Dynamic design of track transition between two different slab tracks

Tao Xin[1,2], Uday Kumar[1] & Liang Gao[2]

[1] *Division of Operation and Maintenance, Luleå University of Technology*

[2] *School of Civil Engineering, Beijing Jiaotong University*

xin.tao@ltu.se

THE NORTHERNMOST UNIVERSITY
of Technology in Scandinavia

2012-	Postdoc in Operation and Maintenance Engineering Luleå University of Technology
2006-2011	Ph.D. in Highway and Railway Engineering School of Civil Engineering, Beijing Jiaotong University
2002-2006	B.S. in Civil Engineering School of Civil Engineering, Beijing Jiaotong University

LULEÅ TEKNISKA UNIVERSITET

Outline

Introduction

Simulation Model

Transition Problems

Transition Remedies

Transition Design

Future Work

Introduction

With the development of high-speed rail system, various types of slab track were put into service in Europe, China and Japan.

China Railway Track System (CRTS)

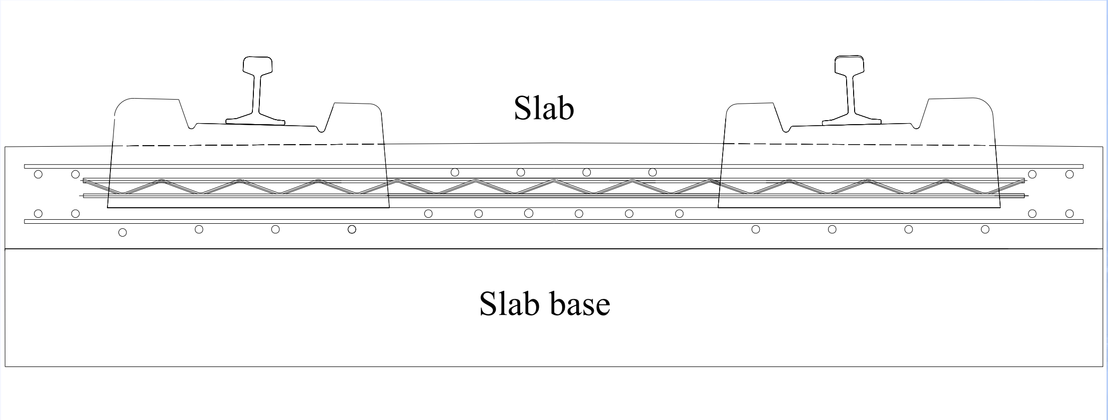
Introduction

Generally speaking, it has been substantiated that the noise level on slab track was 5dB higher than that on the ballast track. (Quarterly report of RTRI, 1997)

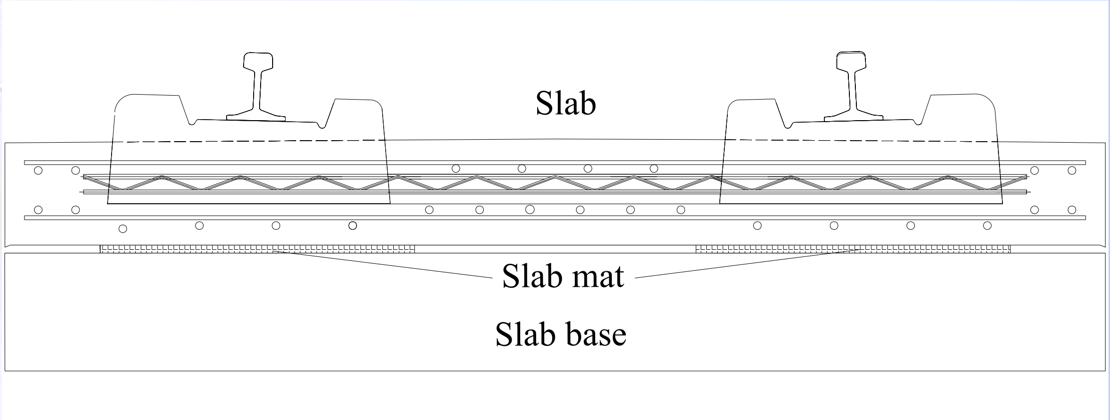
Rail vibration levels on the slab track are 5db higher that those on the ballasted track, particularly for frequencies above 1kHz. (Wang 2010)

Introduction

In order to reduce track vibration into surrounding structures, new slab track is specially designed for vibration sensitive areas like railway stations by inserting soft rubber mats under slabs. The newly designed track is referred to as floating slab track.



Fixed slab track



Floating slab track

Introduction

At the transition point between fixed slab track and floating slab track, a moving wheel experiences a rapid change in elevation and dynamic problems occur because of the abrupt change in the vertical track stiffness.

Transition regions require frequent maintenance. When neglected, the track geometry will deteriorate at an accelerated rate. (Lei & Zhang, 2011)

A vehicle-track dynamic analysis model is established based on self-developed simulation package FORSYS to study the dynamic behaviours of track transition between fixed slab track and floating slab track.

Outline

- Introduction
- Simulation Model
- Transition Problems
- Transition Remedies
- Transition Design
- Future Work

Vehicle-Track Model

The vehicle-track system model is composed of vehicle model, track model and wheel/rail interaction model.

Vehicle model

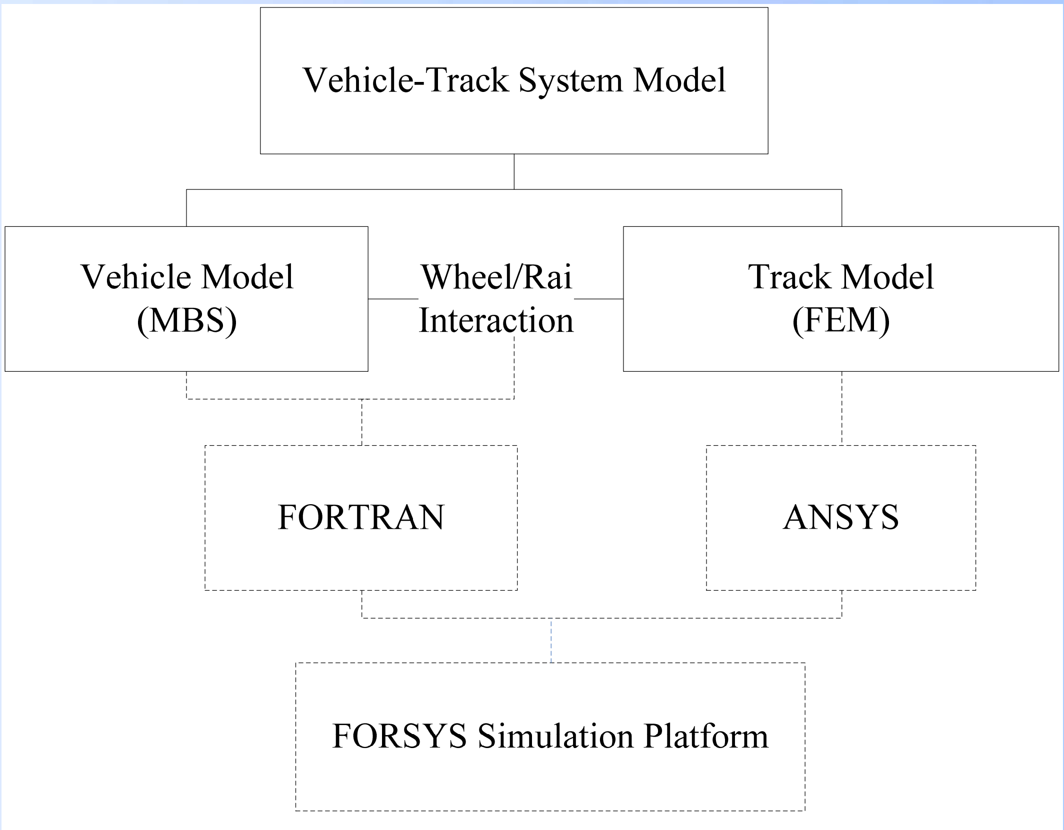
- MBS
- FORTRAN code

Track model

- FEM
- ANSYS software

WRI model

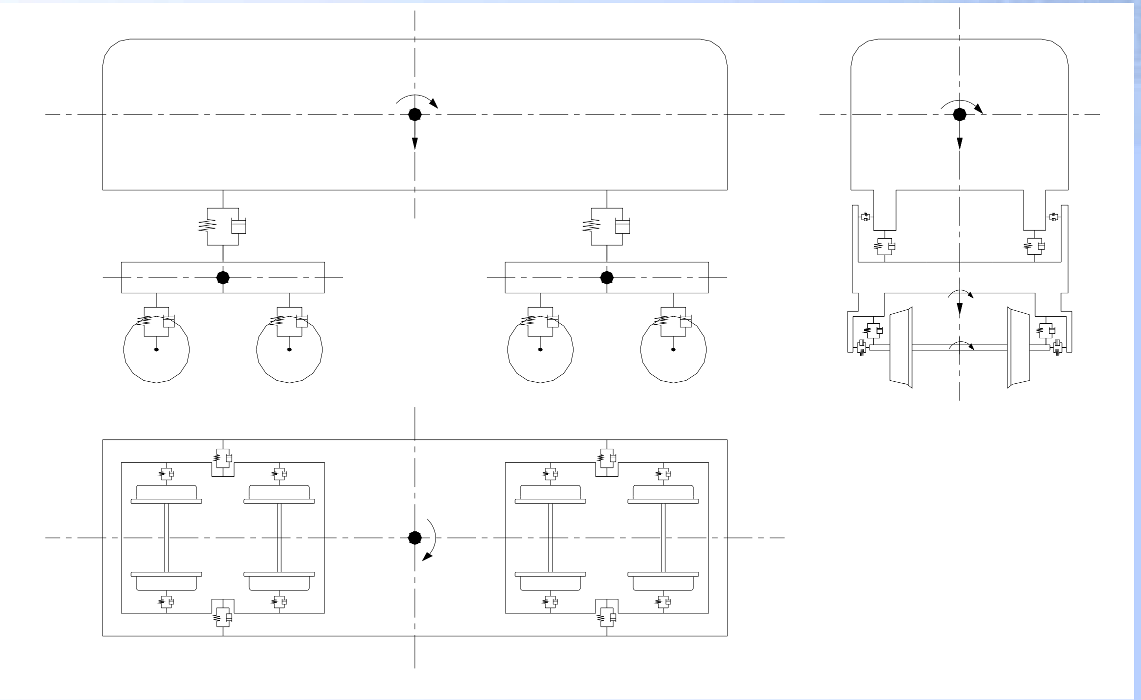
- rigid-flexible coupled
- FORSYS platform



Vehicle Model

The vehicle is composed of car body, bogies and wheel-sets.

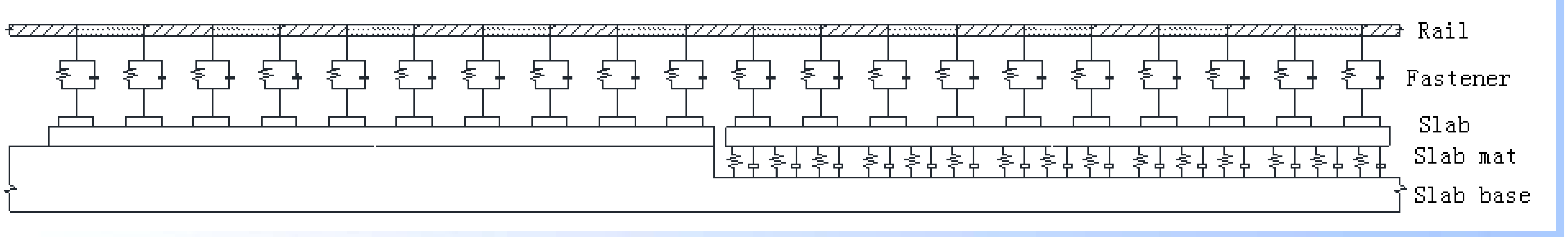
- Car body, bogies and wheel/sets
  - Rigid bodies
- Primary and secondary suspensions
  - spring-dampers



Track Model

The slab track is composed of rail, fastener, slab and slab mat.

- Rail
  - ➢ point supporting beam element
- Fastener
  - ➢ spring-damping element
- Slab
  - ➢ solid element
- Slab mat
  - ➢ spring-damping element



WRI Model

The wheel/rail contact force is calculated by Hertz nonliner elastic contact theory as following:

$$P = \left(\frac{\Delta Z}{G} \right)^{3/2}$$

Where G is contact coefficient, ΔZ is elastic penetration between wheel and rail. The penetration is determined by the relative displacement of wheel and rail at the wheel/rail contact point.

$$\Delta Z = Z_w - Z_r - R$$

Where Z_w is the vertical displacement of wheel, Z_r is the vertical displacement of rail and R refers to the irregularities of rail surface.

Vibration Equation

The system vibration differential equation can be expressed as following:

$$\begin{bmatrix} M_m & 0 \\ 0 & M_f \end{bmatrix} \begin{Bmatrix} \ddot{\delta}_m \\ \ddot{\delta}_f \end{Bmatrix} + \begin{bmatrix} C_m & 0 \\ 0 & C_f \end{bmatrix} \begin{Bmatrix} \dot{\delta}_m \\ \dot{\delta}_f \end{Bmatrix} + \begin{bmatrix} K_m & 0 \\ 0 & K_f \end{bmatrix} \begin{Bmatrix} \delta_m \\ \delta_f \end{Bmatrix} = \begin{Bmatrix} P_m \\ P_f \end{Bmatrix}$$

The subscripts *m* and *f* represent MBS (vehicle model) and FEM (track model).

After the above system vibration equations obtained, Newmark-β method is applied to solve the equations in the time domain.

Outline

- Introduction
- Simulation Model
- Transition Problems
- Transition Remedies
- Transition Design
- Future Work

Transition Problems

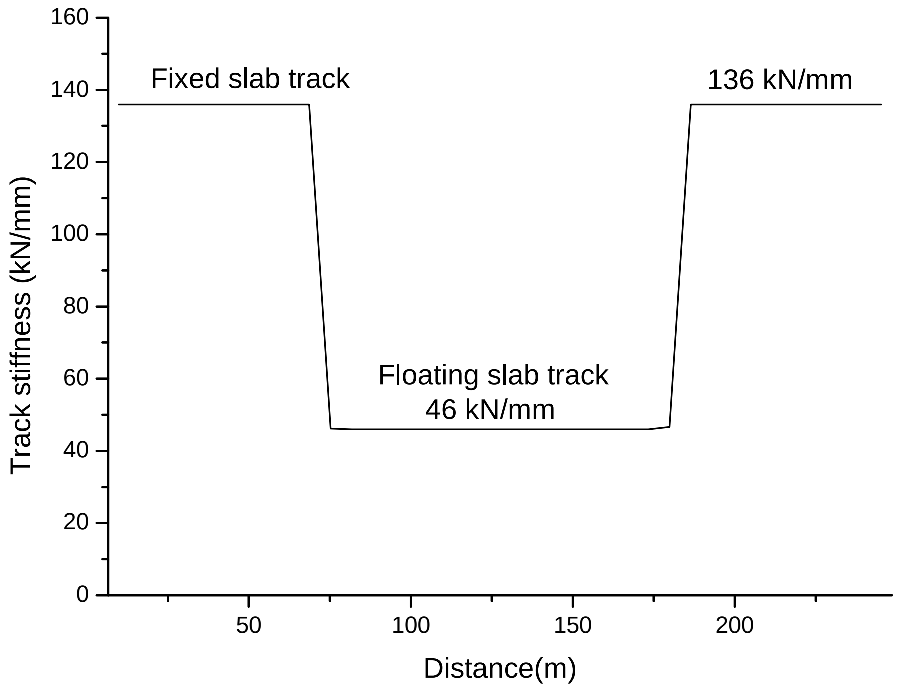
At the transition point between fixed slab track and floating slab track, a moving wheel experiences a rapid change in elevation and dynamic problems occur because of the abrupt change in the vertical track stiffness.

- Track stiffness/modulus
- Wheel/rail contact force
- Rail deflection

Transition Problems

Track stiffness (K_t) is the ratio of the applied wheel load (P) to rail deflection (y):

$$K_t = \frac{P}{y}$$

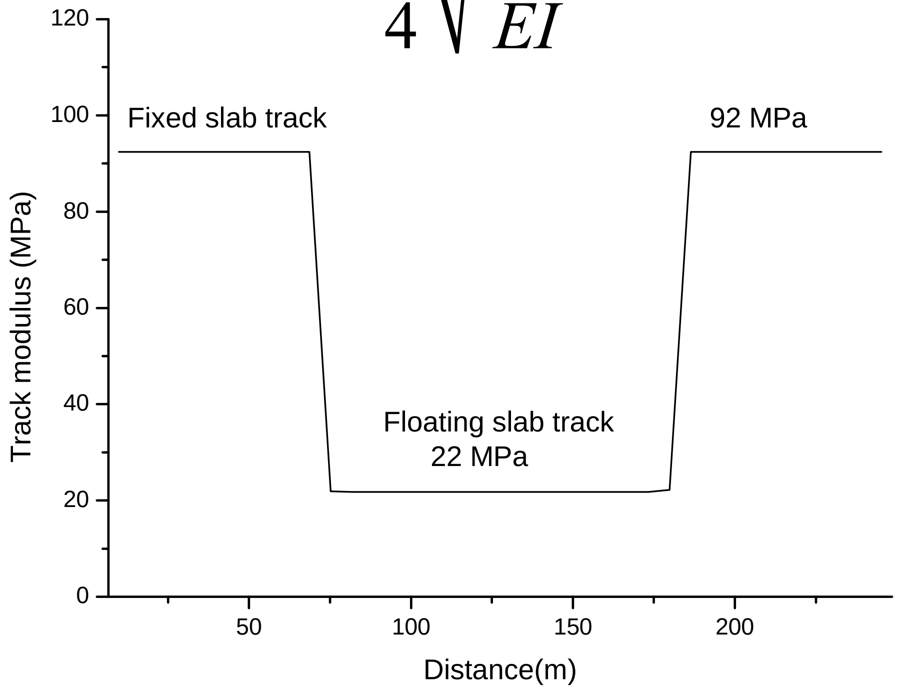


136/36≈3

Transition Problems

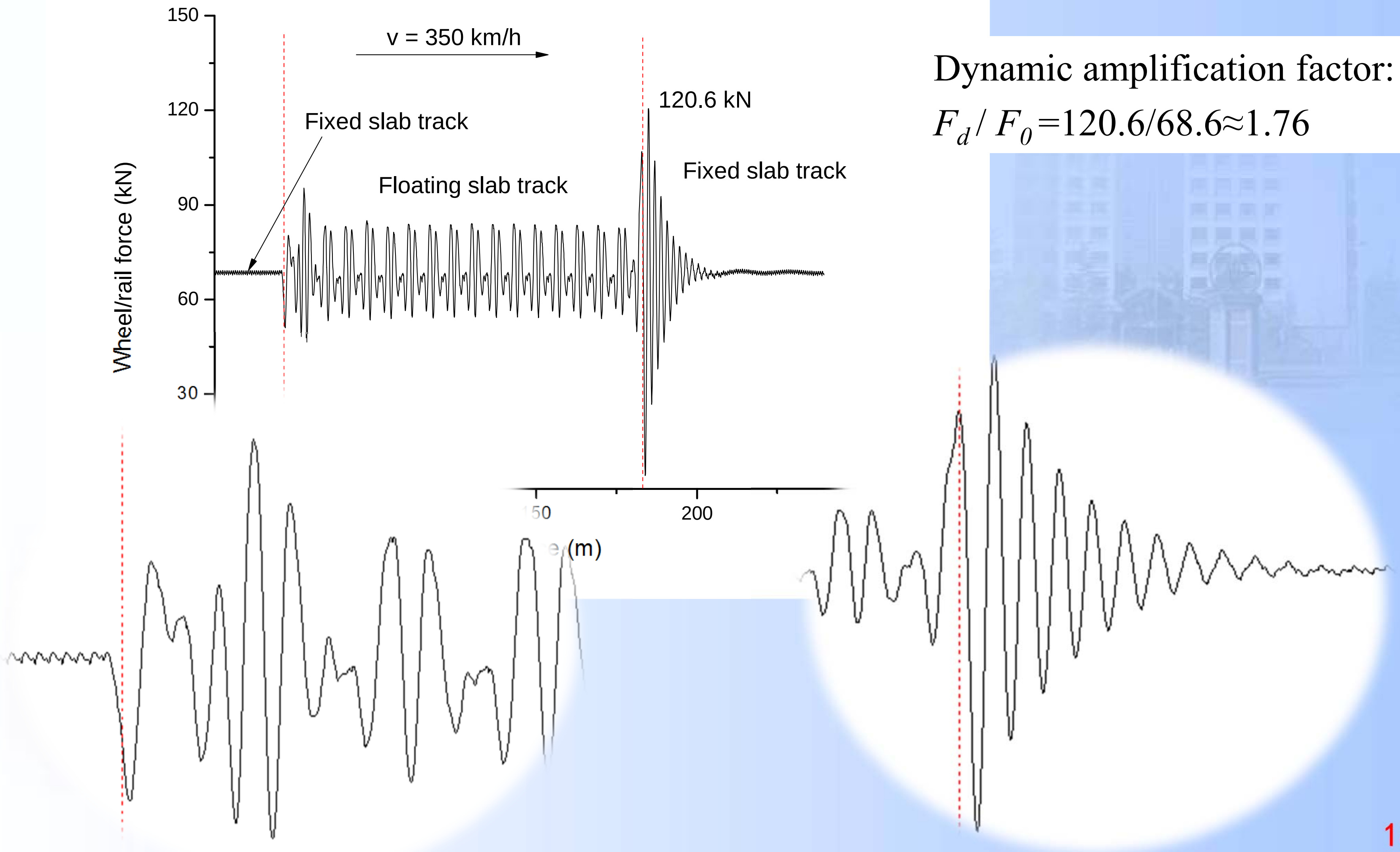
Track modulus is often used as a measure of vertical stiffness of the rail foundation and is defined as the supporting force per unit length of rail per unit vertical deflection under a vertical load, as determined by the following equation (Selig and Waters 1994):

$$u = \frac{1}{4}\sqrt[3]{\frac{K_t^{\,4}}{EI}}$$



92/22≈4

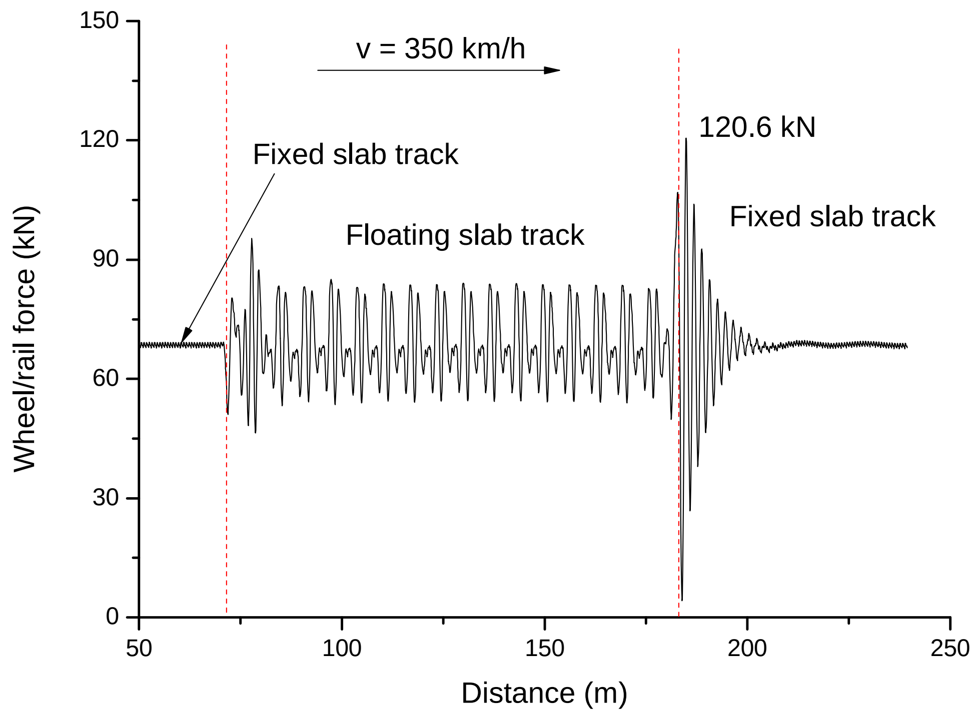
Transition Problems



Dynamic amplification factor:

$F_d / F_0 = 120.6/68.6 \approx 1.76$

Transition Problems



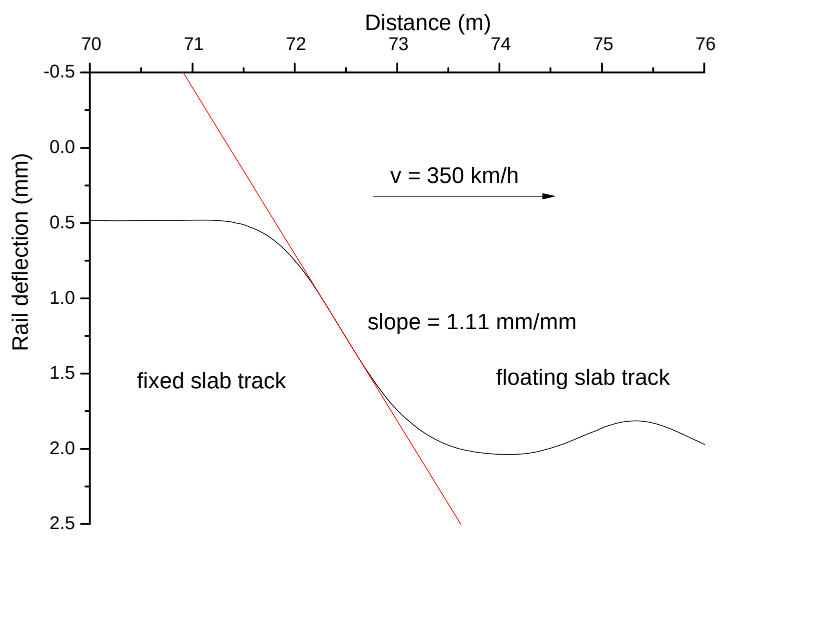
Dynamic amplification factor:

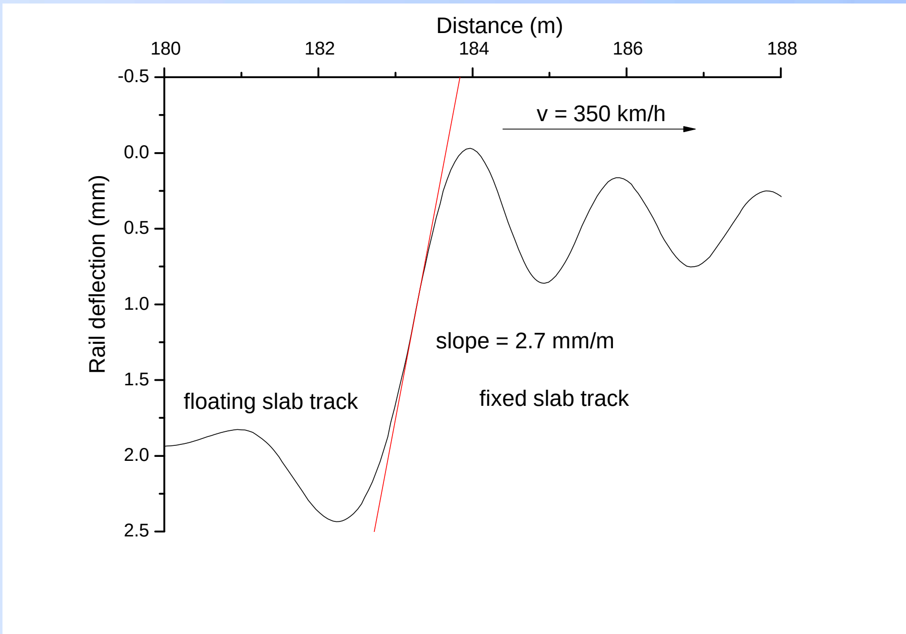
$F_d / F_0 = 120.6/68.6 \approx 1.76$

The dynamic analysis results show that the wheel/rail interaction is larger when vehicle passes the transition from low-stiffness side to high-stiffness side, compared to the passing in the opposite direction.

Even without any initial track irregularities, an abrupt track stiffness change alone would lead to 76% higher dynamic load than static load in the transition.

Transition Problems





The rail deflection difference is 1.5mm occurring in about 2m.

The maximum variation rate of rail deflection is 2.7mm/m, far more than expected.

Transition Problems

At the transition point between fixed slab track and floating slab track, a moving wheel experiences a rapid change in elevation and dynamic problems occur because of the abrupt change in the vertical track stiffness.

↓

- Track stiffness/modulus: 3, 4 times
- wheel/rail contact force: 68.6→120.6kN, 1.76
- Rail deflection: 1.5mm/2m, 2.7mm/m

Outline

- Introduction
- Simulation Model
- Transition Problems
- Transition Remedies
- Transition Design
- Future Work

Transition Remedies

Increase stiffness of low-stiffness side

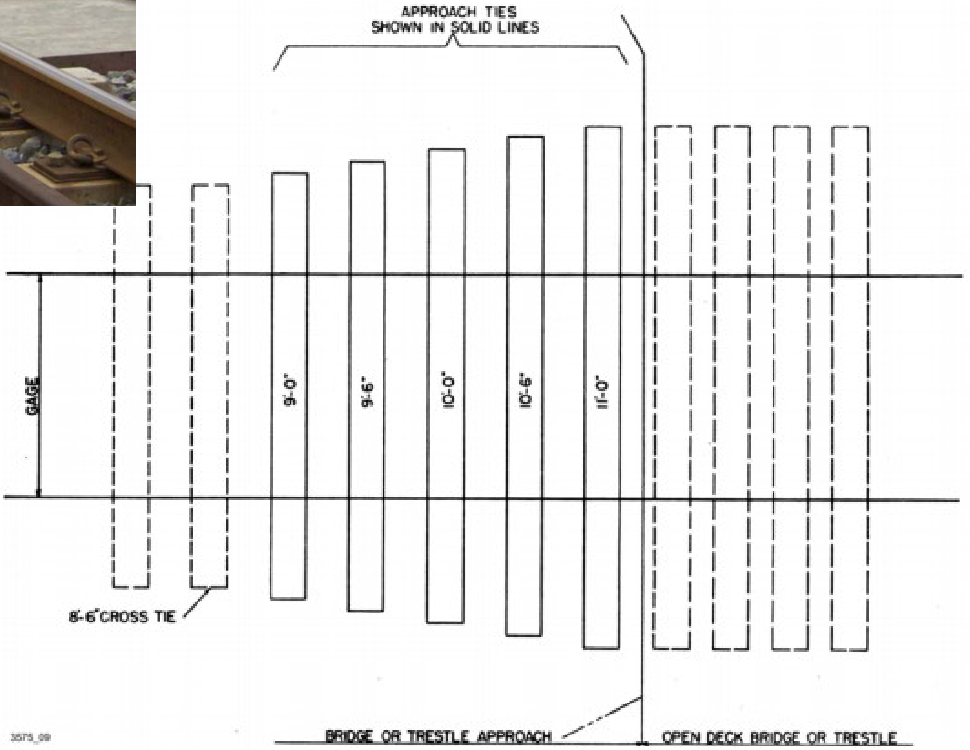
- Additional rail
- Long/wide sleeper
- Reducing sleeper spacing
- Approach slab
- Glued ballast

And/or

Decrease stiffness of high-stiffness side

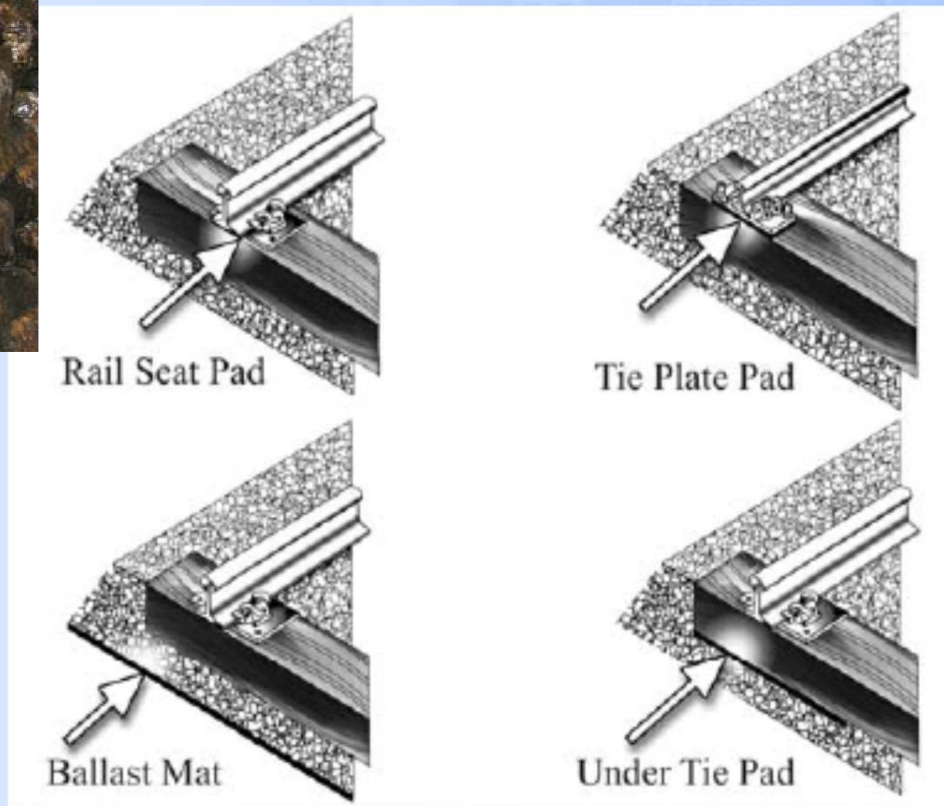
- Rail seat pad
- Sleeper pad
- Slab mat
- Ballast mat

Transition Remedies



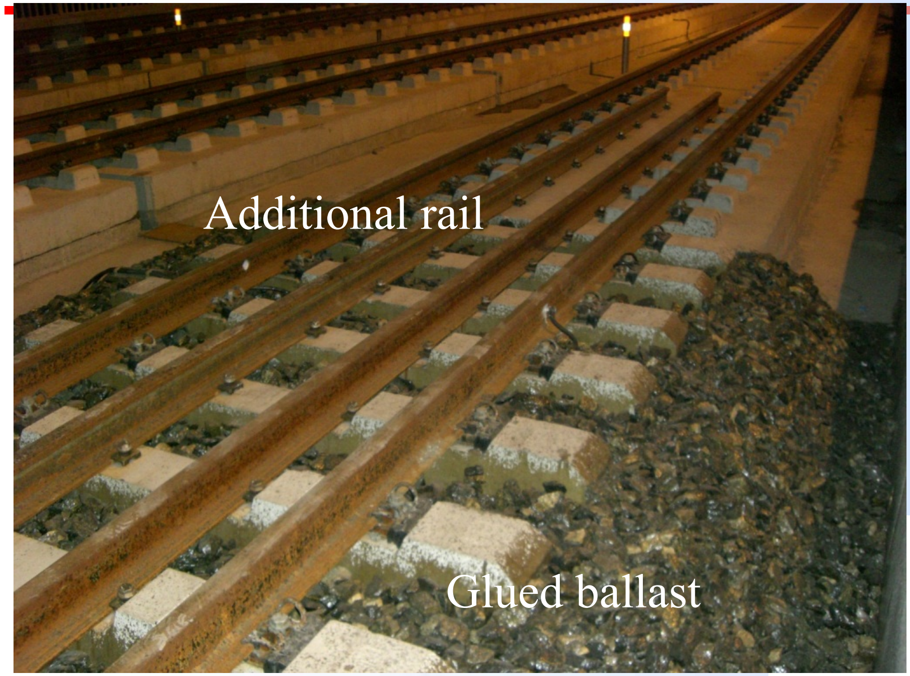
Source: AREMA 2005a.

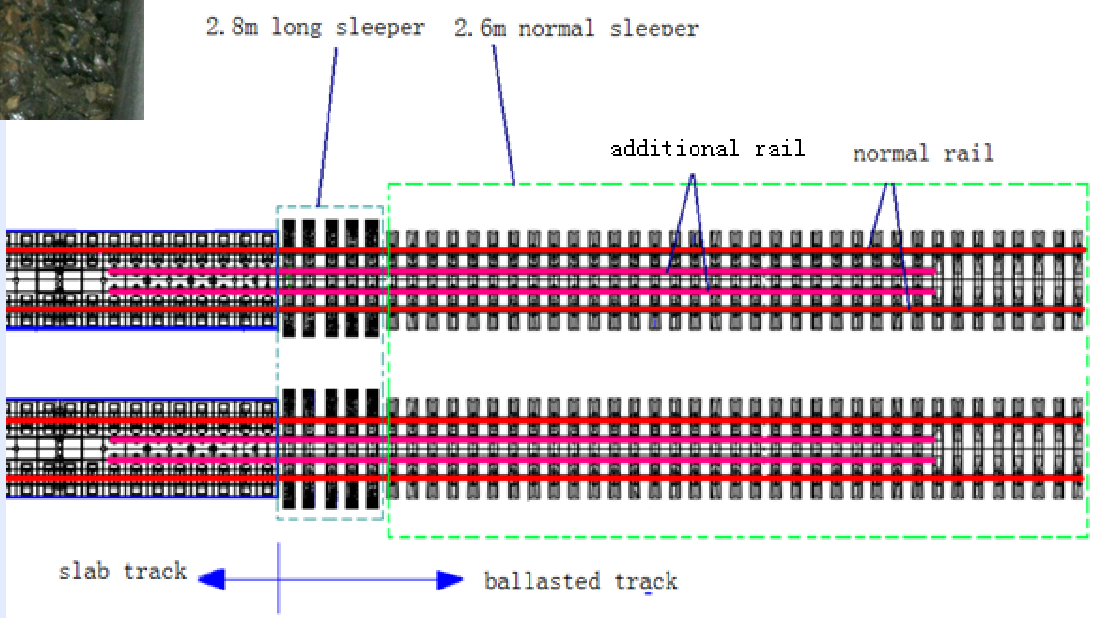
Transition Remedies



(Sasaoka & Davis 2005)

Transition Remedies





Transition Remedies

Increase stiffness of low-stiffness side

- Additional rail
- Long/wide sleeper
- Reducing sleeper spacing
- Approach slab
- Glued ballast

And/or

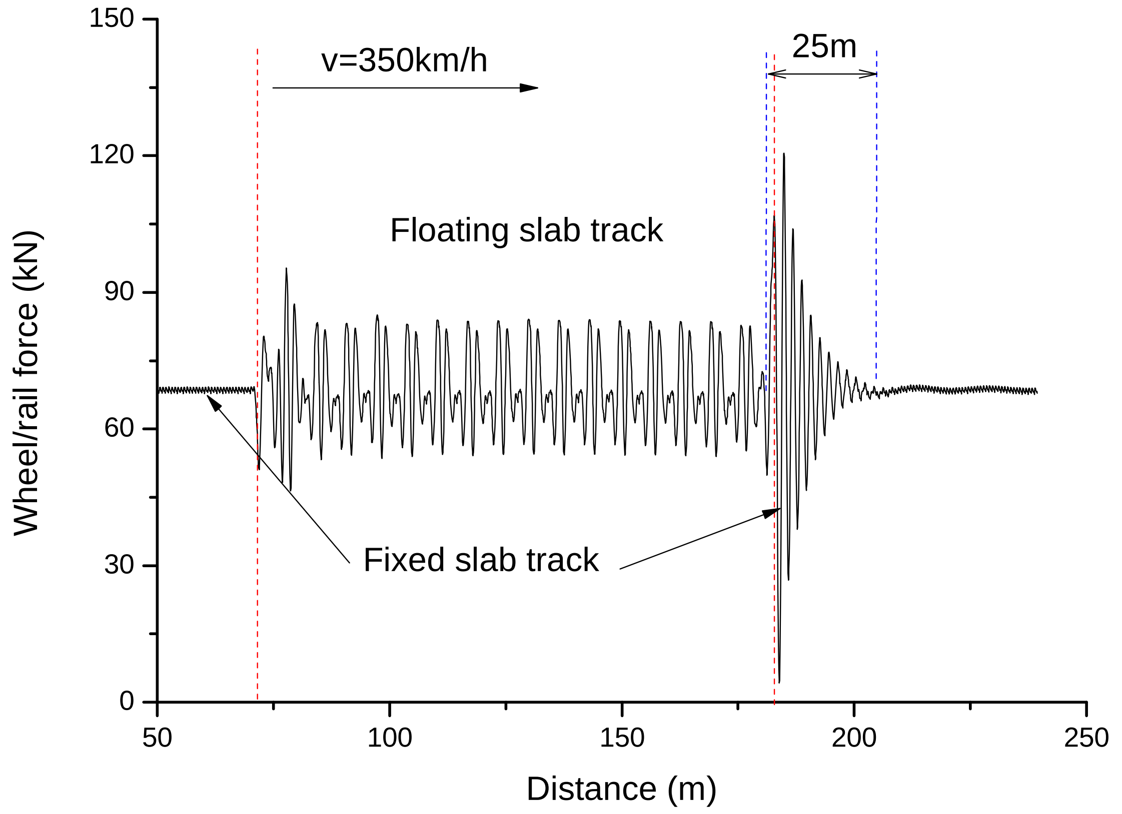
Decrease stiffness of high-stiffness side

- Rail seat pad
- Sleeper pad
- Slab mat √
- Ballast mat

Outline

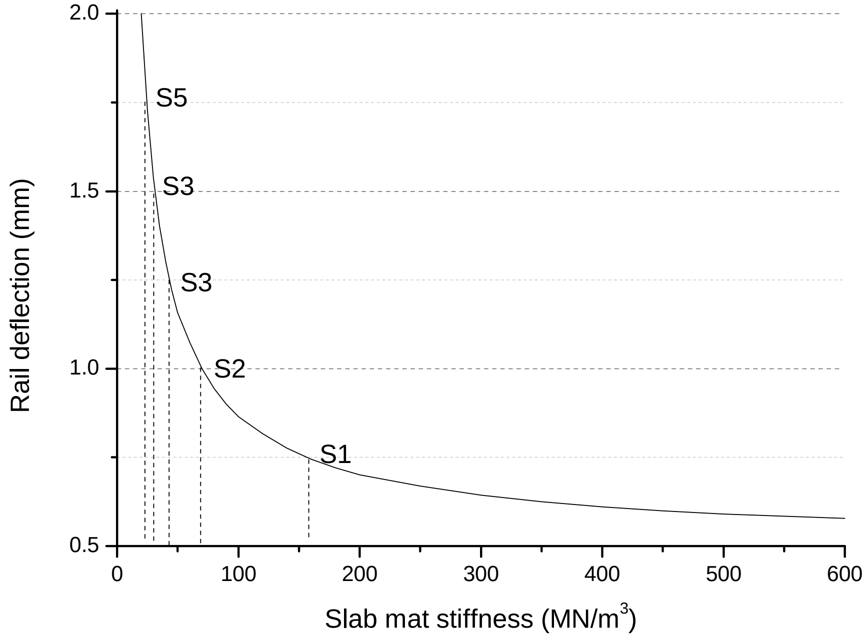
- Introduction
- Simulation Model
- Transition Problems
- Transition Remedies
- Transition Design
- Future Work

Transition Design



Transition length: 25m < L < 50m, 6.54m×5=32.7m √

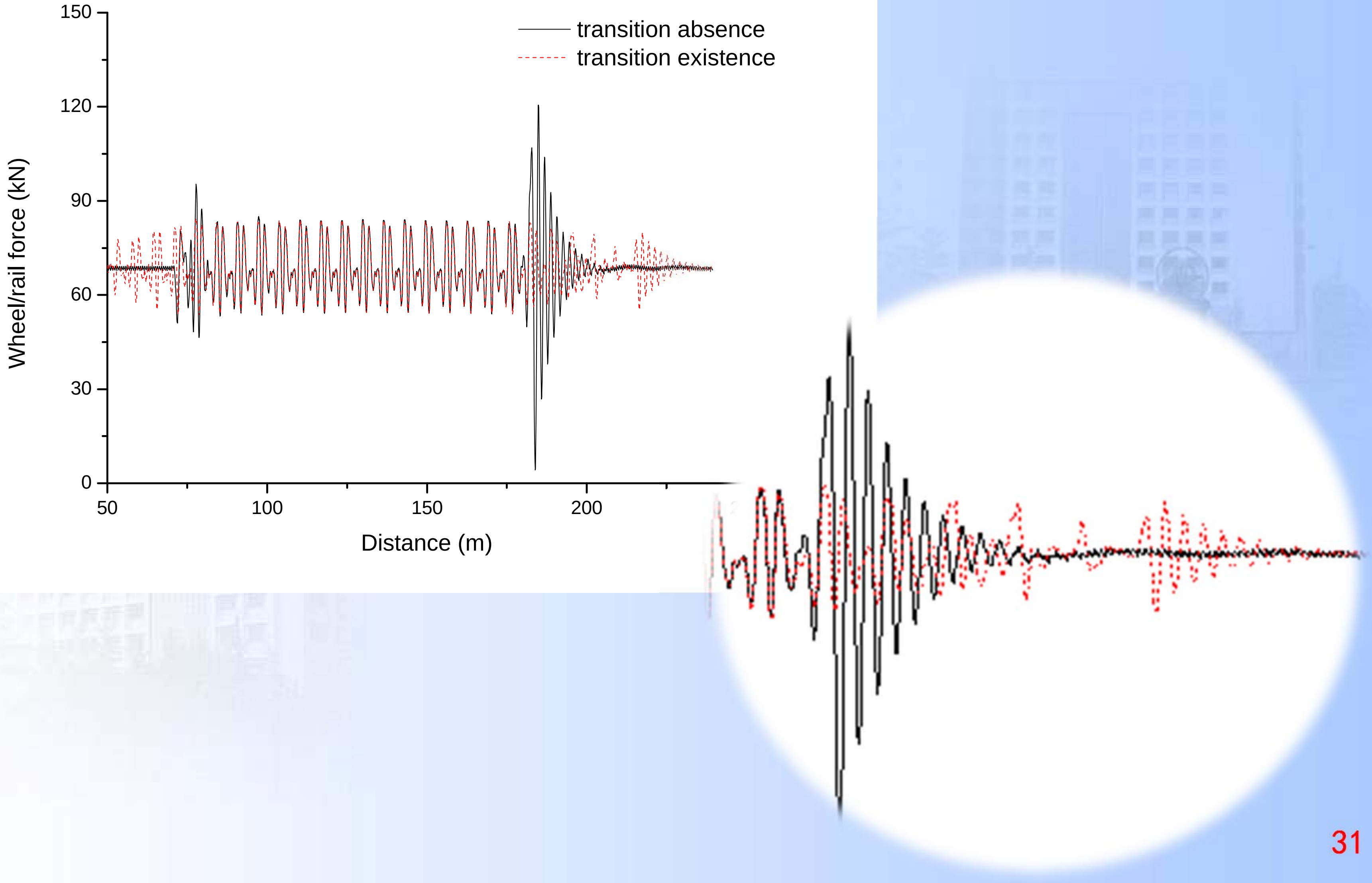
Transition Design



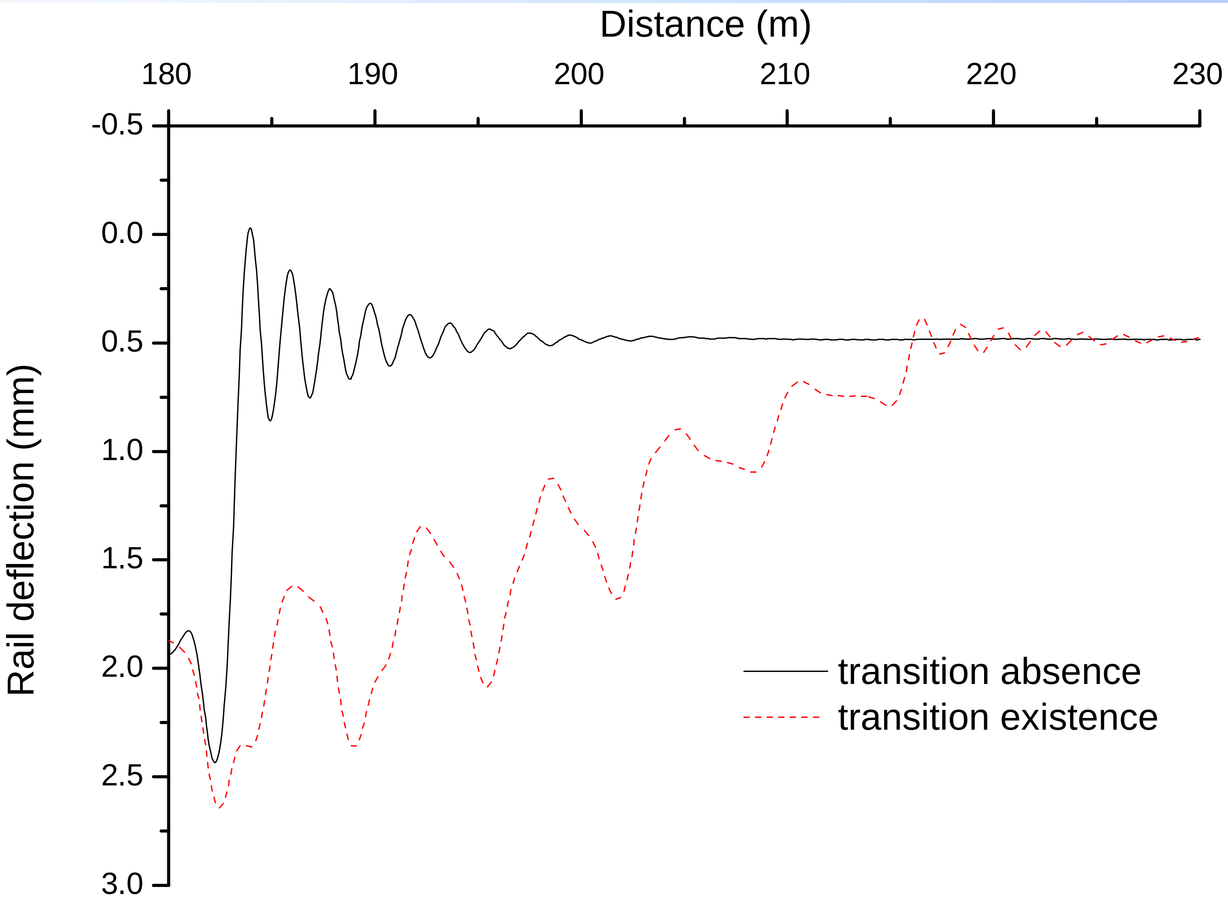
- Equalize the rail deflection
- Provide a gradual stiffness increase

Railway track		Rail deflection(mm)	Slab mat stiffness(MN/m^3)
Fixed slab track		0.5	-
Track transition	S1	0.75	150
	S2	1.0	70
	S3	1.25	40
	S4	1.5	30
	S5	1.75	24
Floating slab track		2.0	20

Transition Design

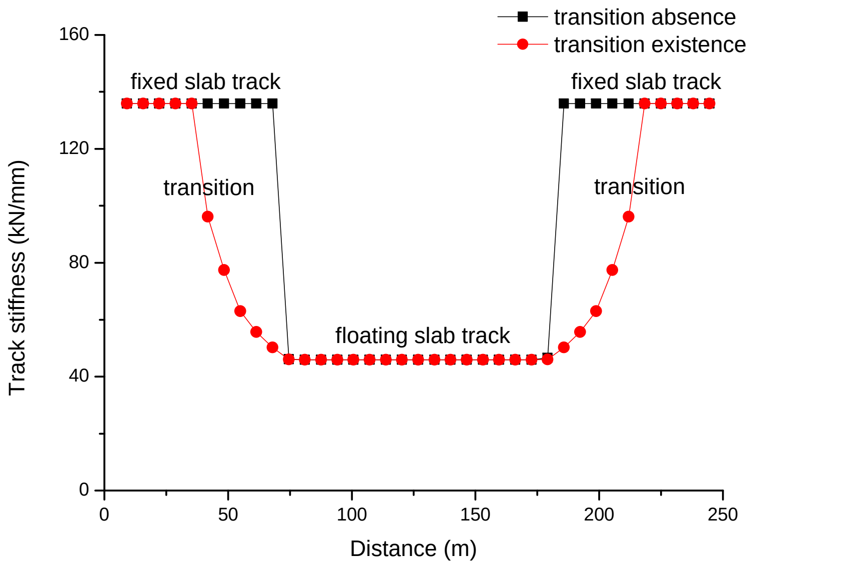


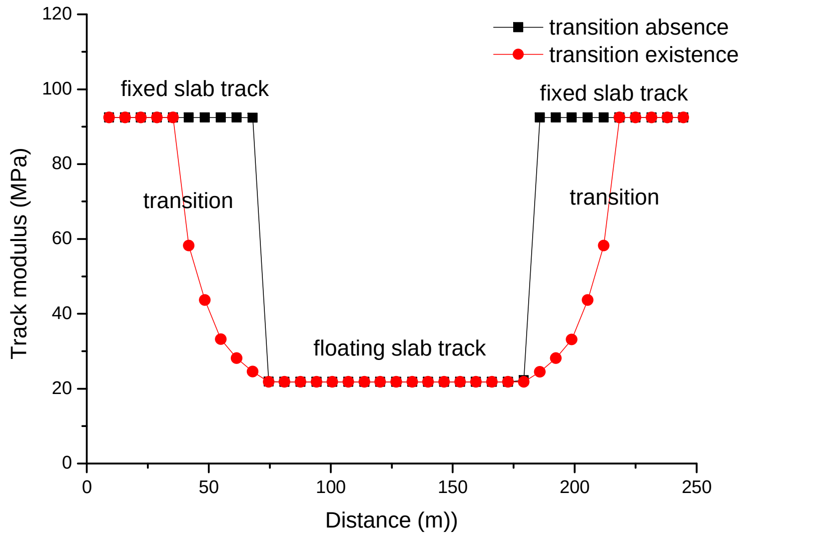
Transition Design



Railway track		Slab mat stiffness (MN/m^3)	Track stiffness (MN/m)	Track modulus (MPa)
Fixed slab track		-	136	92
Track transition	1	150	96	58
	2	70	77	44
	3	40	63	33
	4	30	56	28
	5	24	50	24
Floating slab track		20	46	22

A 'gradual' increase in track stiffness and modulus dose not mean linear change.





LULEÅ TEKNISKA UNIVERSITET

Outline

- Introduction
- Simulation Model
- Transition Problems
- Transition Remedies
- Transition Design
- Future Work

Future Work

- Track faults
  - ✓ Rail surface irregurlarities
  - ✓ Long-term track deformation

- Integrated transition remedies
  - ✓ Slab mat
  - ✓ Additional rail
  - ✓ Fastener stiffness
  - ✓ …

Thank you for your kind attention!

THE NORTHERNMOST UNIVERSITY
of Technology in Scandinavia