Analysis on the Influencing Factors of Fatigue Damage in Truss Bridge

Jiaming Liu *

Chang' an Dublin International College of Transportation, Chang'an University, Xi'an, China

* Corresponding Author Email: 15050140124@xs.hnit.edu.cn

Abstract. Truss bridges are susceptible to fatigue damage due to long-term exposure to external factors. This article mainly analyzes the influencing factors of fatigue damage in truss bridges, including load factors and joint factors. The analysis results indicate that load factors have a significant impact on the fatigue damage of truss bridges. Vehicle loads can cause deformation and stress concentration in bridge structures, leading to the generation of shear stress, which in turn triggers the expansion of stress concentration areas and accumulation of fatigue damage in bridge materials. Additionally, improper vehicle operation, such as overloading, can increase the dynamic strain on the bridge deck, causing deformation and fatigue damage to the main girders. As for joint factors, joints are one of the critical areas for fatigue damage in truss bridges. Stress concentration and deformation at joints increase the risk of fatigue crack formation and propagation. In this way, the life and safety of the bridge can be assessed, and appropriate maintenance and repair measures can be taken to improve the fatigue resistance of the bridge and ensure its safe operation.

Keywords: Truss bridge; fatigue damage; welded joints; vehicle load.

1. Introduction

With the continuous advancement in bridge engineering design and technology, the scale of construction is increasing, and large-scale bridges play a vital role in the national economy and social life. However, due to the long-term exposure of bridge structures to various external factors, they often operate in harsh working conditions, making them vulnerable to the risk of fatigue damage. As revealed by the sudden collapse of the I-35W Bridge in Minneapolis, Minnesota, USA, spanning the Mississippi River in 2007, this tragedy resulted in 145 injuries and 13 deaths [1]. Post-investigation found that the I-35W Bridge had suffered from fatigue damage in certain structures due to a lack of sufficient bridge maintenance during its service life. These damages gradually worsened over the years, ultimately leading to the disaster.

Truss bridges, as an important form of bridges, are characterized by their lightweight, high stiffness, and high strength, and are widely used in highway and railway transportation systems. Therefore, research on the fatigue resistance performance of truss bridges is particularly important. Only by ensuring that bridge structures can effectively withstand fatigue damage can the safe operation of bridges be guaranteed. The structure of a truss bridge determines its influence to fatigue loads during using phase. Compared to static loads, fatigue loads have the characteristics of periodicity and variability, which can lead to cumulative fatigue damage in the structure under long-term repetitive loading [2]. This cumulative fatigue damage may manifest as the generation and propagation of cracks, ultimately resulting in structural failure and collapse [3, 4]. Therefore, it is crucial to analyze and evaluate the fatigue resistance performance of truss bridge structures.

By conducting in-depth research on the fatigue behavior and fatigue performance of truss bridges, it is possible to effectively evaluate the lifespan and safety of bridges and implement appropriate maintenance and repair measures to extend the service life of bridges. This article will analyze the influencing factors of two types of fatigue damage and analyze the fatigue performance of truss bridge structures based on actual bridge engineering cases. Through the analysis presented in this paper, scientific foundations can be provided for the design and maintenance of truss bridges, improving their fatigue resistance performance and ensuring the safe operation of bridges.

2. Load Factor

Truss bridges experience forces from vehicles, pedestrians, and other loads during operation. These loads induce dynamic responses in the bridge structure, leading to stress concentration and strain accumulation. With repeated application of loads, these stresses and strains gradually accumulate, resulting in the formation and propagation of fatigue cracks, ultimately leading to fatigue failure of the bridge.

Shear stress is one of the important factors contributing to fatigue damage in bridges. During the operation of a bridge, vehicle loads because deformation and stress concentration in the bridge structure, resulting in the generation of shear stress. These shear stresses lead to the expansion of stress concentration zones and the accumulation of fatigue damage in the bridge material. According to the research conducted by GAO Et Al. [5], Fig. 1 shows the distribution of selected fatigue hotspots in the experiment. The obtained shear stress history curve is shown in Fig. 2.

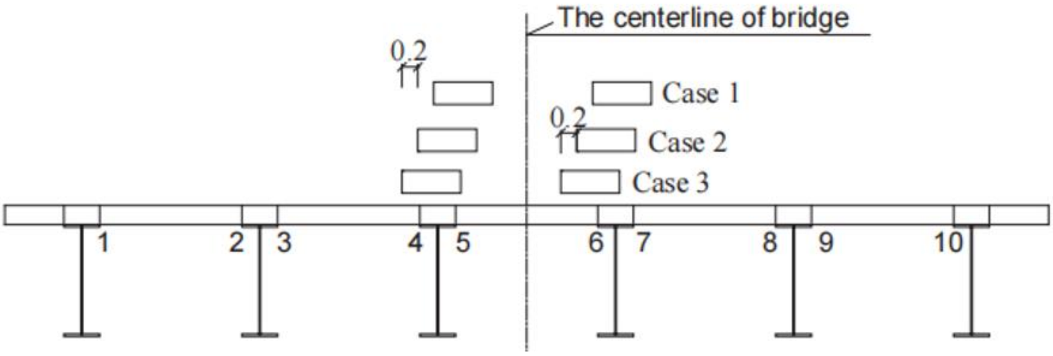
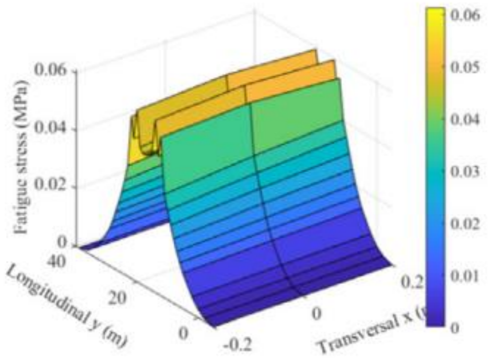
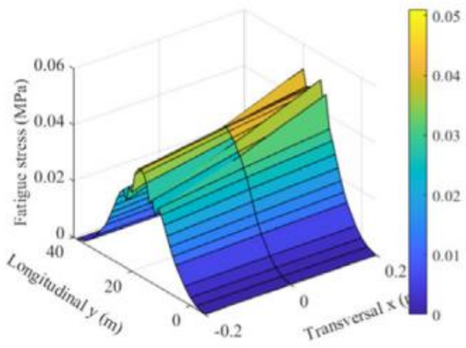


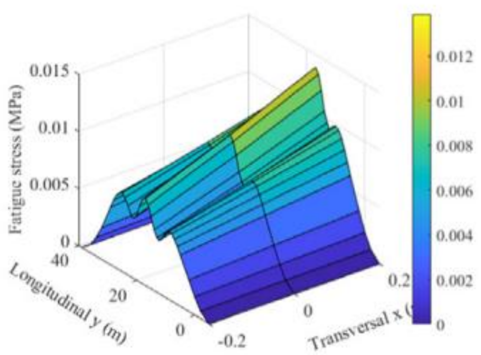
Fig. 1 Distribution of fatigue concern points [5].



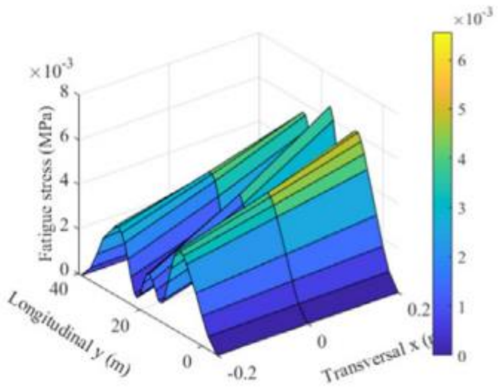
(a) Point 6



(b) Point 7



(c) Point 8



(d) Point 9

Fig. 2 Shear stress at various positions due to vehicles in JTG D64 [5].

In Fig. 2, the X-axis of the coordinates represents the lateral distance of the focal points from the centerline of the bridge, while the Y-axis represents the longitudinal distance from the fatigue center point to the left end of the bridge. By comparing the four plots, it can be observed that the shear stresses at points 6 and 7 are higher than those at points 8 and 9. The reason behind this difference may be attributed to variations in the positions of the vehicle tire loads. Standard fatigue vehicles tend to apply lateral loads closer to the centerline of the bridge, while points 6 and 7 are located near the bridge's centerline. Therefore, when the standard fatigue vehicle passes over the bridge deck, points 6 and 7 experience more direct wheel loading. Additionally, the longitudinal position of the wheels also affects the stress generation. When the wheels are closer to the mid-span position of the bridge, shear stresses increase. As points 6 and 7 are relatively closer to the mid-span position compared to points 8 and 9, the influence of the load is more pronounced, indicating that the bridge is more prone to fatigue damage in these areas. Hence, in practice, it is necessary to pay more attention to the fatigue condition of the interfaces on the lane lines that directly bear vehicle loads.

On the other hand, due to the loading of vehicles near the mid-span of the bridge, the bridge structure undergoes significant dynamic responses, resulting in shear stress concentration at specific fatigue hotspots. These hotspots may include bolt connections, welds, or other vulnerable areas within the bridge structure. Increased shear stress makes it more susceptible to the initiation and propagation of fatigue cracks. Furthermore, as vehicles pass over the bridge, the loads act repetitively on the bridge structure. This repetitive loading leads to the accumulation of stress and strain, gradually weakening the strength and toughness of the bridge material, thereby accelerating the propagation of fatigue cracks and fatigue failure of the bridge. The mechanism behind bridge fatigue damage caused by partial load factors is illustrated in Fig. 3.

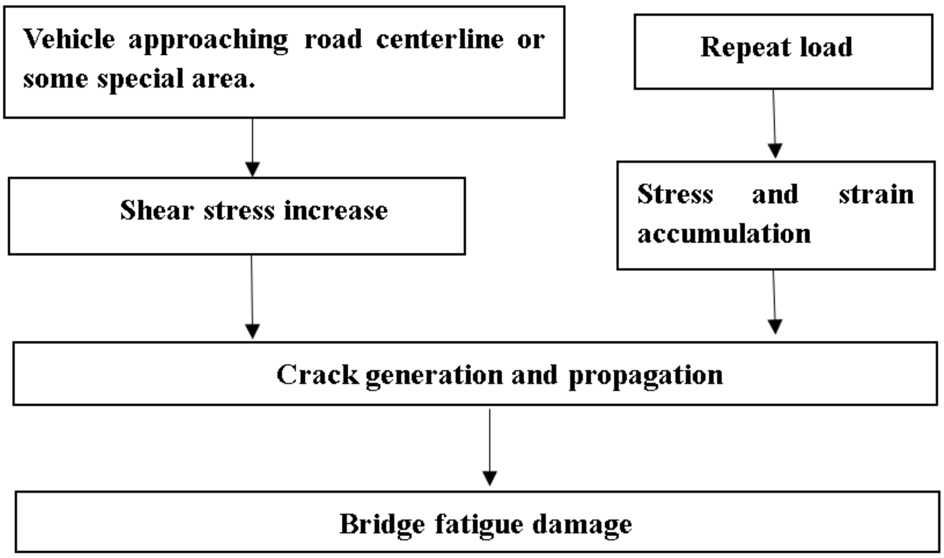


Fig. 3. The mechanism of fatigue damage of bridges caused by partial load factors

Improper vehicle operation during travel can have a significant impact on bridge fatigue damage, such as overloading. Zeng pointed out that overloaded vehicles can significantly increase the dynamic strain on bridge pavements [6]. Table 1 presents the experimental results of dynamic strain peak under 100kN and 130kN axial load.

Table 1. Comparison date of dynamic strain peak under 100KN and 130KN axial load [6].

NO.of Strain guage		1		3		5		24		26		28	
Strain peak (με)		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Axle load	130KN	11	-101	175	-39	221	-50	306	-52	153	-122	22	-182
	100KN	11	-73	102	-32	217	-44	285	-35	140	-76	19	-137
Increase proportion(%)		3	38.1	72.4	21.8	1.6	12.4	7.3	47.2	9.5	60.4	19.8	32.8
Average value(%)		27.2											

The data above indicates that compared to a 100kN axle load, the dynamic strain on the bridge pavement increased by 27.2% with a 130kN axle load, which increases the risk of fatigue damage to the bridge structure. Therefore, dynamic strain is one of the main factors leading to fatigue failure. Wu also explained in the article that overloading has a significant impact on the deformation of bridge girders [7]. In the study, it was found that under the presence of overloaded vehicles, the actual maximum dynamic deflection of the bridge girders exceeded their design maximum dynamic deflection. Wu combined this result with fatigue residual deformation and used a formula to calculate the predicted value of the girder deflection under the condition of overloaded vehicles and 2 million repeated loadings [7]. The predicted value was then compared with the standard value, and the comparison results are shown in Fig. 4.

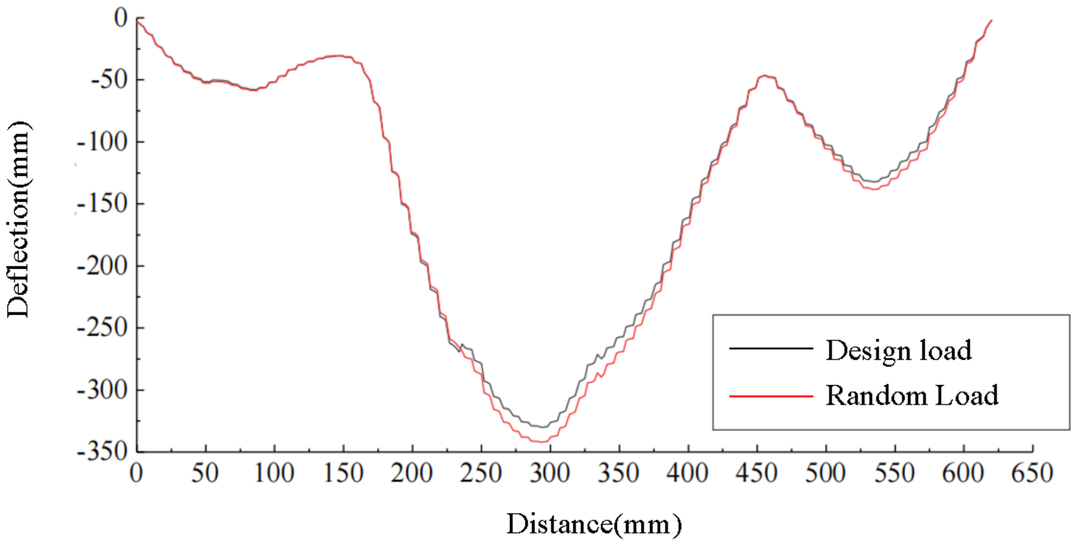


Fig. 4 Long-term deflection variation diagram of main beam under repeated interactions of random vehicle and design vehicle loads [7].

It can be observed from Fig. 4 that under the condition of vehicle overloading, the actual maximum deflection of the bridge exceeds its design deflection value, with the mid-span position of the bridge being the most critical. This illustrates that poor driving behavior exacerbates the fatigue damage to the bridge. Therefore, in order to ensure the safety of bridge structures and prolong their service life, relevant authorities should pay attention to such issues, and it is necessary to impose strict restrictions on overloaded vehicles.

3. Joint Factor

Joints play a crucial role in truss bridges as they are the critical locations where the connecting components of the truss bridge structure come together. During the design and fabrication of truss bridges, special attention needs to be given to the welding quality and fatigue performance of the joints. According to Cui et al. [8], joints, being the connecting points of the truss bridge structure, bear the load transfer and stress concentration from the truss members. The deformation and load distribution of the connecting components at the joints result in stress concentration at the welding joints and connection areas, thereby increasing the risk of fatigue crack initiation and future propagation. This significantly reduces the fatigue life of the welding joints and can even lead to fatigue fracture, as confirmed by Wei [9].

In addition, the panel points in truss bridges may have welding defects such as porosity, cracks, and inclusions. These welding defects can significantly reduce the strength and fatigue life of the welded joints at the panel points, increasing the risk of fatigue damage. These welding defects can serve as initiation points for fatigue cracks, which gradually propagate under cyclic loading, ultimately leading to fatigue failure of the structure.

During the operational phase of a truss bridge, fatigue analysis of the panel points is particularly important. Hu conducted a fatigue damage analysis on the welded joints of the truss bridge using the WeiLai High-Speed Railway Bridge over the Qingrong Railway as an example [10]. The study found that under track irregularities, there is an increase in local stress response and fatigue damage at the bridge's panel points. Specifically, the fatigue damage of the panel points increased under track irregularities, and the reasons for this fatigue damage may include the following points:

The unevenness of the railway track can cause local stress concentration at the welded joints of the bridge. Over time, repeated loading from passing trains can lead to the formation and propagation of fatigue cracks starting from these welded joints.

The unevenness of the railway track can potentially cause resonance of the bridge at specific frequencies, amplifying the dynamic response of the structure. Resonance can significantly increase the stress levels in bridge components, making them more susceptible to fatigue damage. It is crucial to identify and mitigate the resonance effect through appropriate damping and structural modifications to reduce the risk of fatigue damage.

Fatigue accumulation: The unevenness of the railway track results in the continuous cyclic loading of the bridge structure. As trains pass over the track irregularities multiple times, fatigue damage accumulates over time.

This is not limited to the welding joints alone. The unevenness of the railway track can also cause vibrations in the bridge's supports and foundations. Prolonged exposure to stress concentration in these areas can lead to material fatigue and eventual fatigue damage in various components. Based on the above analysis, it is recommended to consider fatigue damage caused by track irregularities in the fatigue analysis of truss bridges used in railway applications.

4. Conclusion

This article analyzes the factors influencing fatigue damage in truss bridge structures and draws the following conclusions:

(1) The generation and propagation of fatigue cracks are one of the causes of fatigue damage in truss bridges. The fatigue damage in truss bridges is influenced by shear stresses. Vehicle loads cause deformation and stress concentration in the bridge structure, resulting in shear stresses. These shear stresses lead to the expansion of stress concentration areas and the accumulation of fatigue damage. Additionally, repeated loading from vehicles results in the accumulation of stress and strain, accelerating crack propagation and causing fatigue damage in truss bridges.

(2) Overloading driving can significantly increase the dynamic strain of bridge deck pavement, thereby increasing the risk of fatigue damage to bridge structures.

(3) Stress concentration at the panel points significantly increases the risk of fatigue crack initiation and propagation. Track irregularities are a concern as they cause an increase in local stress response and fatigue damage at the bridge's panel points. Additionally, the resonance effect and fatigue accumulation caused by track irregularities further exacerbate the fatigue damage at the panel points.

Although some conclusions have been drawn regarding the factors influencing the fatigue performance of truss bridges, there are still limitations and areas that hold promise for further exploration. Firstly, there is relatively limited research on the joint factors and shear stress factors. While the critical importance of joints in the fatigue performance of truss bridges is recognized, there are challenges in providing anti-fatigue protection at the joints. Future research should delve deeper into the fatigue behavior of joints and optimize the design of joint connections to enhance their fatigue strength and durability. Secondly, with the continuous development and innovation of science and technology, such as the use of new materials and novel connection techniques, there is a need for more in-depth research on the fatigue performance of these new technologies. This will help guide the design, construction, and maintenance of new-generation truss bridges, making them more sustainable and reliable in terms of fatigue performance.

References

[1] Liu Weihua and a Ruimei. Analysis of the Causes of I-35W Bridge Collapse in the United States.Journal of China and Foreign Highway, 2011, 31(03):114-118.

[2] Lin Mei. Research on Fatigue Performance and Residual Life of Steel Bridge. Lanzhou University of Technology ,2011.

[3] Dai Li, Liu Qiang, Ma Kezheng, et al. Experimental Study on Fatigue of Full-Scale Cracked Joint of Steel Truss Bridge Beams. Journal of Wuhan University of Technology (Transportation Science & Engineering Edition), 2021, 45(02):308-311.

[4] Tan Jinhua, Zeng Guoliang and Ma Kailong. Research on Fatigue Crack Prevention and Control Methods for Steel Truss Bridges. Journal of Wuhan University of Technology (Transportation Science & Engineering Edition), 2019, 43(04):601-604.

[5] Qingfei Gao, Ziliang Dong, Kemeng Cui, Chenguang Liu, Yang Liu, Fatigue performance of profiled steel sheeting–concrete bridge decks subjected to vehicular loads, Engineering Structures, Volume 213,2020, 110558

[6] Zeng Guodong. Research on Evaluation of Influence Factors on Mechanical Behavior and Fatigue Performance of Steel Bridge Deck Pavement. South China University of Technology, 2020.

[7] Wu Tong. Analysis of the Impact of Vehicle Overloading on Bridge Structure and Service LifeShijiazhuang Tiedao University, 2020.

[8] Cui Chuang, Zhang Qinghua, Bao Yi, et al. Fatigue performance and evaluation of welded joints in steel truss bridges. Journal of Constructional Steel Research, 2018, 148: 450-456.

[9] Xing Wei, Lin Xiao, Shiling Pei, Fatigue assessment and stress analysis of cope-hole details in welded joints of steel truss bridge, International Journal of Fatigue, 2017, 100(1): 136-147.

[10] Hu Chunjian, Sun Hongbin, Lu Dazhi, et al. Fatigue Analysis of Railway Steel Bridges Considering Vehicle-Structure Interaction and Environmental Corrosion. Journal of Railway Science and Engineering, 2023:1-11.