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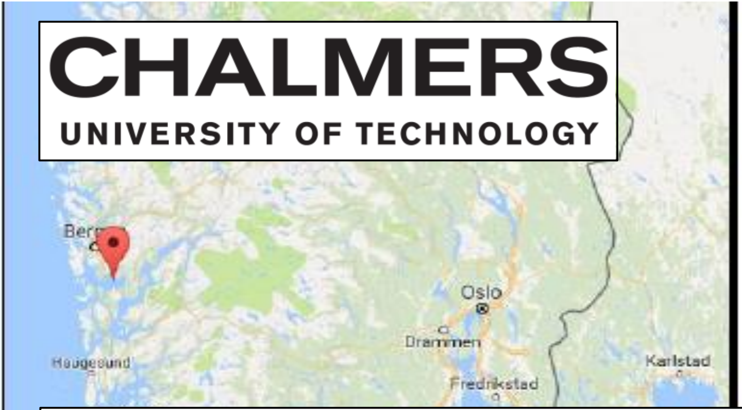

Effect of floating bridge vertical motion on vehicle ride comfort and road grip

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GOALS OF INVESTIGATION

Investigate the influence and analyze the effects of floating bridge vertical motion on:

- **vehicle ride comfort and**
- **vertical force between wheel and ground.**

STEPS OF ANALYSIS

- **INPUTS**
  Road roughness (stationary ground),
  Bridge vertical motion (moving ground).

- **VEHICLE MODEL**
  Bus model (one dimensional 3 Degrees Of Freedom).

- **OUTPUTS**
  Vertical driver's acceleration (weighted *RMS* value),
  Vertical force (Dynamic Load Coefficient – *DLC*).

DISTURBANCES FROM STATIONARY GROUND

- **Road roughness – very good/good condition (class A/B – ISO 8608 standard)**

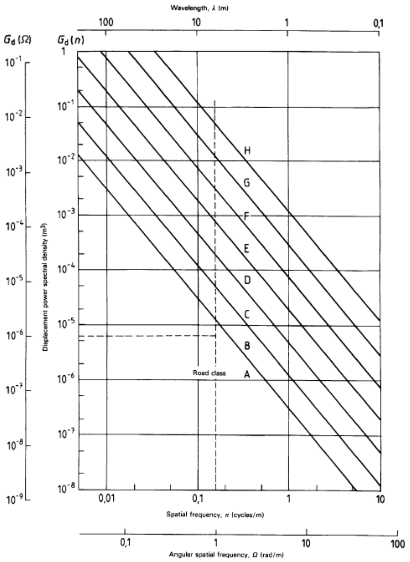


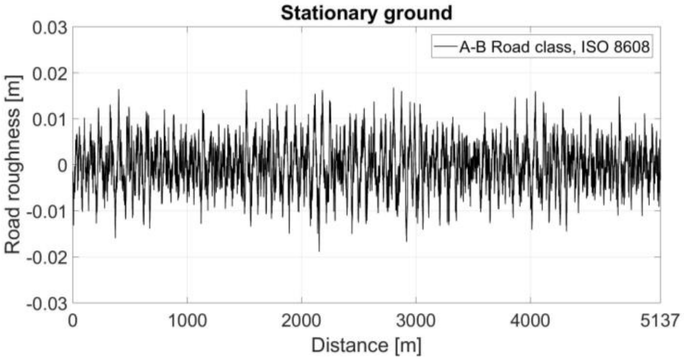
Figure C.2 — Classification of roads

$$\Phi_{\zeta}(n) = \Phi_{\zeta}(n_0) \cdot \left(\frac{n}{n_0}\right)^{-w}$$

$$\zeta(x) = \sum_{i=1}^{N} A_i \cos(n_i x - \alpha_i)$$

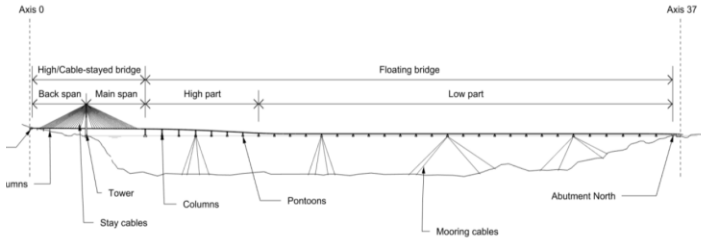
Power Spectral Density → Road Roughness

Road roughness modelling (class A/B – ISO 8608)



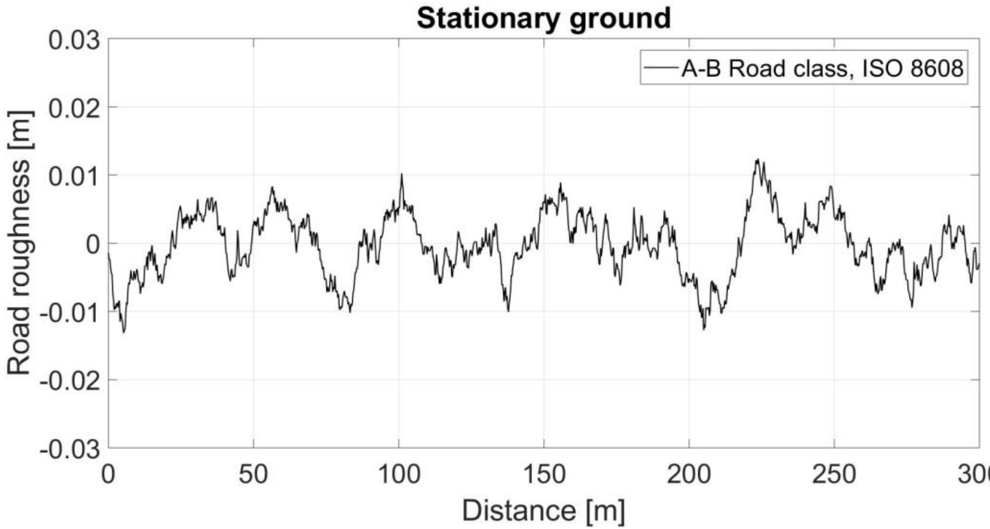
Distance equal to bridge length, L=5137 m.

Road roughness sample (length of 300 m).



L=5137 m

Bjørnafjorden, straight floating bridge



DISTURBANCES FROM MOVING GROUND

Two common approaches on bridge-vehicle interaction:

- (1) bridge-vehicle interaction that refers to the mechanism where bridge vibration is due to vehicle movement and vehicle vibration is due to bridge movement (coupling system) and

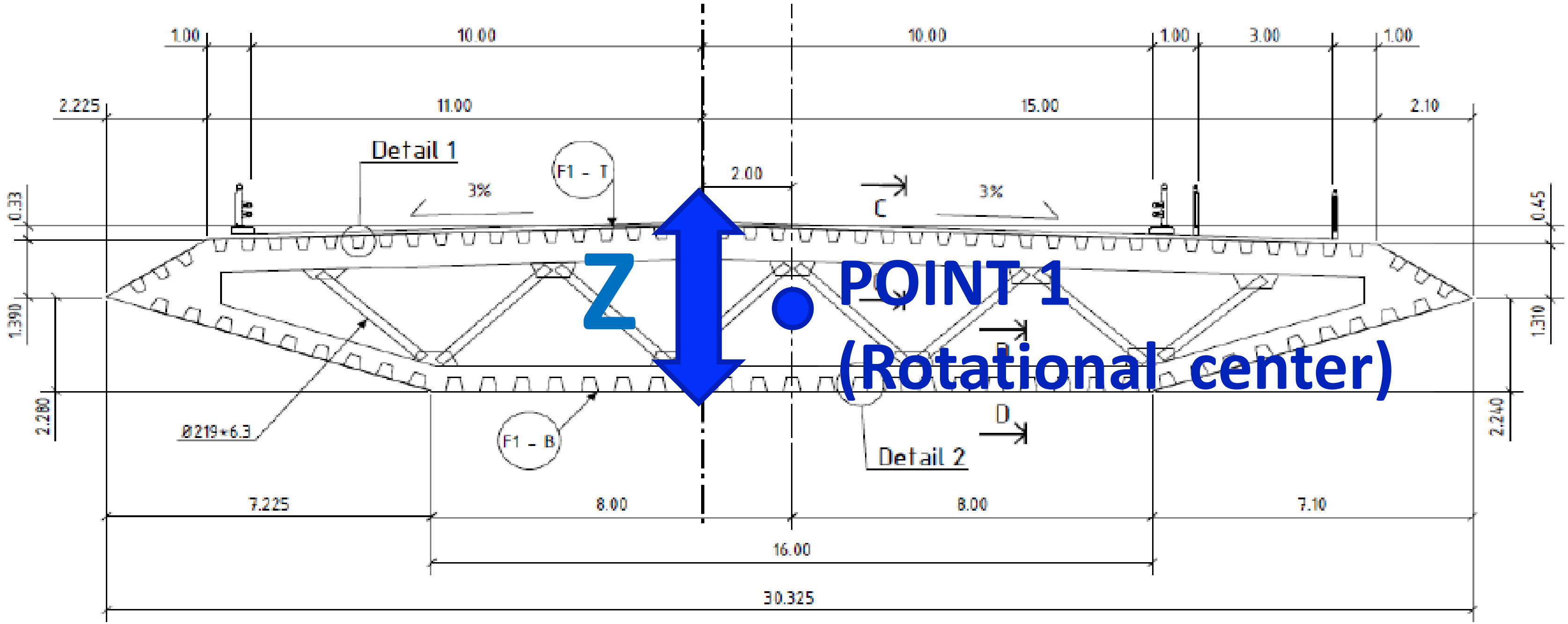
- **(2) bridge-vehicle interaction that refers to the mechanism where vehicle vibration is due to input from bridge vibration.**

DISTURBANCES FROM MOVING GROUND

- In this study, vehicle mass is negligible compared to mass of the bridge. This means vehicle motion does not significantly affect bridge vibration (Siringoringo at al, 2012).

- Vertical bridge displacements input to the vehicle obtained from the actual displacements according to the **time and location** of vehicle's wheels contact with the bridge deck.

Vertical bridge motion (up and dawn, z-direction)

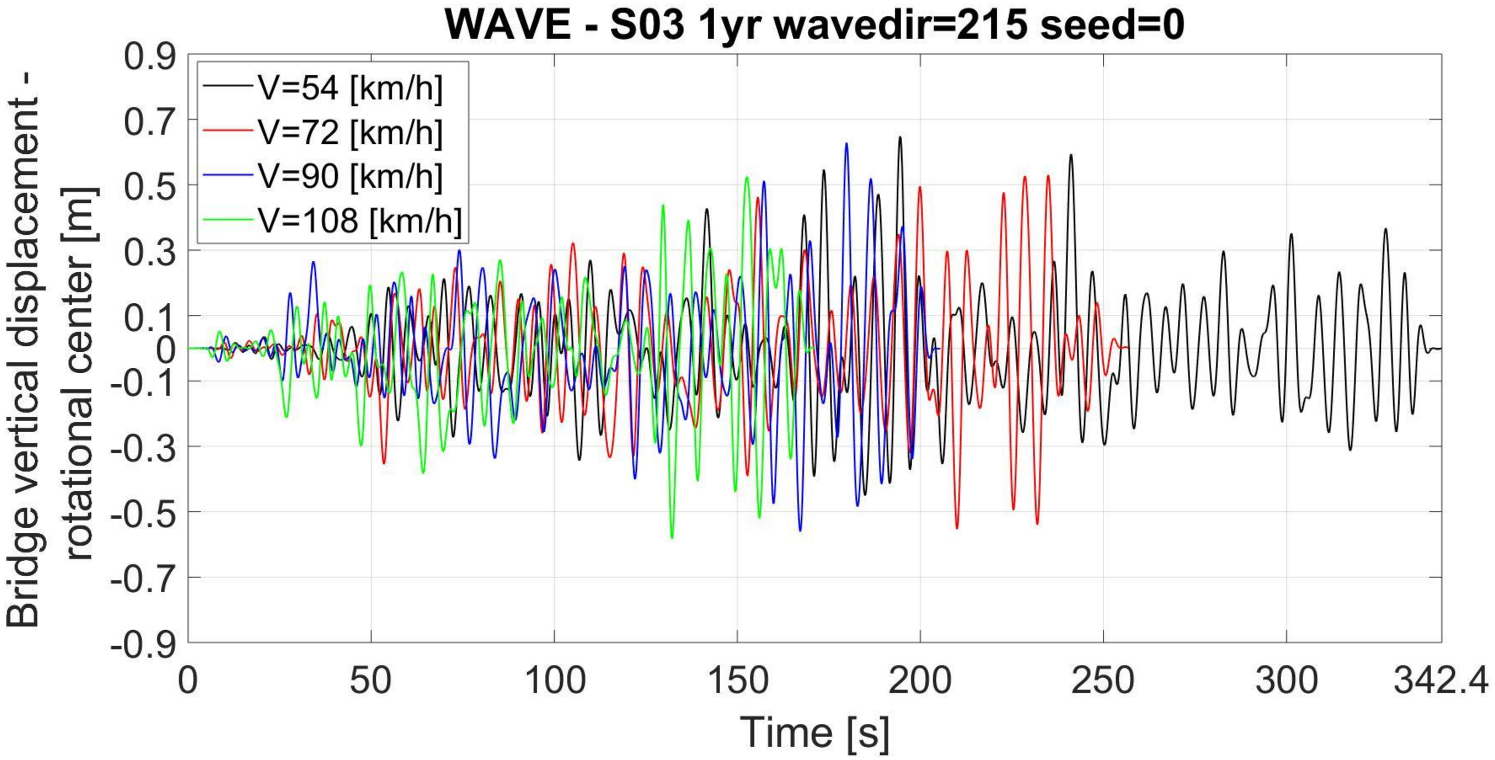


Cross section of the bridge deck

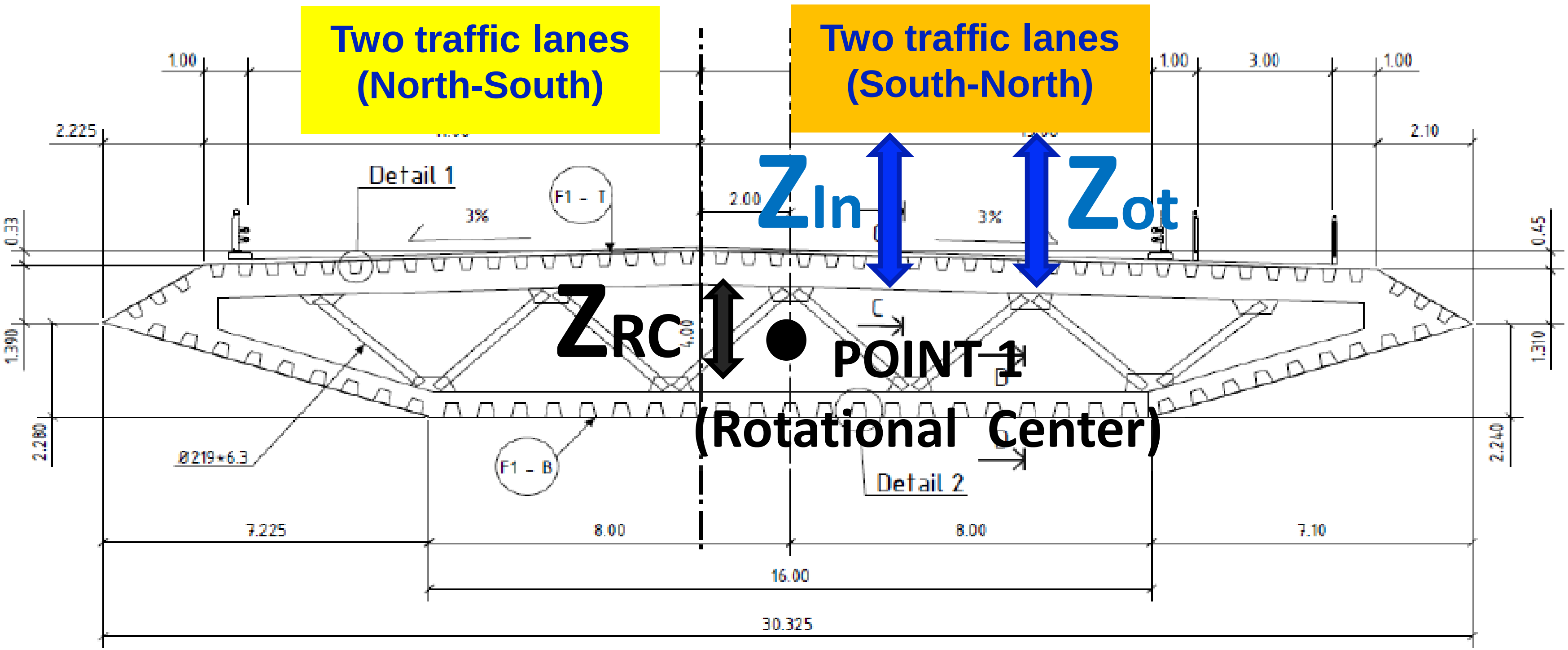
Different 1-year storm conditions

- (I) 1 year response, wave only, wave direction 100 deg (from east);
- (II) 1 year response, wave only, wave direction 215 deg (325 global, from North West);
- (III) 1 year response, wind only, wind direction 90 (from east);
- (IV) 1 year response, wind only, wind direction 270 deg (from west);
- (V) 1 year response, **all loads,** wave + wind [(I) + (III)]
- (VI) 1 year response, **all loads,** wave + wind [(II) + (IV)

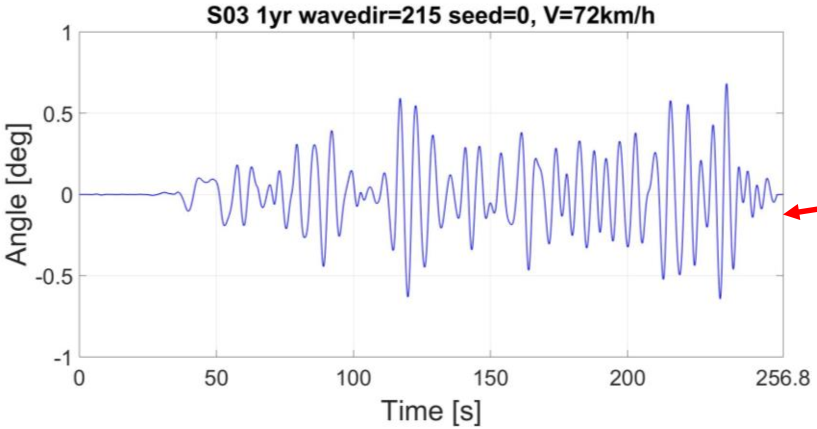
Vertical motion along the bridge due to wave load

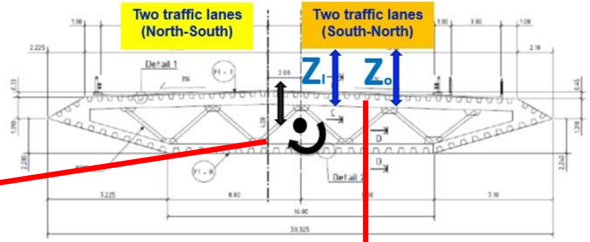


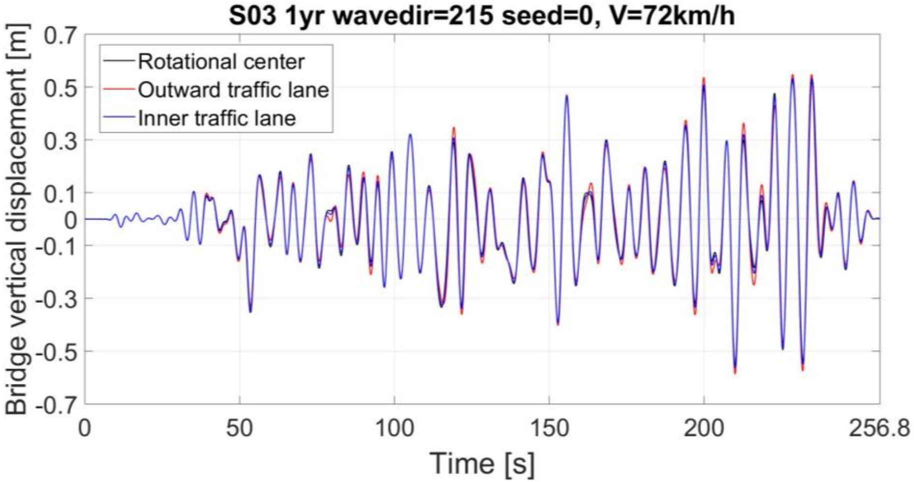
Vertical motions for different traffic lanes



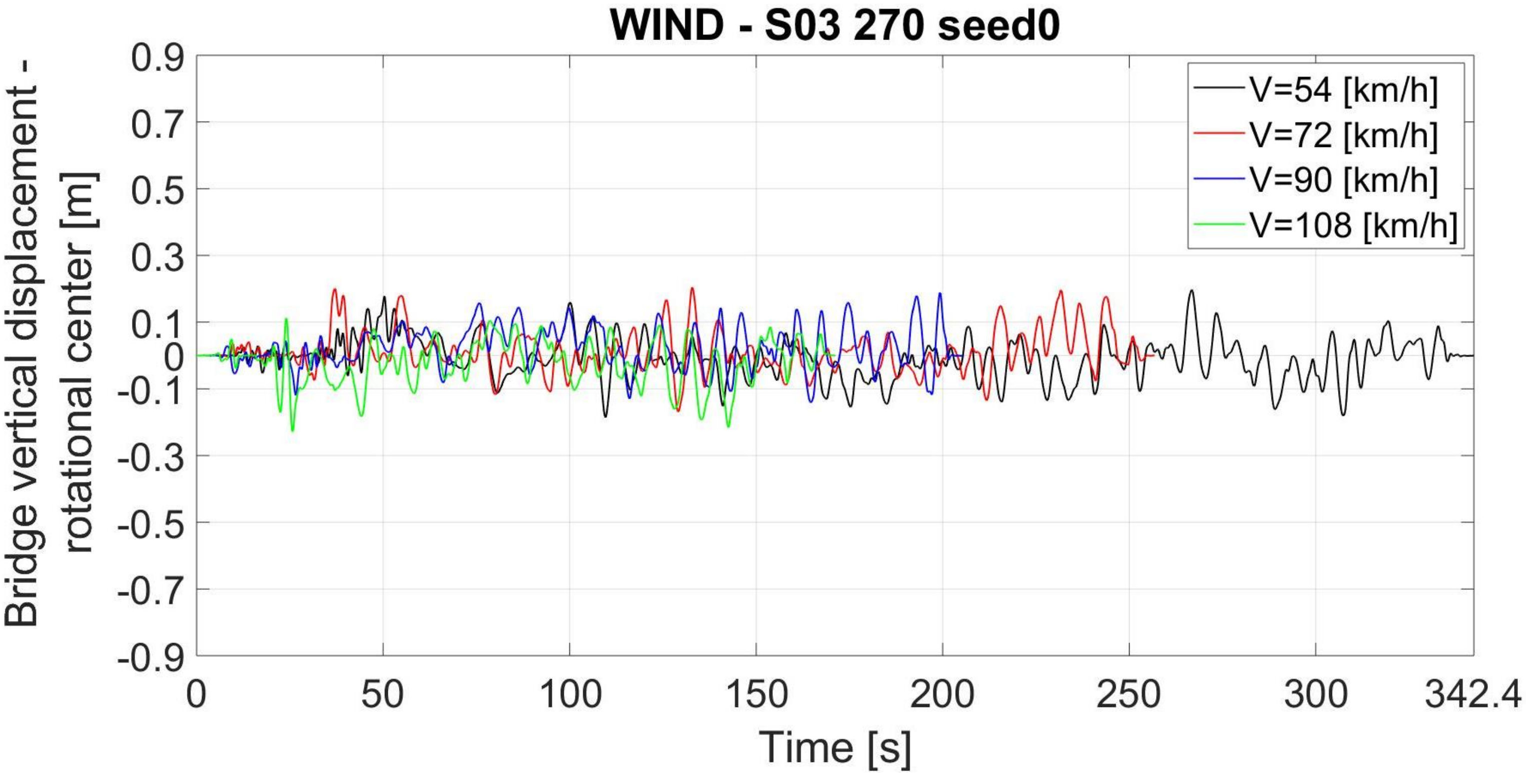
Vertical motions for two different traffic lanes



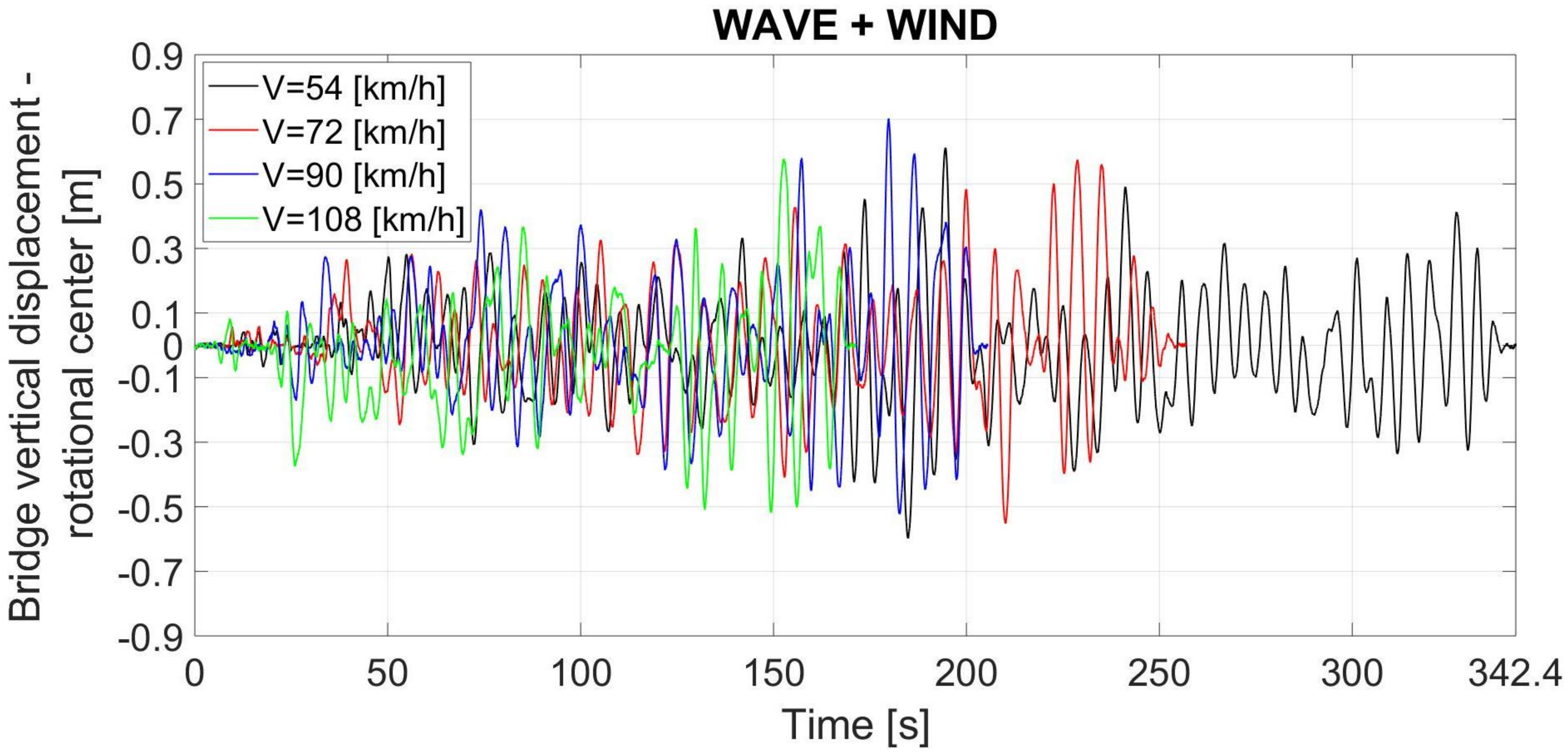




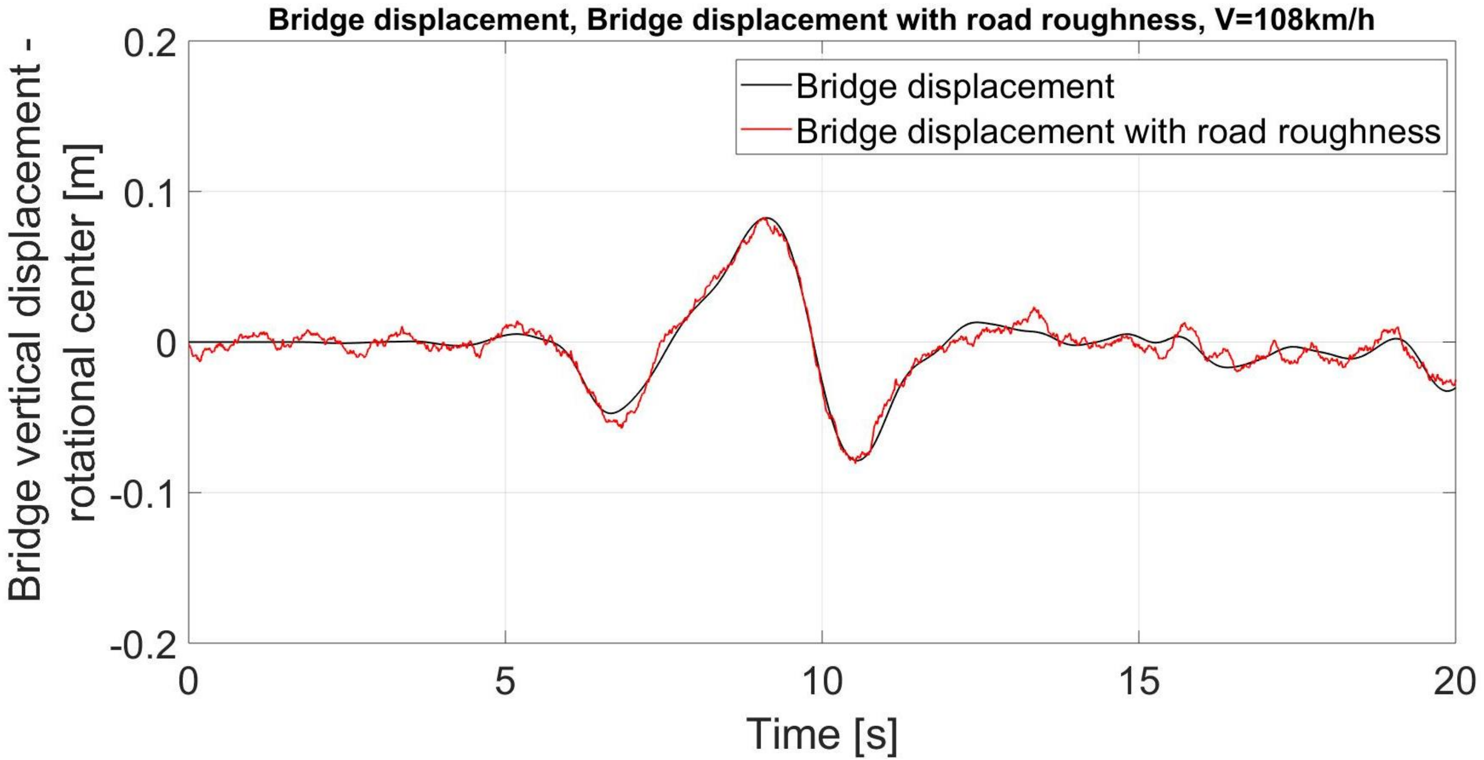
Vertical motion along the bridge due to wind load



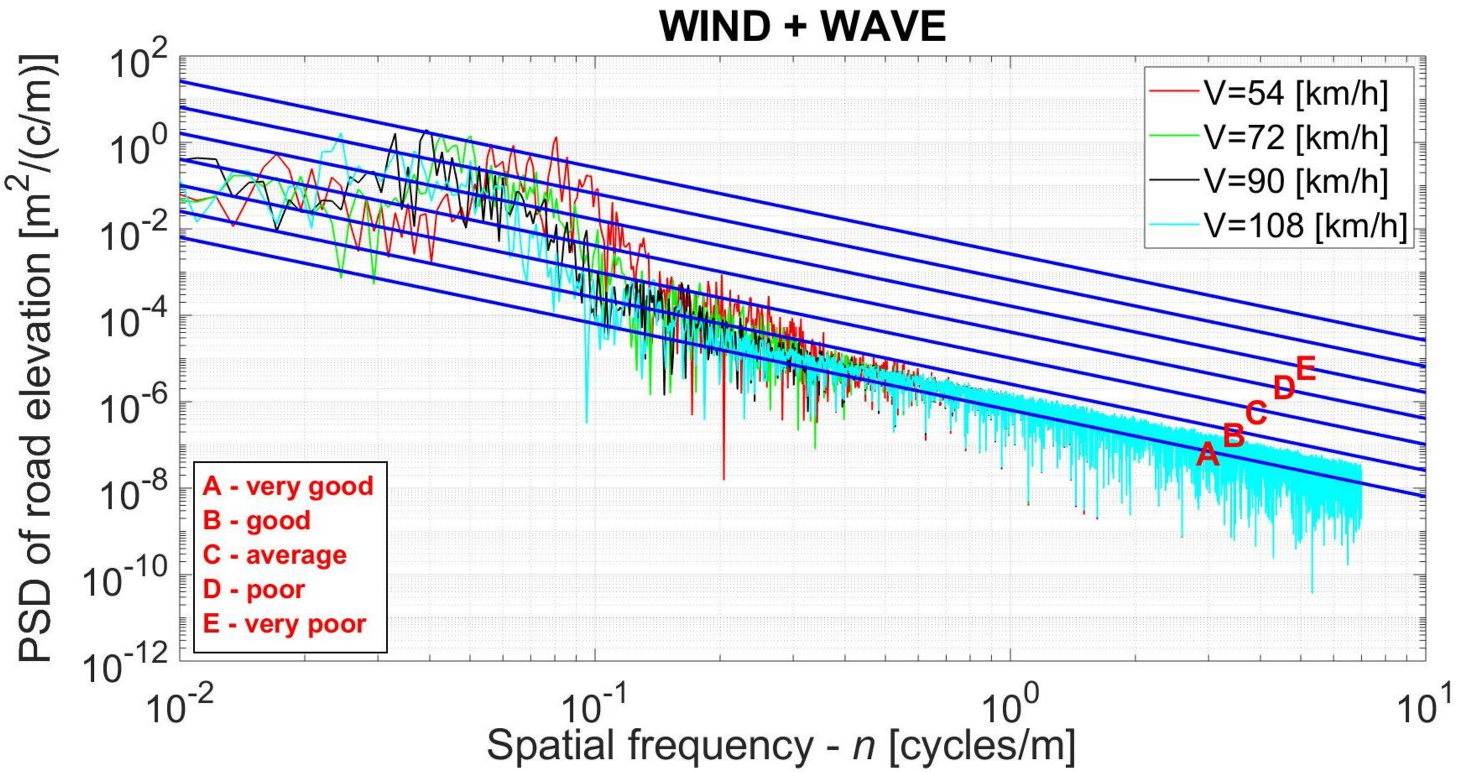
Vertical motion along the bridge due to wind and wave loads



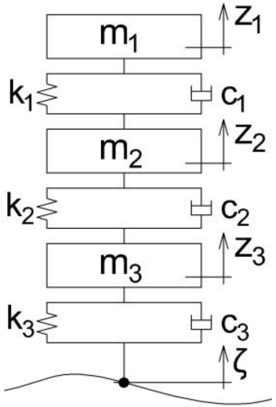
Bridge displacement and road roughness – model input



Bridge displacement as road roughness in ISO 8608



BUS MODEL – one dimensional 3 Degrees Of Freedom



Differential equations of motion:

$$m_1\ddot{z}_1 + c_1\dot{z}_1 + k_1 z_1 - c_1\dot{z}_2 - k_1 z_2 = 0$$
$$m_2\ddot{z}_2 + (c_1 + c_2)\dot{z}_2 + (k_1 + k_2)z_2 - c_1\dot{z}_1 - k_1 z_1 - c_2\dot{z}_3 - k_2 z_3 = 0$$
$$m_3\ddot{z}_3 + (c_2 + c_3)\dot{z}_3 + (k_2 + k_3)z_3 - c_2\dot{z}_2 - k_2 z_2 = c_3\dot{\zeta} + k_3\zeta$$

Concentrated mass	Undamped natural frequencies (Hz)	Damped natural frequencies (Hz)
Seat+driver - m1	2.2916	2.1403
Sprung mass - m2	1.2864	1.2790
Unsprung mass - m3	9.6174	9.4955

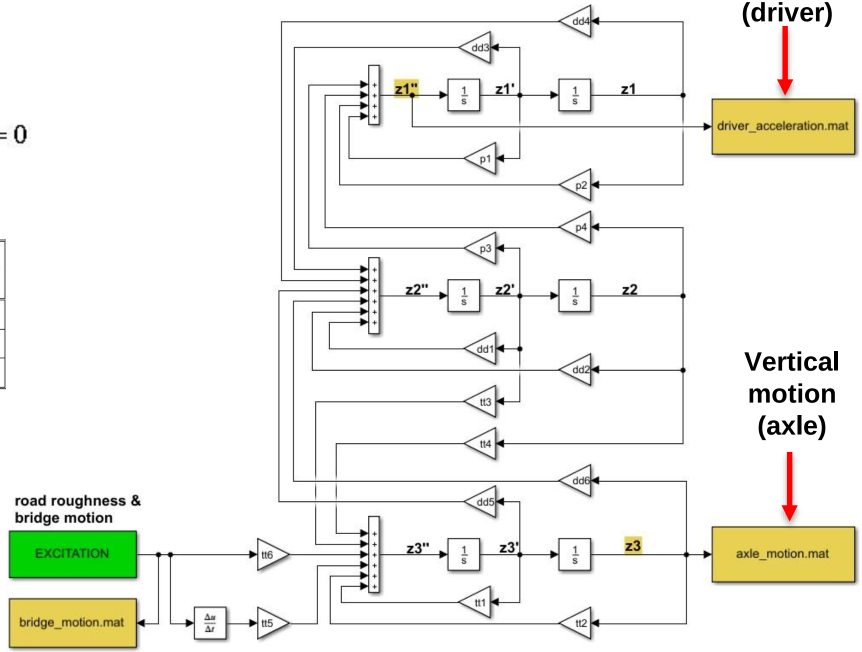
```
% BUS QUARTER MODEL PARAMETERS;
% mass parameters;
m1 = 100;   % driver+seat [kg];
m2 = 4000;  % sprung mass [kg];
m3 = 550;   % unsprung mass [kg];

% oscillatory parameters;
k1 = 20000;   % driver's seat suspension spring stiffness [N/m];
k2 = 320000;  % suspension spring stiffness [N/m];
k3 = 1700000; % bus tyre radial stiffness [N/m];

c1 = 1000;   % driver's seat shock absorber damping [Ns/m];
c2 = 10000;  % suspension shock absorber damping [Ns/m];
c3 = 150;    % wheel damping [Ns/m];
```

Bus data from Ref. (Agostinacchio et al.)

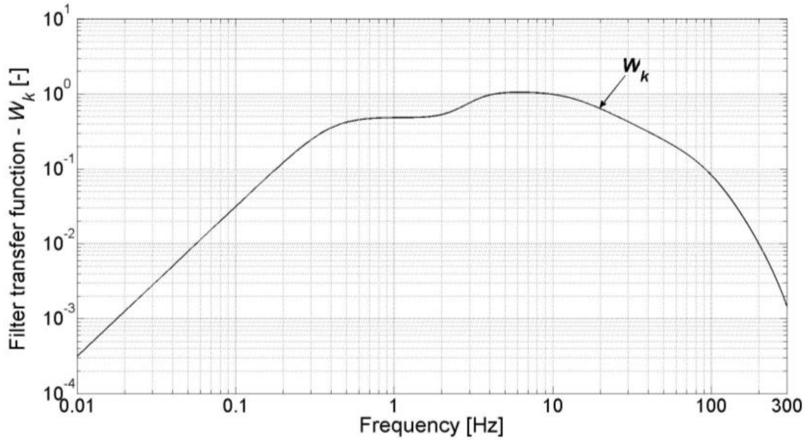
Vertical acceleration (driver)



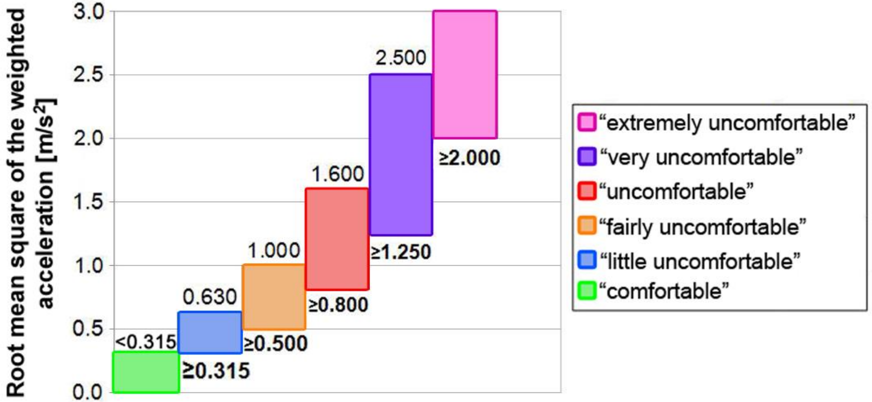
Vertical motion (axle)

MATLAB/SIMULINK

VERTICAL WEIGHTED ACCELERATION – ISO 2631 (1997)



Weighting filter - *Wk*

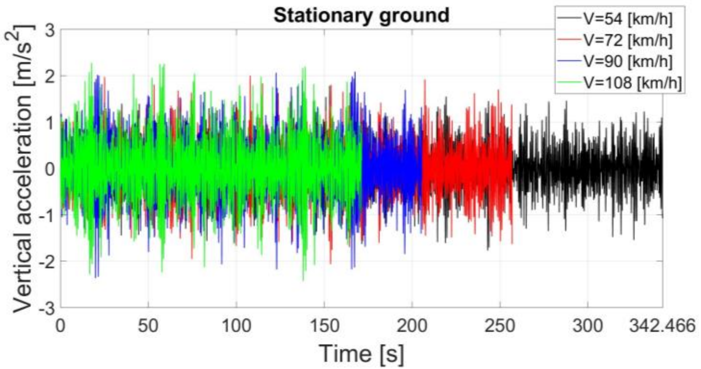


ISO 2631 (1997) criteria

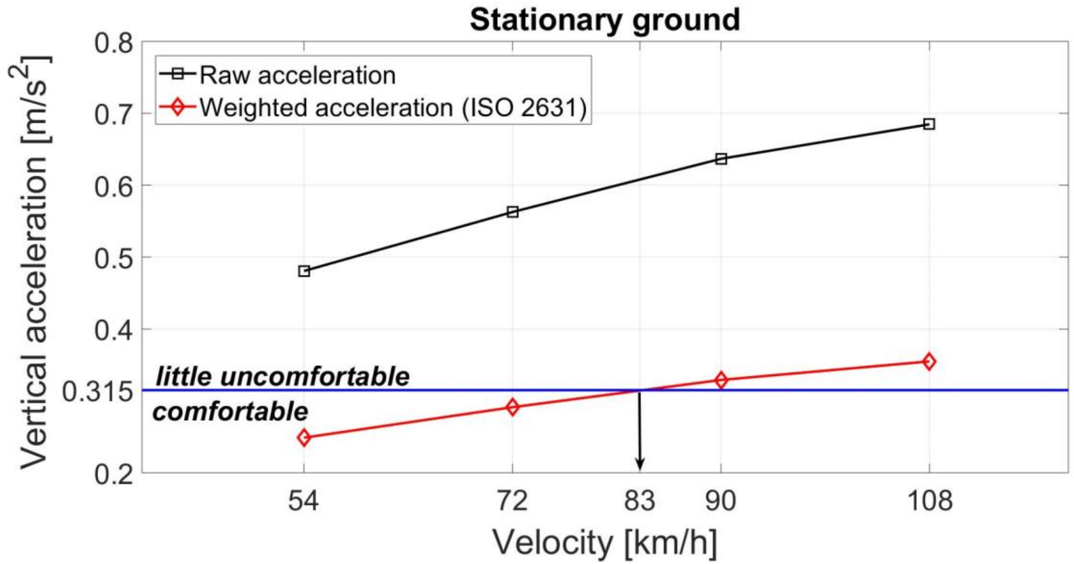
$$\ddot{z}_{rms,w} = \sqrt{\frac{1}{T}\int_0^T \ddot{z}_w(t)^2 dt}$$

***RMS* of the weighted vertical acceleration**

Vertical driver's acceleration



Vertical acceleration



For bus speed above 83 km/h, driving is *'little uncomfortable'.*

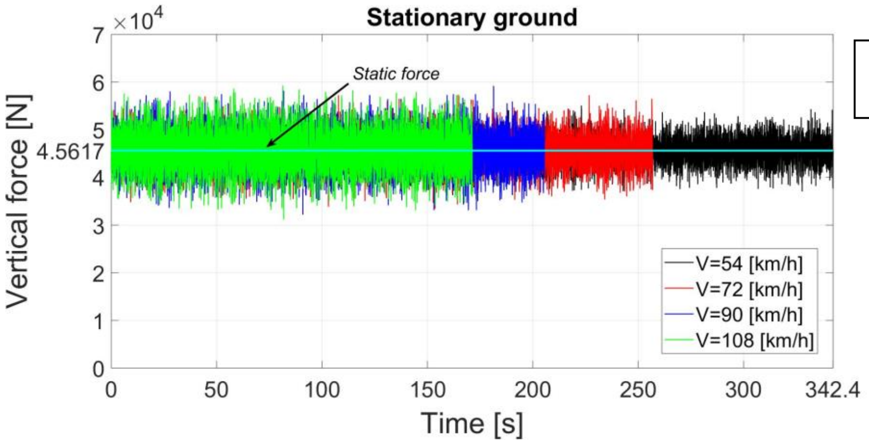
Vertical force – Dynamic Load Coefficient

DLC represents ratio of standard deviation of total axle load (or *RMS* value of dynamic axle load) and static axle load.

$$DLC = \frac{\sigma_Z}{Z_{st}} = \frac{Z_{dyn,RMS}}{Z_{st}}$$

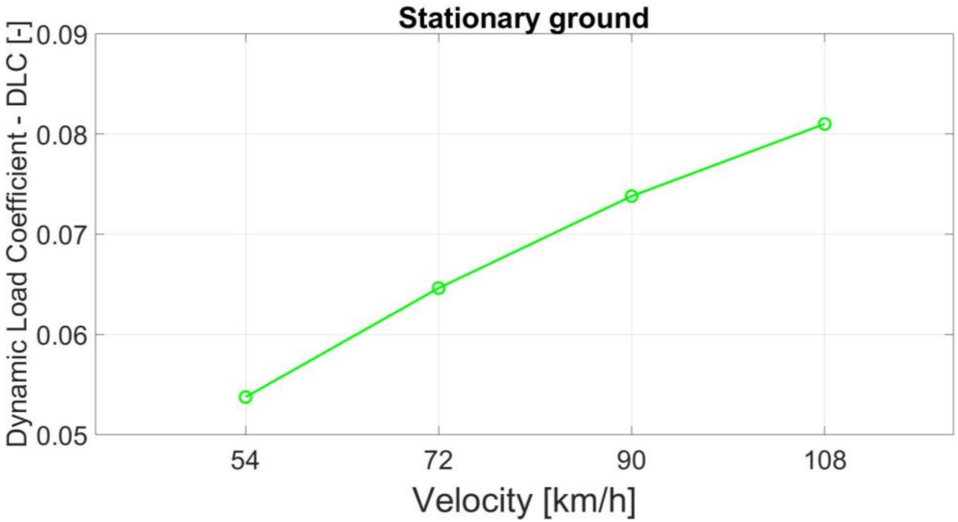
Lower value of *DLC* points out better contact between wheel and road.

Vertical force – Dynamic Load Coefficient



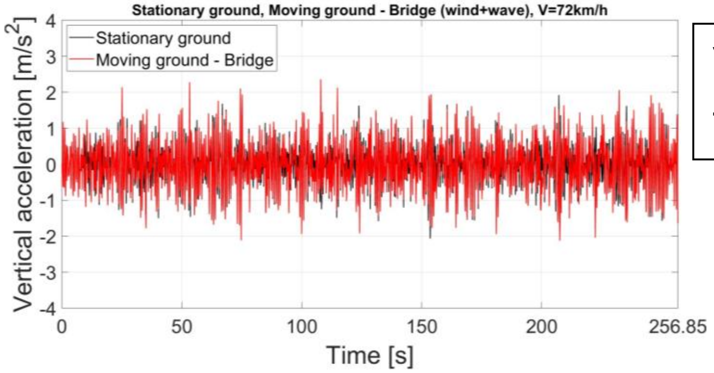
Vertical force

Dynamic Load Coefficient

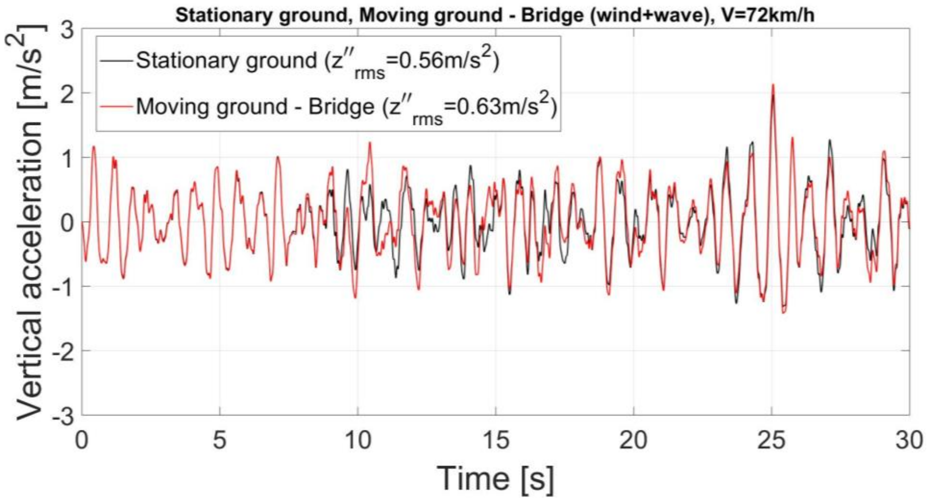


COMPARASION OF BUS MODEL RESPONSES

- **Example of vertical raw acceleration of the driver**

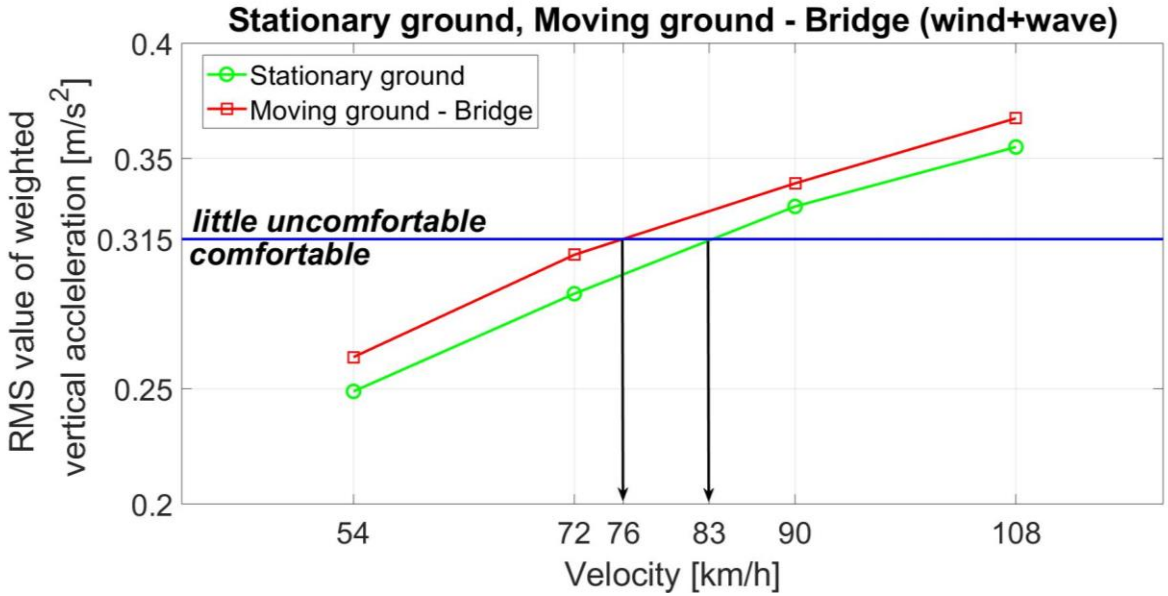


Vertical acceleration signal for bus speed of 72 km/h.



Vertical acceleration signal for 30 s.

Weighted vertical acceleration of the driver



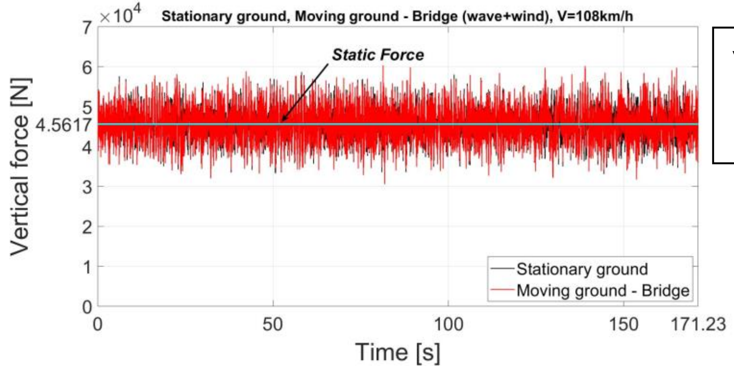
For bus speed above 83 km/h, driving is *‘little uncomfortable’* for stationary ground.

For bus speed above 76 km/h, driving is *‘little uncomfortable’* for moving ground - bridge.

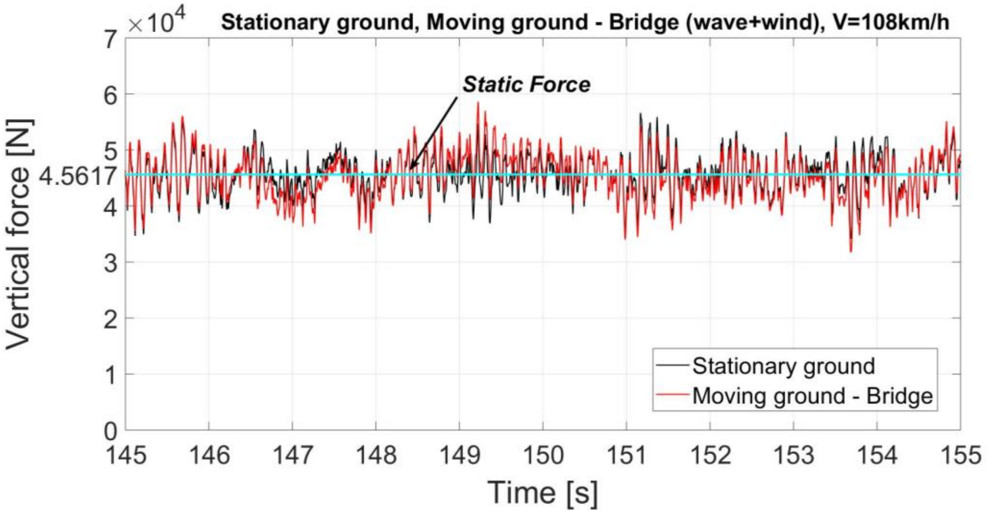
Speed decreases by 8.43 %.

COMPARASION OF BUS MODEL RESPONSES

- **Example of vertical force**

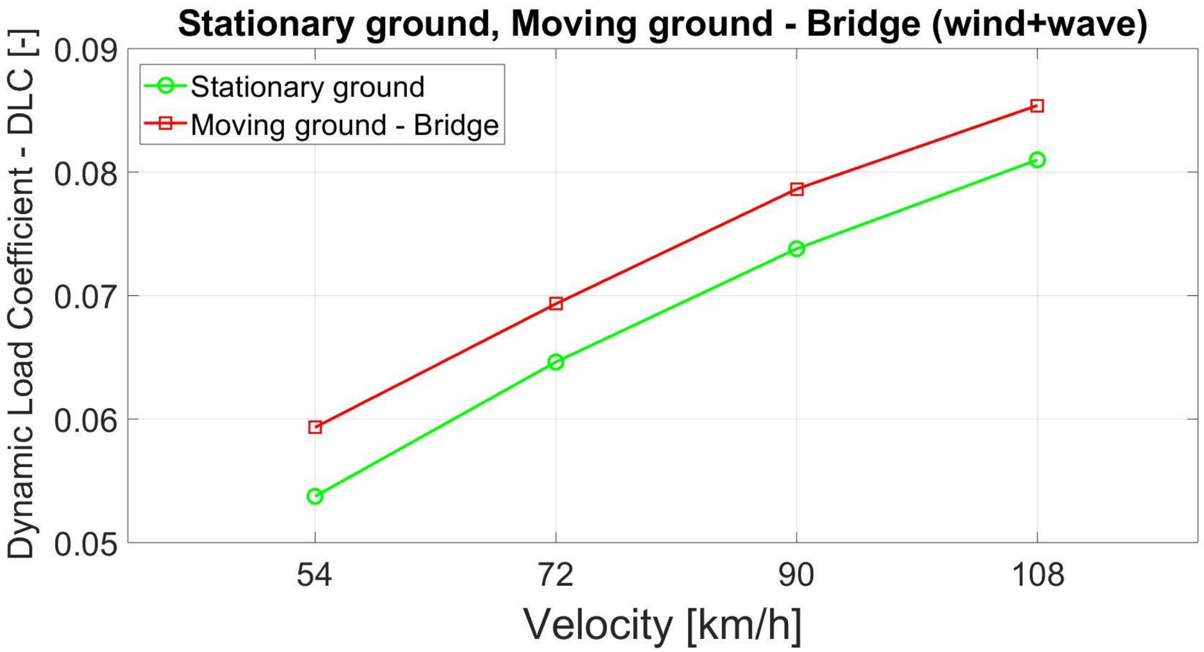


Vertical force signal for bus speed of 108 km/h.



Sample of vertical force signal for 145-155 s.

Dynamic Load Coefficient

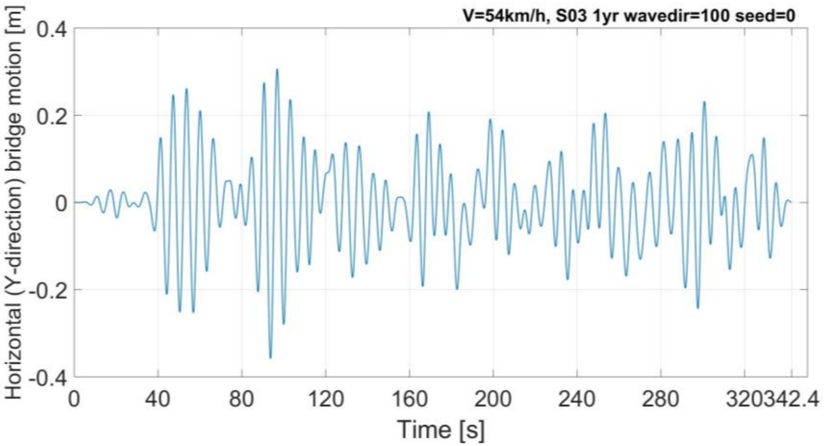


Higher values of *DLC* for the case of moving ground points out higher variation in vertical forces (lower road grip).

FUTURE INVESTIGATION

Building complex model that can capture signals of lateral bridge motion and winds.

Investigate the influence of those loads on **lateral/vertical** vehicle behavior.



Signal of horizontal bridge motion (Y-direction).