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How close the structures can be to the dynamic compaction site?
How to estimate vibrations due to impact compaction more accurately?

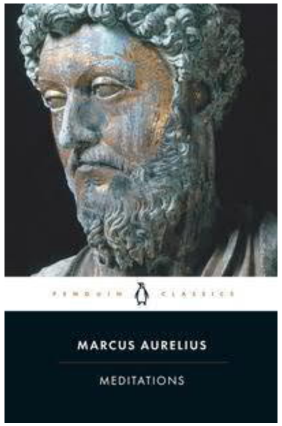
Naum Shpata, Doctoral Researcher

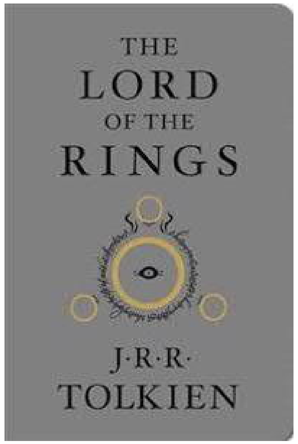
Wojciech Sołowski, Associate Professor

POHJANVAHVISTUSPÄIVÄ

August 21, 2025

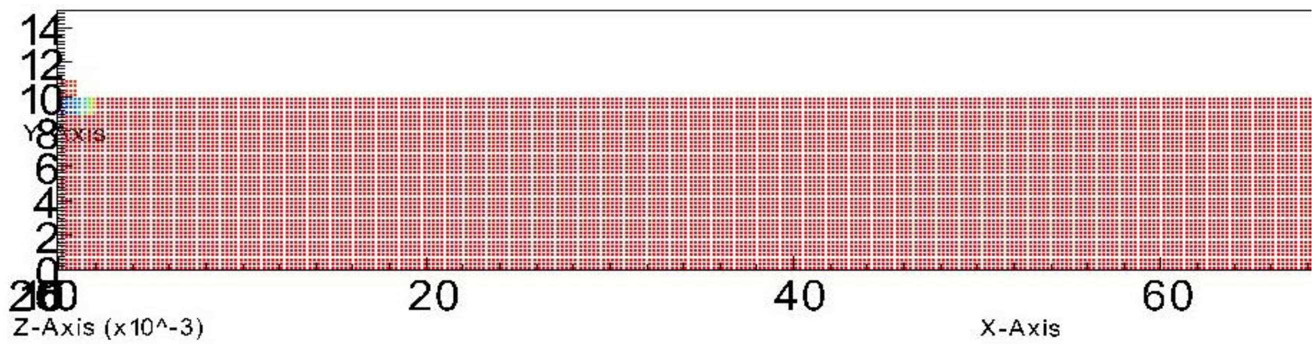
Hello!





Research Topics

- Soil Dynamics
- Constitutive modelling
- Numerical Simulation



Movie. 1. Simulation result from the Dynamic Compaction in Gdańsk in Material Point Method.

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Structure of presentation

- Dynamic compaction (DC) & vibration
- Pivoting from traditional methods to advanced modelling
- Case study: Ruoholahti
- Answering the questions

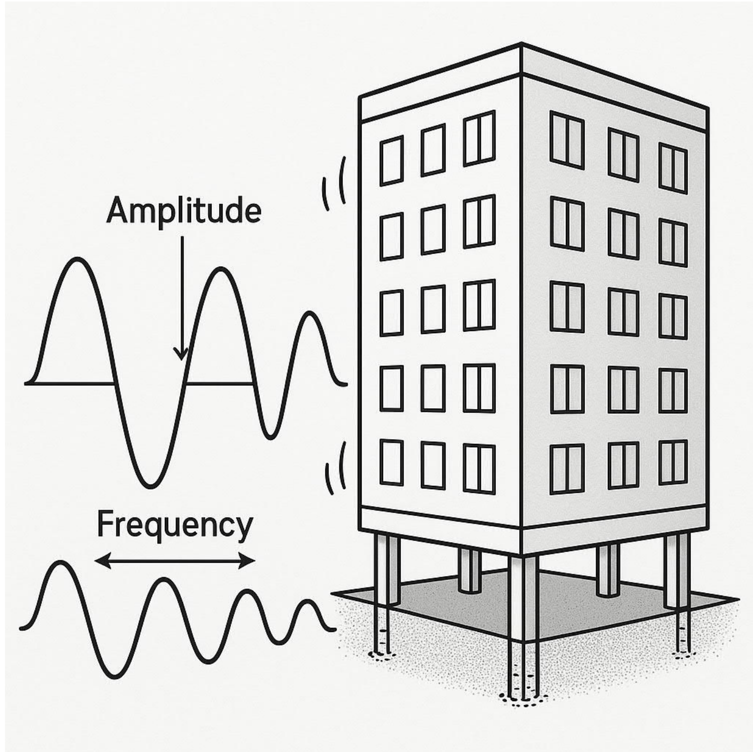


Fig.1. Vibration sketch (generated by A.I.).

Dynamic compaction (DC) & Vibration

- Since ancient times
- Soil improvement method
- Many cases in Finland,

e.g. Ruoholahti, Jätkäsaari, Kruunusillat

- For fine soils: dynamic replacement
- Enviromental issues: Vibrations
- Risk for the nearby structures

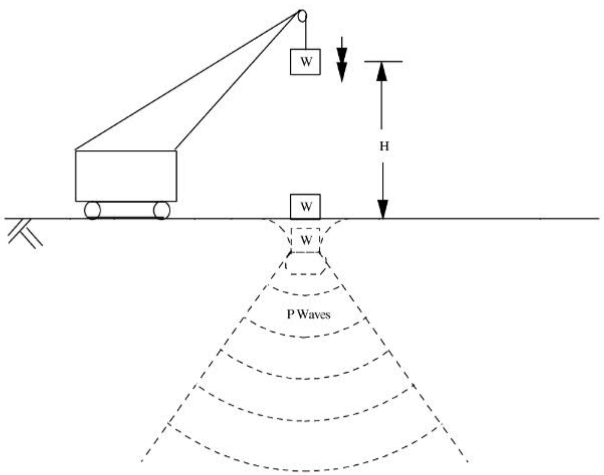


Fig.2. Dynamic compaction schematic (Pan & Shelby, 2002).

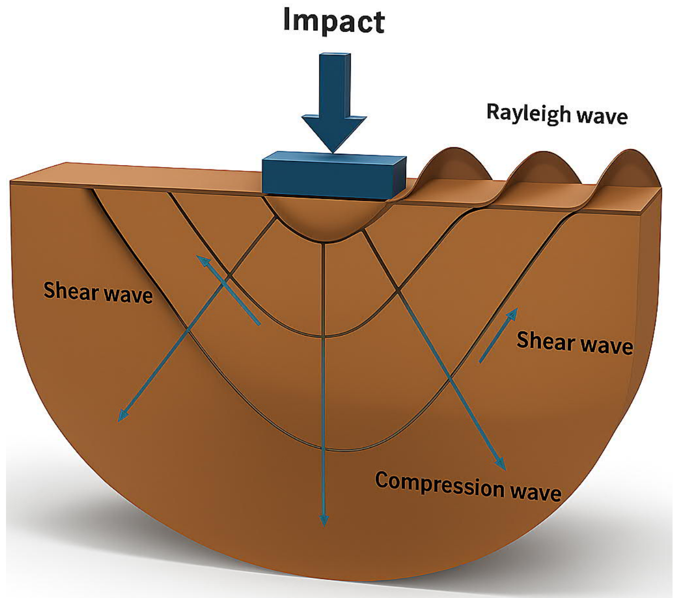
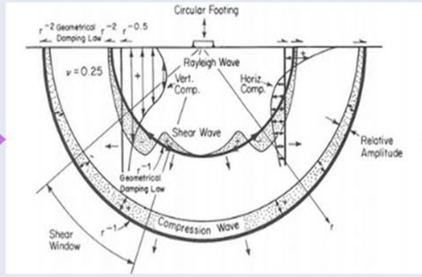


Fig.3. Vibration generation due to impact follows the sketch of Wood (1968).

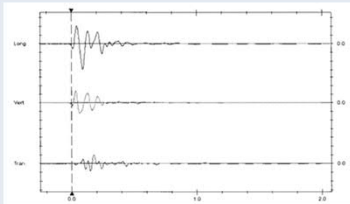
Pivoting from traditional methods to advanced modelling

Impact

Vibrations



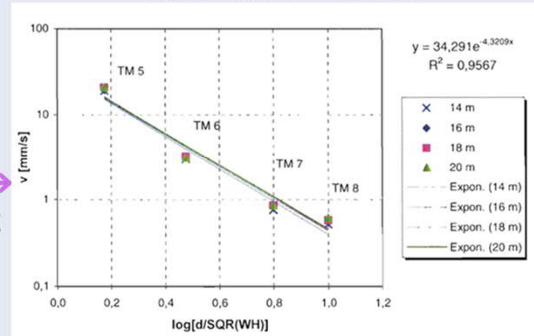
Measurement



Different distances from the impact

Different falling height

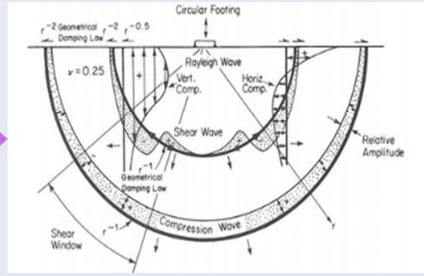
Maximum values



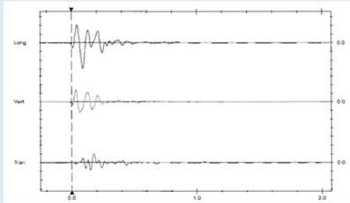
Pivoting from traditional methods to advanced modelling

Impact

Vibrations



Measurement



Different distances from the impact

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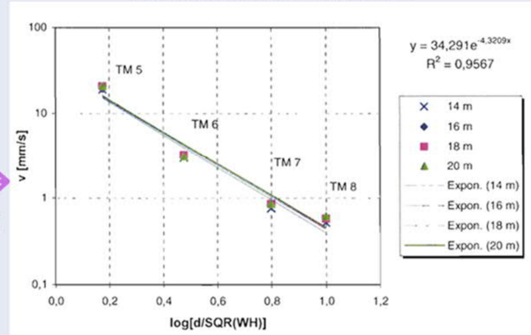

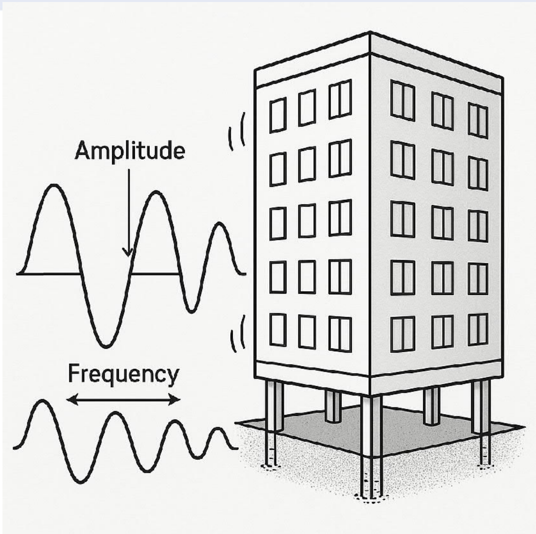

Table1. Vibration thresholds for structural damage
Peak Particle Velocity PPV (mm/s) / **DIN 4150-3:1999**

Type	Short-term at the foundation		
	0-10 Hz	0-50 Hz	50-100 Hz
Commercial/ Industrial	20	20-40	40-50
Residential	5	5-15	15-20
Sensitic/Historic	3	3-8	8-10

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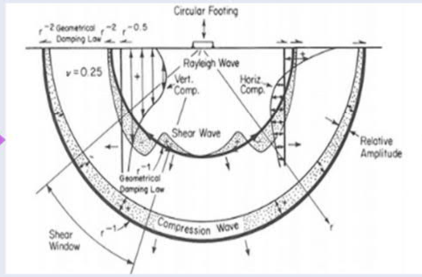
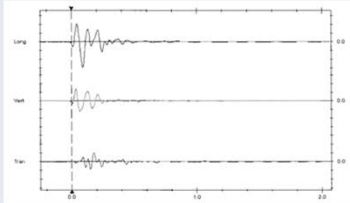
Impact

Vibrations



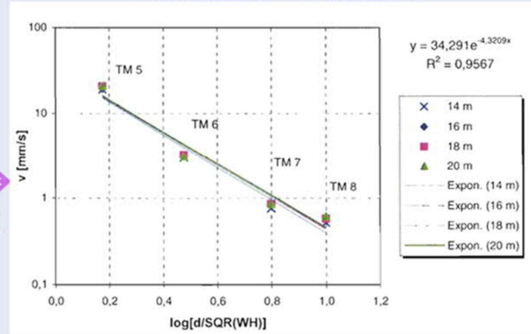
Measurement



Different distances from the impact

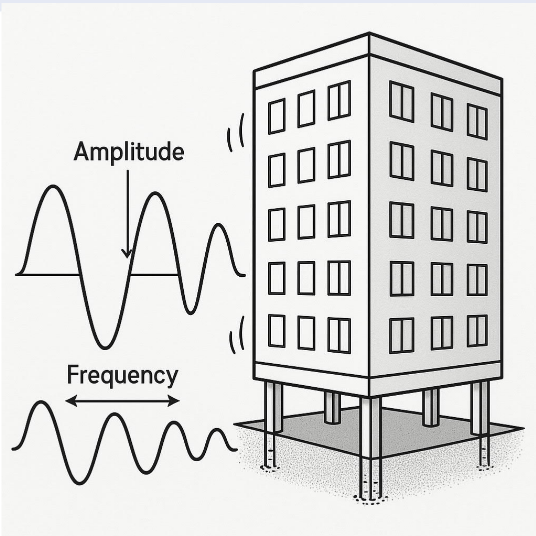
Different falling height

Maximum values



On-site monitoring

- ☑ Trustworthy
- ☑ Simple implementation
- ☒ Costly
- ☒ Not prelimary prediction



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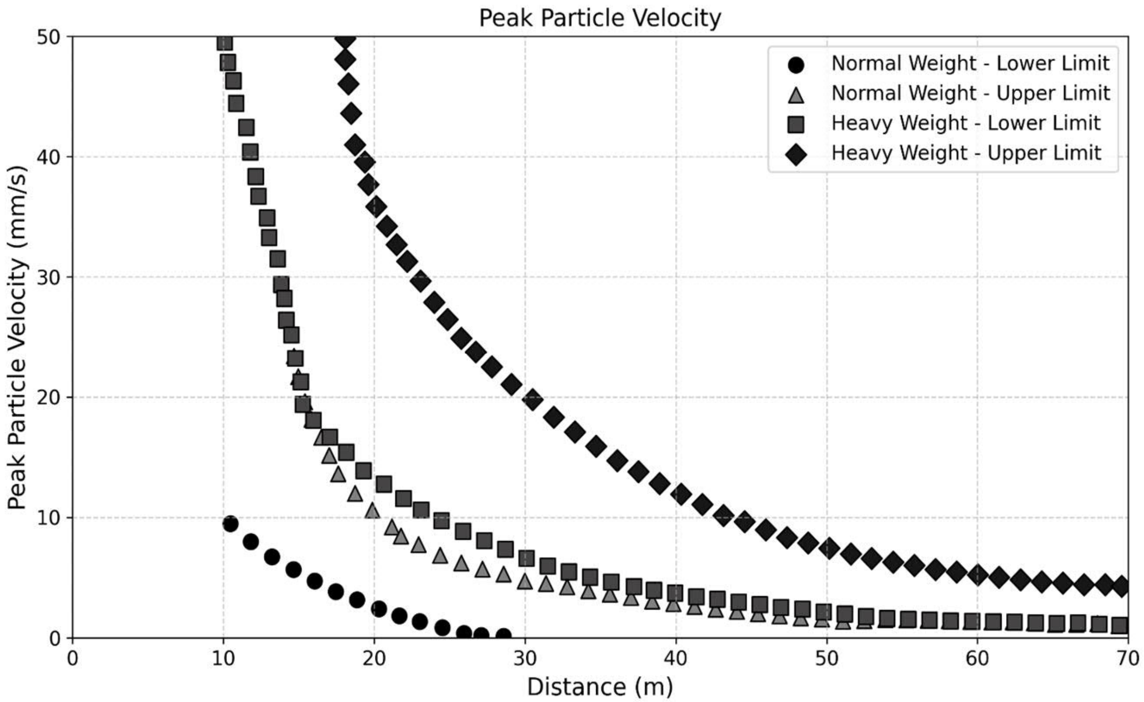


Fig. 4. Empirical estimation of Vibration (graph adopted from Kirsh &Bell, (2012).

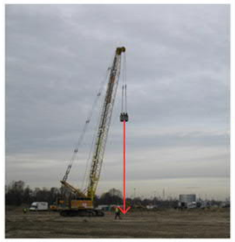
Prediction using semi-empirical methods

☑ ☒ Usually conservative

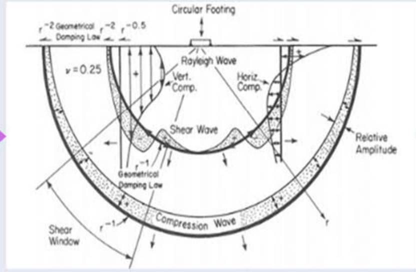
☒ Rough estimation

Pivoting from traditional methods to advanced modelling

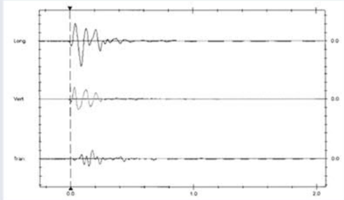
Impact



Vibrations

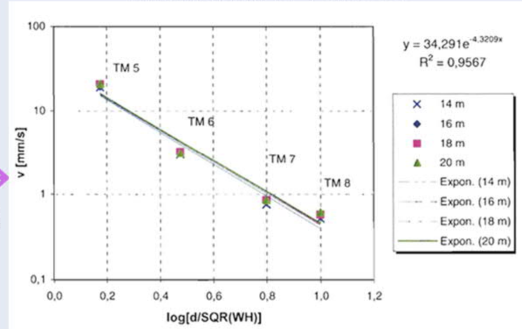


Measurement

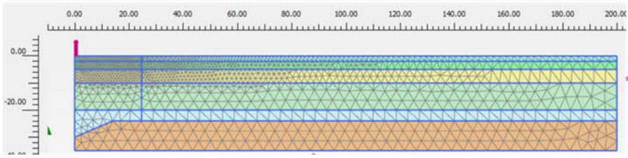


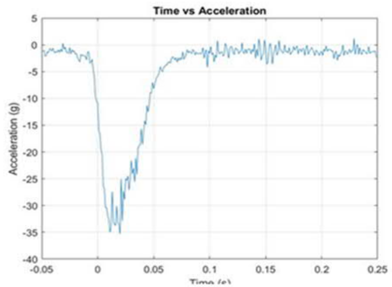
Different distances from the impact
Different falling height

Maximum values



Numerical Model

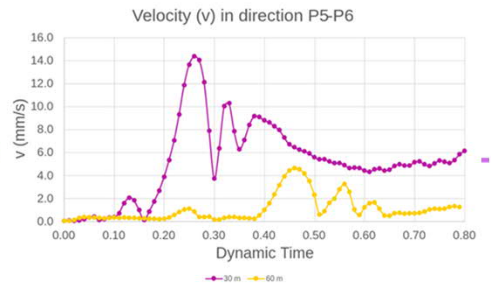




Input signal

Custom Model

Result of the analysis



Pivoting from traditional methods to advanced modelling

Numerical Method

- **Finite Element Method** → PLAXIS 2D
- Finite Volume Method
- Material Point Method
- Discrete Element Method

Input signal

- Empirical
- **Field measurement** → Menard Group

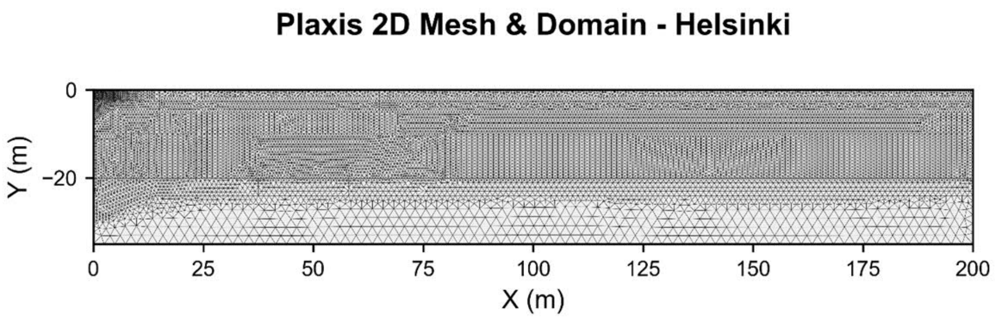


Fig. 5. Simulation domain (Shpata et al., 2025).

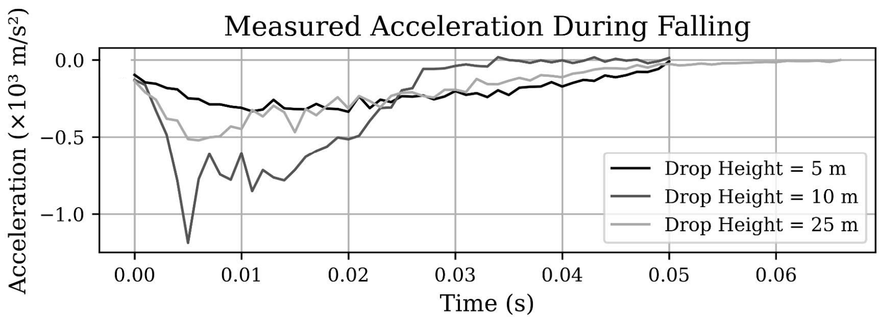


Fig. 6. Measured acceleration during dynamic compaction process (Shpata et al., 2025).

Pivoting from traditional methods to advanced modelling

Numerical Method

- **Finite Element Method** → PLAXIS 2D
- Finite Volume Method
- Material Point Method
- Discrete Element Method

Input signal

- Empirical
- **Field measurement** → Menard Group

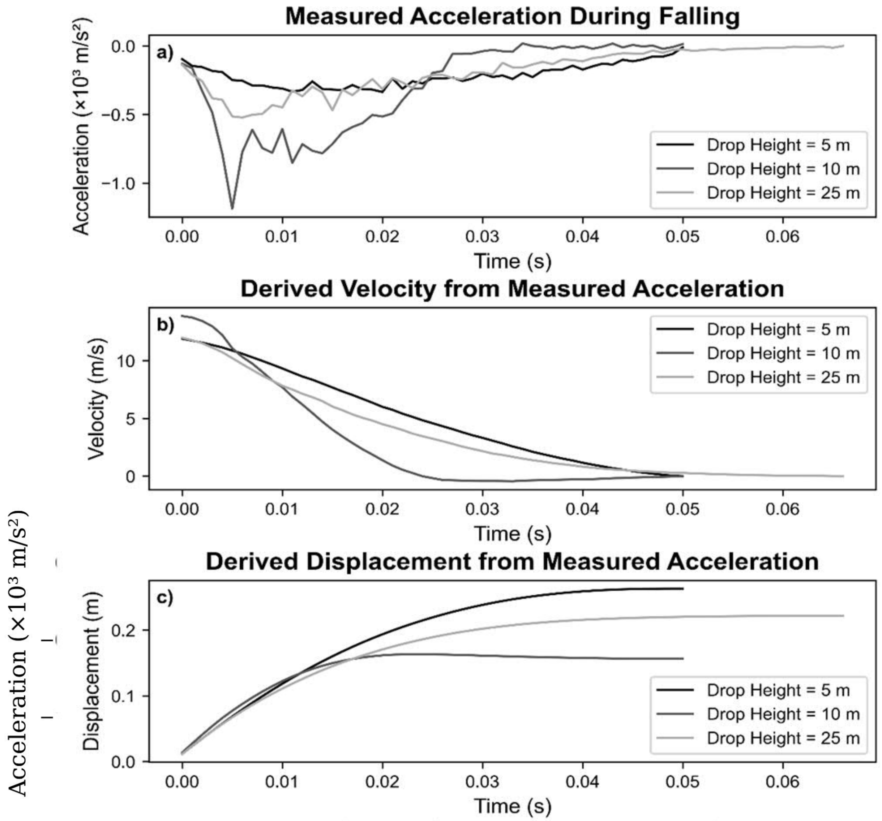


Fig. 6. Measured acceleration during dynamic compaction process (Shpata et al., 2025).

Pivoting from traditional methods to advanced modelling

Soil Behaviour

- Shear strain-dependent stiffness
- Shear strain-dependent damping ratio
- Non-linear relationship

Constitutive model

- **Hardening Soil with small-strain stiffness**
- **Custom model developed at Aalto University**

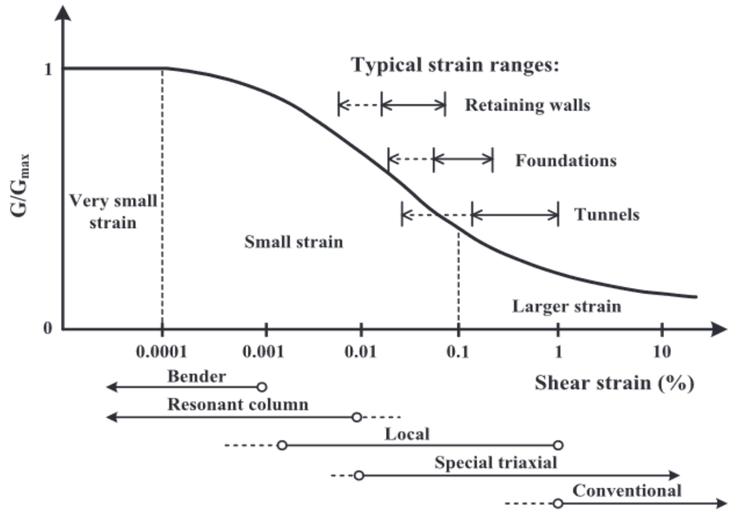


Fig. 7. Degradation curve of soil stiffness (modified after Atkinson & Sallfors (1991)).

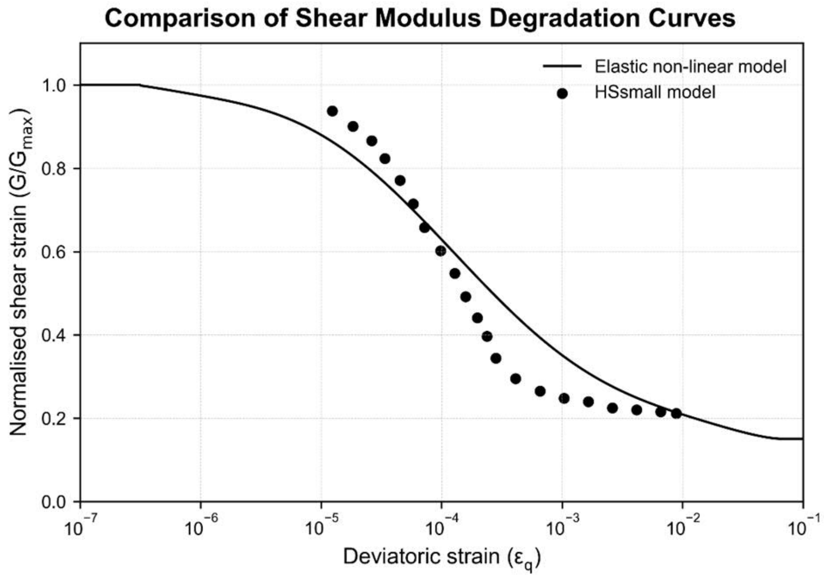


Fig. 8. Stiffness degradation curves (Shpata et al., 2025).

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Hardening Soil with small-strain stiffness

- Standard model - Elastoplastic
- Small-strain shear modulus
- Material damping: Hysteretic behaviour
- 13 parameters

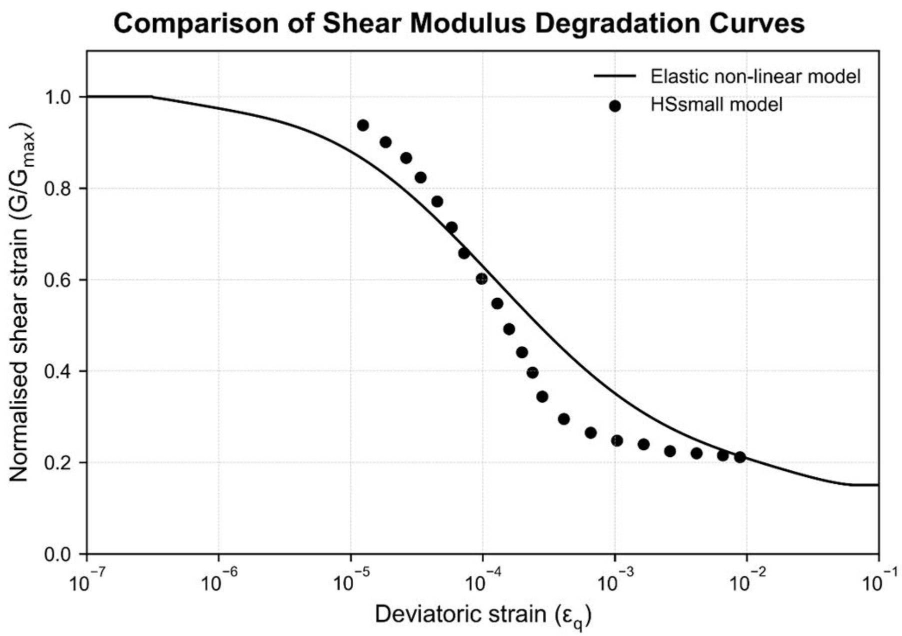

Fig.8. Stiffness degradation curves (Shpata et al., 2025).

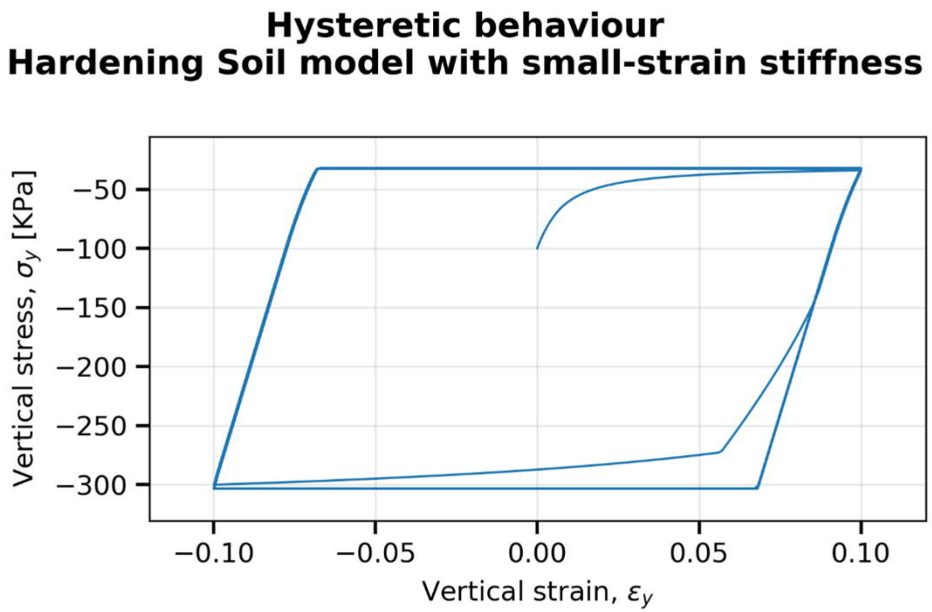

Fig. 9. Hysteretic behaviour of Hardening Soil model with small-strain stiffness.

Pivoting from traditional methods to advanced modelling

Custom model developed at Aalto University

- Fully Elastic
- Small-strain shear modulus
- Material damping: Reyleigh coefficients
- 2 parameters: G_{max}, Poisson's ratio

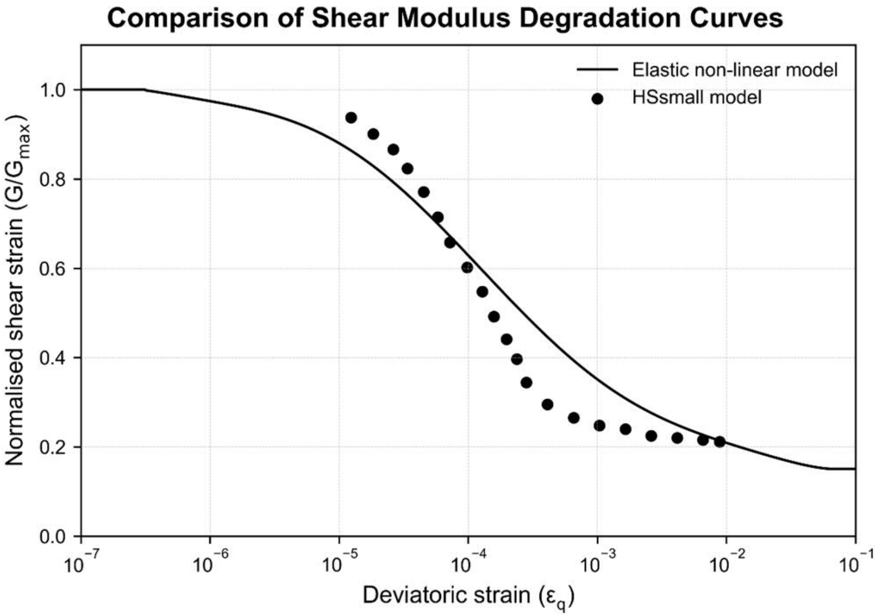

Fig. 8. Stiffness degradation curves (Shpata et al., 2025).

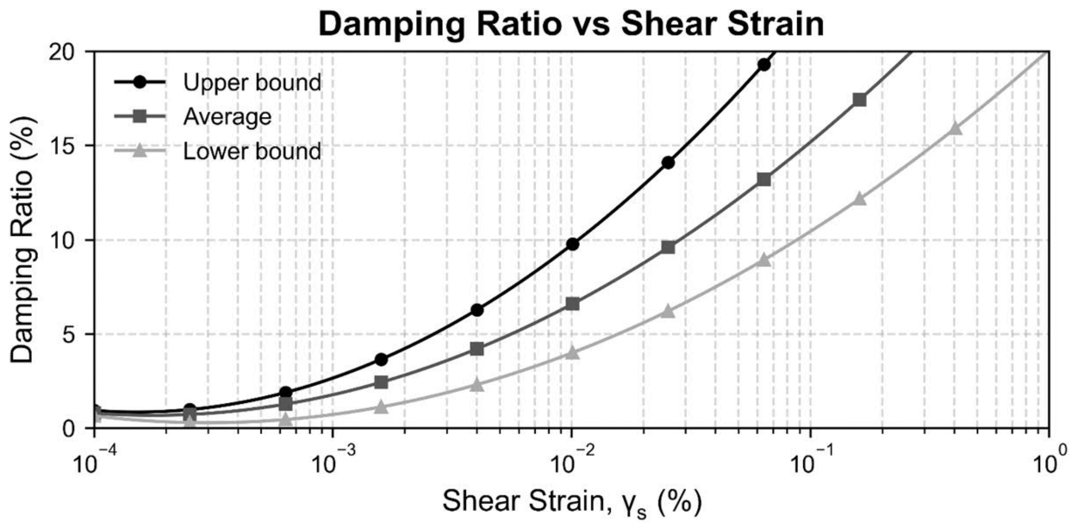

Fig. 10. Damping ratio based on Seed et al. (1968) (Shpata et al., 2025).

Case study: Ruoholahti

Environmental impact

Vibration measurements

Approx. 10 m man-made fill

On top of sand

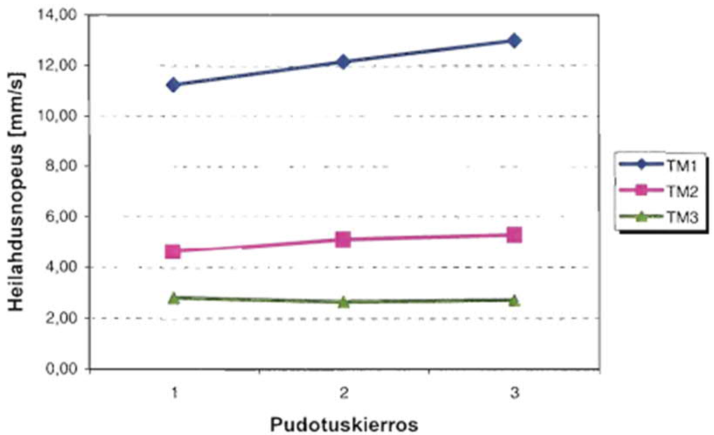

Fig. 11. Vibrations measurements point retrieved from Viljanen & Korhonen (2002).

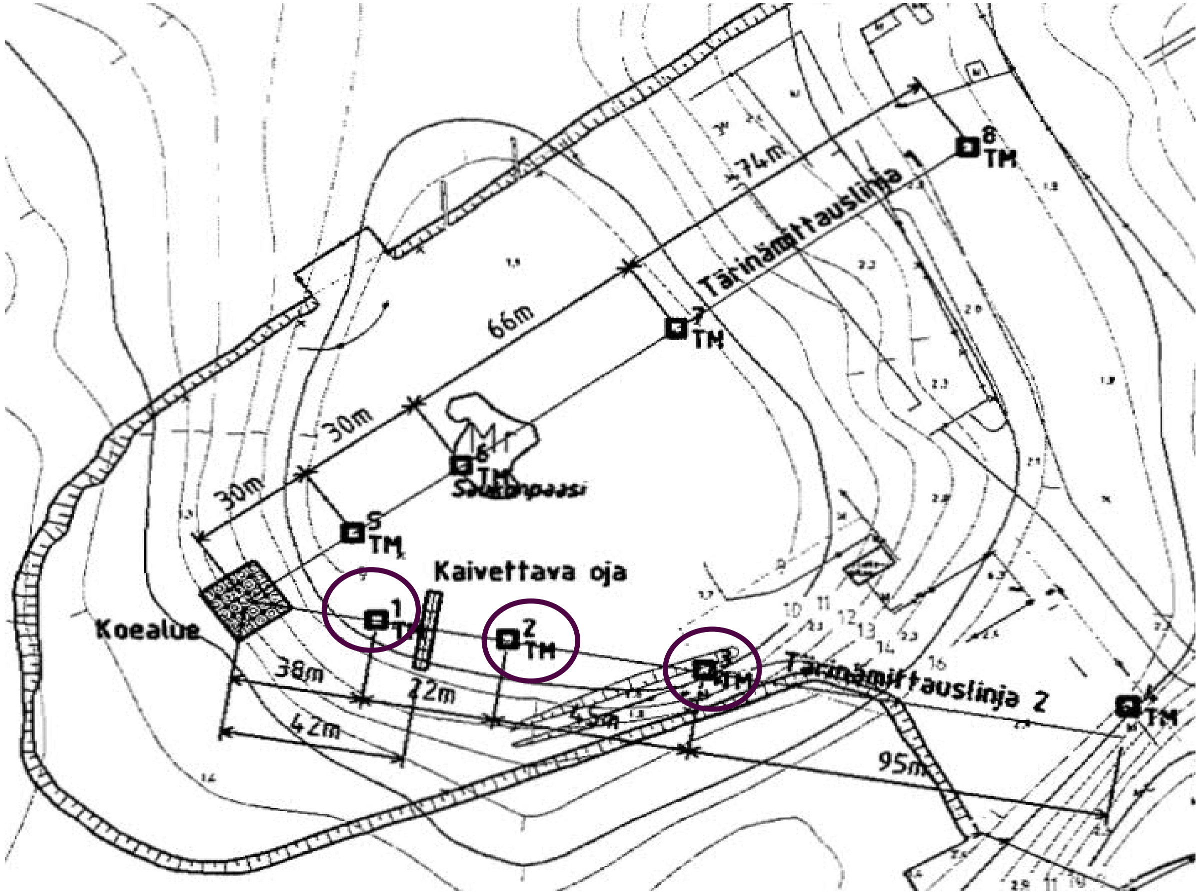

Fig. 12. Map of the measurement point retrieved from Viljanen & Korhonen (2002).

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Case study: Ruoholahti

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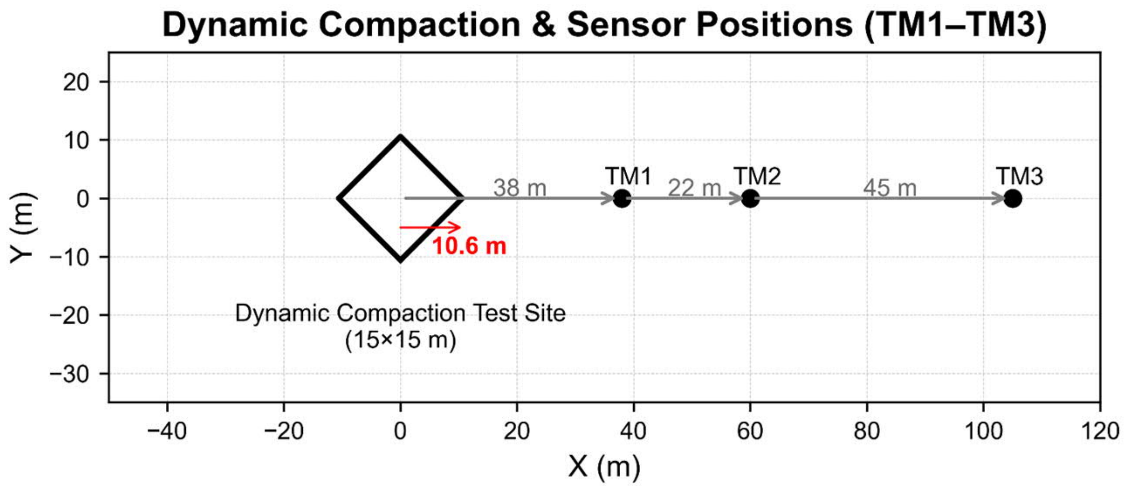
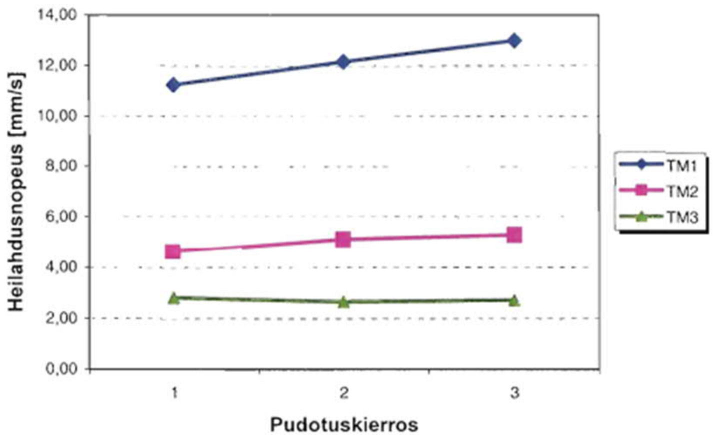


Fig. 13. Simulation geometry (Shpata et. al., 2025).



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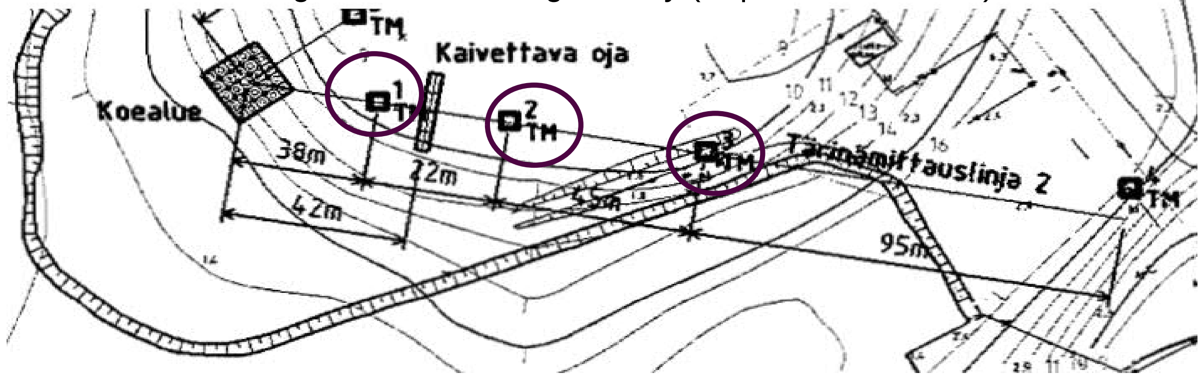


Fig. 12. Map of the measurement point retrieved from Viljanen & Korhonen (2002).

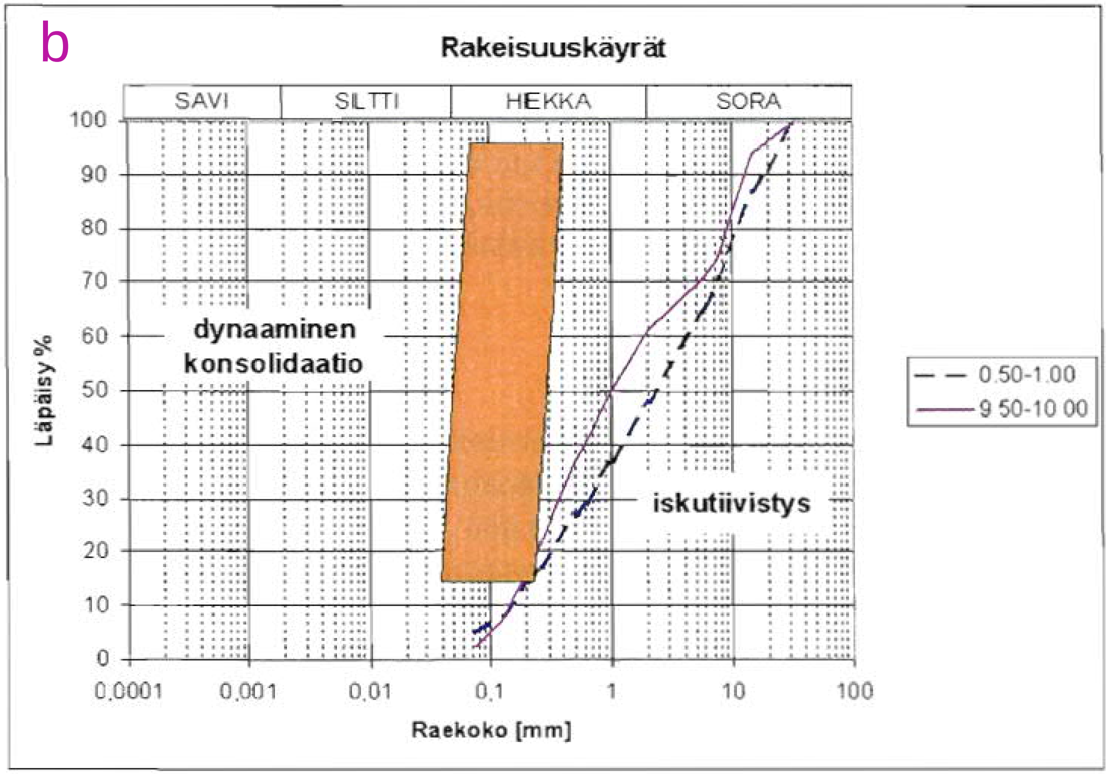
Case study: Ruoholahti

Fig. 14. a,b,c,d. Soil data retrieved from Viljanen & Korhonen (2002).

a

Syvyys [m]	Maalaji	Kerrosrajat	Täyte/luonnontilainen
0.5 – 1.0	srHk	srHk	Täytemaakerros
1.5 – 2.0	srHk		
2.5 – 3.0	srHk		
3.5 – 4.0	Sr	Sr	
4.5 – 5.0	Sr		
5.5 – 6.0	hkSr	hkSr	
6.5 – 7.0	hkSr		
7.5 – 8.0	hkSr		
8.5 – 9.0	Sr	Sr	
9.5 – 10.0	srHk		
10.5 – 11.0	Hk	Hk	Luonnontilainen maa
11.5 – 12.0	Hk		
12.5 – 13.0	Hk		
13.5 – 14.0	Hk		
14.5 – 15.0	Hk		

b



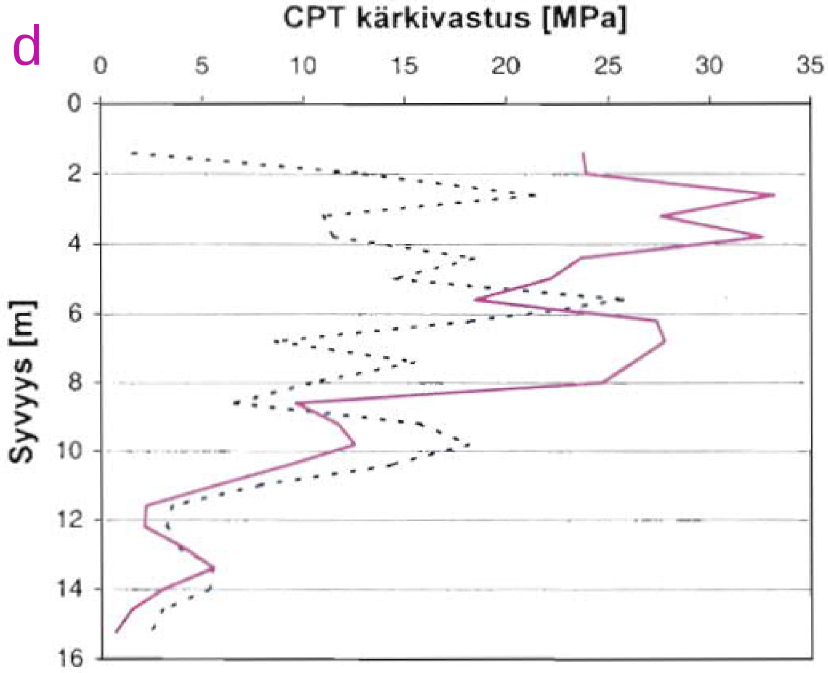
Case study: Ruoholahti

Fig. 14. a,b,c,d. Soil data retrieved from Viljanen & Korhonen (2002).

c

Parametri			Näyte 0.5 – 1.0	Näyte 9.5 – 10.0
Maalaji			hkSr	srHk
Näytteen kokonaismas-sa	m_0	[g]	1200	1600
Kostean näytteen massa	m	[g]	1120,7	1194,9
Tilavuuspaino	γ	[kN/m^3]	21,72	21,33
Kuivatilavuuspaino	γ_d	[kN/m^3]	19,67	19,53
Vesipitoisuus	w	[%]	10,4	9,2
Kivisyys (> 16 mm)	K	[%]	14,1	6,1
Kuivatilavuuspainon maksimi	γ_{dmax}	[kN/m^3]	20,41	19,85
Kuivatilavuuspainon minimi	γ_{dmin}	[kN/m^3]	14,94	16,43
Tilavuuspainon maksimi	γ_{max}	[kN/m^3]	22,29	21,59

d



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Case study: Ruoholahti

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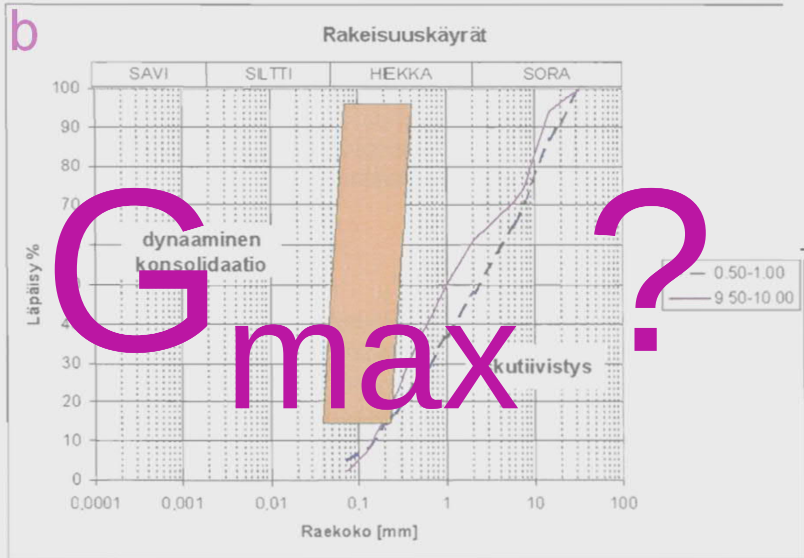
a

Syvyys [m]	Maalaji	Kerrosrajat	Täyte/luonnontilainen
0.5 – 1.0	srHk	srHk	Täytemaakerros
1.5 – 2.0	srHk		
2.5 – 3.0	srHk		
3.5 – 4.0	Sr	Sr	
4.5 – 5.0	Sr		
5.5 – 6.0	hkSr	hkSr	
6.5 – 7.0	hkSr		
7.5 – 8.0	hkSr		
8.5 – 9.0	Sr	Sr	
9.5 – 10.0	srHk		
10.5 – 11.0	Hk	Hk	Luonnontilainen maa
11.5 – 12.0	Hk		
12.5 – 13.0	Hk		
13.5 – 14.0	Hk		
14.5 – 15.0	Hk		

b



G_{max} ?

c

Parametri			Näyte 0.5 – 1.0	Näyte 9.5 – 10.0
Maalaji			hkSr	srHk
Näytteen kokonaismassa	m_0	[g]	1200	1600
Kostean näytteen massa	m	[g]	1120,7	1194,9
Tilavuuspaino	γ	[kN/m^3]	21,72	21,33
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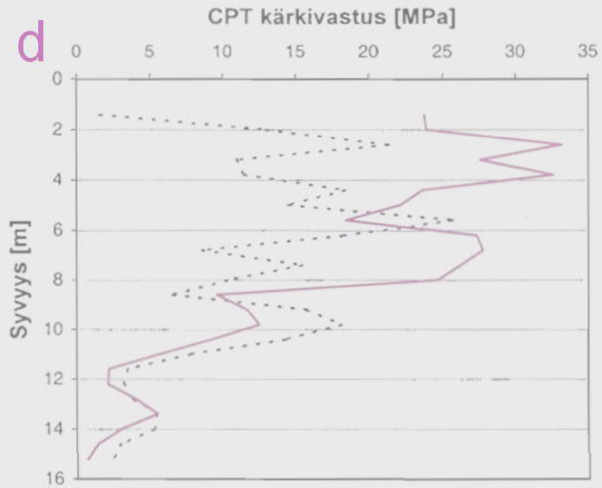
d



Available data from 0.5-1.0 m & 9.5-10.0 m

Few data

Viljanen, J., & Korhonen, O. (2002). *Pudotustiivistys Saukonpaaden täyttöalueella*. Helsingin kaupunki, Kiinteistövirasto Geotekniikka. Retrieved from https://www.hel.fi/static/kv/Geo/Tiedotteet/Tiedote+85.pdf

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Case study: Ruoholahti

$G_{max} = A_g * f(e) * (p')^n$ (Hardin & Black, 1968)

- Soil type (A_g, n)
- Void ratio $(f(e))$
- Stress state (p')

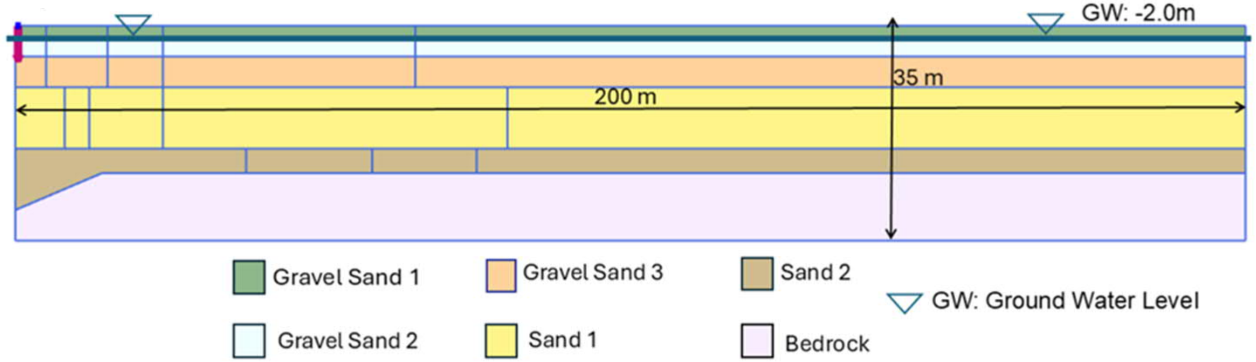

Fig. 15. Axisymmetric section of the simulation domain (Shpata et. al., 2025).

Table 2. Soil properties (Shpata et. al., 2025).

Soil type	Depth (m)	Unit weight γ (kN/m³)	Poisson's ratio (ν)	Void ratio (e)	G_{max} (MPa)
Gravel Sand 1	(0.00 – 2.00)	21.00	0.20	0.33	25
Gravel Sand 2	(2.00 – 5.00)	21.00	0.20	0.33	48
Gravel Sand 3	(5.00 – 10.00)	21.00	0.20	0.33	98
Sand 1	(10.00 – 20.00)	19.00	0.30	0.60	110
Sand 2	(20.00 – 30.00)	19.00	0.30	0.60	139

Case study: Ruoholahti

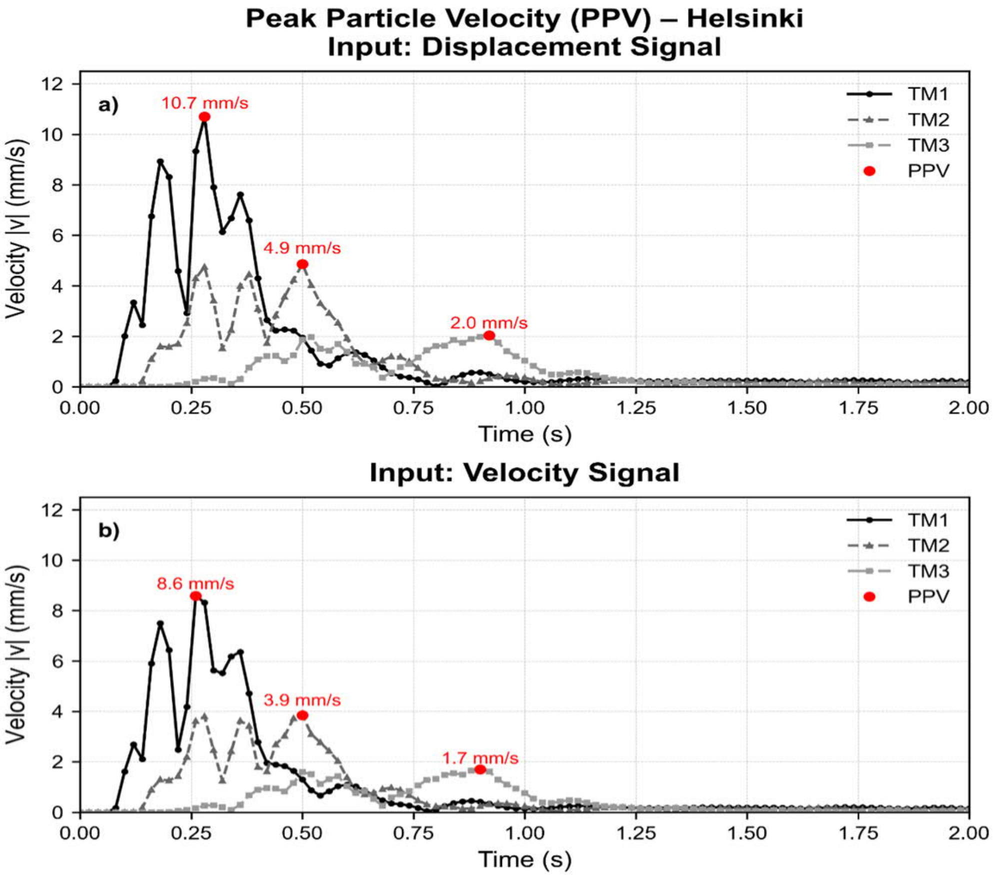

Fig. 16. Simulations results (Shpata et. al., 2025)

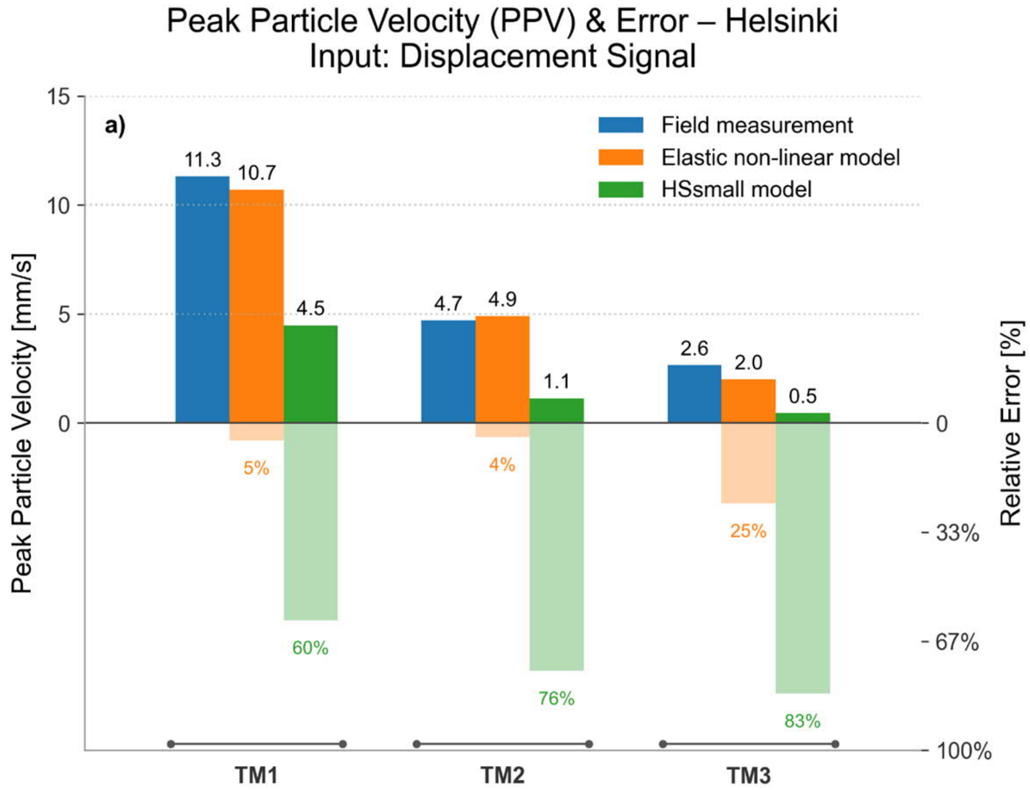

Fig. 17.a) Comparison of the models.

Case study: Ruoholahti

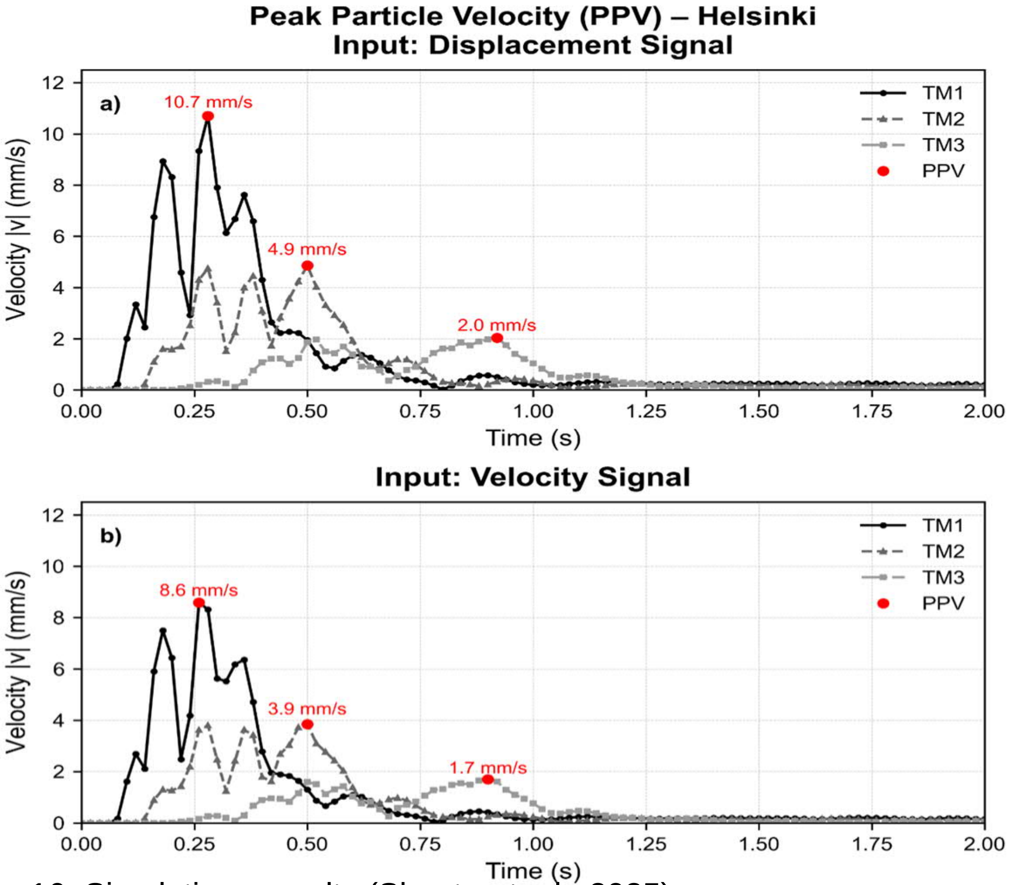

Fig. 16. Simulations results (Shpata et. al., 2025)

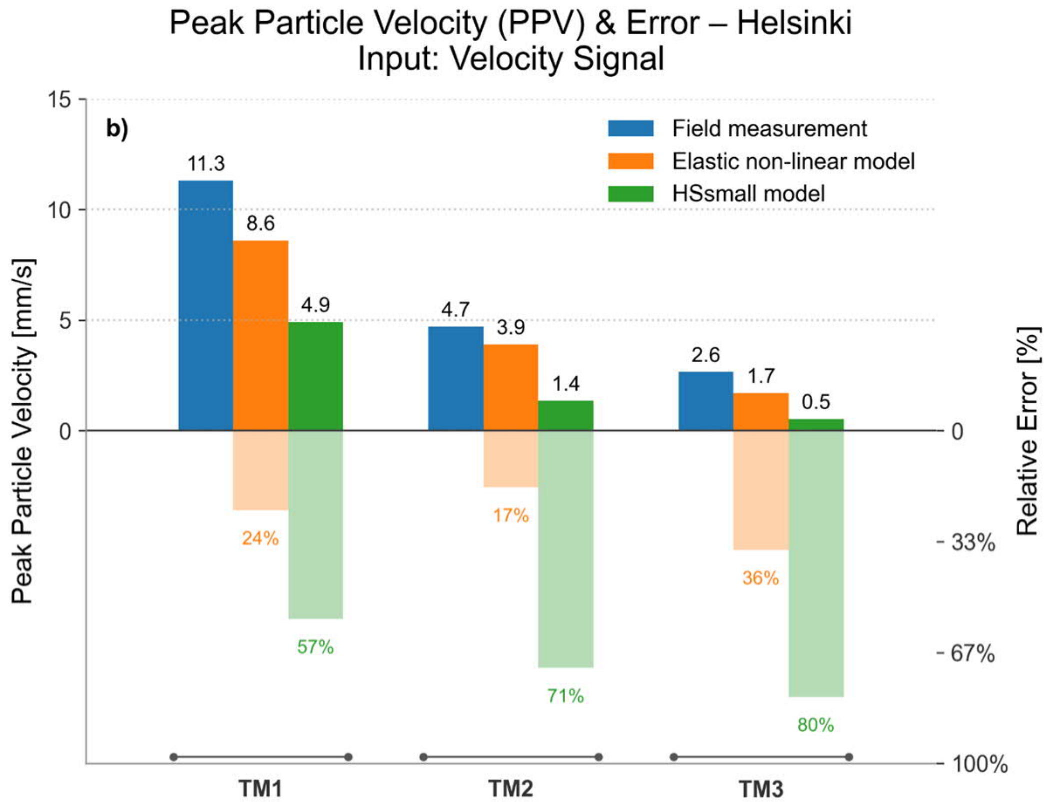

Fig. 17.b) Comparison of the models.

How close the structures can be to the dynamic compaction site?

Wave: frequency & amplitude

Building: Type (resonant frequency, importance)

Ruoholahti case

Proposed framework & standard :

Frequency 8-9 HZ

- High risk for residential buildings at 50–55 meters

Table1. Vibration thresholds for structural damage
Peak Particle Velocity PPV (mm/s) / **DIN 4150-3:1999**

Type	Short-term at the foundation		
	0-10 Hz	0-50 Hz	50-100 Hz
Commercial/ Industrial	20	20-40	40-50
Residential	5	5-15	15-20
Sensitic/Historic	3	3-8	8-10

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How to estimate vibrations due to impact compaction more accurately?

Soil behaviour

- Small-strain shear stiffness (shear strain dependent)
- Damping ratio (shear strain dependent)

Numerical methods

- Proposed model by Aalto ☺☺☺
- Calibration of existing models *ad hoc*

(requires time and expertise)

⚠ Caution advised when using standard models ⚠

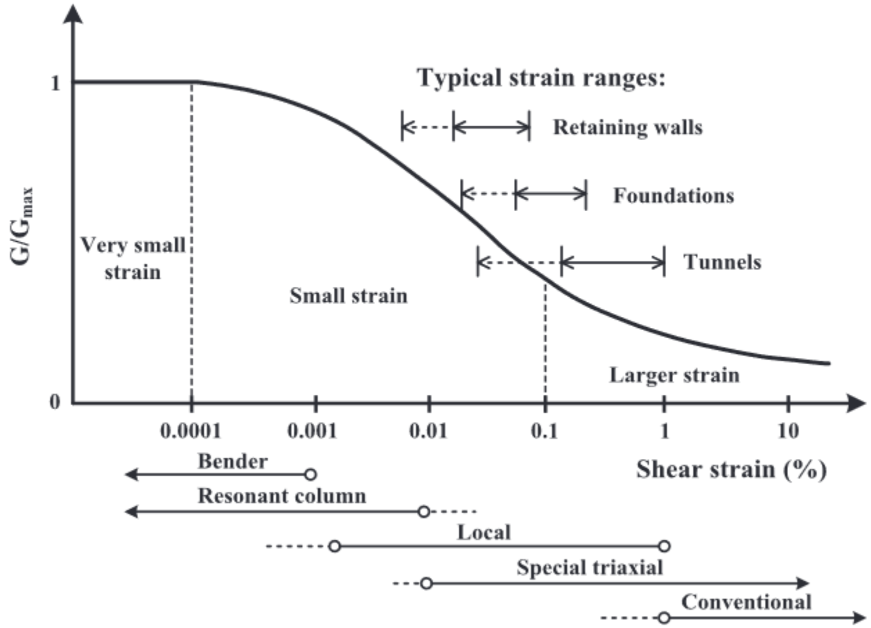

Fig. 3. Generation of vibration (Wood, 1968).

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How to estimate vibrations due to impact compaction more accurately?

Simulation of impact:

- No perfect way due to framework
- Field measurements signals recommended
- Velocity-time signal → acceleration
- Displacement-time signal → velocity

Not an obstacle! ☺

What's Next ?

- Vibration mitigation structures
- Dynamic replacement
- Soil-Structure interaction

Fig. 18. Dynamic compaction in Gdansk Menard Group.

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Thank You!
Kiitos!

Happy to collaborate!
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