DYNAMIC CHARACTERISTICS STUDY AND VIBRATION CONTROL OF MODERN TRAM TRACK SYSTEM

Zheyu Zhang, Anbin Wang, Jian Bai, Zhiqiang Wang

Luoyang Ship Material Research Institute

ER & PLASTICS SCIENCE AND TECHNOLOGY CO. LTD

Format of Presentation

1、Introduction

Modern Tram System

- energy saving (about 1/3 of the subway)
- short construction period
- low cost (about 1/3 of the subway)

Compared with subway

- sharing roads with other transportation vehicles
- adapting to a smaller bend radius
- close to the residential areas

Compared with traditional tram

- safe operation
- vibration and noise reduction

Requirements

1、Introduction

Work Done Flow

Structure design → **Safety evaluation**

stress, displacement
nastran

↓

parameters optimized

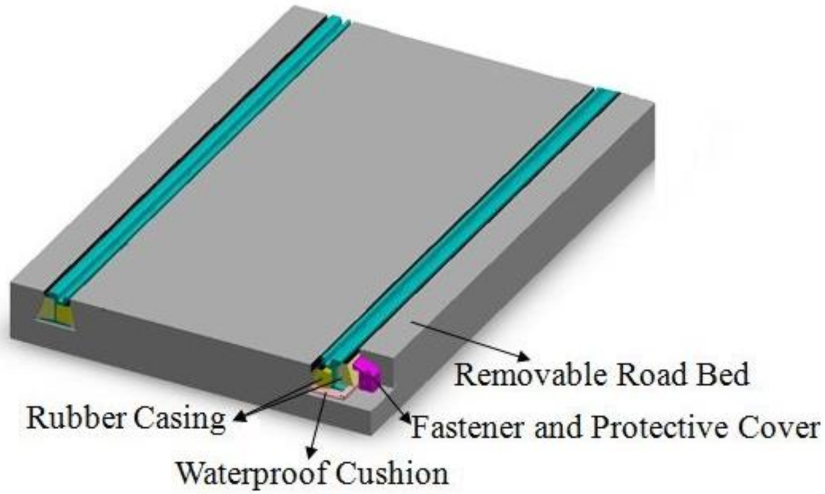
nature frequency
simpack

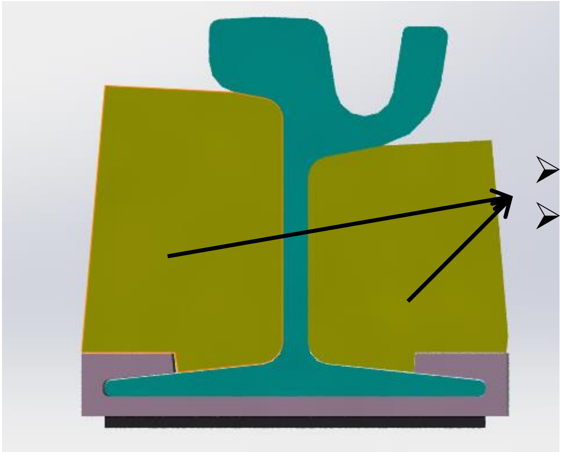
↓

dynamic performance analysis

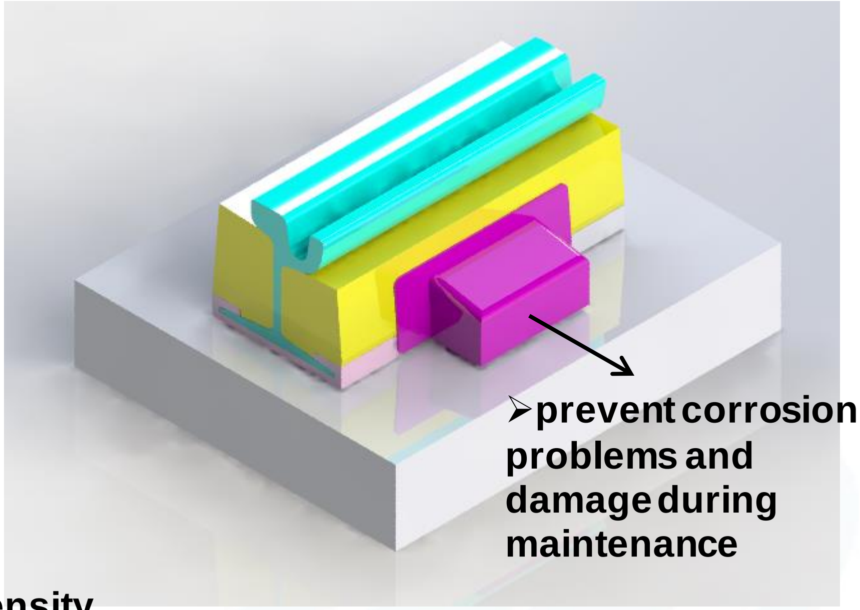
derailment coefficient
simpack

2、Structure of The Track System





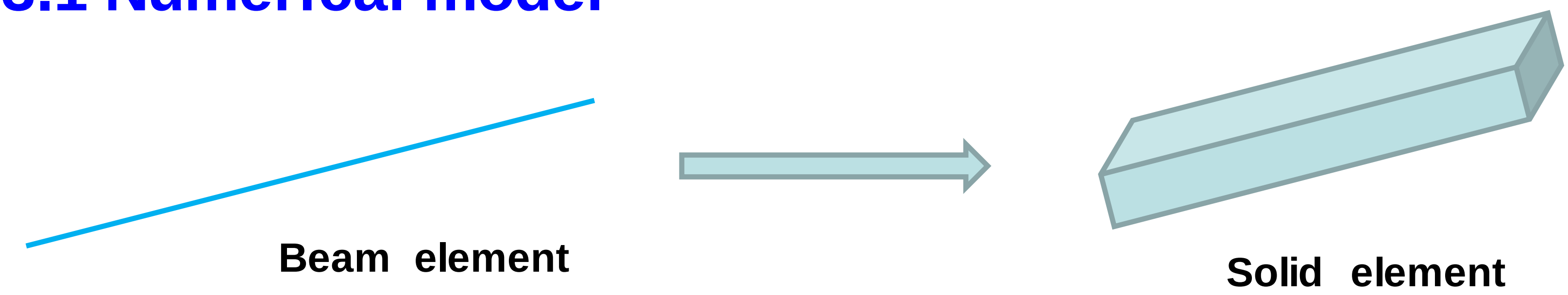
- ➢protection of rails
- ➢increasing line density

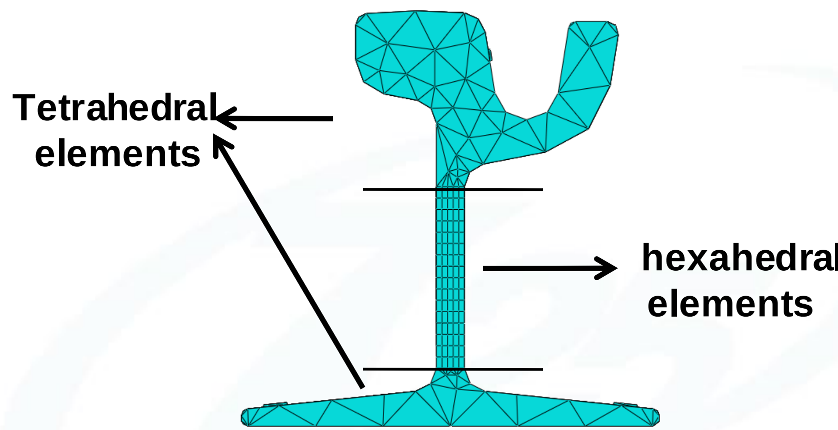


- ➢prevent corrosion problems and damage during maintenance

3、 Safety Evaluations

3.1 Numerical model



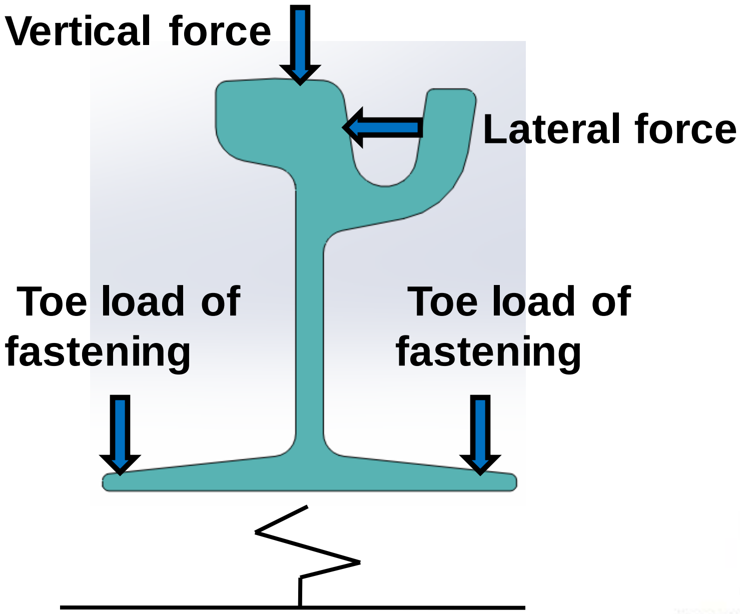


3、 Safety Evaluations

3.2 Tram operating conditions

Table 1. Parameters of the track system.

Structure parameters	value	Structure parameters	value
Rail Young's Modulus(GPa)	210	Rail sectional area(m^2)	76.52E-4
Rail passion ratio	0.3	Rail pad stiffness(kN/mm)	20
Rail moment of inertia(m^4)	3.302E-5	Sleeper spacing(m)	0.625

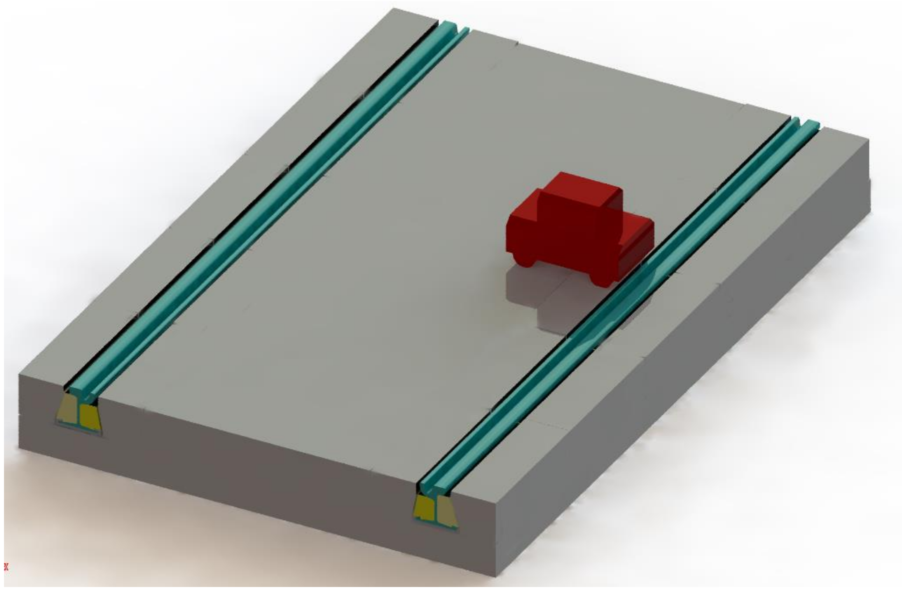


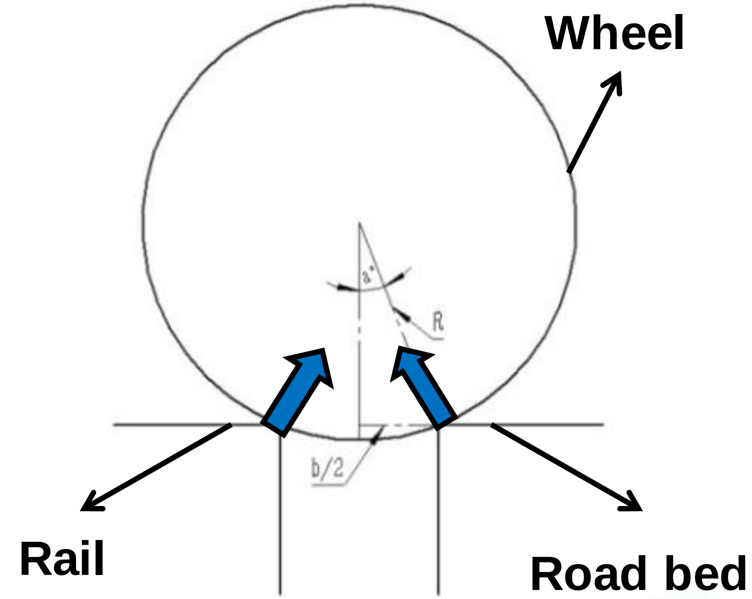
- Maximum rail lateral displacement is 0.97mm (6mm)
- Maximum stress is 214MPa (457Mpa)

——Refer to the class I dynamic rail gauge maintenance standard of the "Railway Line Maintenance Rules"

3、 Safety Evaluations

3.3 Road vehicle rolling conditions





The relationship between vertical displacement and wheel radius

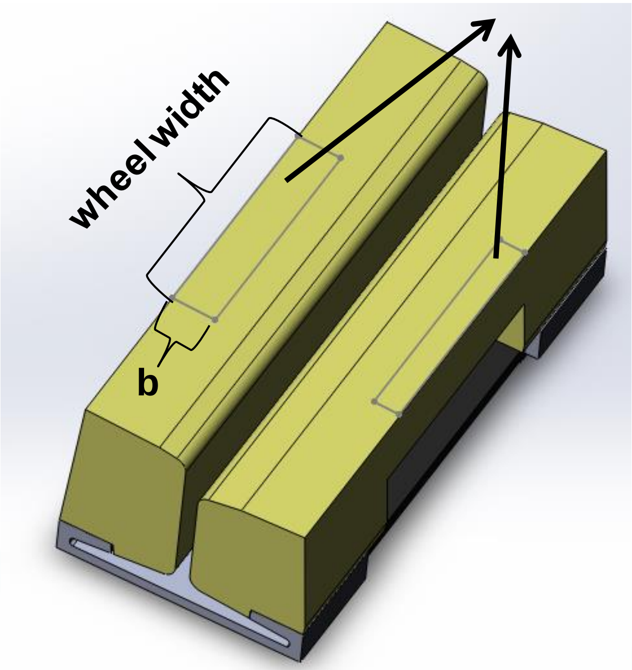
Force is hard to determine,
DISPLACEMENT is adopted

$$\Delta l = R - h = R - \sqrt{R^2 - \left(\frac{b}{2}\right)^2}$$

3、 Safety Evaluations

3.3 Road vehicle rolling conditions

$$\Delta l = R - h = R - \sqrt{R^2 - \left(\frac{b}{2}\right)^2}$$

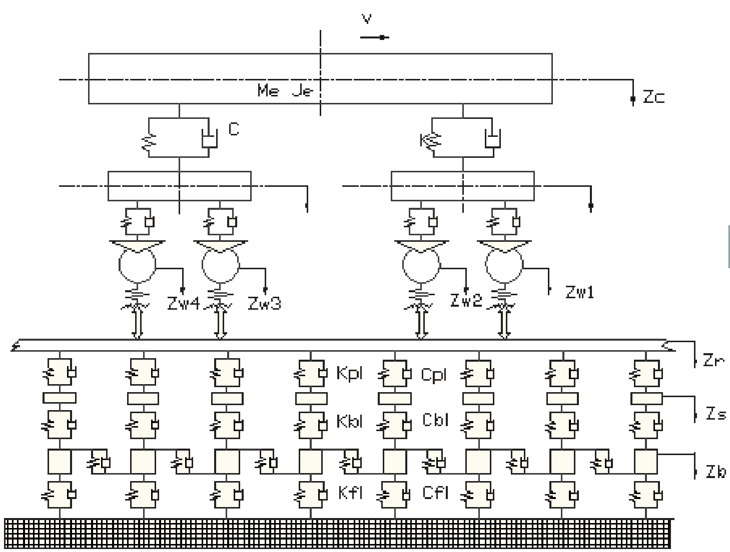


worst condition: the maximum vertical displacement effecting on the maximum contact area

The maximum stress is 0.063MPa
Safety Factor is about 16

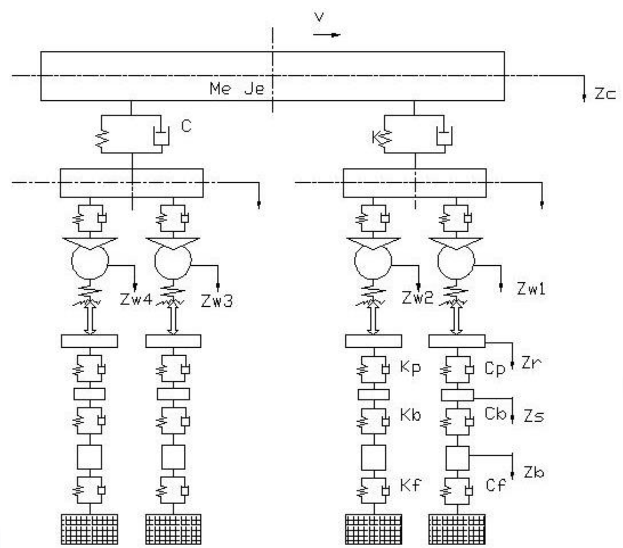
4、The dynamic performance

4.1 Numerical model of the track system



Typical passenger train-track vertical model

Equivalent calculation



Typical passenger train-track vertical simplified lumped equivalent model

Avoid the process of solving the four order partial differential equations of rail dynamics

Equivalent calculation

The mass conversion requires the kinetic energy is constant.

Taking mass conversion of rails as an example

Under load $P_0 e^{i\omega t}$ **the kinetic energy of the rail is**

$T = \frac{3}{4\beta} m_r Z_0^2(t)$ **(Continuous system);** $T = \frac{1}{2} M_r Z_0^2(t)$ **(Equivalent lumped system)**

So $$M_r = (3/2\beta) m_r$$

mass conversion above also applies to the track system under rails

$$M_s = \frac{3}{2\beta} m_s \qquad M_b = \frac{3}{2\beta} m_b$$

Where
$$\begin{cases} k_p = K_{pi} / l_s \\ k_b = K_{bi} / l_s \\ k_f = K_{fi} / l_s \end{cases} \qquad \frac{1}{k_i} = \frac{1}{k_b} + \frac{1}{k_f} + \frac{1}{k_p} \qquad \beta = \left(\frac{k_i}{4EI} \right)^{1/4}$$

Equivalent calculation

The stiffness conversion requires the deflection is constant.

Taking stiffness conversion of rails as an example

Under load $P_0 e^{i\omega t}$ **the deflection of the rail is**

$Z_0(t) = \frac{\beta}{2k_t} P_0 e^{i\omega t}$ **Continuous system** $Z_0(t) = \frac{1}{K_t} P_0 e^{i\omega t}$ **Lumped equivalent system**

So $K_t = \frac{2}{\beta} k_t$

Stiffness conversion above also applies to the track system under rails

$$K_p = \frac{2}{\beta} k_p \qquad K_b = \frac{2}{\beta} k_b \qquad K_f = \frac{2}{\beta} k_f$$

Where
$$\begin{cases} k_p = K_{pi} / l_s \\ k_b = K_{bi} / l_s \\ k_f = K_{fi} / l_s \end{cases} \qquad \frac{1}{k_i} = \frac{1}{k_b} + \frac{1}{k_f} + \frac{1}{k_p} \qquad \beta = \left(\frac{k_i}{4EI} \right)^{1/4}$$

4、The dynamic performance

4.2 System parameters optimized

rail line mass :	60kg/m	(original line density)
	80kg/m	(With rubber casings)
stiffness:	20kN/mm	
	60kN/mm	
	100kN/mm	

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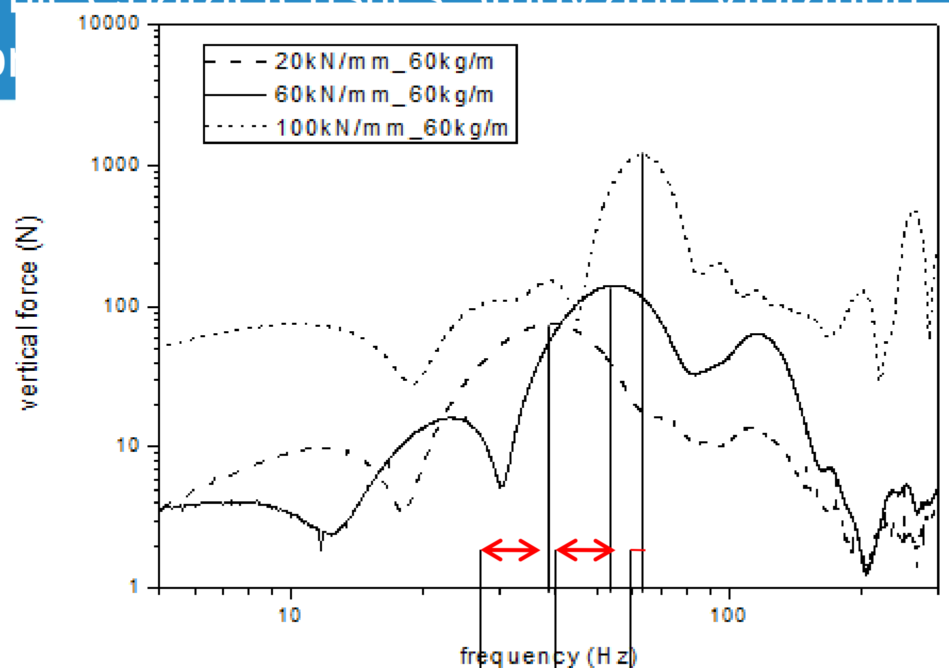
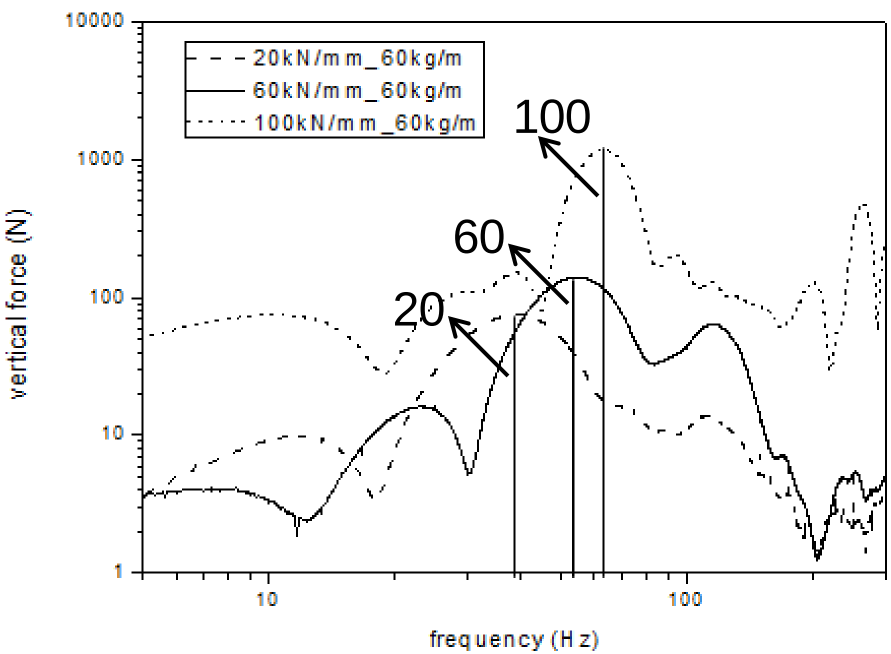
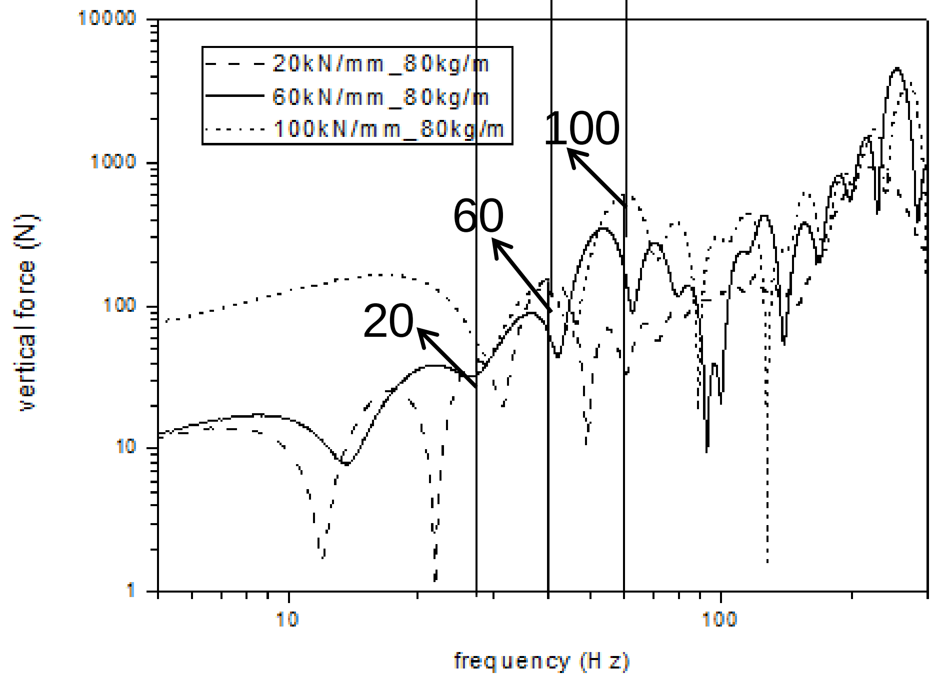
Dynamic Characteristics Study and Vibration Co



rail line mass:80kg/m

Stiffness:20kN/mm





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4、The dynamic performance

4.3 Analysis of the dynamic performance

Traditional road construction

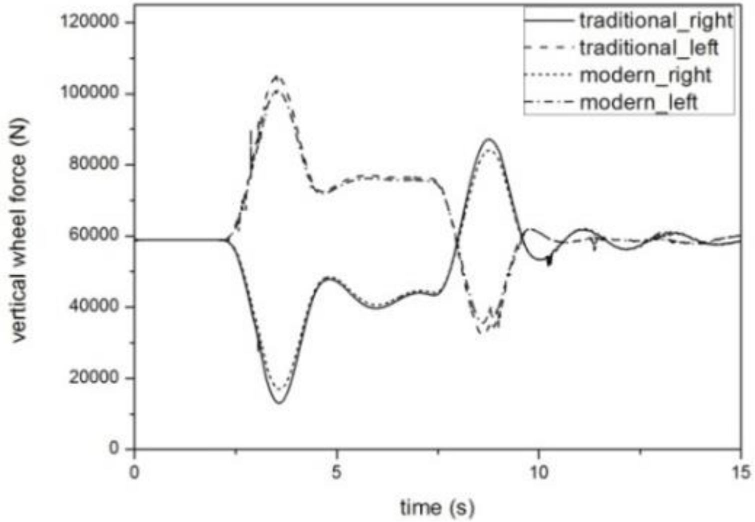
High fastener stiffness: 200kN/mm

VS

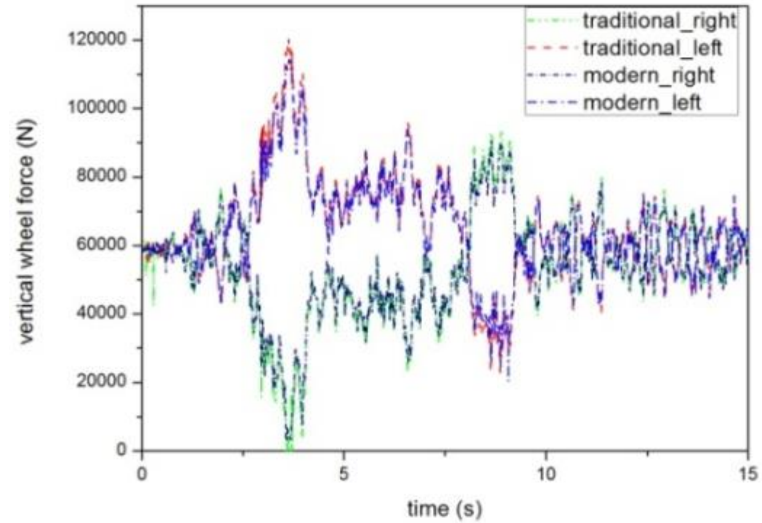
Fastener stiffness of the modern tram system:20kN/mm

Traditional track system		Modern track system	
item	value	Item	value
Rail mass	67.98kg	Rail mass	116.85kg
Sleeper mass	144.31kg	Sleeper mass	183.3kg
Dispersed ballast block mass	758.94kg	Dispersed ballast block mass	963.97kg
Sleeper space	0.625m	Sleeper space	0.625m
Rail pad vertical stiffness	613.2 E6N/m	Rail pad vertical stiffness	62.3 E6N/m
Ballast block vertical stiffness	588.7 E6N/m	Ballast block vertical stiffness	747.8 E6N/m
Foundation vertical stiffness	10E10N/m	Foundation vertical stiffness	10E10N/m

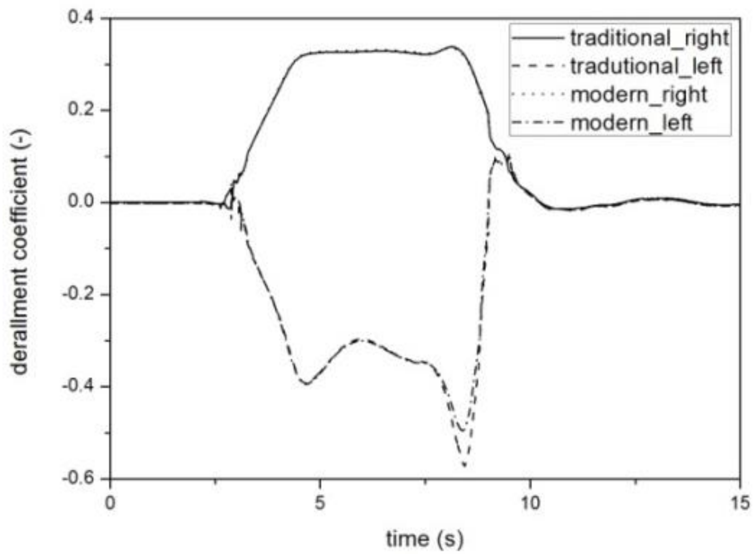
Dynamic Characteristics Study and Vibration Control of Modern Tram Track System



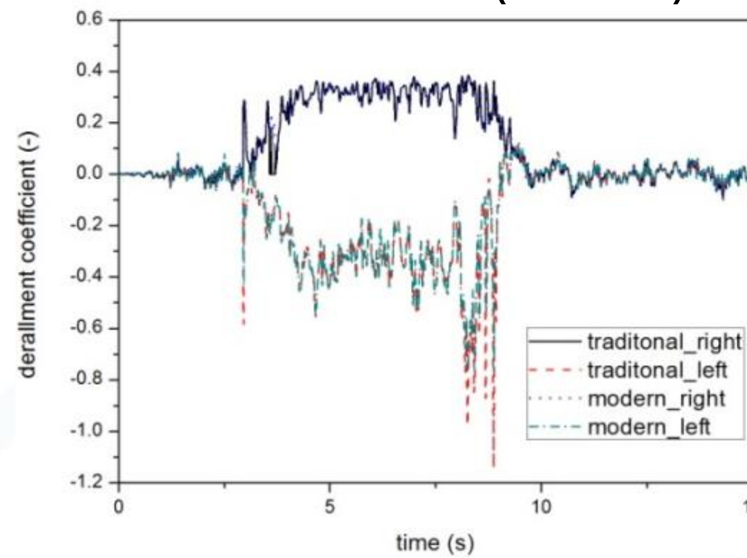
Vertical wheel-rail forces



Vertical wheel-rail forces(with AAR 5)



Derailment coefficients



Derailment coefficients(with AAR 5)

Reduction of modern tram compared to traditional system			
Without excitation	vertical force discrepancy	8.5kN	9%
	derailment coefficient	0.1	16%
With AAR5	vertical force discrepancy	12kN	13%
	derailment coefficient	0.6	36%

5、 Conclusions

1) The modern tram track system is safe in tram normal operation and road vehicle rolling conditions, with sufficient security (the lateral displacement of a rail head is less than 1.9mm, the stress 214MPa), and the rail system components are not destroyed (two rubber blocks maximum stress 0.063MPa).

2) The natural frequency of the track system and the amplitude of wheel-rail force decrease with either the rail pad stiffness decreases, or the rail line mass increases.

3) Compared with the traditional track system, the modern tram track system can obviously reduce the vertical force discrepancy and derailment coefficient on the curve line.

Thank You!