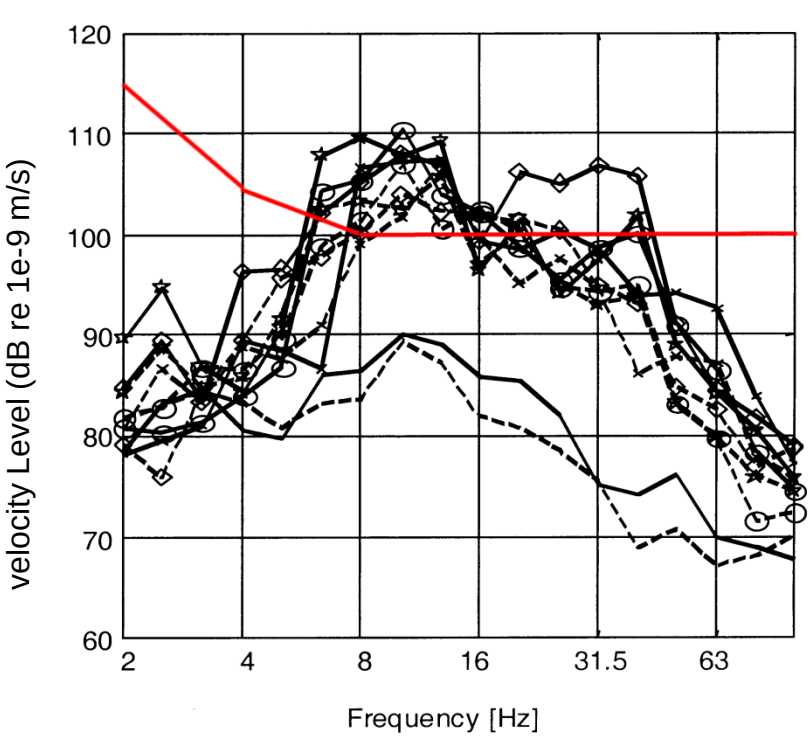
Mitigation of vibration by open trenches and soft wave barriers

- physical mechanisms

Contents

- Background – waves in layered soil
- Ideal open trench
- Soft-filled trench
- Practical installation

Typical frequency content



Vibration at 50 m from a surface railway

Depending on the location high levels of vibration may be found between 10 and 40 Hz

Most other measures are only effective at higher frequencies

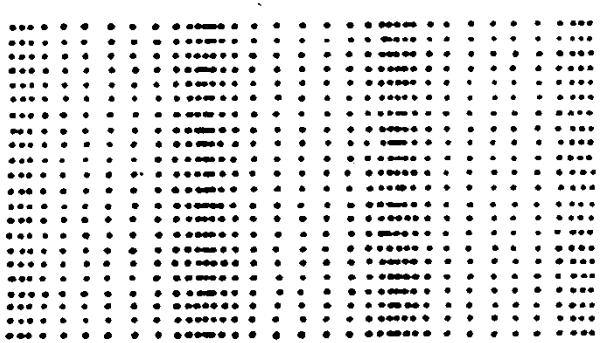
Soil properties

Soil properties can be defined in terms of Young's modulus, Poisson's ratio etc or equivalently in terms of fundamental wave speeds

Longitudinal waves

(P-waves)

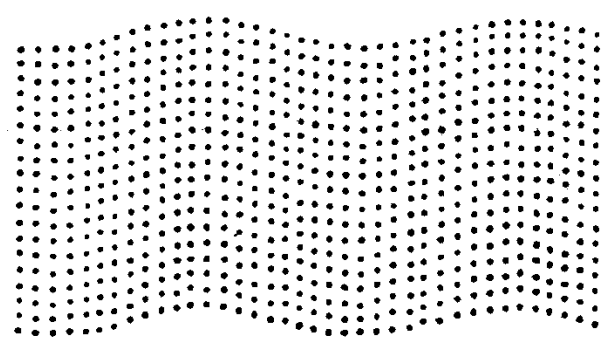
$$c_L = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}}$$



Shear waves

(S-waves)

$$c_T = \sqrt{\frac{E}{2\rho(1+\nu)}} = \sqrt{\frac{G}{\rho}}$$



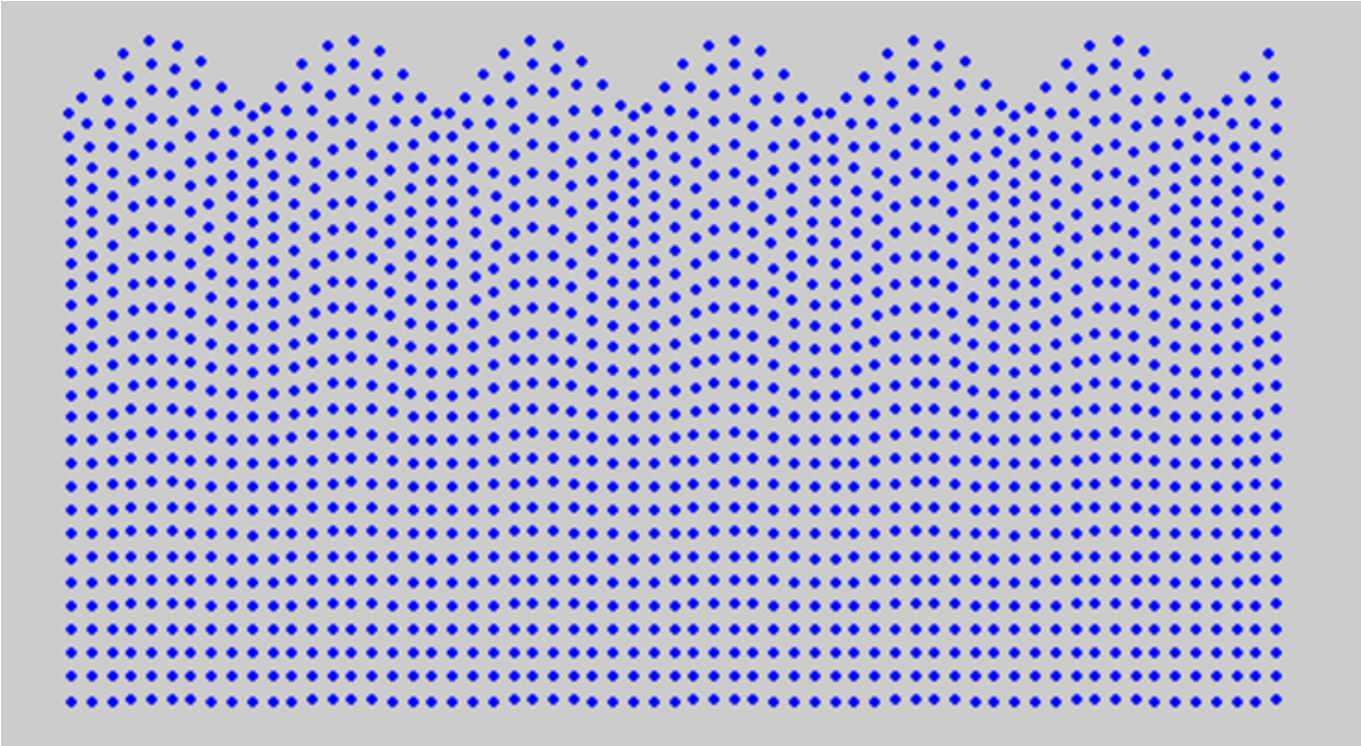
Soil properties

Soil properties vary considerably even for a given type

	P-wave speed m/s	S-wave speed m/s	Density kg/m^3
Clays	1000 – 2500	200 – 800	2000 – 2400
Sands	1500 – 3000	400 – 1200	1900 – 2100
Marls	2000 – 3000	750 – 1500	2100 – 2600
Chalk	2000 – 2500	1100 – 1300	1800 – 2300
Limestone	3000 – 5000	2000 – 3300	2400 – 2700
Granite	5500 – 6000	2500 – 3300	2500 – 2700

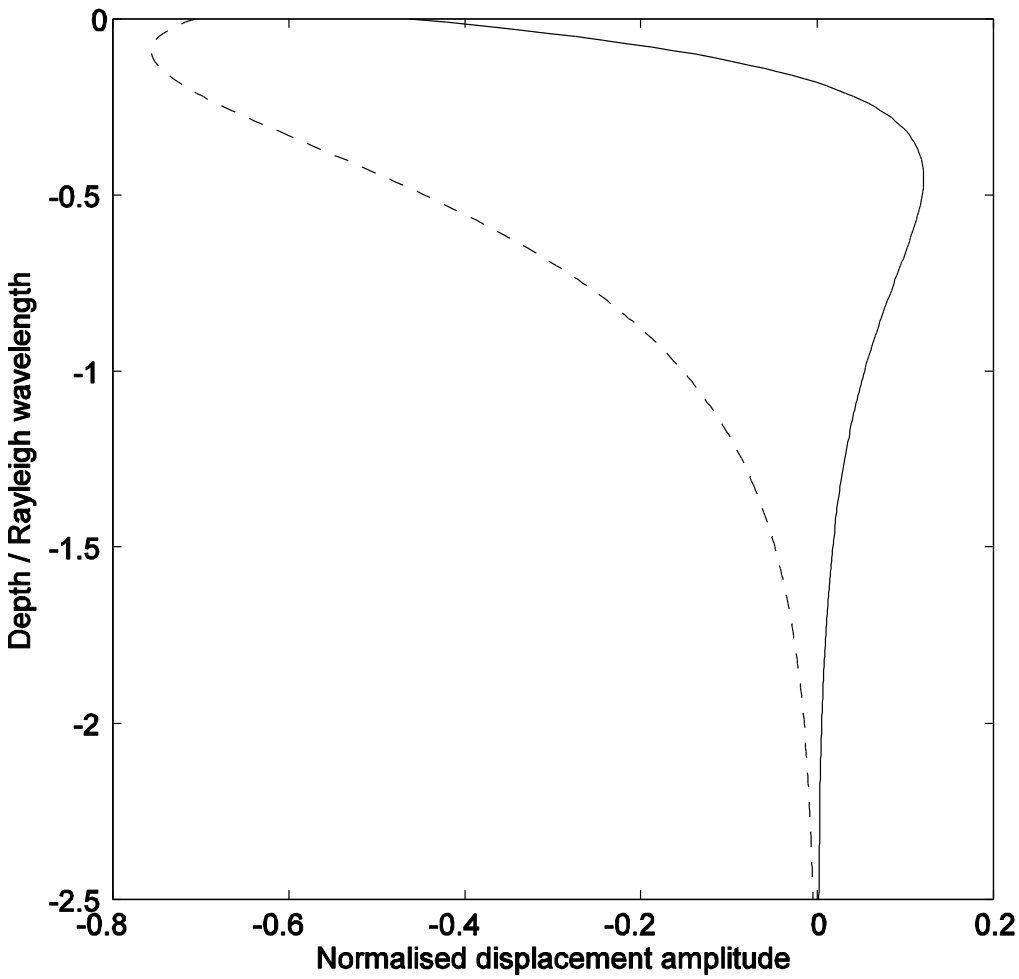
Rayleigh waves in a half-space

In the presence of a free surface, Rayleigh waves are formed



The wave speed is about 92% of the S-wave speed

Rayleigh waves in a half-space



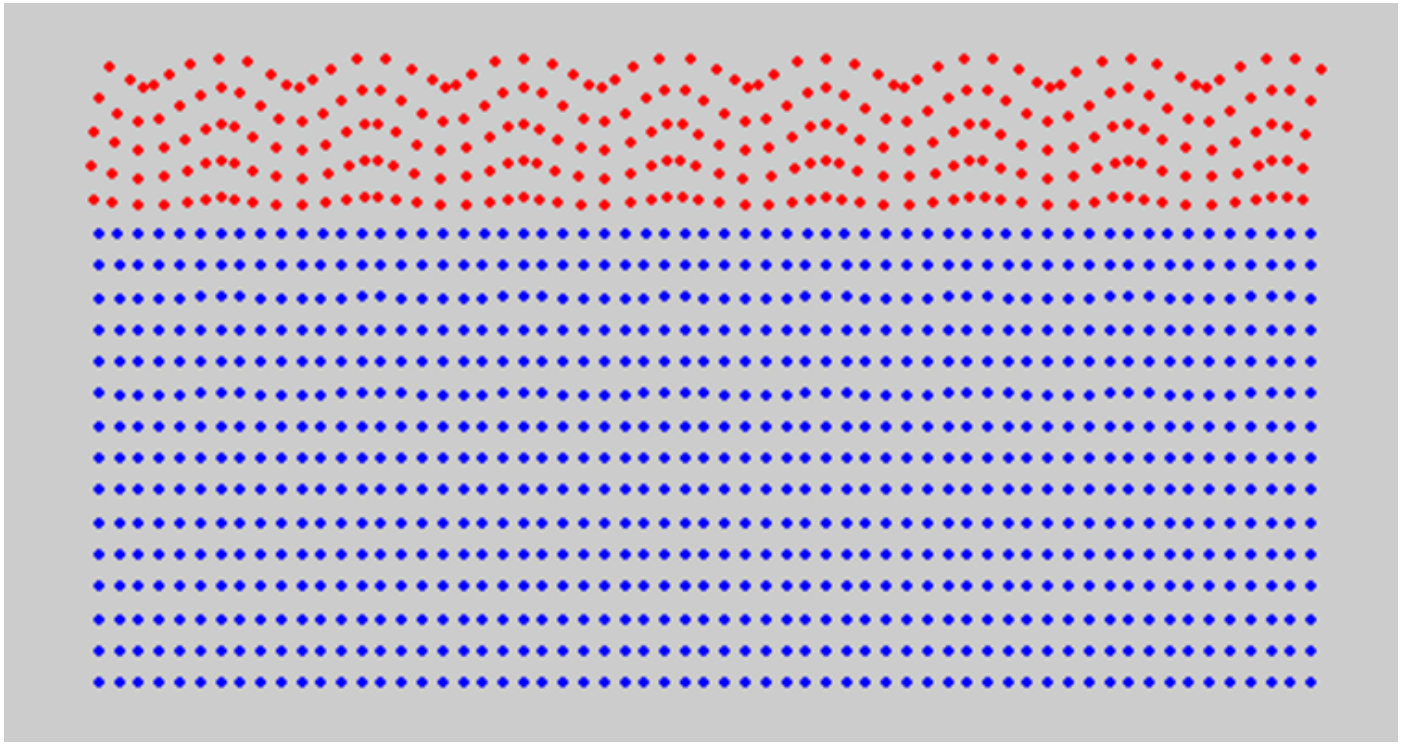
vertical

lateral

Rayleigh waves penetrate about one wavelength into the ground

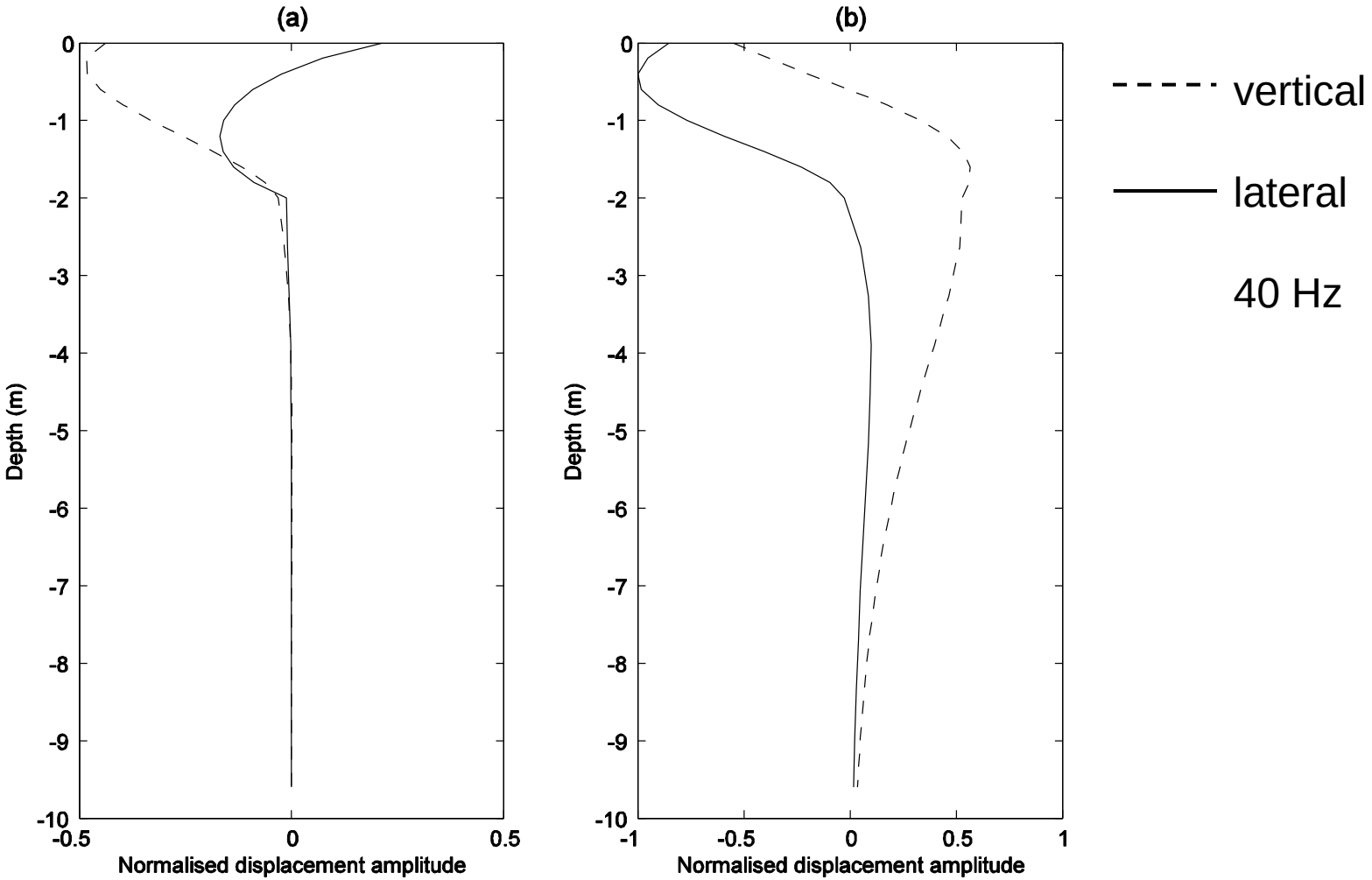
Surface wave in a layered soil

Ground usually consists of layers with different properties

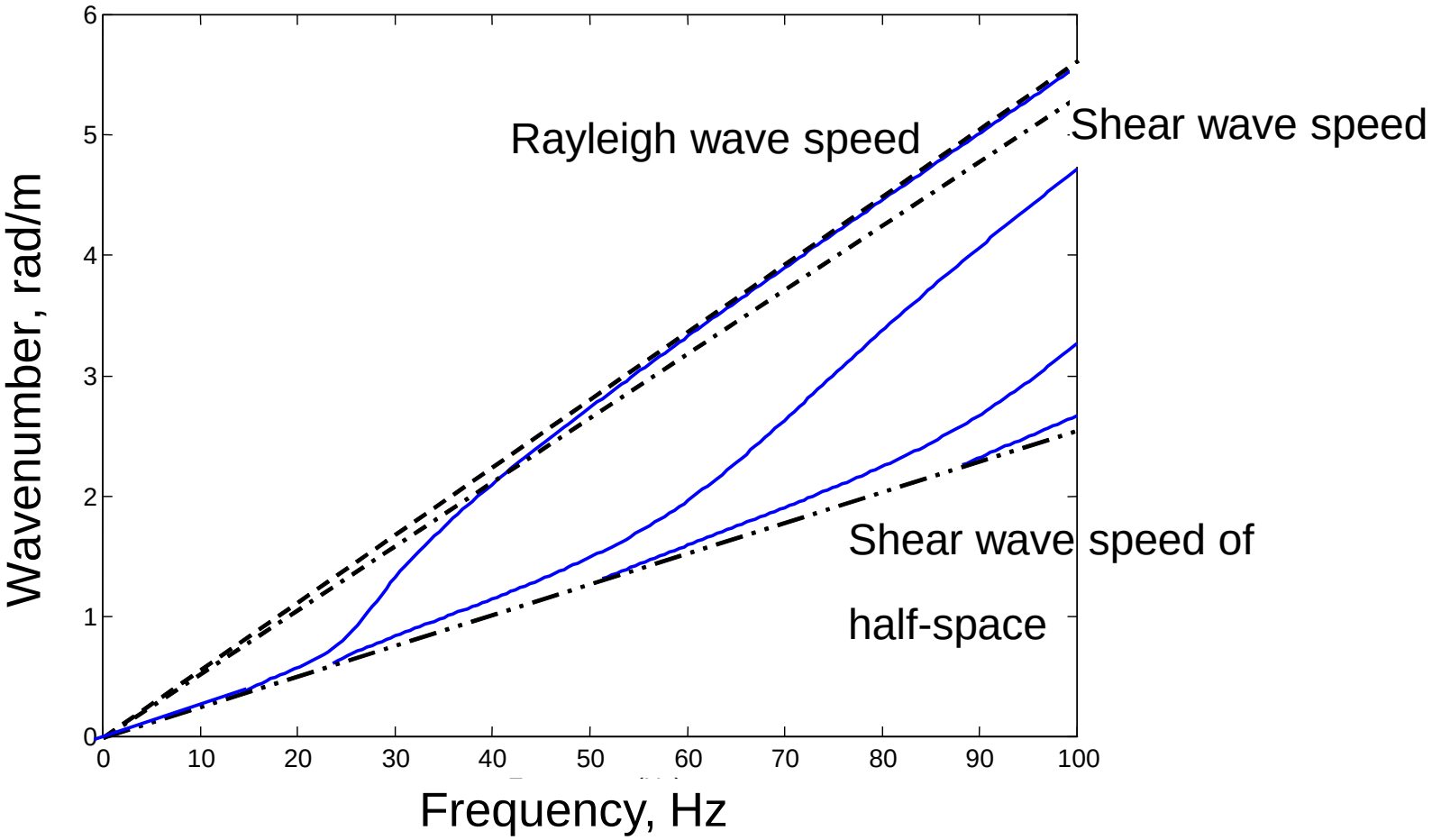


Several different surface-waves can propagate in layered soil

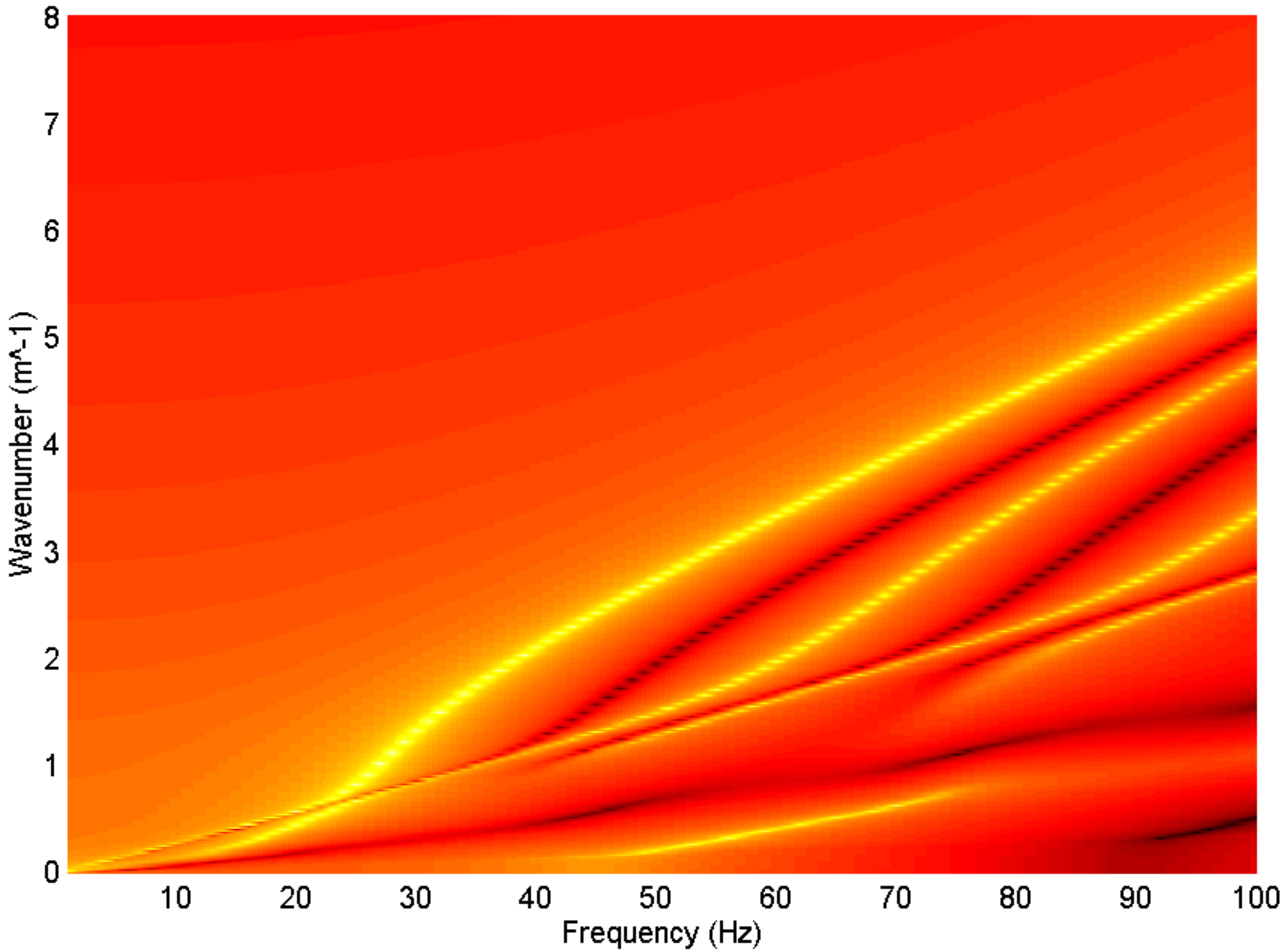
Surface wave in a layered soil



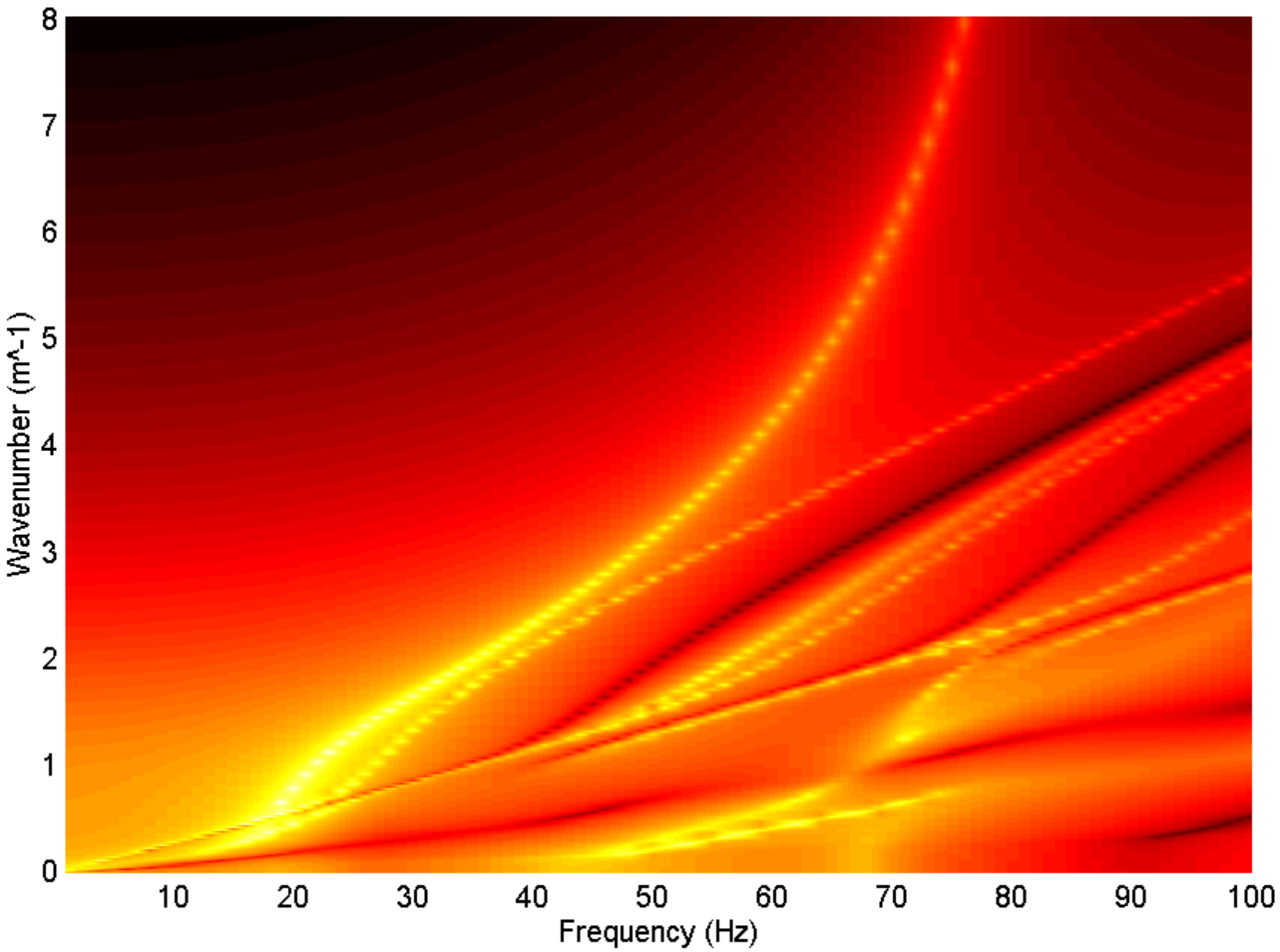
Dispersion diagram of layered soil



Amplitudes of waves excited in the ground



Amplitudes of waves excited in the ground (along track)



Summary (so far)

- Ground vibration from surface railways typically has large amplitudes between 10 and 40 Hz
- High amplitudes are often associated with soft upper layers of soil
- Typical wavespeeds on soft upper layers 100-200 m/s
- Typical wavelengths at problem frequencies 5-10 m

Open trench

- A trench should work like a noise barrier…

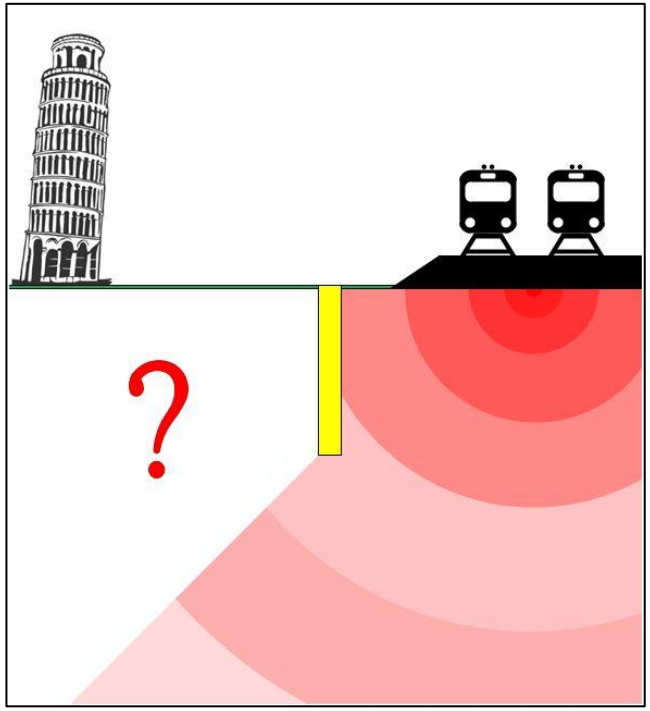
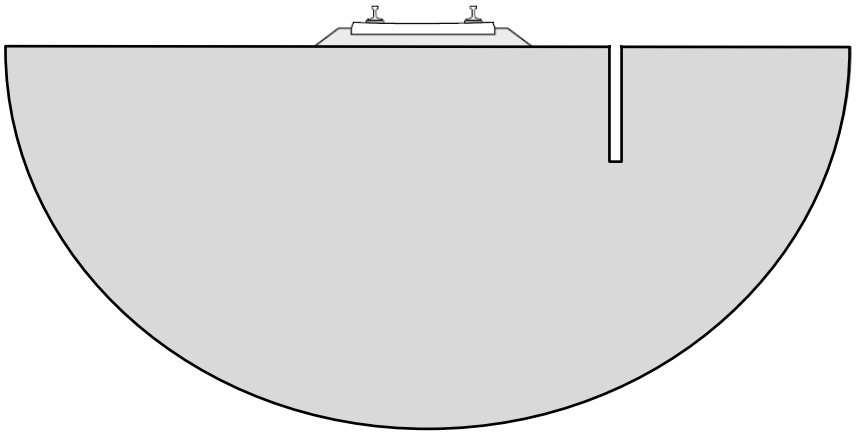
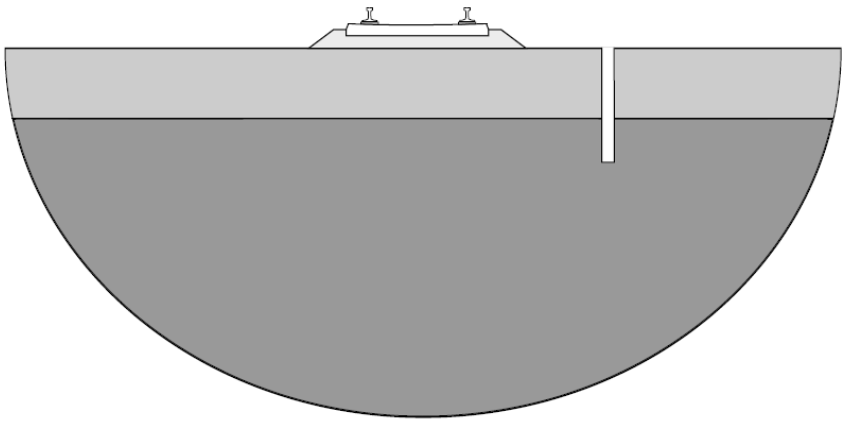


Image: Keller

Open trench

- For a trench in a half-space empirical results suggest 75% reduction achieved if depth is greater than $0.6\lambda_R$
- If typical wavelengths are 5-10 m, trench should be 3-6 m deep
- In a layered soil potential benefit expected if the trench penetrates through soft upper layer



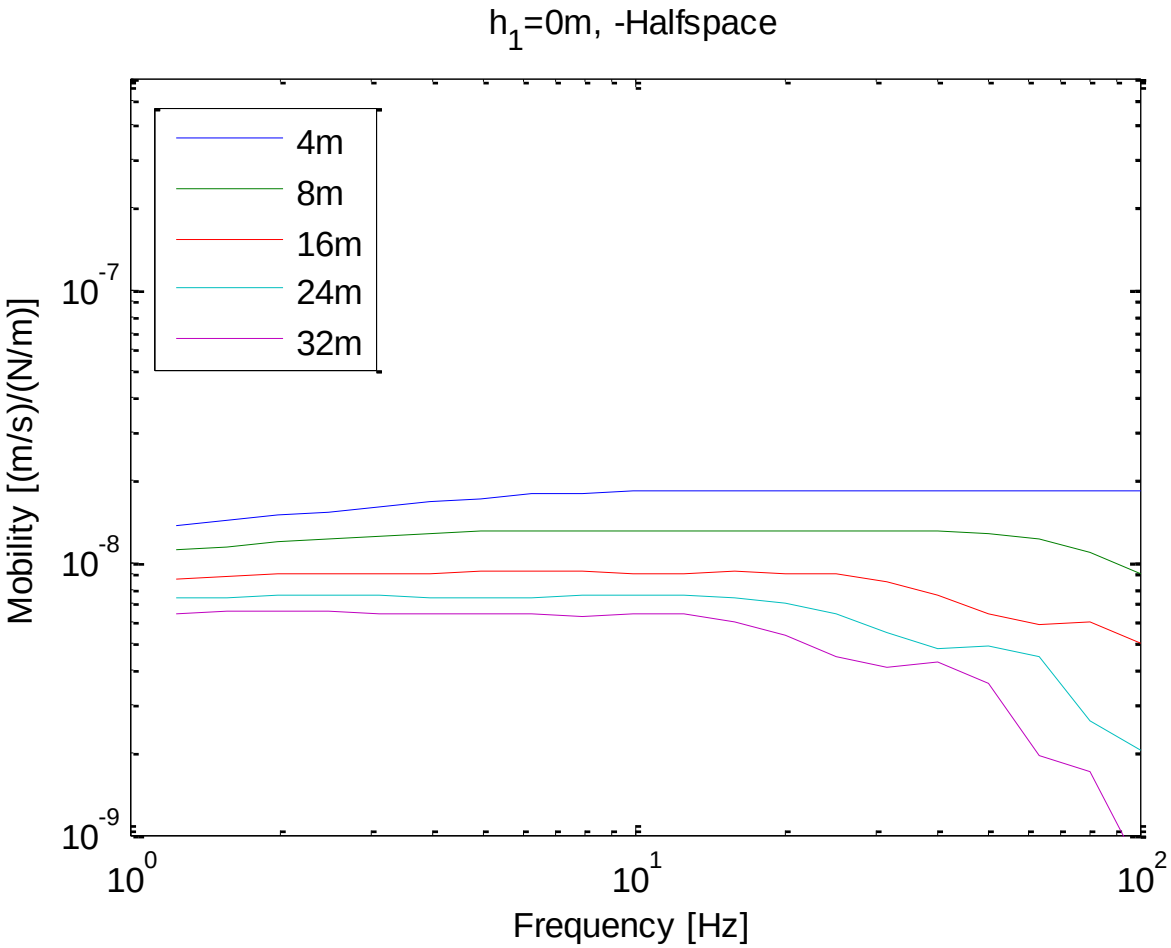


Initial design calculations

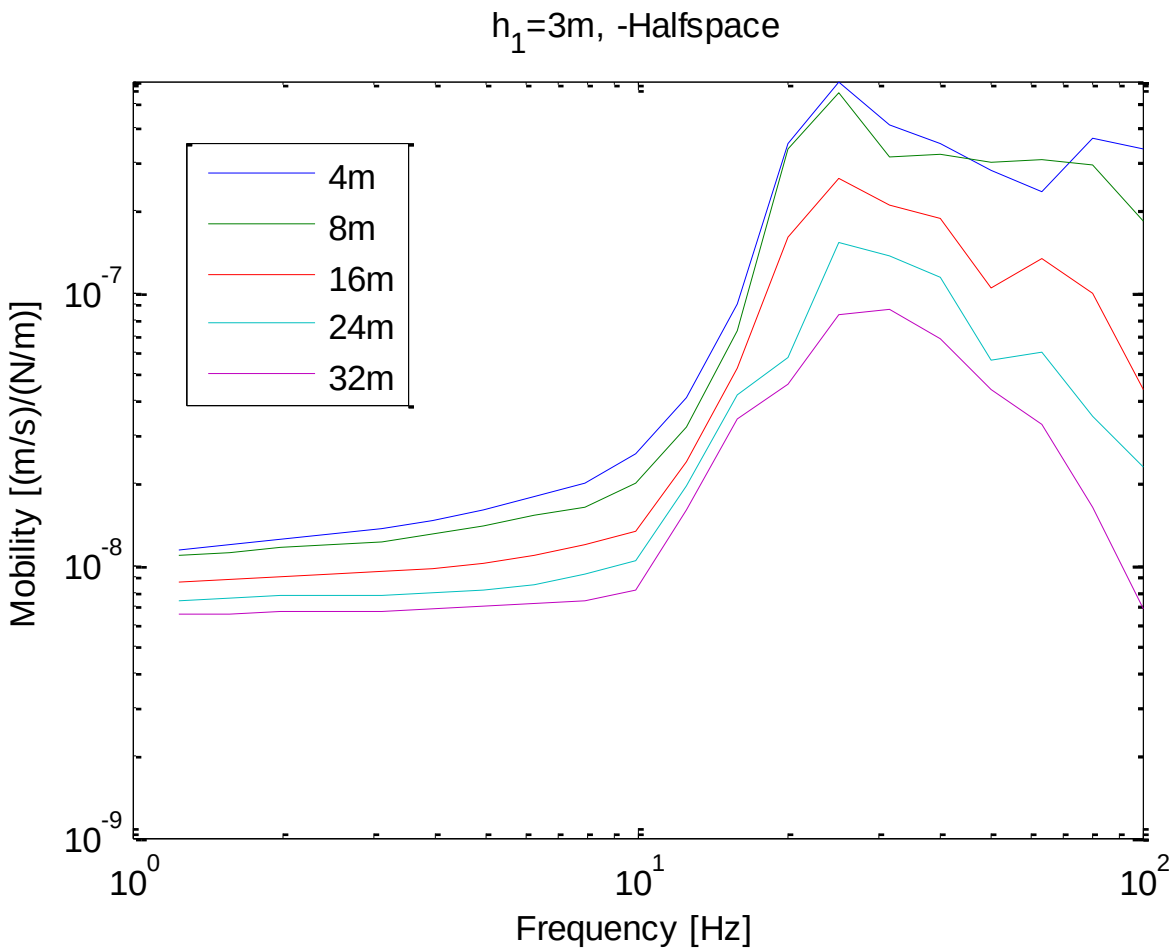
- Soft upper layer overlying stiffer half-space
- Layer depth: in the model 0, 3, 6, 9 m and infinite are considered
- Used 2D FE/BE model

	Shear wave speed (m/s)	Density (kg/m^3)	Poisson's ratio	Damping ratio	Young's modulus (MPa)	Shear modulus (MPa)
Layer	150	1800	0.33	0.03	107.7	40.5
Halfspace	600	2000	0.33	0.1	1915	720

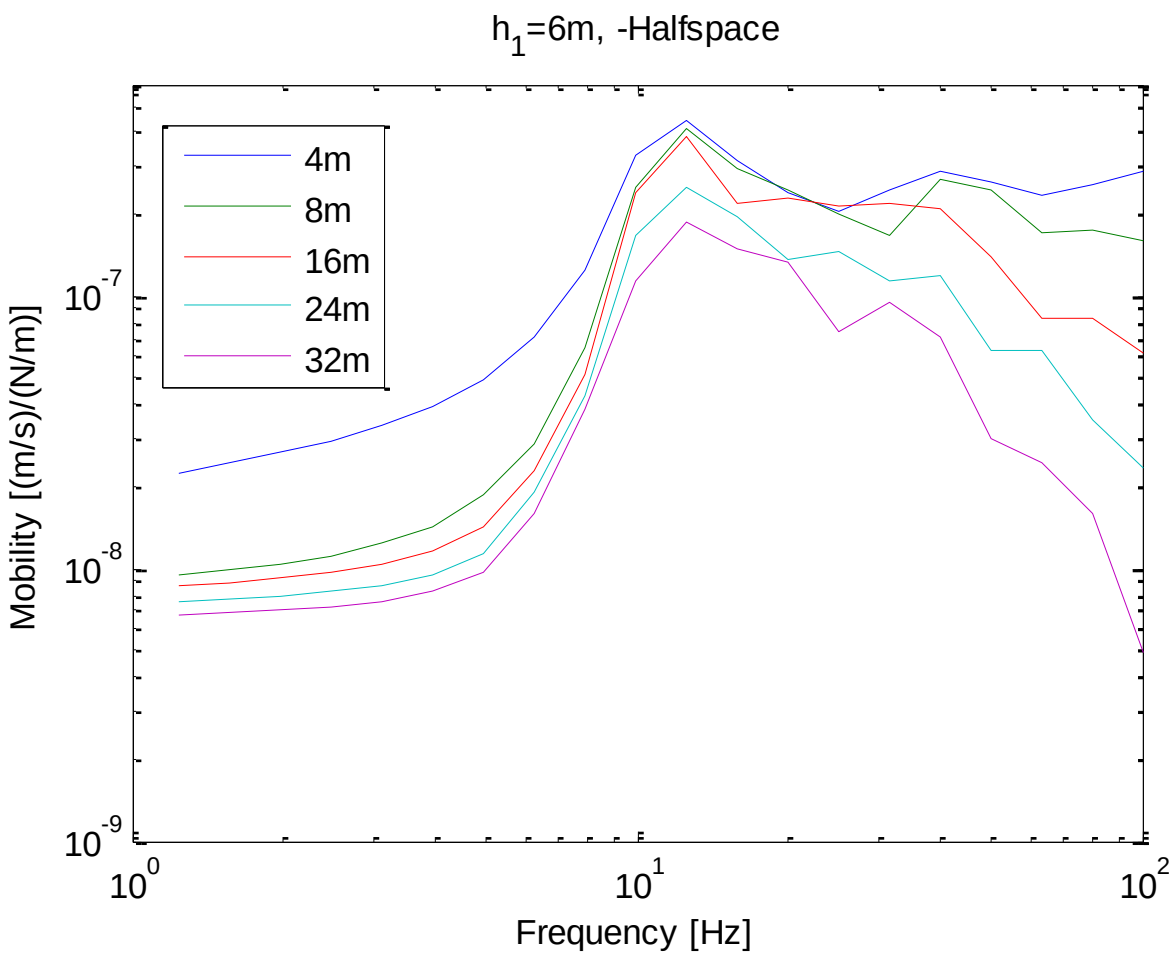
Transfer mobilities 0 m layer



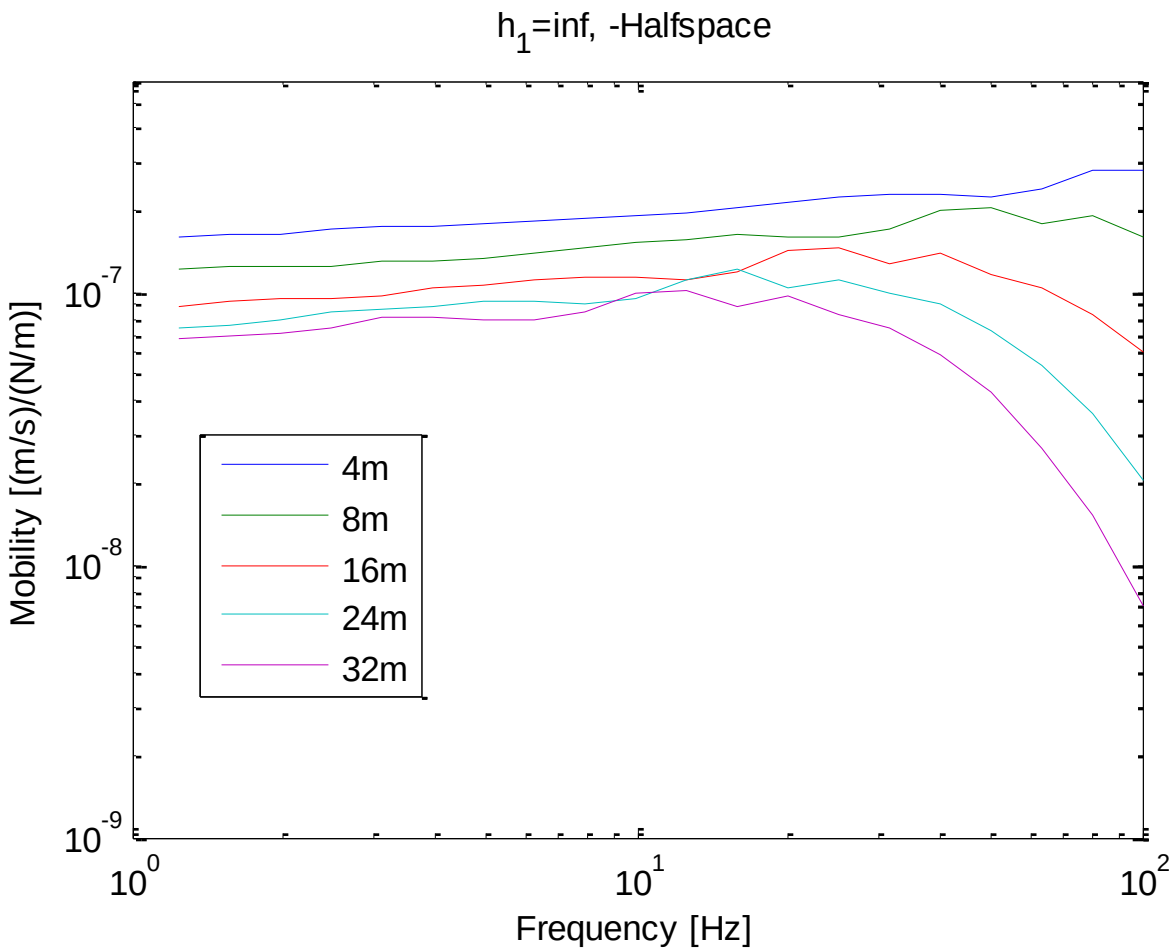
Transfer mobilities 3 m layer



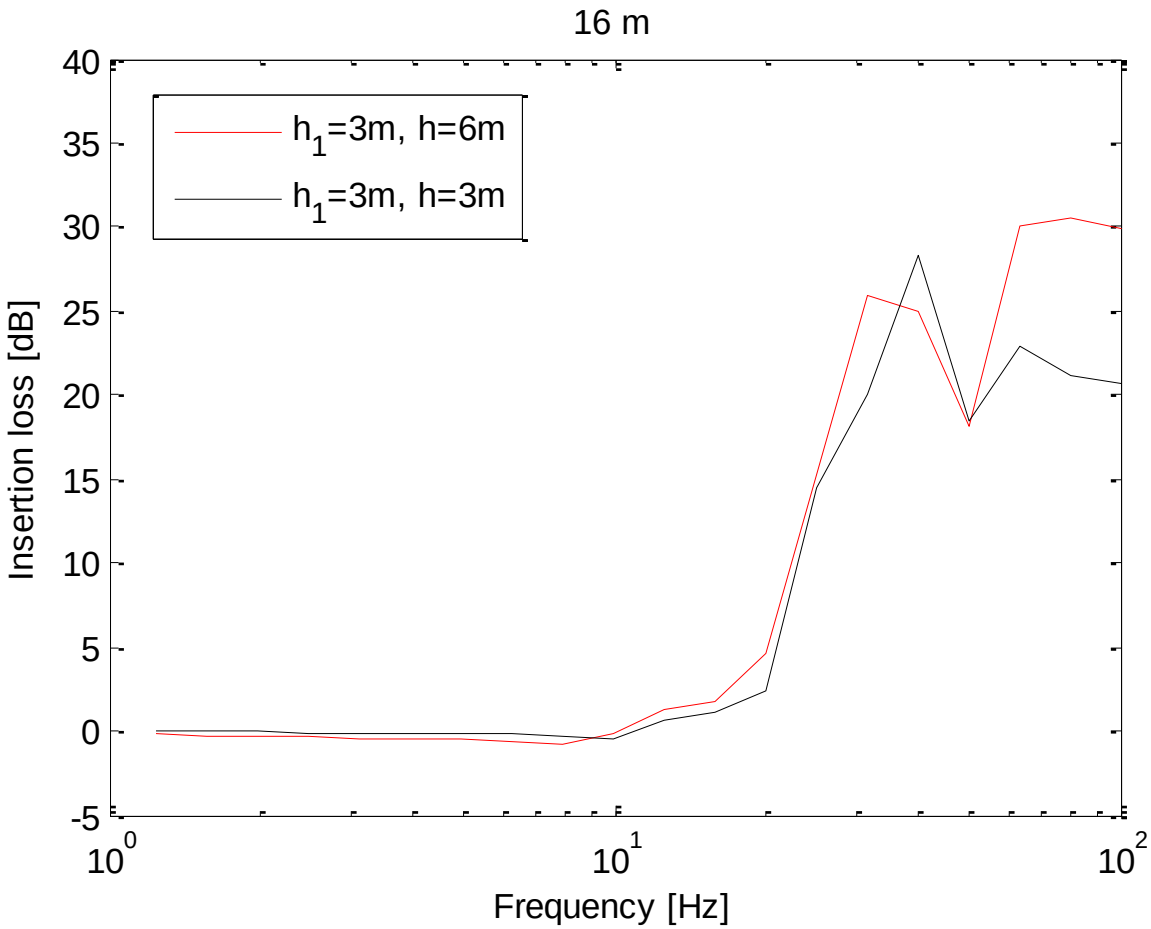
Transfer mobilities 6 m layer



Transfer mobilities ∞ layer

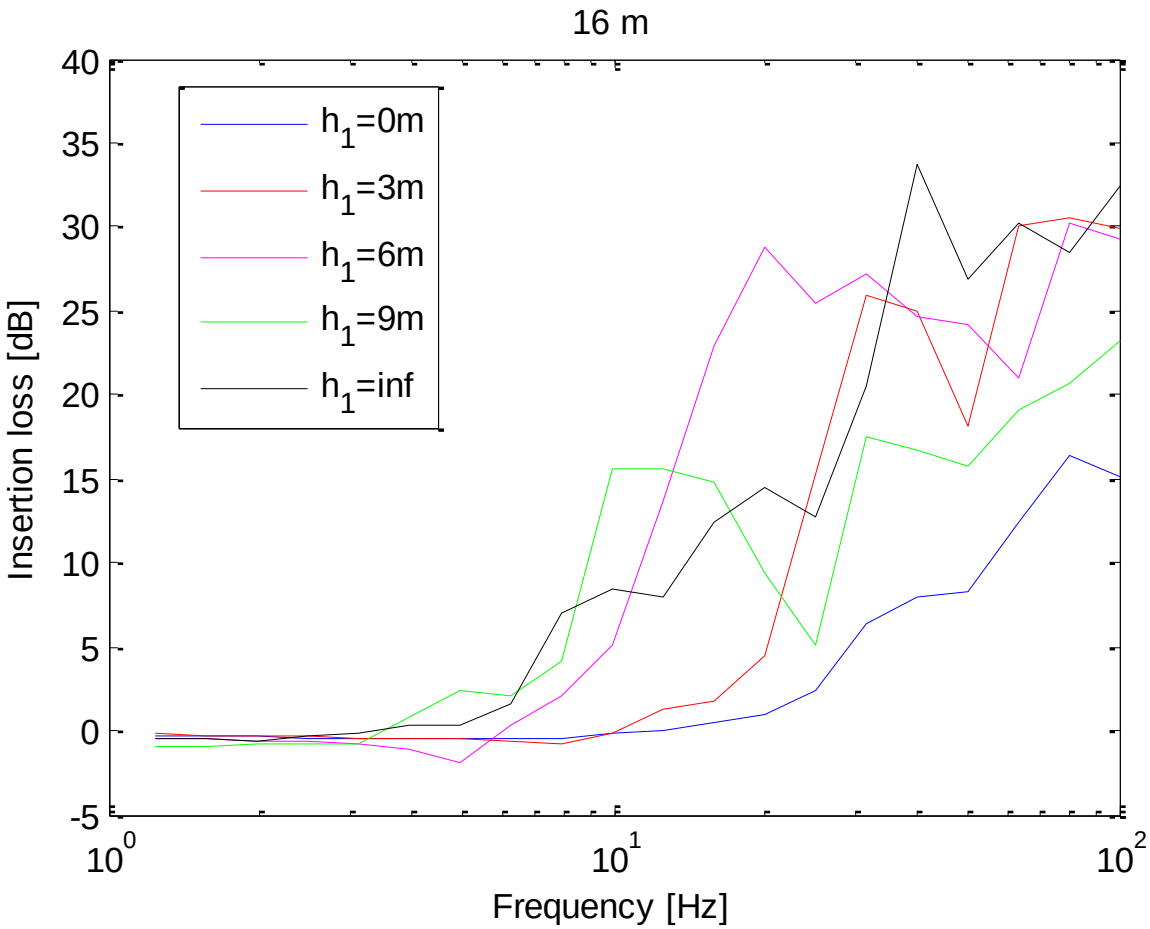


3m layer; 3 or 6m trench



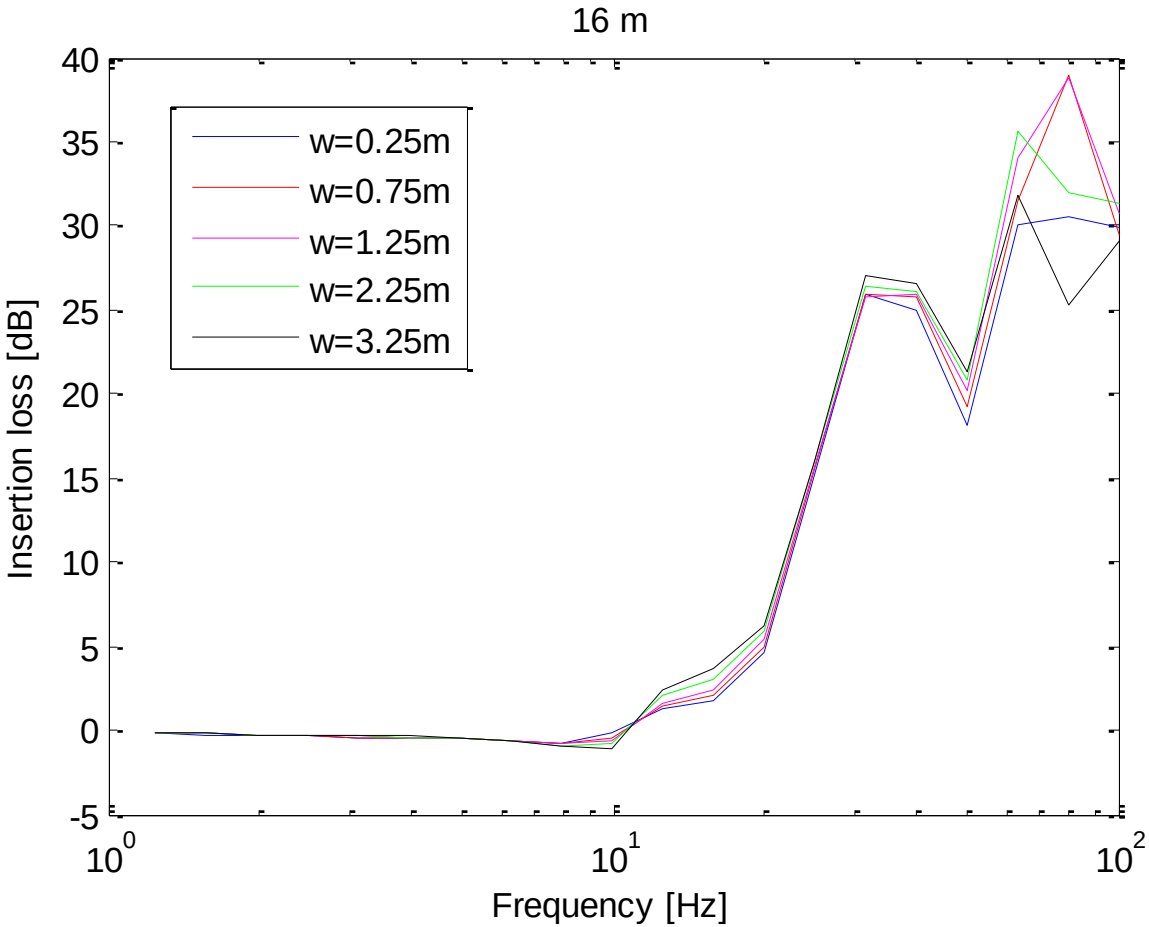
h1=3m,
d=3m,
w=0.25m,
h=3 or 6m

Effect of layer depth (6 m trench)



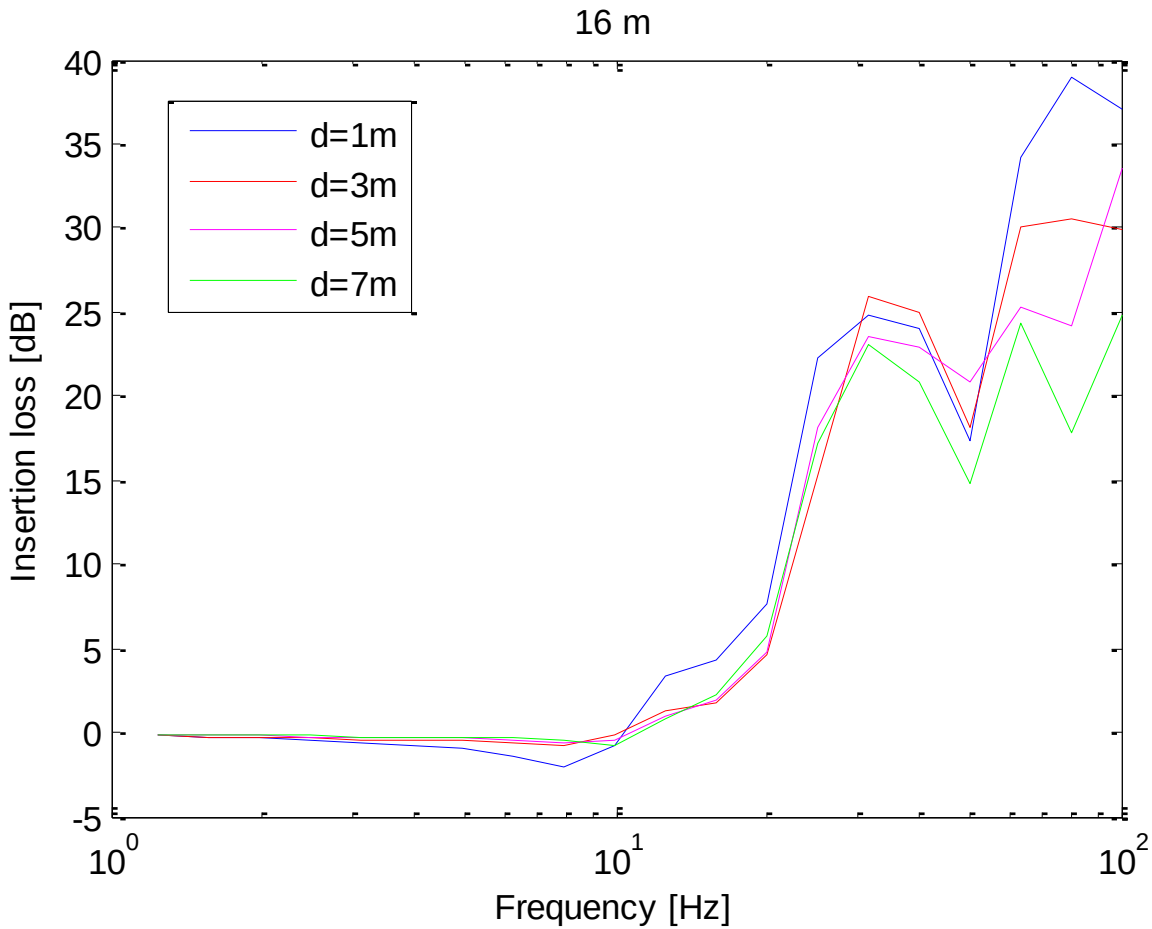
d=3m,
w=0.25m,
h=6m

Effect of trench width



h1=3m,
d=3m,
w=0.25m,
h=6m

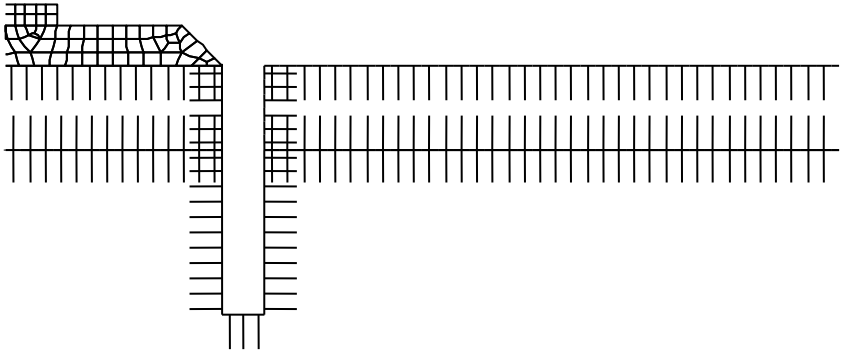
Effect of trench position



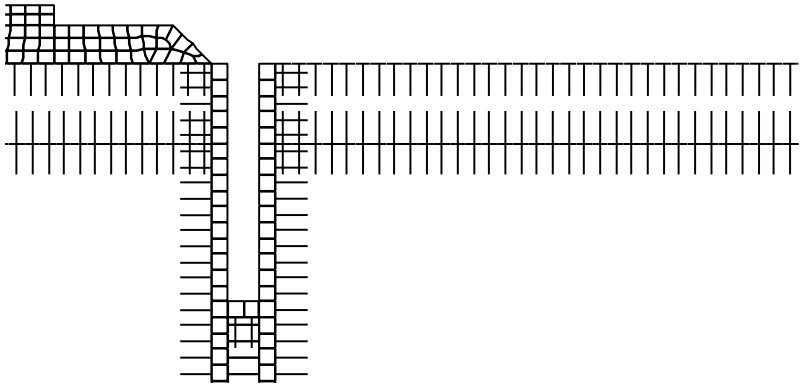
h1=3m,
w=0.25m,
h=6m

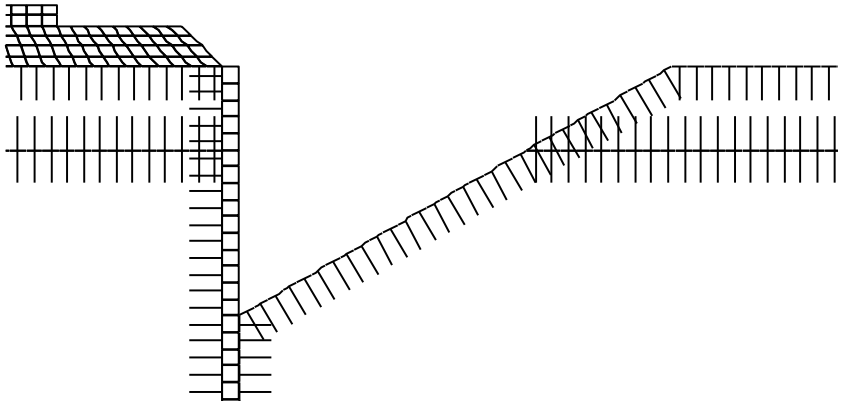
Possible trench designs

- An open trench is an ideal case...



- If the trench is not too deep various possible construction details can be considered





Open trench – summary

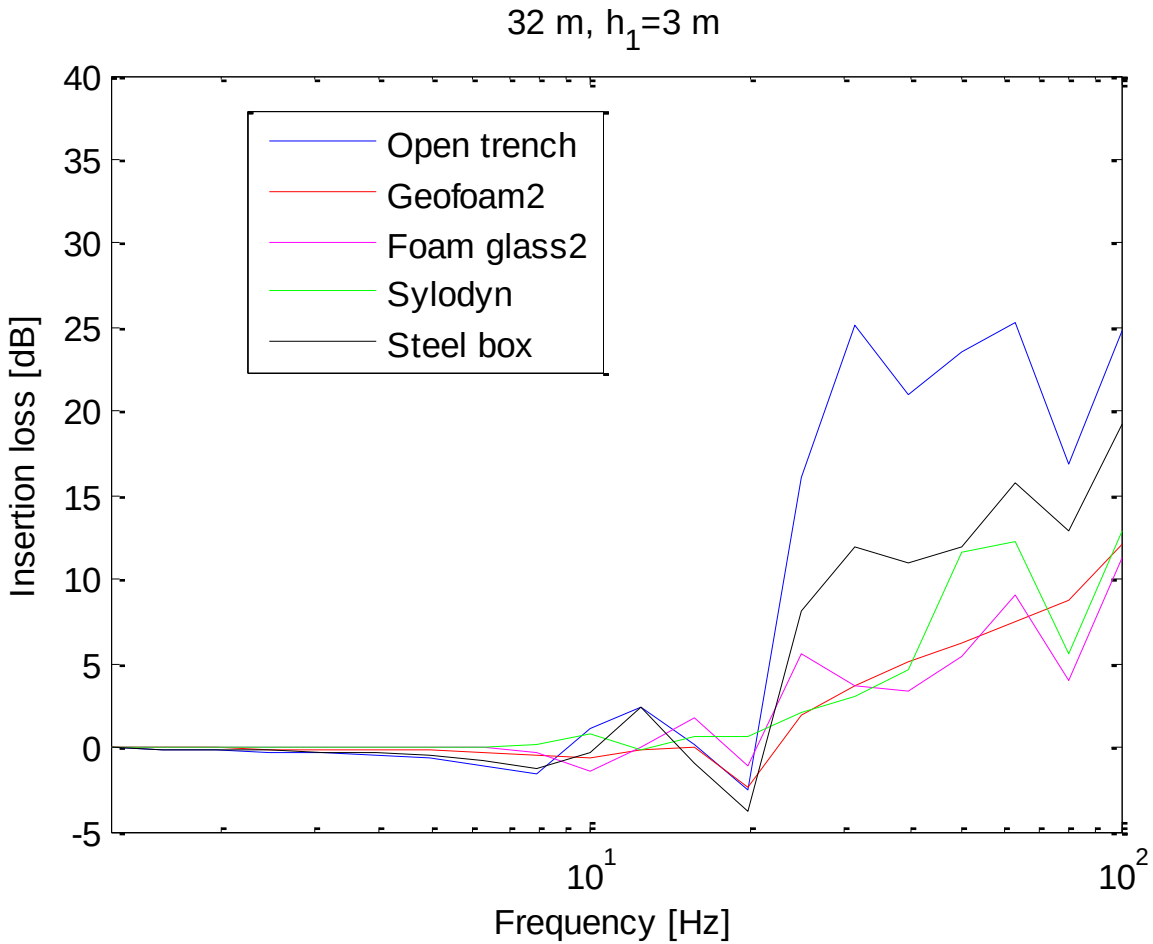
- In a layered soil a trench is beneficial when it cuts through the soft upper layer
- Benefit only found above ‘cut on’ frequency of the upper layer (but this is frequency region where highest vibration levels are expected)
- Benefits of 20+ dB predicted
- Results checked with 2.5D model – trends confirmed although benefit is slightly less than found with 2D model
- But a 6 m deep open trench is not practical…

Open trench – alternatives

- Lined trench
- We can replace the open trench by a filled trench
  - Soft material
  - Stiff/heavy material
- Effectiveness depends on soil stiffness

Soft-filled trench

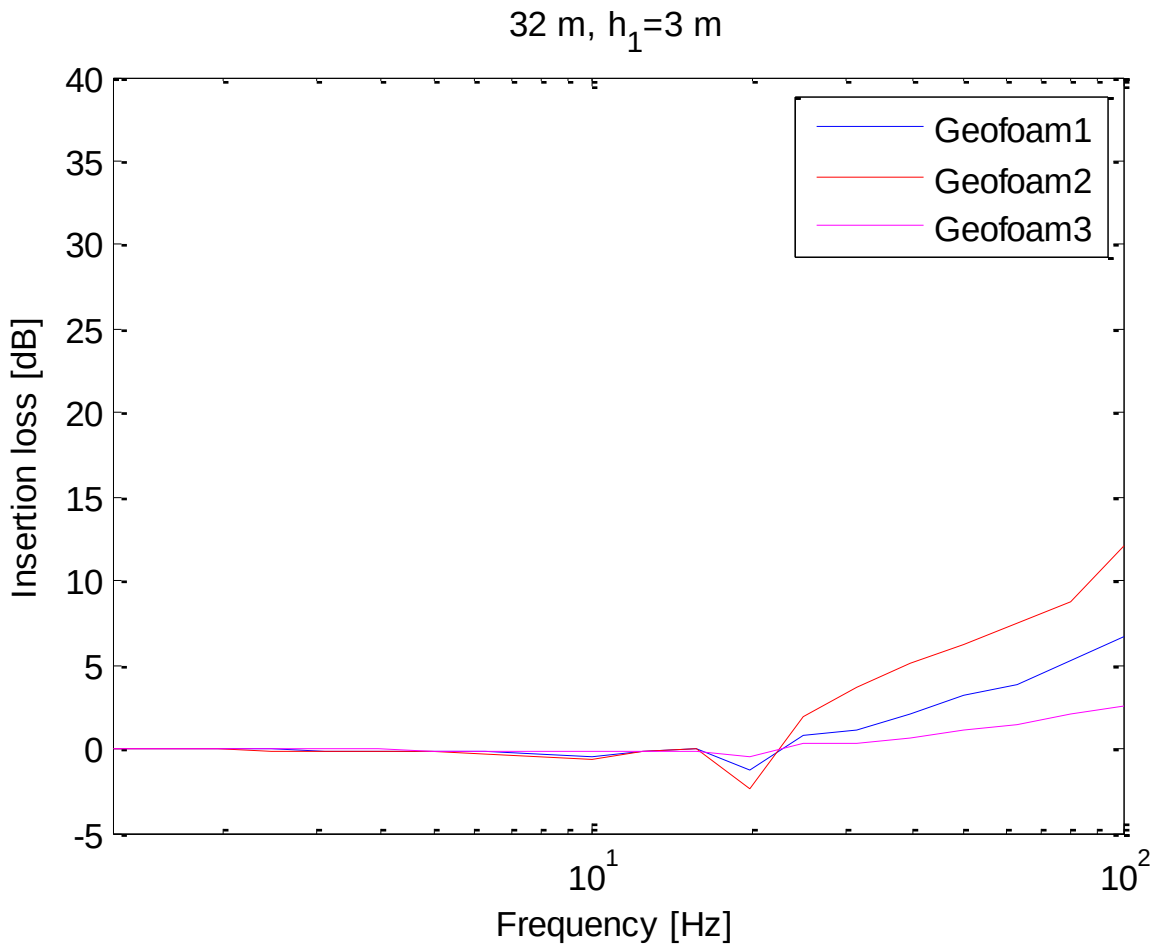
- …various example soft materials



h1=3m,
d=3m,
w=0.25m,
h=6m

Soft-filled trench

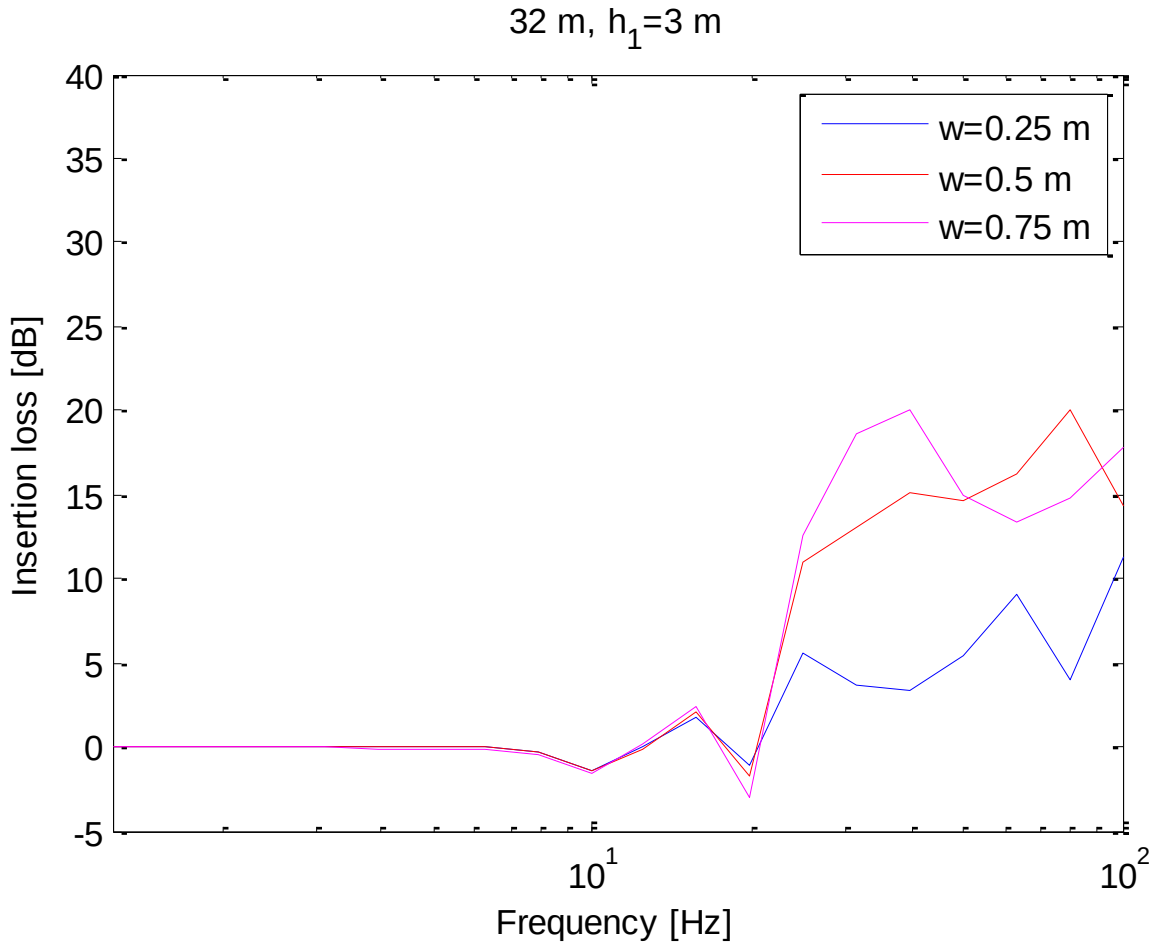
- Benefit dependent on Young's modulus of material



h1=3m,
d=3m,
w=0.25m,
h=6m

Soft-filled trench

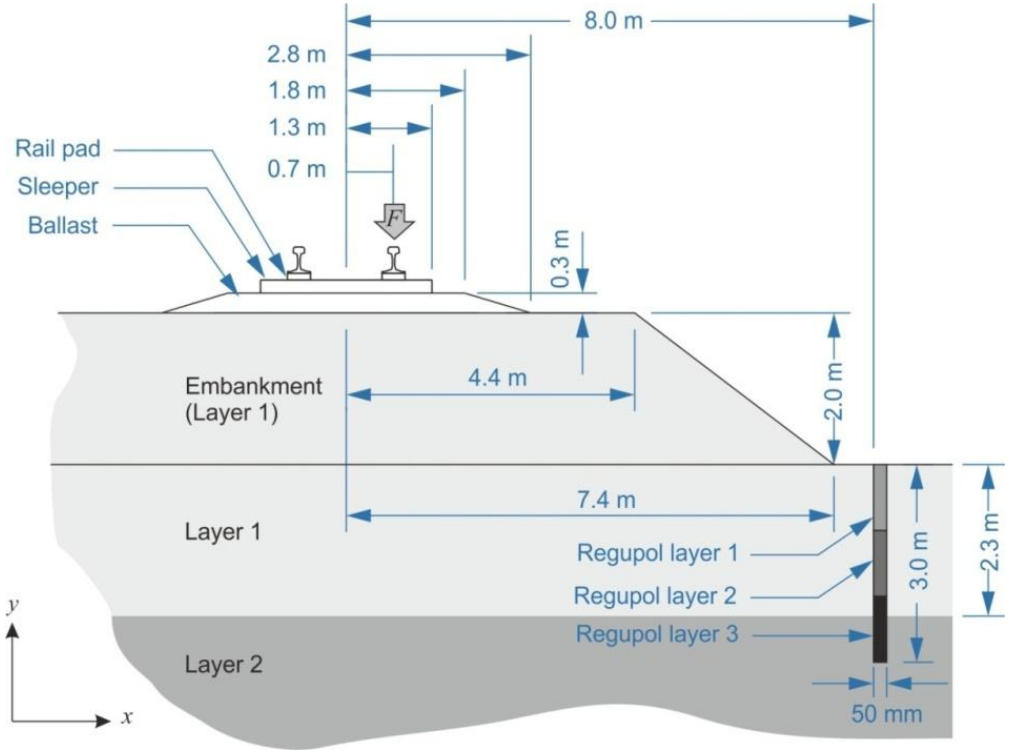
- Benefit dependent on thickness of material



h1=3m,
d=3m,
w=0.25m,
h=6m

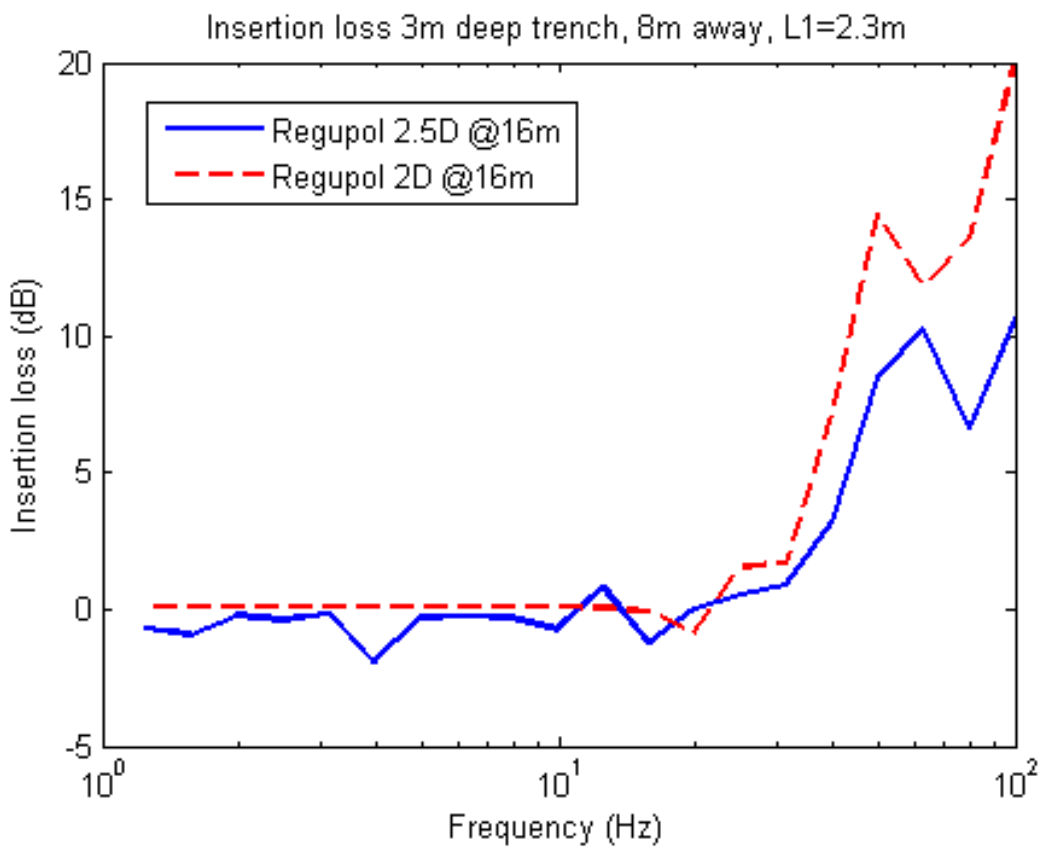
Soft-filled trench

- Example of real material
- Dynamic properties changing with depth
- With track and layered ground – 2D and 2.5D calculations



Soft-filled trench

- Revised ground properties: soft layer now 2.3 m deep

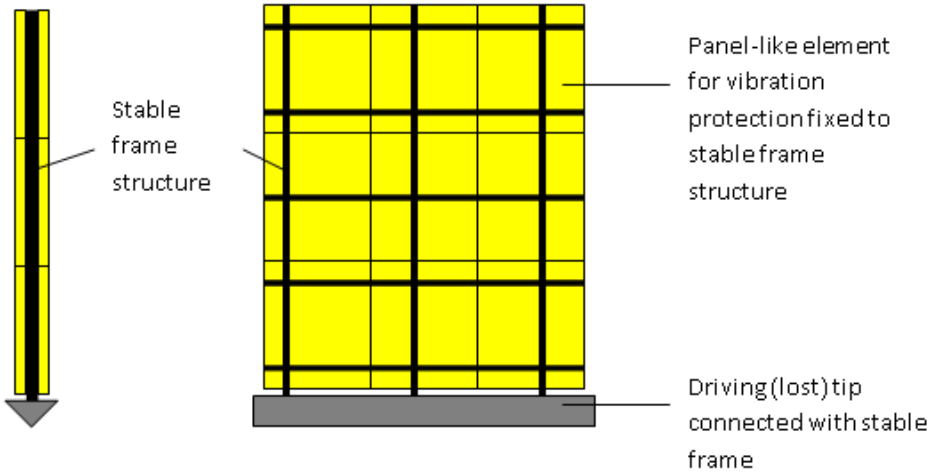


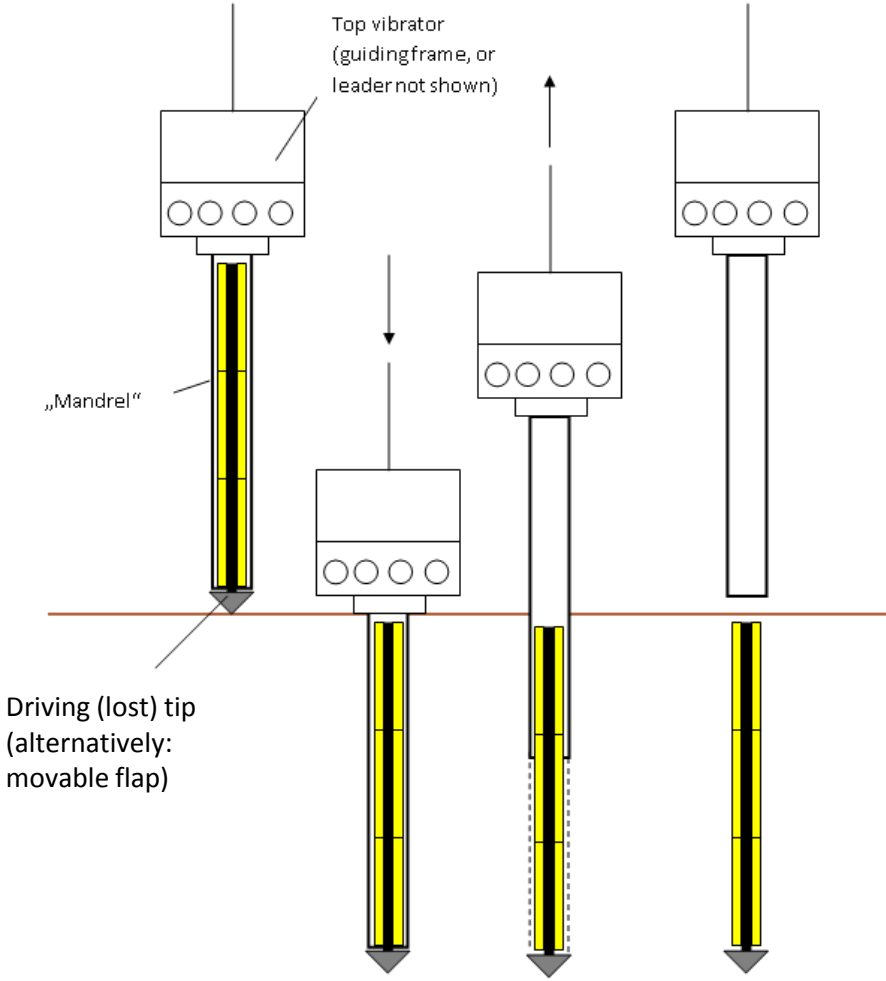
Proposed construction method (Keller)

Keller propose a new method for installation (European patent application filed 22nd March 2012)

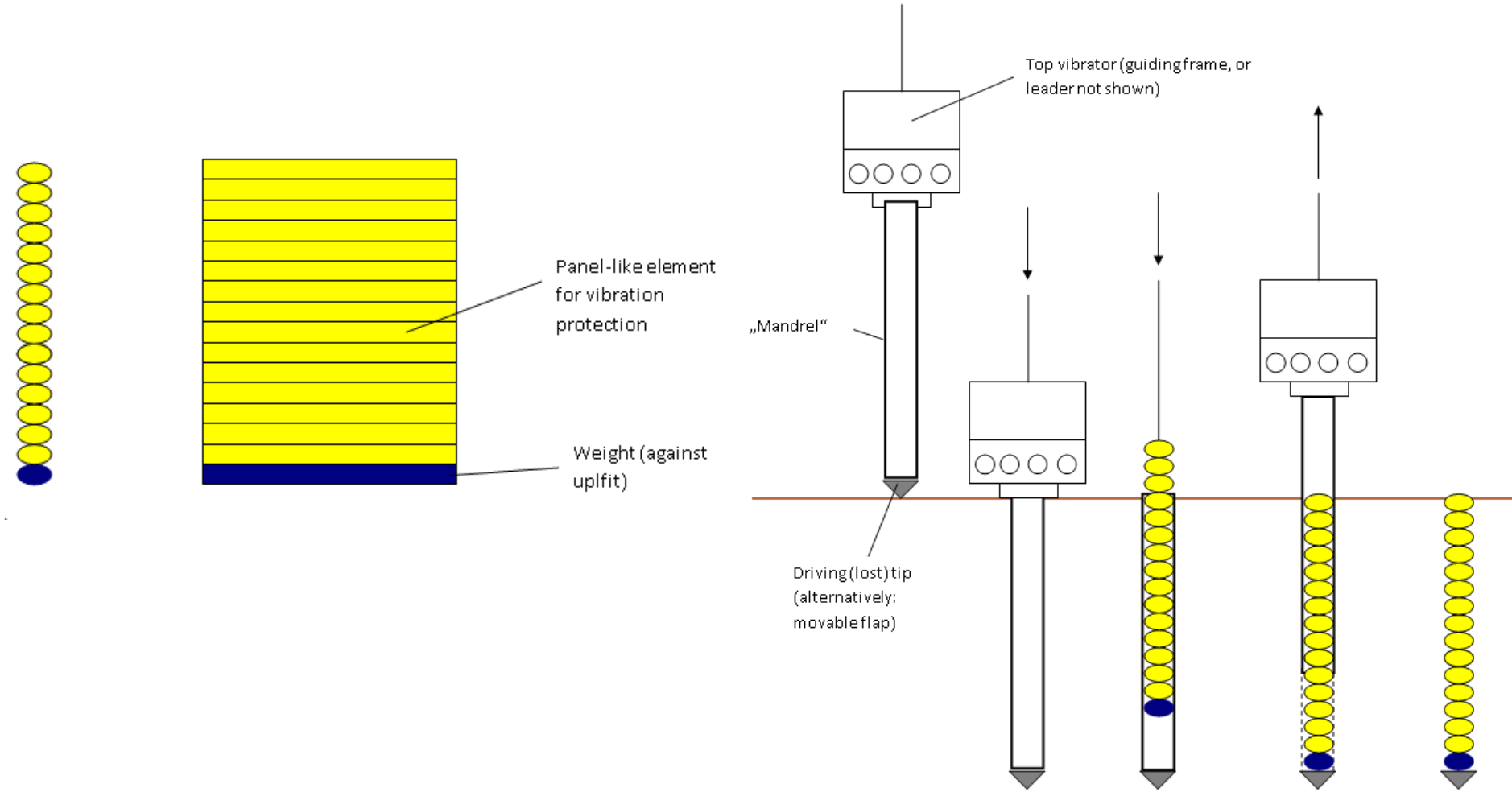
- By means of the proposed method a filled trench as wave barrier can be installed up to greater depth, say 4 to 6 m deep (depending on ground conditions)
- The width of the trench will be adjusted according to the material (thickness) to be installed
- The installation method is practically independent from the depth of ground water level and will not influence the lateral stability of the ballast

Proposed construction method (Keller)





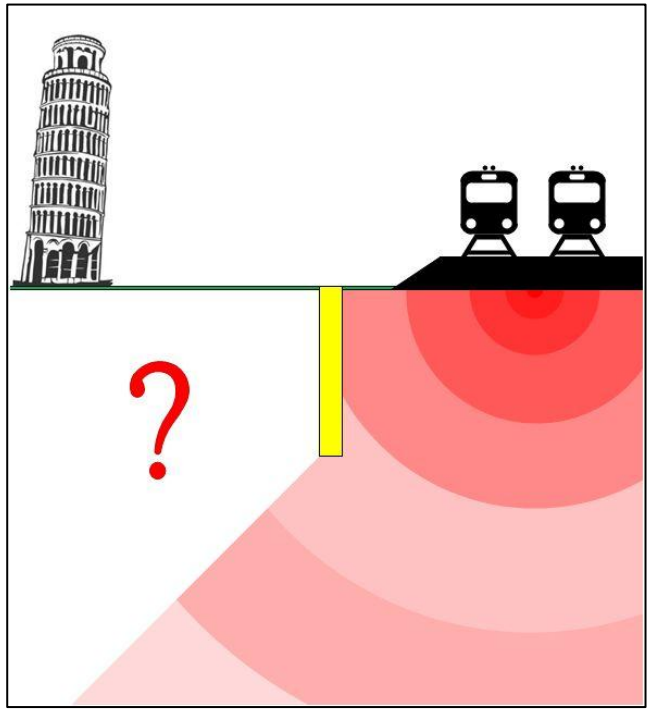
Proposed construction method (Keller)



Field test in Switzerland

- Initial proposed test site in Switzerland was found to have an upper soft layer that was too shallow
- A new site has now been identified
- After confirming the soil properties it is hoped to carry out a trial installation and test this summer

Summary

- Trenches are potentially beneficial for problem sites with a soft upper soil layer
- An open trench is predicted to have a good performance if it cuts through the soft upper soil layer
- A soft-filled trench has a reduced performance but can still be attractive
- Implementation is to be tested at a site in Switzerland

Discussion?