



ハノイ市における繊維質材料混合流動化処理土の埋戻し地盤への適用に関する研究

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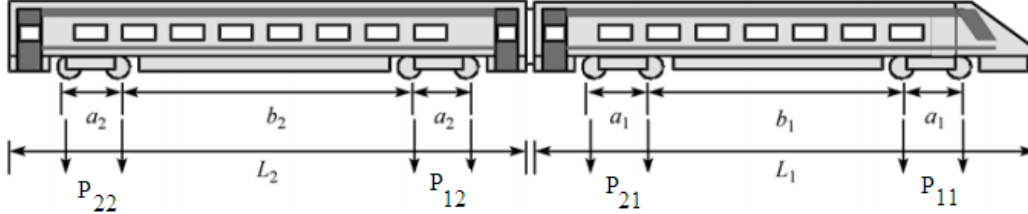
Appendix A

Simulation of moving train load with velocity of 80 km/h by Empirical method

I. Inputs

1. Parameters of metro train

Geometry parameters of train



Total number of cars:

$$N_{car} := 6$$

Speed of train:

$$v := 80 \text{ kph}$$

Distance from analysis point to the first axial of train:

$$l_0 := 3 \text{ m}$$

Static mass of axle:

$$M_0 := 1503 \text{ kg}$$

Load of axles:

Dimension of cars:

Car No.1:	$P1_1 := 122.73 \text{ kN}$	$P2_1 := 122.73 \text{ kN}$	$L_1 := 24 \text{ m}$	$a_1 := 2 \text{ m}$	$b_1 := 16 \text{ m}$
Car No.2:	$P1_2 := 122.73 \text{ kN}$	$P2_2 := 122.73 \text{ kN}$	$L_2 := 24 \text{ m}$	$a_2 := 2 \text{ m}$	$b_2 := 16 \text{ m}$
Car No.3:	$P1_3 := 122.73 \text{ kN}$	$P2_3 := 122.73 \text{ kN}$	$L_3 := 24 \text{ m}$	$a_3 := 2 \text{ m}$	$b_3 := 16 \text{ m}$
Car No.4:	$P1_4 := 122.73 \text{ kN}$	$P2_4 := 122.73 \text{ kN}$	$L_4 := 24 \text{ m}$	$a_4 := 2 \text{ m}$	$b_4 := 16 \text{ m}$
Car No.5:	$P1_5 := 122.73 \text{ kN}$	$P2_5 := 122.73 \text{ kN}$	$L_5 := 24 \text{ m}$	$a_5 := 2 \text{ m}$	$b_5 := 16 \text{ m}$
Car No.6:	$P1_6 := 122.73 \text{ kN}$	$P2_6 := 122.73 \text{ kN}$	$L_6 := 24 \text{ m}$	$a_6 := 2 \text{ m}$	$b_6 := 16 \text{ m}$

2. Parameters of rail:

Sleeper space:

$$L_f := 0.65 \text{ m}$$

Stiffness of Rail Pad:

$$K_{pad} := 120 \cdot 10^3 \frac{\text{kN}}{\text{m}}$$

Modulus of rail:

$$E_r := 2.07 \cdot 10^{11} \frac{\text{N}}{\text{m}^2}$$

Inertia moment of rail:

$$I_r := 30.55 \cdot 10^{-6} \text{ m}^4$$

Rail mass per 1 m:

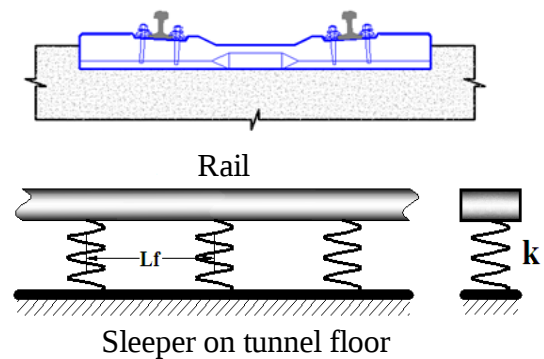
$$m_r := 60 \frac{\text{kg}}{\text{m}}$$

Sleeper mass:

$$m_{slp} := 150 \text{ kg}$$

Wheel diameter:

$$D_w := 0.85 \text{ m}$$



3. Parameters of irregularities:

Types of irregularity that can be modeled including corrugation of rail, arbitrary wheel surface profile and wheel flat:

-) Corrugation of rail surface, wavelength from 30mm to 300mm and 300mm to 1000mm, depth of irregularity from 0.01mm to 0.4mm:

$$L_{ir,1} := 200\text{mm} \quad a_{ir,1} := \begin{cases} 0\text{mm} & \text{if } 0\text{mm} < L_{ir,1} \leq 30\text{mm} \\ 0.01\text{mm} & \text{if } 30\text{mm} < L_{ir,1} \leq 100\text{mm} \\ 0.25\text{mm} & \text{if } 100\text{mm} < L_{ir,1} \leq 300\text{mm} \\ 0.4\text{mm} & \text{if } 300\text{mm} < L_{ir,1} \leq 1000\text{mm} \\ 0 & \text{otherwise} \end{cases}$$

-) Arbitrary wheel surface or wheel flat with wavelength from 0.2 to 1 time of circumference of wheel, irregularity depth of 1mm:

$$\text{Wavelength from: } 0.2\pi \cdot D_w = 0.534\text{m} \text{ to: } 1\pi \cdot D_w = 2.67\text{m}$$

$$L_{ir,2} := 534\text{mm} \quad a_{ir,2} := 1\text{mm}$$

4. Data export parameters

Sampling frequency per 1 sec: SRate := 1000

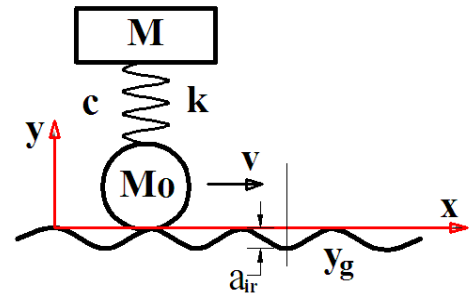
Sampling time: Tend := 6s

II. Dynamic force

1. Dynamic force induced by irregularity

System of one degree of freedom

$M \gg M_0 \rightarrow M$ fix, M_0 oscillate with acceleration y_g :



$$\text{Radian frequency of irregularity: } \omega_{ir,1} := 2 \cdot \pi \cdot \frac{v}{L_{ir,1}}$$

$$\omega_{ir,2} := 2 \cdot \pi \cdot \frac{v}{L_{ir,2}}$$

$$\text{Frequency of irregularity: } f_{ir,1} := \frac{v}{L_{ir,1}} = 111.111\text{Hz} \quad f_{ir,2} := \frac{v}{L_{ir,2}} = 41.615\text{Hz}$$

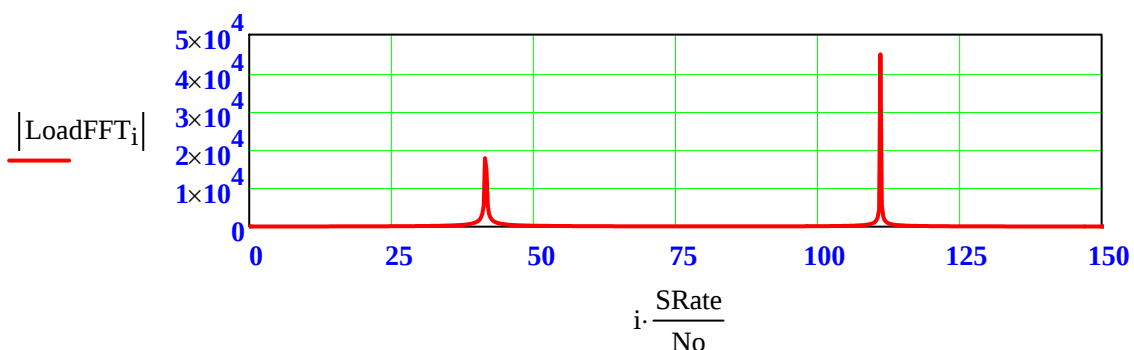
$$\text{Shape function of the irregularity due to wheel flat: } y_{ir,1}(t) := \frac{a_{ir,1}}{2} \cdot (1 - \cos(\omega_{ir,1} \cdot t))$$

$$\text{Shape function of the irregularity due to dipped joint: } y_{ir,2}(t) := \frac{a_{ir,2}}{2} \cdot (1 - \cos(\omega_{ir,2} \cdot t))$$

$$P_{dyn}(t) := M_0 \cdot \frac{a_{ir,1}}{2} \cdot \omega_{ir,1}^2 \cdot \cos(\omega_{ir,1} \cdot t) + M_0 \cdot \frac{a_{ir,2}}{2} \cdot \omega_{ir,2}^2 \cdot \cos(\omega_{ir,2} \cdot t)$$

2. Analysis of frequency P(t), FFT transform

$$No := 2^{12} \quad i := 0 \dots No - 1 \quad Time_i := \frac{i \cdot s}{SRate} \quad P_{dyn_i} := P_{dyn}(Time_i) \quad LoadFFT_i := FFT(P_{dyn})$$



3. Loading ditribution function on tunnel floor:

Bending stiffness of 2 rail: $EI := 2 \cdot E_r \cdot I_r = 1.265 \times 10^7 \frac{\text{m}^3 \cdot \text{kg}}{\text{s}^2}$

Elastic modulus of railpad: $E_{\text{railpad}} := \frac{2 \cdot K_{\text{pad}}}{L_f} = 3.692 \times 10^8 \text{ Pa}$

Elastic stiffness of elastic foundation: $k := E_{\text{railpad}} = 3.692 \times 10^8 \text{ Pa}$

Characteristic length of load distribution on tunnel floor through railpad: $\alpha_{\text{rail}} := \sqrt[4]{\frac{4 \cdot EI}{k}} = 0.608 \text{ m}$

Loading ditribution function on tunnel floor through railpad:

$$\Phi_{\text{rail}}(x) := \frac{1}{2 \cdot \alpha_{\text{rail}}} \cdot e^{\frac{-|x|}{\alpha_{\text{rail}}}} \cdot \left(\cos\left(\frac{x}{\alpha_{\text{rail}}}\right) + \sin\left(\frac{|x|}{\alpha_{\text{rail}}}\right) \right)$$

4. Dynamic loading on tunnel floor

$$t_0 := \frac{l_0}{v}$$

$$P_1(t) := \sum_{n=1}^{N_{\text{car}}} \left[\left[P1_n + P_{\text{dyn}} \left[\frac{v \cdot (t - t_0) - \sum_{s=0}^{n-1} L_s}{v} \right] \right] \cdot \Phi_{\text{rail}} \left[v \cdot (t - t_0) - \sum_{s=0}^{n-1} L_s \right] \right]$$

$$P_2(t) := \sum_{n=1}^{N_{\text{car}}} \left[\left[P1_n + P_{\text{dyn}} \left[\frac{v \cdot (t - t_0) - \sum_{s=0}^{n-1} L_s - a_n}{v} \right] \right] \cdot \Phi_{\text{rail}} \left[v \cdot (t - t_0) - \sum_{s=0}^{n-1} L_s - a_n \right] \right]$$

$$P_3(t) := \sum_{n=1}^{N_{\text{car}}} \left[\left[P2_n + P_{\text{dyn}} \left[\frac{v \cdot (t - t_0) - \sum_{s=0}^{n-1} L_s - a_n - b_n}{v} \right] \right] \cdot \Phi_{\text{rail}} \left[v \cdot (t - t_0) - \sum_{s=0}^{n-1} L_s - a_n - b_n \right] \right]$$

$$P_4(t) := \sum_{n=1}^{N_{\text{car}}} \left[\left[P2_n + P_{\text{dyn}} \left[\frac{v \cdot (t - t_0) - \sum_{s=0}^{n-1} L_s - 2 \cdot a_n - b_n}{v} \right] \right] \cdot \Phi_{\text{rail}} \left[v \cdot (t - t_0) - \sum_{s=0}^{n-1} L_s - 2 \cdot a_n - b_n \right] \right]$$

$$P(t) := P_1(t) + P_2(t) + P_3(t) + P_4(t)$$

III. Results:

Sampling interval: $\underset{\text{wavy}}{dt} := \frac{1\text{sec}}{\text{SRate}} = \mathbf{0.001\,s}$ $t := \mathbf{0}\text{sec}, dt.. \text{Tend}$

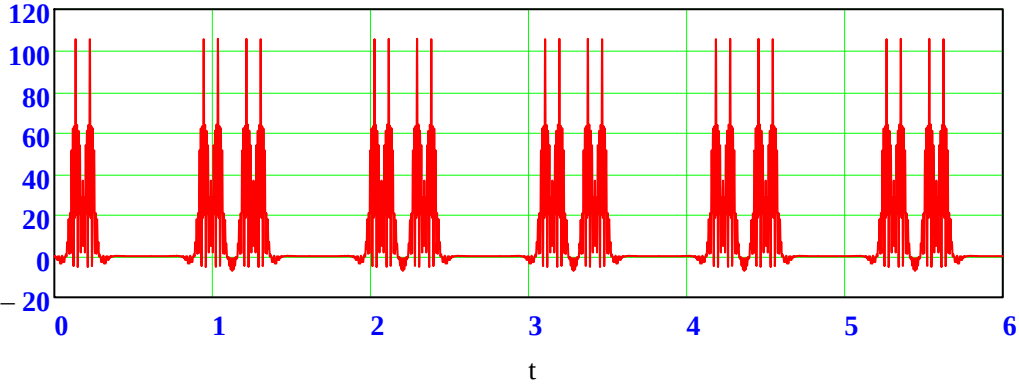
$P(t) =$

-0.772
-0.703
-0.456
-0.136
0.089
0.06
-0.285
-0.865
-1.479
-1.89
-1.944
...

$\cdot \frac{\text{kN}}{\text{m}}$

$\frac{\text{kN}}{\text{m}} \quad \frac{P(t)}{\mathbf{2000}}$

Dynamic load on tunnel from one rail



$\underset{\text{wavy}}{P_i} := P(\text{Time}_i) \quad \text{Load1FFT} := \text{FFT}(P)$

FFT of dynamic force transmit on tunnel from one rail

$\left| \frac{\text{Load1FFT}_i}{\mathbf{2}} \right|$

