Modelling of Groundborne Vibration

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Introduction

Our focus is on the *Measurement & Assessment* of Groundborne Noise & Vibration.

- This forms a substantial part of our work in itself.

- Measurements often lead to the most direct and reliable solutions, given the complex nature of the problems and the inherent uncertainties involved.

- Nevertheless, predictions, and therefore modelling, have their place:

  - when measurements are impossible;

  - to guide design.

Introduction

- Models may be theoretical (analytical or numerical) or empirical:

  - low strains => linear system.

- Both have advantages and disadvantages, which often depend on:

  - the nature of the source;

  - the nature of the transmission path;

  - whether or not a particular receiver is of interest.

Considerations of the Source

There are two fundamental vibration generation mechanisms.

- Quasi-static, due to the passage of each wheel ‘deflection bowl’:

  - low-frequency vibration (0 ~ 20 Hz);

  - generally only significant close to the track;

  - exceptions are ‘supersonic’ trains and ‘parametric’ excitation.

Considerations of the Source

- Wheel-rail ‘roughness’:

    - transient vibration from rail joints, switches and crossings, wheel flats;

    - continuously-welded track and better braking systems;

    - continuous vibration from rail roughness dominates;

    - higher-frequency random vibration (~ 20 ~ 200 Hz).

Considerations of the Source

- Quasi-static and transient responses require modelling in the time domain.

- Response to roughness may be modelled in the frequency domain:

  - pass-by duration sufficient to assume steady-state response.

- Detailed vehicle models are often unnecessary, although careful modelling in the region of the wheel-rail interface is required:

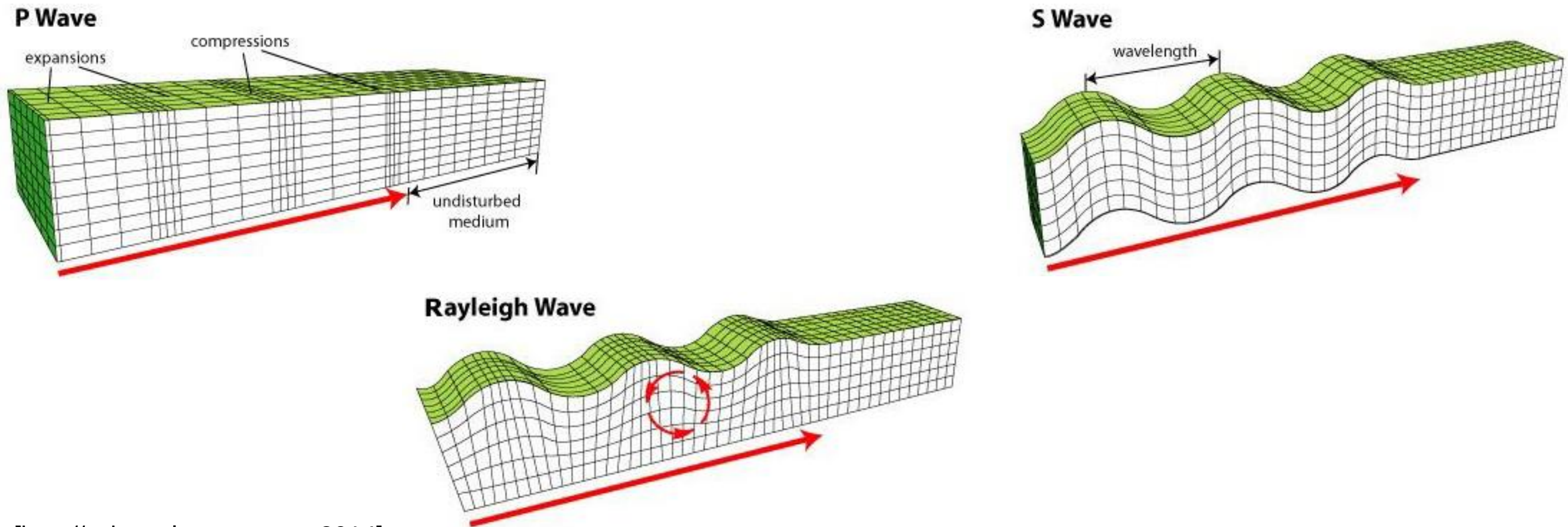
  - focus on the impedance of the wheel and rail;

  - note stiffnesses can depend on preload, frequency and temperature.

Considerations of the Transmission Path

Modelling vibration transmission in the ground is inherently complicated.

- Any modelling must at least account for the propagation of the three wave types, in three dimensions (radiation).



[http://sciencelearn.org.nz, 2014]

Considerations of the Transmission Path

- As a minimum, estimates of the ground density, stiffness (e.g. shear modulus and Poisson’s ratio) and material damping are required.
- Note any components that interrupt transmission (e.g. rail pads, isolation bearings).
- Note further complications: layering, buried structures, etc.
- Uncertainties can limit accuracy but an understanding of the physics helps guide design.

Considerations of the Receiver

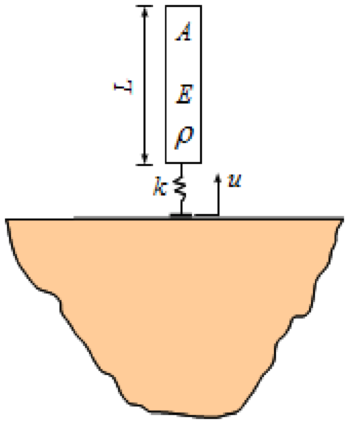
- Receiver models may not be required:

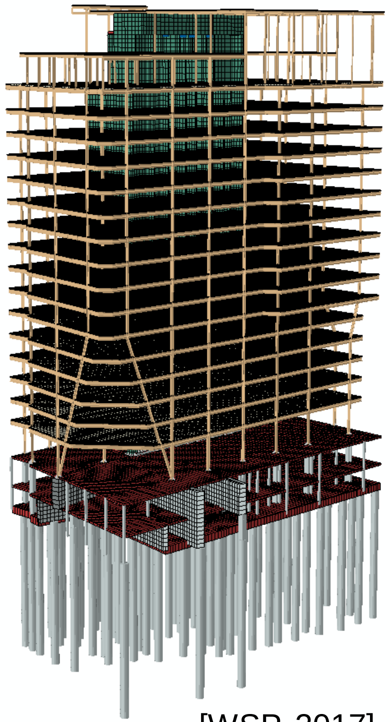
  - focus on ground vibration levels or mitigation at source.

- Building models selected according to application:

  - guiding design (e.g. relative performance of mitigation);

  - detailed models to predict absolute levels.





[WSP, 2017]

Theoretical Models

Theoretical models may be analytical or numerical.

- (Semi-) analytical models now sufficiently comprehensive to capture the essential physics:

    - computationally efficient;

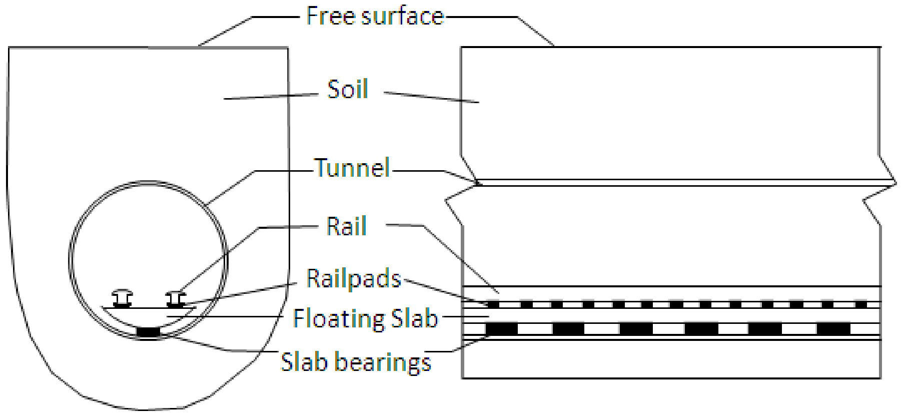
    - limited ability to capture detail (e.g. variations along the track, soil layering).

- Numerical models (FEM, BEM, FDM):

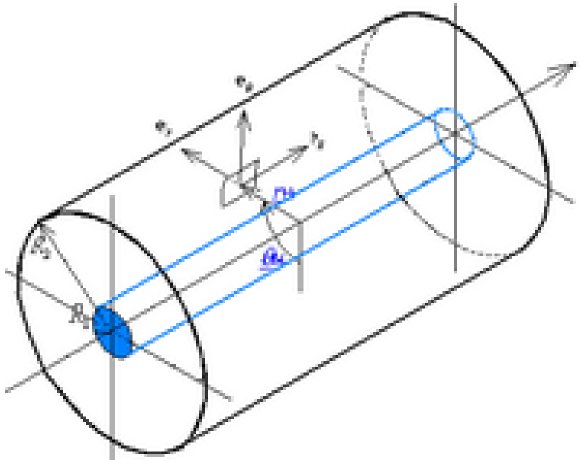
    - may be tailored to a particular project;

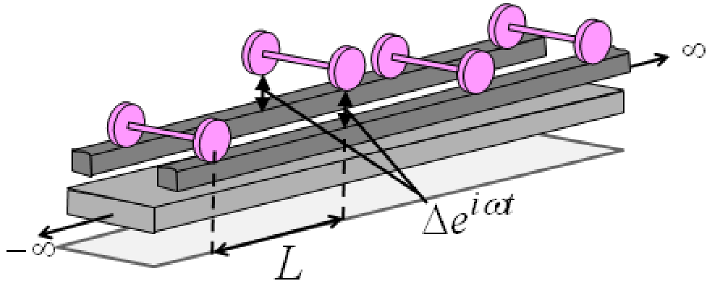
    - can be computationally demanding.

Analytical Models – The PiP Model



A semi-analytical model based on a longitudinally-invariant circular tunnel

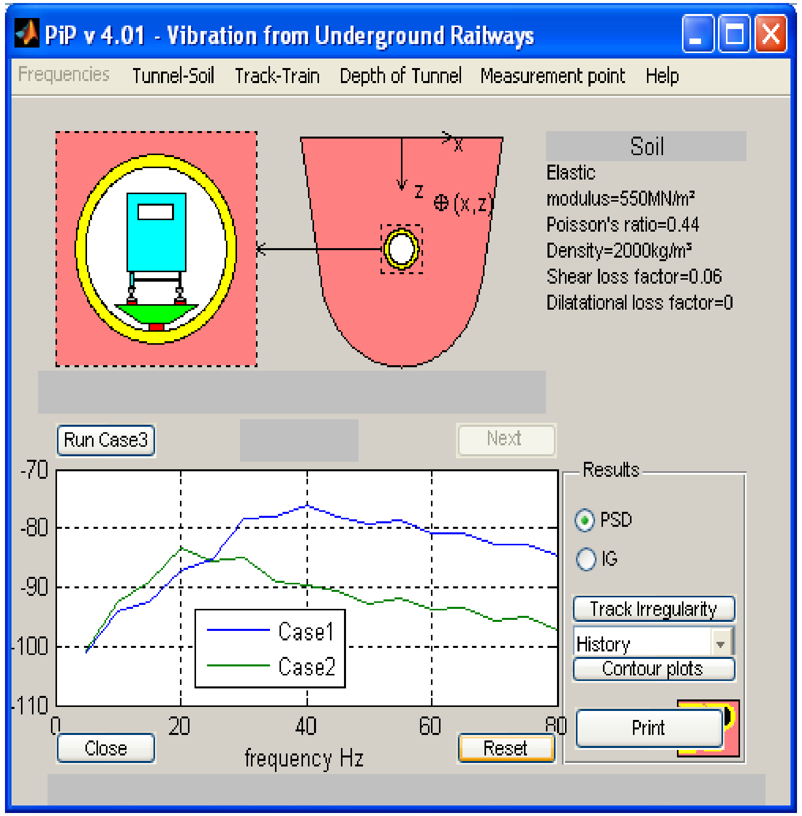


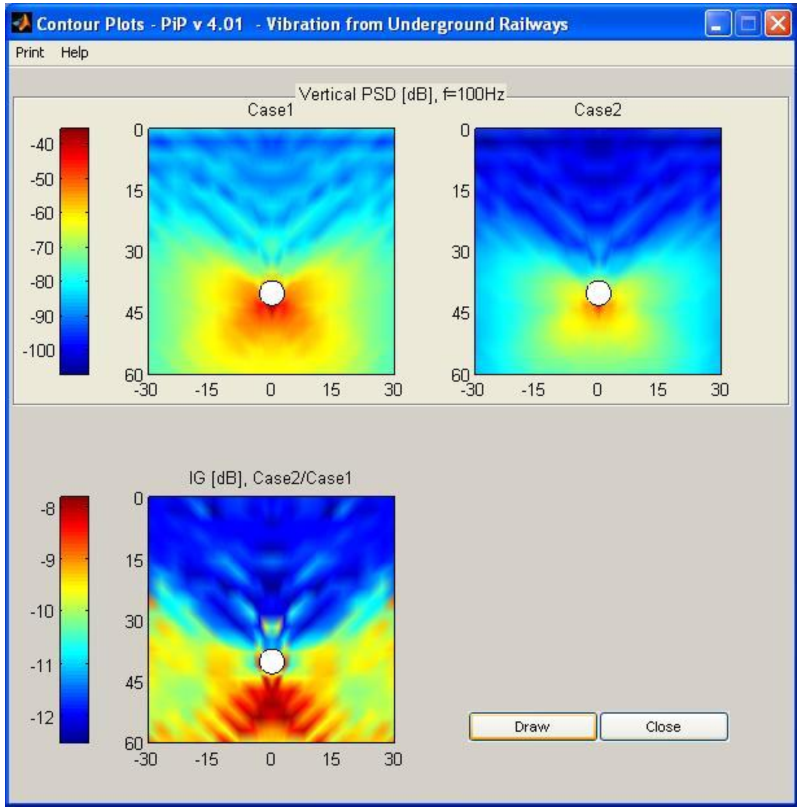


[Forrest, Hunt, Hussein, *et. al.*, 2006-2014]

Analytical Models – The PiP Model

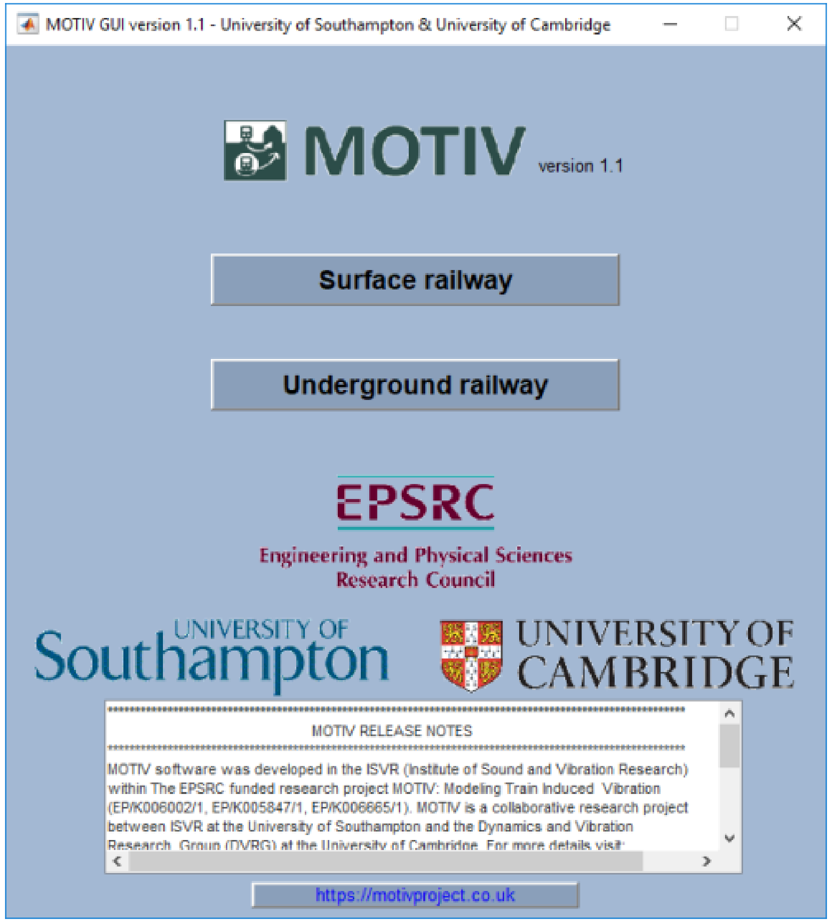
http://pipmodel.com



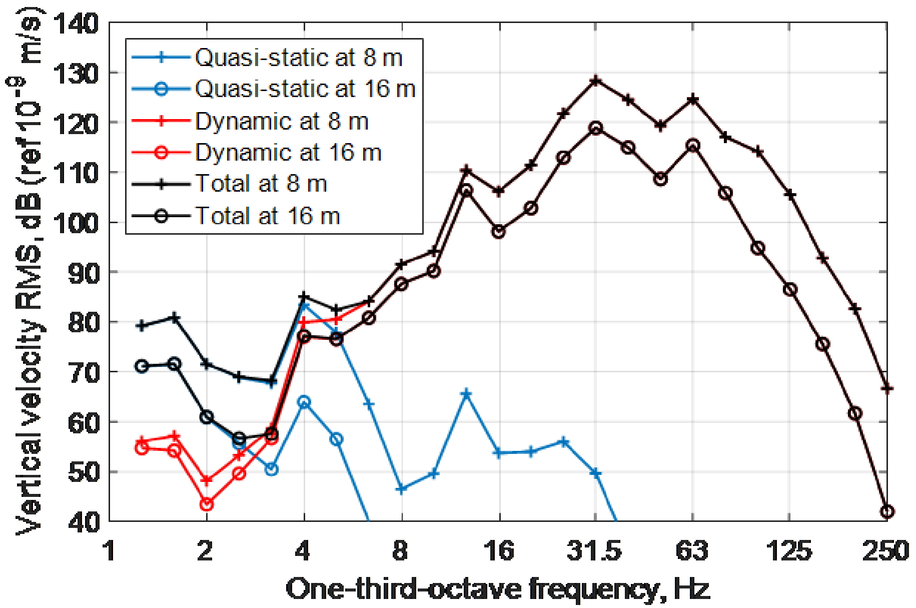


Measurement & Assessment of Groundborne Noise & Vibration

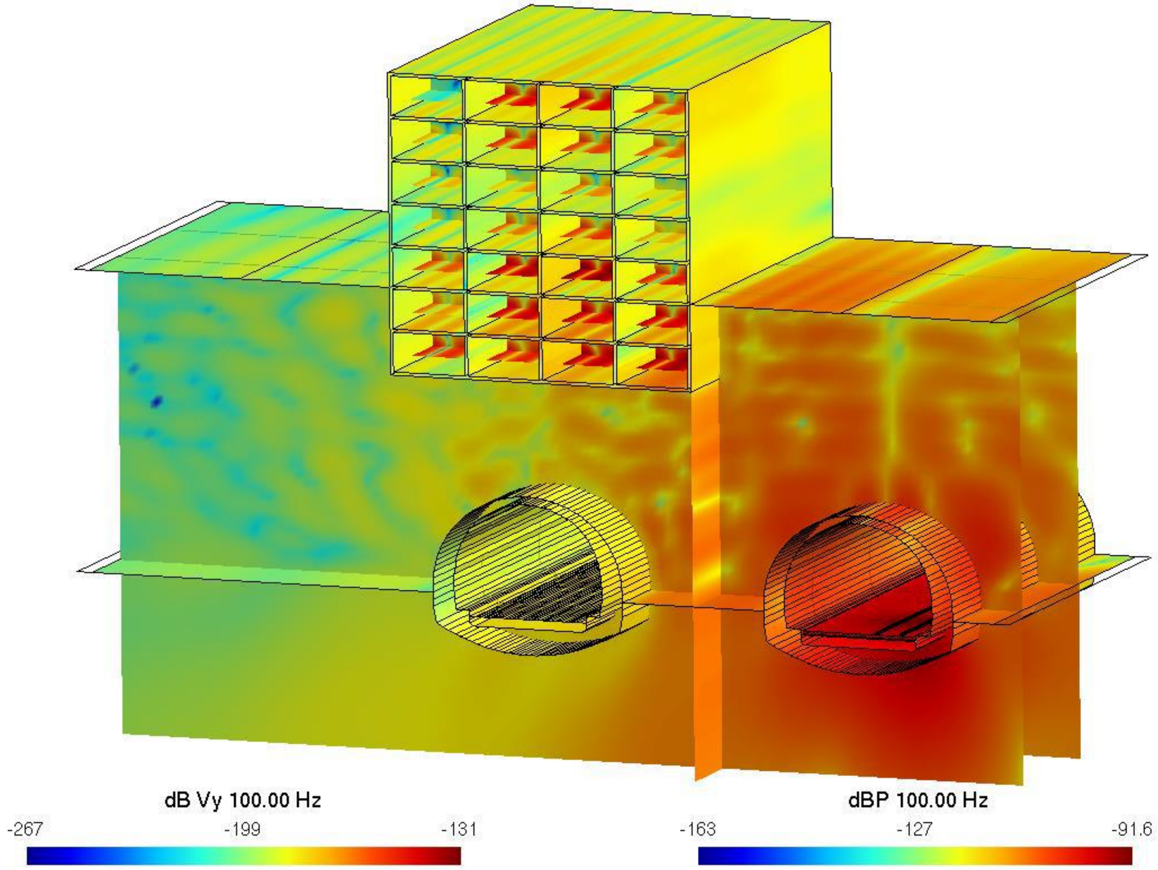
Analytical Models – The MOTIV Model



https://motivproject.co.uk



Numerical Models – MEFISSTO

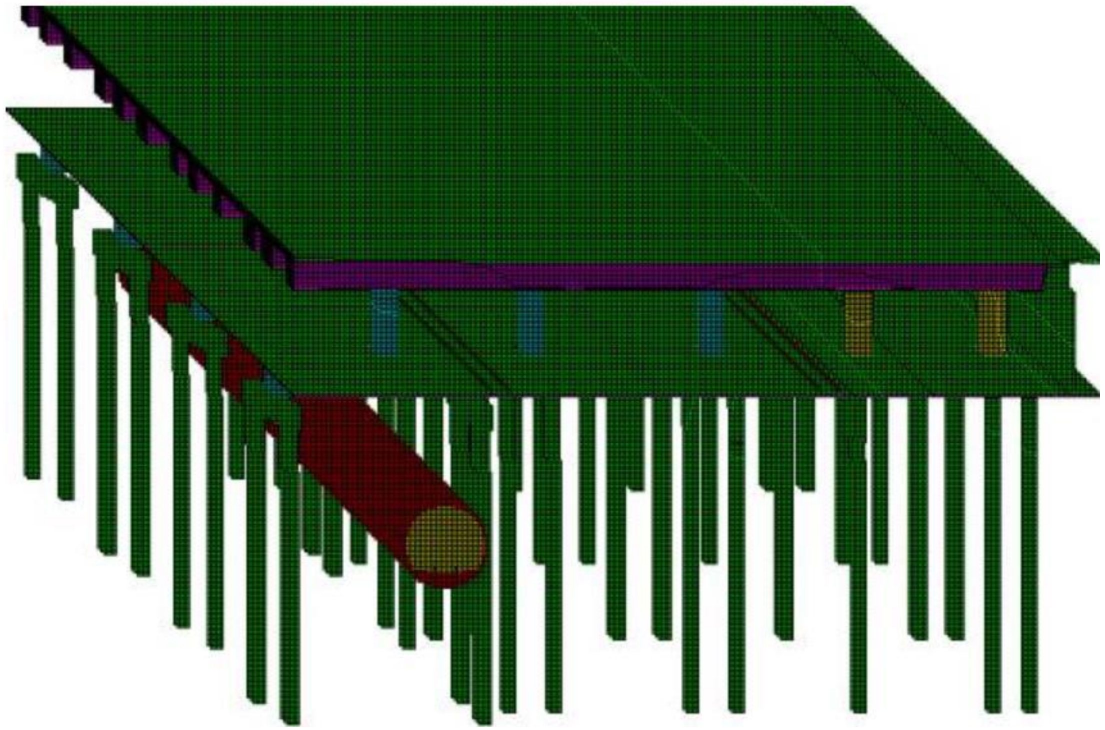


- A combination of FEM and BEM
- 2D, 2.5D and 3D
- Frequency-domain vibration and noise

https://logiciels.cstb.fr/

[Jean, 2016]

Numerical Models – FINDWAVE



- Time-domain FDM
- 3D
- Transient and steady-state vibration and noise

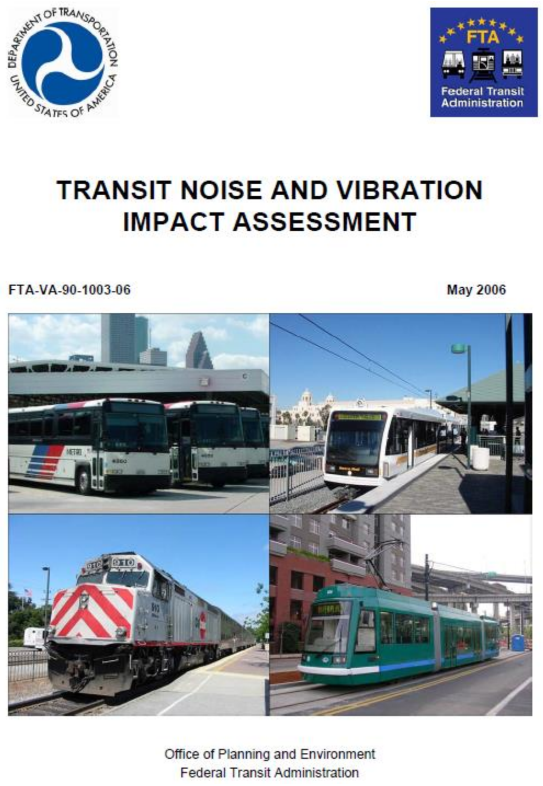
http://ruperttaylor.com

[Thornely-Taylor, 2019]

Empirical Models

Based on a database of field measurements.

- Noise & vibration estimates (third-octave) for a variety of building types, ground conditions and track designs.
- Rapid estimates with minimal computational resources.
- High uncertainty when actual system differs from those in the database.
- ‘Correction factors’ can never account fully for the strong coupling usually associated with vibration.



[Hanson *et al*., 2006, 2012]

Hybrid Models

Based on a combination of theoretical and empirical approaches.

- Theoretical methods can be computationally demanding, and rely on simplifying assumptions and often extensive parameter inputs.

- Accuracy of empirical methods is limited by the underlying measurements and certain simplifications.

- Combining the two approaches mitigates the limitations of both.

- e.g. a new building on an existing site:

  - theoretical model of building;

  - empirical model of site and source.

Conclusions

- Various options for modelling groundborne vibration (analytical, numerical and empirical; time- and frequency-domain).

- Analytical methods are convenient and efficient – probably most useful for scoping assessments and guiding design.

- Numerical methods enable detailed analysis but at the expense of build time and computing time.

- Empirical methods provide rapid estimates with minimal resources, provided the underlying database is sufficiently comprehensive.

- All methods can suffer from significant uncertainty and must be used with care!