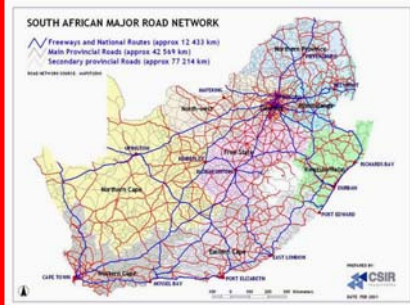
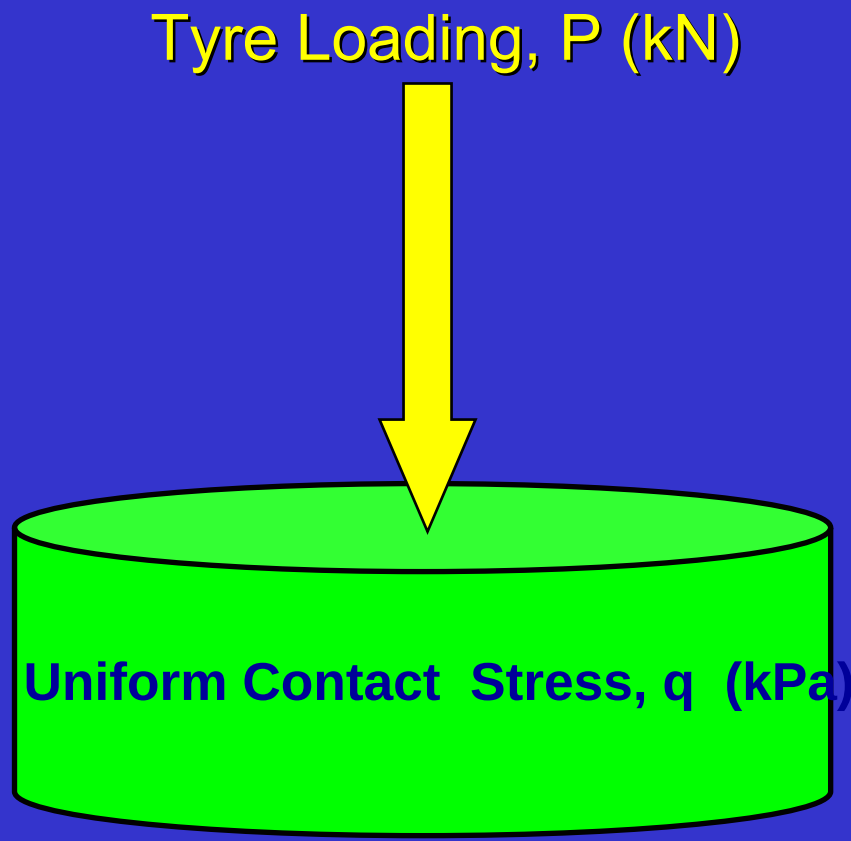
Reconsideration of Tyre-Pavement Input Parameters for the Structural Design of Flexible Pavements

Morris De Beer, CSIR Built Environment
South Africa

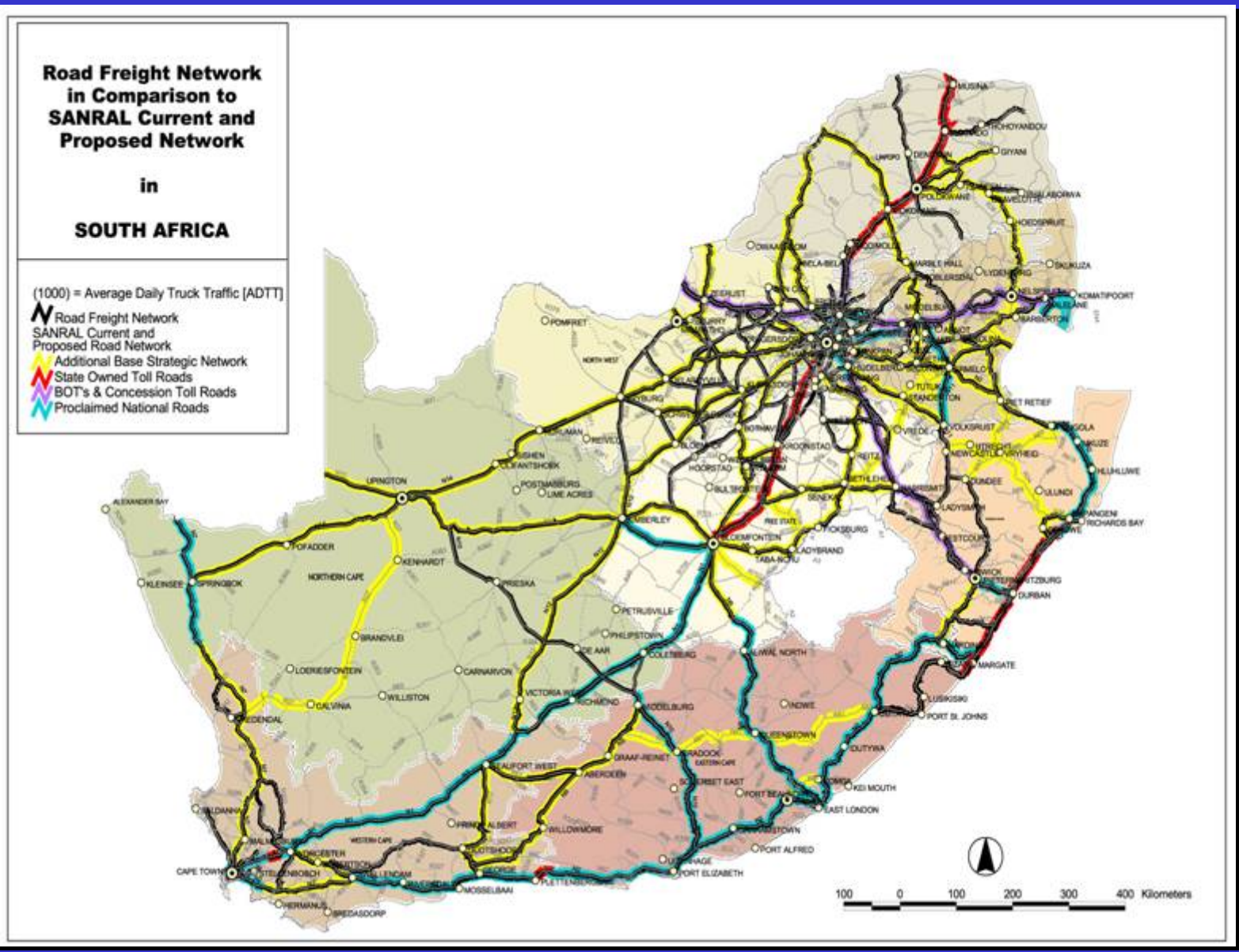


Assumption of Tyre Loading - Pavement Design Modeling:

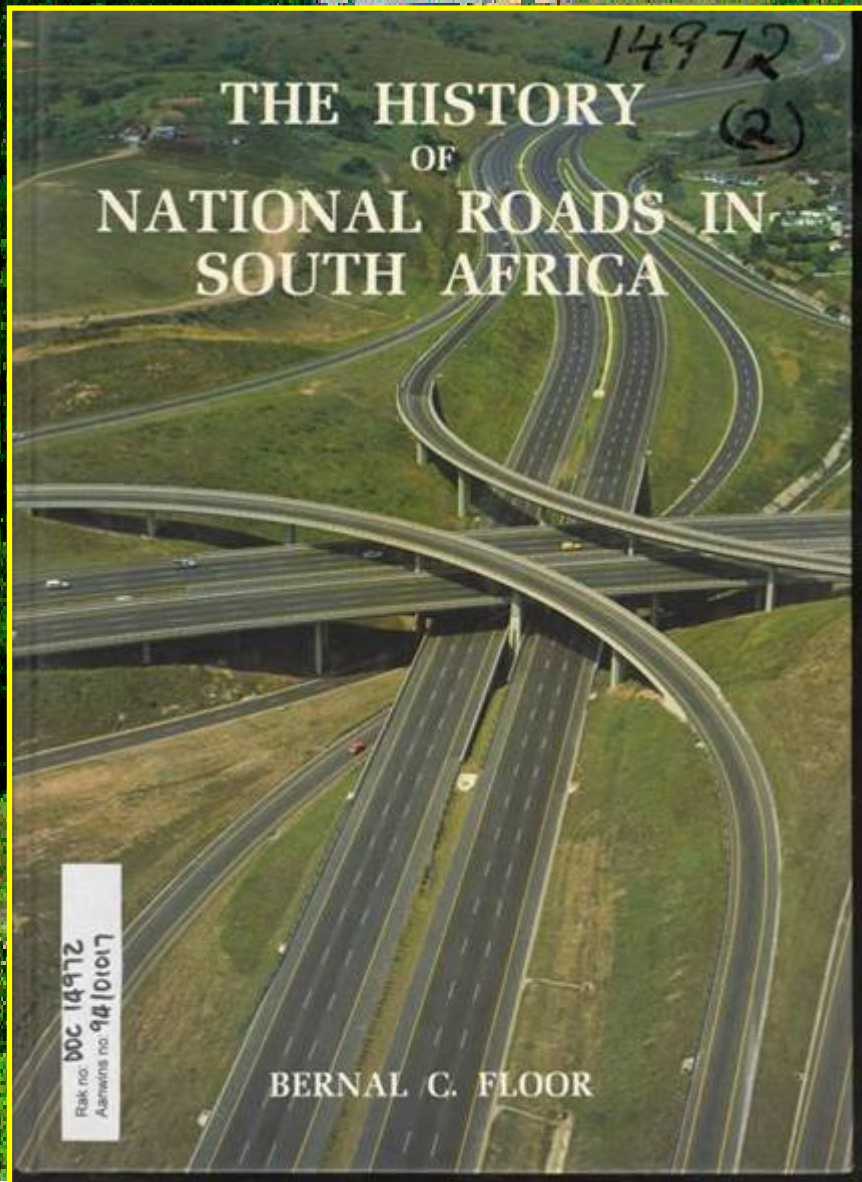
- Circular;
- Variable load;
- Variable pressure, but UNIFORM:



SOUTH AFRICAN MAJOR PAVED ROAD NETWORK ~ 20 000 km



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

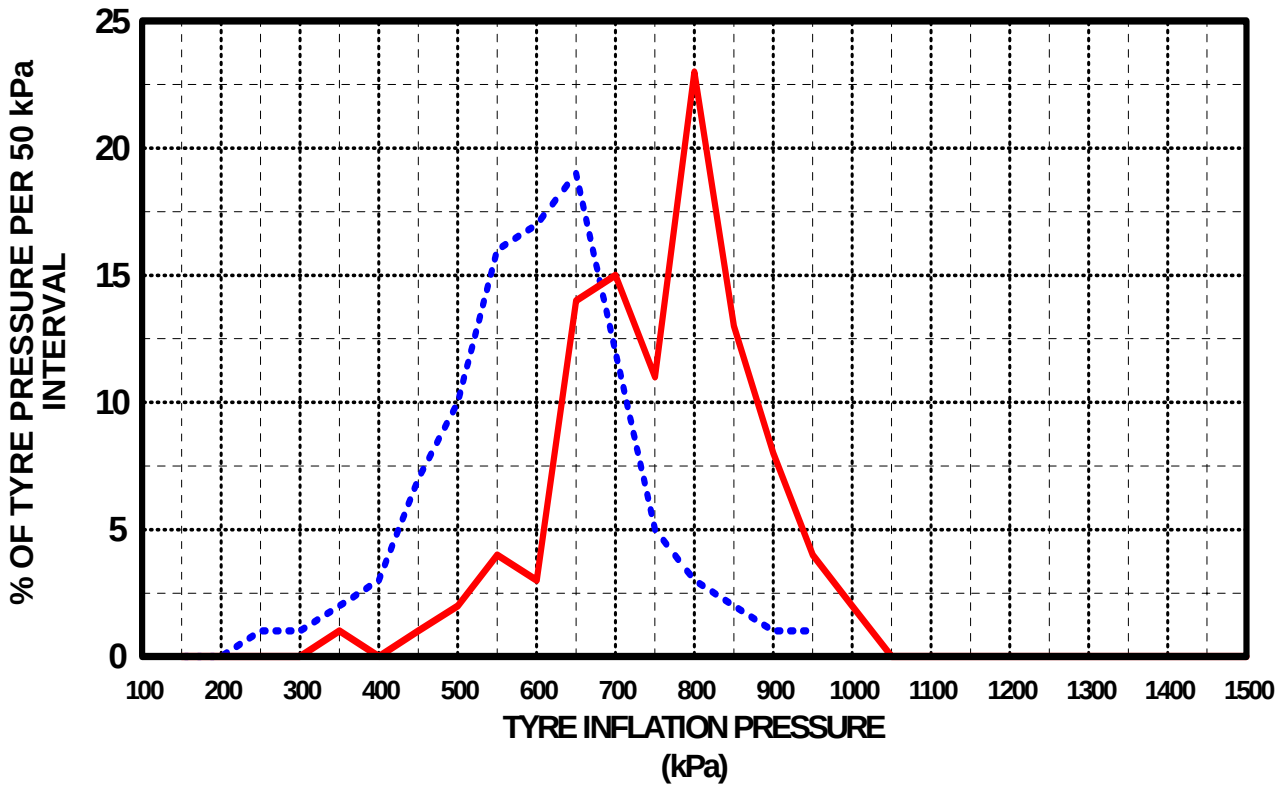



VOLVO
VOLVO


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

ROAD/ PAVEMENT DAMAGE…

ENVIRONMENTAL – MOISTURE CHANGES - SHRINK AND SWELL
("Flapping" of shoulder)

Truck Tyres….

”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

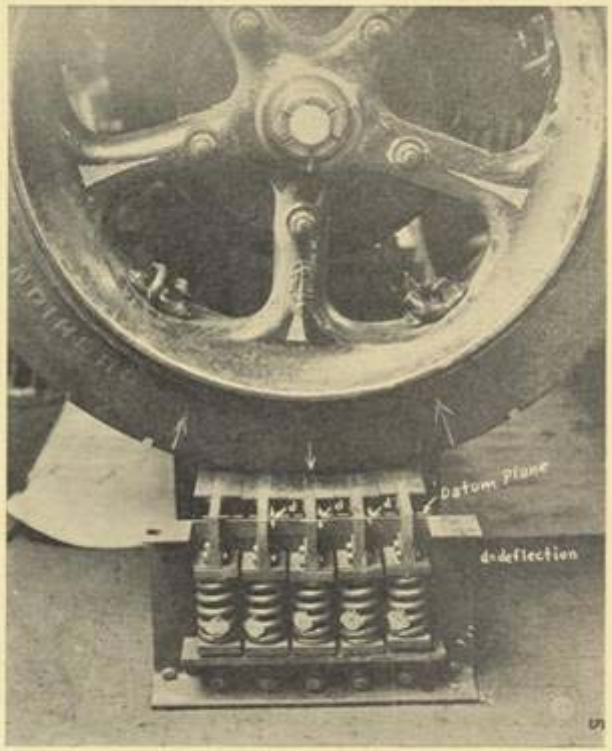
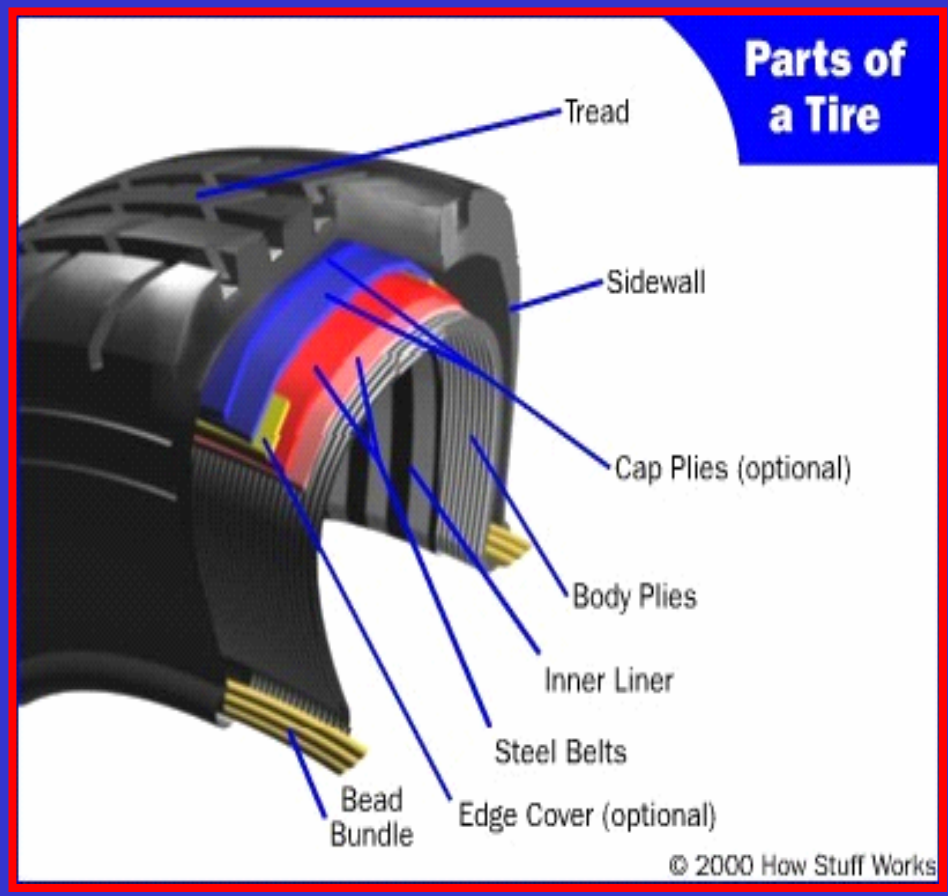


Figure 5

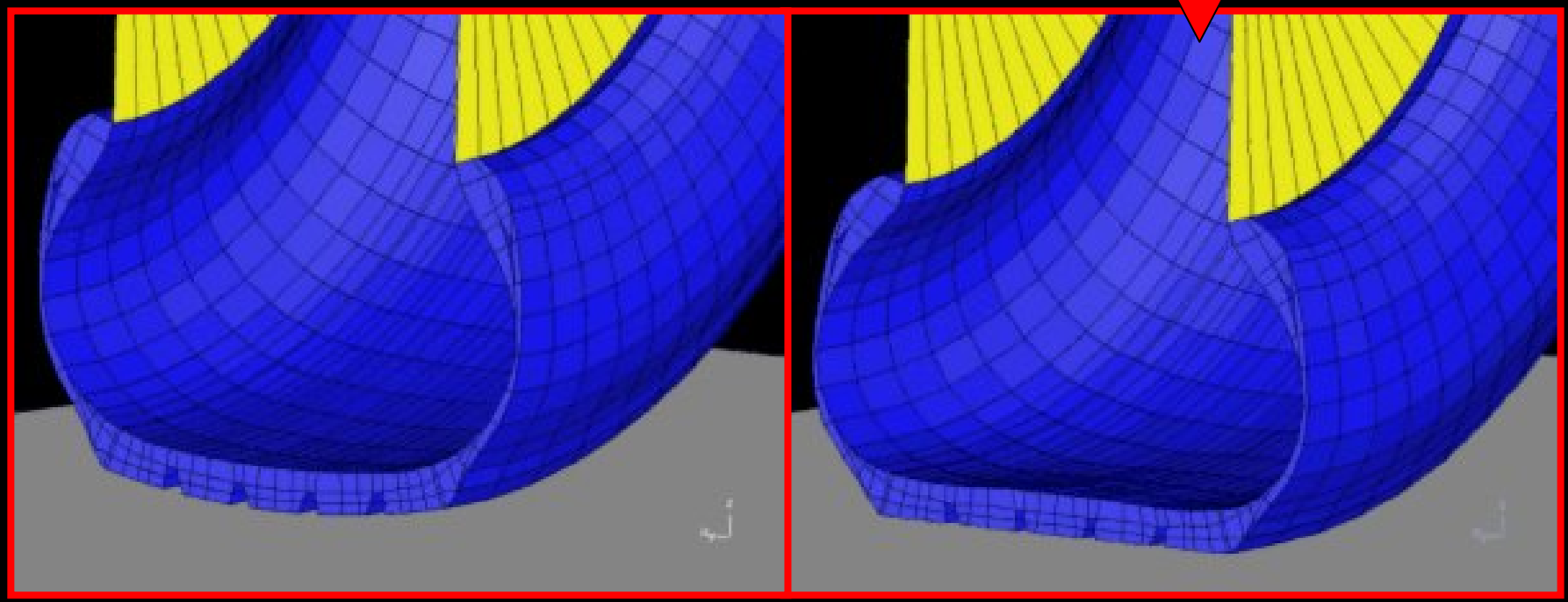
machine was now in position for the impression and also for the determination of the load distribution.

Modern Tyre science…

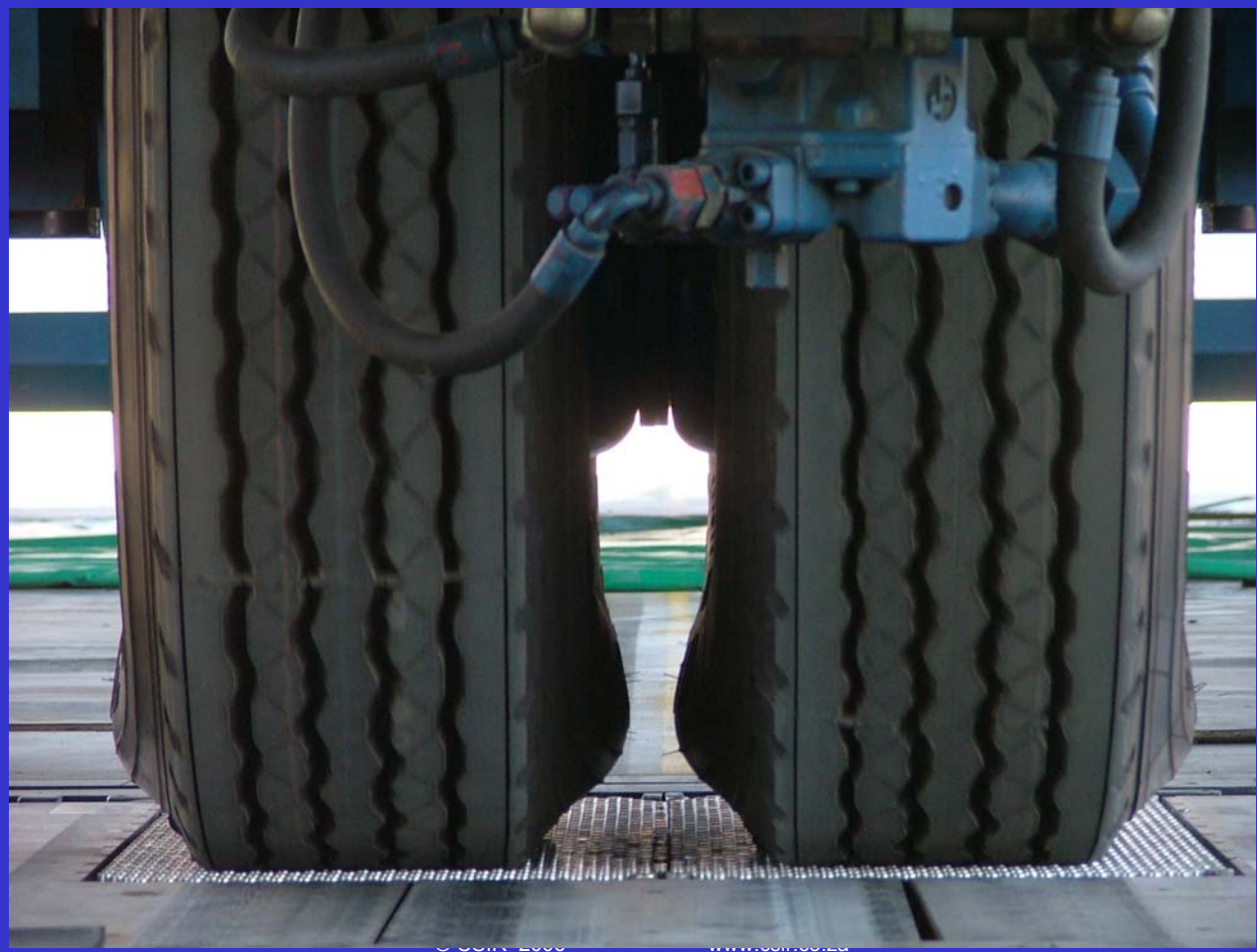


TYRE -NO LOAD

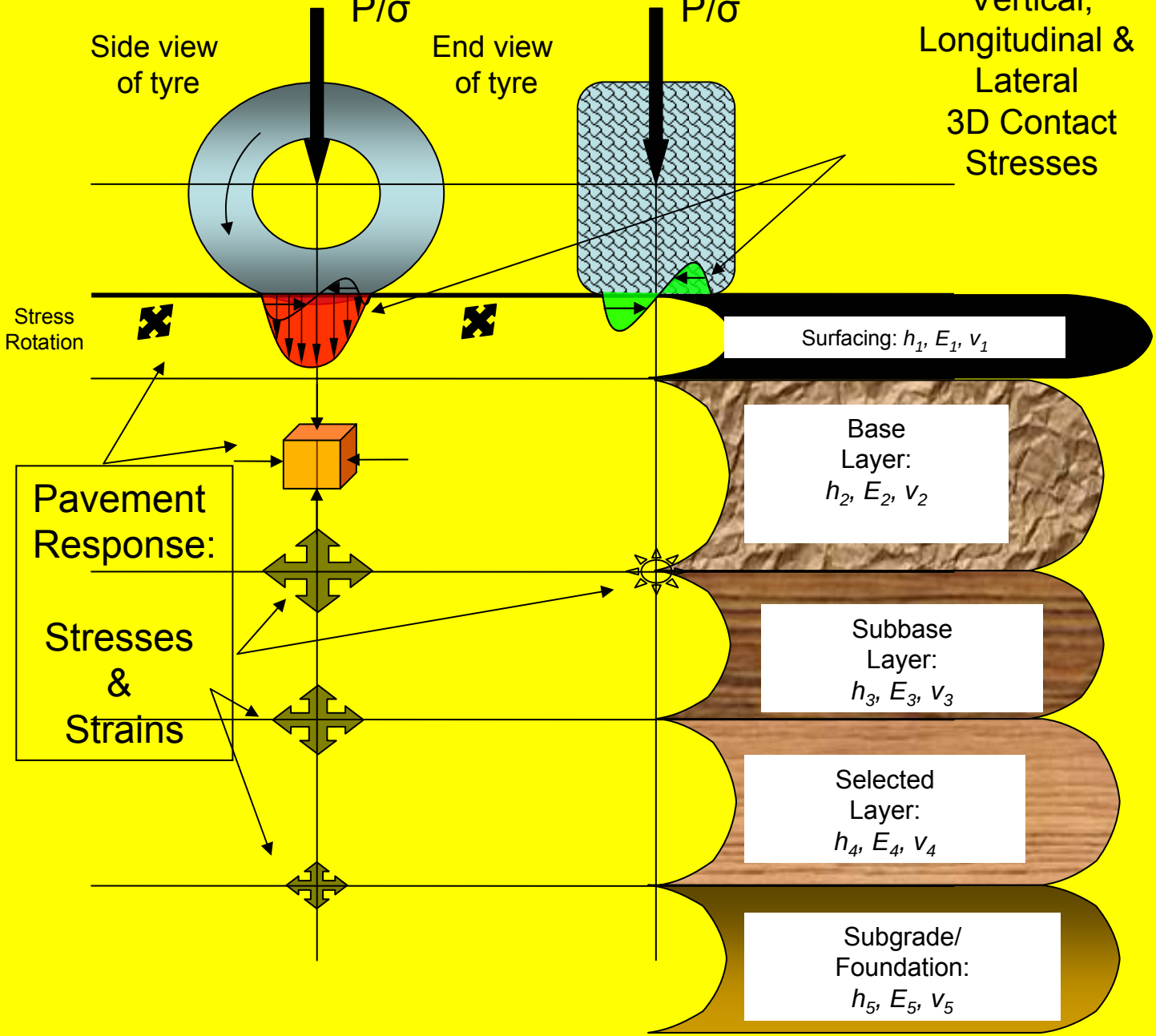
TYRE- WITH LOAD



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



APPLIED LOAD/STRESSES



Vehicle-Tyre-Pavement Interaction:

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

Stress – In – Motion (SIM) Technology

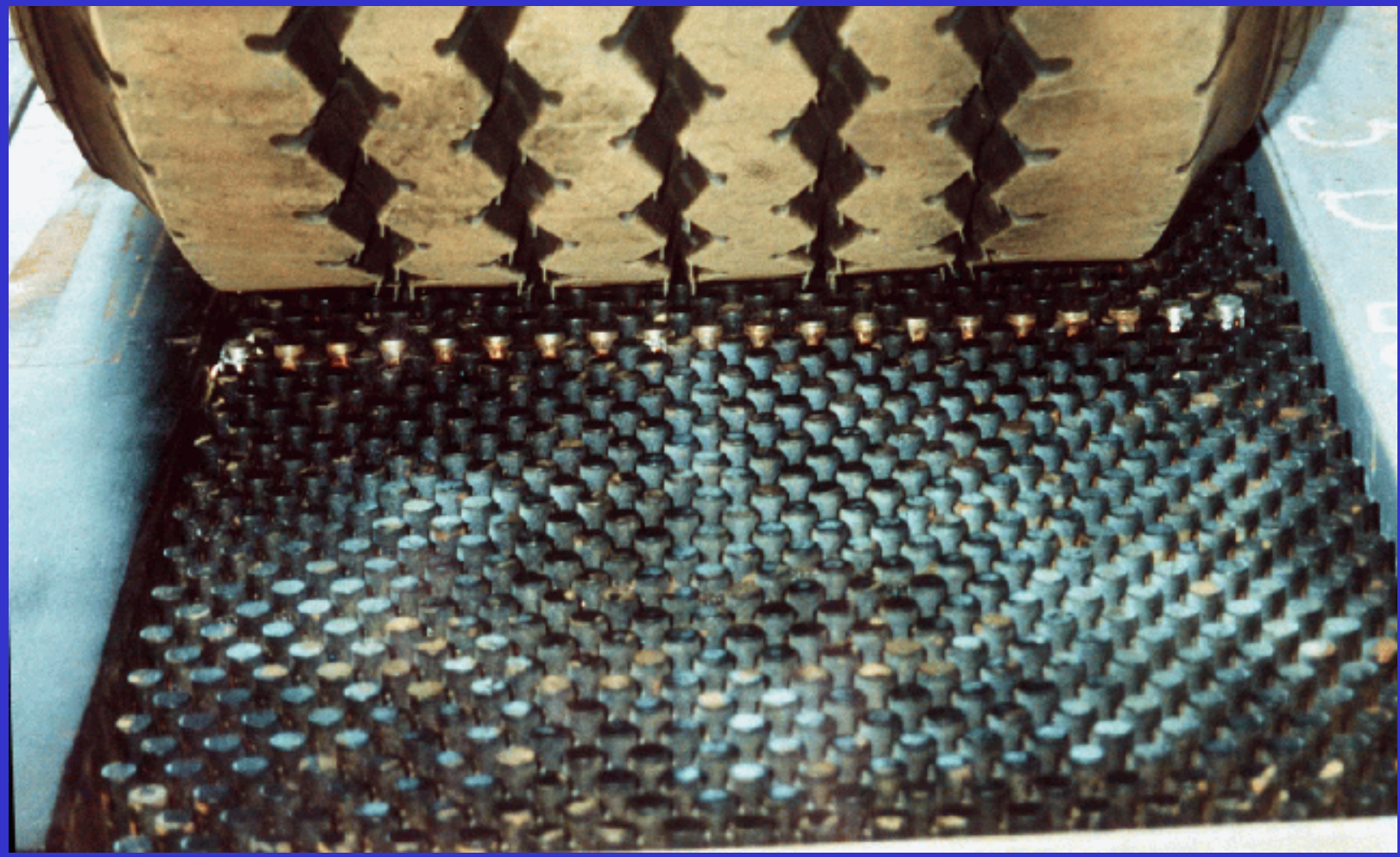
The measurement of 3D tyre/pavement contact stresses from moving vehicles

Heavy Vehicle Simulators (HVS) since 1970s

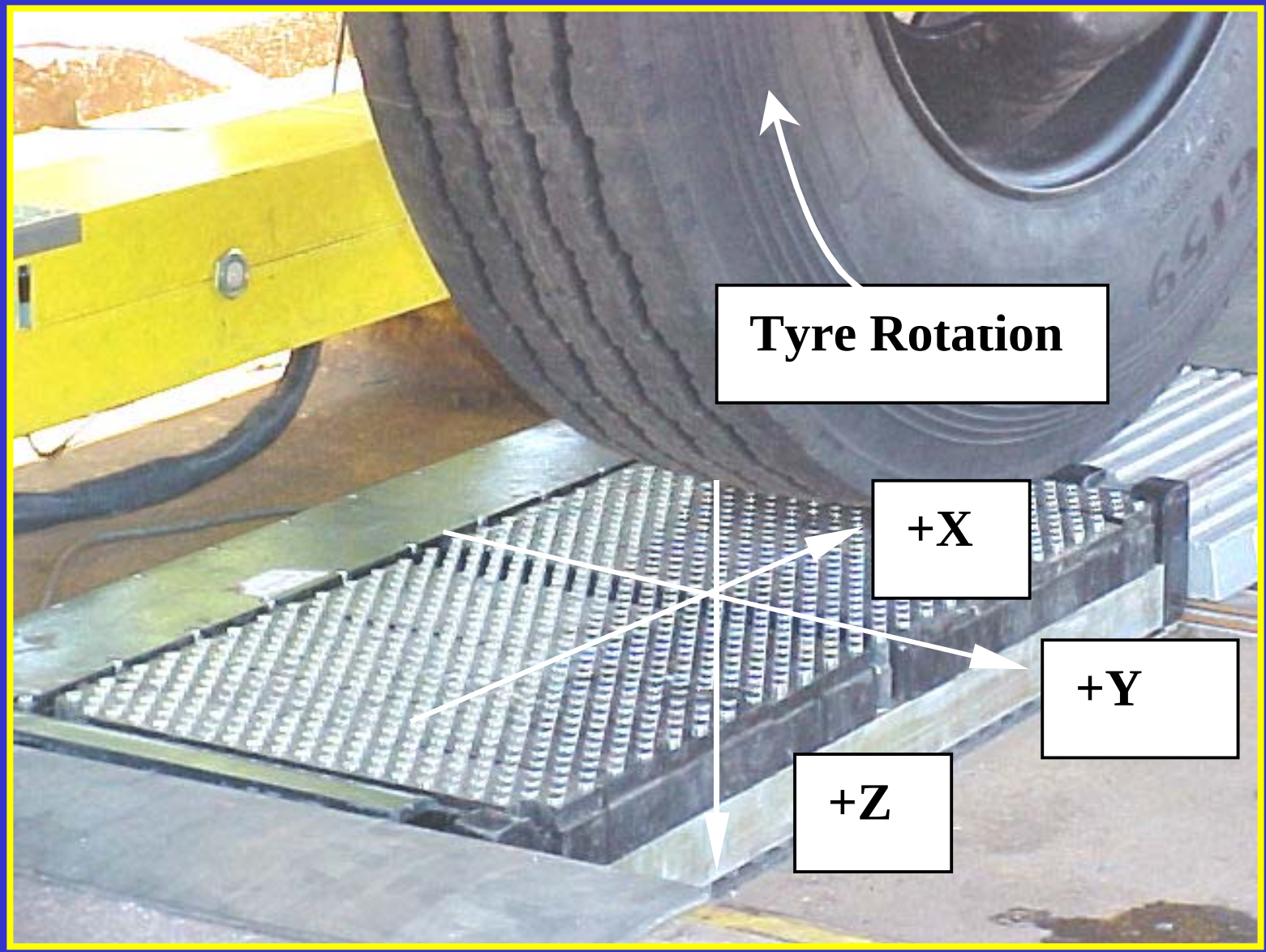
Gautrans HVS Mark IV+

Stress-In-Motion (SIM) MK II SYSTEM (1993-1995)

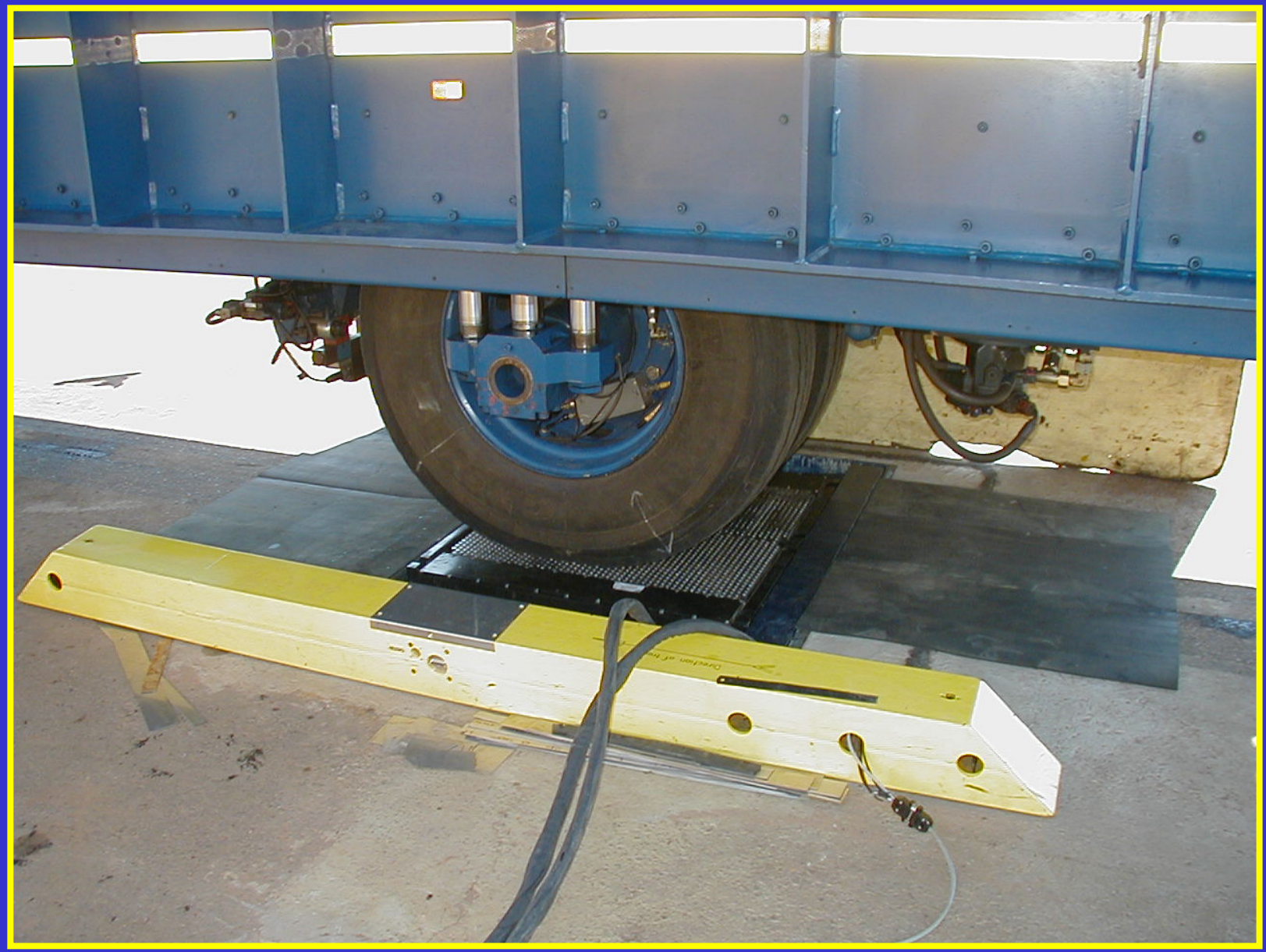
425 /65 R22.5 HVS TIRE ON SIM SYSTEM



LOADS & STRESSES: SAE SIGN CONVENTION

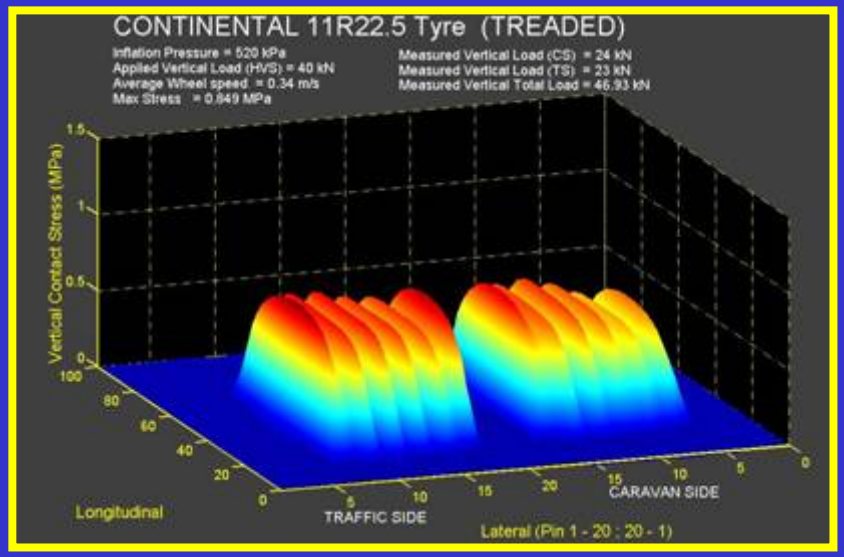


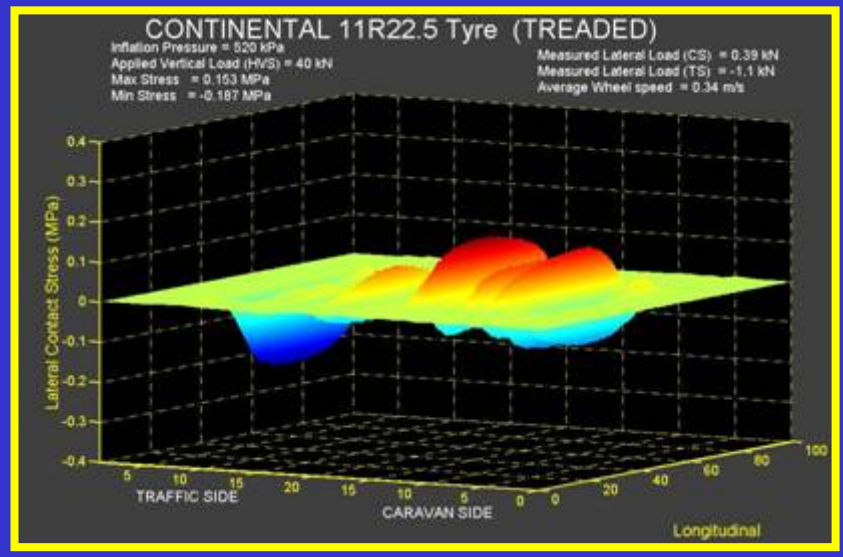
SIM TESTING USING THE HVS - DUAL LOADING



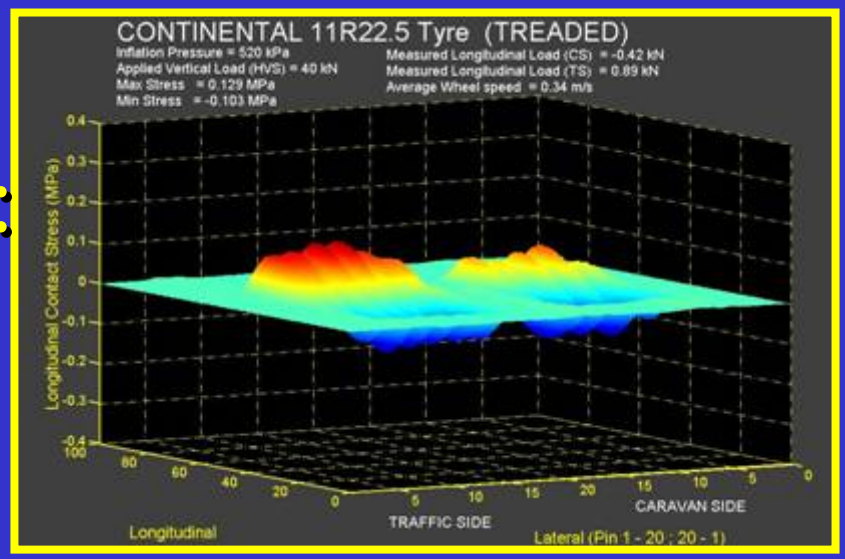
STRESS-IN-MOTION TESTING USING THE HVS

Dual Tyre: 3D-Contact Stresses (Pressure)

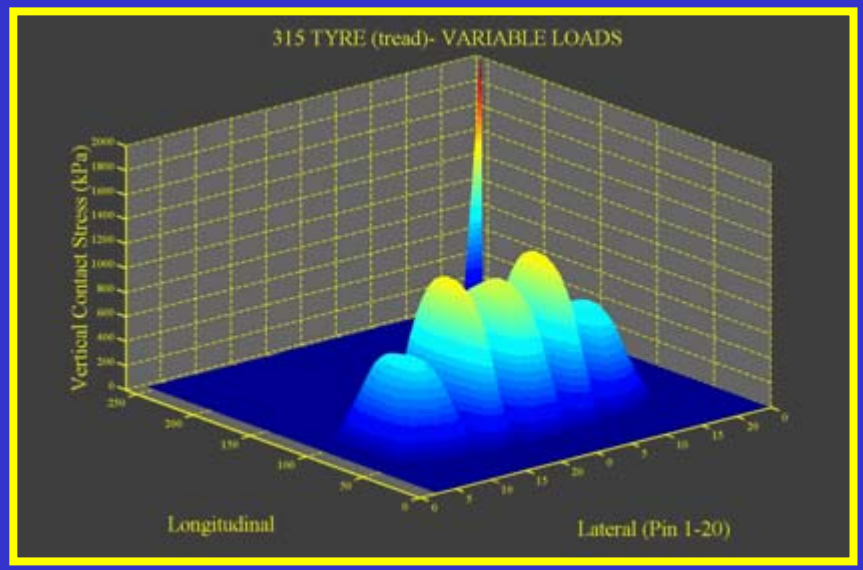


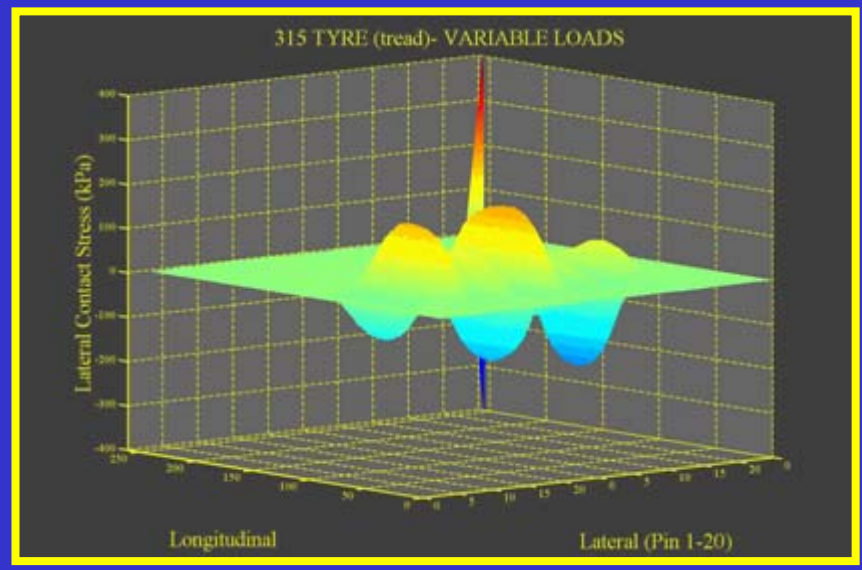


Stress Ratio: 10:3:1

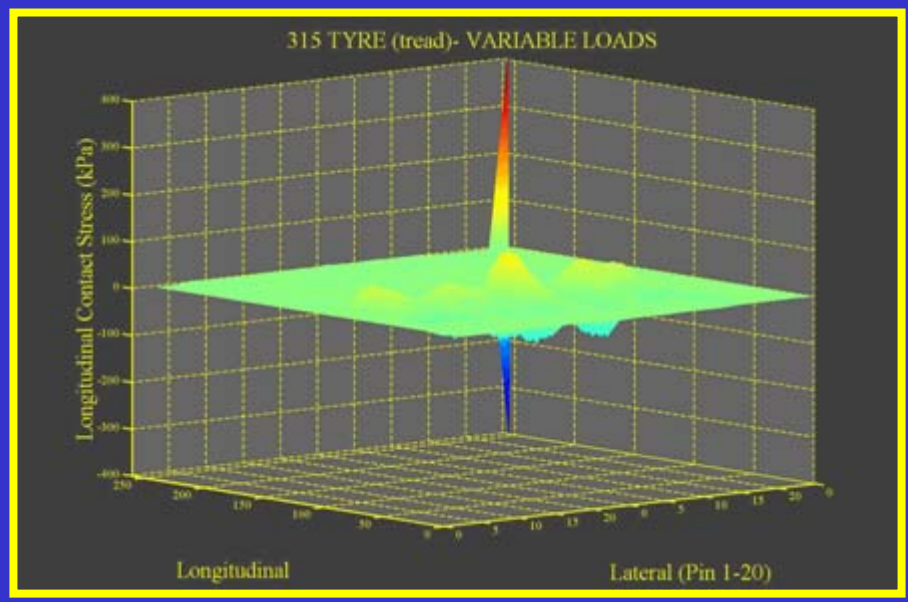


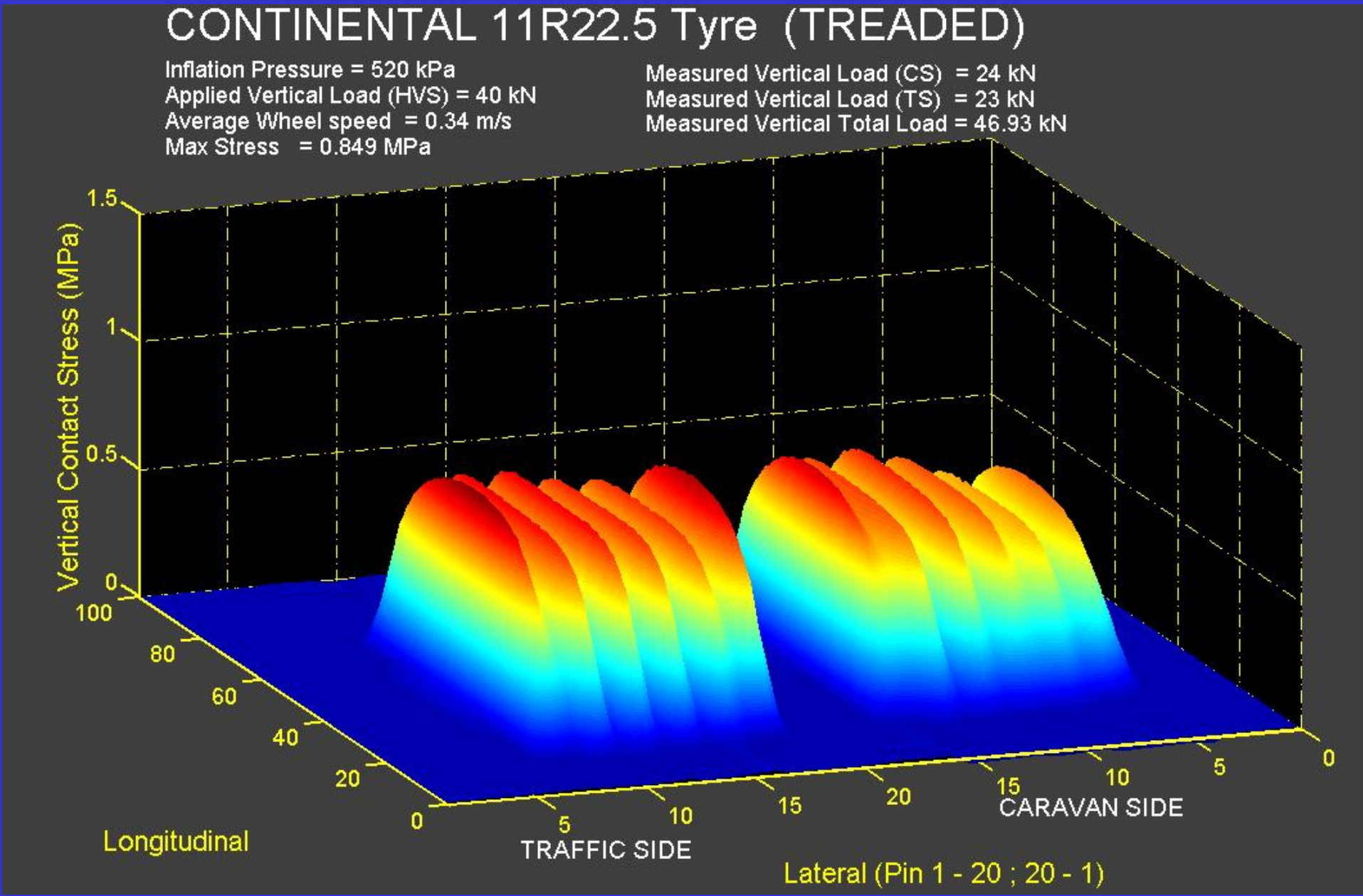
Typical SIM 3D Data Sets -Variable loading:

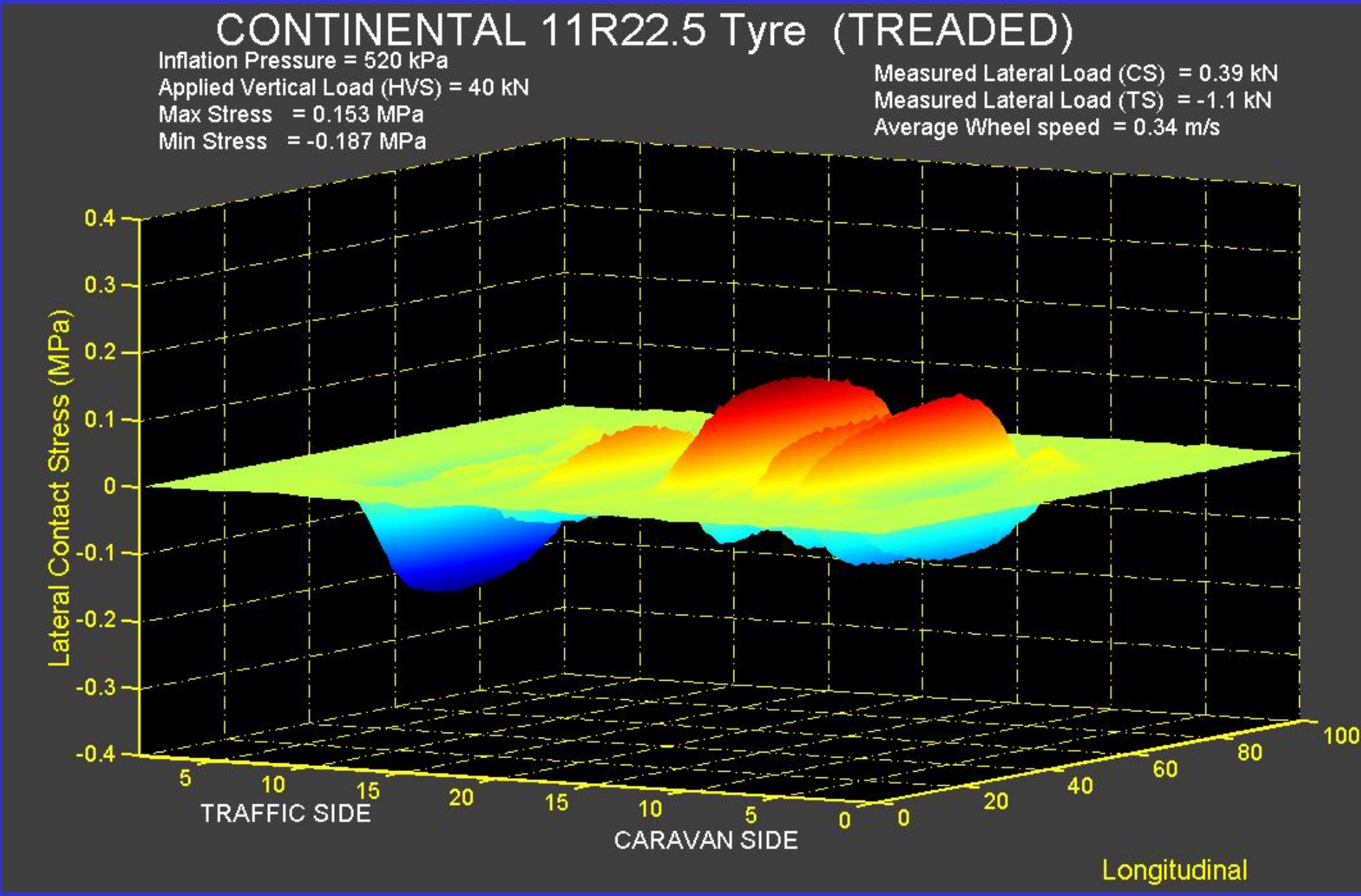


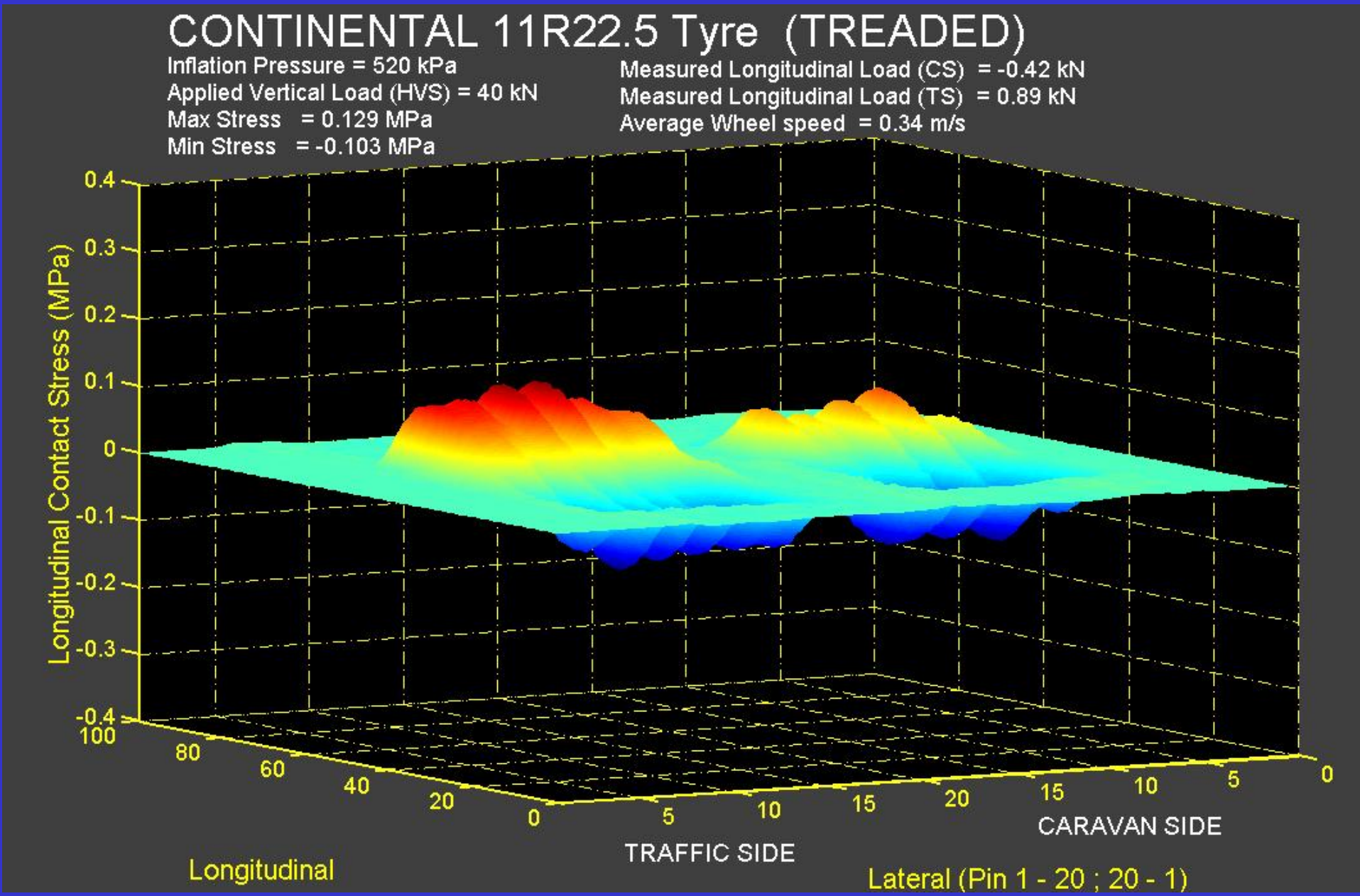


3D – Z,X,Y - Contact Stresses:
Variable loads: 315/80 R22.5 Tire

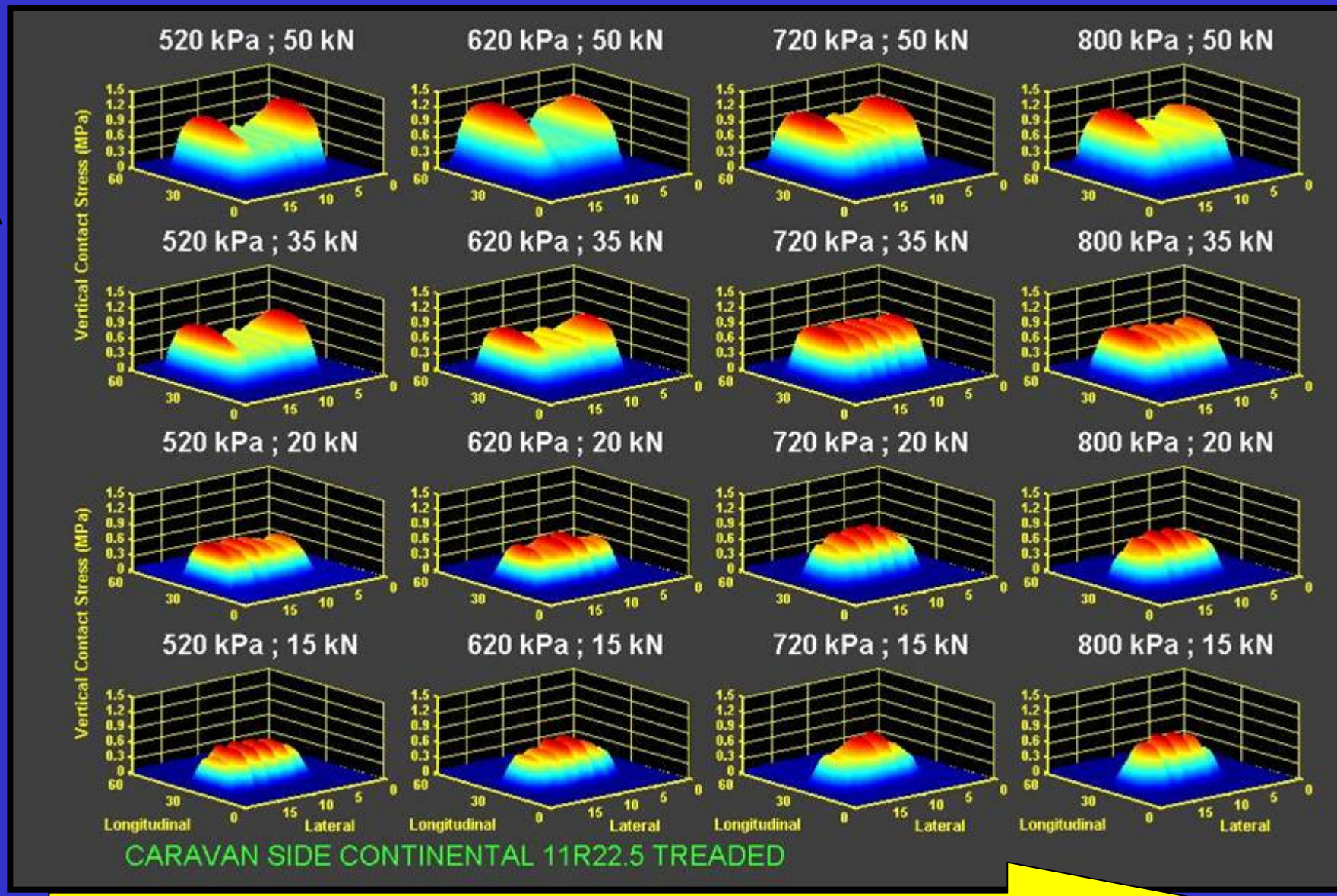



CONTINENTAL 11R22.5 Tyre (TREADED)
Inflation Pressure = 520 kPa
Applied Vertical Load (HVS) = 40 kN
Average Wheel speed = 0.34 m/s
Max Stress = 0.849 MPa
Measured Vertical Load (CS) = 24 kN
Measured Vertical Load (TS) = 23 kN
Measured Vertical Total Load = 46.93 kN
Vertical Contact Stress (MPa)
1.5
1
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

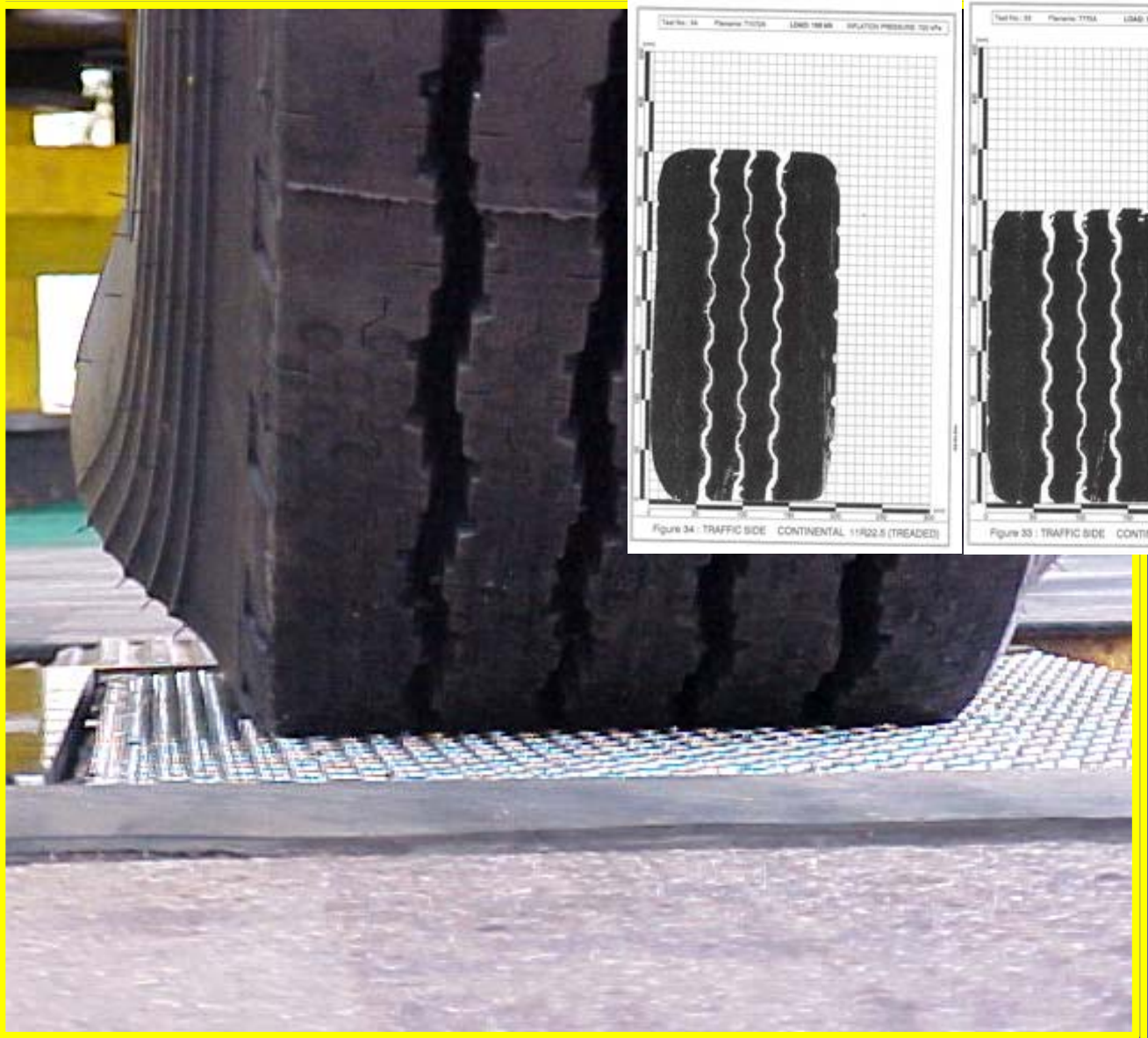

CONTINENTAL 11R22.5 Tyre (TREADED)
Inflation Pressure = 520 kPa
Applied Vertical Load (HVS) = 40 kN
Max Stress = 0.153 MPa
Min Stress = -0.187 MPa
Measured Lateral Load (CS) = 0.39 kN
Measured Lateral Load (TS) = -1.1 kN
Average Wheel speed = 0.34 m/s
Lateral Contact Stress (MPa)
0.4
0.3
0.2
0.1
0
-0.1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

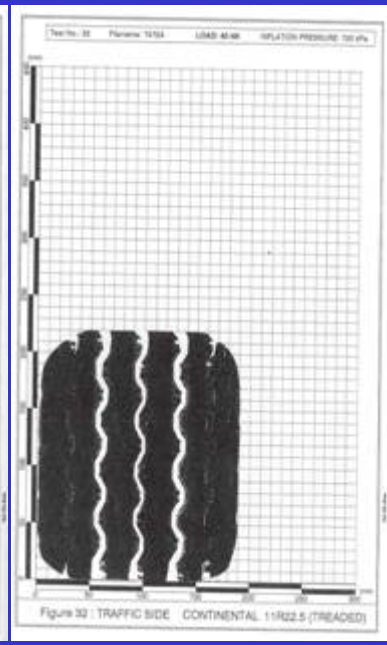

CONTINENTAL 11R22.5 Tyre (TREADED)
Inflation Pressure = 520 kPa
Applied Vertical Load (HVS) = 40 kN
Max Stress = 0.129 MPa
Min Stress = -0.103 MPa
Measured Longitudinal Load (CS) = -0.42 kN
Measured Longitudinal Load (TS) = 0.89 kN
Average Wheel speed = 0.34 m/s
Longitudinal Contact Stress (MPa)
0.4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

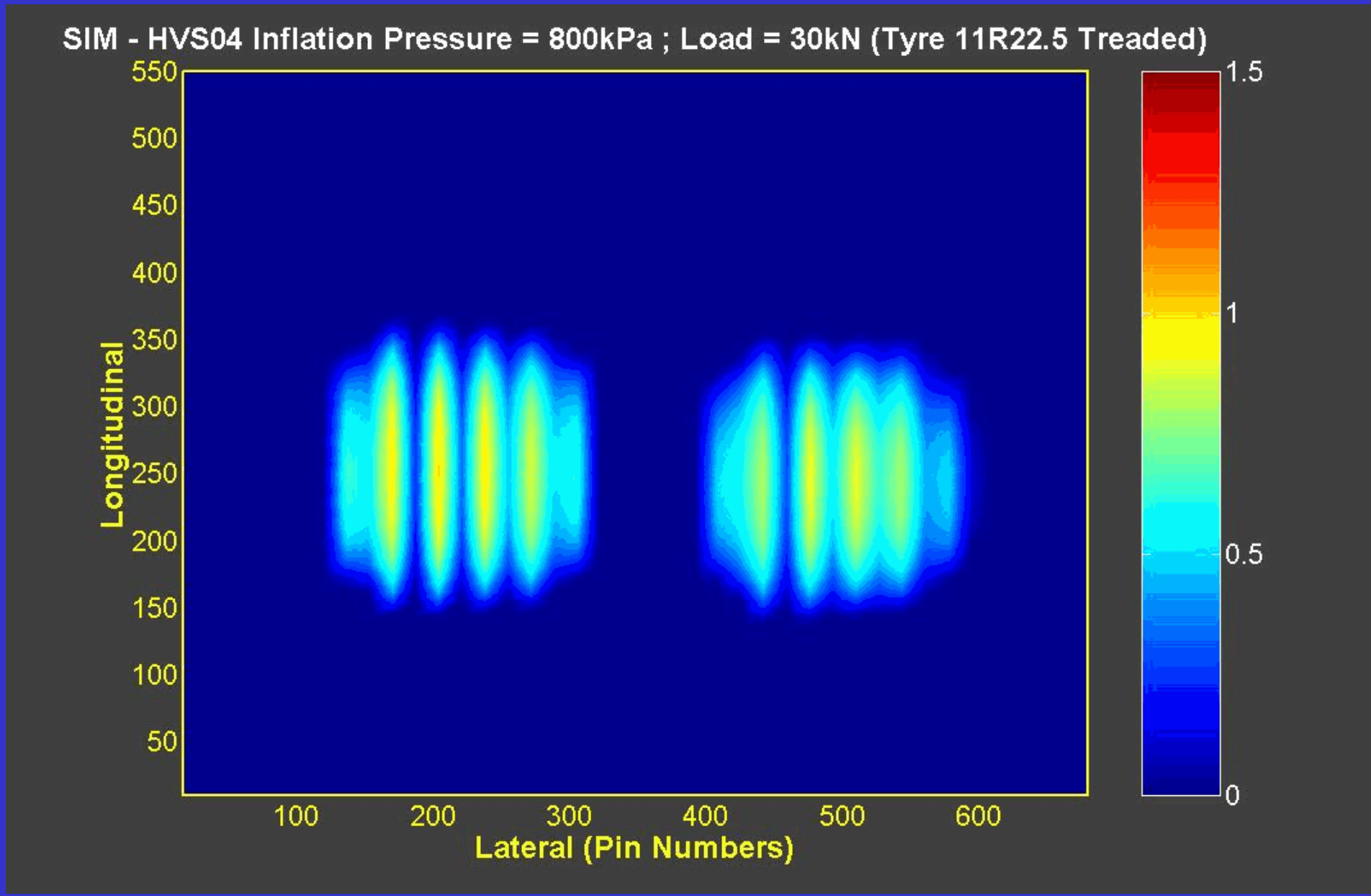
TYRE "FINGER PRINTING": (HVS : SIM : 11R22.5 TYRE)



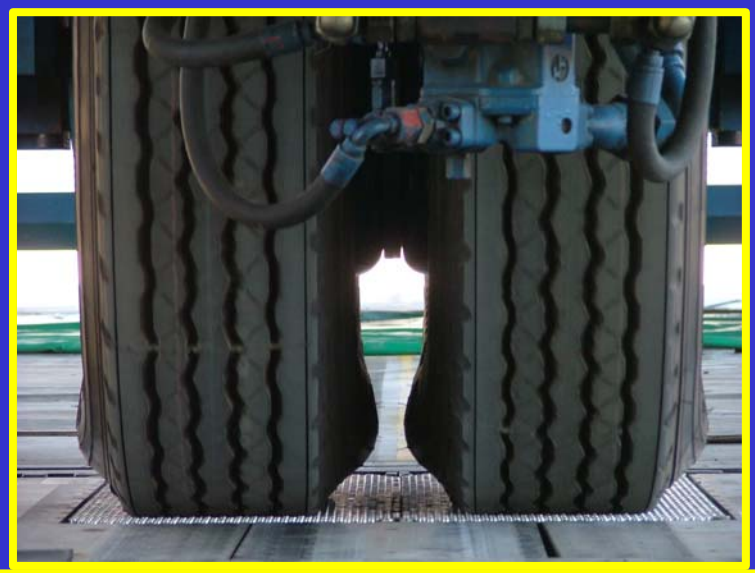
315/80 R22.5 HVS Tyre: Overloaded



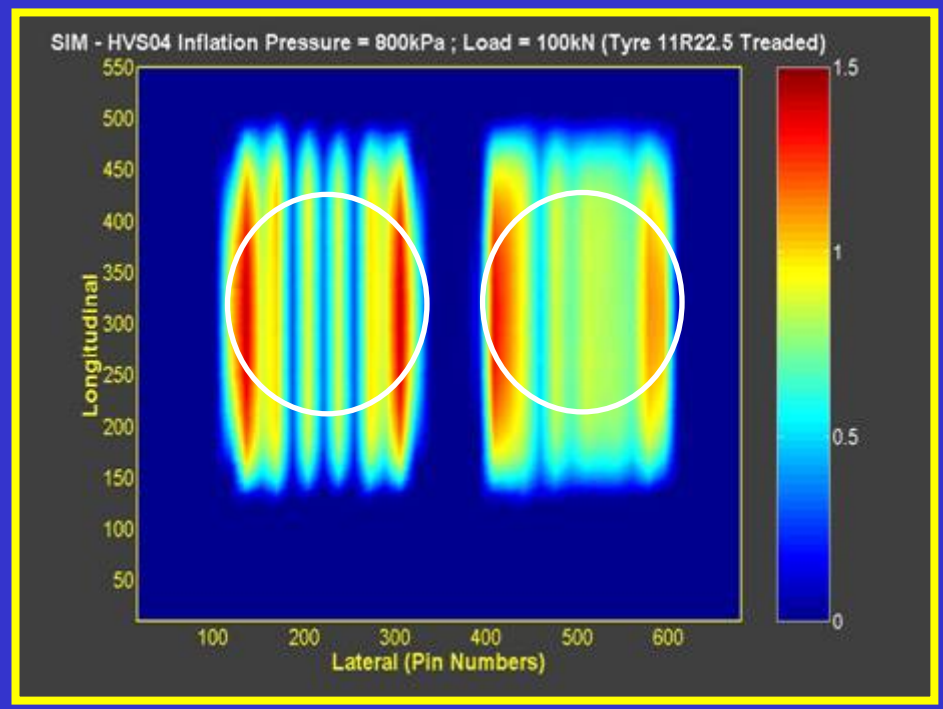


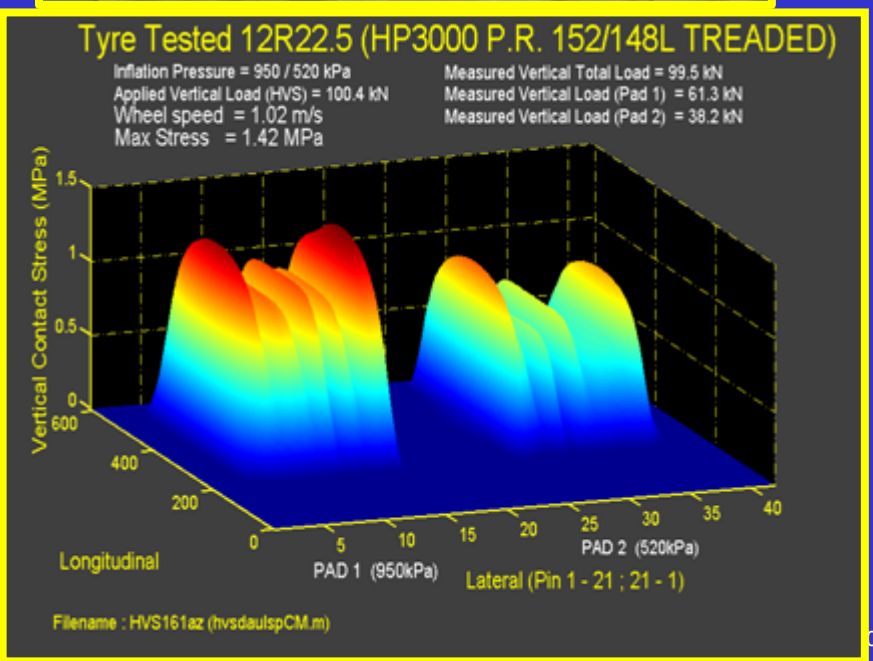

SIM - HVS04 Inflation Pressure = 800kPa ; Load = 30kN (Tyre 11R22.5 Treaded)
Longitudinal
550
500
450
400
350
300
250
200
150
100
50
100
200
300
400
500
600
Lateral (Pin Numbers)
1.5
1
0.5
0

Overloading on Tyres:



Contact Patches: (square not circular)





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

In operation – SIM 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

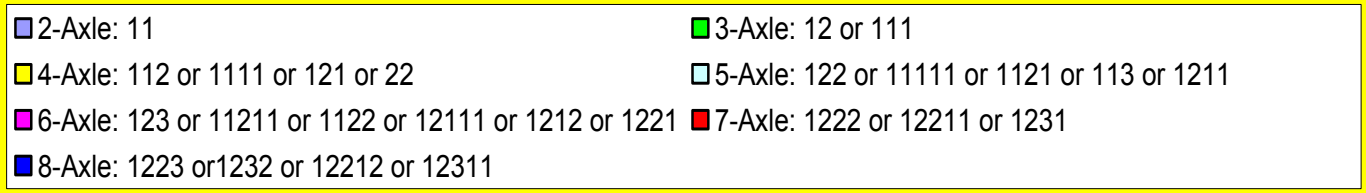
Quad (full) SIM pad configuration at a typical weighbridge site on National Road 3 (N3), near Heidelberg in Gauteng

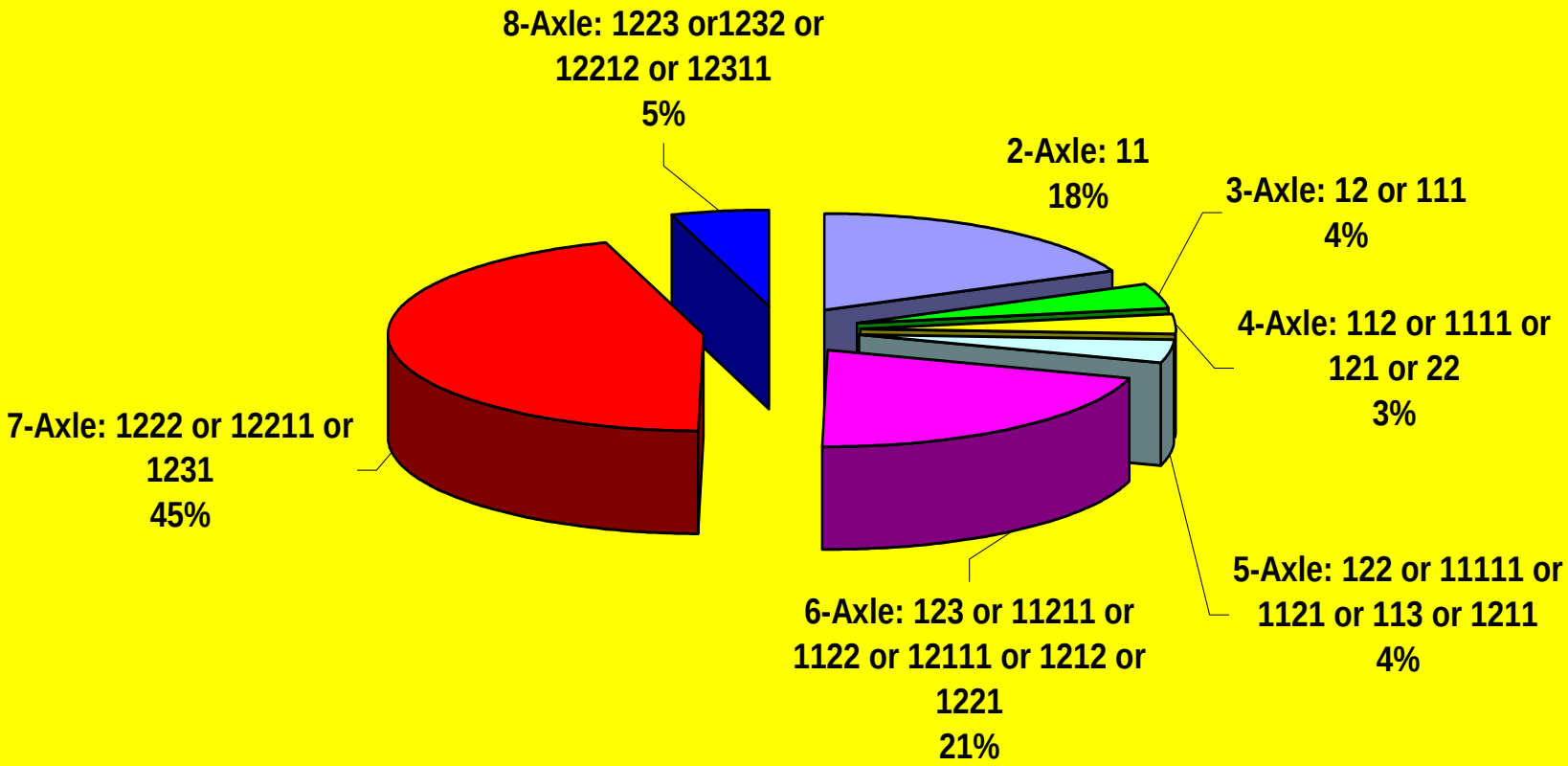
SIM Measurement: N3

"1232" Tanker

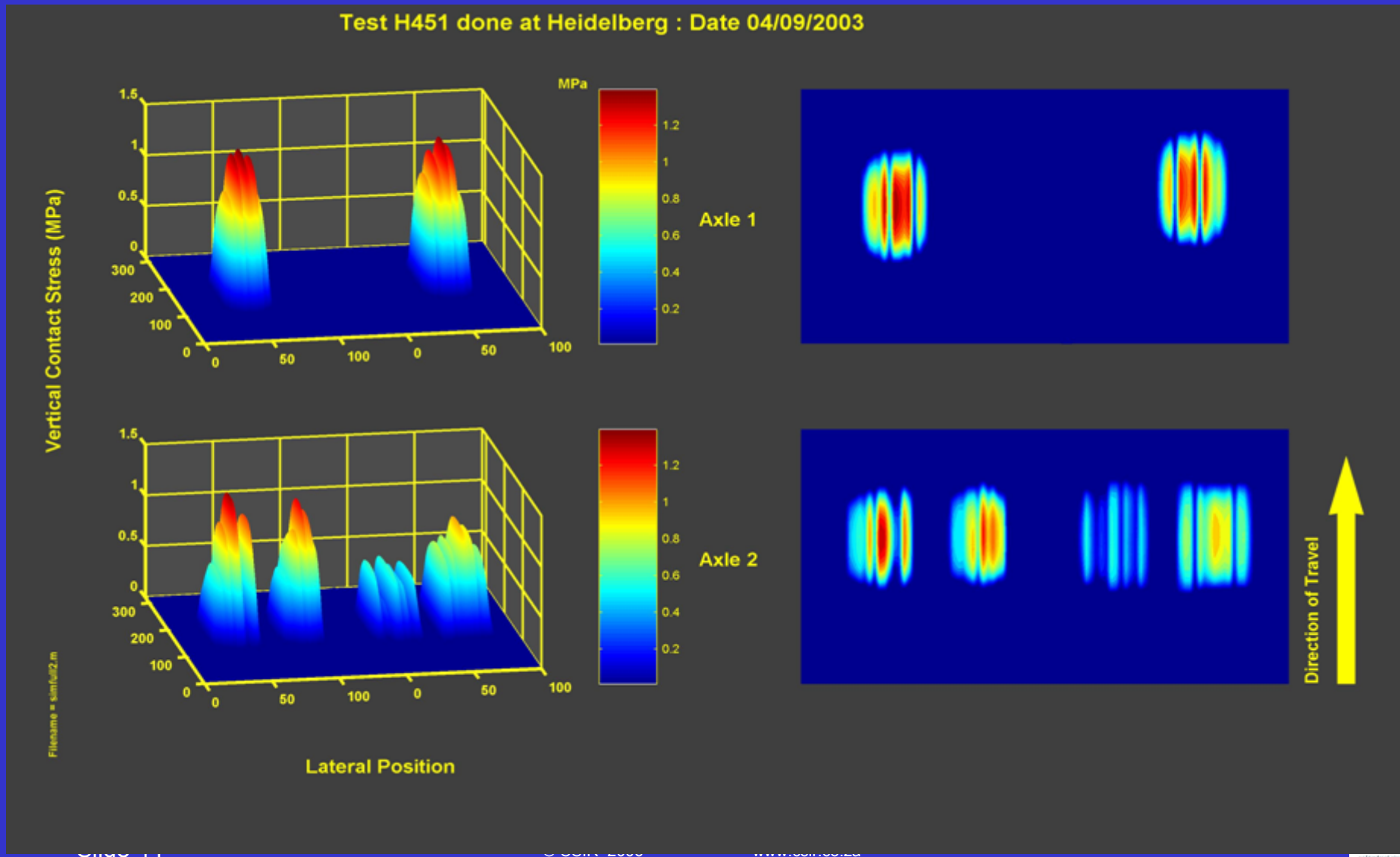
In operation – SIM N3 -TCC …….

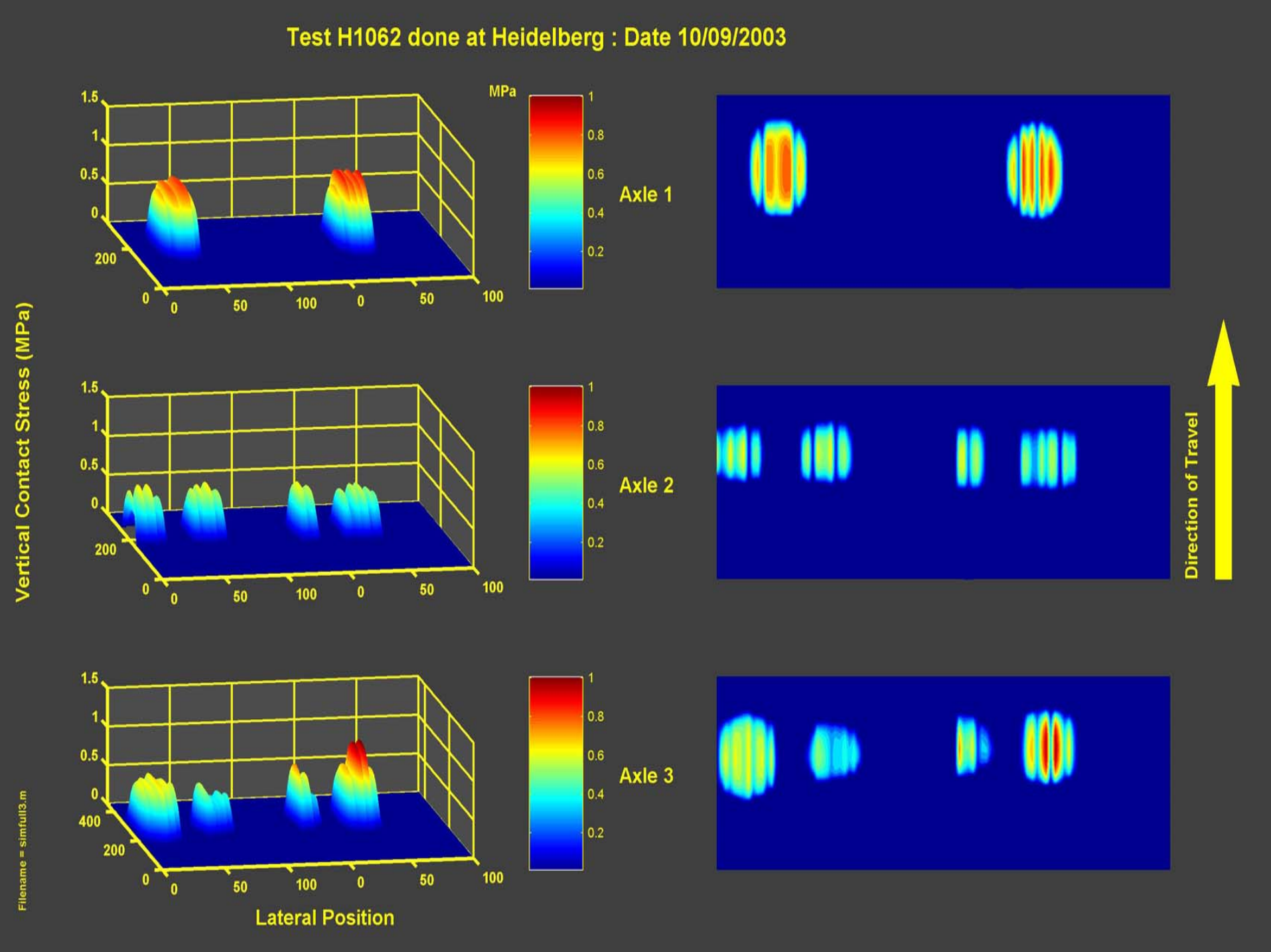
Truck Classification



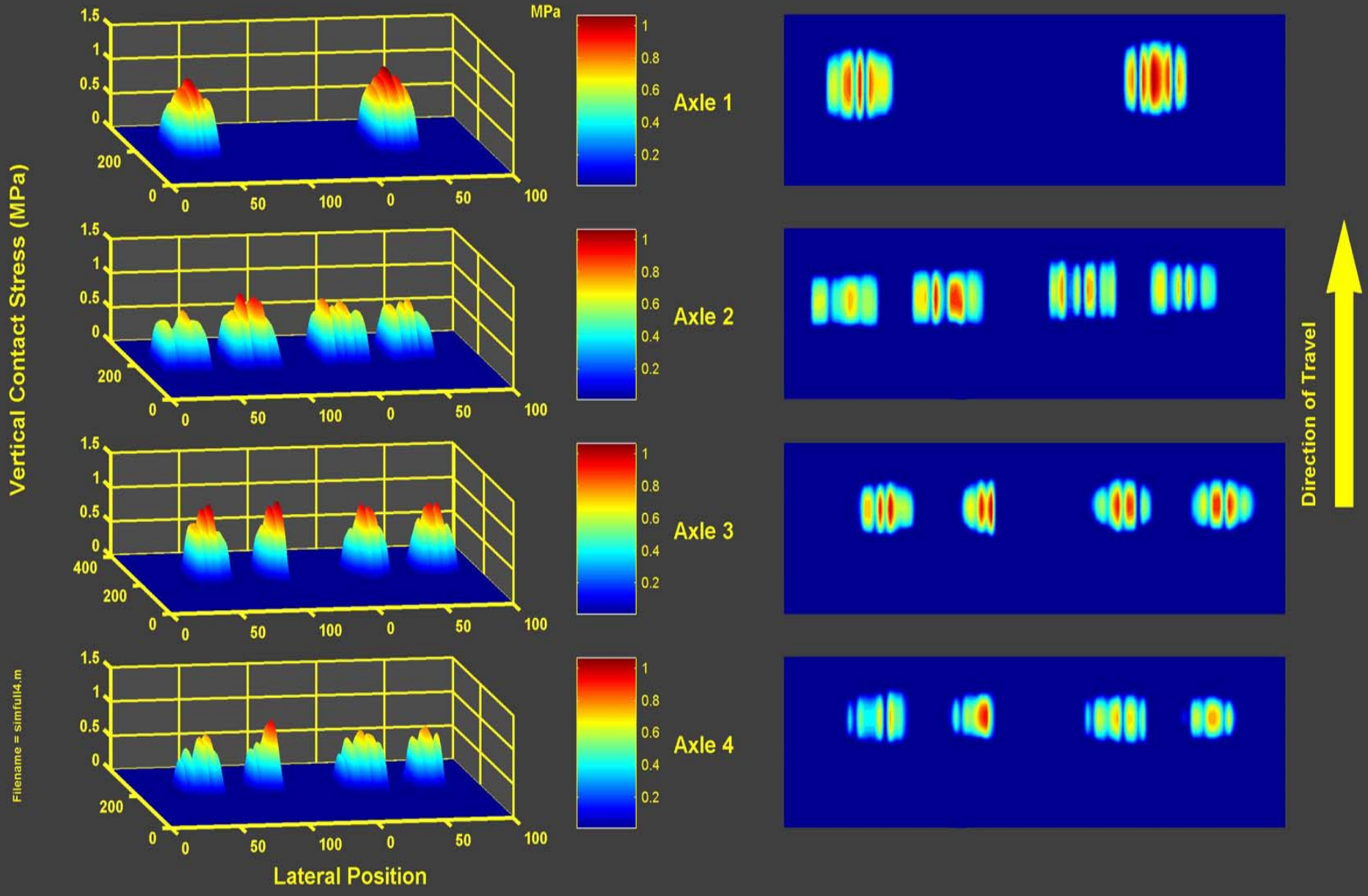


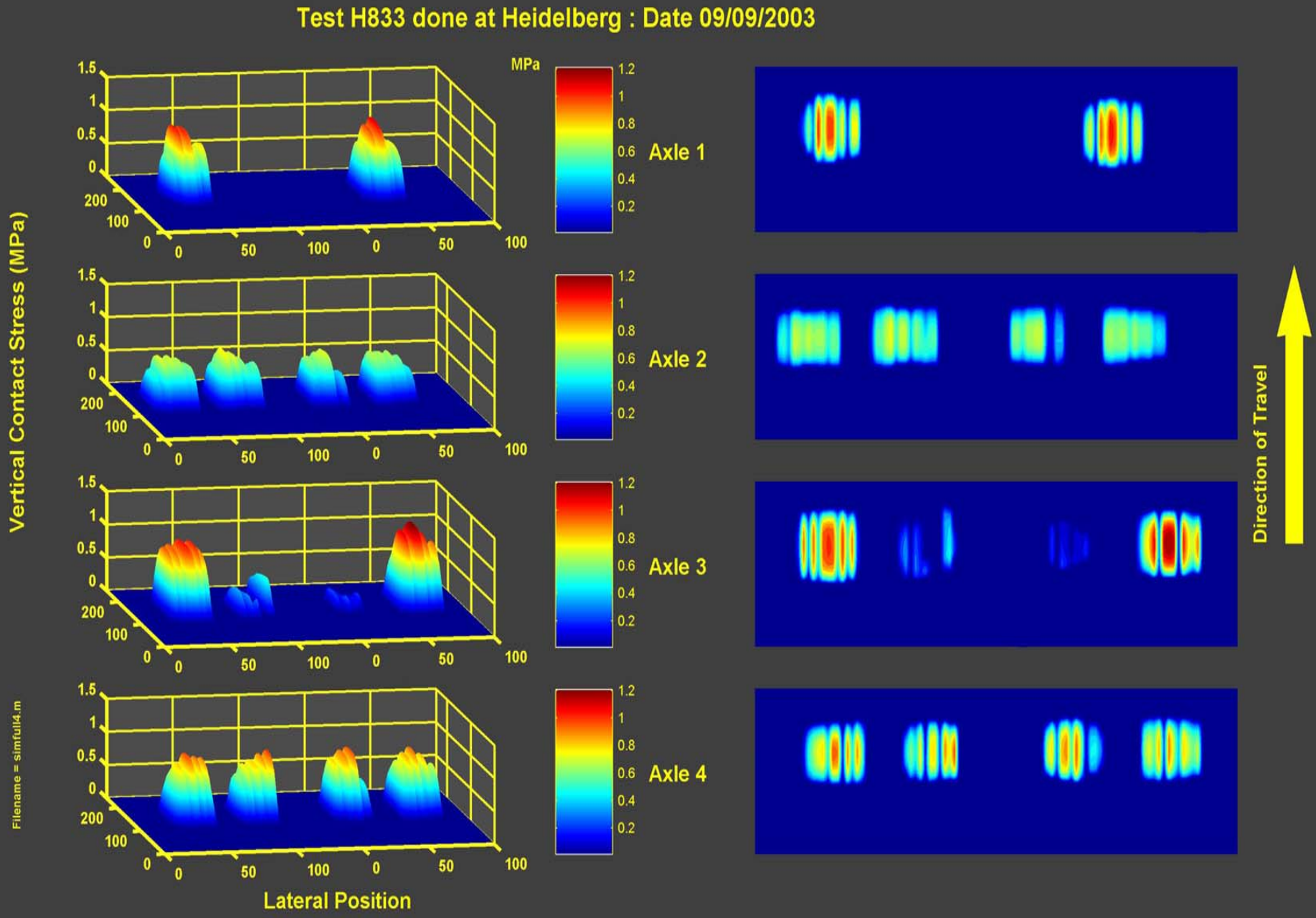
Two Axle Truck – Vertical Contact Stress - Foot Prints

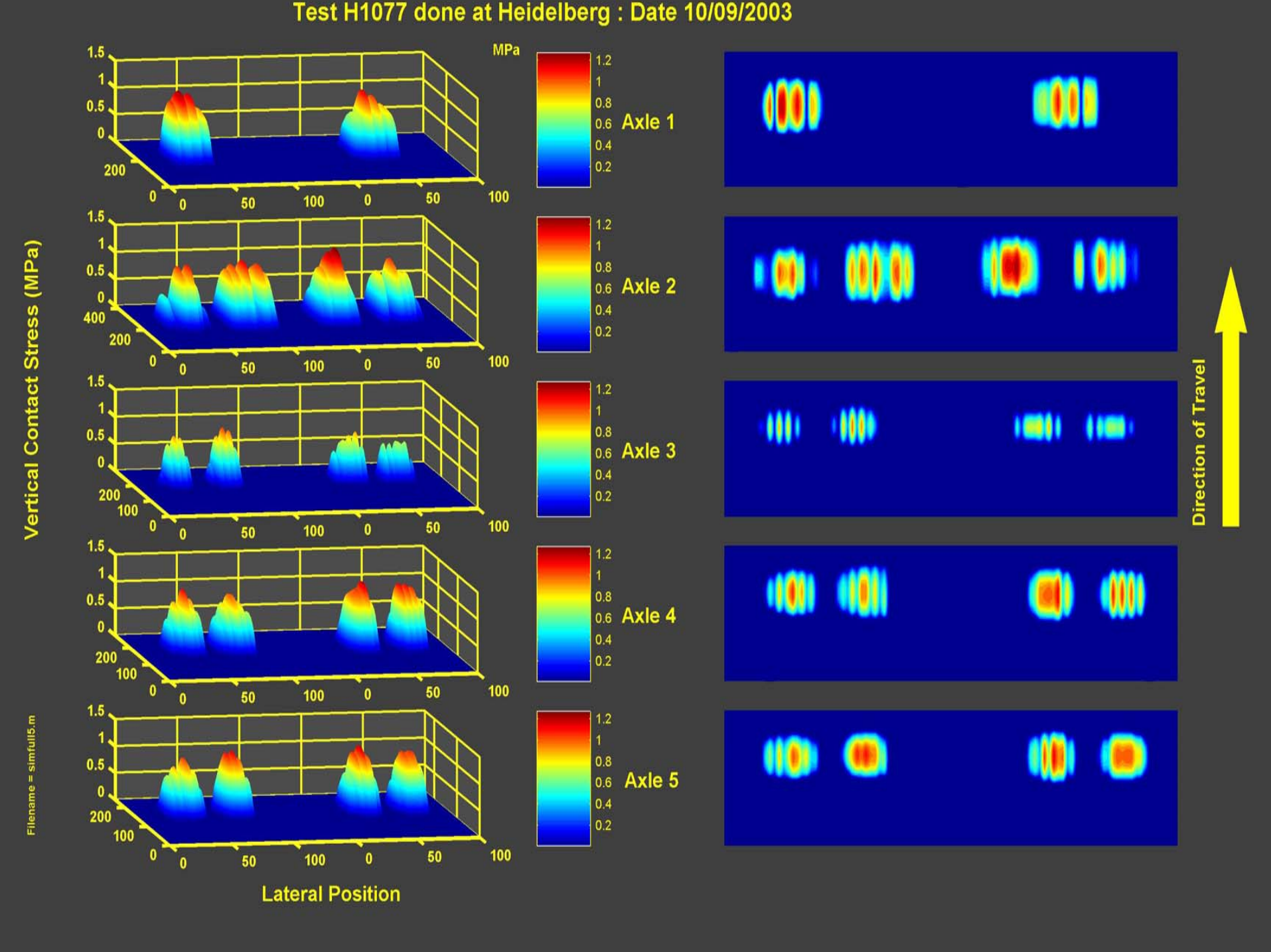


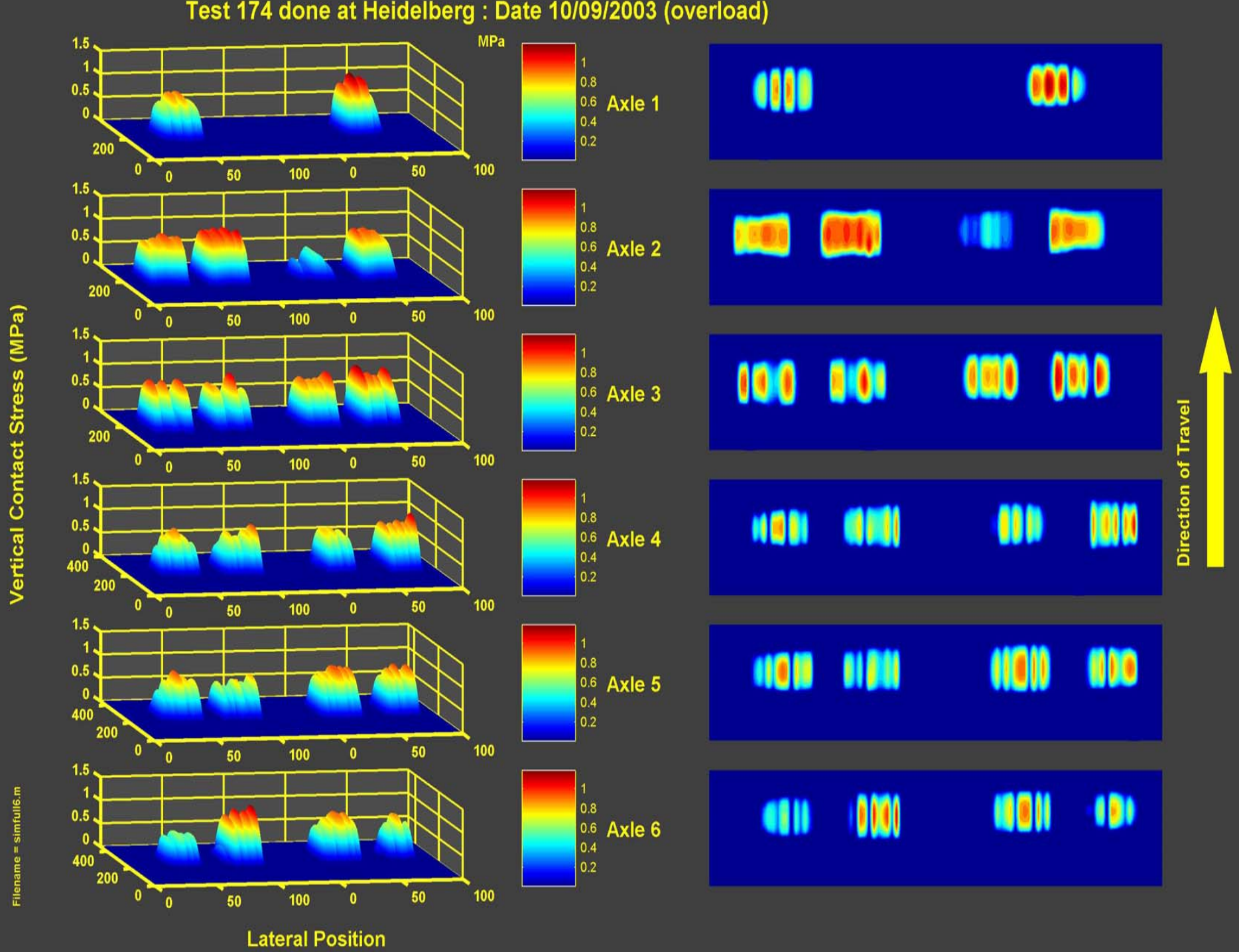

Test H1062 done at Heidelberg : Date 10/09/2003
Vertical Contact Stress (MPa)
MPa
Axle 1
Axle 2
Axle 3
Direction of Travel
Lateral Position
Filename = simfull3.m

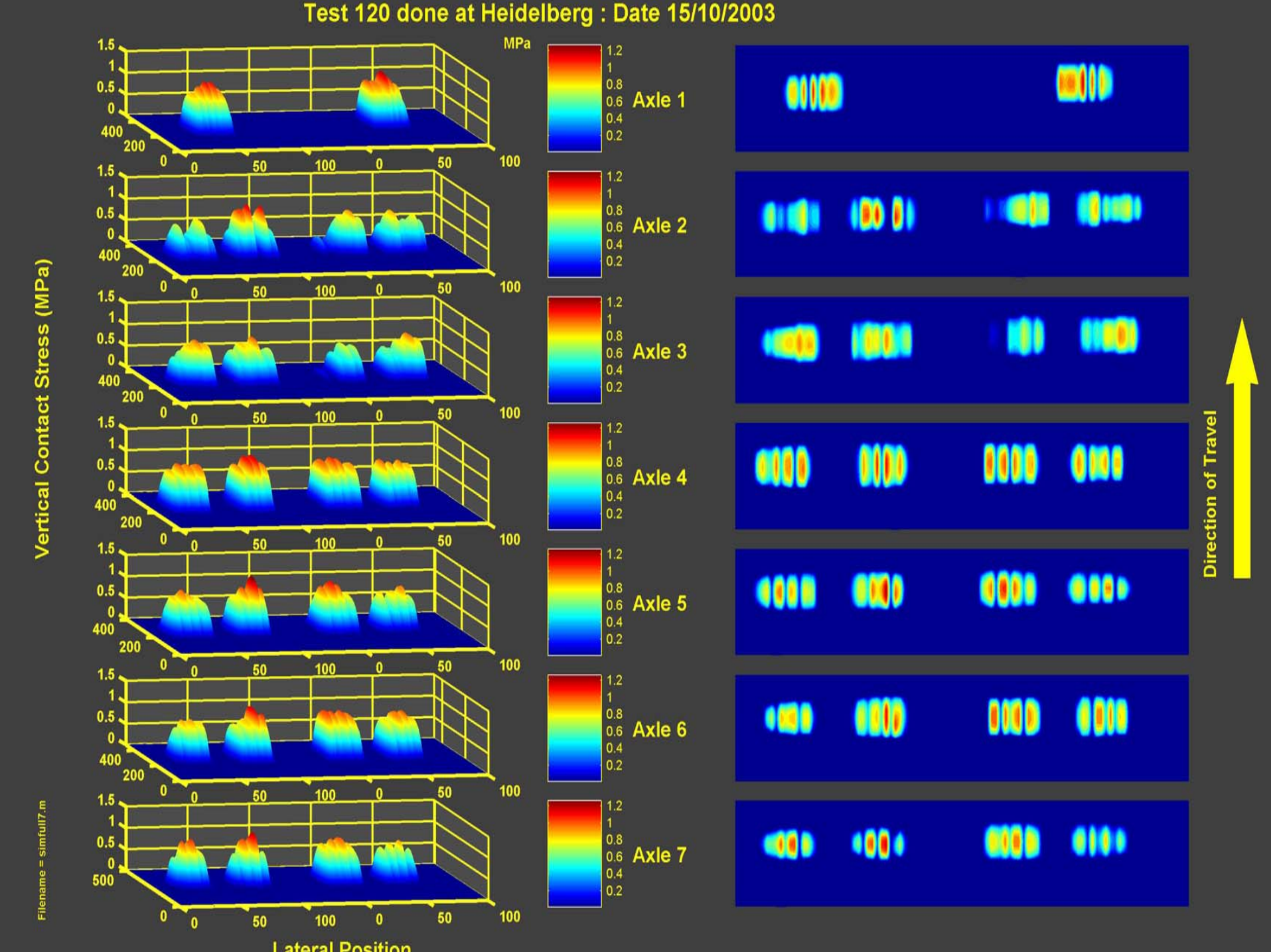
Test H1070 done at Heidelberg : Date 10/09/2003

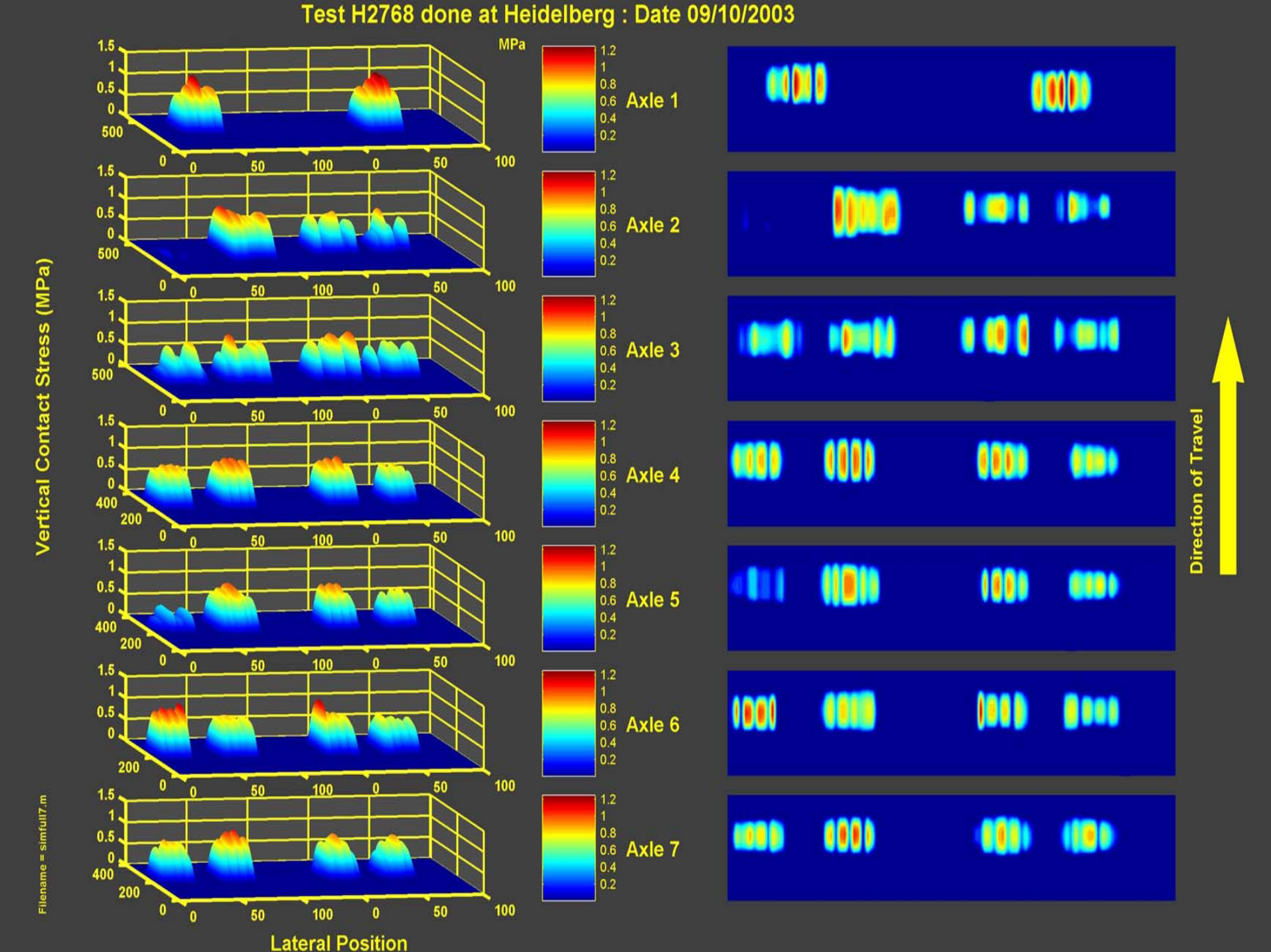


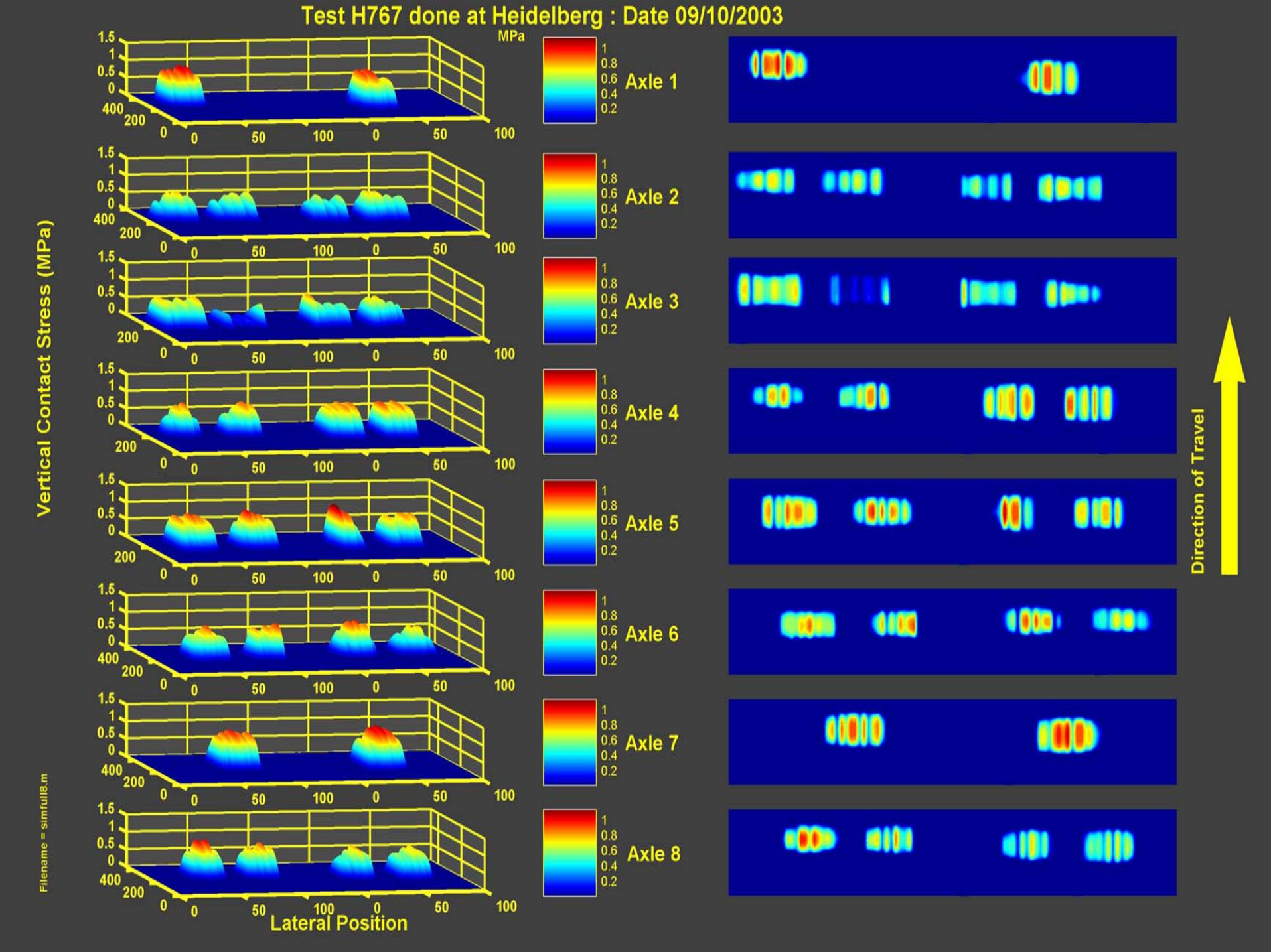

Test H833 done at Heidelberg : Date 09/09/2003
Vertical Contact Stress (MPa)
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Lateral Position
Direction of Travel
Filename = simfull4.m


Test H1077 done at Heidelberg : Date 10/09/2003
Vertical Contact Stress (MPa)
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Lateral Position
Direction of Travel
Filename = simfull5.m

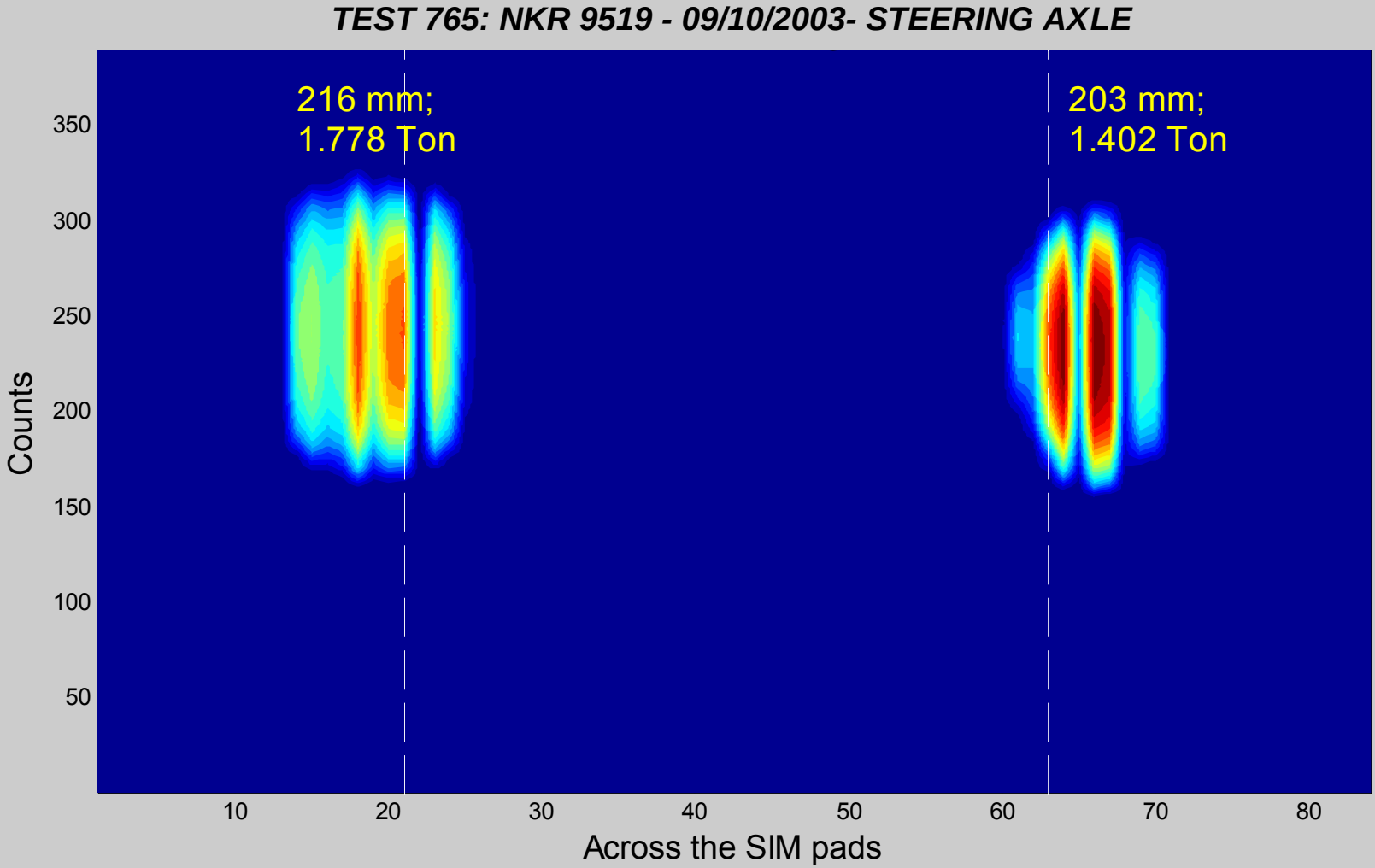

Test 174 done at Heidelberg : Date 10/09/2003 (overload)
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Vertical Contact Stress (MPa)
Lateral Position
Direction of Travel
Filename = simfull6.m


Test 120 done at Heidelberg : Date 15/10/2003
Vertical Contact Stress (MPa)
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Axle 7
Direction of Travel
Lateral Position
Filename = simfull7.m

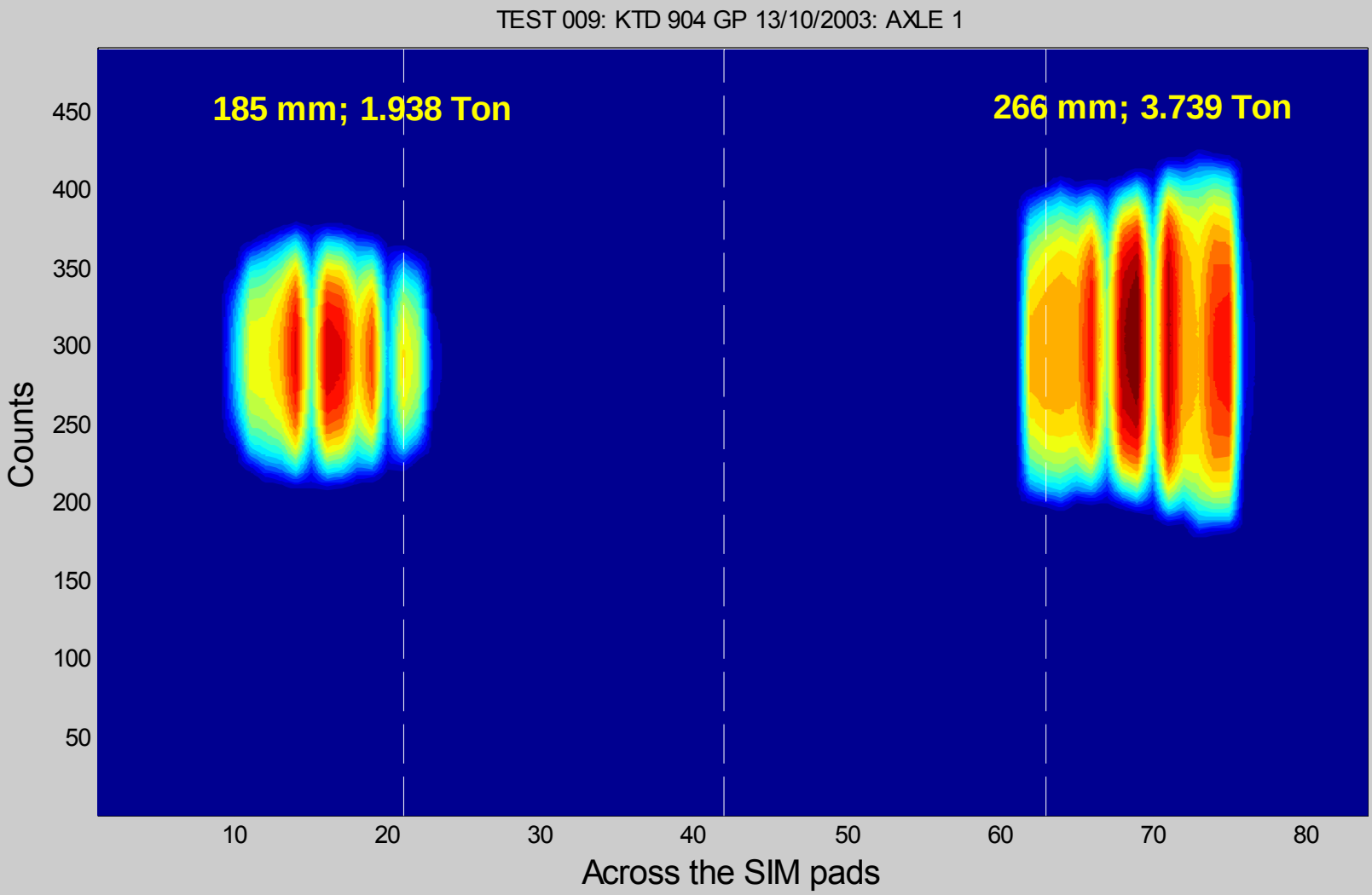

Test H2768 done at Heidelberg : Date 09/10/2003
Vertical Contact Stress (MPa)
Lateral Position
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Axle 7
Direction of Travel
Filename = simfull7.m


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

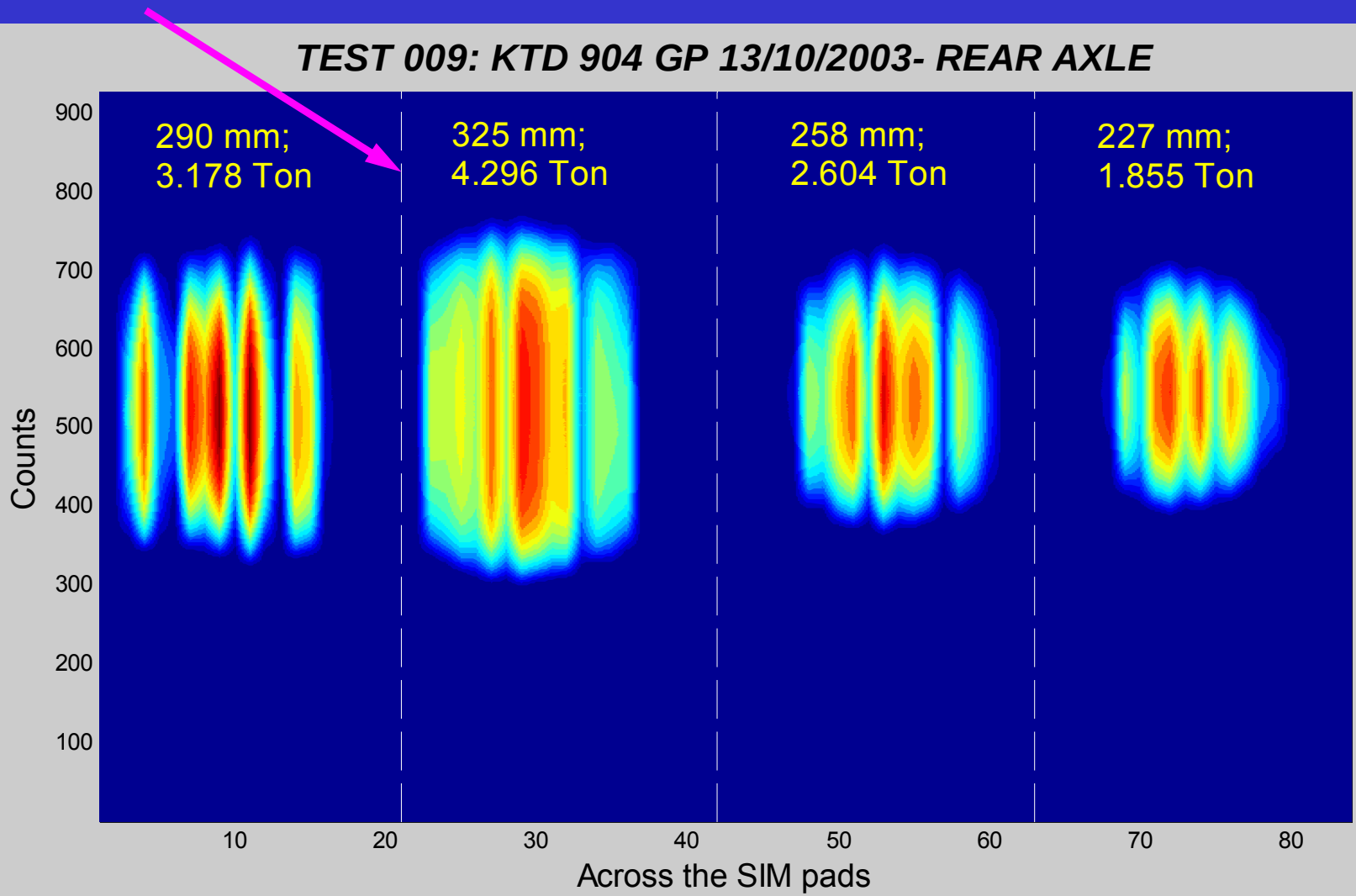
STEERING AXLE



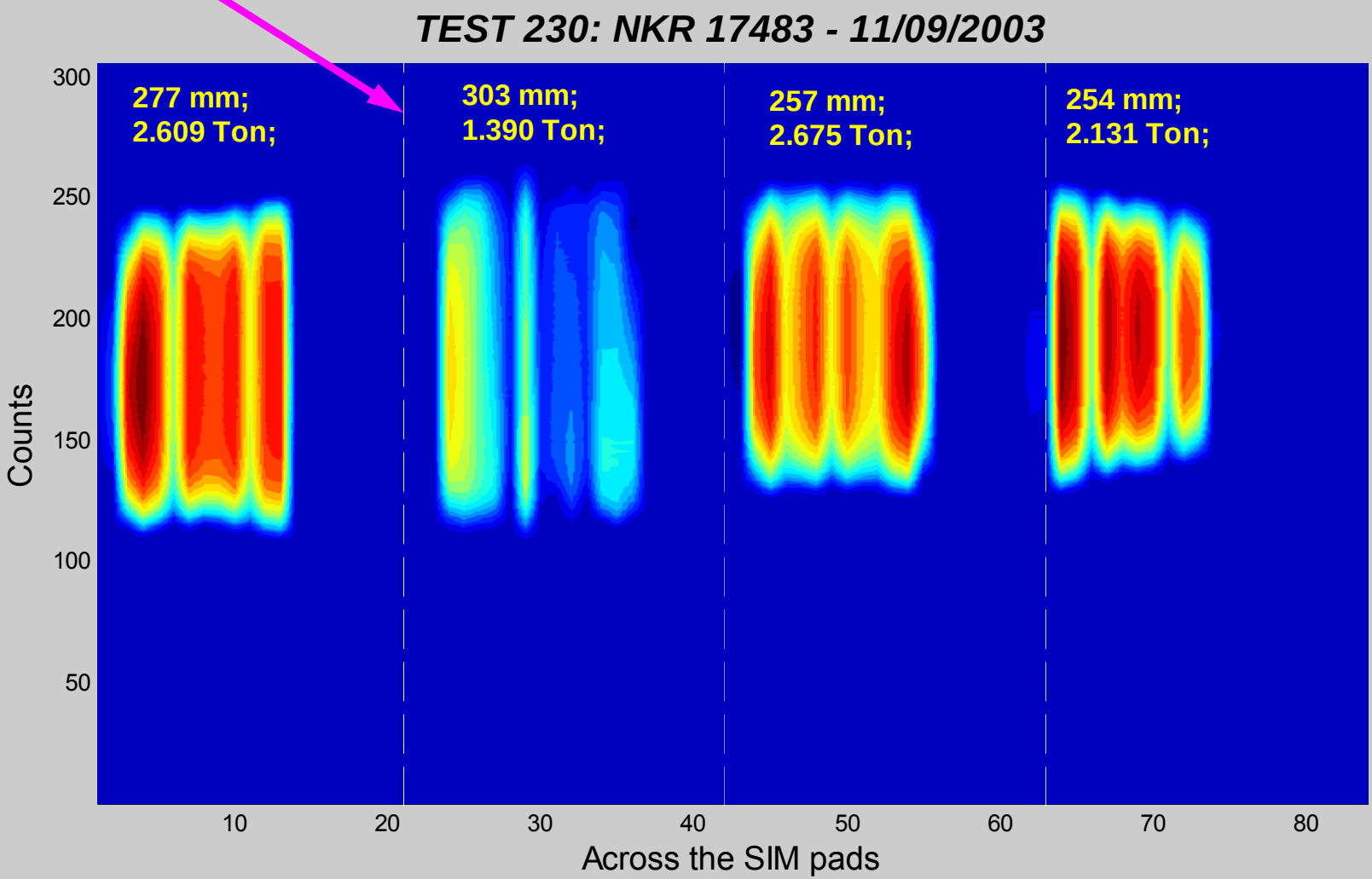
STEERING AXLE – UNEQUAL LOADING



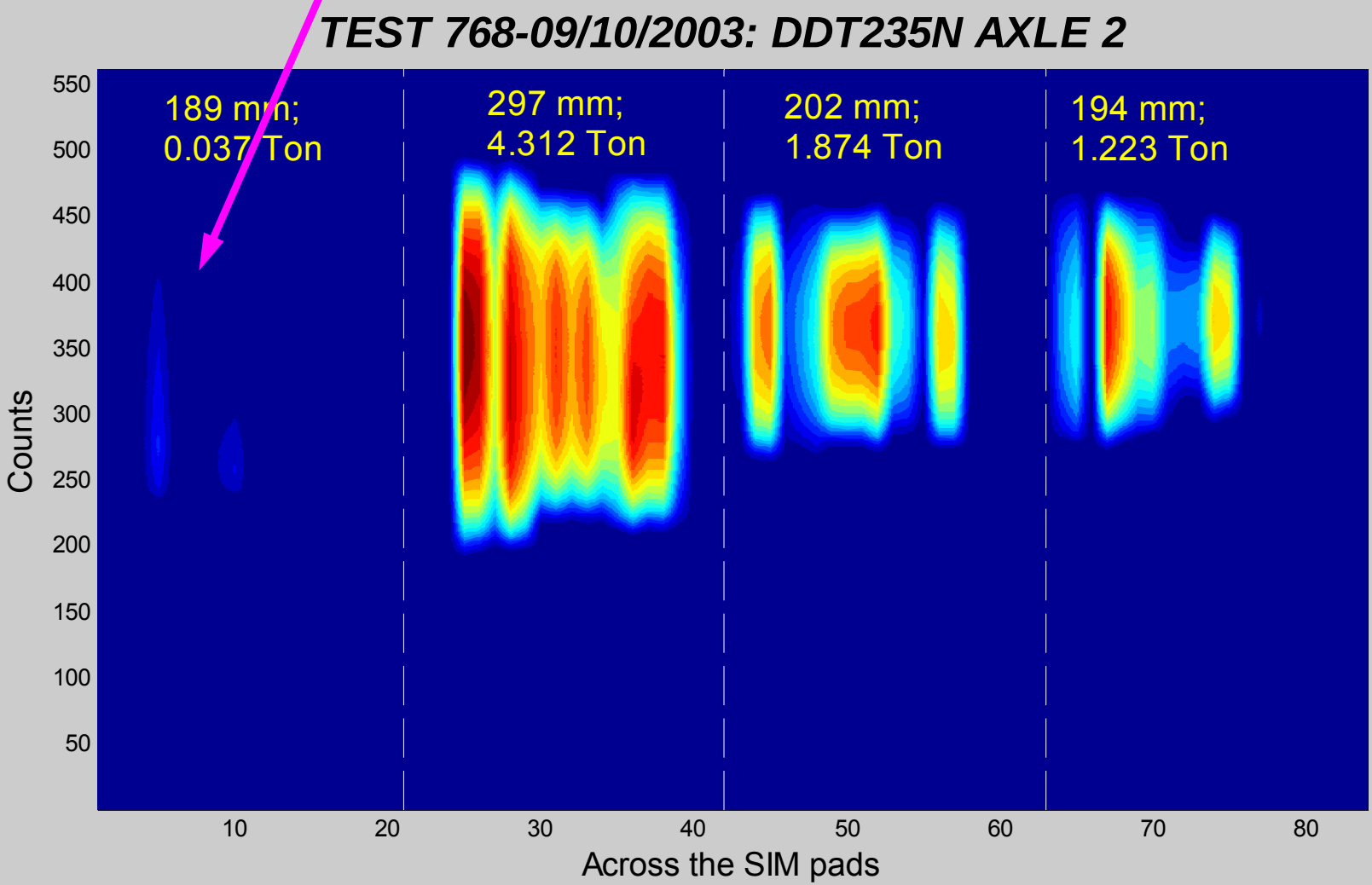
REAR AXLE – UNEQUAL LOADING



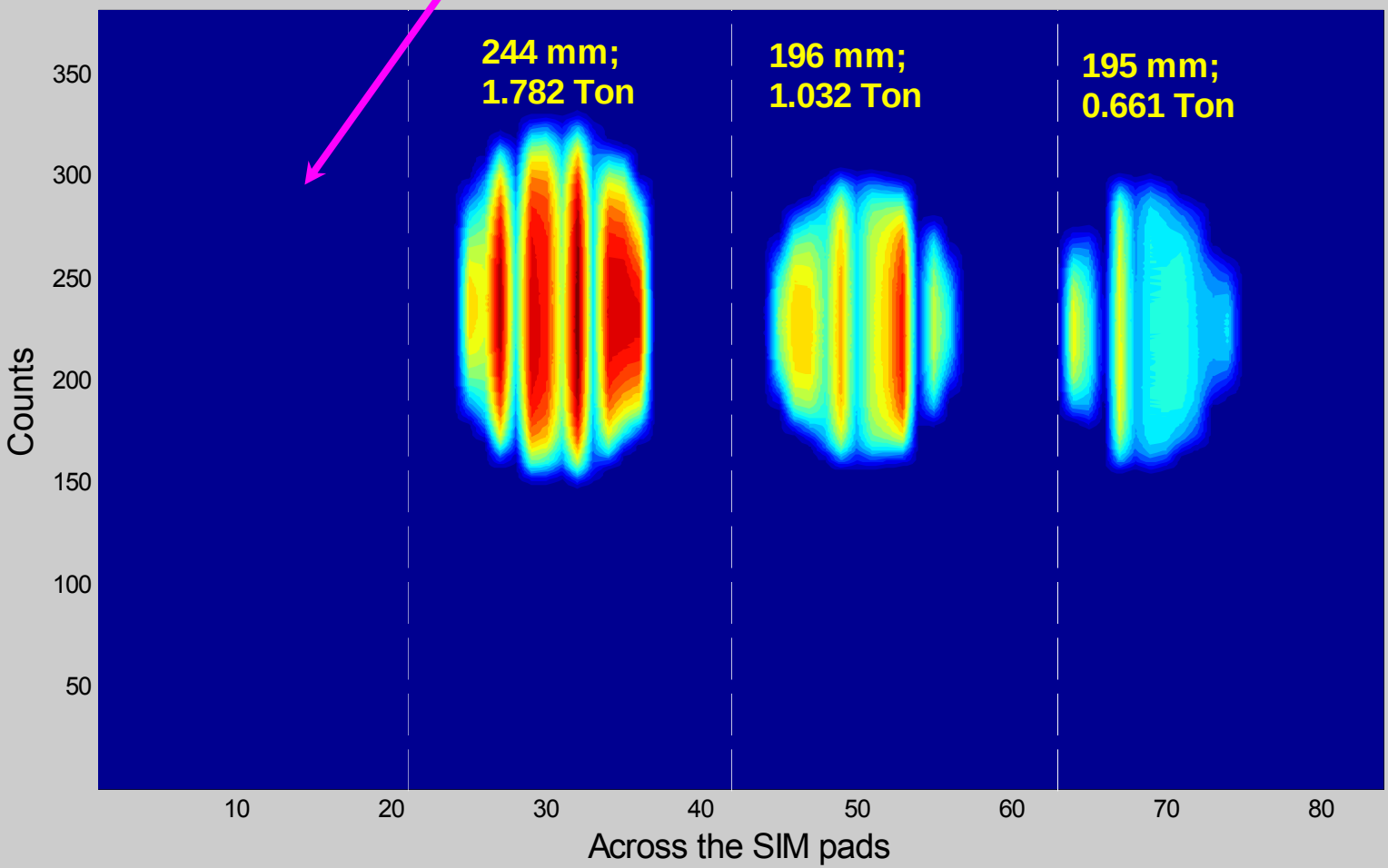
REAR AXLE – UNEQUAL LOADING



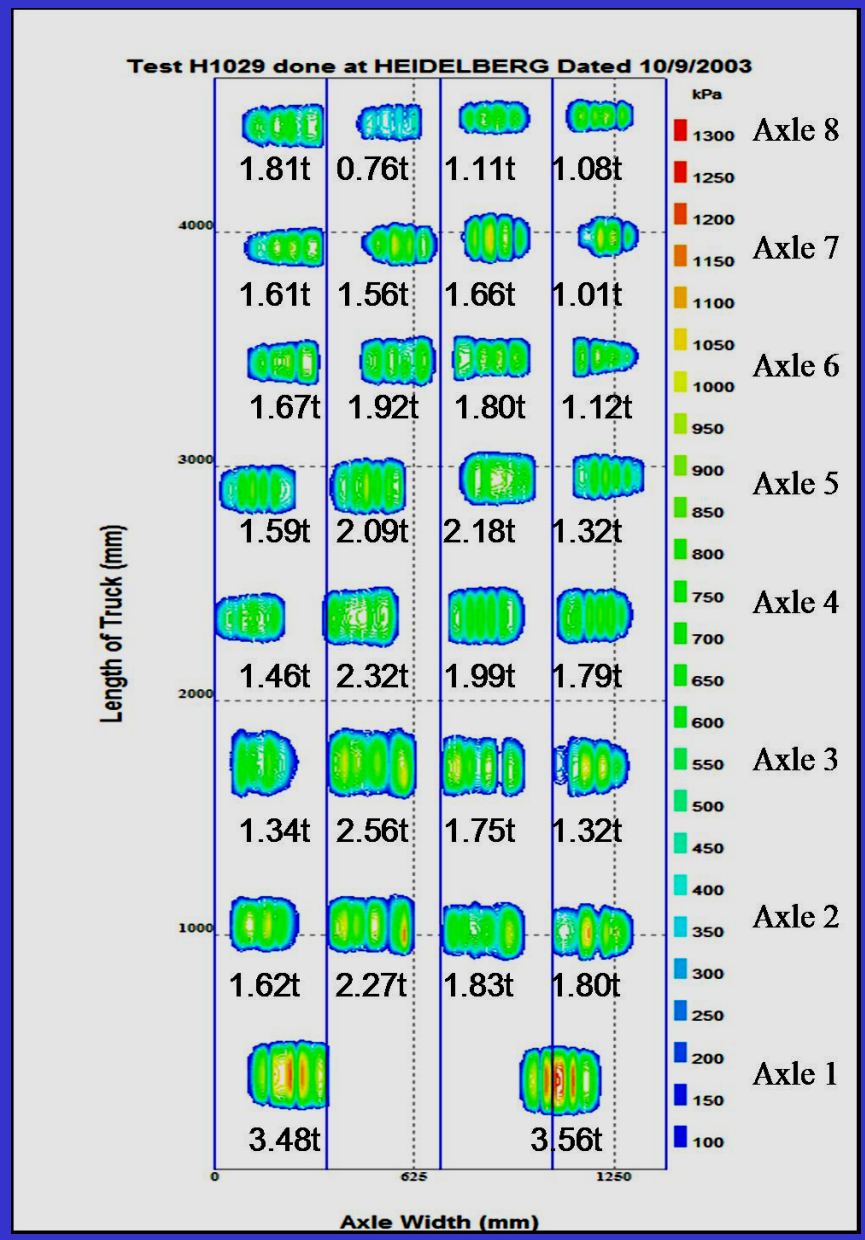
TYRE barely in contact with surface



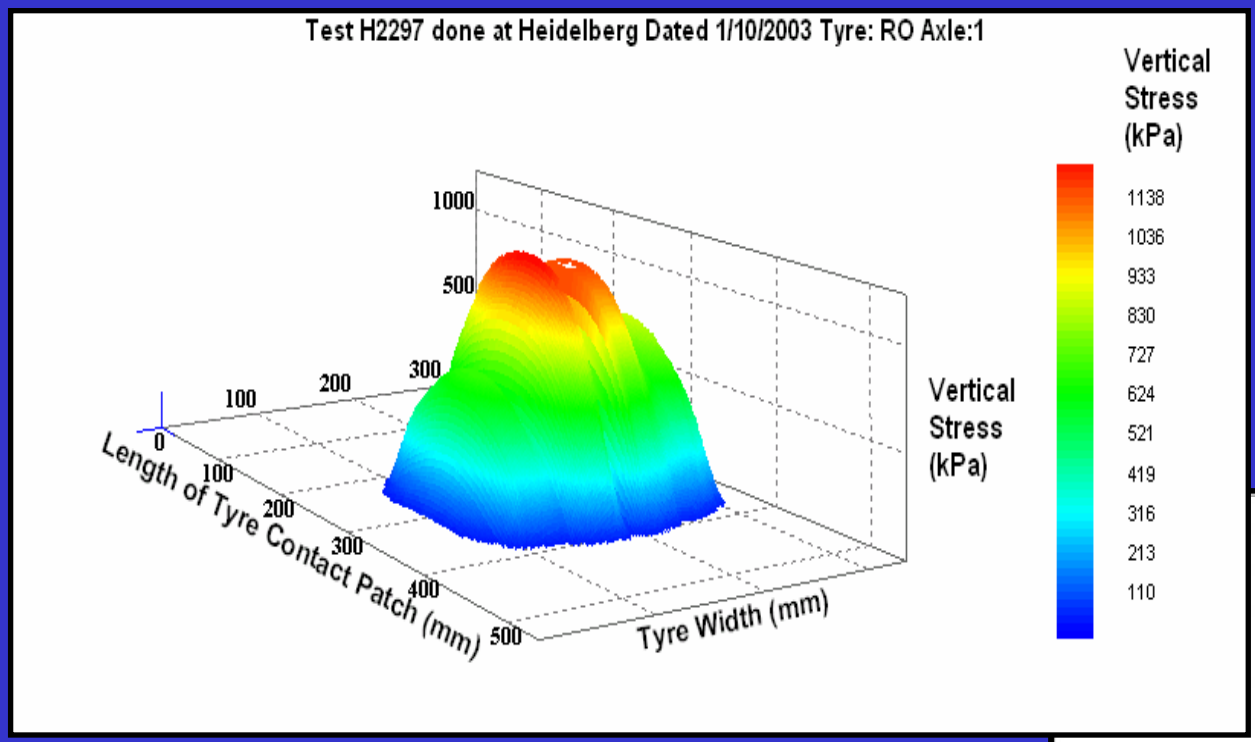
AXLE 2: MISSING TYRE !!

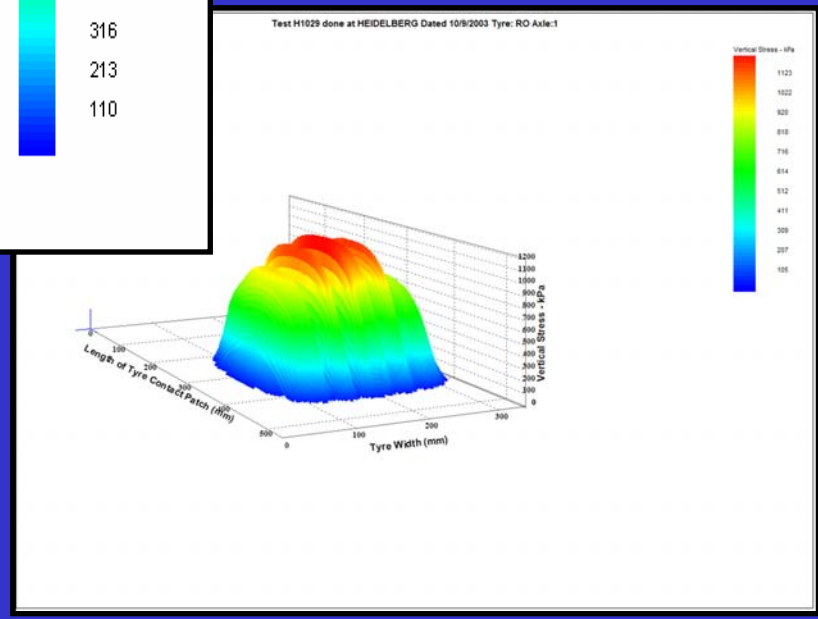


Footprint of an 8-Axle Truck - Figure 7 in Paper

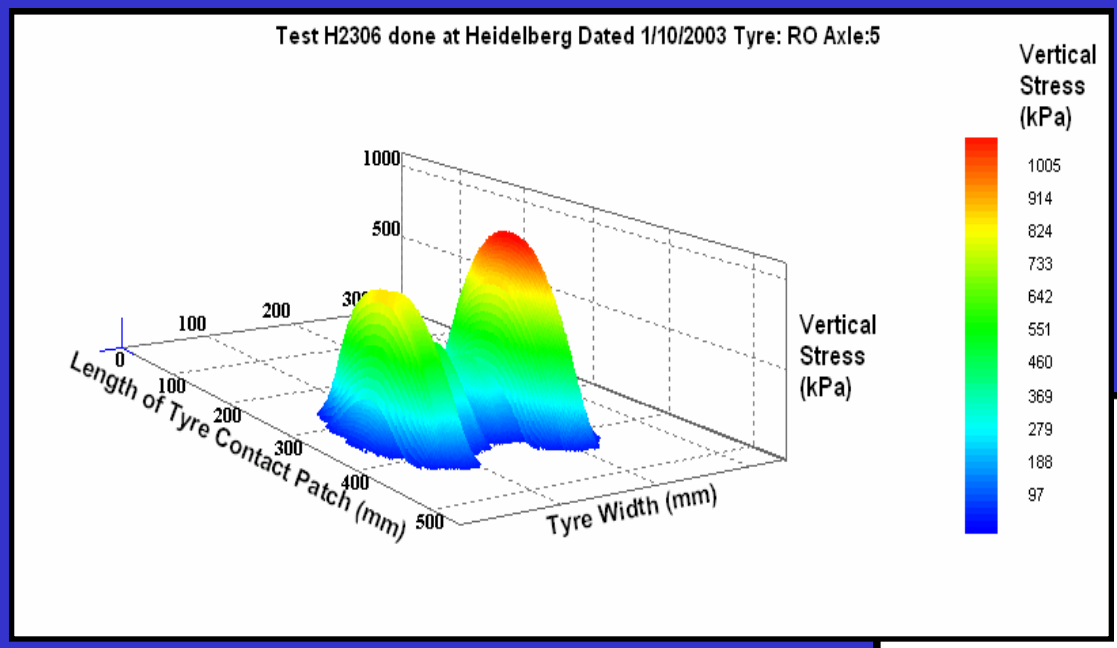


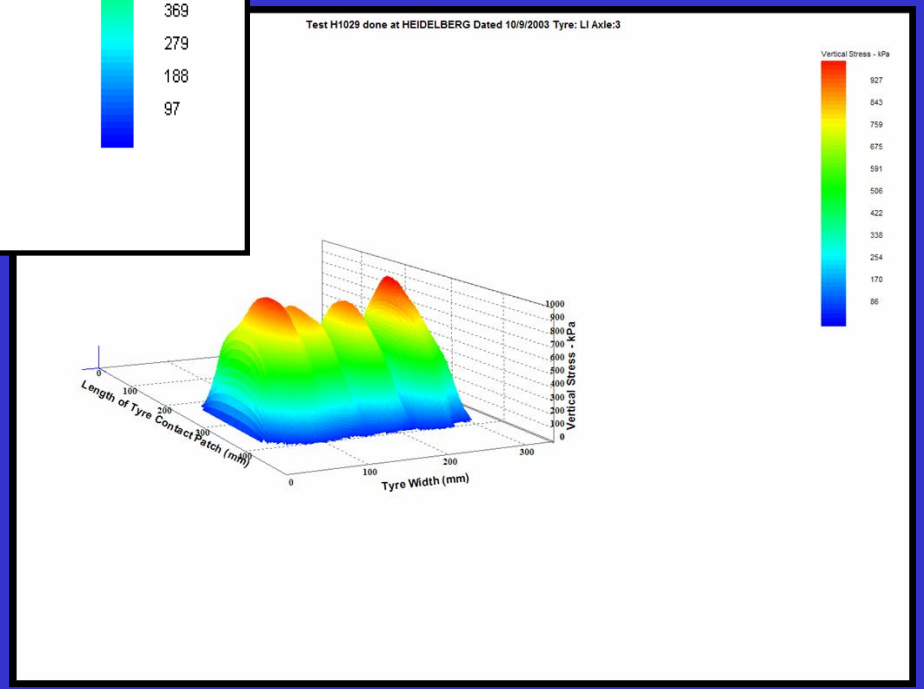
Vertical Contact Stress – "n" Shape



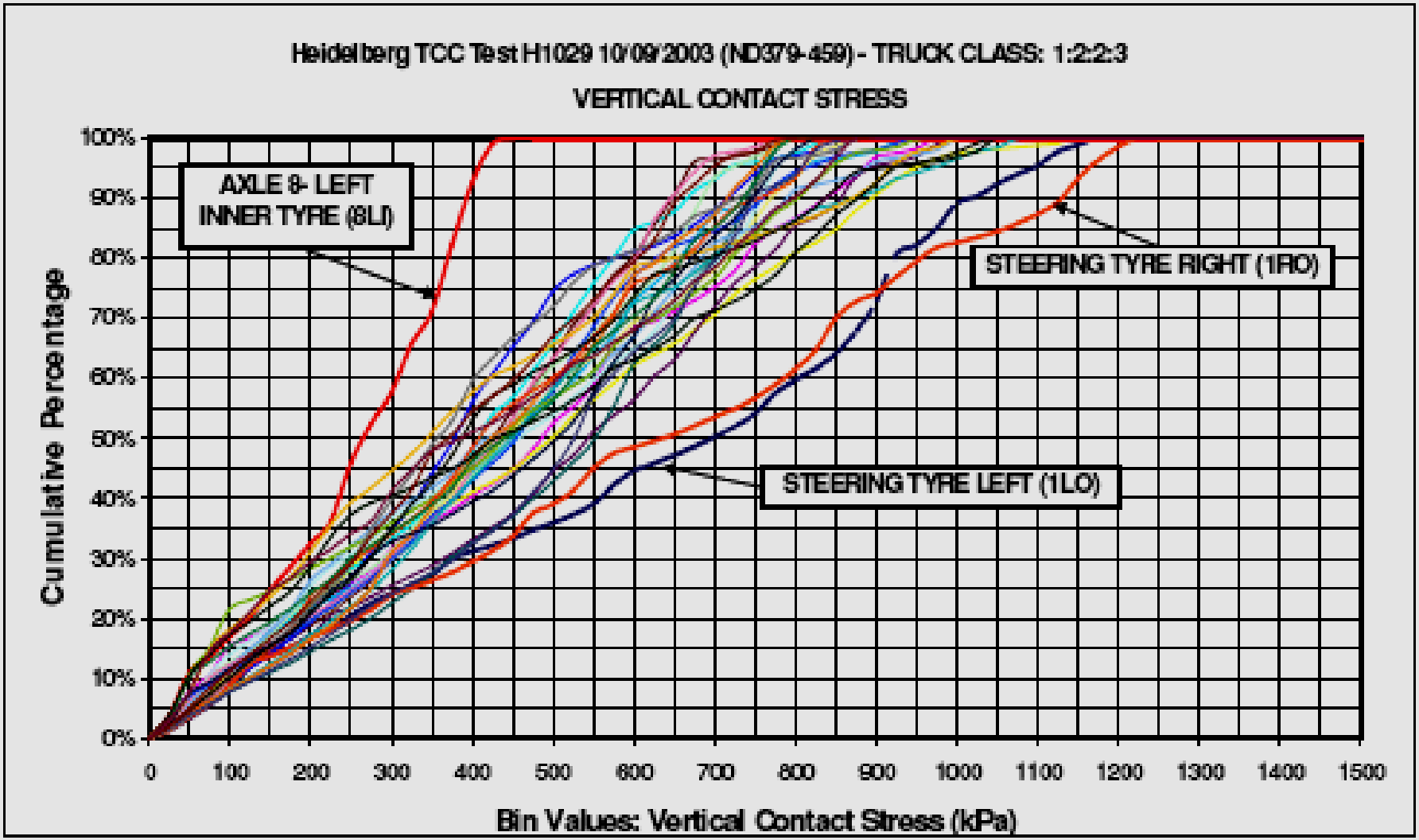


Vertical Contact Stress – "m" Shape

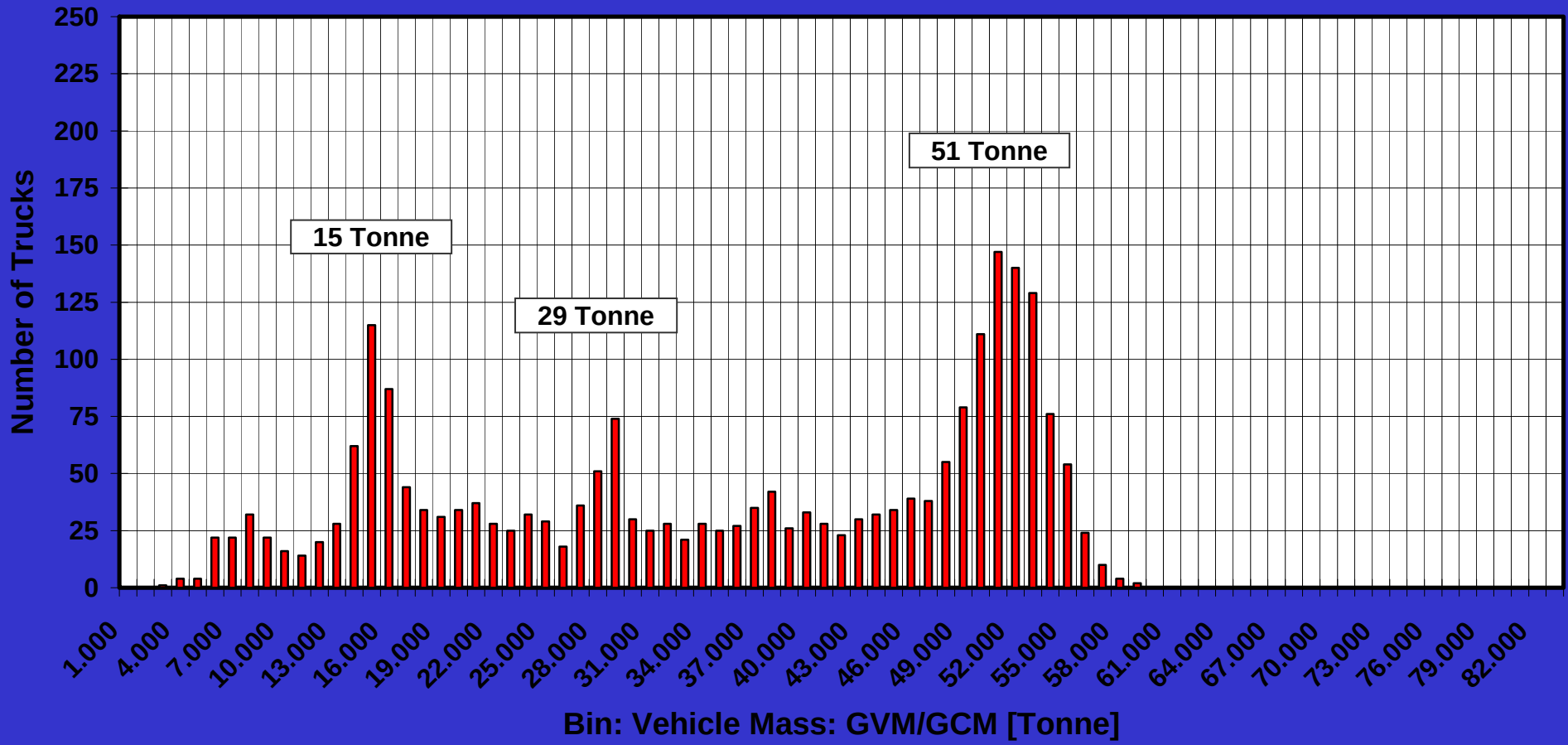




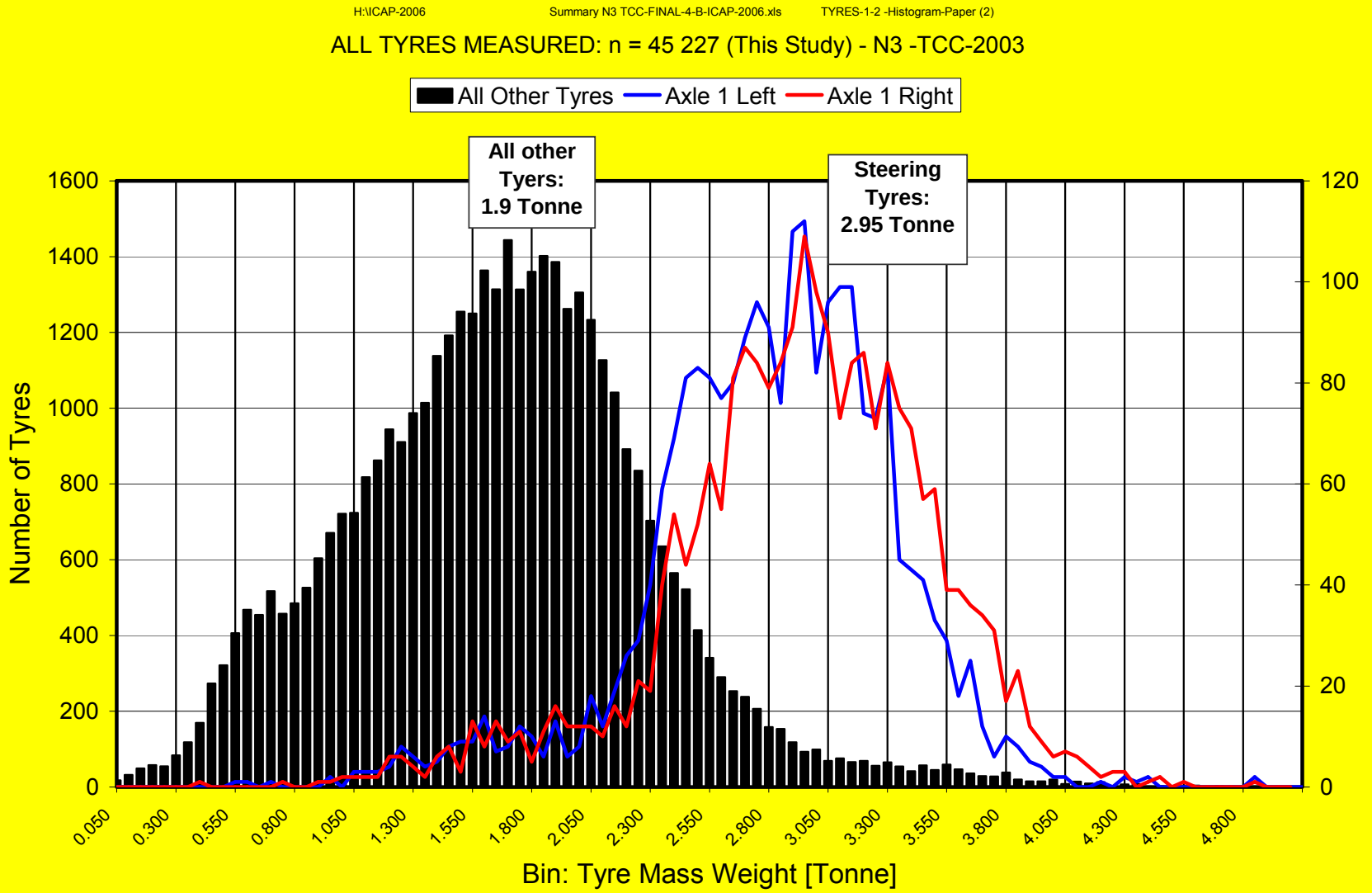
Vertical Stress Cumulative Frequency – N3- 2003



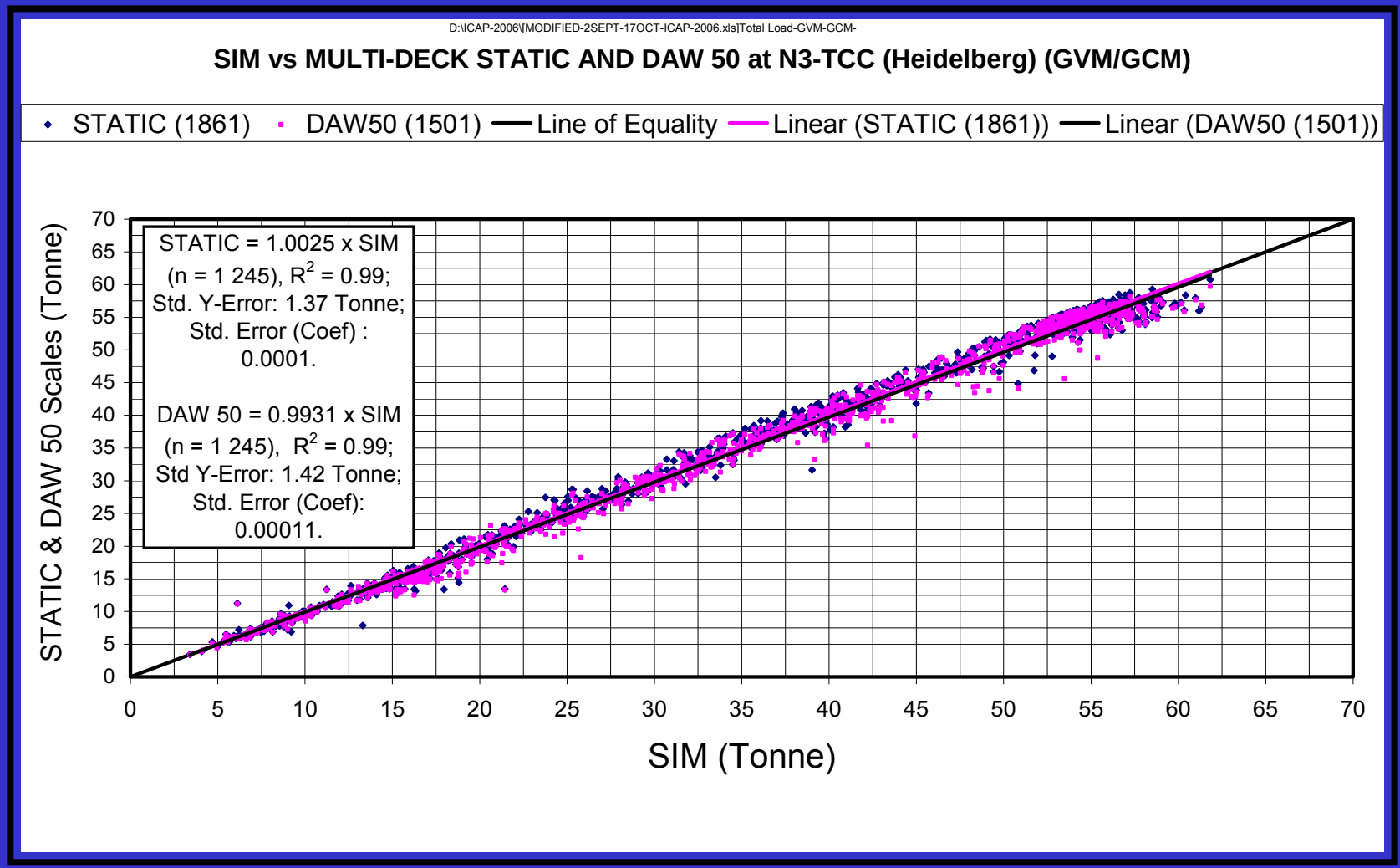
GVM/GCM-SIM N3 TCC - 2003
RESULT RATINGS 1 AND 2 (n = 2 297)
[2 Sept - 17 Oct 2003]



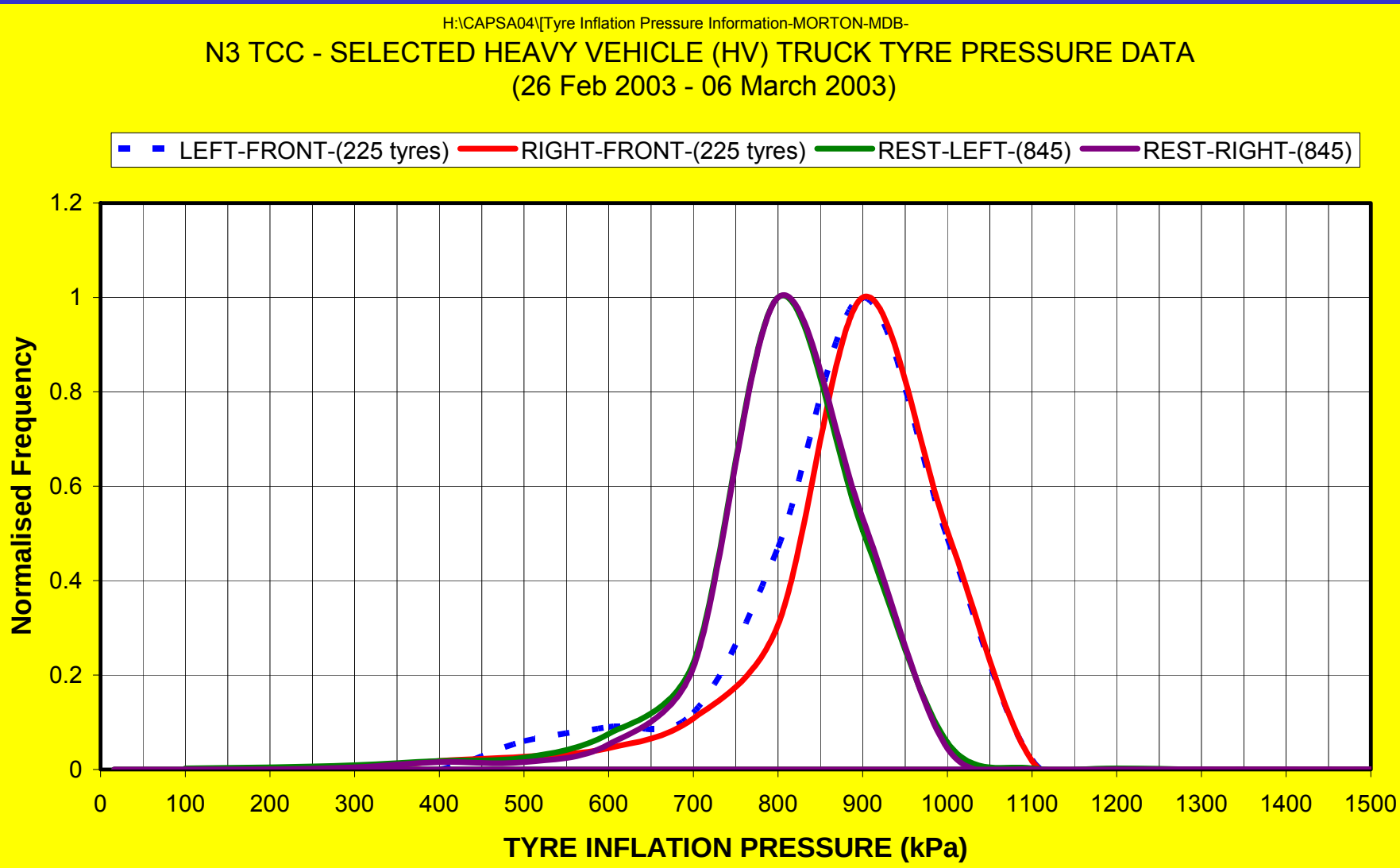
Axle Load Distributions – N3- 2003



LOAD COMPARISON – FIELD WITH REAL TRUCKS N3 TCC - HEIDELBERG



Tyre Inflation Pressure Distributions – N3- 2003



SIMPLIFIED LOADING SHAPES

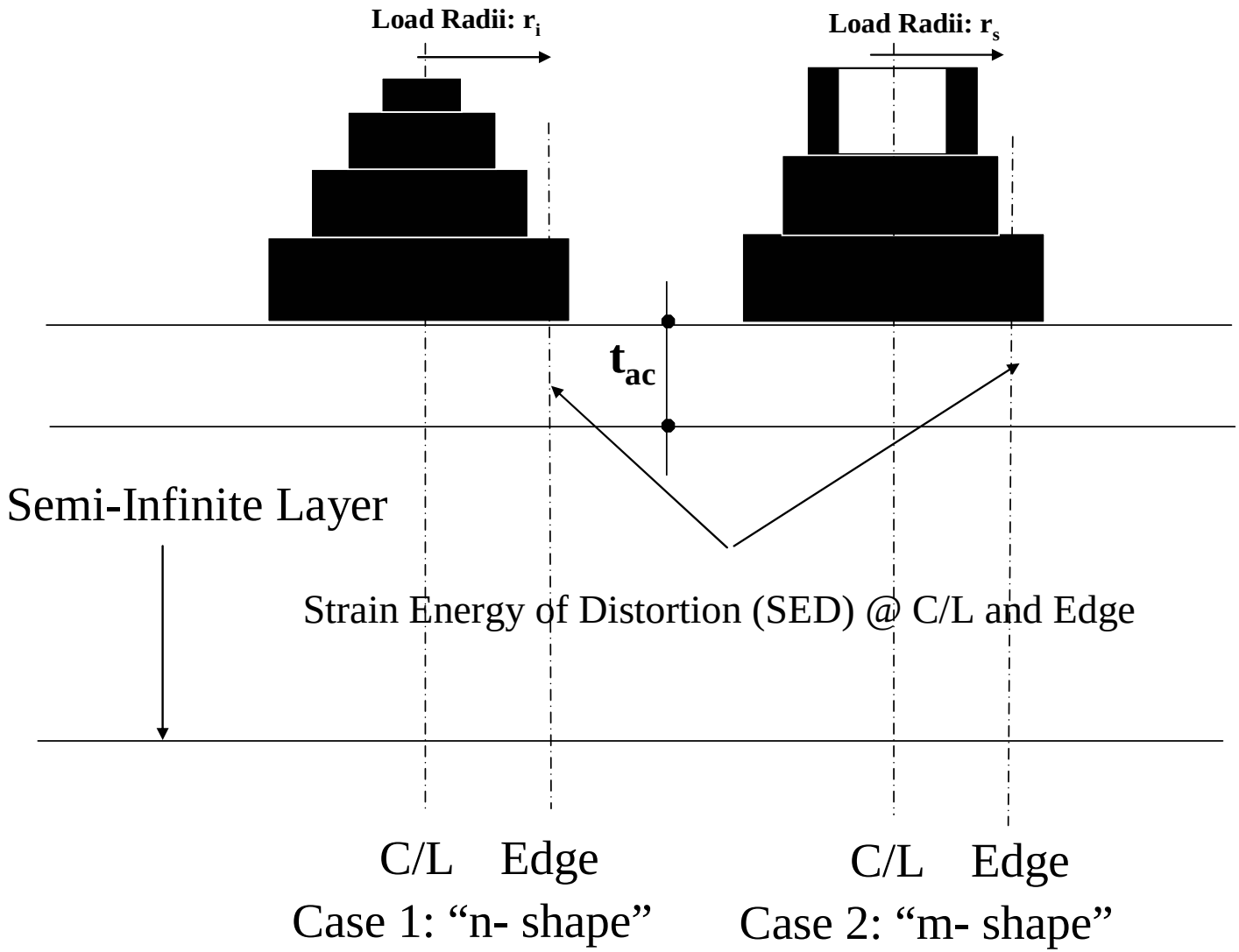
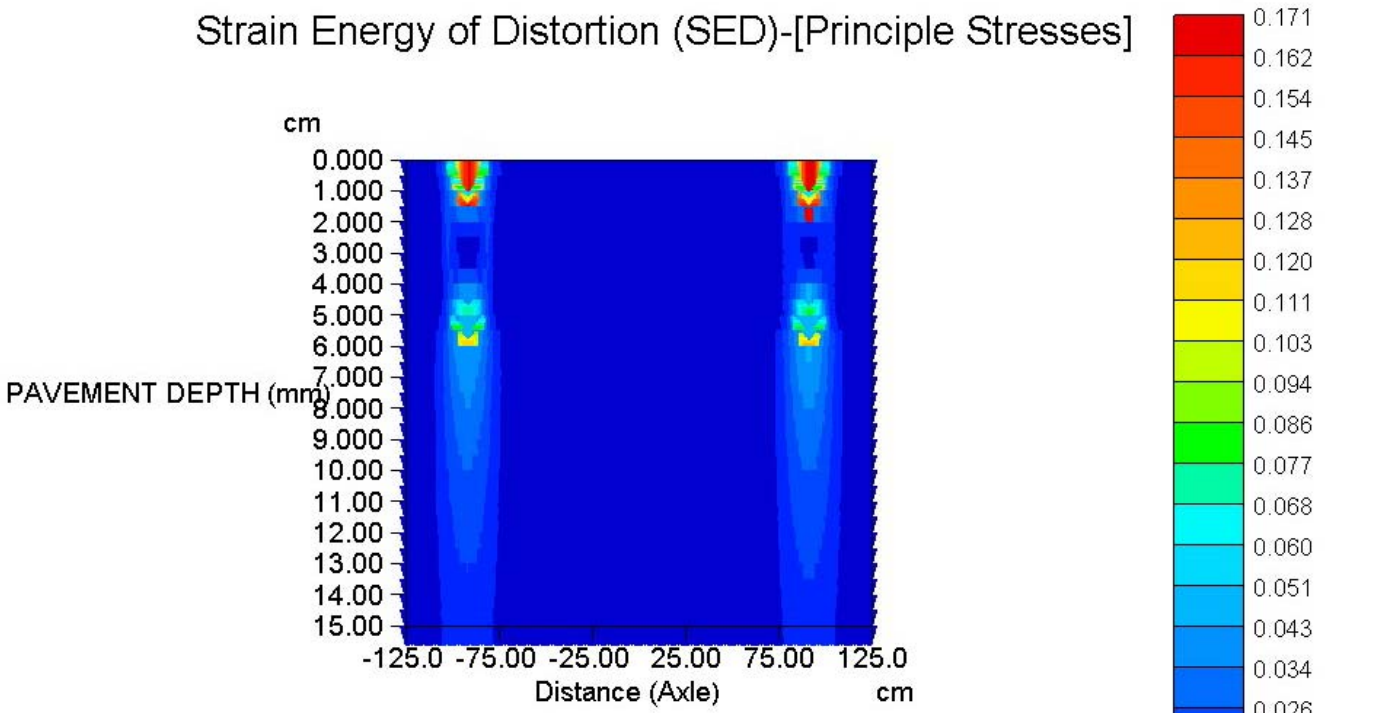
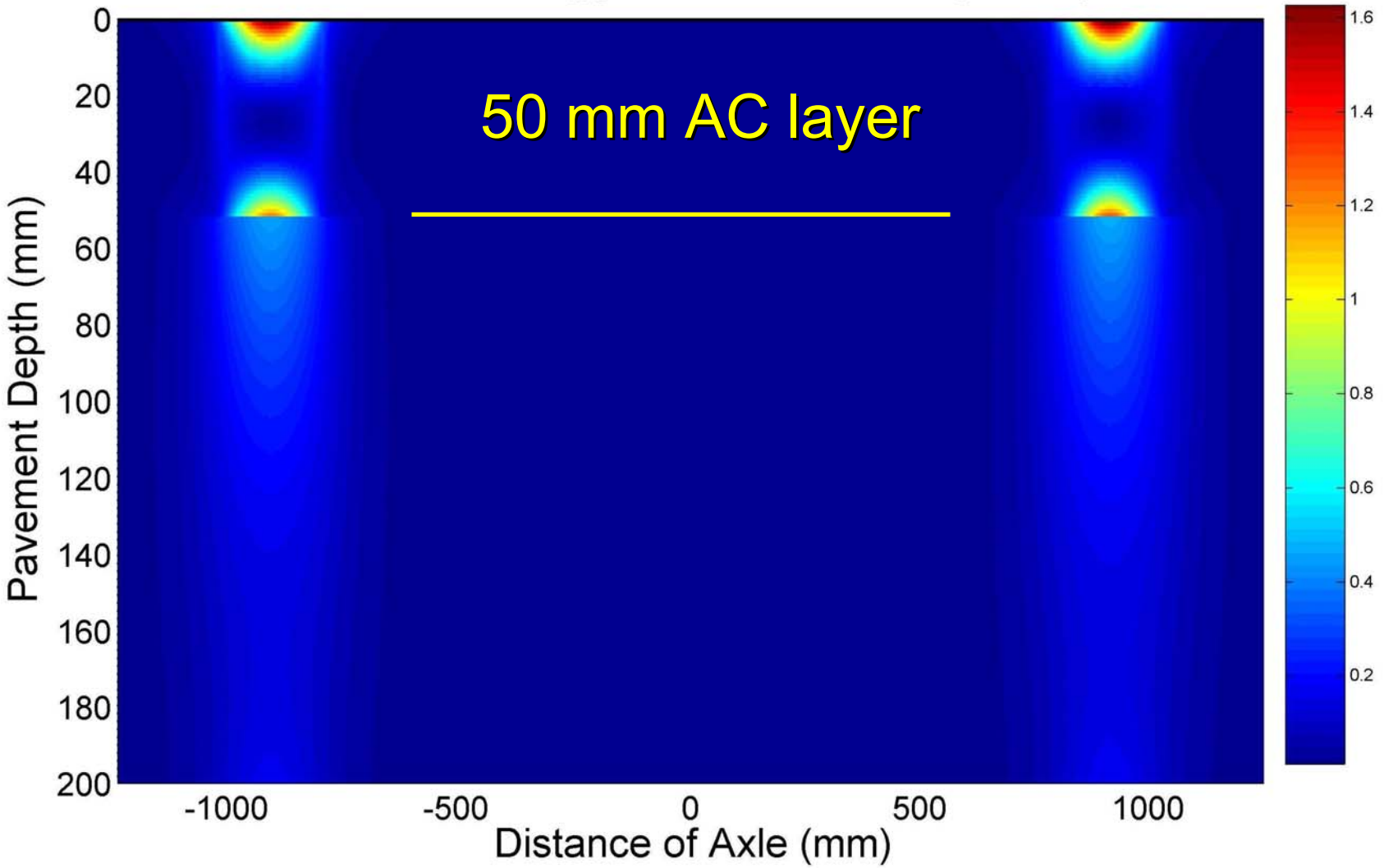


Table 1 Modelling parameters for a 3-layer pavement.

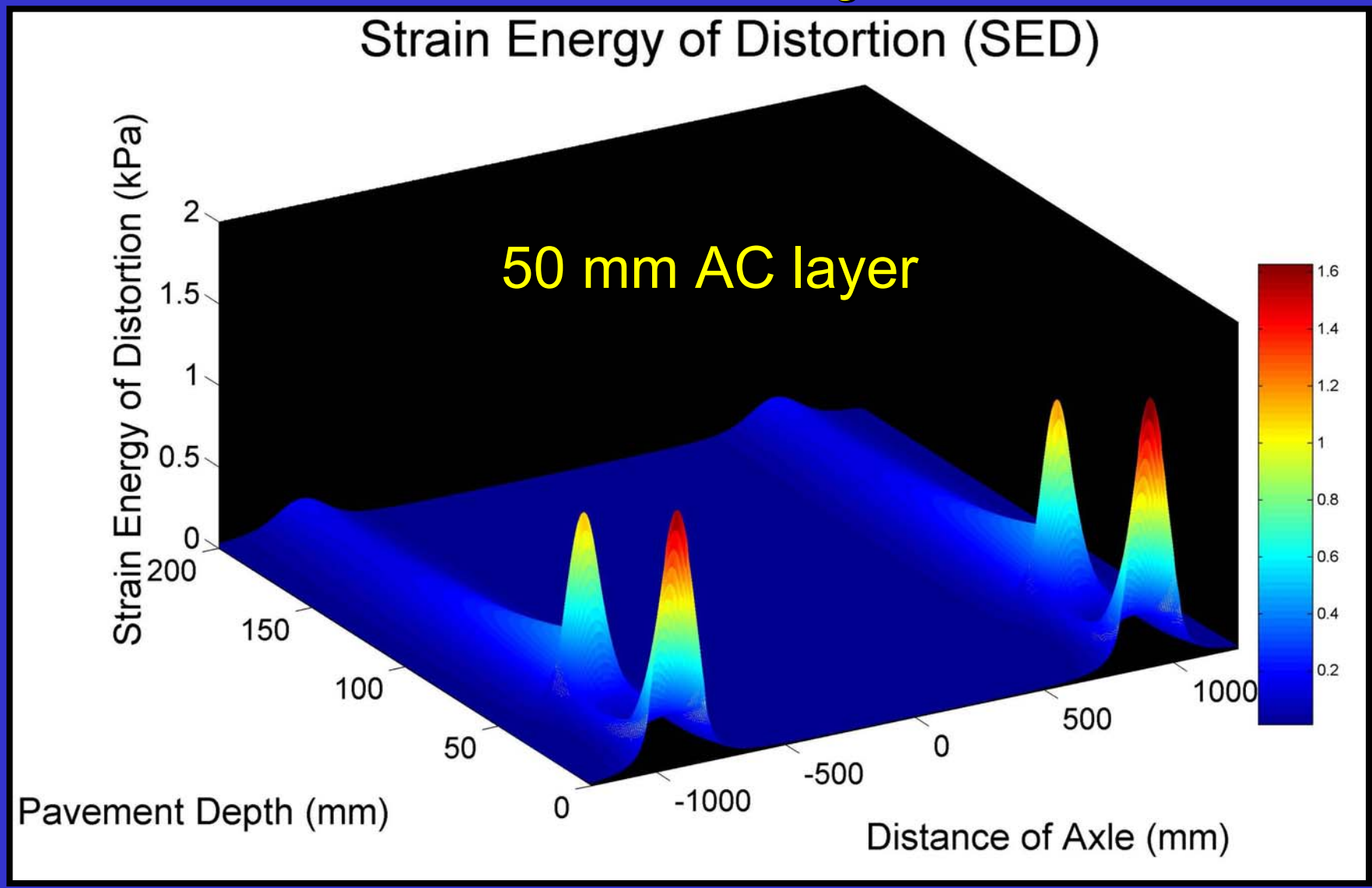
Layers	Elastic Moduli (MPa), Poisson, μ	Loading/Contact Stress	Comments
Asphalt surfacing (AC)	3500, 0.44	See Figure 11	Thickness, $t_{ac:}$ = 50 mm
Granular Base layer	350, 0.35	--	t_{ac} = 150 mm
Subgrade	100, 0.35	--	Semi Inf.

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

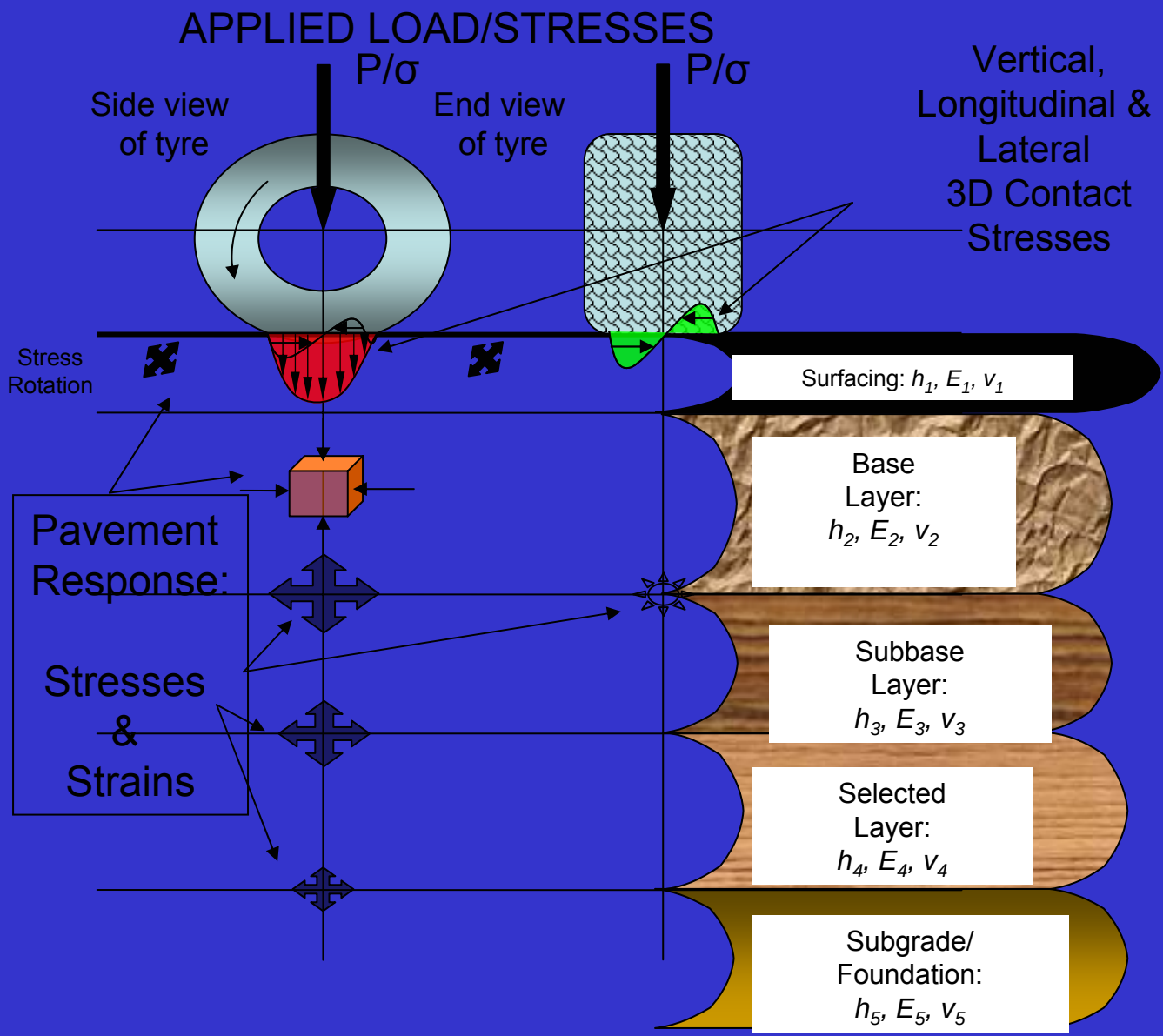



Strain Energy of Distortion (SED)
50 mm AC layer
Pavement Depth (mm)
0
20
40
60
80
100
120
140
160
180
200
-1000
-500
0
500
1000
Distance of Axle (mm)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2

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

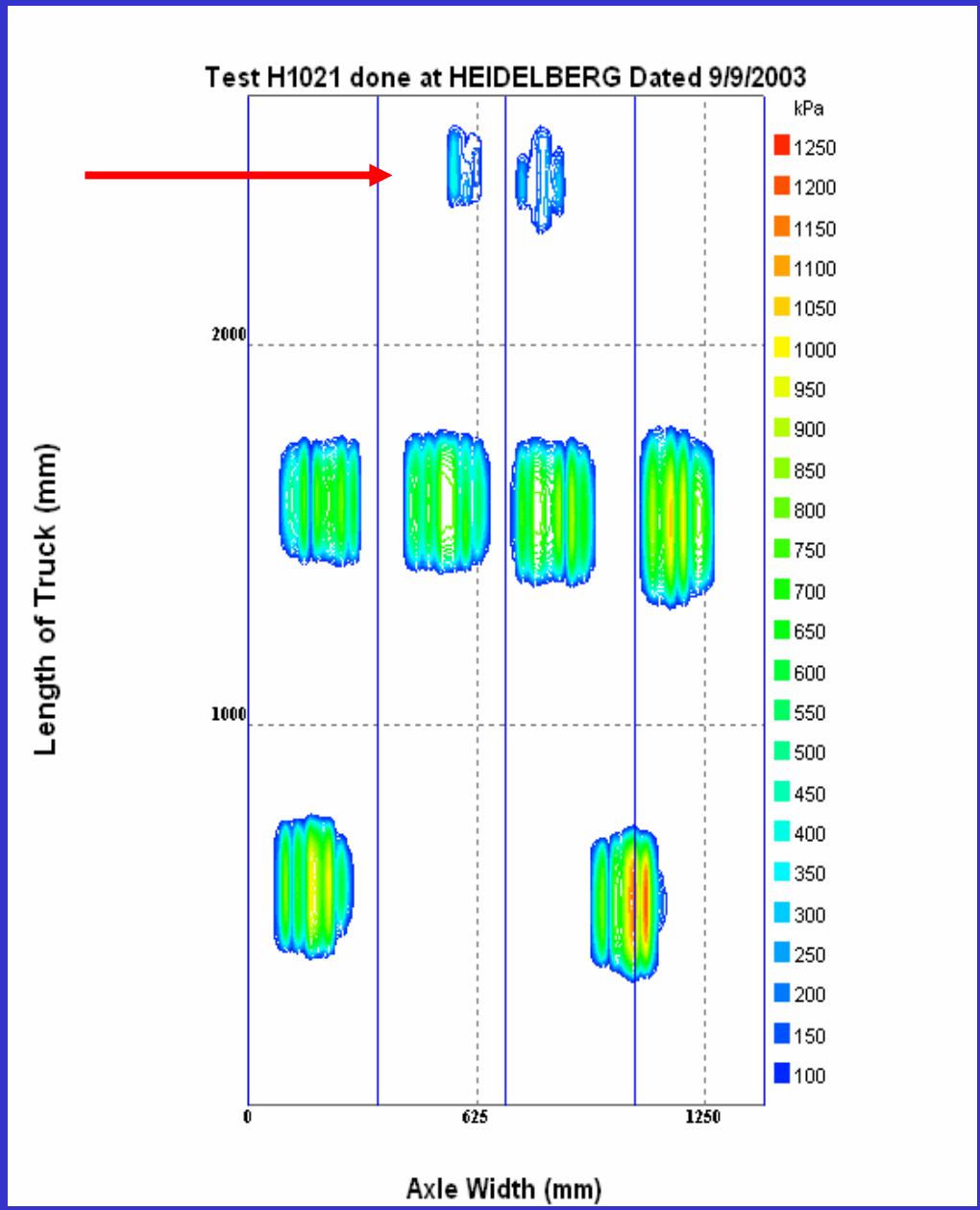


Tools exist to incorporate complex stress conditions at surface…




Thank you for your attention..

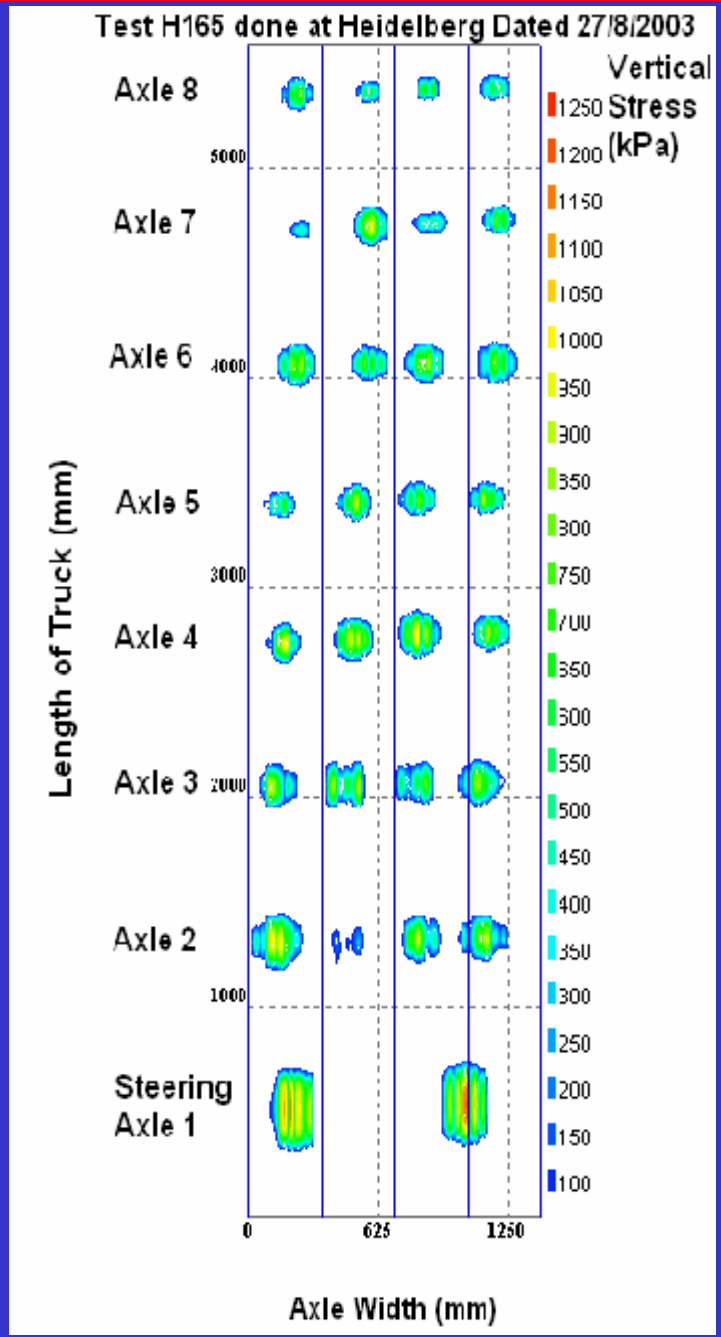
Trailer



Example: 7 Axle

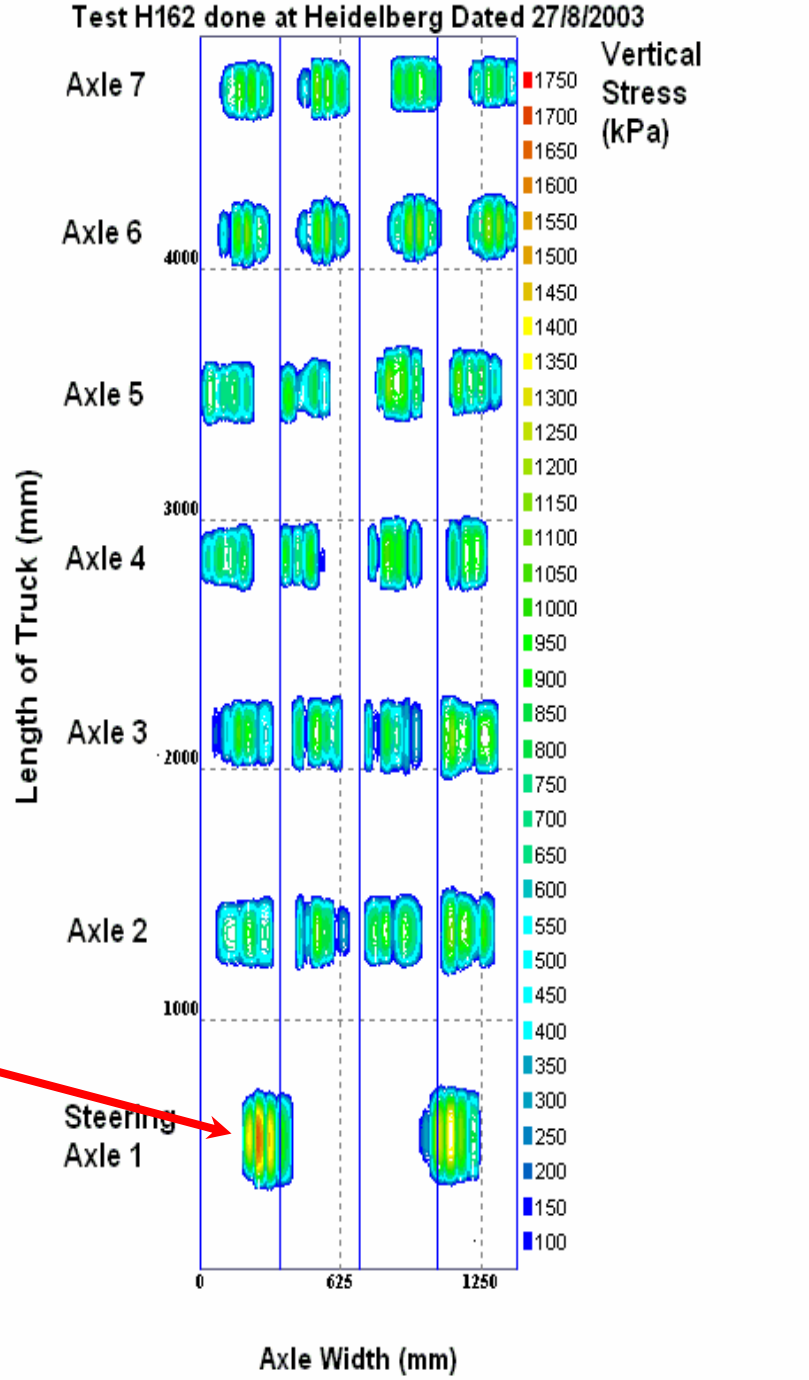
EMPTY Truck (1:2:2:3)

Note Variation in Vertical Contact Stresses on all 30 tyres



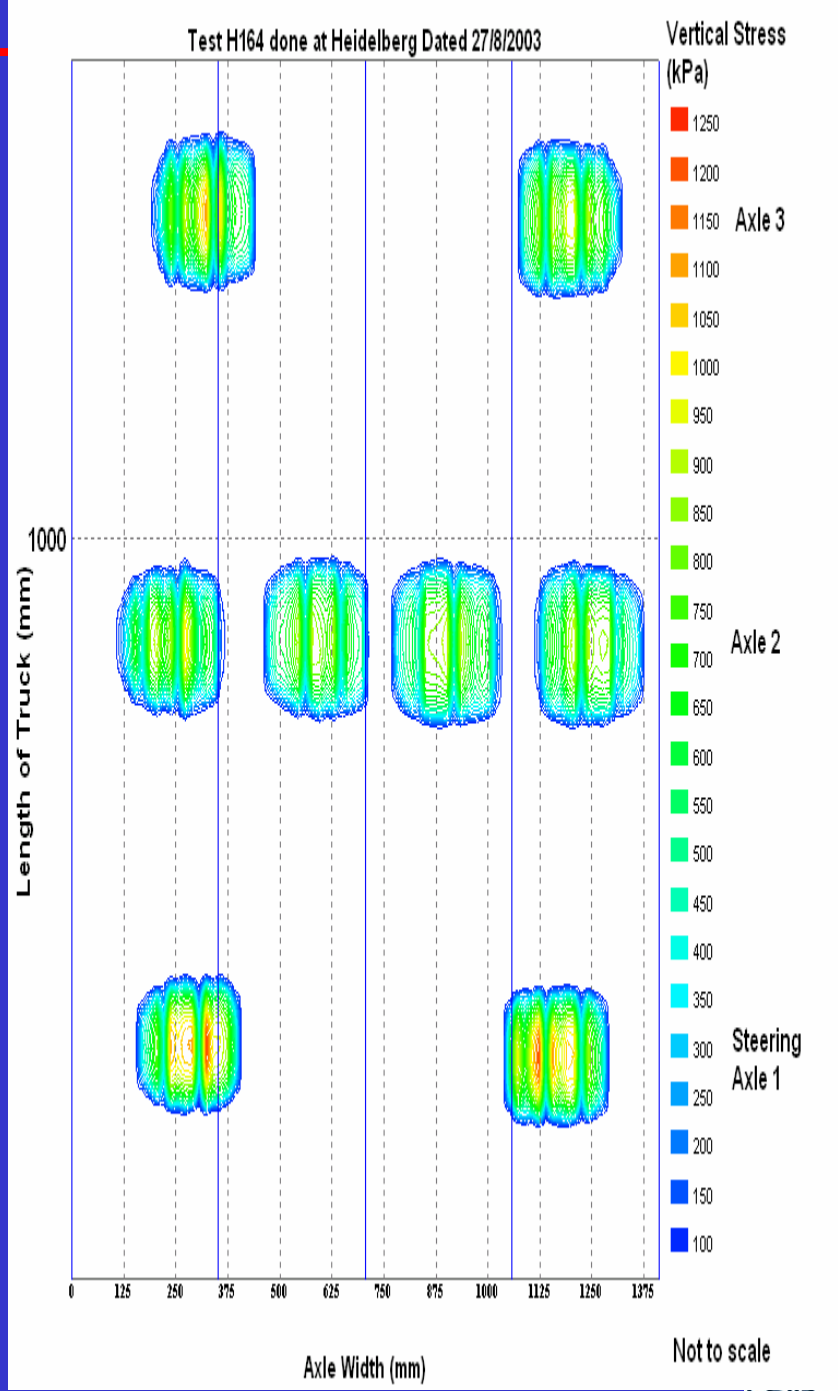
Example: 7 Axle Truck (1:2:2:2) fully loaded with cement

Note Contact Stresses on Steering Tyres



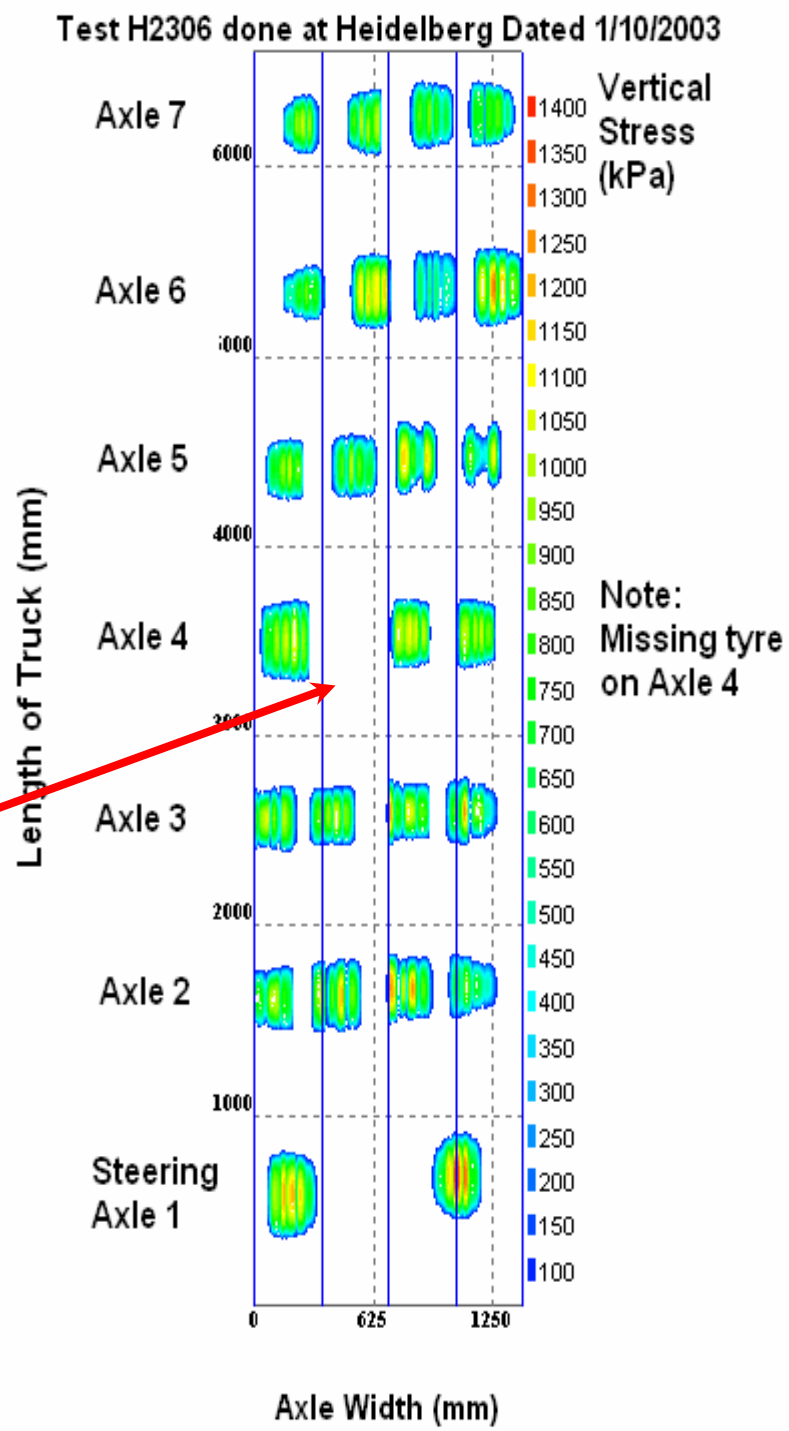
Example: Passenger Bus (1:1:1)

(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 Par... | Pavement Life | Contour Plot | Profile Plot | Diagnostics

Define plane for contour plot

Vertical plane parallel to X-Z

Y offset from origin: 10

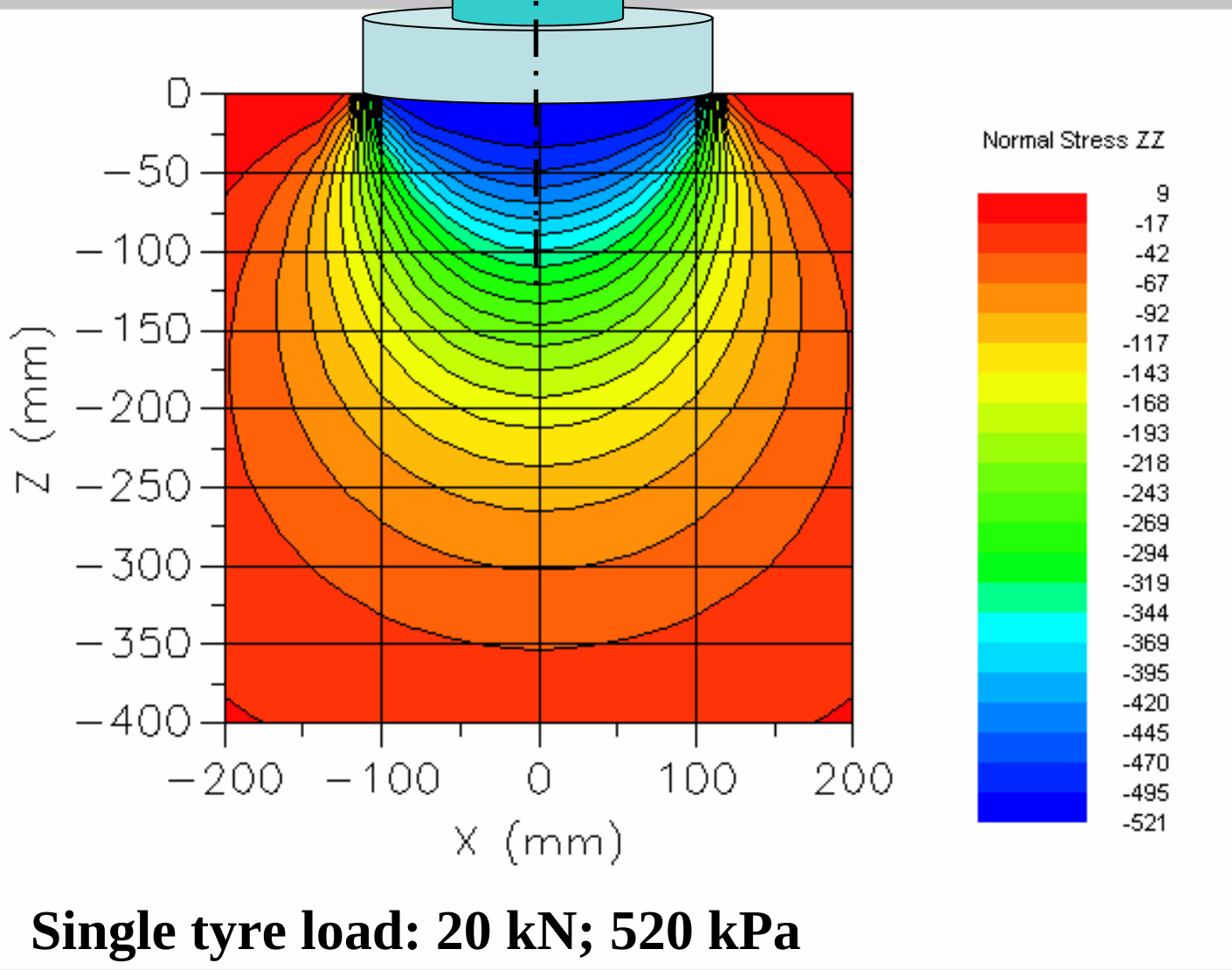
Contour region size (mm): 400

Contour region centred at (mm)

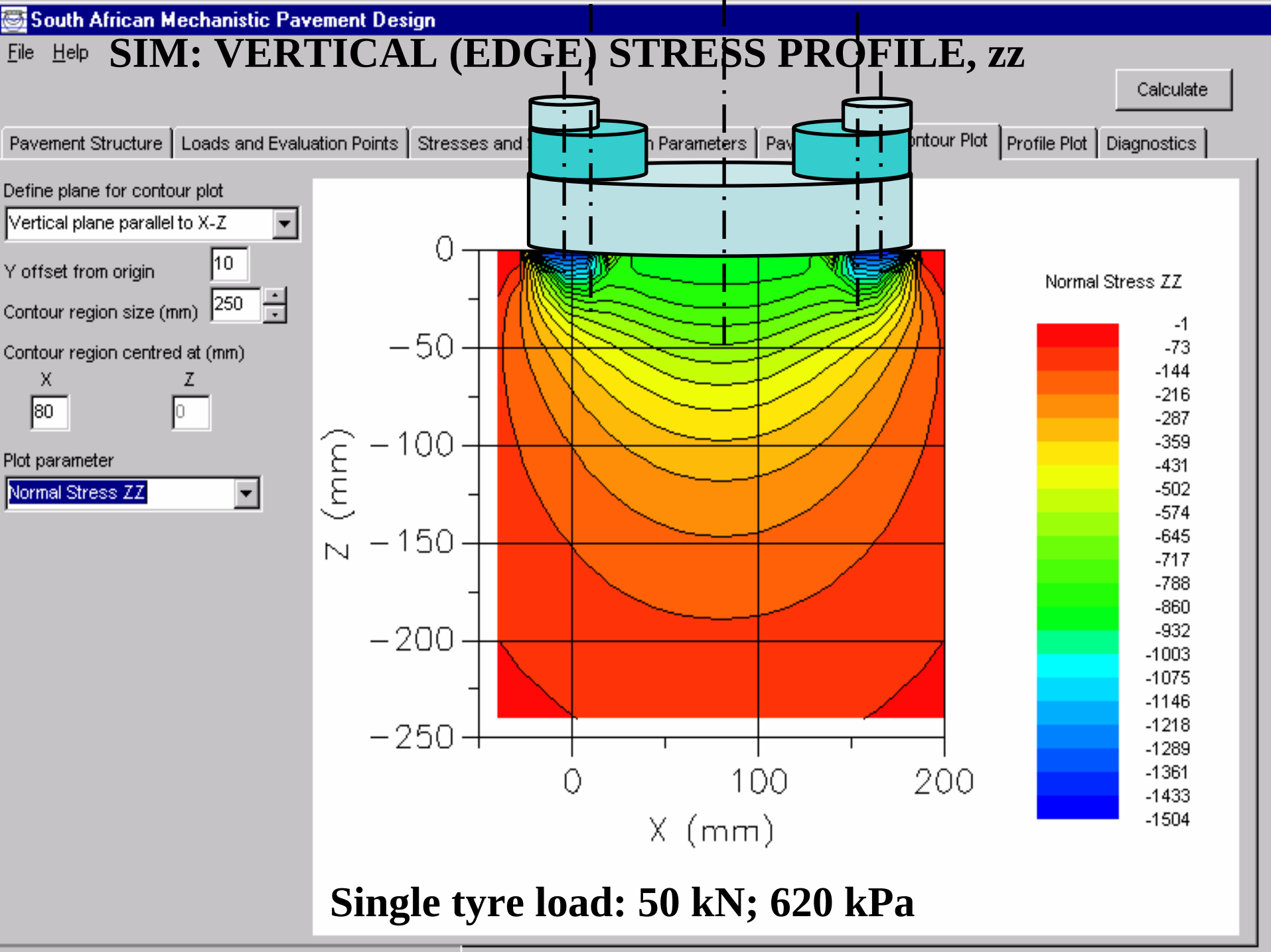
X: 0 Z: 0

Plot parameter

Normal Stress ZZ

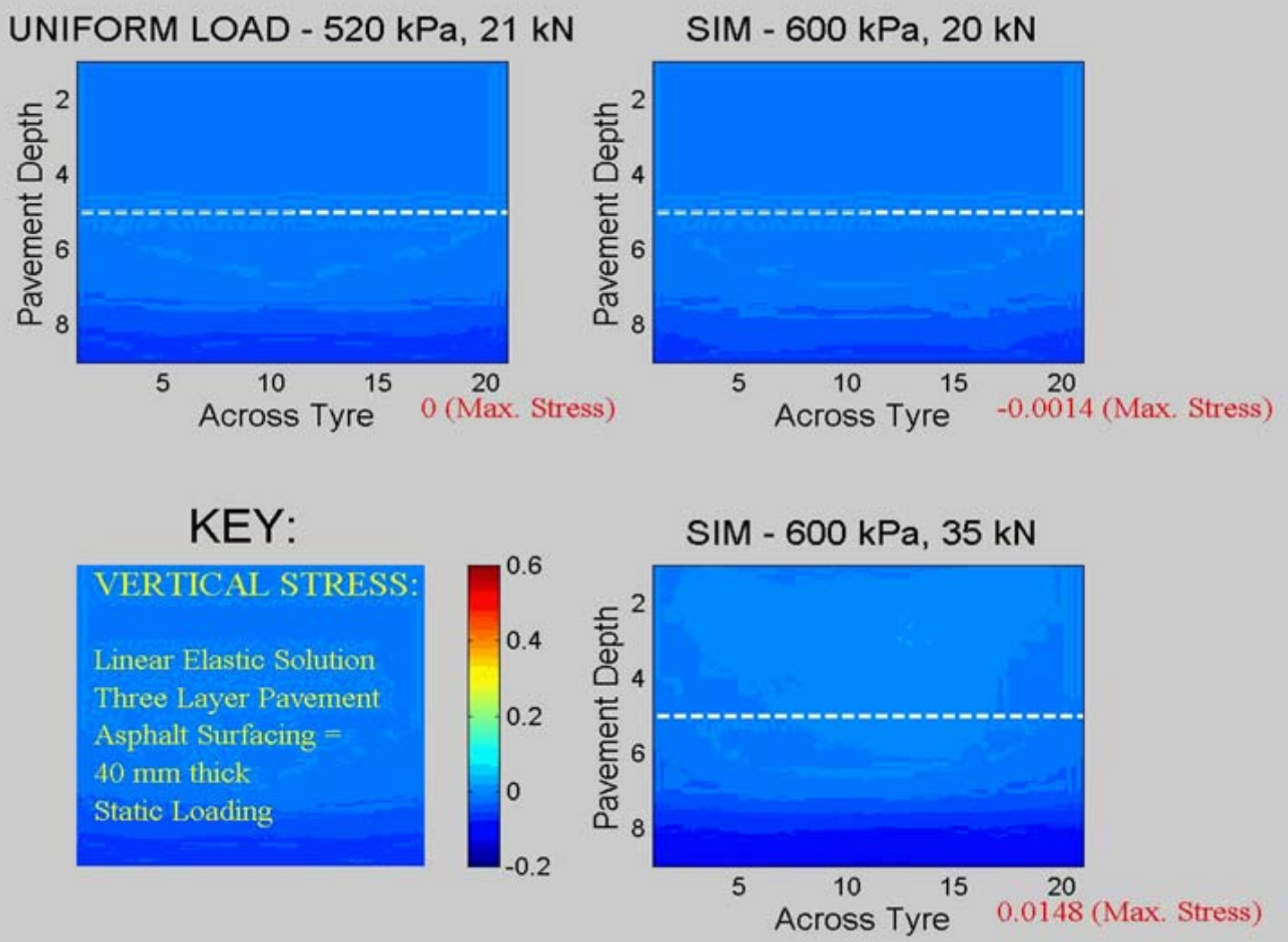


Single tyre load: 20 kN; 520 kPa


South African Mechanistic Pavement Design
File Help
SIM: VERTICAL (EDGE) STRESS PROFILE, zz
Calculate
Pavement Structure
Loads and Evaluation Points
Stresses and
Parameters
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
Z
80
0
Plot parameter
Normal Stress ZZ
0
−50
−100
−150
−200
−250
Z (mm)
0
100
200
X (mm)
Normal Stress ZZ
-1
-73
-144
-216
-287
-359
-431
-502
-574
-645
-717
-788
-860
-932
-1003
-1075
-1146
-1218
-1289
-1361
-1433
-1504
Single tyre load: 50 kN; 620 kPa

Stress Response - Moving Tyre:

MODELED TYRE **REAL-TYRE** (FEM)



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