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Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

Finite element modelling of Ultra-Thin Continuously Reinforced Concrete Pavement

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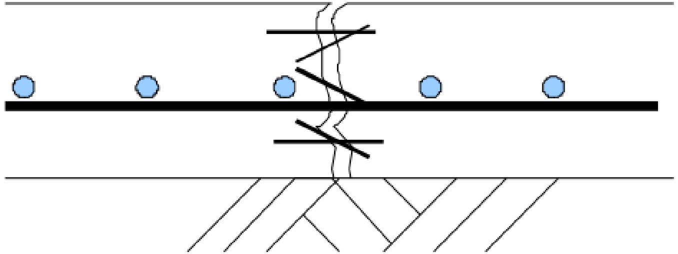
13 November 2018

What is Ultra-Thin Continuously Reinforced Concrete Pavement?

- 50 mm concrete surfacing
- High Strength Steel Fibre Reinforced Concrete
- Steel bar mesh
  - 50 x 50 mm mesh
  - 5.7 mm diameter



What is Ultra-Thin Continuously Reinforced Concrete Pavement?

- Why develop UTCRCP?

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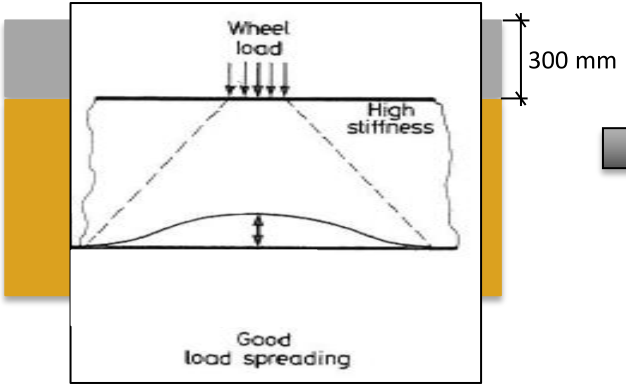
Background

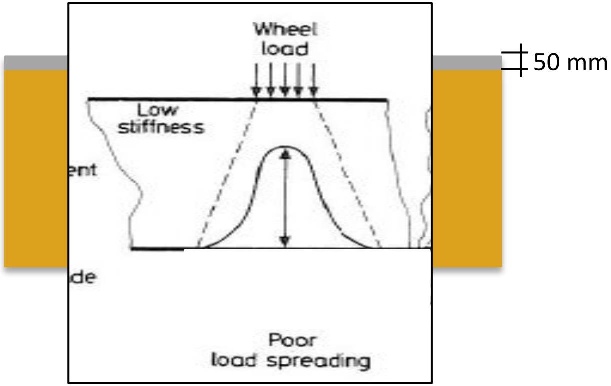
- Perspective on difference in thickness

Conventional concrete pavement



Brown & Selig (1991)

UTCRCP



Brown & Selig (1991)

- Should we consider UTCRCP as a flexible pavement?
- Differential, vertical permanent deformation (rutting)?

Numerical modelling

Part 1: Theoretical deflected shapes

- Beam-on-elastic support

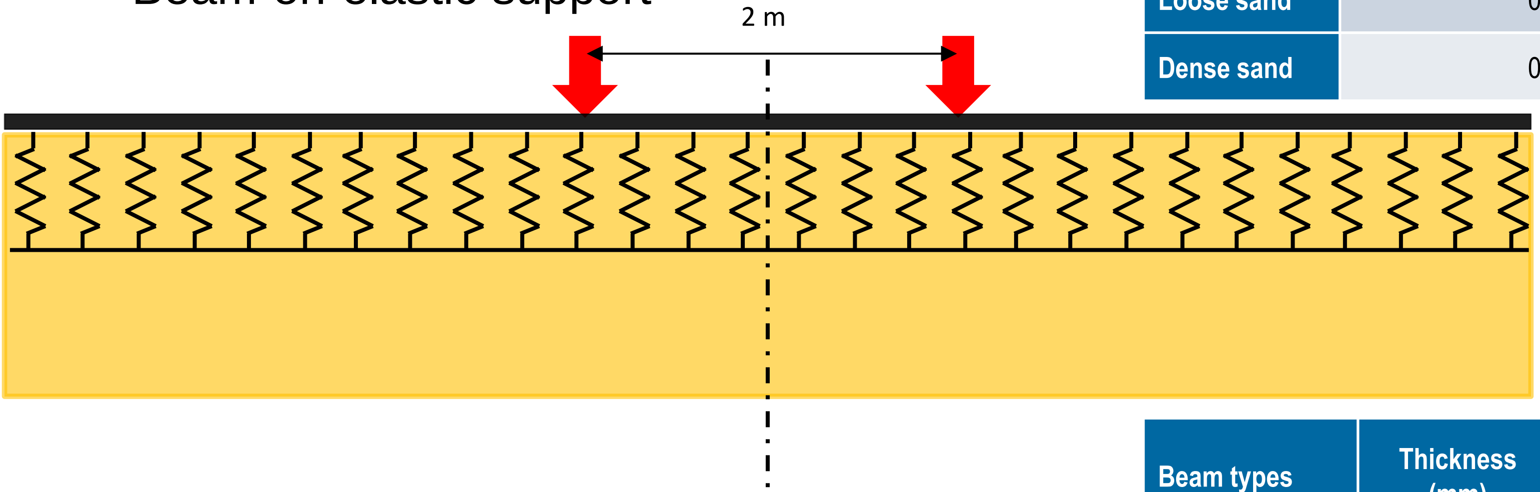
Part 2: 3D finite element analyses of three-layer system

- Part 2.1: Comparison of effect of load configuration on asphalt and concrete bound layer

- Part 2.2: Multivariable analyses of bound layer thickness and base E-value

Part 1 Theoretical deflected shapes

- Beam-on-elastic support



Support types	Modulus of subgrade reaction (MPa/mm)
Loose sand	0.016
Dense sand	0.128

Beam types	Thickness (mm)	Modulus of elasticity (MPa)
Thin asphalt	50	2 759
Thin concrete	50	40 000
Thick concrete	300	40 000

Part 1 Theoretical deflected shapes

- Dense sand

Support types	Modulus of subgrade reaction (MPa/mm)
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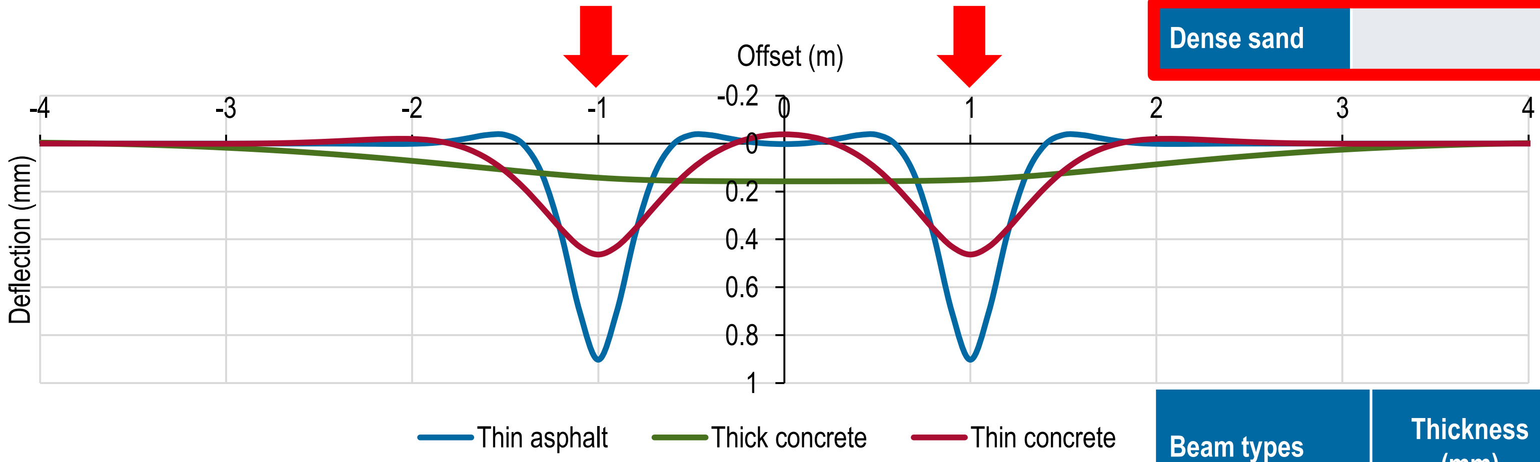

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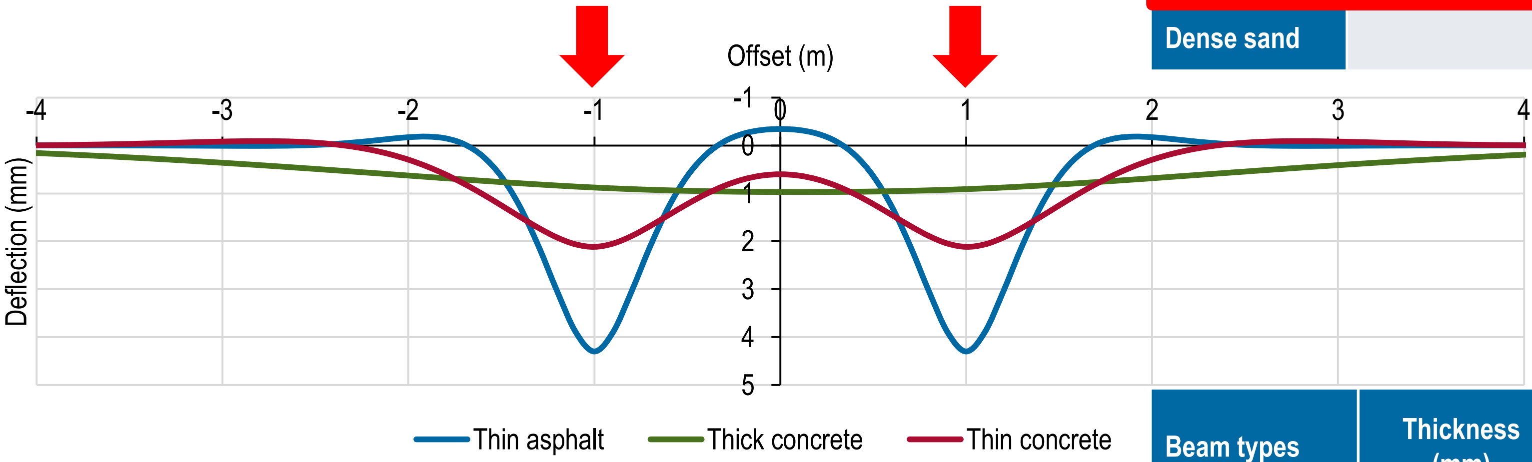
Part 1 Theoretical deflected shapes

- Loose sand



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Thin asphalt	50	2 759
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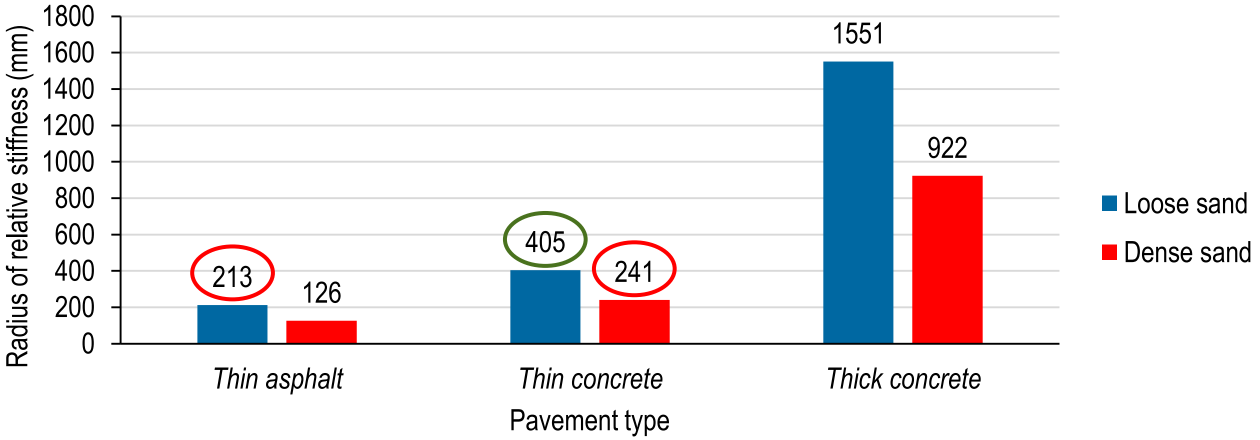
- Descriptor of relative stiffness

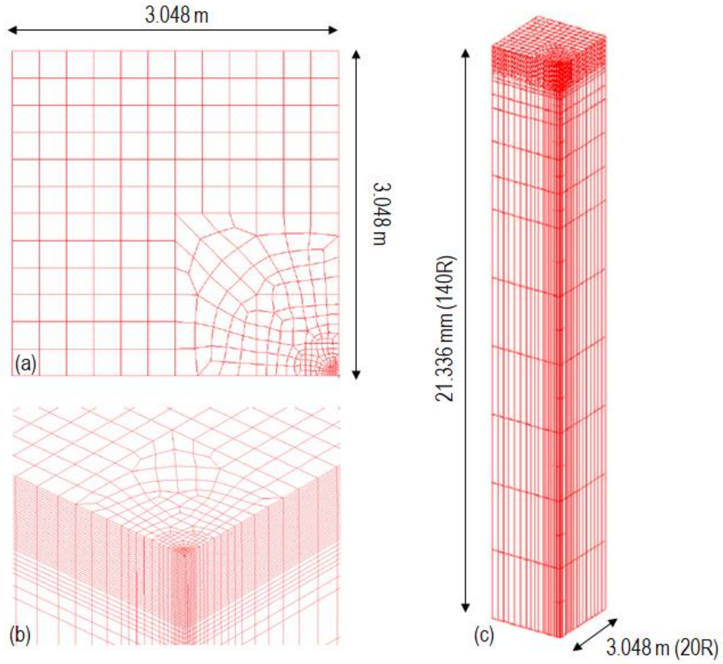
Part 1 Radius of relative stiffness

$$l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}}$$

E – Modulus of Elasticity (MPa)
h – height (mm)
μ – Poisson ratio
k – Modulus of Subgrade Reaction (MPa/mm)



Part 2 3D FEA model from literature – Kim (2007)



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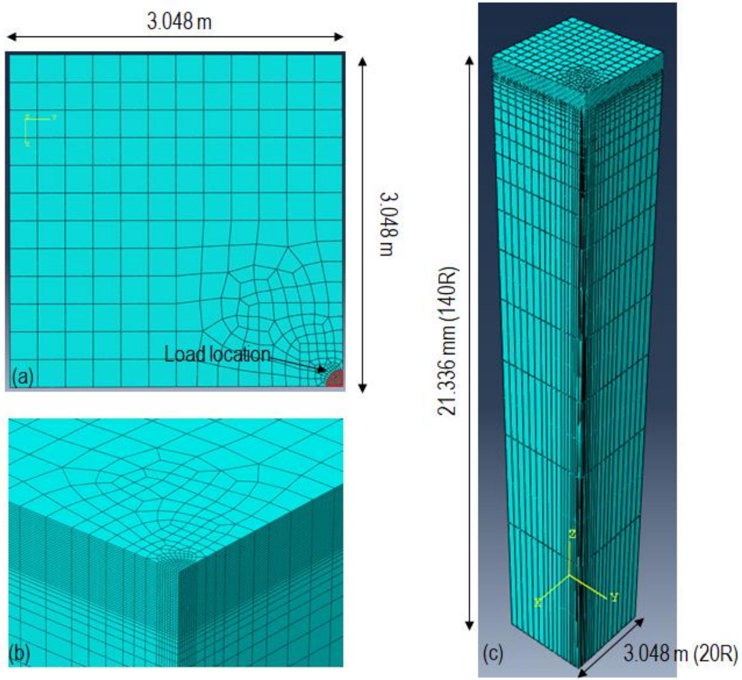
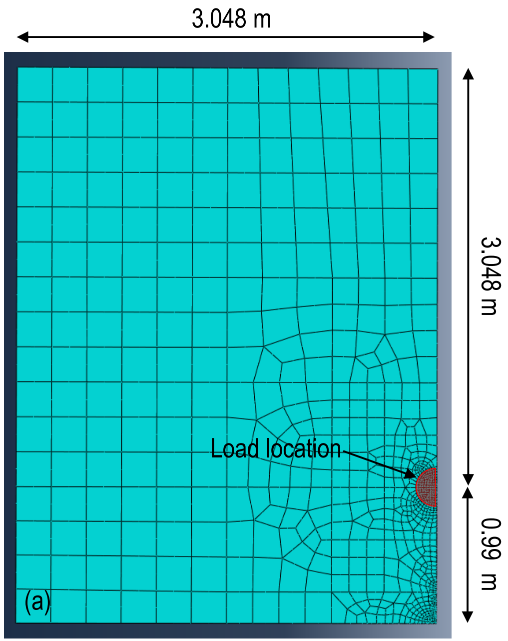
Part 2 3D FEA model from literature - replica

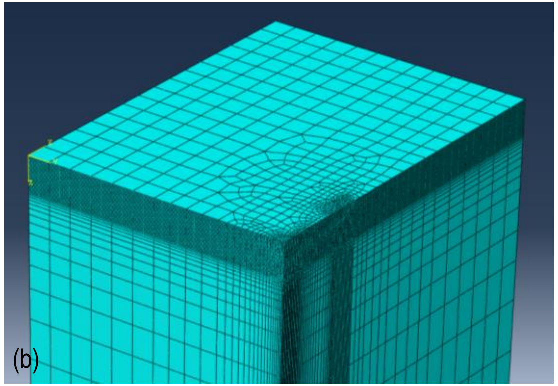


Layer	Thickness (mm)	E (MPa)	Poisson ratio
Asphalt/ Concrete	76	2 759/ 40 000	0.35/ 0.17
Base	305	207	0.4
Subgrade	20 955	41	0.45

- Quarter symmetry
- Boundary conditions
- Interaction
- Load application: 550 kPa, radius = 152.4 mm
- Elements: C3DR20

Part 2 3D FEA model from literature – axle loading





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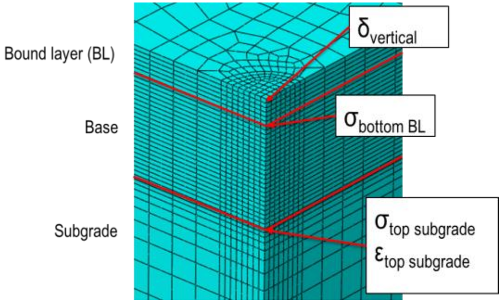
Part 2 Results

Part 2.1: Comparison of effect of load configuration on asphalt and concrete bound layer

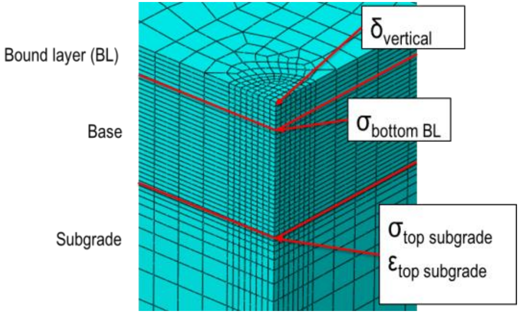
- Critical parameters as per Kim (2007)
- Deflection plots
- Contour plots of displacement in substructure



Part 2.2: Multivariable analyses of bound layer thickness and base E-value

- Surface plots of selected critical parameters
- Deflection plots

Part 2.1 Comparison of load configuration



Critical parameter	Asphalt			Concrete		
	SW	Axle	Difference (%)	SW	Axle	Difference (%)
$\delta_{vertical}$ (mm)	-0.913	-1.011	-10.8	-0.590	-0.692	-17.32
$\sigma_{bottom\ BL}$ (kPa)	1364	1362	0.092	4747	4637	2.341
$\sigma_{top\ subgrade}$ (kPa)	-41.7	-41.9	-0.508	-21.9	-22.3	-1.791
$\varepsilon_{top\ subgrade}$ (μm/m)	-974	-965	0.879	-473	-466	1.395

*Single Wheel loading - SW

**Axle loading - Axle

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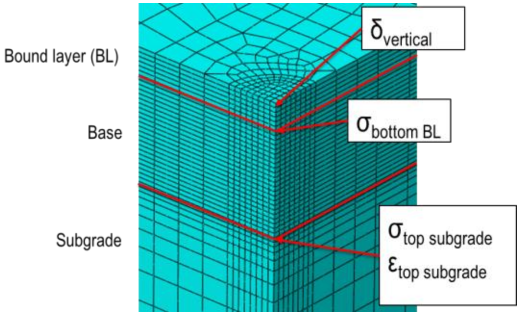

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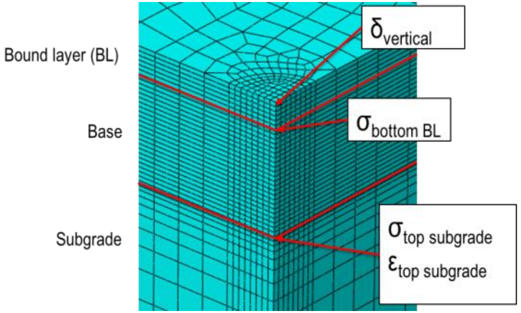

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$$Percentage\ difference = \frac{New\ value - Initial\ value}{Initial\ value}$$

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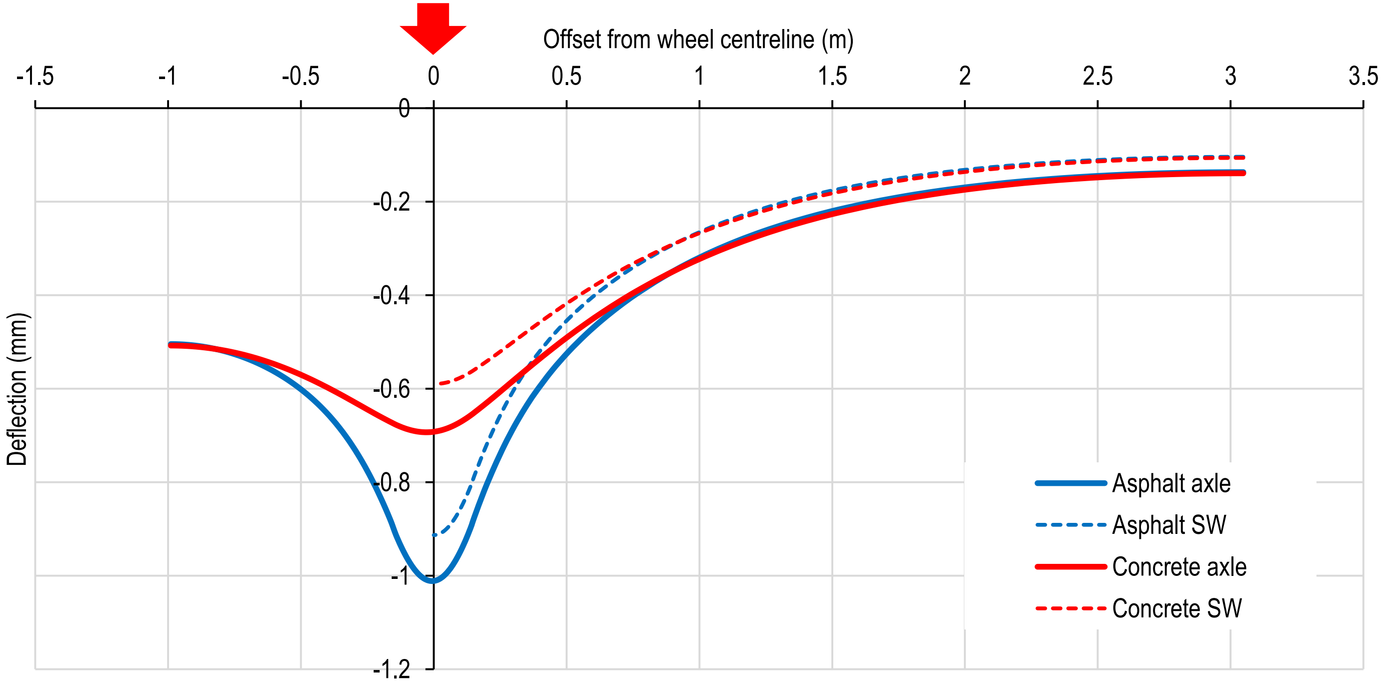
Part 2.1 Deflection plot



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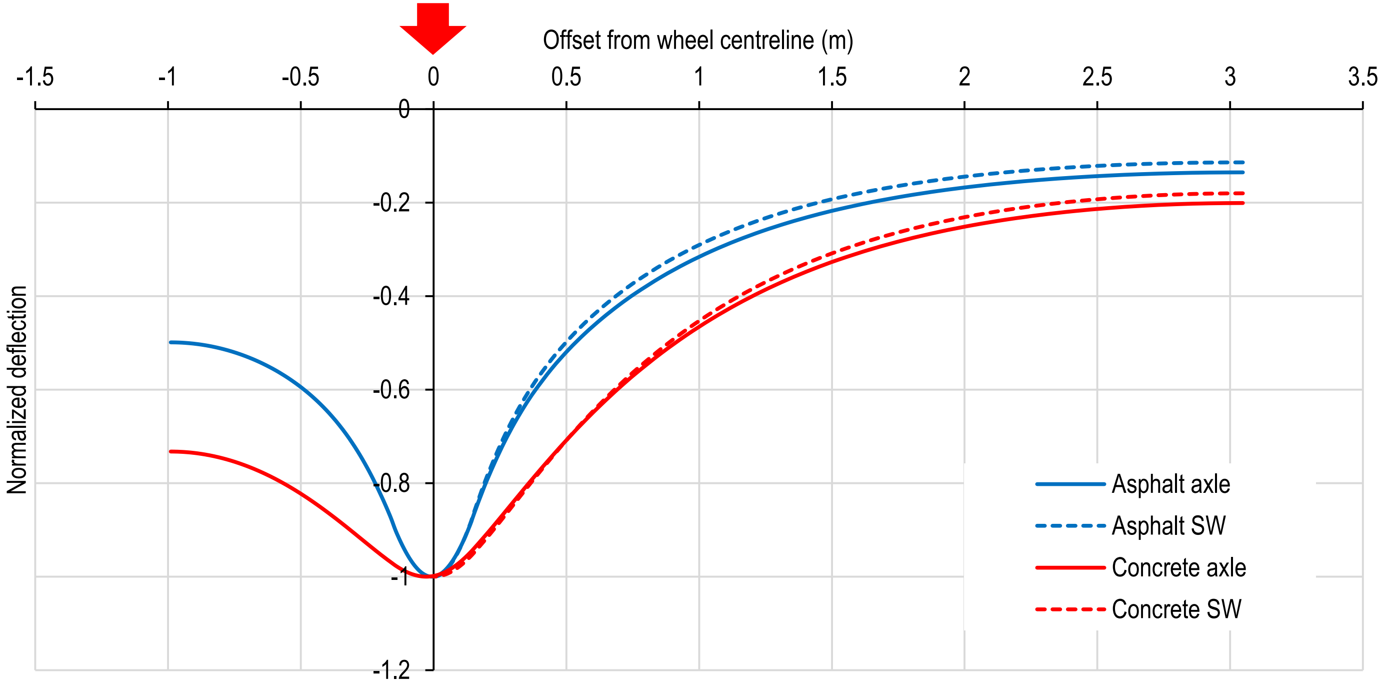
Part 2.1 Deflection plot - normalized



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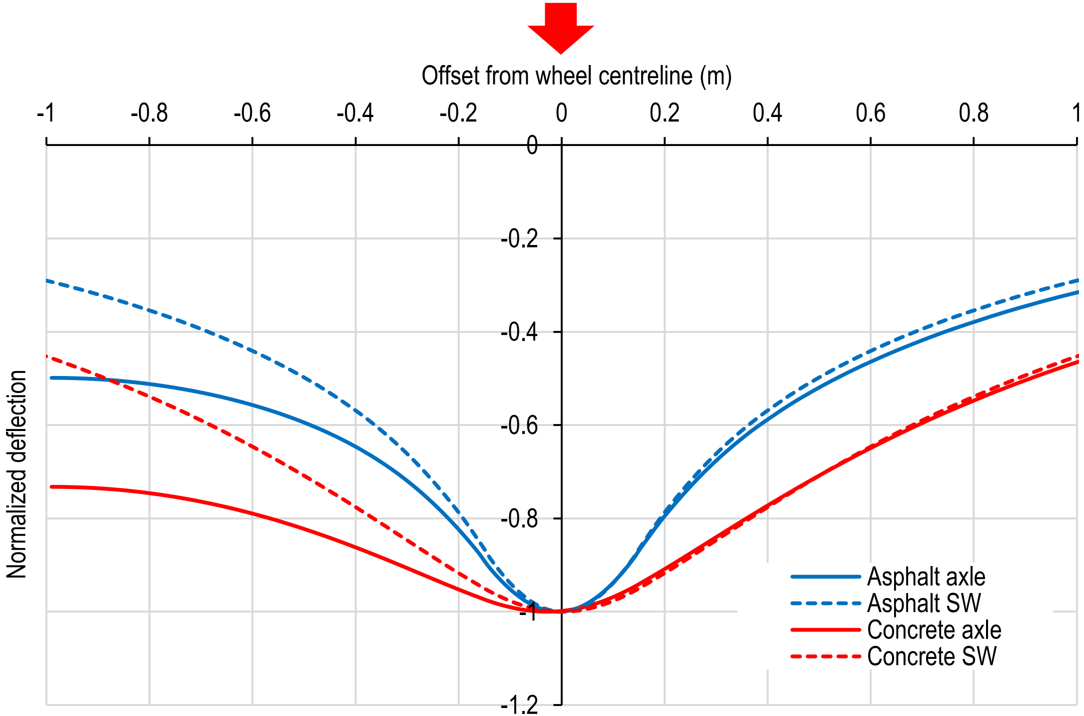
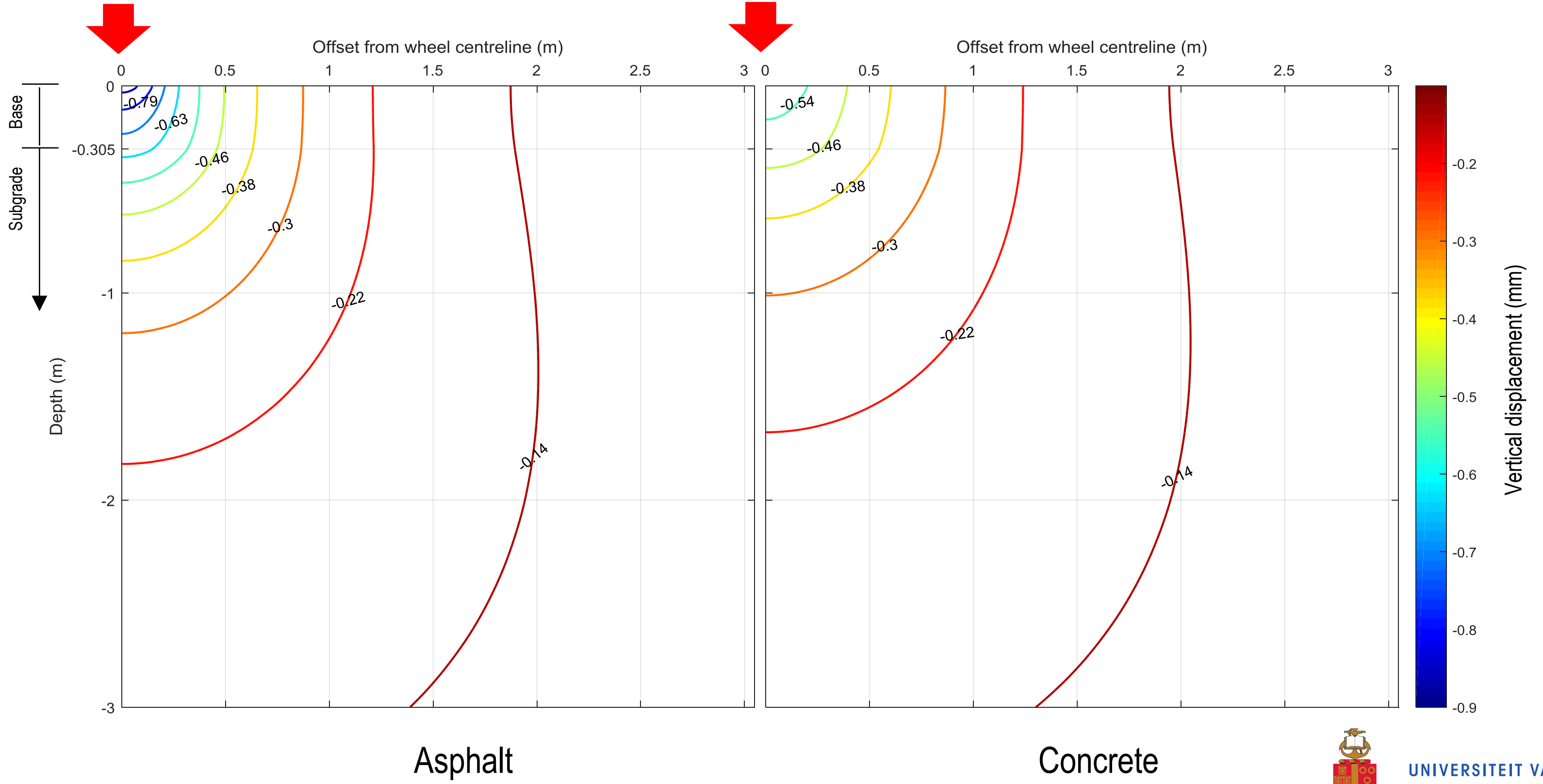
Part 2.1 Deflection plot - normalized



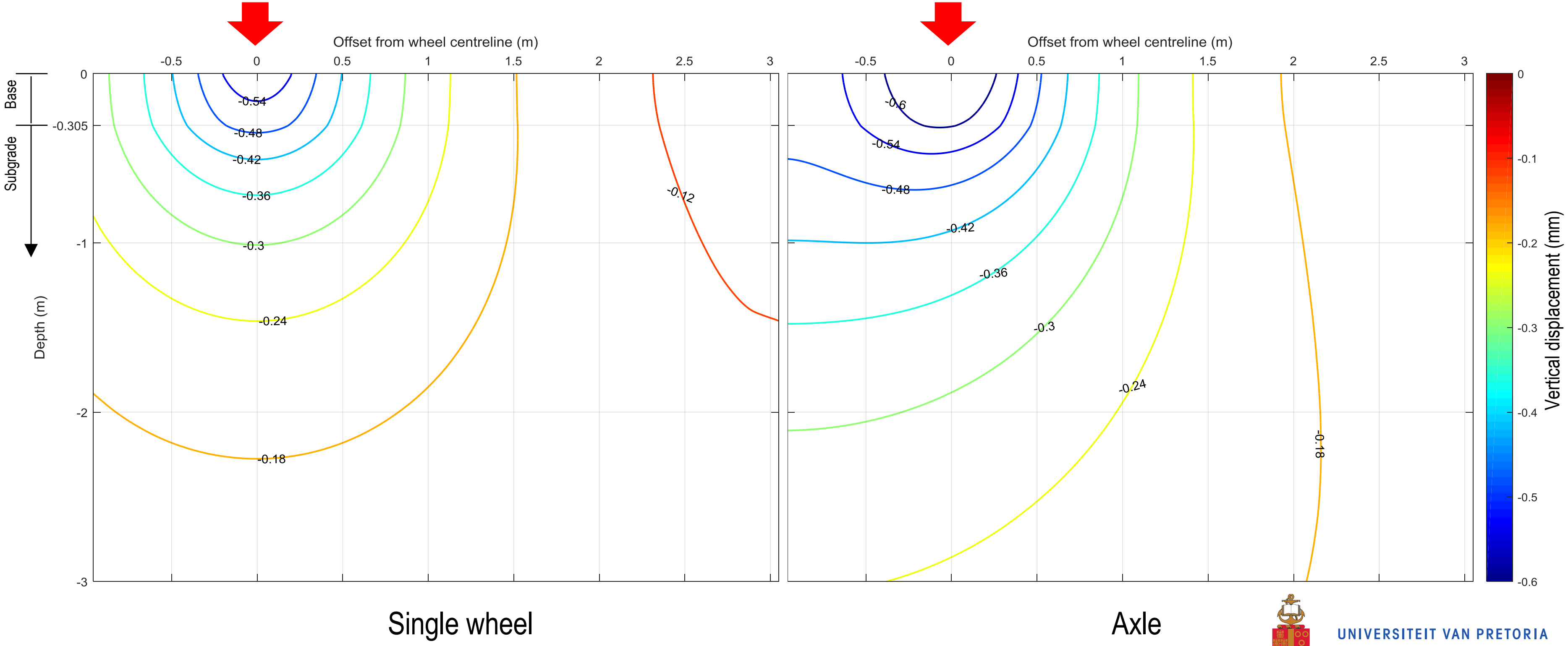
*Single Wheel loading - SW

**Axle loading - Axle

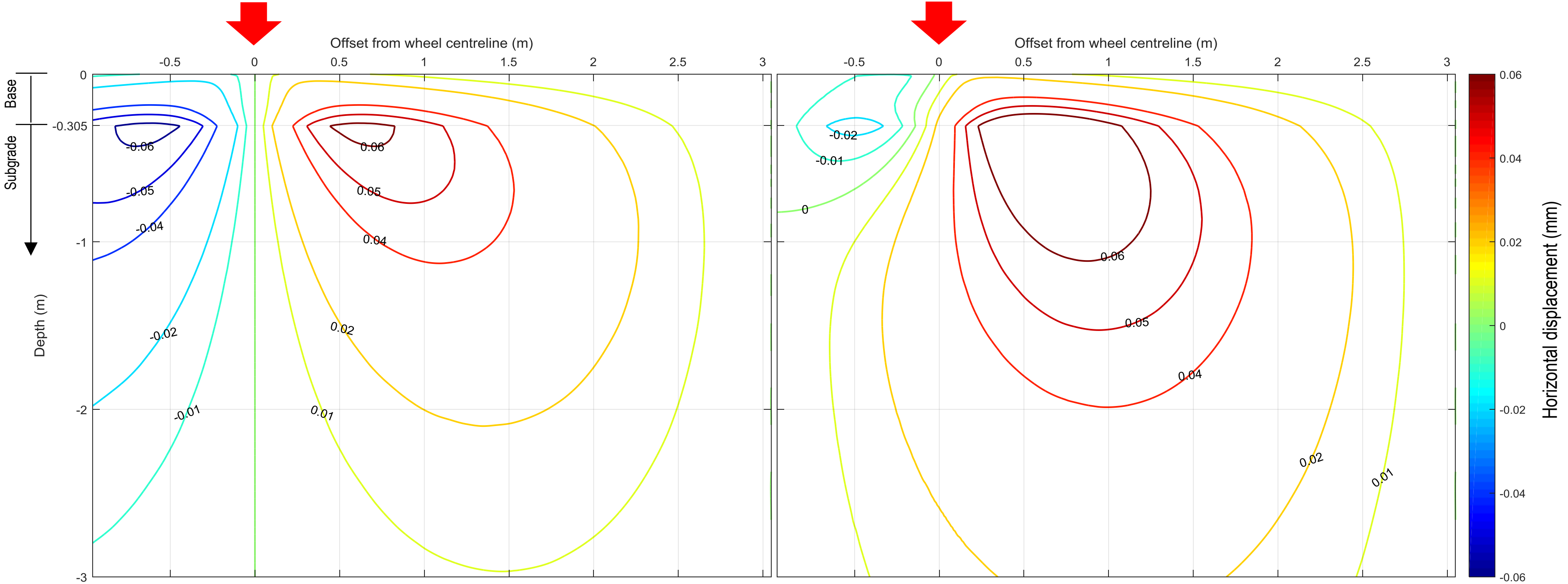
Part 2.1 Vertical displacement: asphalt vs concrete



Part 2.1 Vertical displacement contours



Part 2.1 Horizontal displacement contours



Single wheel

Axle

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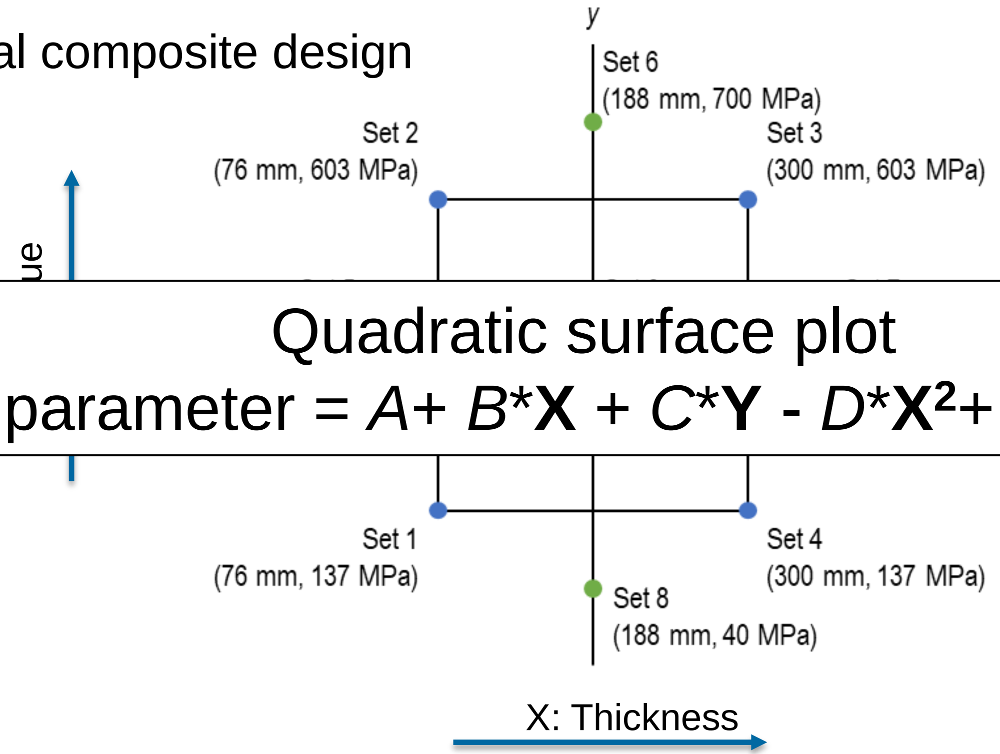
Part 2.2 Multivariable analyses

- Response surface methodology

Part 2.2 Multivariable analyses

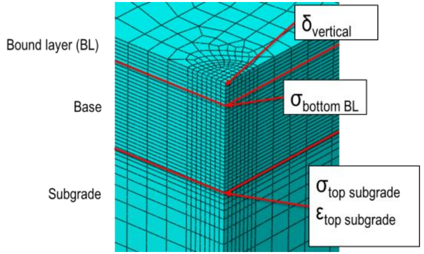
- Central composite design



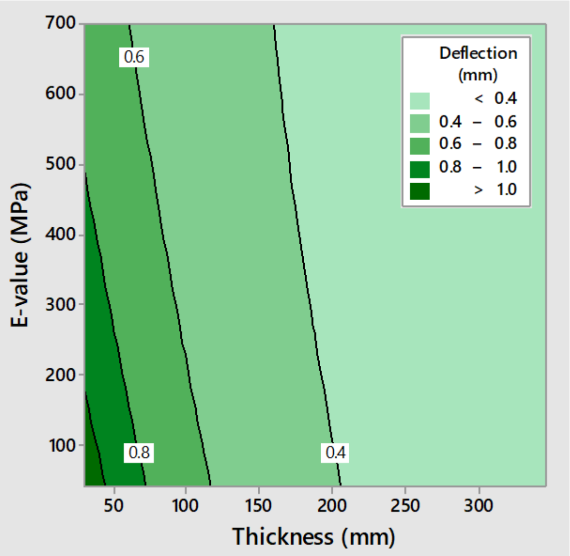
Quadratic surface plot

Critical parameter = $A + B*\mathbf{X} + C*\mathbf{Y} - D*\mathbf{X}^2 + E*\mathbf{Y}^2 - F*\mathbf{X}*\mathbf{Y}$

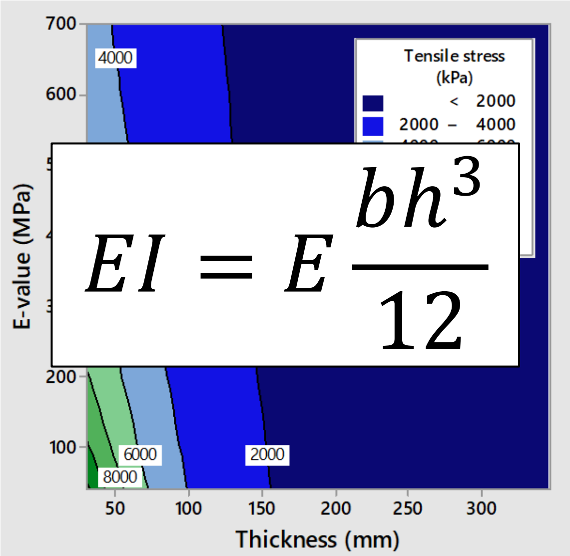
Part 2.2 Surface plots of critical parameters



$\delta_{vertical}$ (mm)

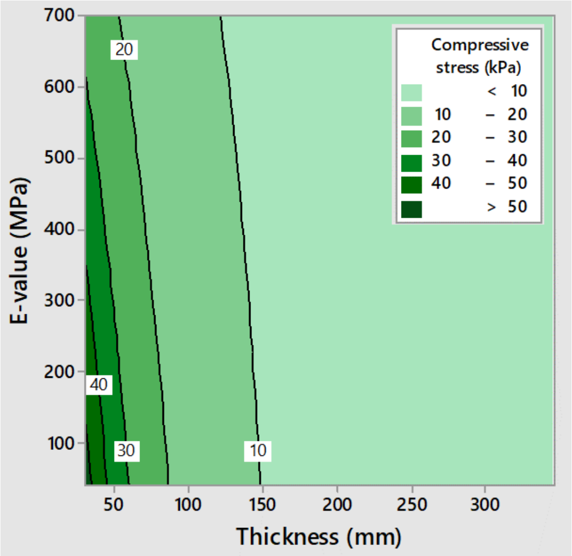


$\sigma_{bottom\ BL}$ (kPa)

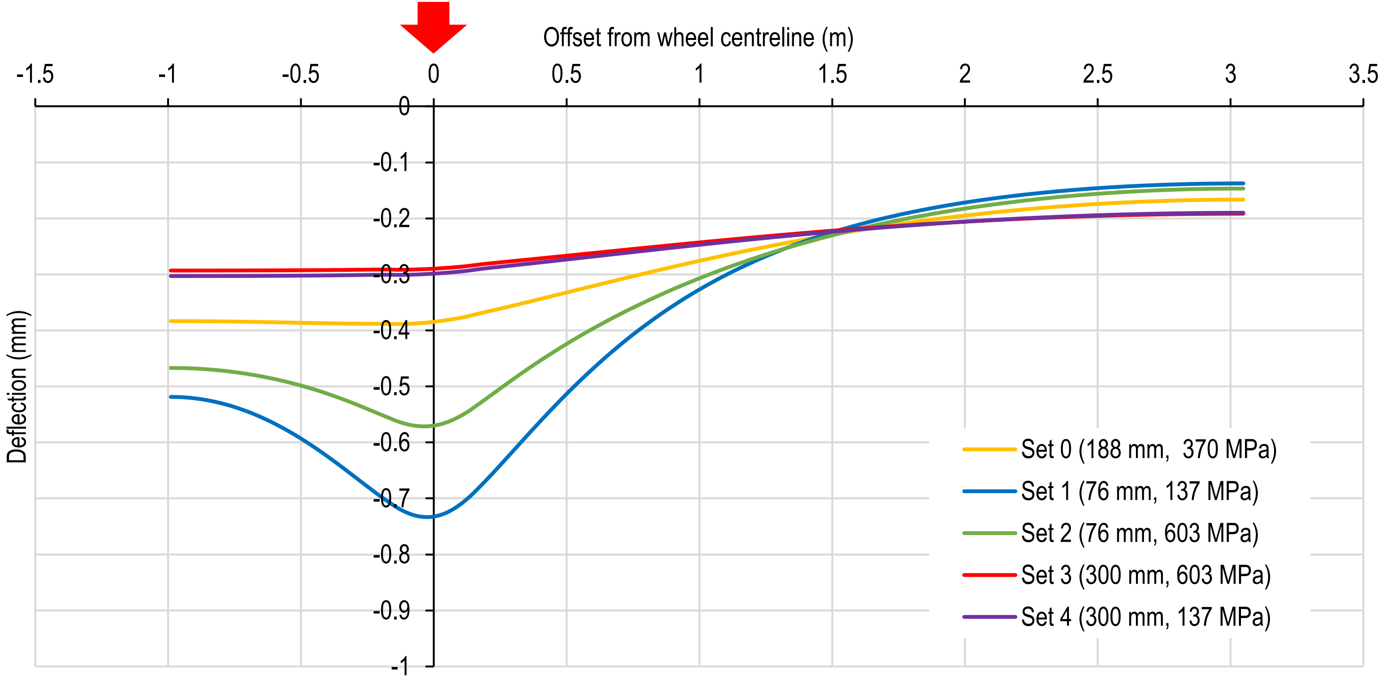


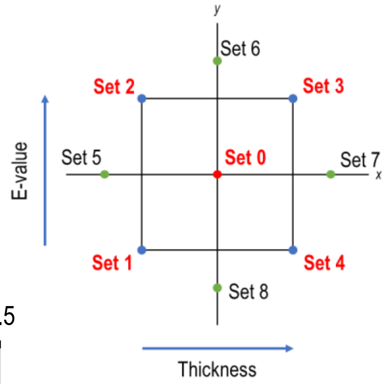
$$EI = E\frac{bh^3}{12}$$

$\sigma_{top\ subgrade}$ (kPa)



Part 2.2 Deflection plot





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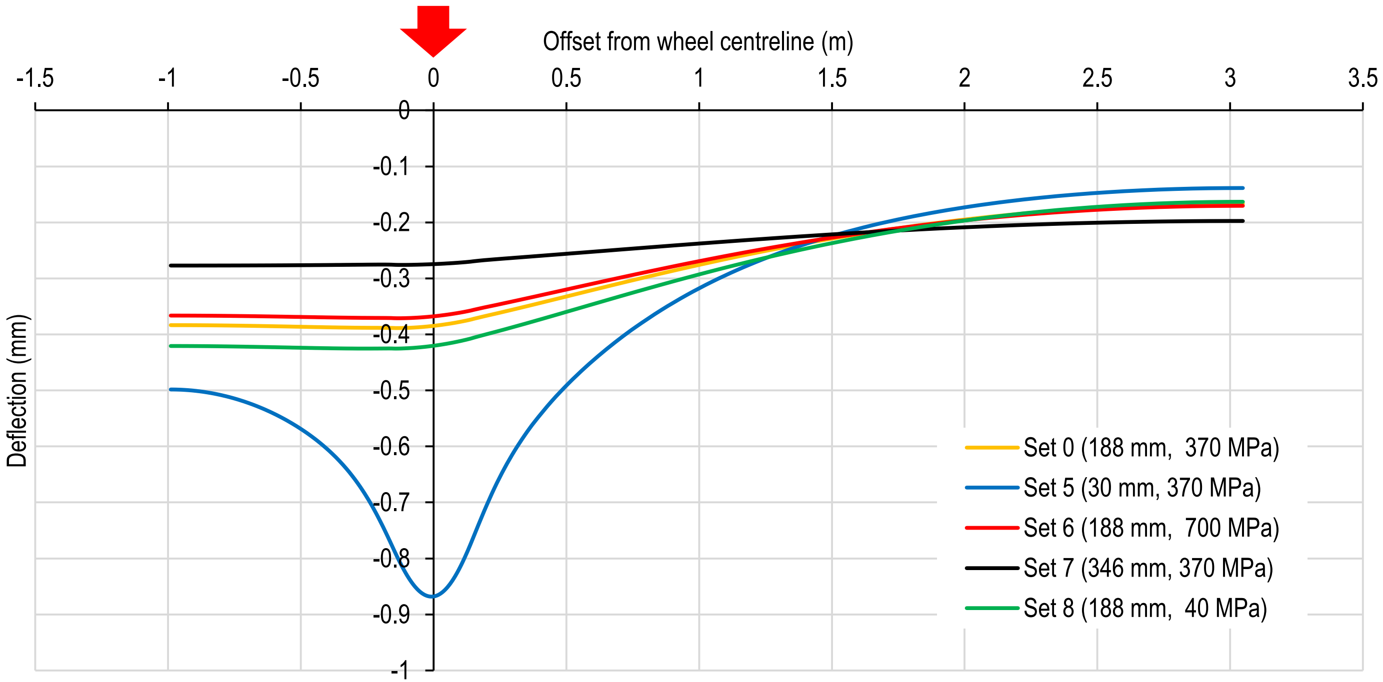

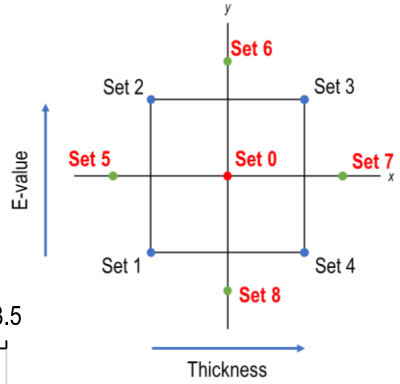

Conclusions

- Relative stiffness controlled deflected shape
  - Especially for thin bound layers
- Axle loading affects concrete pavement slightly more ito critical parameters
- Substructure displacement differs for single wheel and axle loading

Further work

- More complex substructure models
  - Model E-value as a function of confinement
  - Model non-linear elastic-plastic behaviour of soils

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How would you consider this problem?

- Contact me at phia.smit@up.ac.za

Thank you

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