Suspension Bridges Versus Cable-Stretched Bridges: A Comparison of Structural Behaviour and Performance

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Abstract. A suspension bridge and a cable-stayed bridge are compared under various loads and environmental conditions in this study. Under live, dead, and seismic loads, the research investigates axial forces, displacements, bending moments, and shear forces using advanced analytical methods and software such as CsiBridge, SAP2000, and Staad Pro. Steel plays a key role in the construction of suspension bridges and cable-stayed bridges, as this study thoroughly compares both types of bridges. Csi Bridge software is utilized in this study to investigate the axial force, displacement, bending moment, and shear strength of these bridges under various loading conditions. Cable-stayed bridges are recognized for their aesthetic benefits and structural efficiency for medium-to-long spans, and suspension bridges for their high tensile strength and durable design. The two bridge types exhibit different shear forces, displacements, and torsional values, underscoring their unique engineering designs.

Keyword-: Bridges, Suspension Bridge, Cable stayed bridge, shear forces, displacement, torsional values.

1 Introduction

The use of steel in bridge construction is widespread worldwide, from the largest to the smallest. This material provides efficient and sustainable solutions that are versatile and effective. There has long been recognition that steel is an economical option for a variety of bridge types. There are more than 22,000 long span, railway, footbridge, and medium span

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bridges it manufactures every year [1]. Highway structures with shorter spans are increasingly using this material as well. A steel bridge solution benefits society in a variety of ways. Several former industrial, dock, and canal-side areas have been rejuvenated through the building of landmark steel bridges, which embody good design, are quick to build, and contribute to local economic regeneration. There is nothing more important to the infrastructure and landscape of a country than steel bridges [2]. An evocative combination of technology and aesthetics is rare in manmade structures. Large bridges are often constructed with concrete arches instead of steel traditionally used for very long spans. Suspension bridges are most commonly used for large single-spans bridges because of their high tensile strength, which provides a design solution that's more economical than other support methods [3].

Using beam, arch, and suspension spans in combination can create long bridges where suitable support points are available. There are three basic types of bridges: fixed bridge, moveable bridge, and swing-bridge. Movable bridges are generally used where there is a need for greater headroom under the bridge, such as for passing a ship under the bridge [4].

2 Suspension Bridge

Suspension bridges and other technical structures are susceptible to flutter, a fluctuating aerodynamic response. As demonstrated by the fall of the Tacoma Narrows Bridge, it may result in a structural breakdown. In an attempt to enhance flutter performance, barriers and streamlined box girder forms have been optimized. Nonetheless, laboratory settings are frequently used to assess flutter achievement, and structural vibration behaviour evaluation is essential for flutter research and failure analysis [5]. China is building multi-tower, multi-span suspension bridges as shown in Fig. 1, accepting the modern age of river and sea crossing. Reduced main cable tension, anchoring scale, basic span length, and overall cost are benefits associated with these bridges. With the development of China's high-speed railway and highway connections, these bridges are becoming more environmentally friendly, resource-efficient, and sustainable [6].

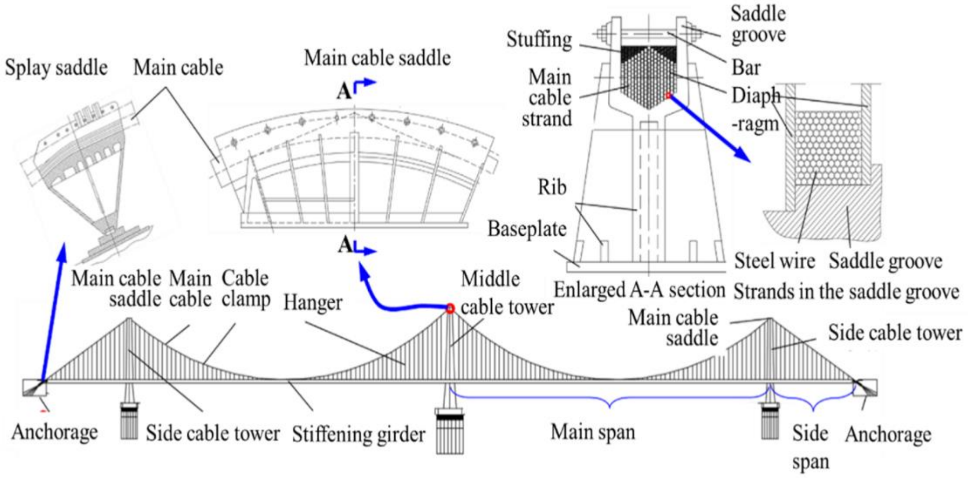


Fig. 1: Suspension bridge based on multiple tower

Because of the amplification effect of static load caused by traffic load, road surface roughness and the vehicle-bridge interaction (VBI) effect have a substantial impact on road bridges safety during operation[6]. Dynamical concepts have enhanced VBI system modeling; investigations have shown three-dimensional approaches and simplified bridge solutions [7]. The use of finite element analysis and modal superposition techniques in the study of complicated bridge models is ongoing. A suspension bridge is a bridge structure that can span a considerable amount of ground, and consists of a bridge deck system, pylons, anchors, suspension cables, and anchor posts. The main cable, which is composed of high tensile strength steel, is critical to the bridge's service life and design life cycle. To extend the life of the bridge, the main cable's integrity is crucial. In addition to soot, dust, sulfides, and chlorides, suspension bridges are exposed to serious corrosion due to pollution [8]. More than ten years have been spent researching corrosion prevention in suspension bridge cables and other components. In suspension bridges, atmospheric corrosion is responsible for more than half of the corrosion loss. Railroad bridges with primary spans longer than 1000 meters are constructed using flexible nanocomposite suspension components. In addition to meeting security regulations for high-speed trains, truss girder structures increase girder rigidity. Due to daily changes and solar radiation, steel's strong heat conduction and linear expansion coefficient might result in non-uniform temperature fields. Truss is an extremely statically indeterminate structure that, when temperatures fluctuate, generates a secondary internal force [9, 10].

3 Cable-Stayed Bridge

A deck, towers to transmit, and cable-stays are the components of a cable-stayed bridge. The deck is supported along its entire length by a number of inclined stays. Large-span structures of bridge with shallow decks are made possible by these bridges, which function as a series of beams as shown in Fig. 2. While towers compress weights to foundations, cable-stays transfer vertical deck loads to them [11]. These extremely inefficient bridges are controlled by the distribution of cable forces and the stiffness of the load-supporting sections. Due to their narrow deck and cable suspension system layout, they offer aesthetically benefits and are an effective structural alternative for medium-to-long spans [12]. Lightweight, flexible, and low-damping stay cables are essential components of cable-stayed bridges. But they are always vibrating due to dynamic stresses, which can lead to fatigue and fracture problems. Security measures such as cross-ties, surface profiling, and structural vibration control mechanisms have been used to enhance their performance in motion [13].

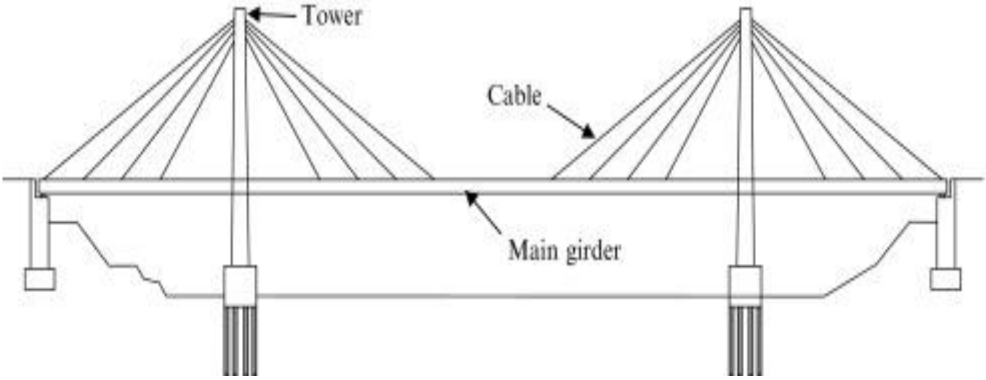


Fig. 2: Schematic representation of cable-stayed bridge

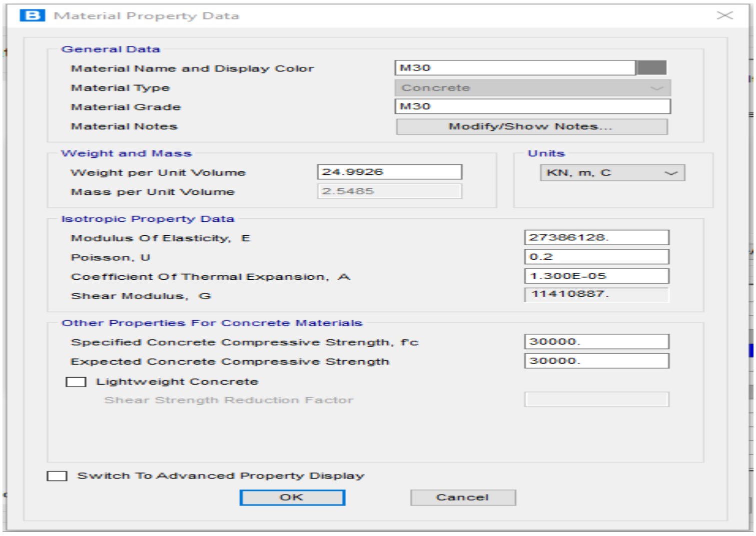
Structural health monitoring (SHM) technological advances is widely used on cable-stayed bridges, which are important connections in the transportation infrastructure, to guarantee their underlying strength and functionality [14]. The well-known method for SHM is updating the finite element model, however because of its size, slenderness, long cable usage, and elevated levels of architectural redundancy, it can be difficult to create an accurate initial model [15]. Because of its enhanced mechanical and physical characteristics, cable structures are being utilized more often in contemporary bridge designs, such as drawbridges, suspension bridges, and cable-stayed bridges. But these buildings' dependability and safety are vital [16]. Around the globe, structural health monitoring, or SHM, is used to evaluate and prevent built bridges. Examining cables is essential to guaranteeing safety because they convey both living and dead weights to towers [17]. As a result of external variables such as fatigue, vibrations, and galvanic corrosion, cables can deteriorate over time, resulting in a lower load capacity, which in turn could negatively influence the strain condition of the structure and the linear smoothness of it [18, 19]. Temperature differences in bridges can generate parametric variation, which can result in inaccurate estimates of mass, damping, and stiffness. Adaptive control techniques are a feasible choice since they can offer robustness in handling these fluctuations [20-23].

4 Methodology

The purpose of this section is to provide an overview of the methodologies employed in order to construct and analyze two different models of bridges: a suspension bridge (Case I) and a cable-stayed bridge (Case II) [24]. The analytical software CsiBridge, alongside similar loading conditions, facilitated the modeling process for each case study [25].

4.1 Designing and Analytical Steps Overview

Step 1: Preliminary Analysis-: Based on a number of academic papers, the first step was to investigate cable-stayed and suspension bridges' reactions to various stresses. To understand the behaviors of these structures, SAP2000 and Staad.Pro were used for detailed evaluations based on axial load, moment, and bending. Some researchers also opted for manual calculations [26].
Step 2: Model Construction-: The models were constructed using Csi Bridge software for each scenario. Bridge restrainers, base springs, bridge bearings, bridge abutments, tendons, bent configurations, and section data were defined and analyzed [27].


Material Property Data

General Data
Material Name and Display Color: M30
Material Type: Concrete
Material Grade: M30
Material Notes: Modify/Show Notes...

Weight and Mass
Weight per Unit Volume: 24.9926
Mass per Unit Volume: 2.5485

Units: KN, m, C

Isotropic Property Data
Modulus Of Elasticity, E: 27386128.
Poisson, U: 0.2
Coefficient Of Thermal Expansion, A: 1.300E-05
Shear Modulus, G: 11410887.

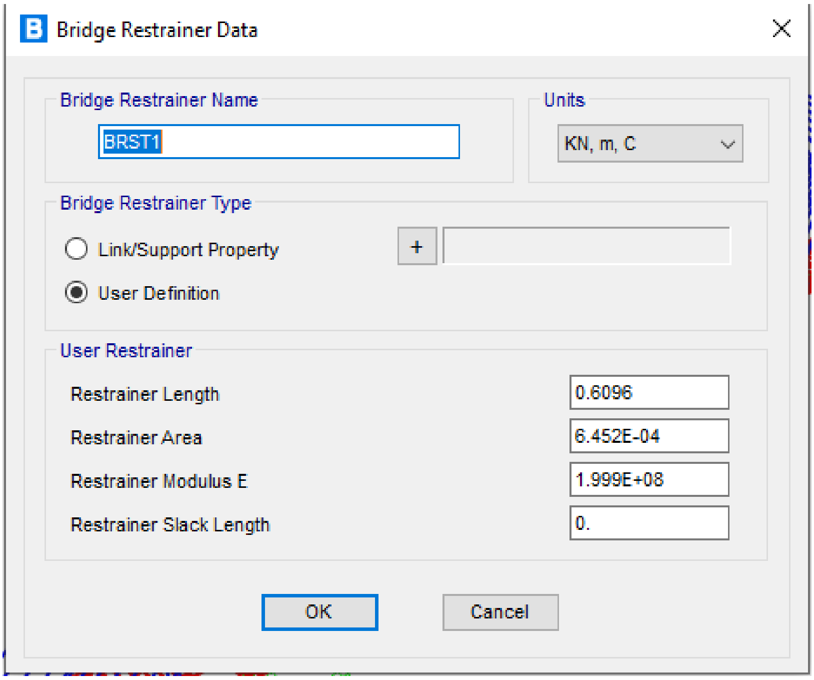
Other Properties For Concrete Materials
Specified Concrete Compressive Strength, f'c: 30000.
Expected Concrete Compressive Strength: 30000.
☐ Lightweight Concrete
Shear Strength Reduction Factor

☐ Switch To Advanced Property Display

Fig. 3: Defining property of concrete.

Step 3: Material Properties Specification-: The Csi Bridge material specification tool was used for two bridge types to determine the concrete, steel, and tendons specifications as shown in Fig.3 [28].

Step 4: Structural Component Definition-: Superstructures were designed to be uninterrupted, supported by single columns, bearing lines, and a 9 meters long cap beam [29]. In order to ensure the smooth operation of the bridge, the bearing data was thoroughly examined in order to ensure the controlled movement between the deck and the piers. In order to prevent embankment erosion and facilitate load transfer to the foundation, abutments were used at both ends of the bridge [30]. In order to create Foundation Spring Data, a release mechanism tailored to the bridge's structural requirements had to be selected. Bridge Restrainers as shown in Fig. 4 were also examined in depth, highlighting their significant role in minimizing deck displacement during seismic events and influencing the bridge's overall dynamics [31].


Bridge Restrainer Data

Bridge Restrainer Name: BRST1

Units: KN, m, C

Bridge Restrainer Type

○ Link/Support Property

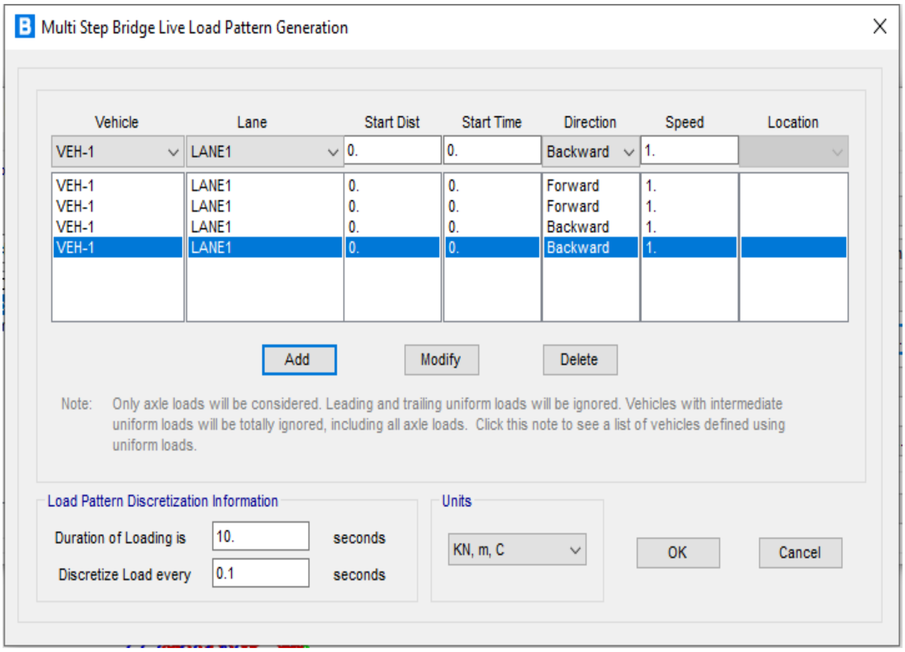
● User Definition

User Restrainer

Restrainer Length	0.6096
Restrainer Area	6.452E-04
Restrainer Modulus E	1.999E+08
Restrainer Slack Length	0.

Fig. 4: Bridge strainer data feed

Step 5: Additional Specifications-: The process proceeded with the definition of lanes for the deck, ensuring the layout was clearly marked and functional for traffic flow [32]. The next step was to ensure uniformity in the section properties of the tendons across the entire range of applications to establish a consistent structural behavior under load around the entire range of applications. There have been meticulous specifications prepared for the vehicle load, ensuring that the bridge can accommodate varying traffic conditions, including a variety of weights and densities of traffic that may be encountered on the bridge [33-36].



Multi Step Bridge Live Load Pattern Generation

Vehicle	Lane	Start Dist	Start Time	Direction	Speed	Location
VEH-1	LANE1	0.	0.	Backward	1.	
VEH-1	LANE1	0.	0.	Forward	1.	
VEH-1	LANE1	0.	0.	Forward	1.	
VEH-1	LANE1	0.	0.	Backward	1.	
VEH-1	LANE1	0.	0.	Backward	1.	

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 10. seconds

Discretize Load every 0.1 seconds

Units: KN, m, C

Fig. 5: Multi Step Bridge Live Load Pattern Generation

1893:2016 standards. In order to ensure that all potential stresses on the structure are accounted for, this rigorous approach was applied to the loading conditions [37]. A comprehensive evaluation of the bridge's structural integrity and performance culminated in a thorough assessment of deformation as shown in Fig. 5. The deformation assessment was used to confirm that the designs of the bridge are resilient and safe when exposed to the anticipated conditions.

According to IS 1893 Part I 2016, a suspension bridge (Fig. 6) and cable-stayed bridge (Fig. 7) are compared regarding seismic loading and vehicle loading. These examples also include geometrical information, along with material and sectional characteristics. In addition to the loading circumstances mentioned above, additional loading circumstances are described as part of the study and necessary for evaluating the behavior of the structure [38-39].

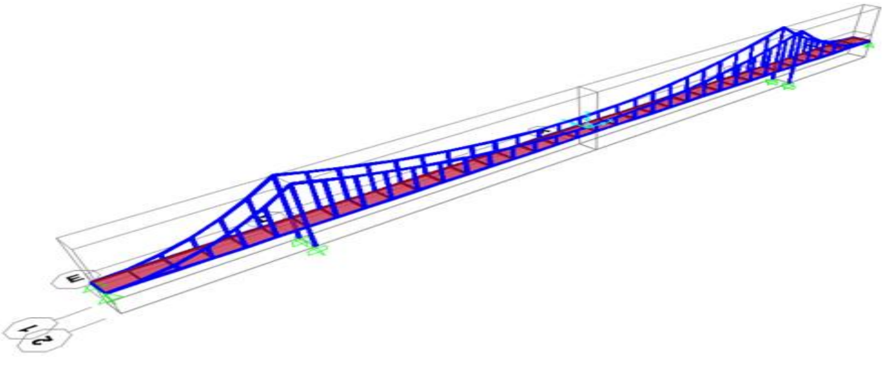


Fig. 6: Suspension Bridge using Staad.Pro

The suspension bridge presented has a geometrical configuration that includes a left span of 20 meters, a significantly longer middle span of 80 meters, and a right span mirroring the left at 20 meters. The deck, which spans the entire length of the bridge, measures 3 meters in width, providing a narrow pathway. Supporting this structure, the height of the first column, denoted as H1, is 5 meters, while the height of the second column, H2, doubles that at 10 meters. The bridge's design incorporates divisions across its structure for added strength and stability: N1 consists of 6 divisions for the shorter spans, N2 encompasses 24 divisions within the lengthy middle span, and N3 again includes 6 divisions, reflecting the symmetry with the bridge's shorter spans. As a result, the bridge's aesthetic appeal and structural integrity are maximized by the minimal sag in the middle span, which is limited to just two meters.

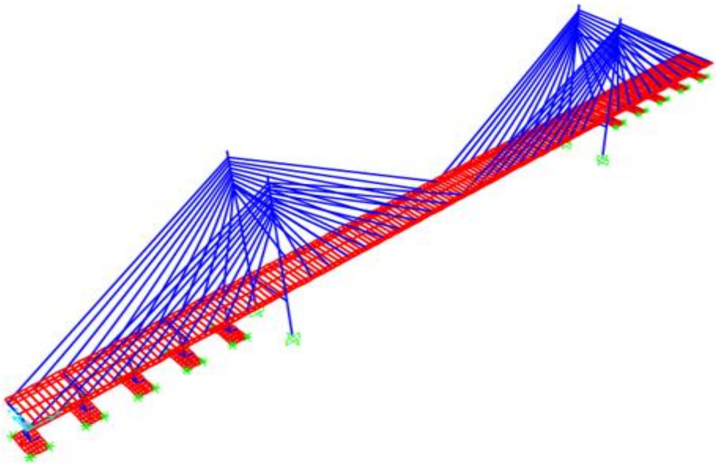


Fig. 7: Cable Stayed Bridge using Staad.Pro

An equivalent left and right span of 150 meters each flanks the main 300-meter span of the cable-stayed bridge described. It consists of a beam slab that stretches across 30 meters in width and 3 meters in depth, situated 15 meters above the ground level and has a width of 30 meters and a depth of 3 meters. An aesthetic and structural benefit of the bridge's cable pattern is its harp configuration. There are three pylons in the bridge, each of which stands at a different height: 35 meters for the central pylon, and 25 meters for the left and right pylons. Each left and right span is supported by five solid rectangular piers. In addition to having an H-shaped pylon and footings that provide support for the bridge, the bridge is anchored on an H-frame type foundation. Notably, the height of the structure above the deck is 100 meters, emphasizing its grandeur. The foundation is fixed, ensuring a stable base with a total depth reaching 40 meters, which secures the bridge's integrity and durability against various environmental stresses.

5 Result and Discussion

The results of two distinct models of hybrid, a suspension, and cable-stayed bridges are shown in terms of axial force, displacement, bending moment, and shear strength. These results are discussed in terms of the relationship between live, dead, and seismic loads. The two models are contrasted in the figures below.

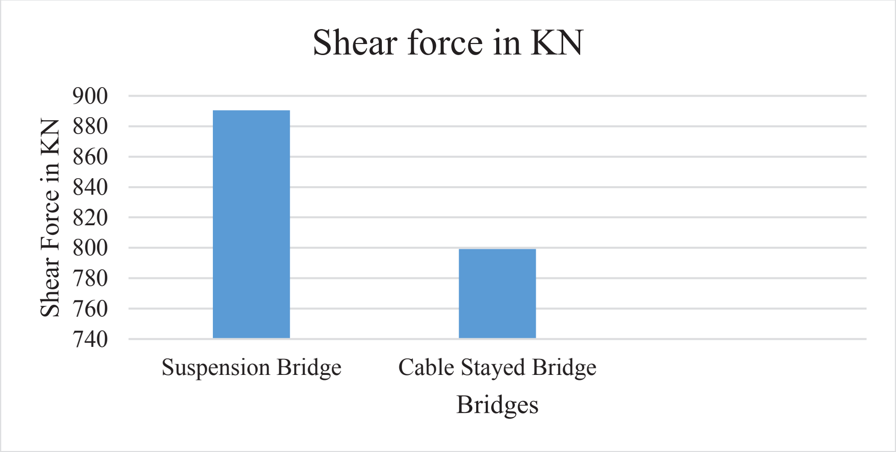


Fig. 8: Shear force in KN for both the bridges

When two structures are pulled apart (or when parts of a single structure are pulled apart), shear stress results. Bridge components could literally split in two if left unchecked by shear stress. Fig. 8 shows the Cable-stayed bridges have a lesser shear force of 749.207 kN than suspension bridges with 885.394 kN. Components resist sliding forces based on shear force, which is a critical factor in bridge design. Different structural approaches to load distribution and force resistance explain the difference in values between the two bridge types.

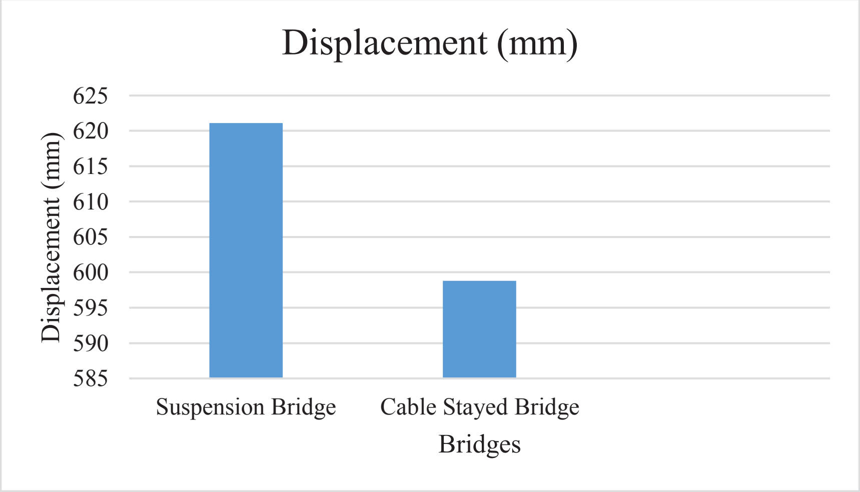


Fig. 9: Displacement (mm) for both the bridges

According to Fig. 9, suspension bridges and cable-stayed bridges deflect or move differently under load, displaying the displacement values (mm). With 622.098 mm displacement, the suspension bridge is slightly higher than the cable-stayed bridge, which has 596.856 mm displacement. It is essential to measure the flexibility and load-bearing efficiency of bridges in order to determine whether they are suitable for heavy traffic. Their distinct engineering designs and how they handle stresses such as weight and wind are evident in the slight difference in displacement between the two types of bridges.

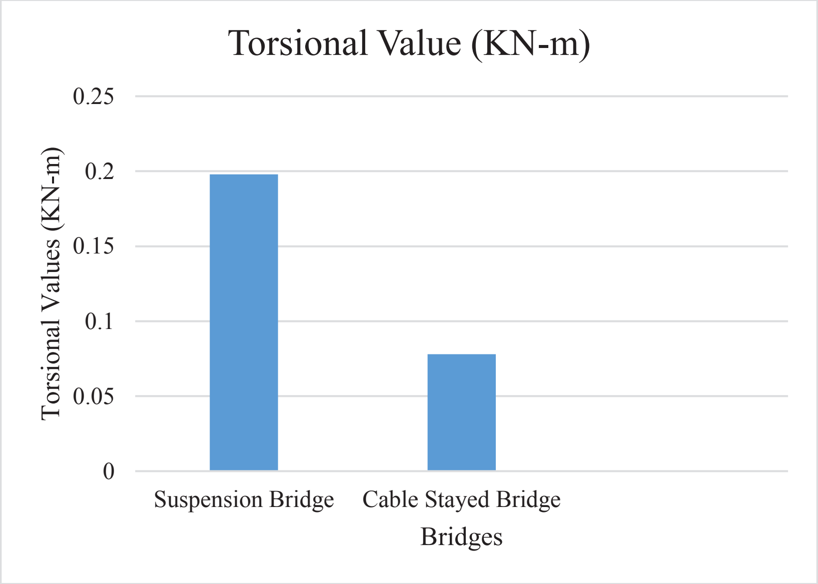


Fig. 10: Torsional Values in KN-m

According to Fig. 10, Suspension bridges are capable of withstanding twisting forces up to 0.188 kN-m, and exhibit torsional values of 0.188 kN-m. Its torsional value is significantly lower than that of the cable-stayed bridge at 0.068 kN-m. Under different loading conditions, different bridge designs have different responses to torsional stresses, affecting their stability and longevity.

6 Conclusion

Material selection, specifically steel, plays a pivotal role in determining the structural integrity and performance of bridges. Although the designs of these two types of bridges differ significantly, they both have distinct advantages when it comes to the way the loads are managed, the beauty, and the efficiency of construction. Cable-stayed bridges, with lower torsional values and higher shear force values, are more efficient in medium-to-long span scenarios due to their lower torsional values. As a result of the study, SHM, corrosion prevention, and the adoption of advanced materials are highlighted as key components in enhancing the durability, safety, and functionality of bridges. A bridge engineer must explore sustainable construction techniques and materials in order to deal with modern infrastructure challenges. In order to ensure bridge construction projects meet engineering standards while also contributing to landscape aesthetics and economic vitality, this analysis provides valuable insights that can be used to guide future bridge construction projects.

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