

# The Influence of Different Marshalling Methods on 30,000-Ton Heavy Haul Trains

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## Abstract

To study the reasonable formation mode of the 30,000-ton heavy-duty train, the article establishes a longitudinal dynamics model of the 30,000-ton heavy-duty train to study the transfer characteristics of the train air braking system; on this basis, two typical operating routes are selected, and the longitudinal impulses under the cyclic braking condition of the train of two different formation modes are analyzed by simulation. The results show that: the train is in consistent type downgrade and regenerative conditions, the location of the maximum hook force changes when the tail locomotive is put in and excised, and the power braking is put in, which helps to improve the train pressure hook force. When the train is passing through a sizeable undulating ramp, the regenerative condition, with power brake input, helps to improve the train pressure hook force when passing through a concave ramp. Power brake removal helps to strengthen the train pulling hook force when the train passes the convex ramp. The longitudinal impulses of the two formations are kept at a low level under each line condition, which provides a reference for the subsequent 30,000-ton heavy-duty train test and the formation selection for normalized operation.

## Keywords

Heavy Haul Railway, Grouping Method, Vertical Impulse, Long Way Down

## 1. Introduction

With the rapid development of China's heavy-duty railroad, China has mastered 30000 tons of heavy-duty trains and more mature operation technology, Shuo Huang Railway and Daqin Railway have been successfully opened for the operation of 30,000 tons of heavy-duty cargo trains. It is in a critical period of catching up with the technical level of developed countries in the field of heavy-duty [1].

30,000 tons of combined train length of nearly 4 km, the locomotive communication quality should be high, while the train's air braking system performance and hook retardation device to meet the requirements of heavy-duty trains. Due to factors such as the diversity of heavy train formation forms and the complexity of line conditions, the train will unavoidably generate strong longitudinal impulses when passing through long grades and variable grades for braking relief [2].

He Wen [3] compared and analyzed the change of longitudinal force between ECP braking (electronically controlled air braking) and conventional braking in variable grades of 30,000-ton heavy-duty trains, and summarized the key influencing factors under braking conditions. Zeng Zhou [4] studied the influence of the distribution form of cargo 2 cars on the longitudinal impulse of heavy trains and concluded that the number of rear wagons should be reduced to minimize the longitudinal impulse.

Troitskiy [5] discussed the rationale for reducing the weight of platform cars in modular electric freight trains to improve traction power distribution and reduce internal kinetic forces. This optimization strategy contributes to the overall efficiency and performance of heavy-haul freight train compositions.

In the realm of heavy-haul railway tunnel infrastructure, Ma W [6] conducted research on the vibration characteristics of railway tunnel substructures under different axle loads and health conditions. The study aimed to assess the dynamic performance of tunnel foundations under varying loads, providing valuable insights into the maintenance and structural integrity of heavy-haul railway tunnels.

Finally, Feng G [7] monitored the dynamic response of track formations with retaining walls to heavy-haul train passage, highlighting the importance of understanding the structural impact of heavy-haul trains on track infrastructure. Overall, the literature on heavy haul trains covers a wide range of topics, including control optimization, energy efficiency, dynamic modelling, braking systems, vibration propagation, and intelligent control methods, all aimed at improving the performance and safety of heavy haul train operations.

This paper focuses on the impact of two different formations on the longitudinal impulse of the train, establishes a simulation model of longitudinal dynamics of the 30,000-ton heavy-duty train, selects the typical operating line of Shuo Huang Railway and the existing manipulation mode, and compares and analyzes the longitudinal impulse characteristics of the heavy-duty train of different formations under the conditions of the long-distance down-gradient line, to provide theoretical support for the subsequent test of 30,000-ton heavy-duty train.

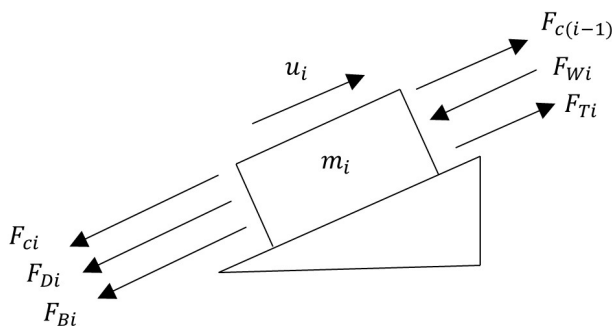
## **2. Longitudinal Dynamics Modelling of Heavy Trains**

The longitudinal dynamics simulation model mainly analyzes the effect of the dynamics between the vehicles of a heavy-duty train on a long downhill ramp, and because of the long formation, the detailed parameters of each vehicle are considered, which will seriously affect the calculation speed, and therefore, a multi-plasmod simulation model is used. In the model, a single vehicle is regarded as an

individual and simplified as a mass point with one longitudinal degree of freedom, and the degrees of freedom of the train are equal to the sum of the number of vehicles. The equations of motion of locomotives and vehicles are established to solve the longitudinal motion process in detail, while all the factors affecting the longitudinal motion of the train must be considered, including the traction braking characteristics of the locomotive, the air braking system, the characteristics of the train's hook and retardation device, and various types of operational resistance. The single-car force situation is shown in **Figure 1**, in which the differential equation of longitudinal dynamics is:

$$m_i \ddot{u}_i = F_{C(i-1)} + F_{Ti} - F_{Ci} - F_{wi} - F_{Di} - F_{Bi}$$

Where:  $i$  is the vehicle number in the range 1~N;  $m_i$  is the mass of the vehicle;  $u_i$  is the displacement of the  $i$ th vehicle;  $F_{C(i-1)}$ ,  $F_{Ci}$  are the front hook force and the rear hook force of the  $i$ th vehicle, respectively, and  $F_{C(i-1)} = 0$  when  $i = 1$ , and  $F_{Ci} = 0$  when  $i = N$ ;  $F_{Ti}$  is the locomotive tractive force of the  $i$ th vehicle, which acts on the locomotive, when it is not a locomotive.  $F_{Ti} = 0$ ;  $F_{Di}$  is the regenerative braking force of the  $i$ th vehicle, which acts on the locomotive;  $F_{Bi}$  is the train aerodynamic braking force of the  $i$ th vehicle; and  $F_{wi}$  is the operating resistance of the  $i$ th vehicle.



**Figure 1.** Individual vehicle stresses.

To achieve model simplicity and operational efficiency improvement, the duct is modeled as an equal-area one-dimensional duct, assuming that the pressurized air inside the duct is isothermal and ignoring the heat exchange between the air and the duct wall, based on the laws of conservation of mass and momentum, the equation for a one-dimensional isothermal N-S duct is:

$$\frac{\partial \rho}{\partial t} + \rho \frac{\partial u}{\partial z} + u \frac{\partial \rho}{\partial z} = 0 \quad (1)$$

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial z} + \frac{1}{\rho} \frac{\partial \rho}{\partial z} + \frac{4f}{d} \frac{u^2}{2} \text{sign}(u) = 0 \quad (2)$$

Where:  $\rho$  and  $\mu$  are the density and flow rate of air, respectively;  $t$  is the time;  $z$  is the coordinate along the pipe;  $d$  is the diameter of the pipe;  $f$  is the friction coefficient; sign is the sign function.

Vehicle base braking consists of air braking force, vehicle base braking device

will brake cylinder pressure into brake tile pressure, and vehicle braking all brake tile pressure together to form the air braking force.

$$K = 10^{-6} \cdot \frac{\pi}{4} \cdot d_z^2 \cdot p_z \cdot \gamma_z \cdot \eta_z \cdot \frac{n_z}{n_k} \quad (3)$$

$$\varphi_{ki} = 0.481 \cdot \frac{K_i + 200}{4K_i + 200} \cdot \frac{2v + 150}{3v + 150} \quad (4)$$

$$F_B = \sum_{i=1}^N \varphi_{ki} \cdot K_i \quad (5)$$

Where:  $K$  -brake pressure;  $d_z$  -brake cylinder diameter;  $p_z$  -brake cylinder pressure;  $\gamma_z$  -vehicle brake multiplier;  $\eta_z$  -brake transmission efficiency;  $n_z$  - number of brake cylinders in the vehicle;  $n_k$  -number of brake shingles in the vehicle;  $\varphi_{ki}$  -calculated friction coefficient;  $v$  -train speed;  $F_B$  -Aerodynamic force.

### 3. 30,000 Tons of Heavy Train Formation

30,000 tons of heavy duty train formation mode heavy combination of trains can be divided into the front, central, and rear trains, the master, from the control locomotive selection 2 (B0 + B0) eight-axle high-power AC drive locomotives, wagons selection of C80 wagons, the tail of the vehicle selection of eight-axle AC locomotives. According to the existing 30,000 tons of heavy-duty train test characteristics, taking into account economic factors, to ensure that the total number of wagons remains unchanged (324 wagons), to determine the two types of train grouping, grouping 1 is “eight-axle locomotive + 108 C80 + eight-axle locomotive + 108 C80 + eight-axle locomotive + 108 C80 + eight-axle locomotive”; grouping 2 is “eight-axle locomotive”; grouping 2 is “eight-axle locomotive”. Formation 2 is “eight-axle locomotives + 108 C80 + eight-axle locomotives + 108 C80 + eight-axle locomotives + 108 C80 + eight-axle locomotives with excision power”.

The typical line of Shuo Huang is selected as the test condition, and the conditions of the test route are shown in the following (Table 1).

**Table 1.** Changes in a gradient of long downhill ramps.

serial number	Type of line condition	Range of slope change/‰
1	long way down	-10‰
2	Long downhill, undulating ramps	[-12, 1.5‰]

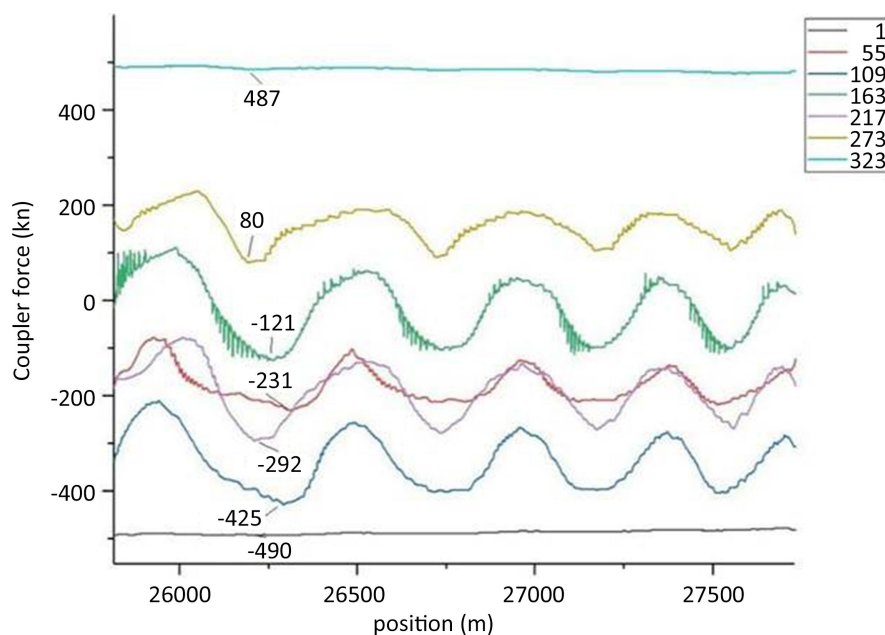
### 4 Dynamic Performance Analysis under Regenerative Braking Conditions

#### 1. Long downhill sections

The simulation location is selected as the train at 10.2‰ down the ramp. The overall train force and part of the vehicle force are analysed based on the tail lo-

comotive input and excitation power.

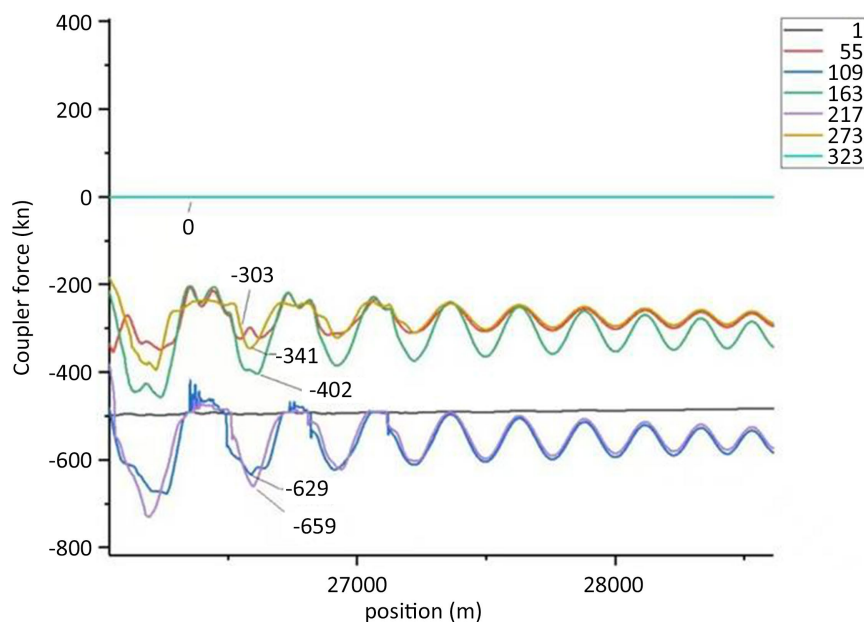
1) Full commitment of power (**Figure 2**)



**Figure 2.** Hook force for some vehicle operations.

When the tail locomotive power is fully engaged, the overall train force is more uniform under the state of mitigation with gate and wind filling, the maximum pulling hook force and the maximum pressure hook force appear in the rear of the main control engine and the tail vehicle, which are  $-490$  kN and  $487$  kN, respectively, and the hook force of the other vehicles do not have a large value.

2) Total power removal (**Figure 3**)



**Figure 3.** Forces on some vehicles in operation.

Tail locomotive power all excision, with brake and filling wind relief state, the train hook force is more concentrated as are pressure hook force, the maximum pressure hook force appeared in from 1 and 2 behind the vehicle, respectively  $-629$  kN and  $-659$  kN, the other vehicles hook force did not appear large value.

Train in consistent type down the ramp, regeneration conditions, the tail locomotive input and excision, the location of the maximum hook force changes, and power braking input, helps to improve the train pressure hook force, the maximum pressure hook force drops of about 25.6%.

2. Undulating ramps at long down ramps

The simulation process simulates that the train enters the small ramp and then enters the large ramp from the large ramp, simulates the change of train force when the train passes through the large undulating ramp, and compares the change of force data under the full input and full removal conditions of the tail locomotive.

1) Full commitment of power (Figure 4)

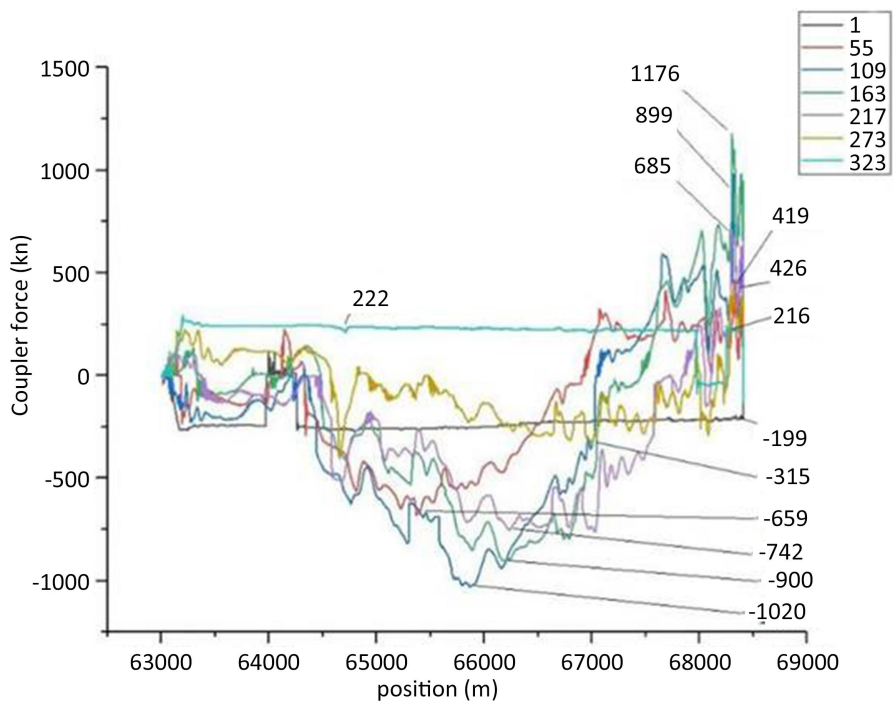
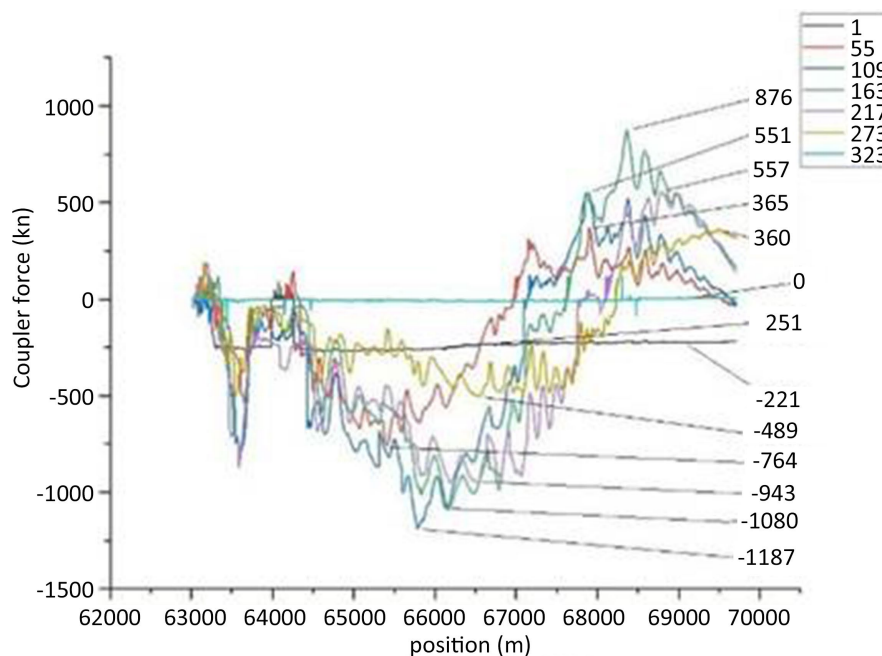


Figure 4. Selected vehicle force diagrams.

When the tail locomotive power is fully engaged, under the condition of 200 kN regenerative force applied to the train, the maximum compression hook force of 1020 kN occurs at position 1 behind the locomotive from 1 locomotive when passing through the concave ramp; the maximum pulling hook force of 1176 kN occurs at position 163 in the middle of the train when passing through the convex ramp.

2) Total power removal (Figure 5)



**Figure 5.** Hitch force diagrams for selected vehicles.

When the power of the tail locomotive is completely removed, the train is under the condition of applying 200 kN regenerative force, and the maximum compression hook force of 1187 kN occurs at position 1 behind the locomotive from 1 locomotive when passing through the concave ramp; the maximum pulling hook force of 876 kN occurs at position 163 in the middle of the train when passing through the convex ramp.

## 5. Conclusions

Train in consistent type down the ramp, regenerative condition, the location of maximum hook force changes when the tail locomotive is put in and removed, power brake is put in, which helps to improve the train's pressure hook force, and the maximum pressure hook force is reduced by about 25.6%.

When the train passes a large undulating ramp, the regeneration condition, power brake input, helps to improve the train pressure hook force. When passing a concave ramp, the maximum pressure hook force reduction is about 14.1%. Power brake removal helps to improve the train pulling hook force when the train passes through convex ramps, with a maximum pulling hook force reduction of about 25.5 per cent.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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