Research on the design method of the automobile design load of the small span bridge in the heavy traffic volume

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Key words: medium span bridge,Standard vehicle load model,probability statistics, vehicle load,design reference period

Abstract. Based on the vehicle load survey data measured by High speed dynamic weighing equipment in Luogang Section of National Highway No.107 and the basic theory of probability and statistics, the parameters such as gross vehicle weight, axle load, wheelbase, vehicle spacing and so on， are statistically analysed in this paper so as to confirm the probability distribution function of the category vehicle load and the representative values of related parameters. The simulation program of random fleet across the bridge was compiled by MATLAB. According to the calculation analysis of the load effect, the probability distribution type, distribution parameters and the standard value of load effect in the design reference period of medium-small span simply-supported bridges can be comfirmed. And on basis of the equivalent principle of load effect, a design load value of standard vehicle is recommended in the paper.The theoretical method is provided for the design of the automobile design load of small span bridges under heavy traffic load.

Introduction

The vehicle load is an important part of the highway bridge live load, especially for small span bridges.it often play a control effect, with the continuous development of the economy, the vehicle load in bridge structure is also in development, However, the load design standard is lagging behind the development of the load, in order to reduce the structure damage of the small span bridge, improve the safety and durability of the bridge, reduce the maintenance cost of the bridge during the operation period.In addition to continuing to manage overload, it is necessary to research the design load of the automobile standard design of the small span bridge under heavy load traffic, put forward a method to design the vehicle load, and provide a theoretical basis for future similar areas to develop vehicle design load.

Statistical Analysis of Vehicle Survey Data

Investigation by the high speed dynamic weighing system to measure the Luogang section 107 State Road a week of vehicle load. We get the vehicle load parameters and the geometric parameters of the vehicles. These parameters include axle load, total weight, vehicle length, vehicle spacing, speed and wheelbase.

Traffic Composition Analysis. According to the measurement of the high speed dynamic weighing system, the vehicle load data was obtained from days in January 8th to 14, the average traffic volume was 33470/day, the maximum traffic volume was 35332. After removal of the error value, analysis the traffic composition, we can get the results are shown in table 1.

Table 1 All lanes of a week through all kinds of vehicle proportion summary table

motorcycle type	lane		
	Edge Lane(1,6lane)	Middle lane(2,5lane)	Inside lane(3,4lane)
The two axle truck	28.70%	28.45%	19.39%
The three axle truck	2.50%	2.87%	2.16%
The four axle truck	1.45%	1.81%	0.90%
The five axle truck	1.15%	1.44%	0.68%
The six axle truck	1.16%	1.40%	0.82%
motor bus	10.91%	3.44%	3.65%
passenger car	54.14%	60.58%	72.41%

Statistical Analysis of Gross Vehicle Weight. Through the analysis of the vehicles load data, drawing the passenger car, motor bus, two axle trucks, three axle trucks, four axle trucks, five axis trucks, six axle trucks gross weight histogram, Then we perform the probability distribution fitting and K-S test. Shows the passenger car, motor bus, two axle truck gross vehicle weight obey lognormal distribution, the three axle trucks, four axle trucks, five axle trucks, six axle trucks gross vehicle weight obey two humped normal distribution[1], as shown in Figure1and Figure2(Take the passenger car and the six axle truck as an example). Parameters such as table 2 shows.

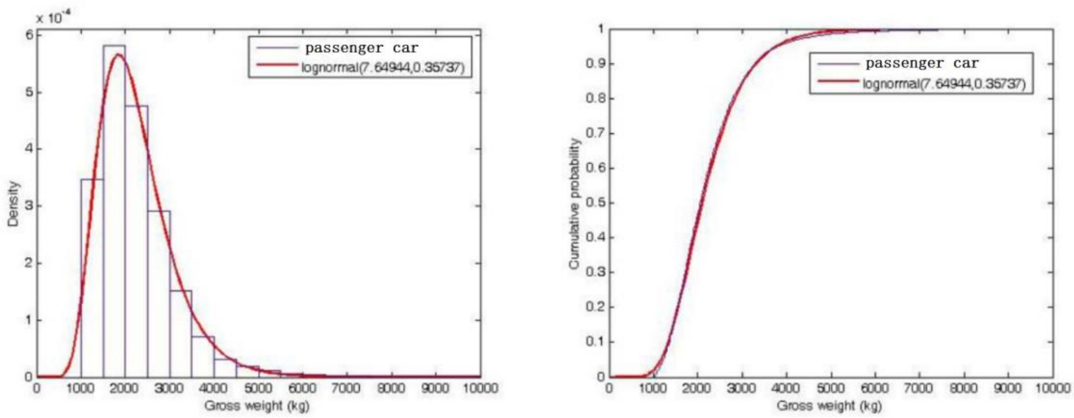


Fig. 1 Passenger car a total weight of probability density function distribution fitting and cumulative probability density function distribution fitting

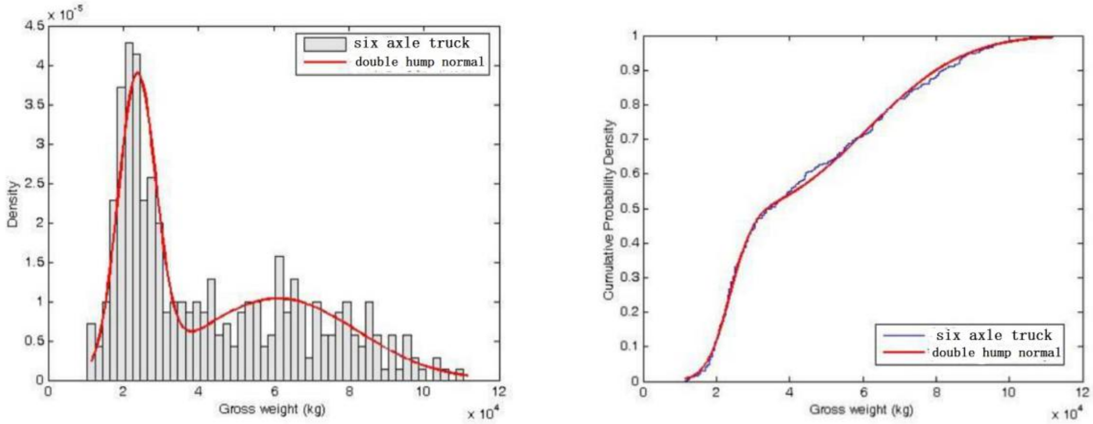


Fig. 2 Six axis vehicle total weight of probability density function distribution fitting and cumulative probability density function distribution fitting

Table 2 The different vehicle load probability distribution types and distribution parameters（In January 9th as an example）

<table>
<tr><td rowspan="2">motorcycle type</td><td rowspan="2">sample capacity</td><td rowspan="2">The type of probability distribution</td><td colspan="5">The probability distribution parameters[kg]</td></tr>
<tr><td colspan="2">μ</td><td colspan="3">σ</td></tr>
<tr><td>passenger car</td><td>16606</td><td rowspan="3">log-normal distribution</td><td colspan="2">7.70357</td><td colspan="3">0.36098</td></tr>
<tr><td>motor bus</td><td>1434</td><td colspan="2">8.89355</td><td colspan="3">0.67226</td></tr>
<tr><td>The two axle truck</td><td>7690</td><td colspan="2">9.60053</td><td colspan="3">0.38295</td></tr>
<tr><td rowspan="2">motorcycle type</td><td rowspan="2">sample capacity</td><td rowspan="2">The type of probability distribution</td><td colspan="5">The probability distribution parameters[kg]</td></tr>
<tr><td>p</td><td>μ1</td><td>μ2</td><td>σ1</td><td>σ2</td></tr>
<tr><td>The three axle truck</td><td>792</td><td rowspan="4">double hump normal distribution</td><td>0.51712</td><td>17162</td><td>33991</td><td>5084.6</td><td>13756</td></tr>
<tr><td>The four axle truck</td><td>445</td><td>0.67791</td><td>21977</td><td>54064</td><td>8817.3</td><td>12781</td></tr>
<tr><td>The five axle truck</td><td>350</td><td>0.44541</td><td>25175</td><td>66534</td><td>6158.4</td><td>20673</td></tr>
<tr><td>The six axle truck</td><td>792</td><td>0.56337</td><td>33155</td><td>84942</td><td>8959.5</td><td>26239</td></tr>
</table>

Analysis of vehicle axle load weight ratio statistics. Because of various vehicle types, vehicle weight and axle load different proportion of the complex relationship is difficult to unity. Therefore, the linear regression of automobile axle load and vehicle weight data using the least squares method, get the regression line between the axle load and the vehicle weight. Observed that the first axis of the intercepts of the linear intercept are larger, the rest axis of the intercepts of the regression lines are small, so the relationship between the rest of the axis except the first axle load and total weight can be approximated from slope of the regression line, and the relationship between the first axle load and total weight can be 1 minus the other axis ratio. The different models of the total load proportion, (the small car for example), as shown in table 3.

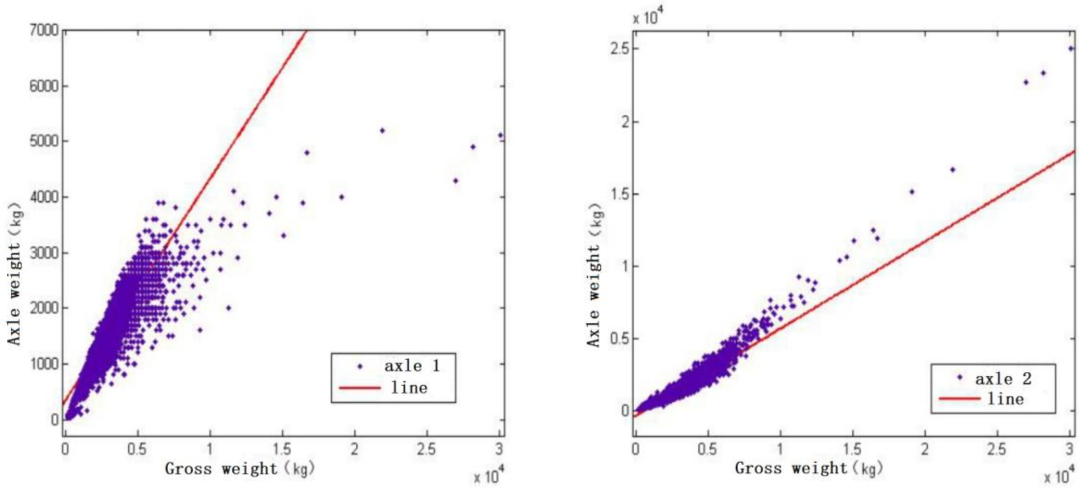


Fig. 3 Small passenger car the axle weight accounted for the total weight ratio of linear regression

Table 3 The different models of axle load of weight ratio

motorcycle type	axle1	axle 2	axle 3	axle 4	axle 5	axle 6	sample capacity
passenger car	0.39	0.61	/	/	/	/	121210
motor bus	0.26	0.74	/	/	/	/	9580
The two axle truck	0.28	0.72	/	/	/	/	51881
The three axle truck	0.17	0.38	0.45	/	/	/	5117
The four axle truck	0.13	0.22	0.32	0.33	/	/	2942
The five axle truck	0.06	0.24	0.25	0.23	0.22	/	2320
The six axle truck	0.04	0.18	0.18	0.20	0.20	0.20	2351

Analysis of different vehicle wheelbase. At present, China has a lot of automobile manufacturers, the wheelbase of same vehicle is various, so in this case can be combined with measured data from each vehicle maximum probability wheelbase as representative of the vehicle wheelbase value, from the 107 National Road a week of measured data, the various types of vehicles every day roughly stable, so use the measured wheelbase of January 8th day as the standard vehicle wheelbase representative value, as shown in table 4.

Table 4 The different vehicle wheelbase representative value

motorcycle type	wheel base [cm]				
	1	2	3	4	5
passenger car	260	/	/	/	/
motor bus	520	/	/	/	/
The two axle truck	450	/	/	/	/
The three axle truck	180	550	/	/	/
The four axle truck	180	430	130	/	/
The five axle truck	330	680	130	130	/
The six axle truck	315	135	620	130	130

Analysis of vehicle spacing statistics. According to the different time interval of adjacent vehicles, vehicle spacing can be divided into general and dense state, the time interval between adjacent vehicles is defined as dense state in the case of less than3S. According to the location of the measuring point, we mainly consider the situation of dense state. Since this investigation does not have a statistical dense state of the vehicle spacing, the proposed use of references[2] of the vehicle spacing distribution form.

General state vehicle spacing probability distribution：

$$f(x) = \frac{1}{\sqrt{2\pi} \times 1.115751x} \exp\left[-\frac{(\ln x - 4.827692)^2}{2 \times 1.115751^2} \right] \tag{1}$$

Dense state vehicle spacing probability distribution:

$$f(x) = \frac{1}{\sqrt{2\pi} \times 0.279707x} \exp\left[-\frac{(\ln x - 1.561165)^2}{2 \times 0.279707^2} \right] \tag{2}$$

Design Load Model For Small Span Bridges

Current automobile load standard of China as "Lane load + Concentrated force" mode, at present international general vehicle load expression forms were also using the "Lane load + Concentrated force" mode[3,4,5,6,7], due to the complex and varied types of vehicles in China, the wheelbase of same models are not uniform, so in considering the concentration effect, we still use one concentrated force model, which is more suitable for on the national conditions of China. So in this paper, we will still take "Lane load + Concentrated force" mode to research standard vehicle load of small span bridge.

Simulation of Vehicle Load Effect. Because the simple supported beam is easy to adjust the parameters, the paper uses a simple beam of small span to carry on the analysis.So we chose 5m, 6m, 8m, 10m, 13m, 16m, 20m, 25m, 30m, 35m, 40m, 45m, 50m, 55m, 60m 15 kinds of span.Take the traffic composition of the side lane as an example, in order to simulate the vehicle load effect in the actual operation process. We use the Monte Carlo principle[8], use above section analysis of gross vehicle weight distribution type, the percentage of axle load weight, representative value of wheelbase, vehicle gap distribution types of results, through the matlab program compiled a day in dense random fleet across the bridge loading program[9]. The vehicle team(Generated by the program random) cross the influence line of middle moment and fulcrum shear force and the program random calculated and recorded the moment effect and the shear effect value. We can get the distribution type of the effect.Through the comprehensive analysis, the middle moment and fulcrum shear force effect of the simple supported beam in small span is the gamma distribution type, as shown in Figure4, the distribution parameters are shown in Table 5.

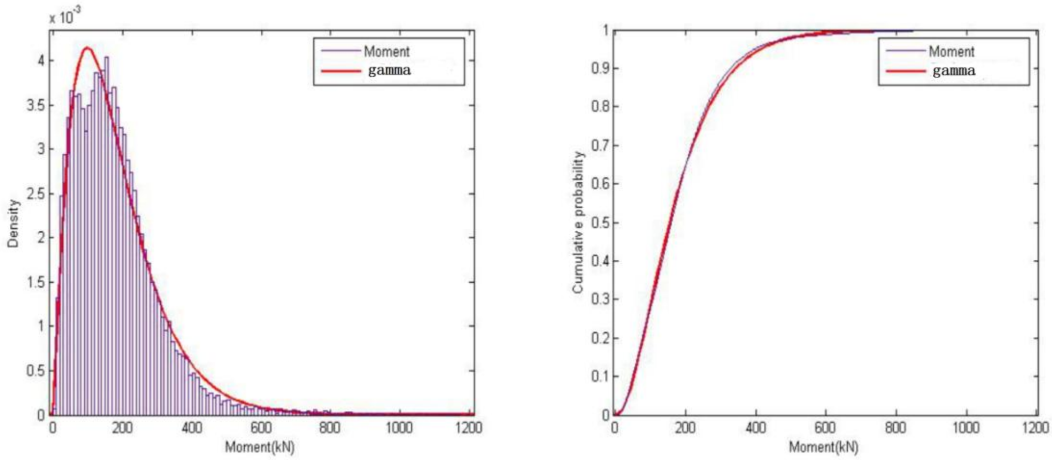


Fig.4 The probability density distribution function fitting and cumulative probability density function distribution fitting

Table 5 The distribution form and parameters of moment effect and fulcrum shear force of simply supported beam with different span

Span[m]	The bending moment at mid span	Fulcrum shear	distributed parameter			
	The type of probability distribution		The bending moment at mid span		Fulcrum shear	
			α	λ	α	λ
5	gamma distribution		1.302734	48.523	1.46475	50.0106
6			1.44793	67.6342	1.54697	51.1804
8			1.73888	92.8747	1.65193	57.6883
10			1.93188	118.856	1.81305	60.5251
13			2.15857	165.477	1.94321	67.2698
16			2.31044	228.673	2.067	72.312
20			2.59617	296.671	2.20214	82.0264
25			2.8962	409.848	2.49729	83.8666
30			3.06827	555.928	2.57855	95.1165
35			3.31387	681.393	2.84524	97.6063
40			3.53684	825.407	3.0187	102.357
45			3.9402	913.613	3.1439	106.499
50			3.96268	1131.45	3.2532	115.254
55			4.41632	1194.56	3.61213	109.75
60			4.50817	1412.76	3.47342	124.993

According to the provisions on variable action (load) standard values of "engineering structure reliability design uniform standards" : when the variable is a random variable, the statistical parameters and probability distribution type should be to observational data as the basis, using parameter estimation and probability distribution test method determine, the level of significance test is 0.05.

"General specification for design of highway bridges and culverts" specified in the design reference period of bridge structures for 100 years.

According to the research results of the reference[1,10], it is assumed that the probability distribution（F(x)） of the vehicle load in the design reference period does not change, that is, the maximum effect of the observation period is independent identically distributed. For example, the value（$X_1, X_2, ..., X_n$）of the effect is the maximum value of all the observation periods. Then the maximum distribution($F_T(x)$)of the design reference period effects can be derived, such as the Eq. 3.

$$F_T(x)=P(M_n\leq x)=P(X_1\leq x,...,X_n\leq x)=F^n(x) \tag{3}$$

Assuming that the vehicle load effect is independent and identically distributed random variables. According to distribution analysis of vehicle load effect. We can use the above method to calculate the standard value of vehicle load effect in the design reference period. assuming that the vehicle load effect is independent and identically distributed every day. The section distribution period is one day. That is, the maximum effect distribution($F_T(x)$) in the design reference period can be calculated by the section distribution（$F(x)$）, as the Eq. 4.

$$F_T(x)=[F(x)]^{36500} \tag{4}$$

The vehicle load effect standard values of design reference period can be obtained from the the Eq. 4 , as shown in table 6.

Table 6 Different span simply supported beam design reference period effect moment, shear span standard value fulcrum

Span(m)	M_0[kN·m]	Q_0[kN]
5	699.299	744.238
6	1003.262	773.513
8	1452.544	888.617
10	1919.657	958.614
13	2768.793	1088.468
16	3912.900	1193.133
20	5282.428	1381.468
25	7587.035	1473.368
30	10511.271	1689.603
35	13261.443	1795.310
40	16472.089	1923.721
45	19030.487	2031.963
50	23622.310	2227.434
55	26079.780	2208.310
60	31112.162	2476.943

Determine the vehicle load model. Expressions of internal forces of simple supported beam bridge:

$$q_kL^2/8+P_kL/4=M_0 \tag{5}$$

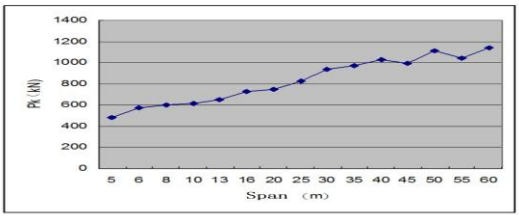
$$q_kL/2+kP_k=Q_0 \tag{6}$$

In the Eq. 5,6: q_k is Lane load, P_k is concentrated force, M_0 is the bending moment at mid span, which is generated by the vehicle team, k is is enhancement coefficient of the shear effect, Q_0 is Shear load at the fulcrum, which is generated by the vehicle team.

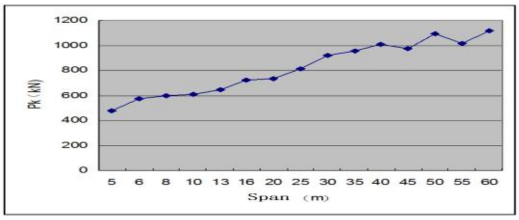
By the Eq. 5 available:

$$P_k=4M_0/L-q_kL/2 \tag{7}$$

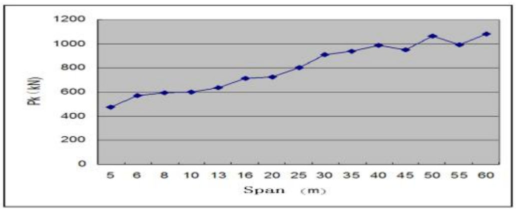
The bending moment standard values and the shear standard values of the different span in the design reference period are presented in the above section. According to the principle of equivalent bending moment effect, the Eq. 7 is used to select different line load as the load base. Take 24kN/m, 25kN/m, 26kN/m, 27kN/m, 28kN/m, 29kN/m, 30kN/m, 31kN/m, 32kN/m, 33kN/m, 34kN/m, 35kN/m, 36kN/m, 37kN/m as the load base, and choose the different load base to determine the concentrated force of the different span, draw different L-P_k curve, due to space limitations, we just draw the Situation of 31kN/m, 32kN/m,33kN/m, 34kN/m, 35kN/m, 36kN/m, as example, as shown in figure 5.



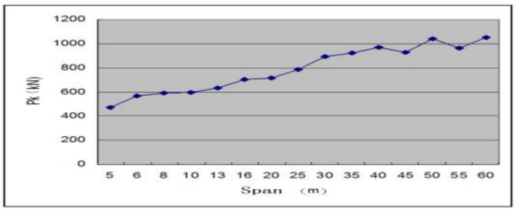
31KN/m



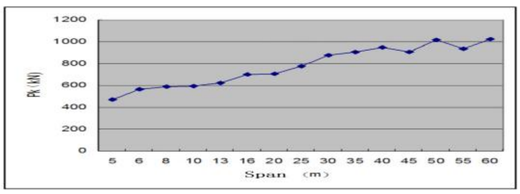
32KN/m



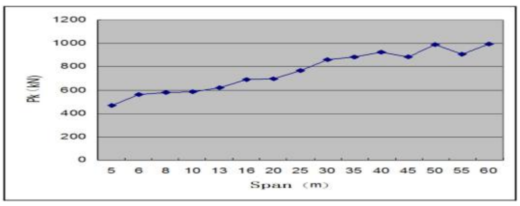
33KN/m



34KN/m



35KN/m



36KN/m

Fig. 5 L—P_k curve

Under the different loading base "L-P_k" curve analysis, can be found in the span is less than or equal to 40 meters, value increases with the increase of the span, approximate linear increase, when span is larger than 40 meters, value changes with the span large floating.

Therefore, we can use the following method to get the concentrated force value : when span is larger than 5 meters and less than 40 meters, using least squares linear regression approach, at 5 meters to 40 meters within the scope of the fitting out a concentrated force and span of linear equations, the concentrated force by the equation determining; less or equal than 5 meters and greater or equal than 40 meters, concentrated force values at the two ends of the equation, as shown in table 7.

Table 7 Standard vehicle design load table

Q_k[kN/m]	Span interva[m]	P_k[k/N]
31kN/m	5<L<40	P_k=14.6L+466
	L<=5,L>=40	539,1050
32kN/m	5<L<40	P_k=14.1L+466
	L<=5,L>=40	536.5,1030
33kN/m	5<L<40	P_k=13.6L+466
	L<=5,L>=40	534,1010
34kN/m	5<L<40	P_k=13.1L+466
	L<=5,L>=40	531.5,990
35kN/m	5<L<40	P_k=12.6L+466
	L<=5,L>=40	529,970
36kN/m	5<L<40	P_k=12.1L+466
	L<=5,L>=40	526.5,950

In order to consider the connection with the existing norms, through the comprehensive analysis, the vehicle design load values of Luogang section are as follows of :

The standard value of line load is 32KN/m; the standard value of concentrated force is selected as follows: the bridge calculation span is less or equal than 5m, the concentrated force is 536.5KN; the bridge calculation span is greater or equal to 40m, the concentrated force is 1030KN; the bridge calculation span is between 5m ~ 40m, the concentrated force is determined by using linear interpolation. Vehicle load calculation method was consistent with current standard.

By applying the equivalent principle, we can calculate the shear effect and the increasing coefficient K value of the supporting point under the effect of the proposed design load. By calculating the value of the concentrated force increasing coefficient of simple supported beam with different span, the value of the increase coefficient is between 1.23 and 1.47. In this paper, the average value 1.325 is used as the coefficient of concentrated force. Therefore, the proposed value of the standard vehicle design load is increased as follows: when calculating the shear effect, the standard value of the concentrated load should be multiplied by 1.325.

Summary and Discussions

In this paper, a detailed analysis of the vehicle load data is carried out in 107 national highway, Luogang, Guangdong, and the following three conclusions are obtained.

- Through the statistical analysis of the data of 107 national highway vehicle load test, we obtained the distribution and parameters of different types of weight. The analysis shows that knowledge: the total weight of the passenger car, motor bus, two axle truck distribution is lognormal distribution; and the total weight of three axle trucks, four axle trucks, five axle trucks and six axle trucks distribution is two humped normal distribution.
- To use the probability distribution, wheelbase, axle load ratio value of different models, we have compiled the program of random vehicle teams cross through the bridge. We have obtained the distribution of the moment effect and shear effect of the small span bridge is the gamma distribution, and obtained the standard value of the design reference period load effect, which provides the basis for the analysis of vehicle load standard.
- According to the principle of equivalent load effect, we convert standard value of load effects in the design reference period to design load standard, Get the car load standards of the recommended value, providing a basis for the formulation of the developed areas of traffic in small span bridge vehicle design load.

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