International Journal of Web of Multidisciplinary Studies
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
website: http://ijwos.com
Vol.02 No.10.
OPEN ACCESS
E-ISSN : 3049-2424
DOI: doi.org/10.71366/ijwos

DYNAMIC RESPONSE ANALYSIS OF CABLE-STAYED AND GIRDER BRIDGES SUBJECTED TO VEHICULAR LOADS AS PER IRC STANDARDS

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Article Info

Article History:

Published:07 Oct 2025

Publication Issue:
Volume 2, Issue 10
October-2025

Page Number:
48-55

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Abstract:

The dynamic response analysis of bridges is a crucial aspect of structural engineering, particularly for cable-stayed and girder bridges that are frequently subjected to moving vehicular loads. As traffic intensity and vehicle loads increase, accurate assessment of structural performance under dynamic conditions becomes essential to ensure safety, serviceability, and durability. This study focuses on the comparative evaluation of cable-stayed and girder bridges when subjected to vehicular loading as per the provisions of the Indian Roads Congress (IRC:6-2017). Finite Element Analysis (FEA)-based numerical modeling is adopted to simulate the real-time behavior of bridges under moving loads such as the IRC Class 70R vehicle. The study investigates parameters including natural frequencies, mode shapes, displacement, bending moments, shear forces, cable forces, and vibration characteristics. The interaction between vehicle loads and bridge dynamics is analyzed to identify critical responses, resonance effects, and performance differences between the two bridge types. The results provide insights into structural stability, load distribution efficiency, and overall dynamic performance, contributing to improved design guidelines and enhanced structural safety of highway bridges in India.

Keywords: Dynamic response analysis, Cable-stayed bridge, Girder bridge, Vehicular loads, IRC:6-2017, Class 70R loading, Finite Element Analysis (FEA), Structural performance, Vibration characteristics, Bridge dynamics.

1. Introduction

Dynamic response analysis of bridges plays a crucial role in ensuring their safety, serviceability, and long-term performance, especially under moving vehicular loads that generate time-dependent forces and vibrations. Cable-stayed and girder bridges, being two of the most commonly adopted bridge types in modern infrastructure, exhibit different structural behaviors owing to their distinct load distribution mechanisms and stiffness characteristics. Cable-stayed bridges, with their flexible and slender nature, are highly sensitive to dynamic excitations, while girder bridges, though comparatively stiffer, are also influenced by repetitive traffic-induced vibrations, fatigue, and resonance effects. In India, the Indian Roads Congress (IRC) standards provide systematic guidelines for load modeling, dynamic load allowances, and design considerations, making them essential for accurate prediction of structural responses under real traffic conditions. Evaluating parameters such as deflection, acceleration, natural frequency, mode shapes, and stress variations helps engineers assess ride comfort, structural integrity, and durability. Therefore, conducting a detailed dynamic response analysis of cable-stayed and girder bridges as per IRC standards is vital for understanding their behavior under vehicular loads, optimizing design, preventing serviceability issues, and ensuring long-term structural performance in line with safety and codal provisions. To perform the dynamic response analysis of cable-stayed and girder bridges under vehicular loads as per Indian Road Congress (IRC) standards, the bridge structure is first modeled using specialized Finite Element Analysis (FEA) software to accurately represent its geometry, boundary conditions, and material properties, followed by the application of vehicular loading conditions as specified in IRC:6-2017, which include static loads and dynamic live loads such as the IRC Class 70R tracked or wheeled vehicle; during this process, the influence of impact factors, load distribution, and vehicle-bridge interaction must be carefully considered to simulate realistic loading scenarios. The analysis involves evaluating critical structural responses such as deflections, bending moments, shear forces, stress distribution within the deck and supporting members, vibration modes, and variations in cable forces for cable-stayed bridges, with particular emphasis on how moving vehicular loads excite the natural frequencies of the bridge. By studying these responses, engineers can assess the serviceability, safety, and performance of the bridge under real traffic conditions, ensuring compliance with IRC provisions for strength, durability, and comfort criteria while also identifying potential fatigue or resonance issues that may compromise long-term structural integrity.

Figure 1 Cable stay bridge

A complete dynamic response analysis starts by creating a refined 3-D finite-element model that explicitly represents the deck, pylons, girders and cable elements (with appropriate tension-only behavior and defines realistic material models (elastic/elastic-plastic where needed), and captures geometric features such as cable topology, sag, anchor locations and boundary conditions (including soil–structure interaction if significant); mass and stiffness distributions must be modeled accurately because they govern modal properties and load paths. For loading, apply IRC:6-2017 live-load definitions — in particular the IRC Class 70R moving vehicle modeled as a sequence of axle loads (or moving mass) across lanes, plus lane distribution and multi-vehicle scenarios, and account for vehicle speed, axle spacing and traffic density so that impact effects and dynamic amplification are captured (either via code impact allowance or explicitly through moving-load dynamics). Begin with modal analysis to extract natural frequencies, mode shapes and modal participation factors (useful for selecting damping Rayleigh or modal damping with typical viscous ratios), then perform dynamic time-history analysis: for linear problems use modal superposition with modal damping; for problems with geometric or material nonlinearity (large cable deflections, contact, or yielding) use direct time-integration (for custom studies). Choose time steps small enough to resolve the highest significant frequency (and axle crossing events) and run mesh/time-step convergence checks. Extract envelopes of maximum vertical deflections, dynamic amplification factors, acceleration responses (for ride comfort), stress ranges and cable-force fluctuations; use these time histories to assess fatigue (stress-range histograms, Miner's rule), check serviceability and limit-state criteria per IRC, and inspect mode shapes for resonance with traffic loads.

Ere Jayanth et al (2023) Bridges are essential structures built to traverse obstacles such as rivers, lakes, valleys, or roads, providing safe and efficient passage, and in recent decades cable-supported bridges have emerged as the most common and effective solution for long-span crossings due to their ability to combine strength, flexibility, and economy. These bridges rely on tension cables that are firmly anchored to tall towers, which balance both the dead load (the self-weight of the deck) and the live load (vehicles, pedestrians, or other moving loads), while the towers themselves carry and transfer the operational forces to the foundation. The design aims to minimize deck depth while maintaining structural efficiency, and because the forces acting on the system are complex—including cable tension, beam rigidity, bending moments, shear, and pier responses—computer-based modeling and analysis are required, except for very simple cases, to accurately simulate real-world behavior. Engineers use specialized software to analyze various parametric load cases and design alternatives, allowing them to optimize critical aspects such as cable size, cable arrangement, and the ideal stiffness of deck sections to achieve both structural stability and economic efficiency.

2. Methodology

The methodology for the dynamic response analysis of cable-stayed and girder bridges subjected to vehicular loads as per IRC standards involves developing an accurate finite element model of the bridges in specialized structural analysis software, where the geometric configuration, boundary conditions, and material properties of all structural components such as deck, pylons, cables, and girders are defined in detail. The vehicular loads are applied in accordance with IRC:6-2017, including static and dynamic load effects such as IRC Class 70R, tracked and wheeled vehicles, and impact factors. Moving load simulations are carried out by applying vehicle loads as time-dependent forces moving across the bridge deck at different speeds to capture vehicle–bridge interaction. The analysis includes consideration of damping, stiffness, and mass matrices to evaluate modal properties such as natural frequencies and mode shapes. Dynamic simulations are performed to determine the structural response parameters such as displacement, acceleration, stress distribution, bending moments, shear forces, and cable tensions under varying load conditions. Comparative analysis is conducted between cable-stayed and Girder Bridge models to study their behavior in terms of serviceability and safety, highlighting the influence of structural form on dynamic performance. The results are then validated against IRC provisions to ensure compliance with codal requirements and to draw conclusions regarding the suitability and efficiency of each bridge type under vehicular loads.

Create two models with **identical plan geometry** (300 m × 7.5 m) and identical span layout. Keep the same mesh density so comparisons are fair. Model girders (I-sections or box girders), deck plate (area elements), and diaphragms at regular intervals, bearings, and piers. If girders are continuous, model continuity with shared nodes or rigid links.

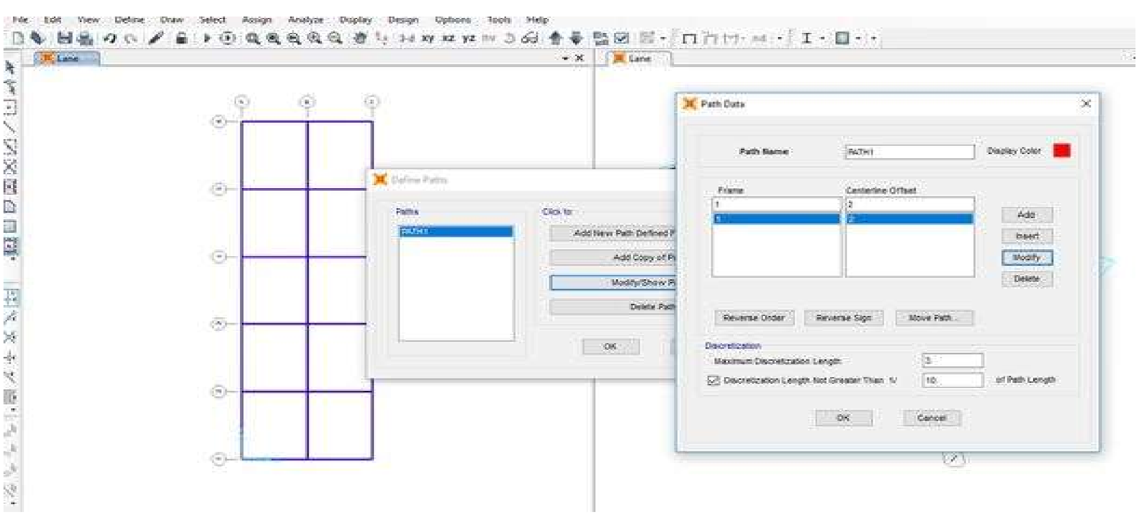

Figure 2 Modeling of girder Bridge

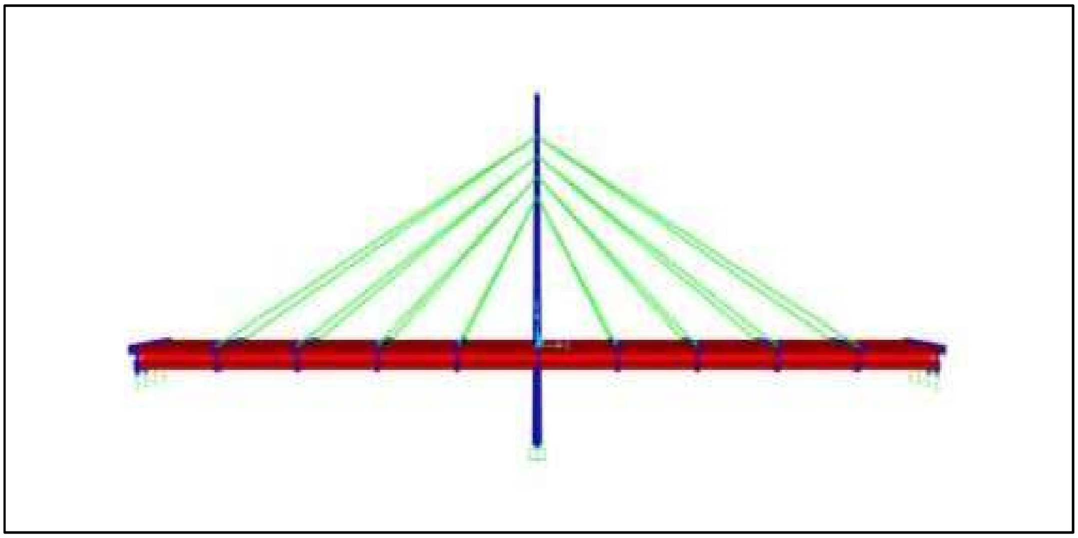

Figure 3 Modeling of cable Stay Bridge

3. Result and discussion

The dynamic response analysis of cable-stayed and girder bridges subjected to vehicular loads as per IRC standards revealed distinct performance characteristics influenced by structural configuration, stiffness, and load-transfer mechanisms; results indicated that cable-stayed bridges exhibited superior load distribution due to the cable–pylon system, leading to lower maximum deck deflections and improved vibration control under IRC Class 70R and Class AA tracked vehicles, while girder bridges, despite their simpler design, experienced higher stress concentrations, greater vertical displacements, and larger dynamic amplification factors under moving loads; time-history and frequency domain analysis showed that cable-stayed bridges effectively reduced natural frequency resonance risks through multiple load paths, whereas girder bridges demonstrated higher susceptibility to dynamic excitations, particularly at mid-span regions; impact factors computed as per IRC:6-2017 highlighted that the dynamic load allowance was more critical for girder bridges, especially for longer spans, while cable-stayed bridges maintained serviceability with reduced oscillations; overall, the discussion emphasizes that although both bridge types satisfy IRC safety and serviceability limits, cable-stayed bridges are more efficient in handling vehicular-induced dynamic effects for longer spans, whereas girder bridges, while economical for medium spans, demand stricter design checks for vibration, fatigue, and comfort criteria under increasing traffic intensity.

The bending moment in a **cable-stayed bridge** is significantly influenced by the stay cables, which directly support the deck and transfer loads to the pylons, resulting in a more uniform distribution of bending moments along the span; the presence of inclined cables reduces negative bending moments over the piers and limits mid-span deflections, making the deck primarily subject to compressive forces near the pylons and tension at mid-span,

Table 1 Bending moment of girders bridge cable-stayed bridge

Girders bridge	Cable-stayed bridge
Bending moment in Kn-m	
689	396

The bending moment comparison between a girder bridge and a cable-stayed bridge highlights the structural efficiency differences between the two systems. In the given data, the girder bridge exhibits a higher bending moment of 689 kN·m, whereas the cable-stayed bridge shows a significantly lower bending moment of 396 kN·m. This difference arises because, in a girder bridge, the entire load of the deck is directly supported by the girders spanning between piers, causing higher internal bending stresses.

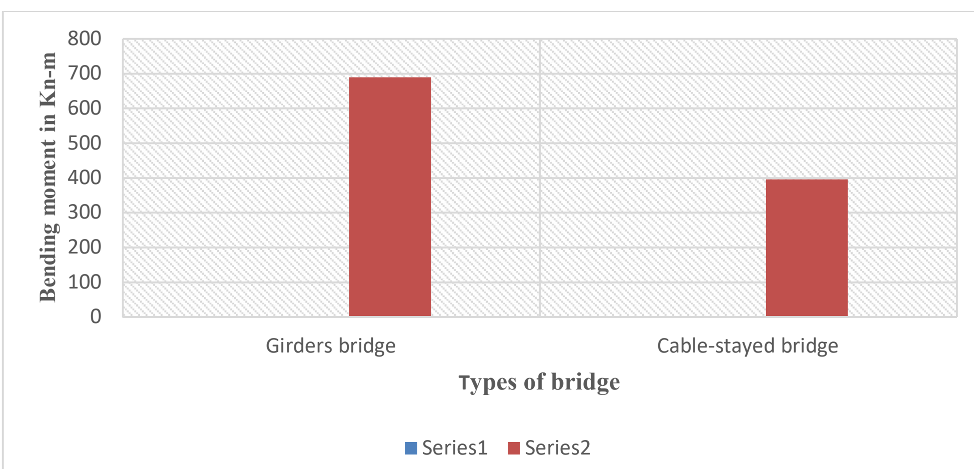

Figure 3 Bending moment graph

4. Conclusion

The dynamic response analysis of cable-stayed and girder bridges subjected to vehicular loads as per IRC standards concludes that while both bridge types demonstrate adequate structural safety under prescribed loading conditions, their responses differ significantly due to their geometry, load transfer mechanisms, and dynamic characteristics. Cable-stayed bridges exhibit superior performance in terms of reduced mid-span deflections, better load distribution through the stay cables, and lower vibration amplitudes under moving loads, making them more suitable for long-span applications where high traffic intensity and heavy vehicular loading are expected. In contrast, girder bridges, though simpler in design and economical for medium spans, show comparatively higher dynamic amplification factors, increased stress concentrations, and greater susceptibility to fatigue and serviceability issues under repeated moving loads. The analysis highlights the importance of considering vehicle speed, bridge span, damping characteristics, and load positioning in evaluating bridge performance, as dynamic effects can significantly influence serviceability and long-term durability. Overall, the study reaffirms that compliance with IRC guidelines ensures safe and reliable bridge design, but careful selection between cable-stayed and girder bridges should be based on span length, functional requirements, economic feasibility, and expected traffic conditions.

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