EFFECTS OF FREEZE-THAW OF ROADBED AND SUBGRADE ON TRAIN VIBRATION AT HIGH-SPEED RAILWAY IN COLD REGIONS

Hokkaido University Student Member Hao Lai
Hokkaido University Student Member 〇Shoulong Zhang
Hokkaido University Fellow Member Tatsuya Ishikawa

1. INTRODUCTION

The frost heaving of frost-susceptible subgrade is a major problem at the railway operations in cold regions. It causes large track irregularity so as to increase train vibration and affects the riding comfort and operational safety of railway transportation. This study focuses on estimating train vibration accelerations due to the deformation of railway structure subject to frost heave and thaw settlement, and proposing some constructive countermeasures for railway engineering.

2. METHODOLOGY

Fig. first, a coupled thermo-hydro-mechanical (THM) analysis for the freezing behavior (Luo et al., 2017) was employed to estimate the track deformation for a railway section located above a box culvert. Next, the vehicle response due to track irregularity in frost heaving area was estimated by a parametric Auto-Regression model with eXtra inputs (ARX) (Furukawa, 2004). Furthermore, the effect of operational speed (OS) down on vehicle vertical acceleration was also estimated. In the end, we evaluated the riding comfort and safety issues.

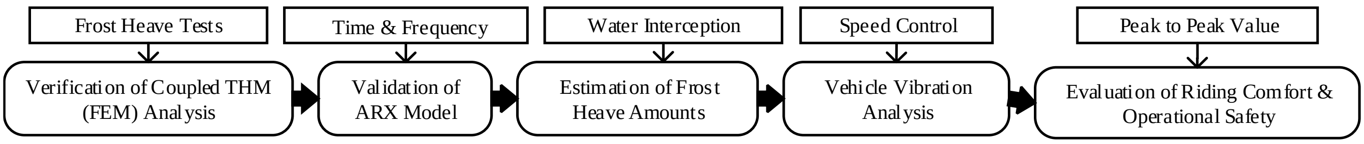
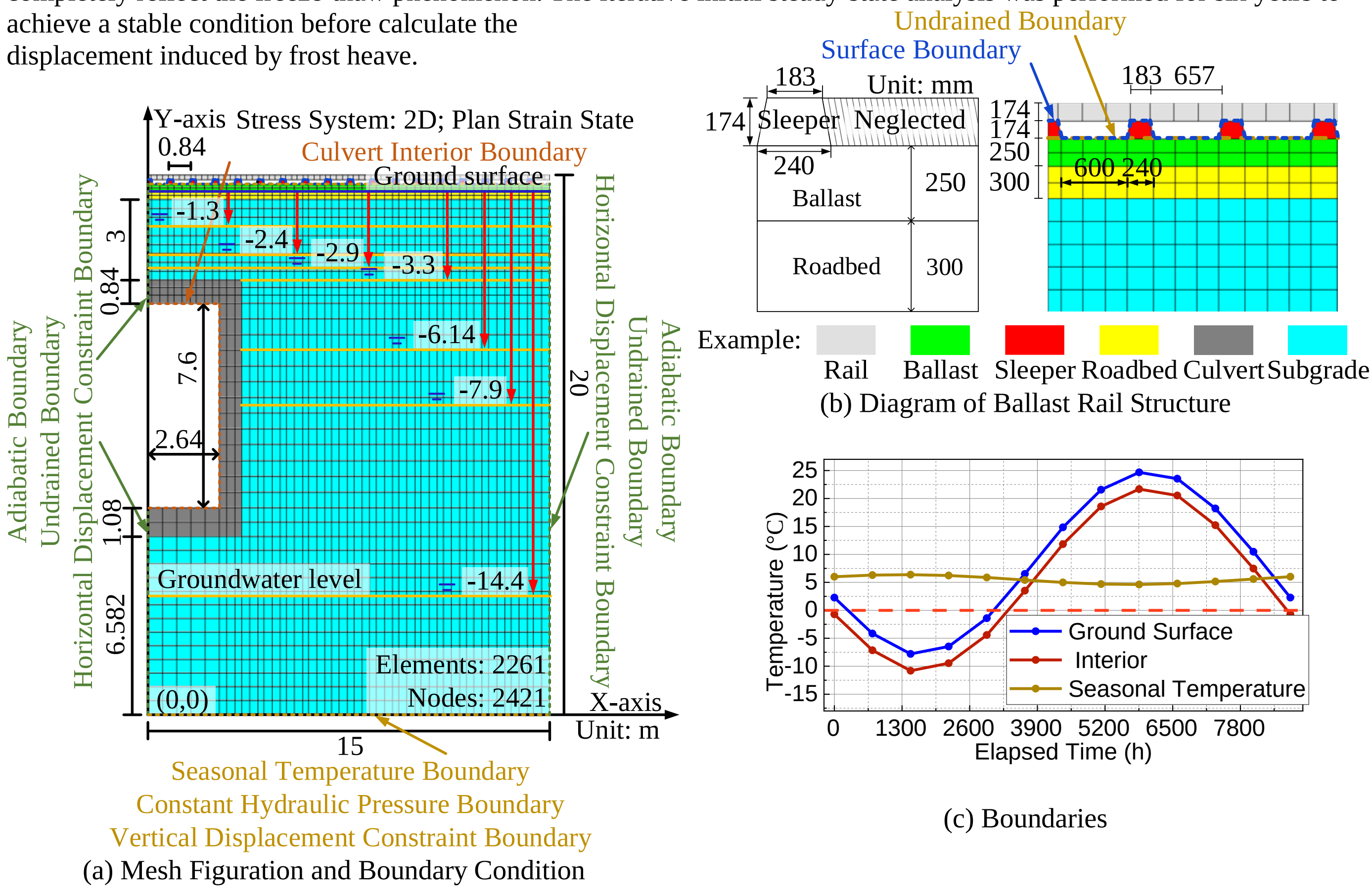


Fig. 1 Research Flow Chart

3. MODEL DESCRIPTION

Fig. 2 shows the ballasted track structure model with a box culvert, which can directly reflect the track deformation due to frost heaving. The input parameters are listed in Table 1. By preliminary calculations, the size and meshing could completely reflect the freeze-thaw phenomenon. The iterative initial steady-state analysis was performed for six years to achieve a stable condition before calculate the displacement induced by frost heave.



(a) Mesh Figuration and Boundary Condition

(b) Diagram of Ballast Rail Structure

(c) Boundaries

Fig. 2 Model and Constraint Boundaries

Keywords: THM analysis, ARX model, Riding comfort evaluation.
Contact address: Kita13-jo, Nishi8-chome, Kita-ku, Sapporo, Hokkaido, 060-8628, Japan, Tel: +81-11-706-6202

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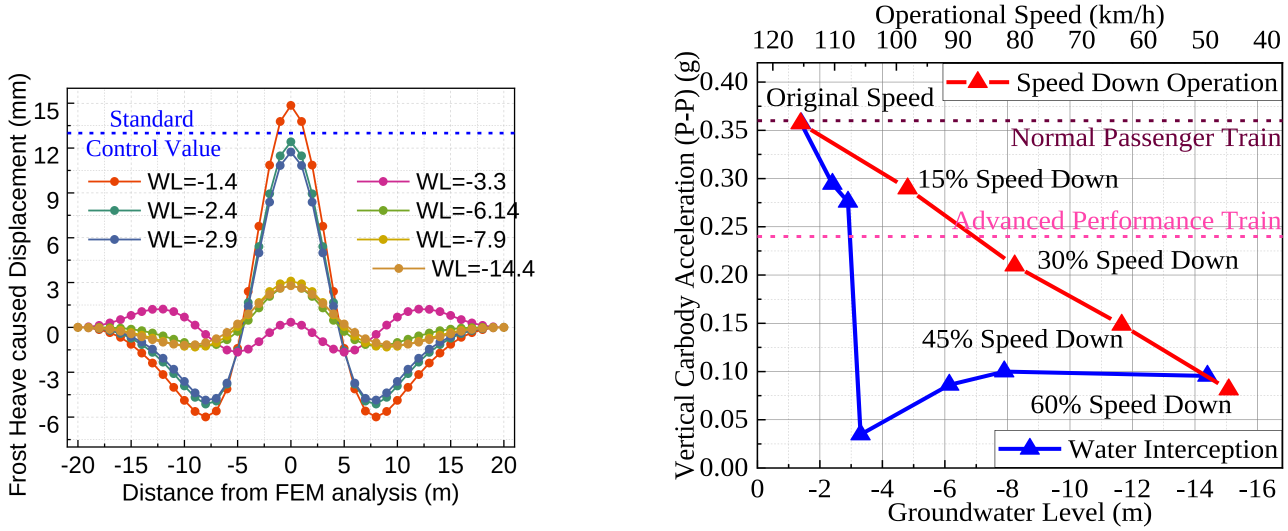
Table 1 Input Parameters for the Numerical Simulation

Sym	Unit	Name of Parameters	Rail	Ballast	Sleeper	Roadbed	Culvert	Subgrade
E_1	MPa	Young's Modulus before Frost heaving	210000	50	35000	200	21700	40
E_2	MPa	Young's Modulus after Frost heaving	210000	400	35000	469	21700	40
ν	/	Posson's Ratio	0.3	0.35	0.17	0.35	0.2	0.33
ρ	MN/m^3	Specific Weight	0.077	0.01667	0.02334	0.01942	0.02354	0.013533
C	J/m^3°C	Volumetric Heat Capacity	3756000	1700000	3030000	1800000	2400000	966000
λ	J/mh°C	Thermal Conductivity	216000	6120	5940	1836	5580	5796
h_h	J/mh°C	Convection Coefficient of Exposed Surface	/	50400	50400	/	50400	/
α	1/°C	Thermal Expansion Coefficient	1.2×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	8.0×10^{-6}	1.0×10^{-5}	1.2×10^{-5}
k_{ij0}	m/h	Saturated Hydraulic Conductivity	0	1.8	0	0.1908	1.5×10^{-9}	3.6×10^{-5}
n	%	Porosity	0	41	0	31.973	5	45.2

By conducting water interception, the track deformation was estimated under several different groundwater levels (WL). Moreover, WL is controlled by giving different values to the constant hydraulic pressure boundary. Besides, we collected the maximum value of vertical displacement at the rail surface (20m on Y-axis) on the freezing process and converted it into 10m-chord versine (see Fig. 3(a)). And then transfer it to irregularity which is used to estimate vertical accelerations by ARX model.

4. RESULTS AND DISCUSSION

As seen in Fig. 3 (a), with WL lowering down, the longitudinal level irregularity induced by frost heaving is decreasing. Especially when WL=-1.4m, it is above the standard control value for maintenance work. From Fig. 3 (b), the corresponding Peak to Peak (P-P) value of vertical carbody acceleration is also decreasing with WL. Notably, when WL is parallel to the top surface of the culvert (-3.3m), the P-P decreases to its minimal. Besides, it is clear to see that the OS is linearly related to the P-P. In order to reduce the vibration to the safety limit of advanced train (Otsuka et al., 2003), a speed cut of approximately 20% ~30% is necessary.



(a) Estimated Frost Heave Amounts (10-chord versine)

(b) Estimated Vehicle Responses

Fig. 3 Simulation Results

5. CONCLUSIONS

▪ The coupled THM analysis can reproduce the real freeze-thaw phenomenon considerably and estimate the frost heave amount along the rail surface. Besides, ARX model can precisely predict the vehicle response to the track deformation due to frost heaving. It is expected to widely use ARX model to estimate vehicle responses in railway engineering.

▪ The P-P is exponentially decreased with the decrease of WL, while linearly decrease with lowering of OS. Therefore, we conclude that both water interception and speed down operation are functional; however, the water interception is more efficient since the P-P value would decrease to its lowest once the WL is lowering to the top surface of culvert.

REFERENCES

Furukawa, A,.: Development of prediction methods on dynamic behaviors of a railway vehicle for efficient track maintenance, Tokyo University, 2004, Ph.D. thesis. (in Japanese)

Otsuka, T., Mitsuru, T., Ohashi, A.: Study on the speed calculation for speed down operation due to frost heaving. Winter Transport Department, JR Hokkaido. 2003. (in Japanese)

Luo, B., Ishikawa, T., Lai, H., Tokoro, T.: Frost heave analysis of ballasted track above box culvert and its influence on train vibration, Proceedings of the 3rd International Symposium on Transportation Soil Engineering in Cold Regions, Guide, China, Sciences in Cold and Arid Regions, 9(3): 229-235. 2017.7.

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