Analysis and prediction of operating vehicle load effects on Highway bridges under the weight charge policy

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Abstract. Under the weight charge policy, the weigh in motion data at a toll station on the Jing-Zhu Expressway were collected. The statistic analysis of vehicle load data was carried out. For calculating the operating vehicle load effects on bridges, by Monte Carlo method used to generate random traffic flow and influence line loading method, the maximum bending moment effect of simple supported beams were obtained. The extreme value I distribution and normal distribution were used to simulate the distribution of the maximum bending moment effect. By the extrapolation of Rice formula and the extreme value I distribution, the predicted values of the maximum load effects were obtained. By comparing with vehicle load effect according to current specification, some references were provided for the management of the operating vehicles and the revision of the bridge specifications.

1. Introduction
For nearly two decades, with the development of China's economy, the transportation volume increased significantly, and highway traffic has become the main way of transportation. However, driven by profit, the fierce competition in the transportation industry led to the increasing of vehicle gross weight and axle load, which posed a serious threat to highways and bridges [1~3]. In order to control the overloaded of vehicle, a number of provinces have successively introduced a weight charge policy. Then, what was the effect of this policy? Some weigh in motion data of operating vehicles from a highway bridge in Guangdong Province are collected. The theoretical simulation analysis and prediction of the load effect are carried out. The results provide a reference for the management of operational vehicles or the adjustment of current bridge codes.

At present, the statistical analysis method about the vehicle loads and load effects of bridge are mainly divided into two broad categories. The one is the use of vehicle load effect as base distribution and to get the maximum vehicle load effect. Such as Wei-bull distribution and lognormal distribution probability distribution were used to fitting out a vehicle load model in one highway [4]. By means of the nonlinear least squares method or maximum likelihood estimation method, the maximum weight of the return period was predicted by two normal distribution function to fit the double-peak distribution function of actual vehicle load [5]. Four normal distributions and six normal distributions were respectively describe the vehicle load in Non-weight toll area and weighted toll area [6,7]. Another category is the tail extrapolation method based on average number of traverses. For example, the Rice
formula was used to fit and forecast the weights and effects of vehicle load under any return periods [8,9].

The common of above methods was that short-term vehicle load samples can be used to predict the characteristics of the sample for a long period. These methods will be introduced in below.

2. Statistics on parameters of vehicle loads
The vehicle load data are all from the weigh in motion and dynamic acquisition system at a toll station on Beijing-Zhuhai Expressway. A total of vehicle load data from one heavy lane for two months in 2014 were collected. Vehicles are generally divided into five types according to the number of axles.

Data statistics showed that the 2 axle vehicles with a total number of 51933 accounted for 64.8% of the total number of vehicles, was the main component of the traffic. While the proportions of 3 to 6 axle vehicles are relatively 3.3%, 2.9%, 2.8% and 26.2%. The total weight of 6 axles is the largest, which often controls the vehicle load effect of medium and small span bridges.

3. Simulation of bridge load effects
Based on the measured data of vehicle load, the characteristics of traffic flow and the weight of each type of vehicles were analyzed. The synthetic traffic flow to simulate the actual vehicle load was generated by using the Monte Carlo method. Synthetic vehicle flow has been generated chart as shown in figure 1.

Figure 1. Synthesis traffic flow chart

Taking two simple supported beam bridges with the span of 30m, 40m as examples, the load effects on the bridges were simulated by the synthetic vehicle flow and the influence line superposition method, and the bending moments of each section in the bridge can be calculated by the Matlab program. As the notable load effect of simple supported beam bridge, the results and probability density distribution of bending moments in mid-span were obtained.

Thus, extreme value I distribution and normal distribution were used to fit the distribution of the results. The extreme value I model can well simulate the effect of traffic flow.

4. Prediction methods of bridge load effects
Based on the above deduced load effects, the maximum value of load effects can be predicted and extrapolated to different return periods by using extreme value I distribution [10] and Rice formula [11].
4.1. Extreme value I distribution
Firstly, the density distribution histogram of the bending moment was fitted by the extreme I type distribution, the formula (1) of fitting distribution curve and the corresponding position parameter $\mu$ and scale parameter $\alpha$ were obtained.

\[ f(x) = a e^{-a(x-\mu)} \exp\left[ -e^{-a(x-\mu)} \right], -\infty < x < +\infty \]  

(1)

Then, the maximum load effect (bending moment) under the return period $M_t$, were calculated. For extreme-I distribution, formula (2) can be used to calculate the maximum load effect ($M_t$) under the specified return period ($R_t$).

\[ M_t = \mu - \frac{1}{\alpha} \ln \left( \frac{R_t}{R_t' - 1} \right) \]  

(2)

4.2. Rice formula
The Rice formula can be used to simulate the probability distribution on condition that the data from a random process obey to the stationary Gauss process. According to the crossing frequency, it is also a method to predict effectively the long period data by using the short period data.

Based on the frequency distribution histogram, the frequency of crossing a threshold can be calculated. The average number of times traversing a threshold per unit of time ($v_x$) can be obtained by the Rice formula [9] which shown as equation (3). In the equation (1) $\sigma, m, \hat{\sigma}$ respectively, the standard deviation, mean value and standard deviation of the crossing times in a random process.

\[ v_x(x) = \frac{1}{\sqrt{2\pi}} \frac{\hat{\sigma}}{\sigma} \exp \left( -\frac{(x - m)^2}{2\sigma^2} \right) \]  

(3)

Trying with different thresholds to fit the distribution law of the histogram, more accurate result will be obtained. The optimal parameters of the Rice formula can be basically determined by the confidence testing with different thresholds.

According to the Rice formula and the reciprocal relationship between the traversing times and the return period, an inverse formula as equation (4) can be deduced. That is, the maximum value under different return periods can be obtained.

\[ x = m + \sigma \sqrt{2 \ln \left( \frac{\sigma}{2\pi R_t} \right)} \]  

(4)

5. Comparison of the results
By calculation and prediction through above two kind methods, the predicted maximum bending moment of a simple supported beam bridge with span of 30m or 40m had been extrapolated under difference return years and was showed in figure 2.

The results showed that the prediction values of extreme I-type formula are close to those of rice formula. The predicted values have a similar trend that rising rapidly in the first 10 years, and growing slowly after10 years.

The bending moments of two simple supported beam bridges(with spans of 30m and 40m) by the current bridge load standard (highway-I) were compared with that predicted by extreme value I distribution and the Rice formula, as shown in Table 1.

Table 1 reflects that under the actual vehicle load, the load effect is 1.9−2.5 times as much as the design load effect. In the next 35 years, if the vehicle distribution rule is constant, this ratio will increase to 3 times.
Figure 2. Predicted maximum bending moment along return years

| Return years | Extreme value I 30m | Extreme value I 40m | Rice formula 30m span | Rice formula 40m span |
|--------------|---------------------|---------------------|-----------------------|-----------------------|
| 0            | 1.91                | 2.28                | 1.88                  | 2.48                  |
| 5            | 2.44                | 2.84                | 2.42                  | 2.80                  |
| 10           | 2.61                | 2.99                | 2.58                  | 2.91                  |
| 15           | 2.65                | 3.06                | 2.59                  | 2.95                  |
| 20           | 2.66                | 3.07                | 2.60                  | 2.98                  |
| 25           | 2.67                | 3.07                | 2.62                  | 3.01                  |
| 30           | 2.68                | 3.08                | 2.63                  | 3.03                  |
| 35           | 2.69                | 3.09                | 2.64                  | 3.07                  |

6. Conclusions
Based on the above research and analysis of the load data of Beijing-Zhuai high-speed vehicles, the following three conclusions are obtained.

(1) The load effect on a simply supported beam with a span of 30 ~ 40 m shows a single peak distribution, and the extreme value I distribution is better than the normal distribution.

(2) The difference between the result value of extreme value I distribution and that of rice formula is about 5% or 7%, so the two methods can confirm each other and provide reference for the extrapolation of vehicle load in the future.

(3) According to the prediction results of the vehicle load effect derived from the extreme I distribution and the Rice formula, the operating vehicle effect is about 1.9 to 3.0 times the design load effect in the following 35 years of recurrence. It showed that under the policy of weighing and charging, the vehicle load varied greatly, and the relevant management departments need to adjust and strengthen the control and management of heavy vehicles.

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