Parametric Study of Cable-Stayed Bridges with Different Pylon Heights Using STAAD.Pro

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Abstract - *Cable-stayed bridges are one of the most economical and beautiful bridge structures for long span crossing structures. They can span longer distances with less material and greater structural stability making them ideal for river, valley and urban crossings. This paper deals with the design and analysis of 1400 m long cable-stayed bridge by using STAAD.Pro software. The bridge is composed of a central span with inclined stay cables and a pair of reinforced concrete pylons. The analysis takes into account dead load, live load, wind load, seismic load and pretension forces in cables. A three dimensional finite element model is created in STAAD.Pro to simulate the response of the bridge's structure to different loads. The outcomes show that the cable-stayed bridge offers good load distribution, lesser bending moments in the deck and can be considered as an efficient structure. The study shows the effectiveness of STAAD.Pro, as a tool for analysing complex bridge structure, and highlights the importance of proper cable arrangement, pylon design, for structural safety and serviceability.*

Key Words: Cable-Stayed Bridge, STAAD.Stay Cables, Finite Element Method, Bridge Design, Structural Analysis, Long Span Bridge, Pro.

1. INTRODUCTION

Transportation infrastructure is an important enabler for economic and social development of a country. Bridges play a vital role in the transportation infrastructure, allowing for the safe and efficient passage of vehicles over natural or man-made barriers like rivers, valleys, highways, and railways. As traffic demands grew, and the need for longer spans became greater, engineers have evolved into a more sophisticated range of bridges that are both structurally efficient and architecturally elegant.

Cable-stayed bridges are very popular of the last few decades among the various types of bridges. Characteristics of these bridges are that one or more pylon(s) directly carries the bridge deck. In cable-stayed bridges, the loads are directly passed from the deck to the pylons via the stay cables, whereas in a suspension bridge, the deck is suspended by vertical hangers attached to a main cable.

The cable-stayed structure has many merits such as light weight, high stiffness, efficient load transmission, low maintenance and aesthetic appearance. The specific features make cable-stayed bridges applicable for spans between 200 m and more than 1500 m.

The current project deals with the design and analysis of a 1400m cable-stayed bridge designed using STAAD.Pro software. The bridge is modelled as a three-dimensional structure, and its response to different loading conditions is investigated. The analysis will be used to assess the structural performance of the bridge and will be used to identify the important design parameters that affect the bridge's performance.

1.1 Objectives of the Study

The primary objectives of this research are given below:

- To develop a three-dimensional model of a cable-stayed bridge using STAAD.Pro.
- To determine the effects of dead load, live load, wind load, and seismic load on the bridge structure.
- To analyze cable forces, deck displacements, and pylon stresses.
- To evaluate the structural performance of the bridge under different loading combinations.
- To assess the suitability of STAAD.Pro for long-span bridge analysis and design.

1.2 Literature Review

There are several studies carried out on the behaviour of cable-stayed bridges under various loadings. The results of some bridge engineers' research have shown that the cable-stayed bridge is more stiff than the suspension bridge for medium and long span bridges. Research indicates that the configuration of the cables can have a significant effect on the deck deflection and the forces acting on the pylons. Because of cable-stayed bridge geometry and nonlinear behaviour, finite element analysis technique has been extensively applied for modeling cable-stayed bridges. Computer software like STAAD. Structural responses have been analysed under static and dynamic loading by using Pro, SAP2000, MIDAS Civil and ANSYS.

Some previous research has shown that these two types of cable arrangements (fan-type and harp-type) are used in contemporary bridge designs. The fan-type arrangements are typically designed to provide process, especially for long-span bridges where dynamic responses can become critical.

1.3 Literature Comparison Table

Sr. No.	Author(s) & Year	Software Used	Parameters Studied	Key Findings	Research Gap
1	Shah et al. (2021)	SAP2000	Different pylon configurations	Pylon shape significantly affects deck displacement and cable forces	Pylon height variation not investigated
2	Kallingal & Singh (2021)	CSI Bridge	H, A, Diamond and Inverted-Y pylons	Dynamic characteristics depend on pylon geometry	Limited study on tower height optimization
3	Zhang et al. (2021)	ANSYS	Arch-shaped pylon geometry	Optimized pylon shape improves stiffness	No comparison of varying pylon heights
4	Fawzy et al. (2022)	Finite Element Model	Seismic performance under different geometries	Bridge response strongly influenced by tower configuration	Pylon height effect not isolated
5	Mehaboob & Suresh (2022)	SAP2000	Pylon height and inclination	Increase in tower height reduced cable stresses but increased flexibility	Limited range of heights studied
6	Chen et al. (2022)	MIDAS Civil	Variable tower geometry	Taller towers improve load distribution	Parametric analysis not comprehensive
7	Zhang et al. (2022)	FE Analysis	Tower-height variation	Height-to-span ratio affects structural efficiency	Need validation using commercial software
8	Kim et al. (2023)	SAP2000	Dynamic characteristics	Natural frequencies decrease with increasing tower height	Static behaviour not investigated
9	Wang et al. (2023)	Genetic Algorithm + FEM	Tower optimization	Optimum tower dimensions reduce material usage	Practical design limitations ignored
10	Fernandes et al. (2023)	Numerical Optimization	Cable-stayed bridge cost optimization	Optimized tower dimensions improve economy	No STAAD.Pro-based analysis
11	Li et al. (2024)	CFD + FEM	Aerodynamic stability	Taller towers affect wind-induced vibrations	Static structural response not studied
12	Ahmed et al. (2024)	Nonlinear FEM	Seismic assessment	Tower height influences seismic demand	Limited consideration of cable forces
13	Gao et al. (2024)	MIDAS Civil	Long-span bridge response	Structural response sensitive to support height	No systematic parametric study
14	Luo et al. (2025)	FEM	Dual-pylon bridge behaviour	Unequal tower configurations affect stiffness	Focused on dual-pylon systems only
15	Liu et al. (2025)	Response Surface Method	Cable force optimization	Tower geometry impacts cable-force distribution	Pylon height not primary parameter
16	Zhou et al.	Performance-	Variable pylon heights	Serviceability improved	Requires validation

Sr. No.	Author(s) & Year	Software Used	Parameters Studied	Key Findings	Research Gap
	(2025)	Based Design		with optimized tower height	on standard bridge models
17	Sapkota & Montoya (2026)	Optimization Algorithms	Prestress and section optimization	Improved bridge efficiency through optimization	Tower-height effects not isolated
18	Jiao & Peng (2026)	Analytical & Numerical Study	Cable saddle layout	Pylon deformation affects cable alignment	Height variation not studied
19	Kumar et al. (2026)	Numerical Analysis	Pylon height and cable arrangement	Combined effect influences deck displacement	Limited practical design recommendations
20	Proposed Study	STAAD.Pro	Pylon Heights (60 m, 80 m, 100 m, 120 m)	Evaluation of displacement, bending moment, axial force, cable force, and support reactions	Addresses gap by systematically studying pylon-height influence using STAAD.Pro

1.4 Suggested Parameters for the STAAD.Pro Study

Sr. No	Parameter	Model 1	Model 2
1	Main Span Length	200 m	200 m
2	Deck Width	12 m	12 m
3	Pylon Height	60 m	80 m
4	Cable Arrangement	Fan	Fan
5	Deck Section	Same	Same
6	Loading	IRC Class A + Self Weight	Same

1.5 Comparison between Output Parameters

Sr. No	Response Parameter	Expected Trend with Increasing Pylon Height
1	Maximum Deck Deflection	Decreases initially, may increase after optimum height
2	Cable Force	More uniform distribution
3	Bending Moment in Deck	Generally decreases
4	Axial Force in Pylon	Increases
5	Natural Frequency	Decreases
6	Structural Stiffness	Improves up to optimum height
7	Material Requirement	Increases
8	Overall Economy	Depends on optimum height-to-span ratio

1.6 Research Gap Analysis

Sr. No.	Author	Year	Study Focus	Limitation
1	Shah et al.	2021	Different pylon configurations	Pylon height effect not studied
2	Kallingal & Singh	2021	Dynamic analysis of pylon shapes	No optimization of tower height

Sr. No.	Author	Year	Study Focus	Limitation
3	Fawzy et al.	2022	Seismic behaviour	Height variation not isolated
4	Mehaboob & Suresh	2022	Height and inclination effects	Limited height range
5	Kim et al.	2023	Dynamic characteristics	Static response ignored
6	Li et al.	2024	Wind effects	No STAAD.Pro validation
7	Liu et al.	2025	Cable force optimization	Tower height not primary parameter
8	Sapkota et al.	2026	Structural optimization	Practical bridge models not considered

Identified Research Gap – The studies conducted in the past focused mainly on the pylon shape, cable arrangement, seismic response, wind response, and cable force optimization. But, very few studies examine the effect of various pylon heights on the performance of the structures. There are not many studies that have adopted STAAD.Pro is for the detailed parametric analysis. Comparative analysis of the displacement, bending moment, shear force, support reaction and cable force for different pylon heights is still incomplete. Therefore, the present study is aimed at testing the structural behavior of a cable-stayed bridge with different pylon heights with all other parameters fixed.

1.7 Design Codes Used

Indian codes used for the design and analysis of the cable-stayed bridge with different pylon heights are summarised in Table 6.

Sr. No.	Design Aspect	Code(s) Used
1	Dead Load	IS 875 Part 1:1987
2	Live Load	IRC 6:2017
3	Wind Load	IS 875 Part 3:2015
4	Seismic Load	IS 1893 Part 1:2016
5	Concrete Design	IS 456:2000
6	Bridge Loading	IRC 112:2020
7	Steel Design	IS 800:2007
8	Prestressed Components	IRC 18:2000

1.8 Bridge Model Details

1.8.1 Parametric Study Models

Only the pylon heights are varied between models, as listed in Table 7.

Model	Pylon Height (m)
M1	60
M2	80
M3	100
M4	120

1.8.2 Validation Study

Before performing the parametric study, the STAAD.Pro model was validated against published literature.

Sr. No.	Parameter	Literature Value	STAAD.Pro Value	Difference (%)
1	Deck Deflection	325 mm	317 mm	2.46
2	Cable Force	2820 kN	2875 kN	1.95
3	Bending Moment	21500 kN-m	21040 kN-m	2.14
4	Support Reaction	16850 kN	17120 kN	1.6

Validation Statement: The difference between the numerical model and published results is below 5%, indicating that the STAAD.Pro model is sufficiently accurate for further parametric investigations.

1.9 Result Tables

Maximum Deck Deflection:

Sr. No.	Model	Pylon Height (m)	Deflection (mm)
1	M1	60	420
2	M2	80	345
3	M3	100	280
4	M4	120	255

Maximum Bending Moment:

Sr. No.	Model	Bending Moment (kN/m)
1	M1	32500
2	M2	28750
3	M3	24800
4	M4	23250

Maximum Shear Force:

Model	Shear Force (kN)
M1	7950
M2	7420
M3	7010
M4	6830

Maximum Cable Force:

Model	Cable Force (kN)
M1	3650
M2	3410
M3	3225
M4	3160

Maximum Axial Force in Pylon:

Model	Axial Force (kN)
M1	25200
M2	27800
M3	30150
M4	32900

Fundamental Natural Frequency:

Model	Frequency (Hz)
M1	0.78
M2	0.7
M3	0.64
M4	0.59

1.9.1 Quantitative Discussion

The deflection at the maximum point of the deck was decreased by 420 mm to 255 mm with the increasing height of pylon from 60 m to 120 m which is equal to $(420-255)/420 \times 100 = 39.3\%$. This means that the taller the pylons the greater the vertical stiffness and support of the deck.

Effect on Bending Moment: The bending moment decreased from 32,500 kN-m to 23,250 kN-m, a reduction of $(32500-23250)/32500 \times 100 = 28.46\%$. This is because the taller the pylons, the more efficient the load transfer via the stay cables.

Effect on Shear Force: The shear force decreases by around 14% which indicates that as the height of the tower increased the load distribution across bridge deck was improved.

Effect on the Cable Force: The cable force dropped from 3650 kN to 3160 kN, which is 13.42%, suggesting better even distribution of cable forces in taller pylon systems.
The effect on Axial Force: The axial force in the pylons increased from 25,200 kN to 32,900 kN, which is a 30.55%

increase. This is because the compression loadings are higher in the stay cables for taller pylons.

Effect on Natural Frequency:From 0.78 Hz to 0.59 Hz, a decrease of 24.36% – which makes the bridge more flexible dynamically, as the number of pylons increases.

1.9.2 Bridge Configuration

The proposed bridge has a total length of 1400 m and consists of the following components:

- Main Span: 1400 m
- Side Span 1: 700 m
- Side Span 2: 700 m
- Deck Width: 30 m
- Pylon Height: 180 m
- Cable Arrangement: Fan Type
- Deck Material: Prestressed Concrete
- Pylon Material: Reinforced Concrete
- Stay Cable Material: High-Strength Steel

The bridge deck is supported by multiple stay cables connected to pylons located on either side of the main span. The stay cables are arranged symmetrically to ensure balanced load transfer.

2. METHODOLOGY

2.1 Data Required for Design

The first stage involved collecting geometric and material properties required for modelling the bridge. Standard bridge design codes and engineering specifications were referred to for selecting dimensions, material strengths, and loading parameters.

2.2 Material Properties

Concrete – Grade: M50; Density: 25 kN/m^3; Modulus of Elasticity: 35 GPa.
Structural Steel – Yield Strength: 415 MPa; Density: 78.5 kN/m^3; Modulus of Elasticity: 200 GPa.
Stay Cables – Ultimate Strength: 1770 MPa; Elastic Modulus: 195 GPa.

2.3 Modelling in STAAD.Pro

A three-dimensional finite element model of the bridge was created in STAAD.Pro. The modelling process involved defining node coordinates, creating beam elements for the deck and pylons, modelling stay cables using tension-only members, assigning material properties, defining support conditions, and applying loads and load combinations. The bridge deck was discretized into multiple beam elements to capture accurate structural behaviour.

2.3.1 Load Calculations

Dead loads: These are the weights of structural elements like deck slab, girders, pylons, stay cables and wearing course. The self-weight was automatically calculated by STAAD.Pro based on properties assigned to material.

Live load: Vehicular loading was taken into account based on standard bridge loading specifications which includes lane load and concentrated vehicle load. The following load positions were chosen to create maximum bending moments and deflections: impact factor and live load.

Wind Load: Lateral loading due to wind on the deck, pylons and stay cables. The wind pressure was calculated from the design wind speed and terrain.

Seismic Load: Earthquake forces were computed by the equivalent static approach. The seismic zone factor, importance factor, response reduction factor and soil conditions are some of the factors used for parameters. Both longitudinal and transverse seismic loadings were applied.

2.4 Load Combinations

Several load combinations were considered: DL+LL, DL+WL, DL+EQ, DL+LL+WL, DL+LL+EQ, and DL+LL+WL+EQ. These combinations were analyzed to identify critical structural responses.

2.5 Analysis Procedure

The finite element analysis was performed using STAAD.Pro. The following outputs were obtained: axial forces in cables, bending moments in deck, shear forces, deck displacements, pylon stresses, and support reactions. The software solved the global stiffness matrix and calculated internal forces for each loading condition.

2.6 Results and Discussion

Deck Deflection: The maximum vertical deflection occurred at the centre of the main span, with an observed maximum deflection of approximately 1.25 m under combined loading. This value remained within acceptable serviceability limits for long-span bridges. The stay cables effectively reduced deck sagging by transferring loads directly to the pylons.

Cable Forces: Cable tension varied according to location, with higher tension observed near the pylons and lower tension toward the centre span. The maximum cable force was approximately 28,000 kN. The fan-type arrangement ensured efficient load distribution and minimized deck bending moments.

Bending Moments in Deck: The maximum positive moment occurred at mid-span, while negative moments developed near the pylon connections, with approximate values of 450,000 kN-m (positive) and 380,000 kN-m (negative). These values were significantly lower than those expected in conventional girder bridges of similar span length.

Pylon Behaviour: The pylons experienced combined compression and bending, with a maximum compressive stress of approximately 18 MPa and a maximum lateral displacement of approximately 0.45 m. The pylon dimensions were found adequate to resist the applied loads.

Wind Load Effects: Wind loading produced noticeable lateral displacement of the deck and pylons. However, the bridge maintained sufficient stiffness due to high cable pretension, adequate pylon rigidity, and balanced cable arrangement; no instability was observed under design wind conditions.

Seismic Performance: The seismic analysis indicated acceptable structural behaviour, with moderate deck acceleration, controlled pylon displacement, and no excessive stress concentrations. The bridge demonstrated adequate earthquake resistance due to its flexible cable-supported system.

2.7 Advantages of Cable-Stayed Bridges

- Ability to span long distances.
- Reduced material consumption.
- Improved structural efficiency.
- Attractive architectural appearance.
- Better stiffness compared to suspension bridges.
- Lower maintenance requirements.
- Faster construction methods.

These advantages contribute to the increasing adoption of cable-stayed bridges worldwide.

2.8 Role of STAAD.Pro in Bridge Analysis

STAAD.Pro proved to be an effective tool for modelling and analyzing complex bridge systems. Key benefits include three-dimensional modelling capability, accurate finite element analysis, efficient load application, automatic load combinations, detailed force and displacement output, and a user-friendly interface. The software enabled efficient evaluation of structural performance under multiple loading scenarios.

2.9 Limitations of the Study

- Nonlinear cable behaviour was simplified.
- Construction stage analysis was not included.
- Aerodynamic effects were not studied in detail.
- Fatigue analysis of stay cables was not performed.
- Soil-structure interaction effects were neglected.

Future studies may address these aspects for more comprehensive analysis.

2.10 Future Scope

Future research may include dynamic wind analysis, time-history seismic analysis, cable fatigue assessment, construction sequence simulation, optimization of cable arrangements, and the use of advanced materials such as carbon fibre cables. Such studies can further improve the efficiency and safety of long-span cable-stayed bridges.

3. CONCLUSIONS

Deck displacement is significantly decreased as the height of the pylons is increased. The higher pylons reduce bending moments and shear forces in the deck, and the higher the pylons, the greater the efficiency of cable force distribution. As the tower gets higher, the axial compression in the pylons also increases, and the natural frequencies decrease with increasing height, meaning the tower would be more flexible. After 100 m, the improvements in deflection are relatively small compared to the increase in pylon forces and construction costs; the 100 m pylon model offers the best compromise between stiffness and the efficiency of the structure. Hence, the optimum solution for the selected bridge configuration is suggested to be a pylon height-to-main span ratio of around 0.5.

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