Dynamic Analysis

The deflection due to dynamic analysis at both same and varying speed is mention below in tabular format.

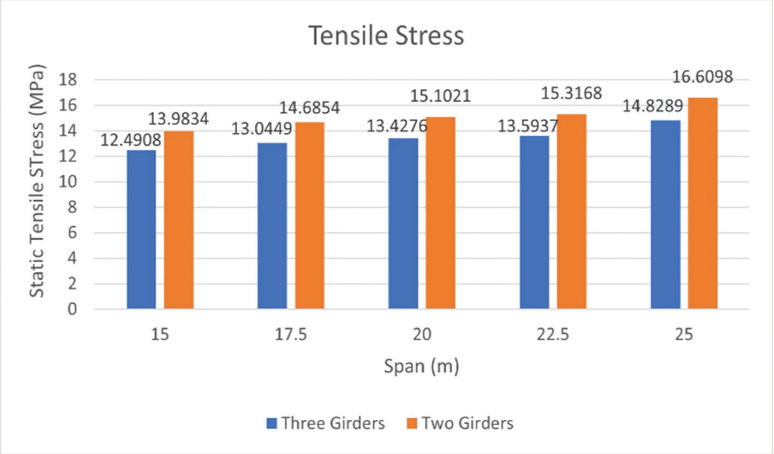


Figure 13: Static Tensile Stress

Table 6: Dynamic Deflection at Constant Speed (40 Km/hr)

Span (m)	Three-girder	Two-girder
15	0.01367 m	0.01368 m
17.5	0.01707 m	0.01712 m
20	0.02034 m	0.02050 m
22.5	0.02187 m	0.02245 m
25	0.02947 m	0.02954 m

Table 7: Dynamic Deflection at Varying Speed (40 km/hr to 120 km/hr)

Span (m)	Dynamic Deflection Three-girder	 Two-girder
15	0.01428 m	0.014334 m
17.5	0.01712 m	0.01716 m
20	0.02043 m	0.02049 m
22.5	0.0219 m	0.0225 m
25	0.02968 m	0.0277 m

The Table 6 and 7 stated that deflection, at both same and varying speed is equal upto third digit even under dynamic analysis and is also within permissible limit as given by IRC 112:2020 which is Span/800 for vehicular.

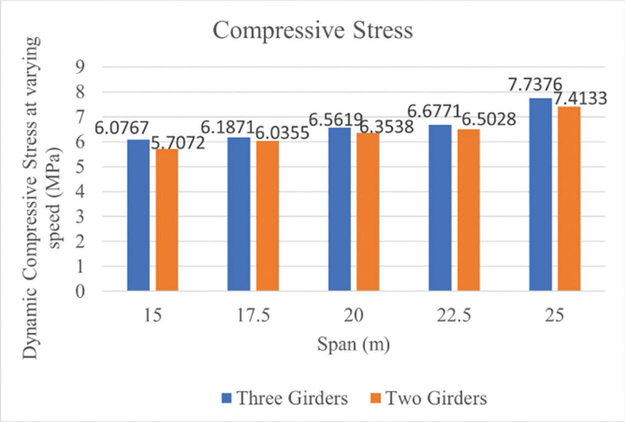


Figure 14: Dynamic Compressive Stress at Constant Speed

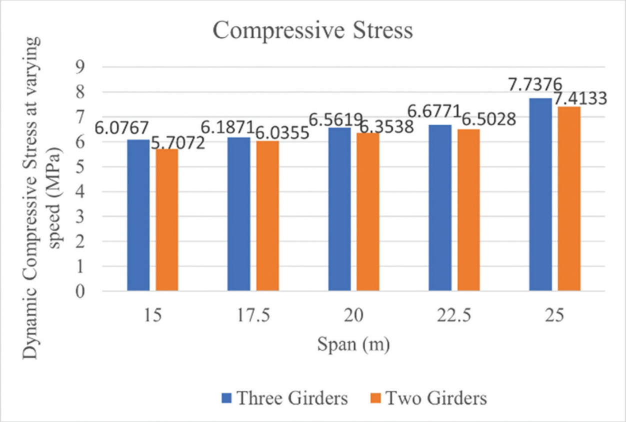


Figure 15: Dynamic Compressive Stress at Varying Speed

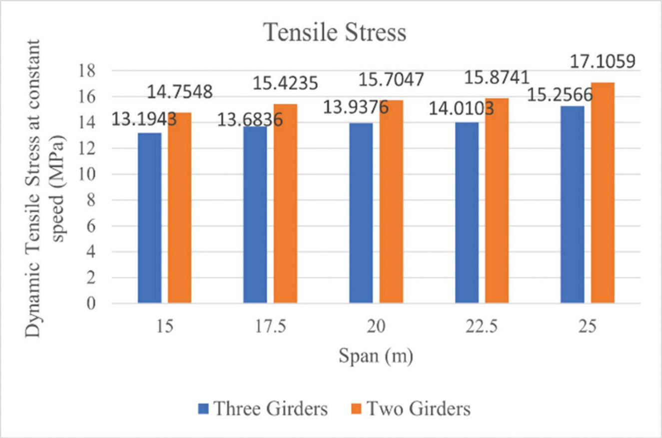


Figure 16: Dynamic Tensile Stress at Constant Speed

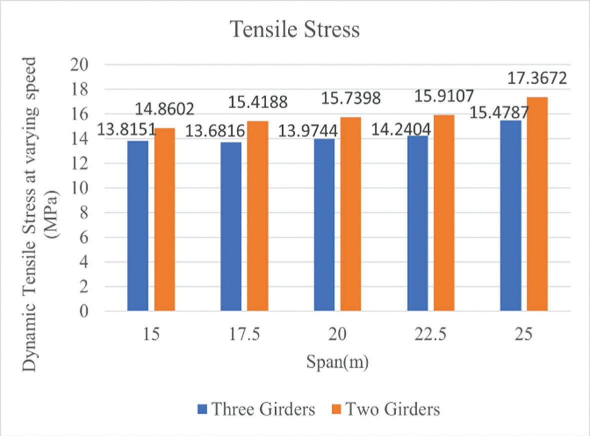


Figure 17: Dynamic Tensile Stress at Varying Speed

The Figure 14, Figure 15, Figure 16, and Figure 17 shows the similar nature as of static analysis which shows that compressive stress at both constant and varying speed seems to be higher in three-girder system whereas the tensile stress seems to be higher in two-girder system under dynamic analysis across all span.

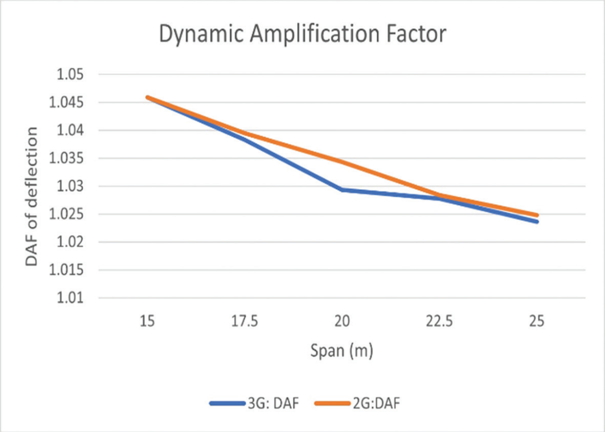


Figure 18: Dynamic Amplification Factor Based on Deflection at Constant Speed

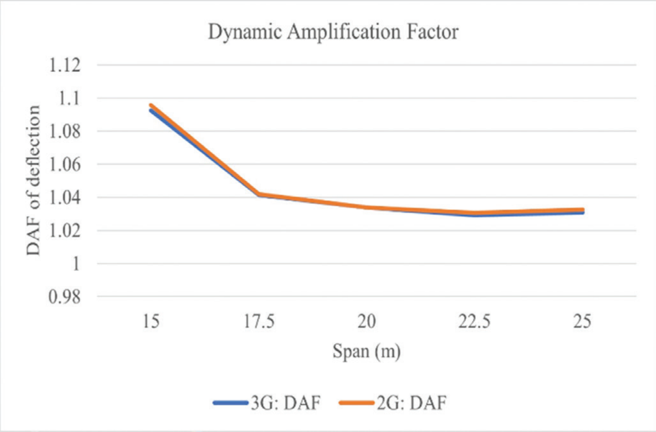


Figure 19: Dynamic Amplification Factor Based on Deflection at Varying Speed

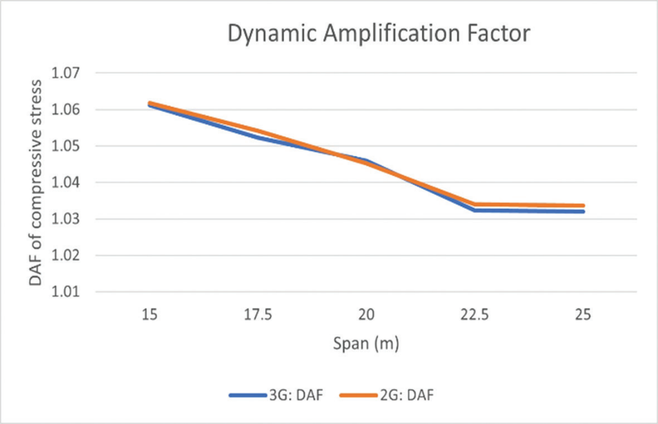


Figure 20: Dynamic Amplification Factor Based on Compressive Stress at Constant Speed

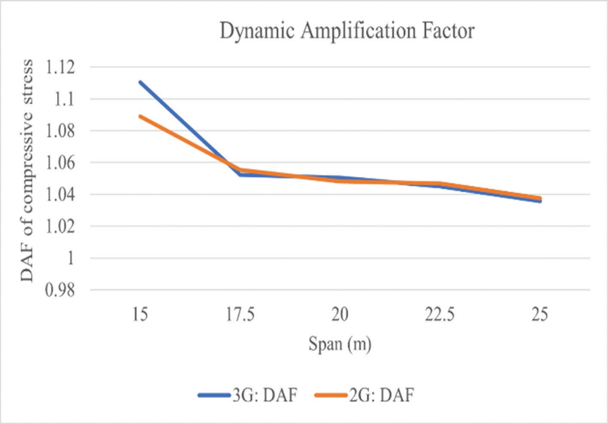


Figure 21: Dynamic Amplification Factor Based on Compressive Stress at Varying Speed

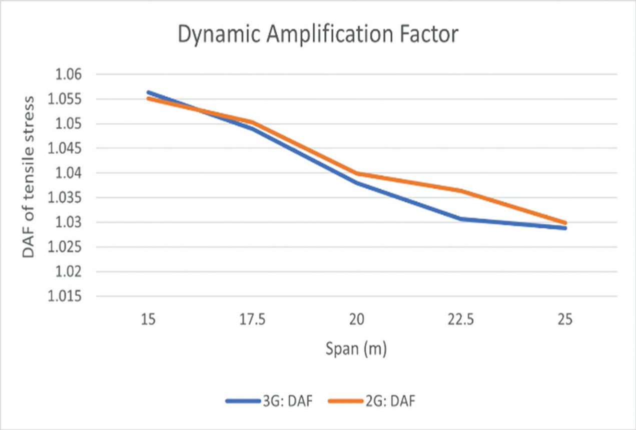


Figure 22: Dynamic Amplification Factor Based on Tensile Stress at Constant Speed

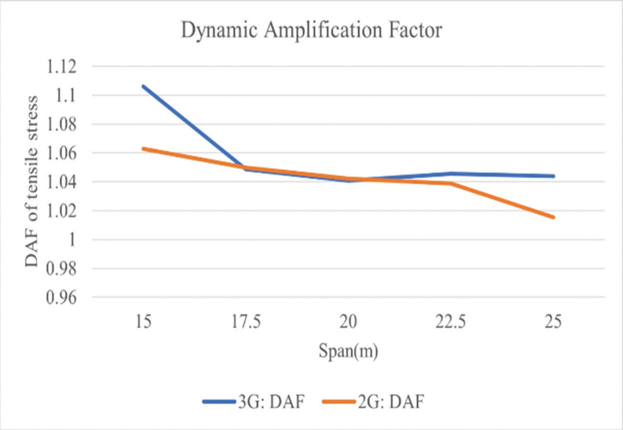


Figure 23: Dynamic Amplification Factor Based on Tensile Stress at Varying Speed

The above Figure 18, 19, 20, 21, 22, and 23 stated that Dynamic Amplification Factor (DAF) for both case constant and varying speed decreases with increase in span. The G means girder in above figure. At shorter length, two-girder exhibit less amplification indicating better performance under dynamic loads whereas at longer span, three-girder seems to be less amplified indicating that it performs better with improved stiffness, resilience under dynamic loads but the result has shown that DAF based on tensile stress even at longer span, two-girder system has low value which may be due to greater number of reinforcements that exhibit better performance under impact load. The result also demonstrated that DAF being higher in short span as compared to longer span, this is because vehicles cross short span bridge more quickly leading to higher impulsive loading and induced greater dynamic effects however on longer span bridge vehicle stays for a longer duration, the transient dynamic effects are spread out reducing peak impact loads and also longer bridge tend to have more structural damping, absorb more of the dynamic effects. From the findings, it is also seen that DAF increases with increase in speed.

3.1.2 Cost and Performance Analysis

Figure 24: Total Cost of Superstructure of Both Girder System

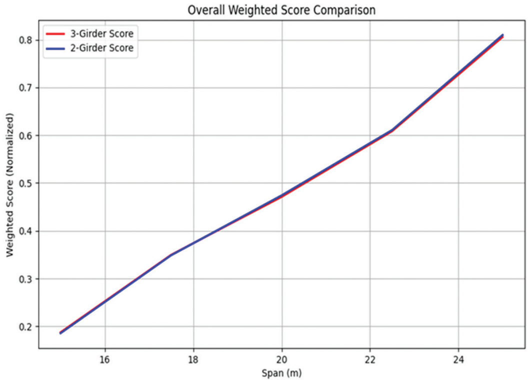


Figure 25: Comparison of Performance of Girder System based on Score

The total cost of deck slab, longitudinal main beam and cross girder was calculated by determining the volume of concrete and reinforcement. The cost of concrete seems to be higher in three-girder system whereas reinforcement cost seems to be higher in two-girder system. Due to extra girder in three girder system that rises cost of concrete for every span. Figure 24 shows that the total cost of three-girder system is higher at all span than two-girder system which is also shown in Table 8 with difference in percentage. Similarly, the overall weighted score was determined by multiplying weightage of each criteria with the normalized value and the result was obtained in terms of graph. The loop function was introduced to check the economic feasibility for both girder system and the result was obtained in terms of graph where it shows the feasibility as per span. The graph has demonstrated that below 20 m, two-girder seems to have better structural performance and above 20m, three-girder seems to be effective one as it has low score in longer span. The low score indicates the suitability of bridge as per span. The output generated in terms of score by python code is mention below:

Table 8: Total Cost of Deck Slab, Main Girder and Cross Girder (Rs)

Span (m)	Three-girder (Rs)	Two-girder(Rs)	Difference in Percentage (%)
15	1051708.77	972069.4124	7.57
17.5	1344297.67	1255664.834	6.59
20	1594250.37	1499868.495	5.92
22.5	1906477.61	1805611.195	5.29
25	2027962.91	1932921.803	4.68

Table 9: Overall Weightage Score

Span (m)	Two-girder	Three-girder
15	0.1858	0.1876
17.5	0.3488	0.3497
20	0,4740	0.4710
22.5	0.6108	0.6085
25	0.8097	0.8055

3.2 Discussions

The static analysis revealed that the compressive stress being higher in three-girder system which is primarily due to the unequal load sharing between the girders that exhibits asymmetrical load path that contribute to higher localized stress. Additionally, there is closer spacing between the girders that induces more stress concentration than wider spacing.

But the tensile stress seems to be higher in two-girder system under same deflection, this is due to deck slab spans between only two girders. So, each girder has to resist a larger portion of bending moment and also due to few load paths that are carried by a girder in two-girder system, tension increases. Whereas in three-girder system there is load distribution among three girders which reduce the demand of high bending moment. Also, the girders are spaced farther apart in two-girder system leading to higher deck bending stress between girders that results in higher tensile stress. This condition also further distinguished by dynamic analysis under constant speed and varying speed. Under both dynamic cases, the compressive stress is higher in three-girder system while tensile stress dominates in two-girder system.

The dynamic analysis provides deeper insights, further highlighting the differences between girder configurations. Due to transient load, the DAF seems to be low at shorter span in two-girder system compared to three-girder system indicating better structural performance. The reason is due to larger and heavier cross-sectional area of individual girder in two-girder system which make them stiffer section that results into higher-frequency structure which vibrates faster, dissipate energy quickly that does not let dynamic load to be accumulated in the structure, while three-girder system have low DAF at longer span suggesting improved stiffness provide efficient and effective structural performance. This is due to presence of extra girder that inherently increase the stiffness of structure. The result also present that the DAF decreases with increase in span and it increases with increase in speed (Iordan et al., 2024).

The output generated by python code shows the low score in between 15 m to 20 m span for two-girder system and when span increase from 20 m to 25 m, it shows the low score for three-girder system underlying that the two-girder system being economical, effective span configuration at shorter span whereas three-girder system becomes a more suitable option, as it provides better structural performance at longer span.

4. Conclusions

The study shows that under both static and dynamic analysis, compressive stress dominates three-girder system while tensile stress dominates in two-girder system. DAF decrease with increase in span making short span more susceptible to transient load which gets more influenced by speed of vehicle. Result confirmed that two-girder system shows better performance at shorter span while three-girder at longer span. Economically, two-girder system are more cost-effective at shorter span while three-girder provide better effectiveness at longer span. Additionally, this is also illustrated by MCDA approach which confirms that two-girder is the more economical choice for short span whereas three-girder seems to be effective at longer span due to better structural performance in terms of deflection and stress.

4.1 Key Conclusion

- The result confirmed that deflection and stress were within permissible limit.
- The findings of dynamic analysis at constant speed shows that lower compressive stress in two girder system than three girder system by 2.19%, 2.56\%, 3.017%, 3.43% and 4.247% while tensile stress is higher in two girder bridge system by 11.82%, 12.72%, 12.97%, 13.3% and 12.12% at 15 m, 17.5 m, 20 m, 22.5 m and 25 m span respectively.
- Similarly, the findings of dynamic analysis at varying speed also shows that same nature but the variation percentage seems higher. The compressive stress of two- girder bridge system is lower by 2.45%, 2.78%, 3.17%, 3.64%, 4.34% than three-girder whereas tensile stress is higher by 11.9%, 12.75%, 12.97%, 13.73% and 12.2% at 15 m, 17.5 m, 20 m, 22.5 m and 25 m span respectively.
- Since, the deflections were made same for both girder system so, dynamic amplification factor at constant and varying speed for both girder system seems to have nearly same value.
- At shorter span, two- girder system is less amplified whereas at longer span, three-girder system seems to be less dynamically amplified, it is seen that DAF based on compressive stress is higher as compared to deflection and tensile stress.
- From the result, it is seen that dynamic amplification factor due to varying speed is more compared to constant speed particularly noticeable at 15 m span. At 15 m span, if we see DAF of deflection in 3 girder it changes from 1.045 to 1.092 and similarly in 2 girder 1.0458 to 1.0958. Similar trend we can see in compressive and tensile stress too.
- From the trend chart, cost of concrete in two-girder seems to be lower by 29.3% to 29.9% across all the span whereas rebar cost increases in two-girder bridge system by 36% to 59% than the three-girder system. But based on total cost in terms of concrete and rebar for superstructure component the variation of cost in two-girder bridge system reduced by 7.6% to 4.68% as compared to three-girder. However, for longer spans, the three-girder system became more economical, narrowing the cost difference to 4.68% due to improved structural efficiency.

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