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Comparison between Analytical Results and Response of the Laboratory-Scaled Truss Bridges under the Moving Car Load

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ABSTRACT

Two sets of the two traditional types of the laboratory-scale -parallel chorded truss bridges under the moving car loads are conducted. Both steel bars used to assemble the bridges and a miniradio-controlled kid-car used as the applied loads are selected from materials available in the market. The experimental programs address the unexpected rebound behavior of the vertical deflection of a truss model under the low speed of the moving car loads. This behavior, however, cannot be detected by the traditional and numerical analysis methods. The rebound behavior of the model may require further investigation.

1. Introduction

A two-parallel chorded truss is commonly used as a bridge structure, which is built up as the distance for joining two areas at the end supports. Difference of the geometric arrangement of its diagonal members converts the applied loading into different manners of the tensile or compressive internal forces causing a bend of the entire truss.A truss span ranging from 9 m to 122 m is economically possible to be selected for forming a bridge structure, although the greater span lengths have occasionally been used (Hibbeler, R. C., 2009). Based on the response of the interaction between the bridge structures and their loads applied, the truss behaviors have been experimentally and analytically investigated by different researchers.

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Bacinskas, *et al*. (2013)employed the aid of full-scale static and dynamic testing to explore the structural condition and the behaviour of the riveted of a historic narrow-gauge railway steel truss bridge built in 1936. For assessment of bridge capacity, an analytical model was developed from conducting the field load tests. Static and dynamic tests of the bridge using two original engines were performed. Additionally dynamic tests using impulse excitation were also investigated. Thestructural responses (stresses, static and dynamic displacements, accelerations, mode shapes, corresponding resonant frequencies and modal damping values) of the bridge superstructure were determined. Investigation has shown that the bridge revealed sufficient capacity for safe operation.

Brunell and Kim (2013) investigated the performance of a steel truss bridges subjected to local damage. The existence of local damage was detected by an indicator called the global safety index of the system based on deflection characteristic. It was emphasized that the development of a repair method capable to address the global redundancy of a damaged truss bridge was required.

Cheng, B., Qian, G., and Sun, H., (2013), used the finite element method to analyze the elastic and elasto-plastic behaviors of trusses consisting of the bowknot/conventional integral joints. The results expressed that the secondary moments at the member ends and the sectional maximum stresses of the un-shrunken segments of the truss were significantly reduced by the section-shrinking of the member ends. Conversely, the vertical stiffness and elastic stability of the bowknot truss were deteriorated comparing to the conventional one. When the steel strength of the shrunken segments had been appropriately improved, the ultimate bearing capacities of axially compressed shrunken members and of Warren trusses with bowknot integral joints were as high as those of uniform members and of conventional trusses, respectively.

The initial main purpose of this study was to set up the basic experimental program of the prototype model to investigate the response of a bridge behavior under the moving load condition. During the verification stage, it was found that the normal speed of the mini radio-controlled kid-car (applied load) was too fast to detect by the dial gauge. The car was then pulled forward with a very low speed. Due to the circumferential model condition, the unexpected rebound behavior of the vertical deflection of a truss model was found. This behavior is then become the point of interested in this study.

2. Experimental Study

Works on the study of the experimental response of the laboratory-scaled truss bridge under the moving car load were divided into three parts. The first part deals with how to design the truss bridge models, which includes the geometric arrangement of its members and organizing the material to fabricate the model by welding. The second and third parts concern with load device and test procedure, respectively, obtaining from the moving car load.

2.1 Truss Bridge Model Design and Manufacture

Two series of the Pratt and Warren types of the Pony truss bridge models were experimental studied. A model was composed of two steel trusses laying in the vertical planes along the two sides of the bridge. Each truss had the longitudinal parallel top and bottom chords as shown in the Figure 1. The truss specimens were named as the *Pt*1, *Wr*1, *Pt*2 and *Wr*2. The first two letters indicated its type while the last letter indicated the series number. Each truss had a total span of 2.50 m and the horizontal dimension of each diagonal member was 25 cm. The depths of the first and second series were 25 cm and 15 cm, respectively.

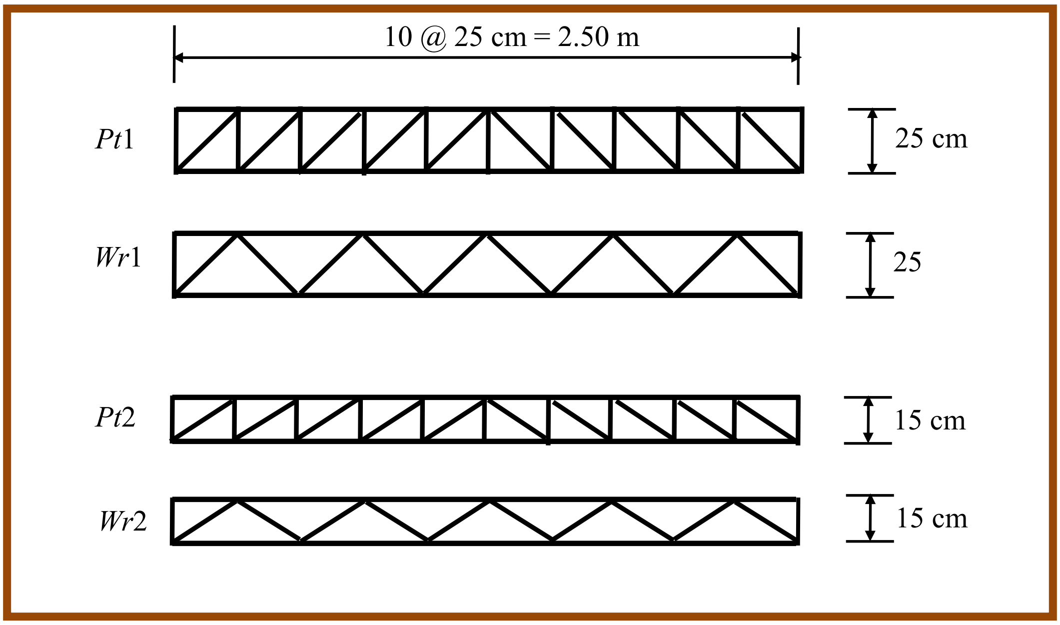


Figure 1: Truss Bridge Models.

The steel bars used to assemble the bridges were intended to select from the smallest size of the materials available in the market. The longitudinal parallel top and bottom chords were made from the 4/8 tube bars, which inner and outer diameters were 18.9 mm and 21.7 mm, respectively. The vertical and diagonal members were the SD24-RB6 reinforcing steel, whose diameter was 6 mm which was the smallest size of the commercial reinforcing steel. In order to stabilize the whole truss system, 6 bars of the SD24-RB6 reinforcing steel were used as the bracings placed at the bottom chords. The main structural assembly of the truss bridge model is shown in the Figure 2. The deck was made from the viva-board of 10 mm thickness.

Figure 2: Truss bridge models in the initially set-up the program.

2.2 Loading Device

A mini radio-controlled kid-car was selected as the applied moving loads due to its available in the market with the affordable budget. Various weights had been experimentally applied to the bridge truss models. However, Table 1 shows the car load distribution only for the two extreme cases, which are the minimum case when the car is empty and the maximum case when the car was loaded until the maximum capacity was reached. The maximum capacity used of the kid-car was 24.04 kg.

Table 1: Load distribution of the car model.

	Empty car load (kg)	Full load (kg)
Front wheels	5.79	12.42
Rear wheels	5.96	11.62
Total car load	**11.75**	**24.04**

2.3 Instrumentation and Test Procedure

The experiment started with the first series of the Pratt and Warren types (*Pt*1 and *Wr*1). In fact, in the second series it was intended to investigate the behavior of the other types (e.g., the Pratt or K-trusses) of the truss models. Basic types of instrumentation were used to monitor the behavior during the tests. A small load cell was placed under the supported bracing which located at one end of the longitudinal bottom chord. Strain gauges were placed at some middle bars to measure the internal forces. The bridge deflection was measured at mid-span underneath the longitudinal bottom chord using a displacement transducer. In the beginning of the test, a dial gauge was set aside the displacement transducer, as shown in the Figure 3, to verify whether the obtained deflection was reasonable.

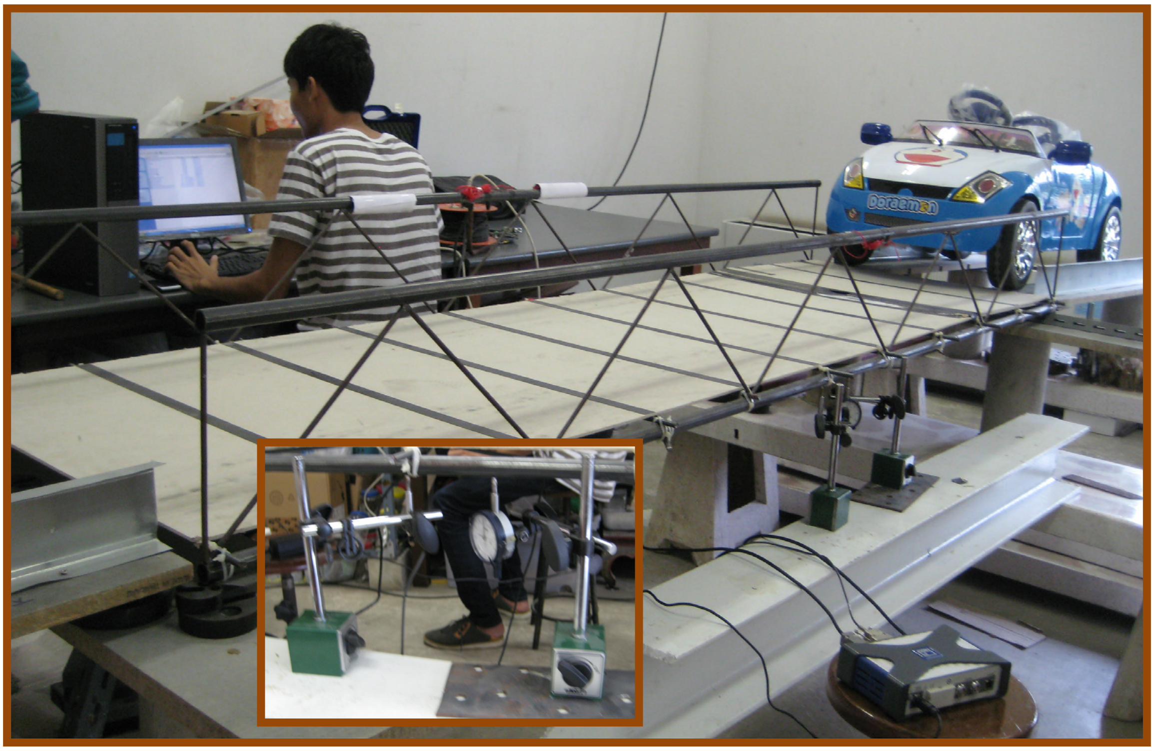


Figure 3: Test Model and Experimental Setup.

During the verification stage, the mini radio-controlled kid-car was pulled forward with a very low speed (0.011 m/s) to allow the vertical deflection of the truss could be detected by the dial gage. Results from the first series revealed the unexpected rebound behavior of the vertical deflection of the *Wr*1 truss model (details are shown in the subsequence section). The vertical deflection behavior was then become the point of interested in this study.

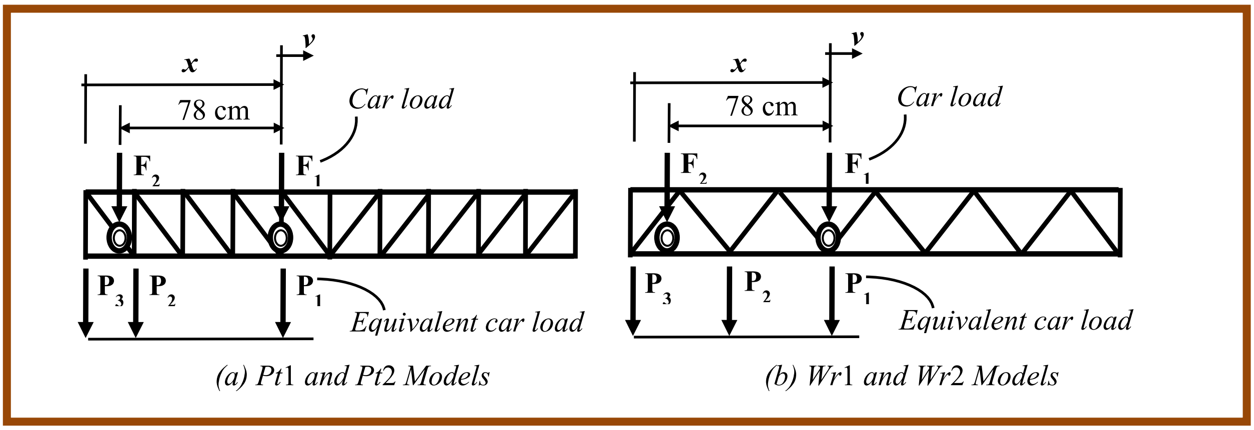
The direction of the second series of the experiment had been changed aimed to validate the behavior of the same types of Pratt and Warren trusses with the different dimension. The specimens were then designed as the *Pt*2 and *Wr*2 by reducing only the height of the truss bridge. Results obtained from the second series of the *Wr*2 truss model also indicated the rebound behavior of the vertical deflection at the mid span point.

3. Analytical Models

Complementary to the experimental investigation, analytical models were conducted on the laboratory scaled truss bridge behavior. Two methodologies of the analytical models were selected. This included the traditional method of virtual work and numerical method using the available commercial finite element software.

3.1 Traditional Analysis (Method of Virtual Work)

By applying the virtual work for the coplanar truss system, the weight of the car were considered as a row of two concentrated live loads and applied at the bottom chord of the truss. The row of loads was referred as the *Car loads* $\mathbf{F}_1$ and $\mathbf{F}_2$ as shown in the Figure 4.



(a) Pt1 and Pt2 Models *(b) Wr1 and Wr2 Models*

Figure 4: Car Load Distribution for 2-D Analysis.

To determine the internal forces developed in each member, the two important assumptions for analysis a truss needs to be included (Hibbeller., R. C., and Yap., K. B., 2012). The first assumption states that the truss members are joined together by smooth pins. The second one requires that all loading are applied at the joint. This assumption could be satisfied by allowing the front wheel to be placed at any joint of the truss. The *Car loads* $\mathbf{F}_1$ could be directly transformed to the Equivalent car load $\mathbf{P}_1$ as shown in the Figure 4. However, the *Car loads* $\mathbf{F}_2$ might need to apply the linear interpolation function to transform into the Equivalent car load $\mathbf{P}_2$ and $\mathbf{P}_3$.

Once the internal forces are obtained, many method of structural analysis can be performed to find the vertical deflection at the mid span of the truss bridge analytical models. In the case of the virtual work method (Laible, J. P., 1985), the displacement of a truss joint can be determined from direct application of the following equation.

$$1 \cdot \Delta = \frac{\sum p \cdot P}{AE} \, L \qquad (1),$$

Where Δ = external joint displacement, p = internal virtual normal force caused by the external virtual unit load, P = internal normal force member caused by the real load, L = length of a member, A= cross-sectional area of a member, and E = modulus of elasticity of a member.

Results obtained from the method of virtual work of the four models (e.g., *Pt*1, *Wr*1, *Pt*2 and *Wr*2) provide the similar manner. The rebound behaviour of the *Wr*1 and *Wr*2 models could not be detected by the traditional analysis.

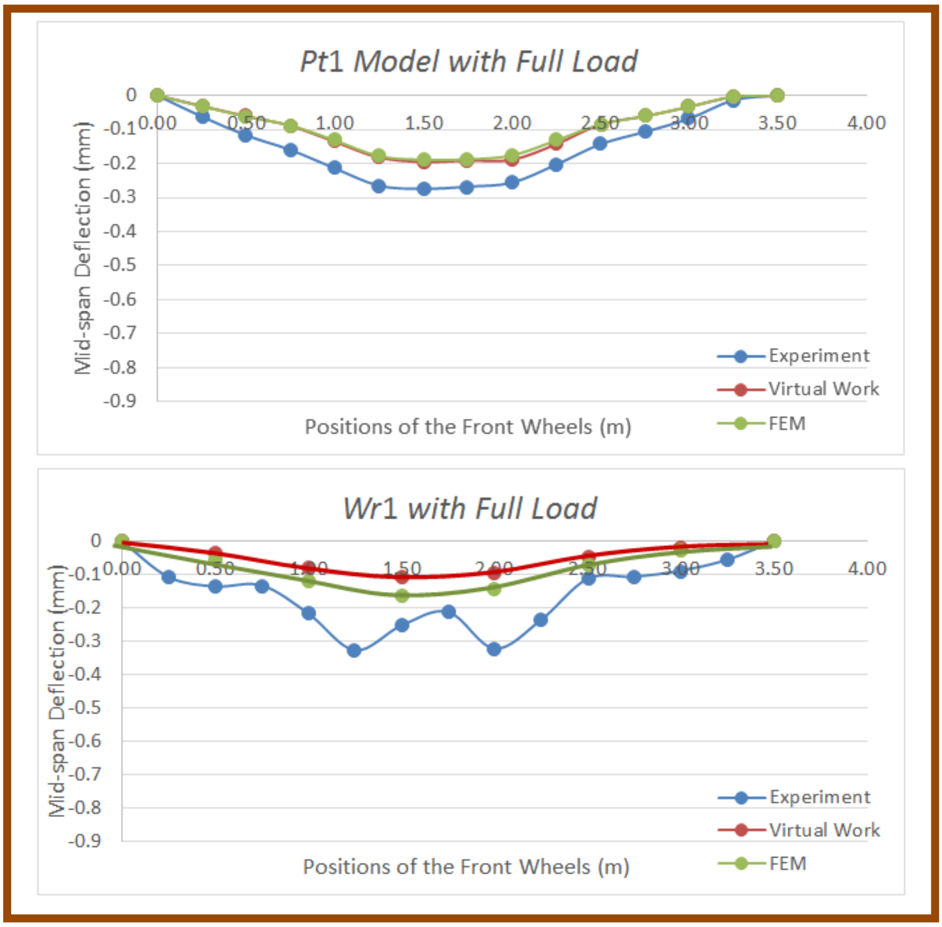


Figure 5: Comparison of vertical deflection history at mid-span of *Pt*1 and *Wr*1

3.2 Numerical Analysis (Finite Element Method)

Finite element method, the static analysis of the simple 2-D truss analysis, was performed aiming to verify whether the unexpected rebound of the *Wr*1and *Wr*2 models could be detected. A commercial software was selected for this purpose. Since the geometry is very simple (only truss members and joints), nodes and elements (two-dimensional truss element) were directly created by the software. The areas of the top and bottom chords were

0.89 cm^2, while the areas of the diagonal and vertical members were 0.283 cm^2. $E = 2.04\text{x}10^6$ ksc. The parameter of interested and presented in this paper is only the vertical deflection at the mid-span point. The car load distribution applied in this case followed the one presented in the Figure 3.

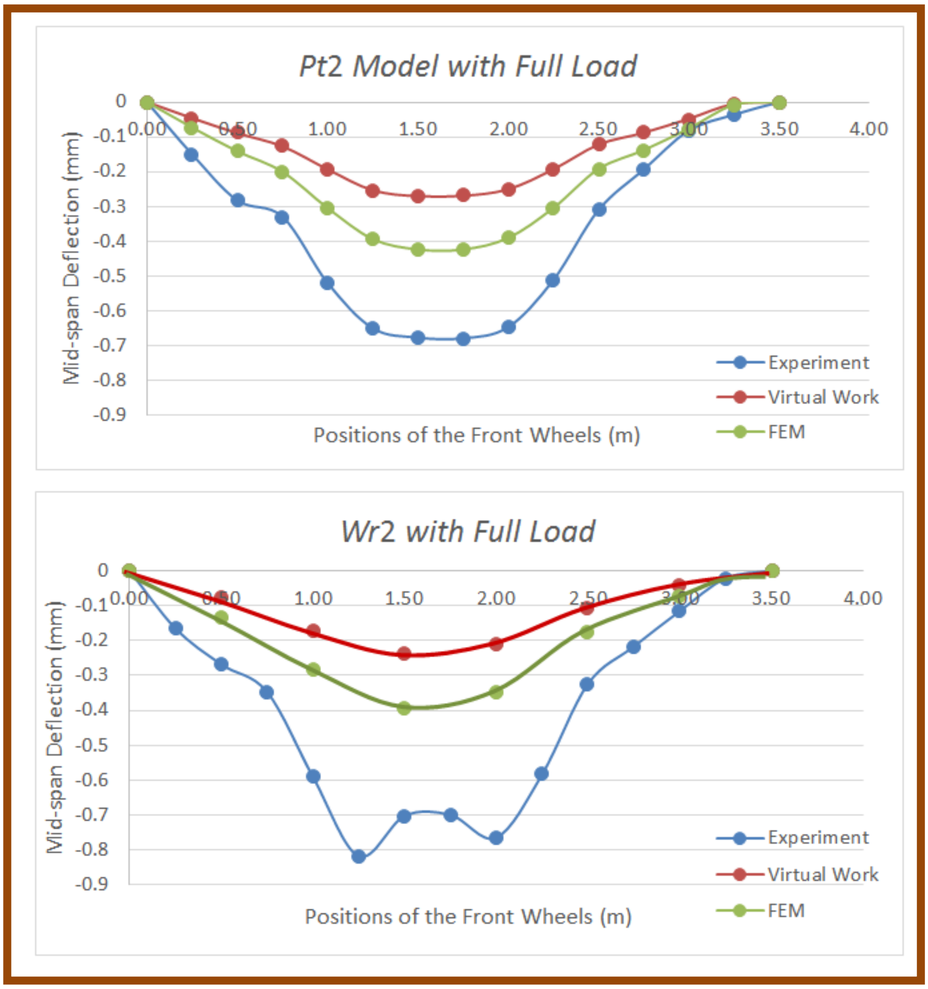


Figure 6: Comparison of vertical deflection history at mid-span of *Pt*2 and *Wr*2.

4. Results

Figure5 shows the comparison of the typical mid-span deflection obtained from the First series, *Pt*1 and *Wr*1. Most lines behave in such a normal manner, except the blue lines of the *Wr*1, which represents results from the laboratory. The blue lines of *Wr*1 appears that the mid-span deflection slightly rebound when the front wheel is approximately located at the distances ranged from 1.25 m to 2.25.

Figure 6 shows the comparison of the typical mid-span deflection obtained from the Second series, *Pt*2 and*Wr*2. Most lines behave in such a normal manner equivalent to the results from the First series. The blue lines of the of *Wr*2, which represents results from the laboratory model, also appears that the mid-span deflection slightly rebound when the front wheel is approximately located at the distances ranged from 1.25 m to 2.25

Although the rebound behavior of the Warren type truss bridge ($Wr1$ and$Wr2$) is in a small magnitude, this response is unexpected to be found and cannot be detected by the elastic static analysis, such as the virtual work and finite element. Static analysis is chosen since the car is moved by pulling forward with a very low speed (0.50 m per 45 second or 0.011 m/s)

5. Discussion

The investigation indicated that the rebound of the vertical deflection obtained from the experiment of the Warren truss models could not be taken into account by the traditional and numerical analysis procedures.

Several sources addressing below may be the source causing this behavior.

1. The geometric arrangement of the diagonal members especially the two bars which form the liked A-shape at the mid-span of the bridge.
2. The spacing of the bracing under the Warren is quite large comparing with those of the Pratt truss. Some amount of applied load may be directly transferred to the joints that far from the mid span but close to the both ends.
3. The combination between the truss loads and the truss weight used in this investigation.

It should be noted that when the position of front wheel is approximately 1 m, the rear wheel just be located on the desk. In addition, when the distance is of approximately 2.75 m, the front wheel just get off from the bridge desk. This means the rebound deflection occurs when all wheels are on the bridge. Since the bridge span (2.50 m) is not significant greater than the span length (0.78 m) of the car wheels, when the car is at the mid-point the distance from each wheels to the nearer supports are very small (0.86 m-by symmetry). With the combination of the geometric arrangement of the members in the A-shape at mid span, most of loads may be directly distributed to both sides of the supports instead of the mid-span. This reduces the load at the mid span resulting to the lesser deflection and consequently the rebound of the behavior.

In order to find the exactly parameters affecting this behavior, future study is required. Moreover, other similar models, such as the Warren truss with the V-shape at mid-span, may need to be constructed and performed the comparison of their response.

6. Conclusion

Two series of the laboratory-scaled parallel chorded truss bridges under the moving car loads were conducted. Each series of the experiments included two traditional types of the steel bridge trusses, which were in the form of the Pratt and Warren types. A mini radio-controlled kid-car was used as the loads applied on the bottom parallel chords of the models with a low speed. The experimental programs addressed the unexpected rebound behavior of the vertical deflection of the Warren truss models under the low speed of the moving car loads. This behavior, however, cannot be detected by the traditional and numerical analysis methods. Further study is required to clarify the parameter influencing the rebound behavior of the Warren truss model.

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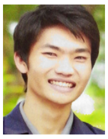

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