Application Research on Wheel Blocking Device in Piggyback Transport Vehicle System

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Abstract. Piggyback transport is an important mode of highway-railway international transportation. The quality of loading and securement is directly related to the safety of transportation. This paper analyzed the piggyback transport vehicle system wheel blocking device using a combination of theoretical calculations and real vehicle tests. The results show that the wheel blocking device meets the requirements of piggyback transport in terms of strength and blocking effect.

Keywords. Piggyback transport, Highway-railway, Transportation safety, Wheel blocking device.

1. Introduction

During the operation of the piggyback transport vehicle system, road freight vehicles are used as the ‘cargo’ transported by the railed piggyback transport vehicle. Its loading and securement directly affect the operation safety of the piggyback transport vehicle system. The wheel blocking device is an important part of the securement structure of the piggyback transport vehicle system. In order to prevent the road wagon from moving forward and backward during the operation of the piggyback transport vehicle system, after the road truck enters the railway piggyback transporter and parked, install wheel blocking device at the front and rear of the road tires to prevent the road truck from moving forward and backward.

Scholars have done some research on this related topic. Li Chen et al [1] analyzed the development of piggyback transportation technology in Europe and America and its enlightenment to China. Wu Xiaodong et al [2] have a research on simulation of military wheel-equipment railway transportation impact test by simpack. Li Xiaohong et al [3] analyzed the factors of affecting loading and reinforcing scheme of large goods in railway. Beskou [4] has a study on dynamic effect of moving loads on road pavements. Takuichiro Ino et al [5] studied on the structural fracture of body structure in railroad car. Foreign countries also use a similar method to fix road trucks, but due to differences in vehicle structure and weight, it is necessary to design the wheel blocking device according to the current state of vehicles in China. This paper uses a combination of theoretical calculations and real vehicle tests to study the characteristics and strength of the wheel blocking device to ensure the safety of piggyback transport operations.

2. Theoretical Calculation of Wheel Blocking Structure Strength

2.1. Strength Check of Loading and Securement

The calculations are carried out by using two working conditions: a fully loaded road truck and an unloaded road truck.
2.1.1. Longitudinal Inertial Force. When loading an unloaded road truck, 
\[ T_L = t_{0L} \times Q_L = (0.0012Q_{ck}^2 - 0.32Q_{ck} + 29.85) \times 17 = 163.55kN \]  
when loading a fully loaded road truck, 
\[ T_L = t_{0L} \times Q_L = 6.78 \times 49 = 332.22kN \]  
where: \( t_{0L} \) is longitudinal inertial force of per ton cargo, kN/t; \( Q \) is Cargo weight, t.

2.1.2. Lateral Inertial Force. When loading an unloaded road truck, 
\[ N_L = n_{0L} \times Q = (2.82 \times 2.2 \times \frac{3.335}{22.6}) \times 17 = 53.46kN \]  
when loading a fully loaded road truck, 
\[ N_L = n_{0L} \times Q = (2.82 + 2.2 \times \frac{0.077}{22.6}) \times 49 = 138.55kN \]  
where, \( n_{0L} \) is the lateral inertial force of per ton cargo, kN/t.

2.1.3. Vertical Inertial Force. When loading an unloaded road truck, 
\[ Q_{cv} = q_{cv} \times Q = (4.54 + 7.84 \times \frac{3.335}{22.6}) \times 17 = 96.68kN \]  
when loading a fully loaded road truck, 
\[ Q_{cv} = q_{cv} \times Q = (4.54 + 7.84 \times \frac{0.077}{22.6}) \times 49 = 223.28kN \]  
where: \( q_{cv} \) is vertical inertial force of per ton cargo, kN/t.

2.1.4. Wind Force. 
\[ W = qF \]  
where, \( q \) is the lateral calculate wind pressure. When the wind-receiving surface is flat, \( q=0.49kN/m^2 \), and when the wind-receiving surface is the side of a sphere or cylinder, \( q=0.245kN/m^2 \); \( F \) is the projected area of the lateral windward surface, m\(^2\). The lateral windward area of highway trucks is about 65.33m\(^2\).
\[ W = 0.49 \times 65.33 = 32.01kN \]  

2.1.5. Friction. Longitudinal friction: 
\[ F_{L}^z = 9.8 \mu Q \]  
lateral friction: 
\[ F_L^h = \mu(9.8Q - Q_c) \]  
where, \( \mu \)--coefficient of friction. It can be calculated that: 
\[ F_{Lh} = 9.8 \times 0.5 \times 17 = 83.3kN \]
\[ F_{in}^z = 9.8 \times 0.5 \times 49 = 240.1 \text{kN} \] (12)
\[ F_{rh}^h = 0.5(9.8\times17 - 96.68) = 34.96 \text{kN} \] (13)
\[ F_{inh}^h = 0.5(9.8\times49 - 223.28) = 128.46 \text{kN} \] (14)

2.1.6. Braking Force. The braking torque of each axle of a six-axle road truck is 20000N•m, and the wheel diameter is 1100mm. The total braking force is:

\[ F_{br} = \frac{6 \times 20000 \times 2}{1100} = 218.18 \text{kN} \] (15)

\( F_{in}^z > F_{br} \), then the calculation of the horizontal movement stability of the heavy truck must be carried out according to \( F_{br} \).

2.2. Calculation of Lateral Overturning Stability

\[ \eta = \frac{9.8Qb}{Nh + Wh} \] (16)

where \( Q \) is the weight of the cargo, \( t \); \( b \) is the distance from the horizontal vertical plane where the center of gravity of the cargo to the overturning point of the cargo, mm; \( T \) is the longitudinal inertial force of the cargo, kN; \( N \) is the lateral inertial force of the cargo, kN; \( h \) is the height of gravity center of the cargo from the horizontal plane where the overturning point, mm; \( W \) is the wind acting on the cargo, kN; \( h_w \)--the height of the combined force of the wind from the horizontal plane where the overturning point, mm. When the overturning stability factor is less than 1.25, reinforcement measures need to be taken.

2.3. Horizontal Movement Stability

If the longitudinal inertial force of the cargo is greater than the longitudinal friction force or 1.25 times the sum of the lateral inertia force and the wind force is greater than the lateral friction force, reinforcement measures shall be taken to prevent the cargo from moving. The longitudinal or lateral force of the reinforcing material should withstand can be calculated as follows:

In the longitudinal:

\[ \Delta T = T > F_{f}^z \] (17)

In the crosswise:

\[ \Delta N = 1.25(N + W) > F_{f}^h \] (18)

when loading an unloaded road truck,

In the longitudinal:

\[ \Delta T = 163.56kN > 83.3kN \] (19)

In the crosswise:

\[ \Delta N = 1.25 \times (53.46 + 32.01) = 106.84kN > 34.96kN \] (20)

It can be known from the plan that in the longitudinal direction, the vehicle's longitudinal movement is limited only by its own wheel blocking device, and the minimum height of the wheel blocking device should be:
\[ h = (0.3744 - 0.0018 \times 103) \times 1100 = 207.9 \text{mm} \]  

when loading a fully road truck,

In the longitudinal:

\[ \Delta T = 332.22kN > 218.18kN \]  

In the crosswise:

\[ \Delta N = 1.25 \times (138.55 + 32.01) = 213.2kN > 128.46kN \]  

At this time, the minimum height of the self-contained wheel blocking device should be:

\[ h = (0.3744 - 0.0018 \times 135) \times 1100 = 144.5 \text{mm} \]

In the horizontal direction, the piggyback transport vehicle can prevent further lateral movement of the road freight truck by carrying the underframe side beams, and the tires have a gap of 20mm from both sides of the side beams, which can play a certain cushioning effect.

### 3. Shock Test Method of the Piggyback Transport Wheel Blocking Device

#### 3.1. Test Equipment

1. Dynamic data acquisition system: used for dynamic data acquisition and processing in impact tests;
2. Resistance strain gauge: test the stress of each part of the wheel blocking device;
3. Speed meter: test the impact speed of the impact vehicle;
4. Pull-type displacement meter: test the displacement of highway trucks;
5. High-definition camera: record the state of road trucks during the impact;
6. Impact vehicle: a fully loaded C80 gondola (number: C80C0005);
7. A road truck with length of 16.5m and total weight of 49t;
8. Impacted vehicle: a group of QT1 piggyback transport vehicle, the tested road vehicle is installed on the impacted vehicle;
9. Obstruction vehicle: one full-load railway wagon.

#### 3.2. Test Point Arrangement

**3.2.1. Arrangement of Stress Measurement Points.** At the front end (impacted end) of the fourth wheel of the road truck, the wheel blocking device is subject to a large force and the strain gauge is affixed to the wheel. Each wheel blocking device has six measurement points, a total of twelve measurement points. The arrangement of measuring points is shown in figure 1, and the corresponding positions of measuring points are shown in figure 2.

**Figure 1.** The layout of stress measurement points of the wheel blocking structure.  
**Figure 2.** Location of the stress measurement points of the wheel blocking structure.

**3.2.2. Displacement Measuring Point Arrangement.** The displacement measurement points are arranged on the axle 1 and axle 3 of the road truck, as shown in figure 3.
3.3. Impact Test Method
The impact test simulates the shunting operation process of a railway station, and is performed by a single-end continuous impact method. Before the test, the impacted vehicle is parked at a fixed impact point, and the vehicle is in a free state. Pre-impact once at a speed of 3km/h, observe the state of the truck or semi-trailer, and determine that there is no abnormality. Increase the impact speed step by step with a gradient of 1km/h. The maximum impact speed is 6km/h. No less than 2 shocks per speed stage. The impact method is shown in figure 4.

3.4. Analysis of Test Results
After the preparation work was completed, an impact test was performed, and a total of 8 impacts were performed with a maximum impact speed of 6.10km/h. The test is shown in figure 5. It is shown that the peak value of each stress measurement point is shown in table 1, and the peak value of each displacement measurement point is shown in table 2.
Table 1. Peak value of each stress measurement point (unit: MPa).

| Speed (km/h) | Point 1 | Point 2 | Point 3 | Point 4 | Point 5 | Point 6 | Point 7 | Point 8 | Point 9 |
|-------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 3.18        | -73.26  | -73.13  | 15.24   | -42.85  | -44.39  | 31.78   | -33.14  | 17.46   | -10.08  |
| 3.28        | -73.13  | -69.13  | 11.45   | -36.58  | -51.43  | 30.97   | -28.94  | 18.34   | -16.03  |
| 4.19        | -69.13  | -63.42  | -18.45  | 20.74   | -67.90  | 47.80   | -55.12  | 22.28   | -17.02  |
| 4.34        | -77.25  | -71.44  | 18.79   | -44.11  | -111.87 | 42.81   | -7.44   | 18.15   | -13.24  |
| 5.34        | -47.71  | -47.89  | -28.28  | -95.58  | -139.58 | 78.91   | -86.61  | 27.15   | -19.29  |
| 5.11        | -72.93  | -82.10  | -28.28  | -120.34 | -124.18 | 39.78   | -85.11  | 26.75   | -17.72  |
| 6.00        | -17.90  | -38.99  | -55.12  | -40.06  | -116.65 | 68.48   | -119.01 | 27.02   | -21.20  |
| 6.10        | -17.90  | -38.99  | -55.12  | -40.06  | -116.65 | 68.48   | -119.01 | 27.02   | -21.20  |

From table 1, it can be seen that the value of the stress measurement point 5 is the largest during the impact process, which is 139.58 MPa, less than the allowable stress 382 MPa specified in the material (Q450NQR1) in TB/T1335-1996 'Code for Design and Test Evaluation of Railway Vehicle Strength', as shown in table 3, meets material safety requirements. It can be seen from table 2 that the maximum displacement of displacement measuring point 2 during impact is 25.78 mm.

Table 2. Peak value of each displacement measurement point (unit: mm).

| Impact speed (km/h) | Point 1 | Point 2 |
|---------------------|---------|---------|
| 3.18                | 9.60    | 12.27   |
| 3.28                | 11.99   | 8.78    |
| 4.19                | 15.67   | 11.99   |
| 4.34                | 7.58    | 9.20    |
| 5.34                | 21.46   | 18.74   |
| 5.11                | 16.68   | 21.13   |
| 6.00                | 25.18   | 20.35   |
| 6.10                | 20.40   | 25.78   |

Table 3. Allowable stress of material for large axle truck body (Unit: MPa).

| Material | Working condition | Allowable stress | Yield strength |
|----------|-------------------|------------------|----------------|
| Q420NQR1 |                   | 356              | 420            |
| Q450NQR1 |                   | 382              | 450            |
| Q500NQR1 |                   | 422              | 500            |
| Q550NQR1 |                   | 464              | 550            |

4. Conclusion
The piggyback transportation is an important mode of highway-railway international transportation. The quality of loading and securement is directly related to the safety of transportation. The method of placing wheel blocking device on the road truck tires can be used to fix the vehicle. Theoretical calculations and actual vehicle tests show that the wheel blocking device with a design height of
207.9mm and the maximum stress value of the impact test is 139.58MPa, which meets permissible stress requirements.

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