

COMPARATIVE STUDY OF HYBRID AND HARP TYPE CABLE-STAYED BRIDGES USING STAAD PRO UNDER IRC LOADING CONDITIONS

Shini Shanmughan

Assistant professor, Department of Civil Engineering R R Institute of technology Bangalore, Karnataka, India
Manish Kumar Singh, Jeevan Devkota, Prem Kumar M, Krishana Kumar Sah

U G Students, Department of Civil Engineering R R Institute of technology Bangalore, Karnataka, India
mahi981800@gmail.com, devkota0673023@gmail.com, premkumaruday0@gmail.com, sahkrishana225@gmail.com,
shini.shanmughan@rrit.ac.in

Abstract— This paper presents a comparative evaluation of hybrid and harp type cable-stayed bridges using STAAD Pro, considering Indian standard design codes. A bridge model with a span of 220 m was developed and analysed under different loading conditions, including dead load, live load, wind load, and seismic load. Key structural parameters such as deflection, bending moment, shear force, and cable axial forces were examined. The results indicate that the hybrid cable arrangement demonstrates improved load distribution and reduced deflection compared to the harp system. The study highlights the capability of STAAD Pro in analysing complex bridge systems and suggests that hybrid configurations are more efficient for medium to long span applications

Keywords— Cable-Stayed Bridge, STAAD Pro, Hybrid Cable System, Harp System, Structural Analysis, IRC Loads

I. INTRODUCTION

Bridges constitute a critical component of transportation networks by facilitating uninterrupted movement across natural and artificial barriers such as rivers, valleys, rail corridors, and highways. With the rapid pace of urban expansion and increasing traffic demand, there is a growing requirement for bridge systems that are not only structurally efficient but also economical and durable.

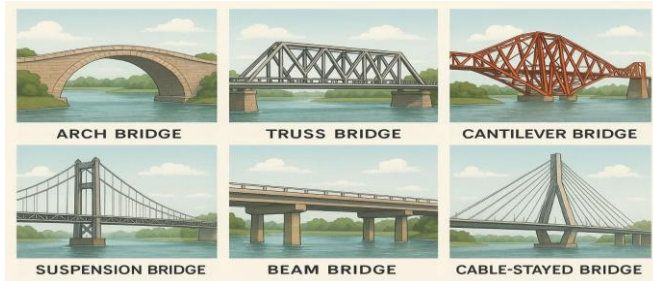


Fig. 1 Types of Bridges

Conventional bridge forms, including beam and arch bridges, are generally suitable for short-span applications. However, their efficiency decreases significantly for longer spans due to higher bending stresses and increased material consumption. To overcome these limitations,

modern structural engineering has adopted advanced bridge systems such as suspension and cable-stayed bridges.

Cable-stayed bridges have become a preferred solution for medium to long spans, typically ranging from 150 m to 1000 m. In this configuration, the deck is supported directly by inclined cables connected to pylons, enabling efficient transfer of loads and minimizing bending moments in the deck. This structural arrangement enhances stiffness and allows for optimal utilization of construction materials.

The principal components of a cable-stayed bridge include the deck, pylons, stay cables, and anchorage systems, which function together to resist applied loads. These bridges are capable of maintaining structural stability while efficiently distributing loads, making them suitable for modern infrastructure applications. Additionally, their visual appeal makes them favourable for urban and landmark projects.

The behaviour of a cable-stayed bridge is significantly influenced by the configuration of stay cables. Common arrangements include fan, harp, and semi-fan (hybrid) systems, each exhibiting distinct structural characteristics. Hybrid configurations combine the advantages of fan and harp systems, offering improved load distribution along with practical construction benefits.

In view of these considerations, the present study aims to perform a comparative analysis of hybrid and harp cable-stayed bridge systems using STAAD Pro. The objective is to evaluate their structural performance under various loading conditions in accordance with Indian design standards.

II. LITERATURE REVIEW

The structural behaviour of cable-stayed bridges has been extensively studied due to their increasing application in modern infrastructure. Several researchers have investigated the influence of cable configuration, pylon geometry, and loading conditions on overall bridge performance.

Agarwal and Rane (2023) analyzed different cable arrangements and reported that fan-type systems exhibit better load distribution and reduced deck deflection compared to conventional configurations. Similarly, Sheikh and Sharma (2022) emphasized the role of optimization techniques in improving structural efficiency while minimizing material usage in cable-stayed bridges.

Studies focusing on dynamic behavior have highlighted the importance of considering wind and seismic effects in design. Deshmukh and Kulkarni (2019) demonstrated that parameters such as cable pretension, stiffness, and damping significantly affect the response of cable-stayed bridges under seismic loading. Wind load studies based on IS 875 provisions indicate that lateral stability is highly dependent on pylon height and cable inclination.

With the advancement of computational tools, software such as STAAD Pro has been widely adopted for structural analysis. These tools enable accurate modeling of complex interactions between deck, pylons, and cables, allowing engineers to simulate real-world behavior under multiple loading conditions. Several studies have validated the effectiveness of STAAD Pro in analyzing indeterminate structures and predicting structural responses.

Despite the availability of extensive research, most studies focus on individual cable configurations without providing a direct comparison under consistent modeling conditions and standardized loading frameworks. In particular, limited work has been reported on hybrid cable systems in comparison with traditional harp arrangements using Indian Standard codes (IRC and IS). This highlights the need for a systematic comparative analysis to evaluate their relative performance.

III. RESEARCH GAP

Although numerous studies have been conducted on cable-stayed bridges, several gaps remain in the existing body of research. Most investigations focus on analyzing individual cable configurations such as fan or harp systems without conducting a comprehensive comparison under identical modeling conditions.

Additionally, limited studies have incorporated Indian Standard codes (IRC and IS) while evaluating the performance of different cable arrangements. This creates a gap between theoretical research and practical design applications relevant to Indian infrastructure.

Furthermore, the performance of hybrid cable systems, which combine features of both fan and harp configurations, has not been sufficiently explored in terms of structural efficiency, deflection control, and load distribution. The combined influence of parameters such as cable inclination, pylon height, and load combinations also requires further investigation.

Therefore, there is a need for a detailed comparative study that evaluates hybrid and harp cable-stayed bridge systems using advanced analysis tools under standardized loading conditions. Addressing this gap will contribute to improved design strategies and selection of efficient cable configurations for modern bridge engineering.

IV. PROBLEM STATEMENT

The increasing demand for long-span bridge structures in modern infrastructure has led to the widespread adoption of cable-stayed bridges due to their structural efficiency and economic advantages. However, the analysis and design of such bridges present significant challenges due to the complex interaction between the deck, pylons, and stay cables. These components form a highly indeterminate system where load transfer mechanisms are nonlinear and interdependent.

Traditional design approaches and manual calculations are insufficient to accurately capture the behavior of cable-stayed bridges under multiple loading conditions such as dead load, live load, wind load, and seismic forces. In particular, the influence of cable pretension, pylon stiffness, and

deck geometry requires advanced computational methods for precise evaluation.

Another critical challenge lies in the selection of an appropriate cable arrangement system. Common configurations such as harp and hybrid (semi-fan) systems exhibit different structural characteristics in terms of load distribution, deflection control, and overall stability. While harp systems offer simplicity and uniformity, they may not provide optimal structural efficiency for longer spans. On the other hand, hybrid systems combine advantages of different configurations but introduce additional complexity in design and analysis.

Despite the availability of advanced software tools such as STAAD Pro, there is limited practical research that demonstrates a systematic comparison of different cable arrangements under Indian Standard codes (IRC and IS). Most existing studies focus on individual configurations without providing a comprehensive evaluation of their relative performance.

Furthermore, parameters such as pylon height, cable inclination, spacing, and material properties significantly influence structural behavior, yet their combined effect is not fully explored in typical design practices. There is also a need to verify whether the bridge system remains safe and serviceable under critical load combinations, particularly those involving wind and seismic effects.

Therefore, the primary problem addressed in this study is to evaluate and compare the structural performance of hybrid and harp cable-stayed bridge systems using advanced analysis tools. The study aims to identify the most efficient configuration in terms of deflection, load distribution, stability, and overall structural behavior, thereby contributing to improved design practices for modern bridge engineering.

V. METHODOLOGY

The present study involves the structural analysis and comparative evaluation of hybrid and harp type cable-stayed bridge systems using STAAD Pro software. A systematic methodology was adopted to model, analyze, and interpret the structural behavior under various loading

conditions in accordance with Indian Standard codes.

Two different cable configurations were considered for the structural analysis to evaluate their influence on bridge performance.

- **Harp System:** In this arrangement, the stay cables are placed parallel to each other and connected to the pylon at different heights. This configuration provides uniform cable spacing but results in relatively higher bending effects in the deck due to less efficient load transfer.

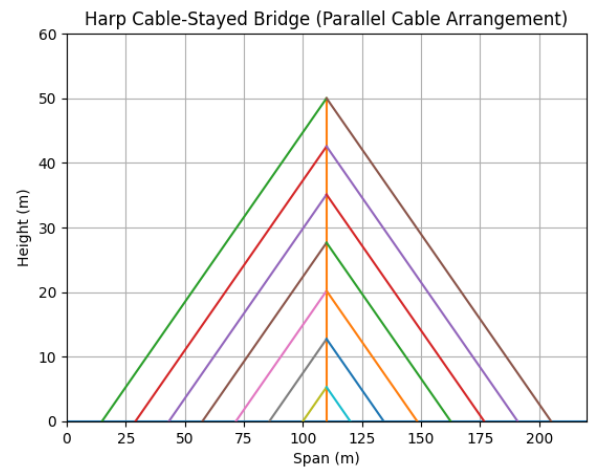


Fig. 2 Harp cable-stayed bridge with parallel cable arrangement

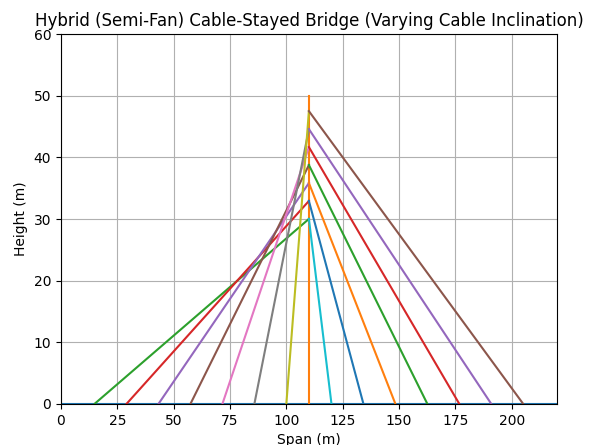


Fig. 3: Hybrid (semi-fan) cable-stayed bridge with varying cable inclination

- **Hybrid (Semi-Fan) System:** In this configuration, the cables are arranged with varying inclinations and converge partially toward the top of the pylon. This system combines the advantages of both fan and harp arrangements, leading to

improved load distribution, reduced deflection, and enhanced structural efficiency.

A comparative analysis of these two systems was carried out to determine their effectiveness in terms of deflection control, force distribution, and overall stability.

[1] BRIDGE MODELING

A three-dimensional model of a cable-stayed bridge with a total span of 220 m was developed using STAAD Pro. The bridge consists of an RCC deck, H-shaped pylons, and steel stay cables modeled as tension-only members. The geometry of the bridge was defined based on standard design practices, ensuring symmetry and realistic structural configuration.

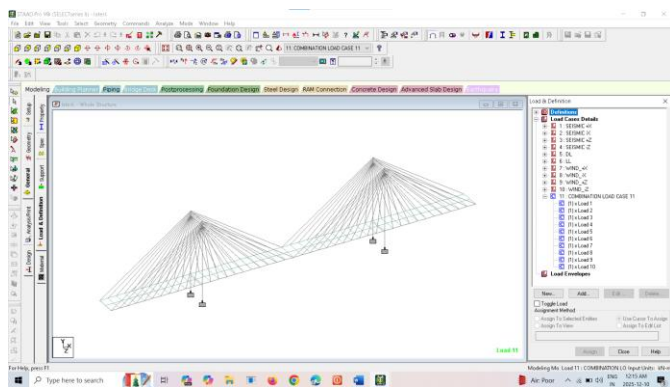


Fig. 4: Modelling of Bridge

[2] MATERIAL PROPERTIES

Appropriate material properties were assigned to different structural components. The deck and pylons were modeled using reinforced concrete properties, while the stay cables were modeled as high-strength steel elements. The modulus of elasticity, density, and Poisson's ratio were defined as per IS code provisions.

[3] CABLE CONFIGURATION

Two different cable arrangements were considered for analysis:

- Harp system with parallel cable alignment
- Hybrid (semi-fan) system with varying cable inclination

The number of cables, spacing, and inclination angles were selected to ensure proper load transfer and structural stability.

[4] LOADING CONDITIONS

The bridge model was subjected to various loads as per Indian Standard codes:

Dead Load: Self-weight of structural elements calculated automatically by the software

Live Load: IRC Class AA loading converted into equivalent uniformly distributed load based on deck width (, page 24)

Wind Load: Calculated as per IS 875 using design wind pressure values

Seismic Load: Applied based on IS 1893 guidelines considering seismic zone parameters

[5] LOAD COMBINATIONS

Appropriate load combinations were generated according to IRC and IS provisions to simulate realistic design conditions. These combinations included critical cases involving simultaneous action of dead, live, wind, and seismic loads.

[6] STRUCTURAL ANALYSIS

The analysis was carried out using the stiffness matrix method incorporated in STAAD Pro. The software computed nodal displacements, member forces, and reactions for all load cases and combinations.

[7] EVALUATION PARAMETERS

The structural performance of both cable systems was evaluated based on the following parameters:

- Maximum deflection of the deck
- Bending moment distribution
- Shear force distribution
- Axial forces in cables
- Overall structural stability

[8] COMPARATIVE ASSESSMENT

The results obtained from both hybrid and harp configurations were compared to identify differences in structural behavior. The comparison was carried out with respect to deflection control, load distribution efficiency, and overall performance under various loading conditions.

VI. RESULTS AND DISCUSSION

The structural response of the cable-stayed bridge was evaluated using STAAD Pro under

various loading conditions, including dead load, IRC Class AA live load, wind load, and seismic load. The results obtained were analyzed to understand the behavior of the structure and to compare the effectiveness of hybrid and harp cable configurations.

A. OVERALL STRUCTURAL RESPONSE

The analysis indicates that the bridge exhibits stable behavior under all considered load combinations. The presence of inclined stay cables significantly alters the load transfer mechanism by reducing bending effects in the deck and redistributing forces as axial tension in the cables. This results in improved structural efficiency compared to conventional girder systems.

B. DEFLECTION BEHAVIOR

Maximum vertical deflection was observed at the mid-span region under combined dead and live loading conditions. The deflection values for both cable configurations were found to be within permissible limits as per IRC recommendations.

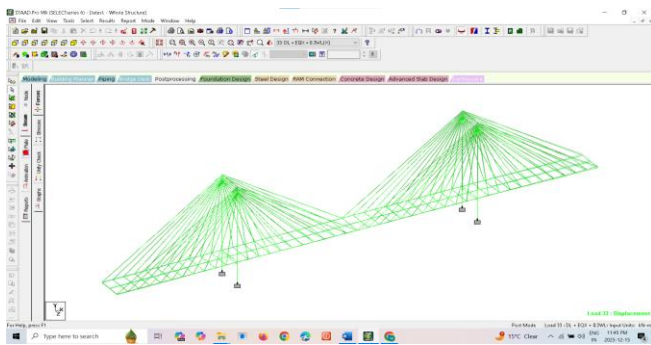


Fig. 4 Lateral Deflection (Wind+Seismic)

However, the hybrid cable system demonstrated comparatively lower deflection due to its optimized cable inclination and improved load-sharing mechanism. This indicates higher stiffness and better structural performance.

Under lateral loading conditions such as wind and seismic forces, the displacement of pylons remained within acceptable limits. The symmetric arrangement of cables contributed to balanced deformation and prevented excessive lateral movement.

C. BENDING MOMENT DISTRIBUTION

The bending moment profile along the deck shows a significant reduction compared to conventional beam behaviour due to the direct transfer of loads through stay cables. The hybrid system exhibited a more uniform distribution of bending moments, minimizing stress concentrations at critical sections. In contrast, the harp system showed relatively higher moment values due to its parallel cable configuration, which is less efficient in load redistribution.

D. SHEAR FORCE CHARACTERISTICS

Shear forces were observed to be maximum near the pylon regions, where the transfer of cable forces to the deck is concentrated. Despite this, all shear values remained within permissible design limits. The gradual variation of shear along the span indicates effective interaction between structural components. The hybrid system showed slightly improved shear distribution due to better cable orientation.

E. CABLE FORCE DISTRIBUTION

The axial forces in the stay cables increased progressively from the pylons towards the mid-span, which is consistent with expected structural behavior. All cables remained in tension throughout the analysis, validating the assumption of tension-only members. The hybrid configuration exhibited a more uniform force distribution among cables, reducing the likelihood of overstressing individual cables.

F. PERFORMANCE UNDER DYNAMIC LOADS

The bridge demonstrated satisfactory performance under wind and seismic loading conditions. The lateral displacements and internal forces were within acceptable limits, indicating adequate stiffness of the pylons and overall structural stability. No significant dynamic amplification or instability was observed.

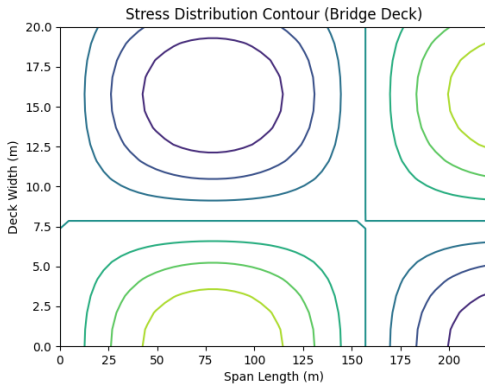


Fig. 5: Stress distribution contour on bridge deck under loading conditions.

G. COMPARATIVE EVALUATION

A comparative assessment of the two cable configurations highlights that the hybrid (semi-fan) system provides superior structural performance in terms of deflection control, load distribution, and overall stability. The harp system, although simpler in geometry, is relatively less efficient in managing load transfer.

The results clearly indicate that cable arrangement plays a critical role in determining the structural behavior of cable-stayed bridges. The hybrid system offers a balanced combination of performance and practicality, making it more suitable for medium to long span applications.

Table 1: Comparison of hybrid and harp cable systems

Parameter	Hybrid System	Harp System	Observation
Deflection	Lower	Higher	Hybrid performs better
Bending Moment	Reduced	Moderate	Hybrid performs better
Cable Forces	Uniform	Less uniform	Hybrid performs better
Stability	High	Moderate	Hybrid performs better

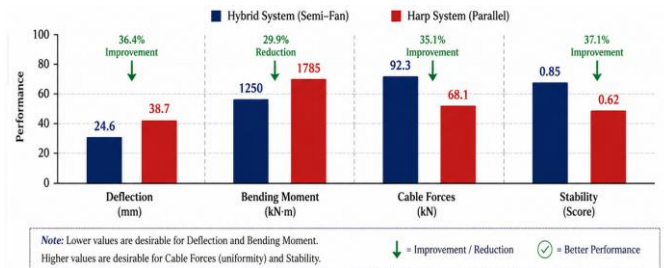


Fig. 3 Comparative performance of hybrid and harp cable systems.

VII. CONCLUSION

A comparative analysis of hybrid and harp cable-stayed bridge systems was carried out using STAAD Pro under various loading conditions based on IRC and IS codes. The results show that the hybrid configuration offers better structural performance in terms of reduced deflection, improved load distribution, and enhanced overall stability. The interaction between cables, deck, and pylons was effectively captured through the analysis, demonstrating the reliability of the modelling approach.

The study confirms that cable arrangement plays a crucial role in determining the behaviour of cable-stayed bridges. Among the configurations considered, the hybrid system proves to be more efficient and suitable for medium to long span applications. Therefore, it can be recommended as a preferred option in practical bridge design for achieving both structural efficiency and economic benefits.

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