19TH ROAD PAVEMENT FORUM
4 & 5 MAY 2010

Modelling of Complex Tyre-Pavement Contact Stresses

Dr James Maina
CSIR Built Environment

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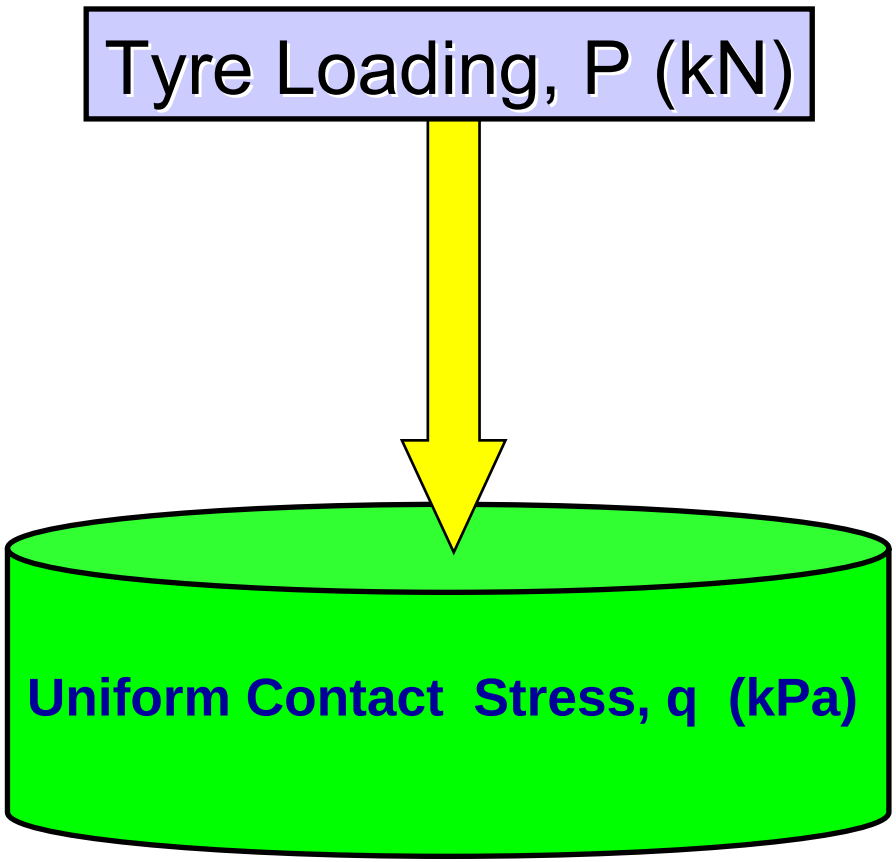
Objective: *Improve Performance Evaluation of Road Pavements by using Measured Tyre Loading*



Assumption of Tyre Loading in Pavement Design

- Circular;
- UNIFORM vertical stress only.



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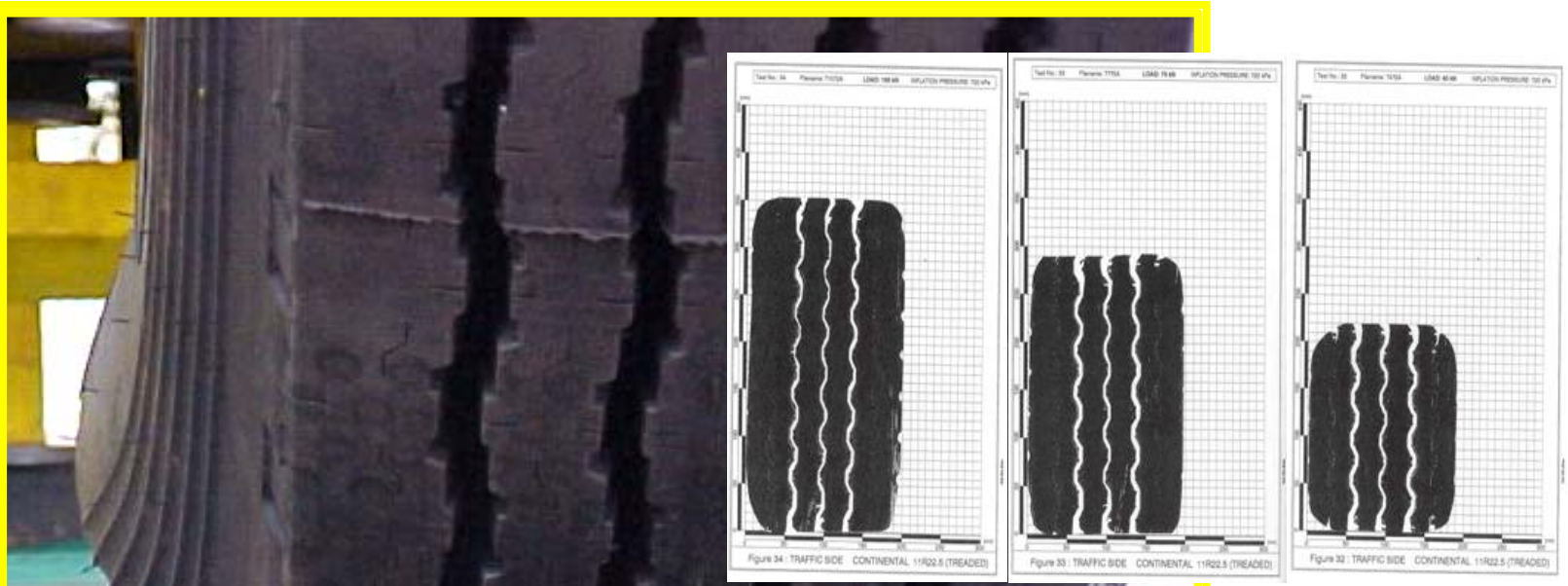
TYRE PRINTS…

TYRE DEFLECTION & TYRE PRINTS…



315/80 R22.5 HVS Tyre:
Overloaded

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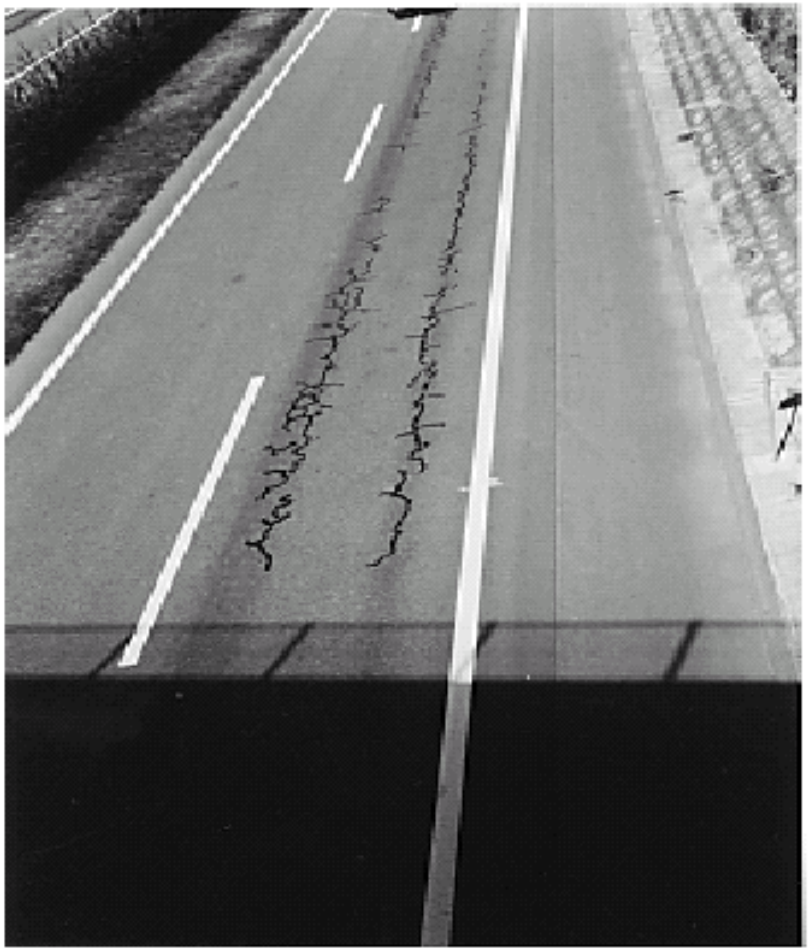
Vehicle-Tyre-Pavement Interaction:

Road Damage....

Road Damage….

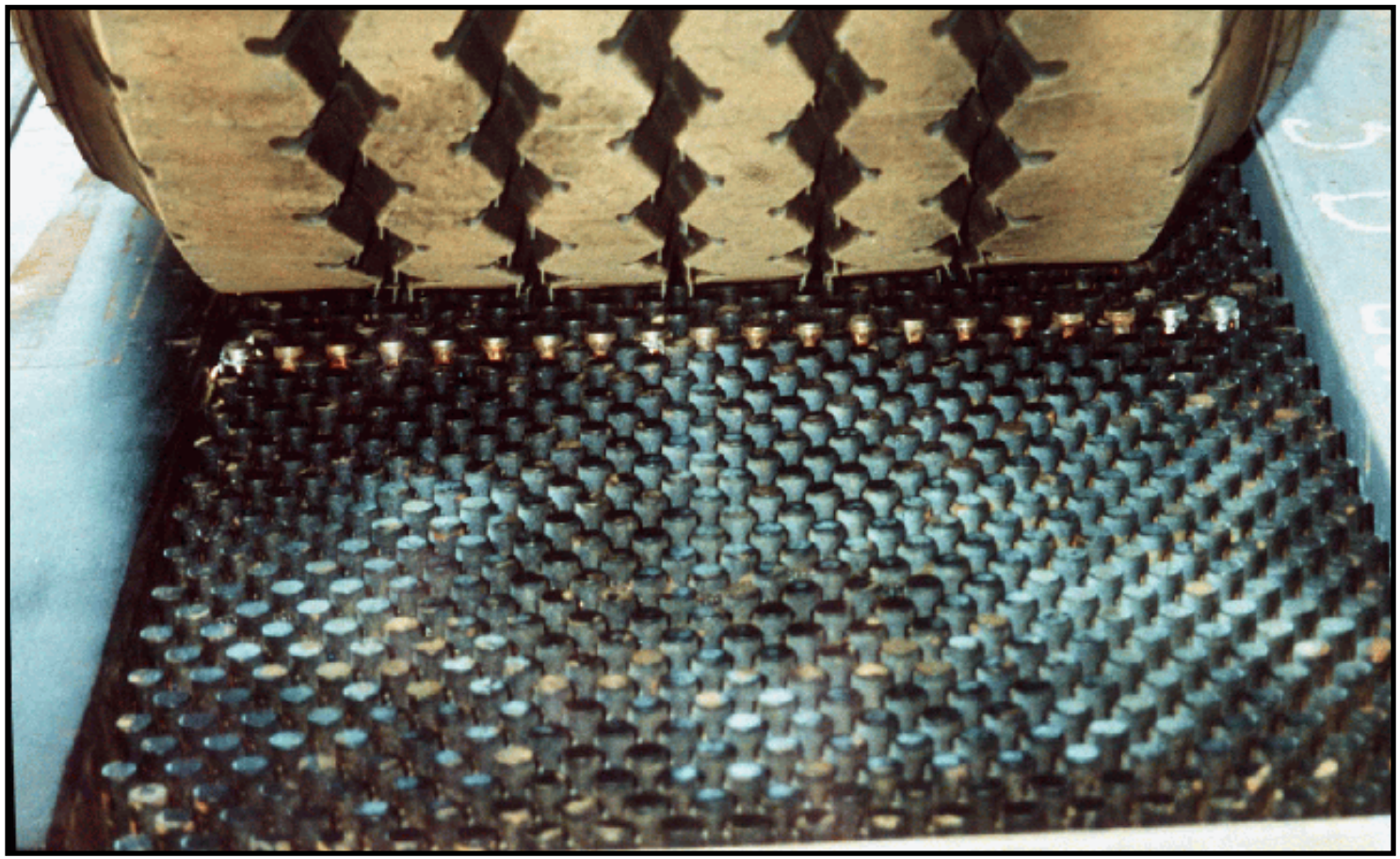


Photograph 1. Top-down Cracking

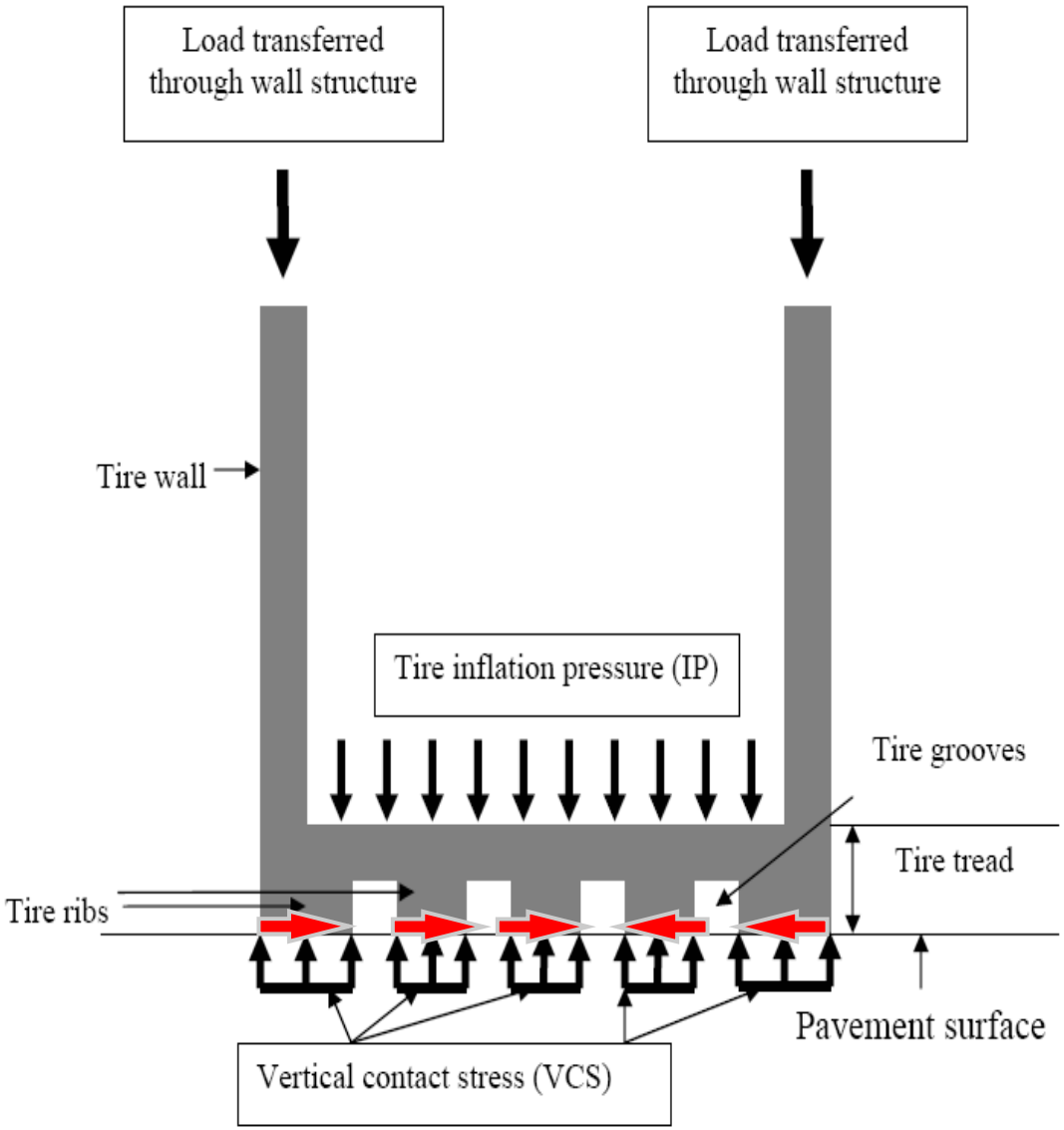
Photograph 2. A Core of Top-down Crack

(Nishizawa and Matsuno)

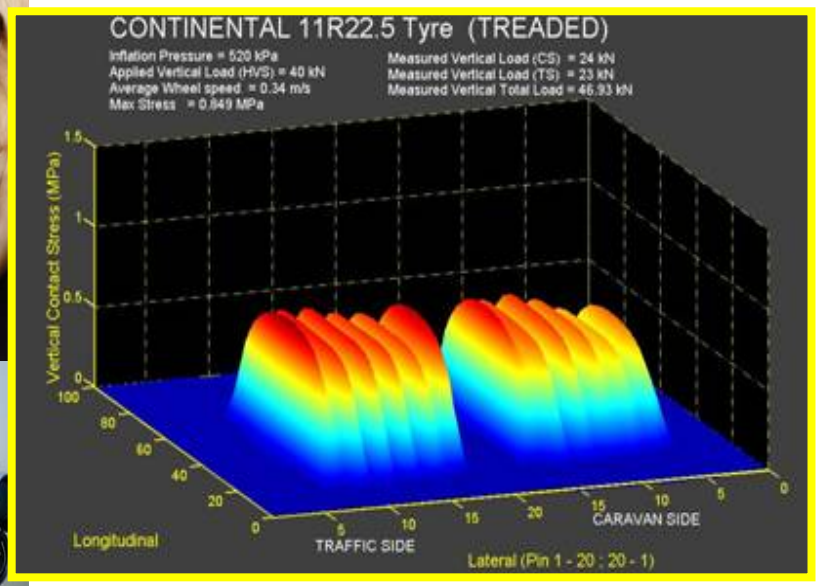
425 /65 R22.5 HVS TYRE ON SIM SYSTEM

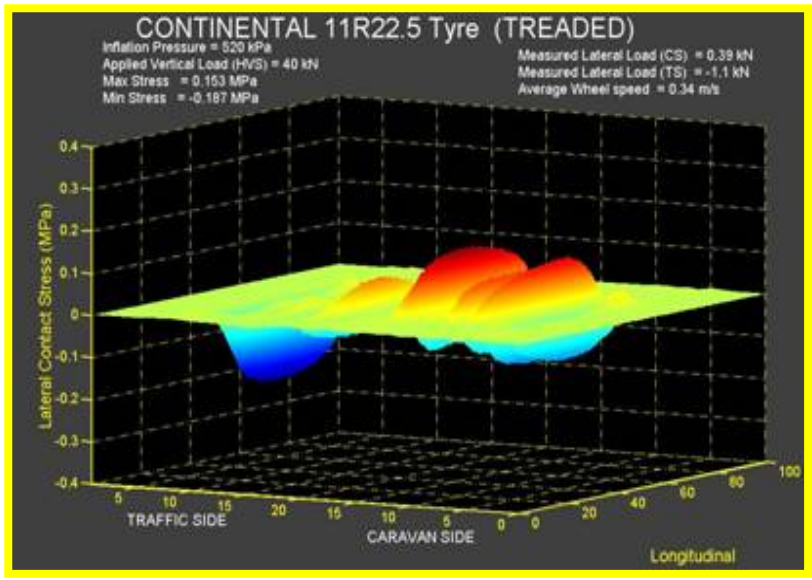


Load transfer mechanism of a tyre (Baladi et al, 2003)

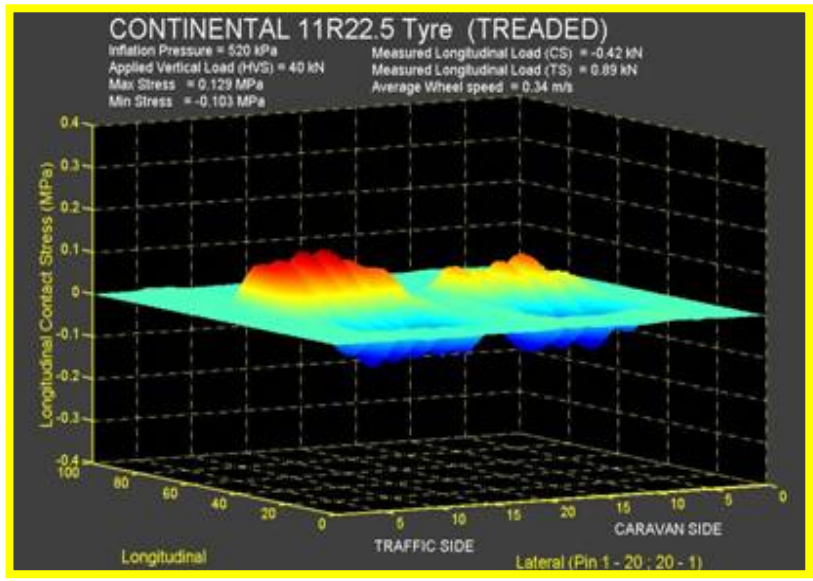


Dual Tyre: 3D-Contact Stresses (Pressure)…





Stress Ratio: 10:3:1



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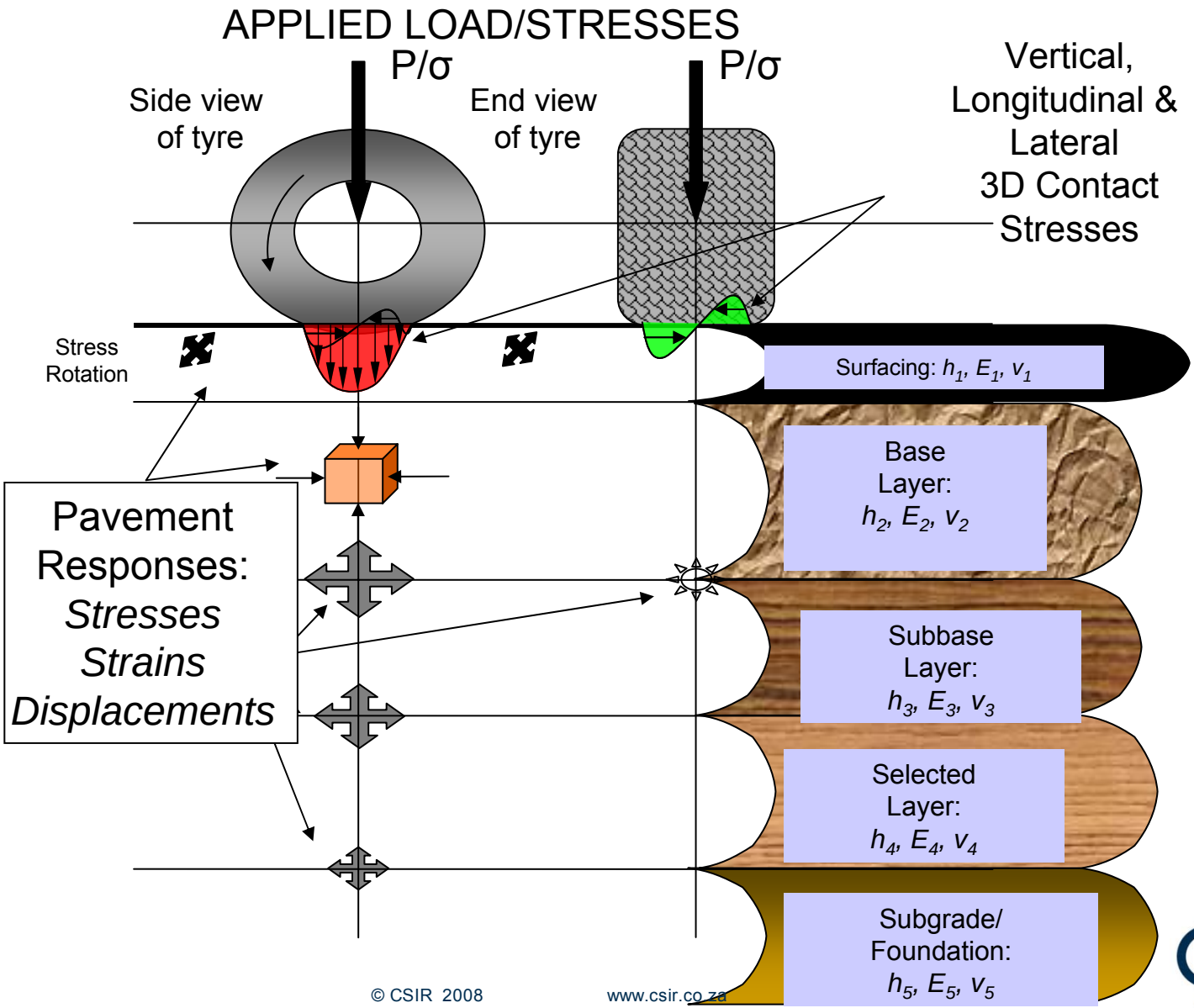
ANALYTICAL ROAD PAVEMENT MODEL….



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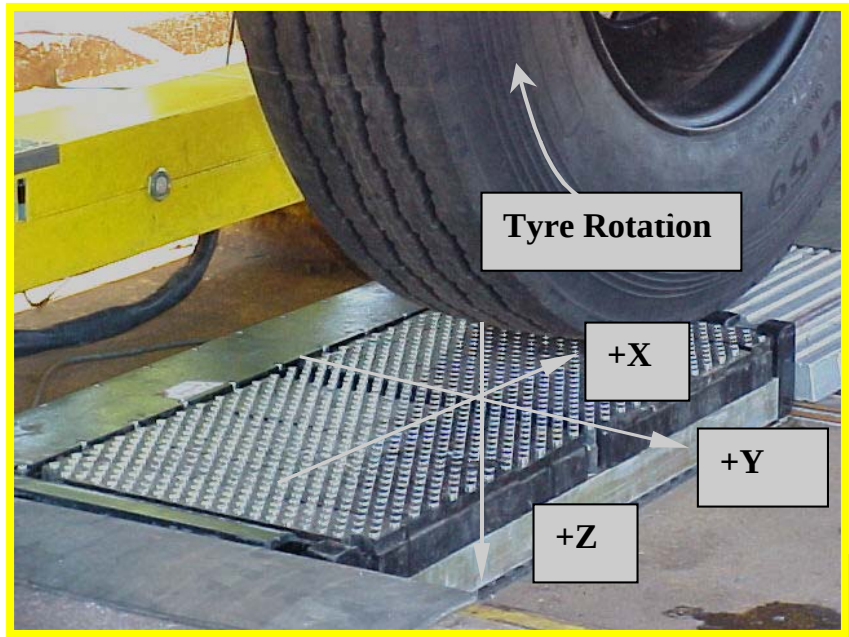
GAMES -> Pavement structural analysis

- **Pavement:** Multilayer elastic system with a possibility of interface slip.
- **Surface load:** Single/Multiple circular **vertical and horizontal** loads.
- **Analysis:** Single/Multiple points of interest.
- **Response:** Stresses, strains, and displacements

LOADS & STRESSES FROM TYRES



PIN AREA & EFFECTIVE AREA

Pin head Area
= 73,90 mm^2

Effective Area (Diamond)
= 250,28 mm^2

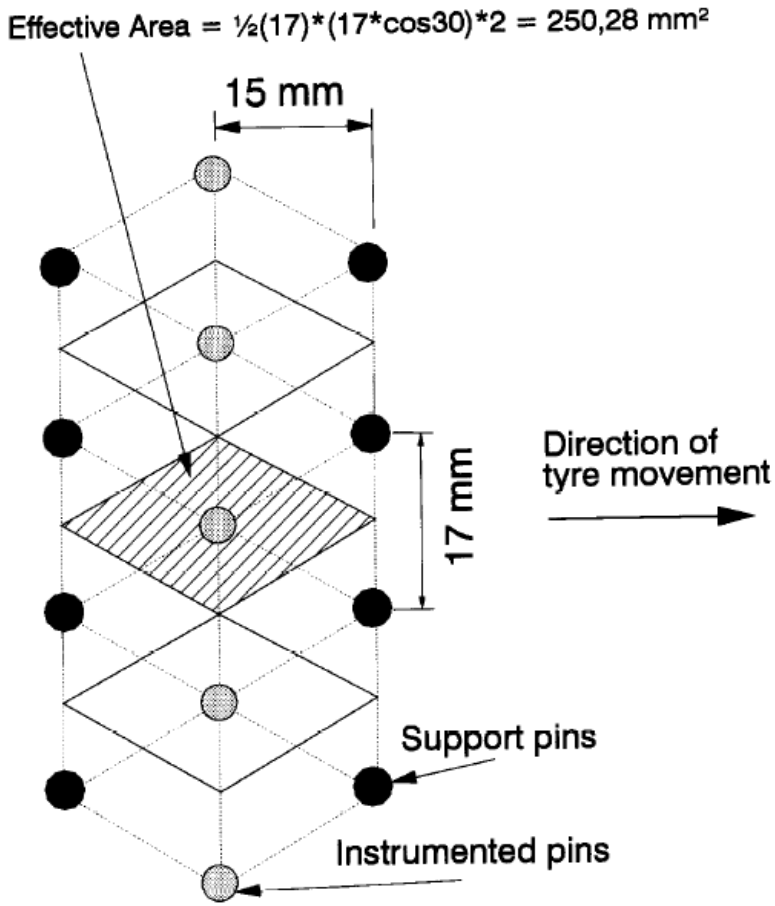
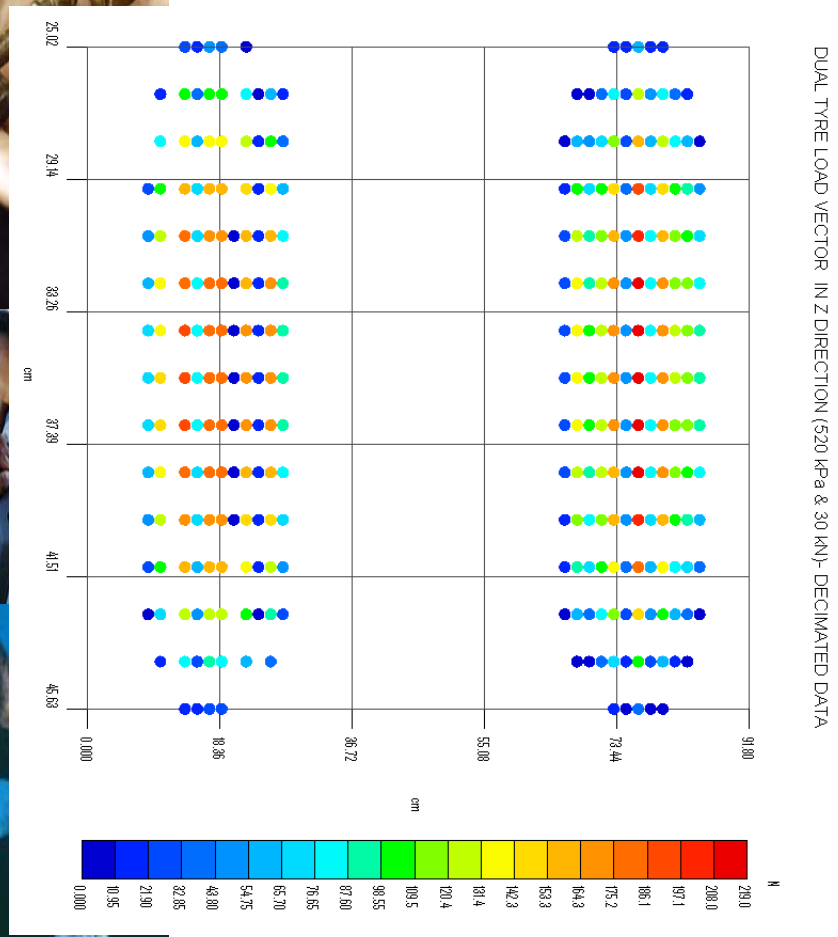
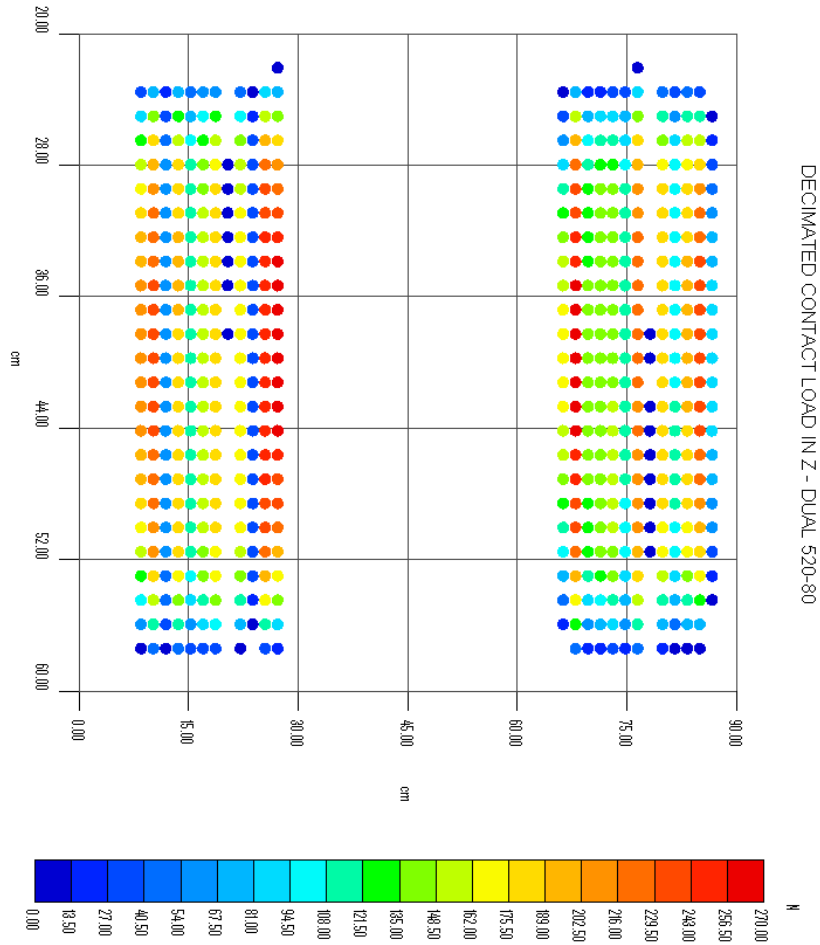


Figure 4
Effective Diamond Shaped Area used for the contact stress calculation in VRSPTA

Dual Tyre- Input Data: Vertical Stress Patterns: “n” and “m” – Shapes…



“n – Shape”



“m – Shape”

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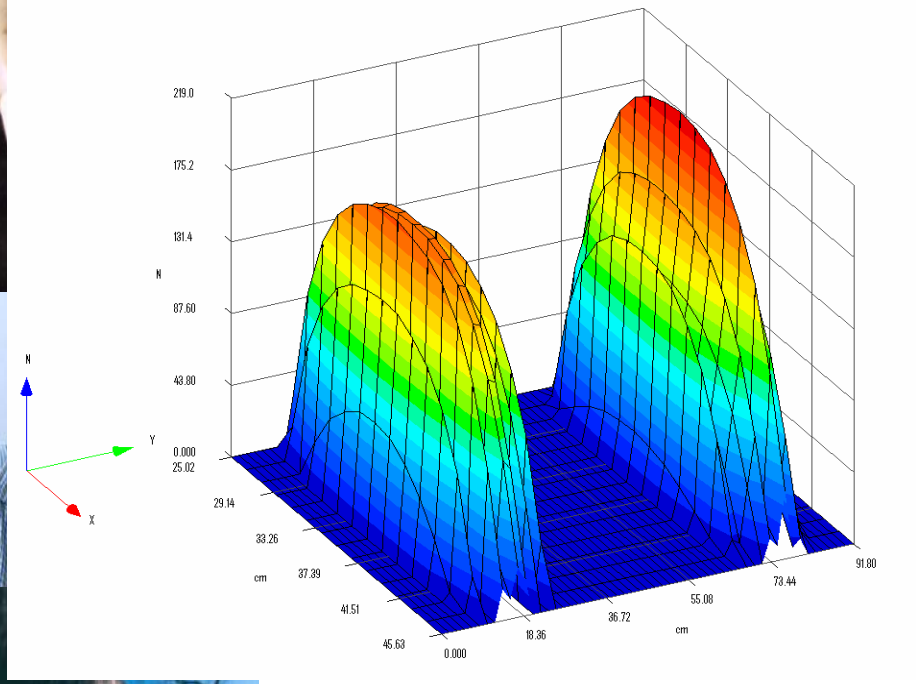
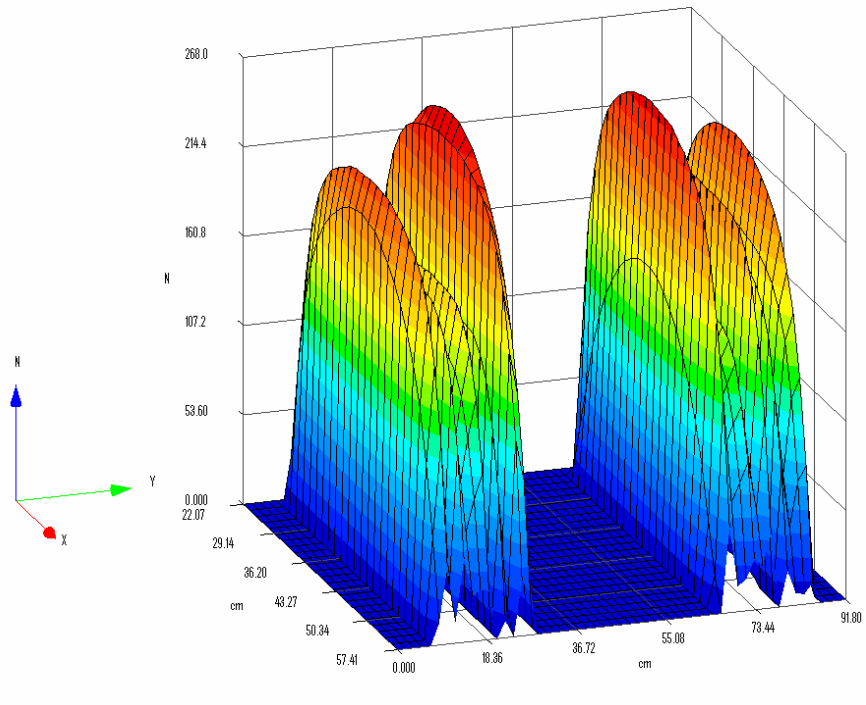
Dual Tyre- Input Data: Vertical Stress Patterns: “n” and “m” – Shapes…

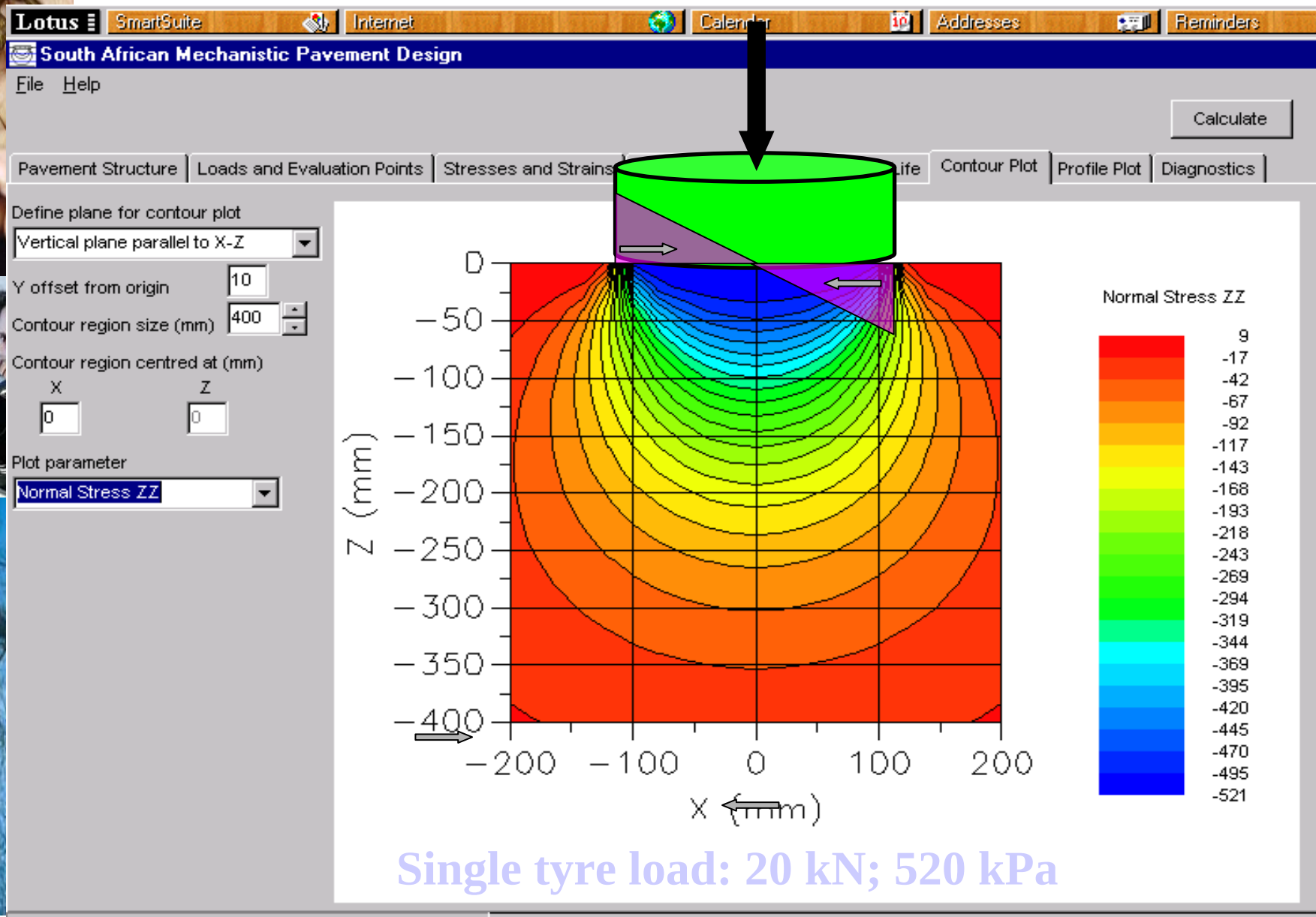


“n – Shape”



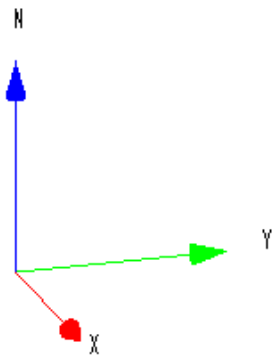
“m – Shape”

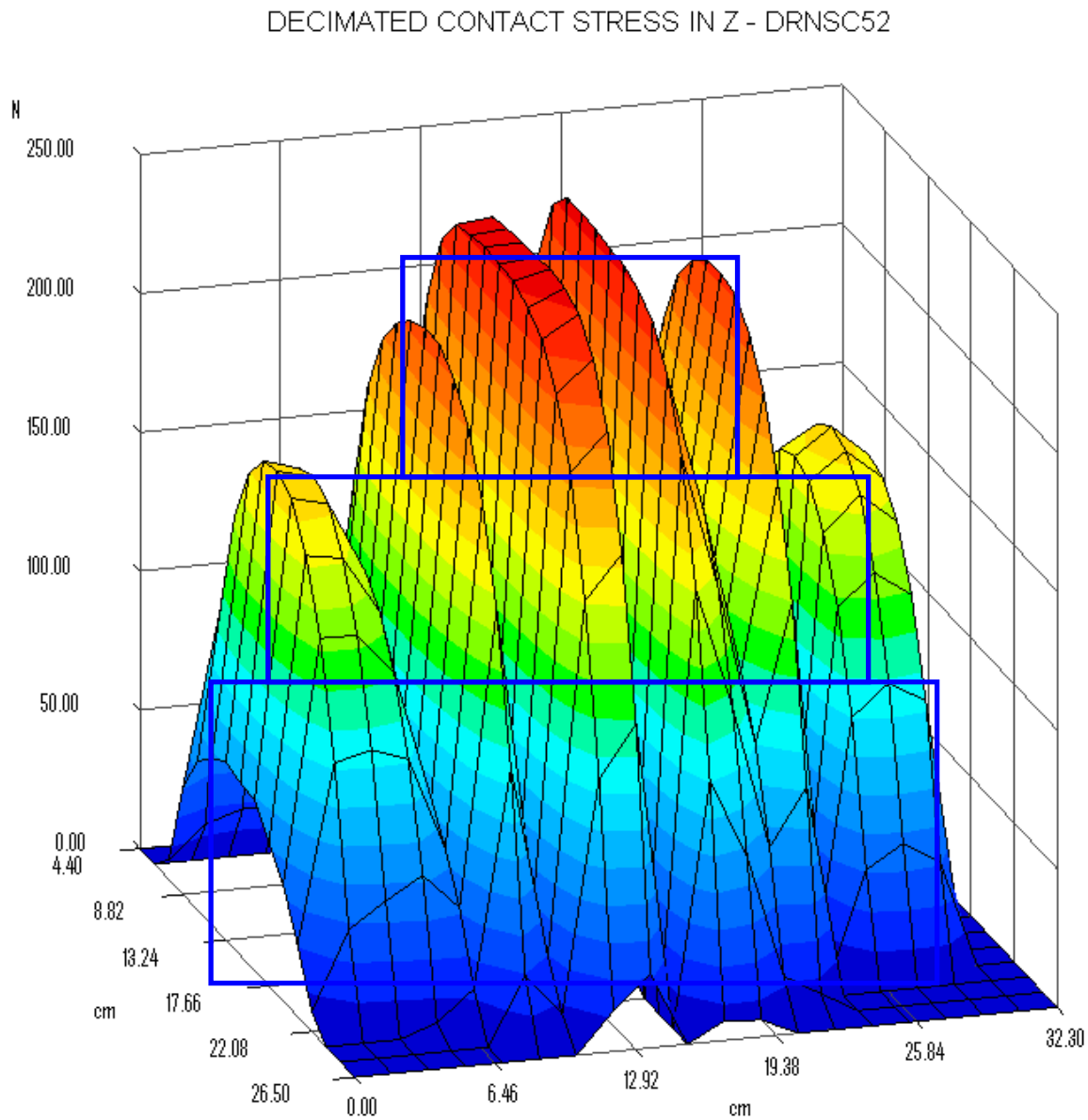
Equivalent Single Circular Contact Stress

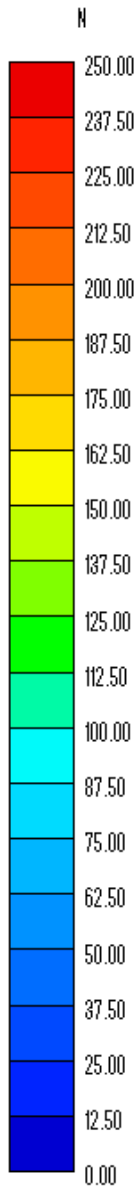


Single tyre load: 20 kN; 520 kPa

Decimated Contact Stresses & Staggered Loads







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n-Shape (vertical only): Staggered circular modeling

Lotus | SmartSuite | Internet | Calendar | Addresses | Reminders

South African Mechanistic Pavement Design

File Help

Calculate

Pavement Structure | Loads and Evaluation Points | Stresses and Strains | Life | Contour Plot | Profile Plot | Diagnostics

Define plane for contour plot

Vertical plane parallel to X-Z

Y offset from origin: 10

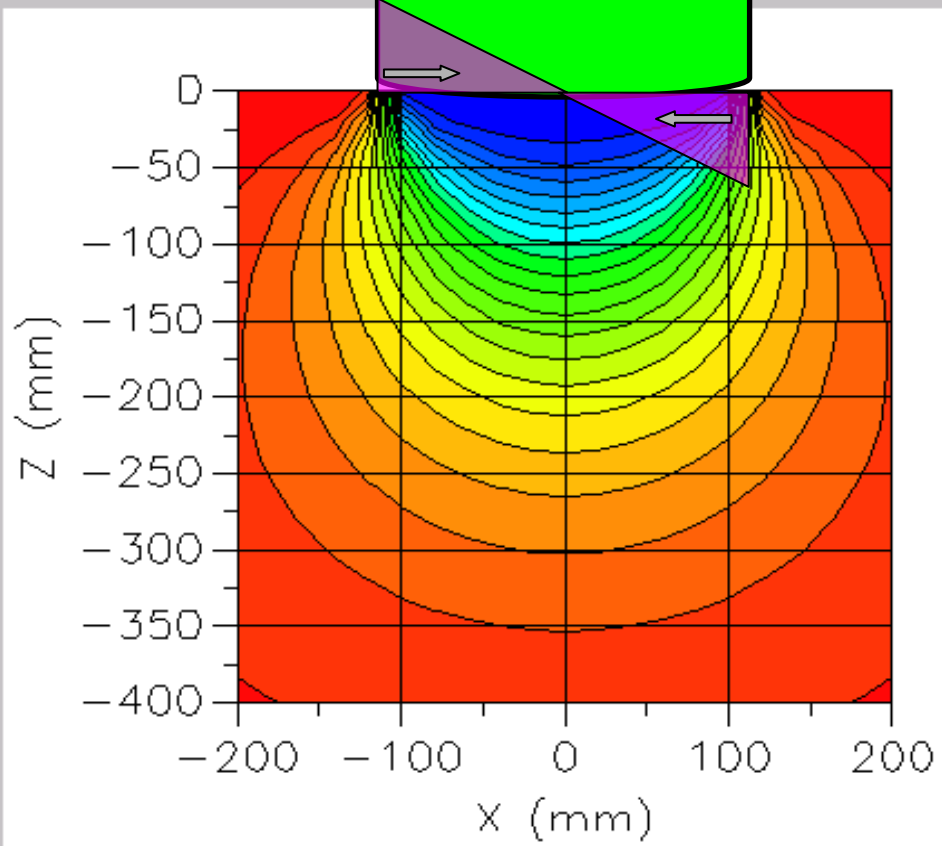
Contour region size (mm): 400

Contour region centred at (mm)

X: 0 Z: 0

Plot parameter

Normal Stress ZZ



Normal Stress ZZ

9
-17
-42
-67
-92
-117
-143
-168
-193
-218
-243
-269
-294
-319
-344
-369
-395
-420
-445
-470
-495
-521

Single tyre load: 20 kN; 520 kPa

n-M-Shape (vertical only): Staggered circular modeling

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South African Mechanistic Pavement Design

File Help

Calculate

Pavement Structure | Loads and Evaluation Points | Stresses and Str | Contour Plot | Profile Plot | Diagnostics

Define plane for contour plot

Vertical plane parallel to X-Z

Y offset from origin: 10

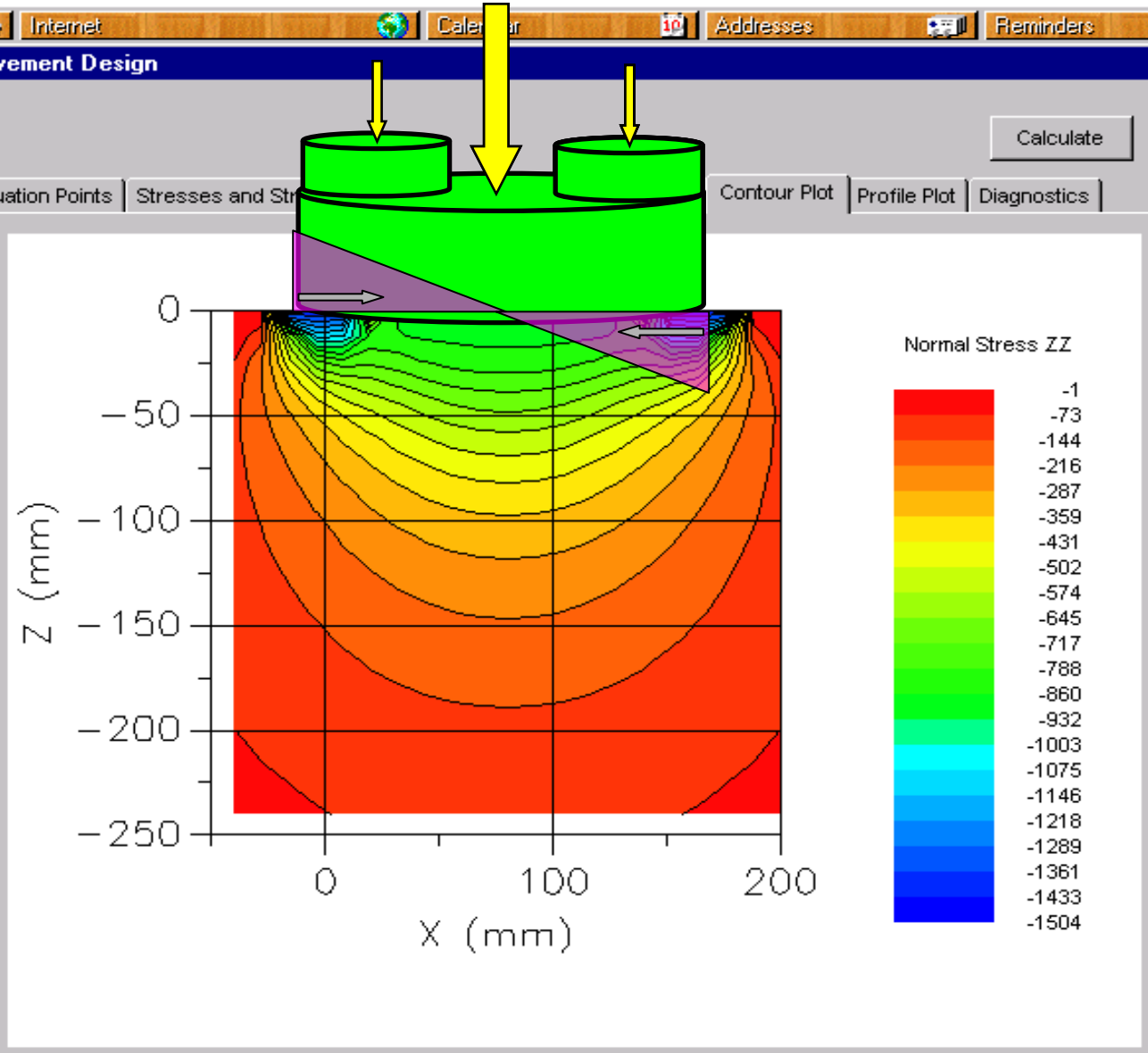
Contour region size (mm): 250

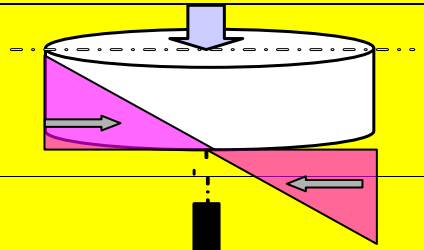
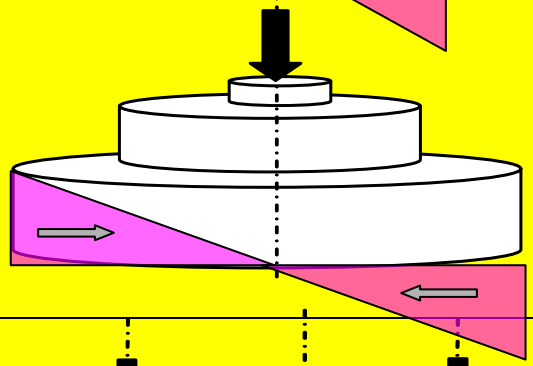
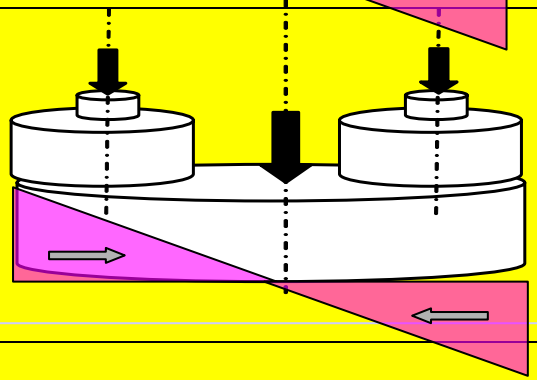
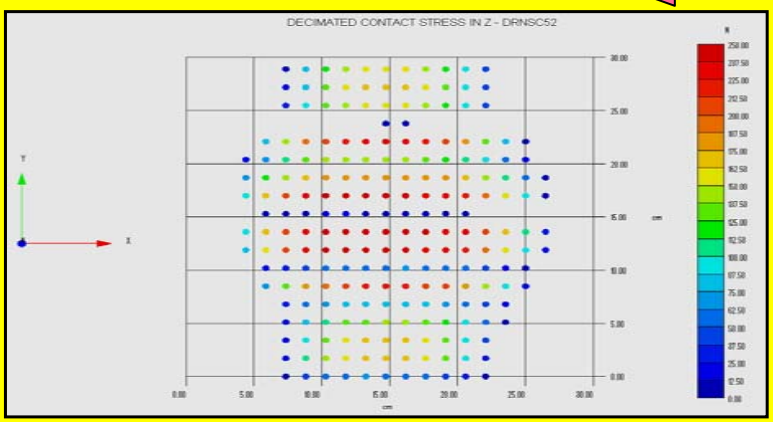
Contour region centred at (mm)

X: 80 Z: 0

Plot parameter

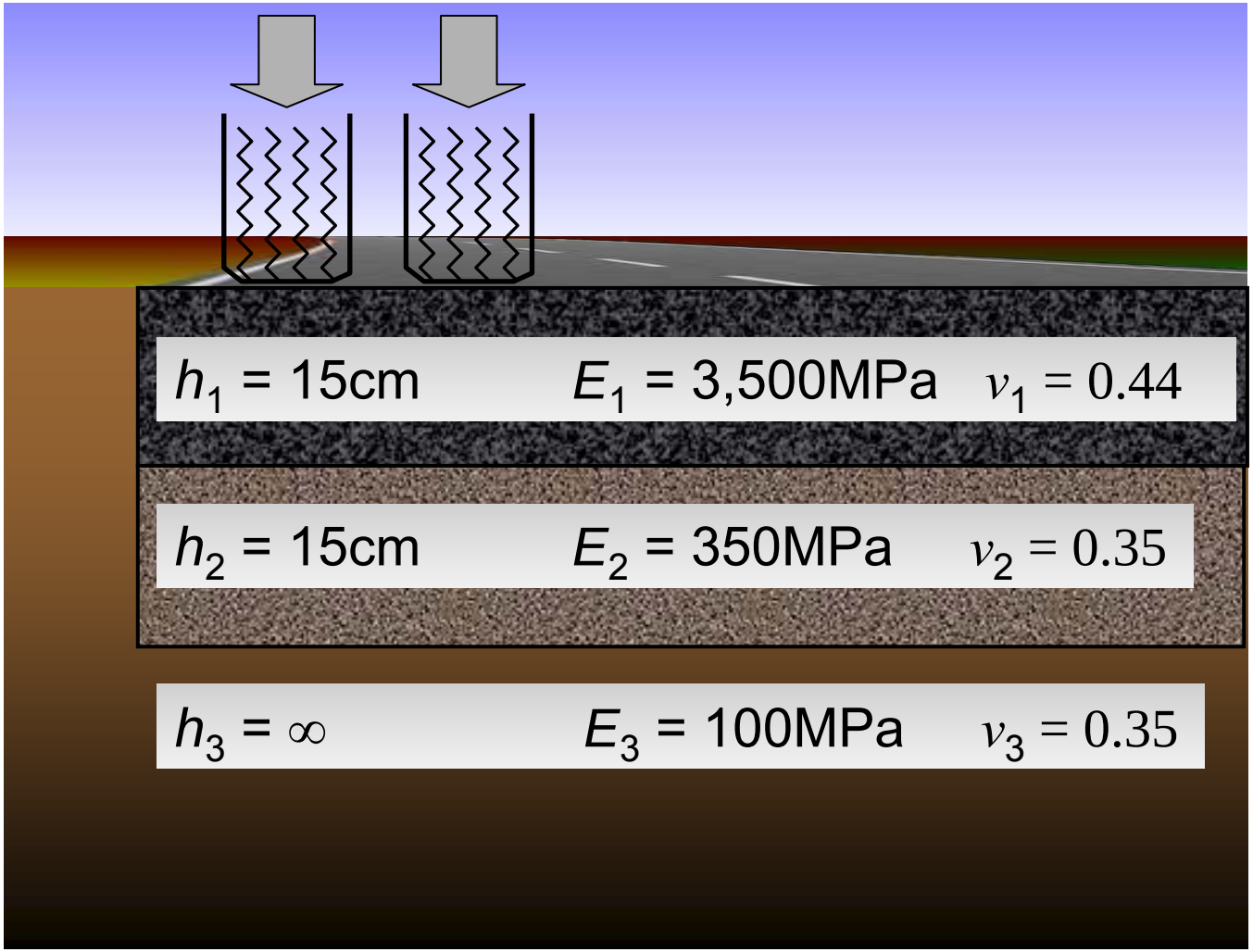
Normal Stress ZZ



Case	Contact Idealization	Shape of Vertical Contact Stress	Comments
1		Traditional Standard Circular disc	With or without lateral load/stresses (Tri - angular)
2		“n - shape” Staggered Circular disc(s)	With or without lateral load/stresses (Tri - angular)
3		“m - shape” Staggered Circular disc(s)	With or without lateral load/stresses (Tri - angular)
4		Full SIM shape (Decimated) : 1D, 2D and/or 3D shape	With or without lateral load/stresses (Tri - angular)

Pavement system under dual tyre loading…

Dual tyre loads



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Road pavement failure consideration…

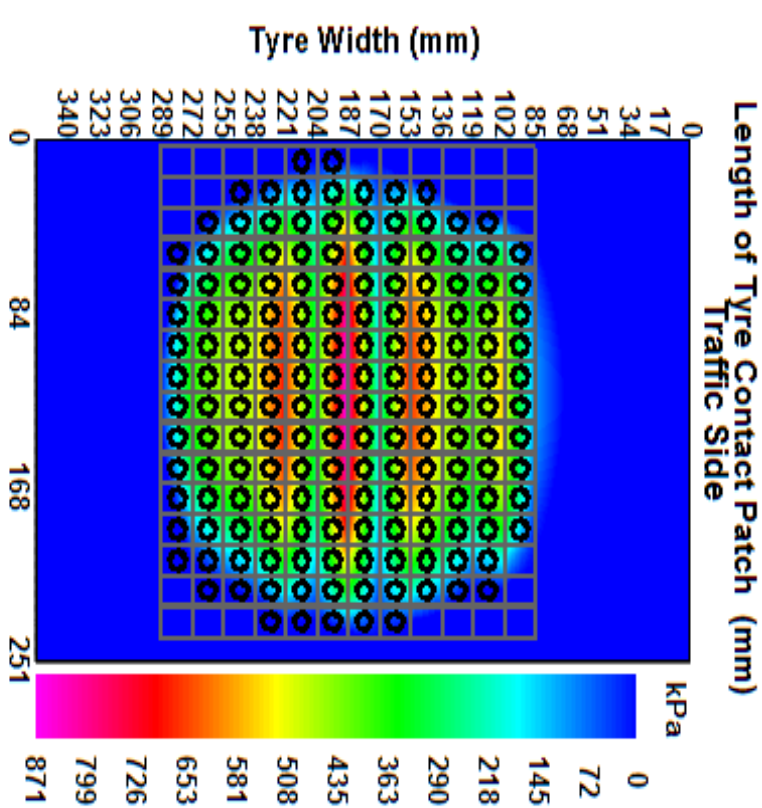
Timoshenko and Goodier (1951) stated that

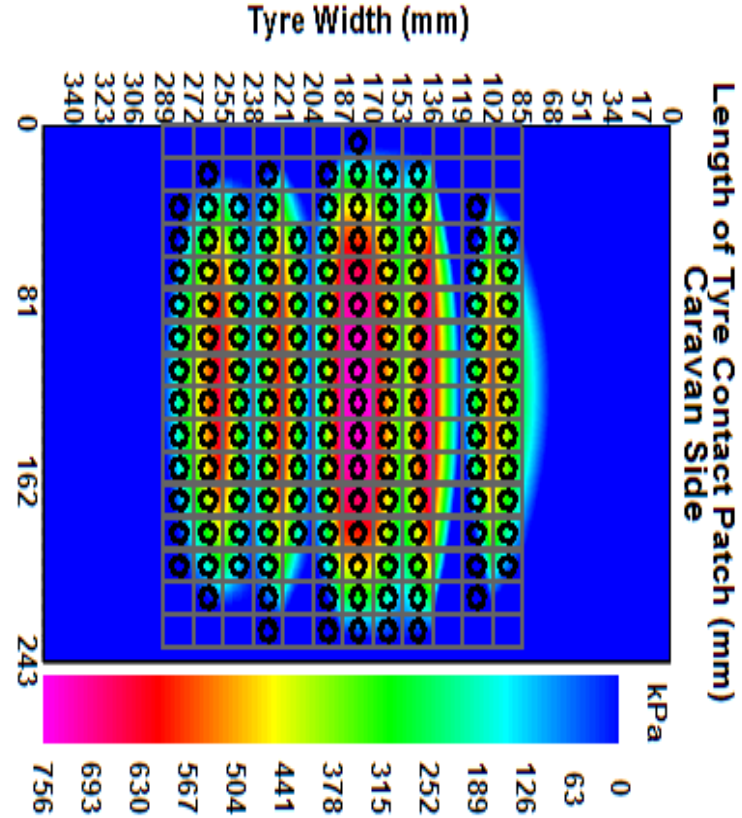
"whatever the stress system, failure occurs when the strain energy of distortion (SED) reaches a certain limit".

$$SED = V_0 - \frac{1-2\nu}{6E}\left(\sigma_x + \sigma_y + \sigma_z\right)^2$$

$$V_0 = \frac{1}{2E}\left(\sigma_x^2 + \sigma_y^2 + \sigma_z^2\right) - \frac{\nu}{E}\left(\sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x\right) + \frac{1}{2G}\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2\right)$$

Multiple discs all rows





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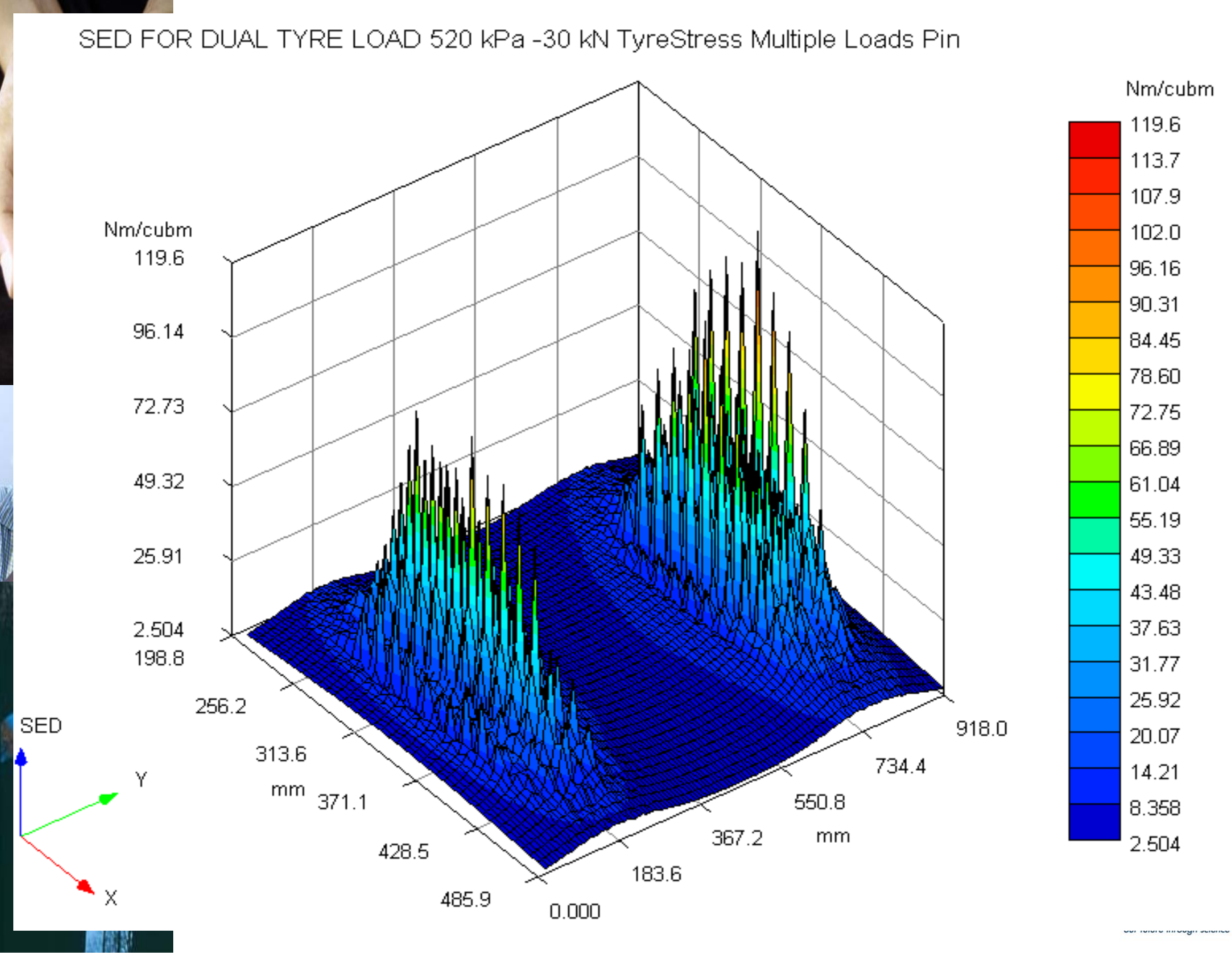
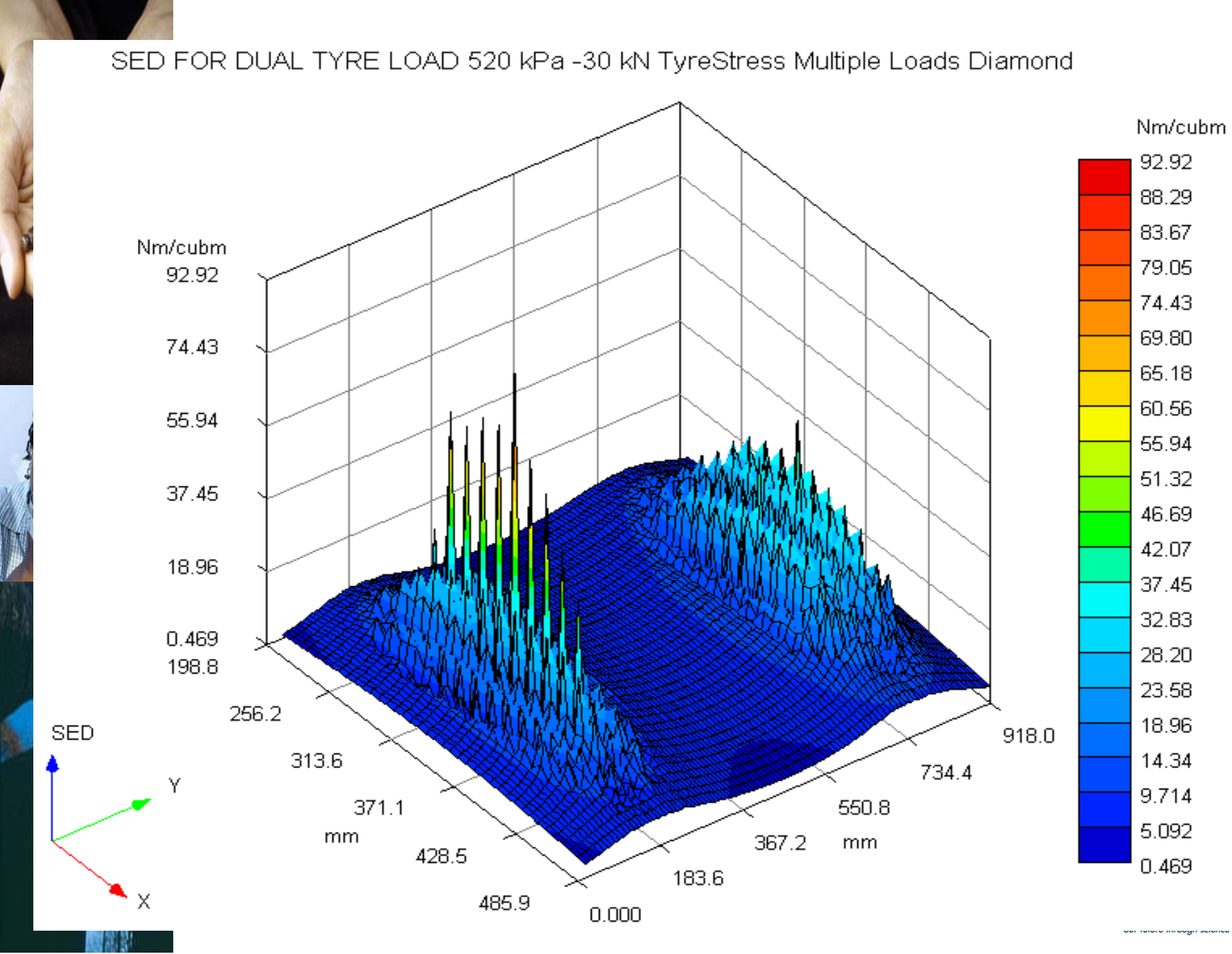
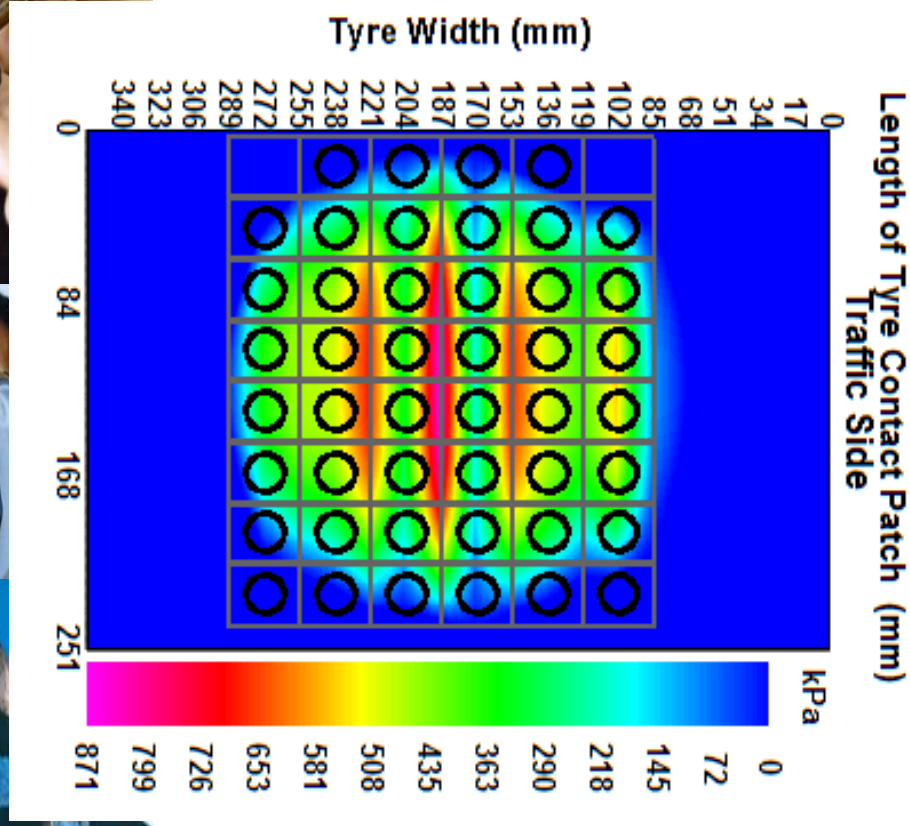
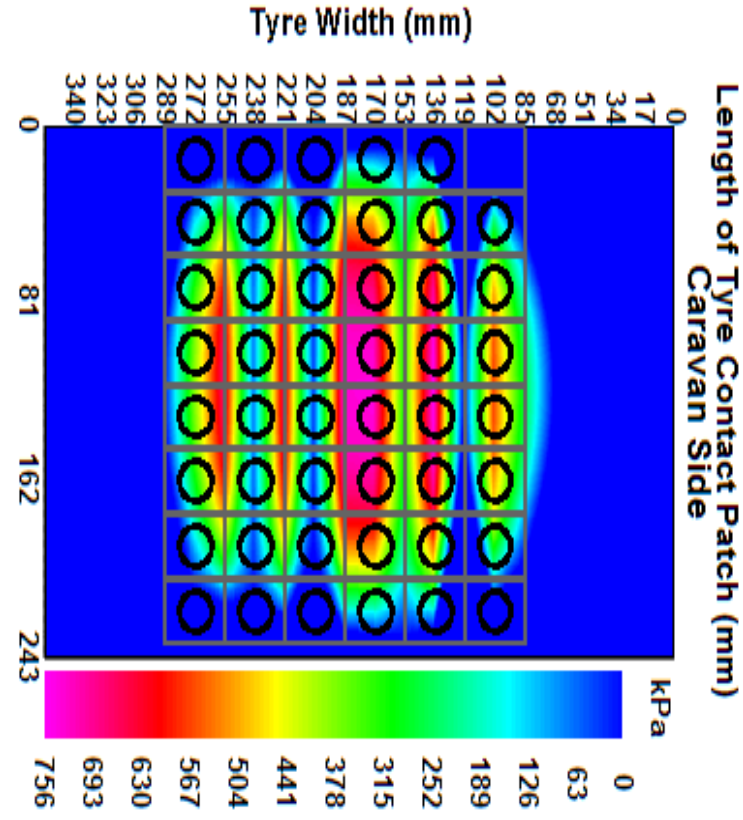

SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Multiple Loads Pin
Nm/cubm
119.6
96.14
72.73
49.32
25.91
2.504
198.8
256.2
313.6
371.1
428.5
485.9
mm
0.000
183.6
367.2
550.8
734.4
918.0
mm
SED
Y
X
Nm/cubm
119.6
113.7
107.9
102.0
96.16
90.31
84.45
78.60
72.75
66.89
61.04
55.19
49.33
43.48
37.63
31.77
25.92
20.07
14.21
8.358
2.504

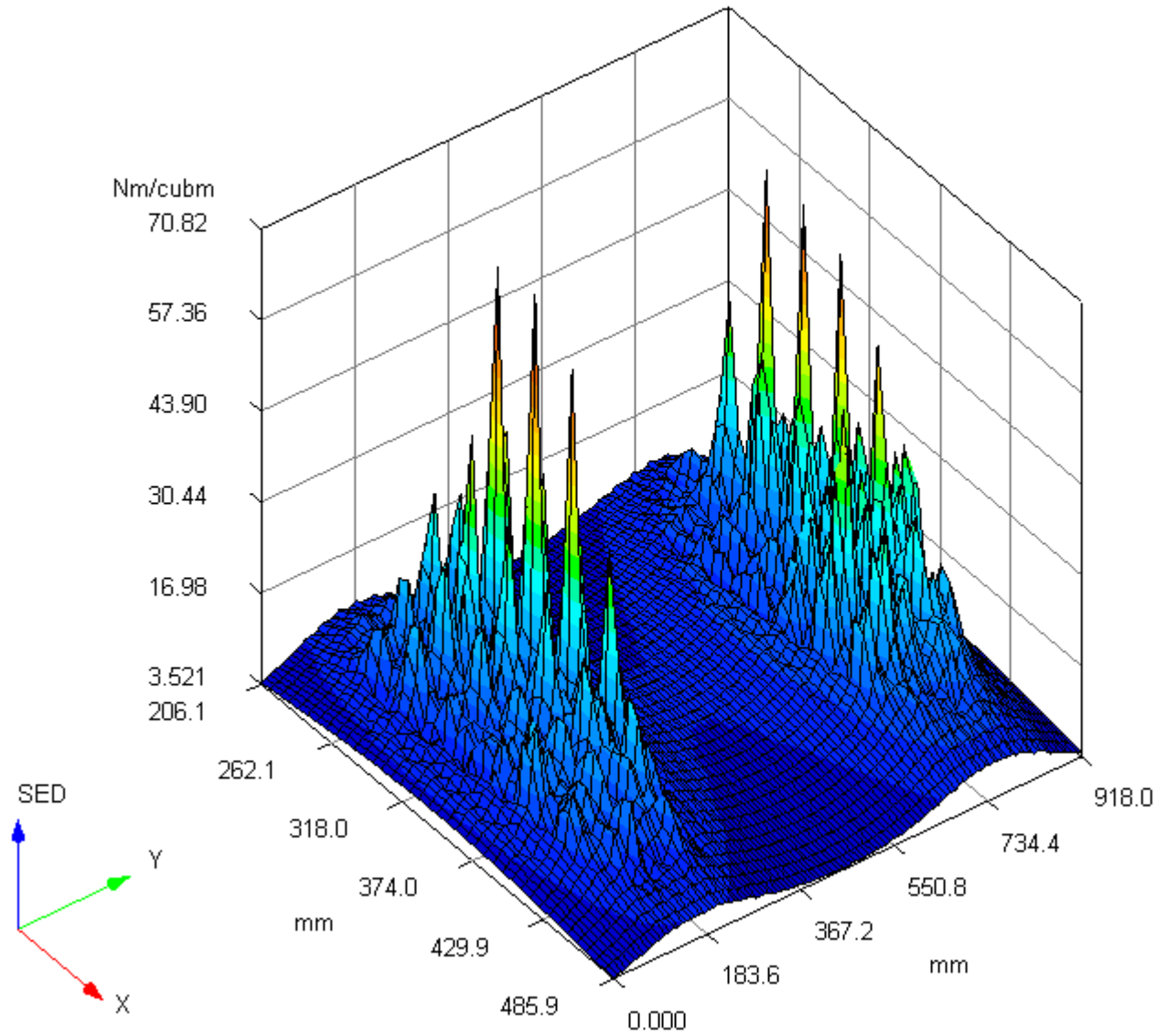

SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Multiple Loads Diamond
Nm/cubm
92.92
74.43
55.94
37.45
18.96
0.469
198.8
256.2
313.6
371.1
mm
428.5
485.9
0.000
183.6
367.2
mm
550.8
734.4
918.0
SED
Y
X
Nm/cubm
92.92
88.29
83.67
79.05
74.43
69.80
65.18
60.56
55.94
51.32
46.69
42.07
37.45
32.83
28.20
23.58
18.96
14.34
9.714
5.092
0.469

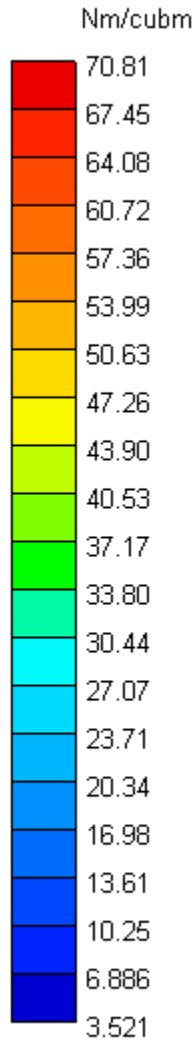
Multiple loads 30kN 6 rows Pin



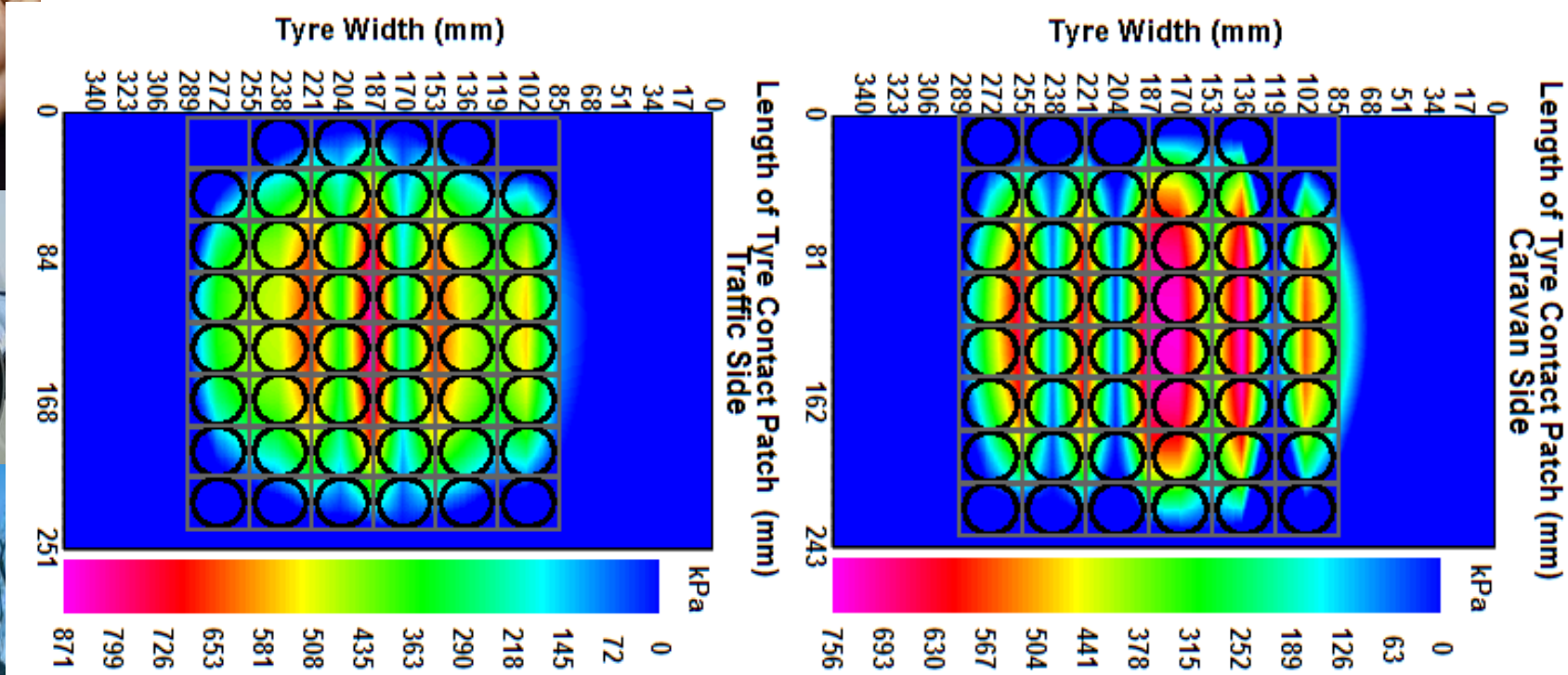


SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Multiple Loads Pin 6 rows





Multiple loads 30kN 6 rows Diamond



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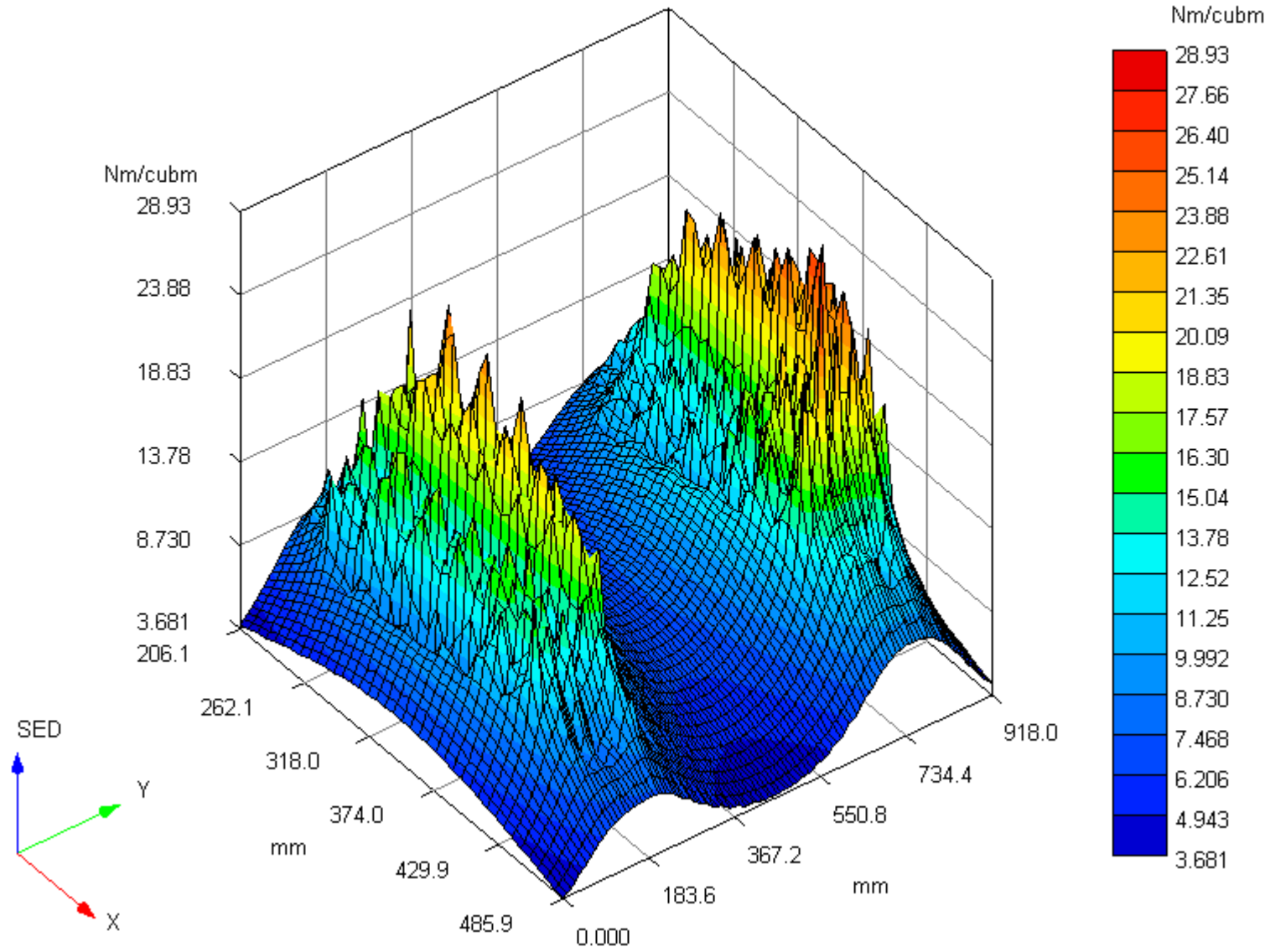
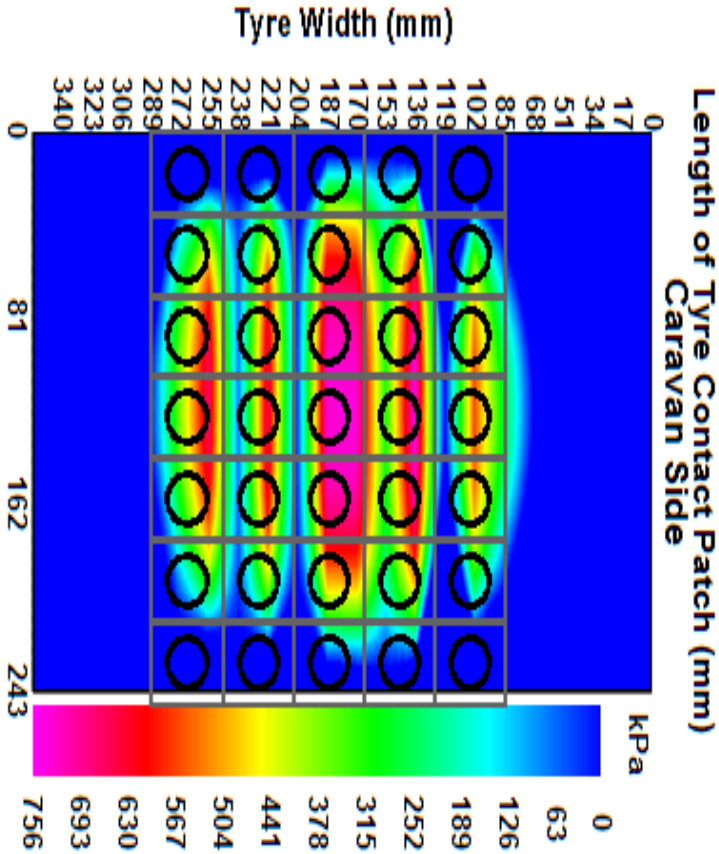
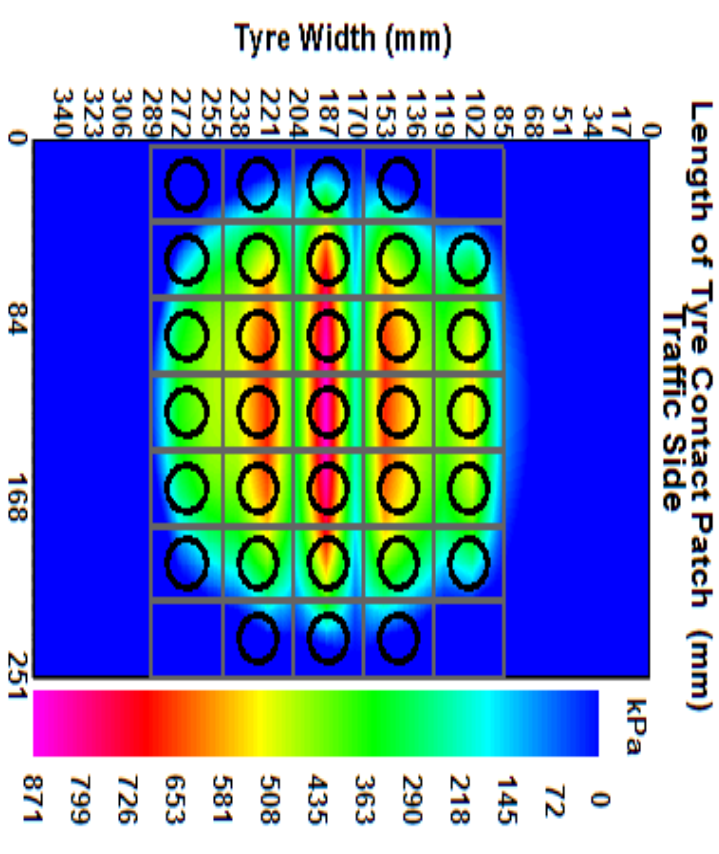
SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Multiple Loads Diamond 6 rows



Multiple loads 30kN 5 rows pin





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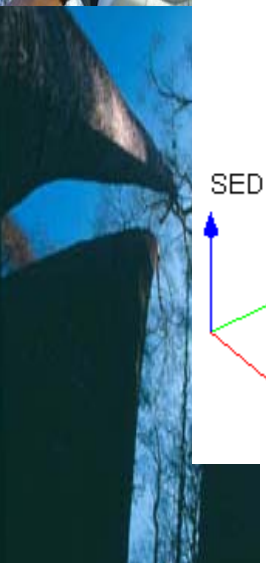
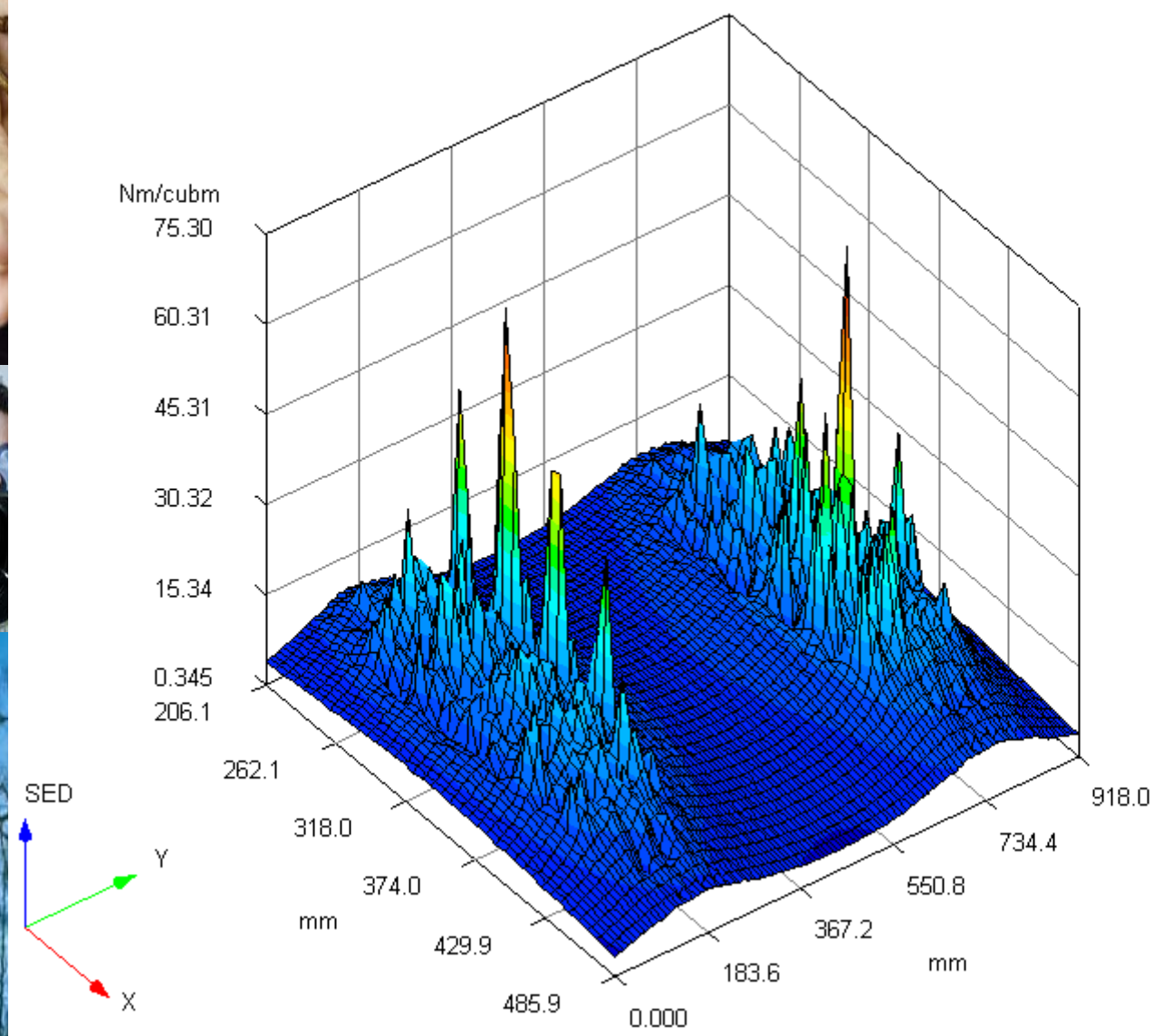
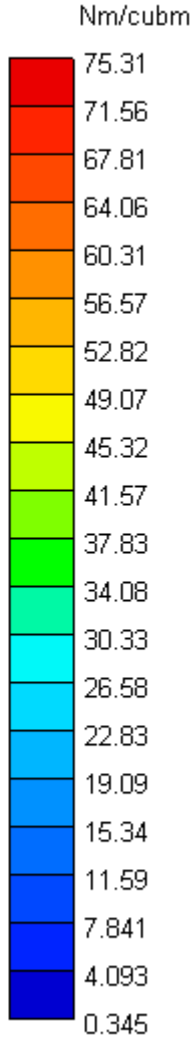
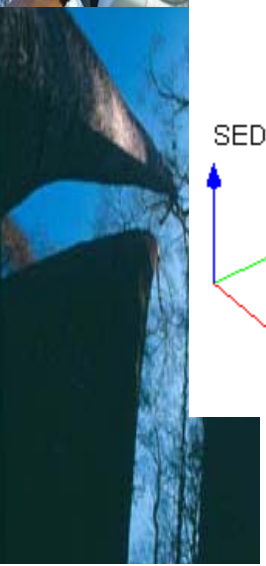


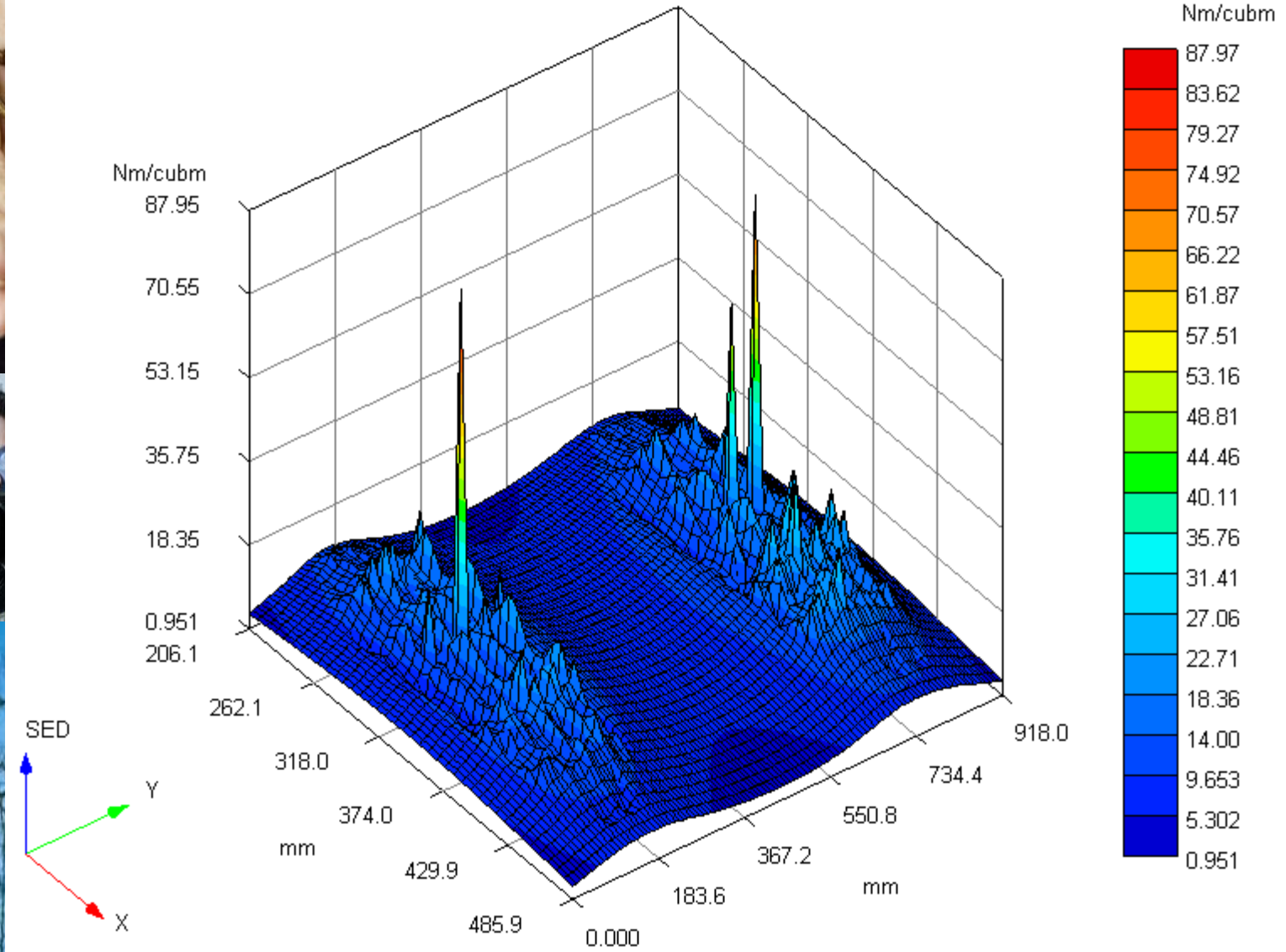
SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Multiple Loads Pin 5 rows



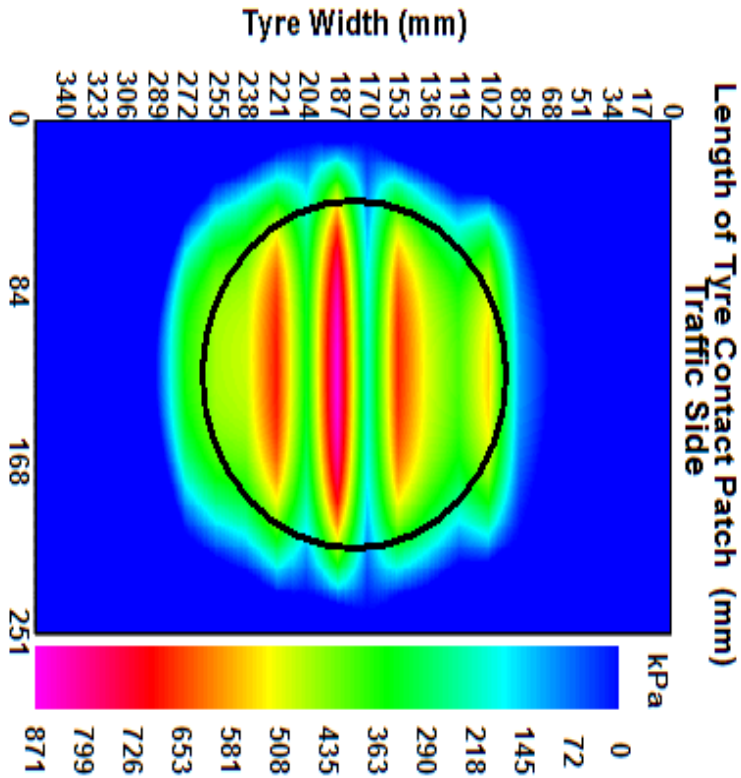


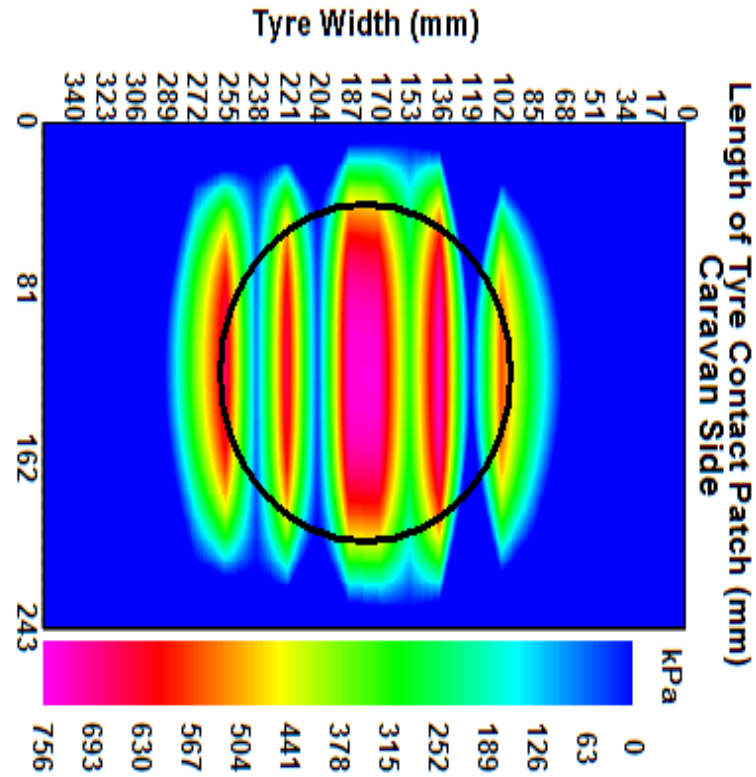


SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Multiple Loads Diamond 5 rows

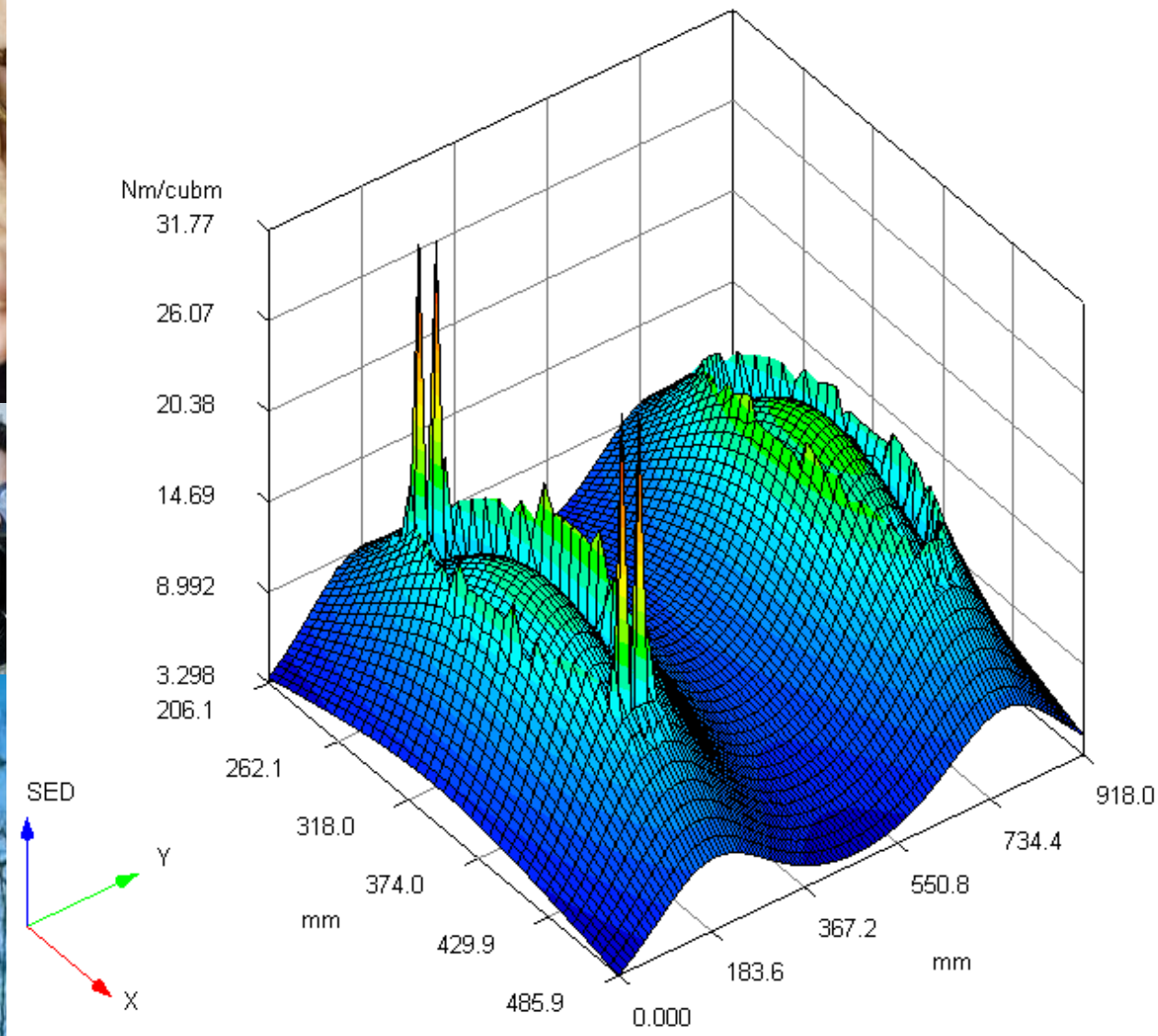


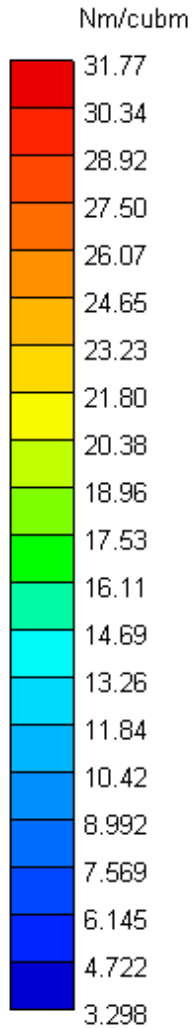
Staggered Discs 1 - Pin



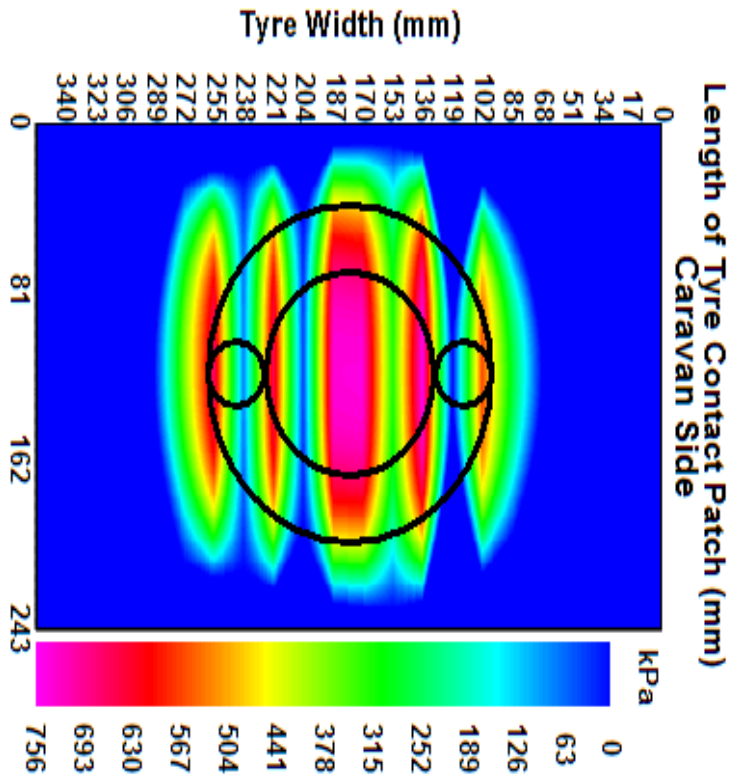


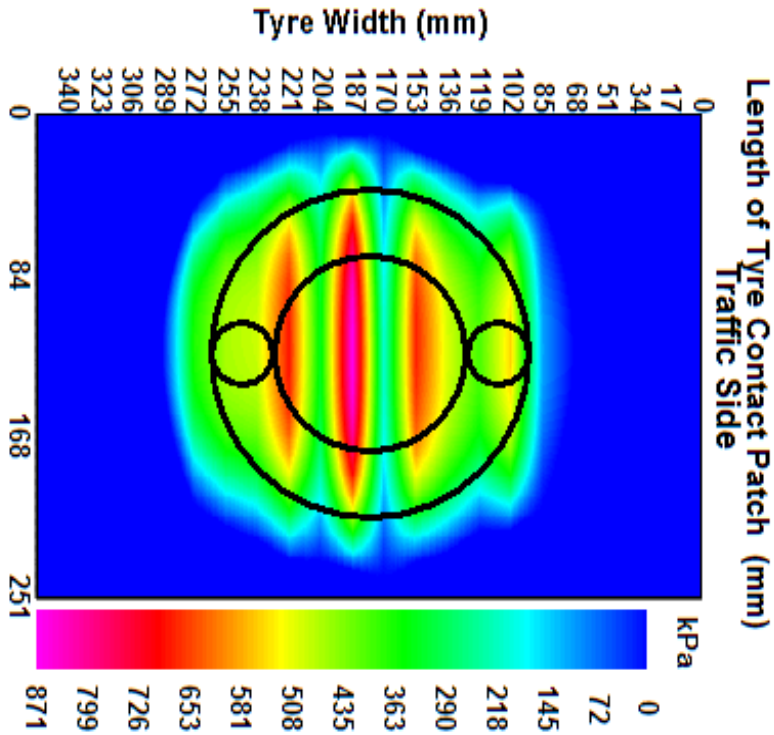
SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Staggered Discs 1 - Pin





Staggered Discs 2 - Pin





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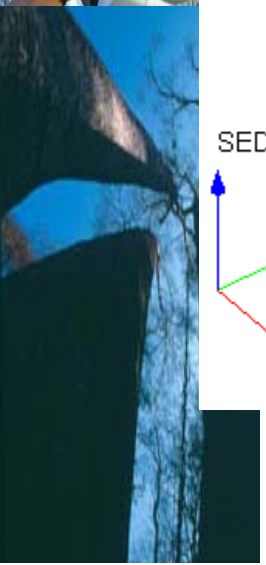
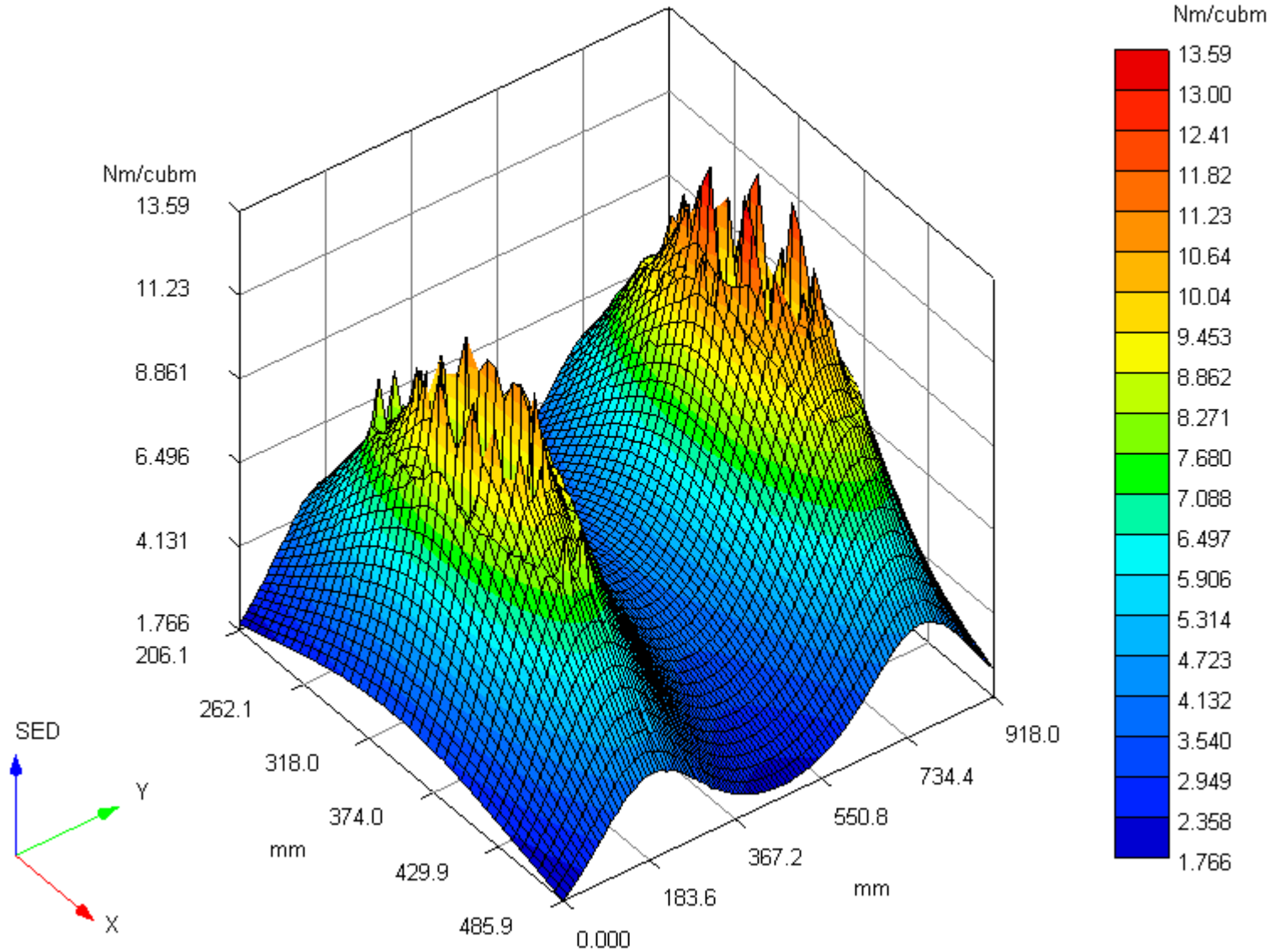
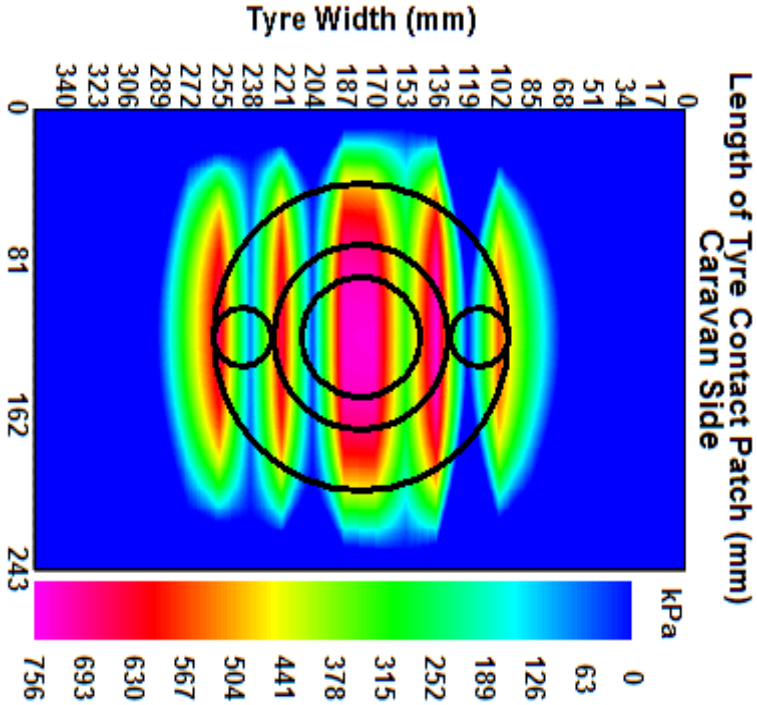
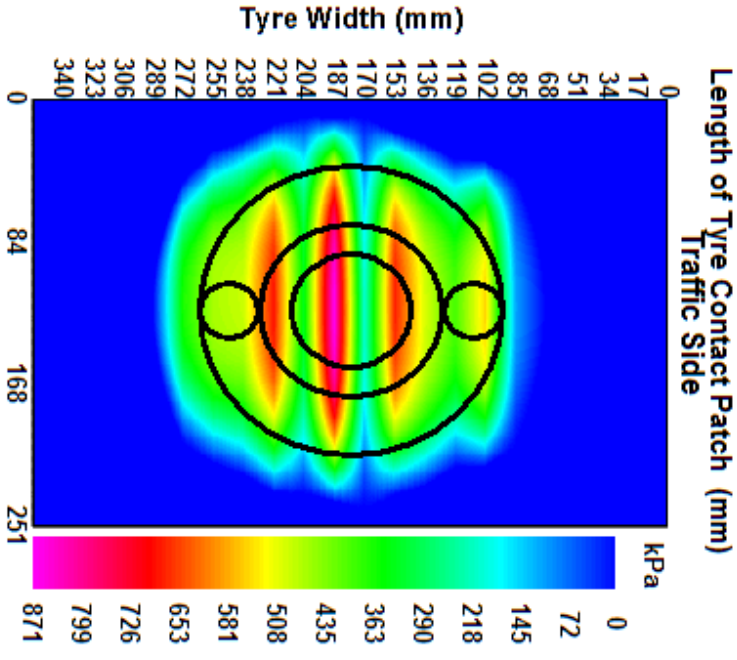


SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Staggered Discs 2 - Pin



Staggered Discs 3 - Pin





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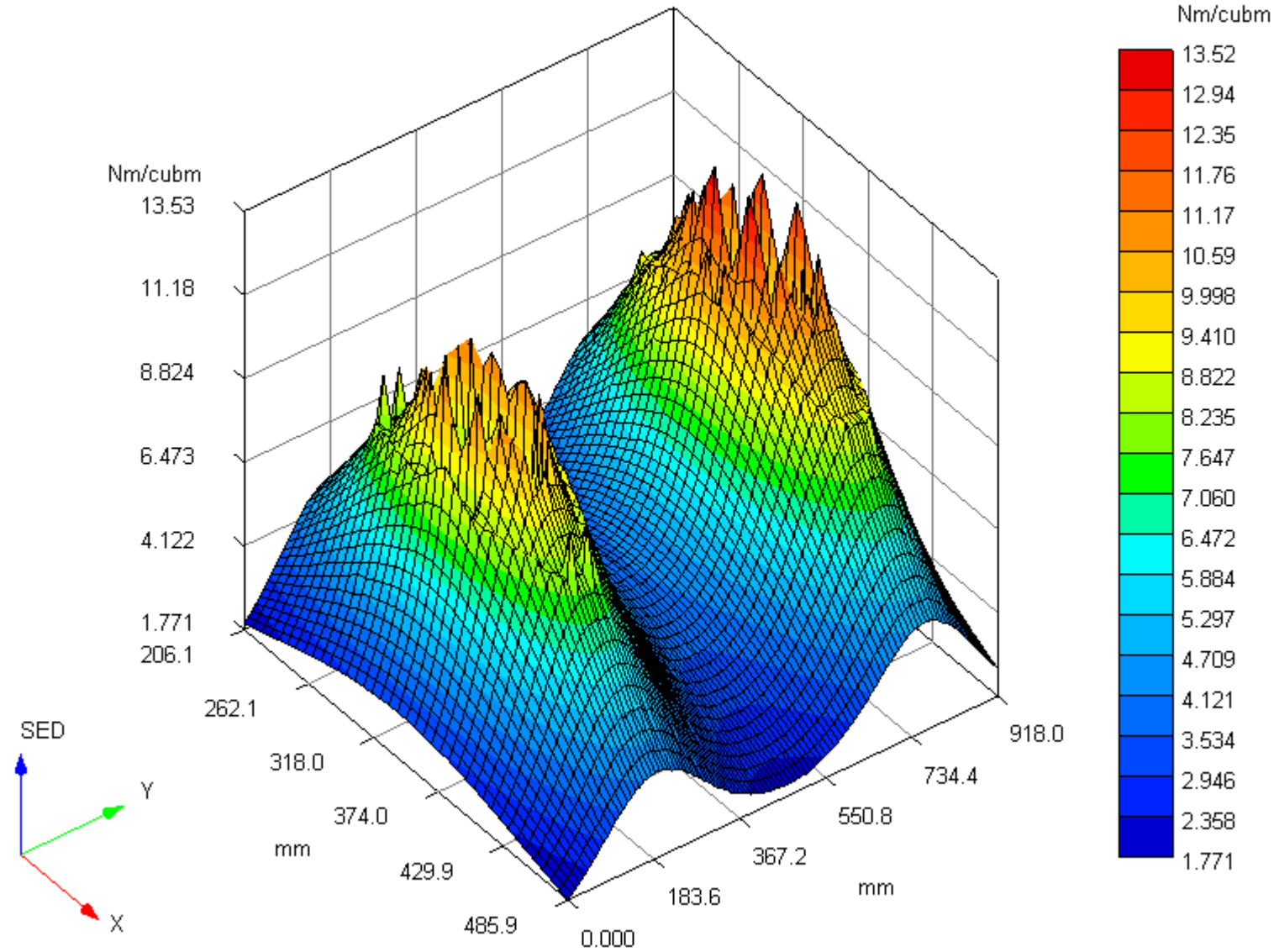
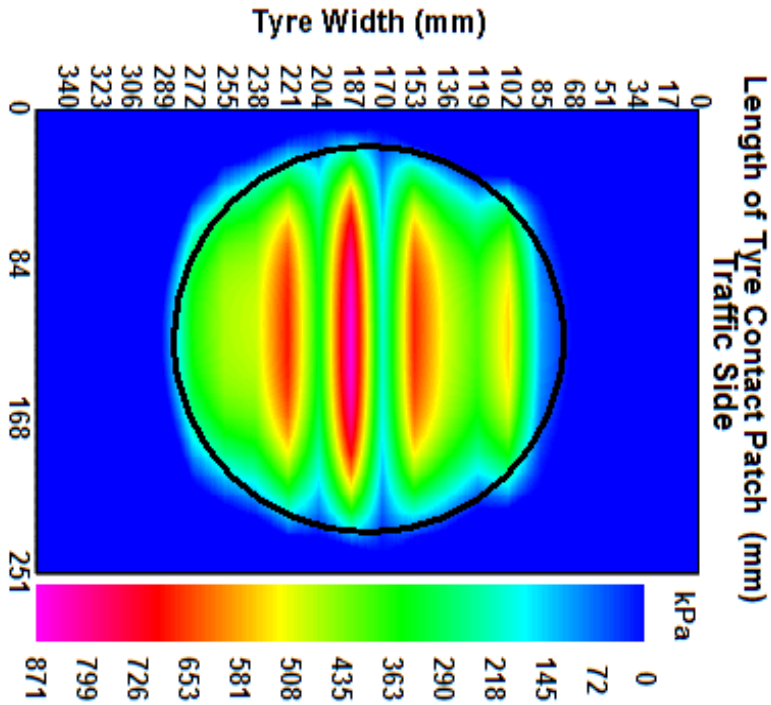
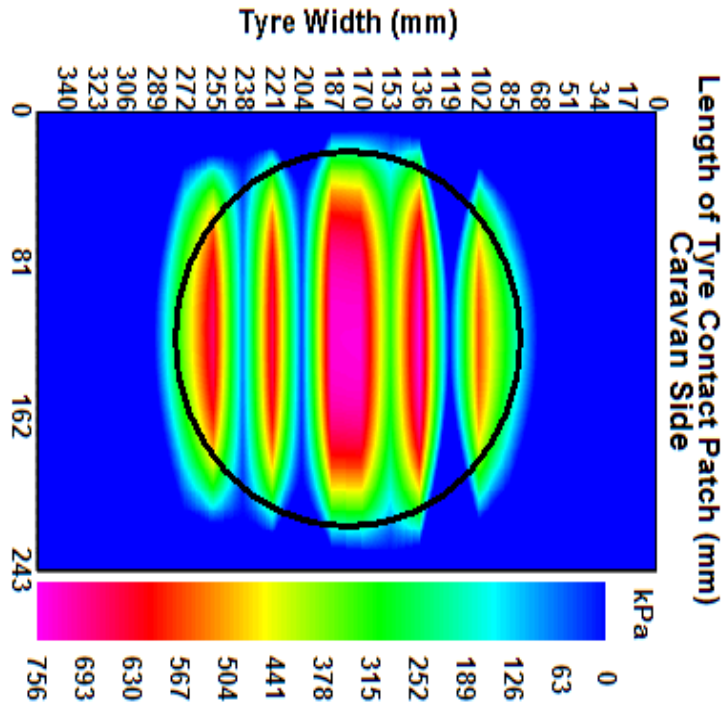
SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Staggered Discs 3 - Pin

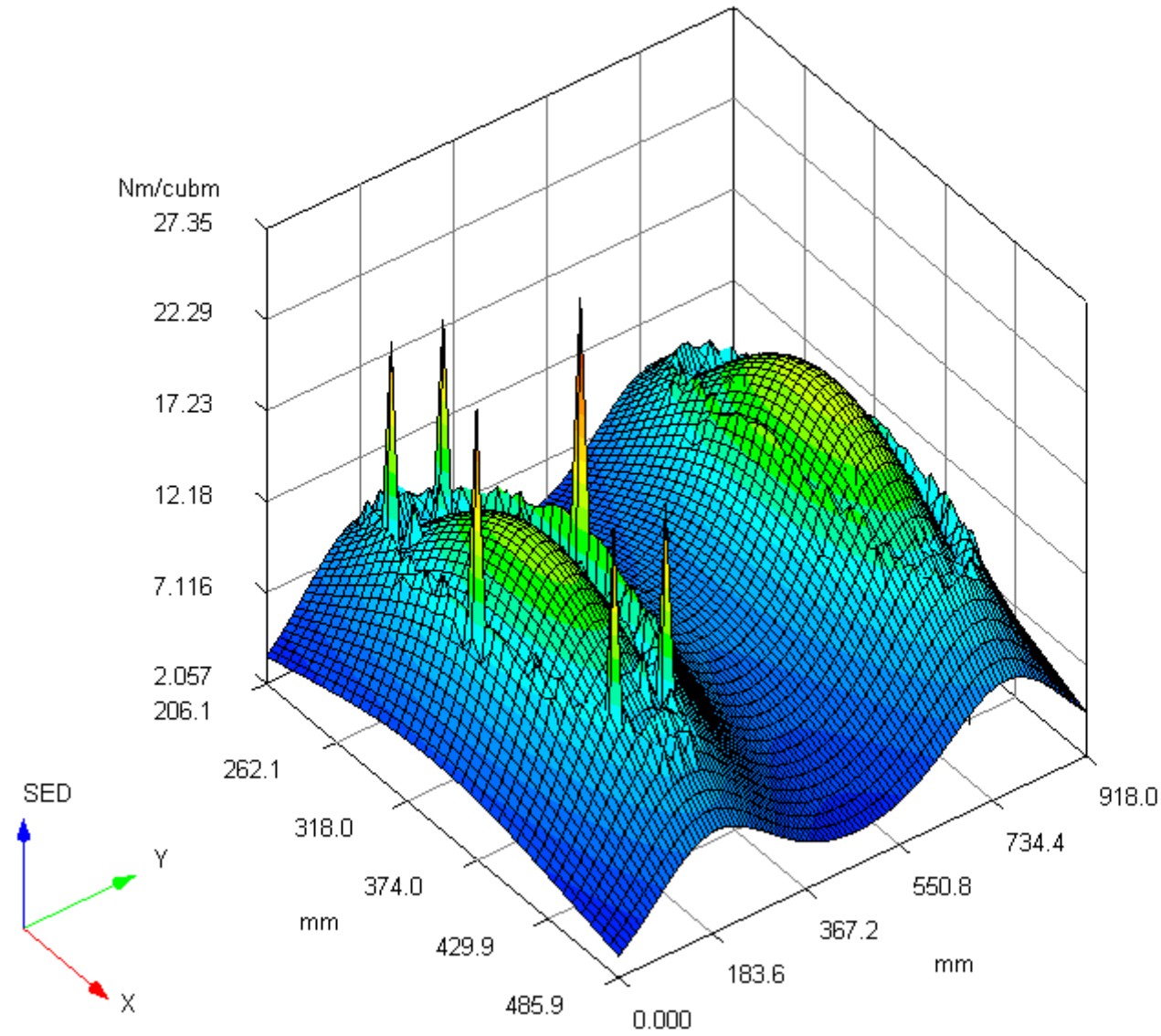


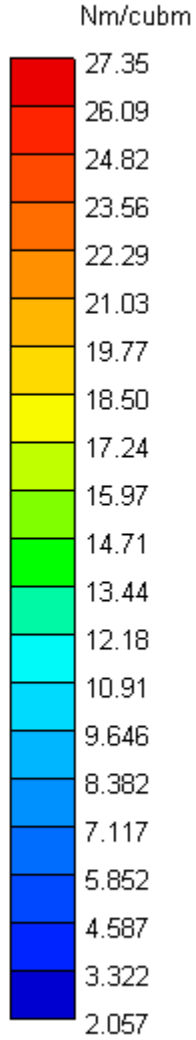
Staggered Discs 1 Diamond



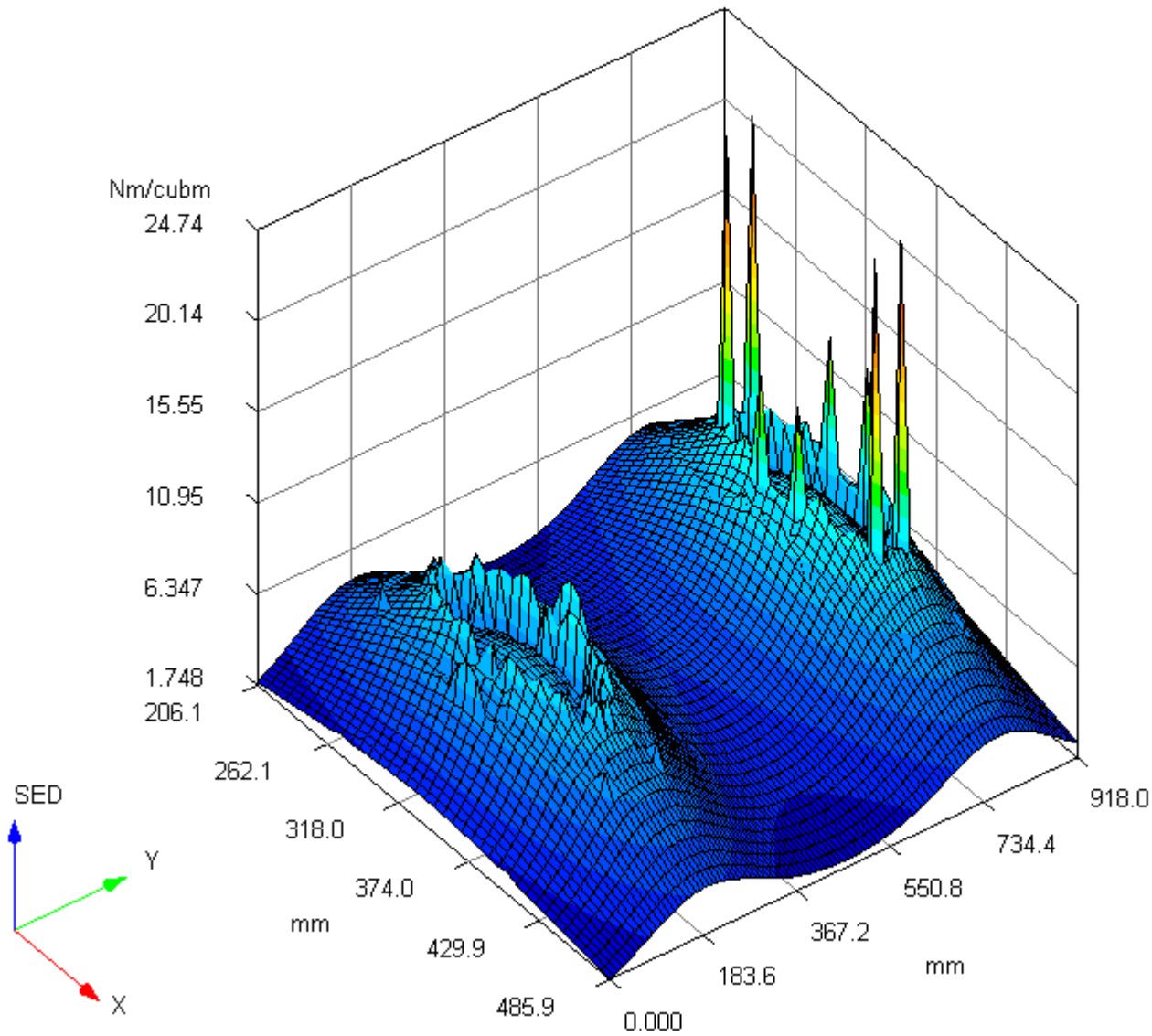


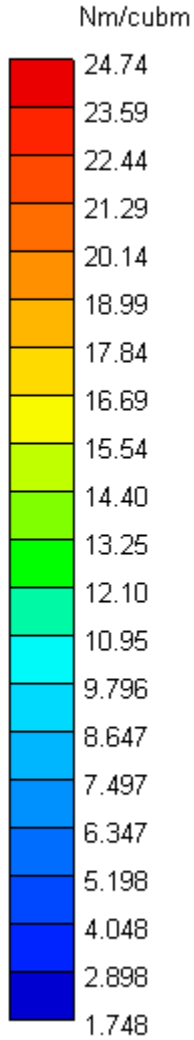
SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Staggered Discs 1 - Diamond





SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Staggered Discs 2 - Diamond





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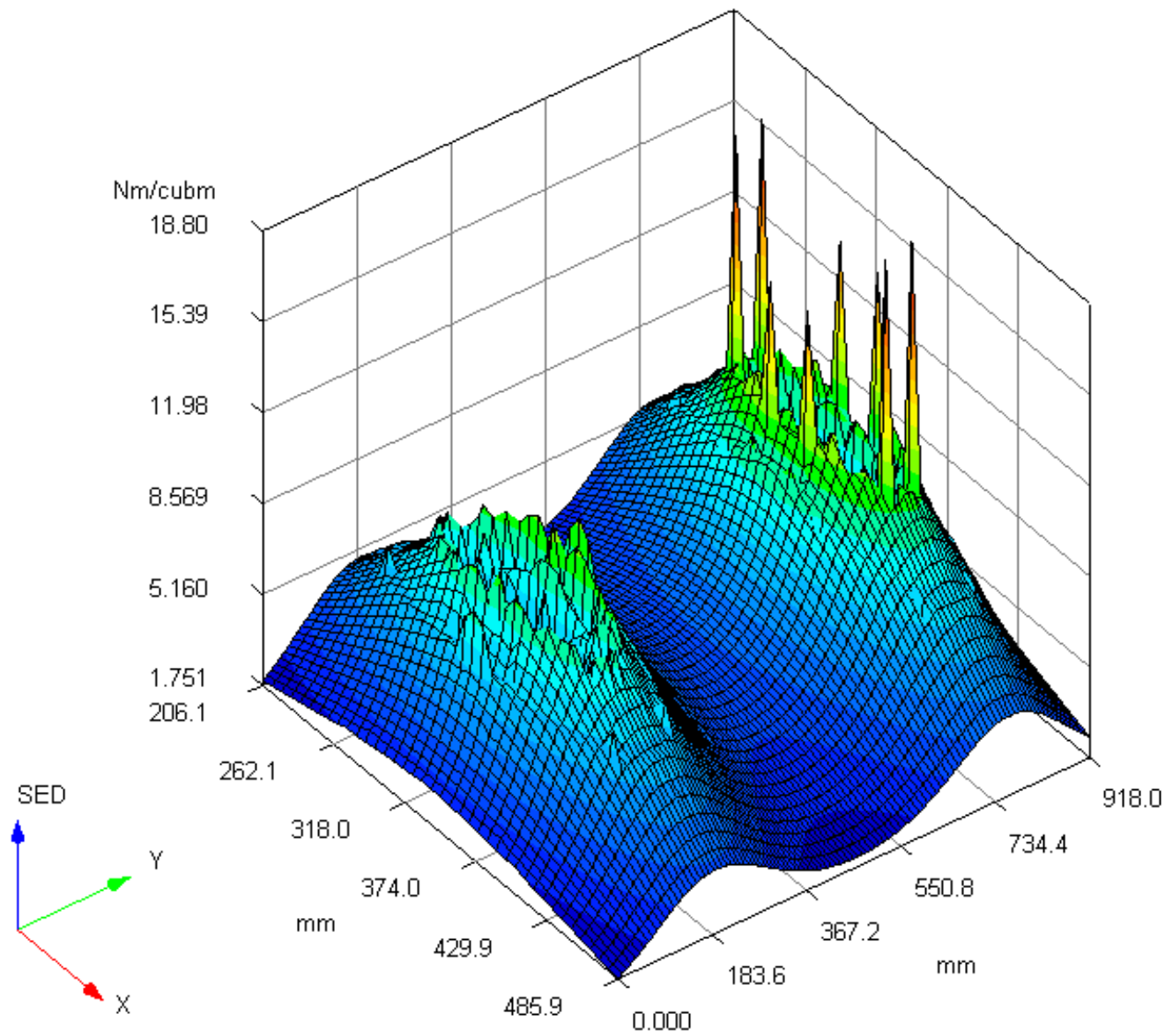
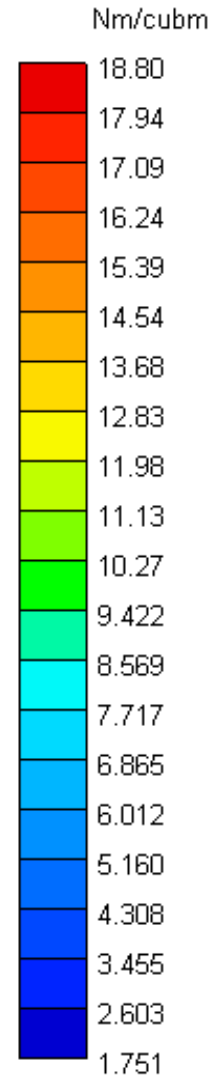
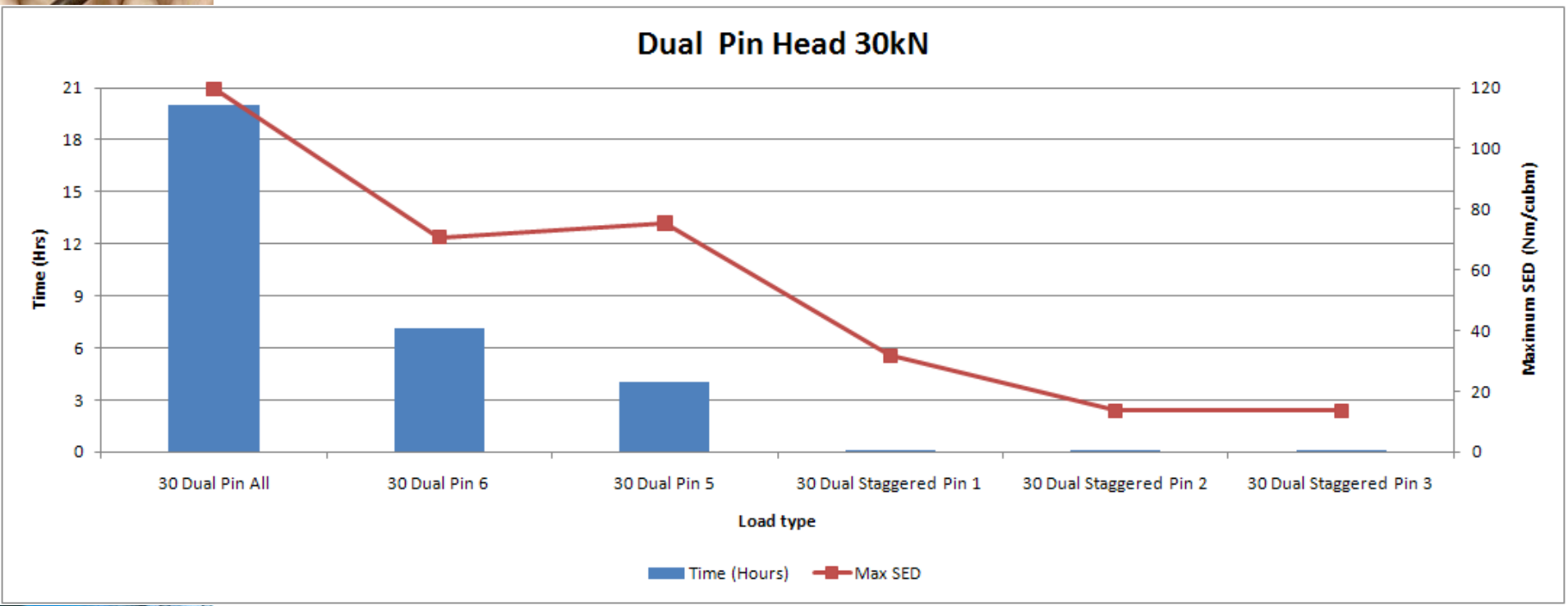
SED FOR DUAL TYRE LOAD 520 kPa -30 kN TyreStress Staggered Discs 3 - Diamond

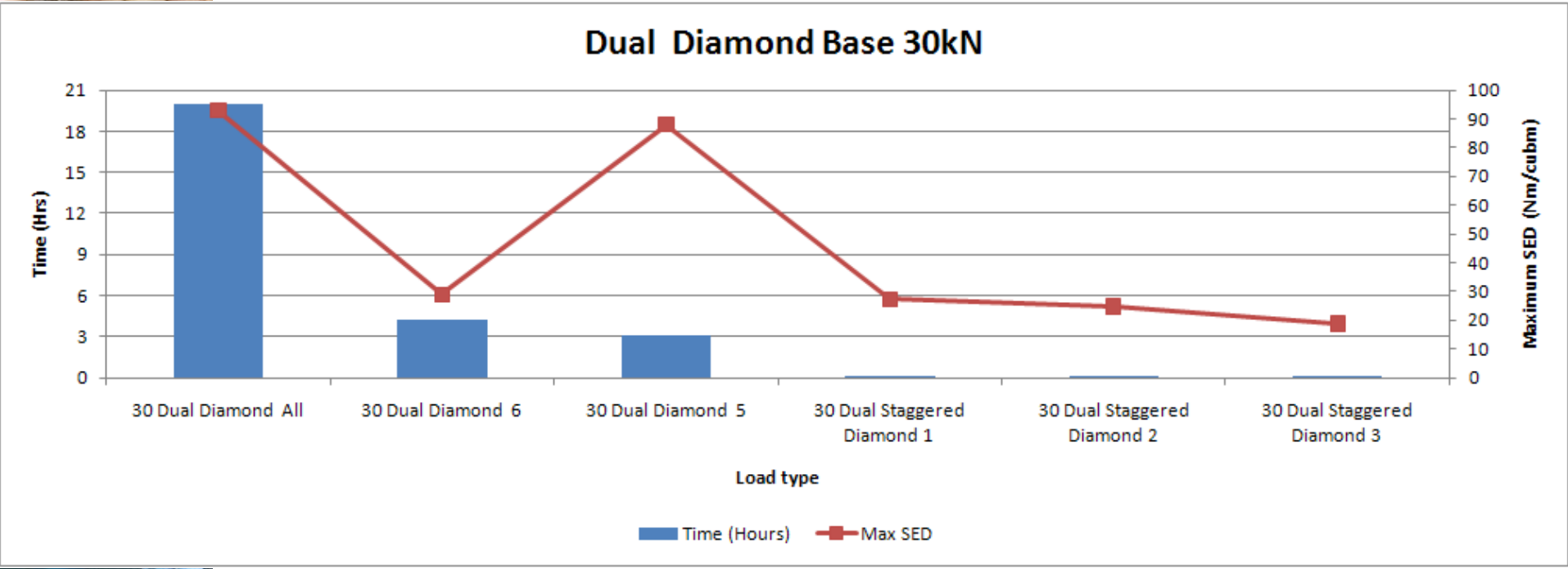




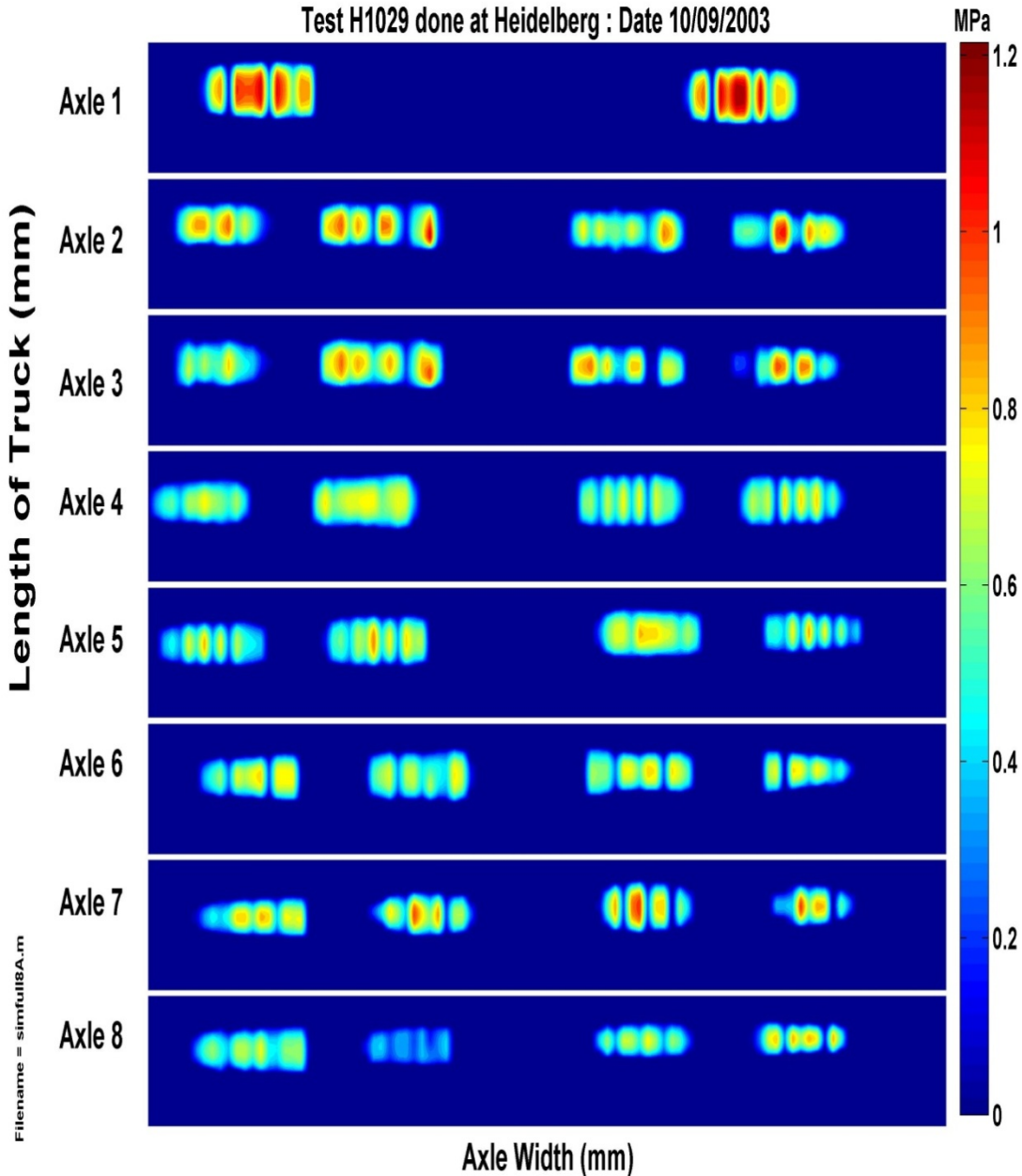
Summary of results – Pin Head



Summary of results – Pin Head



Eight (8) Axle Truck = 30 tyres – Vertical Contact Stress - Foot Prints….



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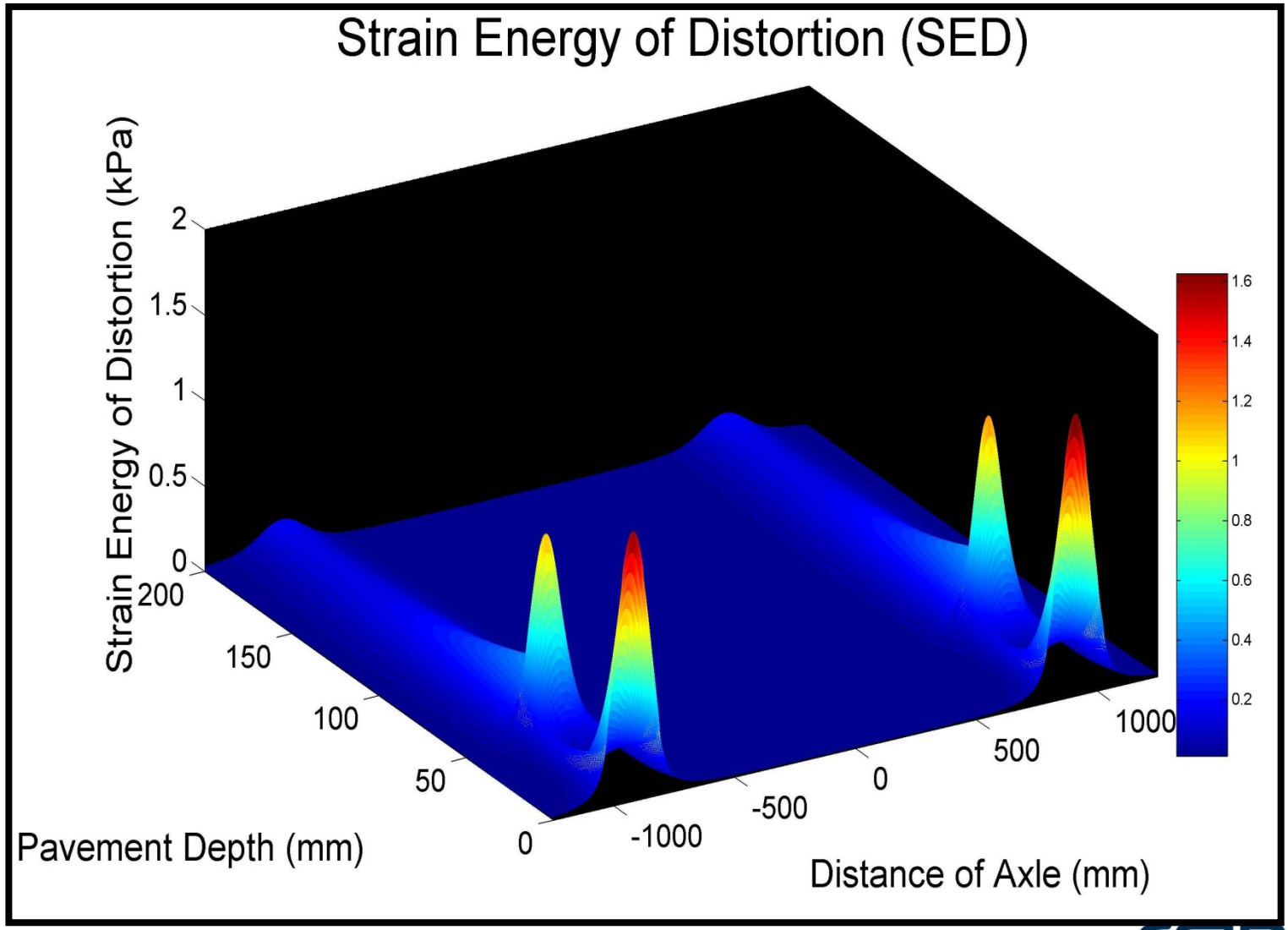
30 Tyres: 1 mm x 1 mm resolution – 500k points – SED under Steering Axle ……



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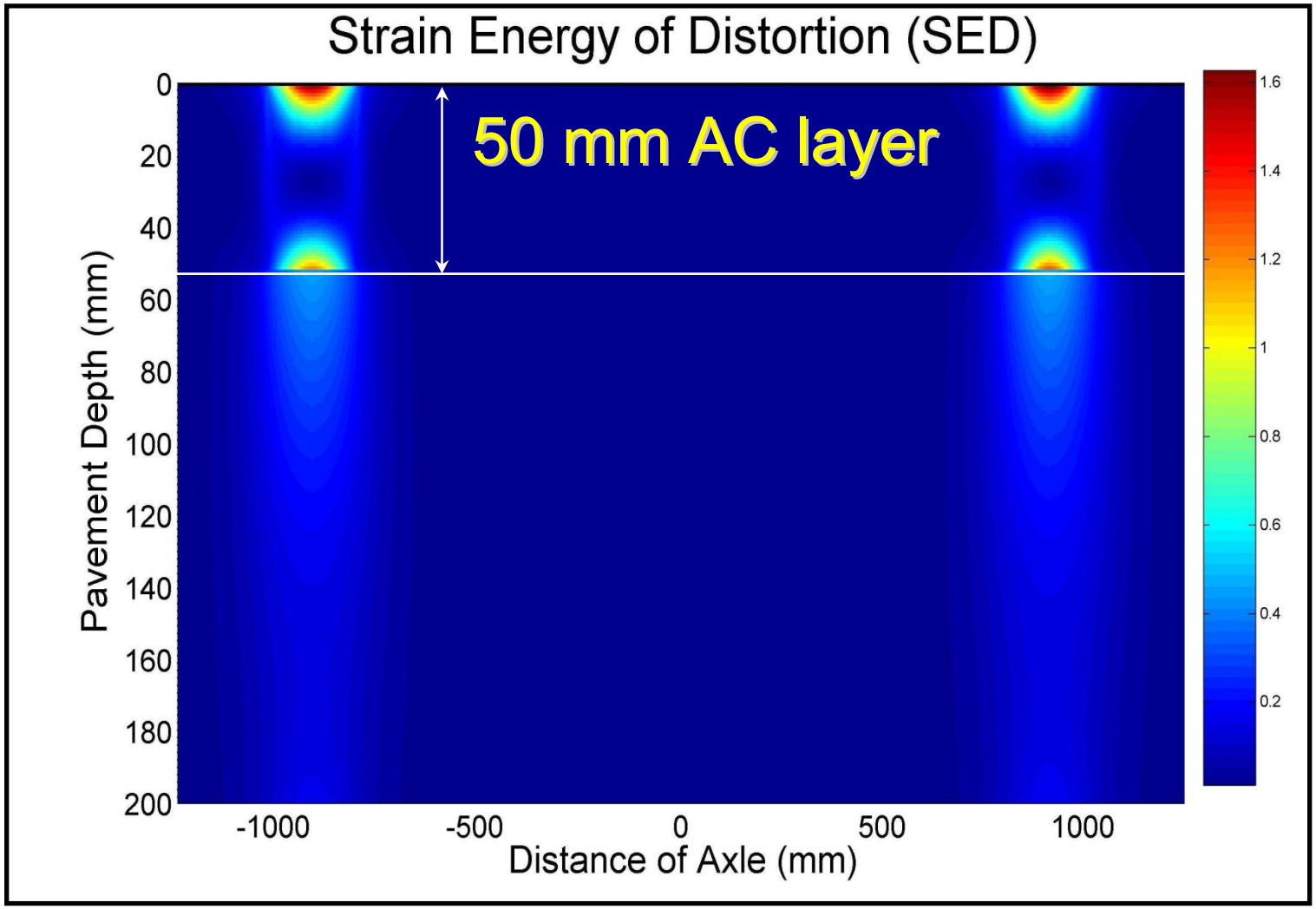
…SED under Steering Axle



Rutting- Controlled testing with Heavy Vehicle Simulator (HVS)…

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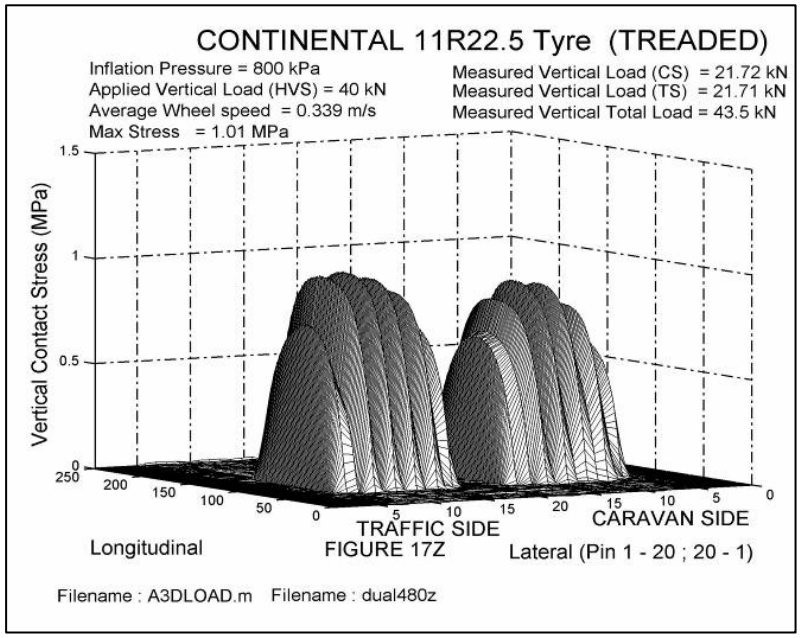
Vertical Tyre Stress: “n-Shape” tyre stress results in “n-Shape” rutting on asphalt layer..



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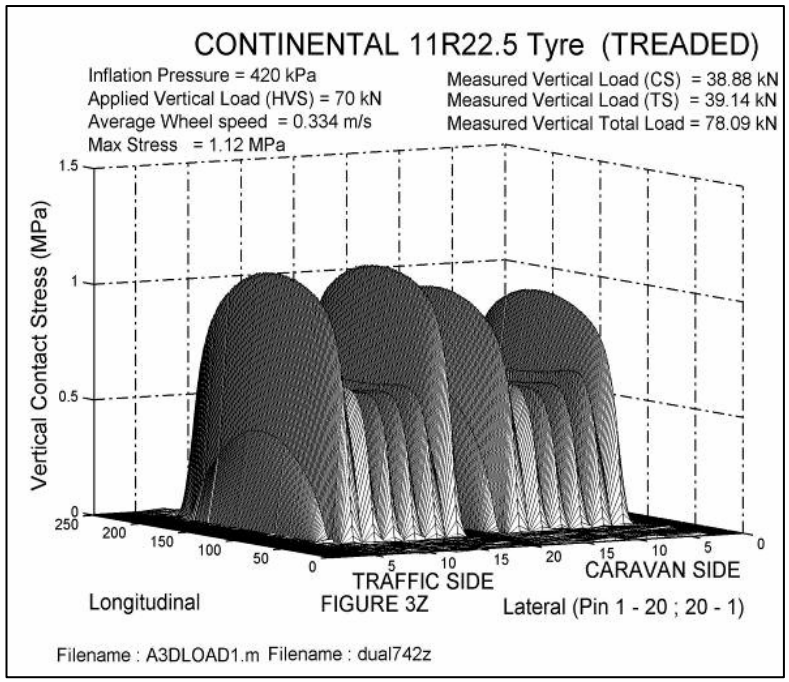
Vertical Tyre Stress: “m-Shape” stress result in “m-Shape” rutting on asphalt layer..



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Summary, Conclusions (1):

- South African Roads, Trucks @ Road Damage – real cause for concern;
- Analytical approach - SED shows good promise for further implementation;
- Tyre Studies with Heavy Vehicle Simulator (HVS);
- Implications for Road Surface Design and Road Preservation/Protection – Important to be implemented



Recommendations:

- Research work is needed to establish if this trend of tyre type is similar for all road pavement structures in South Africa before it is safe to argue against the use of single tyres vs dual tyres.
- Implementing concept of SED in road design
- Numerical development for non-circular (rectangular) loads for realistic simulation of contact stresses.

Thank You!



Summary, Conclusions (2):

- Single wide base tyres induce more than double the potential for failure compared with the dual tyre configuration on the same road pavement.
- Under-inflated-heavily-loaded tyres cause more damage on the surface of the road.
- The top 5 mm to 10 mm of pavements is potentially more prone to failure (top-down cracking or rutting) than was perhaps realised in the past.