Simplification of Vertical Live Loading for In-Service Bridge Pile Foundation

Juan Hu1,2, a) and Jingjing Gao3, b)

1 College of Urban Construction, Zhejiang Shuren University, Hangzhou 310015, China.
2 Key Laboratory of Bridge Detection Reinforcement Technology Ministry of Communications, Chang’an University, College of Highway, Xi’an, 710064, China.
3 Shaanxi Railway Institute, Weinan 714000, China.

a) Corresponding author: hujuanе_816@163.com
b) jiandanyy.student@sina.com

Abstract. In order to determine the distribution of live load on the in-service bridge pile, the live load were statistically analyzed that the distribution at the end of the beam at the fulcrum of the beam and the T beam in the middle and small span of the highway bridge, the proportion of live load is obtained in the counter force at the end of the beam. According to the statistical results, the corresponding relationship between the ratio of cyclic loading and the span of highway bridge is established, and according to the traffic volume and the effective number of trips calculated by different types of vehicles, the relation between the number of cyclic loads and the operation time of the bridge pile foundation is analyzed. The above results were combined with the time cycle of the vehicle on the bridge, a simplified calculation model of static load and live load on bridge pile foundation is established, which the obtained results can be directly applied to the test and loading of in-service bridge pile foundation and to guide the single pile model test in the laboratory, and has a strong application value.

1. INTRODUCTION
At present, the middle and small span concrete beams of standard design are adopted in the superstructure of highway bridges in China. According to the Ministry of transport statistics, by the end of 2016, there were 805 thousand and 300 highway bridges all over the country, with a total distance of 49 million 169 thousand and 700 meters. Thereinto, there were 714854 small bridges, accounting for 88.77% of the total, and there were 19 million 119 thousand and 300 meters, accounting for 38.89% of the total mileage. It can be seen that the proportion of small and medium span bridges in highway construction and operation period was very large. At present, the test procedures and standards for the bearing capacity of the bridge piles were less involved, therefore, in actual testing, there was often no evidence to load, moreover, the cost of actual bridge detection was higher, the model test can meet the requirements of loading and theory.

This paper made a statistical analysis of the box girder and T beam, which are commonly used in the middle and small span of highway bridges in China, the relationship between the live load and the load proportion of the service bridge is established. A simplified model for load calculation on a pile foundation of a service bridge was evolved, which will provide a strong support for the single pile

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd
simulation during the operation of the load and life cycle of the bridge pile foundation bearing capacity judgment.

2. **LIVE LOAD RATIO OF SUPPORT FORCE OF COMMON SPAN CONCRETE BEAM BRIDGE**

Domestic highway bridges usually used 20m, 25m, 30m, 35m and 40m standard span box girders or T beams. Through the analysis of the general design drawings of the superstructure of highway bridge[1], the proportion of live load of these span box girders and T beams were statistically calculated. The statistical results were shown in Figure 1.

![Figure 1](image_url)

**Figure 1.** The ratio of the maximum reaction force (live load + dead load) because of live load distribution at the support of beam end

As can be seen from Figure 1, the proportion of live load in small and medium span bridges was between 20% and 45%, and when span was small, the proportion is too large, when span was large, the proportion is too small.

According to statistical results, in this paper, the ratio of live load was adopted the proportion with 20%, 40% and 50% respectively, and simplified pile top cyclic loading was carried out. 20% was corresponded to the 35m and 40m box girders, 40% was corresponded to the 20m box girder, the 25m and the 30mT beam, 50% was corresponded to the 20mT beam.

3. **TRAFFIC VOLUME CONVERSION MODEL AND CYCLIC LOADING TIMES**

3.1. **Vehicle Classification**

To evaluate the influence of the live load on the bearing capacity of the bridge during the operation of the road and bridge, vehicle loads on daily traffic should be considered. Vehicle load models were listed in the bridge design codes in the United States, the United Kingdom and Japan[2-3]. At present, China has large traffic volume and high proportion of overweight vehicles, The axle load model for the design and evaluation of highway bridges was not given in the code for bridge design[4-6]. Based on the document[7], the vehicle load data of the passing vehicles were monitored for 10 days for reference.

3.2. **Live Load Cycle Times Converted Operating Life**

(1) **Common Standard Span Live Load Statistics**

A two-way four lane road was calculated, according to the literature[7], the 2 axles to 6 axles vehicle and other models in common standard span 20m to 40m box girder and T beam load distribution, the reaction force at the end of the beam was calculated. And the proportion of the reaction force at the end of the beam caused by each model was calculated, as shown in Figure 2 and figure 3.

In Figure 2 and Figure 3, beams with span of 20m to 40m were used, and the ratio of the reaction force of the beam end of the different types of vehicles was between 16.8% and 61%, Table 2-3 models induced by box girder middle beam end pivot reaction proportion ranged from 16.8% to 36%, T-beam fulcrum force caused by the proportion ranges from 32.2% to 61%, and most of them were...
between 20% and 50%. When the load was the most unfavorable, the pile foundation will produce an effect that satisfies the statistical range in figure 1.

![Graph](image1)

Figure 2. The proportion of maximum counter force of beam end support with different axles of loader in box girder for grade I highway

![Graph](image2)

Figure 3. The proportion of maximum counter force of beam end support with different axles of loader in T-girder for grade I highway

(2) Traffic Volume Calculation

Similarly, according to the literature[7] two-way four car road section for the most unfavorable loading, The number of vehicles was calculated which were carrying a cyclic loading effect on a common bridge whose span was from 20m to 40m. As shown in TABLE 1. Calculated the proportion of each axle type vehicle in the TABLE 1in the cloth load, and listed them in TABLE 2. The calculation can be common highway span from 20m to 40m bridge pile foundation cyclic load effect model of the number of vehicles loaded, Calculate the proportion of each axle type vehicle in the TABLE 1 in the load, and list them in TABLE 2.

As shown in TABLE 1and table 2, For the common highway spans from 20m to 40m, the traffic flow of the pile foundation of the bridge had cyclic loading effect, and the traffic flow was mainly consisted with 2-axles to 6-axes vehicle type, in the distributed load, the proportion of 2-axes vehicle and 3-axes vehicle were larger, they were about 19.44% to 23.47%, the proportion of the other 4 models was basically the same, account for about 14.5%.

### TABLE 1. Loading capacity of different types of common span.

| Models | Span(m) | 2 axles | 3 axles | 4 axles | 5A axles | 5B axles | 6 axles | Total (cars) |
|--------|---------|---------|---------|---------|----------|----------|---------|--------------|
|        | 20      | 4.6     | 4.6     | 2.6     | 2.6      | 2.6      | 2.6     | 19.6         |
|        | 25      | 6       | 6       | 4.4     | 4.4      | 4.4      | 4        | 29.6         |
|        | 30      | 6.2     | 6.2     | 4.4     | 4.4      | 4.4      | 4        | 30           |
|        | 35      | 8.4     | 8.2     | 6       | 6        | 6        | 6        | 40.6         |
|        | 40      | 10      | 8.4     | 6.2     | 6.2      | 6.2      | 6.2     | 43.2         |

### TABLE 2. Proportion of the different types of box girder and T-beam(%).

| Models | Span(m) | 2 axles | 3 axles | 4 axles | 5A axles | 5B axles | 6 axles | 12.27 |
|--------|---------|---------|---------|---------|----------|----------|---------|-------|
|        | 20      | 23.47   | 23.47   | 13.27   | 13.27    | 13.27    | 13.27   | 13.27 |
TABLE 3. The operating time corresponding to the number of live load cycles under standard axle load.

| Live load type | Test cyclic load ratio β | Percentage of cyclic load (dead load + live load) | Cycle times of test loading (10000 times) | N=100Number of cycles converted to different models (times /d) | T (Operation time / year) |
|----------------|--------------------------|-----------------------------------------------|------------------------------------------|----------------------------------------------------------|---------------------------|
| 2-axle acted on the middle box | 0.1 | 20% | 10 | 10~21.7 | 12.6~27.4 |
| 3-axle acted on the side box | 0.2 | 40% | 5 | 11.9~21.7 | 6.3~11.5 |
| 3-axle to 6-axle acted on the T beam | 0.25 | 50% | 1 | 11.9~38.4 | 0.7~2.3 |

4. SIMPLIFIED MODEL OF CYCLIC LOADING TIME AND LIVE LOAD

4.1. Live Load Cyclic Loading Time

According to the common concrete beam bridge by different speeds of different span girder bridge, it calculated the load at the pile of time at which a car acts on a pile foundation (i.e. cycle) was between 1.20s-5.76s, taking into account the randomness of traffic, the period of live load will only be greater than this value. Therefore, the live load cycle was 5s for the model test.

Ignore the unevenness of the bridge surface, according to Xie Dingyi and other literatures[8-10], the comparative characteristics of dynamic loads induced by different causes in were known, when the load was on the soil for 2.0s-100s, it was considered the static problem. Therefore, loading and load simplification in the model test were considered the static problem.

4.2. Simplified Load Model

The calculation of live load, dead load, the relationship between time and cycle number, and according to the characteristics of vehicle load on the beam of the highway bridge in the operation period of the static load and live load model was simplified as shown in Figure 4, and then to guide the single pile static load and cyclic loading model test.
Ps——dead load, \( Ps = 0.4Q_{uk} \), Unit(kN); Q_{uk}——Standard value of vertical ultimate bearing capacity of single pile, Unit(kN); Pc——Cyclic load amplitude, \( P_c = a(P_s + P_c) = \beta Q_{uk} \), \( a \) is the ratio between the cyclic load and (dead load + live load), \( a \) was taken respectively as 0.2(20%), 0.4(40%) and 0.5(50%). \( \beta \) is the ratio between cyclic load and ultimate bearing capacity of single pile is the ratio of cyclic load, \( \beta \) was taken respectively as 0.1(10%), 0.2(20%) and 0.25(25%). \( f \)——Cyclic load cycle, \( f = 0.2\text{Hz} \).

5. CONCLUSION

(1) The ratio of live load was taken statistics to the dead load and live load generated by the live load during the small and medium span operation for the highway bridge spans with 25m, 30m, 20m 35m and 40m. And it determined the load and cyclic loading range of single pile model test, the corresponding relationship between the ratio of cyclic loading and the span of the highway bridge where the pile foundation was built was established.

(2) During the operation of the road bridge, the vehicle load on the pile foundation is calculated, according to the loading span of common highway bridge, the ratio of the counter-force at the end of the beam is calculated, the relation between the number of live load cyclic loading and operation time was determined.

(3) The live load cycle was determined by calculating the live load during the operation of the highway bridges running speed, thus simplifying the computation model of the static load and live load, the ratio of static load and cyclic load for ultimate bearing capacity of single pile guide single pile model test.

ACKNOWLEDGEMENTS

This work was financially supported by the Basic Research Fees for Special Operations of Central Universities in 2017 (Natural Science) Key Research Platform Open Fund Project (310821171119) and the Introduction talent project of Zhejiang Shuren University (2016R001) and the project of Shaanxi Provincial Education Department (15JK1168).

REFERENCES

[1] China first highway investigation and Design Institute, Shaanxi Highway Survey and Design Institute, Jiangsu traffic planning and Design Institute, Jiangxi Jiaotong designing Institute, Anhui Highway Survey and Design Institute. General drawing of highway bridge and culvert[M]. Beijing:People Communications Press, 2006.10.

[2] AASHTO. AASHTO LRFD bridge design specifications-section3 (SI) : loads and loadfactors[S]. Washington DC: America Association of State Highway and Transportation Officials, 2004.

[3] Japan Road Association. Code for design of highway bridges. II steel bridge[S]. Tokyo: Japan
Road Association,2002.

[4] Wang Ronghui, Chi Chun, Chen Qingzhong, etc. Study on the Model of the Fatigue-loaded Vehicles in Guangzhou Trestle Bridges[J]. Journal of South China University of Technology(Natural Science Edition),2004, (12) :94-96.

[5] WANG Chunsheng, CHEN Airong, CHEN Weizhen. Assessment Methods of Remaining Fatigue Life and Service Safety for Riveted Steel Bridges[J]. JOURNAL OF TONGJI UNIVERSITY(NATURAL SCIENCE),2006, (03) :325-330.

[6] Jia Yi, Tang Like, Li Fuhai, etc. BEARING CAPACITY EVALUATION OF A PRESTRESSED SIMPLY SUPPORTED T GIRDER BRIDGE ON LOAD TESTING[J]. Industrial Construction,2017,47(04):71-75+5.

[7] SUN Shouwang, SUN Limin. Statistic Model of Vehicle Loads for Highway Bridges[J]. JOURNAL OF TONGJI UNIVERSITY(NATURAL SCIENCE) , 2012, Vol.40 No.240 (2) :198-204.

[8] Xie Dingyi. Soil dynamics [M]. Higher Education Press, 2011.5

[9] Wang Jiexian. Dynamic foundations and foundations [M]. Science Press, 2001.5.

[10] Xue Shouyi. Advanced soil mechanics [M].China Building Material Industry Press, 2007.10.

[11] Hu Juan, Sheng Li, Hu Minping. MODEL TEST OF THE BEARING PROPERTIES OF SERVICE BRIDGES PILED FOUNDATION IN LOESS[J]. Industrial Construction,2017,47(02):87-93.

[12] HU Juan, SONG Yi-fan, HE Shuan-hai. Research on model tests of bearing capacities for composite pile foundation under static and cyclic loading in sand[J]. Journal of Dalian University of Technology. 2015,55(03):305-311.