

# Dynamic Behavior of Truss Bridge Structures Subjected to Moving Load

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## Abstract

This study presents a comprehensive analysis and design of steel truss railway bridges, focusing on the comparative performance of Warren, Pratt, and Howe trusses under static and dynamic loading conditions. Utilizing STAAD Pro software, the research evaluates a 366-meter-long railway bridge with specific seismic and wind considerations, designed per IS 1893 (Part III): 2016 and IS 875 (Part III): 2015 guidelines. Key parameters such as time period, natural frequency, displacement, and acceleration were analyzed using data from the 2001 Bhuj earthquake to simulate realistic seismic conditions. Results highlight the superior performance of the Warren truss, which demonstrated significantly lower displacement, shorter time periods, higher natural frequencies, and reduced acceleration compared to Pratt and Howe trusses. Structural optimization of the Warren truss reduced its self-weight by 14.2%, enhancing its economic viability. This study underscores the effectiveness of the Warren truss for railway bridge applications, providing insights into efficient and resilient design strategies for modern infrastructure.

**Keywords:** Truss Bridge Structures, Moving Load, Comprehensive Analysis, STAAD Pro software

## 1. Introduction

Truss bridges are among the most significant and widely used structural systems in the construction of railway and highway networks, owing to their efficient load-carrying capabilities and structural performance. The analysis and design of truss bridges have been extensively studied to optimize their performance under dynamic and static loading conditions. Several researchers have focused on evaluating the seismic response, dynamic behavior, and structural efficiency of various truss types, including Pratt, Warren, and Howe configurations. The Study conducted seismic analyses of these truss types using STAAD.Pro, highlighting their suitability under different loading scenarios [1]. Also, study emphasized the dynamic response of truss bridges to moving loads and vehicles, which are critical for railway and highway applications [2],[3]. Similarly, research provided a comprehensive review of the development and advancements in truss bridges, underscoring their historical and modern significance [4].

Recent studies have also explored damage detection, fatigue life analysis, and seismic resistance of truss bridges under varying

conditions. For instance, the research investigated damage detection in Warren trusses using frequency change correlations [5], while study examined train-induced responses for cable-stayed railway bridges. Furthermore [6], The study on comparative analyses of different truss configurations, offering insights into their structural behavior under diverse loading conditions [7] and [8]. The ongoing advancements in analytical methods and material technology continue to enhance the reliability and efficiency of truss bridge designs, making them indispensable in modern infrastructure development.

The structural integrity and performance of railway bridges have been a critical focus for civil engineering research due to their role in ensuring safe and efficient transportation. Various studies have highlighted the importance of analyzing fatigue life, seismic effects, and structural configurations to enhance the design and longevity of these bridges. A parametric study to assess the fatigue life of plate girder railway bridges under varying rolling stock velocities, emphasizing the dynamic interactions between trains and bridge structures [9]. Similarly, A study analyzed railway bridge sections under seismic loading, aligning

their study with railway provisions to address earthquake resilience [10]. Investigations focused on optimizing truss bridge designs to identify the most suitable configurations for practical implementation [11], while research provided a comparative analysis of truss-type steel railway bridges under railway loading conditions [12]. The study explored the analysis and design of a 24-meter-long steel girder bridge subjected to special vehicle loads, shedding light on the structural behavior of girders under heavy loads [13]. Additionally, research examined the design of road-cum-railway bridge superstructures, providing insights into combined vehicular and railway load management [14]. These studies collectively contribute to advancing the understanding and development of railway bridge design strategies. The dynamic behavior of railway bridges under moving loads has been a critical area of research in structural engineering due to its significance in ensuring safety and performance. Various studies have focused on finite element modeling and the dynamic response of railway bridges to evaluate their structural integrity and optimize design configurations. The Study developed finite element models to analyze the dynamic response of railway bridges subjected to moving loads, emphasizing the influence of speed and load variations [15]. Similarly, research explored the dynamic performance of steel truss bridges under high-speed moving loads, highlighting the importance of considering bridge geometry and material properties [16]. Comparative analyses of truss bridge configurations under dynamic loading, reveal that different structural layouts significantly affect dynamic behavior [17]. The fundamental principles of vehicle-bridge interaction dynamics, as discussed and provided a theoretical framework for these studies, offering insights into the coupled effects of moving vehicles and bridge structures [18]. Furthermore, study investigated the impact of truss configurations on railway bridge dynamics, suggesting that optimized configurations can enhance structural performance and reduce vibrations [19]. This study aims to investigate the dynamic behavior of truss bridge structures subjected to moving loads, with a particular focus on comparing the performance of Warren, Howe, and Pratt trusses. By evaluating parameters such as displacement, acceleration, natural frequency, and time period, this research provides insights into the optimal truss configuration for improved structural performance. The findings are expected

to contribute to the development of more efficient and reliable bridge designs.

## 2. Steel Truss Bridge

Steel is one of the most widely utilized materials for constructing bridges of various sizes across the globe. Its versatility and efficiency make it an ideal choice, offering sustainable and cost-effective solutions. Over the years, steel has been regarded as an economical option for diverse bridge types, including long-span bridges, railway bridges, footbridges, and medium-span highway bridges. Recently, it has also gained popularity for shorter-span highway structures due to its numerous advantages.

Steel bridges offer several societal benefits, from their aesthetic appeal to their rapid construction. Iconic steel bridges often symbolize exemplary design and have played a pivotal role in revitalizing former industrial, dockland, and canal-side areas. These bridges consist of connected elements, typically straight members, that experience tension, compression, or a combination of both under dynamic loading conditions. Trusses, which can be constructed from materials like timber, steel, or composite systems, are among the most prominent structural forms used in bridge construction. In this study, steel trusses, specifically for bridge applications, are the focus due to their superior mechanical properties.

Compared to other materials such as concrete or wood, steel exhibits higher strength, ductility, and toughness. However, to ensure durability and protect against corrosion, steel surfaces must be painted or coated. Truss bridges, like other bridge types, can be classified as either simple or continuous structures. While the arrangement of truss members allows for countless design possibilities, most bridges fall into a few well-known truss types, commonly used in structural engineering. The primary components of a steel truss bridge are depicted in the figure, showcasing their functional and structural integration.



**Fig 1 Steel Truss Bridge**

### 1) Howe truss

The Howe truss is a structural design for truss bridges, consisting of chords, vertical members, and diagonal components. In this configuration, the vertical members are subjected to tensile forces, while the diagonal members primarily experience compressive forces.

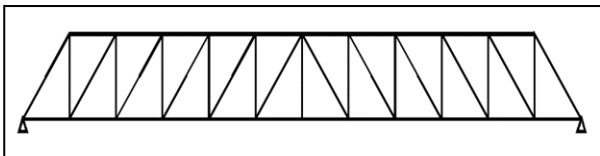


Fig 2 Howe truss

### 2) Pratt truss

This truss design features diagonal members that incline downward toward the center, creating a distinct contrast to the configuration of the Howe truss. In this arrangement, the diagonal members are subjected to tensile forces, while the vertical members experience compressive forces.

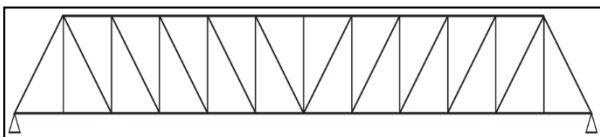


Fig 3 Pratt truss

### 3) Warren truss

The Warren truss bridge is a widely recognized and frequently utilized design, with numerous examples spanning across the globe. This study delves into various aspects of the Warren truss bridge, including its historical development, functional principles, advantages, disadvantages, and other noteworthy features.

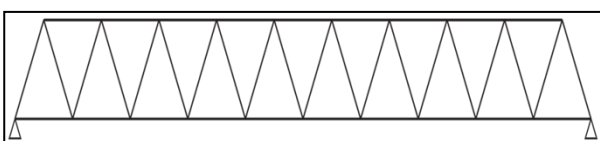


Fig 4 Warren truss

## 3. Problem Statement

This study focuses on the analysis and design of various types of trusses for a steel bridge located in Pune. The research involves using STAAD PRO software for structural analysis and design. The bridge under consideration has a total length of 366 meters and a width of 7.6 meters, comprising 30 spans of 12.2 meters each. It accommodates two broad-gauge railway tracks with a track width of 1.676 meters. For seismic analysis, the structure is designed considering Seismic Zone III in

accordance with IS 1893 (Part III): 2016. Wind load calculations are performed following the guidelines of IS 875 (Part III). A comparative study of the Warren truss, Pratt truss, and Howe truss is undertaken to evaluate their performance.

Table 1. Models

Model No	Model Type
Model 1	Pratt Truss
Model 2	Howe Truss
Model 3	Warren Truss

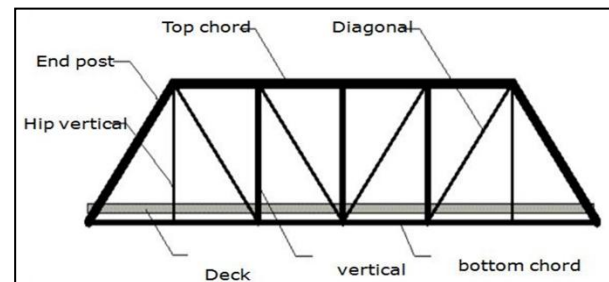


Fig 5 Bridge Details

### Members Used for Analysis

- Top Chord - ISMB 600
- End Post - ISMB 600
- Hip Vertical – ISMC 250
- Vertical - ISMC 250
- Bottom Chord - ISMB 600
- Diagonal - ISMC 250

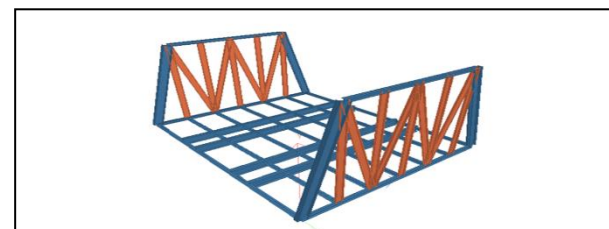


Fig 6 Pratt Truss

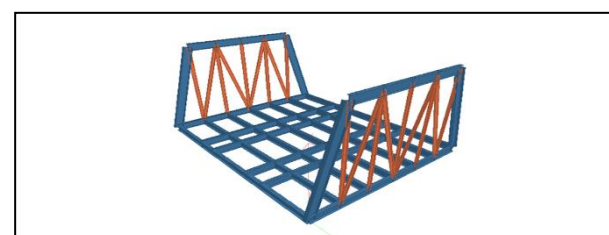


Fig 7 Howe Truss

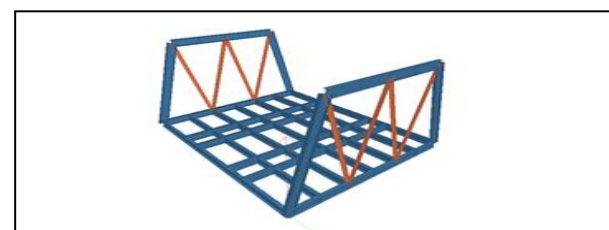


Fig 8 Warren Truss

#### 4. Analysis of bridge

The present research focuses on the analysis and design of truss bridge structures using STAAD Pro software, a widely utilized tool for structural engineering and analysis. The study considers a truss bridge with a total span length of 366 meters and a width of 7.6 meters, ensuring a realistic and practical representation for bridge applications. For seismic analysis, the bridge is designed based on the specifications outlined in IS 1893 (Part III): 2016, which provides the criteria for earthquake-resistant structures in India. Seismic Zone III is considered for this analysis, representing a moderate seismic hazard level that is common in many parts of the country. The dynamic response of the bridge under seismic loading conditions is examined to ensure the structure's safety and performance during earthquake events.

Wind analysis is conducted in accordance with IS 875 (Part III): 2015, which details the guidelines for wind loads on structures. This analysis helps evaluate the impact of wind forces on the bridge, ensuring stability and durability under varying wind conditions. To provide a comprehensive comparison, the study examines three common truss configurations: the Warren truss, the Pratt truss, and the Howe truss. Each of these truss types has unique characteristics that influence their structural behavior under static and dynamic loading conditions. The performance of these configurations is assessed and compared to identify the most efficient truss design for the given bridge dimensions and loading criteria. For the dynamic analysis, the bridge's response to real-world earthquake events is simulated using data from the 2001 Bhuj earthquake. This earthquake, which had a magnitude of 7.7 and caused significant damage in the Gujarat region of India, is used as a benchmark for evaluating the dynamic performance of the truss bridge. The seismic details of the Bhuj earthquake, including its intensity, duration, and ground motion characteristics, are incorporated into the analysis to provide realistic insights into the bridge's behavior under similar seismic conditions. This research aims to provide a detailed understanding of the structural behavior of different truss configurations under dynamic and static loading conditions, contributing to the development of optimized and resilient bridge designs.

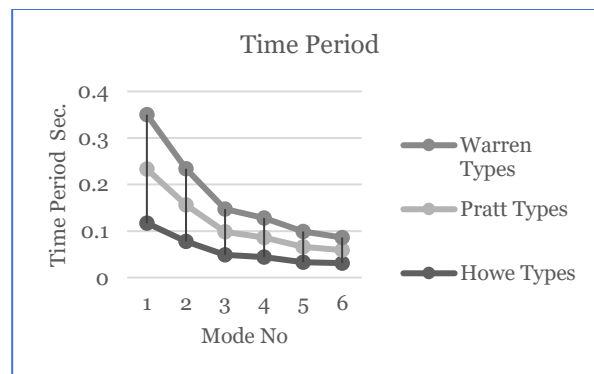
#### 5. Bhuj Earthquake

The Bhuj region is identified as a high-seismic-risk zone according to the IS 1893 Building Code for India, which provides guidelines for earthquake-resistant structures. On January 26, 2001, at approximately 8:46 a.m. (IST), the western Indian state of Gujarat experienced a devastating earthquake. According to estimations by the US Geological Survey (USGS), the earthquake had a magnitude of 7.9 on the Richter scale. Peak ground acceleration (PGA) recorded near Bhuj was approximately 0.3g. The earthquake's focus was relatively shallow, estimated at approximately 16 km below the surface. The epicenter was located near the town of Bhuj in the Kutch region of Gujarat, an area known for its susceptibility to seismic activity. Over 20,000 lives were lost, more than 150,000 people were injured, and thousands of buildings were damaged or destroyed.

Using the seismic data from this event, a time history analysis was performed to evaluate the dynamic response of structures. The analysis included determining the time period and natural frequency of the bridge under the influence of the Bhuj earthquake. The results of this dynamic analysis are presented and discussed in the table 2.

**Table 2. Time Period**

<b>Time Period</b>			
<b>Mode</b>	<b>Howe Types</b>	<b>Pratt Types</b>	<b>Warren Types</b>
1	0.117	0.116	0.117
2	0.078	0.078	0.078
3	0.049	0.049	0.049
4	0.044	0.042	0.042
5	0.033	0.033	0.033
6	0.031	0.028	0.027



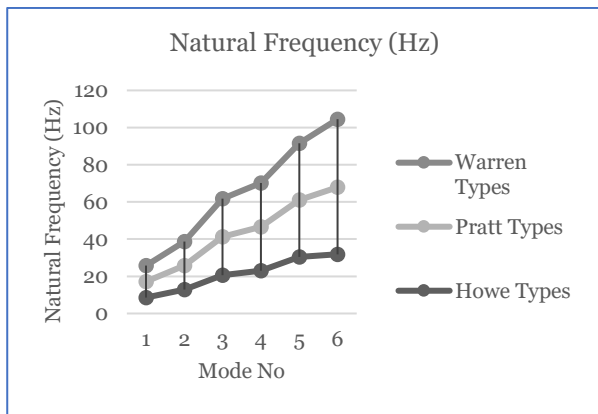
**Graph 1 Time Period Results**

The above graph shows the results of a time period for nonlinear dynamic analysis. The time period of a structure is its natural period of oscillation when

subjected to ground shaking in the event of an earthquake. So, according to the analysis, Warren type of bridge has less time period than Pratt and Howe than 5-10%, so Warren type of truss is economic.

**Table 3 Natural Frequency (Hz)**

<b>Natural Frequency (Hz)</b>			
<b>Mode</b>	<b>Howe Types</b>	<b>Pratt Types</b>	<b>Warren Types</b>
1	8.565	8.595	8.576
2	12.891	12.892	12.885
3	20.591	20.592	20.59
4	22.972	23.665	23.605
5	30.484	30.52	30.472
6	31.861	36.03	36.618

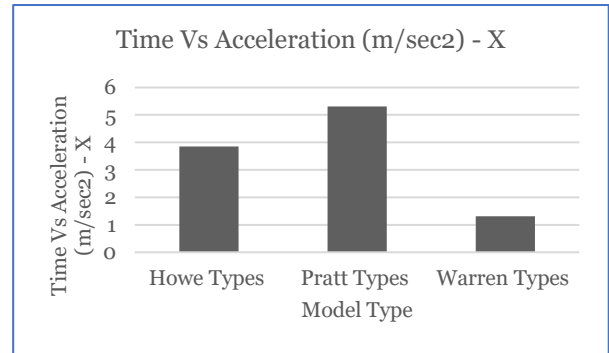


**Graph 2 Natural Frequency (Hz)**

The above graph shows the results of a Natural Frequency for nonlinear dynamic analysis. The natural frequency of a structure is the rate of the exchange of kinetic and potential energy within the structure. So, according to the analysis, Warren type of bridge has high Natural Frequency than Pratt and Howe than 5-10%, so Warren type of truss is economic.

**Table 4 Time Vs Acceleration (m/sec<sup>2</sup>) – X**

<b>Time Vs Acceleration (m/sec<sup>2</sup>) - X</b>		
<b>Howe Types</b>	<b>Pratt Types</b>	<b>Warren Types</b>
3.85	5.31	1.31

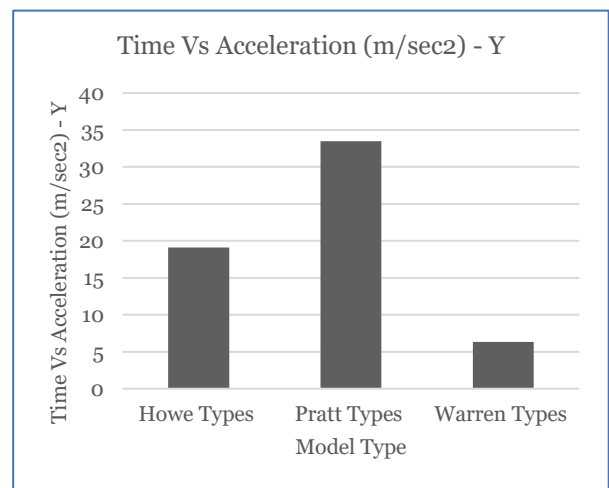


**Graph 3 Time Vs Acceleration (m/sec<sup>2</sup>) – X**

The above graph shows the results of a Time Vs Acceleration for X direction for nonlinear dynamic analysis. The results of a Time Vs Acceleration X direction is less for warren type of truss.

**Table 5 Time Vs Acceleration (m/sec<sup>2</sup>) – Y**

<b>Time Vs Acceleration (m/sec<sup>2</sup>) - Y</b>		
<b>Howe Types</b>	<b>Pratt Types</b>	<b>Warren Types</b>
19.1	33.5	6.33

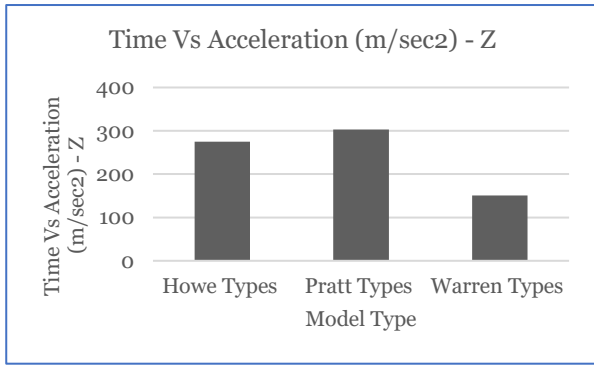


**Graph 4 Time Vs Acceleration (m/sec<sup>2</sup>) – Y**

The above graph shows the results of a Time Vs Acceleration for Y direction for nonlinear dynamic analysis. The results of a Time Vs Acceleration Y direction is less for warren type of truss.

**Table 6 Time Vs Acceleration (m/sec<sup>2</sup>) – Z**

<b>Time Vs Acceleration (m/sec<sup>2</sup>) - Z</b>		
<b>Howe Types</b>	<b>Pratt Types</b>	<b>Warren Types</b>
19.1	33.5	6.33



**Graph 5 Time Vs Acceleration (m/sec<sup>2</sup>) –Z**

The above graph shows the results of a Time Vs Acceleration for Z direction for nonlinear dynamic analysis. The results of a Time Vs Acceleration Z direction is less for warren type of truss.

### 6. Design of Warren

After the static and dynamic analysis of the different types of bridge, it is concluded that the warren type of truss is more economical than the pratt and Howe types of truss. The analysis should recommend the warren type of truss for the railway bridge on the Bhima River. Then it is necessary to design Warren Bridge.

**Table 7 Bridge Details for design**

Sr. No	Description
1	Span of Bridge 12.5m
2	Width of Bridge 15m
3	Lanes 2 Lanes
4	Total Height 7.5 m
	Slab thickness
5	(average) 0.26m
6	Type of Loading IRC class A Train
	EQ+WL+DL+THER
7	Loads MAL
	III (IS 1893:2016
	(Part1) Table 3,
8	Seismic zone Clause 6.4.2)
9	Location Pune (Annex E)
	0.16 (IS 1893:2016
	Zone factor (Z) (Part1) Clause
10	6.4.2.1)
11	Type of soil Medium Soil
	5 % 16 (IS 1893:2016
12	Damping (Part1) Clause 7.2.4)
	Response
	reduction 5
	factor(R)
	Importance
13	factor (I) 1.5

Member Name	Before Design	After Design
<b>Top Chord</b>	ISMB 600	ISHB 200
<b>End Post</b>	ISMB 600	ISHB 200
<b>Bottom Chord</b>	ISMB 600	ISWB600H
<b>Diagonal</b>	ISMC 250	ISHB200

### 7. Conclusion

The Warren truss demonstrated significantly lower displacement compared to the Howe truss (76.51% less) and the Pratt truss (64.77% less), making it structurally more stable under static loading conditions.

The Warren truss exhibited a 12.9% shorter time period and a 15.32% higher natural frequency compared to the Howe truss. Similarly, it showed a 3.57% shorter time period and a 1.58% higher natural frequency compared to the Pratt truss.

In terms of time vs. acceleration performance, the Warren truss demonstrated 65.97% lower acceleration than the Howe truss and 75.32% lower acceleration than the Pratt truss.

For time vs. displacement, the Warren truss displayed 14.64% less displacement compared to the Howe truss and 33% less displacement compared to the Pratt truss.

Based on Structural Design Improvement, the Warren truss was selected for design optimization. The self-weight of the truss was reduced from 324 kN (before design) to 278 kN (after design), reflecting an efficient design modification.

### Acknowledgement

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### Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

### Author Contribution

*The Mr. Khan Mohammadahmed Habib* Conducted the numerical modelling, dynamic analysis, and simulations of the truss bridge structures and *Dr. R. M. Desai*. Conceptualized the research problem, designed the study, and provided guidance throughout the work *Dr. S.P. Patil* Analysed the results, prepared the figures and

tables, and reviewed the manuscript for technical accuracy.

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#### **Standard Codes**

- [20] IS: 875-2015 Wind Loads on Buildings and Structures
- [21] IS 1893 – 2002 Earthquake Resistant Design of Structures
- [22] IS 800 (2007) Code for general construction in steel structures.
- [23] IRC-24-2001 for the design of steel or wrought iron bridges carrying rail
- [24] **IRC Class A- Loads Considered for Design of Bridge Structures**