William W. Hay Railroad Engineering Seminar

"High-Speed Rail Ballast Flight and Measures"

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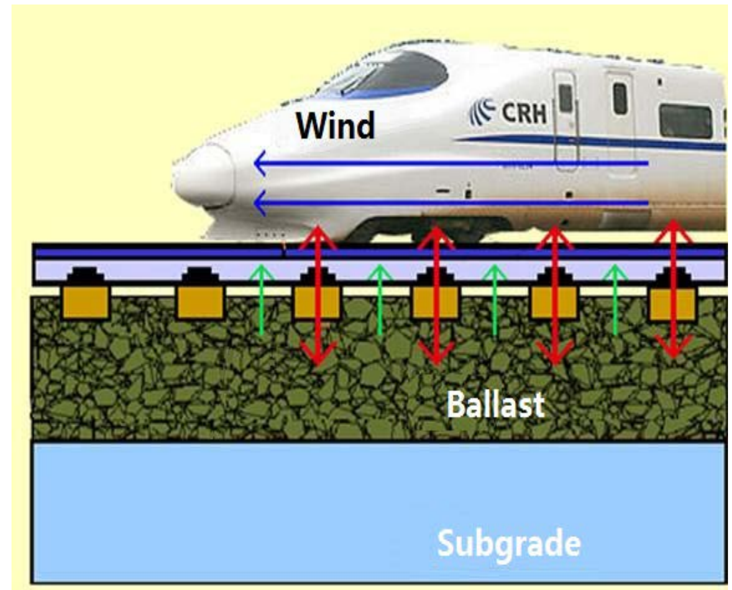

Date: Friday, April 29 2016

Time: Seminar Begins 12:20

Location: Newmark Lab, Yeh Center, Room 2311
University of Illinois at Urbana-Champaign

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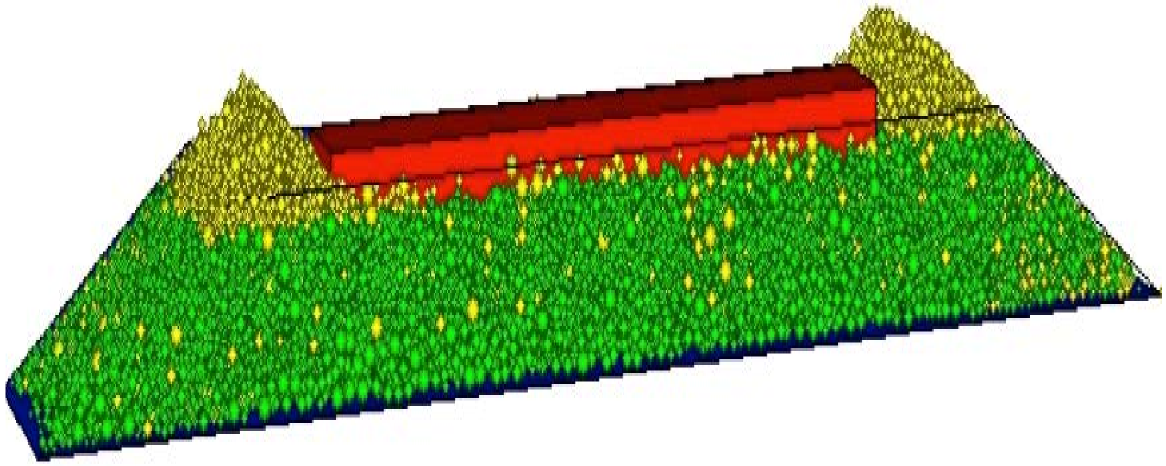
Outline

- Background
- Research progress
- Experience in china
- Future development

Research Topics

1. High speed railroad ballast flight **(350+)**
2. Modern ballasted track structure**(Composite)**
3. Ballast bed mechanics and application



HSR network


20K km (125, 000miles)
时速每小时300-350km
时速每小时200-250km
时速每小时160-200km
磁悬浮

China Slab track

CRTS Ⅰ SLAB

CRTSII SLAB

CRTSII TWO-BLOCK

CRTS Ⅰ TWO-BLOCK

Slab degradation

Water, temperature, settlement

Why China uses slab track?

Challenge	Reason	Solution
1.Ballast flight	Dust drift	Optimization
2.Extra tough ballast resource	Low price	Increase price
3.Modern ballast rail	Traditional view	USP, PU, Geogrid, Ballast mat, Asphalt layer etc.)
4.Degradation and maintenance	Short life and cost	Maintenance period prolong 1.5 times

Ballasted track

Cyclic loading

Bearing ability
Elasticity
Drainage

Ballast redisplacement, breakage and wear

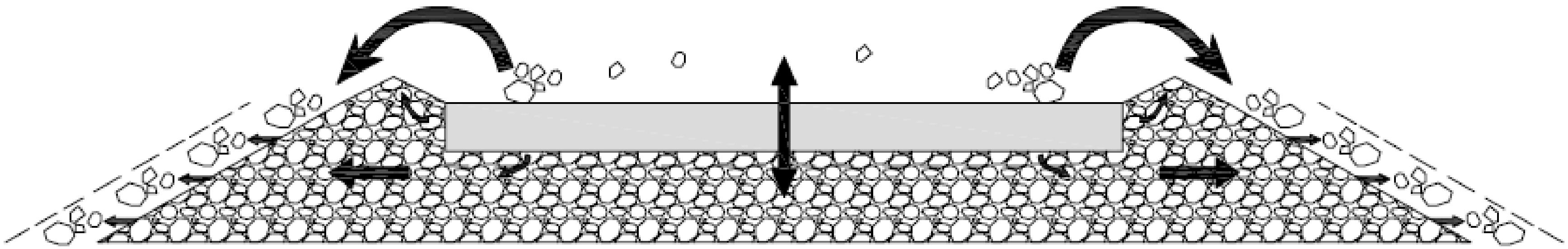
Settlement
Rigidity
Fouling

Function

Degradation

High Speed Ballasted track

Max 574.8 km/h(358miles/h)



Development

Generation	Speed km/h	Topic
1	200+	Strength
2	300+	Dynamic stability
3	350+	Safety and LCC

Current challenge

Environment	Russia	freeze & thaw , Snow	400 km/h
Geotechnical	Iran	desert & earthquake	300 km/h
Operation	France	Shared corridor	220 km/h

Ballast migration

- The displacement and accumulation.
  - Void creation on ballast bed, lateral stablity
  - Increase ballast flight

Dust flight in existed HSR

- Dustbin and ballast fines were drifted away, especially for the 200-250km/h exited HSR, and delusion of so-called ballast flight.

  China speed up experience.

- Solutions:
- Fresh ballast add-in and undercutting.
- Prevent the foreign particle intrusion into ballast, such as cover or glue coated coal car, and train toilet updated.

Ballast flight in snow zone(Russia)

- Snow into ice, and from cold to warm zone, hit ballast or train etc.
- HA-DA HSR in china:
- 1000 km, the minimum T: -40°
- Winter speed :200 km/h
- Summer speed: 300 km/h
- *Solutions:*
  - De-icing operations
  - Snow removal
  - Turnout Heating system
  - Slow down

(Norway,2012)

(Japan,2015)

Ballast flight

Train speeds above (300 km/h) the ballast particle acquires enough momentum from both wind and dynamic forces to hit the moving train

- Possible consequences:

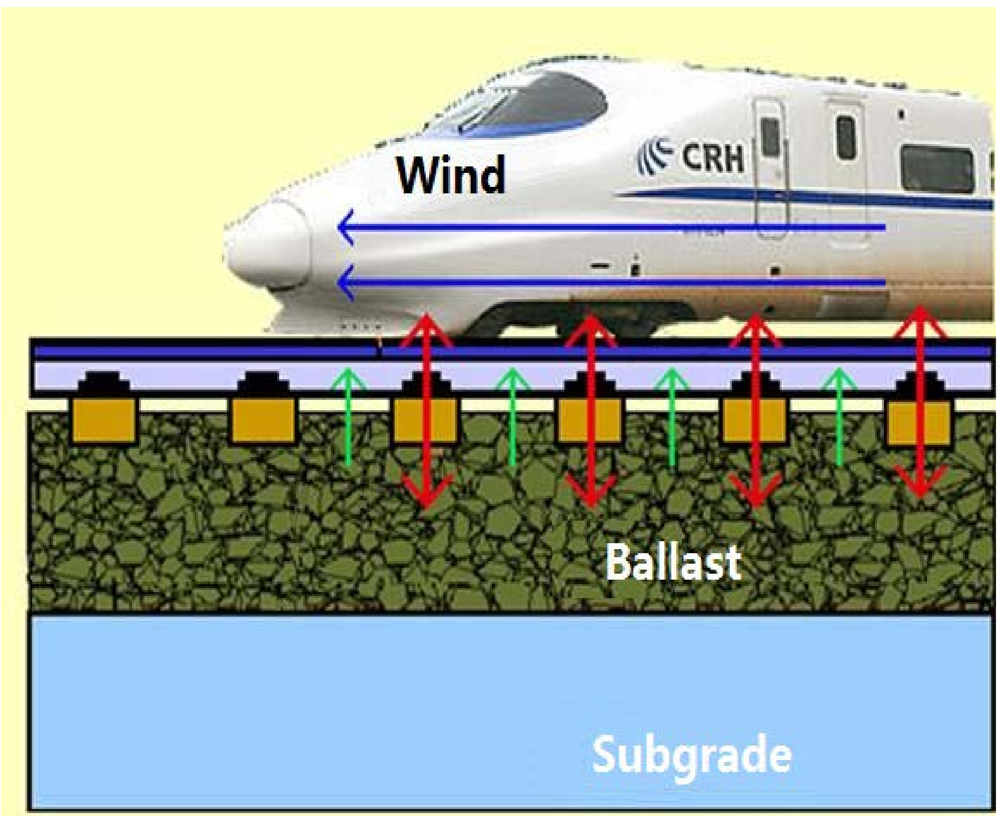
•Damage on railhead and train

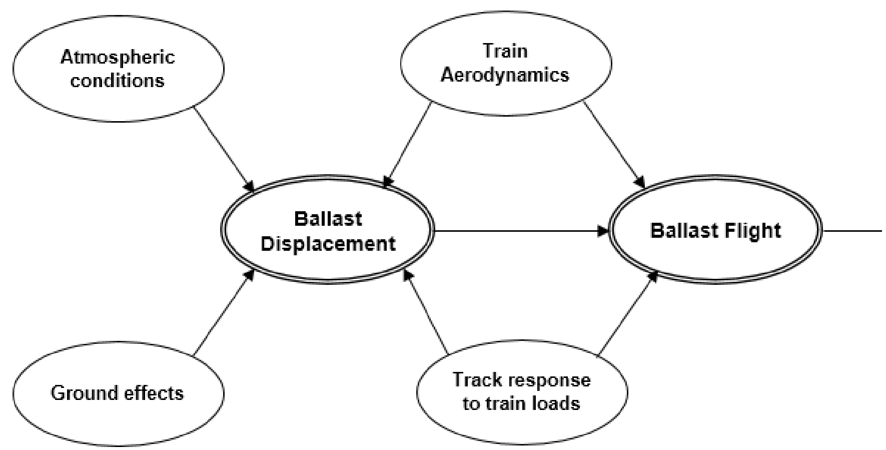
•Potential damage to adjacent surroundings

(Bedini et al. 2012)

Ballast flight mechanism and risk

- In associate with train, track, aerodynamics etc.





(Bedini et al. 2012)

Lab tests

(Hideyuki TAKAI,2015)

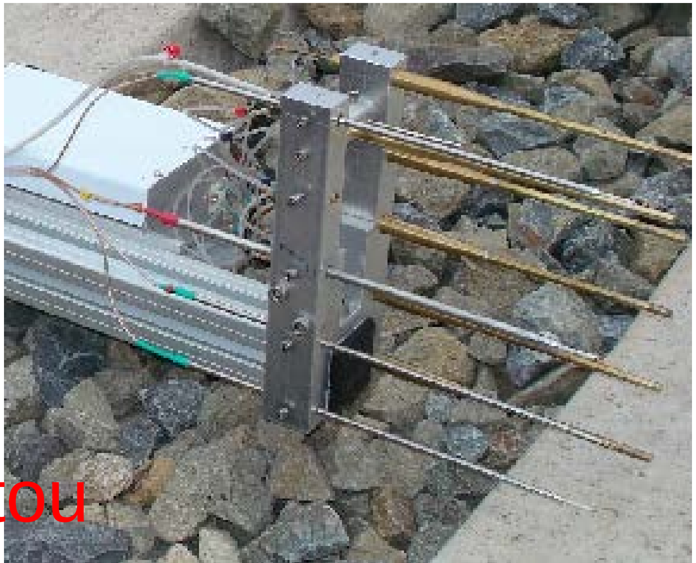
Air cannon

Vibration & wind tunnel (Gilles,2014)

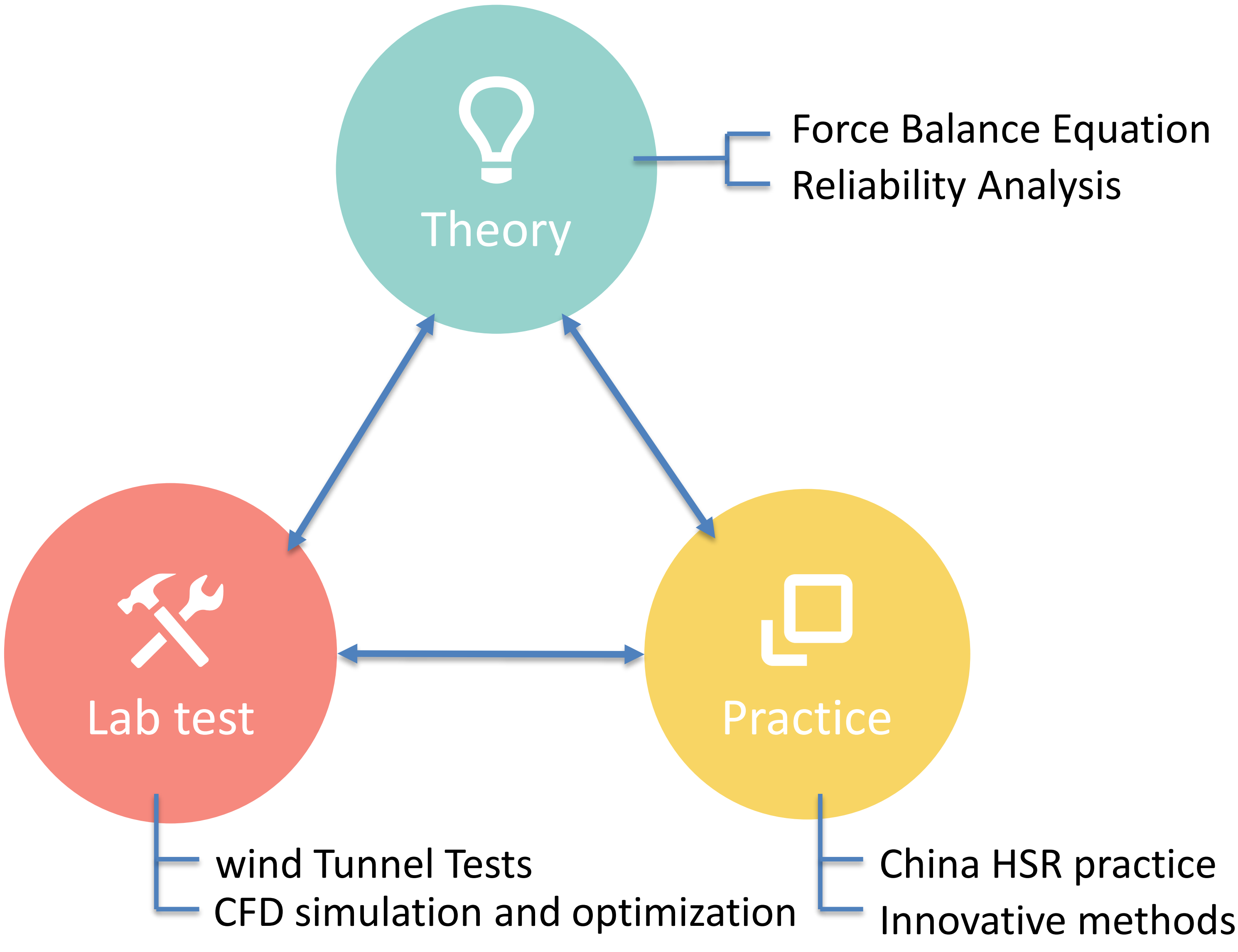
Wind tunnel (H.B Kwon,2010)

Site tests

(W.Powrie,2013)



Research in practice



Force Balance Equation Method

$$F_w + F_a = mg + ma_{\text{Total}} + F_i$$

$$ma_{Total} = F_w - mg + F_a \quad (1)$$

$$ma_{Total} = F_w - mg + ma = F_w - m(g - b_a) \quad (2)$$

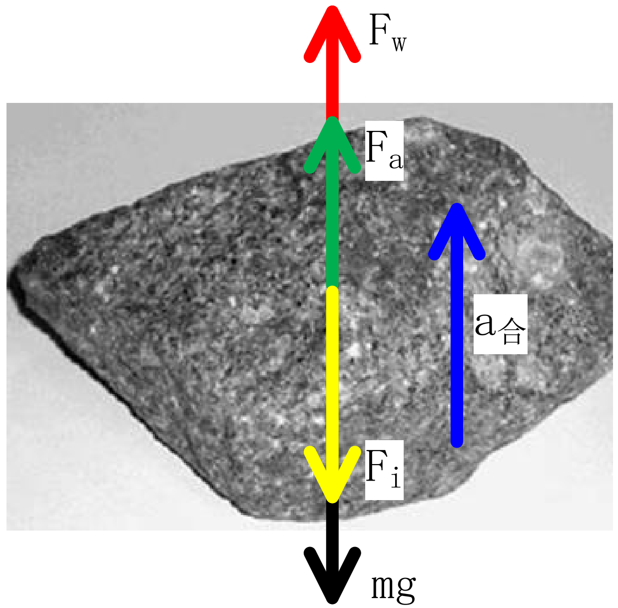
$$F_w = \int_0^A \int_{v_1}^{v_2} f(A) f(v) \mathrm{d}A \mathrm{d}v \quad (3)$$

$$F_w = \alpha \int_0^A f(A) \mathrm{d}A \quad (4)$$

Put (4) into (2), It is

$$ma_{Total} = \alpha \int_0^A f(A) \mathrm{d}A - m(g - b_a) \quad (5)$$

vibration of ballast could be determined for the HSR.



Wind and vibration are main factors

F_i Is vital for ballast particle stability, compaction and bonding can be used to increase the ability.

g is gravity

α is wind coefficient

b_a is ballast acceleration

$$a_{Total} = \frac{\alpha \int_{0}^{A} f(A)\mathrm{d}A}{m} - (g - \mathrm{b}_a) \quad (6)$$

Ballast shape, area/mass can be used to increase ballast particle stability.

$$\mathrm{m} = \iiint p\,dx\,dy\,dz \quad (7)$$

$$a_{Total} = \frac{\alpha}{\int_0^Z p\,dz} - (g - \mathrm{b}_a) \quad (8)$$

Depend on the ballast acceleration and ballast flat shape, and density

p is ballast density

$\int_0^Z dz$ is ballast flat or height

- ✓Ballast mass/shape/density is important for ballast flight
- ✓Ballast acceleration reduction is efficient way to control ballast flight

Reliability Analysis

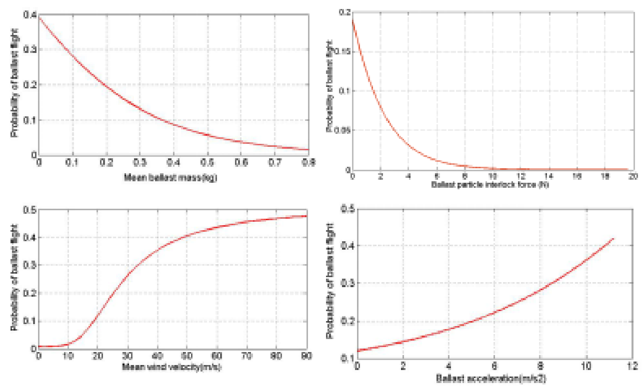
Based on the Force Balance Equation, by different Reliability risk assessment method , We could specific the ballast risk index, or the specific operation conditions.

- Reliability Assessment on HSR Ballast Flight Based on Monte Carlo

Condition:

- Mass
- Interlock force
- Mean wind velocity
- Acceleration

Probability of ballast flight



Risk evaluation:

N	10^6
Number of ballast flight grains	126108
Probability of ballast flight	12.61%

Monte Carlo simulation : N block ballast are simulated

JING guoqing;DING dong; SHAO SHUAI , Reliability Assessment on High Speed Railway Ballast Flight Based on Monte Carlo , *Journal of Railway Science and Engineering, 2016*

Ballast particle wind tunnel test

✓Ballast particle start to move with the wind speed about 18m/s

✓Ballast move distance correlated with shape and size of ballast particle.

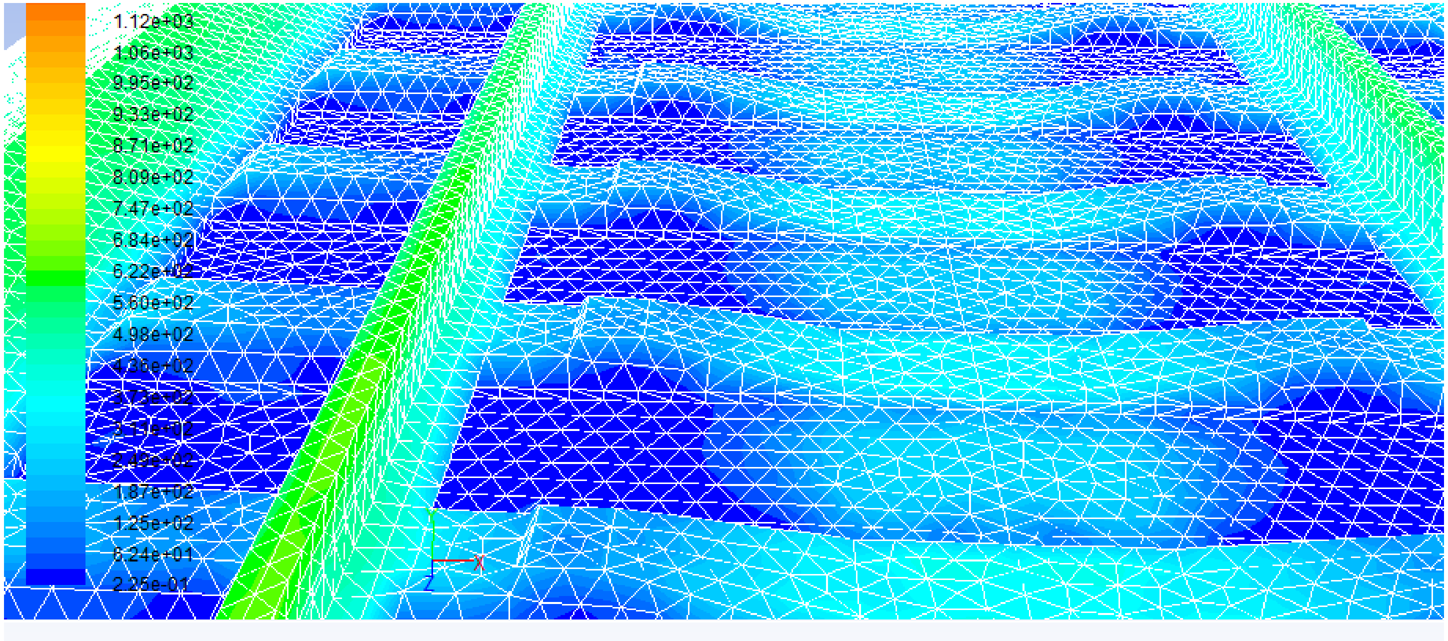
Ballast bed wind tunnel test

- Bond ballast layers
- Wind force distribution
- Ballast size and shape effects
- Shoulder shape and geometry
- Wind Speed up to 30m/s, (equal to 350km/h train)

Wind tunnel tests on ballast bed(on-going)

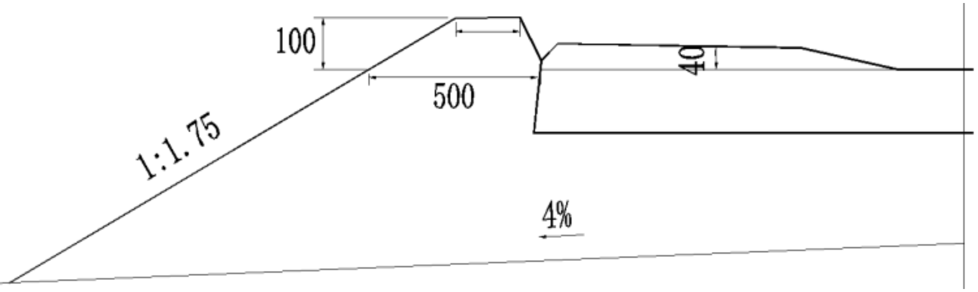
Ballasted track aerodynamic by CFD

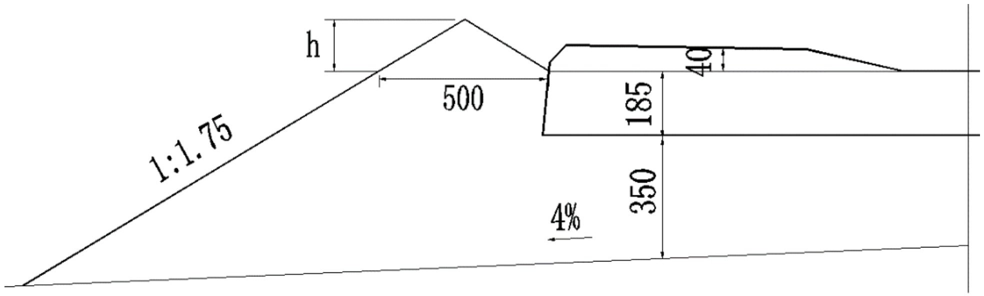
- High speed ballast bed aerodynamic effects
- Track stability vs. ballast flight risk (Computational Fluid Dynamics, CFD)

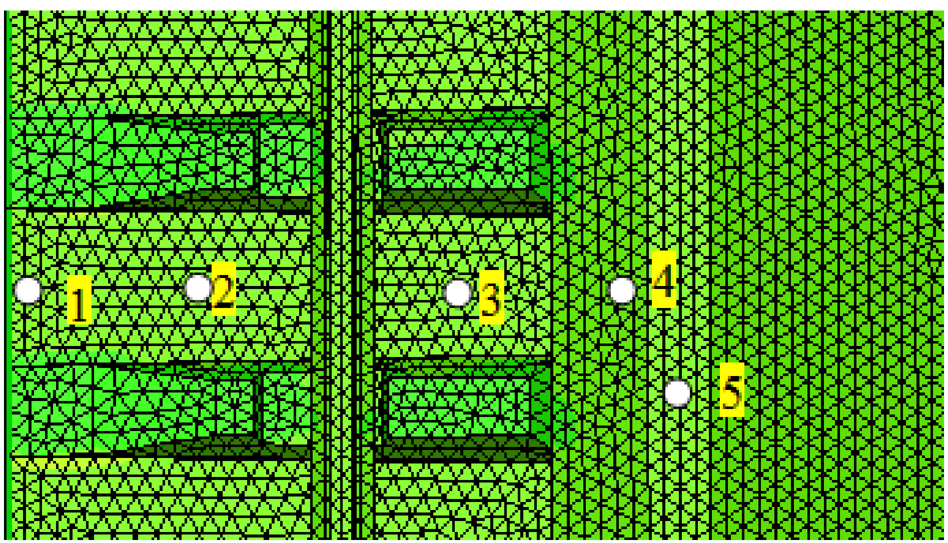


CFD evaluation of ballast bed

Aerodynamic shoulder



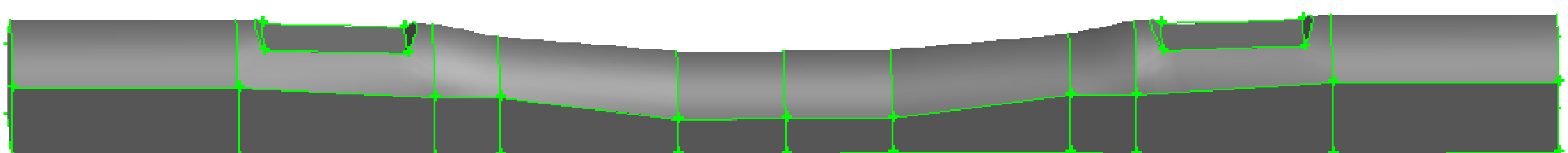




- Shoulder ballast height and shape
- Wind pressure increase with shoulder height.

Aerodynamic sleeper

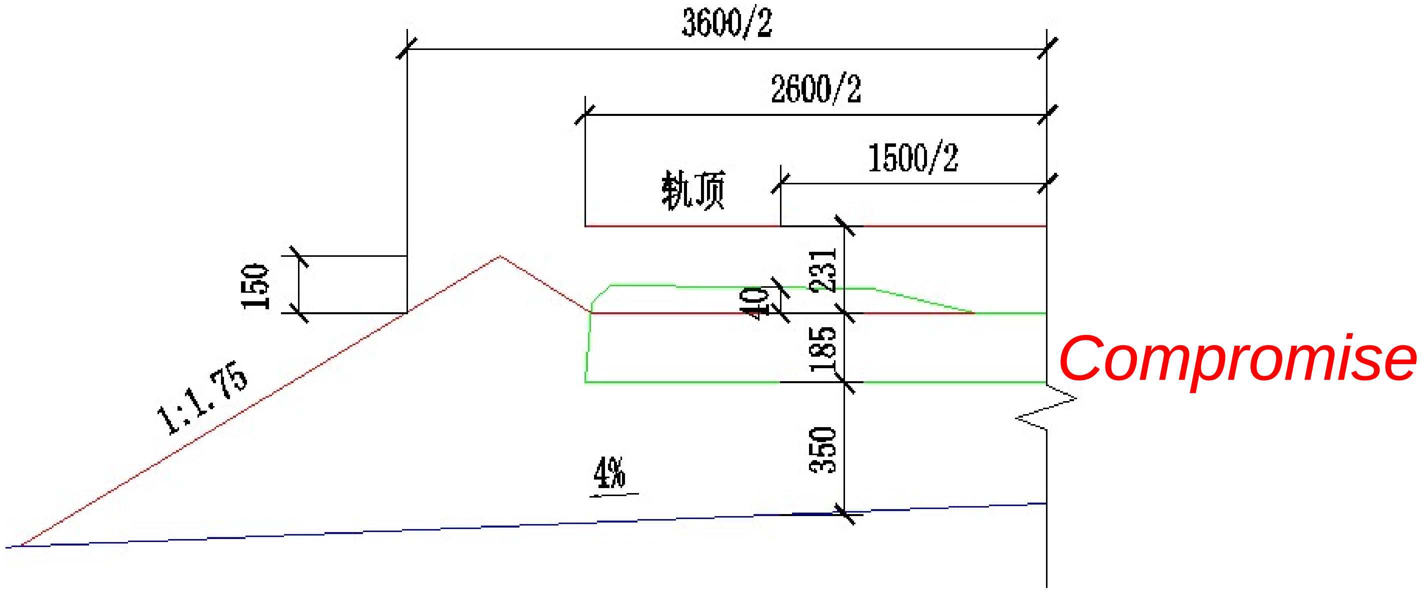
Aerodynamic sleeper (ADIF)



China HSR Practice

- ***Reduce shoulder ballast height with speed increase***
- ***Compact ballast bed***
- ***Reduce crib ballast level***
- ***Take measures to prevent ballast flight***

• Reduce shoulder height



150mm for HSR 200-250km/h, lateral resistance >10 kN/sleeper (longitudinal 12)

100mm for HSR 250-300km/h, lateral resistance > 12 kN/sleeper (longitudinal 14)

My proposal and taken:

0 mm for HSR 350km/h, and -50mm for 400km/h

• Compact ballast bed

speed (km/h)	Longitudinal (kN/sleeper)	Lateral (kN/sleeper)	Support stiffness (kN/mm)	Density (g/cm3)
200~250	≥12	≥10	≥110	≥1.75
250~300	≥14	≥12	≥120	≥1.75

Compaction of ballast bed is difficult , and damage to ballast aggregates.

Particle size gradation?

- Reduce ballast bed level

Compromise

Reduce crib ballast level: middle of sleeper parallel with ballast,

under rail and turnout zone is 30-40mm (200-250km/h), under rail and turnout zone is 30-40mm (250-300km/h).

• Measures shall be taken

China method

Japan method

- Ballast bonding system is conventional method applied in China HSR, especially for the transition zone and long bridges.

• Measures taken (Hefu HSR)

1. Zero height ballast shoulder
2. Smaller than 30mm, flat than 10mm were eliminated from bed surface.
3. Hefu HSR with 330km/h (206m/h) no ballast flight(2015).

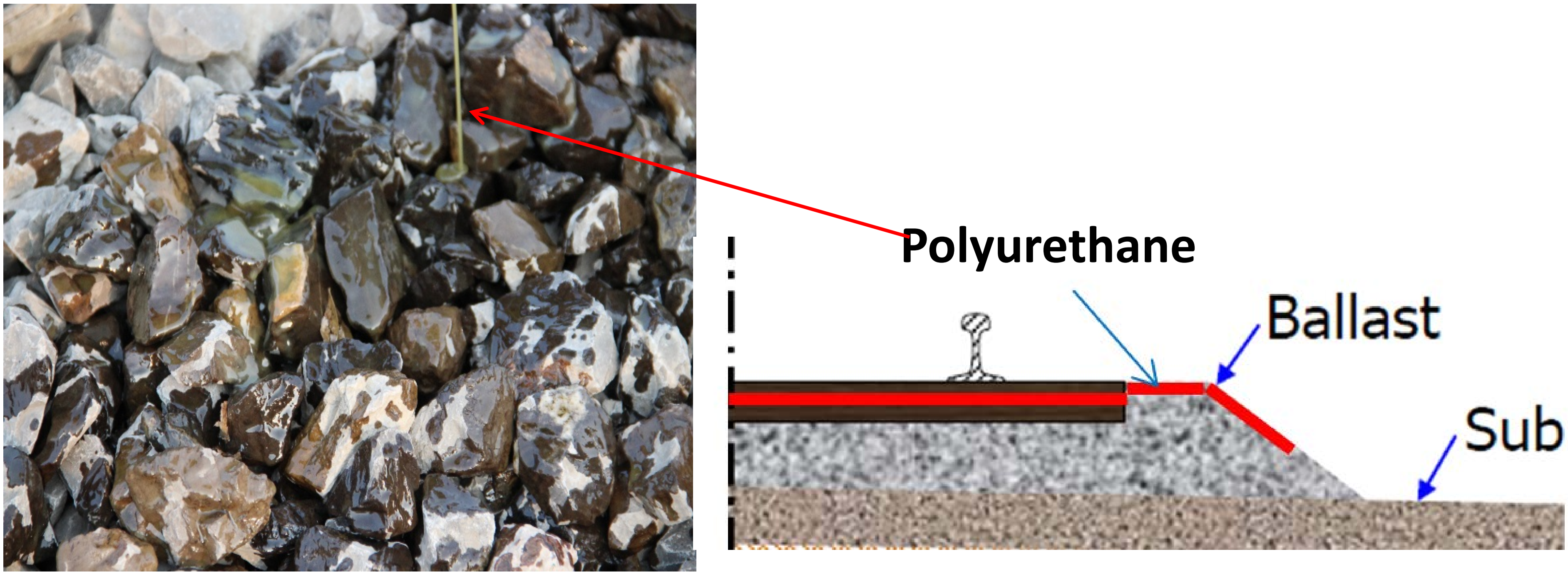
2km once was slab track, then removed and replaced with ballast track, due to big settlement (former old lake)

Hefu HSR- the most beautiful HSR in china, operation 1 July 2015

Note: 350km/h tests on Yellow River Bridge, no ballast flight by marked color(2013)

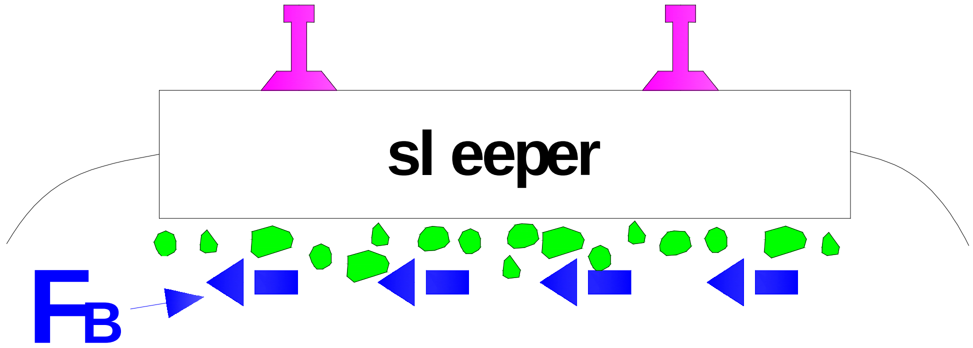
Innovation methods

• Soft polyurethane (1)

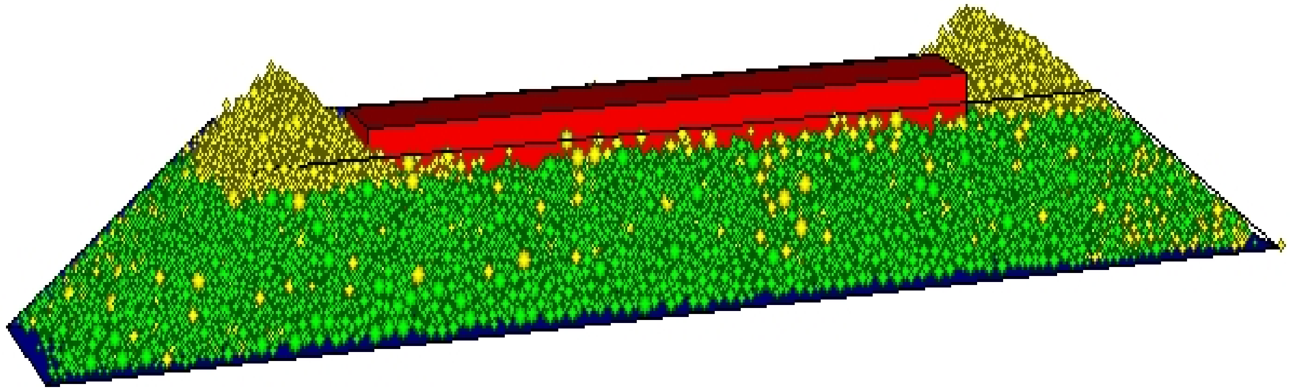


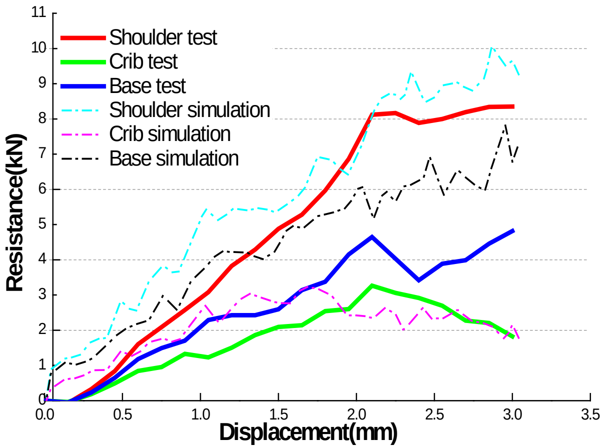
- *Polyurethane(PU) at proper strength, which could be tamped*
- *surface application (3-5cm)*
- *soft polyurethane*
- *On-going test at BJTU*

• Patented method and material (2)



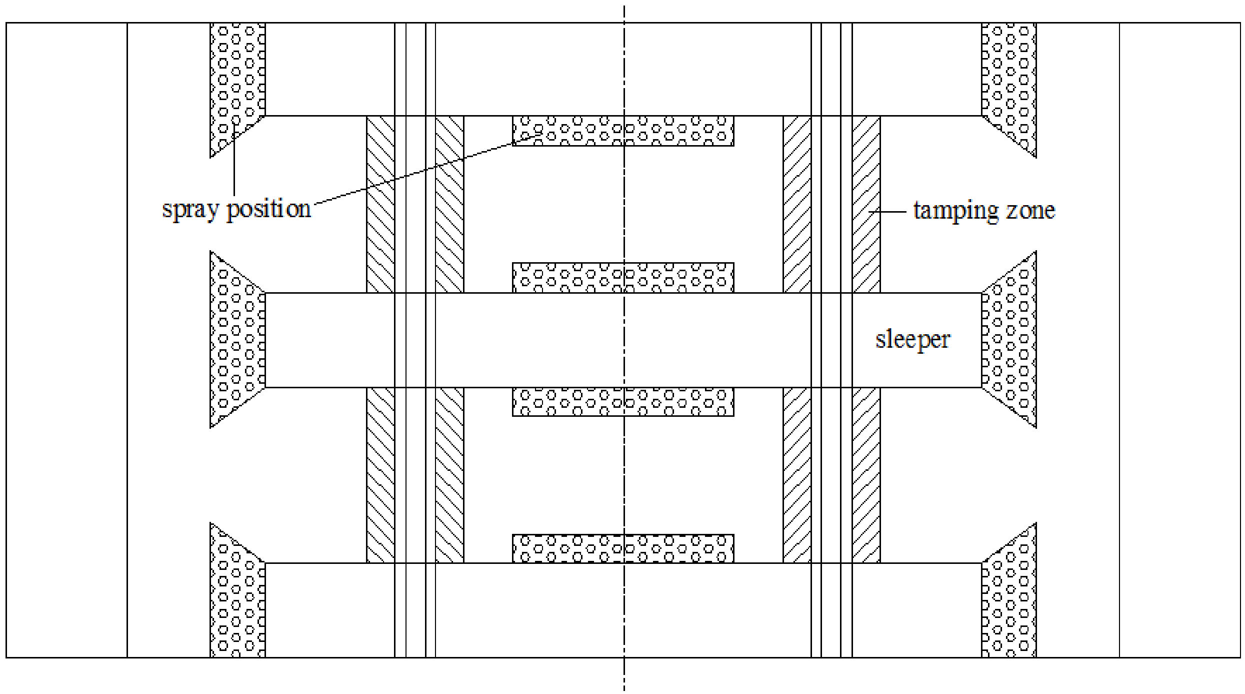
1. *Contribution and evolution, for example up-lift*
2. *Ballast-sleeper interaction optimization*

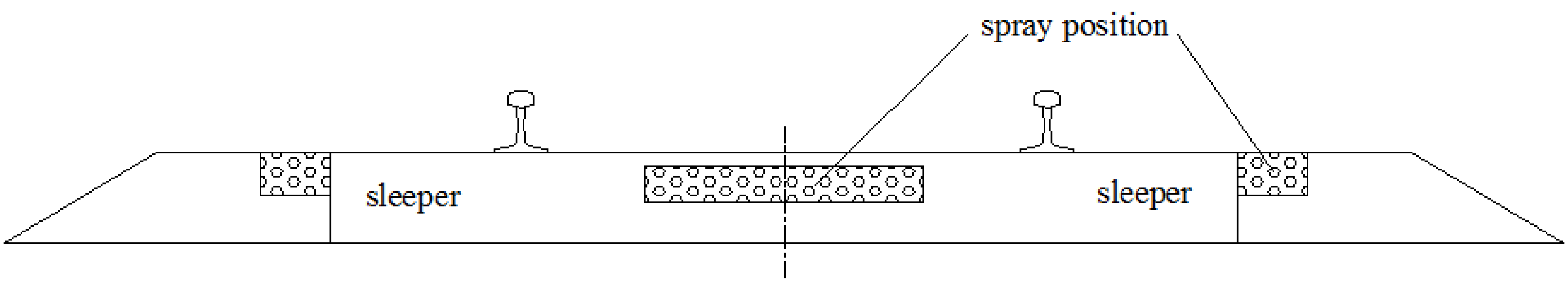




Shoulder part PU application results in 3 times lateral resistance

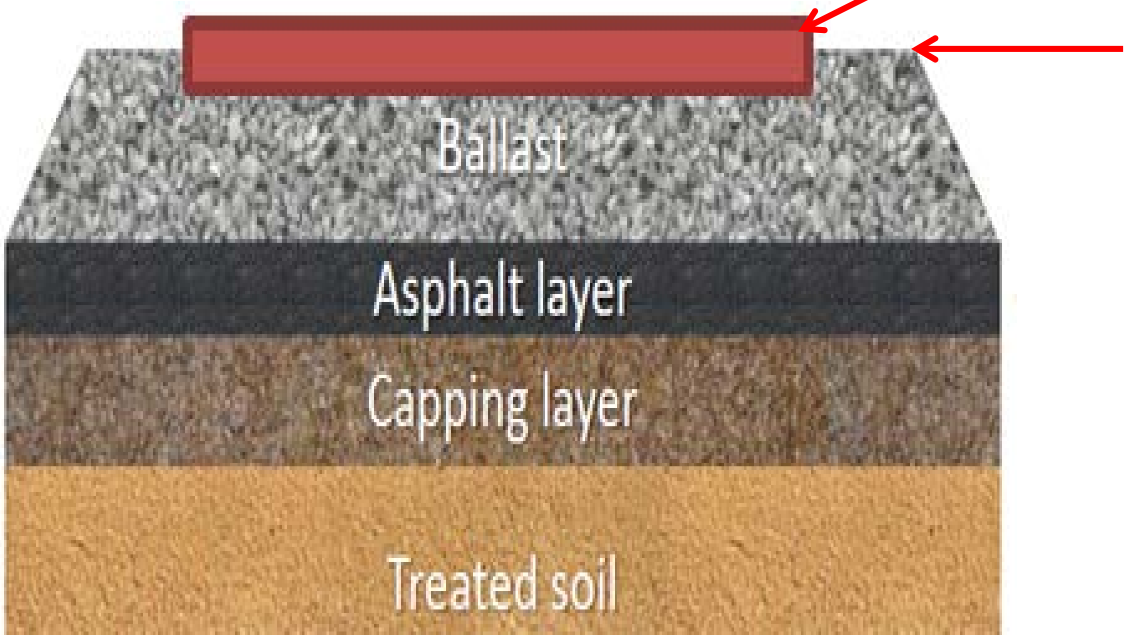
- *Sleeper side part PU application results in 1 time lateral resistance*





- *Polyurethane at specific position, beyond the tamping zone*

• Structure design (3)



1. **Big or frame tie, fastener**
2. **-50 mm shoulder ballast**
3. **Asphalt sub-ballast layer**

CFD coupled with FEM(DEM)