HEAVY VEHICLE OVER BRIDGES ON THE ROUTE TO TRANSPORT COAL IN SHAANXI, NORTHWEST CHINA

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ABSTRACT

This paper describes numerous overweight and overloaded vehicles on the Fu-Dian Highway, Shaanxi, China. On the base of investigation, 9 types of load models are sorted. Taking gross weight and axle–load as abscissa, and proportion of corresponding load range vehicles to total vehicles as ordinate, gross weight and axle-load histograms are drawn out. According to the above results, various assessment load models are carried out. The bearing capacity of reinforced bridges and load effect of overweight vehicles are calculated. The paper also raises suggestions for the road management authority.

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1. BACKGROUND OF FU-DIAN HIGHWAY TRANSPORTATION

Shenfu coalfield is one of the biggest coalfields in China. A great deal of coal was sold to other places everyday. Many sellers refit the vehicles privately by lengthening, widening and adding height in pursuit of their own profit. The refitted vehicles are seriously overweight. Almost all of the main ways for transporting coals work so tiredly that the highways and bridges are damaged badly.

Fugu-Dianta way is one of the main transporting coals ways in the 309 national highway. The vehicles are very centralized and overweight seriously. The authors do a great deal of investigation and statistics and analysis in situ. Found from the results in recent years, the transportation units or persons change the dimensions of the vehicles to pursue the short economic profit with the improving profit of transporting coal. The gross weight and axle load of the vehicles are over the bridge designing standard and limiting load standard. The proportion of many heavy cars, containers semi trailers and full trailers is more and more, and the loading grade is higher and higher. Many vehicles' weight doubles to the legal limit. The heaviest container and semi trailer were loaded near 118t, and its longest box is near 15m. The serious overloading leads into the jamming. The distance between vehicles kept only 3.0m to 5.0m on many working bridges. The old ways were destroyed. Such situation threatens to the safety of the vehicles and passengers.

Fu-Dian arterial highway built was expected to substitute the old primary roads. There are 59 long, medium and short span bridges from 6m to 25m,angled from 0ºto 45º,200 channels and culverts along the way, including simple and continuous systems, hollowed board and box section. The forms of the bridges are complicated and various.

2. INVESTIGATION AND ANALYSIS OF LOAD MODELS

2.1 Investigation Objects

In this investigation, the lighter and other normal freight vehicles were ignored. The paper only took transporting coals vehicles which load more than 5t into account, including single, double-axle trucks, full trailers (single-and double-wheel) and single, double, trice-axle container semi trailers. According to the loading and axes distributing characteristics, the vehicles were divided into 8 types, such as weight trucks, double, trice-axle container semi-trailers and full trailers, etc. The codes of axle types are: 1+1,1+2,1+1+s/2, 1+1 1+1,etc. The number "1", "2" and "3" represents single, double, trice-axle respectively. "S/" represents semi- trailer, and " " for the full trailer. Except coal vehicles, oil vessel trucks are also considered because of serious overweight, even though there are little, axle type 2+2. Overweight passenger cars were ignored.

In this investigation, the vehicles centralized on Fugu-Dianta way in 309 national route. Metaging and measuring and weighing of the vehicles concentrated on coal weighting institute at the bottom of Huanghe bridge near Fugu city, adopting static electronic measuring system. The data were saved as database. 690 vehicles were weighed with three times each week in this investigation.

2.2 The Analysis of Vehicles Conformation

The distributing of every kind of vehicle is revealed in figure 1.

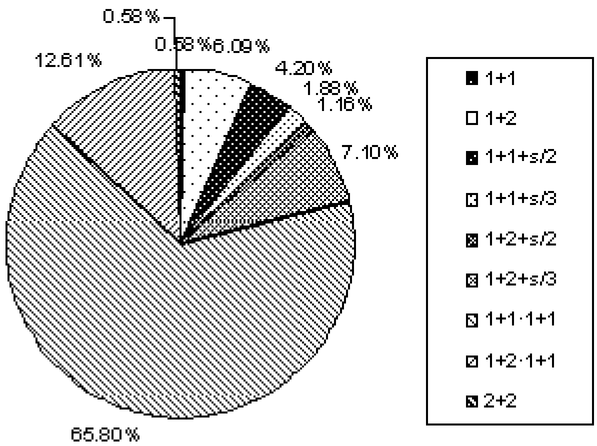


Figure 1. Proportion of vehicle.

2.3 Drawing Gross Weight and Axle-Load Histograms

In order to reflect the distributing of load directly and found assessment load correctly, the paper, taking gross weight and axle–load as abscissa, and proportion of corresponding load range vehicles to total vehicles as ordinate, draws out gross weight and axle-load histograms in figure 2 and 3. The paper also does more statistics to the weight of the some type of vehicles which have more swatches, drawing out their gross weight histograms, calculating their medium value, variance and 95% probability as the theory of confirming assessment load.

From the figure 2, gross weight are mainly distributed in range of 40t-50t, owed to full trailers, axle type 1+1 1+1. This accords with the investigation in situ. Single axle-load was in range of 14t～20t, contributed by owner trucks' back axle of full trailers. For double～axle, in range of 28t～36t, some are contributed by semi trailers, others by trucks of full trailers (1+2 1+1). For trice～axle, in range of 62t～66t, all of them contributed by semi trailers, including load types of 1+2+s/3 and 1+1+s/3. In figure 2, x represents gross of vehicles, but in figure 3, "x" and "p" represent the load weight of vehicles and probability under the condition of axle～load weight.

2.4 Confirming Assessment Load Models

The assessment load of bridge must be confirmed again according to the actuality. The paper takes the integer a =0.05 of gross weight of 9 types as gross weight of assessment load, for example, the weight truck, 1+2, $x_{0.95}$=405.79kN, takes 410kN as its gross weight for calculations convenient.

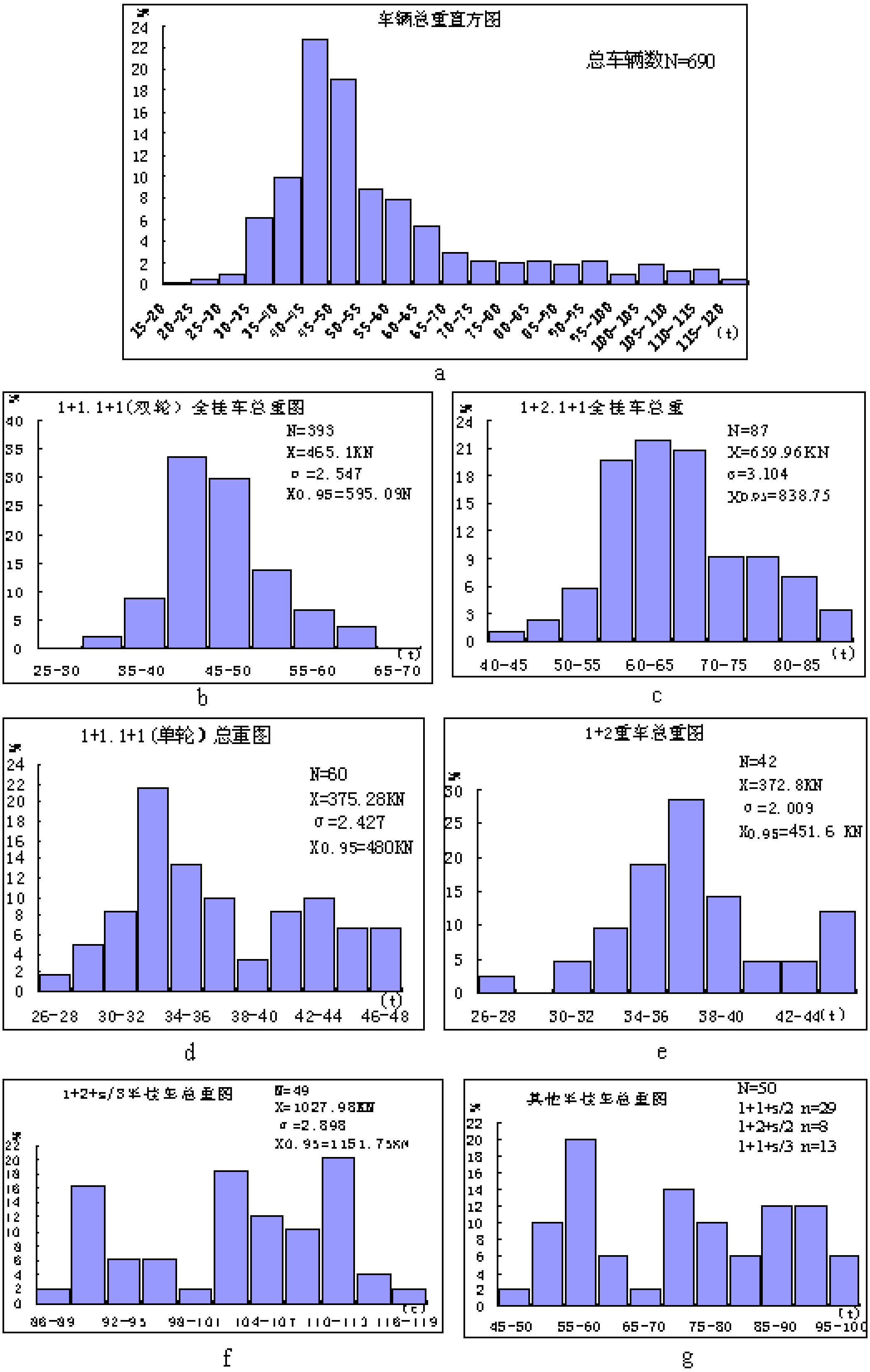


Figure 2. (a,b,c,d,e,f,g) load model.

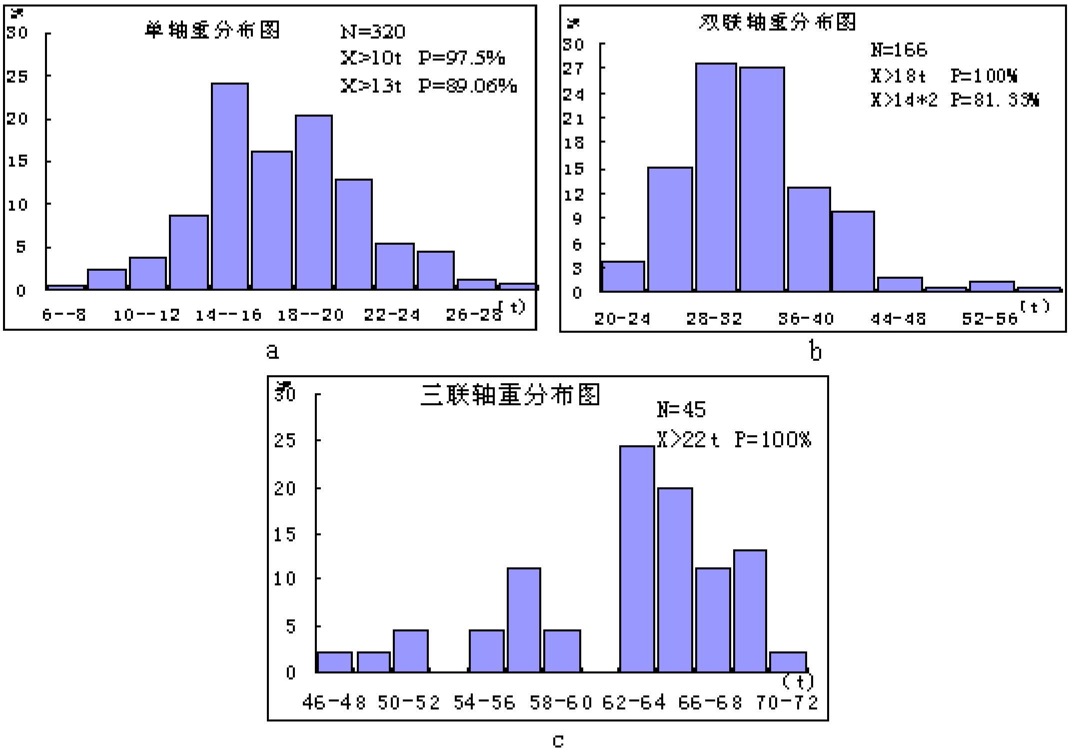


Figure 3. (a,b,c) vertical load.

3. COMPARING BEARING CAPACITY OF BRIDGES WITH LOAD EFFECT

3.1 Objects of Checking Computations

In order to reduce calculations and ensure the safety of the structure, the representative semi trailer, type of 1+2+s/3, was selected as checking load model of all vehicles. The mode of disposing load was the same as Qichao-20.

All kinds of bridge structures in Fu-Dian arterial highway were collected in Table 1. Only the other spans were calculated.

Table 1. Bridge structures on Fudian arterial highway.

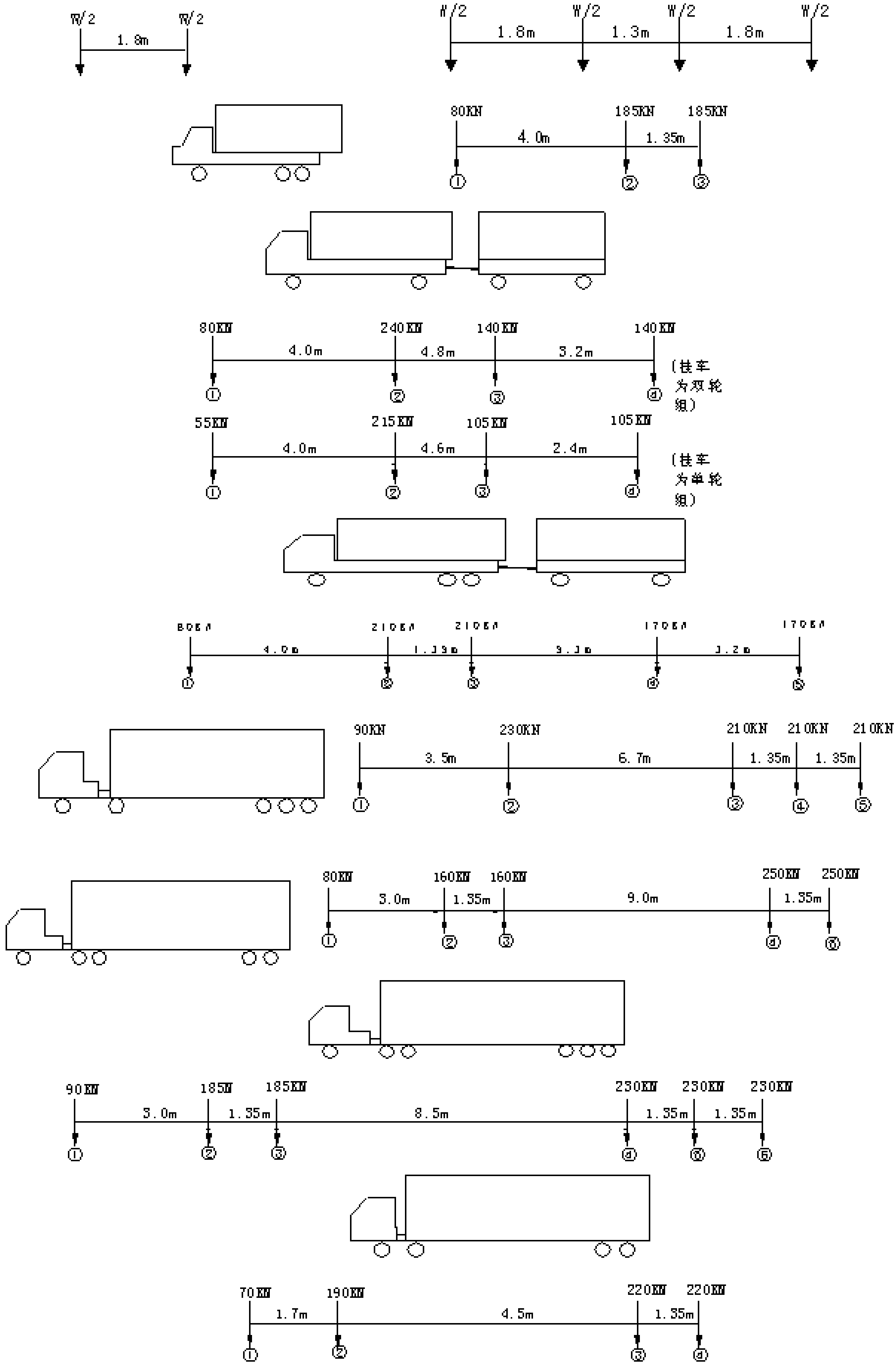
span \ form	Material	Section form	Angle	Structure system
6	Reinforcing concrete	Hollow board girder	0^0, 15^0, 20^0, 30^0, 45^0	Simple-span (continuous surface)
8				
10				
13				
16	Prestressed concrete			
20				
25	Prestressed concrete	Box girder	0^0, 15^0, 30^0, 45^0	continuous

3.2 Contrasting Results

First, carrying capacity (including bearing shear force, mid-span bending moment) of every bridges was checked on designing condition. Then, the effect of the standard load, Qichao －20, and the most dangerous assessment load, 1+2+s/3, were checked.

The results revealed carrying capacity of bridge on the designing condition cannot be adapted to the needs of load effect of overweight vehicles on working condition. Bridges should be reinforced to increase their carrying capacity. Nine loading types are shown in Table 2 as below.

Table 2.



W/2
1.8m
W/2
W/2
1.8m
W/2
1.3m
W/2
1.8m
W/2
80KN
185KN
185KN
4.0m
1.35m
80KN
240KN
140KN
140KN
4.0m
4.8m
3.2m
(挂车为双轮组)
55KN
215KN
105KN
105KN
4.0m
4.6m
2.4m
(挂车为单轮组)
90KN
230KN
210KN
210KN
210KN
3.5m
6.7m
1.35m
1.35m
80KN
160KN
160KN
250KN
250KN
3.0m
1.35m
9.0m
1.35m
90KN
185KN
185KN
230KN
230KN
230KN
3.0m
1.35m
8.5m
1.35m
1.35m
70KN
190KN
220KN
220KN
1.7m
4.5m
1.35m

4. REINFORCEMENT OF BRIDGES UNDER HEAVY VEHICLES AND SECURITY EVALUATIONS

4.1 Reinforcing Measures of Bridges in Fudian Highway

Fu-Dian arterial highway has finished the permanent load construction of the first phase. The hollow boards and girder are all simple-span systems except the continuous box girders. Considering the checking results and the factors above, the paper puts forward the following reinforcing measures.

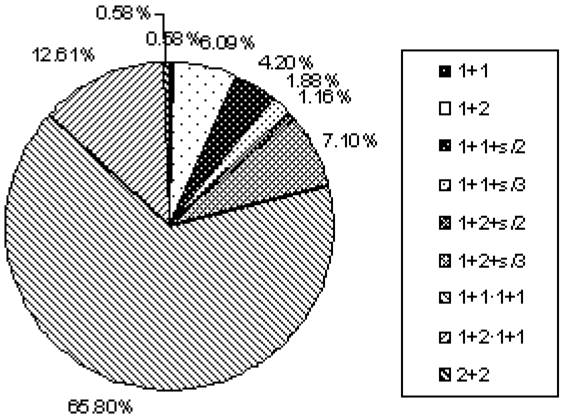


Figure 4. 10m beam cross section reinforcement.

4.1.1 Enhancing Cross Section

Keeping thickness of 10cm cast-in-place concrete and 9cm asphalt layer on its surface unchangeable. Enhancing the concrete grade from 30# to 40# is only for reinforced concrete slab girders, but for prestressed slab girders. Concrete in reaming seam was also enhanced using tiny expanding concrete. Structural reinforcing steel bar should be deployed to ensure new concrete to work properly. This way can increase more section areas but littler weight of the components to improve properties of enduing force in pressing section. Except this, it not only improves capability of resistance force in whole section, but also increased rigidity of the slab and girder and resistance distortion. Figure 4 reveals reinforcement of a piece of beam.

By the disposal of the construction, cast-in-place concrete and slab were felt up reliably, so they work together as a whole. Its analysis of forces was the same as the combined components.

4.1.2 Adding Reinforcing Steel Bar in Reaming Seam

In order to increase carrying capacity of slab girder further, more main reinforcing steel bars were deployed. Every steel bar has bending ends, and interleaving its places back and front, but its length doesn't change. The stirrup has different forms in mid-span and bearings separately. The joint is sealed with 40# slightly expanding concrete. The diameters and numbers of the steel bar can be seen in Table 3.

Table 3. Reinforcing steel bar in reaming seam of every bridge.

Bridge structure	Reinforced board and girder				Prestressed board and girder	
	6m	8m	10m	13m	16m	20m
Steel bar applied	2Φ20+2Φ22	4Φ22	4Φ28	4Φ28	4Φ28+2Φ22	6Φ28

4.2 Security Evaluation of Bridge Structure

The security checking and computations of the bridge structure include two parts: calculating resistance forces, checking and computations of load effect.

4.2.1 Calculating Resistance Forces

- resistance forces of the original hollow slab;
- resistance forces after enhancing cast-in-place concrete layer;
- resistance forces after considering reinforcing steel bar in reaming seam and cast-in-place concrete layer.

The results are revealed in Table 4.

Table 4. Resistance forces of each bridge after reinforcement.

resistance force / content / calculations		Mid span bending moment		Shear force	
		Value (KN)	Increasing proportion（%）	value（KN）	Increasing proportion（%）
L=6m	Original hollow board	265.2	—	494.3	—
	Considering cast-in-place concrete layer	361.1	36.1	556.8	12.6
	Considering two reinforcements	462	74.2	633.8	28.2
L=8m	Original hollow board	425.4	—	557.7	—
	Considering cast-in-place concrete layer	—	—	—	—
	Considering two reinforcements	556.9	30.9	843	51.16
L=10m	Original hollow board	606	—	792.18	—
	Considering cast-in-place concrete layer	779.64	28.7	887.43	12.02
	Considering two reinforcements	976.7	61.2	1085.46	37.02
L=13m	Original hollow board	921	—	817.54	—
	Considering cast-in-place concrete layer	1127.3	22.4	894.45	9.41
	Considering two reinforcements	1383.6	50.2	1249.74	52.8
L=16m	Original hollow board	—	—	—	—
	Considering cast-in-place concrete layer	1322.45	—	—	—
	Considering two reinforcements	1758.53	—	638.13	—
L=20m	Original hollow board	1728.84	—	—	—
	Considering cast-in-place concrete layer	2528.49	46.2	428.42	—
	Considering two reinforcements	2583.43	49.4	750.89	—

From the Table 4, the resistance forces of the structure have improved after applying two reinforcing measures. For example, for reinforced hollow slab of 10m span, mid-span bending moment has improved 61.2%,and shear 371%. For the bridges of other spans, bending moment improved 30.9%, shear force as 28.2% at least.

4.2.2 Load Effect Calculations

- the internal forces calculations under the original design load
- the internal forces calculations under the overweight load models
- checking structures under two limit state combinations

<u>4.3 Principles for Simplified Calculations of Internal Forces</u>

- Simplification of load lateral distribution factor:
  Overweight vehicles deployed load were as normal car in two lanes to calculate lateral distribution factor.
- Load combination coefficient:
  When calculating, load combinations were abided by principles of cars, considering impacting factor.
- Analysis of the checking results:
  When internal forces were over resistance forces, fluctuating was of 5% of resistance forces. The checking and calculations may pass.

4.4 Checking and Calculations Results

From Table 5, mid-span bending moment of slab and girder for spans 6m and 8m cannot be adapted to the most disadvantageous overweight load. But comparing to the original slab, loading carrying capacity has improved more. All shear force can pass. Internal forces of other bridges all can pass. The results reveal the applicability of these two reinforcing measures. As permanent reinforcing measures, they can serve all the time and construction and the program is simple and convenient. So they can be suggested and widely used in the similar engineering.

Table 5. Checking and calculations results.

contents / span		Load model	Resistance force after reinforcement	Ultimate limit state		Service limit state			
				Load combination Ⅰ	result	Crack width（mm）	Result	Distortion（mm）	Result
6m	Mid-span bending moment (kN m)	Ⅷ	462	488.2	Not pass	0.11	Pass	2.7	Pass
	Shear force(kN)		633.8	555.9	pass				
8m	Mid-span bending moment (kN m)		556.9	737.8	Not pass	0.13	Pass	4.5	Pass
	Shear force(kN)		843	575.6	Pass				
10 m	Mid-span bending moment (kN m)	Ⅷ	976.7	1016.8	Pass	0.109	Pass	16.52	Pass
	Shear force(kN)		1085.46	620.75	Pass				
13 m	Mid-span bending moment (kN m)		1383.6	1428.04	Pass	0.119	Pass	21.27	Pass
	Shear force(kN)		1249.74	686.3	Pass				
16 m	Mid-span bending moment (kN m)		1758.53	1700.51	Pass	—	—	—	—
	Shear force(kN)		638.13	647	Pass				
20 m	Mid-span bending moment (kN m)		2584.43	2514.83	Pass	—	—	—	—
	Shear force(kN)		750.89	755.25	Pass				

5. LIMITING LOAD AND CONTROLLING TRANSPORTATION LOAD BY DEPARTING DRIVEWAY FOR OVERWEIGHT VEHICLES

5.1 Management Suggestions for Bridges Under Overweight Vehicles

From checking the results after the reinforcement, part of the bridges in carrying capacity cannot meet the needs of a lot of vehicles that are seriously overloaded.

So the following management measures were suggested to solve this problem further:

5.1.1 Weight of Loading Goods

This should be controlled in the carrying capacity allowable range and distributed in a longer range as possible, or taken down the goods and divided into small parts for more trucks. The vehicles of multi-wheels or multi-axes and distributed axes were advocated to carry coals.

5.1.2 Transportation Management

Fudian Highway Takes the Overweight Vehicles as Assessment Load under the most disadvantageous transportation condition. That equals to lightening burden and improving carrying capacity of bridges.

The following measures were to be taken:

- controlling vehicles by departing driveway may be into semi-container trailers and heavy, full trailers way.
- ensuring running distance, vehicles should run in the middle of the bridge as possible.
- when overweight vehicles run on the bridges, speed should be limited. Acceleration, fast speed, and sudden braking are all not allowed.

5.1.3 Keeping Good Maintenance of the Bridge

The conditions and carrying capacity of the bridges should be checked, inspected, and measured after the bridge put into use to confirm the practical carrying capacity and safety each bridge which limits the load of the working vehicles.

6. CONFIRMING EQUIVALENT UNIFORM LOAD

Equivalent uniform load is used to calculate limiting standard of vehicles and evaluate safety under limited loads. At first, carrying capacity of every bridge is evaluated practically and expressed in corresponding standard equivalent uniform load. Then, equivalent uniform loads of every load models are calculated and concluded the controlling equivalent uniform load for all load models.

6.1 Equivalent Uniform Load

The utmost influence value $S_{max}=k\ \omega$. (1)

K is called the equivalent uniform load, ω is the influence area corresponding to influence value S_{max}.

The equivalent uniform load expression from formula (1) may be as:

$$K= S_{max}/\omega \quad (2)$$

6.2 Bridge Allowable Standard Load

From 《Highway Designing Code》, bearing capacity checking and calculations formula are as followings:

$$S_d(\gamma_g G;\gamma_q \sum Q) \le \gamma_b R_d\left(\frac{R_c}{\gamma_c};\frac{R_S}{\gamma_s}\right) \quad (3)$$

Here the load effect is the maximum. Load combination is at the ultimate limit state I.

$$1.2S_G+1.4S'_{Q_1}=S_d(\gamma_g G;\gamma_q \sum Q)=\gamma_b R_d\left(\frac{R_c}{\gamma_c};\frac{R_S}{\gamma_s}\right) \quad (4)$$

S_G—gravity effect permanent load;

S'_{Q_1}—changeable load, car(including impacting force),crowd load effect. In this paper, it means overweight load effect (including impacting force).

Then:
$$S'_{Q_1}=\frac{\gamma_b R_d\left(\frac{R_c}{\gamma_c};\frac{R_S}{\gamma_s}\right)-1.2S_G}{1.4} \quad (5)$$

Here,

$$S'_{Q_1} = \phi \cdot (1+\mu) \cdot m_c \sum P_i \cdot \eta_i \qquad (6)$$

$\sum P_i \cdot \eta_i = S_{max} = K\omega$

ϕ —driveway reduction coefficient, if two driveway, $\phi = 1$

$1+\mu$ —impacting coefficient;

m_c —lateral distributing factor in mid span;

P_i —each axle load of overweight vehicles;

η_i —ordinate of internal force influence line corresponding to P_i.

Ω —influence line area in loading range, others as same as criteria.

Then get:

$$K = \frac{\gamma_b R_d\left(\frac{R_c}{\gamma_c};\frac{R_S}{\gamma_s}\right) - 1.2S_G}{1.4(1+\mu)\cdot m_c\omega} \qquad (7)$$

In formula (7),uniformly distributed load K is expressed as K'. K' is defined as allowable standard load of bridge. And K' (just for mid-span bending moment) of every span is calculated in Table 6.

Table 6. Allowable standard uniform load of every bridge on Fu-Dian highway.

Span (m)	Calculating section	Resistance force(kN·m)	Dead load (kN·m)	Live Load effect(kN·m)	Impacting coefficient	Lateral distribution factor	S_{max}	Calculation span(m)	Influence line area(m^2)	Equivalent uniform load K' (kN/m
6	mid-span	462	58.87	279.54	1.29	0.353	613.874	5.6	3.92	156.60
8		556.9	116.08	298.29	1.2775	0.335	696.997	7.6	7.22	96.54
10		976.7	193.36	531.91	1.2625	0.33	1276.701	9.6	11.52	110.82
13		1383.6	355.6	683.49	1.24	0.31	1778.059	12.6	19.85	89.60
16		1758.53	544.52	789.36	1.2175	0.246	2803.053	15.6	30.42	92.15
20		2583.43	925	1052.45	1.1875	0.234	3831.706	19.5	47.53	80.61
6	bearing	633.8	42.05	416.67	1.29	0.5	646.002	5.6	2.8	230.72
8		843	61.09	549.78	1.2775	0.5	860.712	7.6	3.8	226.50
10		1085.46	80.57	706.27	1.2625	0.5	1118.841	9.6	4.8	233.09
13		1249.74	112.9	795.90	1.24	0.5	1283.710	12.6	6.3	203.76
16		750.89	139.62	416.67571	1.2175	0.5	684.478	15.6	7.8	87.75
20		638.13	188.81	293.97	1.1875	0.5	495.107	19.5	9.75	50.78

6.3 Equivalent Uniform Loads of Every Overweight Load Models

By formula (2), the paper gives the Equivalent uniform load of every load models at different calculating point in different spans or loaded length. The final results are given in Table 7.

Table 7. Equivalent uniform load of load model (e.g. load models VIII and IX).

Span or load length（m）	Load model Ⅷ				Load model Ⅸ			
	Mid-span bending moment	l/4 Bending moment	l/4 Shear force	Bearing shear force	Mid-span bending moment	l/4 Bending moment	l/4 Shear force	Bearing shear force
2	212.00	262.93	350.22	290.00	220.00	239.20	318.22	289.00
4	189.00	187.33	249.78	227.00	146.00	170.00	226.67	182.50
5.6	167.09	166.33	221.59	186.07	119.39	129.59	172.70	136.43
7.6	138.37	137.40	183.39	148.42	95.29	101.75	135.67	116.05
9.6	116.32	116.90	155.56	123.54	81.25	88.19	117.41	101.88
12.6	93.73	93.39	124.44	100.48	71.05	77.94	104.13	86.35
15.6	78.24	78.90	105.07	91.67	63.77	67.94	90.94	73.59
19.6	63.52	70.25	94.15	81.84	54.35	57.48	76.92	61.12
25	56.96	61.10	81.49	68.80	45.70	46.42	61.87	48.80

6.4 Controlling Equivalent Uniform Load of Load Models

In view of departing driveway to control and manage transportation, all the vehicles are divided into two classes:

- Heavy and full trailers.(including load models Ⅰ, Ⅱ, Ⅲ(double wheels and single wheel), and IV, corresponding code:1,2,3,4,5)
- Semi and container trailers(including load models V, VI, VII, VIII and IX corresponding code: 6,7,8,9,10)

The definition of the controlling equivalent uniform load of load models is described as given spans or loaded length and given place, the equivalent uniform maximum in the calculating point of all load models. It is expressed with [K_{max}], row matrix, in mathematics:

$$[K_{max}]=[K_{max}^{(1)},\ K_{max}^{(2)},\ \ldots,\ K_{max}^{(9)}]。\qquad (8)$$

$K_{max}^{(i)}$ -controlling equivalent uniform load of load models of No.i span or load length.

$K_{1max}^{(i)}=\max\{K_1^{(i)}, K_j^{(i)},\ \ldots,\ K_5^{(i)}\}$ i =1,2,…,9; j=1,2,…5

$K_{2max}^{(i)}=\max\{K_6^{(i)}, K_j^{(i)},\ \ldots,\ K_{10}^{(i)}\}$ i =1,2,…,9; j=6,7,…10

$K_j^{(i)}$—equivalent uniform load of No.j kind of load model in No.i code of span or loaded length. Table 8 gives out controlling equivalent uniform load of two class vehicles.

Table 8. Controlling equivalent uniform load.

Code	Span or loaded length(m)	Controlling equivalent uniform load value（kN/m）							
		Heavy truck and full trailer				Semi trailer or container trailer			
		mid-span bending moment	l/4bending moment	l/4shear force	Bearing shear force	mid-span bending moment	l/4bending moment	l/4shear force	Bearing shear force
1	2	240	233.60	311.11	276.00	250	272.00	362.67	329.00
2	4	139	162.00	216.00	174.00	189.00	192.67	256.89	227.00
3	5.6	113.78	125.85	167.62	132.50	167.09	166.33	221.59	186.07
4	7.6	90.86	96.40	128.65	105.26	138.37	137.40	183.39	148.42
5	9.6	77.86	83.22	111.11	90.63	116.32	116.90	155.56	123.54
6	12.6	65.51	68.53	91.15	80.32	93.73	93.39	124.44	100.48
7	15.6	62.79	66.18	87.98	73.97	78.24	78.90	105.07	91.67
8	19.6	53.31	56.64	72.93	60.82	63.52	70.25	94.15	81.84
9	25	47.62	49.66	61.72	50.56	56.96	61.10	81.49	68.80

7. CONFIRMING LIMITING LOAD STANDARD

7.1 Limiting Load Parameter

7.1.1 Limiting Load Coefficient Λ
Definition of load coefficient :

$$\lambda_{ij}=\frac{K_i^{'}}{K_{ij}} \quad (i=1，2，\cdots，6；j=1，2，\cdots，10). \qquad (9)$$

λ_{ij} is limiting load parameter of the No.j kind of load model on the No.i bridge.
$K_i^{'}$ mid-span allowable standard uniform load on No.i bridge. Looking for in Table 6.
K_{ij} mid-span equivalent uniform load of No.i bridge under the No.j kind of load model.
By formula (9), limiting load parameter λ_{ij} of every kind of load models is calculated in Table 9.

Table 9. Limiting load parameter of load model.

Bridge code	Calculating span	Load model code	1	2	3	4	5	6	7	8	9	10
		Standard uniform load	I	II	III 2-wheel	III 1-wheel	IV	V	VI	VII	VIII	IX
			Equivalent uniform load of every load model									
1	5.6	156.60	85.71	100.26	85.71	76.79	113.78	130.10	152.55	135.52	167.09	119.39
2	7.6	96.54	63.16	80.06	63.16	56.51	90.86	103.88	126.45	108.17	138.37	95.29
3	9.6	105.53	52.52	69.01	52.52	47.40	77.86	85.94	106.77	89.41	116.32	81.25
4	12.6	87.95	42.33	56.94	47.57	41.42	65.51	68.03	85.66	71.05	93.73	71.05
5	15.6	92.15	35.17	47.99	42.08	37.80	62.79	59.83	71.33	58.51	78.24	63.77
6	19.5	80.61	28.95	39.57	38.94	33.53	53.31	52.69	62.47	43.94	63.52	54.35
1	5.6	Limiting load parameter	1.827	1.562	1.827	2.039	1.376	1.204	1.027	1.156	0.937	1.312
2	7.6		1.529	1.206	1.529	1.708	1.062	0.929	0.763	0.892	0.698	1.013
3	9.6		2.009	1.529	2.009	2.227	1.355	1.228	0.988	1.180	0.907	1.299
4	12.6		2.078	1.545	1.849	2.123	1.343	1.293	1.027	1.238	0.938	1.238
5	15.6		2.620	1.920	2.190	2.437	1.468	1.540	1.292	1.575	1.178	1.445
6	19.5		2.785	2.037	2.070	2.404	1.512	1.530	1.290	1.835	1.269	1.483

7.1.2 Limiting Load Parameter of Load Models
From Table 9, the paper finds the limiting parameter minimum of every load models for all bridge spans, and takes this minimum as the limiting load parameter of load model, expressing in mathematics: $\lambda_j=\min\{\lambda_{1j}，\lambda_{2j}，\lambda_{3j}，\lambda_{4j}，\lambda_{5j}，\lambda_{6j}\}$。(j=1,2，…，10). (10)

Then get $\lambda=[\lambda_1，\lambda_2，\cdots，\lambda_{10}]$=[1.529，1.206，1.529,1.708,1.062,0.929，0.763，0.892，0.698，1.013].

7.2 Confiming Limiting Load Standard of Overweight Vehicles

From formula(9),when $\lambda \geqslant 1$，that is $K^{'} \geqslant K$ ，carrying capacity is enough and no limitations；when $\lambda<1$，carrying capacity cannot be adapted to the load effect, limiting load of vehicles. Known from parameter $\lambda=[\lambda_1，\lambda_2，\cdots，\lambda_{10}]$ above, some kinds of load models need to be limited.

If $\lambda \geq 1$, it then keeps the former load standard, if $\lambda < 1$,woking load standard value from the statistics and analysis is multiplied by the corresponding limiting load coefficient. and the final value is a model restrained load standard. Ensuring probability after limiting load is figured out according to the histograms of weight, and the results are listed in the Table 10.

From Table 10, Ensuring probability of model Ⅷ and Ⅵ is 0 after the limiting load. It says that no vehicle could satisfy the demand. And model Ⅴ's Ensuring probability is also low, only 54%. While the other vehicles, ensuring probability is beyond 80%, and heavy truck and full trailer need not limit. So the method of limiting load is applied to a few load models, which there are less, and the weight reduced less. So it will not bring economic loss to transportation, but it can reduce the damage to the bridges and save the expenditure in great degree.

Table 10. Limiting load standard of every load model.

Load model	I	II	III (double wheel)	III (single wheel)	Ⅳ	Ⅴ	Ⅵ	Ⅶ	Ⅷ	Ⅸ
Limiting load paramete	1.529	1.206	1.529	1.708	1.062	0.929	0.763	0.892	0.698	1.013
Limit or not	not	not	not	not	not	limit	limit	limit	limit	not
Working load standard(kN·m)	320	450	600	480	840	800	950	900	1150	700
Original ensuring probability	95%									
Limiting load standard(kN·m)	320	450	600	480	840	740	720	800	800	700
New ensuring probability	95%					54%	0%	80%	0%	95%

8. CONFIRMING CONTROLLING LOAD OF TRANSPORTATION BY DEPARTING DRIVEWAY

Overweight vehicles running in the departing driveway are a controlling transportation means by artificial way. It not only reduces traffic accident by vehicles running on their own ways, but also avoid the most disadvantageous loading effect of bridge and the most disadvantageous distributing loading effect, utilizing carrying capacity enough, and it is also a best supplement for limiting load.

<u>8.1 Load Sharing After Departing Driveway</u>

8.1.1 Load Sharing Theory

According to the investigation in situ and statistics and analysis of weight, the double driveway is divided for heavy, heavier trucks, full trailers and semi and container trailers way.

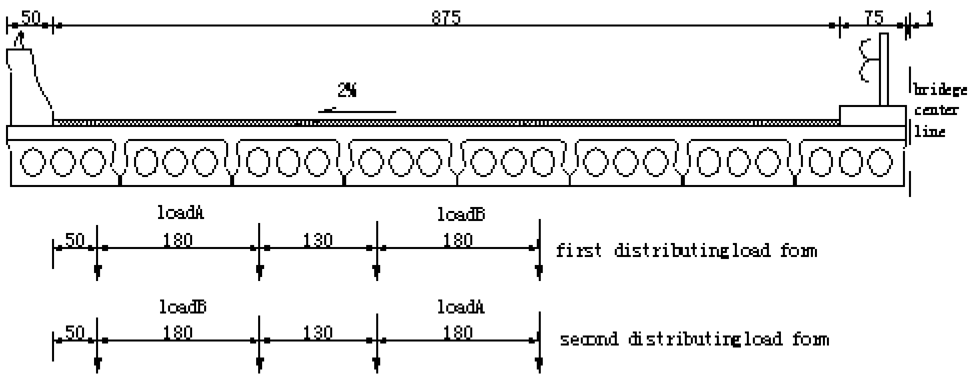


Figure 5. Transverse loading form.

The controlling equivalent uniform load(mid-span bending moment) for the first one is expressed with A, the second one, B. So there are two forms of load lateral distribution in figure 6.

Load transverse distribution coefficients corresponding to A and B are m_{ai}, m_{bi} respectively, they can be used to distribute equivalent loads. And the equations are:

Load A: $a_i = A \cdot m_{ai}$ (11a)

Load B: $b_i = B \cdot m_{bi}$ (11b)

8.1.2 Final Value of Equivalent Uniform Load

Superpose equivalent loads and get the new functionary load, q_i

qi= $a_i + b_i$ i=1，2，…，4 (12)

Final value：

q=max{q1，q2，…，q4} 。 (13)

In this method, involving every possible equivalent loads distributed on each girder, it is safe enough. The equivalent loads are calculated in Table 11

Table 11. Final equivalent uniform load value q.

loading form \ span (m)	5.6	7.6	9.6	12.6	15.6	19.5
The first distributing load form	53.71	42.26	34.61	26	18.09	13.97
The second distributing load form	50.13	37.18	30.73	23.59	16.73	13.41

From Table 11, equivalent uniform load under the first distributing load form is the maximum.

8.2 Internal Force Checking and Calculations for Bridge Structure

To judge vehicles' security after departing driveway, it is necessary to check carrying capability of bridges.

8.2.1 Checking Carrying Capability by Equivalent Uniform Load

From Table 6, allowable load K' of each bridge is confirmed, and equivalent uniform load in Table 11 has considered lateral factor. In order to compare conveniently, allowable load K' is usually translated into uniform load. The translated uniform load is compared with final equivalent load q.

Here q^h represents translated uniform load by allowable standard load K'

$q_i^h = K_i' \cdot m_{ci}$ （i=1，2，…，6） (14)

K_i'—allowable standard load of the No.i bridge.

m_{ci}—mid-span lateral factor corresponding to the No.i bridge when double lines in Landscape.

Giving a definition of differencing parameter μ for equivalent uniform load.

$$\mu = (q_i - q_i^{h}\text{£©}q_i^{h} \times 100\% \quad i=1，2，\cdots，6 \tag{15}$$

q_i—final equivalent uniform load corresponding to the No.i bridge mid span after departing driveway. Searching for in Table 11.

q_i^h— The translated uniform load corresponding to the No.i bridge mid span.

When $\mu \le 0$， carrying capacity of bridge is enough.

When $0 〈 \mu \le 5\%$，carrying capacity of bridge can be adapted to overweight load effect；

When $\mu 〉 5\%$，carrying capacity of bridge cannot be adapted to overweight load effect, and some reinforcements are necessary to ensure vehicles pass safely.

8.2.2 Differentiation of Carrying Capacity

According to the formulas (14) and (15), the equivalent uniform load is verified under the first distributing load form, and the results are listed in Table 12.

Table 12. Checking and calculations under the first distributing load form.

Bridge code	Calculating Span L_0(m)	Standard Load $K_i^{'}$ (kn/m)	Final value q_i (kn/m)	Lateral distribution factor m_{ci}	Translated load q^h(kn/m)	M%	Pass or not
1	5.6	156.60	53.71	0.353	55.28	-2.84	Pass
2	7.6	96.54	42.26	0.335	32.34	30.67	Not
3	9.6	105. 53	34.61	0.330	36.57	-5.37	Pass
4	12.6	87. 95	26.00	0.310	27.78	-6.39	Pass
5	15.6	92.15	18.09	0.246	22.67	-20.19	Pass
6	19.5	80.61	13.97	0.234	18.86	-25.94	Pass

From Table 12, all the bridge can pass except 8m-span bridge. The second distributing load form is omitted, the results also can't ensure all the bridges pass.

Therefore, the paper advises applying limited loads and controlling transportation by departing driveway at the same time on Fu-Dian highway, and some other management techniques can be used too. For example, restricting the types and number of overweight vehicles if passing the bridges at the same time. It can be done to ensure that traffic is safe and to avoid destroying bridge structures.

9. SUMMARY

This paper investigated the overweight condition for every kind of vehicles, analyzing investigating results, drawing out load histograms, confirming load models of bridges on Fu-Dian highway and supplying academic basis for overweight vehicles over bridges managements.

The paper puts forward two permanent reinforcements for being building bridges according to the overweight situation on Fu-Dian highway, and calculates the resistance force and internal force under representative load models of bridges after reinforcements, offering references for studying of overweight vehicles passing bridges in future.

The paper also suggests some managements by carrying capacity of some bridges which cannot be adapted to overload effect after reinforcements. One is limiting load for vehicles, calculating limiting parameter and standard of every load models. The other is controlling transportation by departing driveway in landscape orientation, checking carrying capacity by equivalent uniform load. In transportation management, these two measures are simple and convenient. Their effects are remarkable. The authors suggest that these two measures be applied at the same time.

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