



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

メタデータ	言語: eng 出版者: 公開日: 2015-12-22 キーワード (Ja): キーワード (En): 作成者: ズウオン, クワン フン メールアドレス: 所属:
URL	https://doi.org/10.15118/00005132

Appendix B

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

I. Inputs

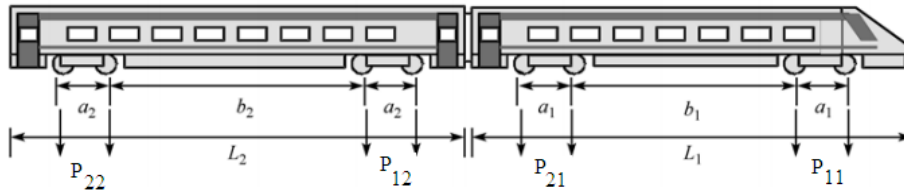
1. Parameters of metro train

Distance from analysis point to the first axial of train: $L_o := 3\text{m}$

Speed of train: $v_t := 80\text{kph}$

Total number of cars: $N_{car} := 6$

Geometry parameters of train



Car length:

$L_{car_1} := 24\text{m}$ $L_{car_2} := 24\text{m}$ $L_{car_3} := 24\text{m}$ $L_{car_4} := 24\text{m}$ $L_{car_5} := 24\text{m}$ $L_{car_6} := 24\text{m}$

Fixed axle spacing:

$a_{car_1} := 2\text{m}$ $a_{car_2} := 2\text{m}$ $a_{car_3} := 2\text{m}$ $a_{car_4} := 2\text{m}$ $a_{car_5} := 2\text{m}$ $a_{car_6} := 2\text{m}$

Axle spacing between 2 bogie:

$b_{car_1} := 16\text{m}$ $b_{car_2} := 16\text{m}$ $b_{car_3} := 16\text{m}$ $b_{car_4} := 16\text{m}$ $b_{car_5} := 16\text{m}$ $b_{car_6} := 16\text{m}$

2. Parameters of cars in the analysis model

Car body mass (1/8 car): $m_s := \frac{32000}{8}\text{kg}$

Bogie mass (1/4 bogie): $m_u := \frac{5540}{4}\text{kg}$

Wheel mass (1/2 axle): $m_w := \frac{1503}{2}\text{kg}$

Car mass in total:

$M_{car} := 8 \cdot (m_s + m_u + m_w) = 49092\text{kg}$

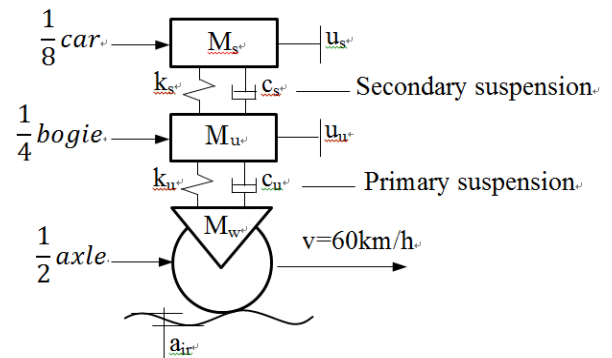
Wheel spring stiffness: $k_u := 2360 \frac{\text{kN}}{\text{m}}$

Bogie spring stiffness: $k_s := 530 \frac{\text{kN}}{\text{m}}$

Wheel damping coefficient: $c_u := 78.4 \frac{\text{kN} \cdot \text{s}}{\text{m}}$

Bogie damping coefficient: $c_s := 90.2 \frac{\text{kN} \cdot \text{s}}{\text{m}}$

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



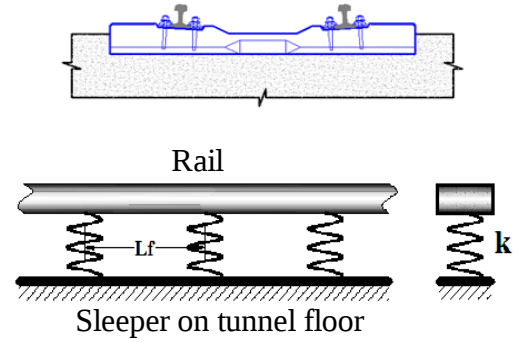
3. Parameters of track:

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

Rail Pad stiffness: $K_{\text{railpad}} := 120 \cdot 10^3 \frac{\text{kN}}{\text{m}}$

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

Inertia moment of one rail: $I_r := 30.55 \cdot 10^{-6} \text{m}^4$



4. Parameters of wheel-rail irregularity

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

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

$$L_{ir_1} := 200\text{mm} \quad a_{ir_1} := \begin{cases} 0\text{mm} & \text{if } 0\text{mm} < L_{ir_1} \leq 30\text{mm} \\ 0.01\text{mm} & \text{if } 30\text{mm} < L_{ir_1} \leq 100\text{mm} \\ 0.25\text{mm} & \text{if } 100\text{mm} < L_{ir_1} \leq 300\text{mm} \\ 0.4\text{mm} & \text{if } 300\text{mm} < L_{ir_1} \leq 1000\text{mm} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Frequency from: } \frac{v_t}{3000\text{mm}} = 7.407 \cdot \text{Hz} \quad \text{to: } \frac{v_t}{200\text{mm}} = 111.111 \cdot \text{Hz}$$

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

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

$$L_{ir_2} := 534\text{mm} \quad a_{ir_2} := 1\text{mm}$$

$$\text{Frequency from: } \frac{v_t}{\pi \cdot D_w} = 8.322 \cdot \text{Hz} \quad \text{to: } \frac{v_t}{0.2\pi \cdot D_w} = 41.609 \cdot \text{Hz}$$

Wheel-rail irregularity equation, is vertical displacement of wheel:

$$u_{ir}(t) := \sum_{i=1}^2 \left[\left(\frac{a_{ir_i}}{2} \right) \cdot \left(1 - \cos \left(2 \cdot \pi \cdot \frac{v_t}{L_{ir_i}} \cdot t \right) \right) \right]$$

Vertical vibration velocity of wheel:

$$v_{ir}(t) := \sum_{i=1}^2 \left[\left(\frac{a_{ir_i}}{2} \right) \cdot \left(2 \cdot \pi \cdot \frac{v_t}{L_{ir_i}} \right) \cdot \sin \left(2 \cdot \pi \cdot \frac{v_t}{L_{ir_i}} \cdot t \right) \right]$$

Vertical vibration acceleration of wheel:

$$w_{ir}(t) := \sum_{i=1}^2 \left[\left(\frac{a_{ir_i}}{2} \right) \cdot \left(2 \cdot \pi \cdot \frac{v_t}{L_{ir_i}} \right)^2 \cdot \cos \left(2 \cdot \pi \cdot \frac{v_t}{L_{ir_i}} \cdot t \right) \right]$$

5. Data export parameters:

Sampling frequency per 1 sec: $\text{SRate} := 1000$

Sampling time: $\text{Ttotal} := 9\text{s}$ Choose: $\frac{1}{v_t} \cdot \left(2L_o + \sum_{i=1}^{N_{\text{car}}} L_{\text{car}_i} \right) = 6.75\text{s}$

Integral time step: $\Delta t := \frac{1\text{sec}}{\text{SRate}}$

Integral time step total: $n := \frac{\text{Ttotal}}{\Delta t}$

Calculation index: $i := 0, 1..n$
 $t := 0, \Delta t.. \text{Ttotal}$

II. Calculation:

Newmark direct integration method:

1. Matrices of differential equation:

$$\mathbf{M}_{\text{sys}} := \begin{pmatrix} \mathbf{m}_s & \mathbf{0} \\ \mathbf{0} & \mathbf{m}_u \end{pmatrix} \quad \mathbf{C}_{\text{sys}} := \begin{pmatrix} \mathbf{c}_s & -\mathbf{c}_s \\ -\mathbf{c}_s & \mathbf{c}_s + \mathbf{c}_u \end{pmatrix} \quad \mathbf{K}_{\text{sys}} := \begin{pmatrix} \mathbf{k}_s & -\mathbf{k}_s \\ -\mathbf{k}_s & \mathbf{k}_s + \mathbf{k}_u \end{pmatrix}$$
$$\mathbf{R}_i := \begin{pmatrix} \mathbf{0} \\ \mathbf{c}_u \cdot \mathbf{v}_{iR}(i \cdot \Delta t) + \mathbf{k}_u \cdot \mathbf{u}_{iR}(i \cdot \Delta t) \end{pmatrix}$$

2. Condition at $t=0$, no vibration

$$\mathbf{u}_i := \begin{pmatrix} \mathbf{0} \\ \mathbf{0} \end{pmatrix} \text{m} \quad \mathbf{v}_i := \begin{pmatrix} \mathbf{0} \\ \mathbf{0} \end{pmatrix} \frac{\text{m}}{\text{s}} \quad \mathbf{w}_i := \begin{pmatrix} \mathbf{0} \\ \mathbf{0} \end{pmatrix} \frac{\text{m}}{\text{s}^2}$$

3. Time step Δt , integral parameters Newmark and factors a_i :

Choose: $\delta := 0.5$ $\alpha := 0.25$

$$a_0 := \frac{1}{\alpha \cdot \Delta t^2} \quad a_2 := \frac{1}{\alpha \cdot \Delta t} \quad a_4 := \frac{\delta}{\alpha} - 1 \quad a_6 := \Delta t \cdot (1 - \delta)$$

$$a_1 := \frac{\delta}{\alpha \cdot \Delta t} \quad a_3 := \frac{1}{2\alpha} - 1 \quad a_5 := \frac{\Delta t}{2} \cdot \left(\frac{\delta}{\alpha} - 2 \right) \quad a_7 := \delta \cdot \Delta t$$

4. Effect stiffness matrix:

$$\mathbf{K}_{\text{eff}} := \mathbf{K}_{\text{sys}} + a_0 \cdot \mathbf{M}_{\text{sys}} + a_1 \cdot \mathbf{C}_{\text{sys}}$$

5. Iterative calculation for time integral step to have u , v , w :

$i := 0, 1..n - 1$

$$\mathbf{R}_{\text{eff}_{i+1}} := \mathbf{R}_{i+1} + \mathbf{M}_{\text{sys}} \cdot (a_0 \cdot \mathbf{u}_i + a_2 \cdot \mathbf{v}_i + a_3 \cdot \mathbf{w}_i) + \mathbf{C}_{\text{sys}} \cdot (a_1 \cdot \mathbf{u}_i + a_4 \cdot \mathbf{v}_i + a_5 \cdot \mathbf{w}_i)$$

$$\mathbf{u}_{i+1} := \mathbf{K}_{\text{eff}}^{-1} \cdot \mathbf{R}_{\text{eff}_{i+1}}$$

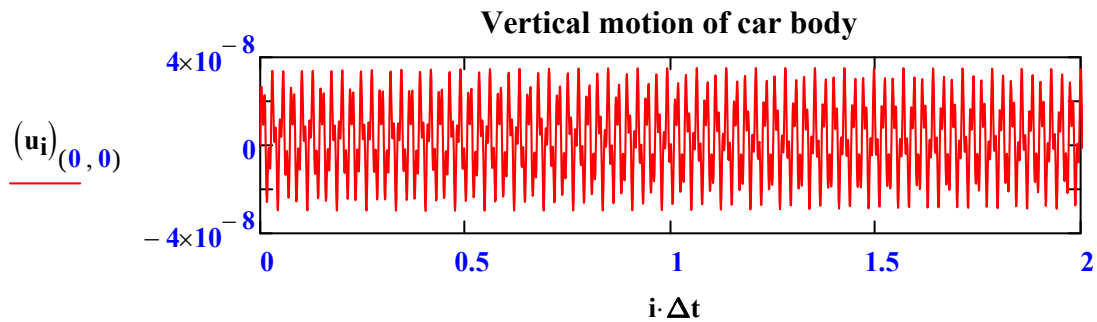
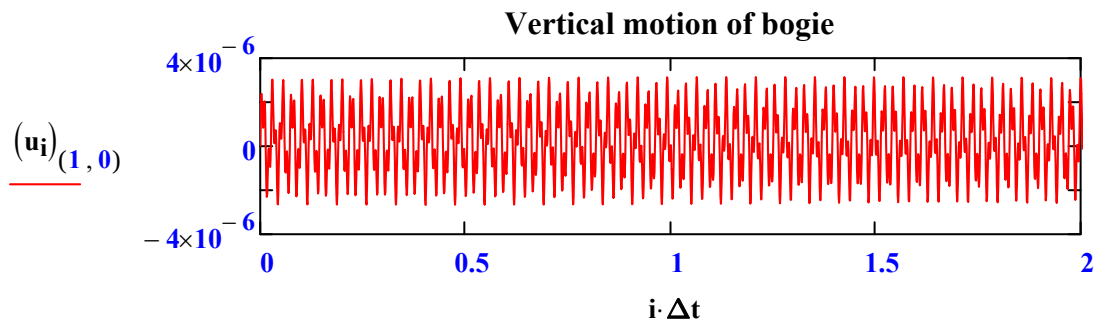
$$\mathbf{w}_{i+1} := a_0 \cdot (\mathbf{u}_{i+1} - \mathbf{u}_i) - a_2 \cdot \mathbf{v}_i - a_3 \cdot \mathbf{w}_i$$

$$\mathbf{v}_{i+1} := \mathbf{v}_i + a_6 \cdot \mathbf{w}_i + a_7 \cdot \mathbf{w}_{i+1}$$

6. Displacement of Bogie and Car body:

$$\begin{pmatrix} u_i \end{pmatrix}_{(1,0)} = \begin{pmatrix} u_i \end{pmatrix}_{(0,0)} =$$

0	m	0	m
$1.217 \cdot 10^{-6}$		$1.361 \cdot 10^{-8}$	
$2.085 \cdot 10^{-6}$		$2.332 \cdot 10^{-8}$	
$2.374 \cdot 10^{-6}$		$2.654 \cdot 10^{-8}$	
...		...	



7. Dynamic force on rail:

Car body acceleration $\mathbf{Wcar}_i := (\mathbf{w}_i)_{(0,0)}$

Bogie acceleration: $\mathbf{Wbogie}_i := (\mathbf{w}_i)_{(1,0)}$

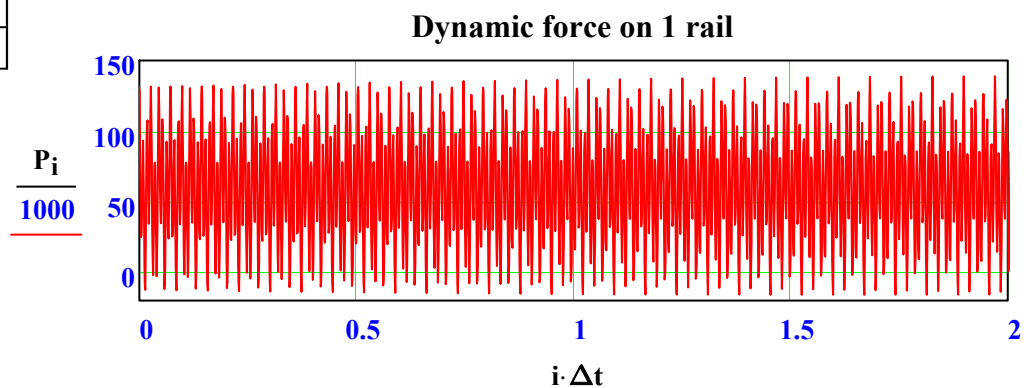
Wheel acceleration: $\mathbf{Wwheel}_i := \mathbf{w}_{ir}(i \cdot \Delta t)$

Dynamic force on rail: $\mathbf{P}_i := (\mathbf{m}_w + \mathbf{m}_u + \mathbf{m}_s) \cdot \mathbf{g} + (\mathbf{m}_w \cdot \mathbf{Wwheel}_i + \mathbf{m}_u \cdot \mathbf{Wbogie}_i + \mathbf{m}_s \cdot \mathbf{Wcar}_i)$

$\mathbf{P} =$

	0
0	131.652
1	127.03
2	88.386
3	59.117
4	...

$\cdot \text{kN}$



$\max(\mathbf{P}) = 139.12 \cdot \text{kN}$

8. Loading ditribution function on tunnel floor

Bending stiffness of rail: $EI := E_r \cdot I_r$

Stiffness of railpad: $K_{\text{pad}} := \frac{K_{\text{railpad}}}{L_f}$

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

Loading ditribution function on tunnel floor through railpad:

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

9. Dynamic loading on tunnel floor:

$$\Theta(x) := \Phi_{\text{rail}}(x)$$

$$F_{1w}(t) := \sum_{i=1}^{N_{\text{car}}} \left(P \cdot \left(\frac{\left| v_t t - L_0 - \sum_{j=0}^{i-1} L_{\text{car}_j} \right|}{v_t \cdot \Delta t} \right) \cdot \Theta \left(v_t t - L_0 - \sum_{j=0}^{i-1} L_{\text{car}_j} \right) \right)$$

$$F_{2w}(t) := \sum_{i=1}^{N_{\text{car}}} \left(P \cdot \left(\frac{\left| v_t t - L_0 - \sum_{j=0}^{i-1} L_{\text{car}_j} - a_{\text{car}_i} \right|}{v_t \cdot \Delta t} \right) \cdot \Theta \left(v_t t - L_0 - \sum_{j=0}^{i-1} L_{\text{car}_j} - a_{\text{car}_i} \right) \right)$$

$$F_{3w}(t) := \sum_{i=1}^{N_{\text{car}}} \left(P \cdot \left(\frac{\left| v_t t - L_0 - \sum_{j=0}^{i-1} L_{\text{car}_j} - a_{\text{car}_i} - b_{\text{car}_i} \right|}{v_t \cdot \Delta t} \right) \cdot \Theta \left(v_t t - L_0 - \sum_{j=0}^{i-1} L_{\text{car}_j} - a_{\text{car}_i} - b_{\text{car}_i} \right) \right)$$

$$F_{4w}(t) := \sum_{i=1}^{N_{\text{car}}} \left(P \cdot \left(\frac{\left| v_t t - L_0 - \sum_{j=0}^{i-1} L_{\text{car}_j} - 2 \cdot a_{\text{car}_i} - b_{\text{car}_i} \right|}{v_t \cdot \Delta t} \right) \cdot \Theta \left(v_t t - L_0 - \sum_{j=0}^{i-1} L_{\text{car}_j} - 2 \cdot a_{\text{car}_i} - b_{\text{car}_i} \right) \right)$$

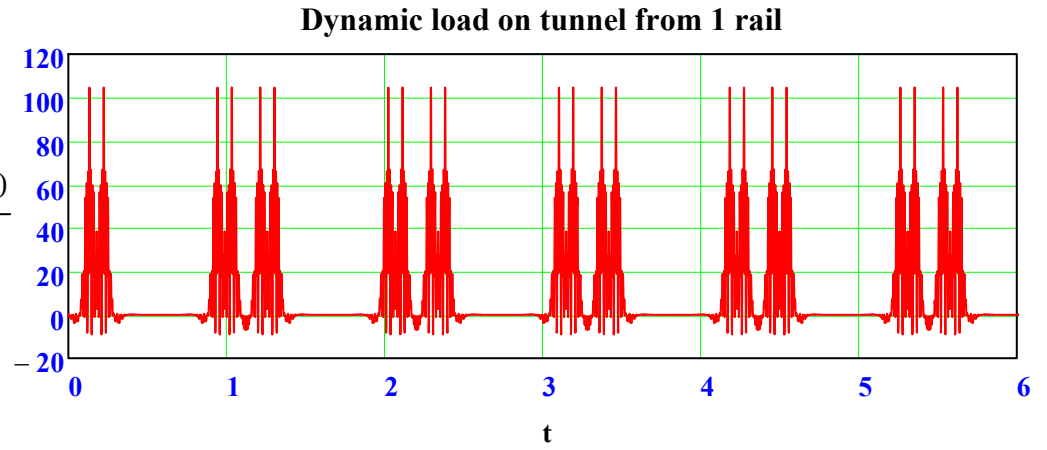
$$F_{\text{tunnel}}(t) := F_{1w}(t) + F_{2w}(t) + F_{3w}(t) + F_{4w}(t)$$

III. Results.

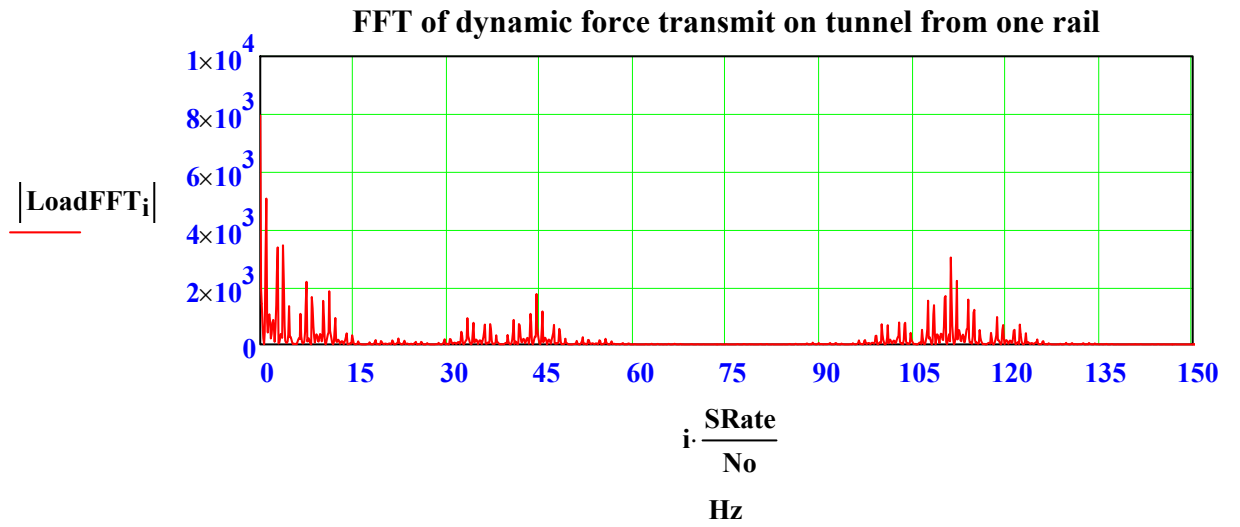
$$F_{\text{tunnel}}(t) =$$

-0.403	$\cdot \frac{\text{kN}}{\text{m}}$
-0.33	
-0.236	
-0.025	
0.051	
0.085	
-0.147	
...	

$$\frac{F_{\text{tunnel}}(t)}{1000}$$



$$\text{No} := 2^{13} \quad i := 0.. \text{No} - 1 \quad \text{Time}_i := \frac{i \cdot s}{\text{SRate}} \quad \text{Val}_i := F_{\text{tunnel}}(\text{Time}_i) \quad \text{LoadFFT} := \text{FFT}(\text{Val})$$



$$\max(\text{Val}) = 104.687 \cdot \frac{\text{kN}}{\text{m}}$$

$$f_{\text{DynLoad}_1} := \begin{cases} \frac{v_t}{L_{\text{ir}_1}} & \text{if } a_{\text{ir}_1} > 0 \\ 0 & \text{otherwise} \end{cases} \quad f_{\text{DynLoad}_2} := \begin{cases} \frac{v_t}{L_{\text{ir}_2}} & \text{if } a_{\text{ir}_2} > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$f_{\text{Load}} := \max(f_{\text{DynLoad}}) = 111.111 \cdot \text{Hz}$$

