5th International Symposium on Weigh-In-Motion
HVParis 2008, May 19-22 2008

STRESS-IN-MOTION (SIM) - A NEW TOOL FOR ROAD INFRASTRUCTURE PROTECTION ?

Morris De Beer
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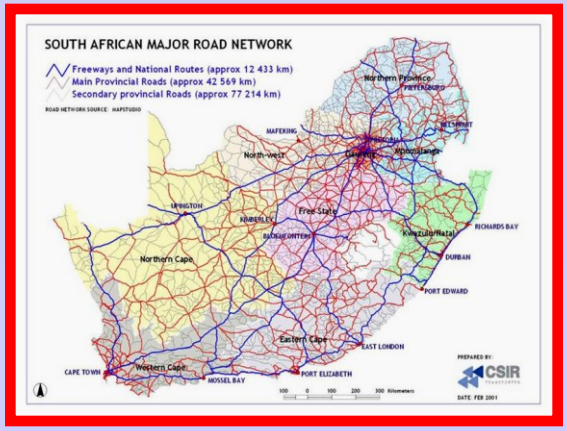


PROGRAMME FOR SESSION TODAY

- Introduction - (Morris De Beer)
- Overloading in South Africa - Paul Nordengen;
- Tyre-Road-Interactions - Morris De Beer/Wynand Steyn;
- Rural Transport, Accessibility and sustainable development – Brian Marrian
- Road Construction in China - CATS.

STRUCTURE OF PRESENTATION:

- Pavement (Road) Surfacing failures- related to design ?
- Overview of Stress-In-Motion (SIM) Technology;
- R & D – Equipment & Measurements;
- Typical Data Sets;
- SIM Data Handling/Validation – NB !;
- Applications - Dynamic Loading;
- Advanced Pavement Analysis (ELSYM5/FEM);
- Pavement Design: Quo Vadis –?
- Summary & Conclusions

HEAVY VEHICLE SIMULATOR (HVS)

SINCE 1970s

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

Vehicle-Tyre-Pavement Interaction:

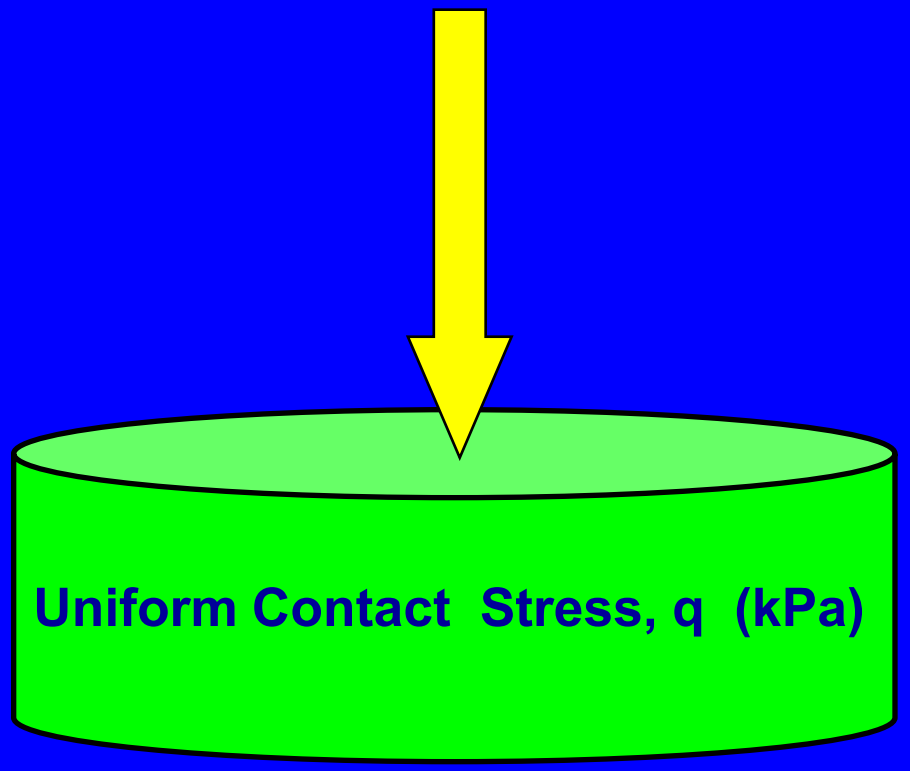
STRESS-IN-MOTION (SIM) Technology

Morris De Beer, CSIR Transportek

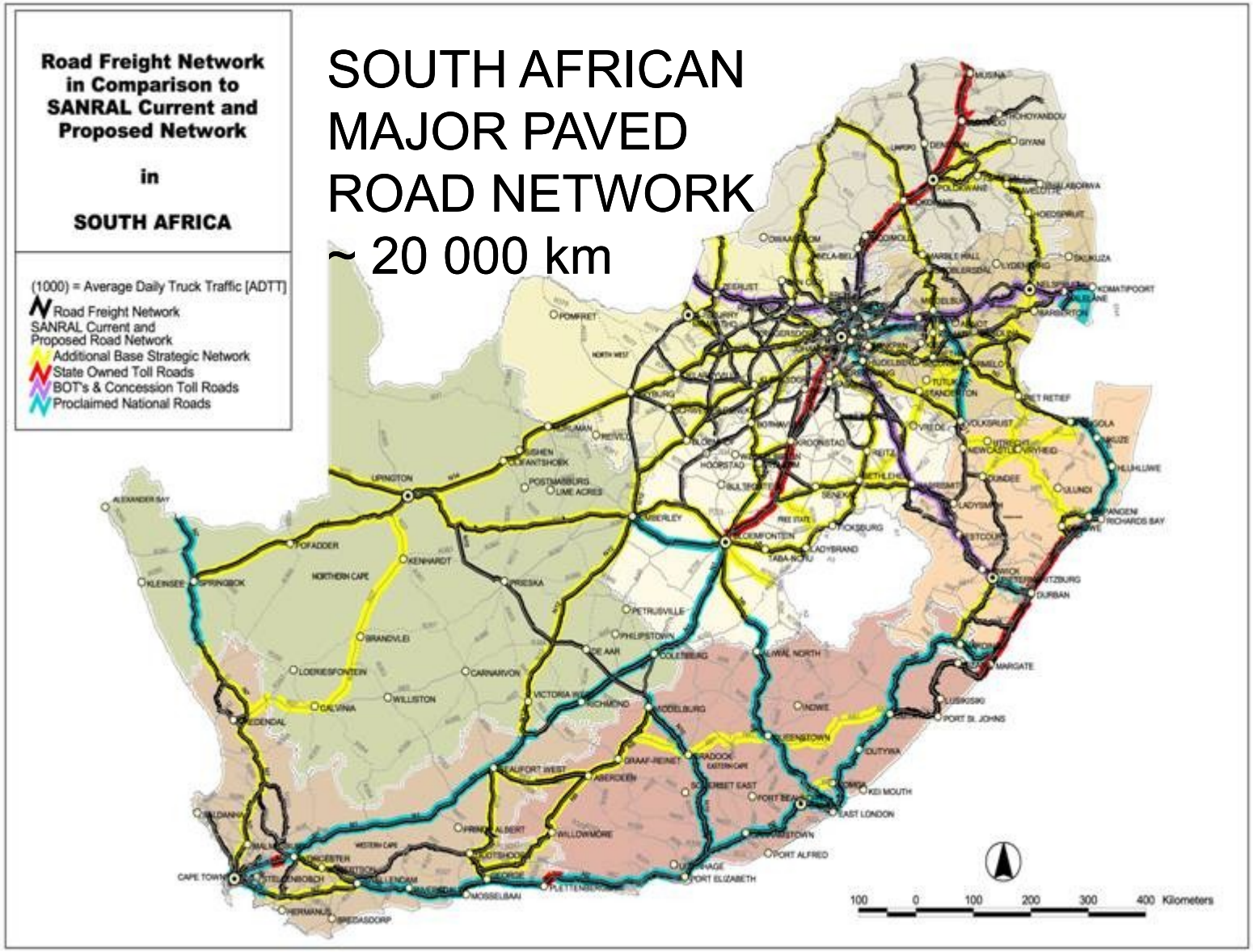
Assumption of Tyre Loading -Pavement Design Modeling:

- Circular;
- Variable load;
- Variable pressure,

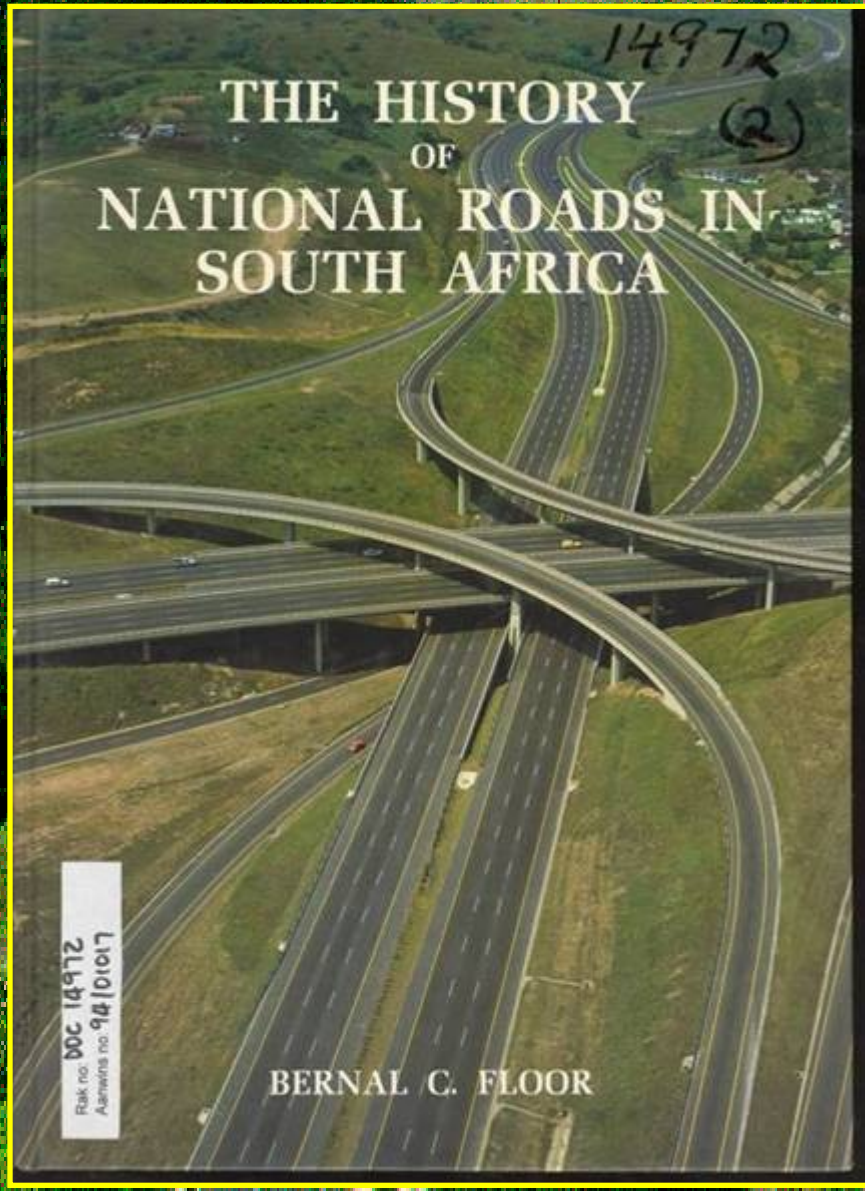
but UNIFORM:



SOUTH AFRICAN MAJOR PAVED ROAD NETWORK ~ 20 000 km



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




30 6 2004


VOLVO
VOLVO


30 6 2004


9 10 2003

Truck Tire Inflation Pressure in South Africa

~ 20 % Increase in 20 Years

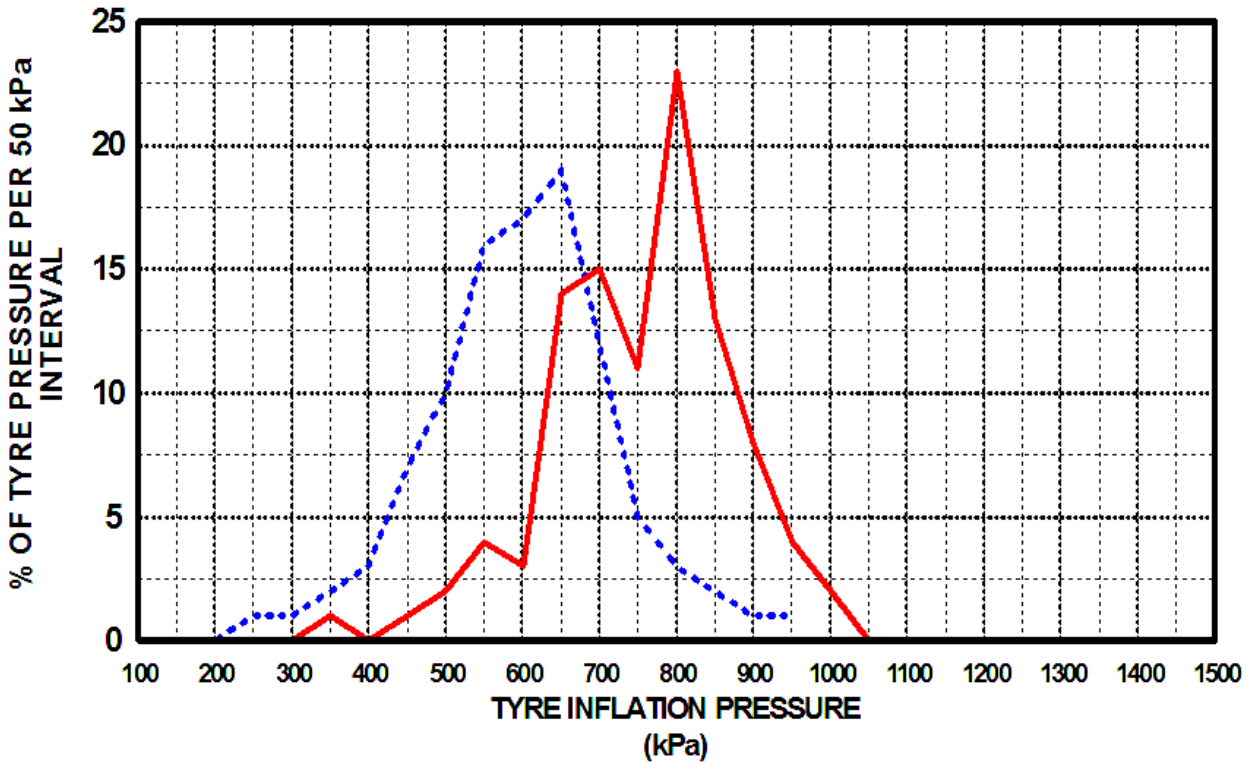
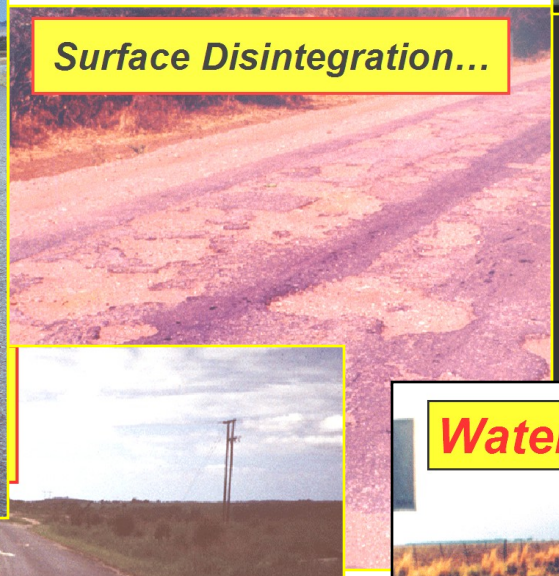


FIGURE 1

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



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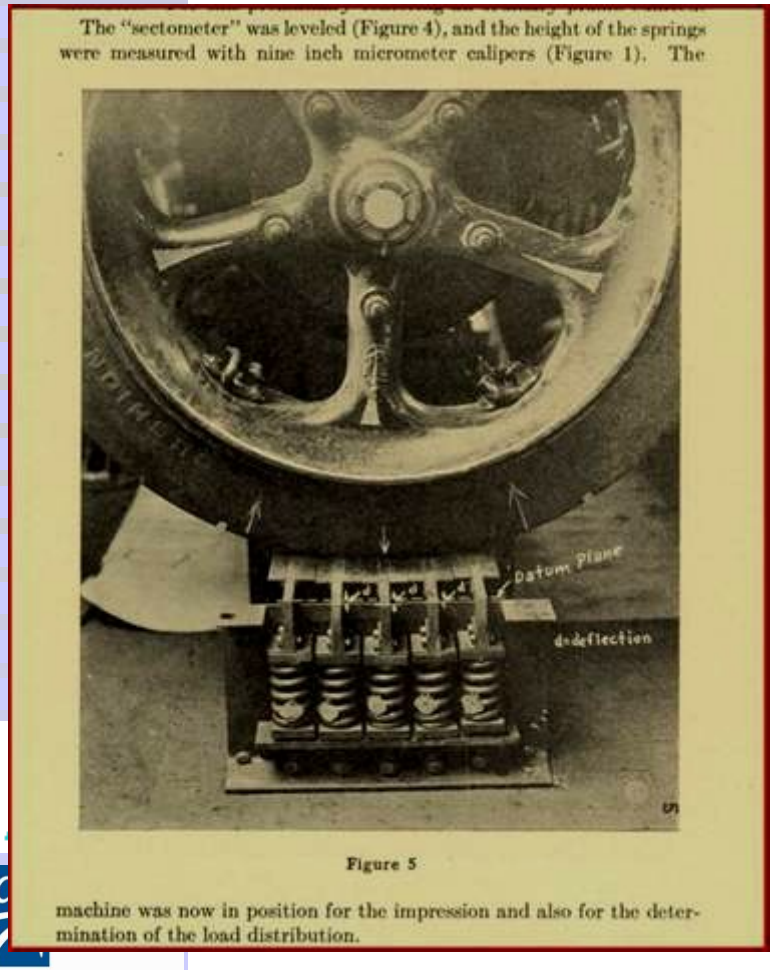
16 9 2004

”Sectometer”
S. Eckens, 1928

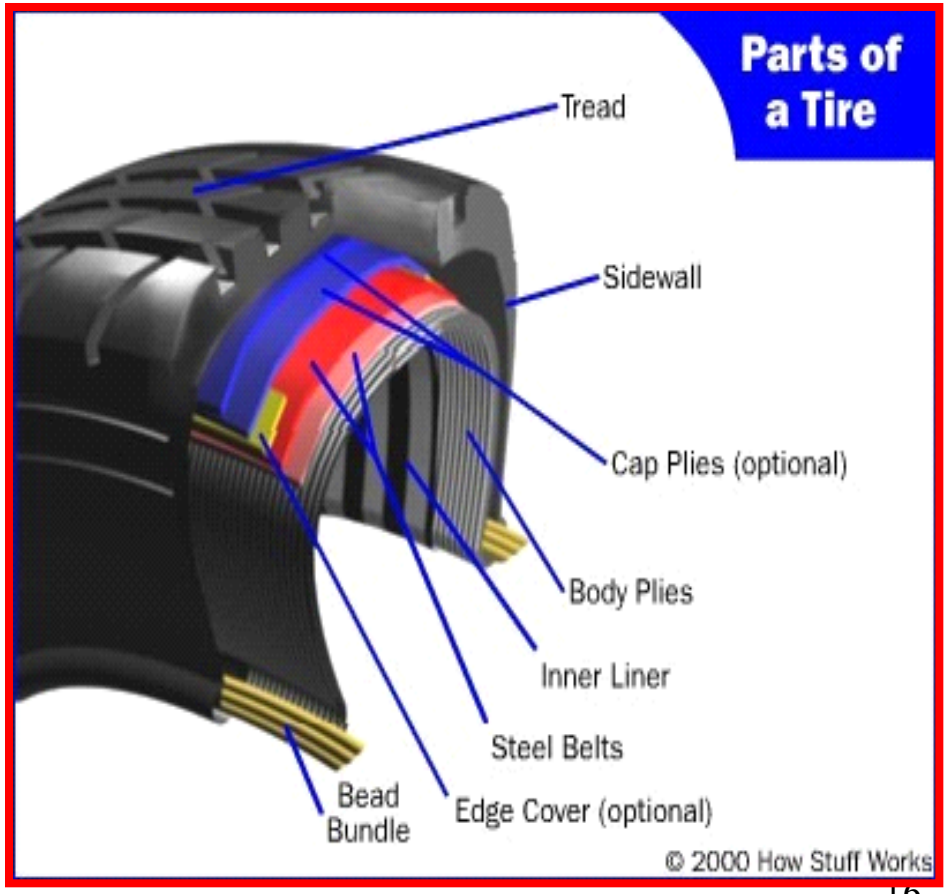


The "sectometer" was leveled (Figure 4), and the height of the springs were measured with nine inch micrometer calipers (Figure 1). The

Figure 5

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

Modern Tyre science…



Gautrans HVS Mark IV+

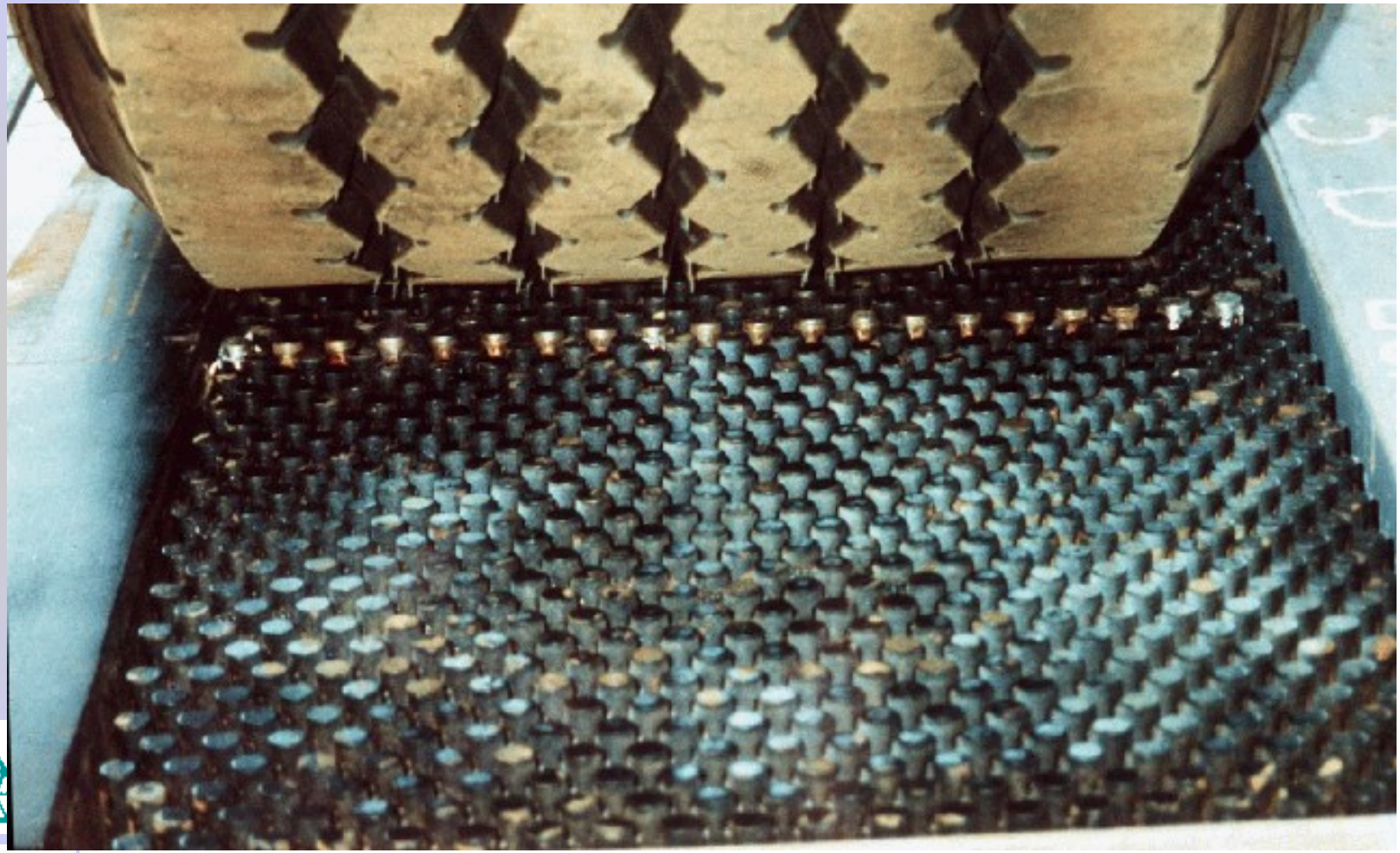
Stress - In - Motion (SIM) - SIM Mk II:
CSIR Transportek: '93-'95

315/80 HVS TYRE ON SIM Mk II SYSTEM

SINGLE SIM PAD FOR HVS TESTING

CSIR
TRANSPORTEK

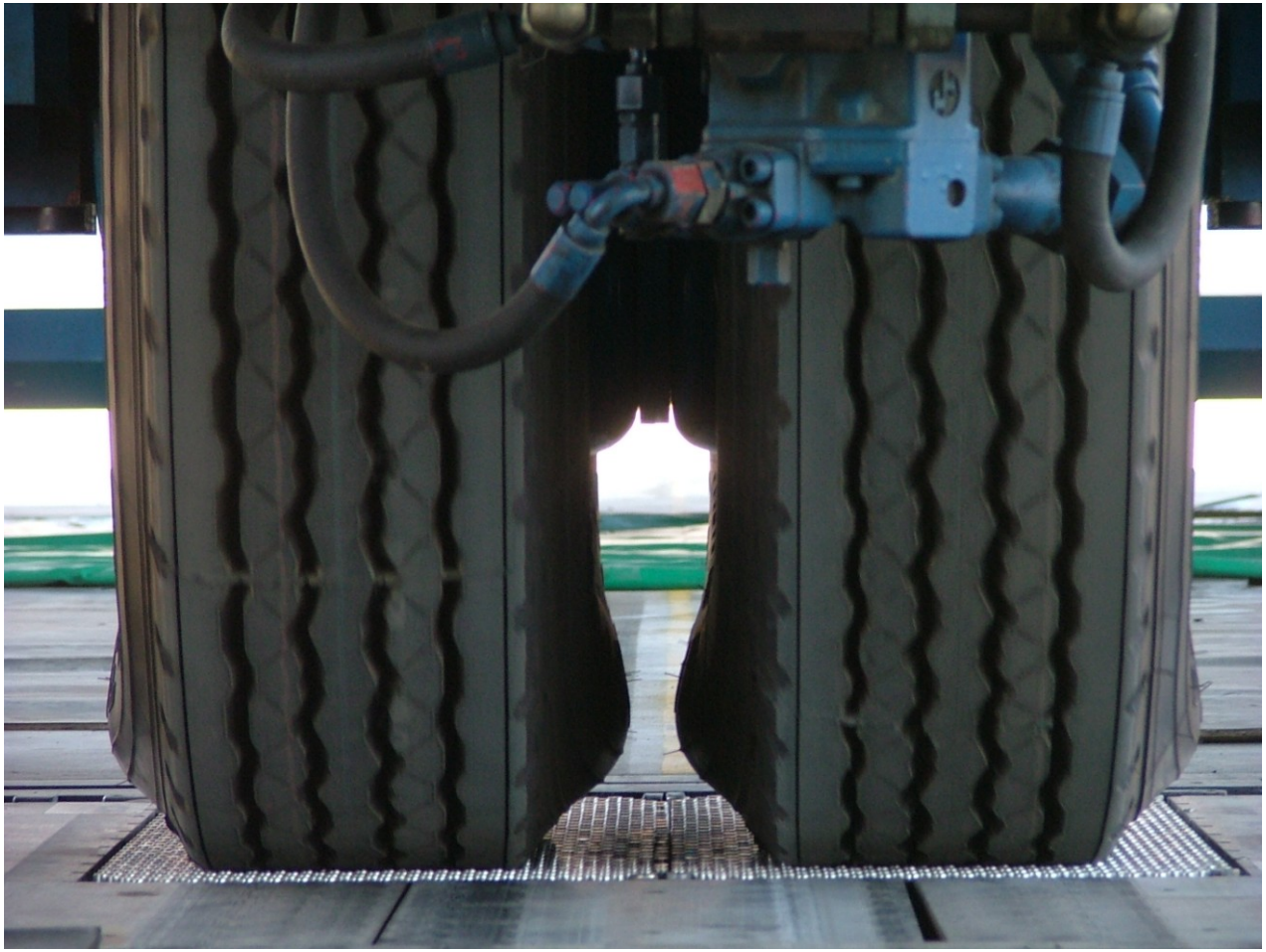
425 /65 R22.5 HVS TIRE ON SIM SYSTEM



STRESS-IN-MOTION TESTING USING THE HVS
Dual Load Configuration – Twin SIM pads

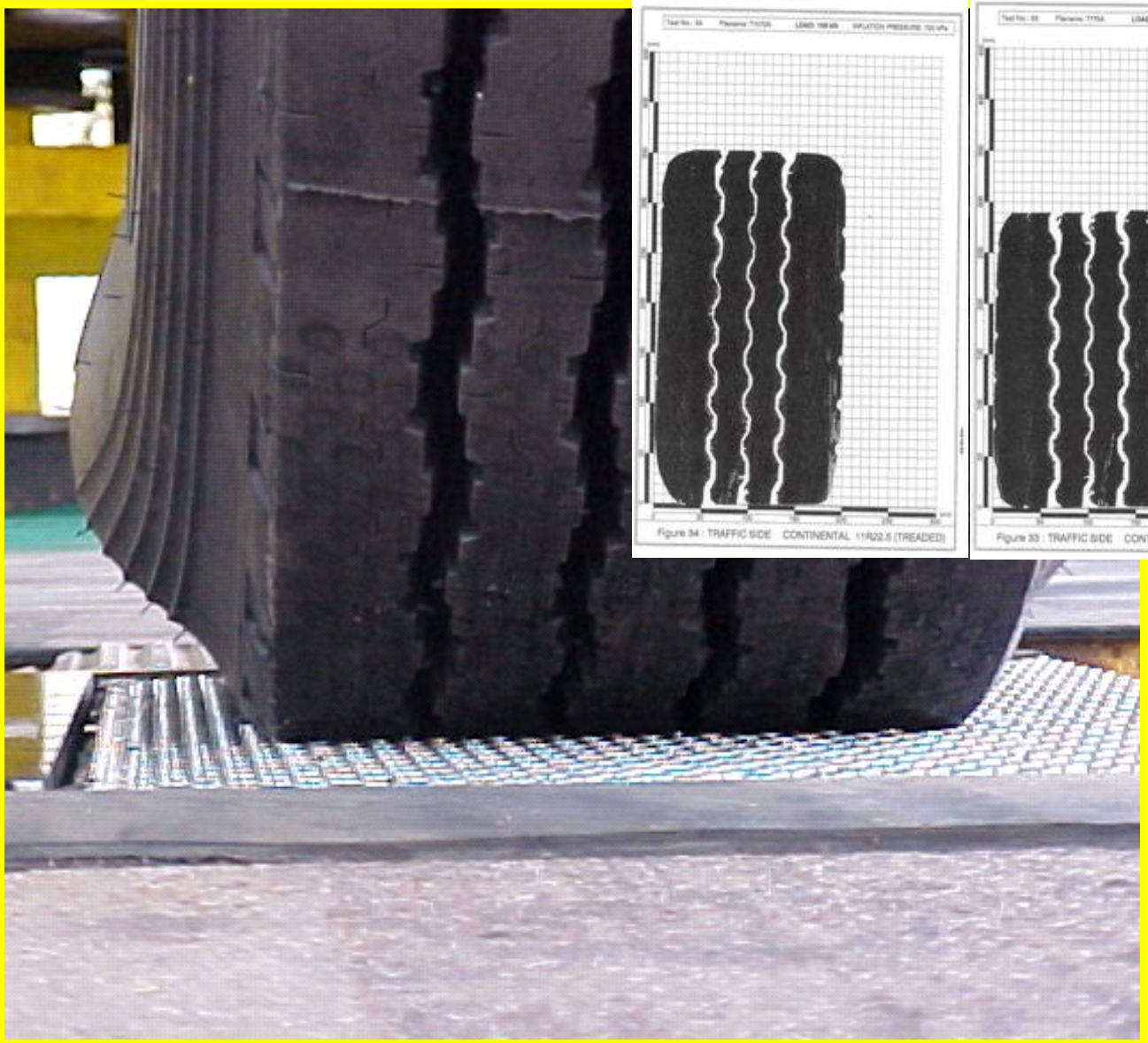
STRESS-IN-MOTION TESTING USING THE HVS

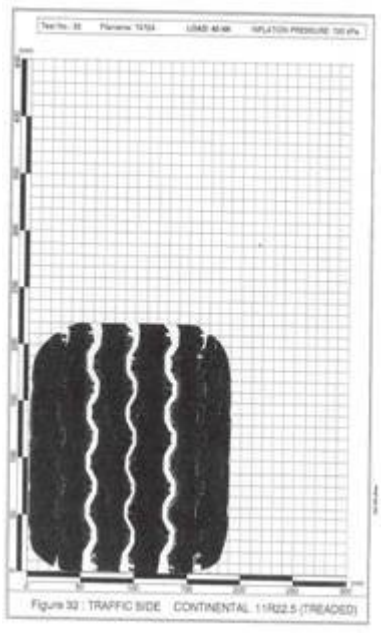
HEAVY VEHICLE SIMULATOR (HVS) DUAL TEST TYRES (12R22.5)



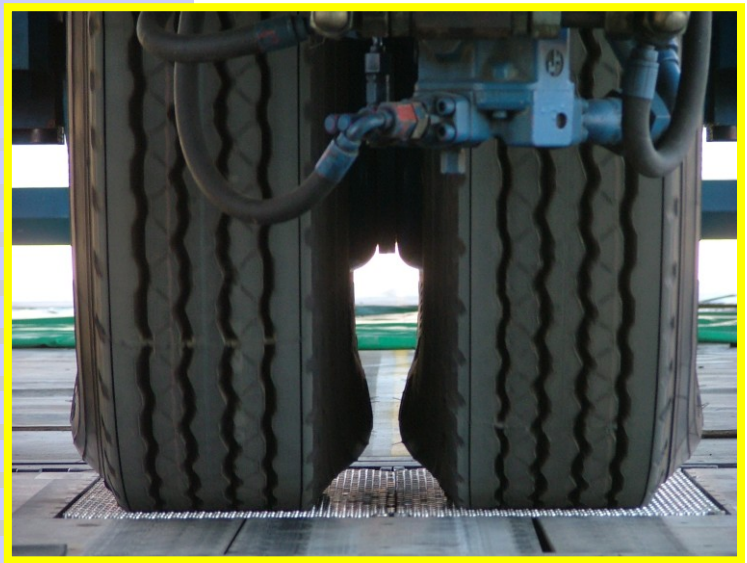
TYRE DEFLECTION & TYRE PRINTS – NB !

315/80 R22.5 HVS Tyre: Overloaded

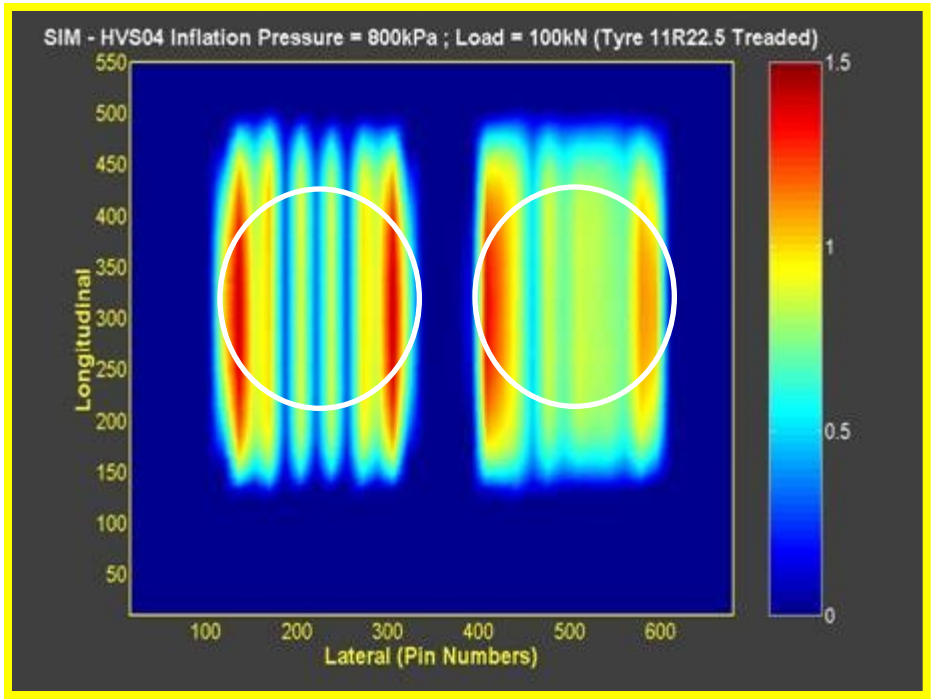


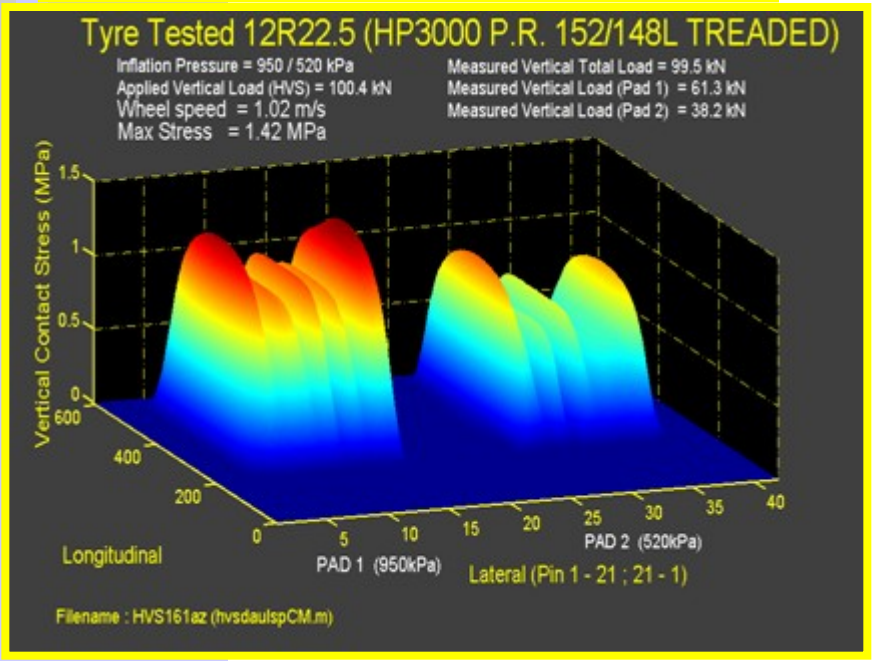


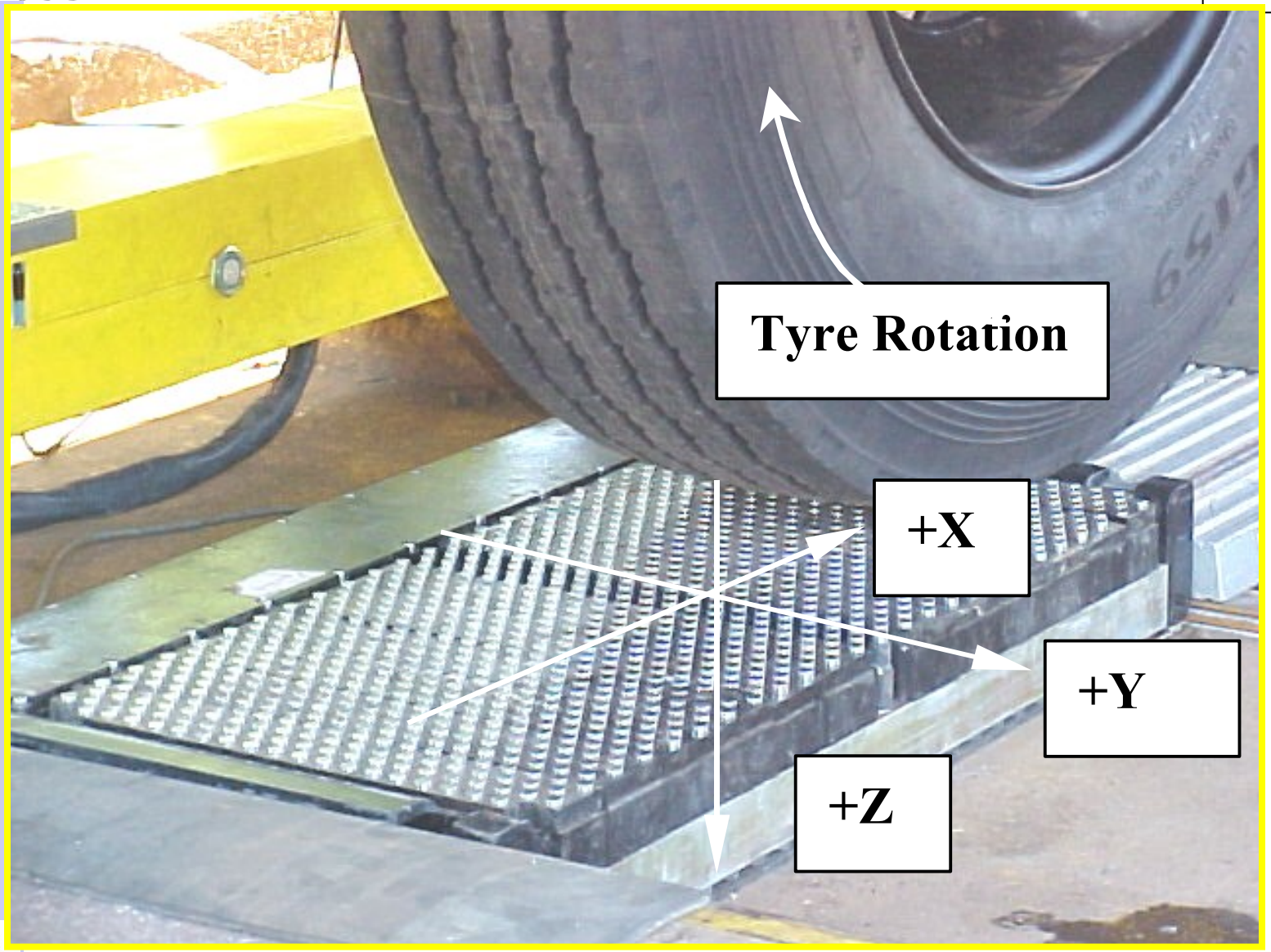
Overloading on Tyres:



Contact Patches: (square not circular)

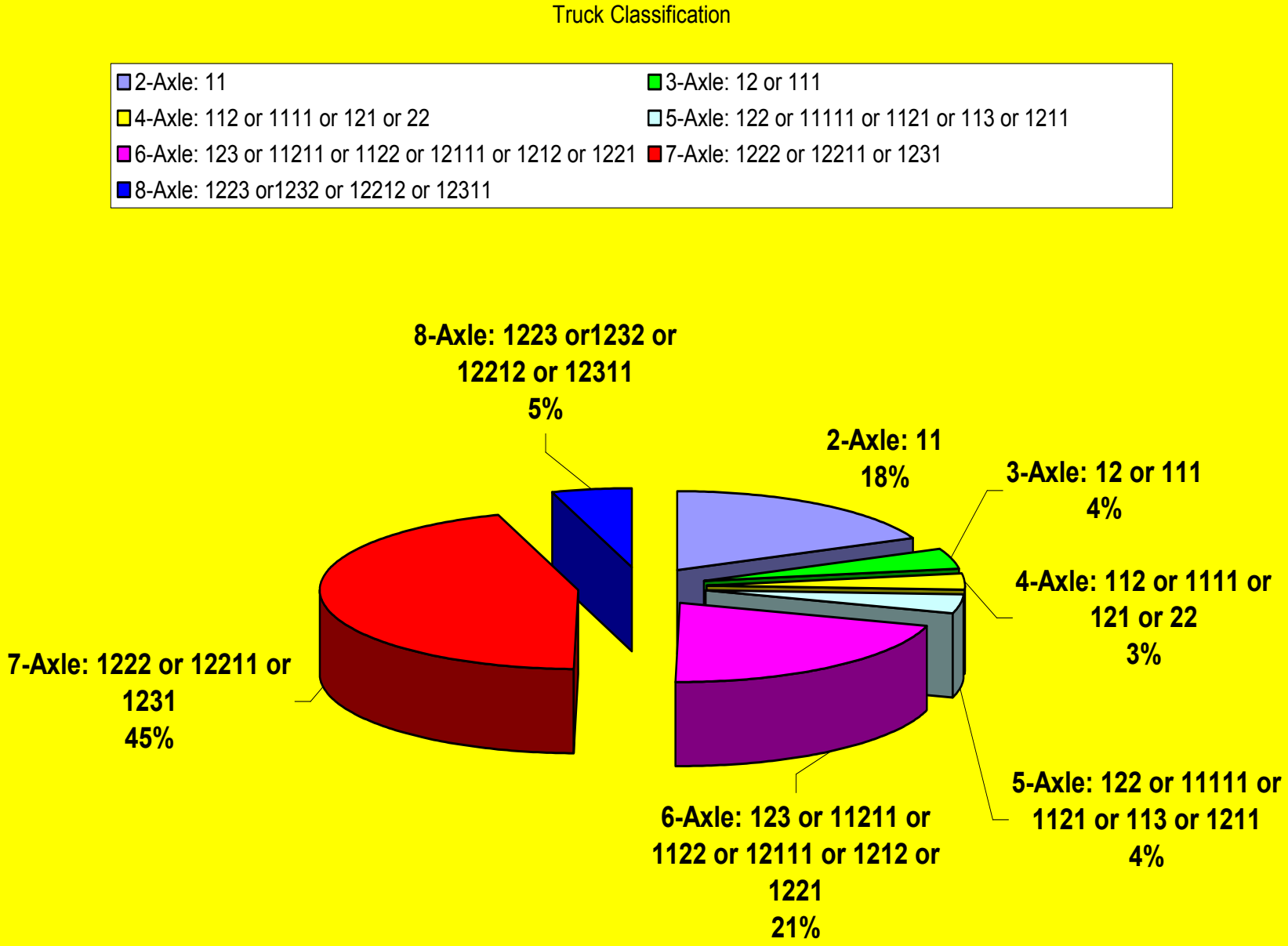





Tyre Rotation
+X
+Y
+Z

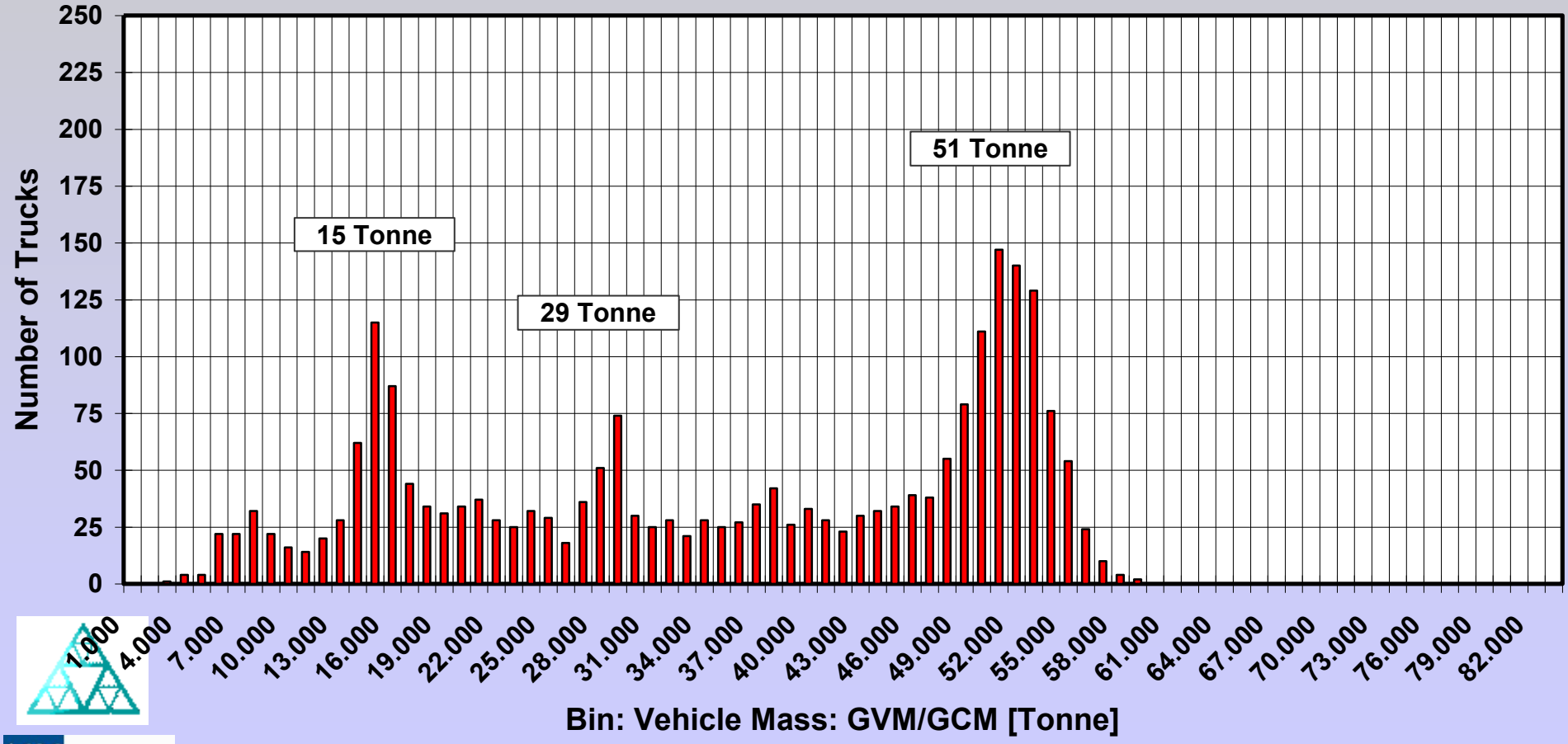
Vehicle-Tyre-Pavement Interaction:

STRESS-IN-MOTION
(SIM)
Technology – Since 1992-3

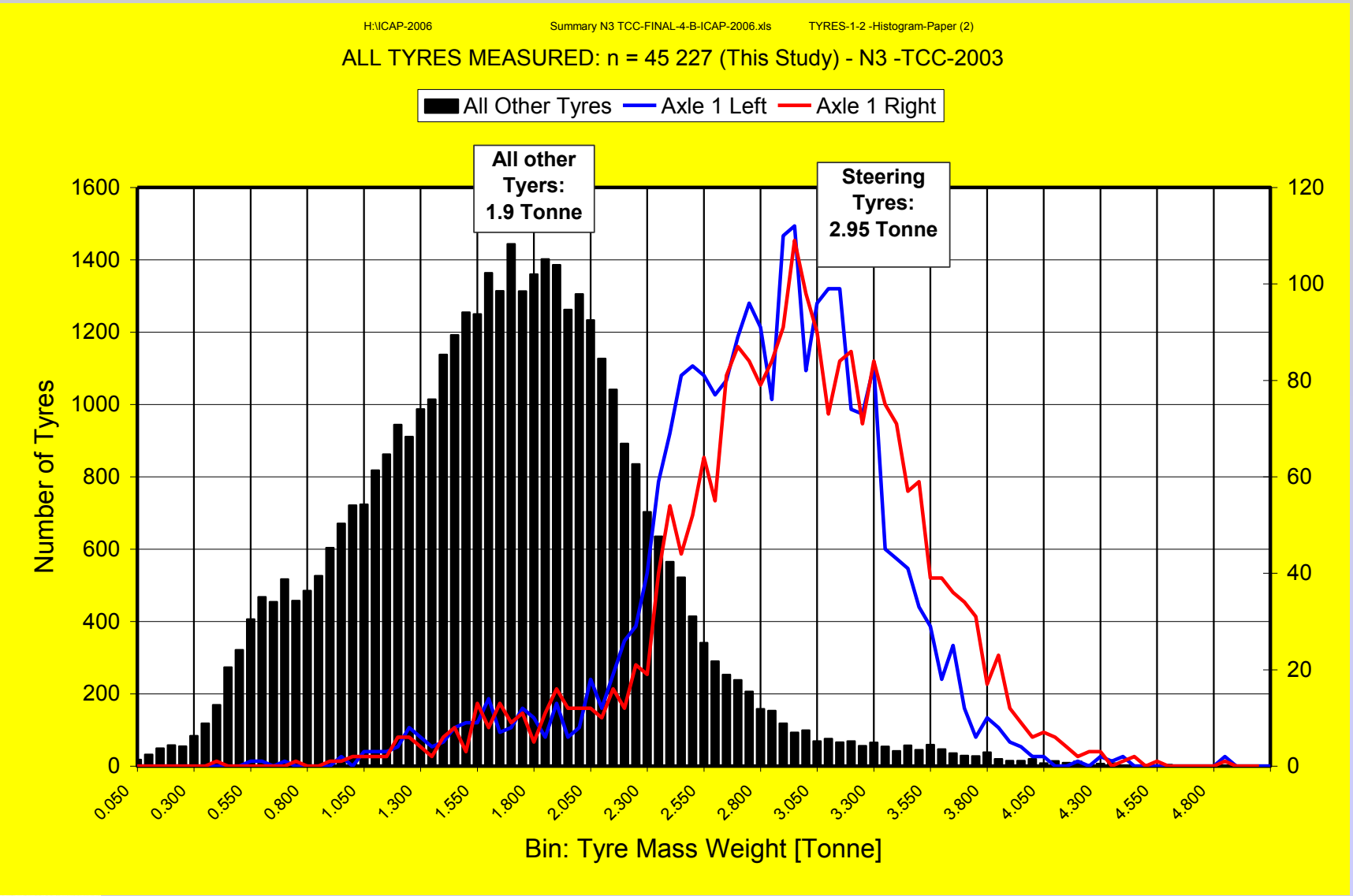

Truck Classification
2-Axle: 11
3-Axle: 12 or 111
4-Axle: 112 or 1111 or 121 or 22
5-Axle: 122 or 11111 or 1121 or 113 or 1211
6-Axle: 123 or 11211 or 1122 or 12111 or 1212 or 1221
7-Axle: 1222 or 12211 or 1231
8-Axle: 1223 or1232 or 12212 or 12311
8-Axle: 1223 or1232 or 12212 or 12311 5%
2-Axle: 11 18%
3-Axle: 12 or 111 4%
4-Axle: 112 or 1111 or 121 or 22 3%
7-Axle: 1222 or 12211 or 1231 45%
5-Axle: 122 or 11111 or 1121 or 113 or 1211 4%
6-Axle: 123 or 11211 or 1122 or 12111 or 1212 or 1221 21%

Quad (full) SIM pad configuration at a typical weighbridge site on National Road 3 (N3), near Heidelberg in Gauteng

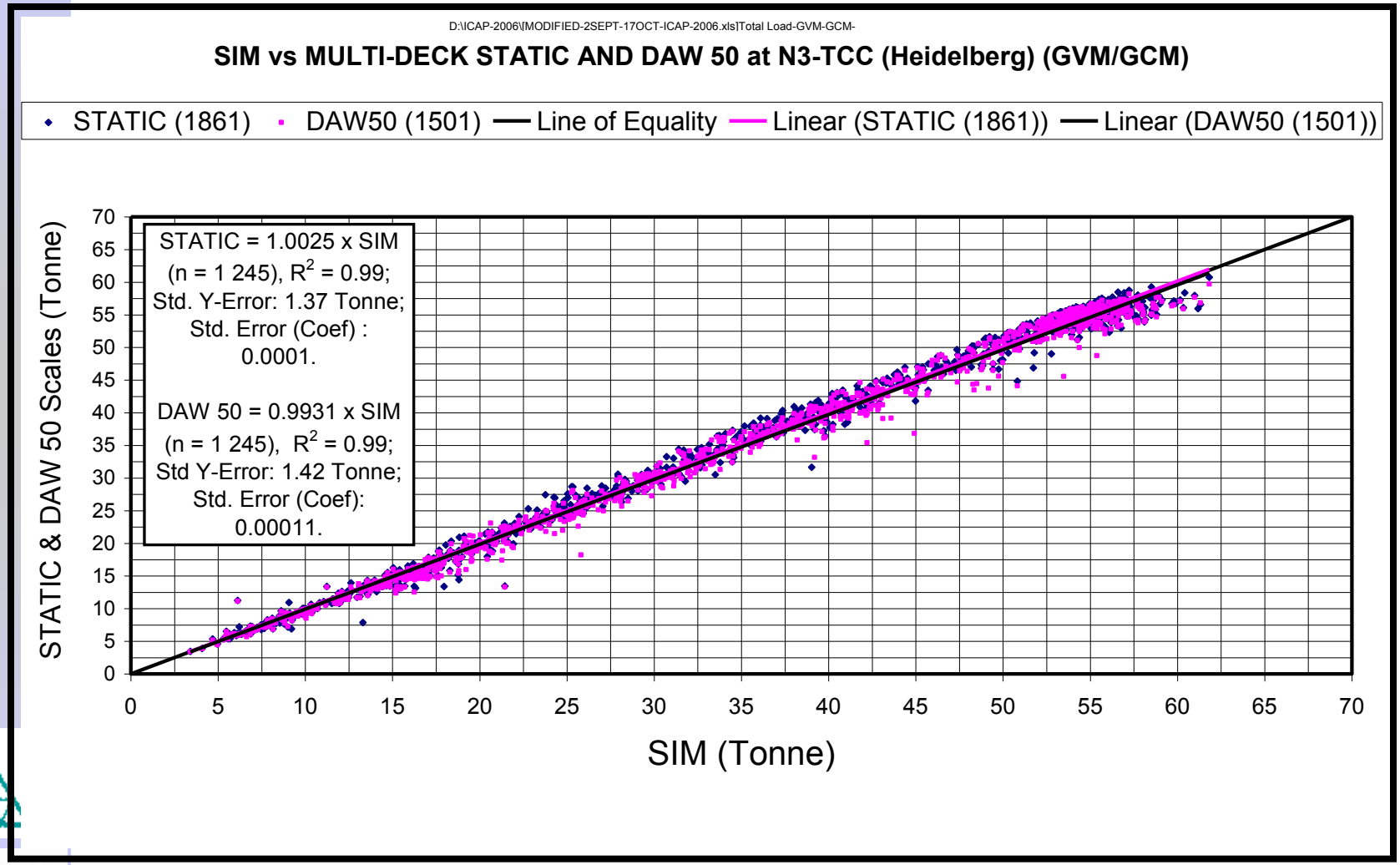
GVM/GCM-SIM N3 TCC - 2003
RESULT RATINGS 1 AND 2 (n = 2 297)
[2 Sept - 17 Oct 2003]



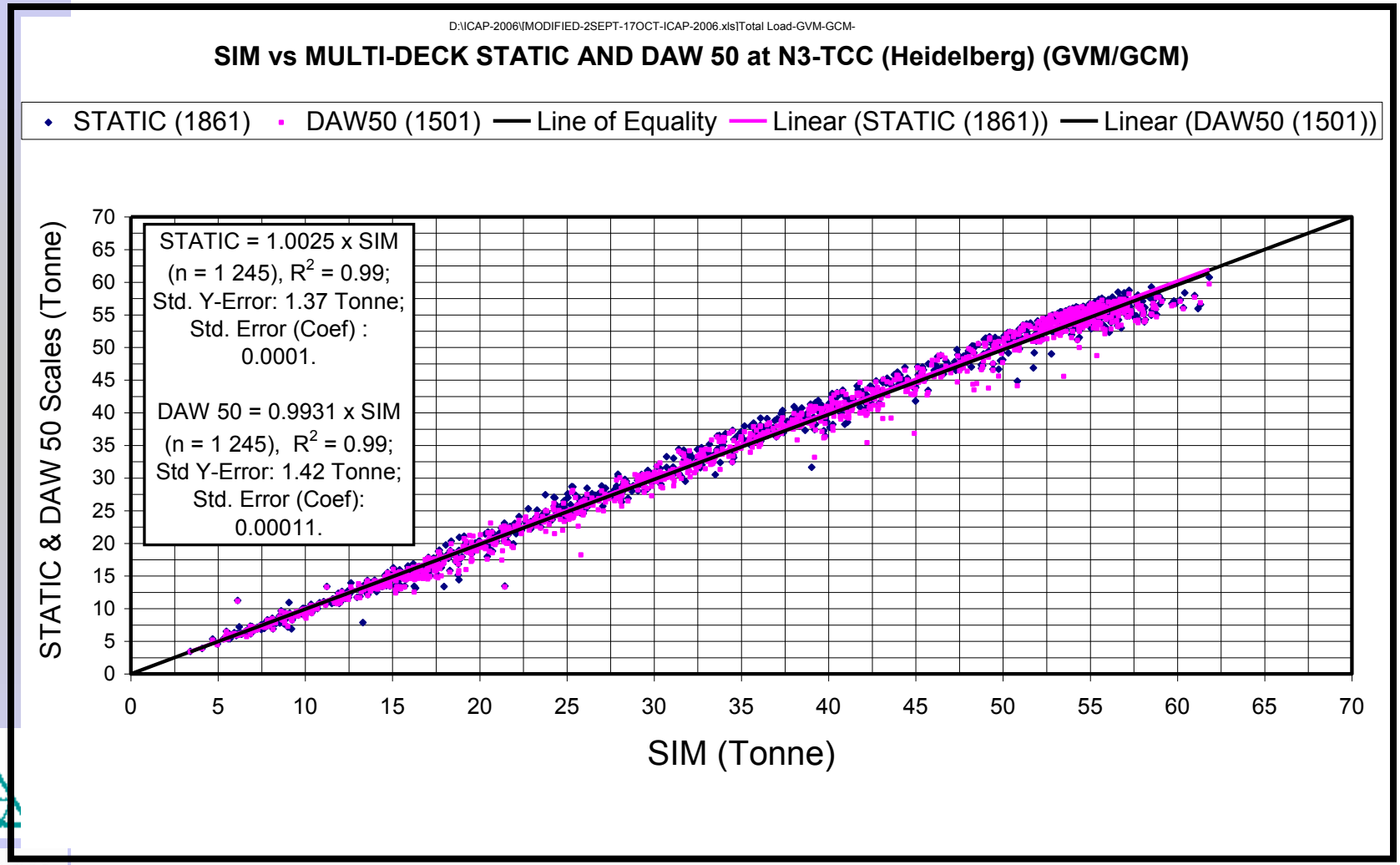
Axle Load Distributions – N3- 2003



LOAD COMPARISON – FIELD WITH REAL TRUCKS
N3 TCC - HEIDELBERG



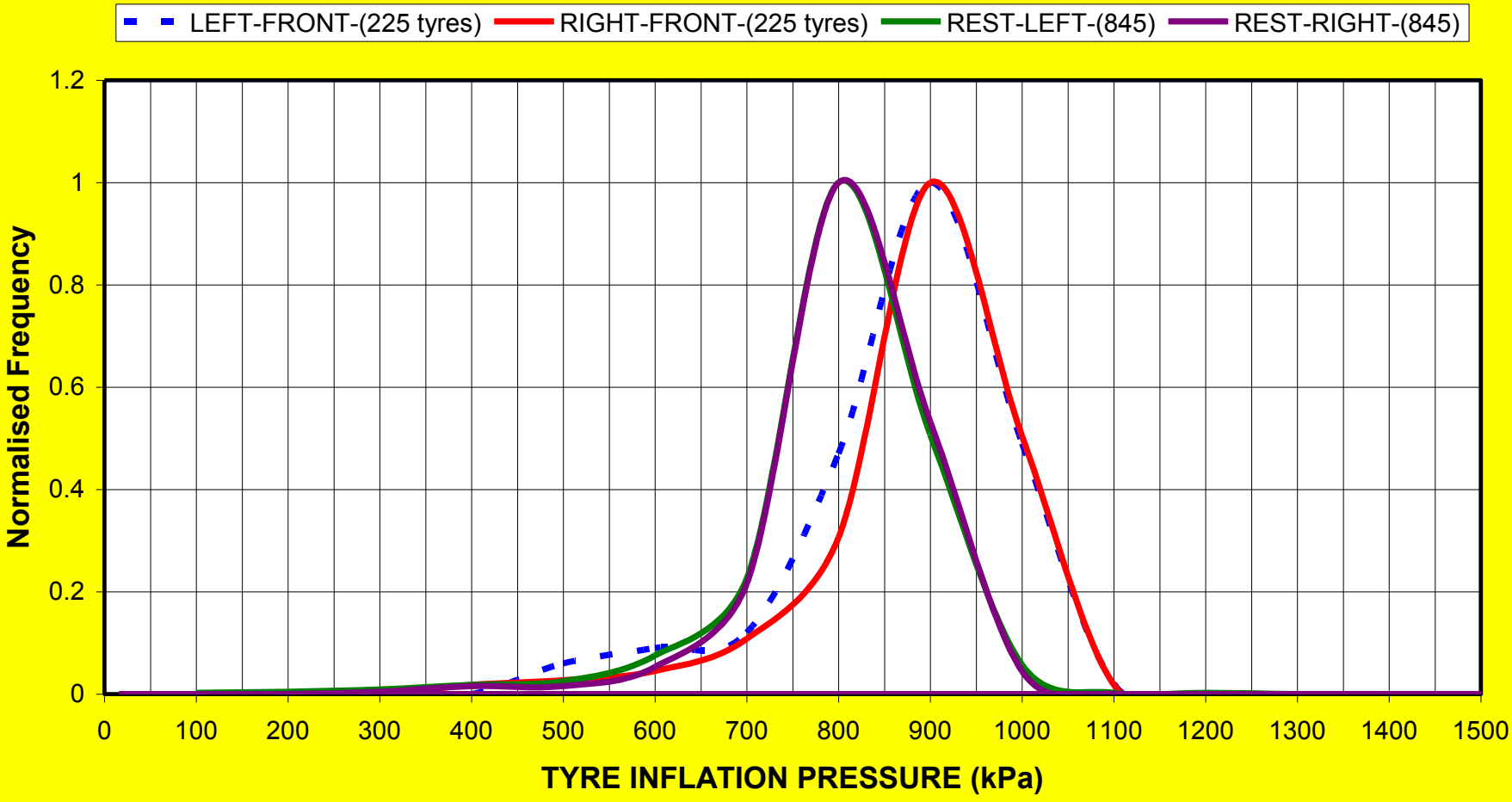
LOAD COMPARISON – FIELD WITH REAL TRUCKS
N3 TCC - HEIDELBERG



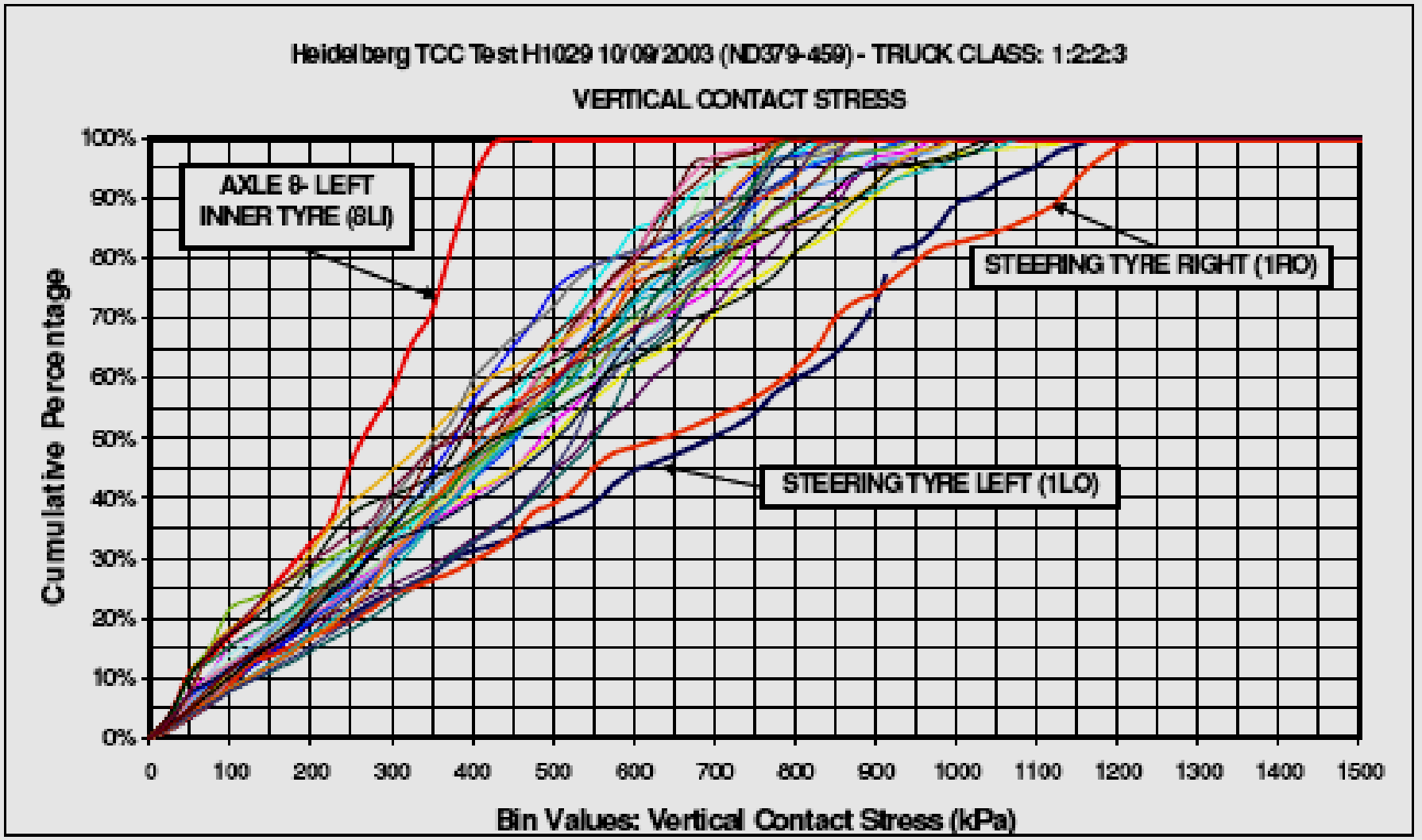
Tyre Inflation Pressure Distributions – N3- 2003

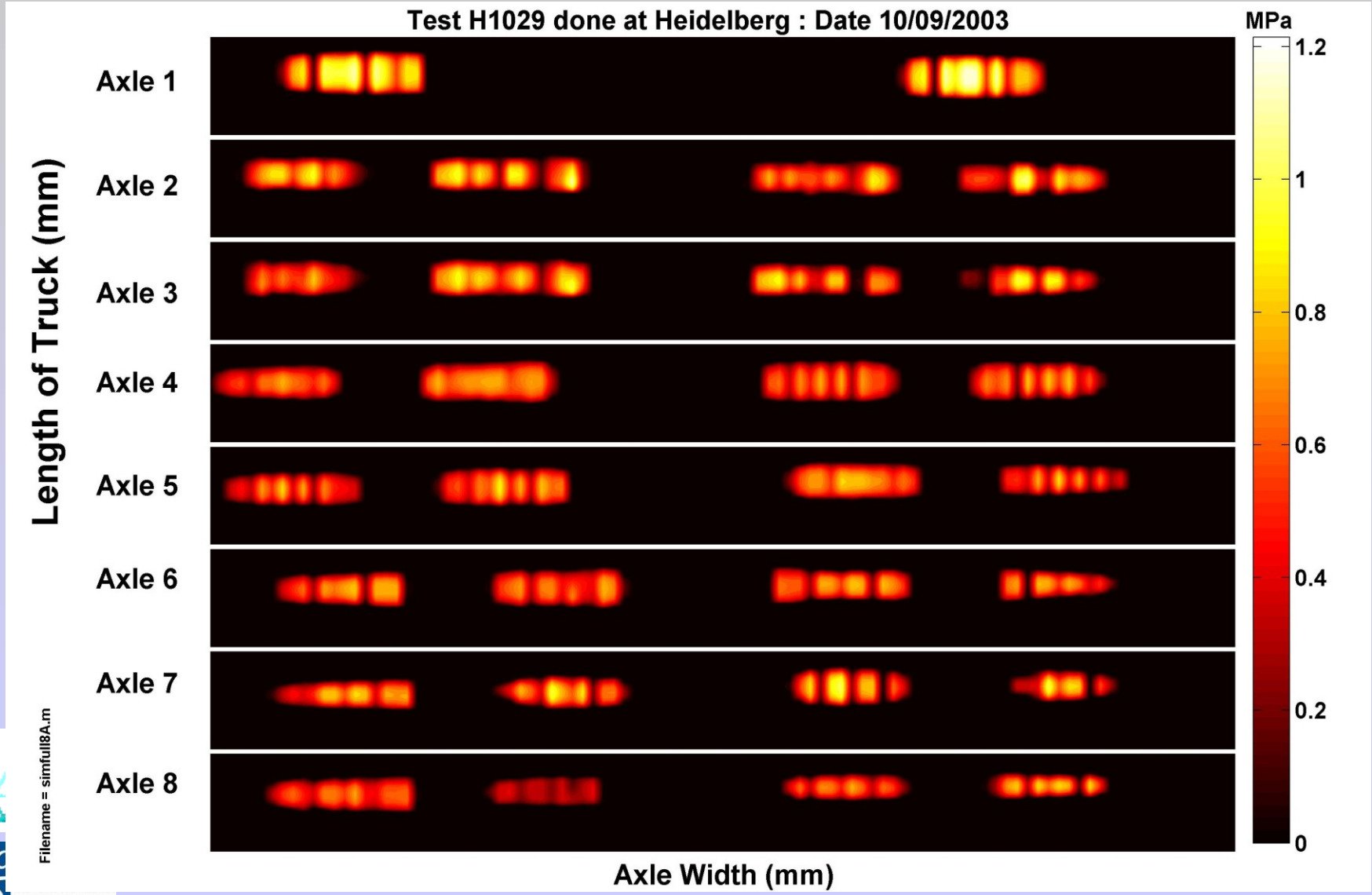
H:\CAPSA04\[Tyre Inflation Pressure Information-MORTON-MDB-

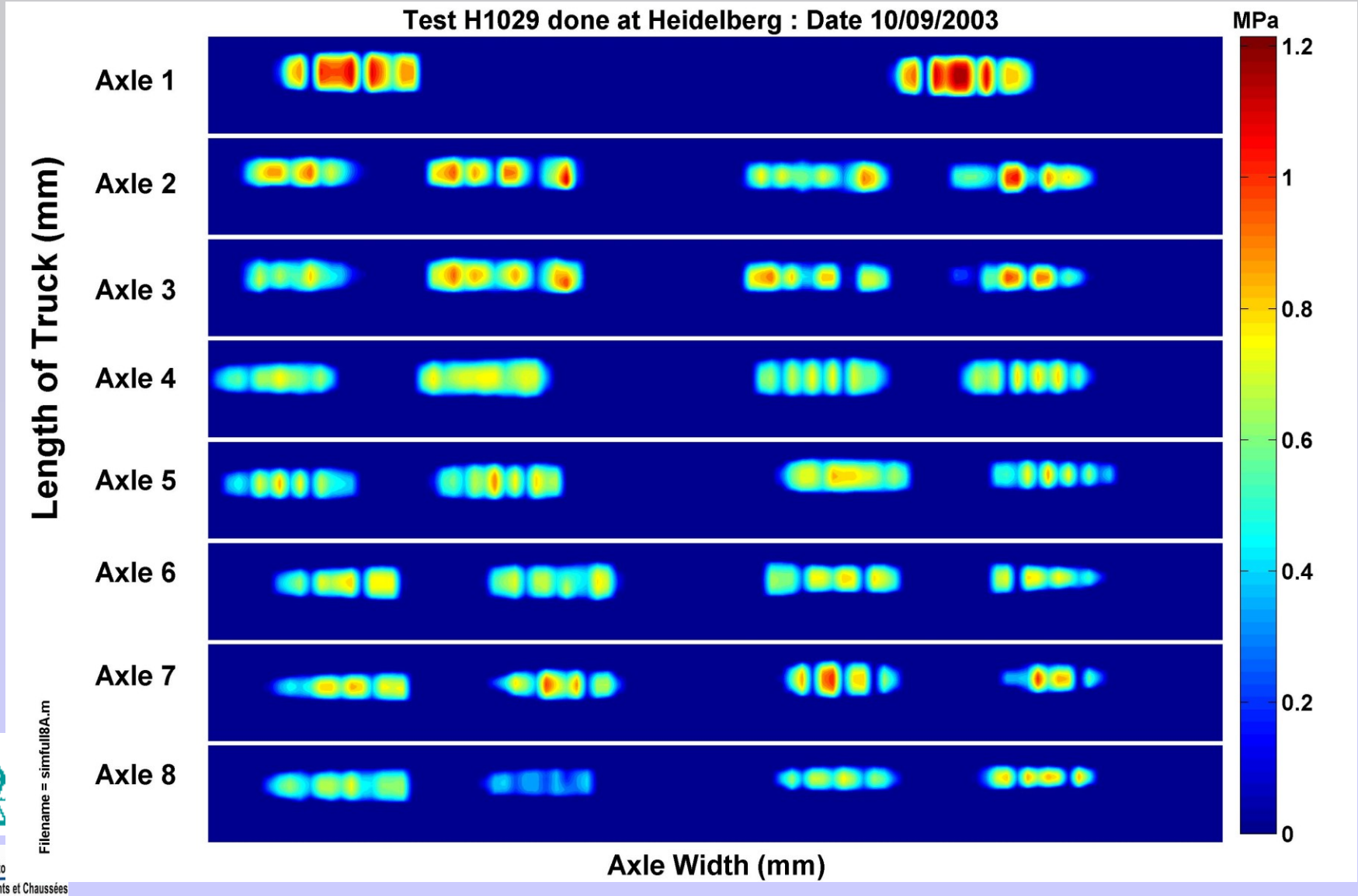
N3 TCC - SELECTED HEAVY VEHICLE (HV) TRUCK TYRE PRESSURE DATA
(26 Feb 2003 - 06 March 2003)

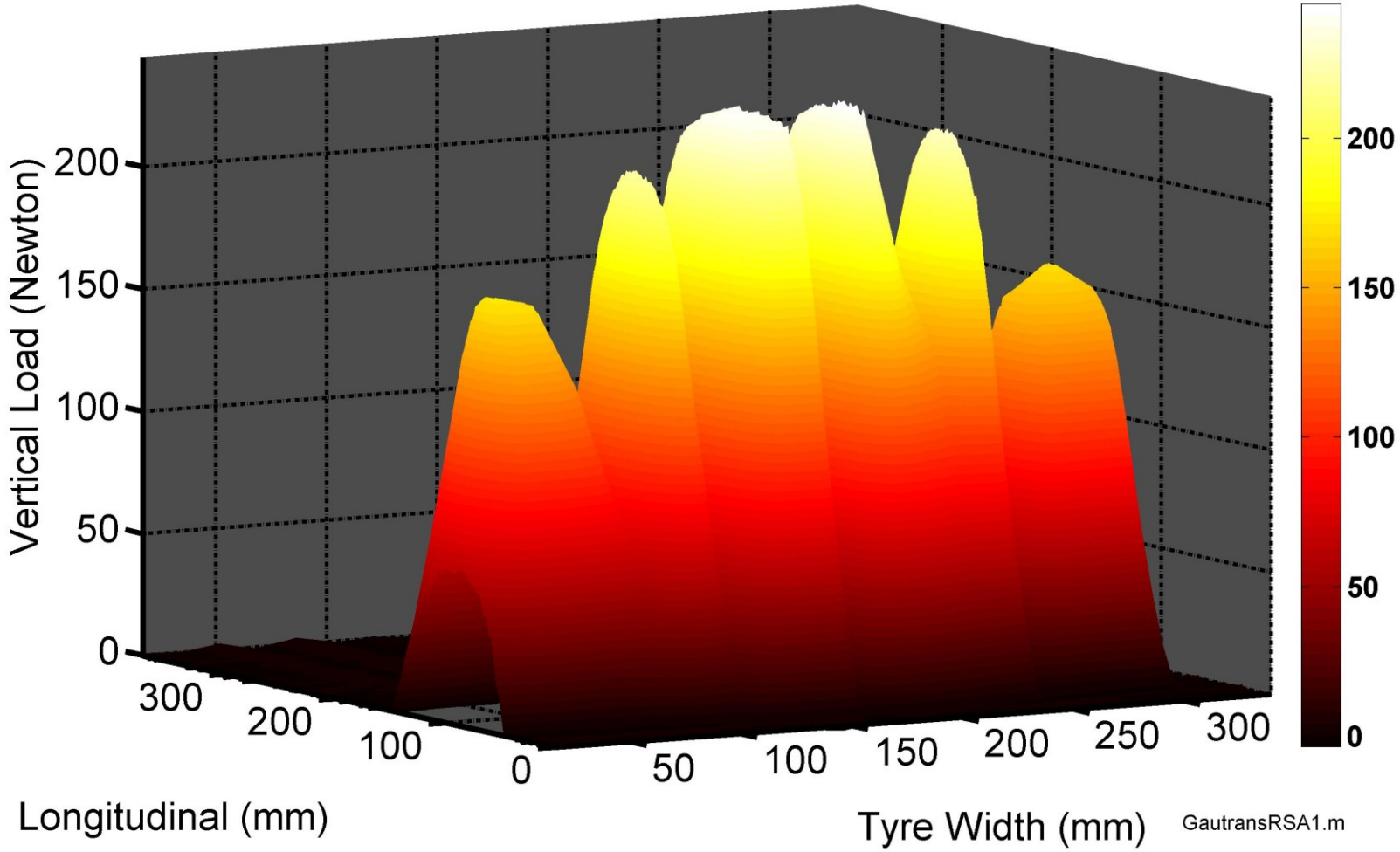


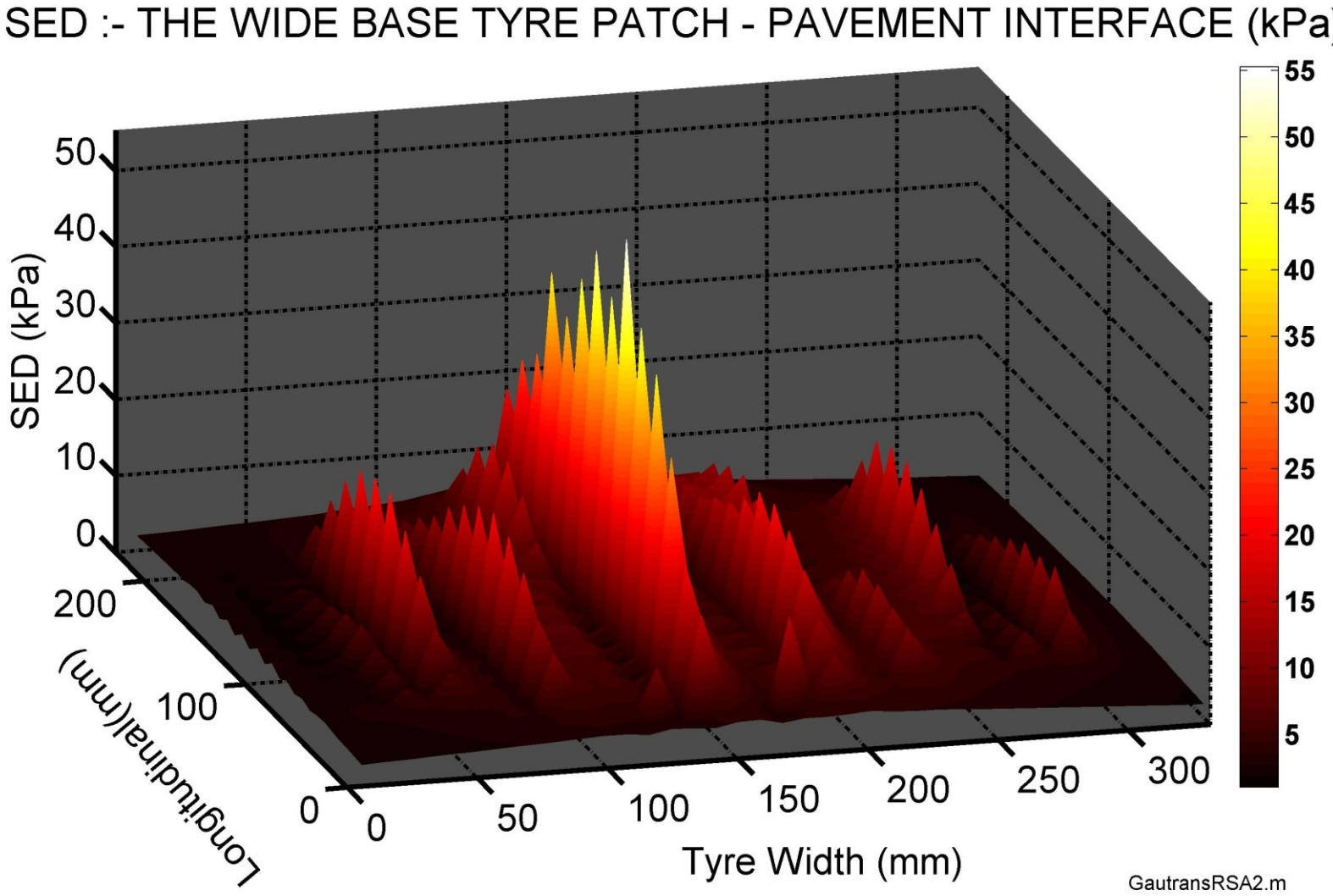
Vertical Stress Cumulative Frequency – N3- 2003



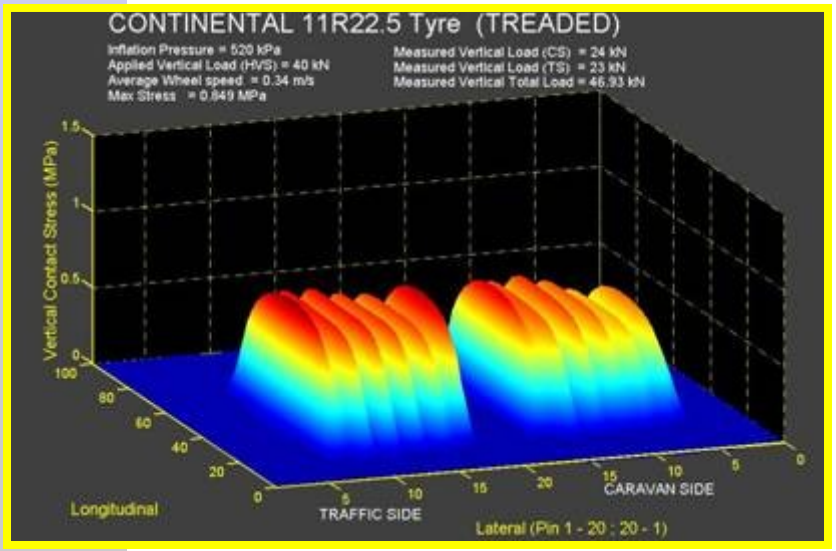

Test H1029 done at Heidelberg : Date 10/09/2003
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Axle 7
Axle 8
Length of Truck (mm)
Axle Width (mm)
Filename = simfull8A.m
MPa
1.2
1
0.8
0.6
0.4
0.2
0

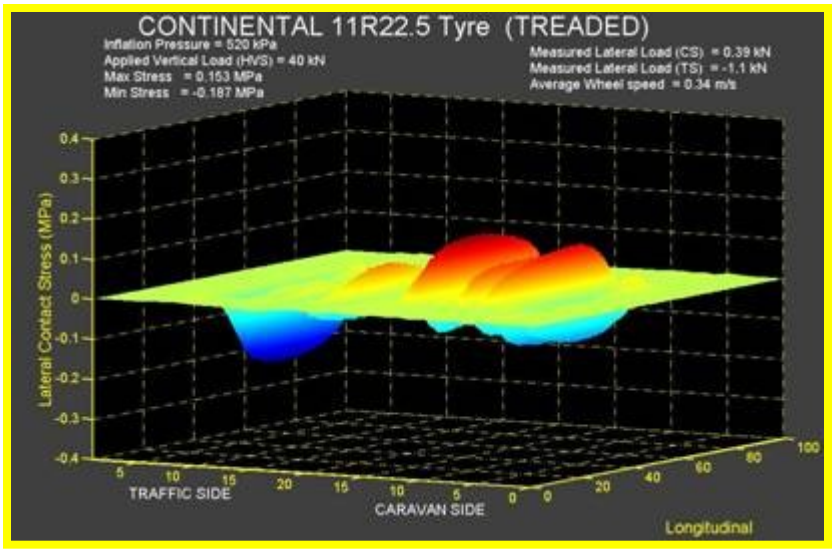

Test H1029 done at Heidelberg : Date 10/09/2003
MPa
1.2
1
0.8
0.6
0.4
0.2
0
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Axle 7
Axle 8
Length of Truck (mm)
Axle Width (mm)
Filename = simfull8A.m


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)
200
150
100
50
0
GautransRSA1.m

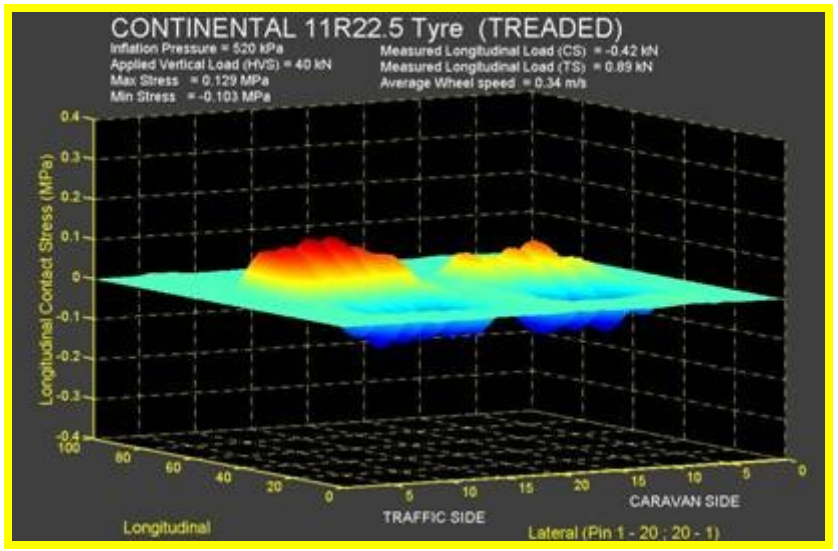

SED :- THE WIDE BASE TYRE PATCH - PAVEMENT INTERFACE (kPa)
SED (kPa)
50
40
30
20
10
0
Longitudinal(mm)
200
100
0
0
50
100
150
200
250
300
Tyre Width (mm)
55
50
45
40
35
30
25
20
15
10
5
GautransRSA2.m

Dual Tyre: 3D-Contact Stresses (Pressure)





Stress Ratio: 10:3:1



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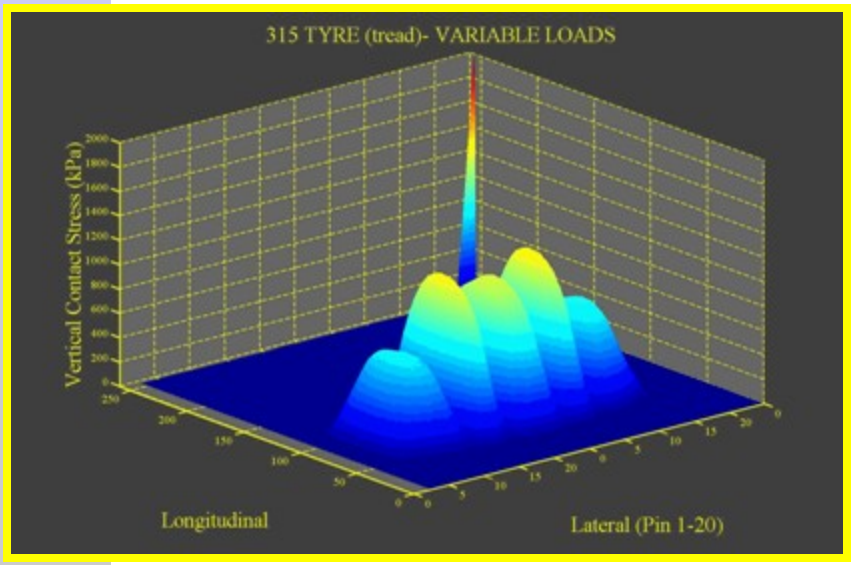
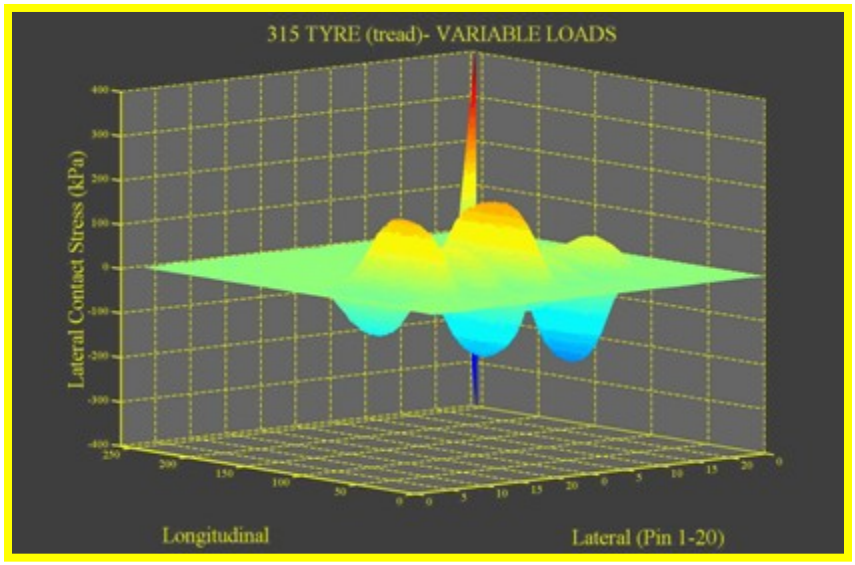
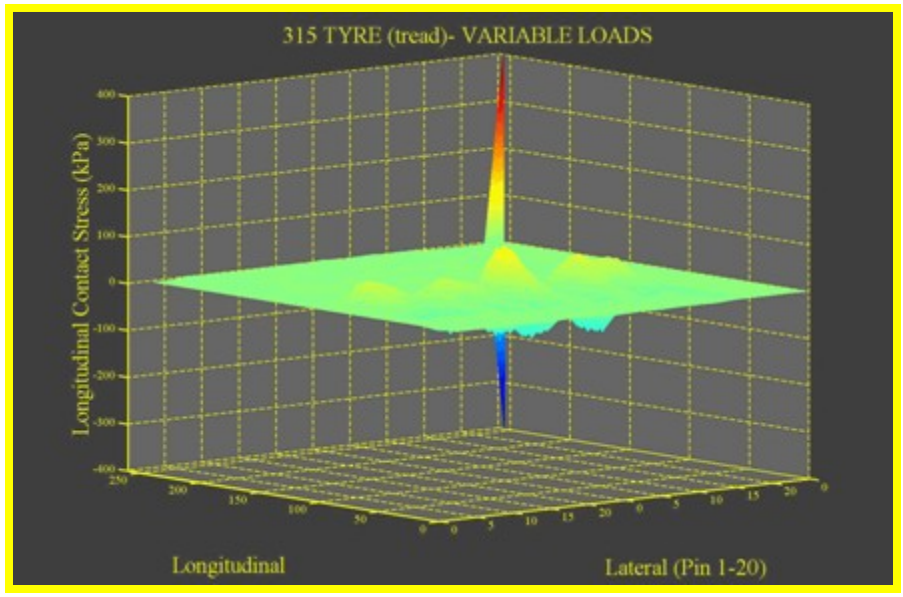
L'esprit de recherche au cœur des réseaux

Typical SIM 3D Data Sets - Variable loading:

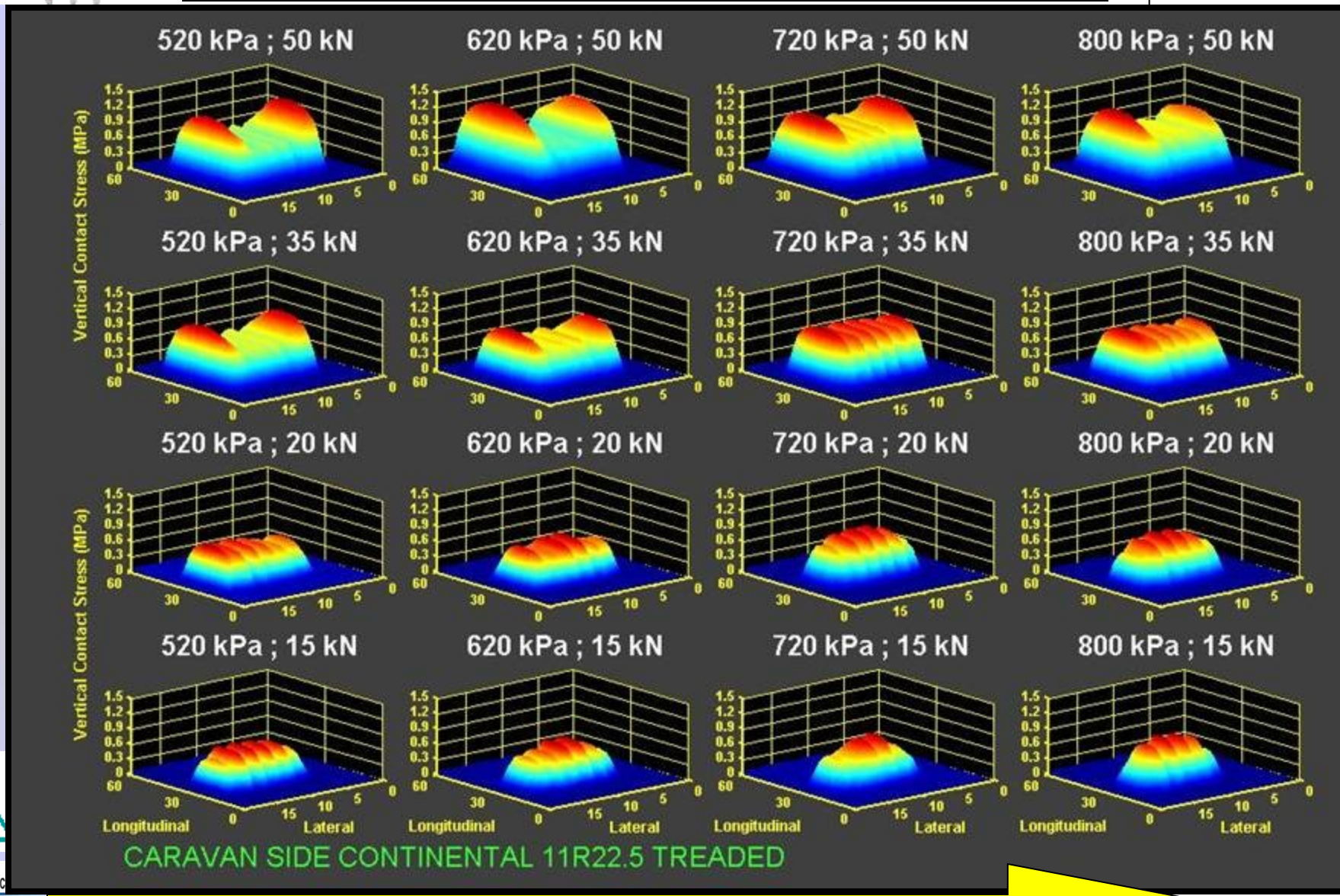






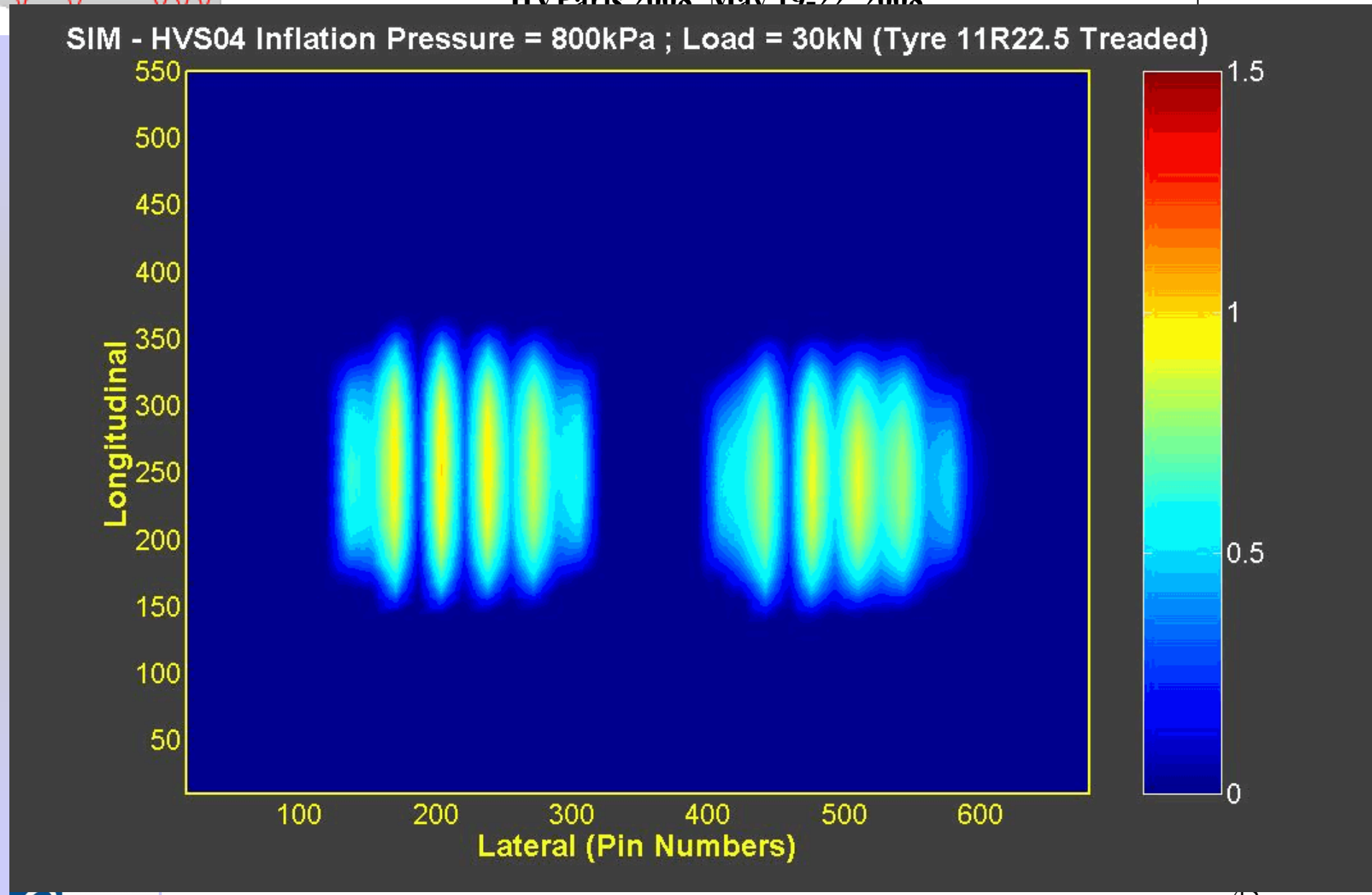
3D – Z,X,Y - Contact Stresses: Variable loads: 315/80 R22.5 Tire

TYRE "FINGER PRINTING" (HVS SIM: 11R22.5 TYRE)



LOAD

INFLATION PRESSURE



STRESS-IN-MOTION (SIM) TESTING ON N3 - FREEWAY

Quad (full) SIM pad configuration at a typical weighbridge site on National Road 3 (N3), near Heidelberg in Gauteng

SIM In operation – N3-TCC …….

DAW 50 SCALE - National Road 3 (N3), near Heidelberg in Gauteng

MULTI-DECK SCALE - National Road 3 (N3), near Heidelberg in Gauteng

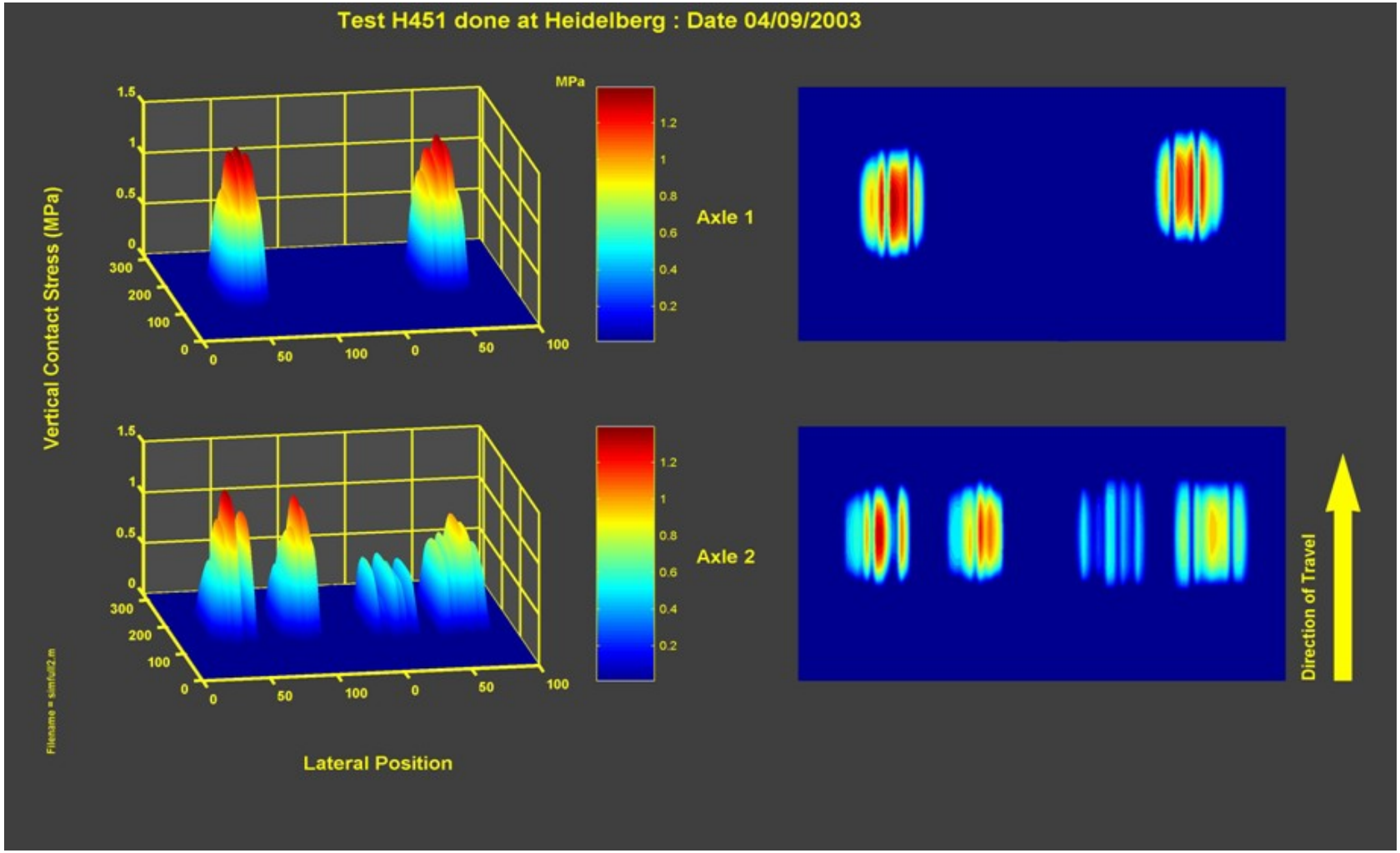
Quad (full) SIM pad configuration at a typical weighbridge site on National Road 3 (N3), near Heidelberg in Gauteng

SIM Measurement: N3

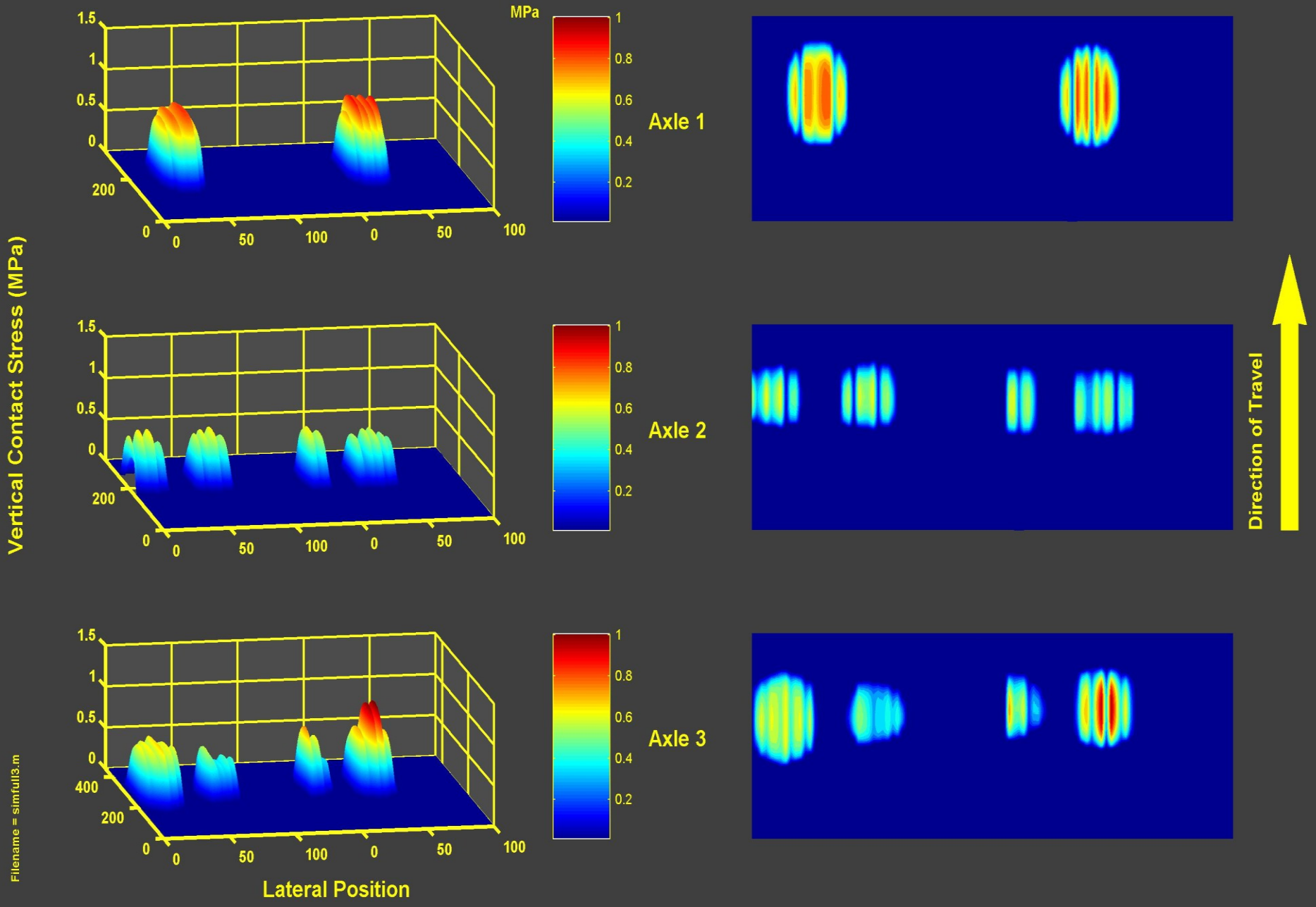
"1232" Tanker

In operation – SIM N3 -TCC …….

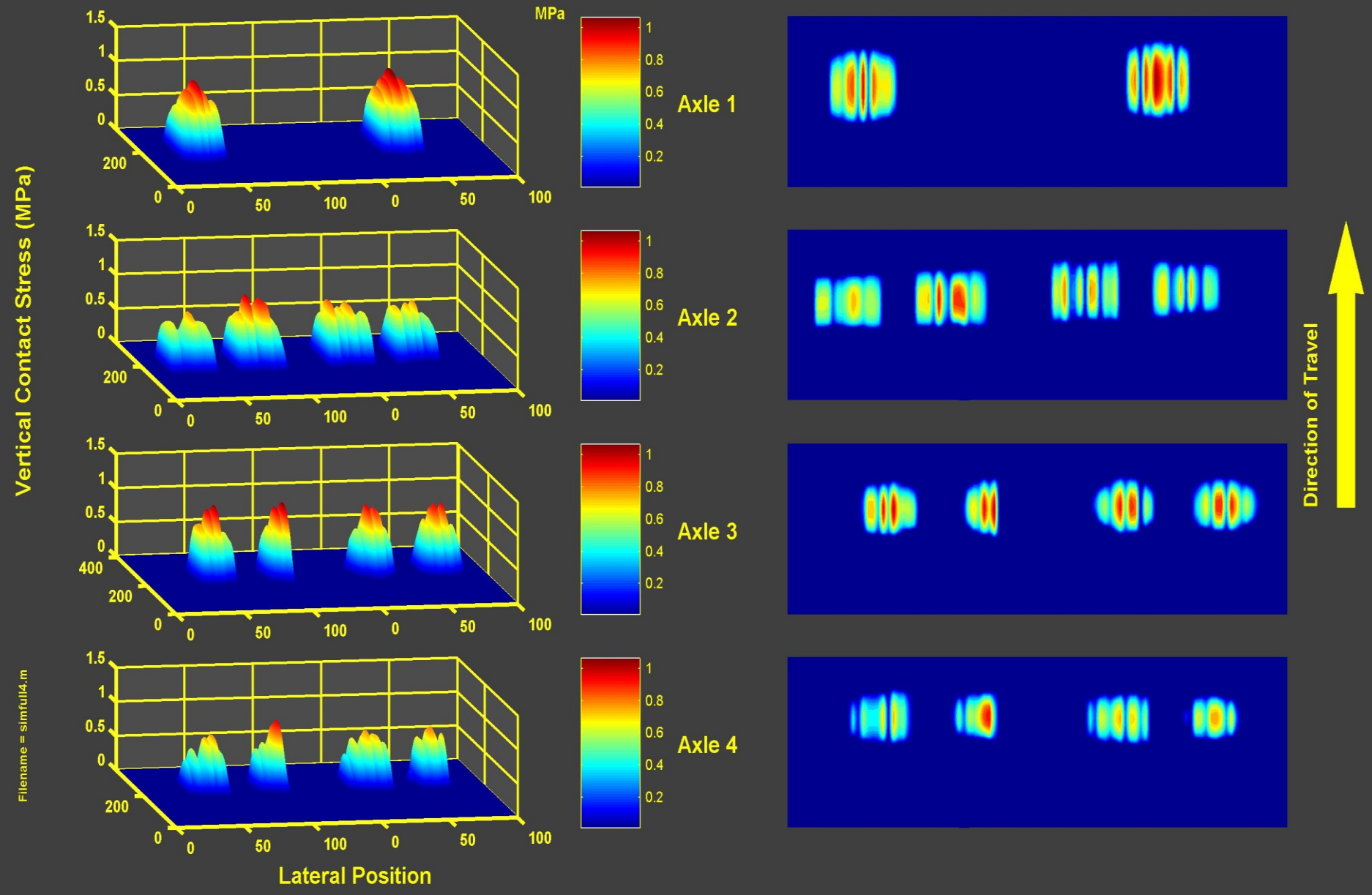
Two Axle Truck – Vertical Contact Stress - Foot Prints

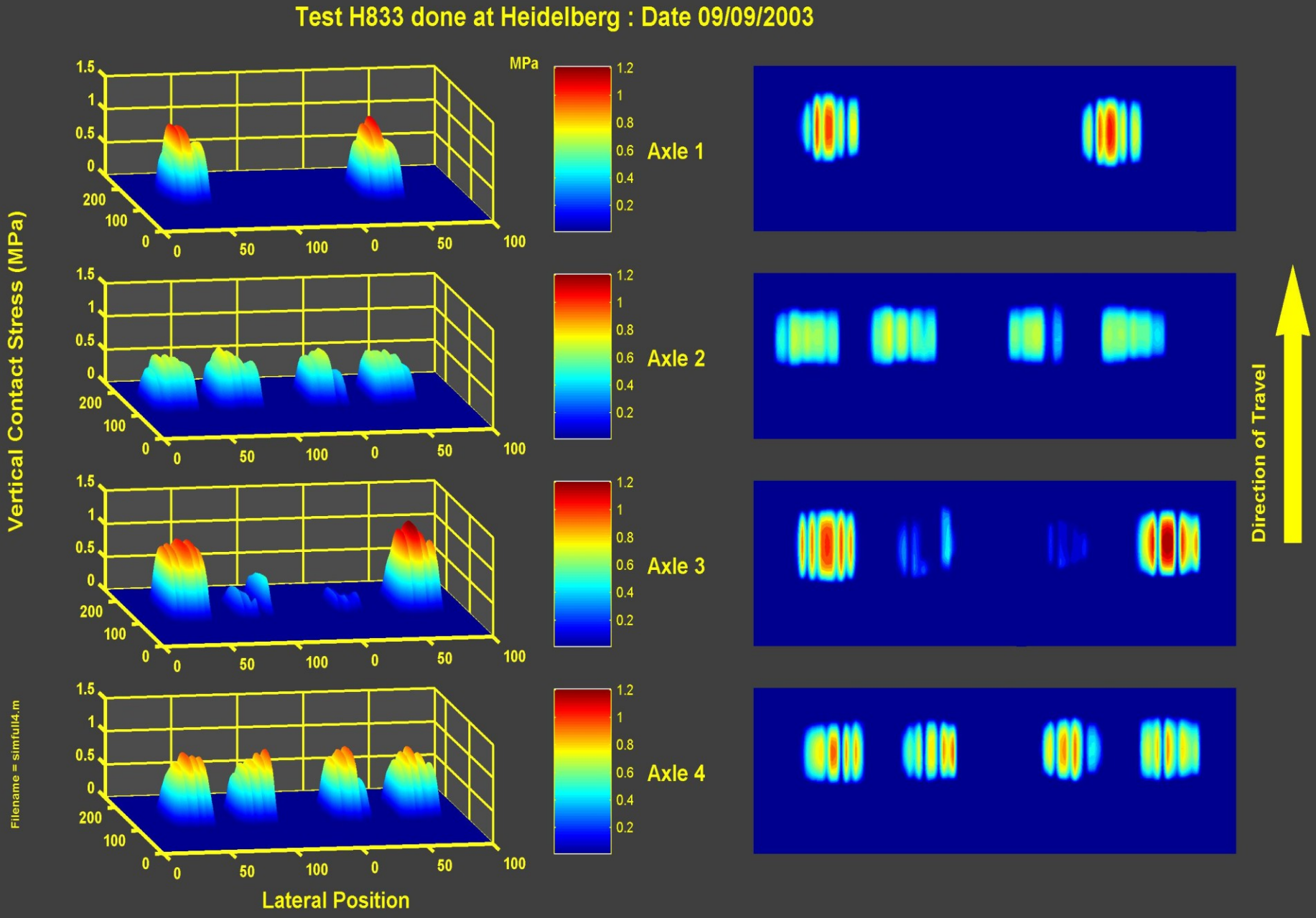


Test H1062 done at Heidelberg : Date 10/09/2003

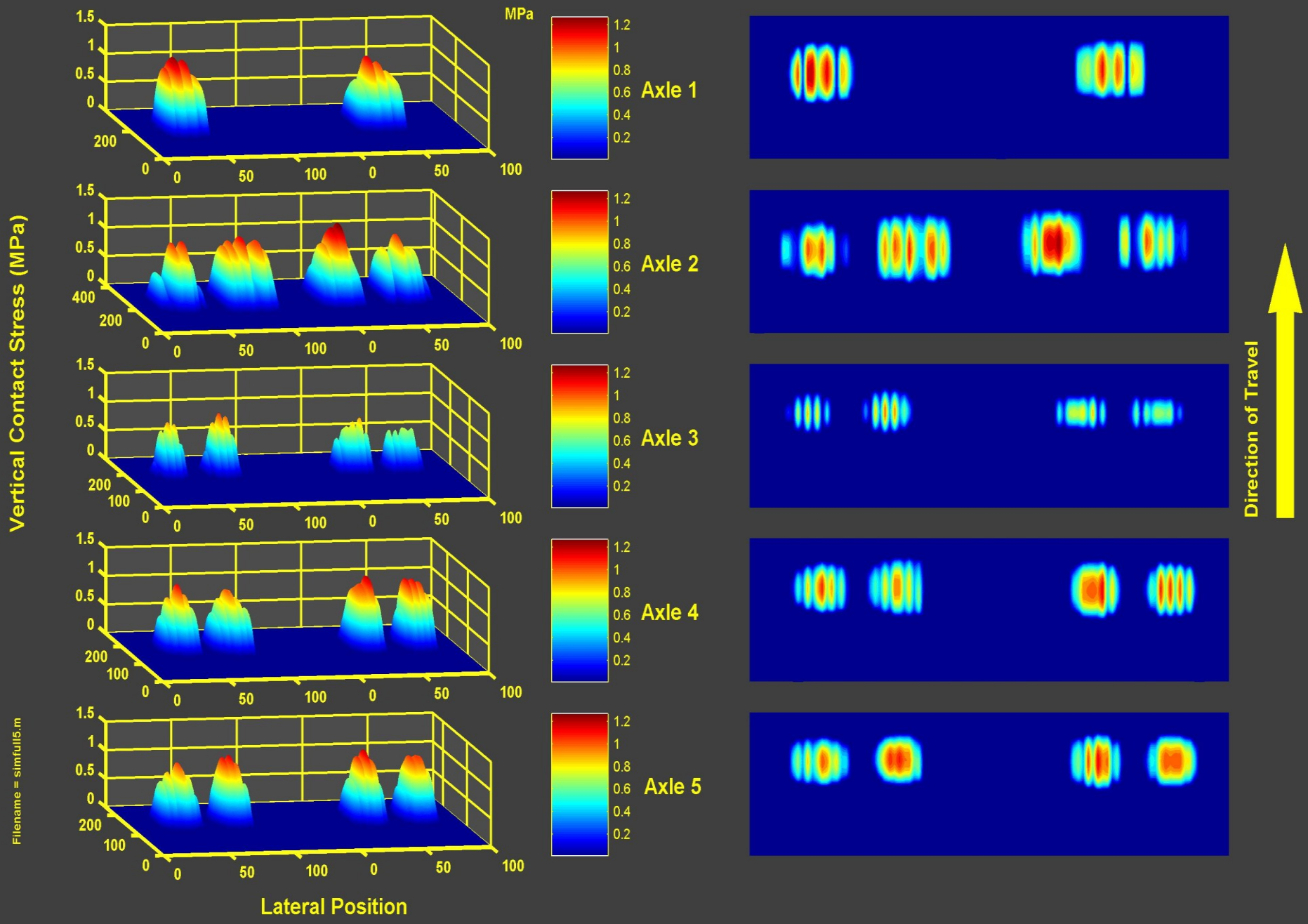


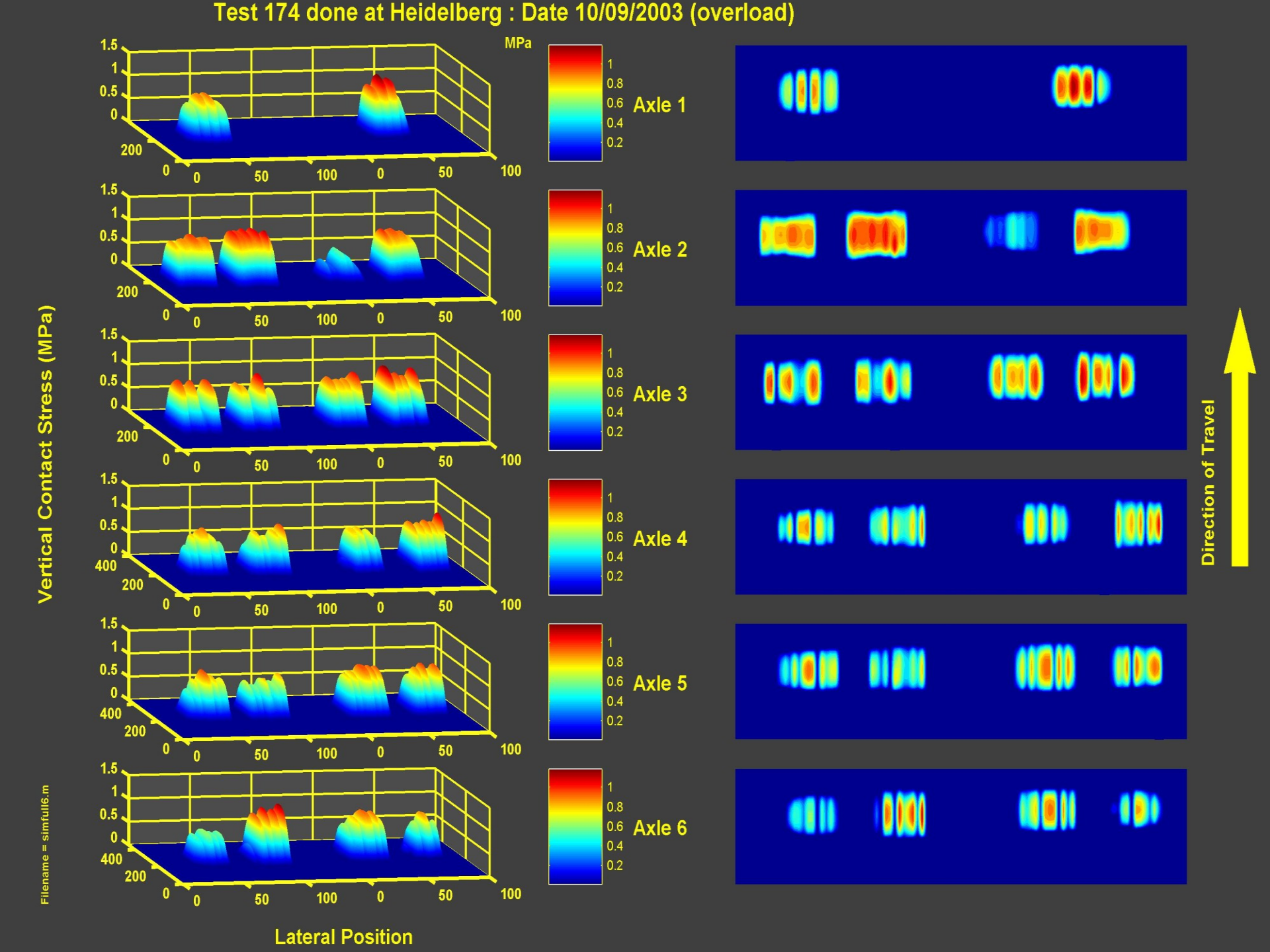
Test H1070 done at Heidelberg : Date 10/09/2003



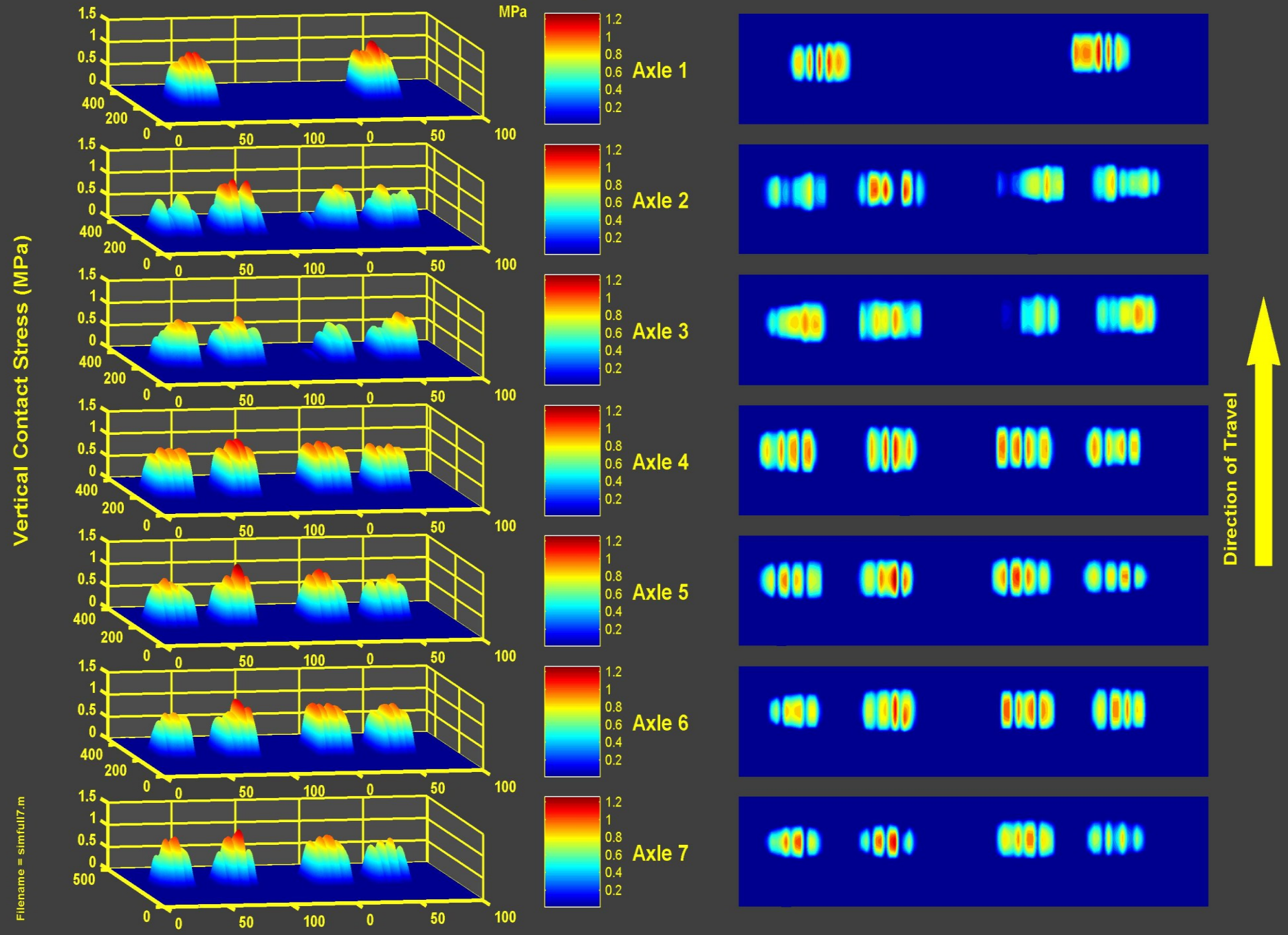

Test H833 done at Heidelberg : Date 09/09/2003
Vertical Contact Stress (MPa)
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Lateral Position
Direction of Travel
Filename = simfull4.m

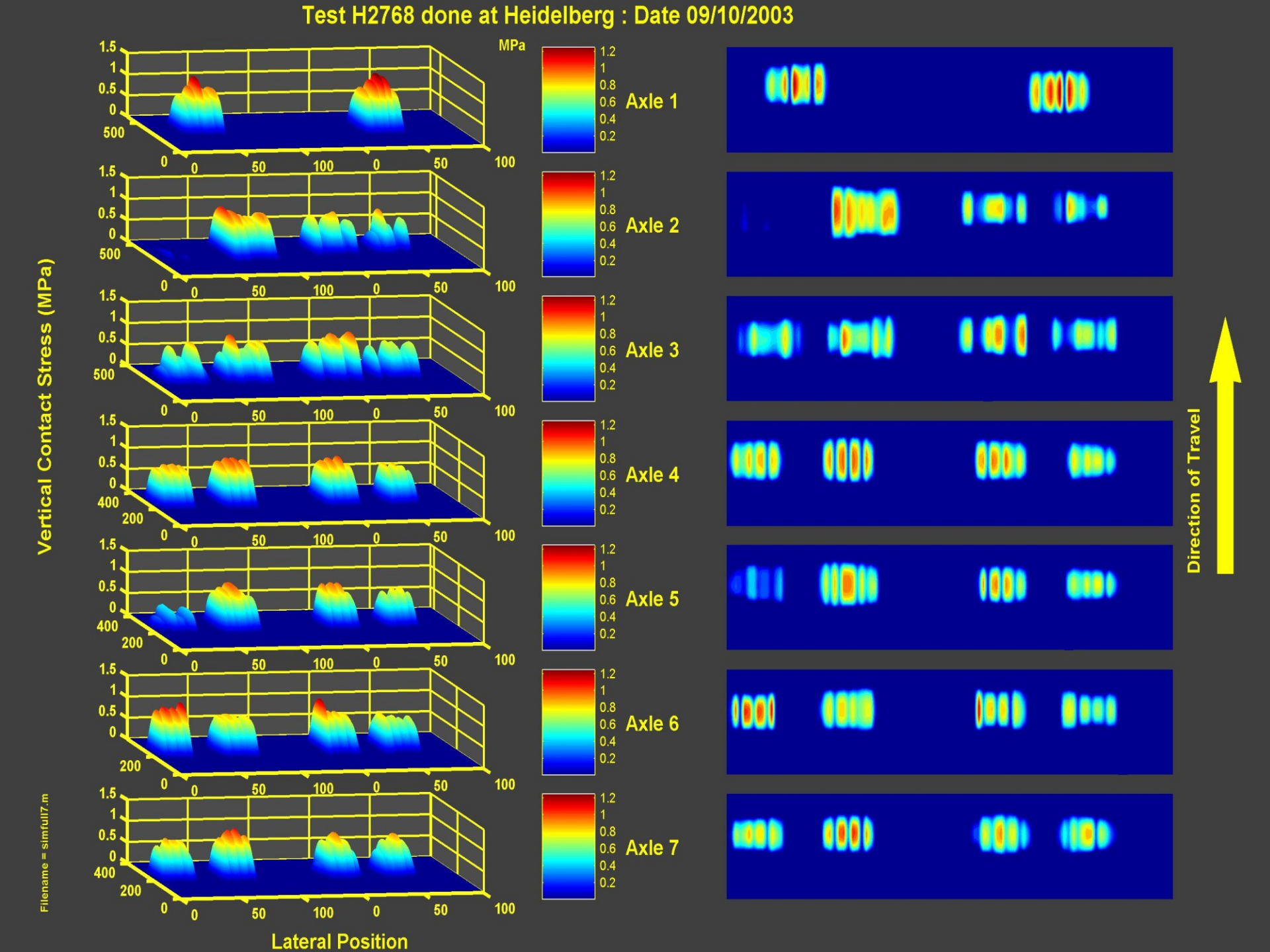
Test H1077 done at Heidelberg : Date 10/09/2003

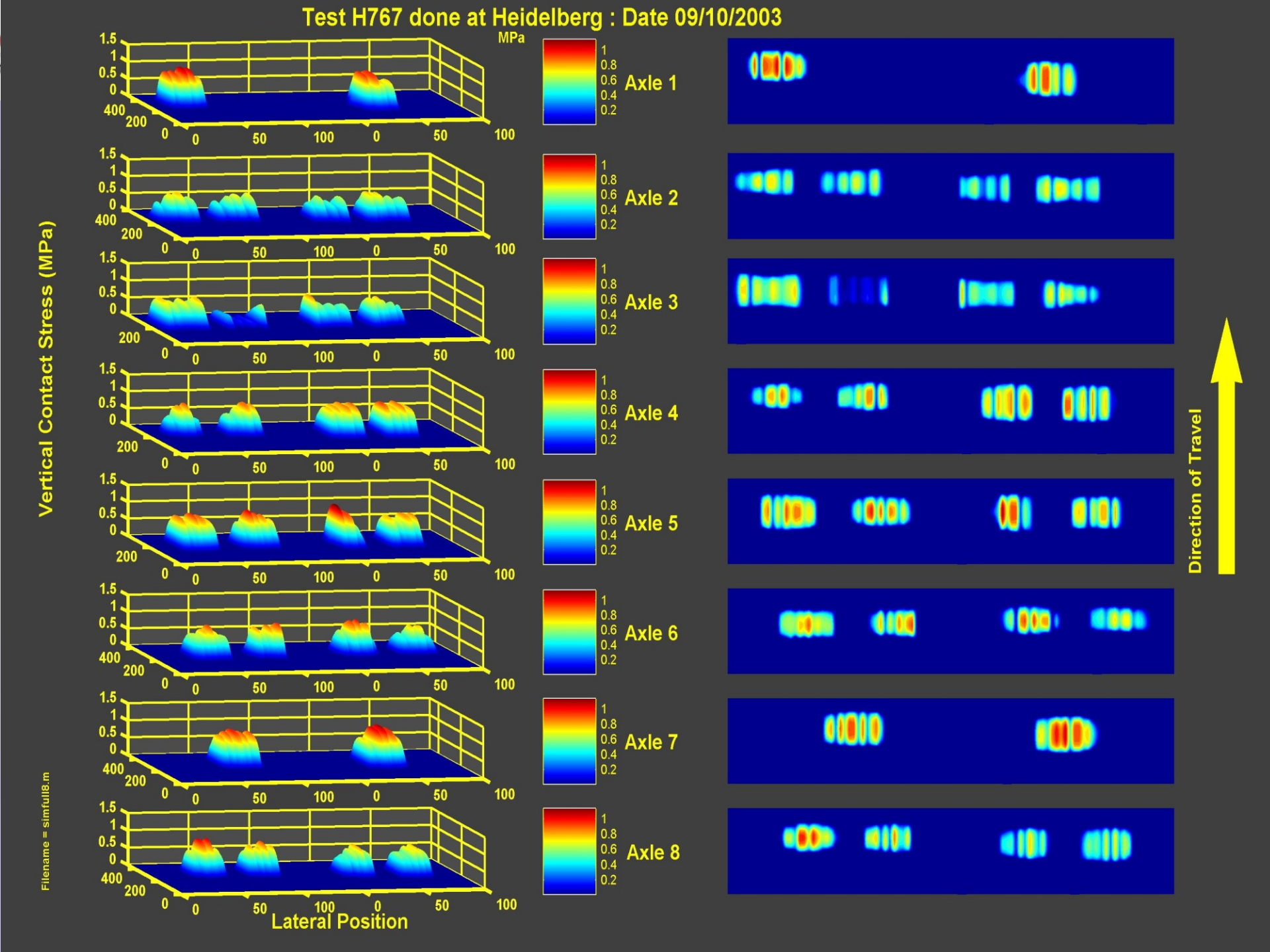



Test 174 done at Heidelberg : Date 10/09/2003 (overload)
Vertical Contact Stress (MPa)
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Direction of Travel
Lateral Position
Filename = simfull6.m

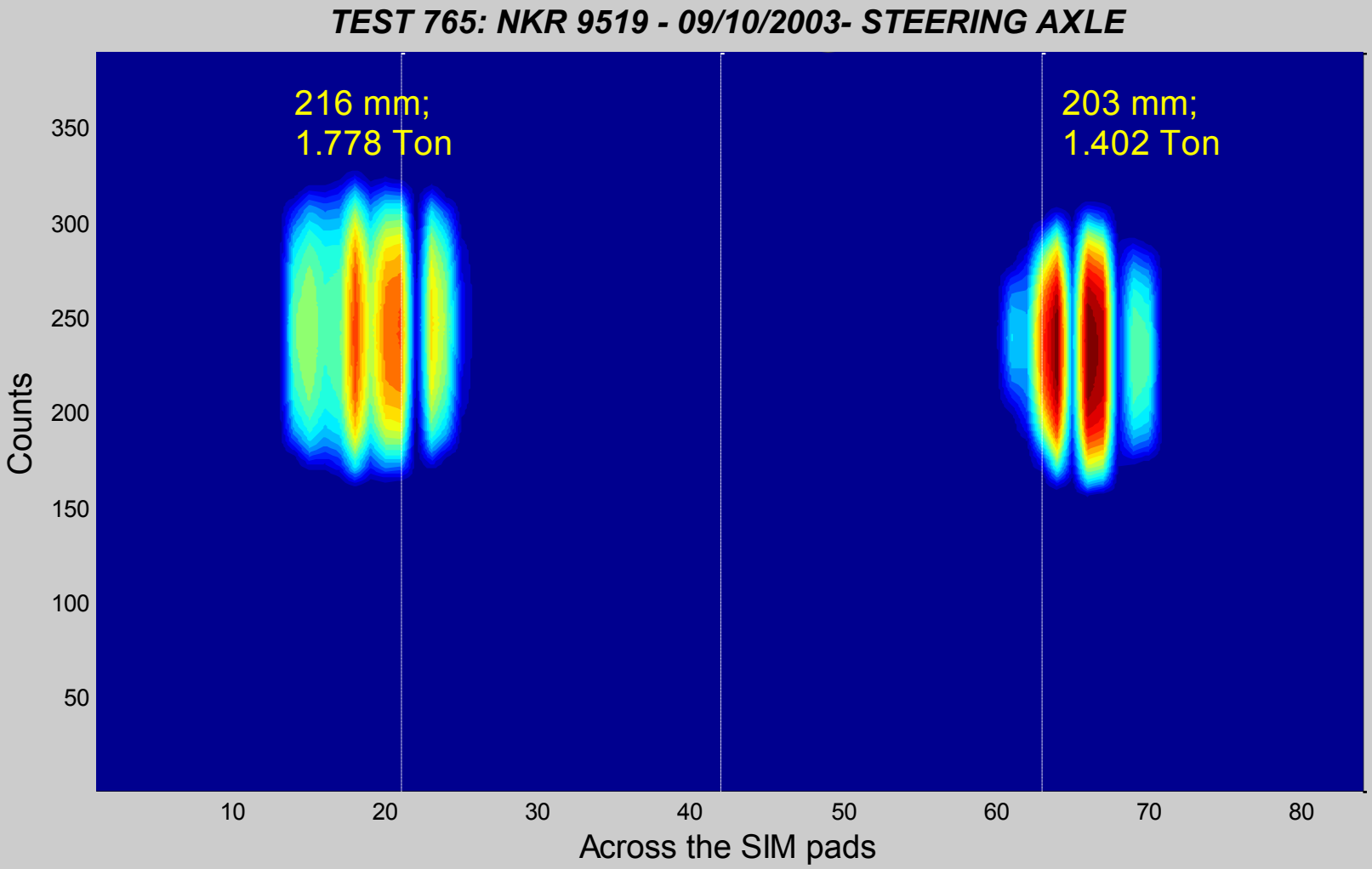
Test 120 done at Heidelberg : Date 15/10/2003



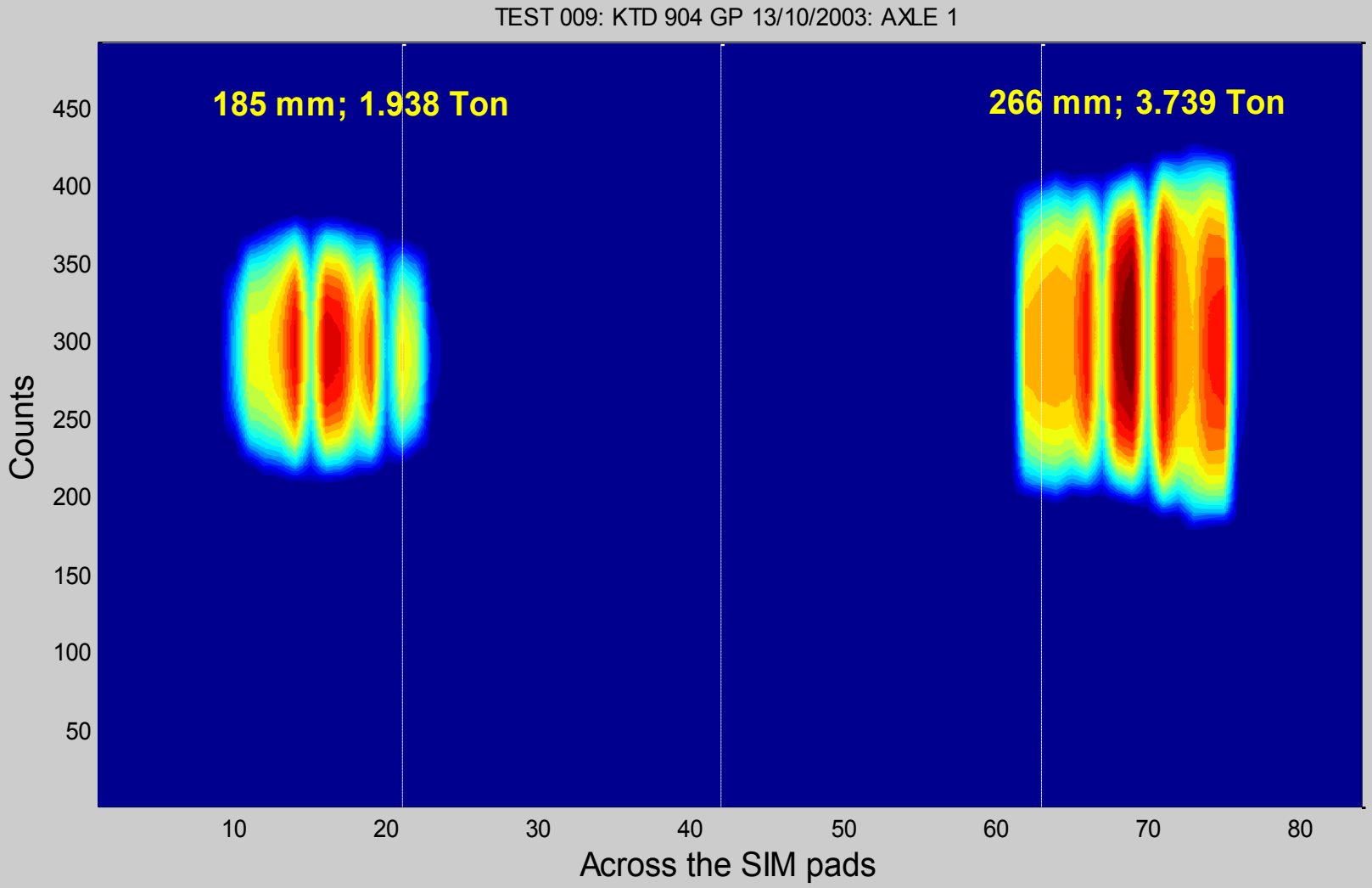

Test H2768 done at Heidelberg : Date 09/10/2003
Vertical Contact Stress (MPa)
Lateral Position
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Axle 7
Direction of Travel
Filename = simfull7.m


Test H767 done at Heidelberg : Date 09/10/2003
Vertical Contact Stress (MPa)
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Axle 7
Axle 8
Lateral Position
Direction of Travel
Filename = simfull8.m

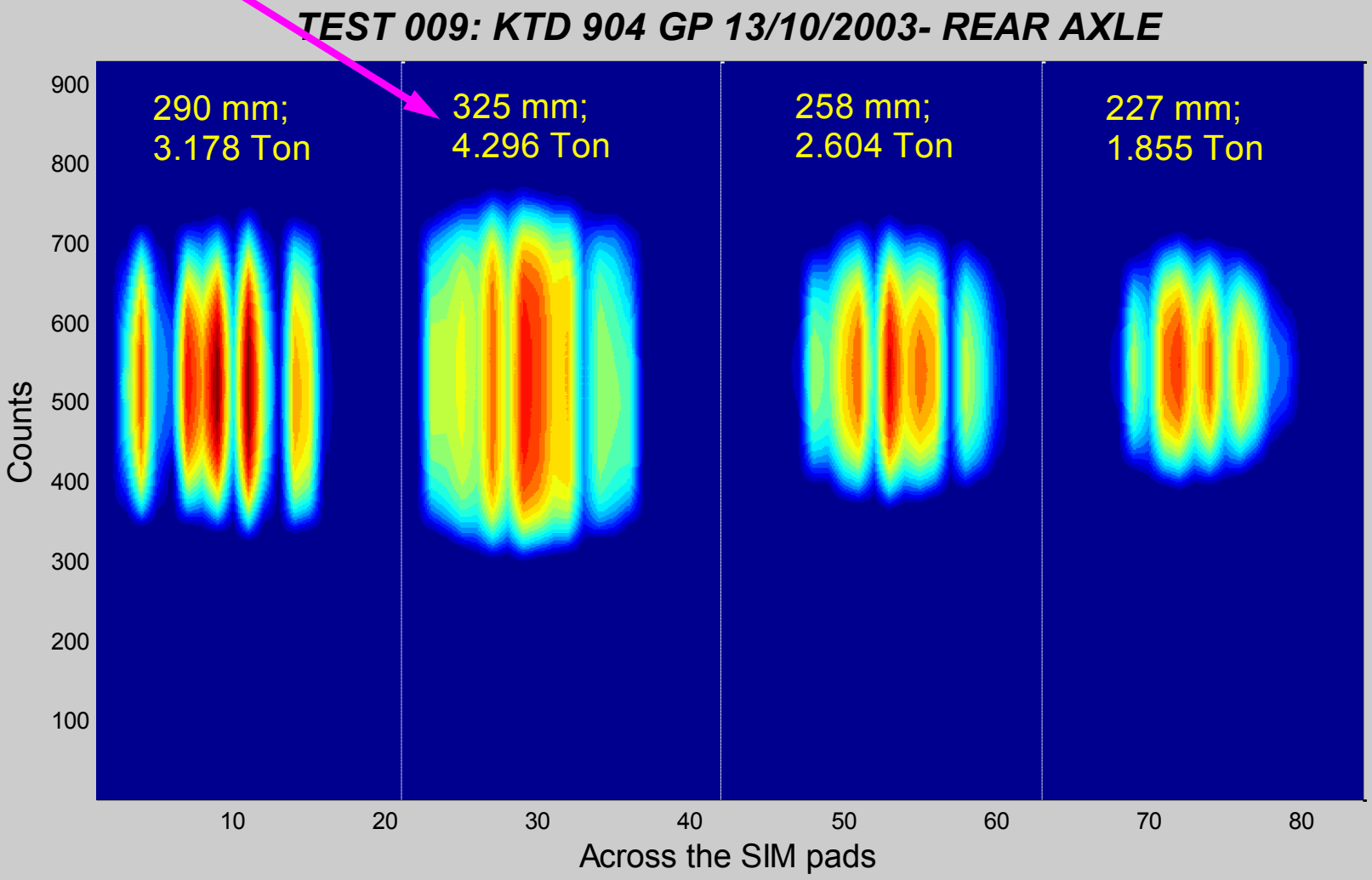
STEERING AXLE



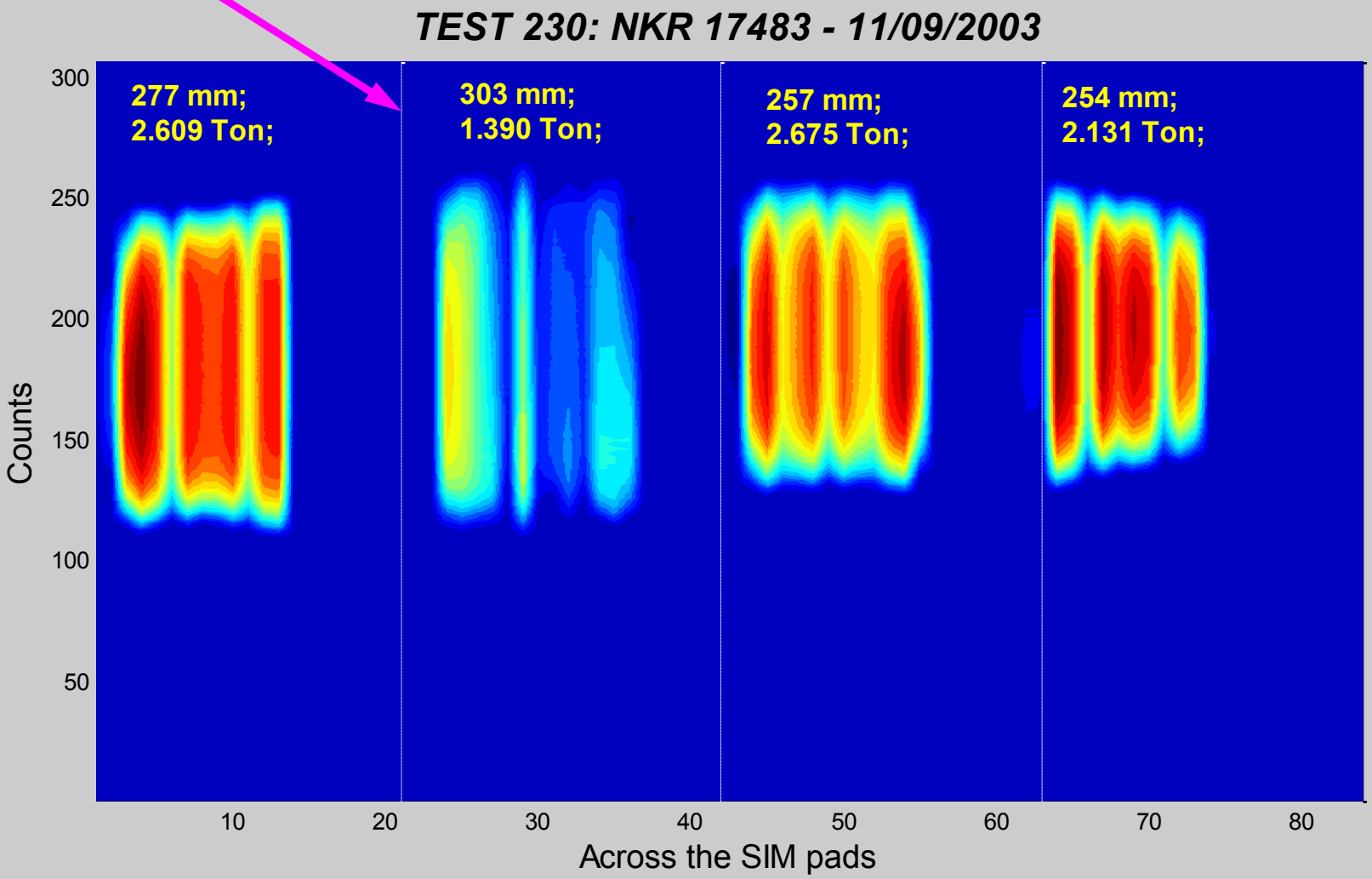
STEERING AXLE – UNEQUAL LOADING



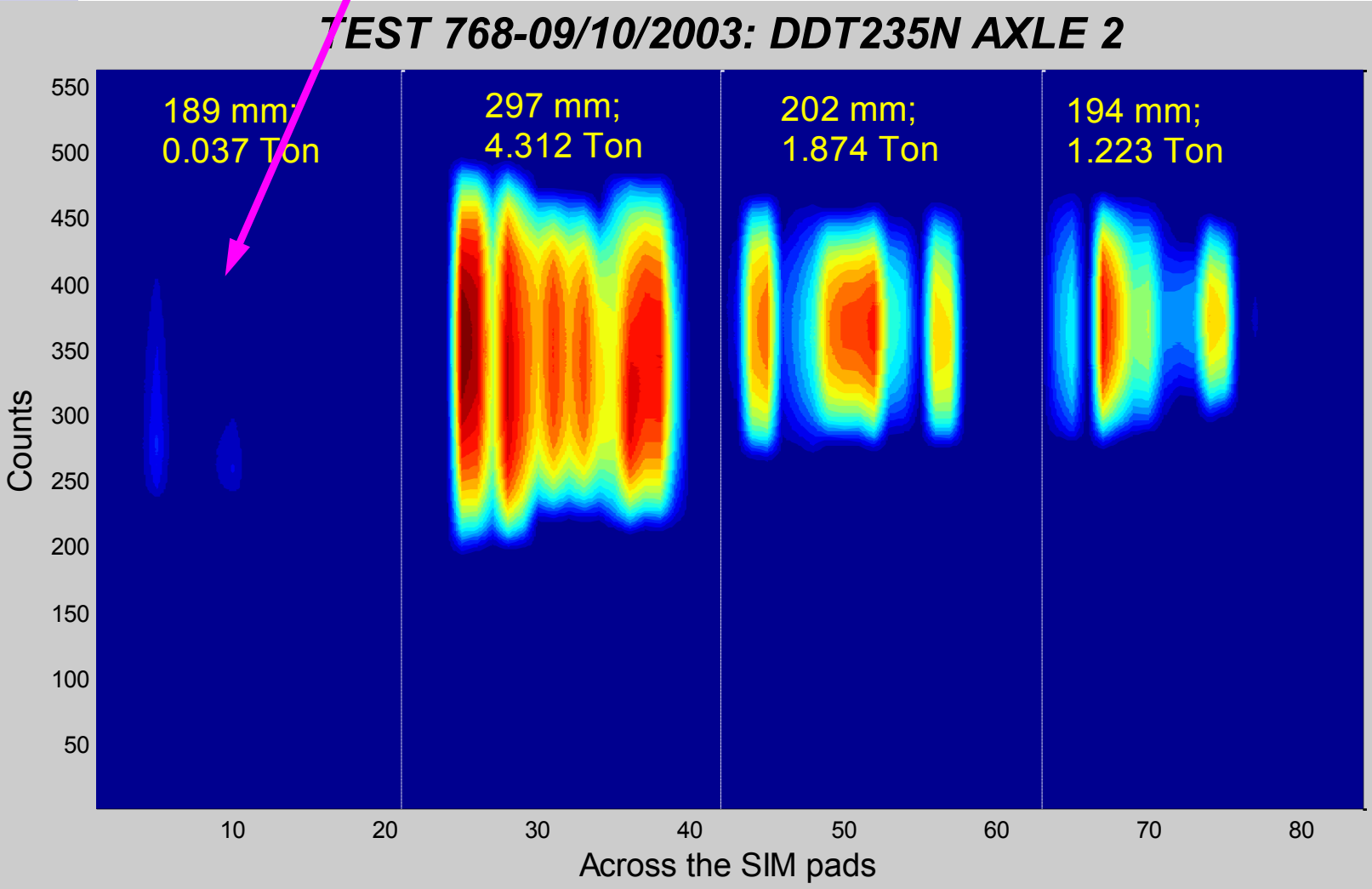
REAR AXLE – UNEQUAL LOADING



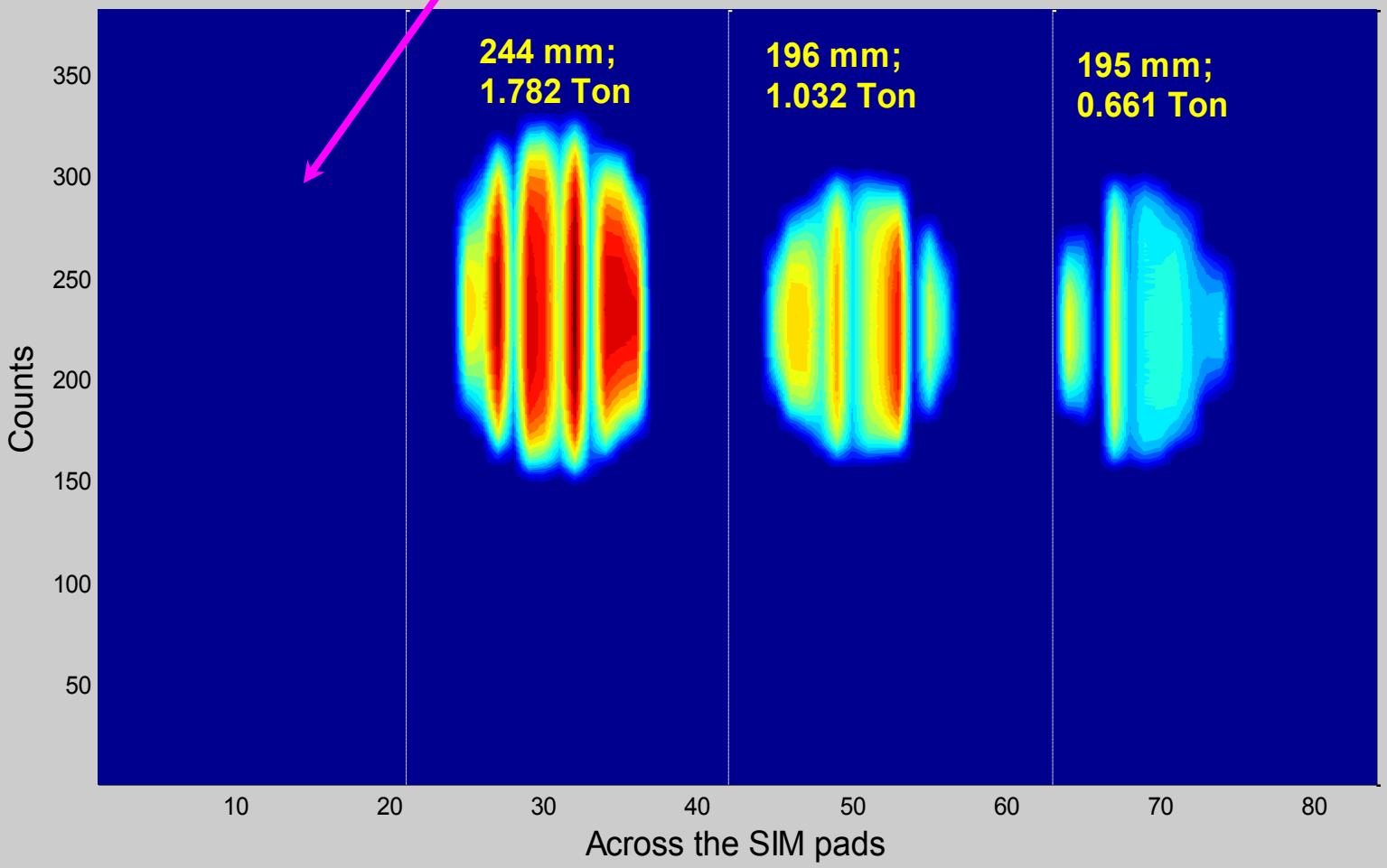
REAR AXLE – UNEQUAL LOADING

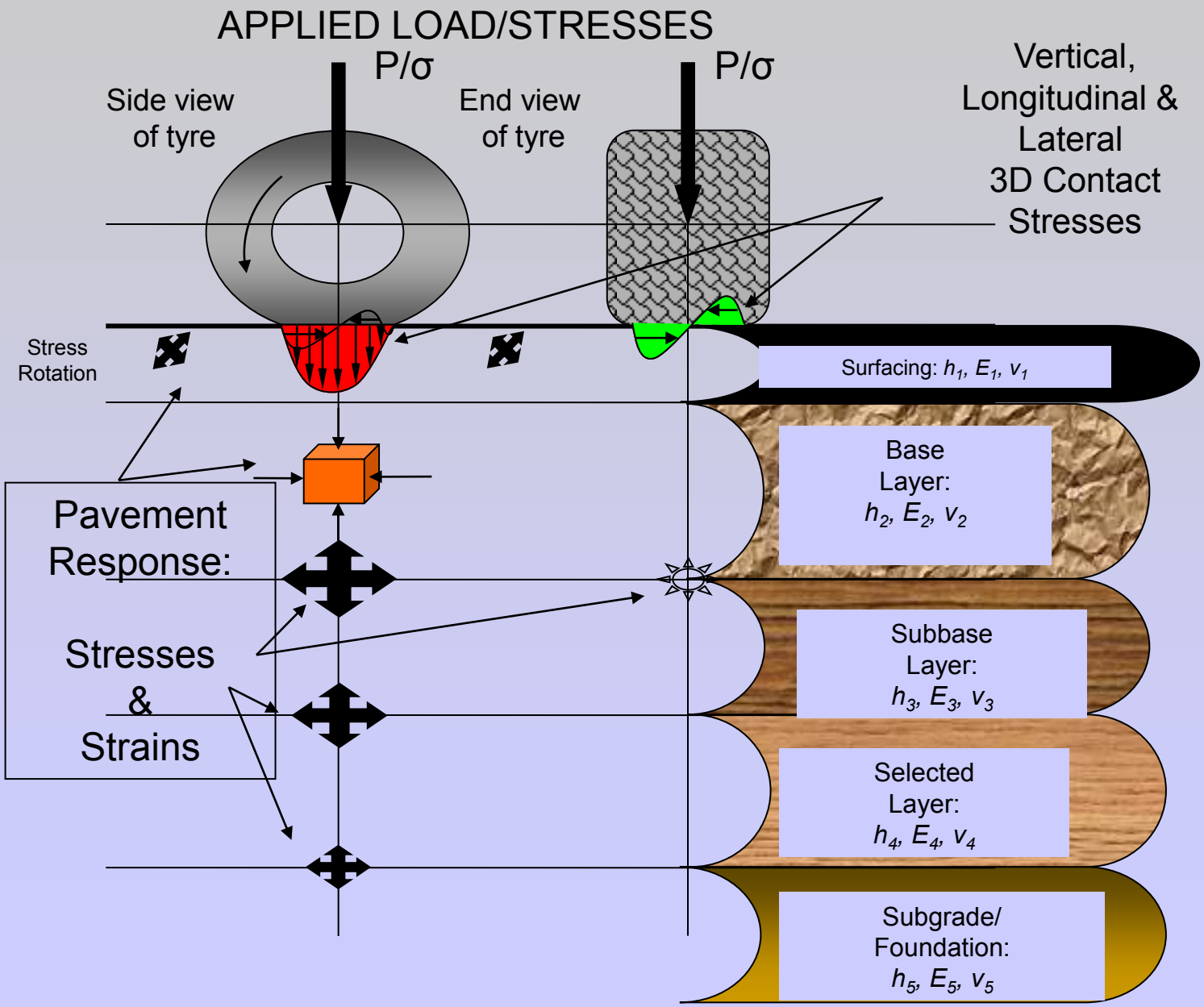


TYRE BARELY IN CONTACT WITH SURFACE

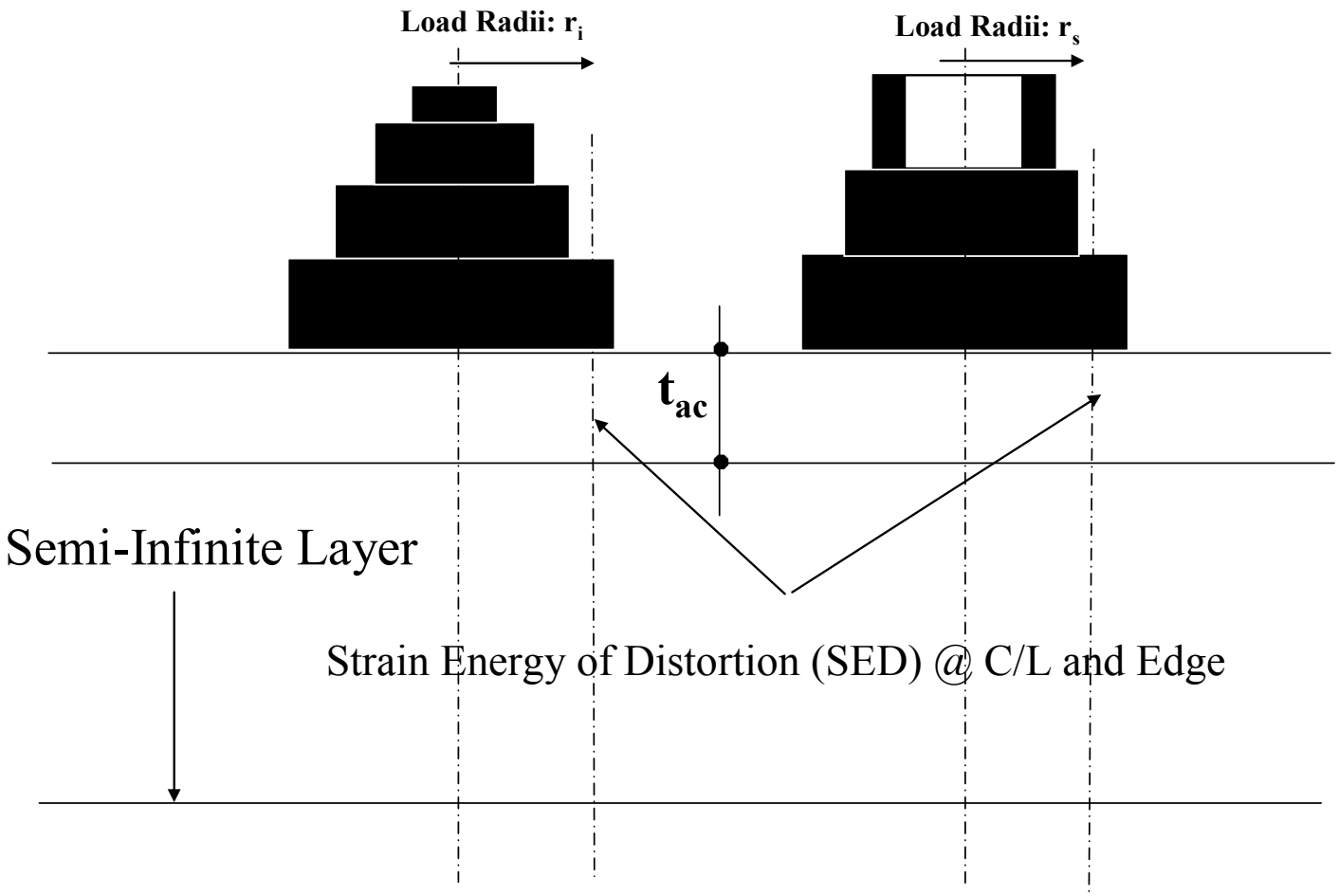


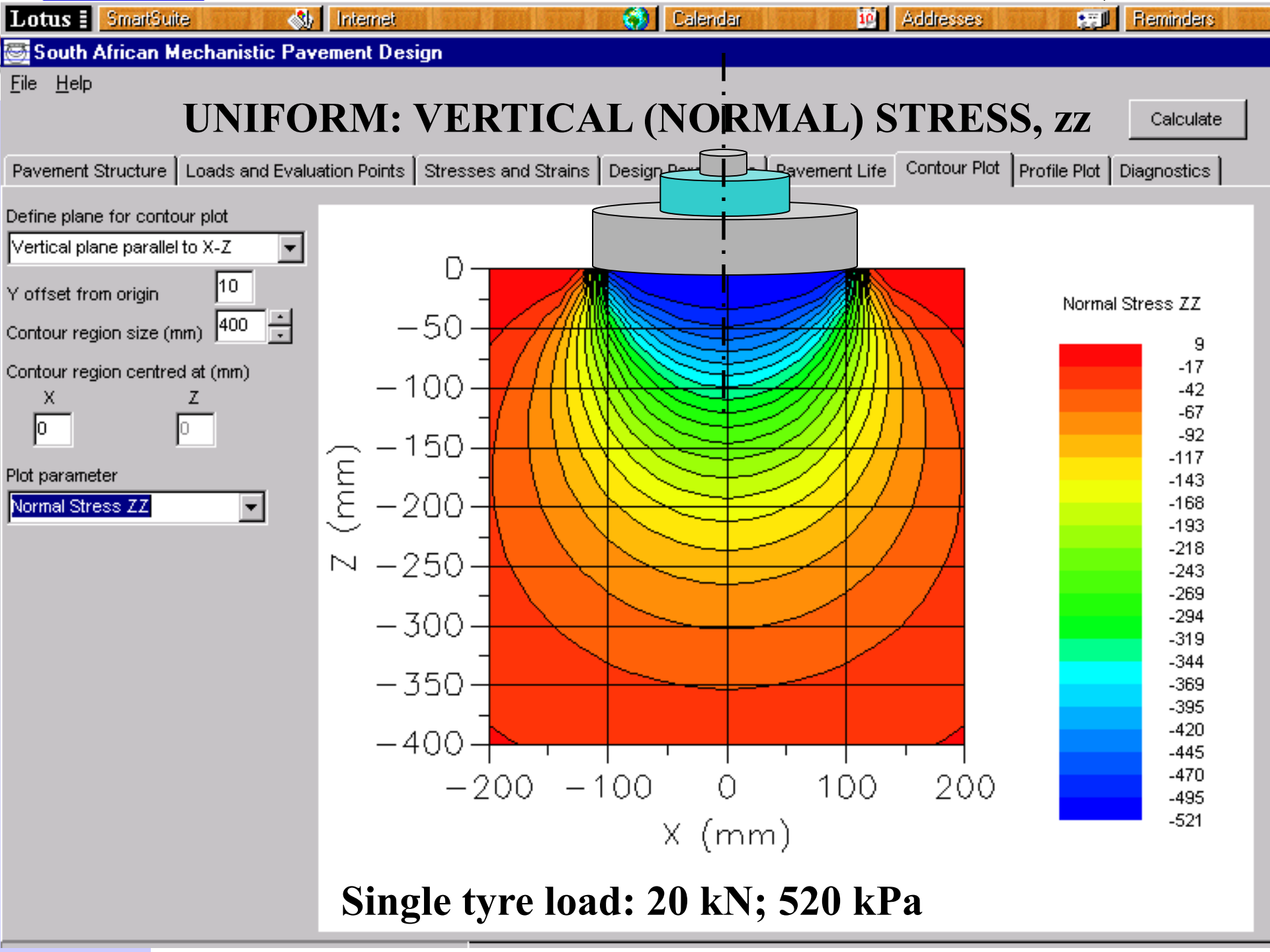
AXLE 2: MISSING TYRE !!



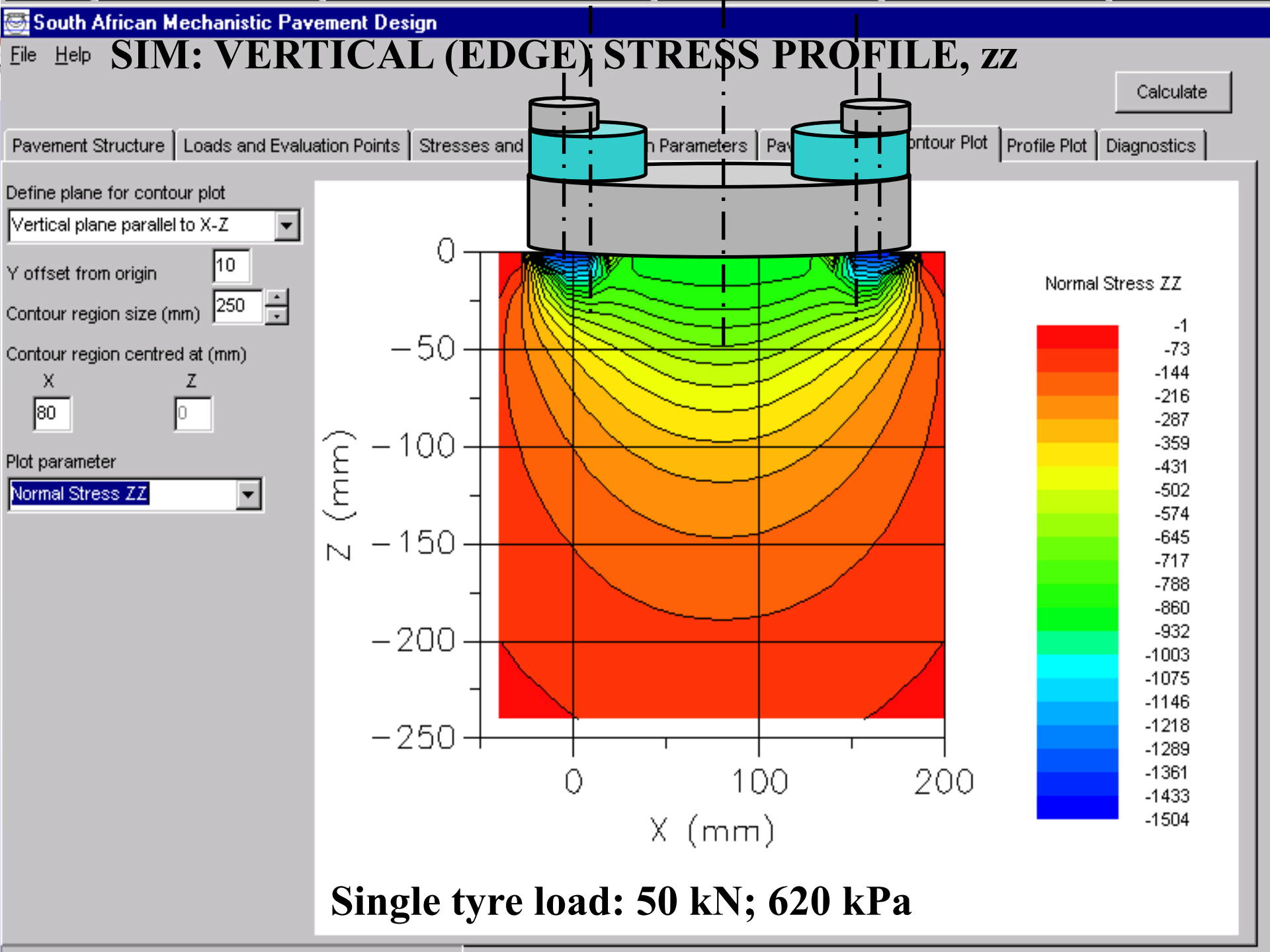

APPLIED LOAD/STRESSES
P/σ
P/σ
Side view of tyre
End view of tyre
Vertical, Longitudinal & Lateral 3D Contact Stresses
Stress Rotation
Surfacing: h_1, E_1, v_1
Base Layer: h_2, E_2, v_2
Subbase Layer: h_3, E_3, v_3
Selected Layer: h_4, E_4, v_4
Subgrade/ Foundation: h_5, E_5, v_5
Pavement Response:
Stresses & Strains

SIMPLIFIED LOADING SHAPES




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
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
Z
0
0
Plot parameter
Normal Stress ZZ
0
−50
−100
−150
−200
−250
−300
−350
−400
Z (mm)
−200
−100
0
100
200
X (mm)
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

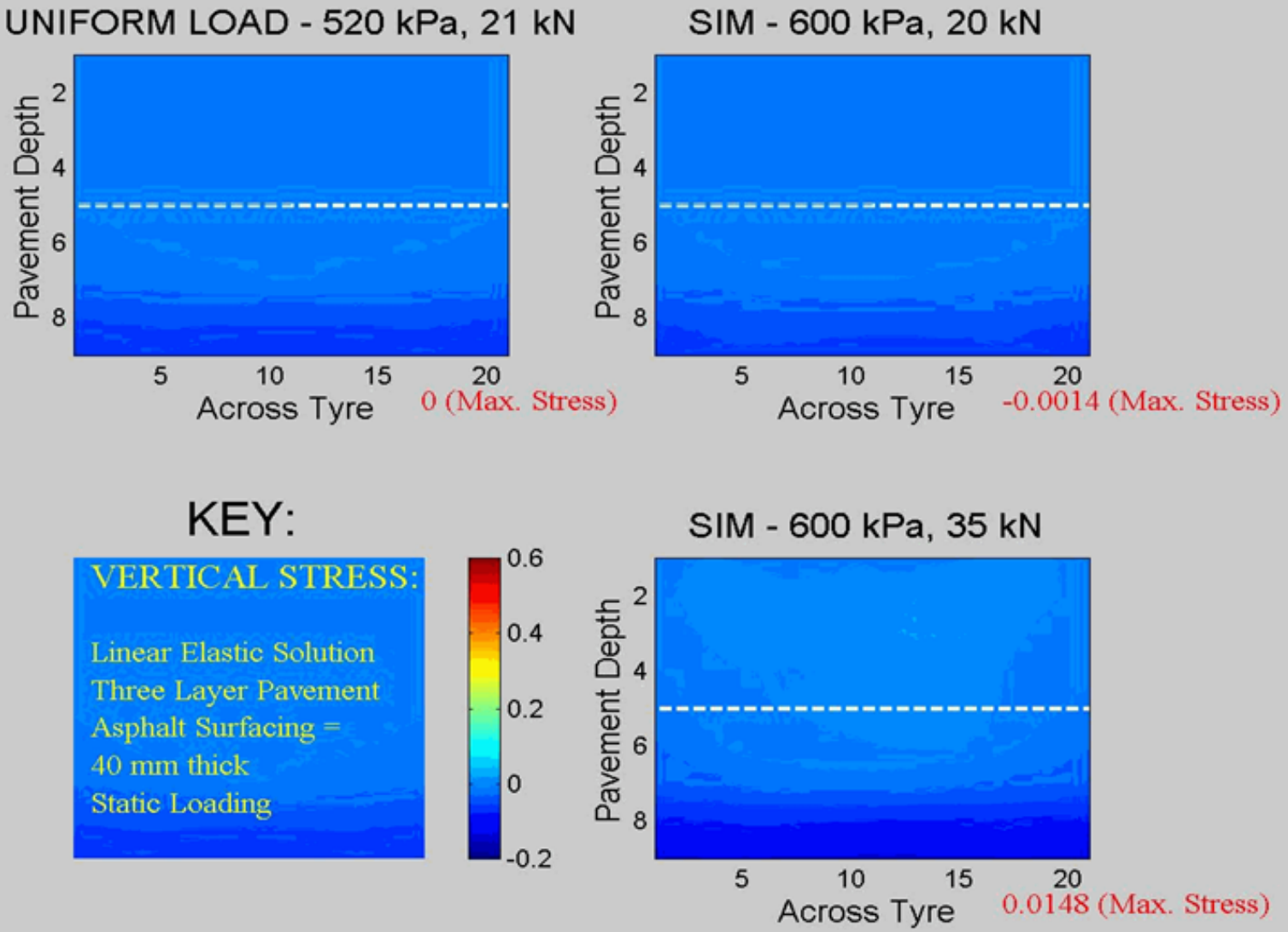
SIM: VERTICAL (EDGE) STRESS PROFILE, zz



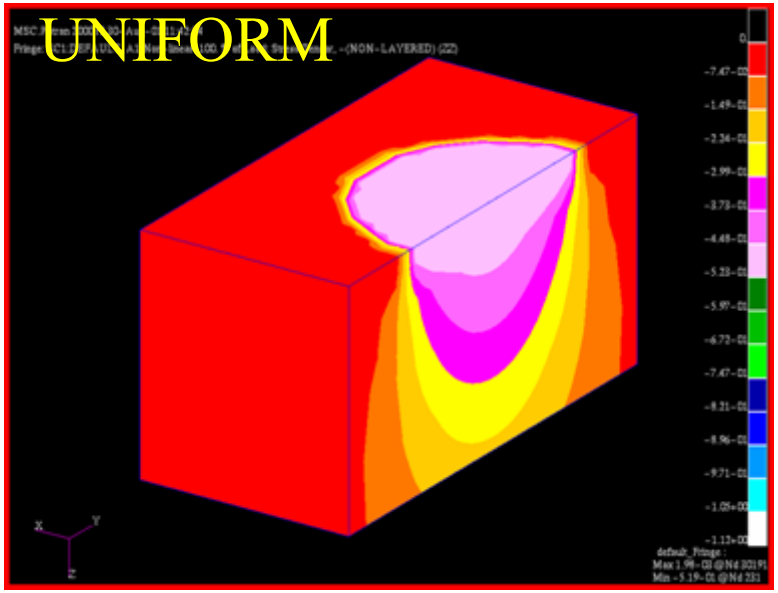
Single tyre load: 50 kN; 620 kPa

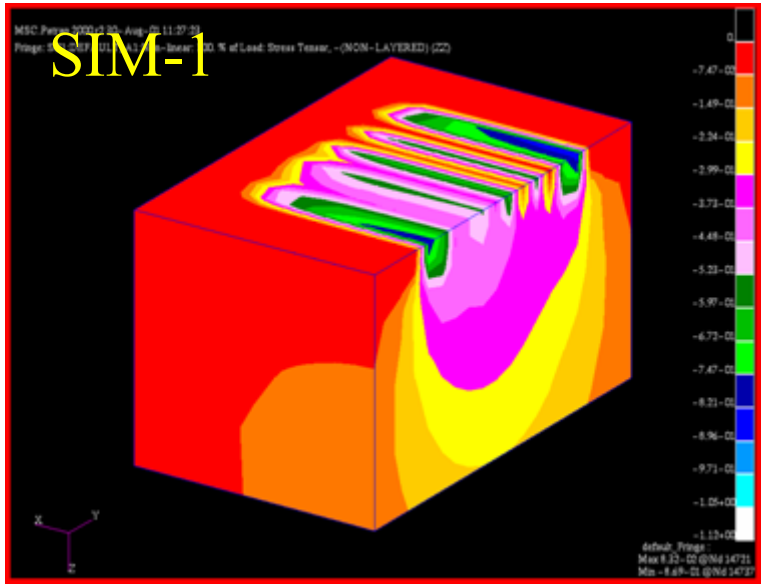
MODELED TYRE

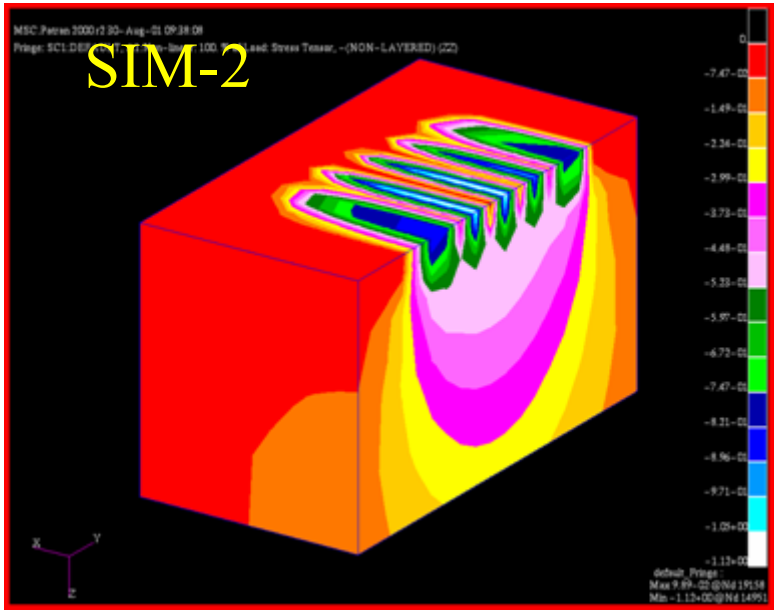
REAL-TYRE

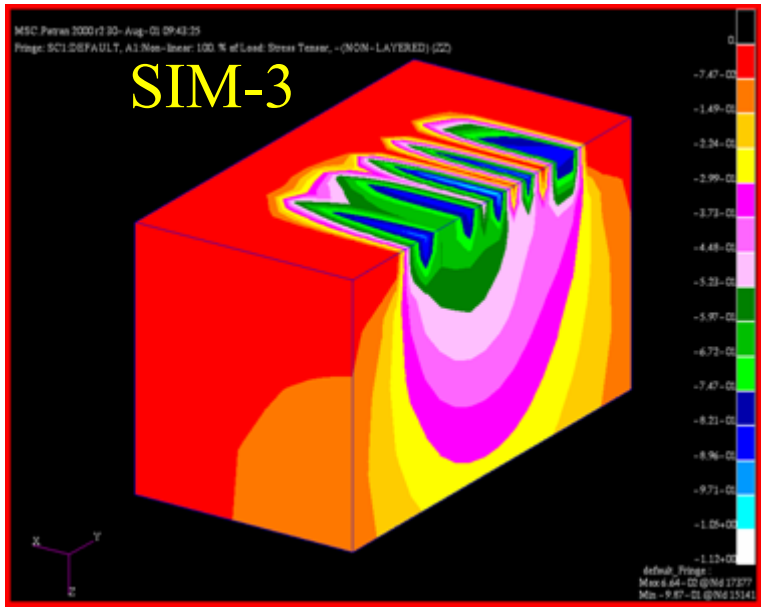


Finite Element Analysis (CSIR):Uniform vs Non-Uniform Stress





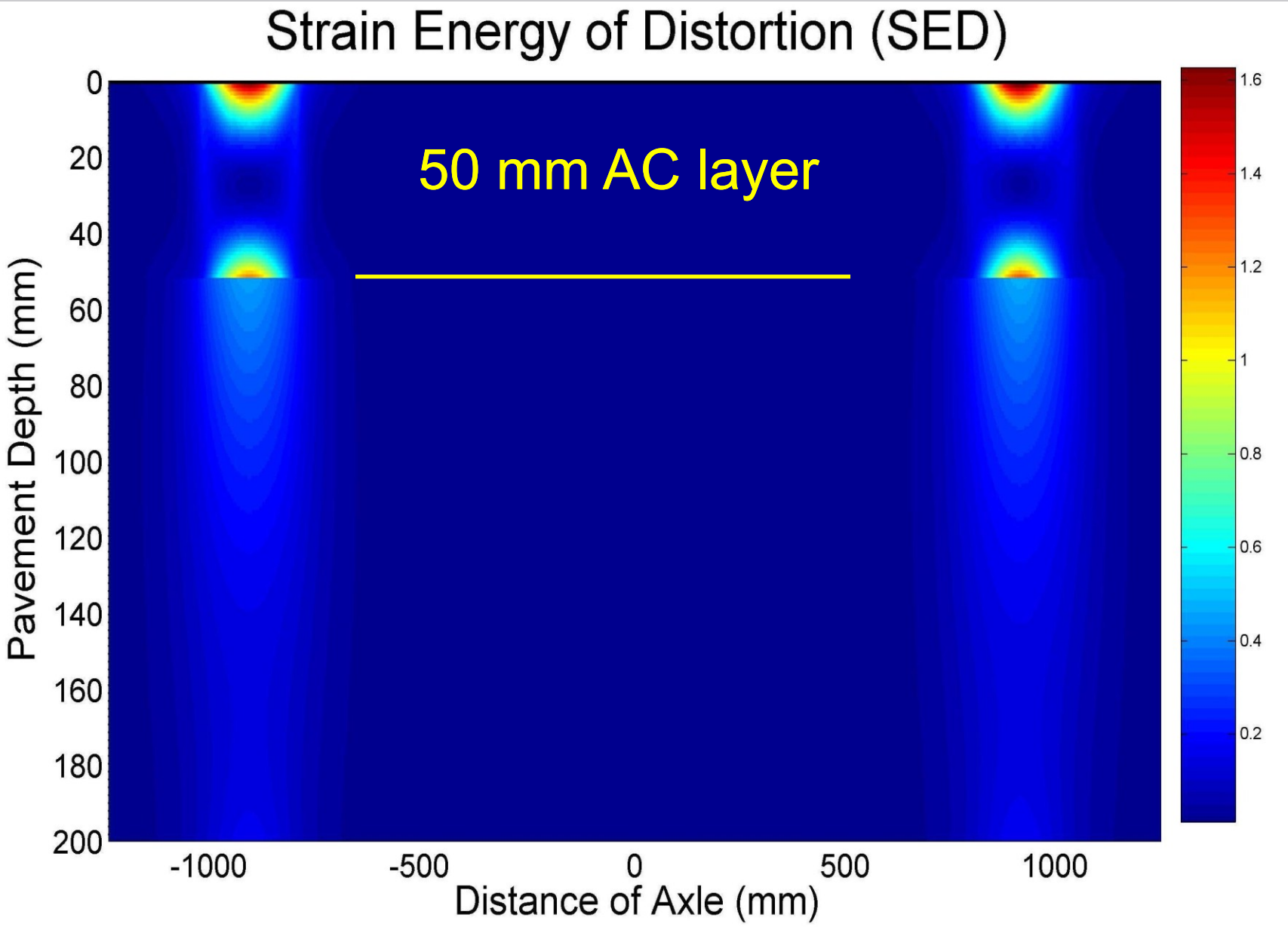




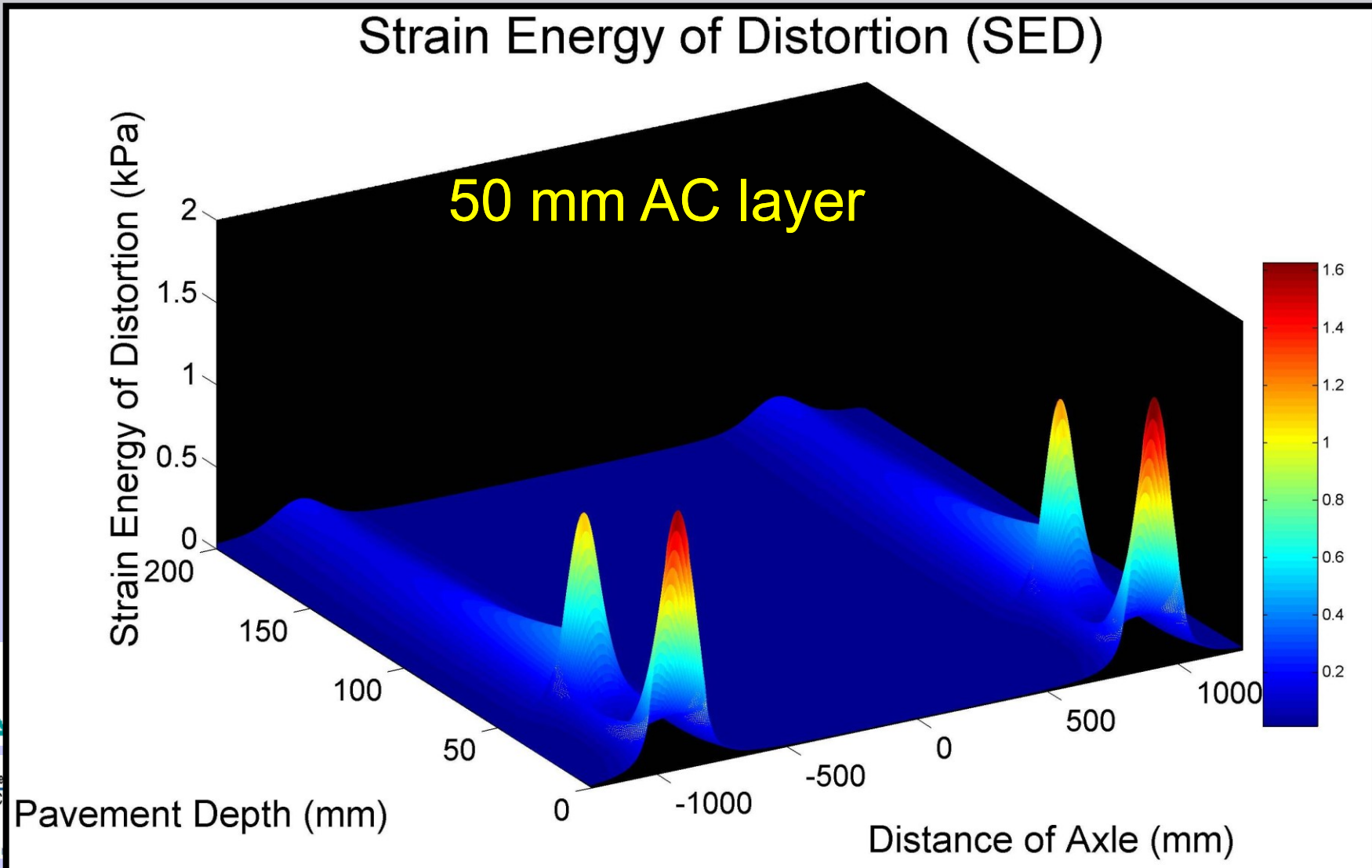
TITLE

- Level 1
  - Level 2

- Please do not write text smaller than Arial 20 pt
- Do not exceed 1 slide per minute, i.e. 12-15 slides in average (the oral presentations will last for 12 to 15 mn, the remaining time being for Q/A and discussion)
- Take care to display clear graphs and pictures, with readable legends, and characters not smaller than Arial 16
- Focus on the most important idea and findings, avoid long text, and give priority to visual matters (graphs, photos, diagrams…)
- Introduce briefly the objectives of the presentation and give some clear conclusions

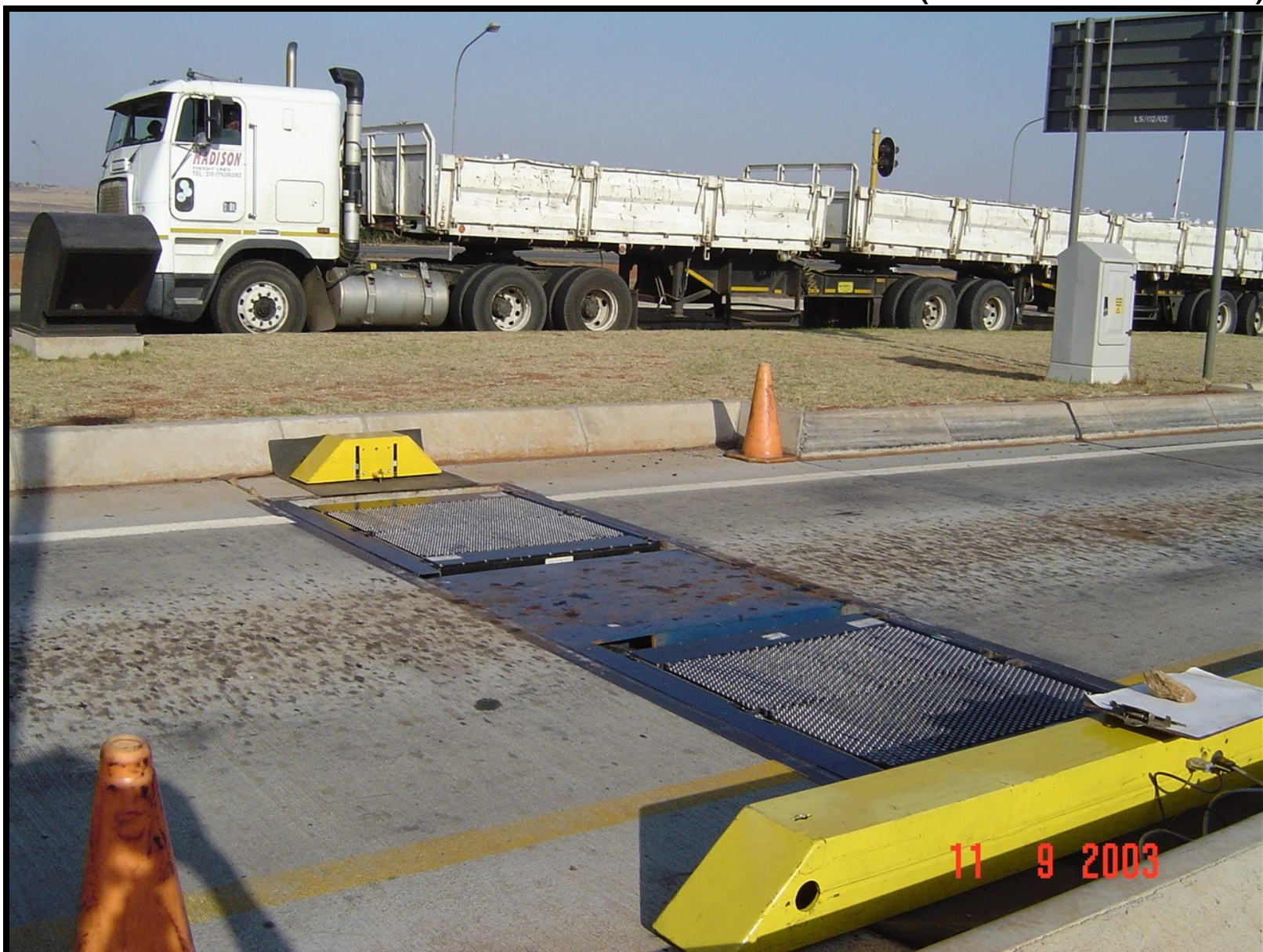

Strain Energy of Distortion (SED)
50 mm AC layer
Pavement Depth (mm)
0
20
40
60
80
100
120
140
160
180
200
-1000
-500
0
500
1000
Distance of Axle (mm)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2

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



QUAD SIM PAD TESTING AT WEIGH-BRIDGE SITE: N3 NORTH – HEIDELBERG TRAFFIC CONTROL CENTRE

STRESS-IN-MOTION TESTING ON N3 NORTH (HEIDELBERG)



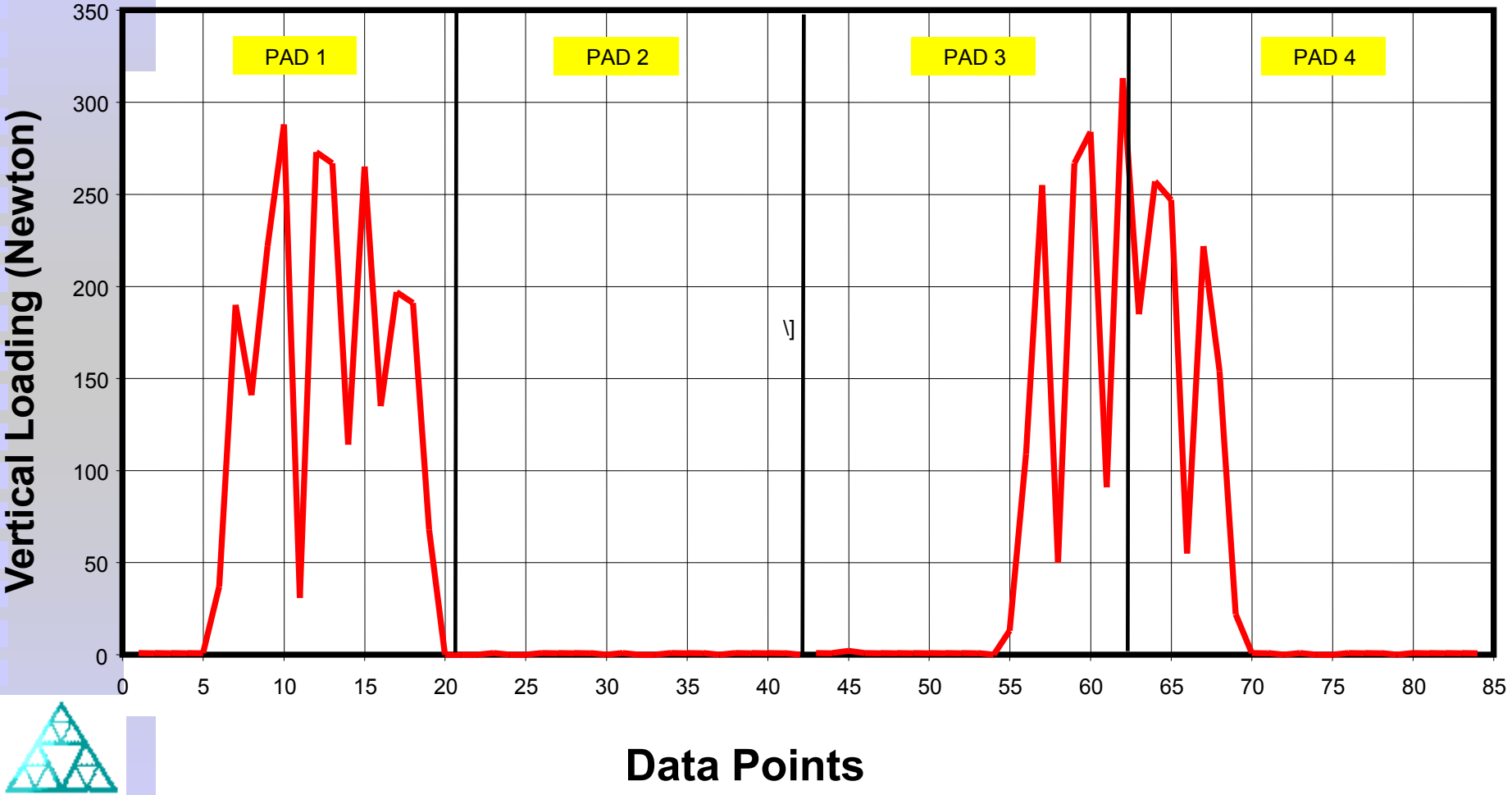
STRESS-IN-MOTION TESTING ON N3 NORTH (HEIDELBERG)

“123” Truck

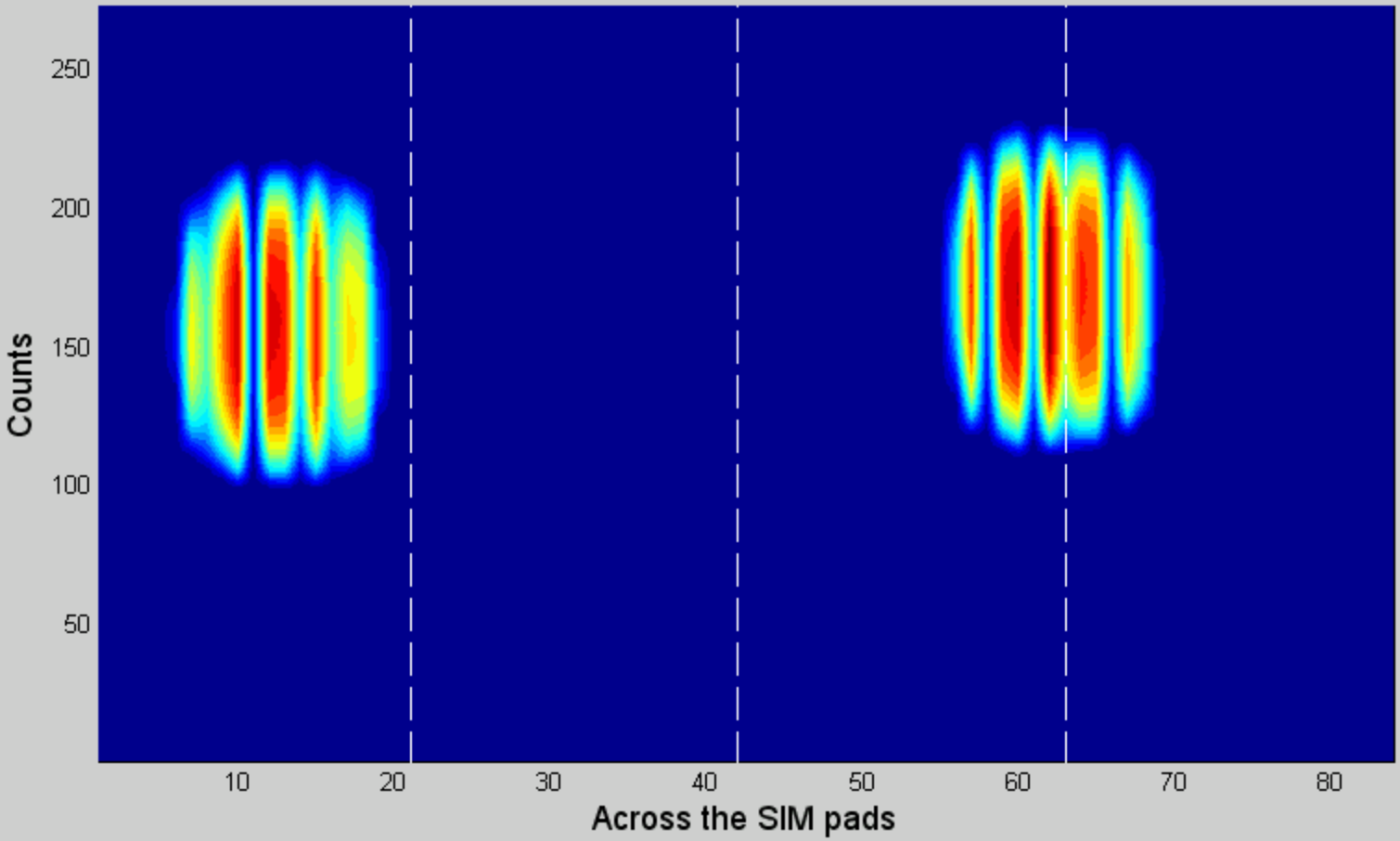
Registration No
ND475336

STEERING AXLE

Test No.
733



STEERING AXLE



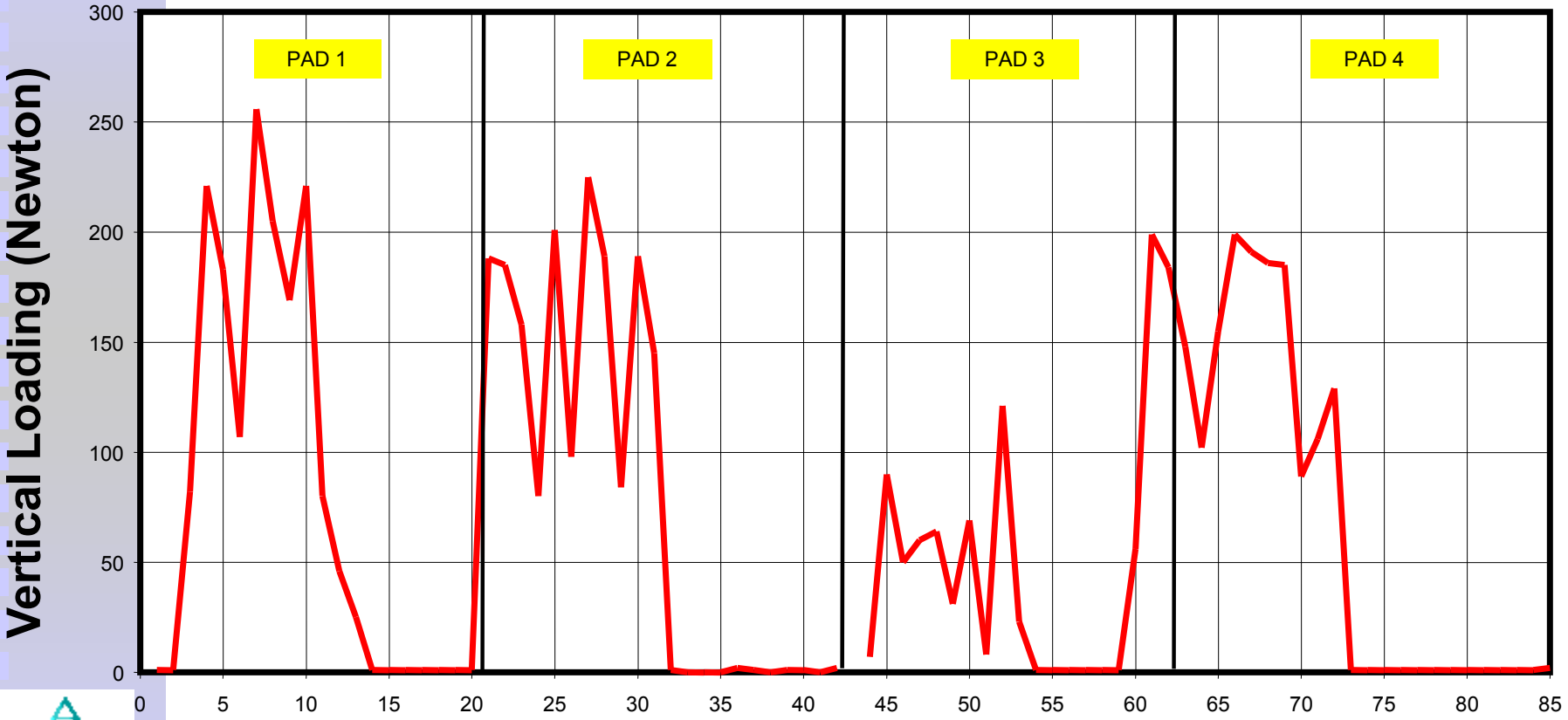
AXLE 2

Registration No .

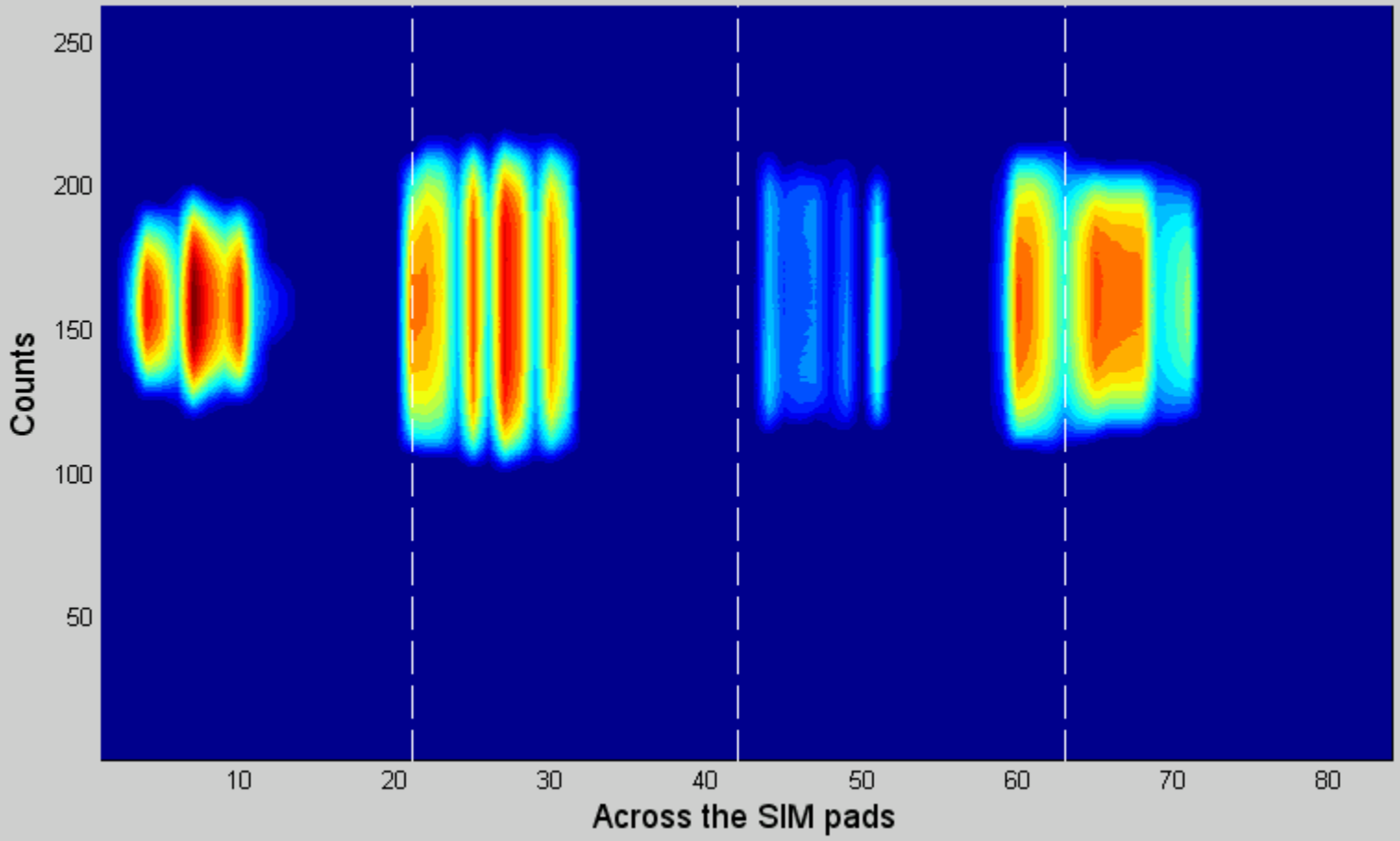
ND475336

Test No.

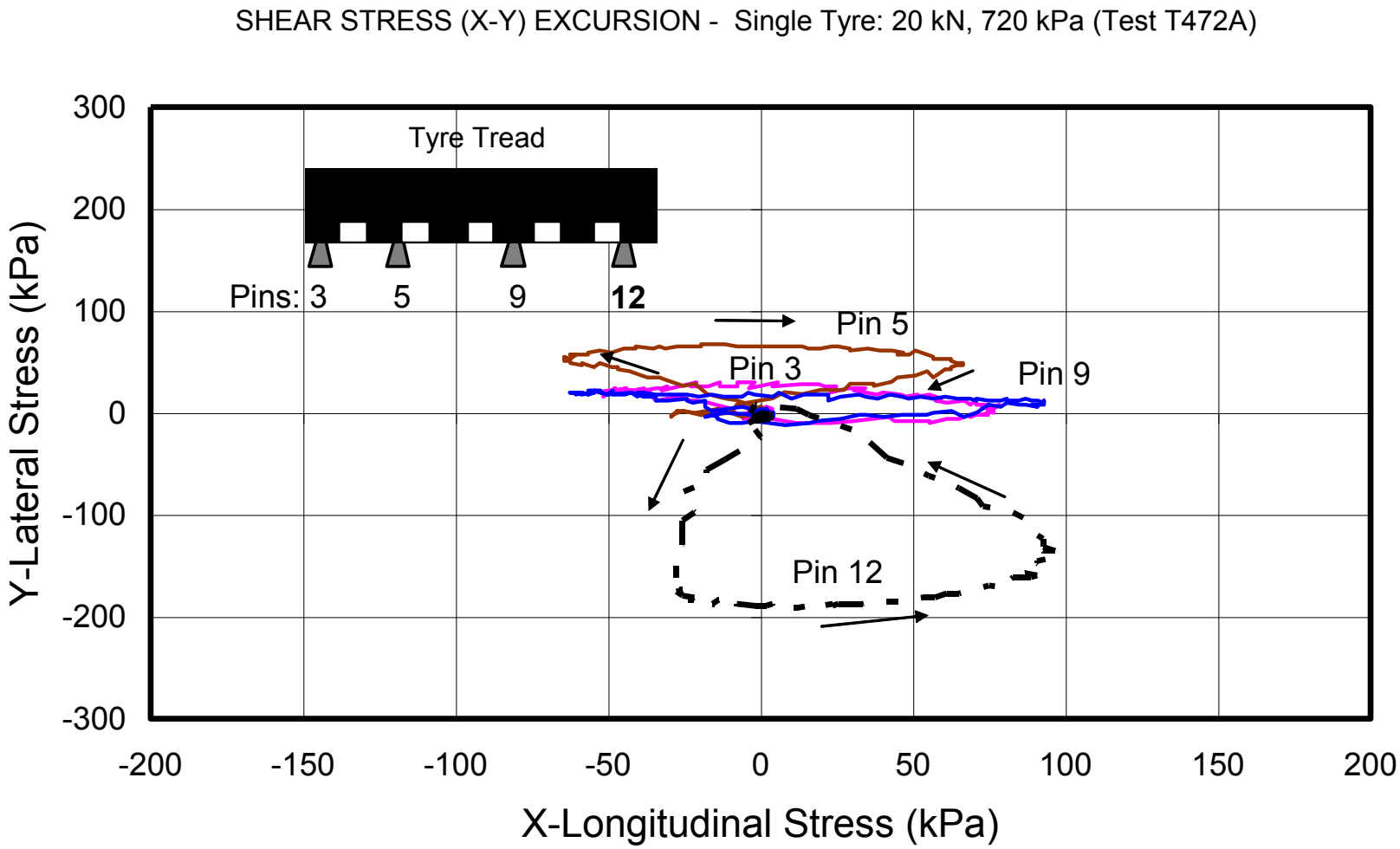
733



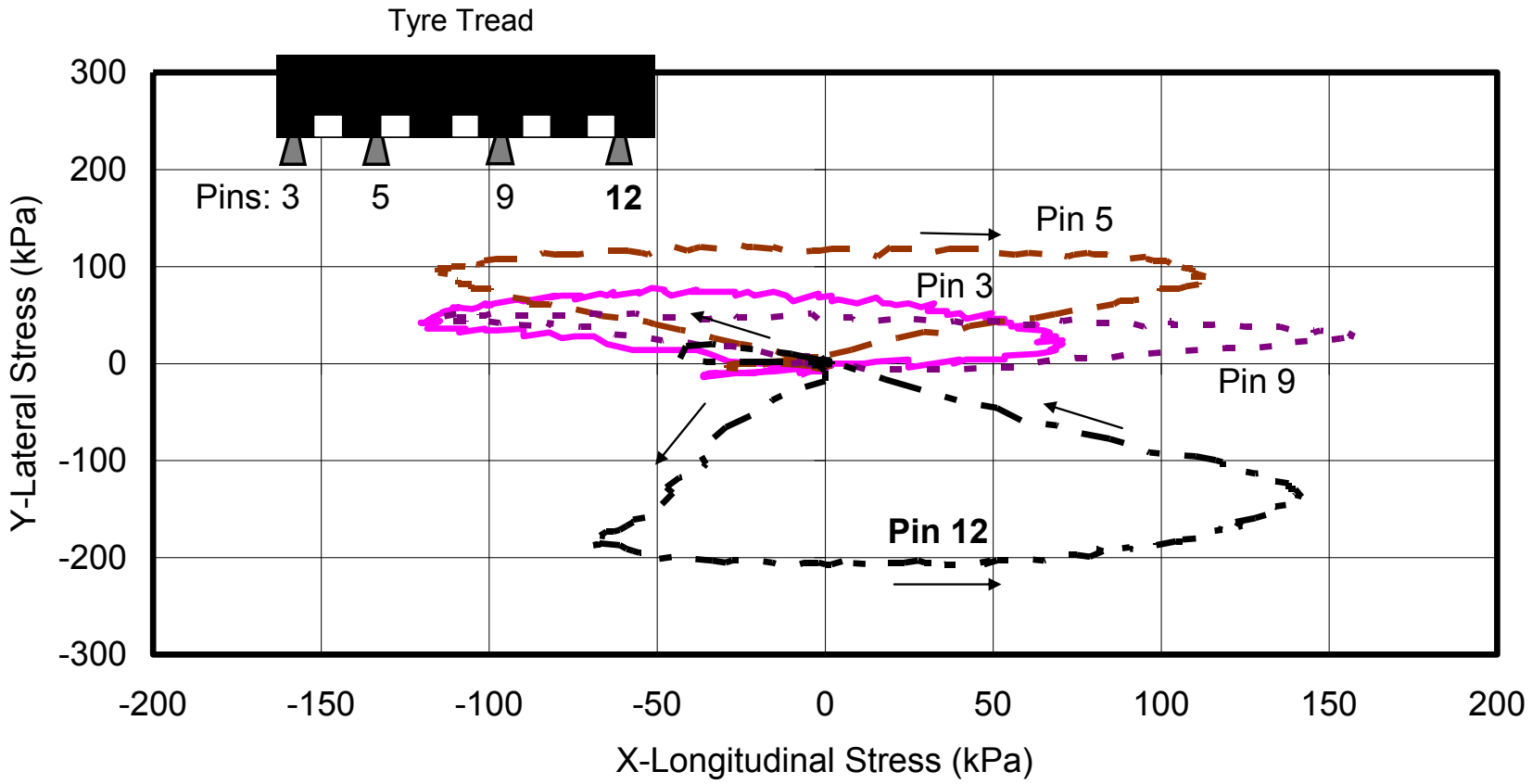
AXLE 2


250
200
150
100
50
Counts
10
20
30
40
50
60
70
80
Across the SIM pads

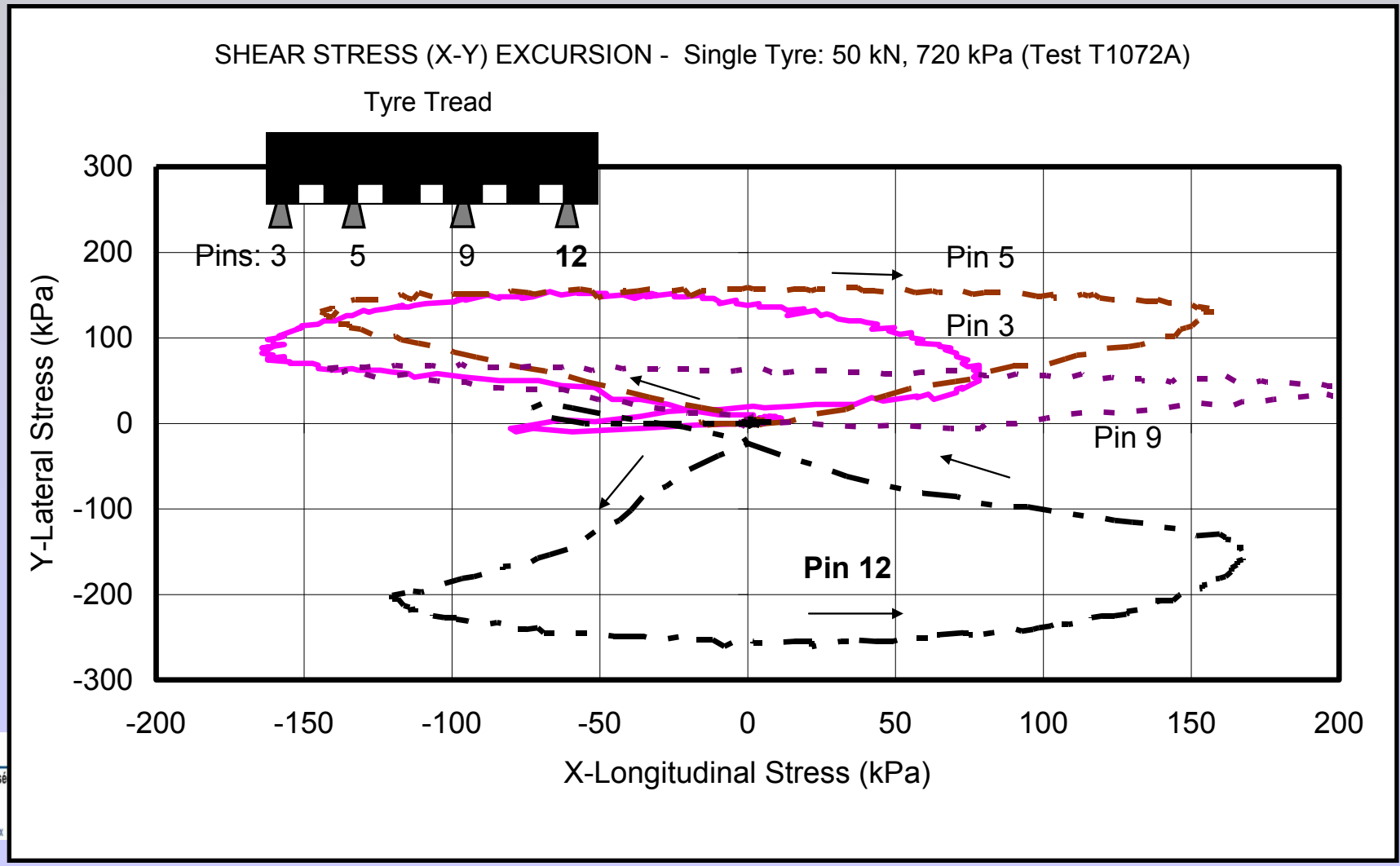
TANGENTIAL (SHEAR) STRESS EXCURSIONS: (20 kN, 720 kPa)



TANGENTIAL (SHEAR) STRESS EXCURSIONS: (35 kN, 720 kPa)



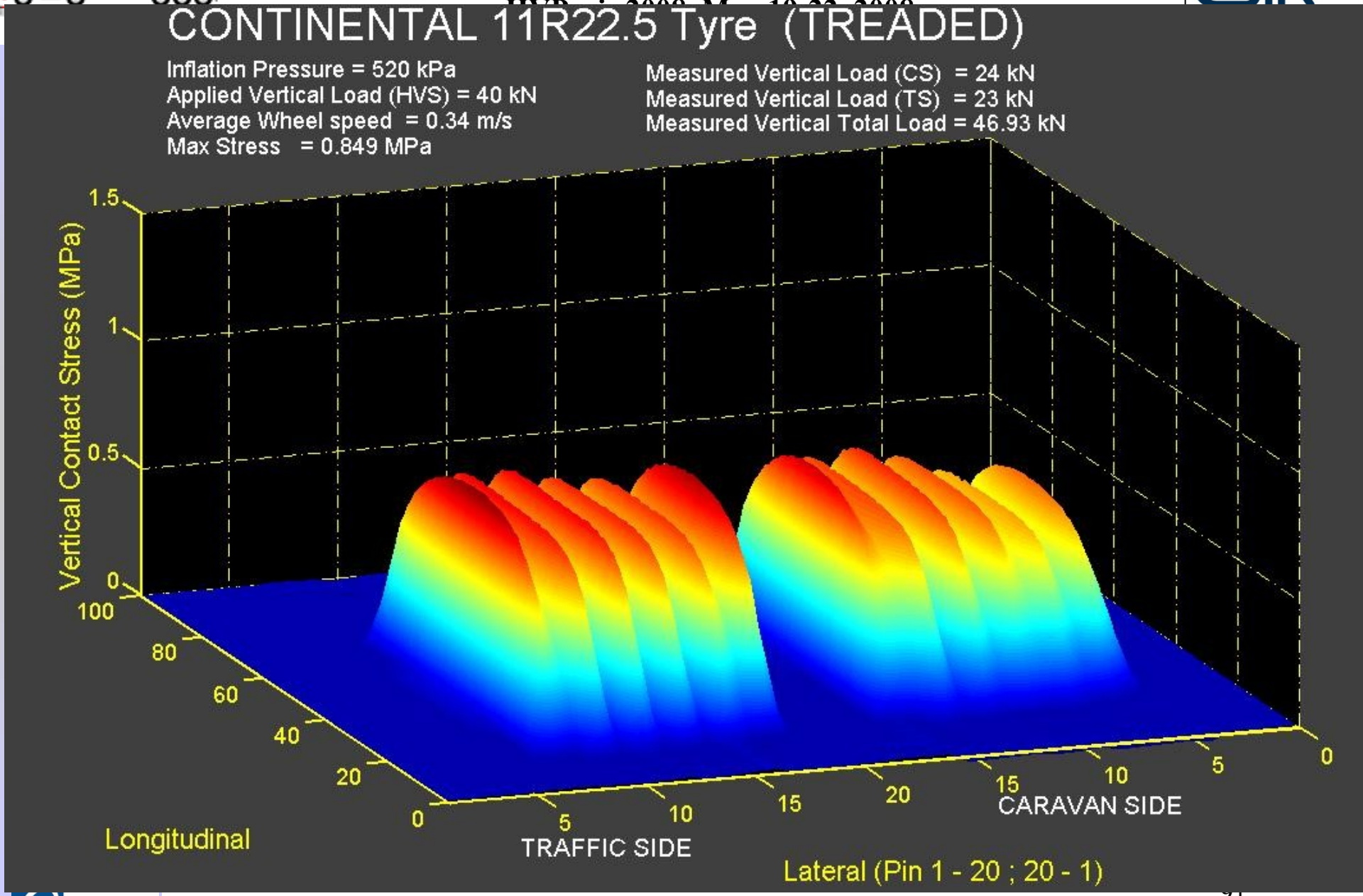
TANGENTIAL (SHEAR) STRESS EXCURSIONS: (50 kN, 720 kPa)

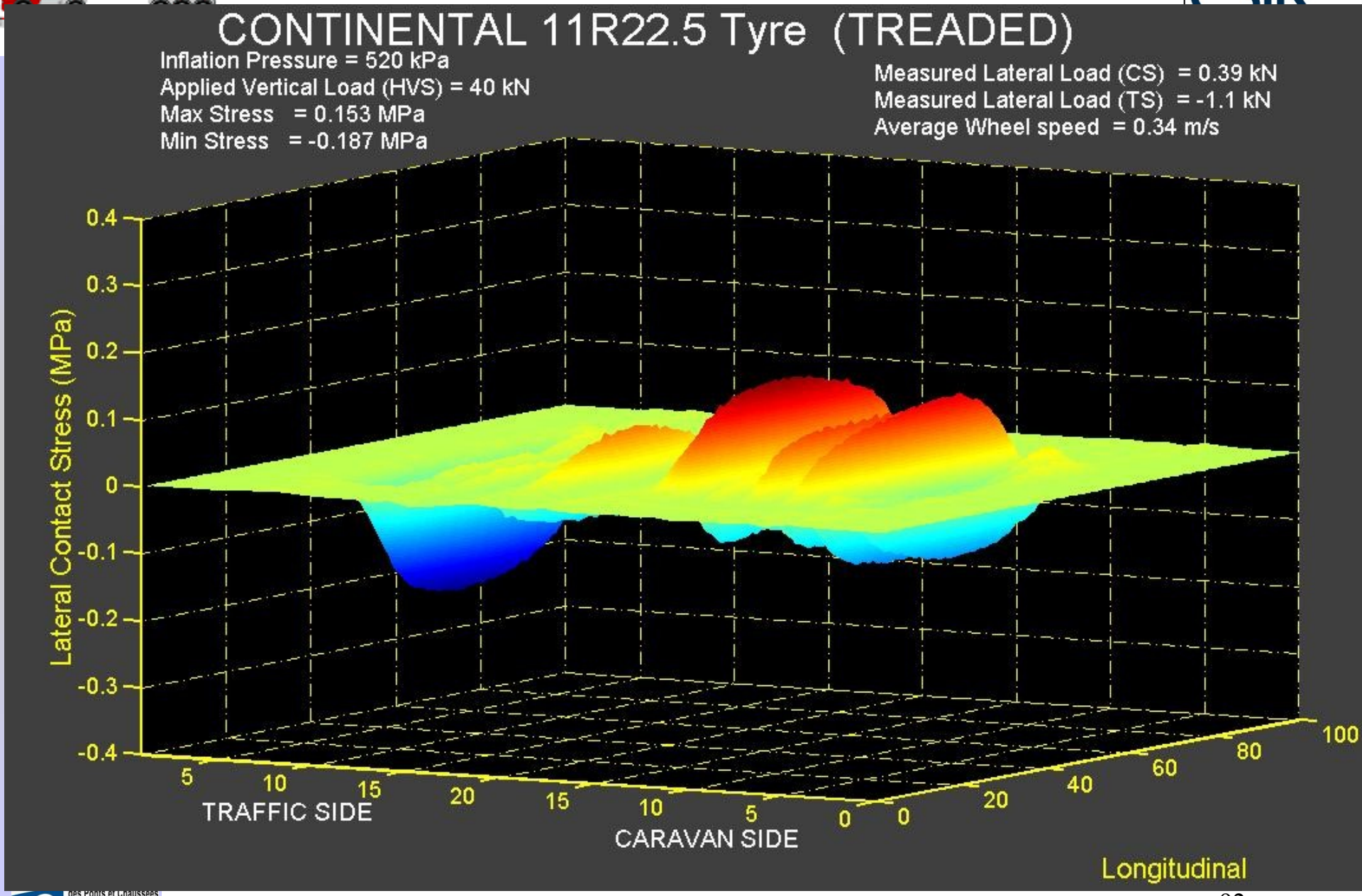


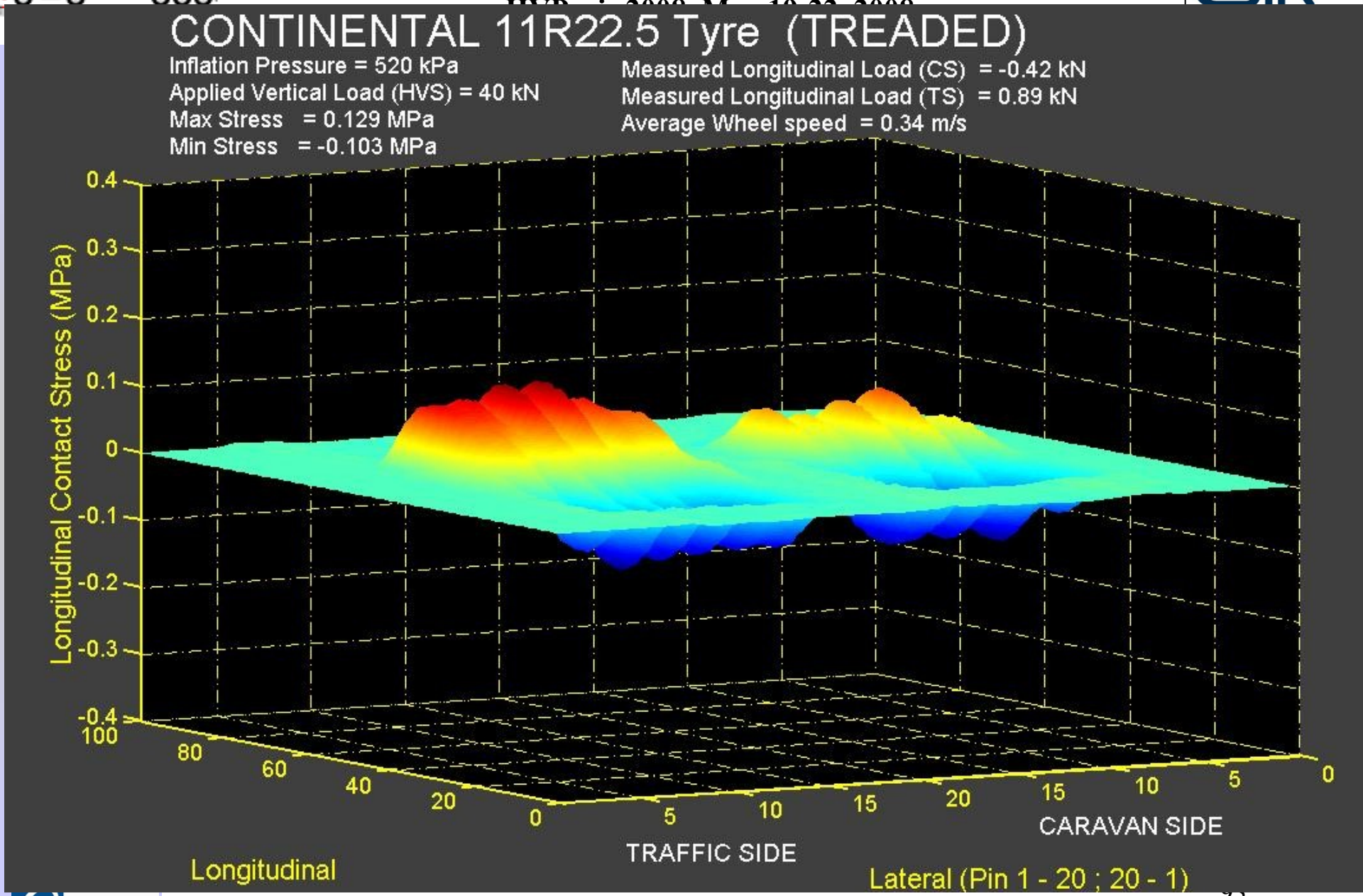
Thank You for listening…

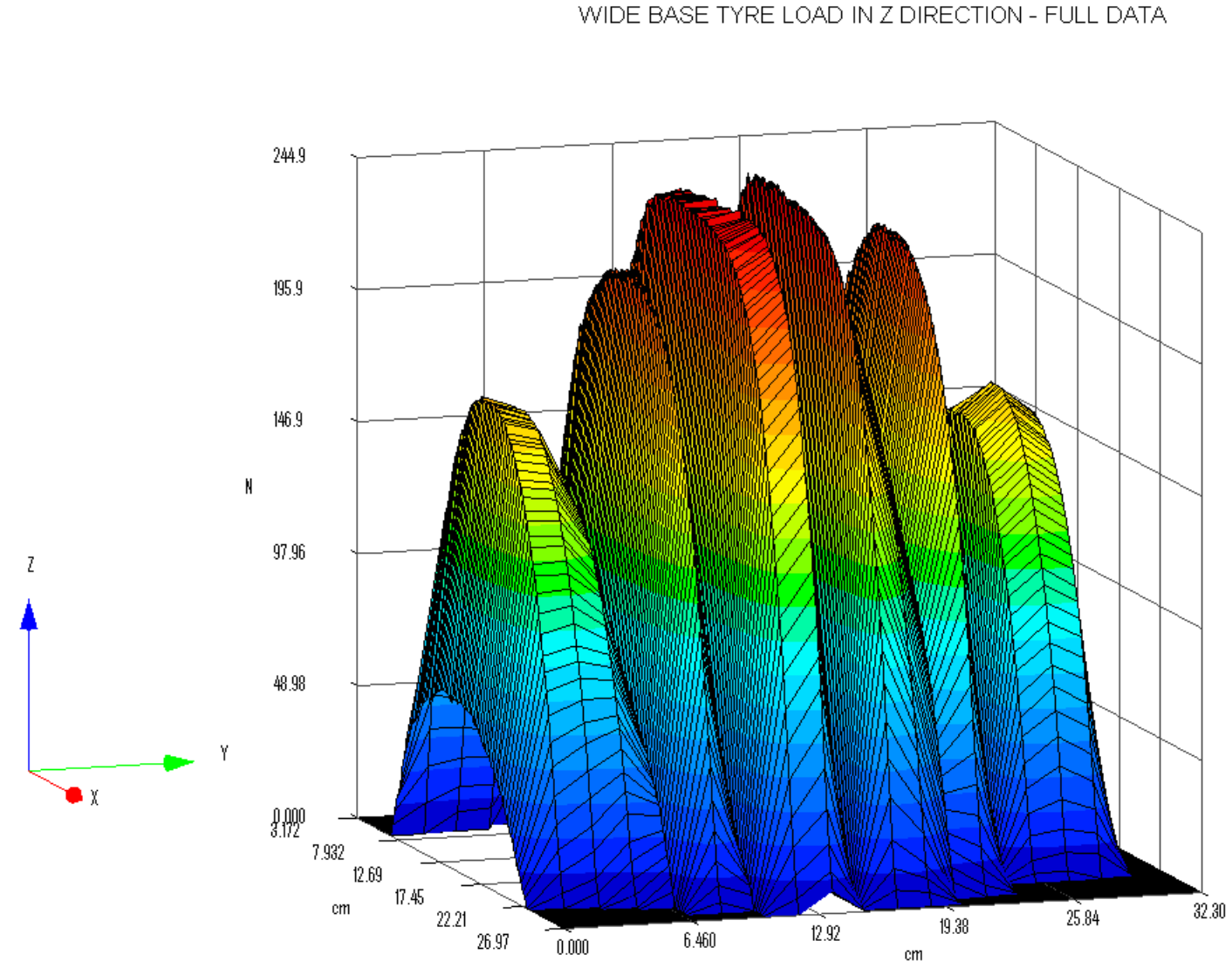
…any Questions ?

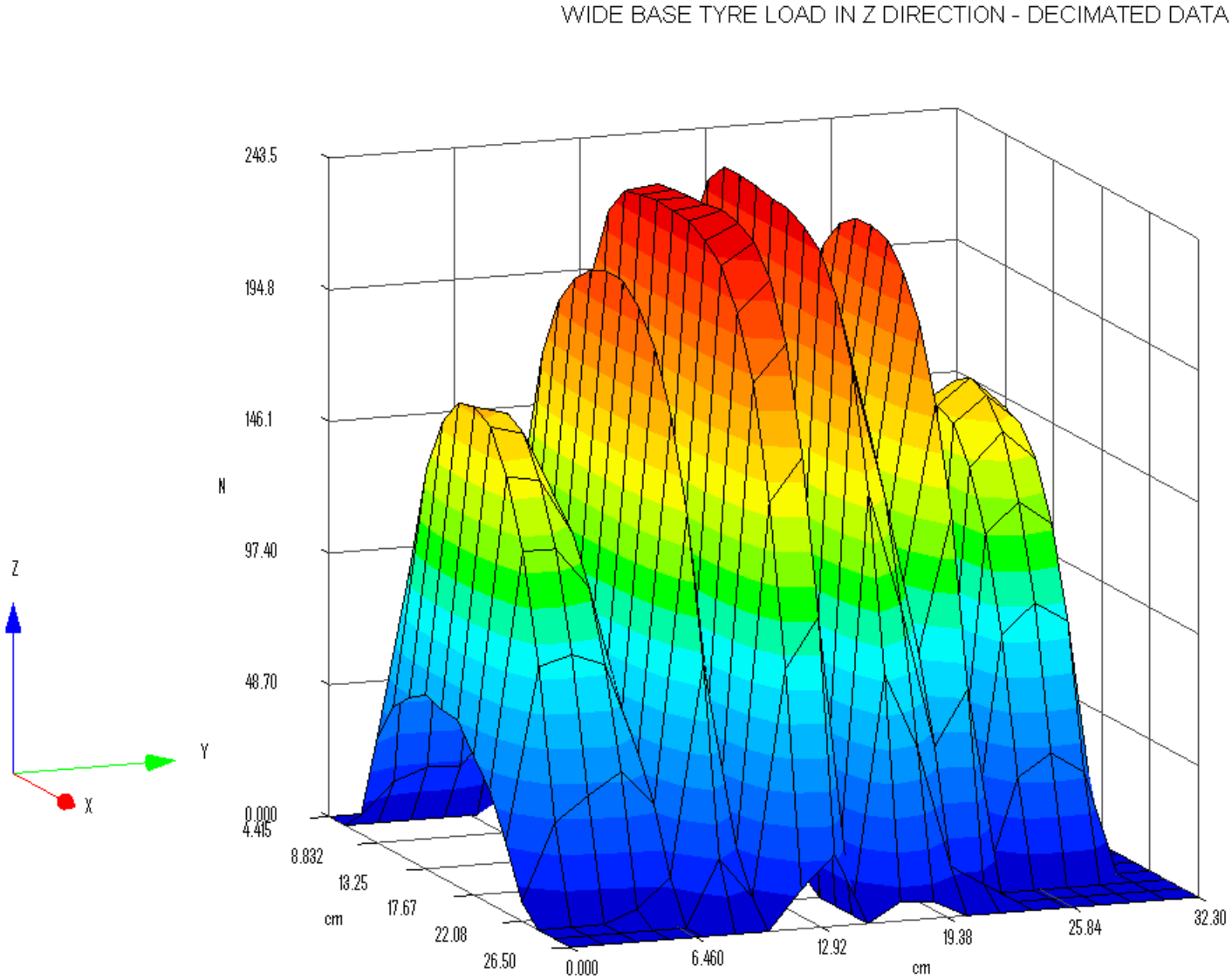

Thank you for your attention..

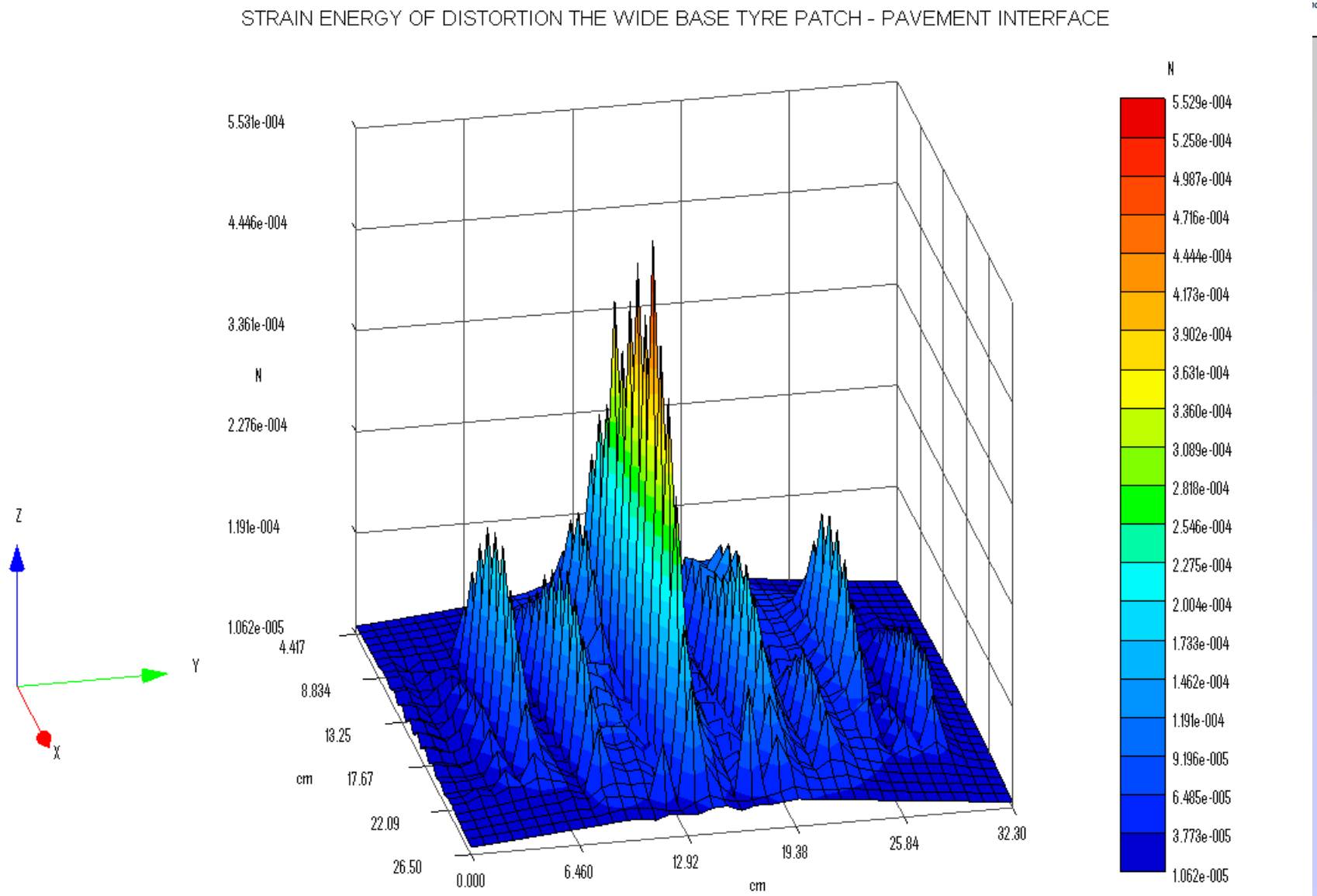

CONTINENTAL 11R22.5 Tyre (TREADED)
Inflation Pressure = 520 kPa
Applied Vertical Load (HVS) = 40 kN
Average Wheel speed = 0.34 m/s
Max Stress = 0.849 MPa
Measured Vertical Load (CS) = 24 kN
Measured Vertical Load (TS) = 23 kN
Measured Vertical Total Load = 46.93 kN
Vertical Contact Stress (MPa)
1.5
1
0.5
0
100
80
60
40
20
0
Longitudinal
0
5
10
15
20
TRAFFIC SIDE
Lateral (Pin 1 - 20 ; 20 - 1)
15
10
5
0
CARAVAN SIDE


CONTINENTAL 11R22.5 Tyre (TREADED)
Inflation Pressure = 520 kPa
Applied Vertical Load (HVS) = 40 kN
Max Stress = 0.153 MPa
Min Stress = -0.187 MPa
Measured Lateral Load (CS) = 0.39 kN
Measured Lateral Load (TS) = -1.1 kN
Average Wheel speed = 0.34 m/s
Lateral Contact Stress (MPa)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
5
10
15
20
TRAFFIC SIDE
15
10
5
0
CARAVAN SIDE
0
20
40
60
80
100
Longitudinal

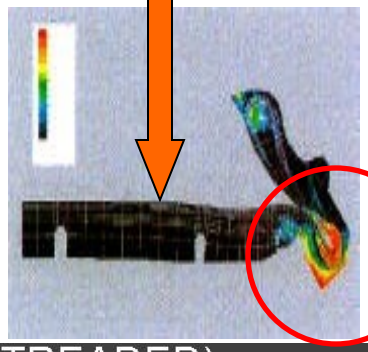

CONTINENTAL 11R22.5 Tyre (TREADED)
Inflation Pressure = 520 kPa
Applied Vertical Load (HVS) = 40 kN
Max Stress = 0.129 MPa
Min Stress = -0.103 MPa
Measured Longitudinal Load (CS) = -0.42 kN
Measured Longitudinal Load (TS) = 0.89 kN
Average Wheel speed = 0.34 m/s
Longitudinal Contact Stress (MPa)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
100
80
60
40
20
0
Longitudinal
0
5
10
15
20
TRAFFIC SIDE
15
10
5
0
CARAVAN SIDE
Lateral (Pin 1 - 20 ; 20 - 1)


WIDE BASE TYRE LOAD IN Z DIRECTION - FULL DATA
N
244.9
232.7
220.4
208.2
195.9
183.7
171.4
159.2
146.9
134.7
122.5
110.2
97.96
85.72
73.47
61.23
48.98
36.73
24.49
12.25
0.000
244.9
195.9
146.9
97.96
48.98
0.000
N
Z
Y
X
3.172
7.932
12.69
17.45
22.21
26.97
cm
0.000
6.460
12.92
19.38
25.84
32.30
cm

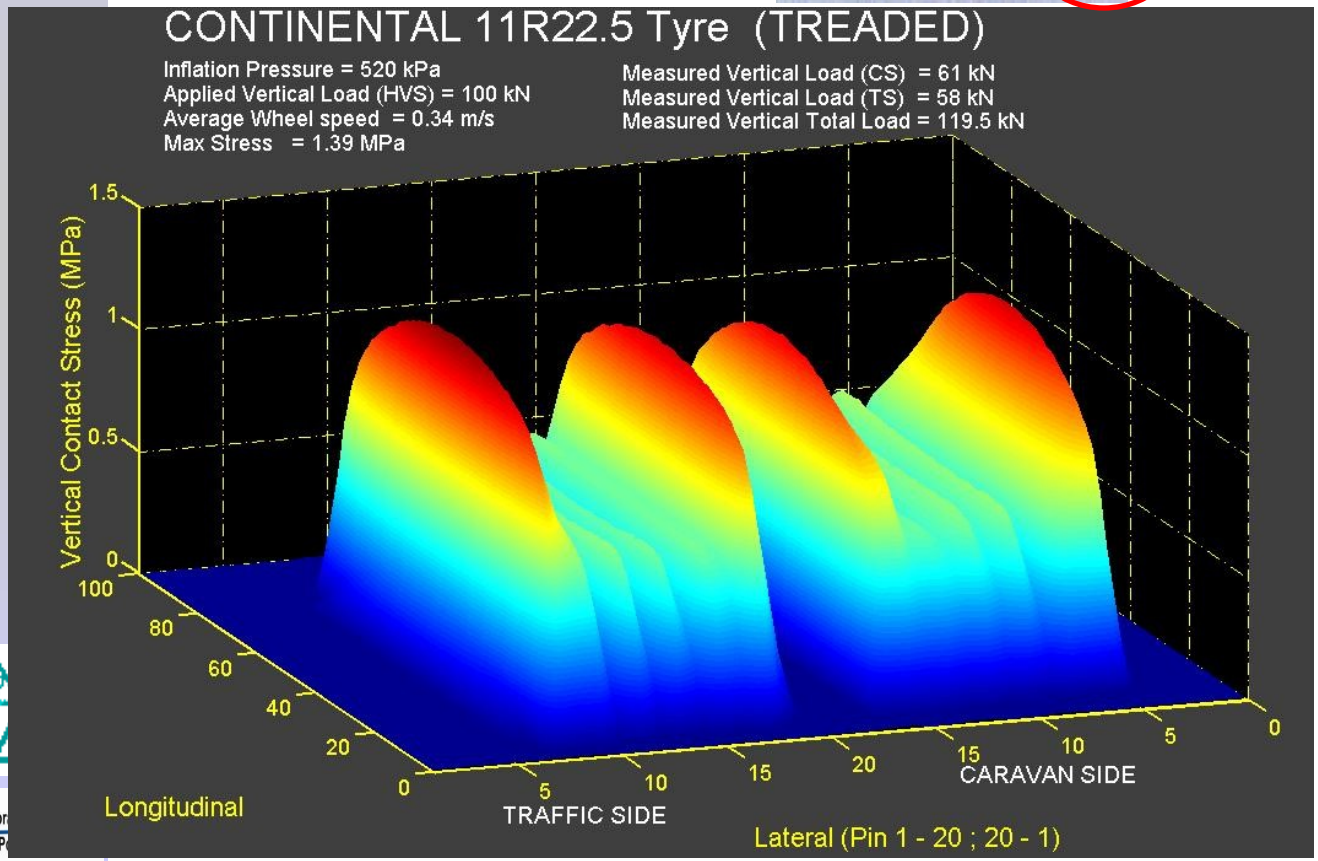

WIDE BASE TYRE LOAD IN Z DIRECTION - DECIMATED DATA
N
243.5
231.3
219.2
207.0
194.8
182.6
170.5
158.3
146.1
133.9
121.8
109.6
97.40
85.23
73.05
60.88
48.70
36.53
24.35
12.18
0.000
243.5
194.8
146.1
N
97.40
48.70
0.000
Z
Y
X
4.415
8.832
13.25
17.67
22.08
26.50
cm
0.000
6.460
12.92
19.38
25.84
32.30
cm

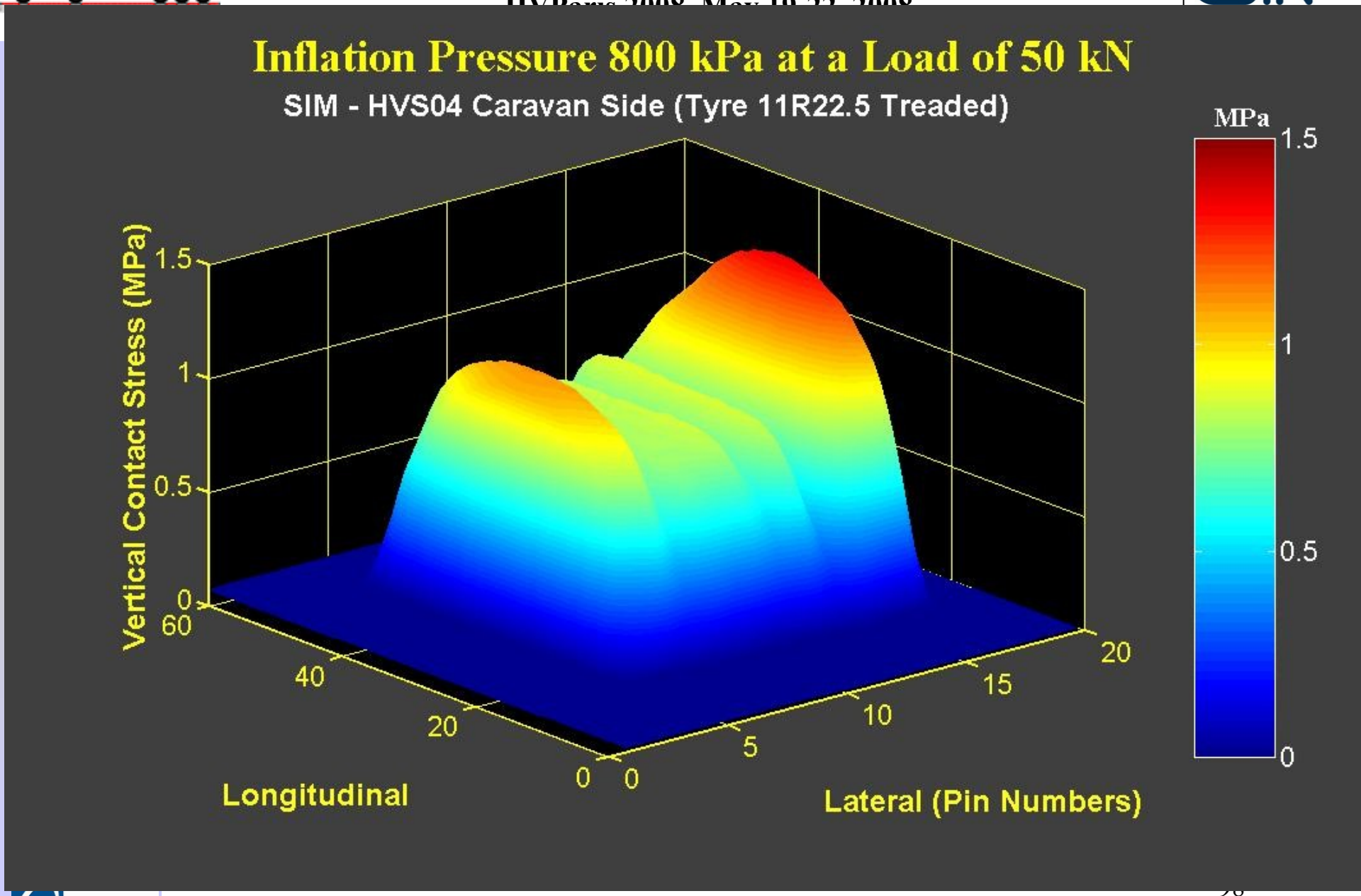

STRAIN ENERGY OF DISTORTION THE WIDE BASE TYRE PATCH - PAVEMENT INTERFACE
N
5.531e-004
4.446e-004
3.361e-004
N
2.276e-004
1.191e-004
1.062e-005
Z
Y
X
4.417
8.834
13.25
cm
17.67
22.09
26.50
0.000
6.460
12.92
19.38
25.84
32.30
cm
N
5.529e-004
5.258e-004
4.987e-004
4.716e-004
4.444e-004
4.173e-004
3.902e-004
3.631e-004
3.360e-004
3.089e-004
2.818e-004
2.546e-004
2.275e-004
2.004e-004
1.733e-004
1.462e-004
1.191e-004
9.196e-005
6.485e-005
3.773e-005
1.062e-005

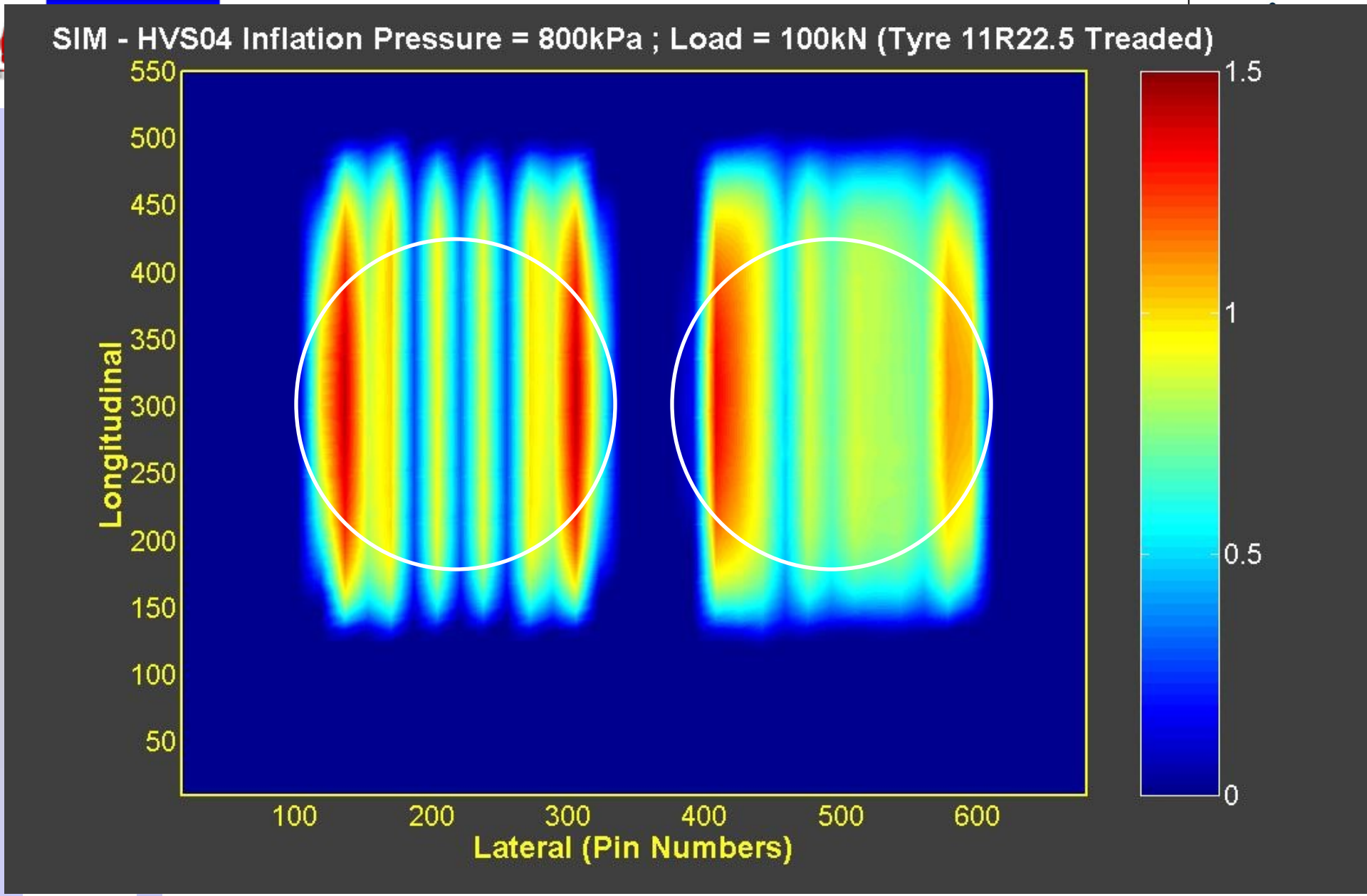
OVER-LOADING/UNDER INFLATION



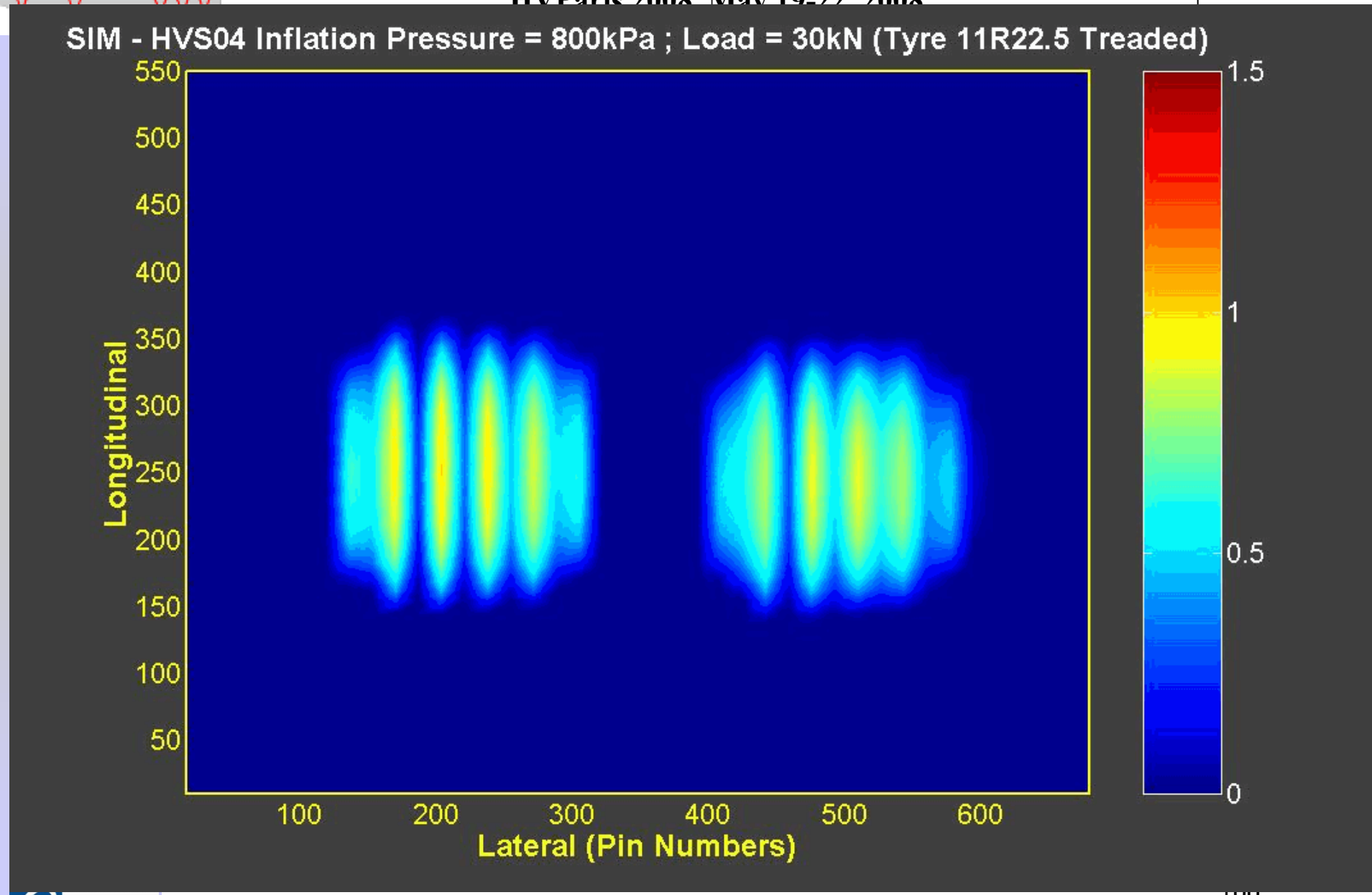
Tyre Edge




Inflation Pressure 800 kPa at a Load of 50 kN
SIM - HVS04 Caravan Side (Tyre 11R22.5 Treaded)
MPa
1.5
1
0.5
0
Vertical Contact Stress (MPa)
1.5
1
0.5
0
60
40
20
0
Longitudinal
0
5
10
15
20
Lateral (Pin Numbers)

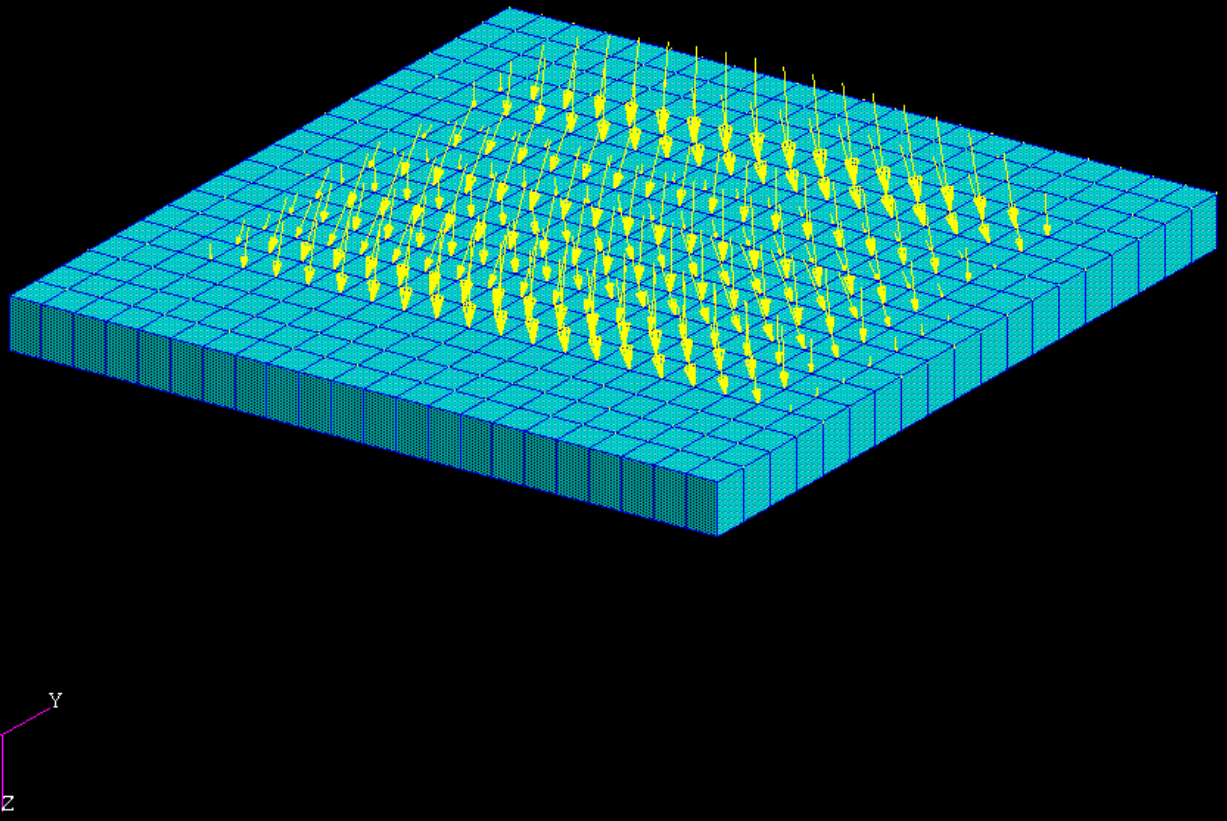


LCPC Laboratoire Central des Ponts et Chaussées
L'esprit de recherche au cœur des réseaux

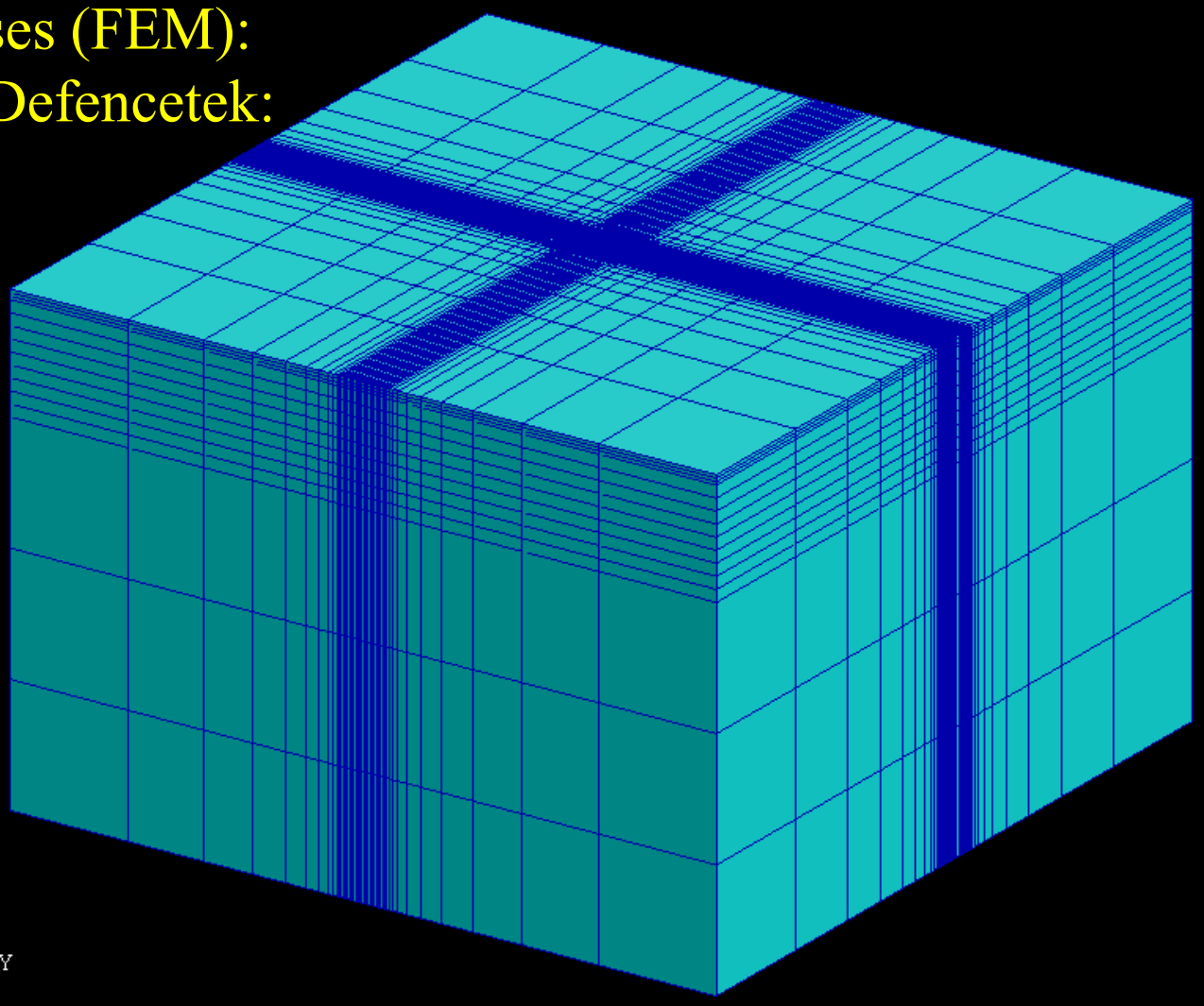


Application of non-uniform tyre loading:

Finite Element Analyses (FEA),(NASTRAN; FEAP- California

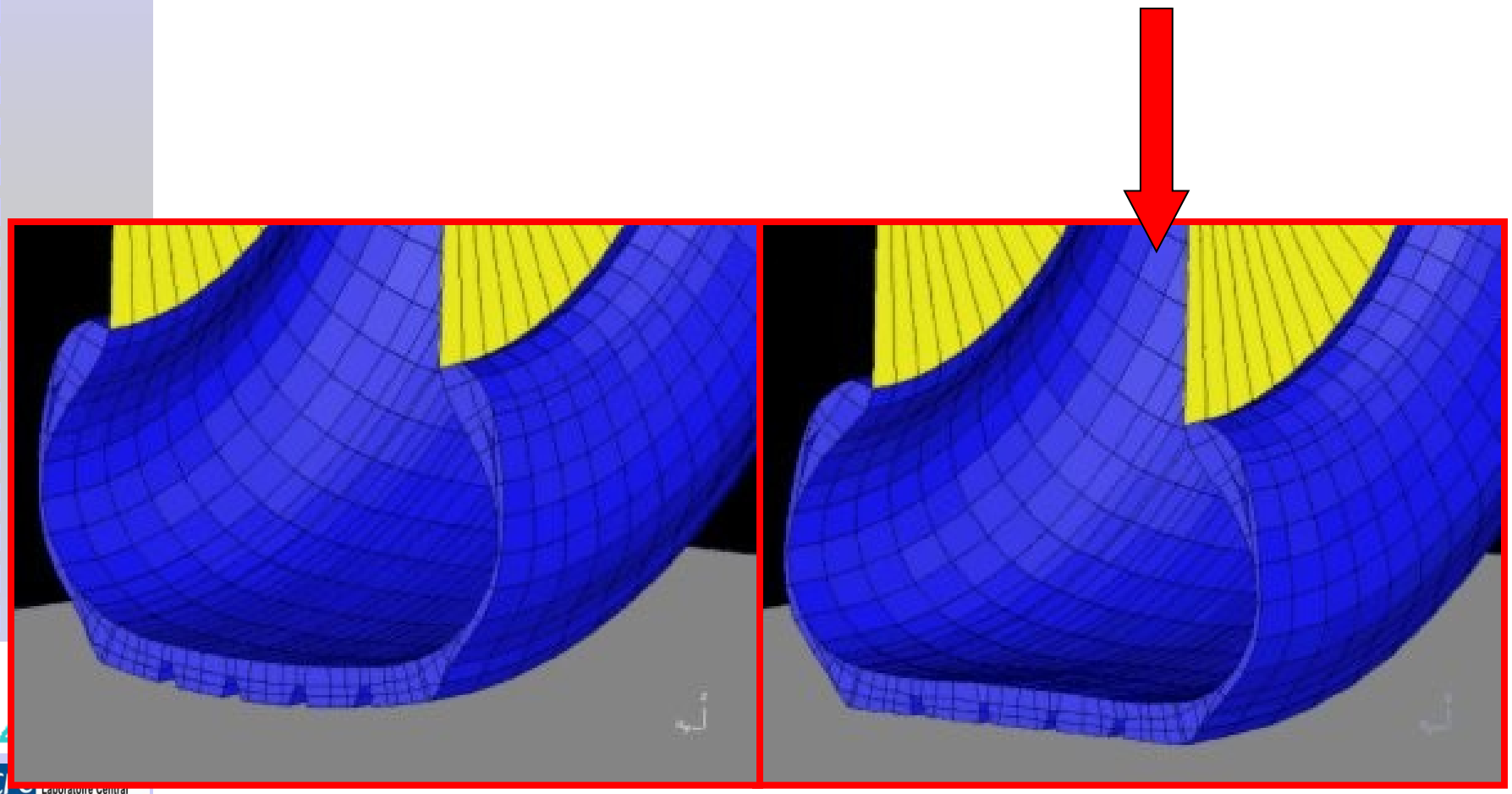


3D - Finite Element Analyses (FEM): CSIR Defencetek:

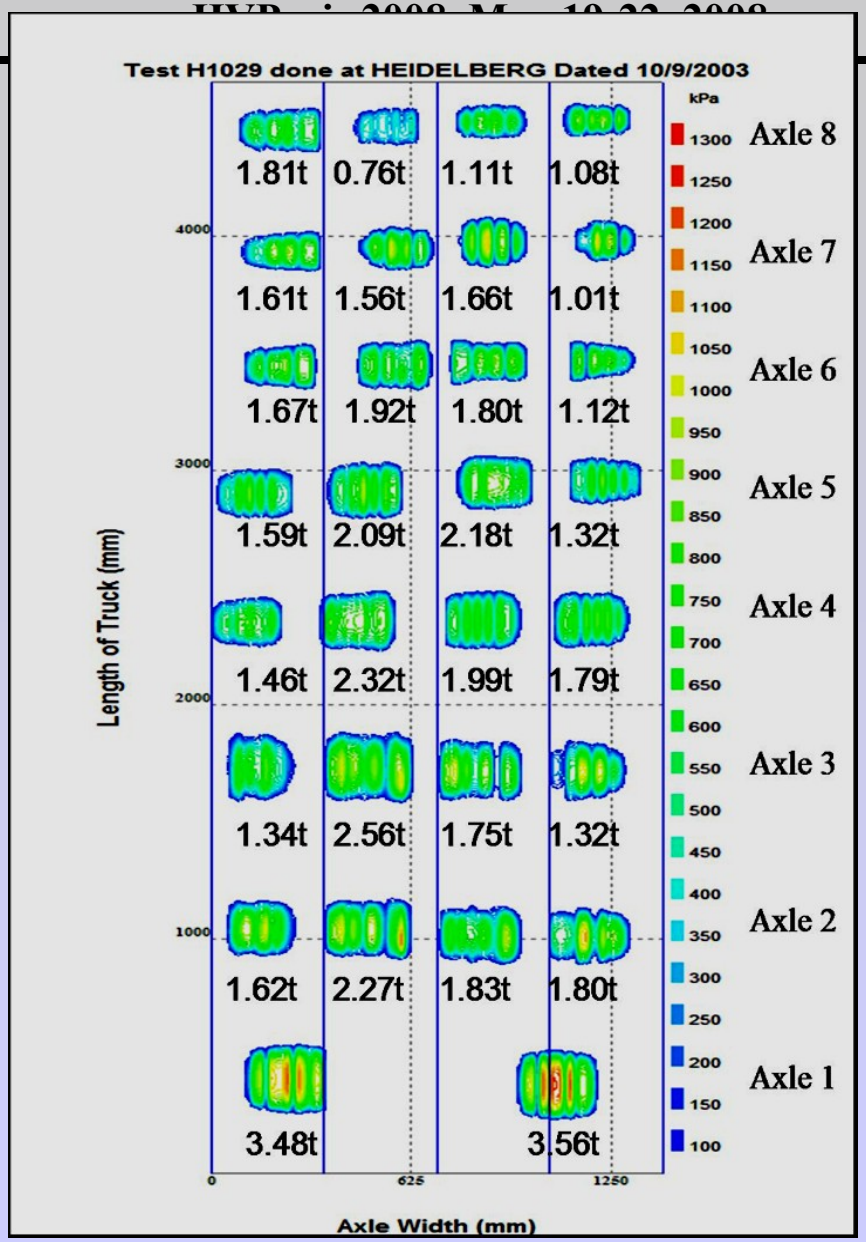


TYRE- WITH LOAD

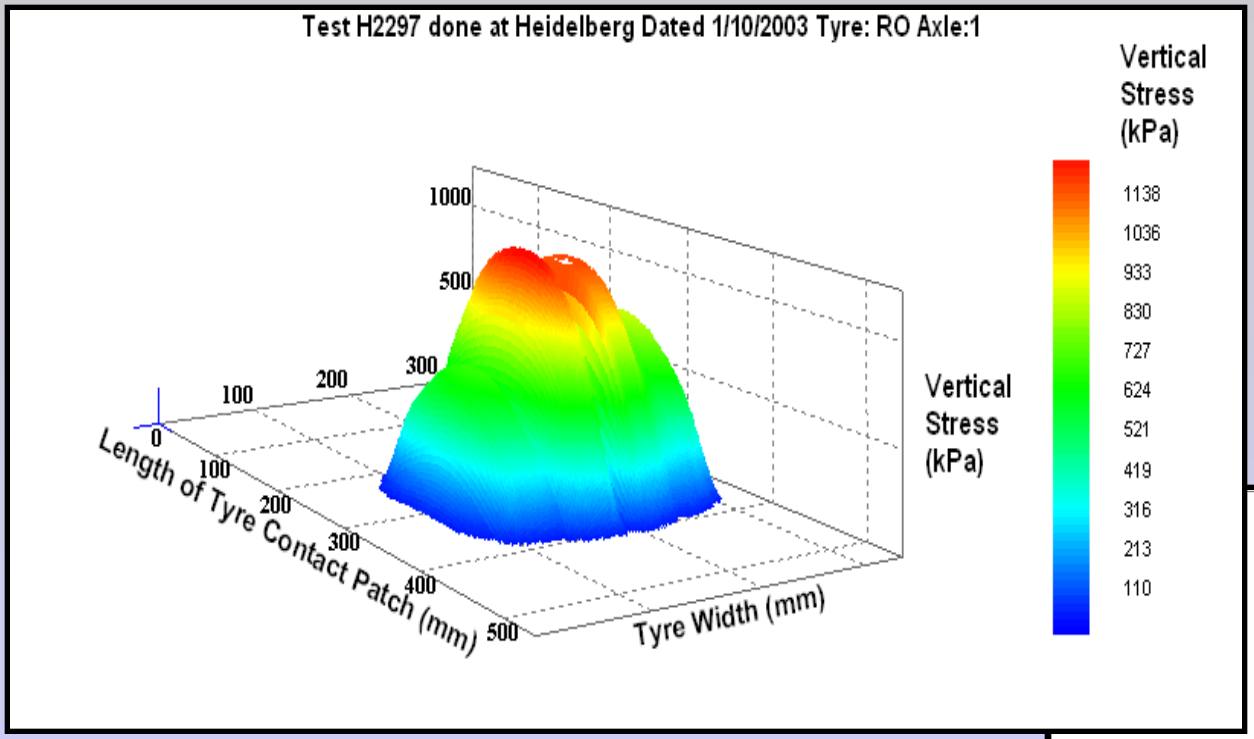
TYRE -NO LOAD

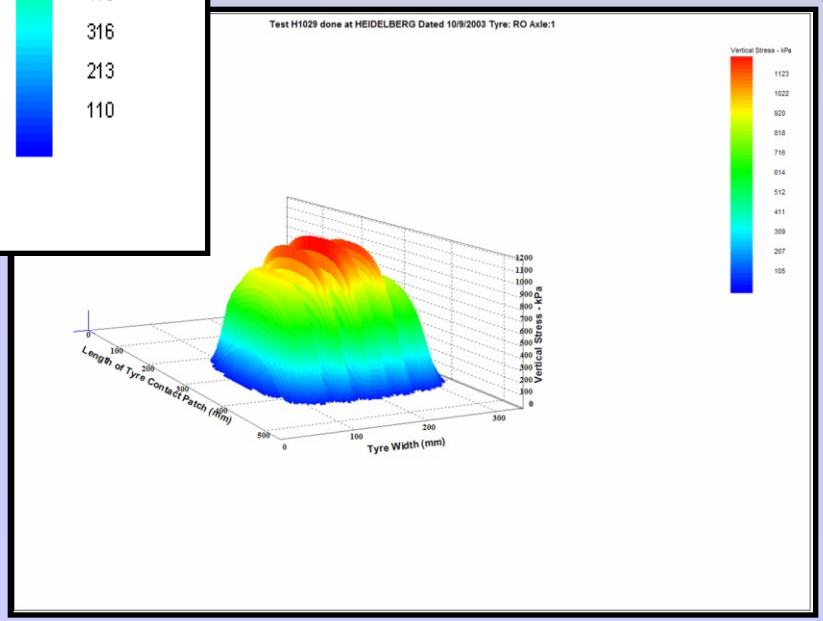


Footprint of an 8-Axle Truck - Figure 7 in Paper



Vertical Contact Stress – "n" Shape





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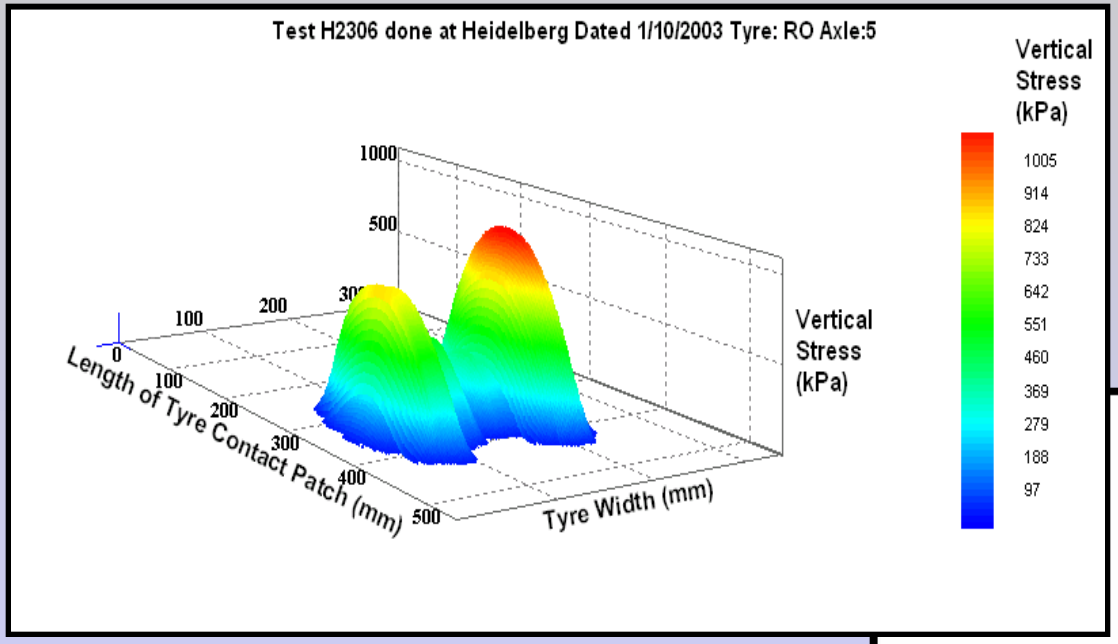
Vertical Contact Stress – "m" Shape



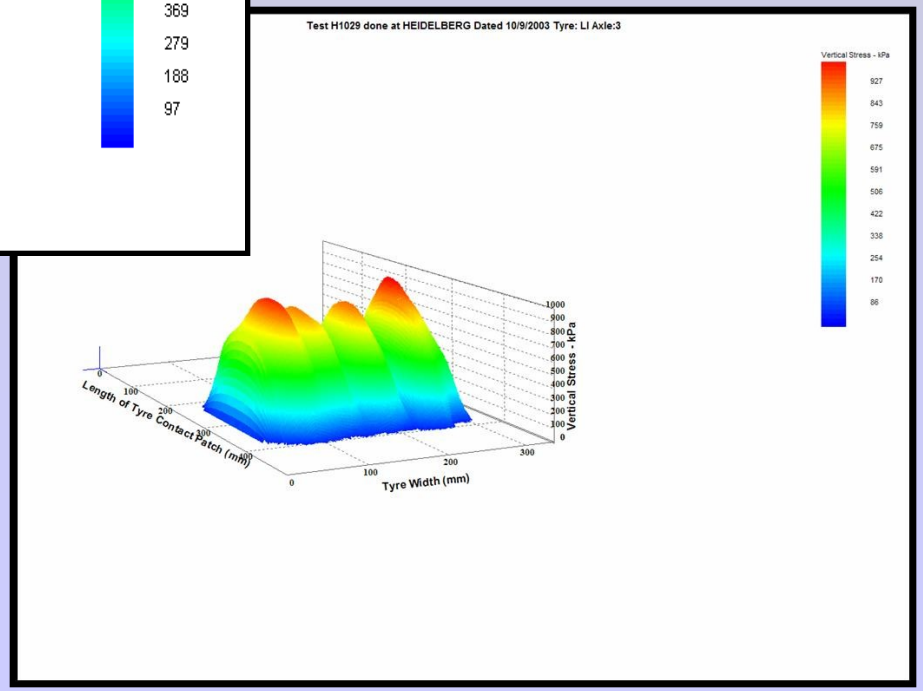
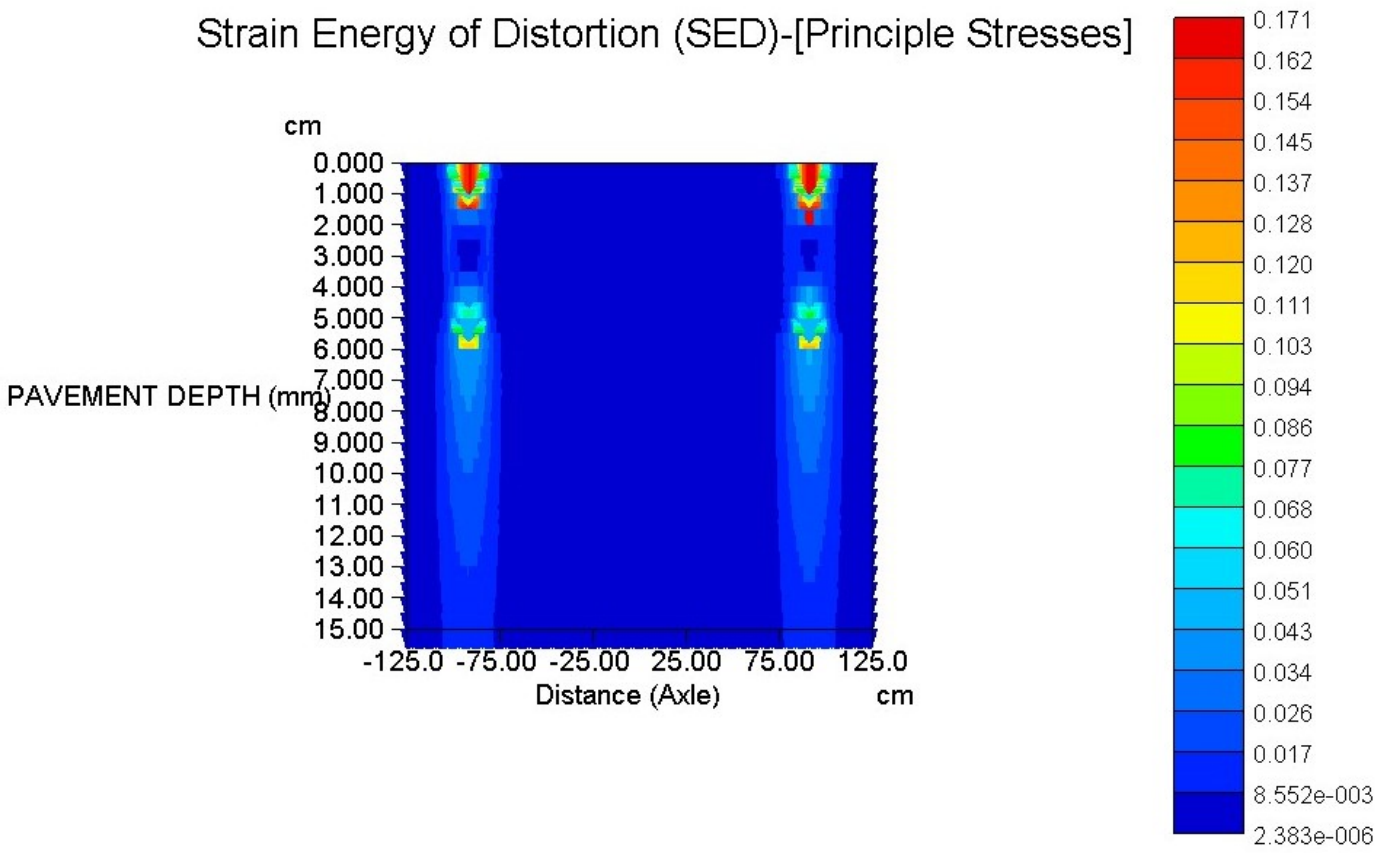


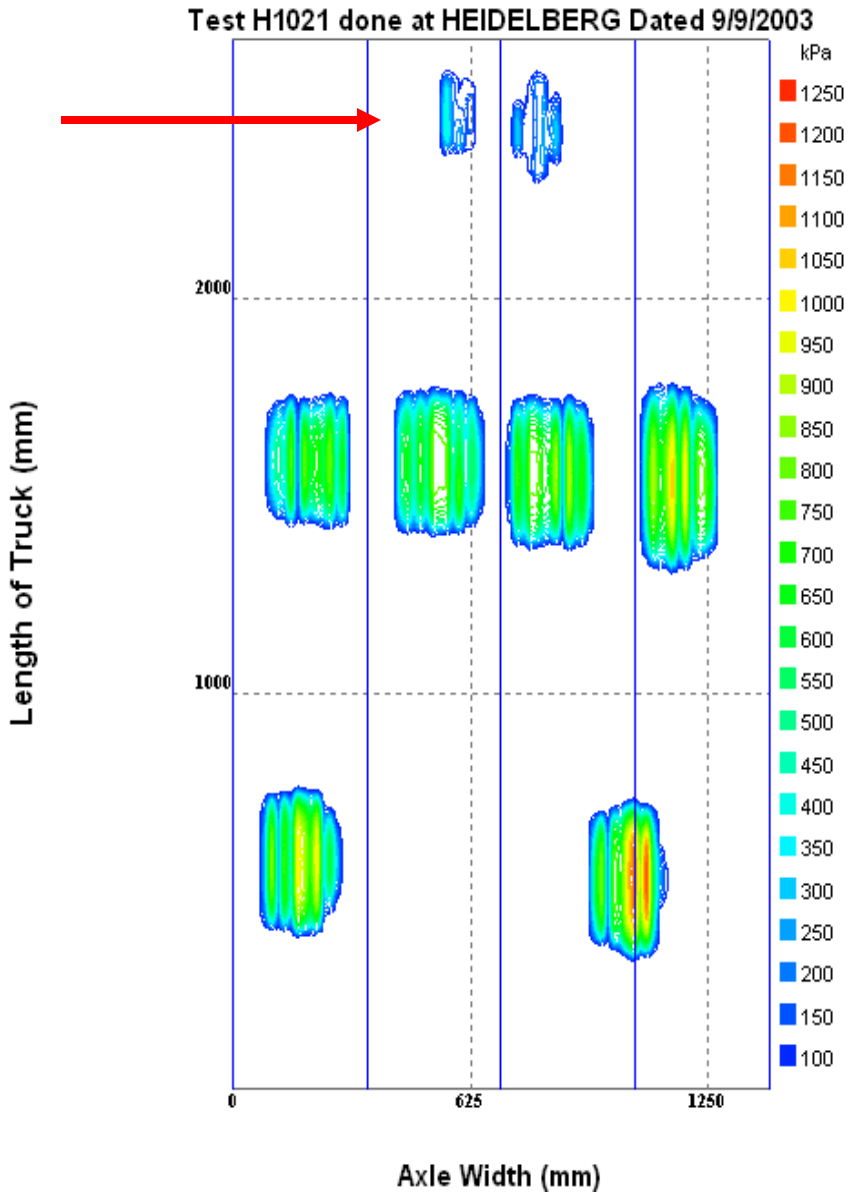
Table 1 Modelling parameters for a 3-layer pavement.

Layers	Elastic Moduli (MPa), Poisson, μ	Loading/Contact Stress	Comments
Asphalt surfacing (AC)	3500, 0.44	See Figure 11	Thickness, $t_{ac:}$ = 50 mm
Granular Base layer	350, 0.35	--	t_{ac} = 150 mm
Subgrade	100, 0.35	--	Semi Inf.

1 x Truck - 30 Tyres: 20 mm x 20 mm resolution – 20k points – SED under Steering Axle -



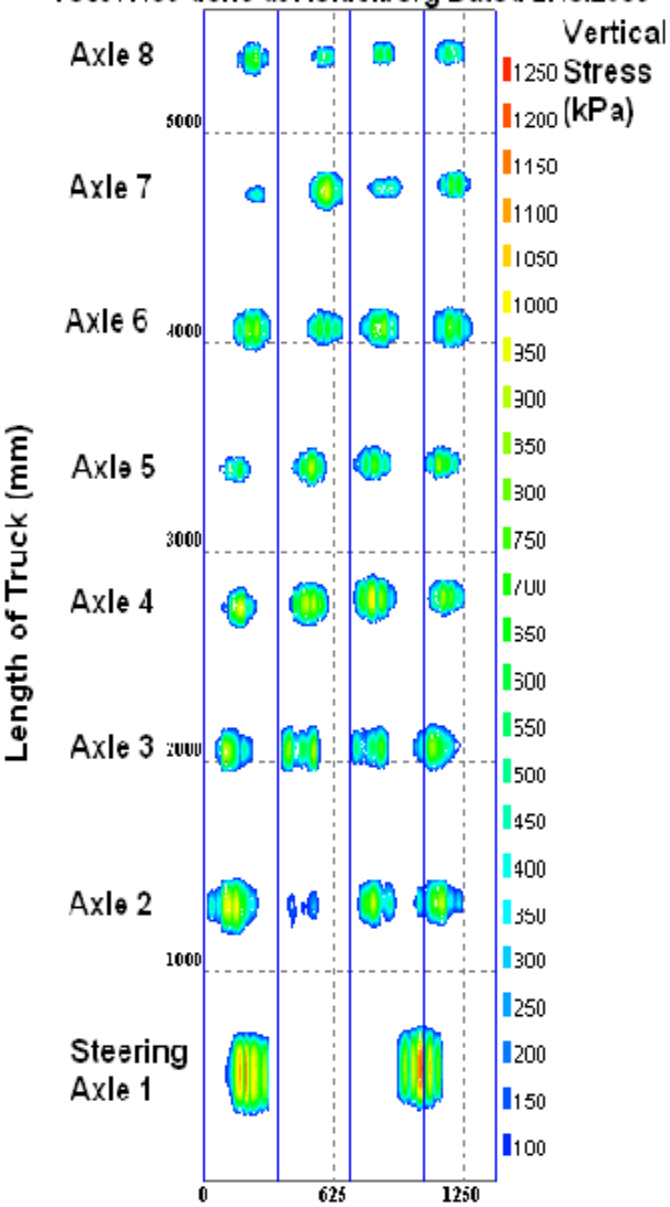
Trailer


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

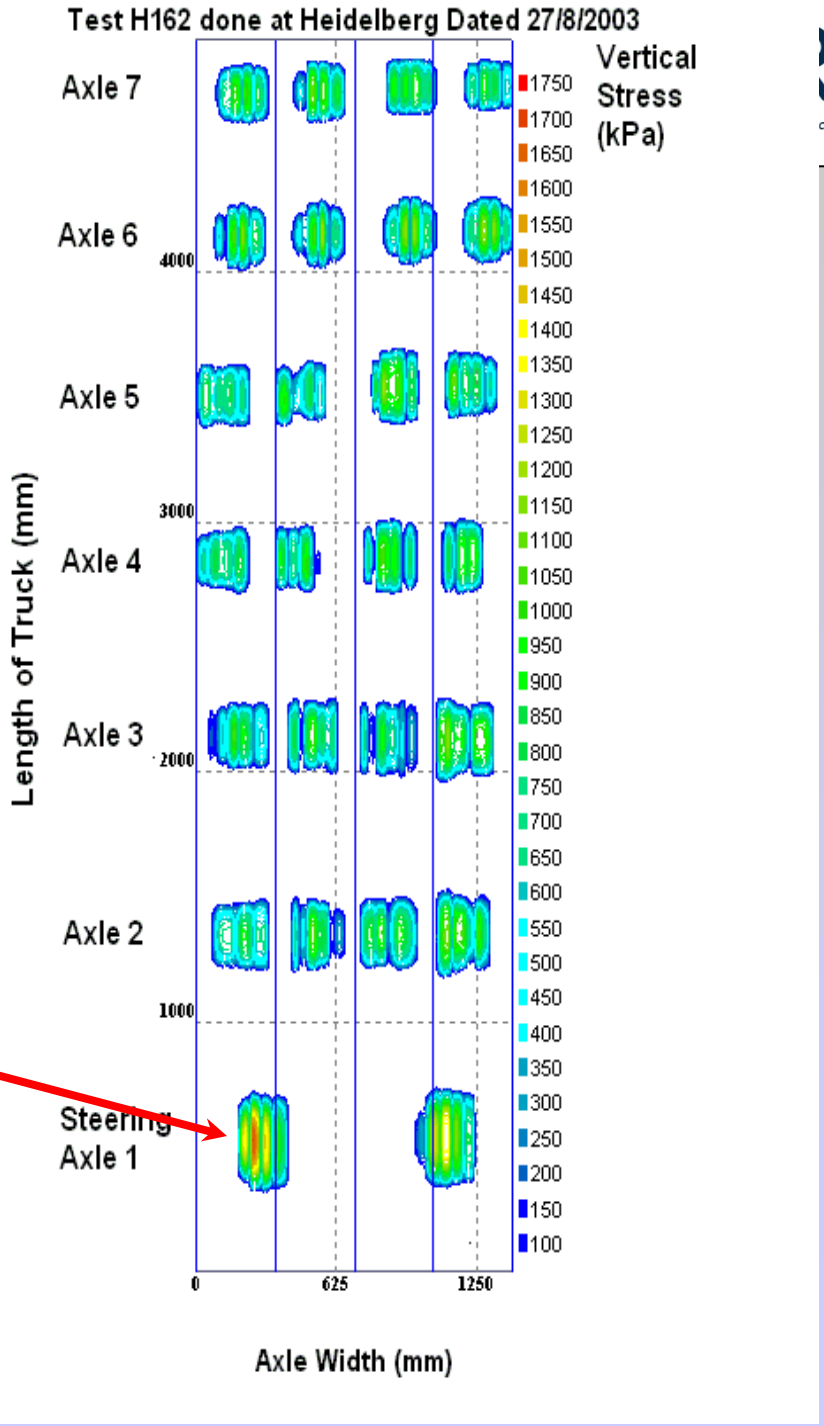
EMPTY Truck (1:2:2:3)

Note Variation in Vertical Contact Stresses on all 30 tyres



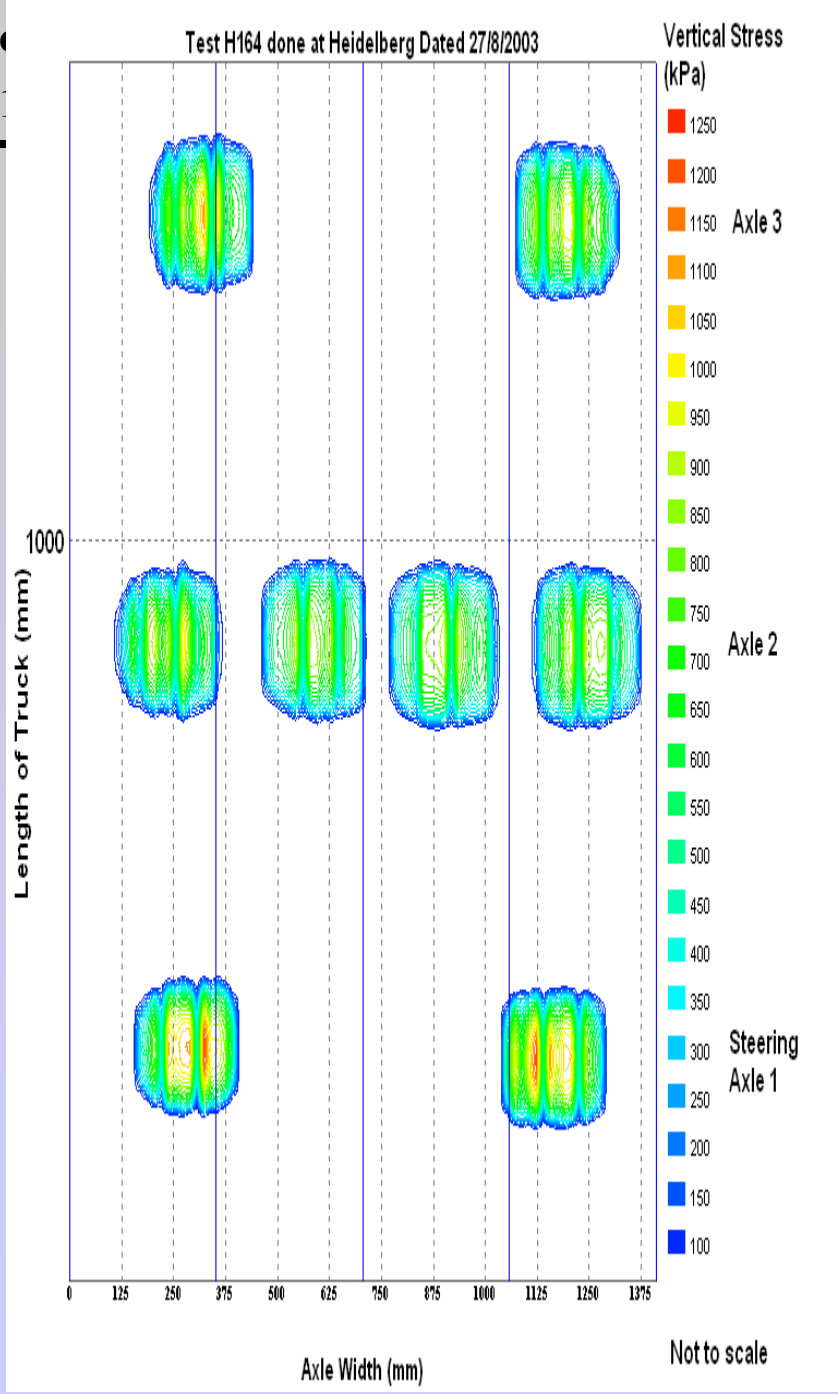
Example: 7 Axle Truck (1:2:2:2) fully loaded with cement

Note Contact Stresses on Steering Tyres



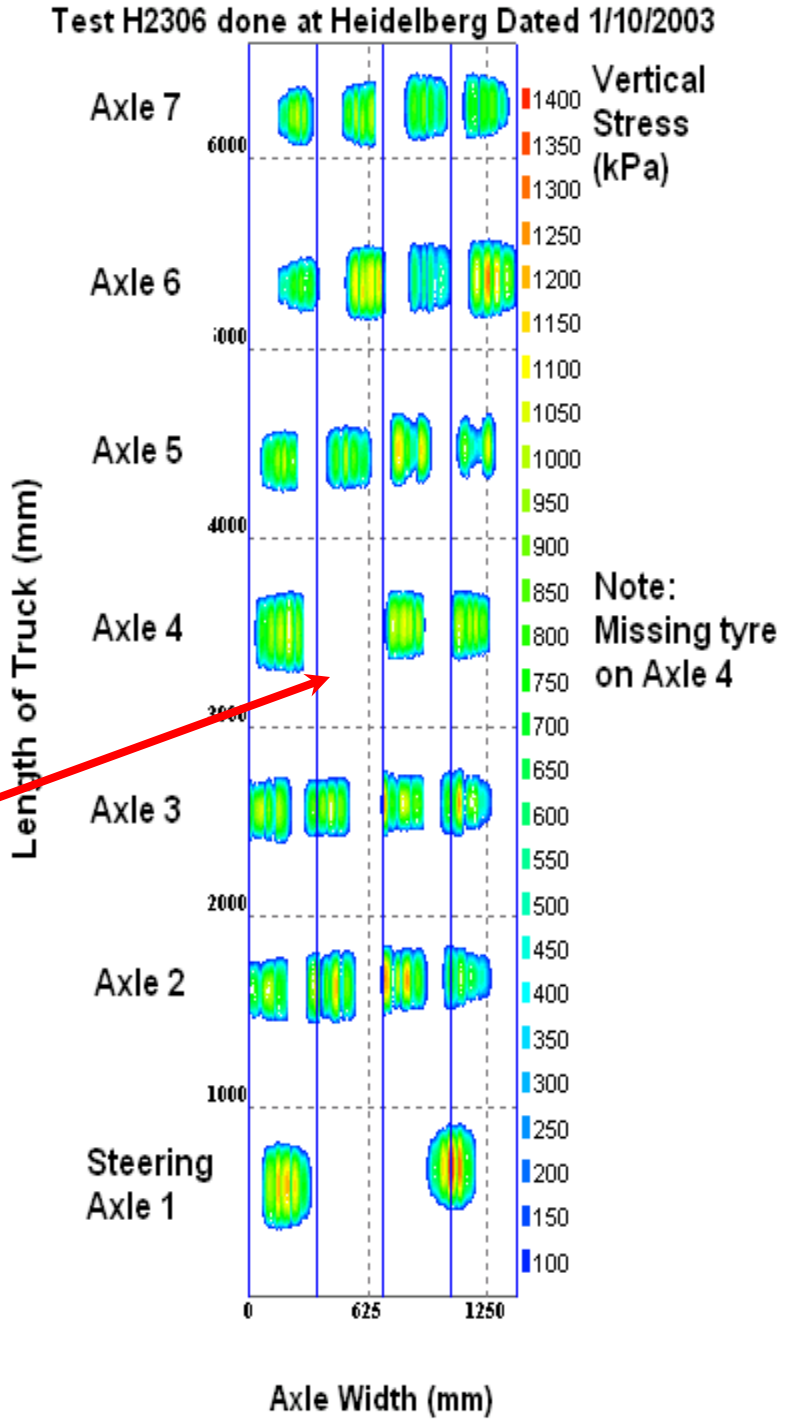
Example: Passenger Bus (1:1:1)

(FIGURE NOT TO SCALE)



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

Note the missing tyre



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