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Finite Element–Based Structural Analysis and Design Optimization of an Rcc Suspension Bridge Deck using Staad.Pro

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ABSTRACT

Bridges are vital components of transportation infrastructure, ensuring safe and efficient movement of vehicles and pedestrians across obstacles such as rivers, valleys, and roadways. This project presents the comprehensive analysis and design of a Reinforced Cement Concrete (RCC) bridge using STAAD.Pro in accordance with Indian Roads Congress specifications and relevant Indian Standard codes. Both 2D and 3D models of the RCC T-beam bridge were developed to evaluate structural behavior under various loading conditions including dead load, live load, impact load, and wind load as per IRC 6-2000 and IS 456:2000 provisions. Vehicle load classifications such as IRC Class A, Class AA, and 70R were considered to determine critical bending moments and shear forces. The structural components including deck slab, longitudinal girders, cross girders, columns, and substructure elements were analyzed for permissible stresses and deflections. Foundation design was carried out using STAAD Foundation by considering various footing alternatives such as pile foundations and raft foundations based on soil conditions and bearing capacity. The comparison between 2D and 3D analysis results indicates minimal variation, validating the reliability of simplified analytical approaches for standard loading conditions. The study demonstrates that finite element–based software significantly improves accuracy, efficiency, and optimization in bridge design while ensuring structural safety, serviceability, and durability.

KEYWORDS : RCC Bridge, T-Beam Bridge, STAAD.Pro, Finite Element Analysis, IRC 6-2000, IS 456:2000, Vehicle Load Classification, Class AA Loading, Impact Factor, Bridge Substructure, Pile Foundation, Structural Analysis, Bending Moment, Shear Force, Bridge Design Optimization

I.INTRODUCTION

Bridges are essential elements of modern transportation networks, enabling uninterrupted movement of vehicles and pedestrians across natural and artificial obstacles such as rivers, valleys, roads, and railways [1], [2]. With rapid urbanization and increasing traffic demands, the need for structurally efficient, durable, and economical bridge systems has grown significantly. Reinforced Cement Concrete (RCC) bridges are widely adopted due to their strength, durability, low maintenance requirements, and adaptability to various span lengths and loading conditions [3], [4]. In recent years, RCC bridges have gained importance in congested urban areas where land availability is limited, and compact structural solutions are required [10], [11].

The design and analysis of RCC bridges must be carried out carefully by considering all possible loading conditions such as dead load, live load, impact load, wind load, and seismic forces [1], [6], [7]. In India, bridge design is governed by standards issued by the Indian Roads Congress, particularly IRC 6-2000 for loading specifications and IS 456:2000 for reinforced concrete design [1], [3]. These codes ensure that bridges are designed with adequate safety, serviceability, and durability throughout their intended lifespan [2], [4]. Vehicle load classifications such as IRC Class A, Class AA, and 70R play a crucial role in determining critical bending moments and shear forces during analysis [1], [12].

With advancements in computational tools, structural analysis software such as STAAD.Pro has become an indispensable tool for bridge engineers [10], [13]. Finite Element Analysis (FEA) enables accurate modeling of complex bridge geometries and loading conditions, providing detailed information on stress distribution, deflection patterns, and internal force behavior [8], [10]. This project focuses on the analysis and design of an RCC T-beam bridge using both manual calculations and software-based modeling. A comparative evaluation of 2D and 3D models is carried out to validate results and assess the reliability of simplified analysis approaches [10], [13]. The study aims to develop a systematic and efficient methodology for RCC bridge design that ensures structural safety, economy, and long-term performance [4], [9].

II. LITERATURE REVIEW

The analysis and design of Reinforced Cement Concrete (RCC) bridges have been extensively studied by various researchers using both conventional analytical methods and modern finite element techniques. Earlier studies primarily relied on simplified one-dimensional approaches based on codal provisions. However, with the advancement of computational tools, three-dimensional finite element modeling has become a preferred approach for evaluating bridge behavior under complex loading conditions. Researchers have emphasized the importance of comparing manual design procedures with software-based analysis to achieve accurate and economical designs.

Ronghe G.N. and Gatfane Y.M. (2004–2005) carried out analysis and design of an RCC bridge model and demonstrated the feasibility of modeling bridge systems using software tools. Their study indicated that finite element analysis provides better insight into stress distribution and deformation patterns compared to traditional manual methods. Similarly, R. Shreedhar (2012) performed a comparative study between one-dimensional analytical methods and three-dimensional finite element modeling using STAAD.Pro. The results showed that FEM analysis generally produces slightly lower bending moments and shear forces compared to conservative IRC-based calculations, confirming that IRC provisions ensure safe but often conservative designs.

Amit Saxena (2013) conducted a comparative study between T-beam girder and box girder bridges and concluded that T-beam bridges are more economical for moderate spans due to reduced concrete quantity and lower dead load effects. Mahesh Pokhrel (2013) compared bridge design using IRC, AASHTO, and Eurocode provisions and observed significant differences in load factors and safety margins, with Eurocode often resulting in more optimized designs. M.G. Kalyanshetti (2013) investigated load distribution using Courbon's theory and suggested modifications to improve its accuracy for varying spans.

Further studies addressed serviceability and material optimization. Manjeetkumar M. Nagarmunnoli (2014) examined the influence of deck slab thickness on structural performance and reported that reduction in slab thickness significantly affects bending stiffness and increases stresses, which may lead to serviceability problems. Rajamoori Arun Kumar (2014) compared RCC and prestressed concrete (PSC) T-beam bridges and concluded that PSC girders exhibit improved moment resistance and reduced material consumption. Praful N.K. (2015) compared Courbon's method, Guyon-Massonet method, and STAAD.Pro analysis, finding that software results closely match Courbon's method for IRC loading cases.

Recent research also explored advanced topics such as blast loading and dynamic effects. Pallvi Rai (2016) studied the response of T-beam bridges under blast loading using FEM and concluded that conventional RCC bridges may require retrofitting to withstand extreme loading conditions. Sandesh Upadhayay (2016) suggested prestressing techniques to improve load-carrying capacity and serviceability performance of T-beam bridges. Phani Kumar (2016) analyzed prestressed box girder bridges as per IRC:112 and emphasized the need for increased cover and detailing requirements in updated codes.

From the reviewed literature, it is evident that finite element–based software such as STAAD.Pro plays a crucial role in modern bridge design. While traditional IRC-based analytical methods ensure safety through conservative assumptions, three-dimensional modeling provides more realistic stress distribution and enables structural optimization. However, further research is needed in areas such as soil-structure interaction, nonlinear analysis, dynamic loading, and long-term durability assessment to enhance the reliability and efficiency of RCC bridge design.

III.WORKING METHODOLOGY

The methodology adopted for the analysis and design of the RCC T-Beam bridge consists of systematic planning, analytical evaluation, and software-based modeling. Initially, all basic design data were collected, including span length, carriageway width, material properties (grade of concrete and steel), bearing type, safe bearing capacity of soil, seismic zone, and basic wind speed. The bridge geometry was finalized based on functional requirements and IRC specifications. The structural components considered in the study include deck slab, longitudinal girders, cross girders (diaphragms), piers, pier cap, and foundation system. Preliminary sizing of structural members was carried out using codal recommendations to ensure adequate depth, stiffness, and serviceability control before detailed analysis.

The next step involved calculation of loads acting on the bridge. Dead loads were computed from the self-weight of deck slab, girders, diaphragms, wearing coat, crash barriers, and other permanent components using the unit weight of concrete. Live loads were applied as per IRC provisions, including Class A and Class AA tracked/wheeled vehicles. Impact factors were considered according to span length and vehicle type. Additional loads such as wind load, seismic load, and longitudinal braking forces were calculated as per relevant clauses of Indian Roads Congress codes, particularly IRC 6-2000. Load combinations were generated to identify critical bending moments, shear forces, and reactions. Manual calculations were performed for verification of bending moments and shear forces in longitudinal girders and deck slab.

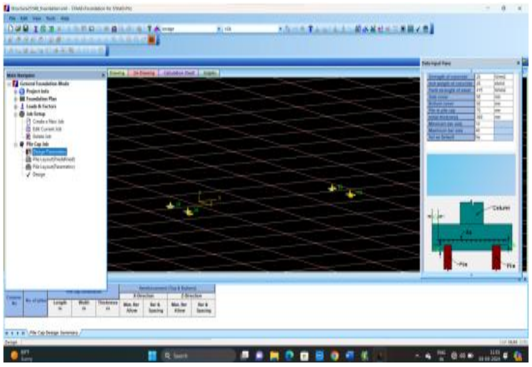

Fig.1 – Pile Arrangement Selection in STAAD Foundation

Fig.1 shows the pile arrangement configuration window in STAAD Foundation. The interface displays predefined pile group layouts (such as 7-pile, 9-pile, etc.) arranged symmetrically under the column. The hexagonal layout with circular pile positions indicates a selected pile cap configuration. This stage represents the foundation planning phase, where the engineer selects a suitable pile group based on axial load, moment demand, and soil bearing capacity. Proper pile arrangement ensures uniform load distribution and structural stability of the substructure.

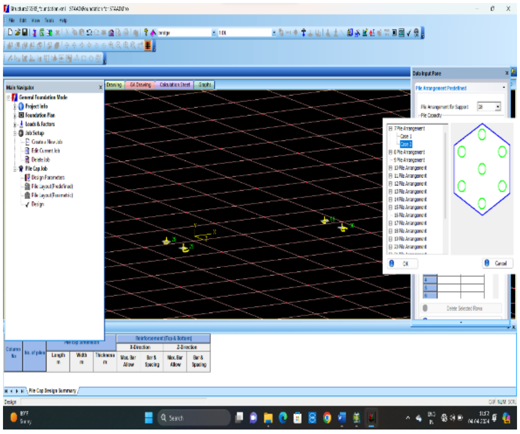

Fig.2 – Foundation Geometry and Reinforcement Layout

Fig.2 presents the detailed drawing view of the pile cap and column arrangement. The plan view shows the hexagonal pile cap with piles placed at defined spacing. The elevation view above illustrates the column, pile cap thickness, and pile embedment depth. The reinforcement details for top and bottom layers are displayed in the summary table. This stage confirms geometric dimensions, reinforcement requirements, and structural detailing of the foundation system.

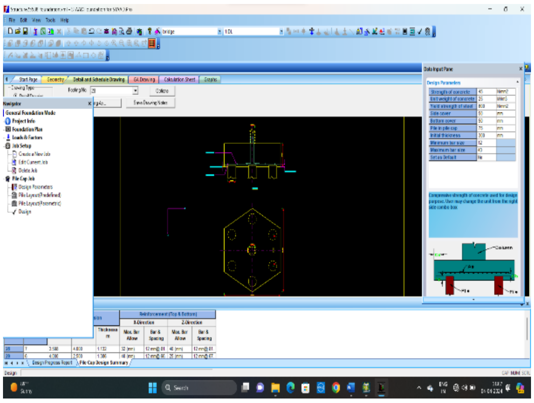

Fig.3 – General Arrangement (GA) Drawing of Substructure

Fig.3 shows the GA drawing layout of multiple bridge supports and pile caps. The drawing includes longitudinal alignment, spacing between piers, and structural layout of foundation elements along the bridge length. This diagram represents the overall structural configuration of the bridge substructure. It ensures proper alignment, spacing consistency, and load transfer from superstructure to foundation.

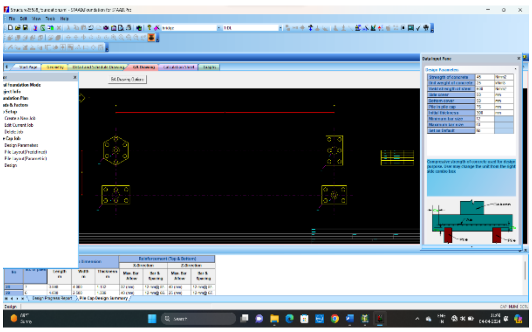

Fig.4 – Data Input Panel and Foundation Design Parameters

Fig.4 displays the data input panel used for foundation design in STAAD Foundation. Parameters such as grade of concrete, grade of steel, safe bearing capacity, pile diameter, pile length, and allowable stresses are defined here. The diagram confirms that all material and soil parameters are entered before running the foundation analysis. This stage is critical as accurate input values directly influence structural safety and optimization results.

IV.CONCLUSION

The present study focused on the detailed analysis and design of an RCC T-Beam bridge using both manual calculations and software-based modeling. The structural components including deck slab, longitudinal girders, cross girders, piers, pier cap, and foundation were analyzed under various loading conditions as per IRC provisions. Dead load, live load (Class A and Class AA), impact load, wind load, and seismic load were considered to ensure realistic loading scenarios. Critical load combinations were generated according to codal guidelines to determine maximum bending moments, shear forces, axial forces, and support reactions.

The structural analysis carried out using STAAD.Pro provided accurate internal force distribution and displacement results. The comparison between manual calculations and software outputs showed close agreement, validating the modeling approach. Reinforcement design was performed in accordance with IS 456:2000 and loading provisions of IRC 6-2000 published by the Indian Roads Congress. The results confirm that the bridge components satisfy strength, serviceability, and stability requirements.

From the analysis, it is observed that the T-Beam bridge system is structurally efficient for medium span bridges. Proper consideration of impact factor and load combinations significantly influences design results. The use of finite element modeling enhances accuracy compared to conventional analytical methods. Substructure and foundation design further ensured adequate load transfer to soil strata without overstress or excessive settlement.

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