STRUCTURAL RESPONSE OF BAILEY BRIDGE SPANS UNDER MOVING VEHICLE LOADS

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Abstract

Bailey truss bridges are commonly used as temporary structures in emergency traffic situations, such as rescue operations and the repair of aging bridges. Studying the impact of load velocity on bridge structures is essential for determining appropriate operational conditions. This article examines the effect of vehicle speed on the internal forces of truss members and the deflection of the bridge span. The study employs the finite element method using SAP2000 software, the moving load model has an axial load diagram of the real truck. The results indicate that vehicle velocity has a minimal impact on the internal forces of the truss members and the deflection of the bridge spans. Based on these findings, suitable vehicle velocity regulations can be established to optimize traffic flow across the bridge when necessary.

***Keywords**: Bailey bridge; dynamic coefficient; vehicle speed; moving load; structural response; axial force.*

1. Introduction

Bailey truss bridges are commonly used as temporary structures in emergency traffic situations, such as repairing aging bridges, supporting rescue operations during natural disasters like storms and floods, and serving national defense and security missions. Temporary bridges often have velocity limits, which impact traffic flow. In many cases, increasing vehicle speed over the bridge is necessary to prevent congestion caused by high traffic volumes. Therefore, studying the impact of vehicle speed on the load-bearing capacity of the bridge is essential for developing appropriate operational strategies.

Numerous studies have been conducted on the dynamic effects of moving loads on bridge structures [1]-[4]. However, no research has specifically focused on Bailey truss bridges. This article examines the influence of vehicle speed on axial forces in truss members and the deflection of the bridge span. The findings will provide a scientific basis

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for evaluating the operational capacity of this type of bridge, particularly in assessing its ability to handle traffic when used as a temporary structure in critical situations.

2. Model for determining the internal forces of truss members and the deflection of Bailey bridges under dynamic load effects

2.1. Introduction to the model

The dynamic response analysis of general bridge structures and Bailey bridges under the effect of moving vehicles is a complex problem. The interaction between the vehicle and the bridge occurs at the contact points between the wheels and the bridge surface. The vibration of the bridge is induced by the load exerted by the vehicle.

According to [5], various models have been developed to analyze the oscillation of bridge span structures under moving load effects, ranging from simple to complex. These include: models that consider only the velocity of the load while ignoring the bridge mass and inertia forces; models that disregard bridge mass but account for inertia forces and velocity; and models that incorporate both the velocity and mass of the load, as well as moving loads that consider the bridge mass.

The model used in this study is a complex one, but it most accurately represents real-world conditions. It accounts for both the velocity and mass of the load, as well as the bridge mass when analyzing the moving load effects (Fig. 1).

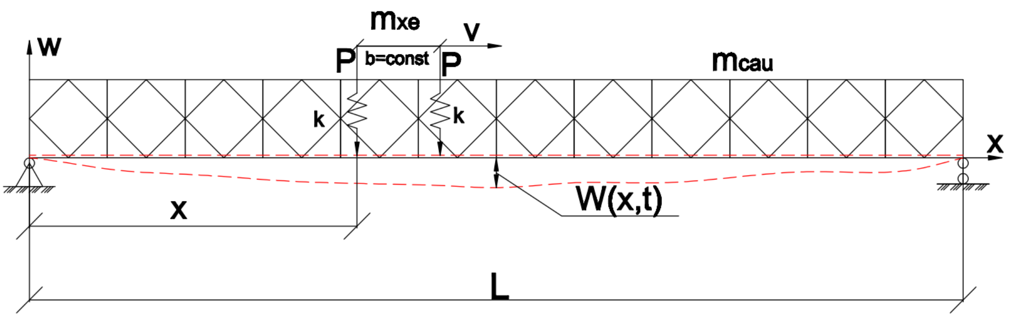

Fig. 1. Interaction model between the Bailey steel truss bridge and the moving vehicle load.

In Fig. 1, P is the gravity of the moving load (N); b is the distance between the two axles and its value is constant; v is the velocity of the moving load (m/s); m_{xe} is the mass of the moving load (kg), m_{cau} is the mass of the span structure (kg); t is the instantaneous time (s).

The motion equation of the system can be rewritten as follows:

$$M_{xe} \cdot W_{xe}^{''} + K_{xe} \cdot W_{xe}^{'} + C_{xe} \cdot W_{xe} = P_{xe}(t) \quad (1)$$

$$M_{cau} \cdot W_{cau}^{''} + K_{cau} \cdot W_{cau}^{'} + C_{cau} \cdot W_{cau} = P_{cau}(t) \quad (2)$$

in which M_{xe} and M_{cau} are the mass matrices of the vehicle and bridge, respectively.

K_{xe}, K_{cau} are the stiffness matrices of the vehicle and bridge respectively; C_{xe}, C_{cau} are the resistance matrices of the vehicle and bridge respectively; P_{xe}, P_{cau} are the forces acting on the vehicle and bridge respectively; W_{xe}, W'_{xe} and W''_{xe} are the displacement, velocity and vertical acceleration of the vehicle; W_{cau}, W'_{cau} and W''_{cau} are the displacement, velocity and vertical acceleration of the bridge.

Based on the above theory, the author developed a dynamic interaction model between the Bailey steel truss bridge structure and the vehicle using the finite element method. The model was implemented and analyzed using SAP2000 software to solve the problem. Due to the limited scope of the article, the survey results are presented using theoretical analysis conducted with SAP2000 software. In this study, the model supported in SAP2000 is used, so the load model is a moving load model but the axle load diagram is that of an actural truck.

2.2. Basic data of Bailey steel truss bridge and vehicle load moving on the bridge

According to [6], [7], the Bailey steel truss bridge structure is assembled from panel frames, each measuring 3.055 m in length and 1.5 m in height, and made of steel. The structure has a cross-section that is symmetrical about the central axis along the length of the bridge.

The Bailey bridge can be assembled in various cross-sectional configurations and span lengths, depending on the number of panel frames used. The cross-section and dimensions of the truss bars are shown in Tab. 1.

Tab. 1. Structure of bars in Pano frame

No.	Name of chord	Shape, dimension (mm)
1	Upper chord	2 shape steel C 105 × 48 × 5
2	Vertical chord	Shape steel C 78 × 38 × 5
3	Diagonal chord	Shape steel C 75 × 35 × 4
4	Lower chord	2 shape steel C 105 × 48 × 5

To investigate the impact of vehicle velocity, the authors selected the commonly used cross-section type of Bailey bridge, often employed as a temporary structure - type 1/1. This type features a single truss plane on each side, with each truss plane consisting of only one panel frame floor. It is chosen because it has the simplest structure, the fastest assembly time, and is suitable for emergency traffic situations. The bridge has a width of B = 4.2 m and is designed for one lane.

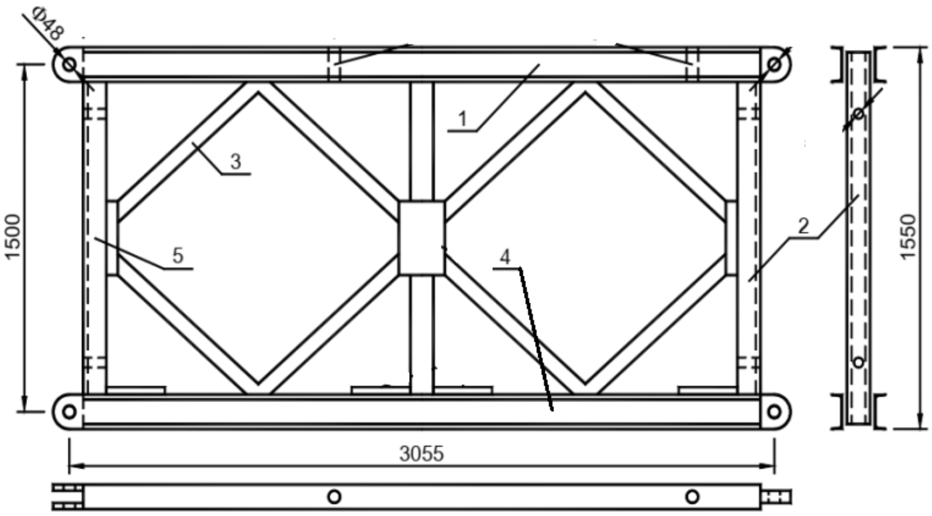

Fig. 2. Panel frame of Bailey steel truss bridge.

To ensure reliability, two structural span length options were selected for investigation:

- Option 1: L = 18.29 m, consisting of 6 bays.
- Option 2: L = 27.43 m, consisting of 9 bays.

According to the load table of Bailey bridge in [5], [6], this type of bridge structure can withstand a load from 11 tons to 27 tons depending on the traffic level, whether it is safe or careful. Based on the types of trucks commonly used in our country today, and to match the load specified for the above type of structure, the load chosen for the survey is the Kamaz 4326 truck, the total weight of the vehicle and the maximum cargo is 12.3 tons [8]. The vehicle consists of 4 axles, 2 axles in the front and 2 axles in the rear. The load of the 2 rear axles P_1 = 7.1 T or P_1 = 71 kN; the load of the 2 front axles P_2 = 5.2 T or P_2 = 52 kN. The distance between the two axles is l_{xe} = 4.2 m.

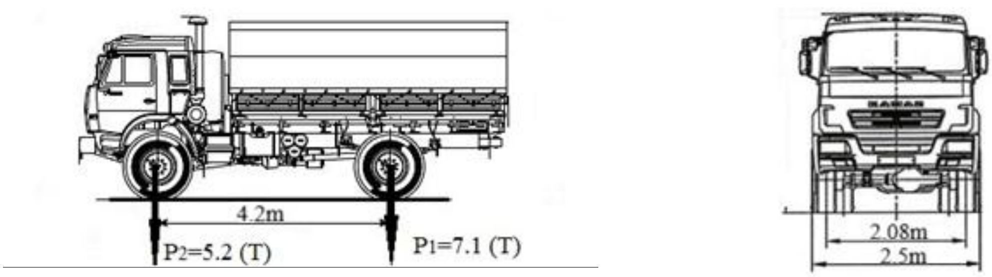

Fig. 3. Popular trucks in Vietnam.

With the Bailey bridge structure and vehicle load as described above, the influence of vehicle velocity on the axial force in the truss and the deflection of the span structure is investigated. To accurately reflect the performance of the model, the study considers velocity changes in the range of v = 2.5 m/s (9 km/h) to v = 20 m/s (72 km/h), as Bailey bridges are commonly used as temporary structures in emergency traffic situations, the vehicle velocity across the bridge is typically limited to less than 50 km/h.

2.3. Dynamic coefficient of Bailey steel truss bridge

The dynamic coefficient is denoted as (1 + IM) [9], [10], determined by the formula:

$$1 + IM = \frac{S_{d\max}}{S_{t\max}} \tag{3}$$

in which $S_{t\max}$ is maximum static internal force or static displacement, $S_{d\max}$ is maximum dynamic internal force or dynamic displacement, considered at the same position on the structure. Use formula (3) to calculate the dynamic coefficient of displacement at each node according to the vertical displacement at the lower and upper edges of the truss. The dynamic coefficient of the longitudinal force of the lower edge, upper edge, vertical bar and diagonal bar is also calculated according to this formula.

2.4. Application of finite element method on SAP2000 software for survey

To solve the problem of evaluating the dynamic impact of loads on the bridge span structure, as described above, the authors employed the finite element method using SAP2000 software [11]. The vertical bars, horizontal bars, and diagonal bars of the panel frame, along with the longitudinal and horizontal beams of the bridge deck system, are modeled using frame elements. The deck panels are modeled with shell elements. Each panel frame consists of rigidly connected bars, and the panel frames are articulated at the two ends of the upper and lower crossbars of each frame. The vertical, diagonal and edge members of the truss are considered as basic members subjected to tension, compression and bending simultaneously. The truck is modeled as a 4-axle load, the load of the vehicle acting on the bridge is transmitted through the wheels at the 4 axles, that is, transmitted through each wheel of the rear axle $\frac{P_1}{2} = 35.5$ kN, transmitted through each wheel of the front axle $\frac{P_2}{2} = 26$ kN.

Use the time history analysis function to enable the software to account for the effect of the load over time. Based on this, consider the impact of the moving load velocity on the internal force values of the truss and the vertical displacement of the bridge structure. Below are some images of the Bailey bridge model in SAP2000 software.

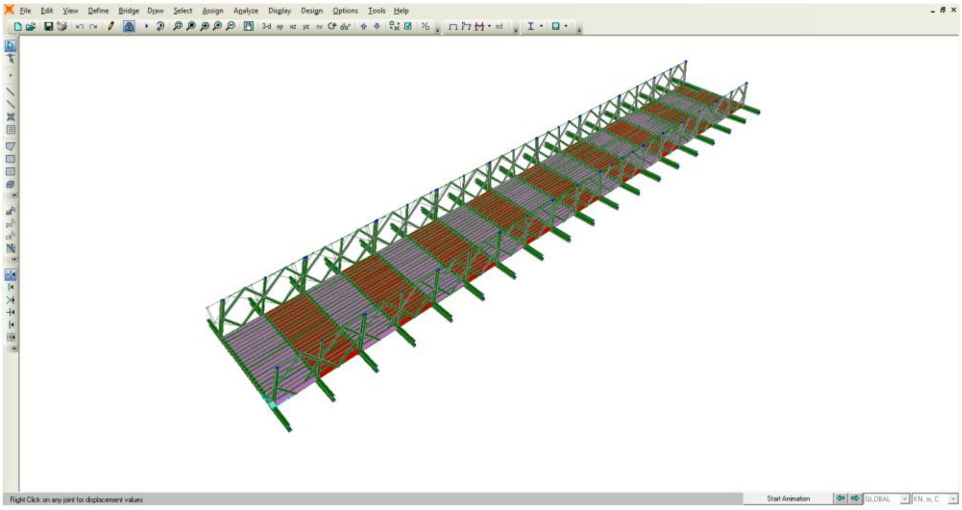

Fig. 4. Model of Bailey bridge.

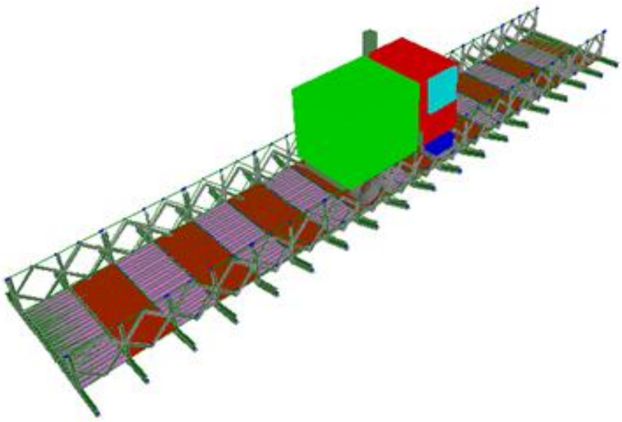

Fig. 5. Moving load on the bridge when using time history analysis.

2.5. Survey results

The survey results of the dynamic coefficient (1 + IM) for the vertical displacement and the axial force in the lower chord of the Pano frame, when the vehicle is moving at velocities ranging from v = 2.5 m/s (9 km/h) to v = 20 m/s (72 km/h), are presented in Tab. 2. In this table, the vehicle's velocity is considered zero when the dynamic effects of its movement are not taken into account.

In this article, only the results of the axial force analysis of the bottom chord in the truss compartment at the mid-span cross-section, as well as the deflection analysis at the same cross-section, are presented.

Table 2, 3 show the values of the axial force in the truss bars, the dynamic coefficient of the axial force, the displacement of the span structure, and the dynamic coefficient of the displacement for bridges with spans L = 18.29 m and L = 27.43 m. The obtained results include the time-dependent vertical force and displacement values. However, these graphs and data are considered intermediate results. The authors have chosen not to present these intermediate results, but instead to report only the final results- specifically, the maximum vertical force and displacement values corresponding to each velocity.

Tab. 2. Survey results of Bailey bridge L = 18.29 m

Name of factors	Velocity (m/s)								
	0	2.5	5	7.5	10	12.5	15	17.5	20
Maximum axle load (KN)	-152	-158	-161	-160	-162	-157	-165	-160	-159
Dynamic coefficient (1+IM) axle load	1.00	1.03	1.06	1.05	1.06	1.03	1.08	1.05	1.04
Maximum displacement (m)	-0.0138	-0.0140	-0.0141	-0.0143	-0.0143	-0.0141	-0.0147	-0.0143	-0.0142
Dynamic coefficient (1+IM) displacement	1.00	1.01	1.02	1.03	1.04	1.02	1.07	1.04	1.03

Tab. 3. Survey results of Bailey bridge L = 27.43 m

Name of factors	Velocity (m/s)								
	0	2.5	5	7.5	10	12.5	15	17.5	20
Maximum axle load (KN)	-244	-255	-257	-258	-250	-254	-264	-255	-264
Dynamic coefficient (1+IM) axle load	1	1.04	1.05	1.06	1.03	1.04	1.08	1.05	1.08
Maximum displacement (m)	-0.0405	-0.0413	-0.0416	-0.0422	-0.0408	-0.0429	-0.0439	-0.0432	-0.0430
Dynamic coefficient (1+IM) displacement	1	1.02	1.03	1.04	1.01	1.06	1.08	1.07	1.06

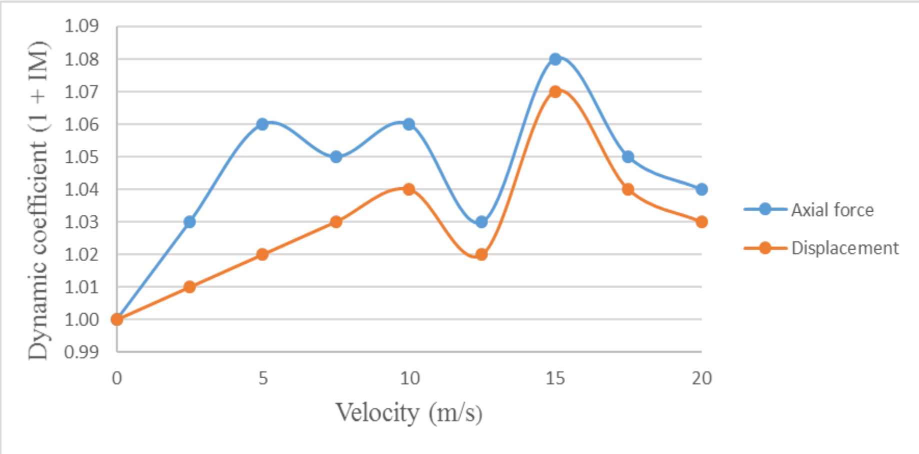

Fig. 6. Survey results of Bailey bridge L = 18.29 m, the variation of the dynamic coefficient (1 + IM) with changing velocity.

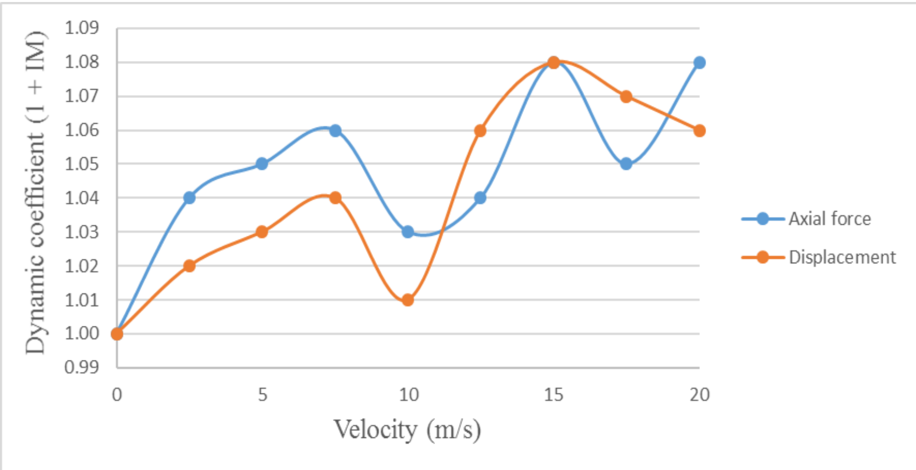

Fig. 7. Survey results of Bailey bridge L = 27.43 m, change of dynamic coefficient (1 + IM) when velocity changes.

Through the graphs in Figs. 6, 7, it can be seen that the dynamic coefficient of deflection is quite small. With length of bridge L = 18.29 m, L = 27.43 m, the values of this coefficient increase and decrease irregularly within the investigated load velocity range from v = 2.5 m/s (9 km/h) to v = 20 m/s (72 km/h), and range from 1.01 to 1.08. This indicates that the influence of load velocity on deflection is quite small for Bailey steel truss bridges.

This can be explained by the fact that the structure of the Bailey truss is relatively rigid, and the truss compartments are short, resulting in a small effect of the load on the dynamic coefficient of deflection. The graph shows that the largest value of this coefficient is 1.08, corresponding to a load velocity of 15 m/s (54 km/h).

The graphs in Figs. 6, 7 also demonstrate that the influence of the load velocity on the dynamic coefficient of the longitudinal force in the truss is similarly small. With length of bridge L = 18.29 m, L = 27.43 m, within the investigated load velocity range from v = 2.5 m/s (9 km/h) to v = 20 m/s (72 km/h), the values of this coefficient also increase and decrease irregularly, and range from 1.03 to 1.08. These results are entirely consistent with the findings published in [12] for other steel truss bridge models that are not Bailey steel trusses.

In the case of a moving load on a bridge with a length of L = 18.29 m, within the investigated load velocity range from v = 2.5 m/s (9 km/h) to v = 20 m/s (72 km/h), the internal force in the truss bars and the displacement of the span structure, when the vehicle moves at a speed of v = 10 m/s (36 km/h), are greater than the values of these parameters when the speed is v = 12.5 m/s (45 km/h). Similarly, in the case of a moving load on a bridge with a length of L = 27.43 m, within the investigated load velocity range from v = 2.5 m/s (9 km/h) to v = 20 m/s (72 km/h) the internal force in the truss bars and the displacement of the span structure, when the vehicle moves at a speed of v = 7.5 m/s (27 km/h), are greater than the values of these parameters when the speed is v = 10 m/s (36 km/h).

This demonstrates that the displacement of the structure is not entirely proportional to the speed of the moving load. This can be explained by resonance effects, as well as the position of the axial load during the vehicle's movement. Although the vehicle moves at a lower speed, it can generate greater internal forces and displacements in the structure if the axle is positioned in the middle of the span and resonance occurs. This result is consistent with the findings in [13] for other types of steel truss bridge models.

The above results show that the axial force in the truss and the displacement of the Bailey steel truss bridge span are not entirely proportional to the speed of the load. This finding also aligns with the conclusions and observations in publications such as [12], [13], even though the models in those studies involve different types of steel truss bridges, different loads, and different analysis methods. This suggests that the results of the analysis regarding the influence of vehicle speed on the axial force in the truss and the displacement of the Bailey bridge structure in this article are reliable.

3. Conclusion

The influence of the velocity of the moving load on the bridge on the deflection of the span structure and the stress in the truss bars of the Bailey steel truss bridge is not large. The deflection of the span structure and the stress in the truss bars are not proportional to the velocity of the moving load on the bridge. The results obtained are consistent with observations in other research studies, even though the models and methods used differ, indicating the reliability of the results.

For the Bailey steel truss bridge structure, within the investigated load velocity range from v = 2.5 m/s (9 km/h) to v = 20 m/s (72 km/h), the dynamic coefficient of the longitudinal force in the bars and the displacement ranges from 1.02 to 1.08. Thus, if necessary, based on the specific vehicle load and in comparison with the allowable load table (depending on the safe or careful operation level of this type of bridge), it is possible to increase the vehicle speed over the bridge to enhance traffic flow during operation, thereby reducing traffic congestion or addressing emergency situations.

This article focuses on investigating the theoretical influence of load velocity on the deflection and internal forces of the main truss of a Bailey steel truss bridge. Future studies will further develop this research direction, including an investigation of the impact of varying vehicle loads and experimental evaluations. The authors look forward to discussing this topic further with colleagues.

Acknowledgement

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References

[1] S. Sorrentino and G. Catania, “Dynamic analysis of rectangular plates crossed by distributed moving loads”, *Mathematics and Mechanics of Solids*, Vol. 23, Iss. 9, pp. 1291-1302, 2018. DOI: 10.1177/1081286517719120

[2] N. X. Toản, N. T. K. Loan và N. D. Thảo, “Phân tích hệ số động lực trong cầu giàn thép dưới tác dụng của tải trọng xe 3 trục mô hình 2 khối lượng”, *Tuyển tập Hội nghị khoa học toàn quốc lần thứ nhất về Động lực học và Điều khiển*, Đà Nẵng, ngày 19-20/7/2019, tr. 30-36, 2019. DOI: 10.15625/vap.2019000252

[3] N. X. Toản và N. T. K. Loan, “Ứng dụng phương pháp phần tử hữu hạn phân tích hệ số động lực của cầu dầm bê tông cốt thép dưới tác dụng của tải trọng xe thay đổi”, *Tạp chí Khoa học và Công nghệ - Đại học Đà Nẵng*, Vol. 20, No. 4, tr. 87-91, 2022.

[4] M. V. Le *et al.*, "Ensemble soft computing models for prediction of deflection of steel-concrete composite bridges”, *Arabian Journal for Science and Engineering*, Vol. 49, pp. 5505-5515, 2024. DOI: 10.1007/s13369-023-08474-5

[5] N. M. Hải, Đ. A. Tú, B. T. Thành và N. H. Thuấn, "Độ võng động của cầu giàn thép đường sắt dưới tác dụng của đoàn tàu: Kết quả nghiên cứu trên mô hình số và thực nghiệm hiện trường", *Tạp chí Khoa học Giao thông vận tải*, Số đặc biệt, tháng 11/2018, tr. 97-105, 2018.

[6] P. Q. Nhật, *Lắp ráp cấu kiện Bailey trong các công trình giao thông và xây dựng*. Nxb Đồng Nai, 2022.

[7] Technical Manual TM 5-277. Bailey Bridge, M2. [Washington, D.C.]: Dept. of the Army, 1972.

[8] KAMAZ 4326: Technical specifications [Online]. Available: https://gruzovik.biz/articles/kamaz-4326-tekhnicheskie-kharakteristiki [Accessed Apr. 10, 2025]

[9] *AASHTO LRFD Bridge Design Specifications*, 6th edition, American Association of State Highway and Transportation Officials, Washington, D.C., 2012.

[10] *Thiết kế cầu đường bộ*, Tiêu chuẩn quốc gia TCVN 11823-1:2017, Bộ Khoa học và Công nghệ, 2017.

[11] P. N. Hoàng (Chủ biên), *Hướng dẫn sử dụng phần mềm SAP2000 trong tính toán kết cấu công trình*. Nxb Xây dựng, 2022.

[12] N. M. Phương, "Phân tích đánh giá hệ số động lực của cầu giàn chịu tác dụng của đoàn tải trọng chuyển động", *Tuyển tập Hội nghị khoa học toàn quốc lần thứ nhất về Động lực học và Điều khiển*, Đà Nẵng, ngày 19-20/7/2019, tr. 87-92. DOI: 10.15625/vap.2019000261

[13] X. T. Nguyen *et al.*, "Dynamic response analysis of truss bridges under the effect of moving vehicles", *Journal of Materials and Engineering Structures*, Vol. 9, pp. 447-454, 2022.

ỨNG XỬ CỦA KẾT CẤU NHỊP CẦU BAILEY DƯỚI TÁC DỤNG CỦA TẢI TRỌNG DI ĐỘNG

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Tóm tắt: Cầu giàn thép Bailey thường được sử dụng làm cầu tạm trong một số tình huống giao thông khẩn cấp như phục vụ cứu hộ cứu nạn, sửa chữa cầu cũ. Việc nghiên cứu ảnh hưởng vận tốc tải trọng đến kết cấu cầu có tính cấp thiết, để đưa ra chế độ khai thác phù hợp. Bài báo trình bày việc nghiên cứu ảnh hưởng của vận tốc xe chạy trên cầu đến giá trị nội lực thanh giàn và độ võng của kết cấu nhịp. Các tác giả sử dụng phương pháp phần tử hữu hạn trên phần mềm SAP2000. Kết quả nhận được cho thấy vận tốc xe chạy có ảnh hưởng không lớn đến giá trị nội lực thanh giàn và độ võng của kết cấu nhịp cầu, trên cơ sở đó có thể quy định tốc độ xe phù hợp để tăng lưu lượng xe qua cầu khi cần thiết.

Từ khóa: *Cầu Bailey; hệ số động lực; vận tốc; tải trọng di động; chuyển vị; lực dọc.*

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