Improved Performance Evaluation of Road Pavements by Using Measured Tyre Loading

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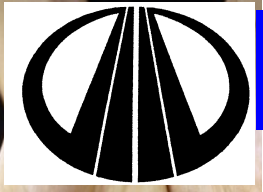
CSIR Built Environment, South Africa

RMPD Seminar, March 4, 2009 at CSIR

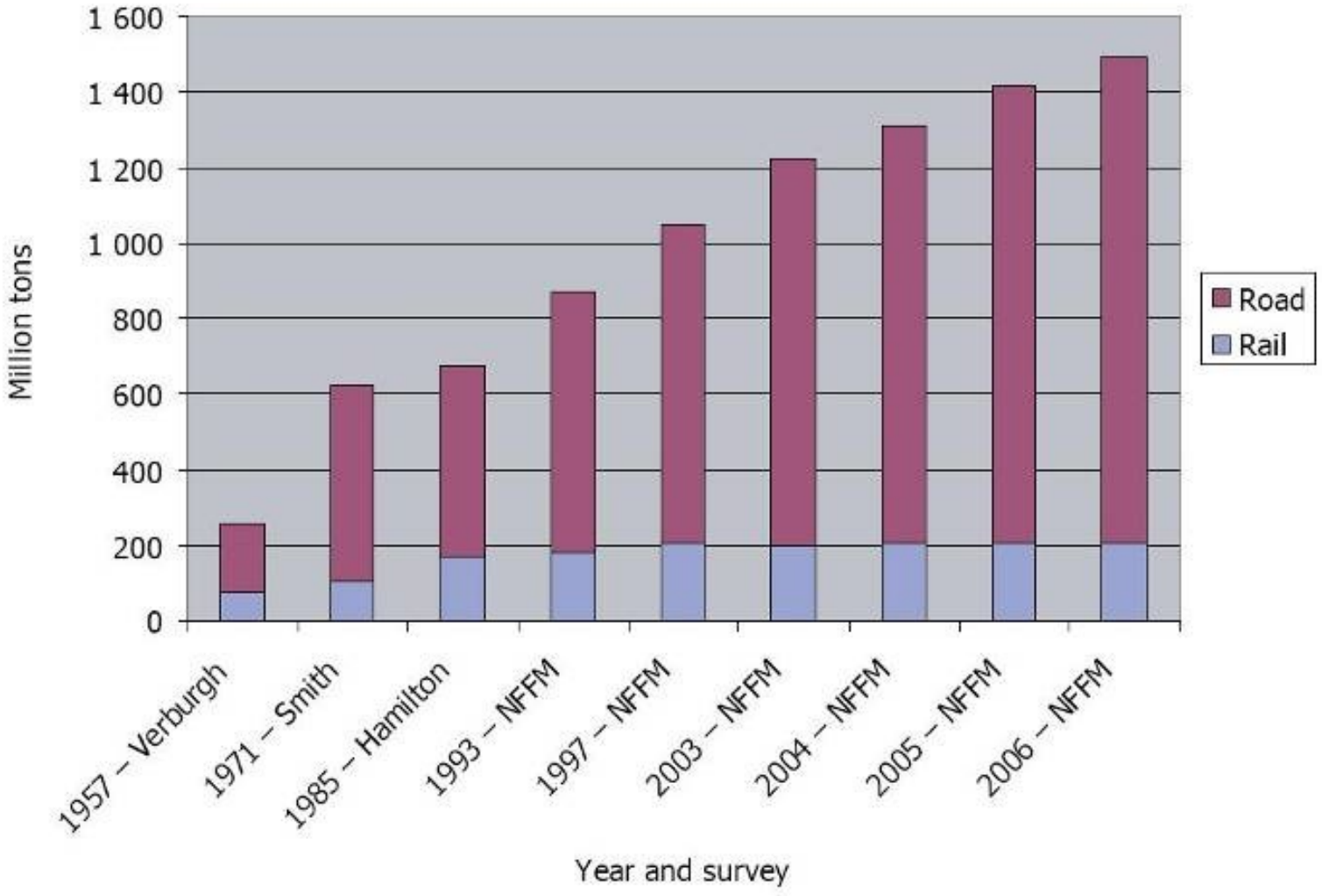
our future through science

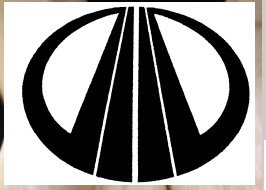


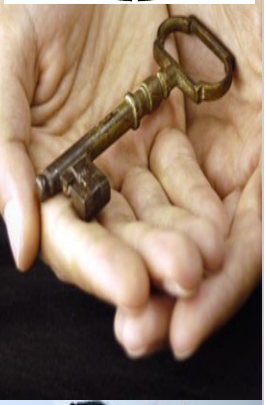
LAYOUT OF PRESENTATION

- South African Roads, Trucks @ Road Damage;
- Introduction into Stress-In-Motion (SIM) technology;
- Tyre Studies with Heavy Vehicle Simulator (HVS);
- Full Scale SIM Testing @ N3-Traffic Control Centre (TCC) - Heidelberg, SA @ typical SIM Results;
- Implications for Road Surface Design and Road Preservation/Protection – Analytical Evaluations..
- ….
- Summary, Conclusions and Recommendations

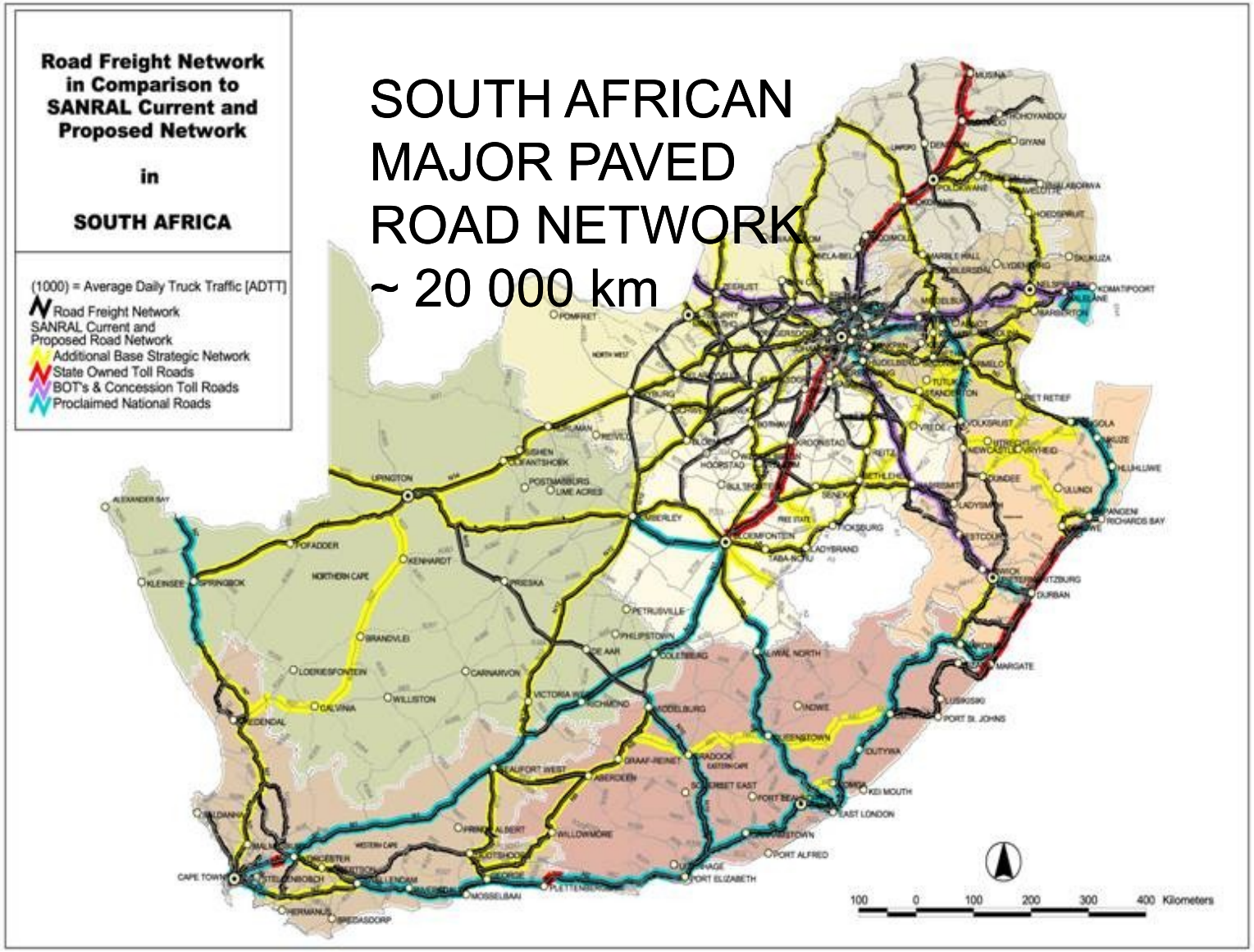
Freight Transport in SA (CSIR Logistics Report, 2007).



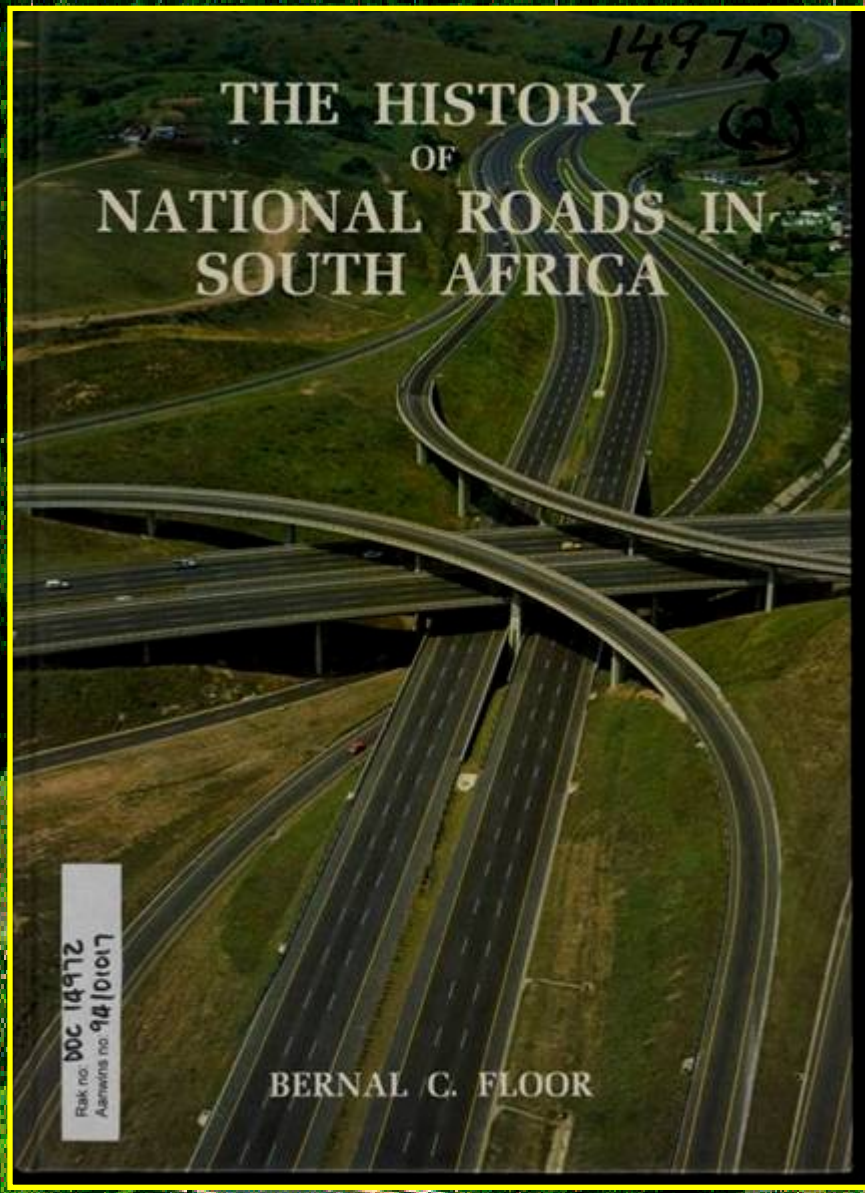


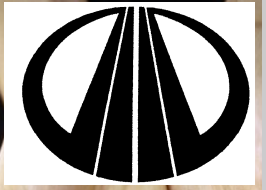


SOUTH AFRICAN MAJOR PAVED ROAD NETWORK ~ 20 000 km



7 700 km National Roads in SA of Freeway/Expressway standard

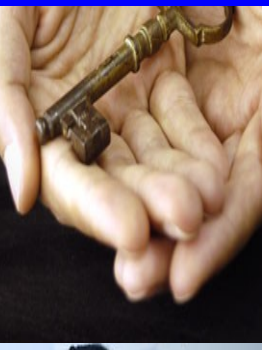




Thin Asphalt Surfacings (30 mm to 50 mm) on crushed rock: Economical in dry regions.

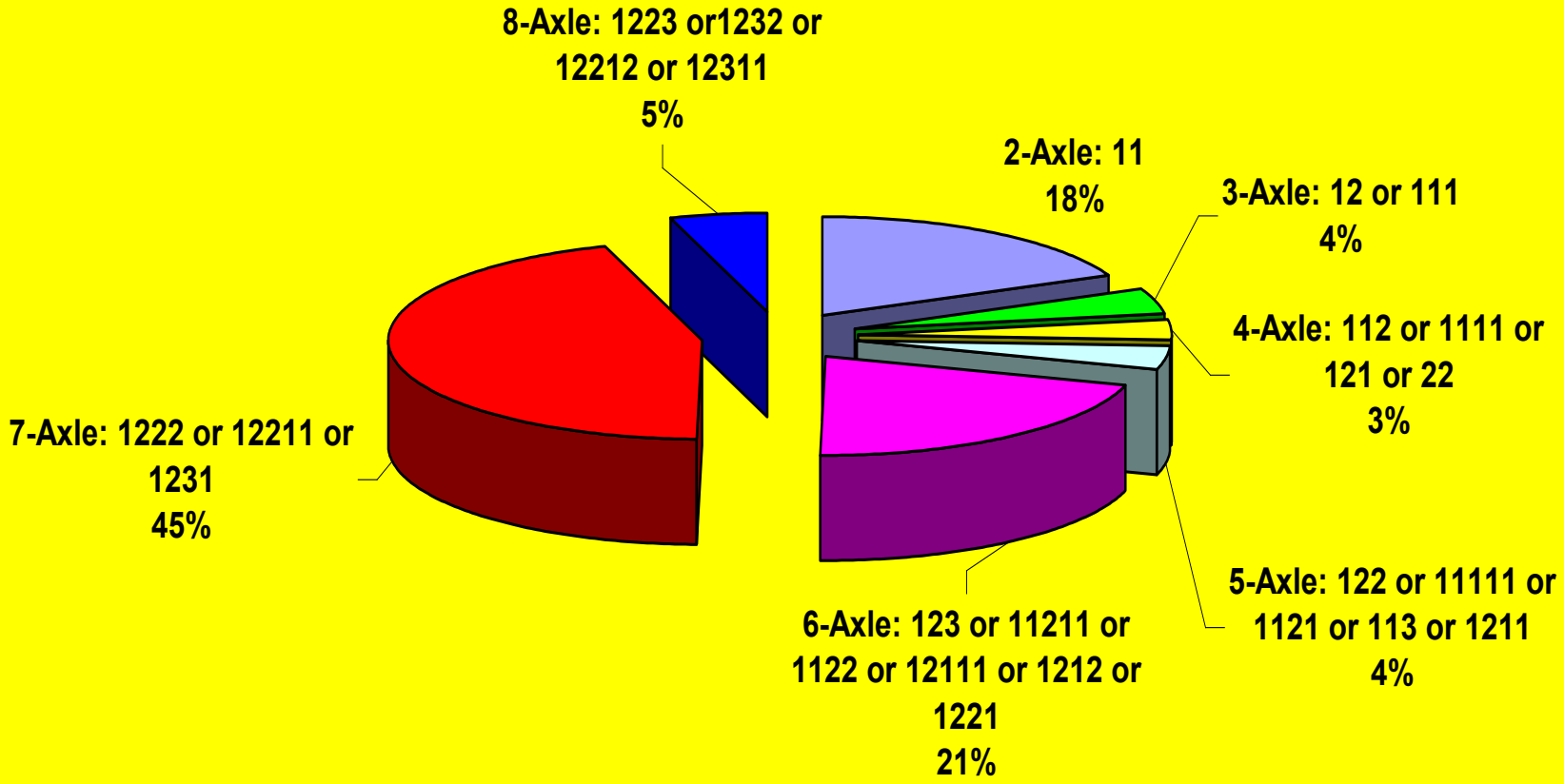
Heavy Vehicles….

Paper today:
Improved Performance Evaluation of Road Pavements by Using Measured Tyre Loading



- SA: 750 000 km of roads - 20 % paved;
- Pavement Engineering critical for upgrade & sustainability;
- Stress-In-Motion (SIM) study part of this process;
- Paper report on major 6 week R&D SIM study on National Road (N3);
- Included DAW 50 and Static Scale (1 245 paired data sets);
- SIM: 2 292 Truck, 12 830 Axles, 45 165 tyres measured;
- Sample of 1 090 tyres for Inflation pressure (March 2003);

Truck Classification



Truck Tyre Inflation Pressure in South Africa

~ 20 % Increase in 20 Years

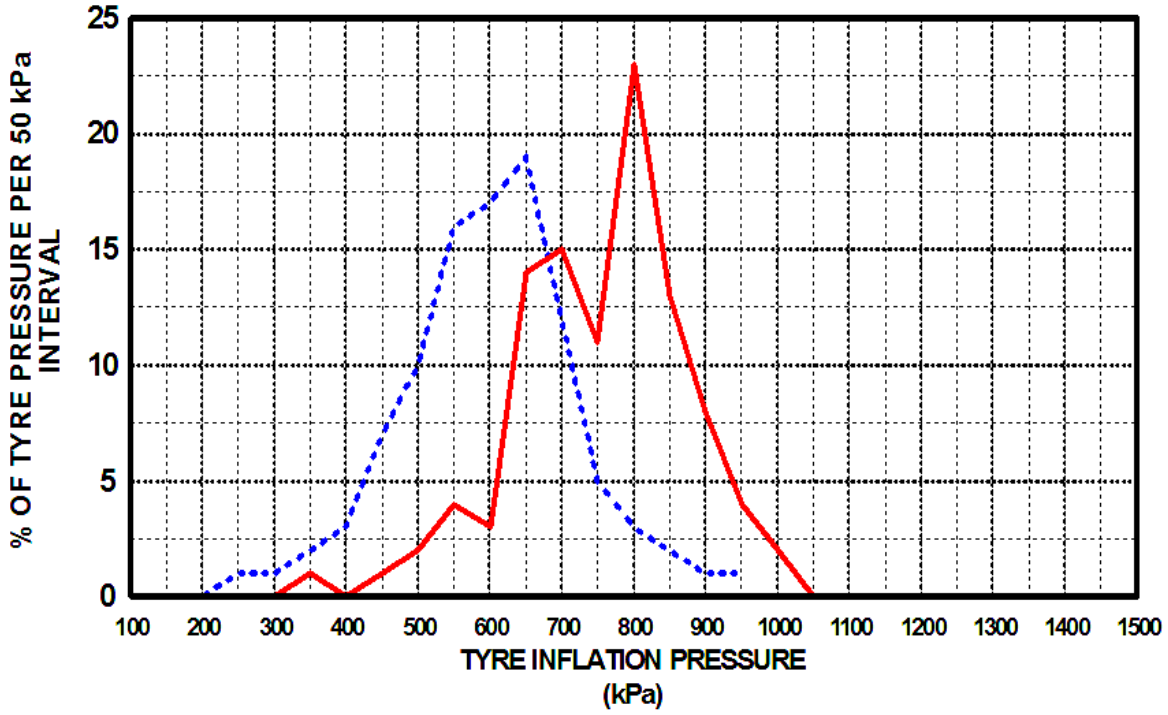


FIGURE 1

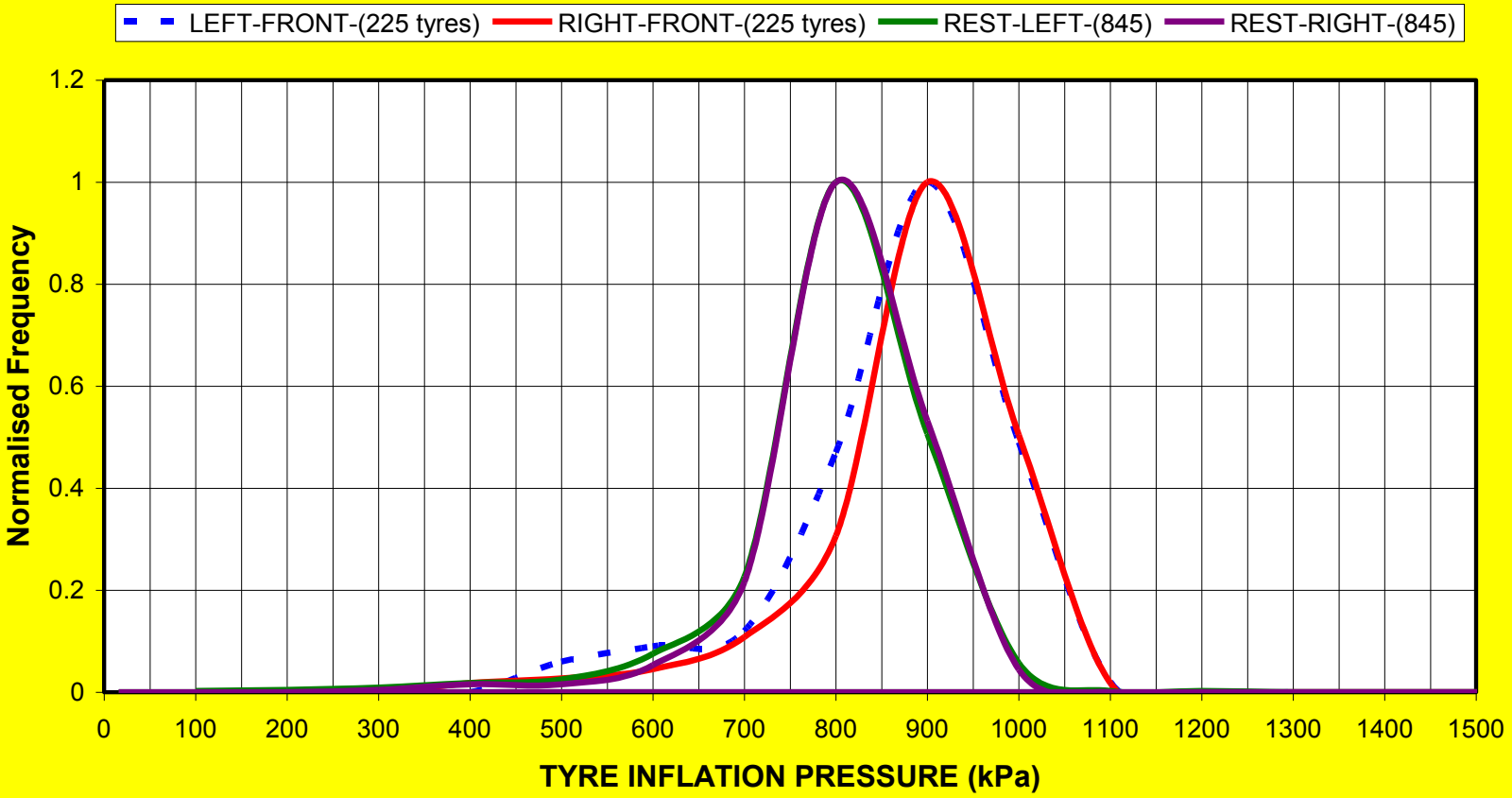
AVERAGE MEASURED TYRE INFLATION PRESSURE DISTRIBUTIONS OF HEAVY VEHICLES (AXLE LOADS > 7 000 kg) ON ROADS IN THE PROVINCE OF GAUTENG, SOUTH AFRICA

c:/capsaf1.wmf

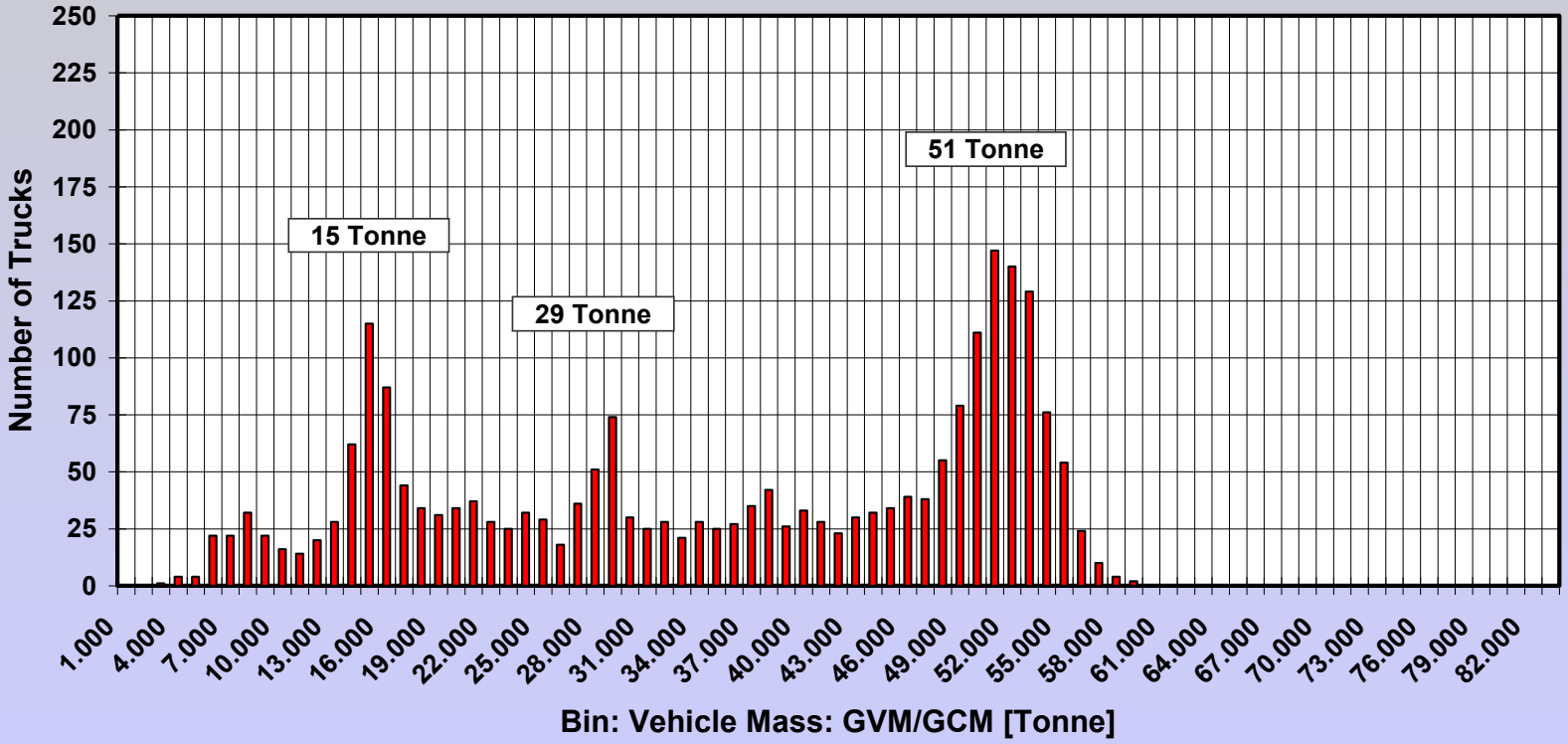
Tyre Inflation Pressure Distributions – N3 - 2003

H:\CAPSA04\[Tyre Inflation Pressure Information-MORTON-MDB-

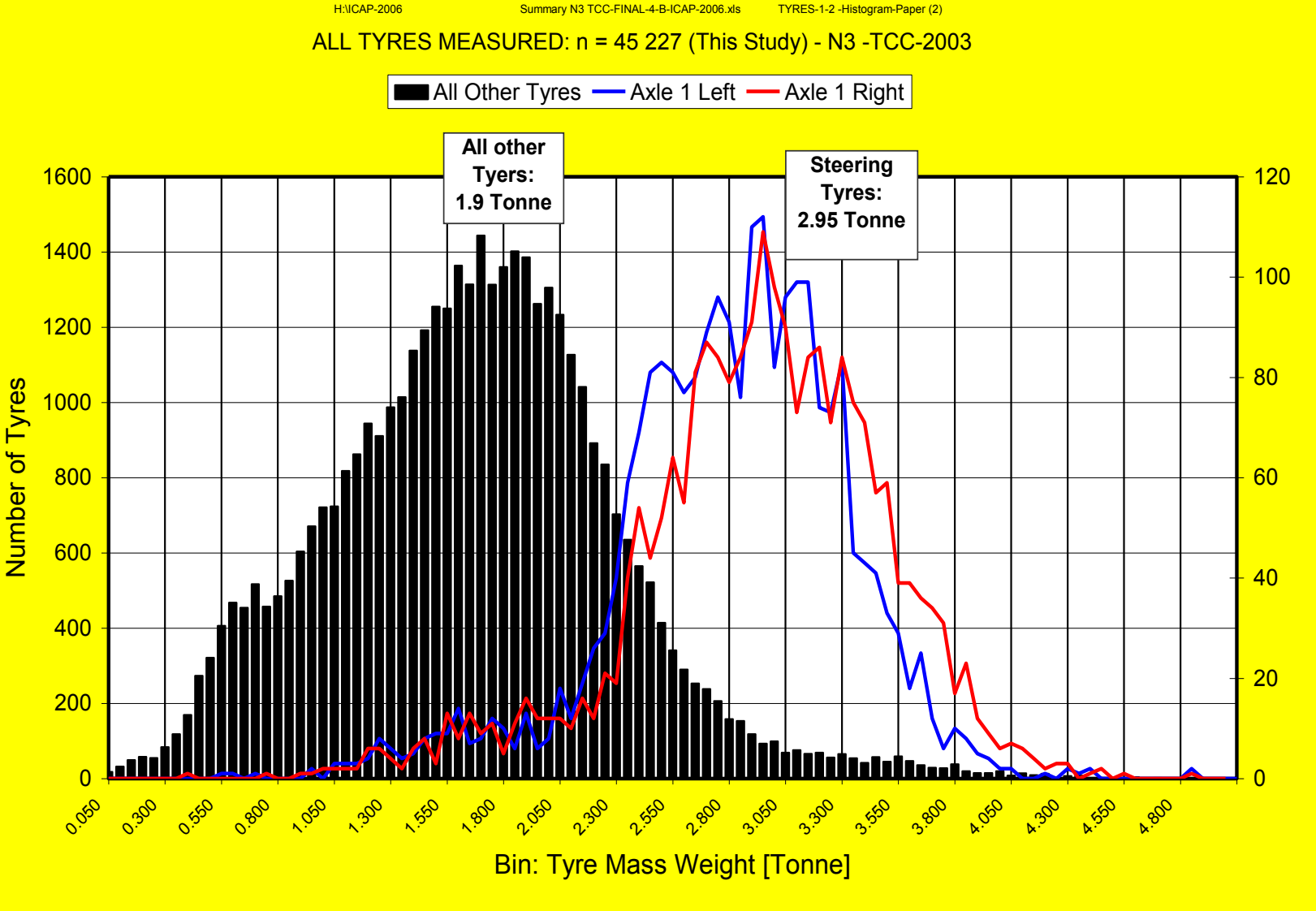
N3 TCC - SELECTED HEAVY VEHICLE (HV) TRUCK TYRE PRESSURE DATA
(26 Feb 2003 - 06 March 2003)



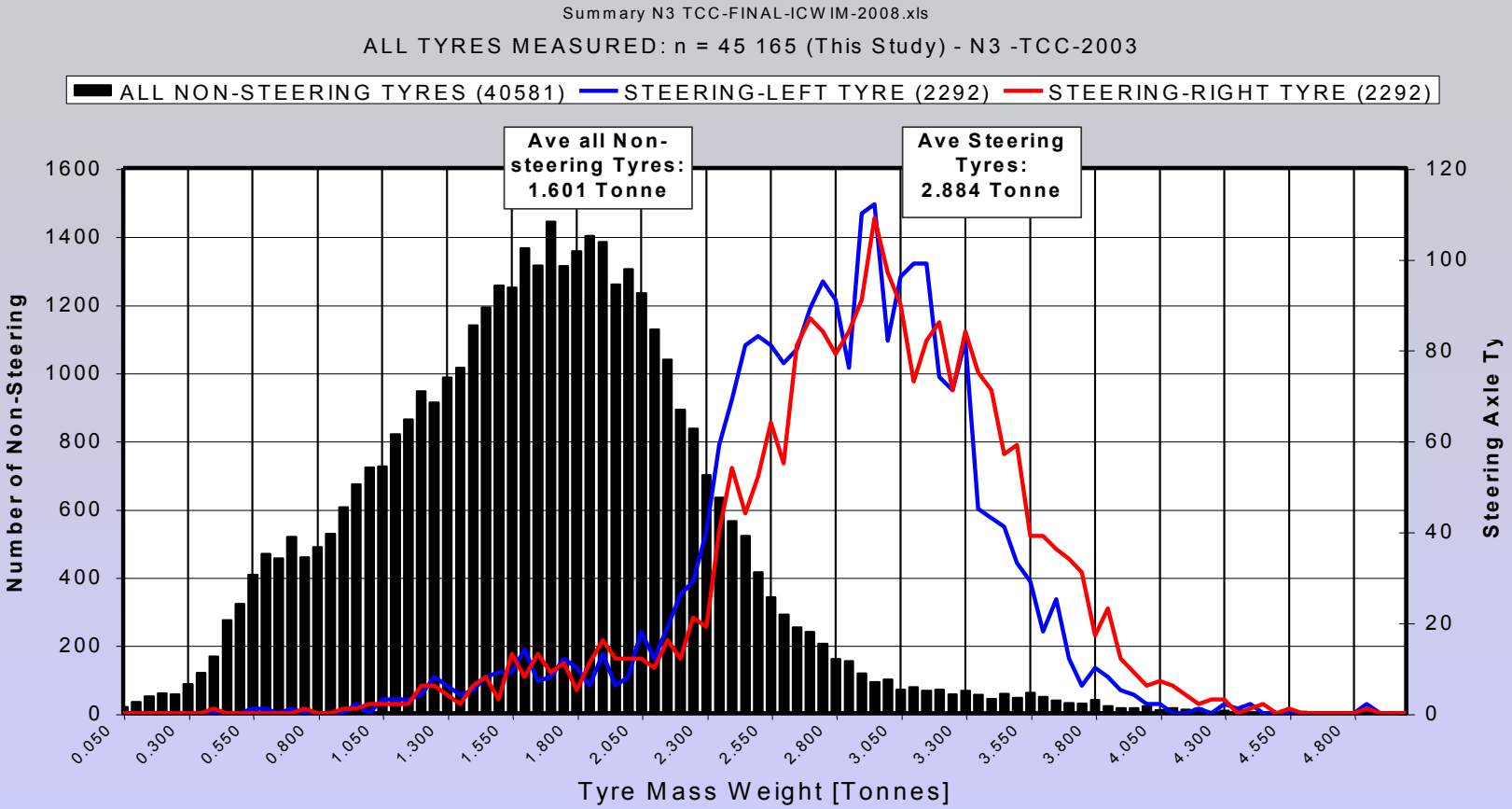
GVM/GCM-SIM N3 TCC - 2003
RESULT RATINGS 1 AND 2 (n = 2 297)
[2 Sept - 17 Oct 2003]



Axle Mass Distributions – N3 - 2003

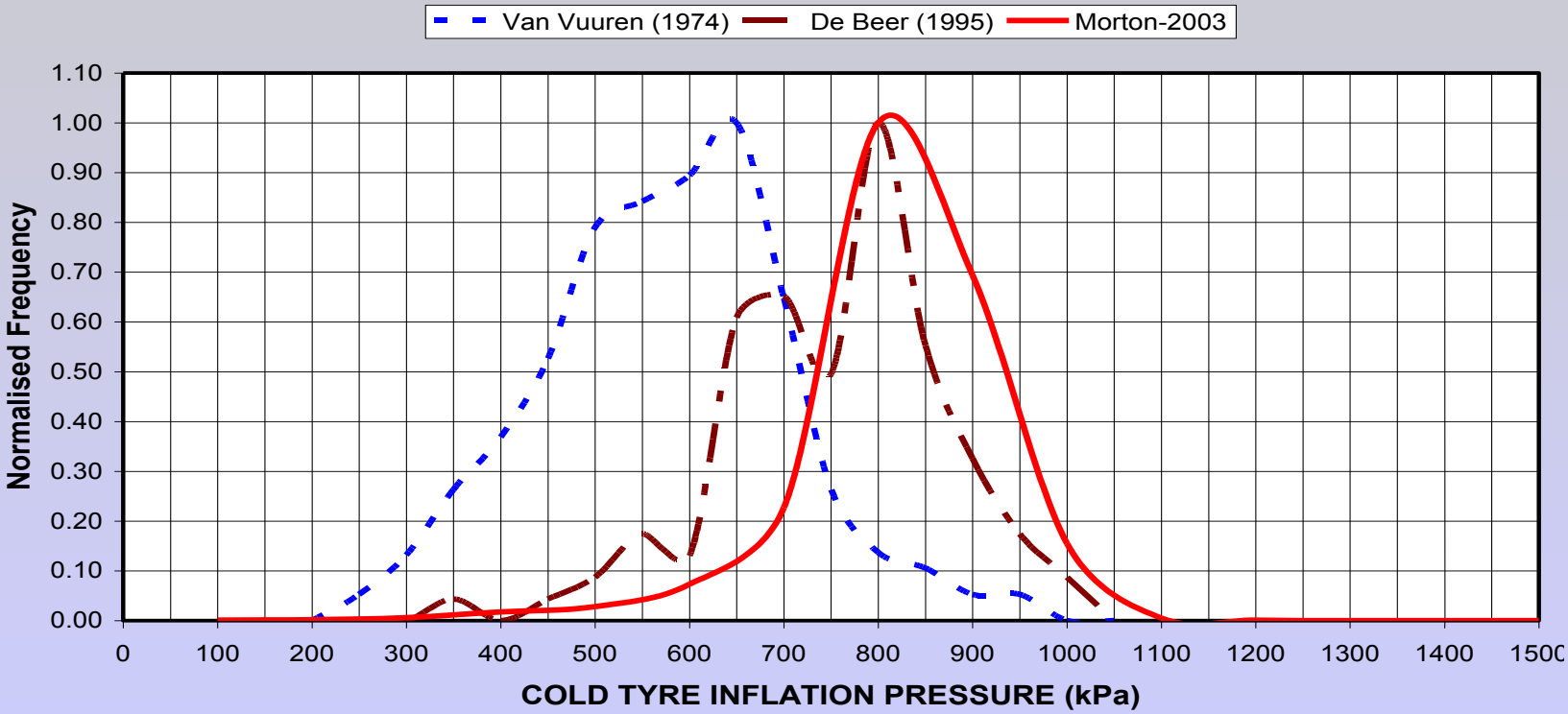


Tyre Mass…..

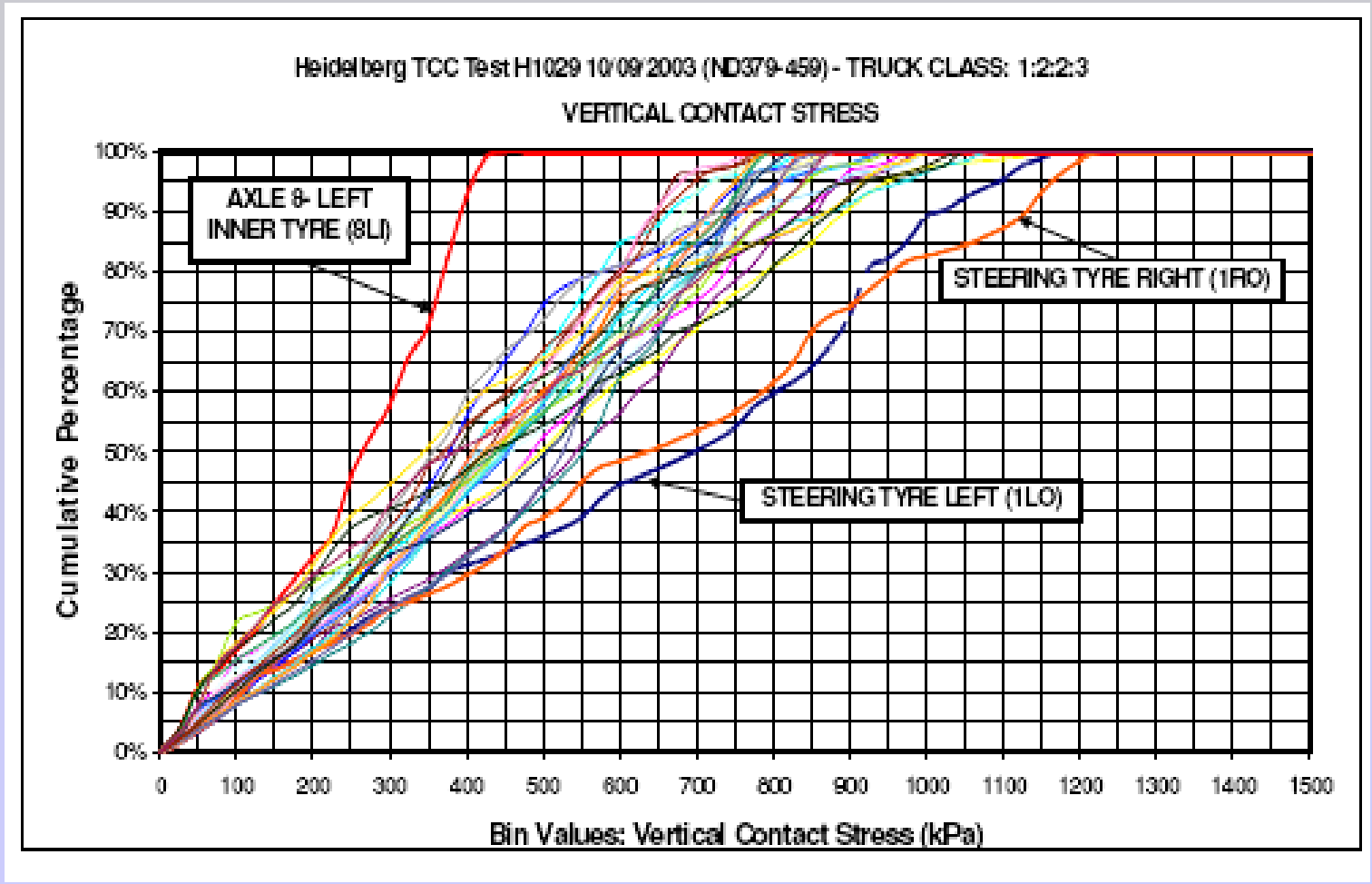

Summary N3 TCC-FINAL-ICWIM-2008.xls
ALL TYRES MEASURED: n = 45 165 (This Study) - N3 -TCC-2003
ALL NON-STEERING TYRES (40581)
STEERING-LEFT TYRE (2292)
STEERING-RIGHT TYRE (2292)
Ave all Non-steering Tyres: 1.601 Tonne
Ave Steering Tyres: 2.884 Tonne
Number of Non-Steering
Steering Axle Ty
Tyre Mass Weight [Tonnes]
0
200
400
600
800
1000
1200
1400
1600
0
20
40
60
80
100
120
0.050
0.300
0.550
0.800
1.050
1.300
1.550
1.800
2.050
2.300
2.550
2.800
3.050
3.300
3.550
3.800
4.050
4.300
4.550
4.800

Tyre Pressure Data…

NORMAILIZED SAMPLE OF HEAVY VEHICLE (HV) TRUCK TYRE PRESSURE DATA



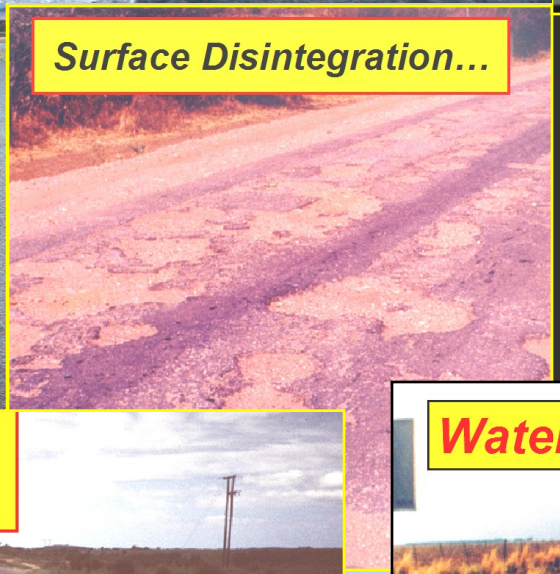
Vertical Stress Cumulative Frequency – N3- 2003

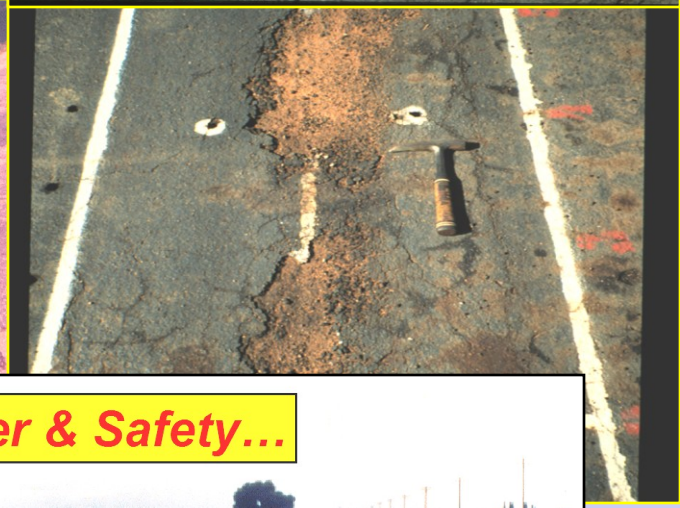



RUTTING


Fatigue Cracking and aging


Delamination..


Surface Disintegration…




POTHOLES :
Water & Loads …


Water & Safety…

Road Damage….

Modern Tyre Science…

”Sectometer”
S. Eckens, 1928

The "sectometer" was leveled (Figure 4), and the height of the springs were measured with nine inch micrometer calipers (Figure 1). The

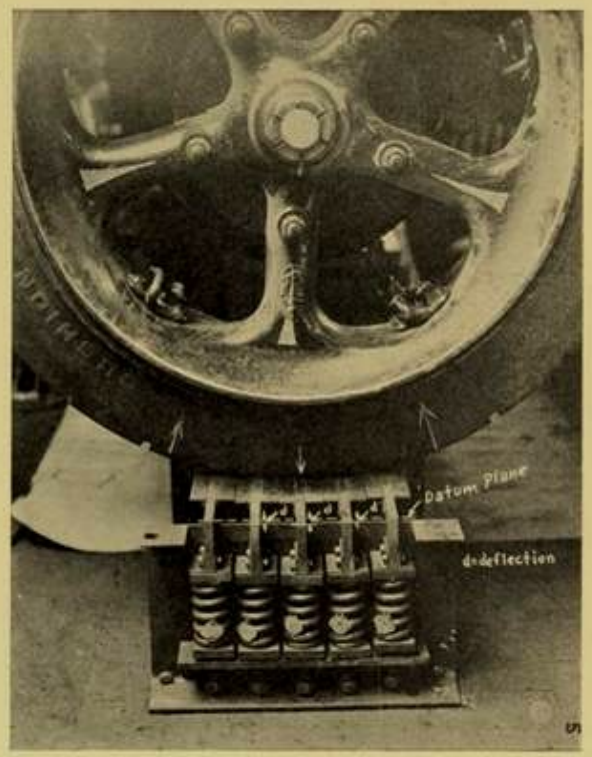
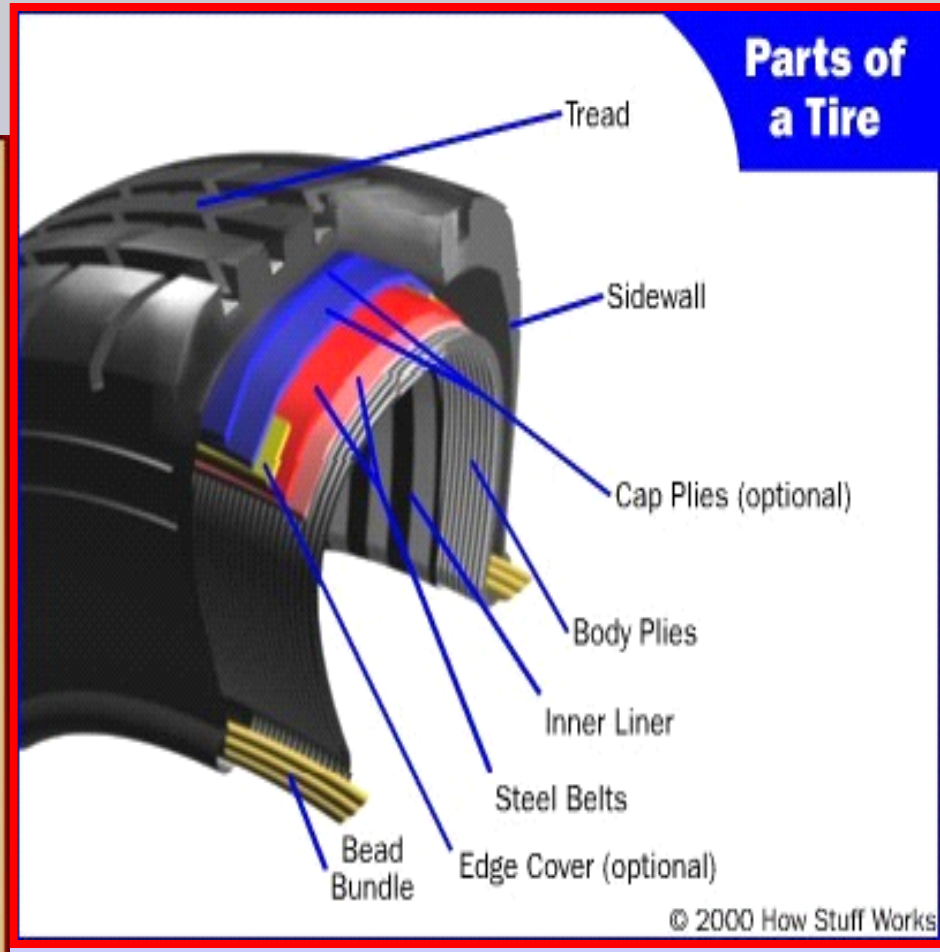
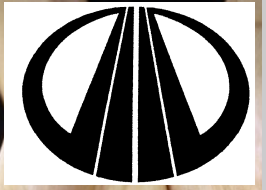


Figure 5

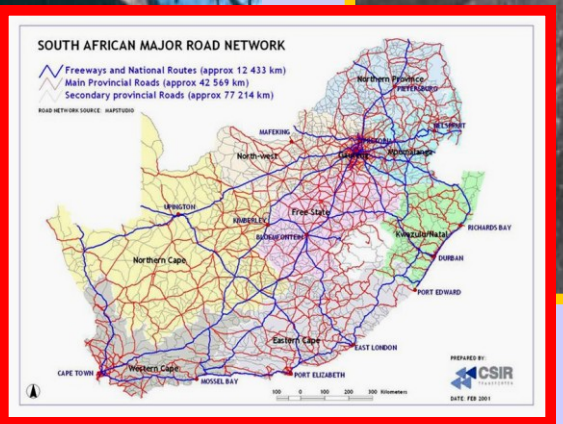
machine was now in position for the impression and also for the determination of the load distribution.



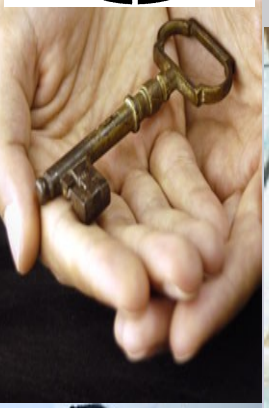


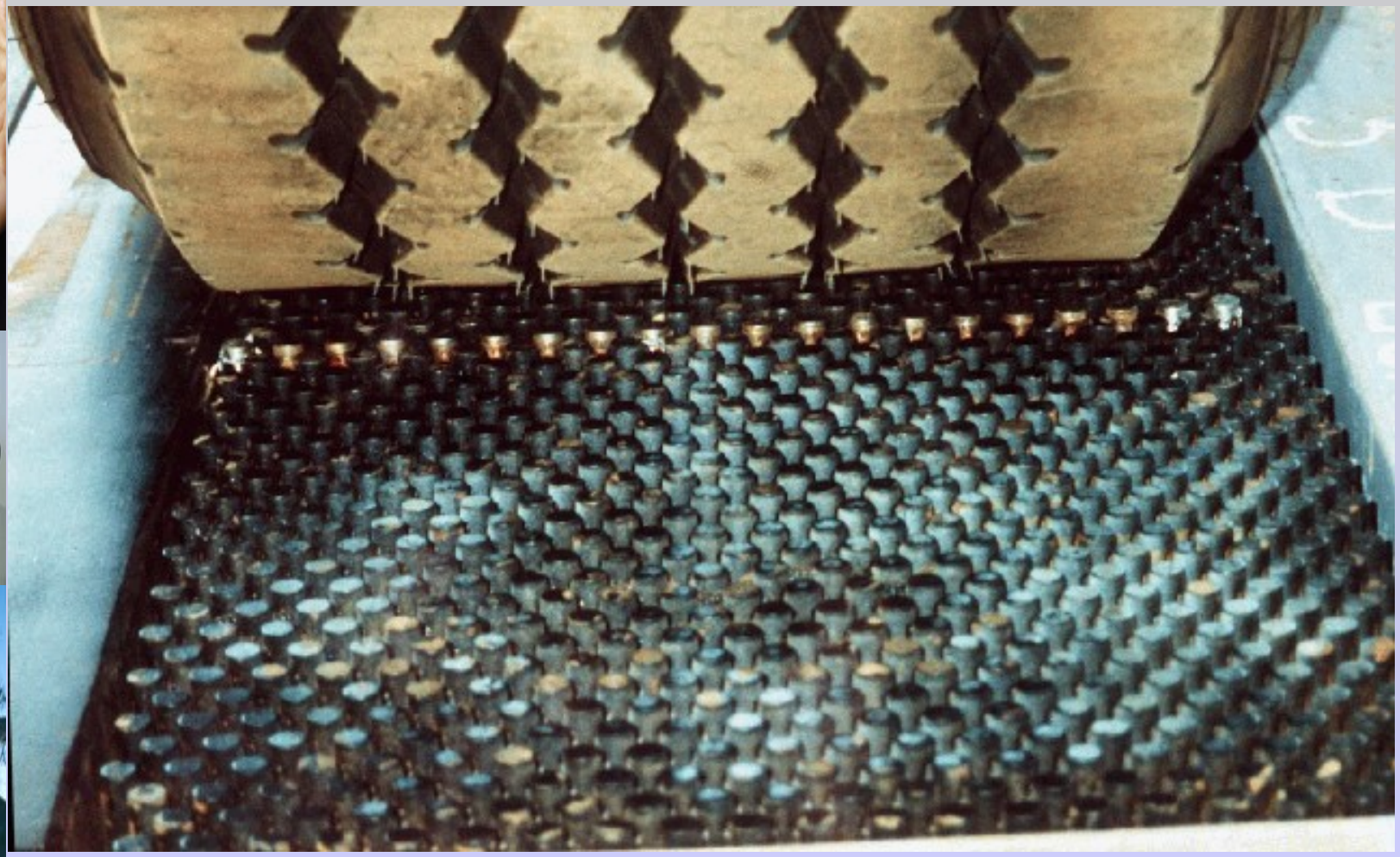
Vehicle-Tyre-Pavement Interaction:

STRESS-IN-MOTION (SIM) Technology



425 /65 R22.5 HVS Tyre on SIM System



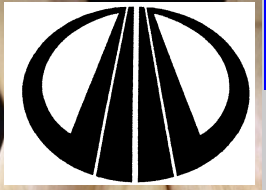


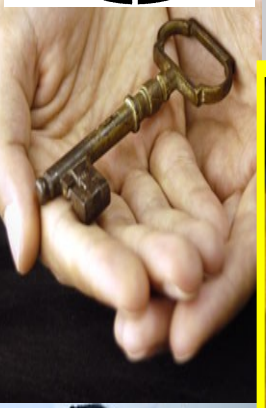
Stress-In-Motion testing with HVS Dual Load Configuration – Twin SIM pads -

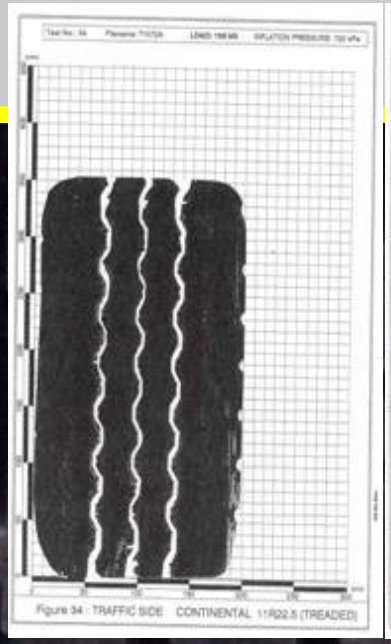
Stress-In-Motion testing with HVS Dual Load Configuration – Twin SIM pads -

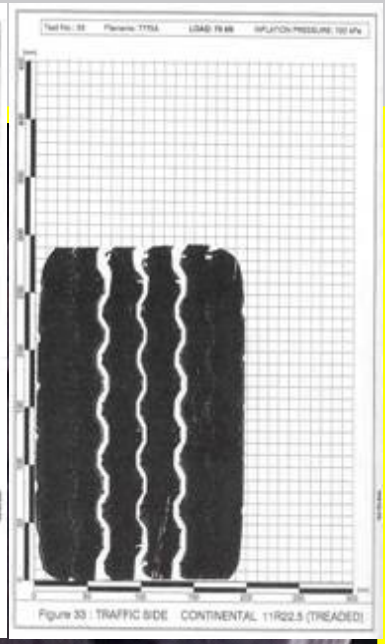
Tyre Deflection & Tyre Prints…

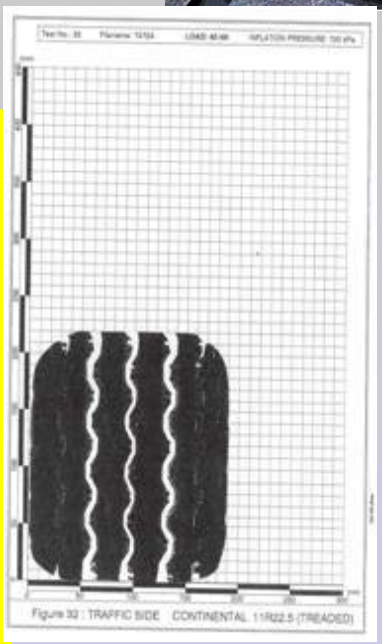
Tyre Deflection & Tyre Prints…

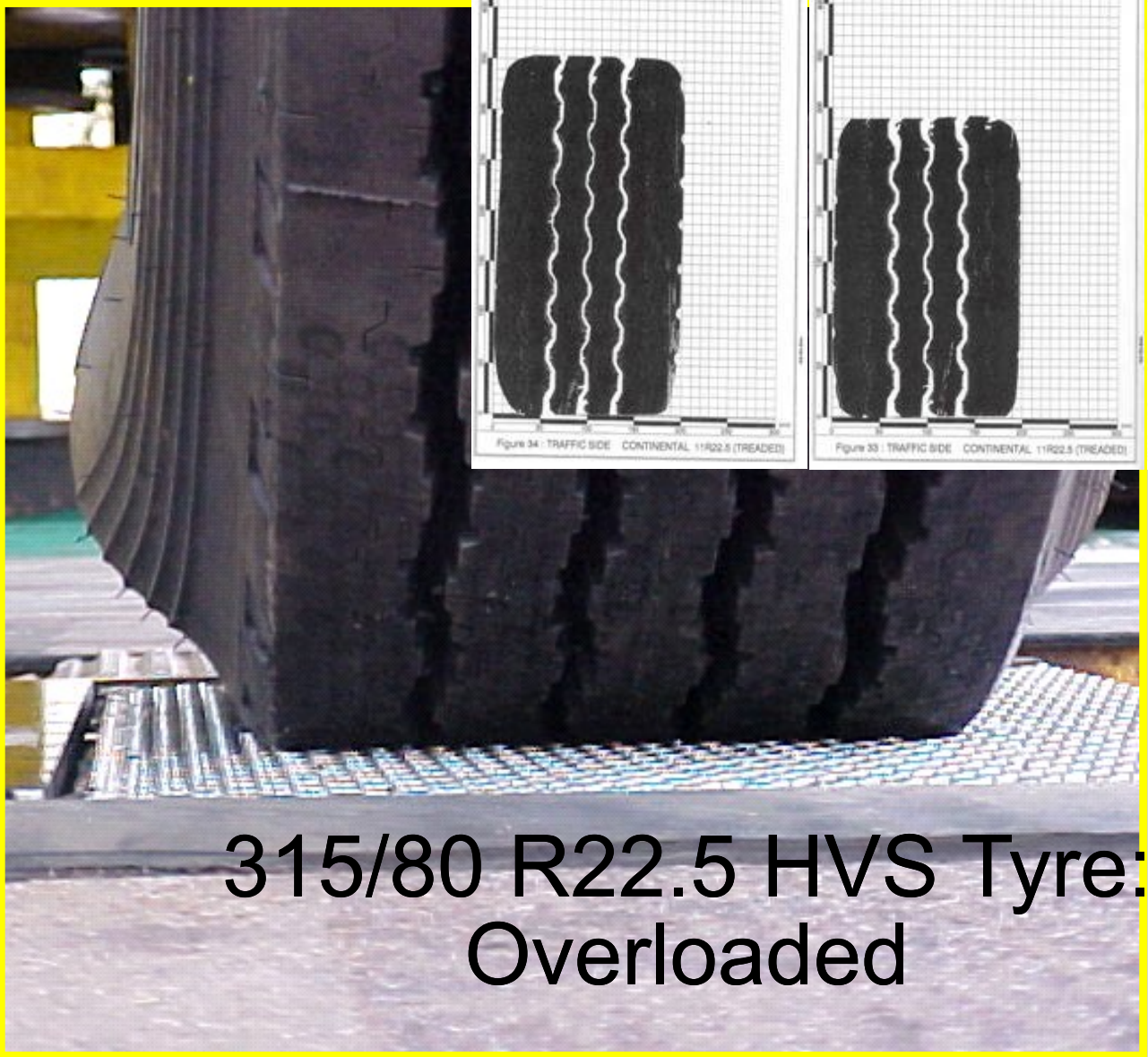












315/80 R22.5 HVS Tyre: Overloaded

Quad SIM Pad Testing at Weigh-Bridge Site: N3 North – Heidelberg Traffic Control Centre

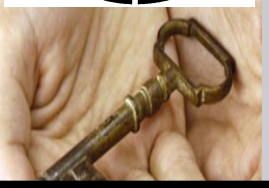
MULTI-DECK SCALE - National Road 3 (N3 - Heidelberg Traffic Control Centre -

DAW 50 SCALE - National Road 3 (N3)
- Heidelberg Traffic Control Centre -

Quad (full) SIM pad configuration at National Road 3 (N3) - Heidelberg Traffic Control Centre -

SIM systems at National Road 3 (N3)
- Heidelberg Traffic Control Centre -

Stress-In-Motion (SIM) Testing at National Road 3 (N3) - Heidelberg Traffic Control Centre -

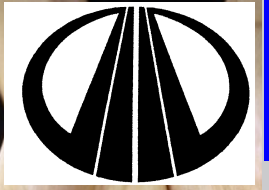


Quad (full) SIM pad configuration at National Road 3 (N3) - Heidelberg Traffic Control Centre -

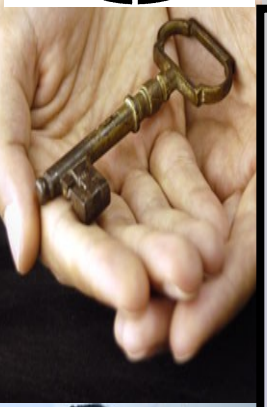
Quad (full) SIM pad configuration at National Road 3 (N3) - Heidelberg Traffic Control Centre -

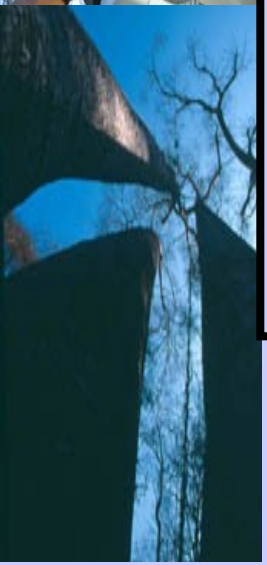
SIM Measurement at National Road 3 (N3)
- Heidelberg Traffic Control Centre - “1232” Tanker…

SIM In operation at National Road 3 (N3)
- Heidelberg Traffic Control Centre -



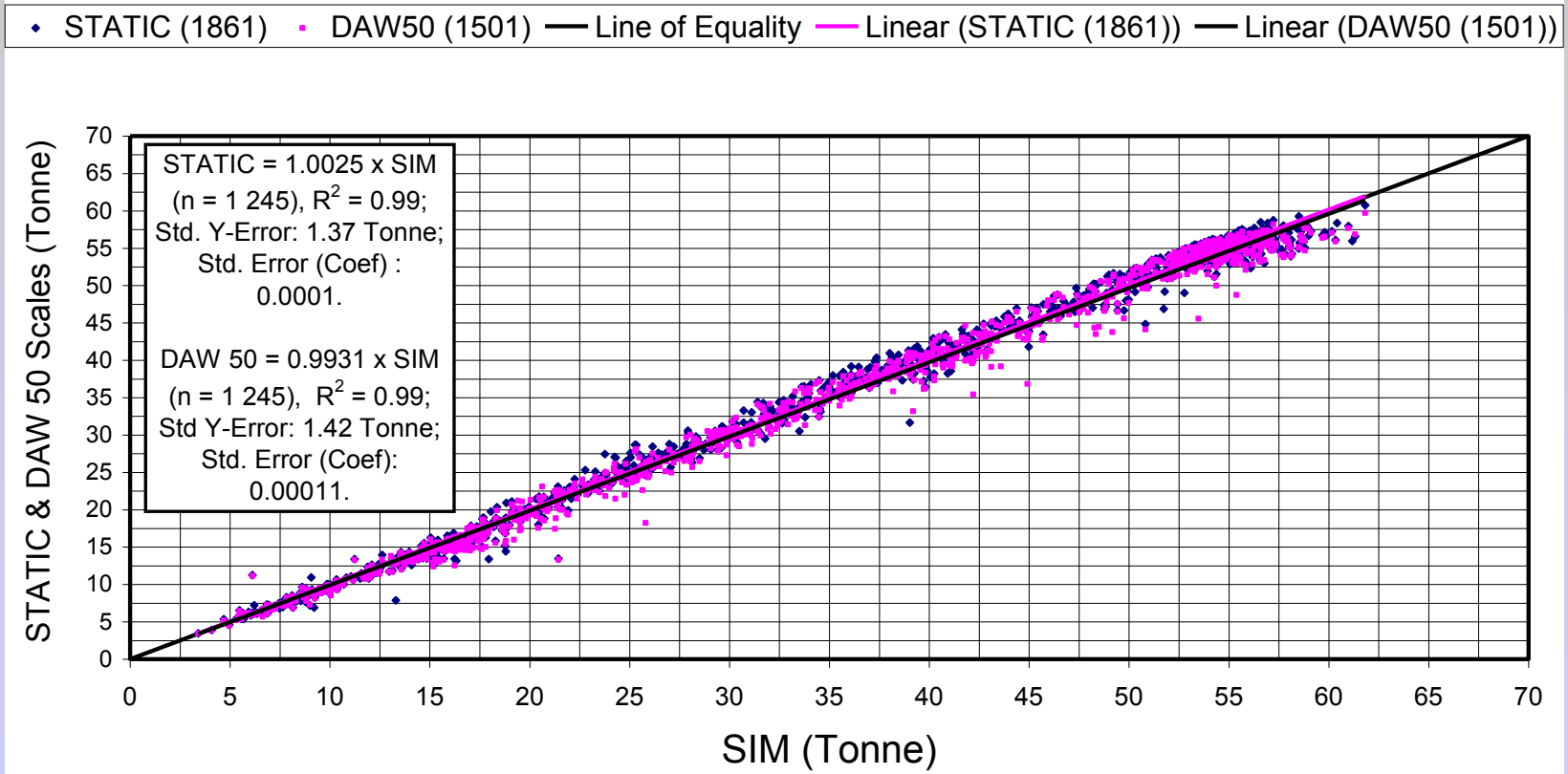
Mass Comparison – Static, DAW 50 Vs SIM



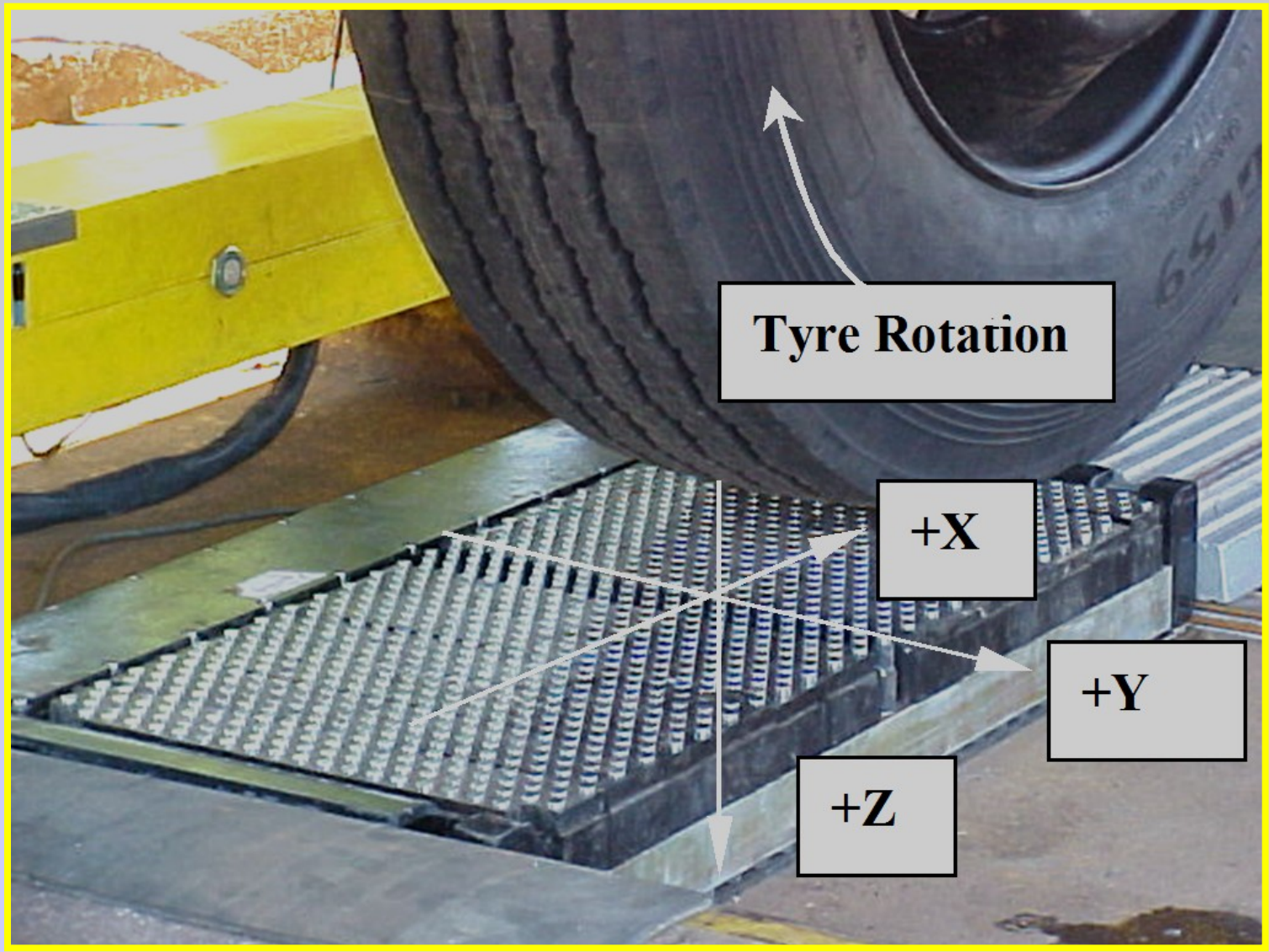


D:\ICAP-2006\[MODIFIED-2SEPT-17OCT-ICAP-2006.xls]Total Load-GVM-GCM-

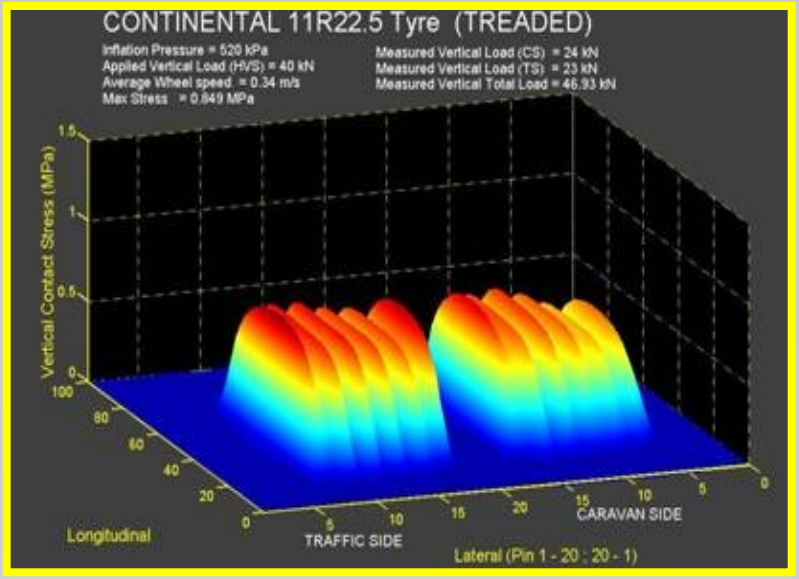
SIM vs MULTI-DECK STATIC AND DAW 50 at N3-TCC (Heidelberg) (GVM/GCM)

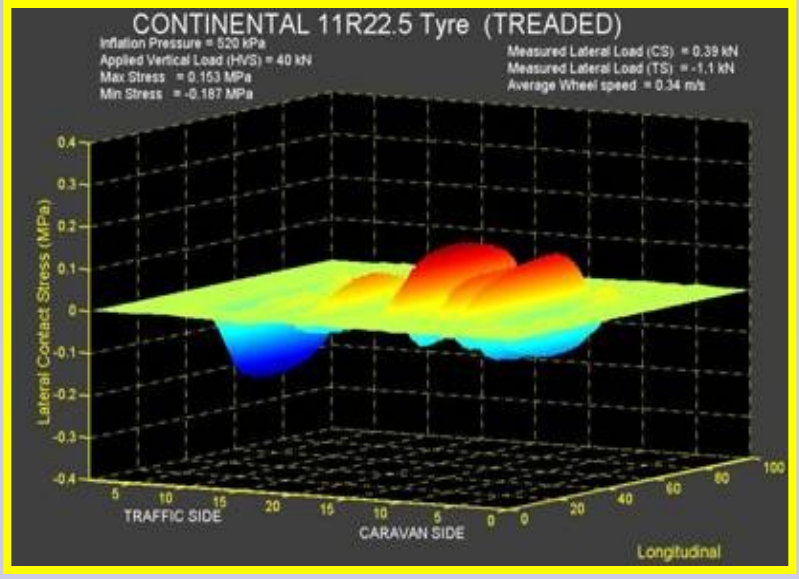


Loads & Stresses: SAE Sign Convention

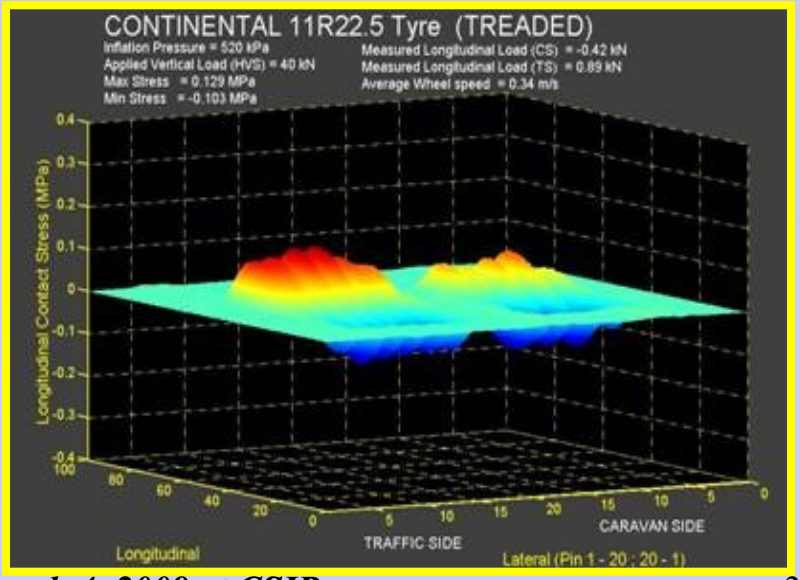


Dual Tyre: 3D-Contact Stresses (Pressure)…

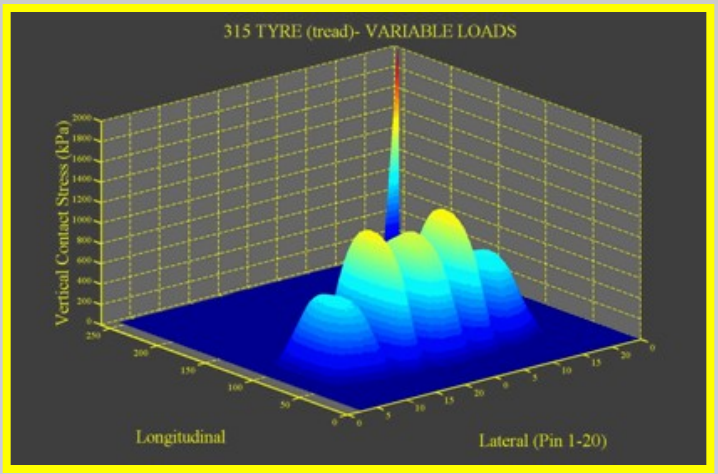


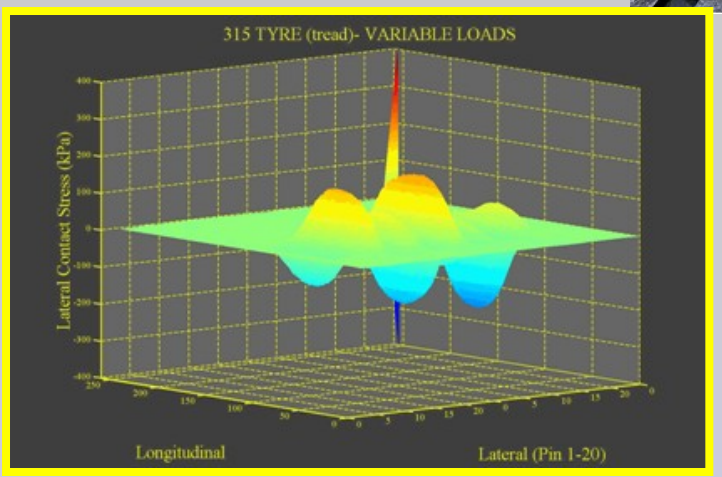


Stress Ratio: 10:3:1

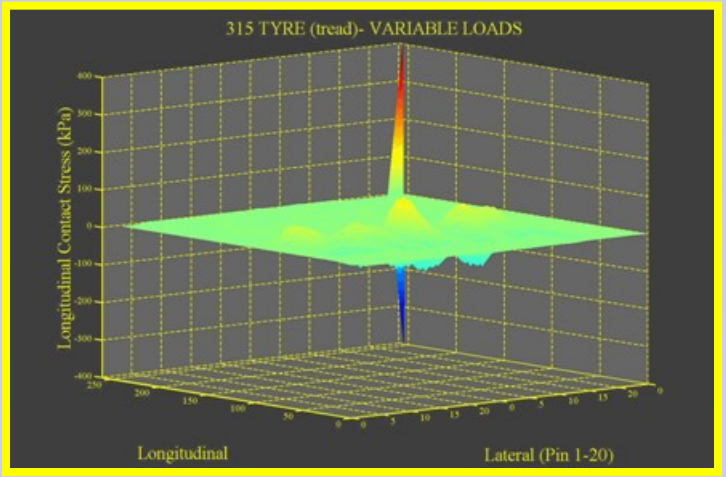


Typical SIM 3D Data Sets -Variable loading

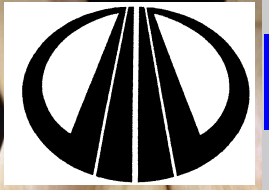




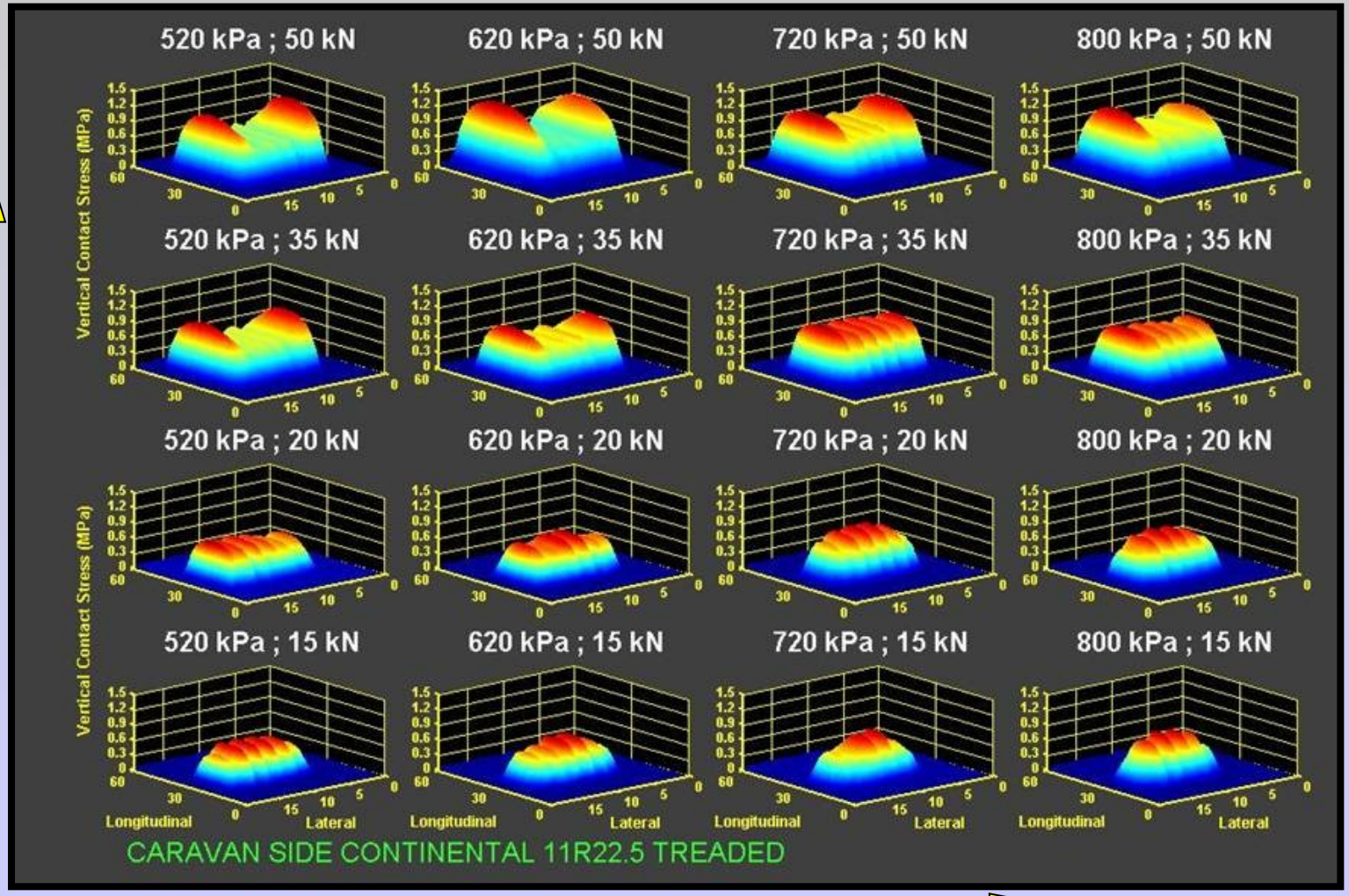
3D – Z,X,Y - Contact Stresses: Variable loads: 315/80 R22.5 Tire



Tyre “Finger Printing” - (11R22.5 TYRE)…

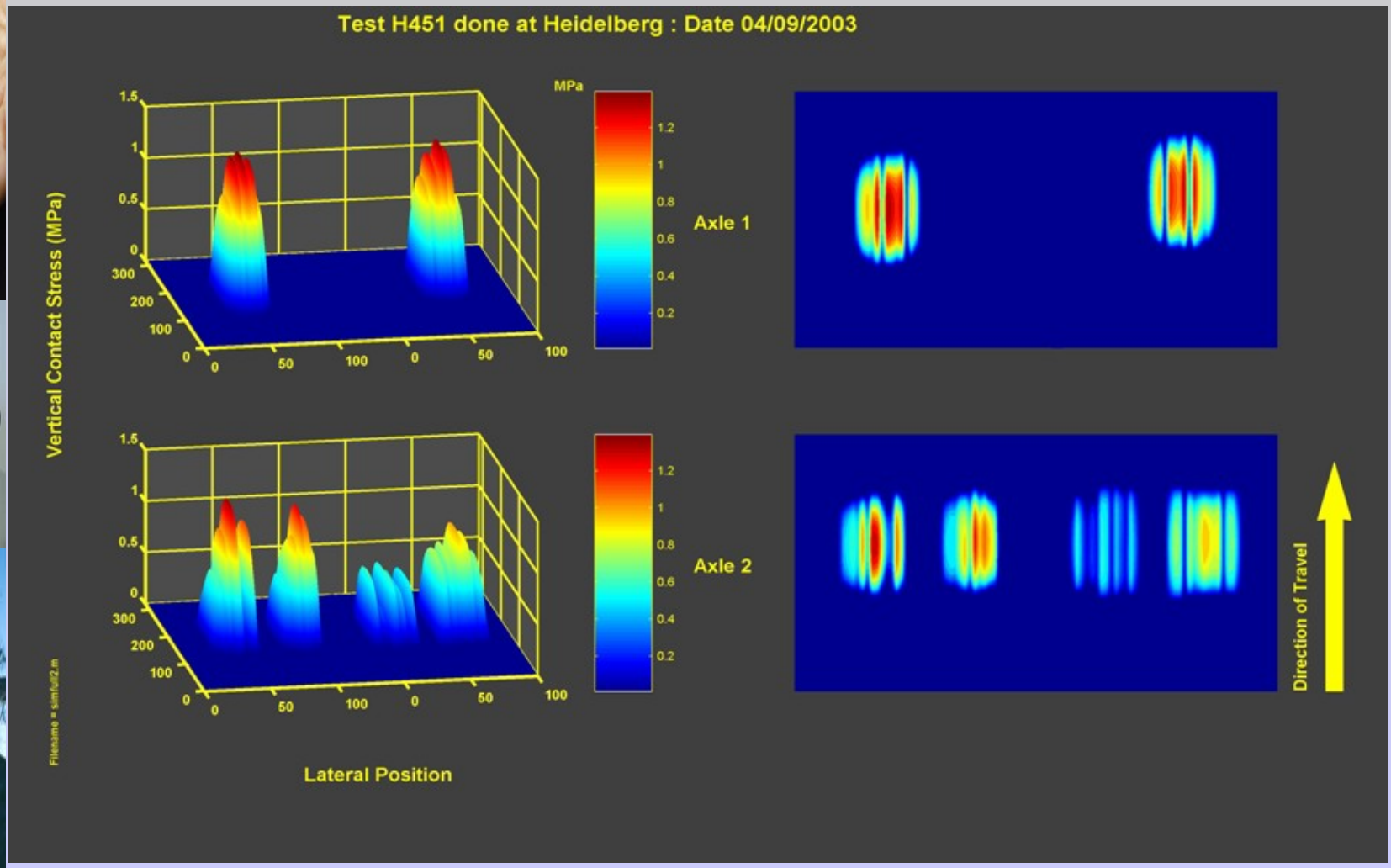


LOAD

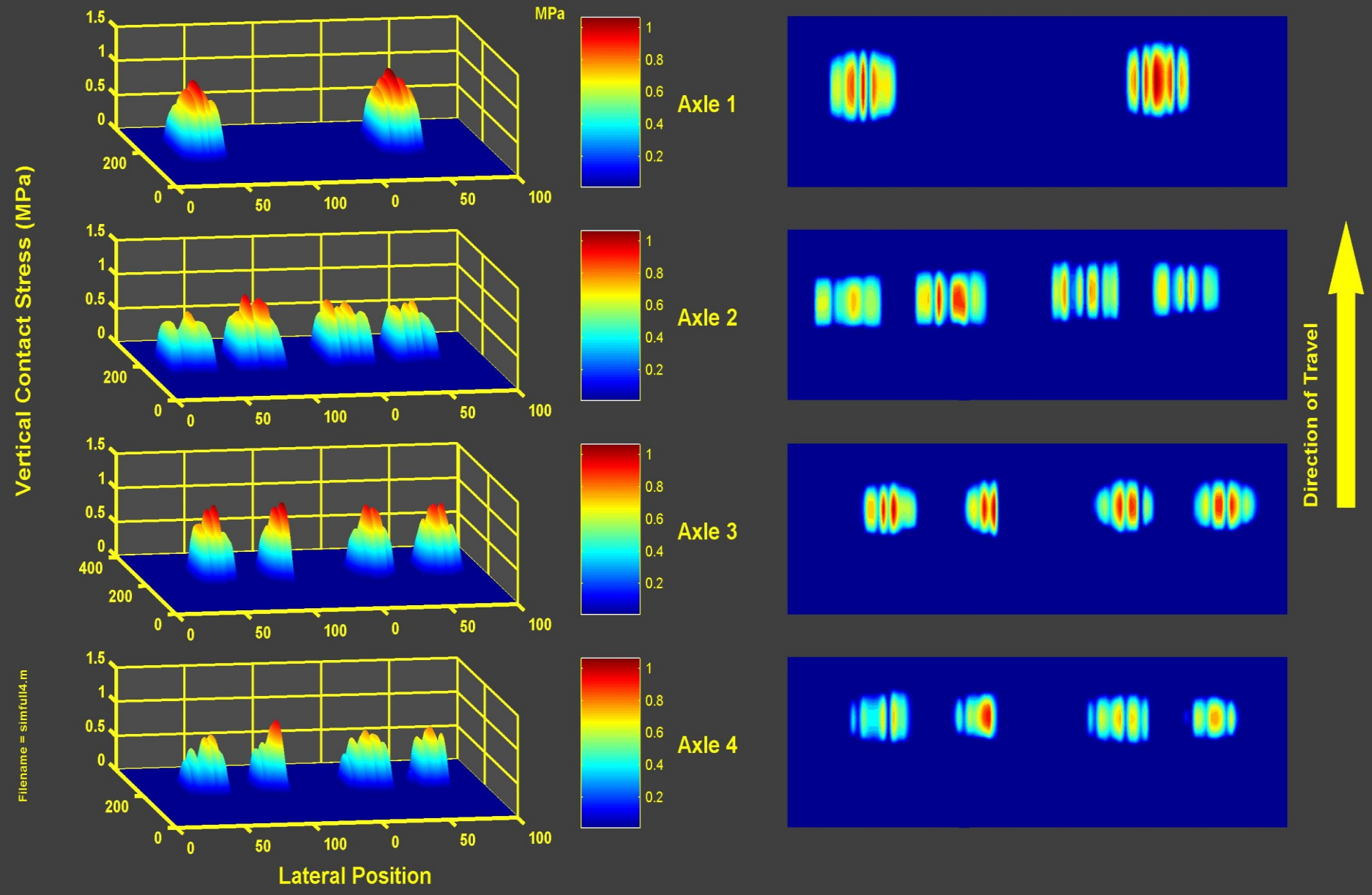


INFLATION PRESSURE

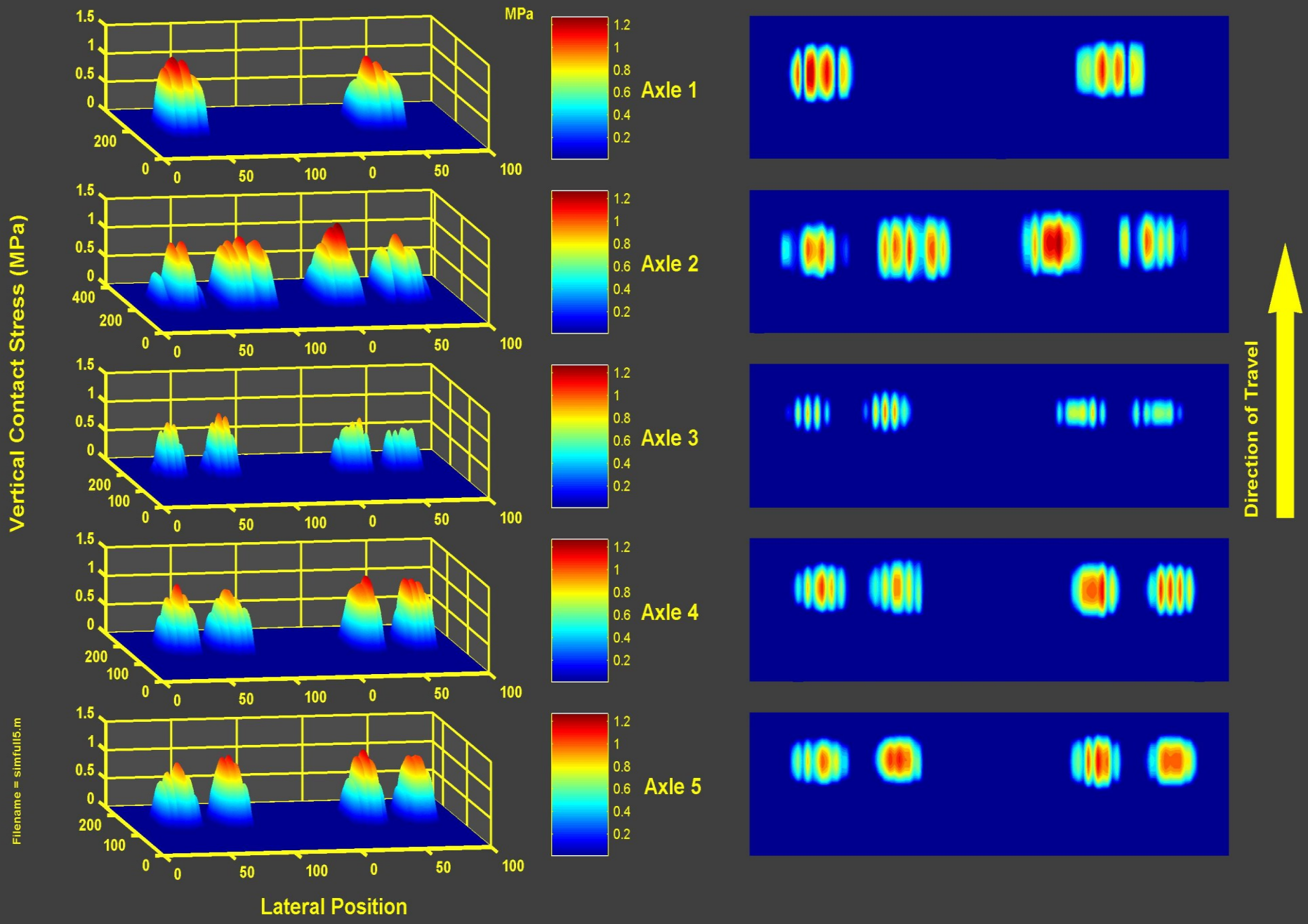
Two Axle Truck – Vertical Contact Stress
- Foot Prints -

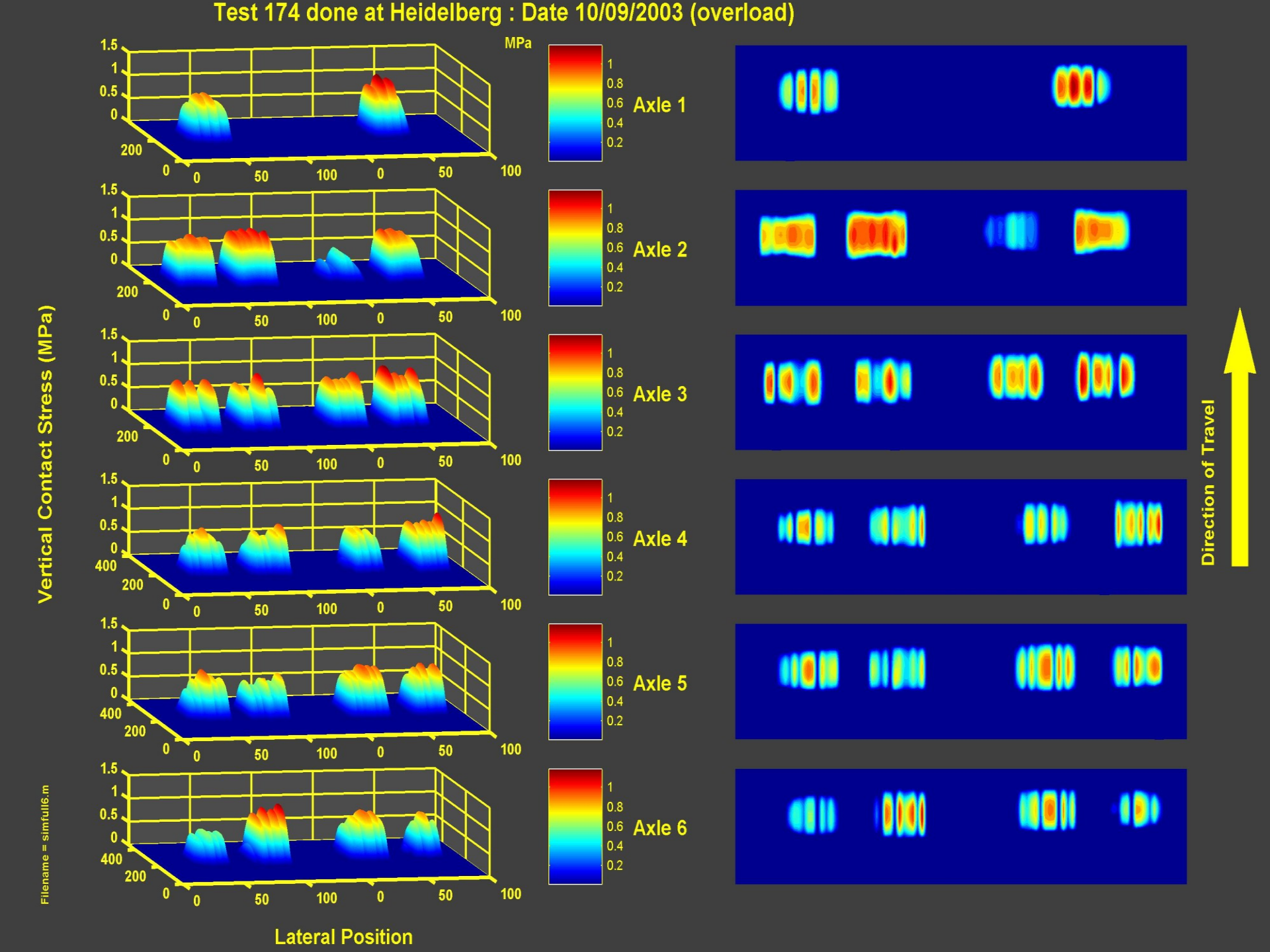


Test H1070 done at Heidelberg : Date 10/09/2003

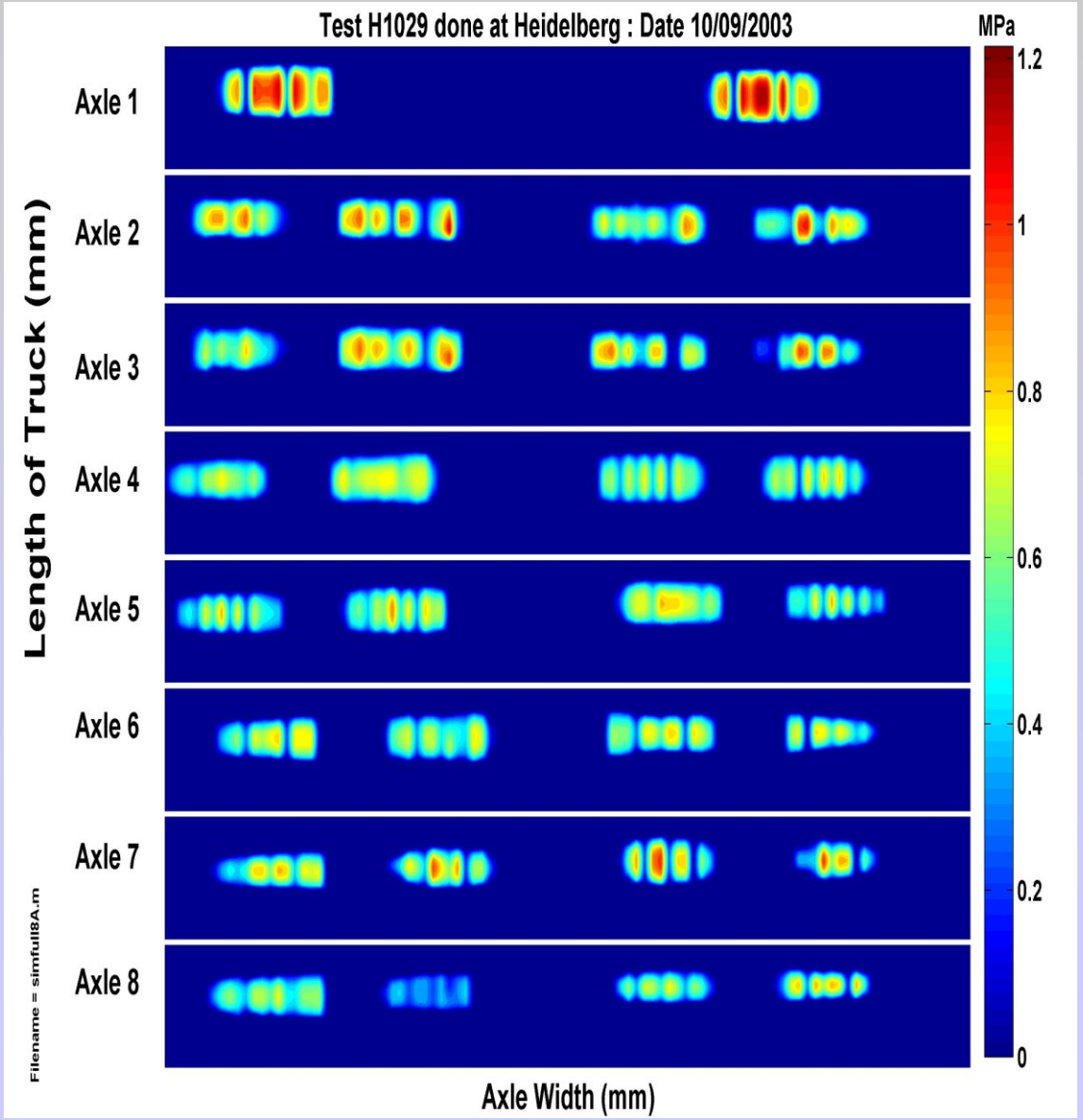


Test H1077 done at Heidelberg : Date 10/09/2003

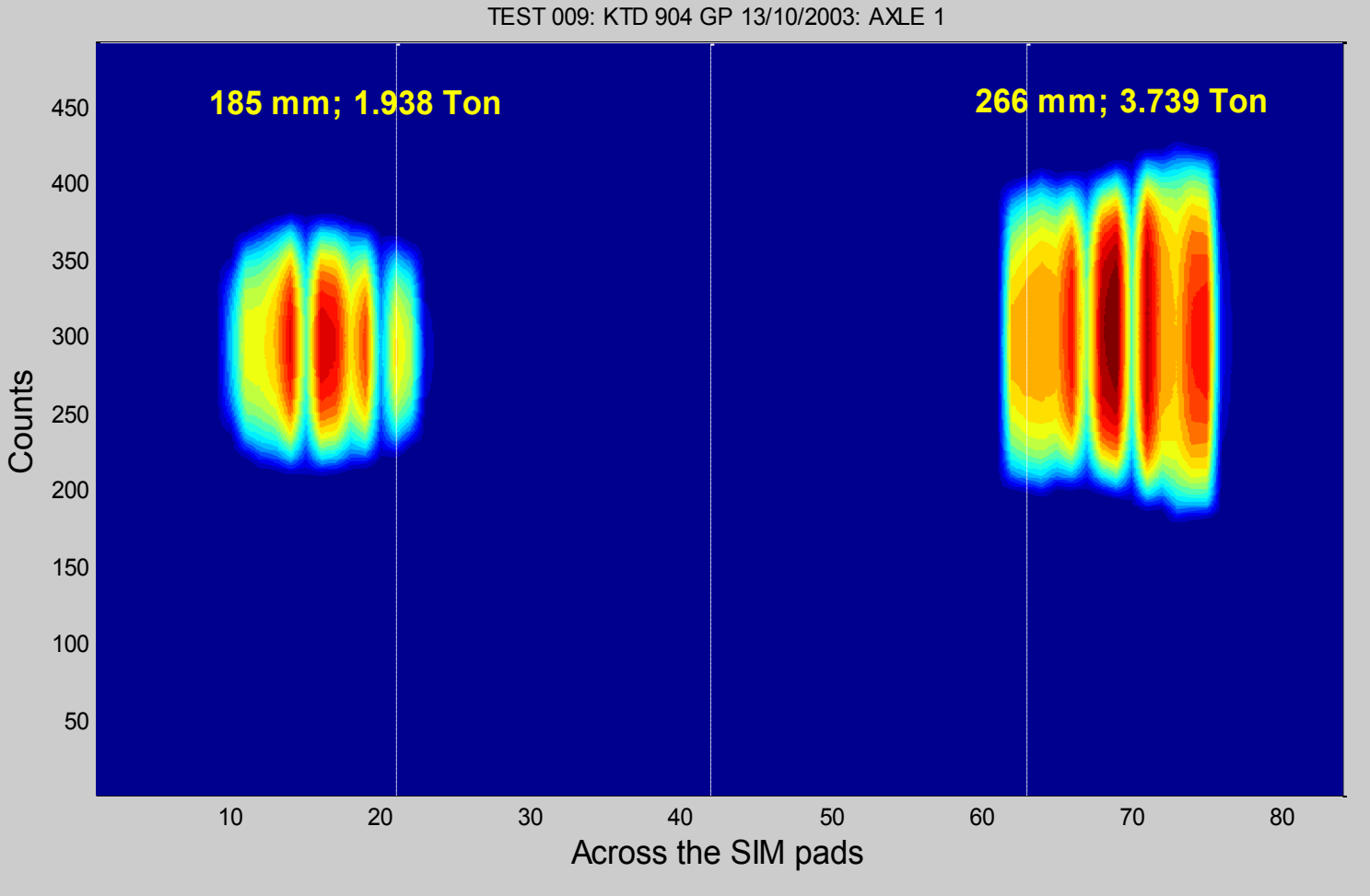


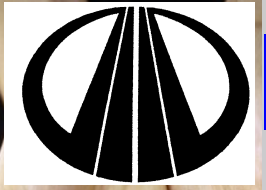

Test 174 done at Heidelberg : Date 10/09/2003 (overload)
Vertical Contact Stress (MPa)
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Lateral Position
Direction of Travel
Filename = simfull6.m

Eight Axle Truck – Vertical Contact Stress
- Foot Prints -



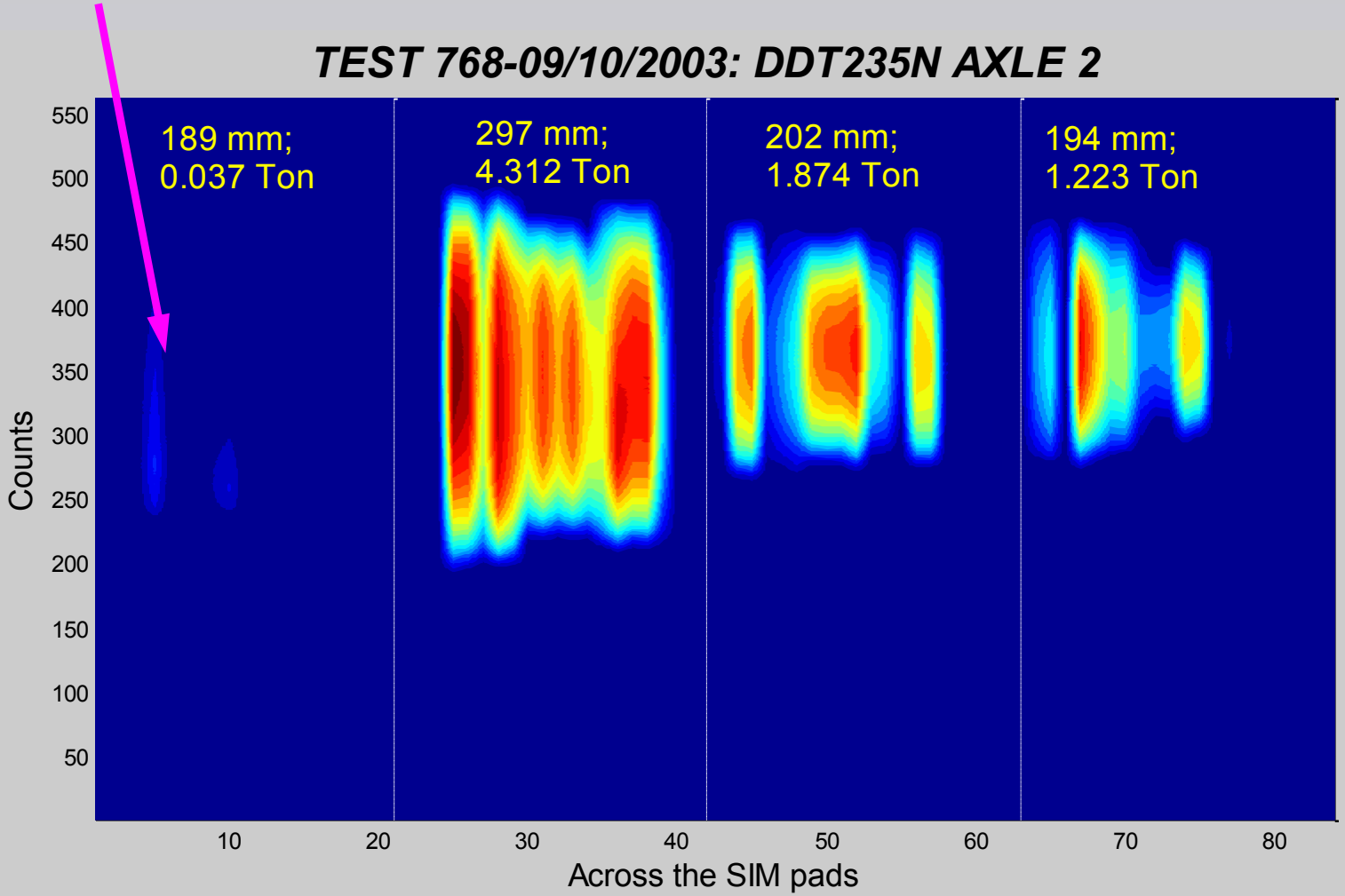
Steering Axle – Unequal (*unbalanced*) Loading

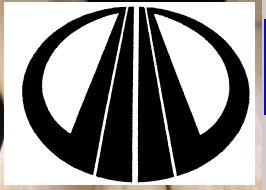




Unequal (*unbalanced*) Loading…

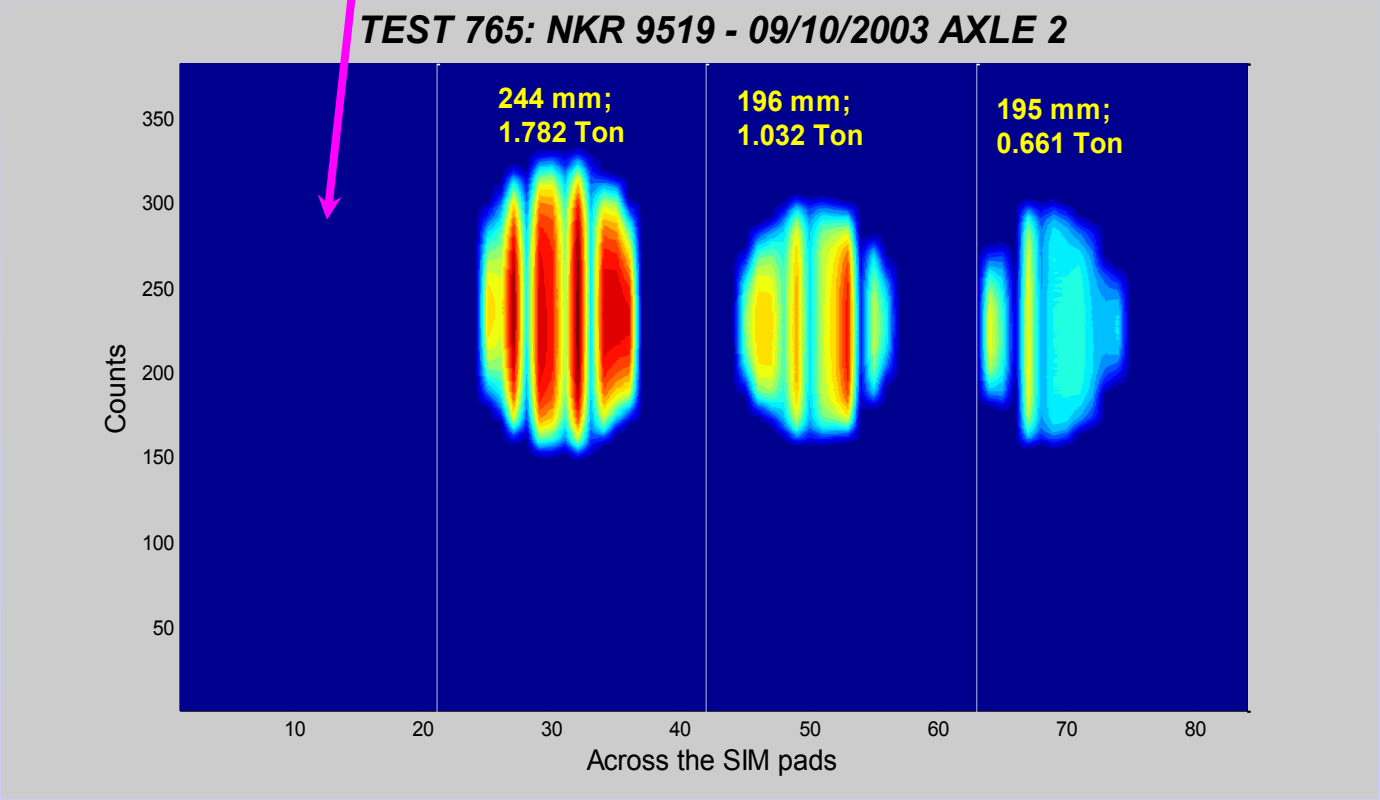
TYRE BARELY IN CONTACT WITH SURFACE

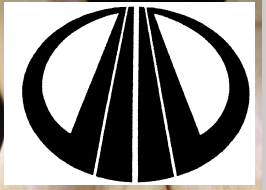




Unequal (*unbalanced*) Loading…

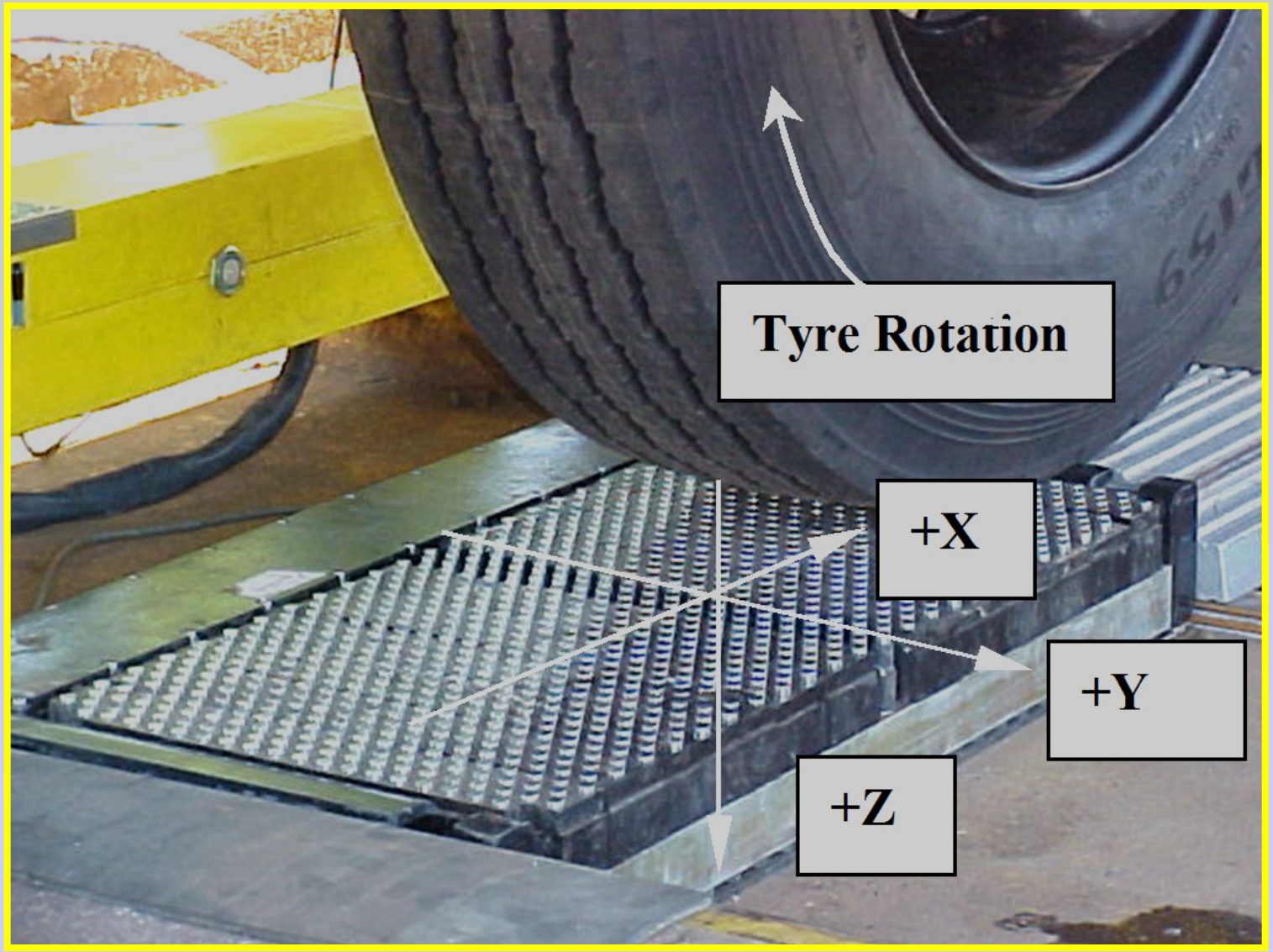
AXLE 2: MISSING ONE TYRE!!



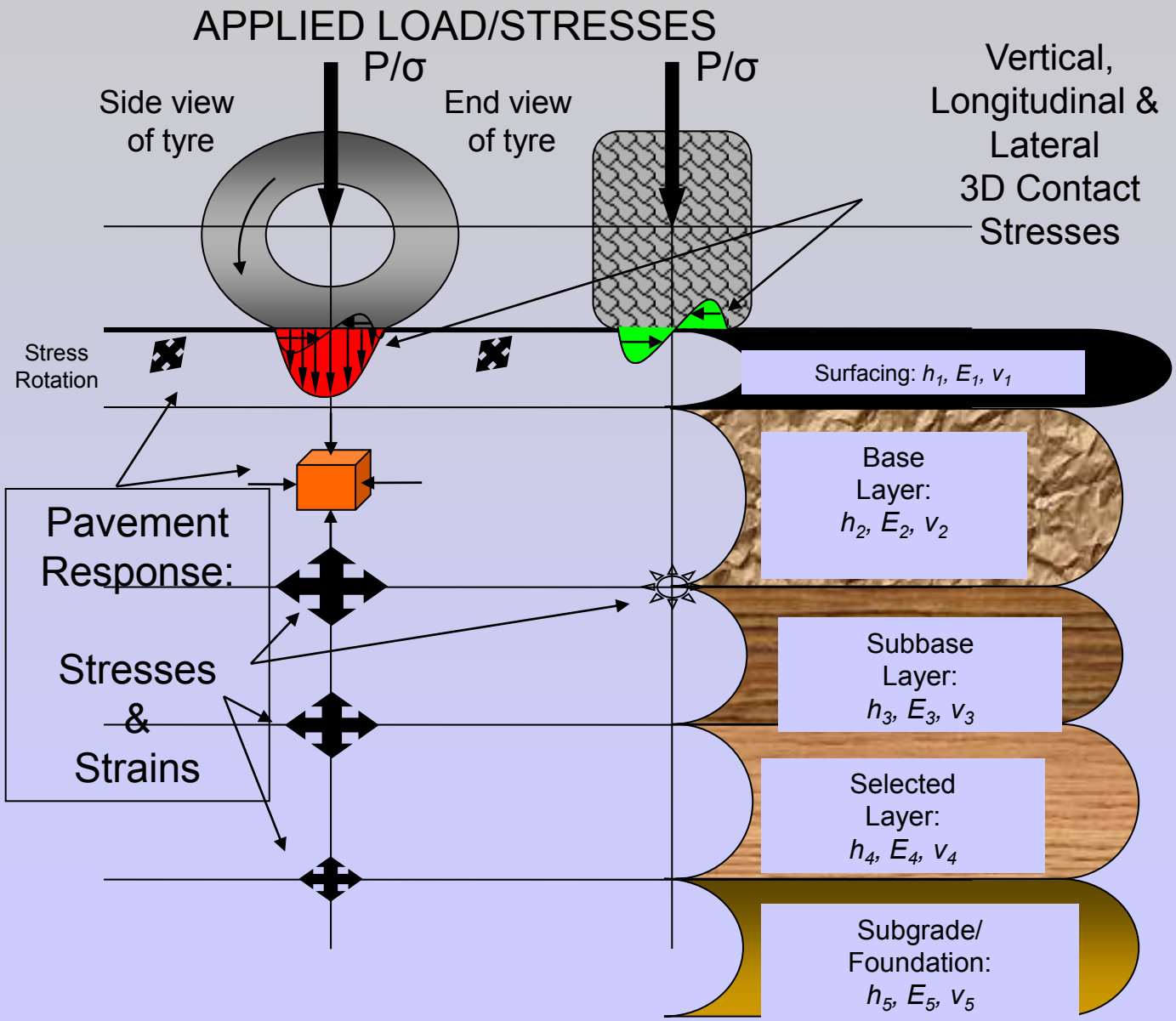


Use n**umerical analysis software** together with the concept of Strain Energy of Distortion (SED) to quantify Pavement's *Potential for Failure*

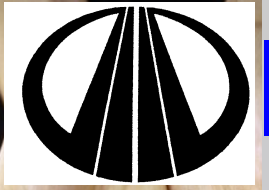
Loads & Stresses: SAE Sign Convention



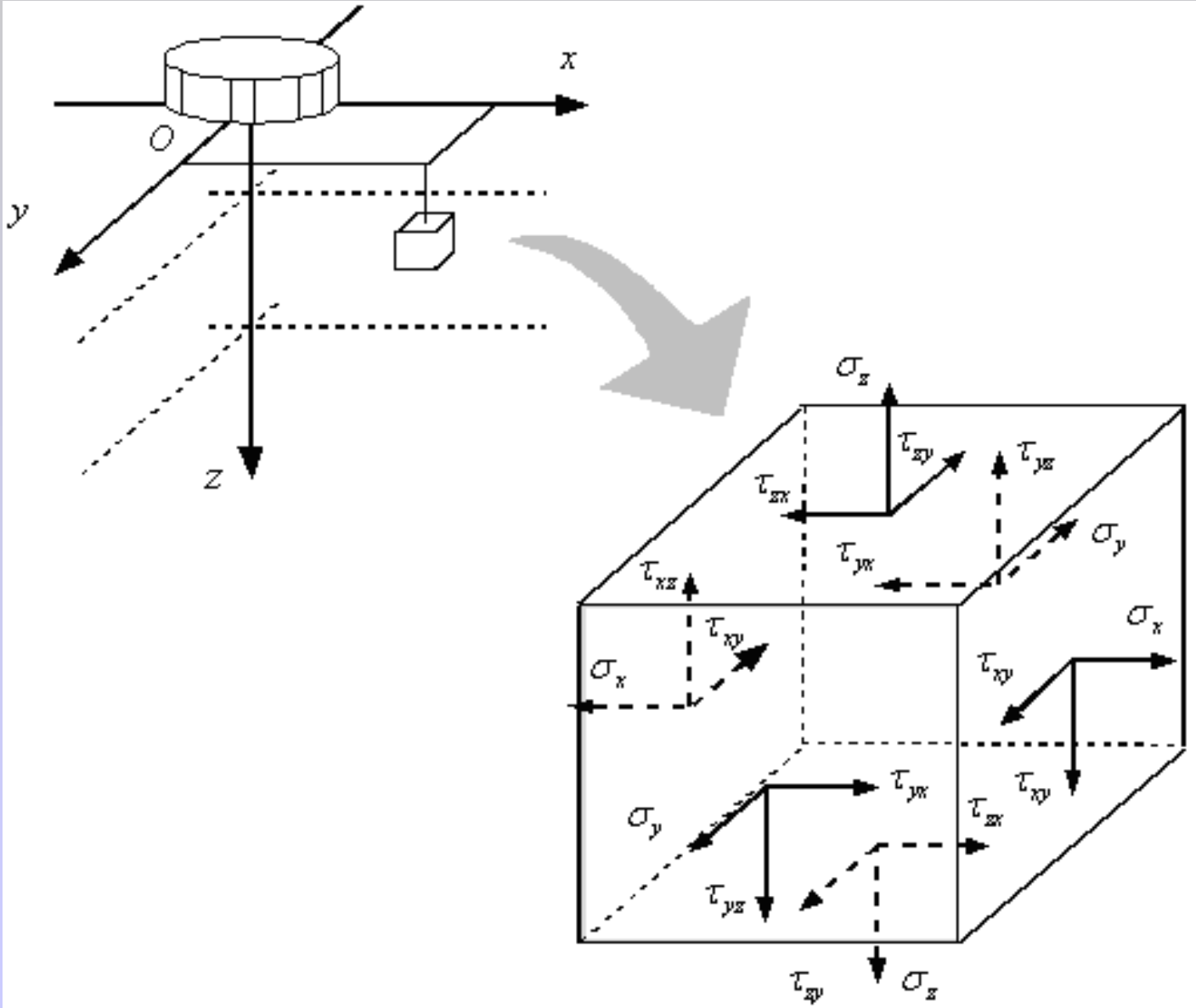
Road Pavement Model….



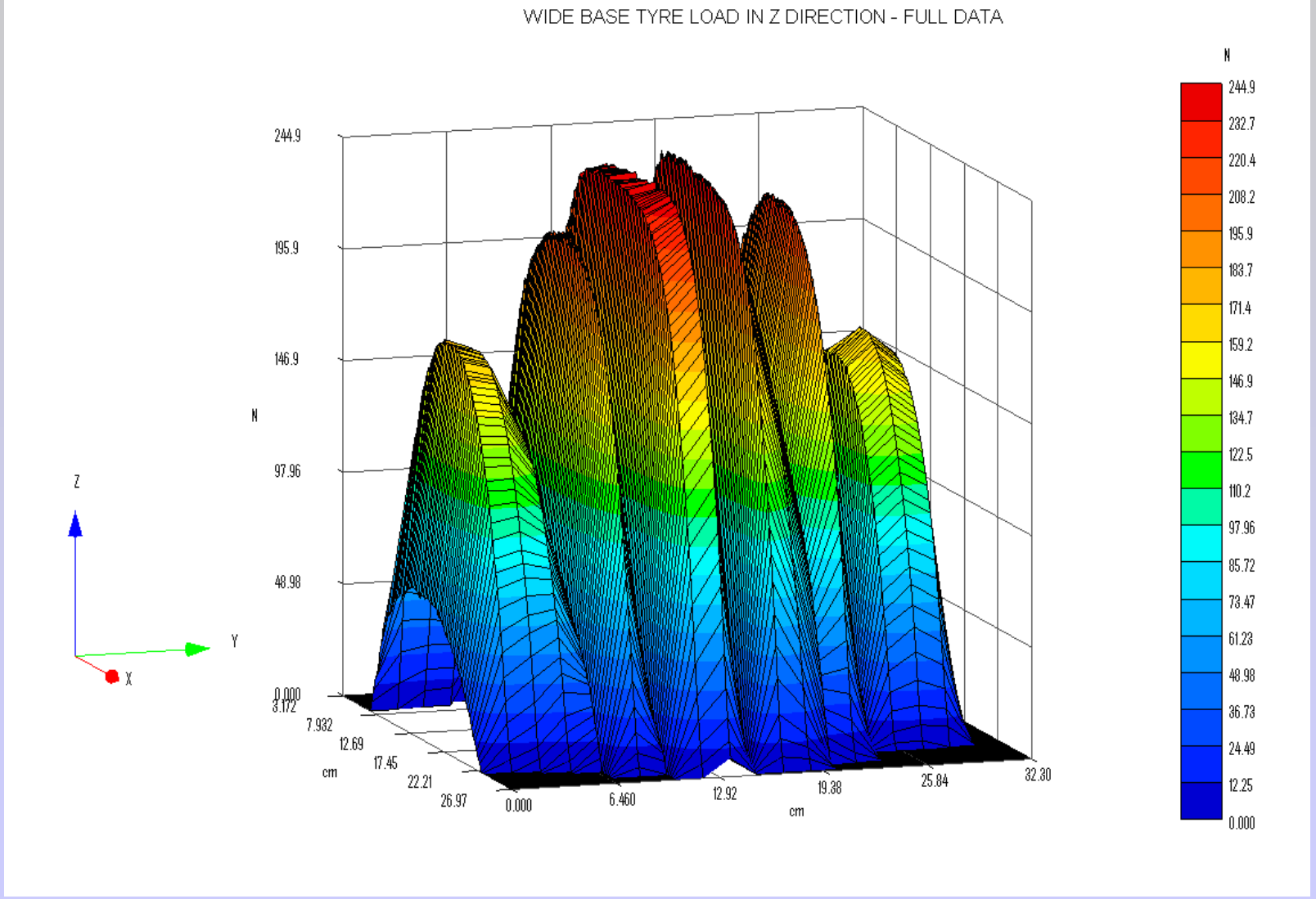
Stresses within a Road Pavement Structure



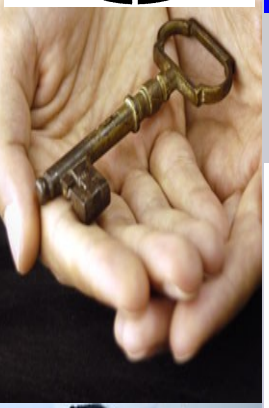


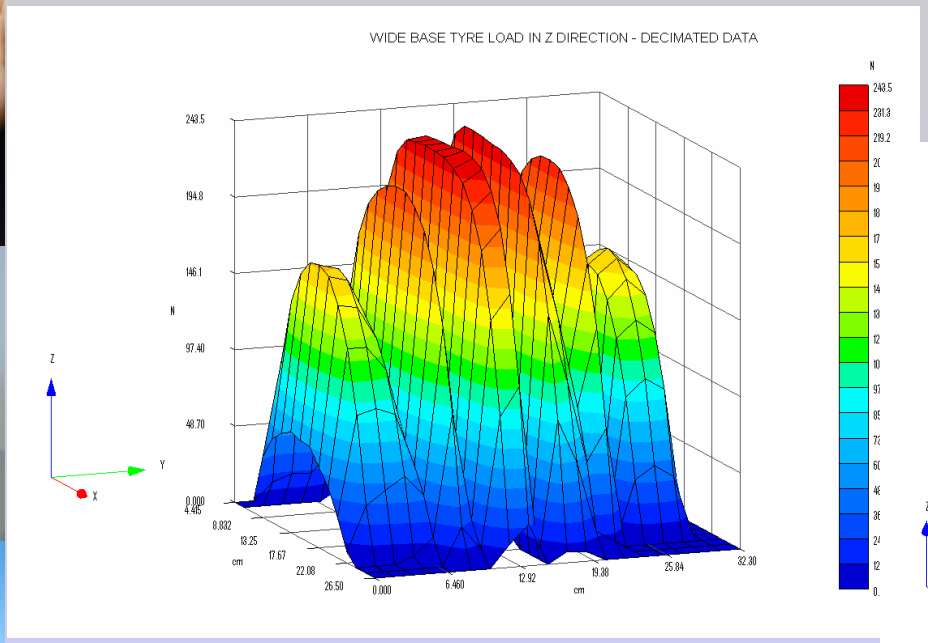


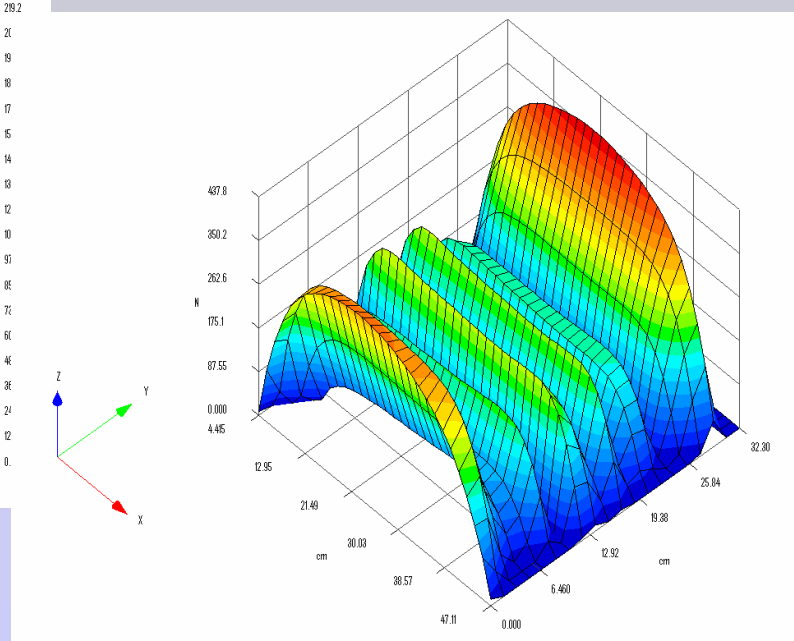
Wide Base Single Tyre - Measured Data: “n” – Shape…



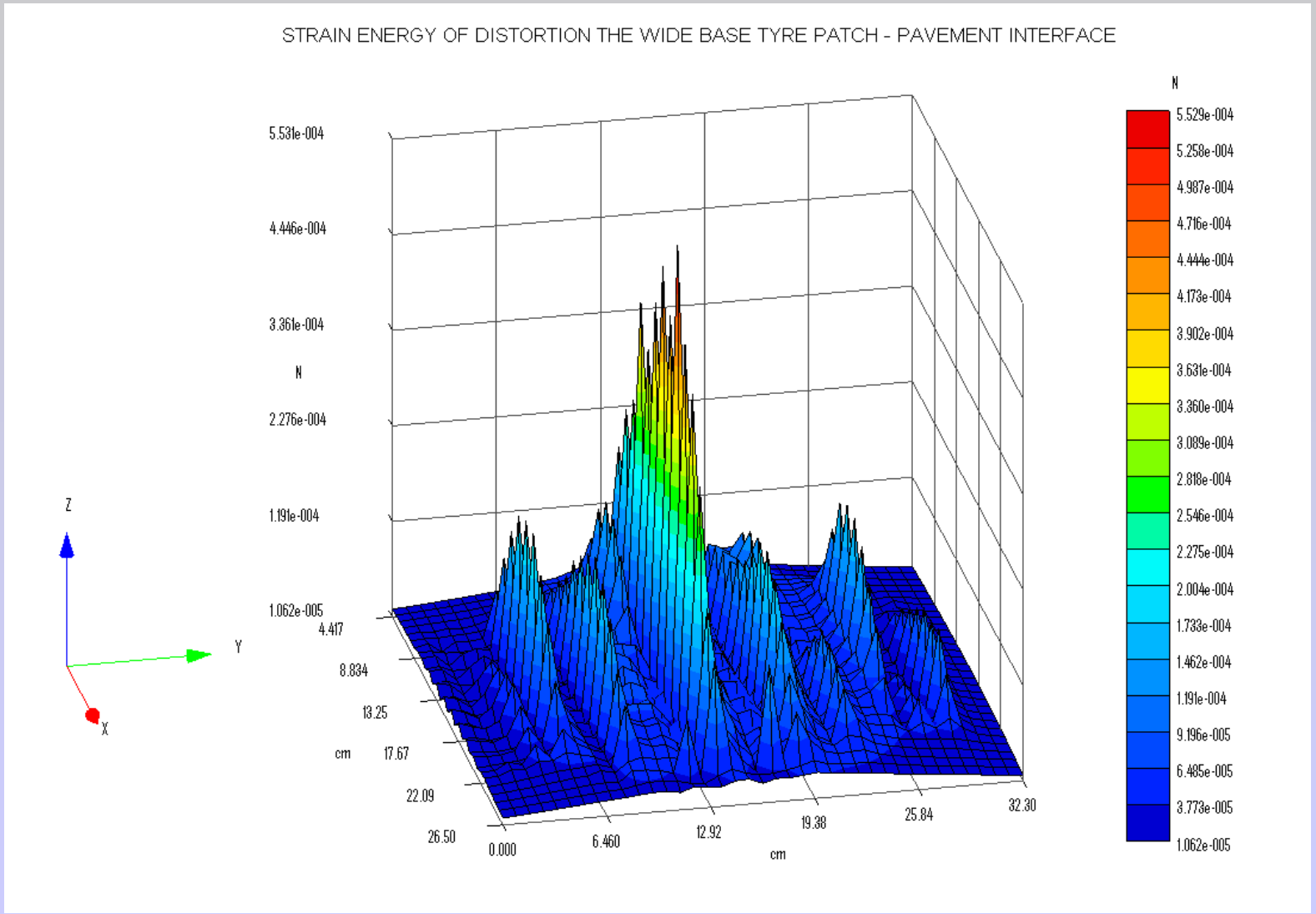
Wide Base Single Tyre - Input Data: “n” and “m” – Shapes…



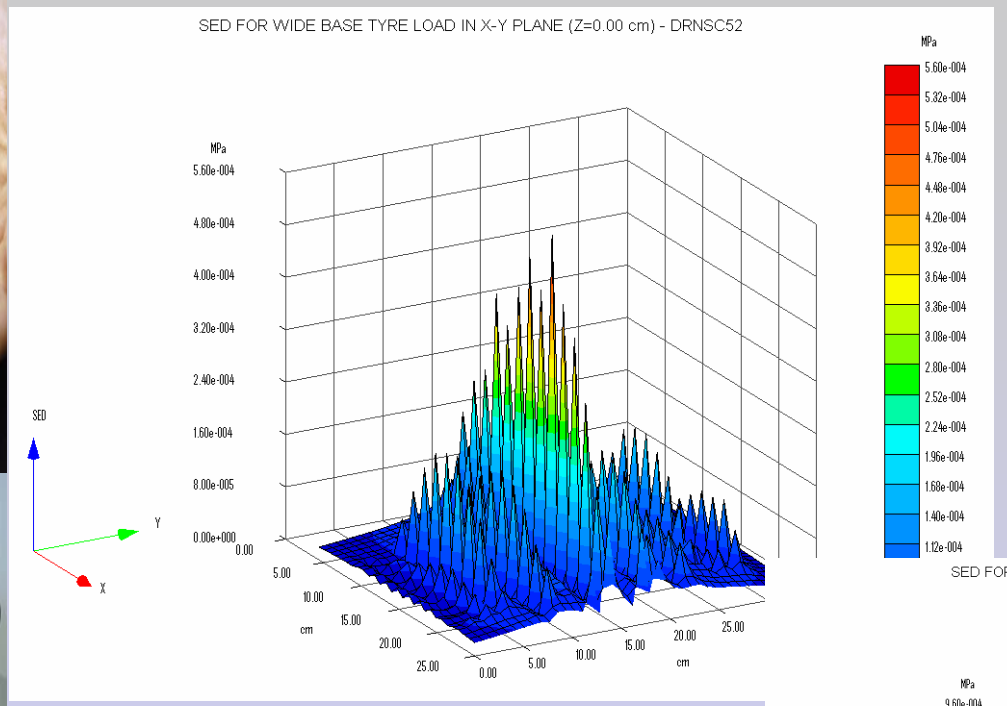


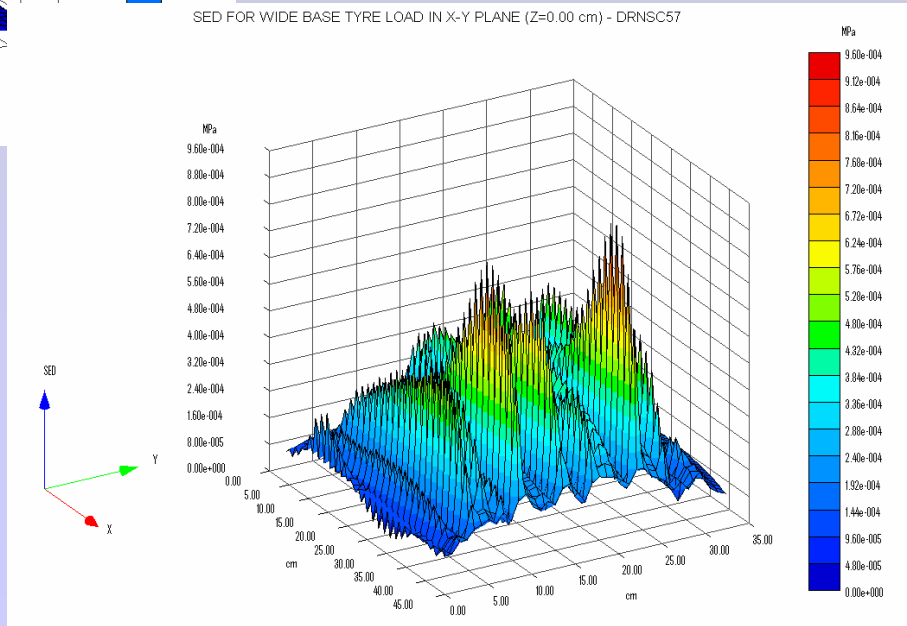


SED for Wide Base Single Tyre Input Data “n” – Shape

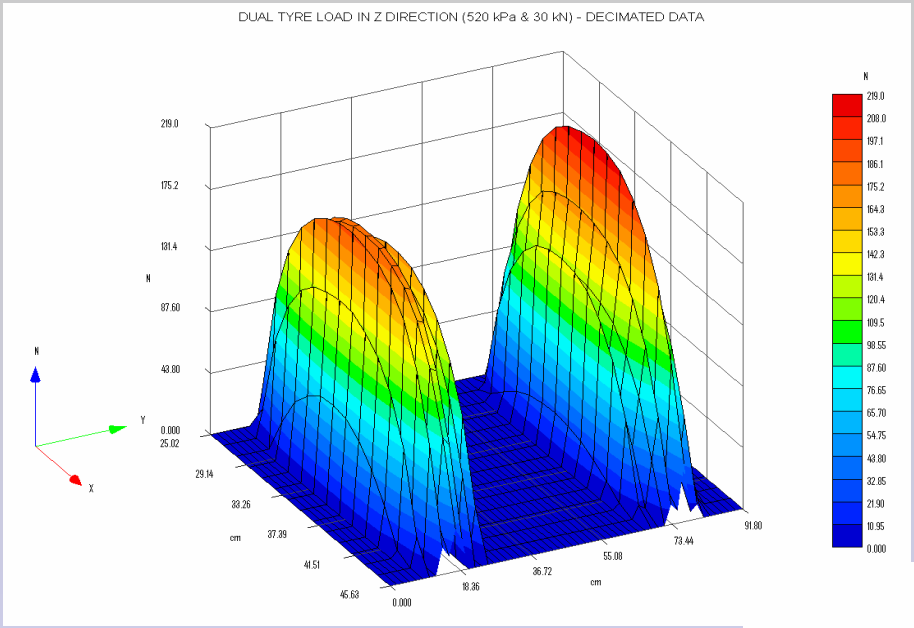


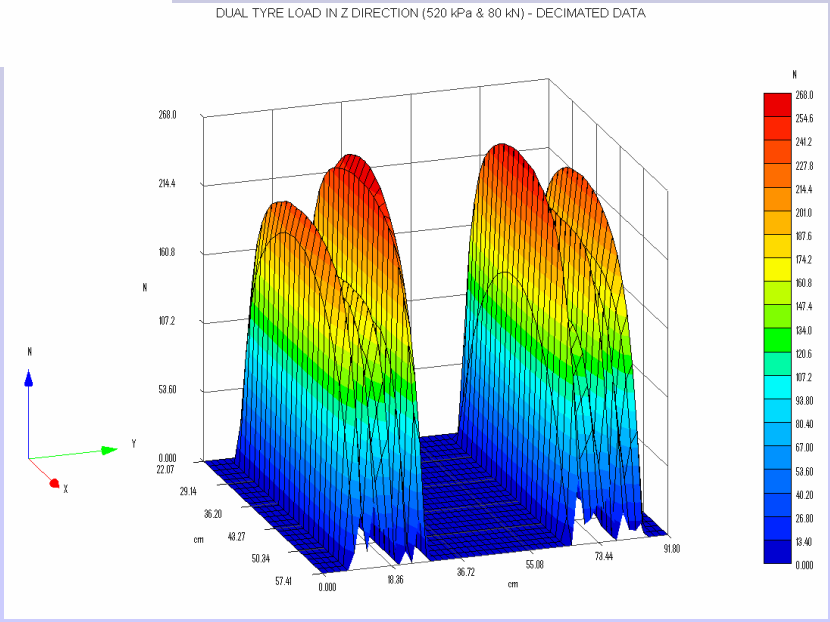
SED for Wide Base Single Tyre Input Data “n” and “m” – Shapes



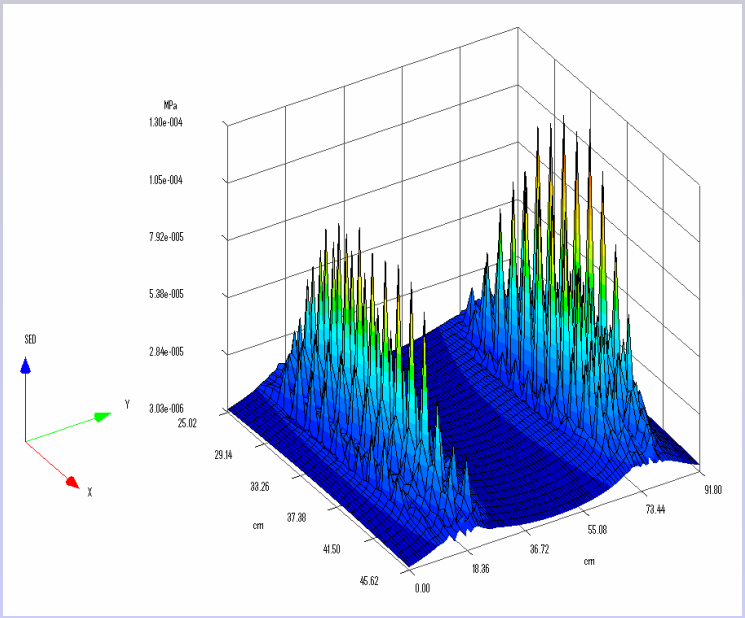


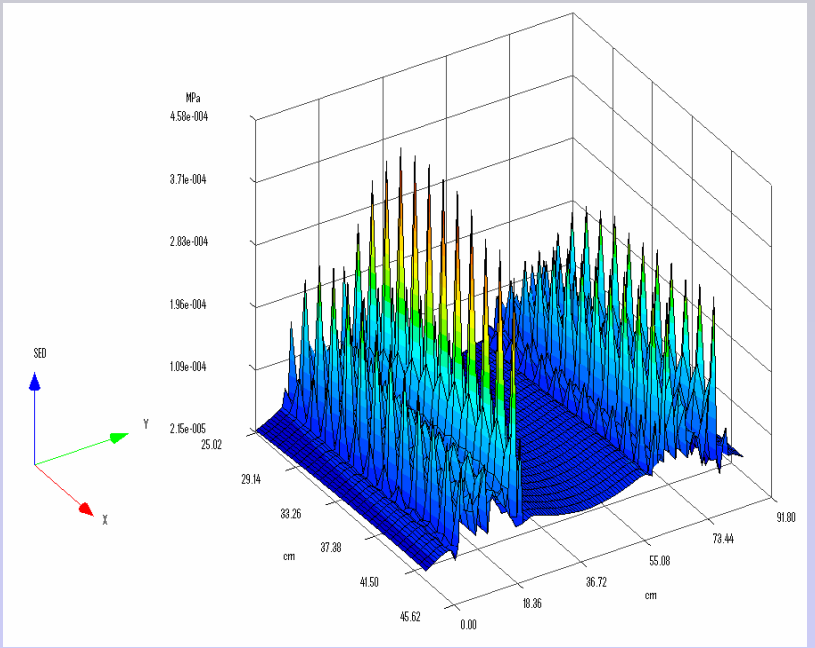
Dual Tyre - Input Data: “n” and “m” – Shapes…



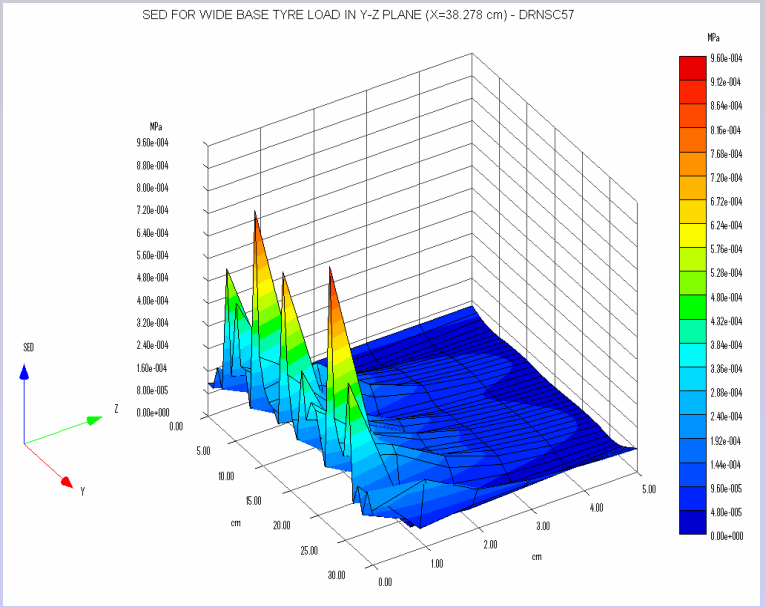


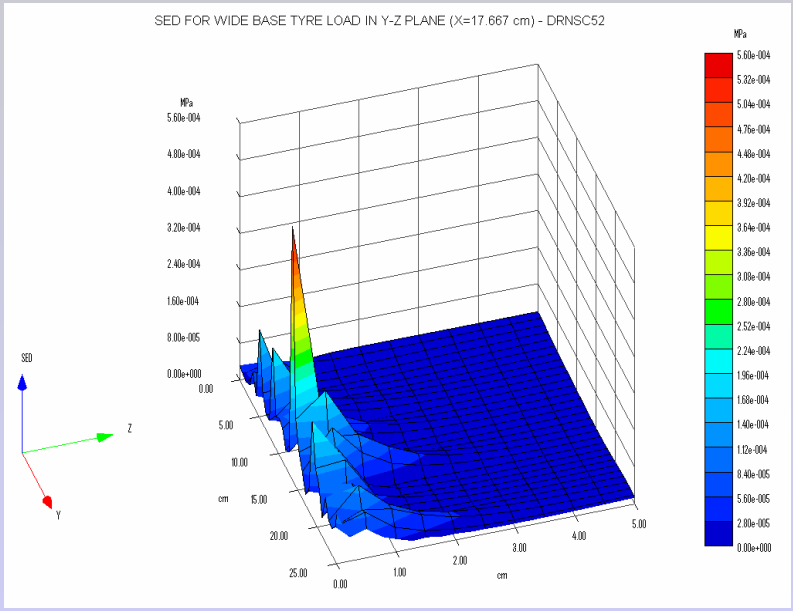
SED for Dual Tyre Input Data “n” and “m” – Shapes



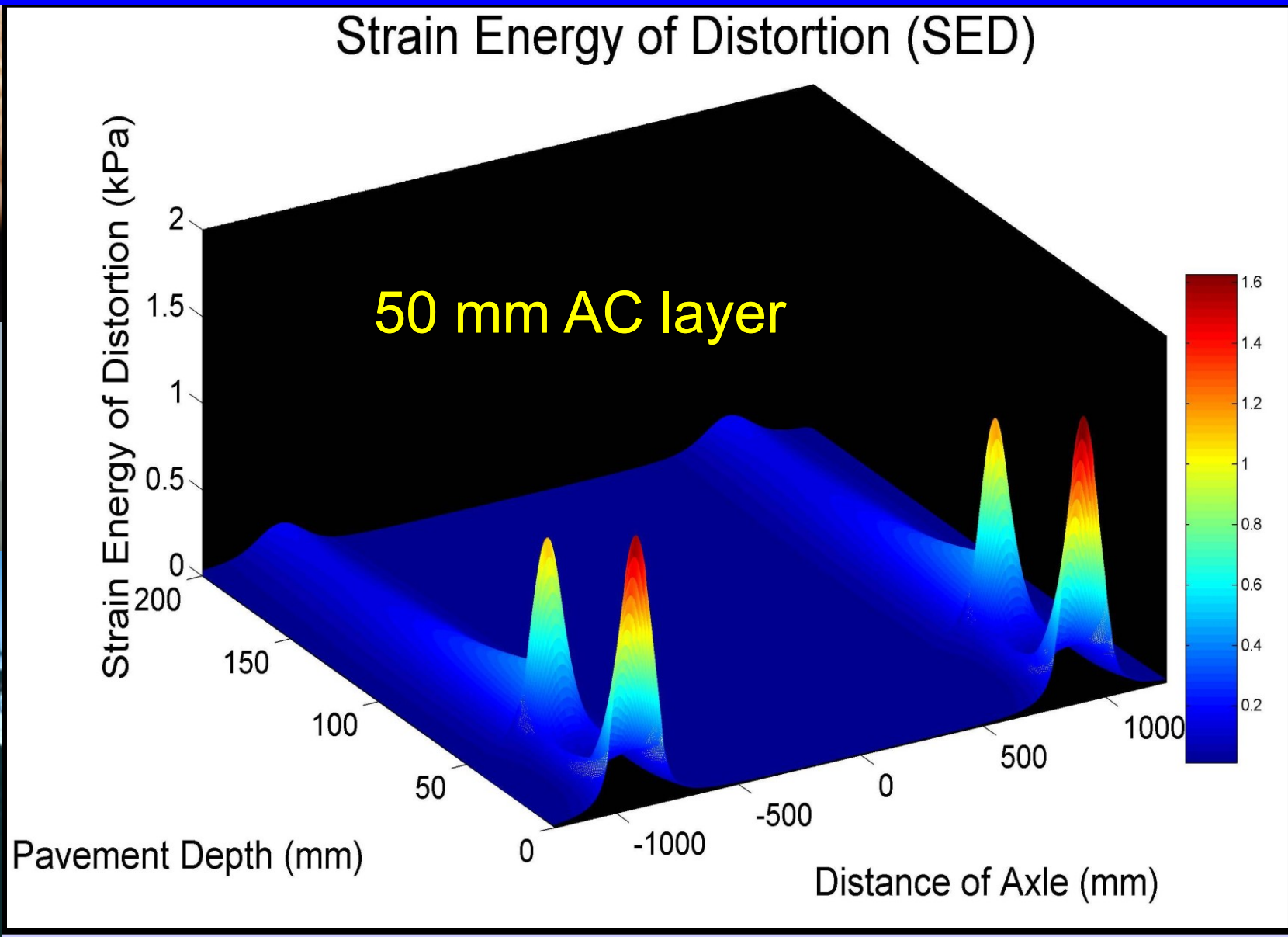


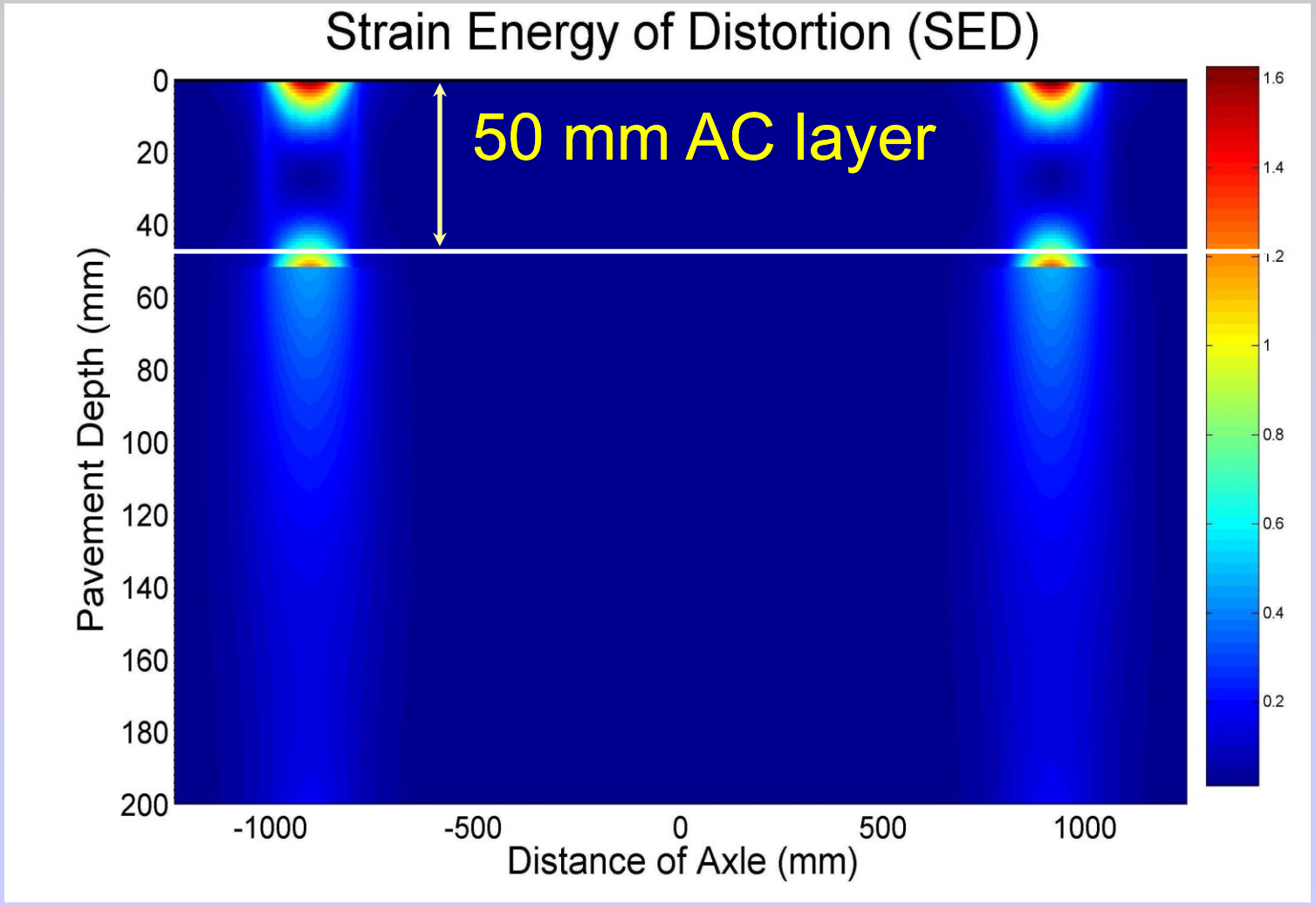
Strain Energy of Distortion (SED) – Dissipation with depth…





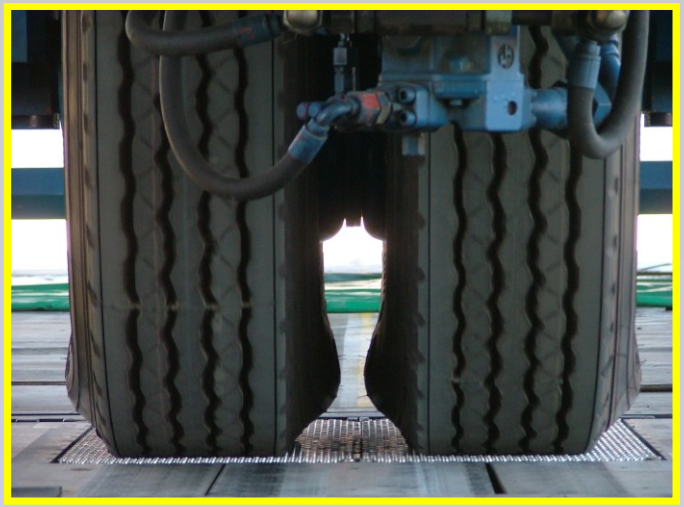
1 x Truck - 30 Tyres: 1 mm x 1 mm resolution – 500k points – SED under Steering Axle *(ICAP, 2006)…*

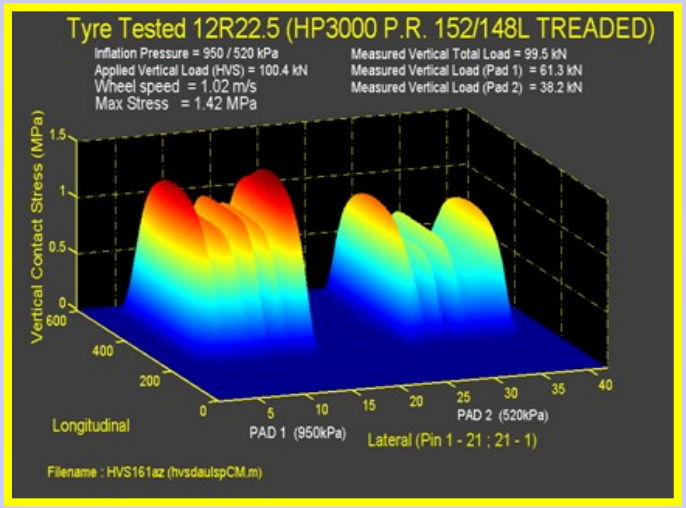



Strain Energy of Distortion (SED)
50 mm AC layer
Pavement Depth (mm)
0
20
40
60
80
100
120
140
160
180
200
-1000
-500
0
500
1000
Distance of Axle (mm)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2

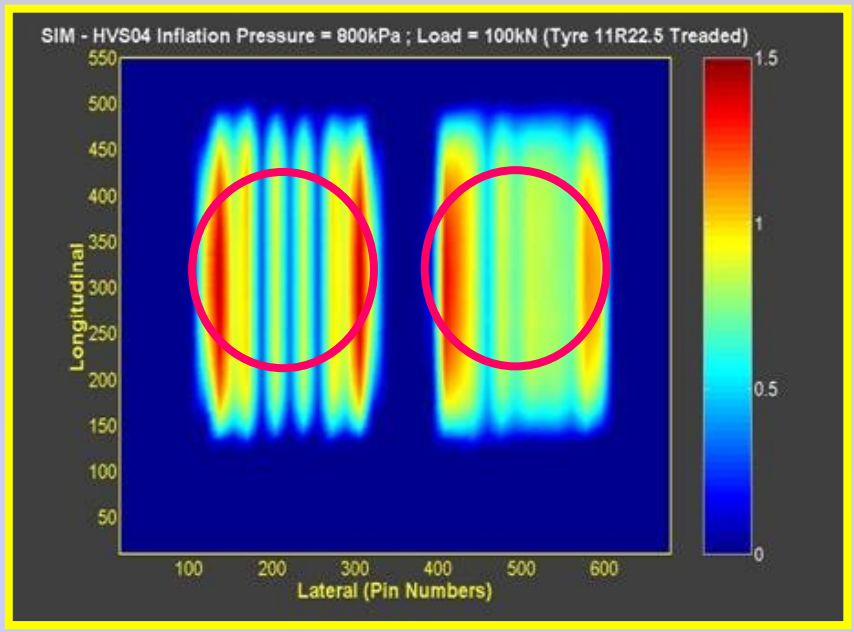
Gautrans Heavy Vehicle Simulator (HVS) Mark IV+: Loading Device for Controlled loading tests on roads..

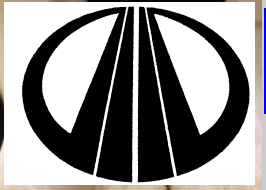
Overloading on Tires on HVS





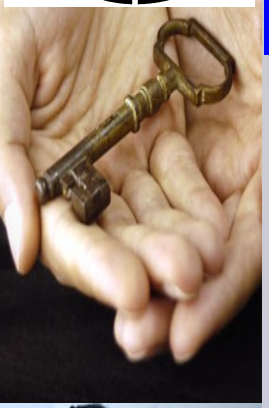
Contact Patches: (square not circular)

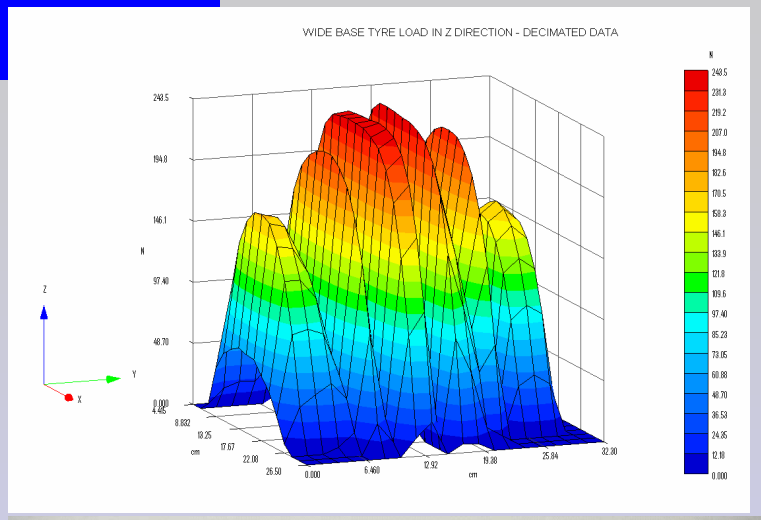


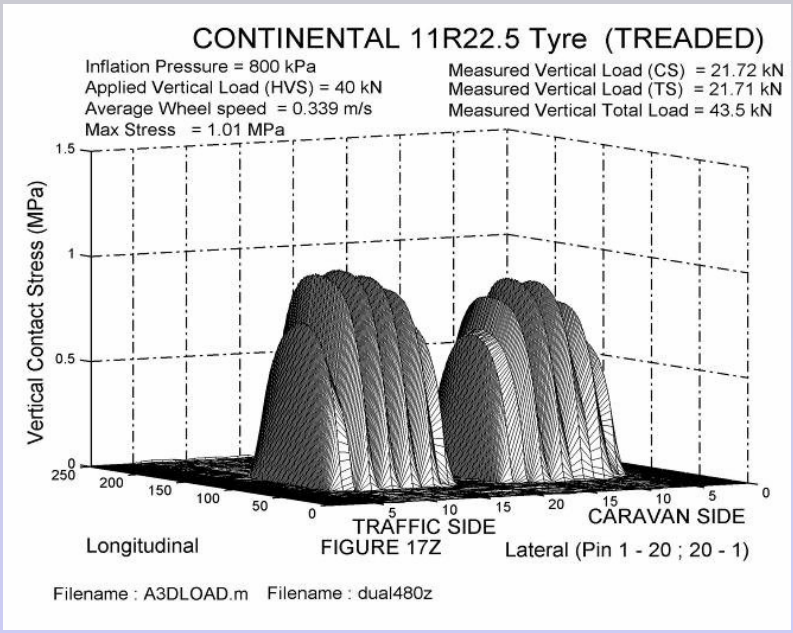


Rutting- Controlled testing with HVS…

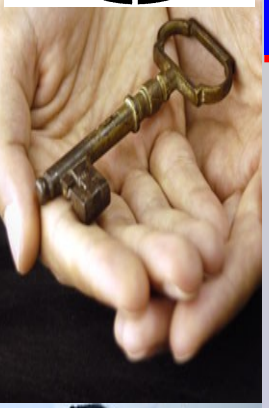
Vertical Tyre Stress – “n-Shape” rutting - channelised Traffic with HVS…

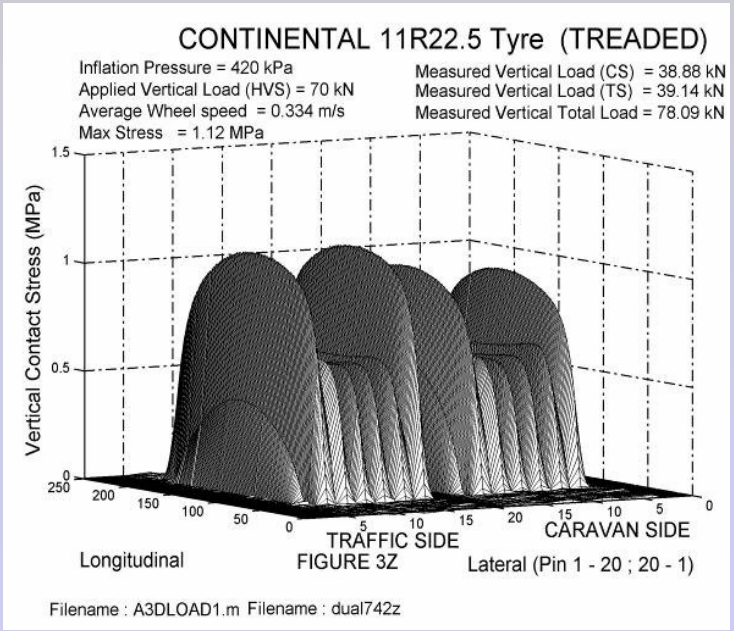


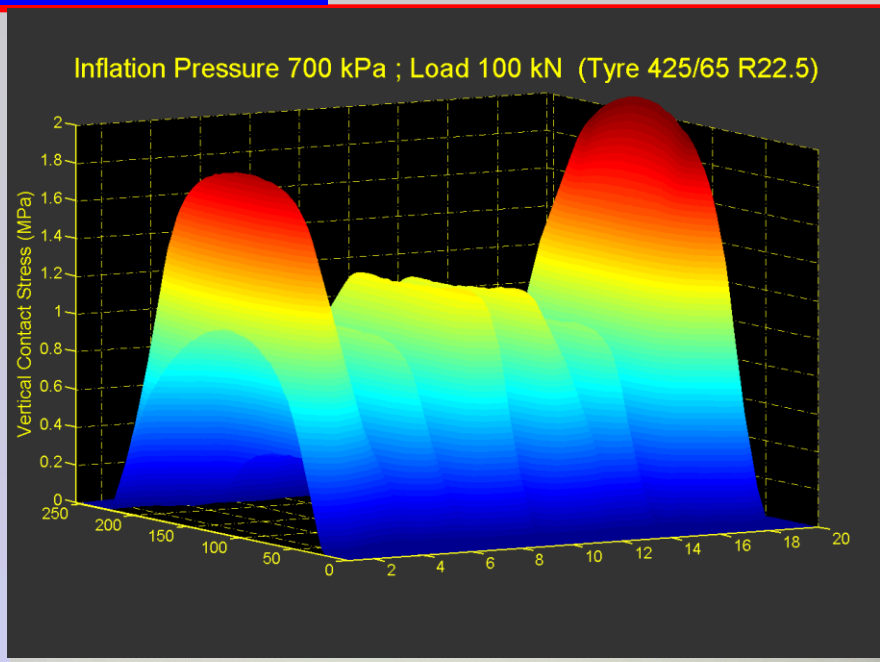




Vertical Tyre Stress – “m - Shape” rutting - channelised Traffic with HVS…







Conclusions

- South African Roads, Trucks @ Road Damage – real cause of concern;
- Successful Demonstration - Stress-In-Motion (SIM) technology;
- Implications for Road Surface Design and Road Preservation/Protection – Important to be implemented;
- SIM future of WIM ??.

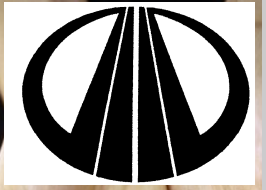



Conclusions- based on SED Evaluation:…

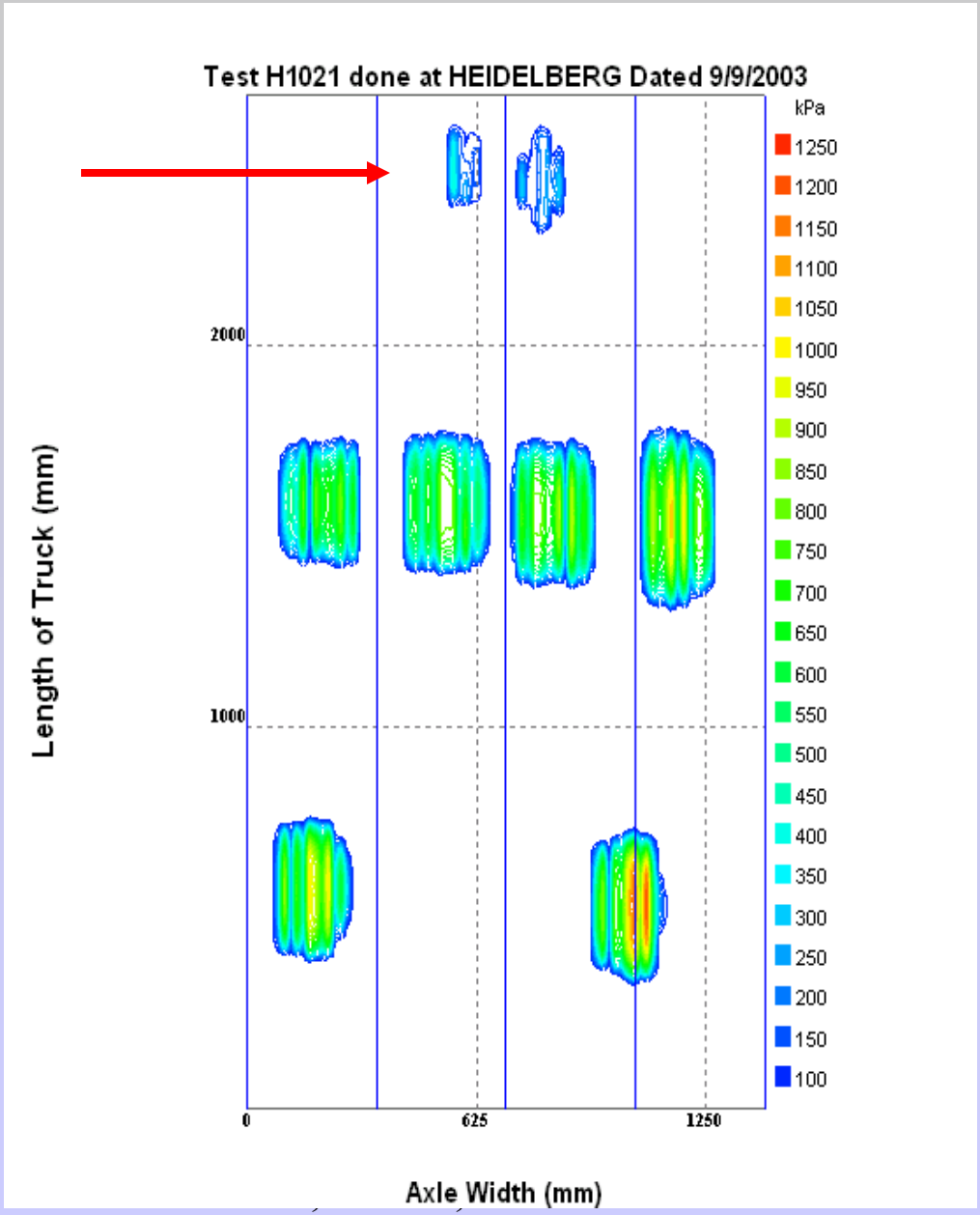
- Depending on the shape of the vertical contact stress distribution, the damaging effect in terms of SED of the single tyre appears to be 2.0 to 4.3 times higher than dual tyres under the same total loading.
- For both tyres, the damaging effect appears to be between 1.7 and 3.5 higher for the m-shape contact stress distribution.
- The top 5 mm to 10 mm of road pavements is potentially more prone to failure (top-down cracking or rutting) than was perhaps realised in the past.

Thank You for listening…

…any Questions ?



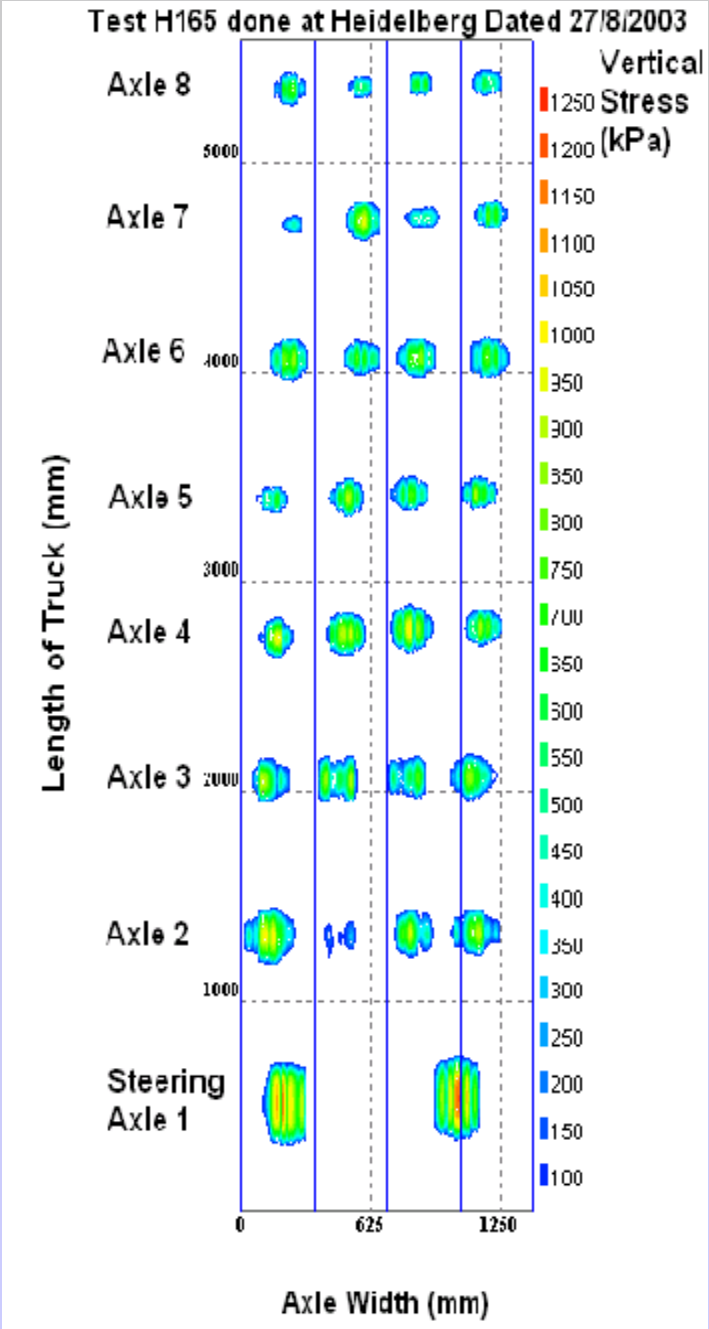
Trailer


Test H1021 done at HEIDELBERG Dated 9/9/2003
kPa
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
2000
1000
0
625
1250
Length of Truck (mm)
Axle Width (mm)

Example: 7 Axle

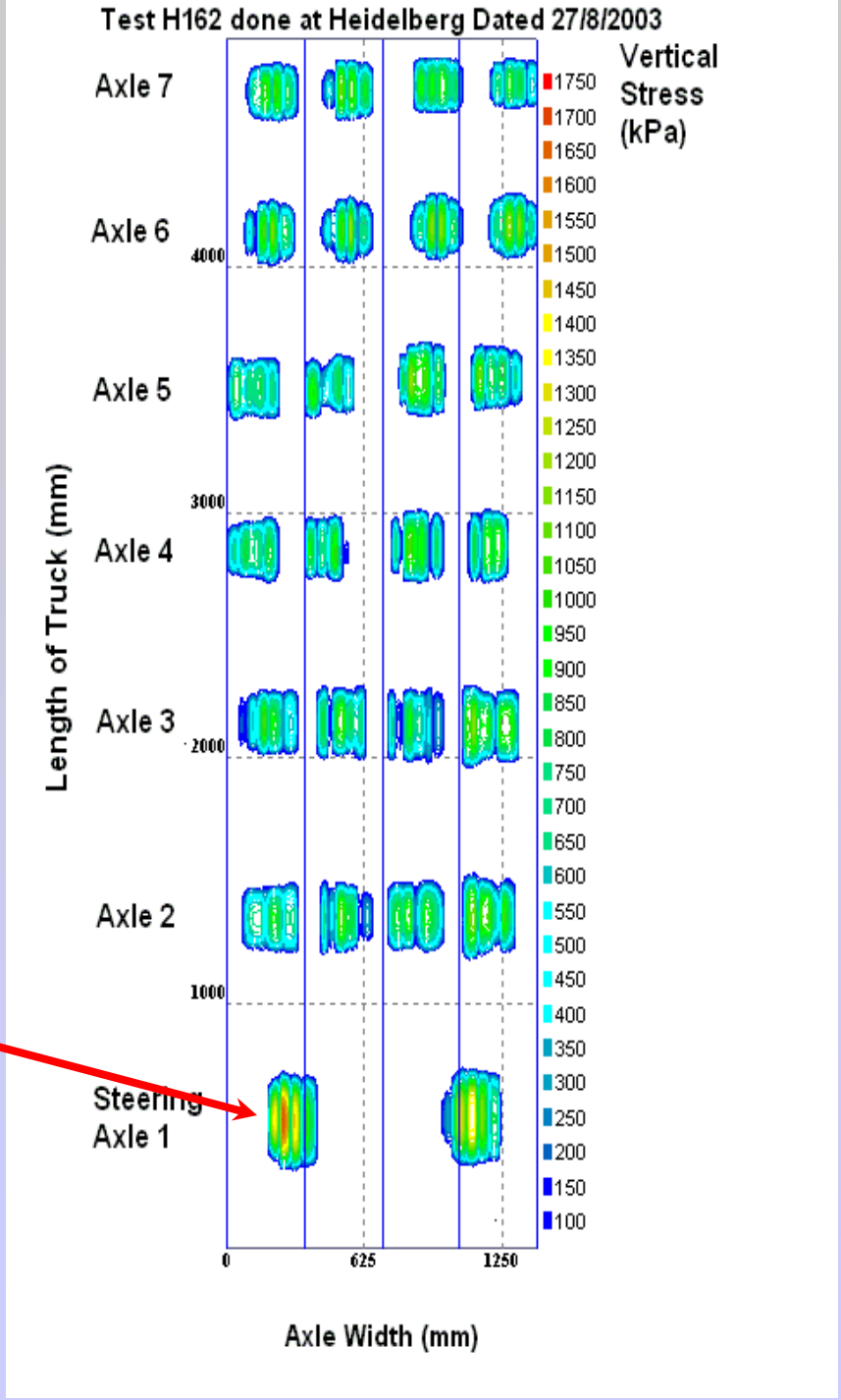
EMPTY Truck (1:2:2:3)

Note Variation in Vertical Contact Stresses on all 30 tyres



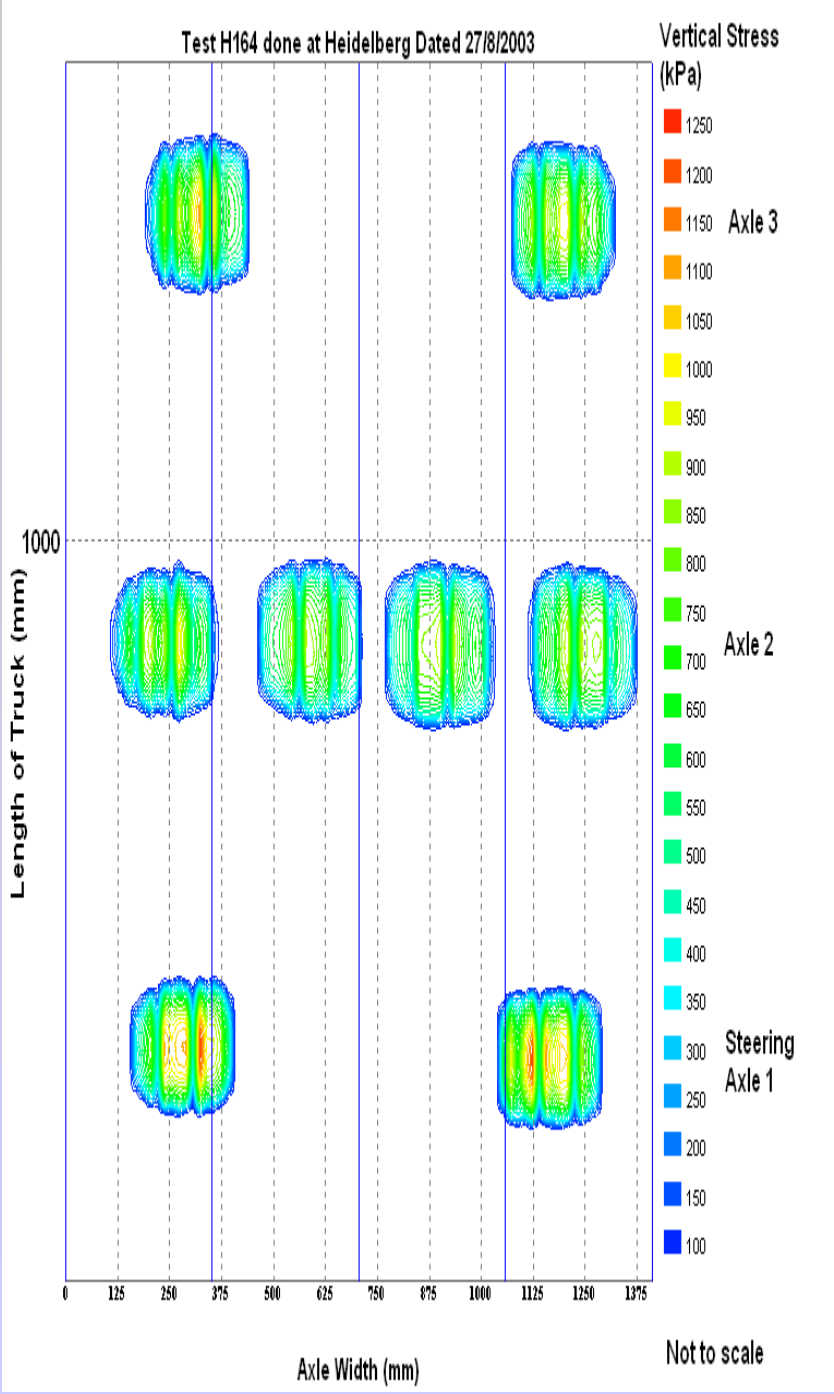
Example: 7 Axle Truck (1:2:2:2) fully loaded with cement

Note Contact Stresses on Steering Tyres



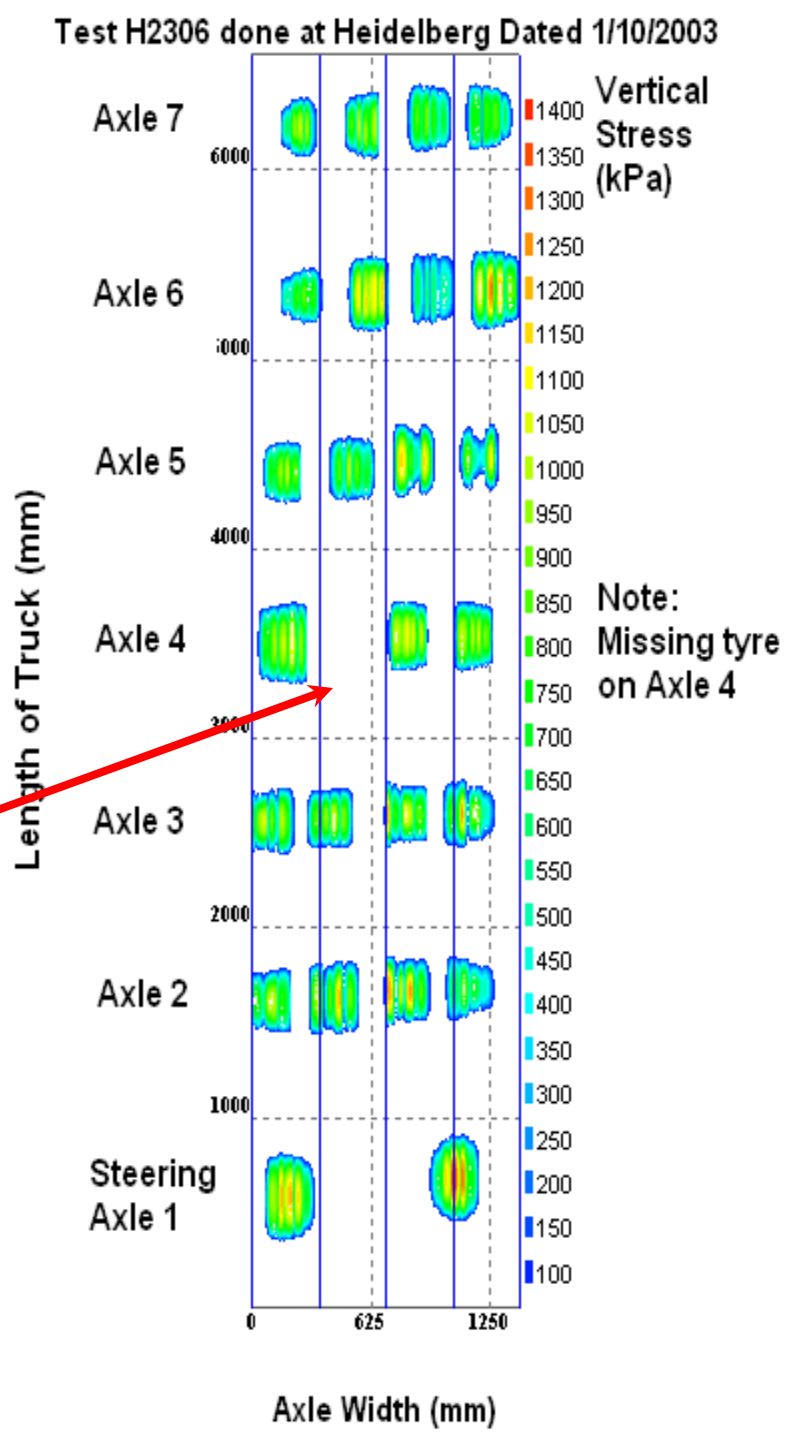
Example: Passenger Bus (1:1:1)

(FIGURE NOT TO SCALE)



Example: 7 Axle Truck (1:2:2:2)

Note the missing tyre



Lotus | SmartSuite | Internet | Calendar | Addresses | Reminders

South African Mechanistic Pavement Design

File Help

UNIFORM: VERTICAL (NORMAL) STRESS, zz

Calculate

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

Define plane for contour plot

Vertical plane parallel to X-Z

Y offset from origin: 10

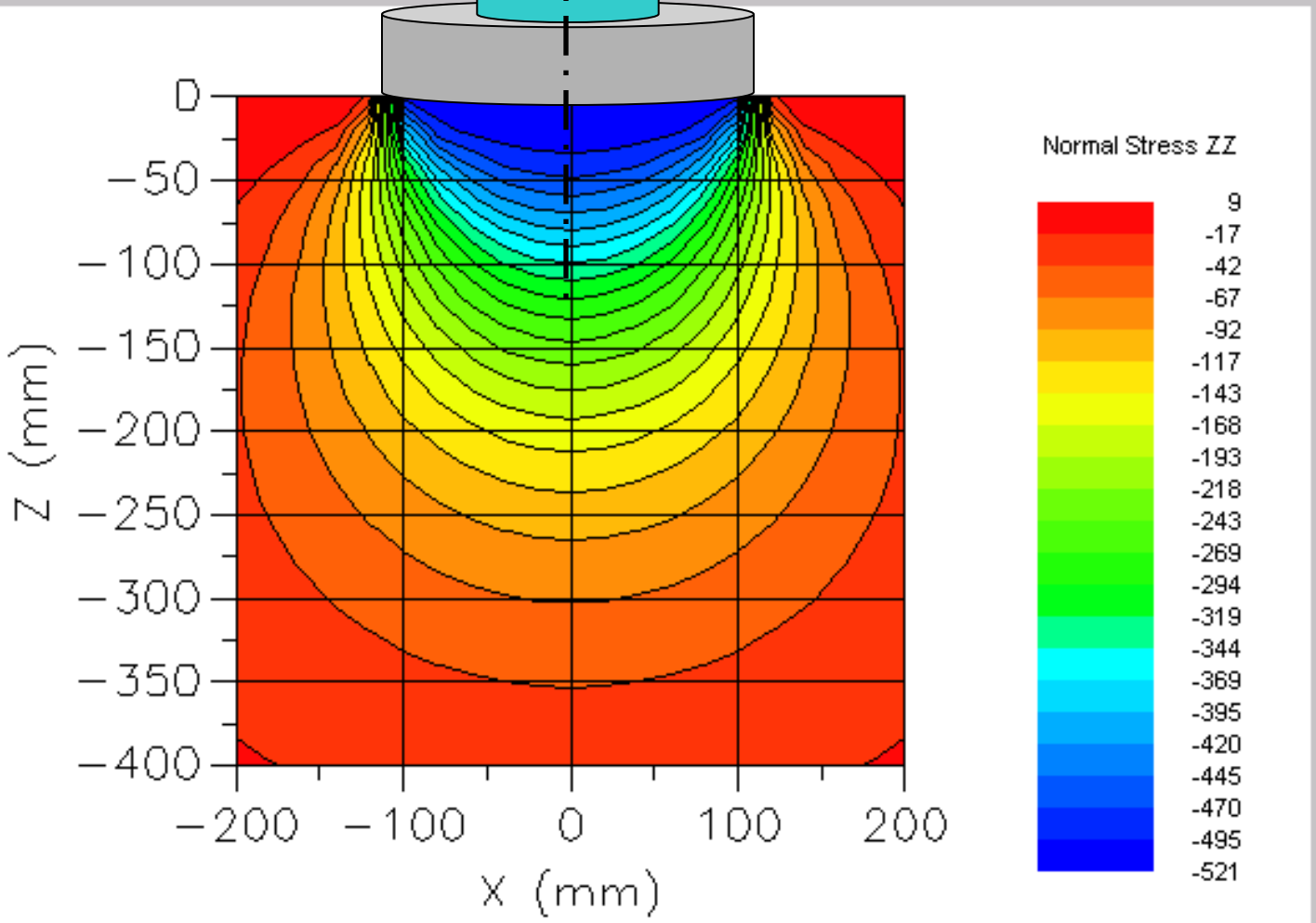
Contour region size (mm): 400

Contour region centred at (mm)

X: 0 Z: 0

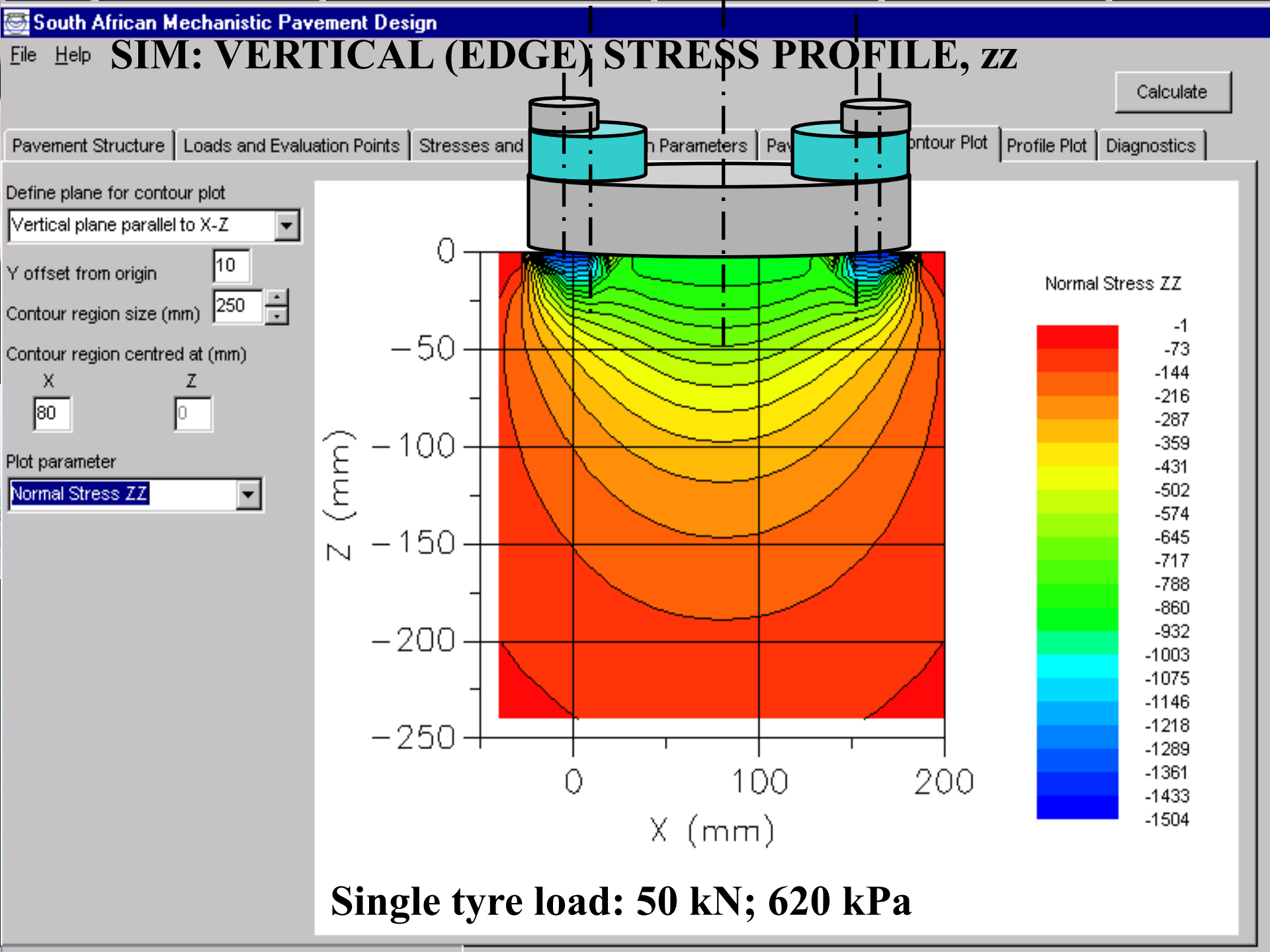
Plot parameter

Normal Stress ZZ



Single tyre load: 20 kN; 520 kPa

SIM: VERTICAL (EDGE) STRESS PROFILE, zz



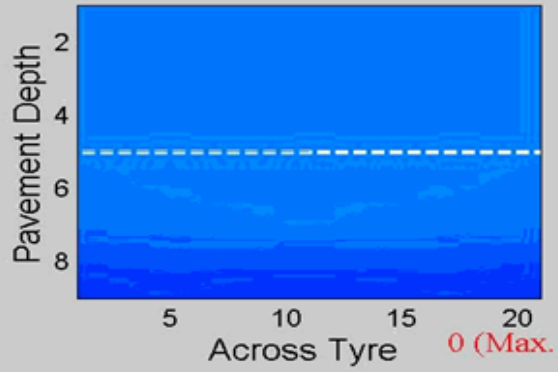
Single tyre load: 50 kN; 620 kPa

Stress Response - Moving Tyre (FEM):

MODELED TYRE

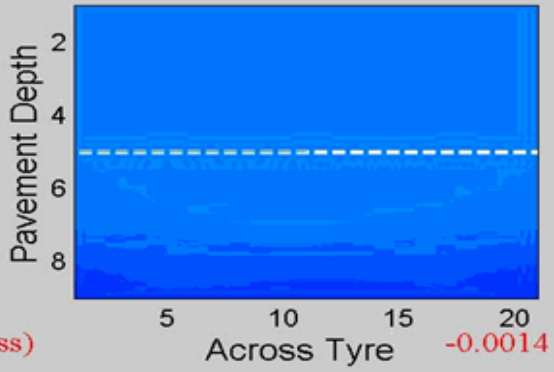
REAL-TYRE

UNIFORM LOAD - 520 kPa, 21 kN



0 (Max. Stress)

SIM - 600 kPa, 20 kN

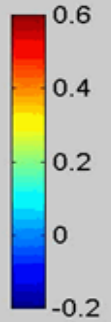


-0.0014 (Max. Stress)

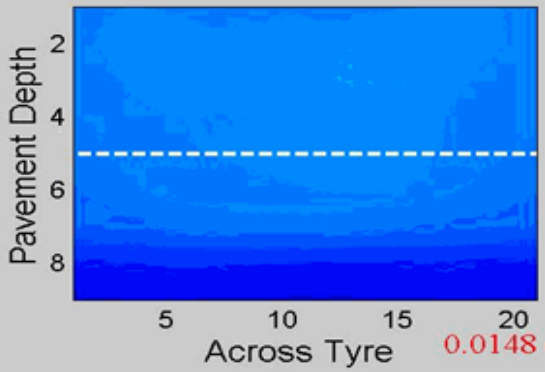
KEY:

VERTICAL STRESS:

Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading

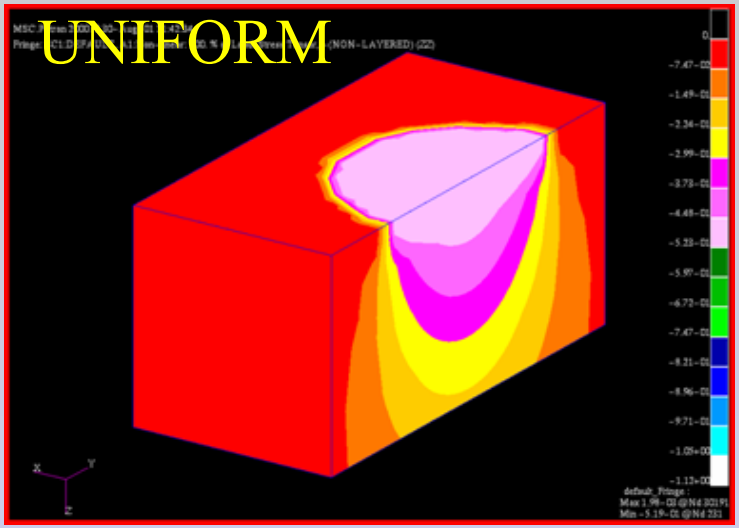


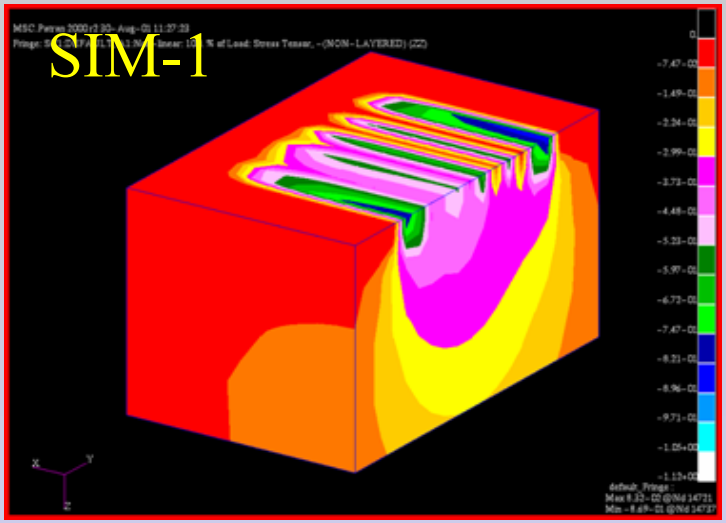
SIM - 600 kPa, 35 kN

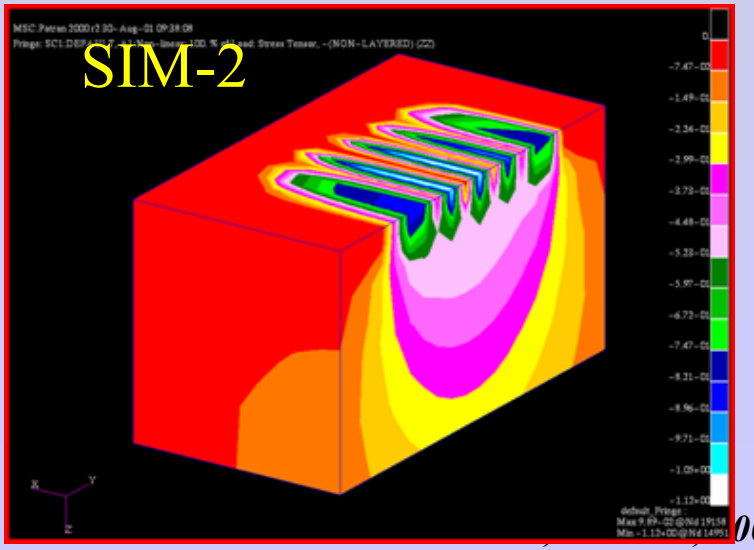


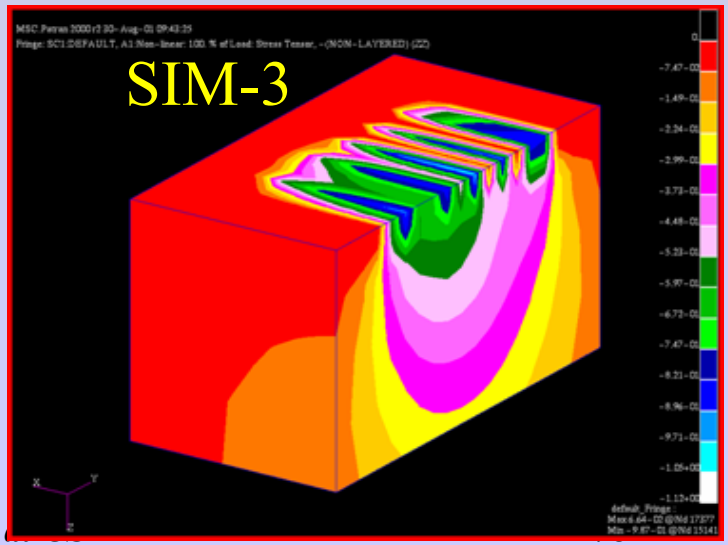
0.0148 (Max. Stress)

Finite Element Analysis (CSIR):Uniform vs Non-Uniform Stress….





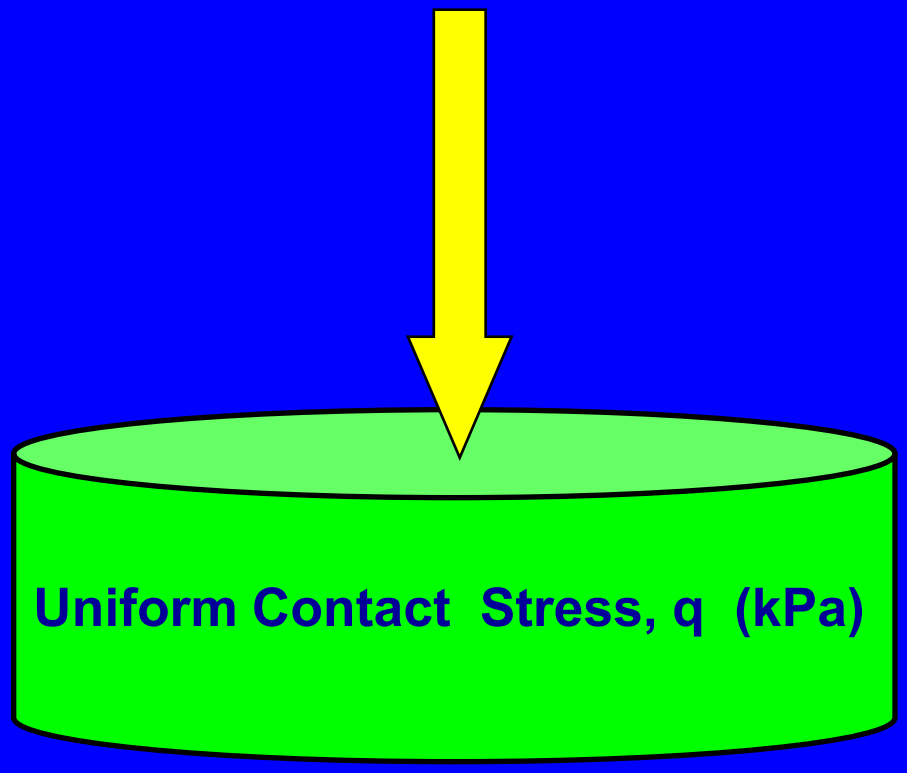





Thank you for your attention..

Assumption of Tyre Loading - Pavement Design Modeling:

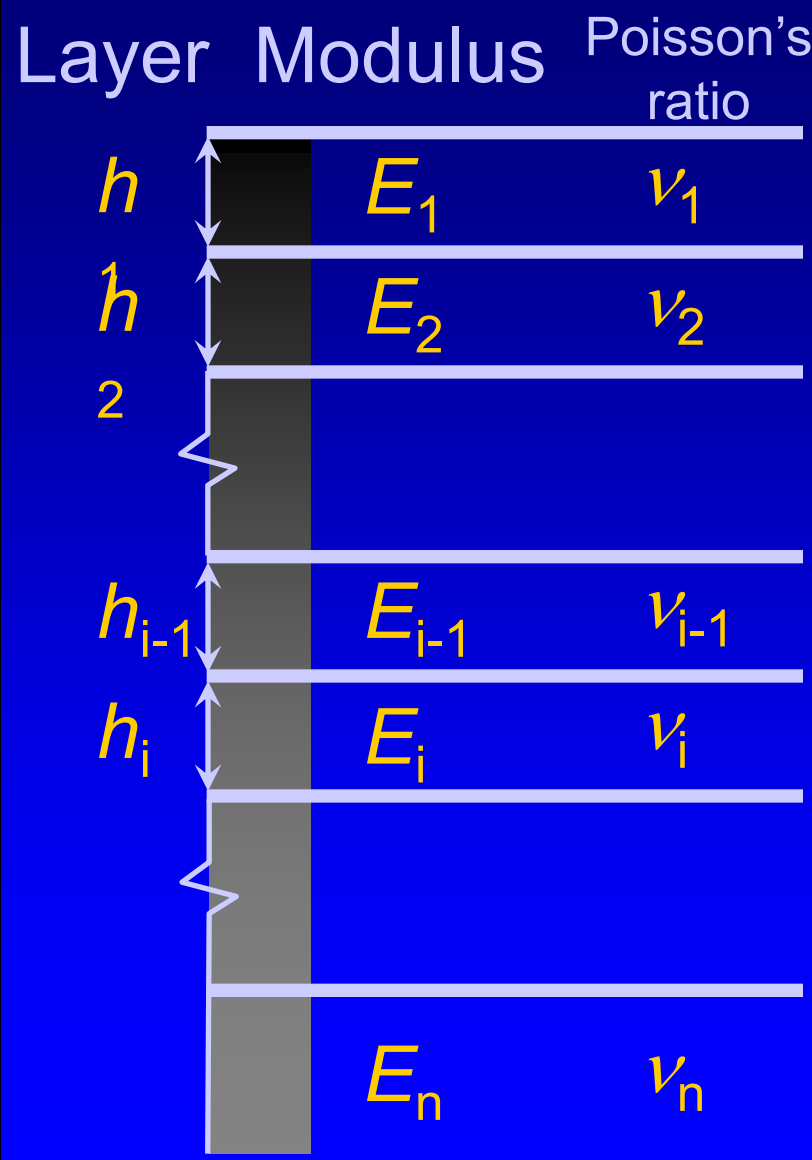
- Circular;
- Variable Vertical load;
- Variable pressure, but UNIFORM & No Shear Forces included.

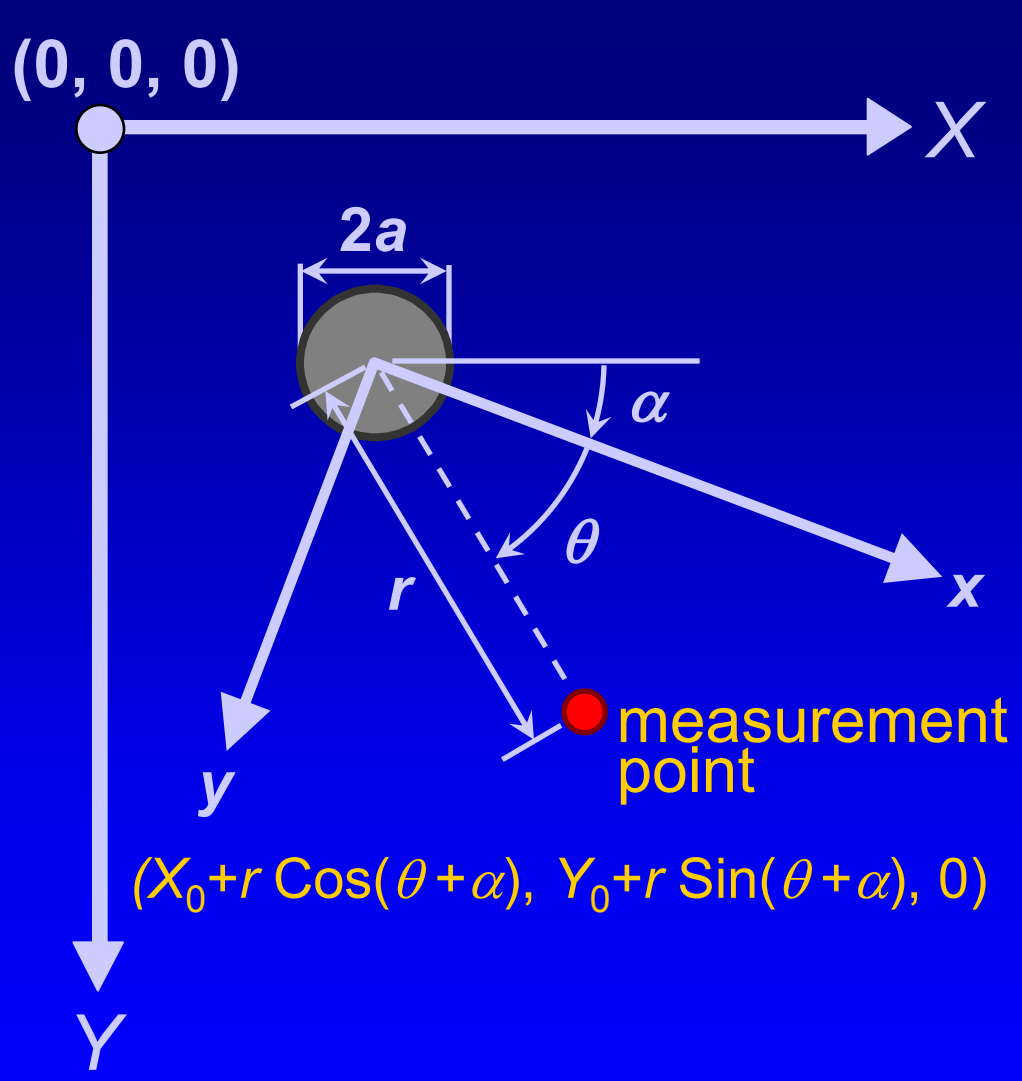


General Features & Assumption

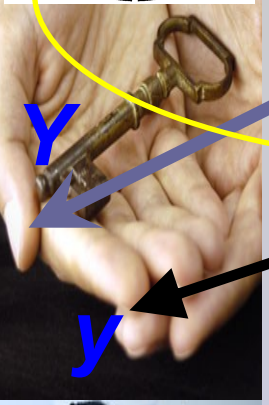
- **Pavement:** Multilayer elastic system with a possibility of interface slip.
- **Surface load:** Single/Multiple circular loads.
- **Analysis:** Single/Multiple points of interest.
- **Response:** Stresses, strains, and displacements

Multilayer Structural Model





Global Cartesian coordinate system



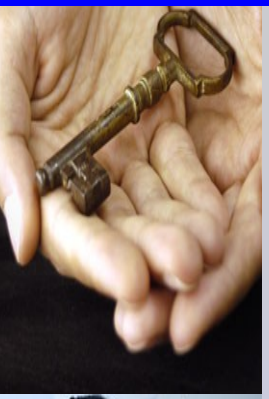
Local Cartesian and cylindrical coordinates

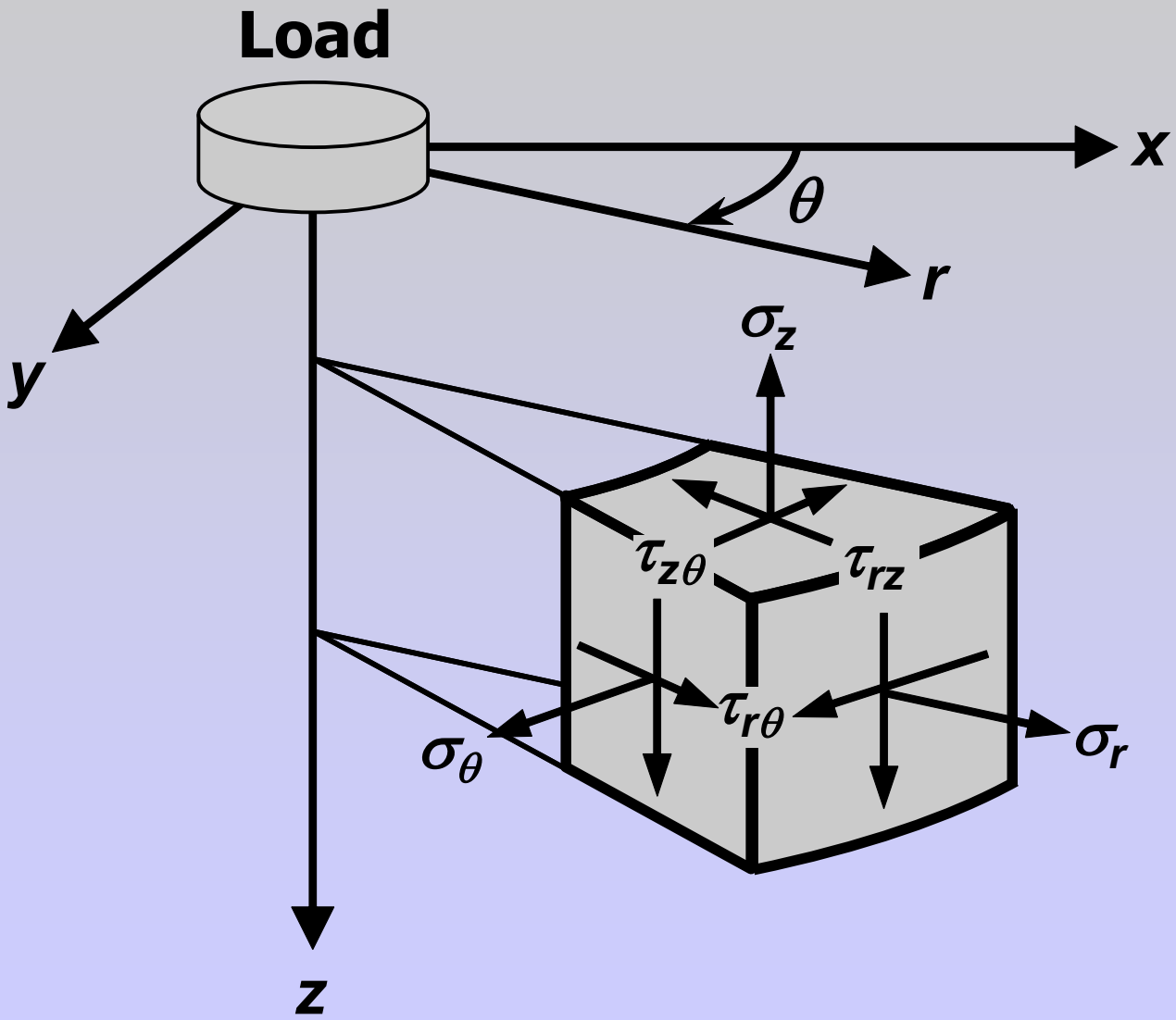
load

Stress acting on an element

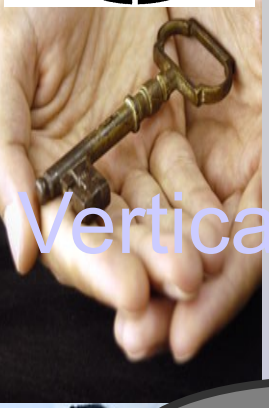
Arrows give directions for positive sign

Stresses within a Road Pavement Structure
- $r\theta z$ Axes -





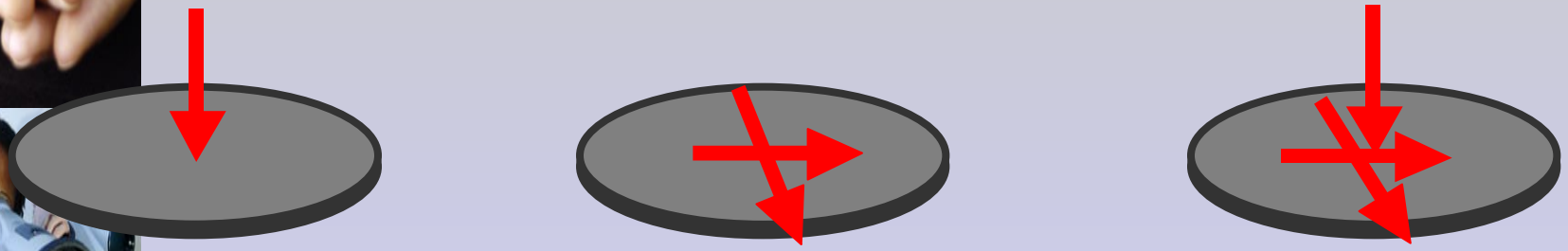
Uniformly distributed circular load



Vertical load

Horizontal load

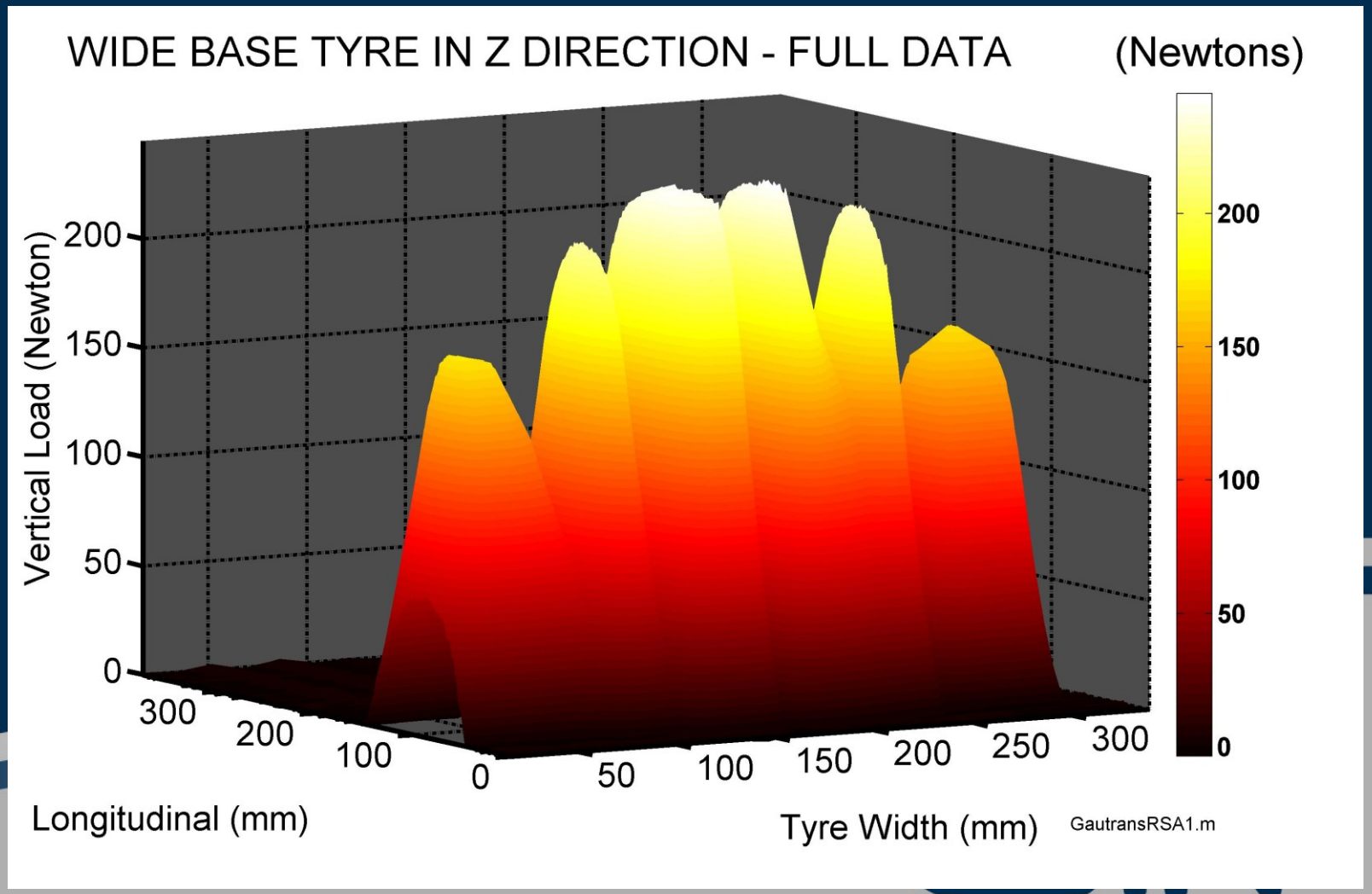
vertical + horizontal loads

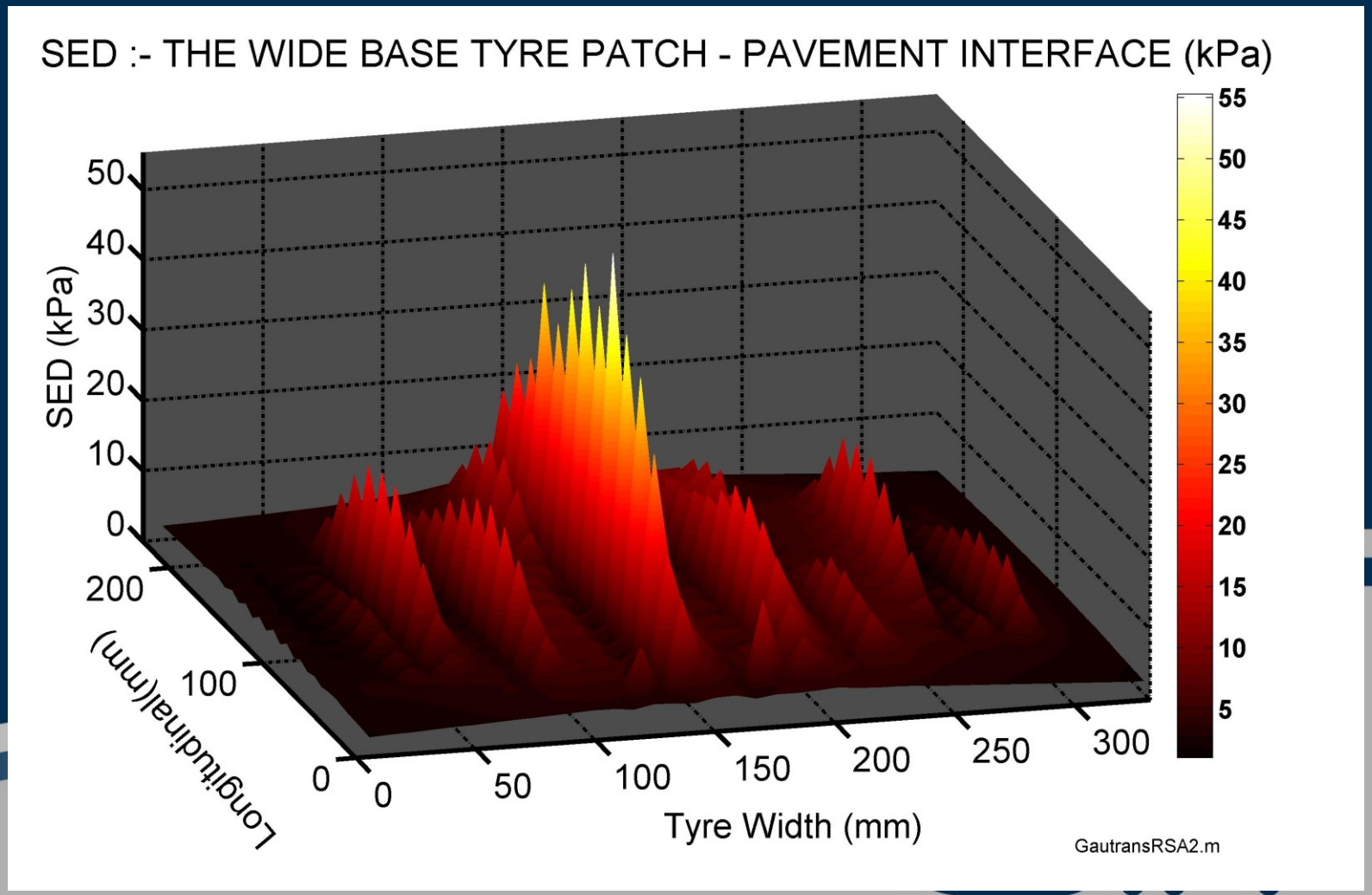


surface

Base

Subgrade


WIDE BASE TYRE IN Z DIRECTION - FULL DATA
(Newtons)
Vertical Load (Newton)
200
150
100
50
0
300
200
100
0
Longitudinal (mm)
50
100
150
200
250
300
Tyre Width (mm)
GautransRSA1.m
200
150
100
50
0


SED :- THE WIDE BASE TYRE PATCH - PAVEMENT INTERFACE (kPa)
SED (kPa)
50
40
30
20
10
0
200
100
0
Longitudinal(mm)
0
50
100
150
200
250
300
Tyre Width (mm)
55
50
45
40
35
30
25
20
15
10
5
GautransRSA2.m