SEMINARIO - TOPIC

Tyre- Pavement Contact Stresses

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Layout of Presentation

- Background – South African road situation ;
- Increase in inflation pressures over time;
- Research with Accelerated Pavement Testing (APT) Devices;
- R&D on tyre-pavement contact stresses, using *Stress-In-Motion (SIM)* technology;
- Pavement damage & Analyses in SA context;
- The way forward;
- Conclusions en Recommendations

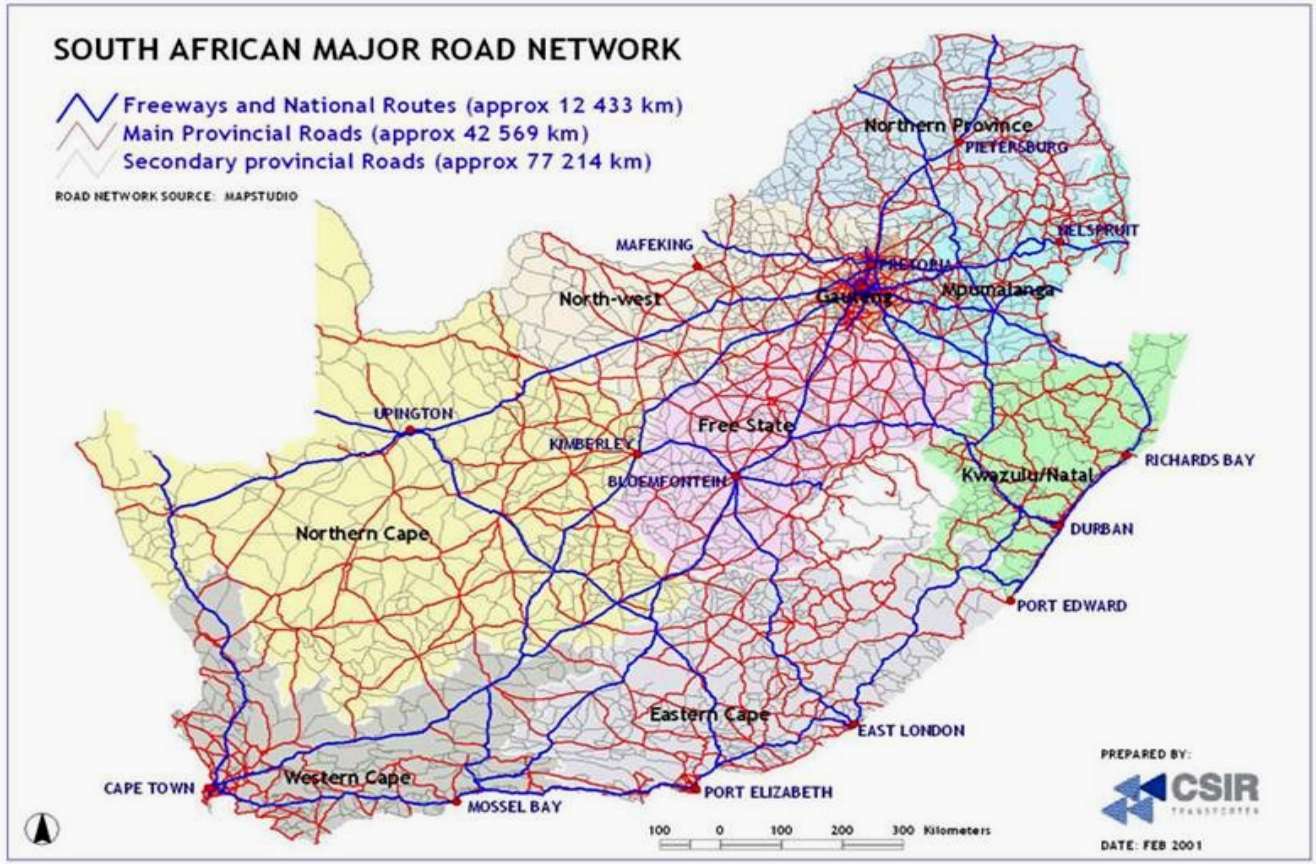
STRESS-IN-MOTION (SIM) TECHNOLOGY

- Since the 1990s – improvement necessary in tyre-pavement interaction model;
- "Uniform & Circular" shape not representative - studying road surface failures with HVS;
- *Stress-In-Motion (SIM)* devices developed;
  - New 3D shapes and sizes of tyre-pavement contact stress regimes measured;
  - Implementation in linear and non-linear pavement models (new challenge);

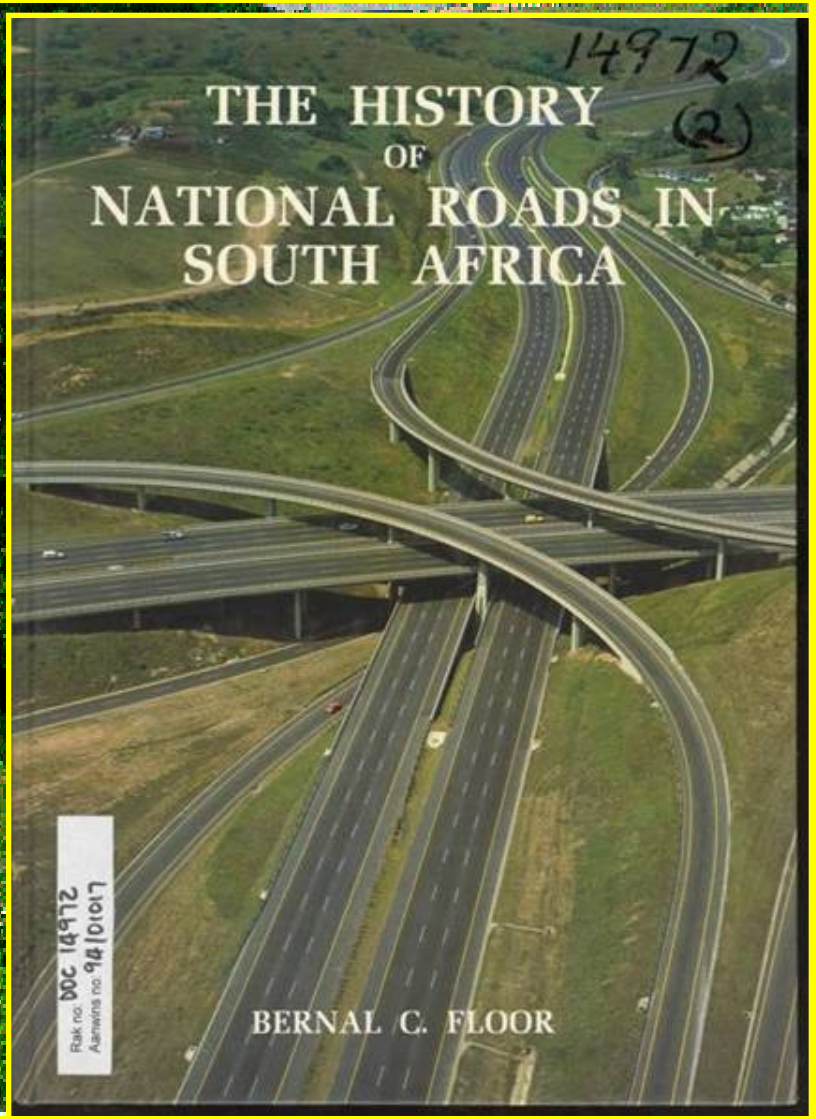
Heavy Vehicle Simulator (HVS) testing since 1975…

…PRACTICAL SOLUTIONS NEEDED !!

Total - all Roads in SA ~ 750 000 km



Thinly Surfaced (12 mm -50 mm) Flexible Pavements -


14972
(2)
THE HISTORY
OF
NATIONAL ROADS IN
SOUTH AFRICA
Rak no: DOC 14972
Aanwins no: 94/01017
BERNAL C. FLOOR

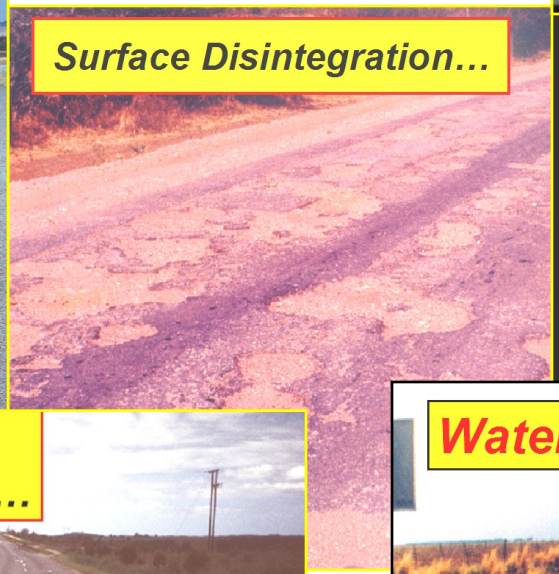
Typical Heavy Vehicles (HVs)


RUTTING


Longitudinal Flow of Asphalt


Fatigue Cracking and aging


Delamination..


Surface Disintegration…


POTHOLES :
Water & Loads …


Water & Safety…

Road Pavement Damage….

Tyre Types on Steering Axles - Recently:

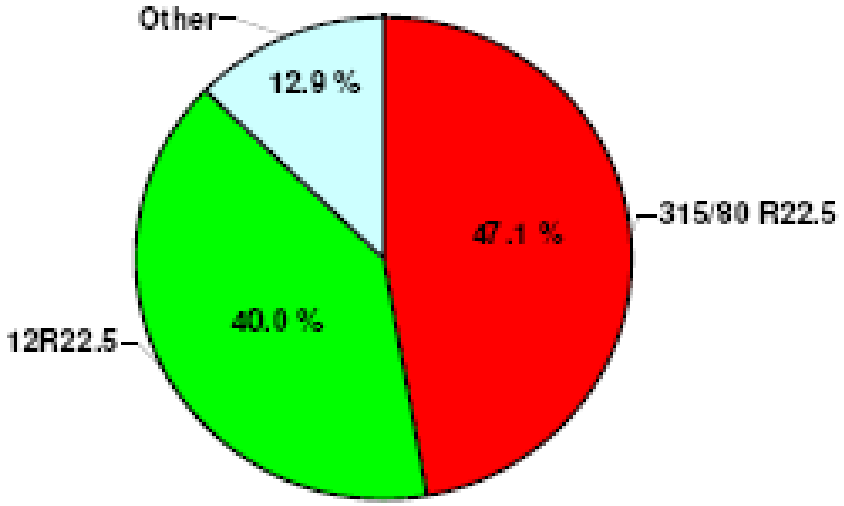


Figure 3: Distribution of left tyre type on steering axles of 225 Heavy Vehicles (HVs) on the N3-North (Heidelberg) (Tyre Data from Morton and Theyse, 2004)

Truck Tire Inflation Pressure in South Africa:

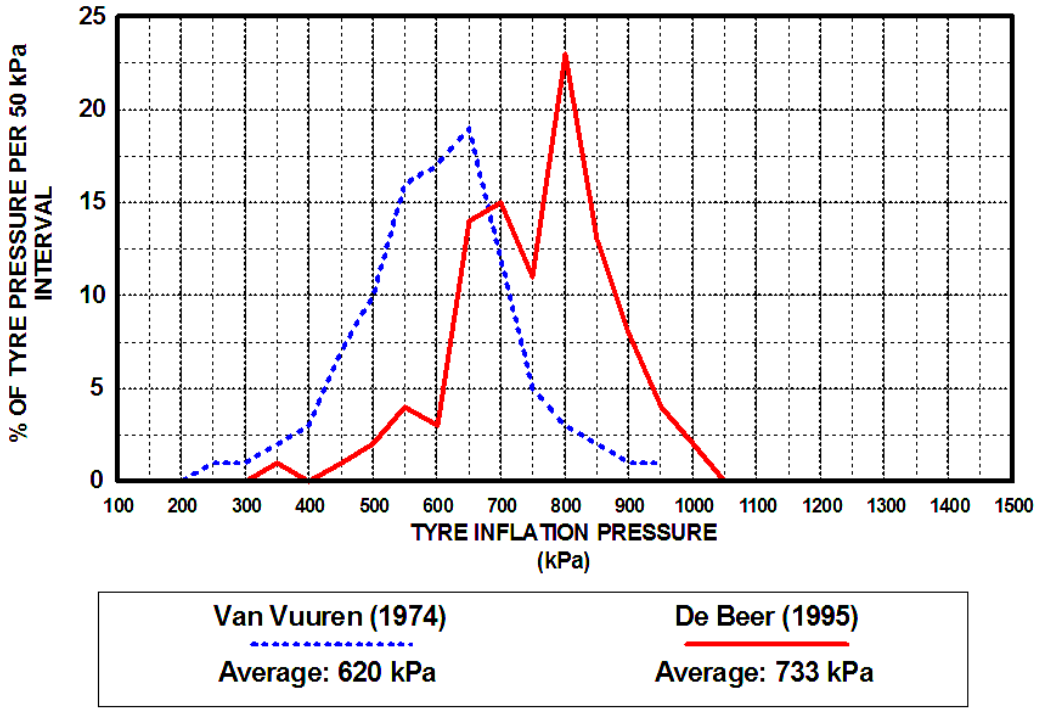


FIGURE 1

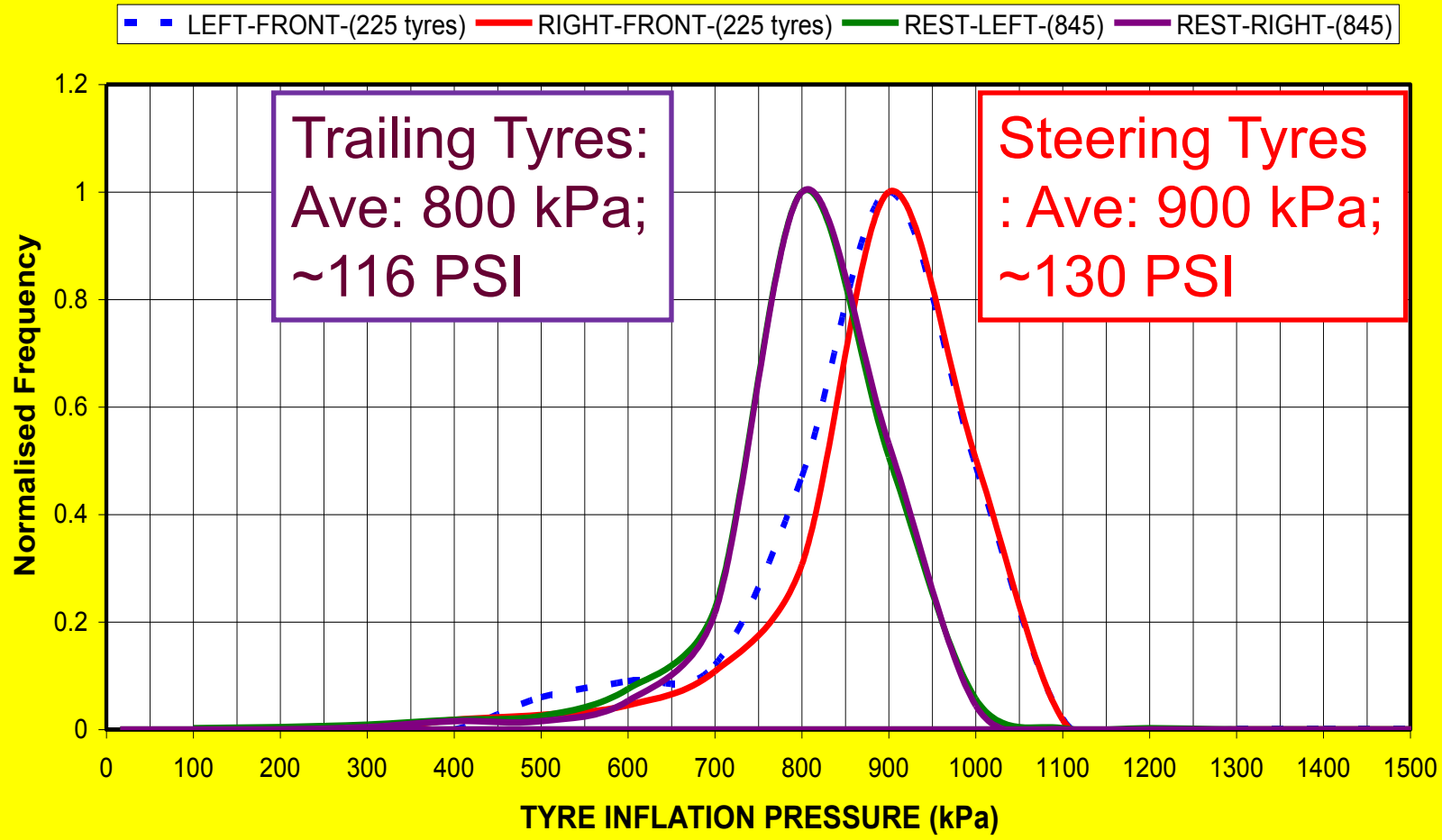
AVERAGE MEASURED TYRE INFLATION PRESSURE DISTRIBUTIONS OF HEAVY VEHICLES (AXLE LOADS > 7 000 kg) ON ROADS IN THE PROVINCE OF GAUTENG, SOUTH AFRICA

c:/capsaf1.wmf

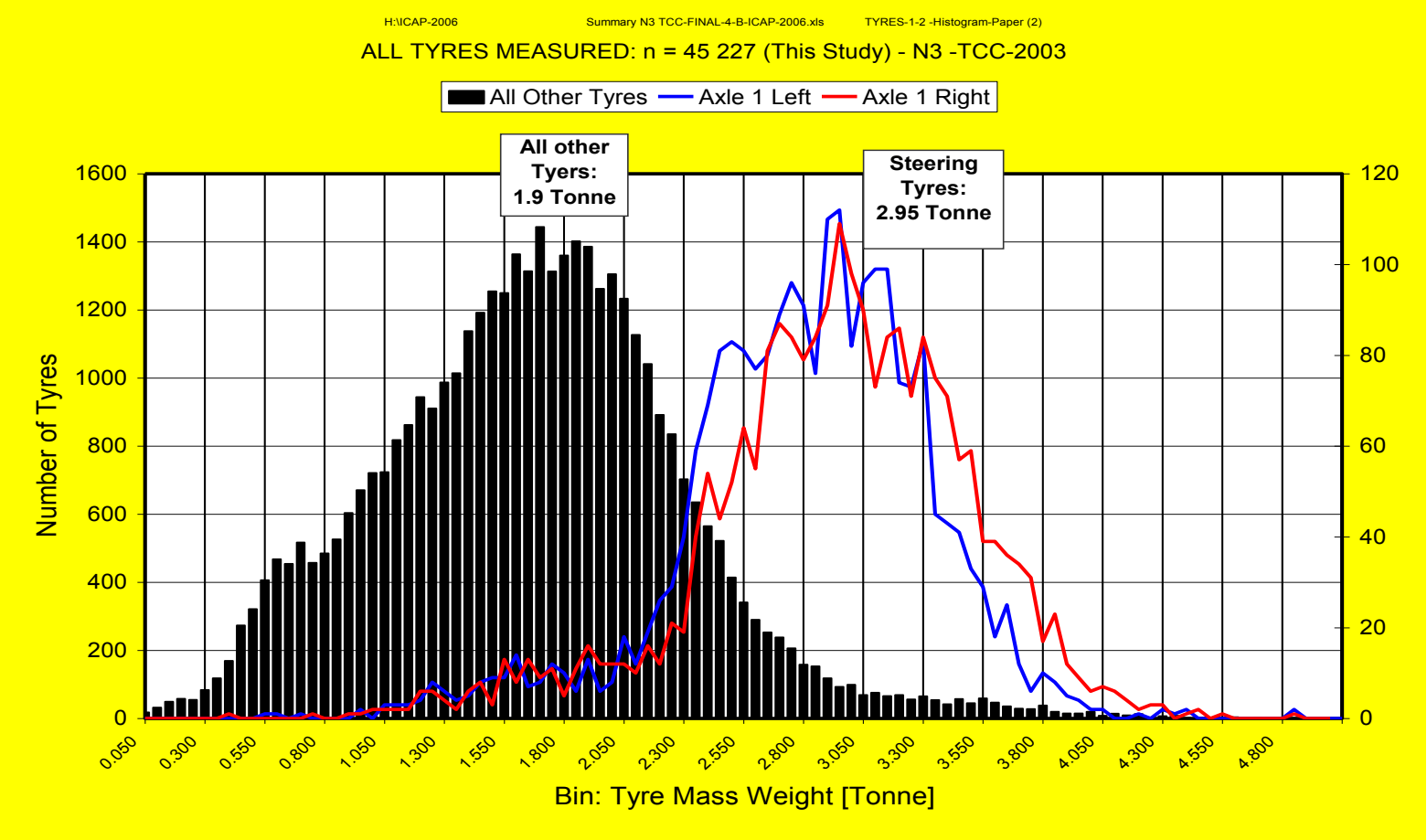
~ 20 % Increase in 20 Years

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

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



Tyre Weight (Mass) Distribution - 2003



HVS Mk IV+ Test Tyres

DUAL: 12R22.5

SINGLE: 315/80 R22.5

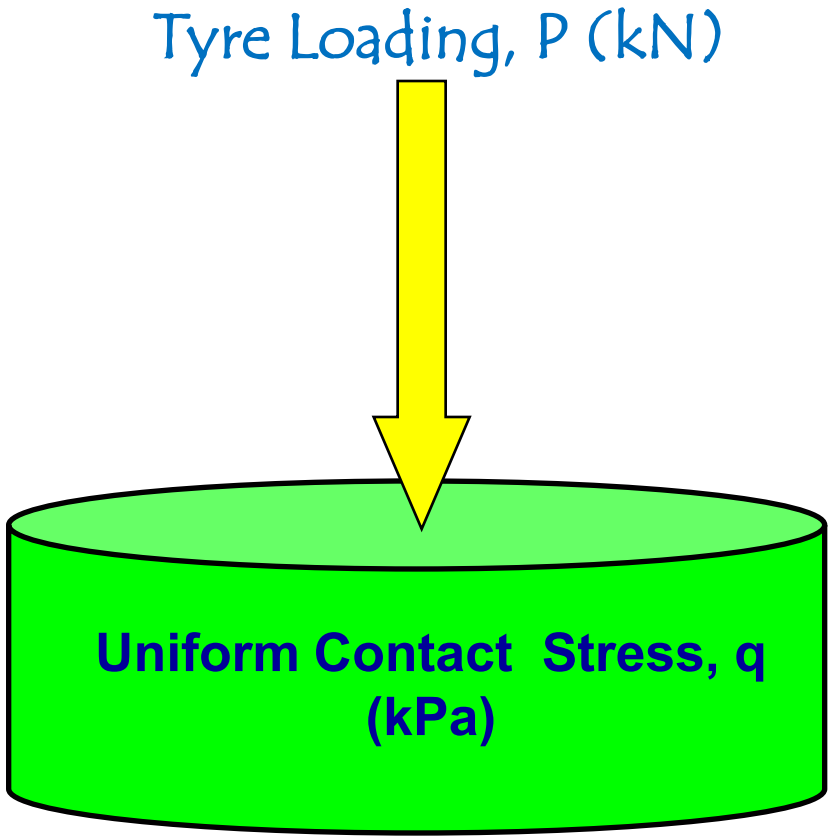
425/65 R22.5 tyre in South Africa

Vehicle-Tyre-Pavement Interaction:

Stress-In-Motion (SIM) Technology

Assumption of Tyre Loading - Pavement Design Modeling:

- Circular;
- Variable load;
- Variable pressure, but Uniform…..



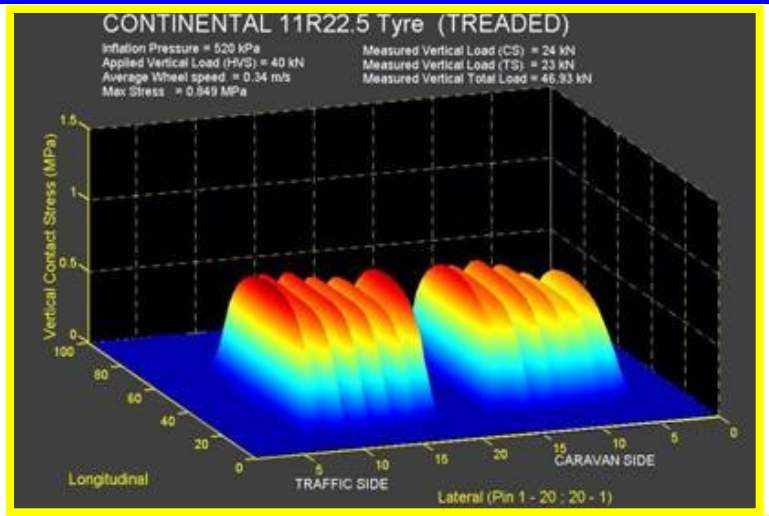
Stress – In – Motion (SIM) Technology

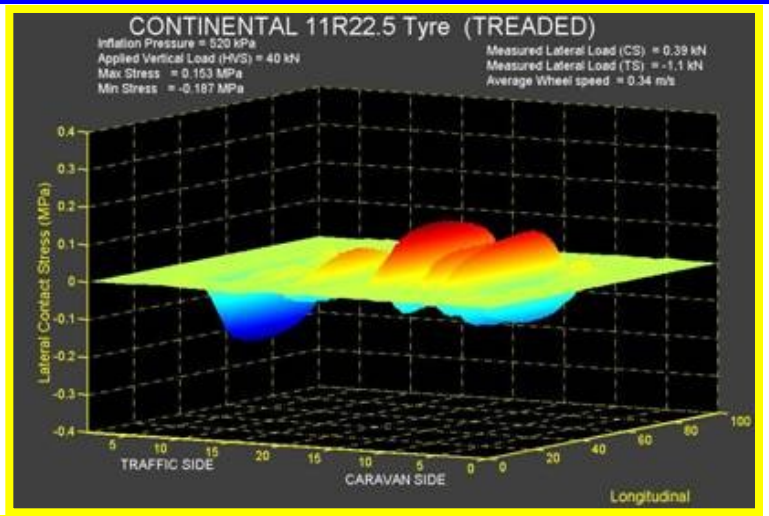
The measurement of 3D tyre/pavement contact stresses from moving vehicles

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

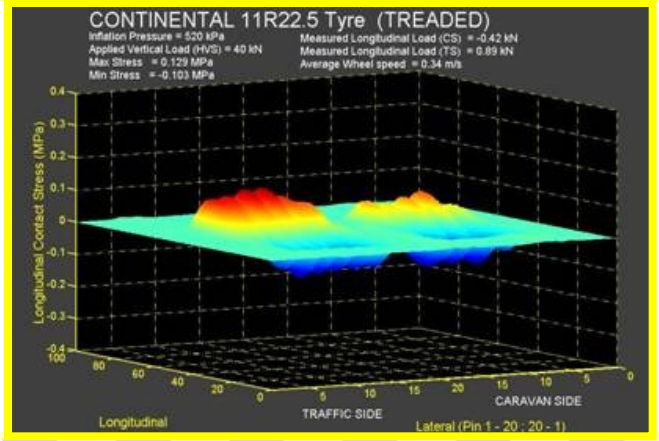
315/80 HVS TYRE ON SIM Mk II SYSTEM

Dual Tyre: 3D-Contact Stresses (Pressure)…80 kN Single Axle… (..ESAL)



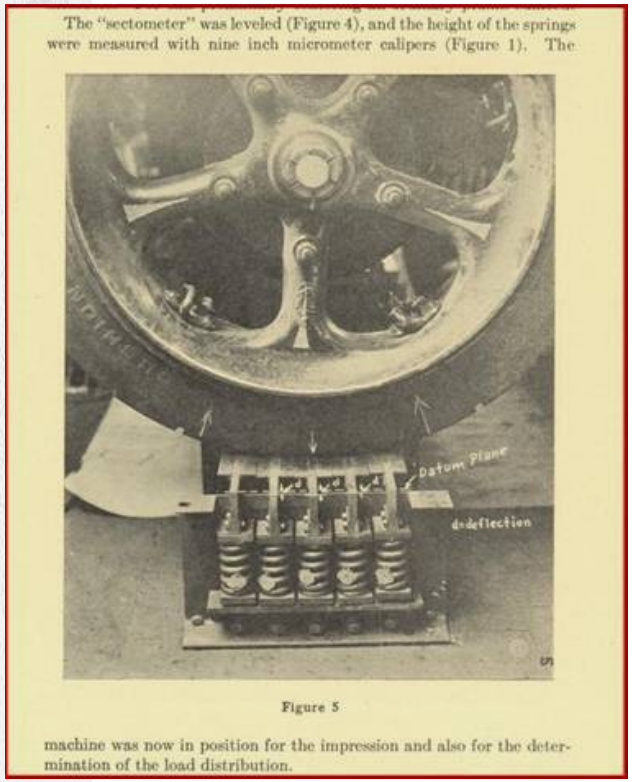


Stress Ratio: 10:3:1



Truck Tyres….

”Sectometer”
S. Eckels, 1928



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

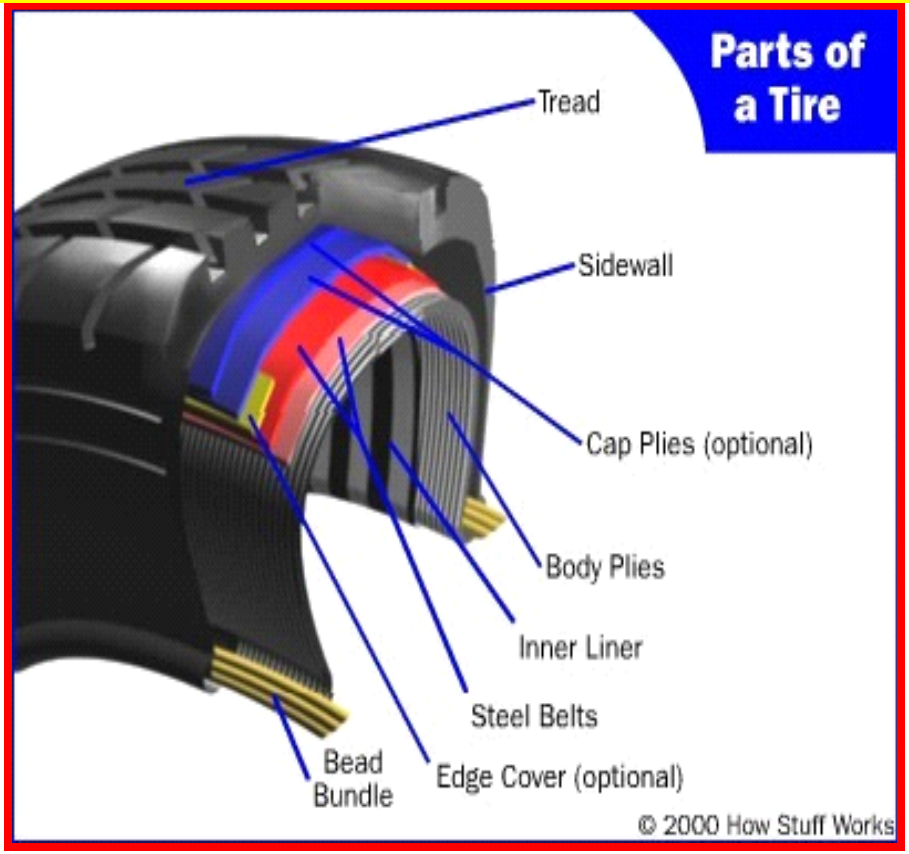
datum plane

deflection

Figure 5

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

Modern Tyre science…



Heavy Vehicle Simulator (HVS) - Since 1970s

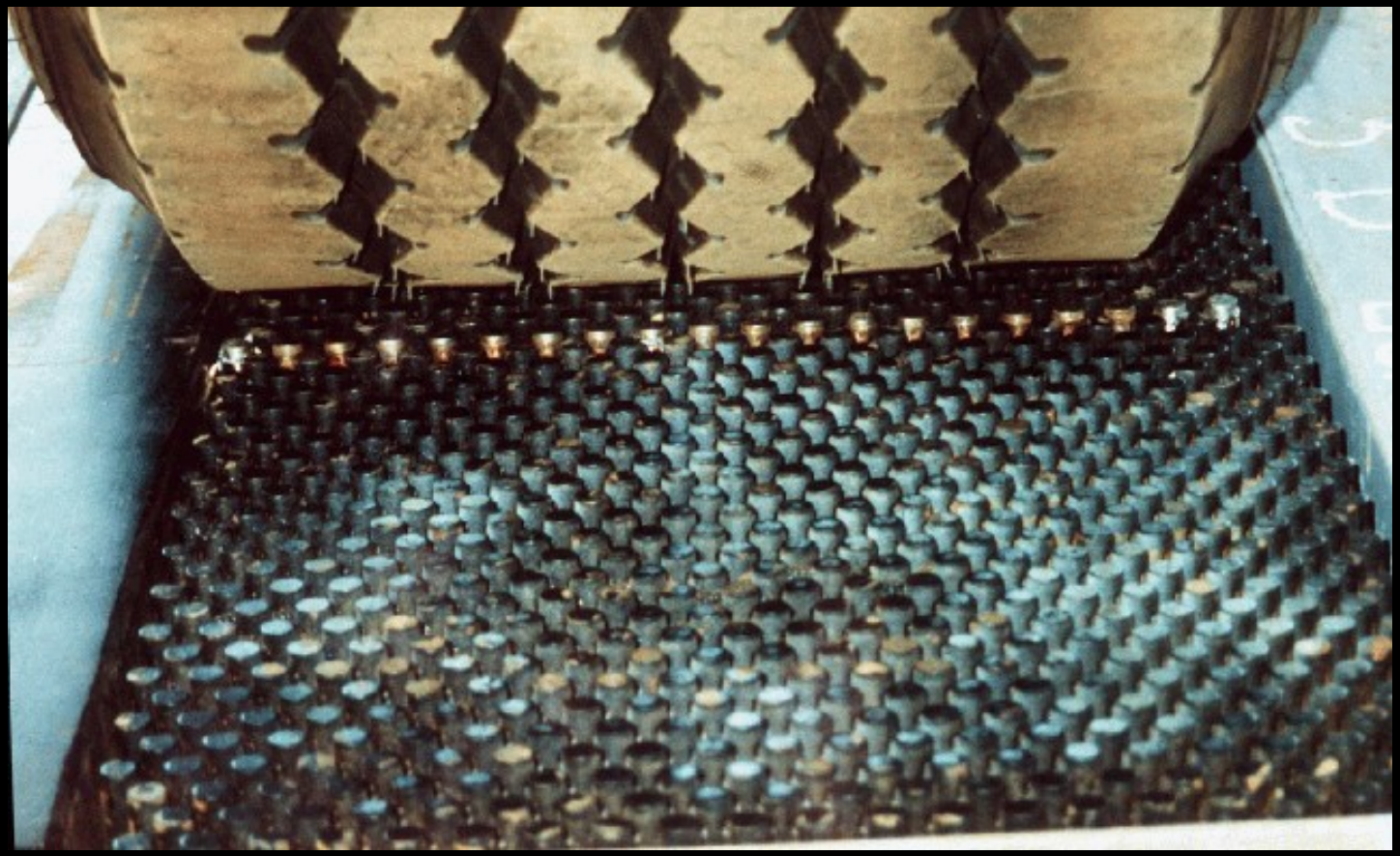
Oct 2004 - HVS – SIM Tests

SINGLE SIM PAD FOR HVS TESTING

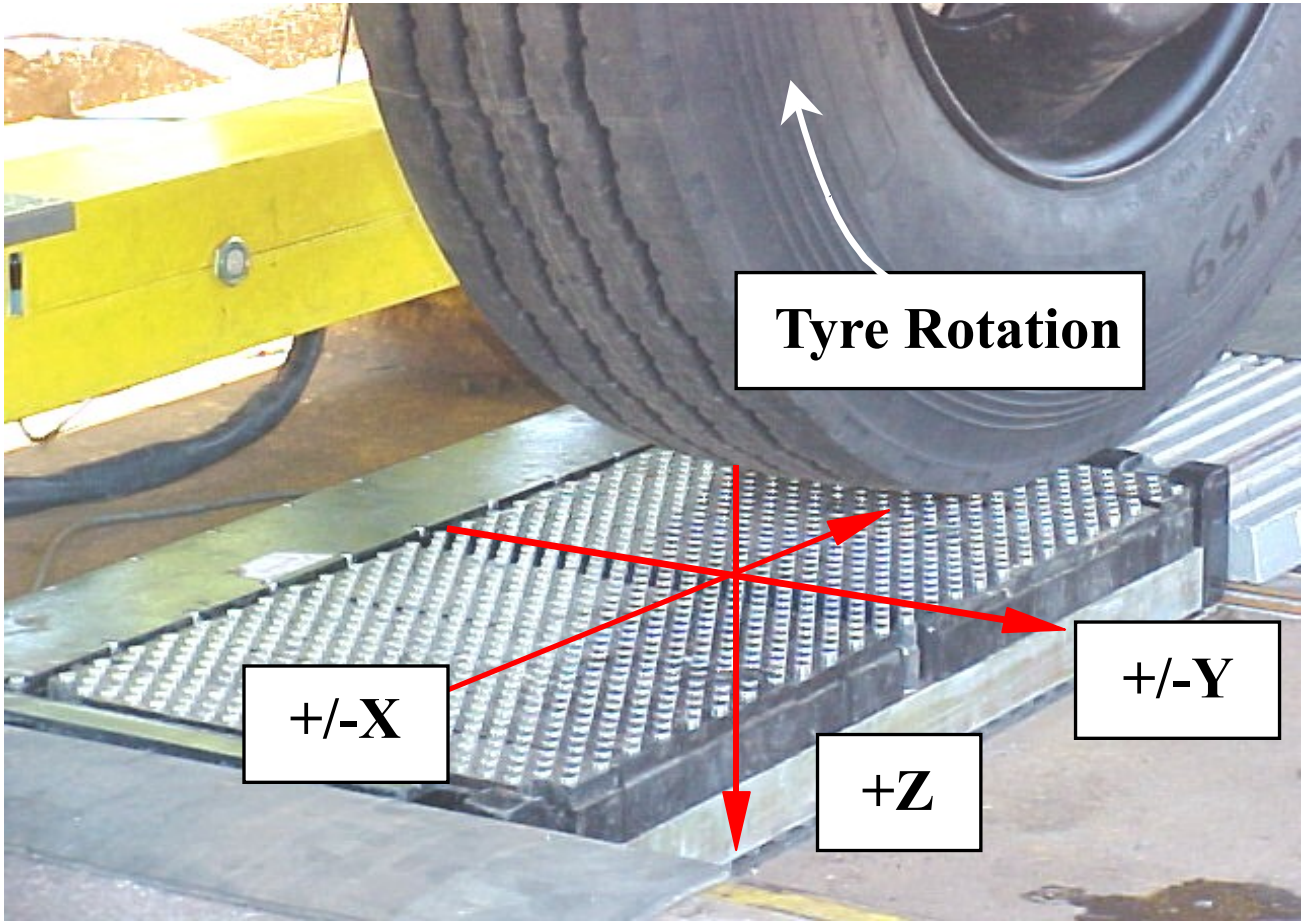
Stress – In – Motion (SIM) – SIM Mk II: CSIR : '93-'95

315/80 HVS TYRE ON SIM Mk II SYSTEM

425 /65 R22.5 HVS Tyre: Single pad SIM system (Use with HVS)



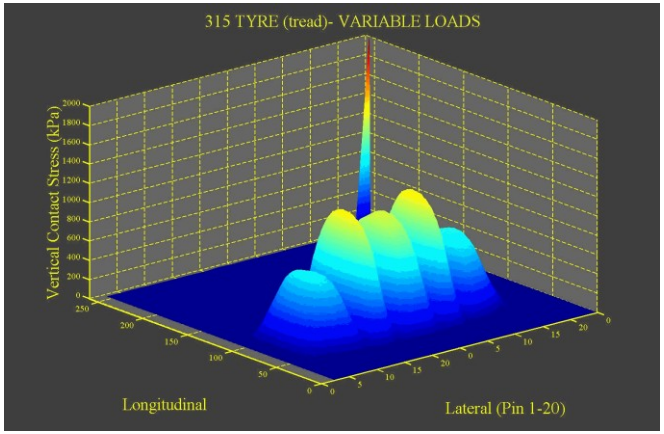
SAE sign convention:X-Long,Y-Lateral & Z -Vertical loads/stresses



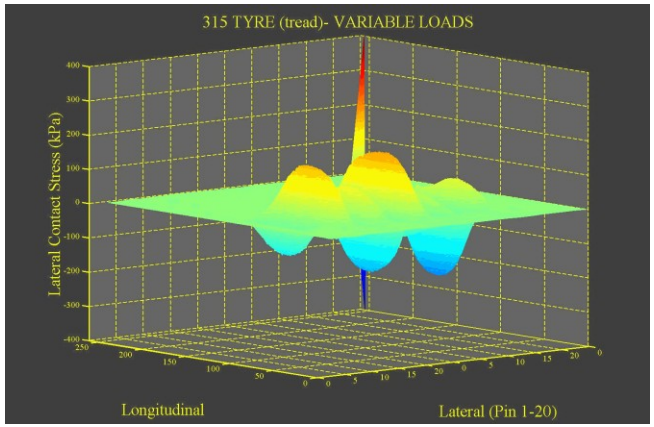
Tyre-Surface Interaction on textured surface - 3D Stress Regimes

Typical SIM Data Sets: *Z, X, Y - Contact Stresses @ Variable loads: 315/80 R22.5 Tire*

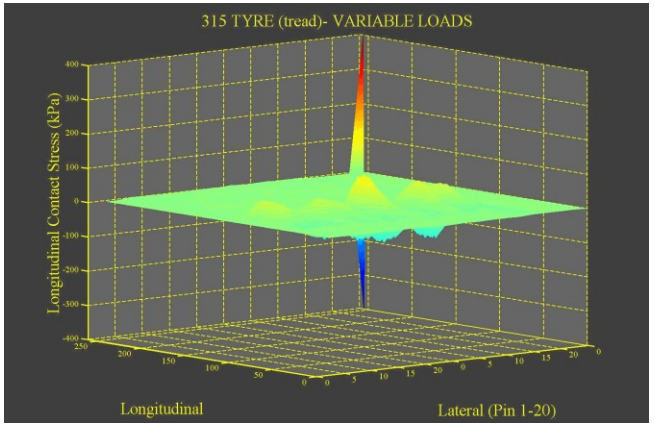
Z: Vertical Stress



Y: Lateral Stress

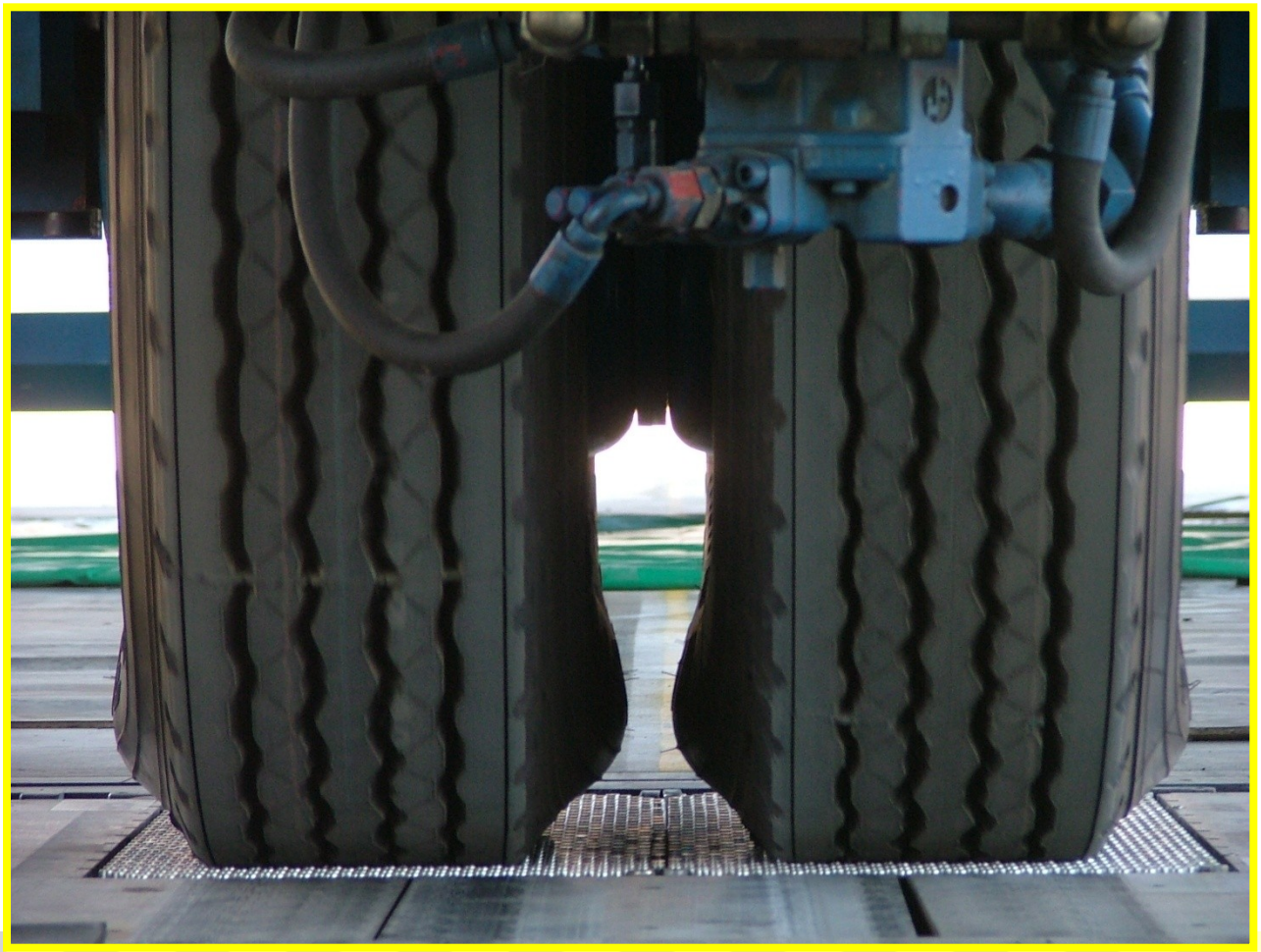


X: Longitudinal Stress

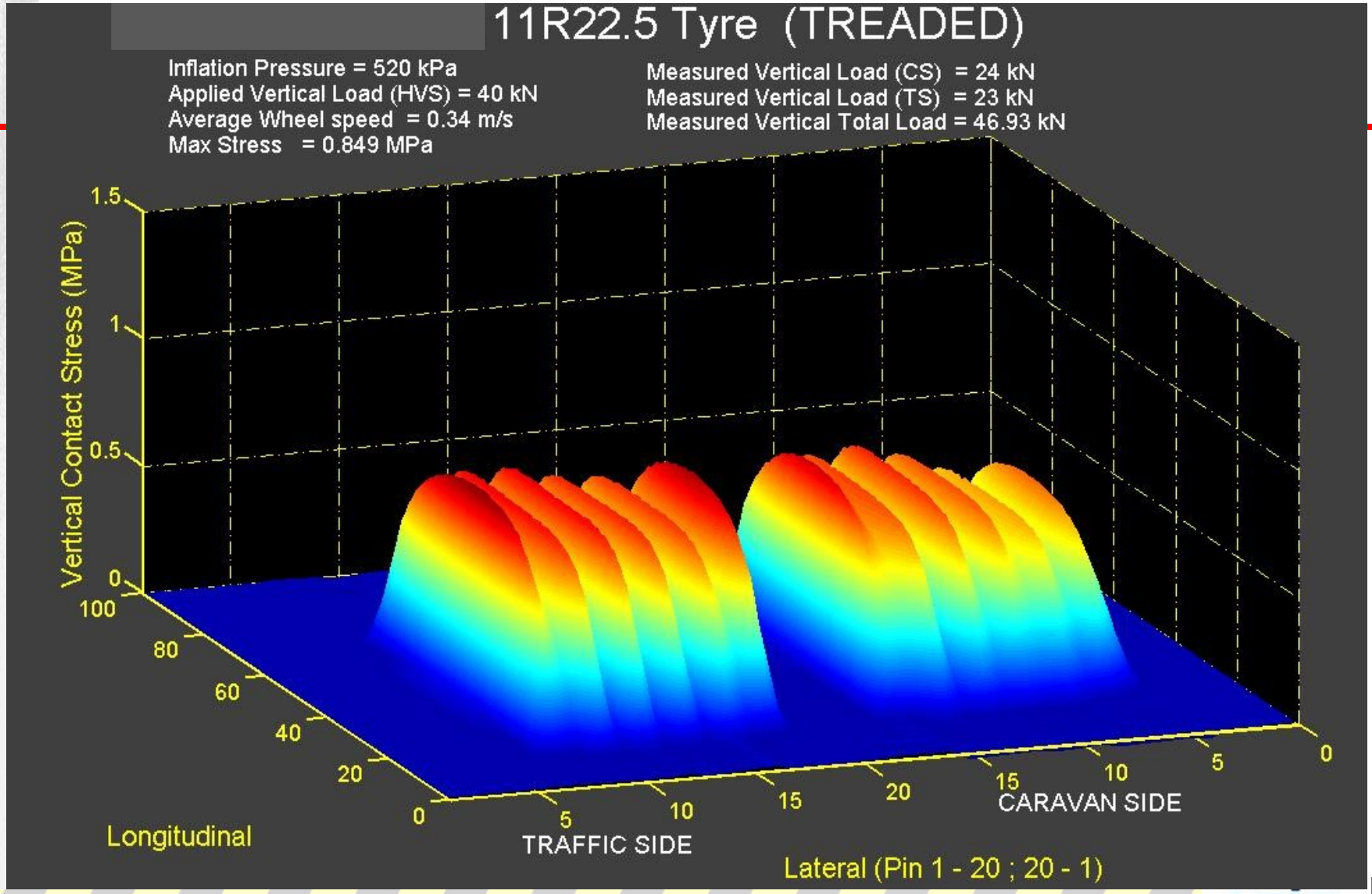


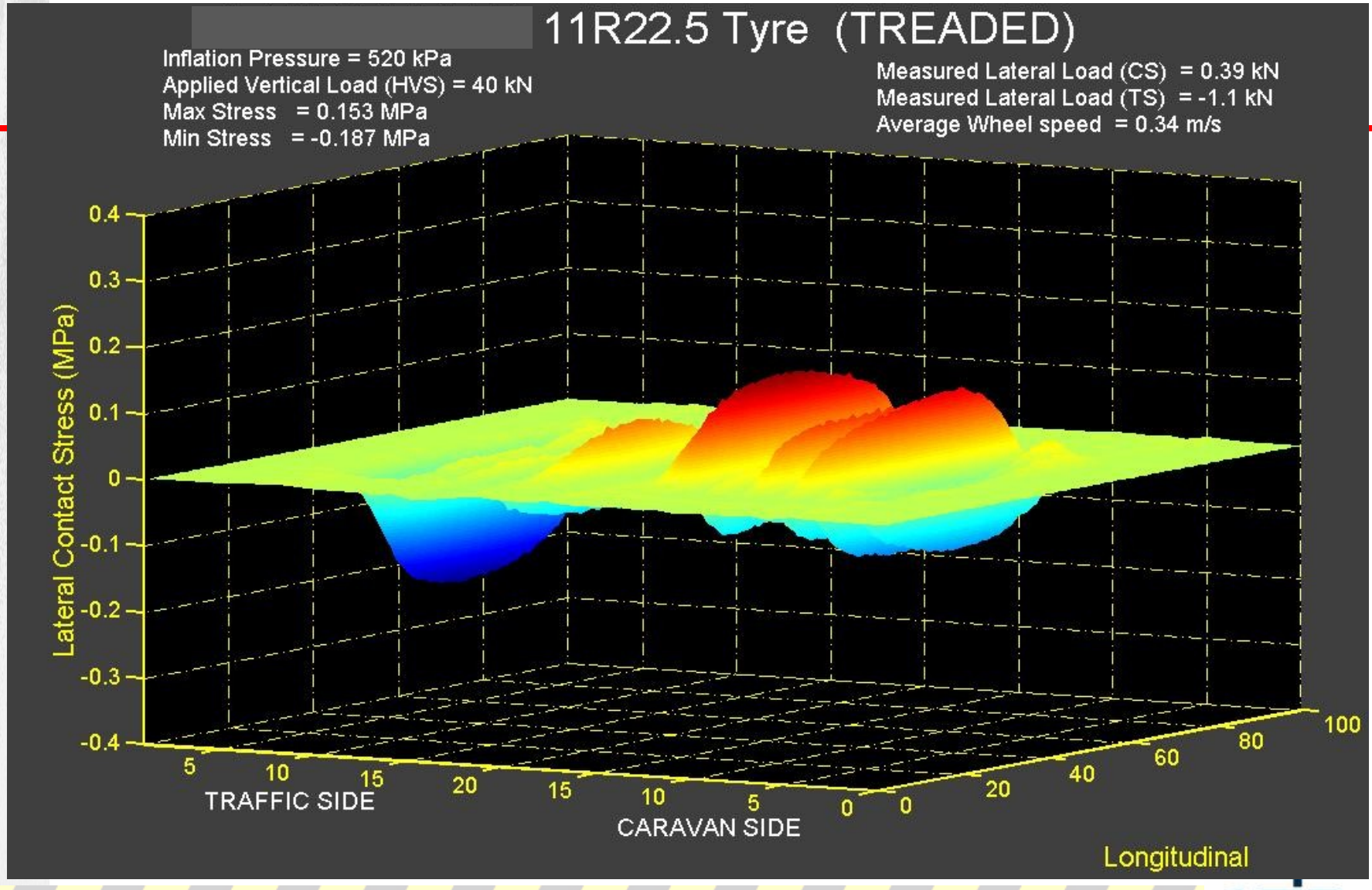
STRESS-IN-MOTION TESTING USING THE HVS

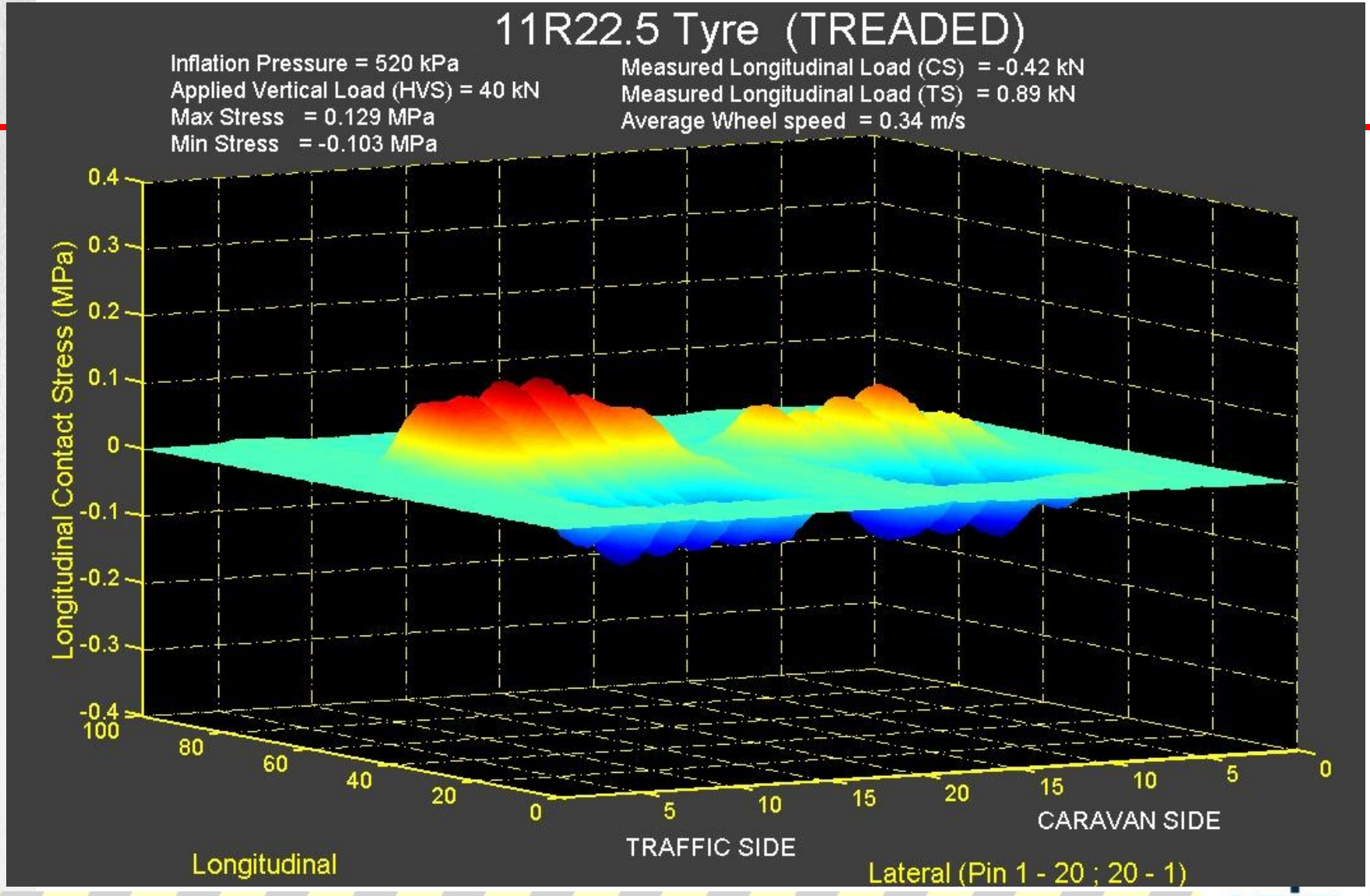
(HVS) - DUAL TEST TYRES (12R22.5)



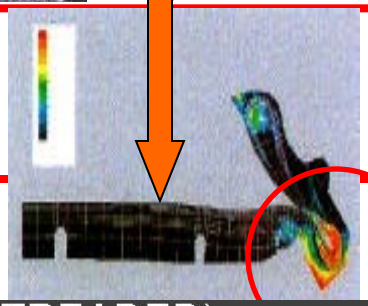
Stress-In-Motion (SIM) testing using the Heavy Vehicle Simulator (HVS)- Dual Load Configuration – Twin (dual) SIM pads


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
15
10
5
0
CARAVAN SIDE
Lateral (Pin 1 - 20 ; 20 - 1)

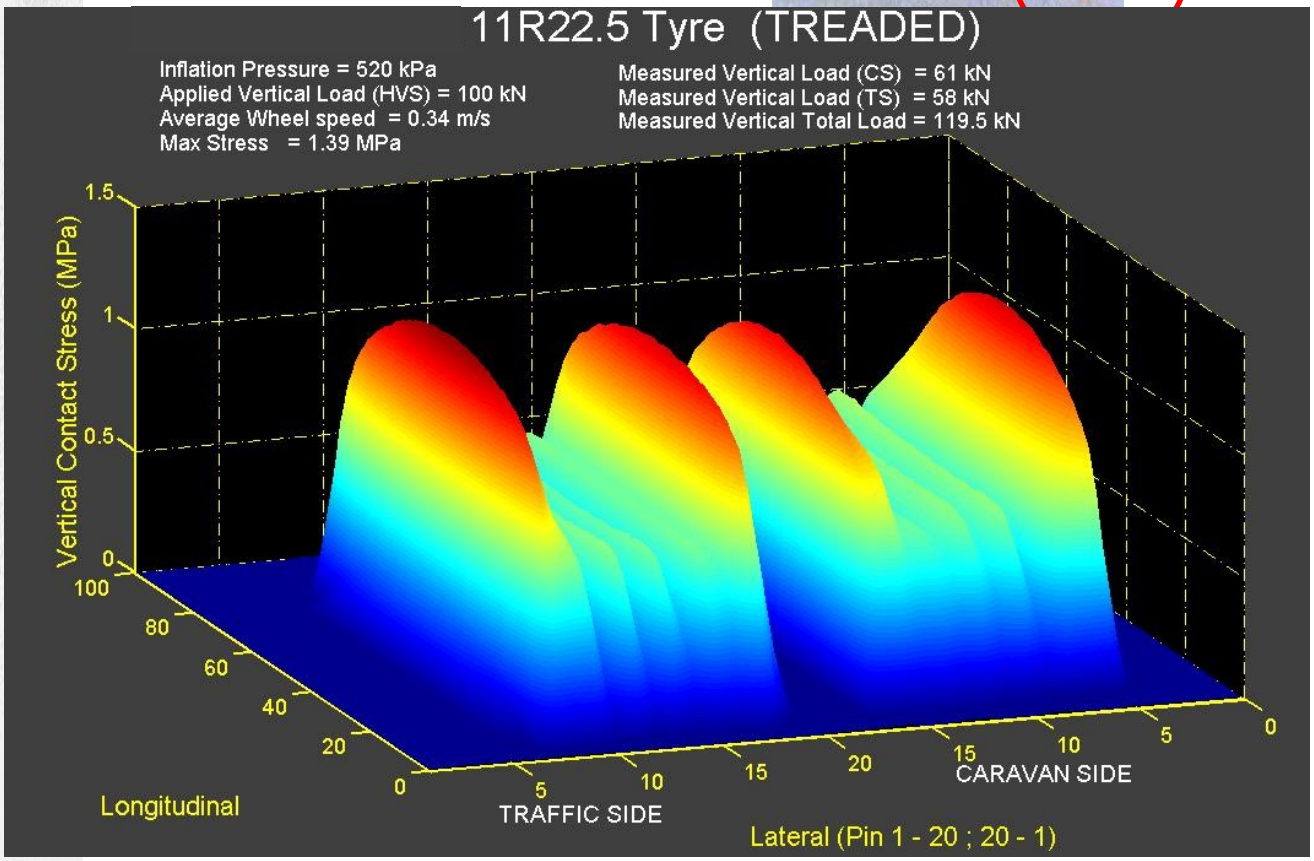

11R22.5 Tyre (TREADED)
Inflation Pressure = 520 kPa
Applied Vertical Load (HVS) = 40 kN
Max Stress = 0.153 MPa
Min Stress = -0.187 MPa
Measured Lateral Load (CS) = 0.39 kN
Measured Lateral Load (TS) = -1.1 kN
Average Wheel speed = 0.34 m/s
Lateral Contact Stress (MPa)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3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

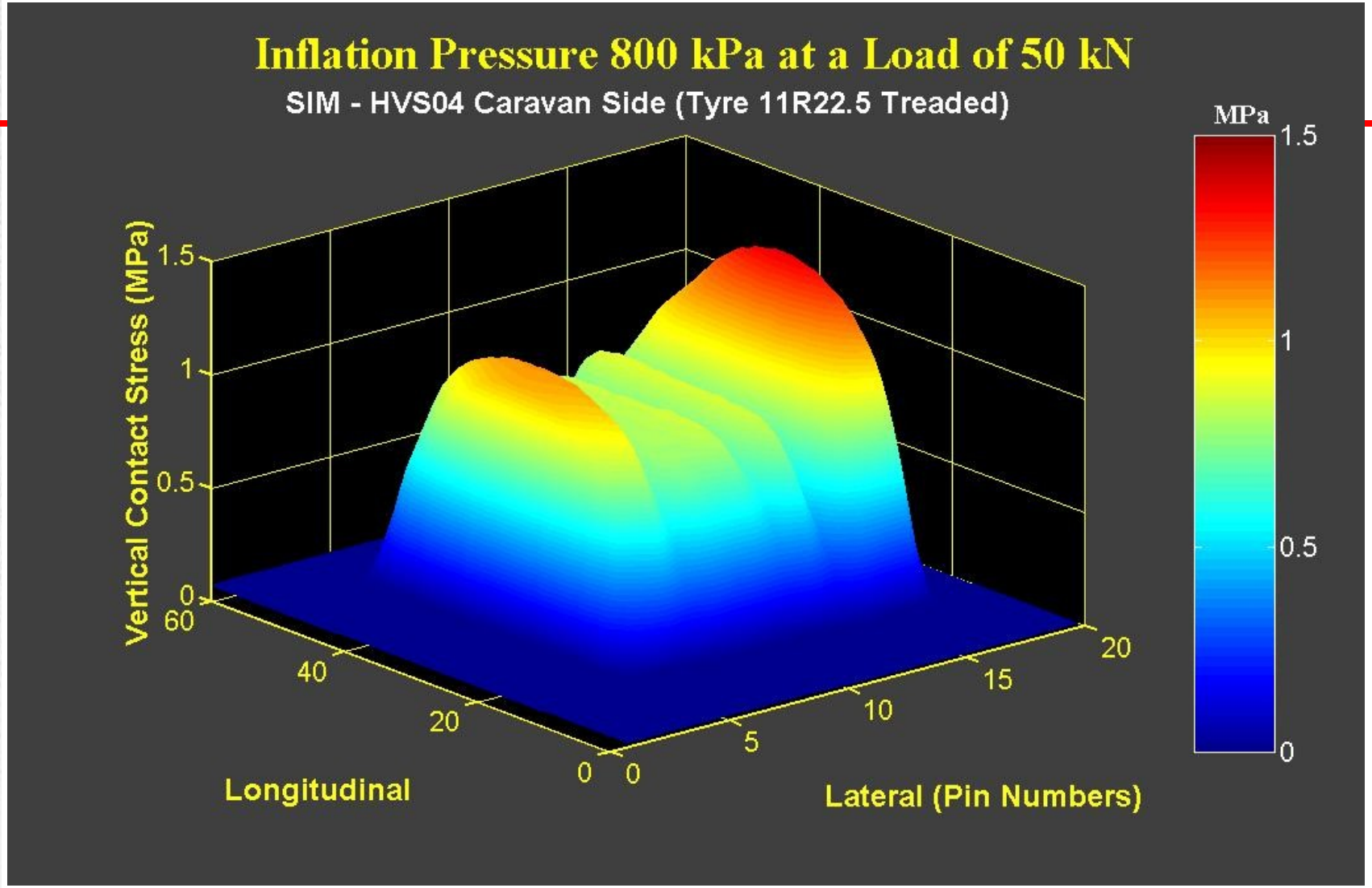

11R22.5 Tyre (TREADED)
Inflation Pressure = 520 kPa
Applied Vertical Load (HVS) = 40 kN
Max Stress = 0.129 MPa
Min Stress = -0.103 MPa
Measured Longitudinal Load (CS) = -0.42 kN
Measured Longitudinal Load (TS) = 0.89 kN
Average Wheel speed = 0.34 m/s
Longitudinal Contact Stress (MPa)
0.4
0.3
0.2
0.1
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)

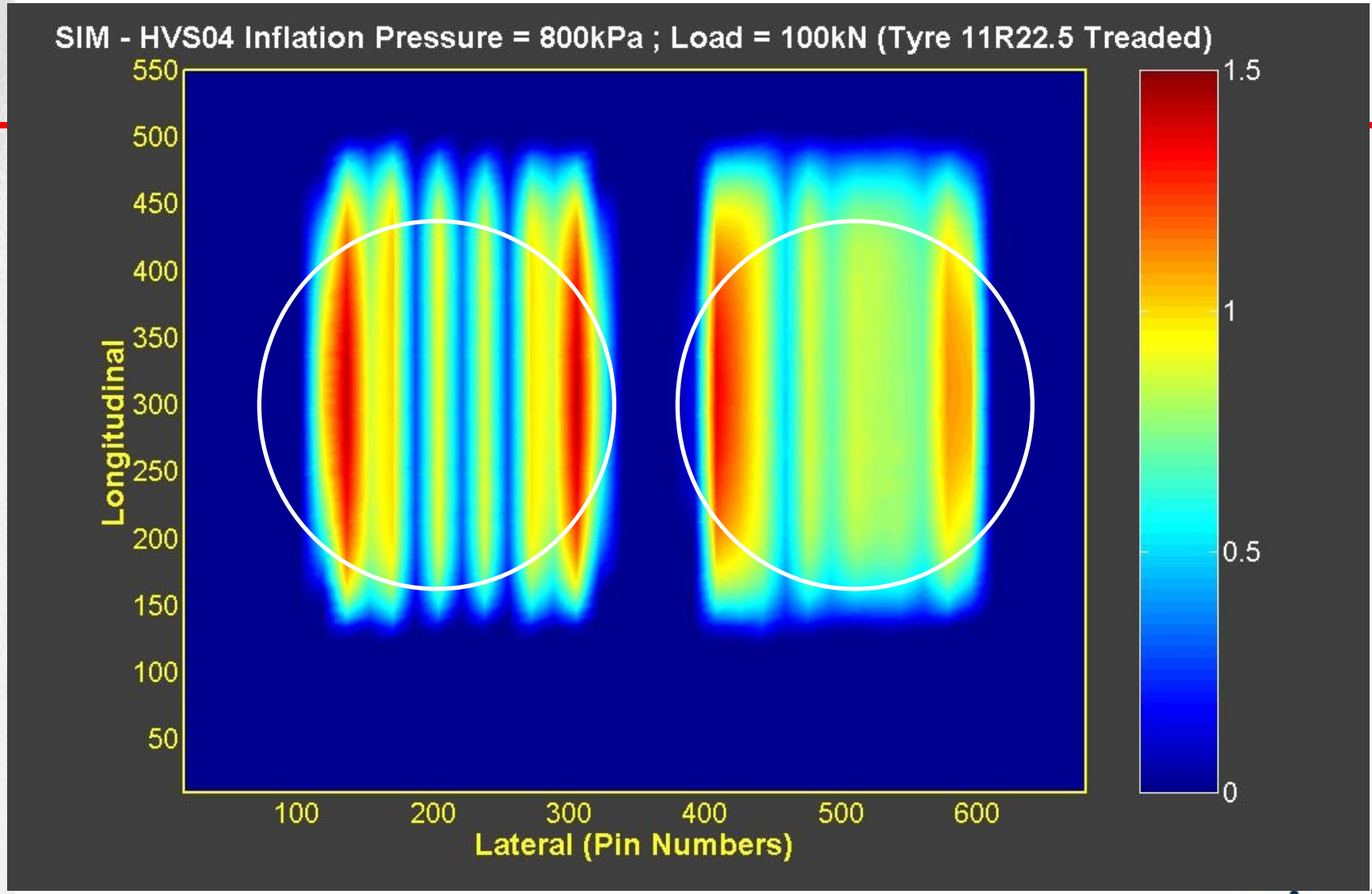
OVER-LOADING/UNDER INFLATION

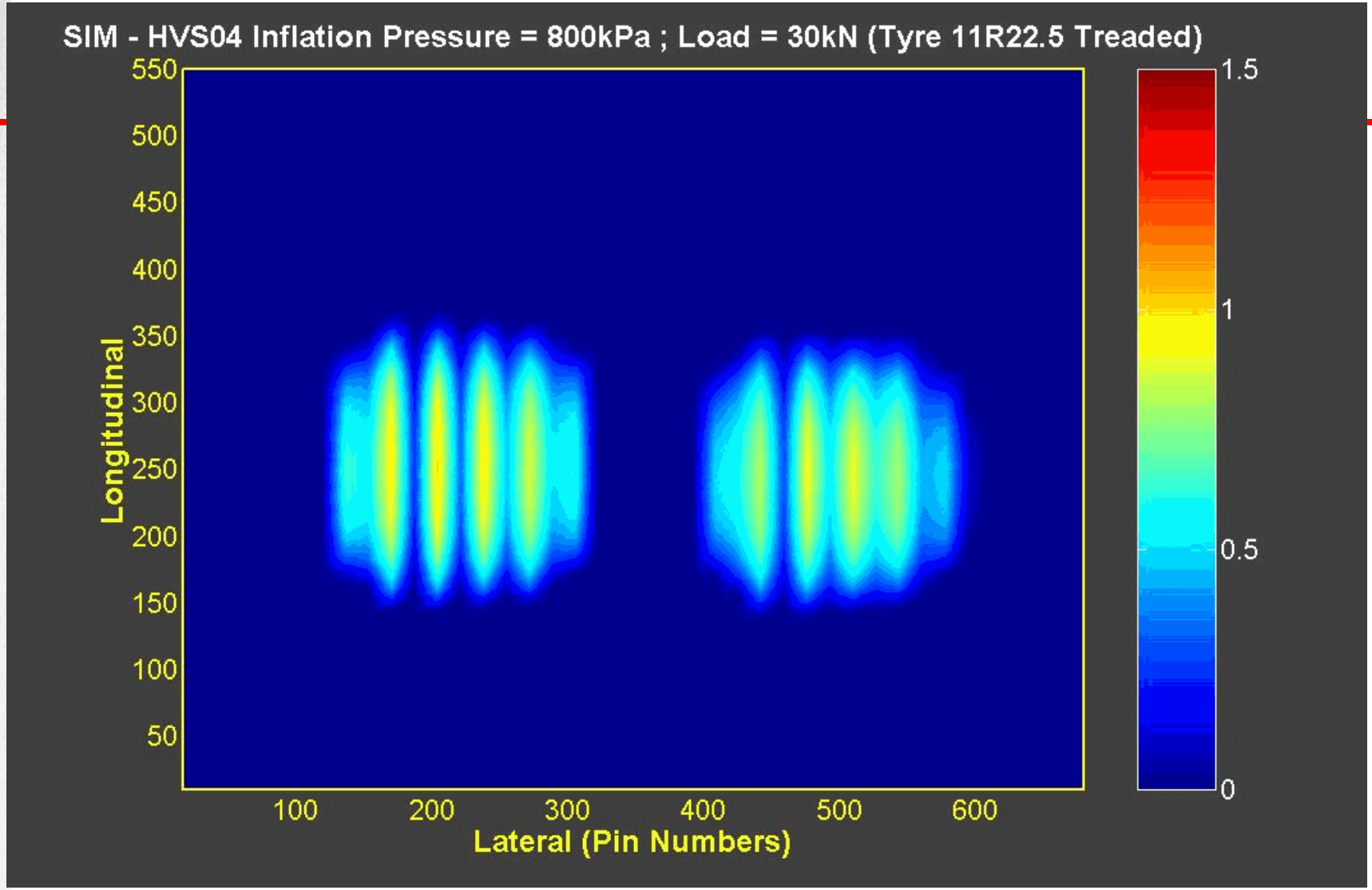


Tyre Edge

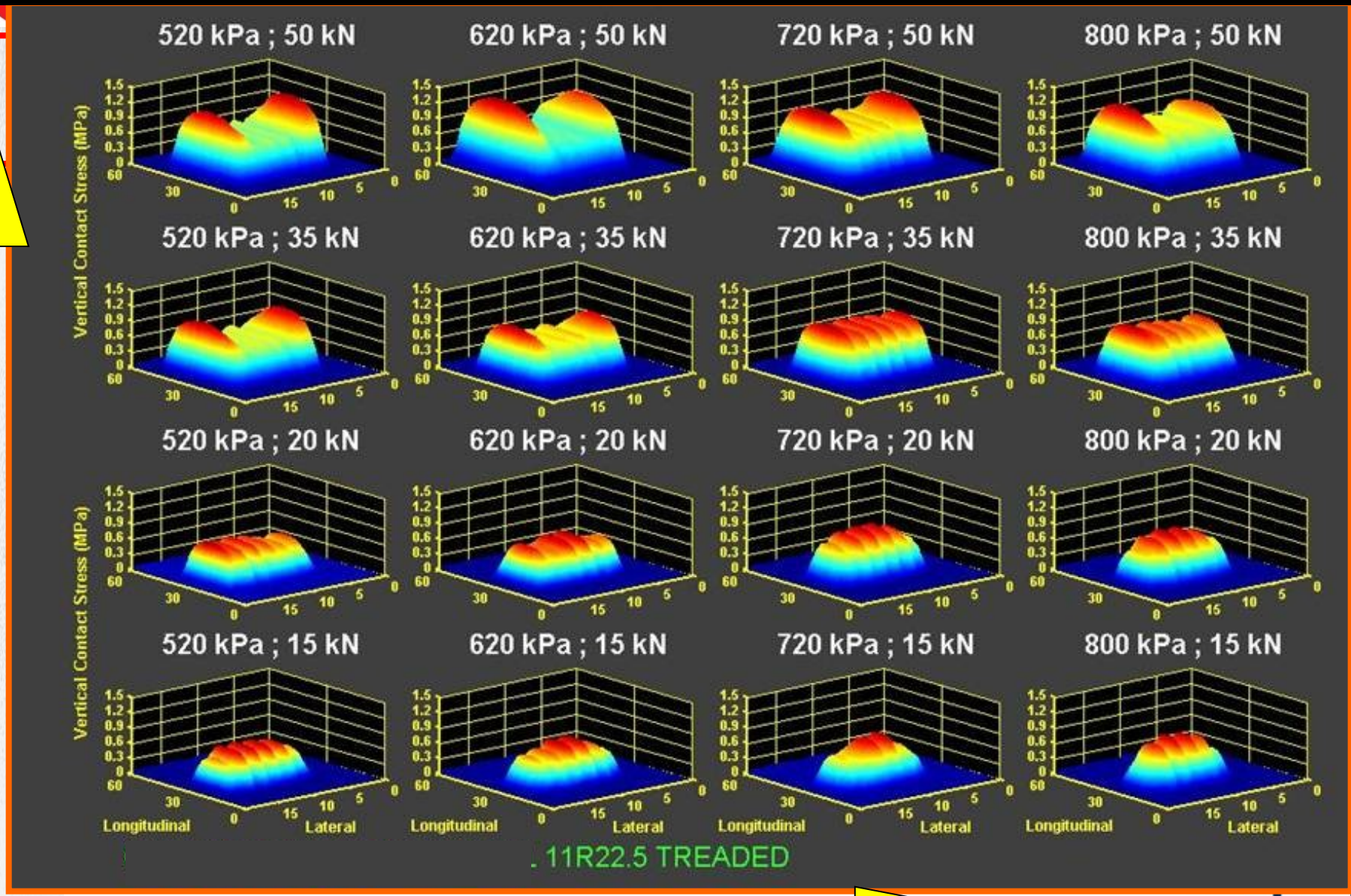



Inflation Pressure 800 kPa at a Load of 50 kN
SIM - HVS04 Caravan Side (Tyre 11R22.5 Treaded)
MPa
1.5
1
0.5
0
Vertical Contact Stress (MPa)
1.5
1
0.5
0
60
40
20
0
Longitudinal
0
5
10
15
20
Lateral (Pin Numbers)


SIM - HVS04 Inflation Pressure = 800kPa ; Load = 100kN (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


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

TYRE "FINGER PRINTING": VERTICAL STRESS PROFILES



LOAD

INFLATION PRESSURE

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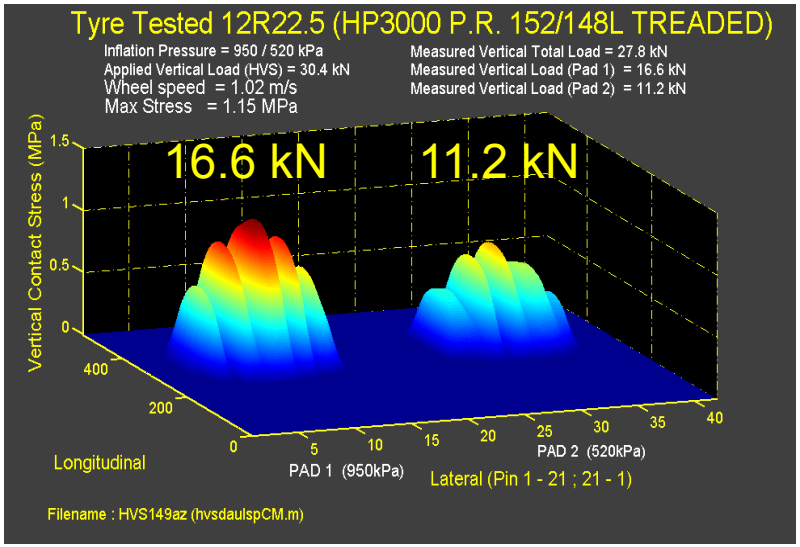
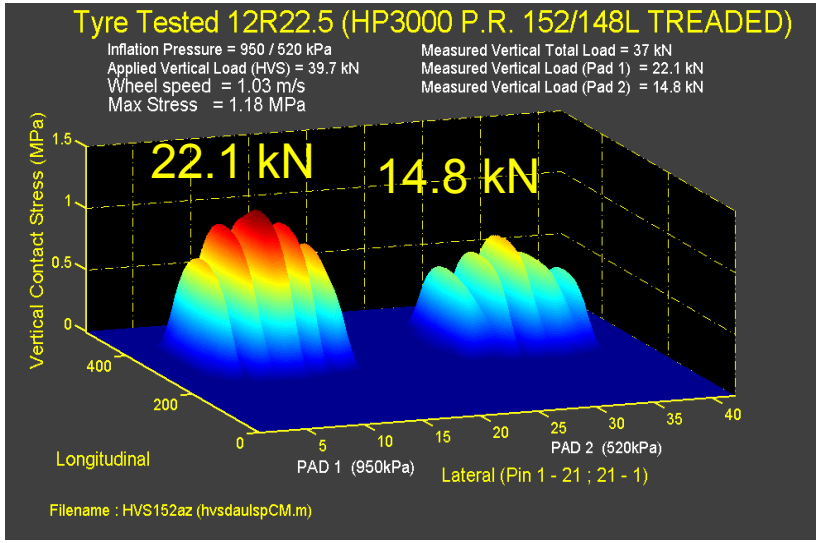
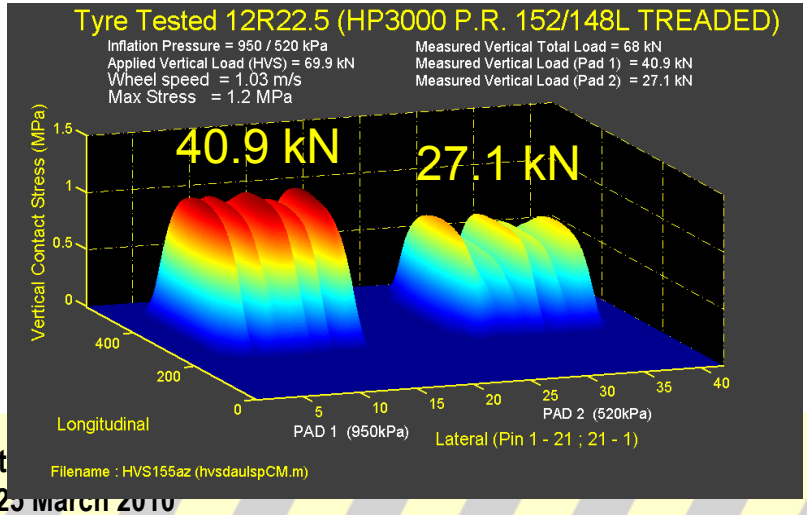
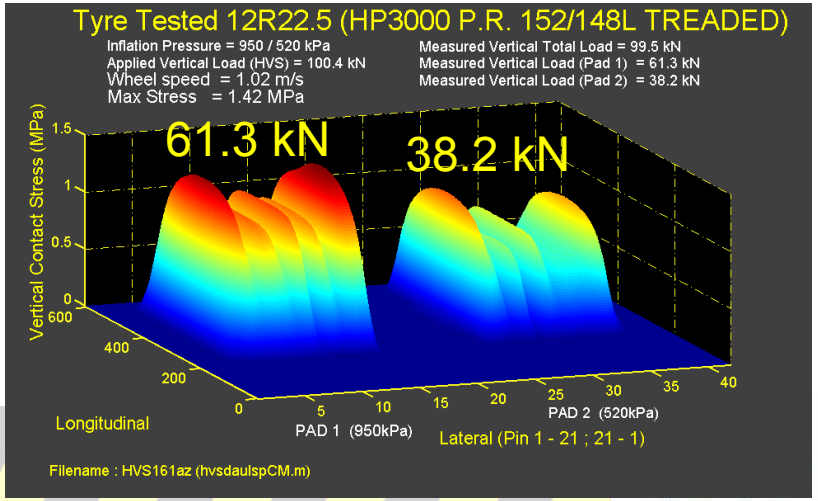
Differential Tyre Pressure(12R22.5): 950/520 kPa @ 30 kN; 40 kN; 70 kN and 100 kN









SIM systems..

Quad Stress-In-Motion (SIM) system:

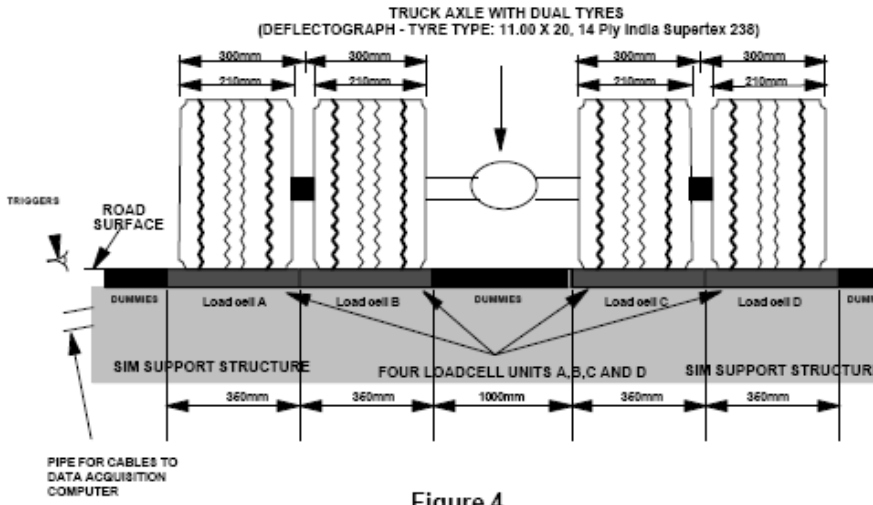


Figure 4

TYPICAL LAYOUT OF THE VRSPTA MARK III SIM SYSTEM
WITH A TYPICAL TRUCK AXLE (DUAL TYRES)

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

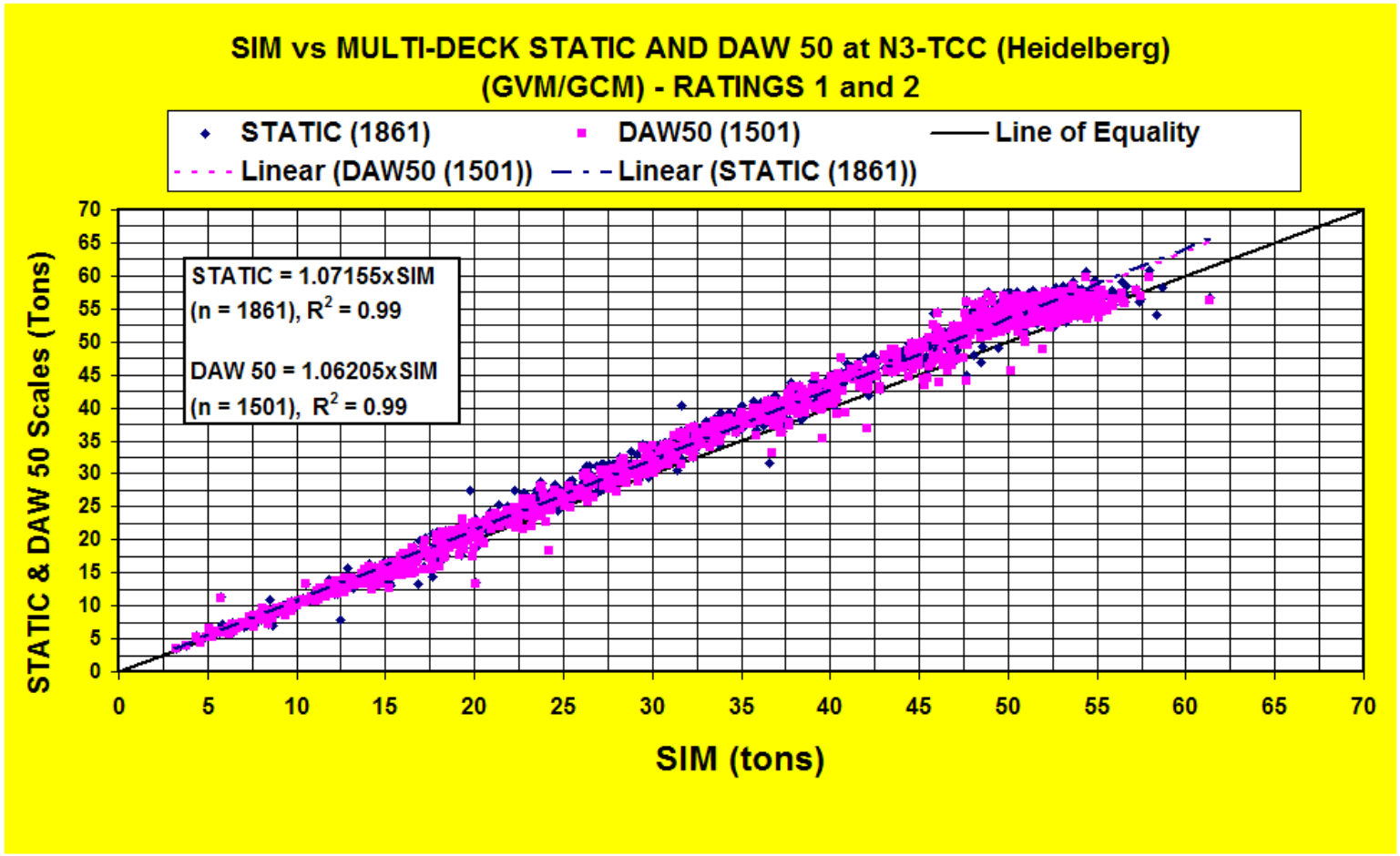
STRESS-IN-MOTION TESTING ON N3 NORTH (HEIDELBERG): QUAD SIM SYSTEM IN OPERATION

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

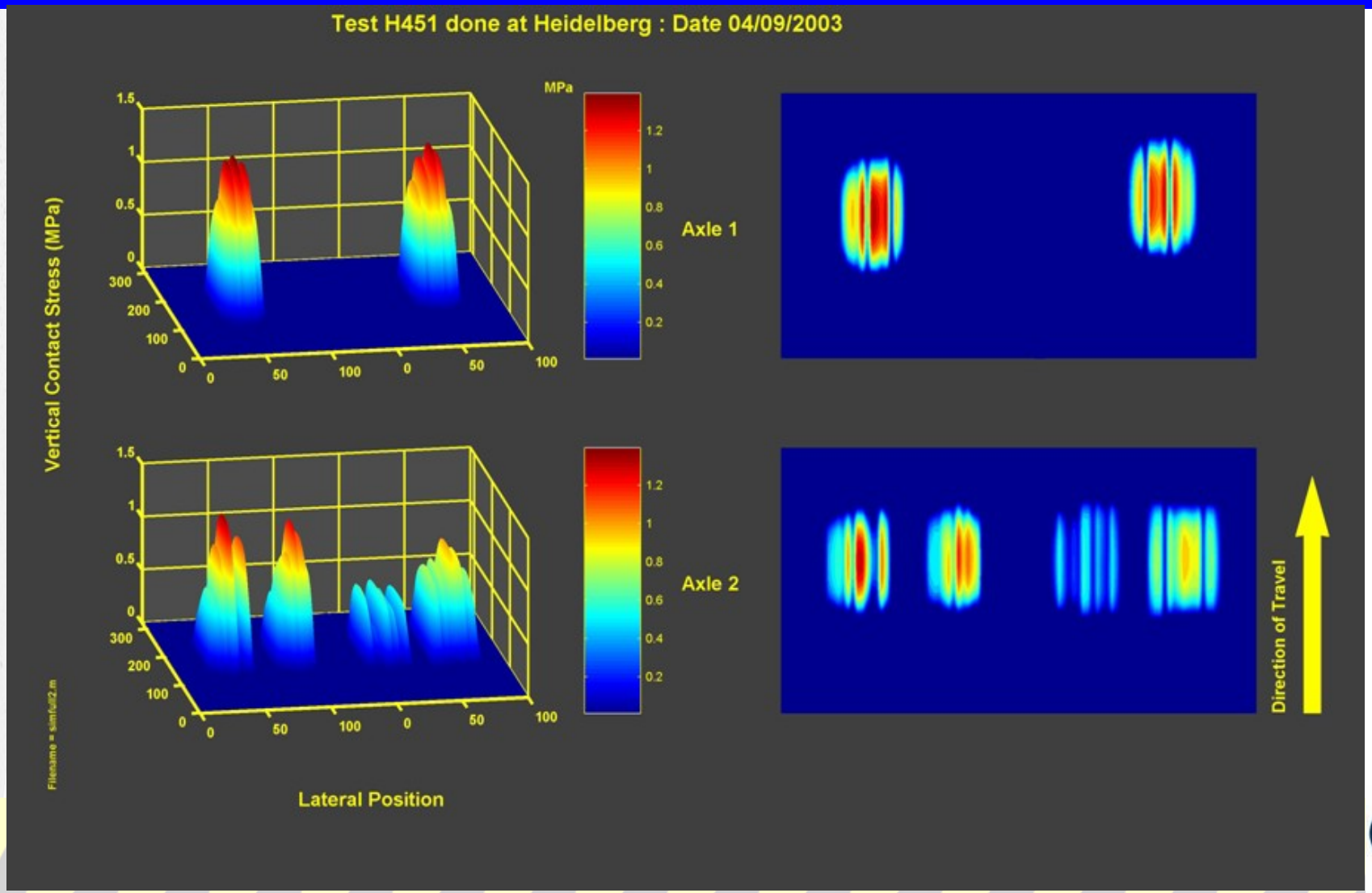
Example SIM testing during 2003

Example SIM testing during 2003

LOAD COMPARISON – FIELD WITH REAL TRUCKS N3 TCC

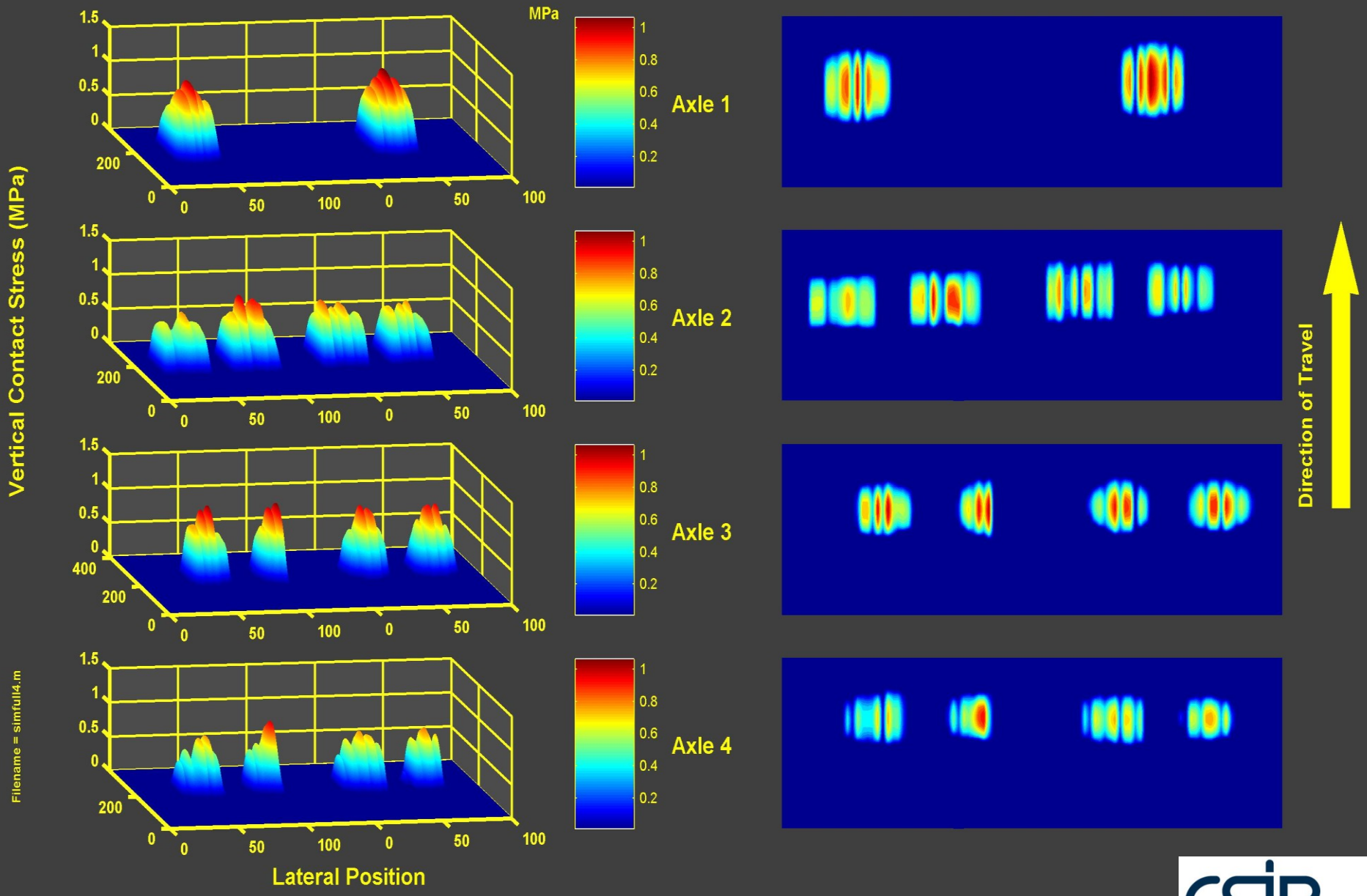


Measured Tyre Foot Prints :Two Axle Truck – Vertical Contact Stress –…..



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

4 Axle Truck….



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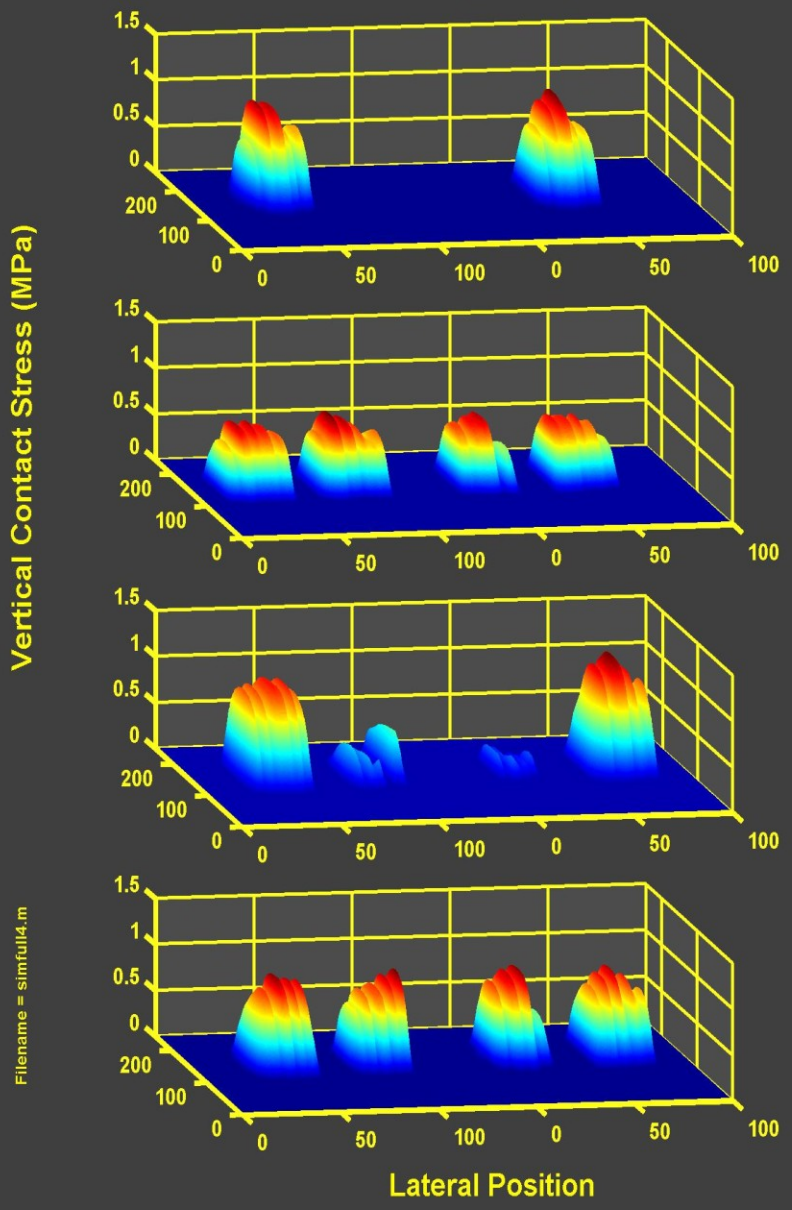
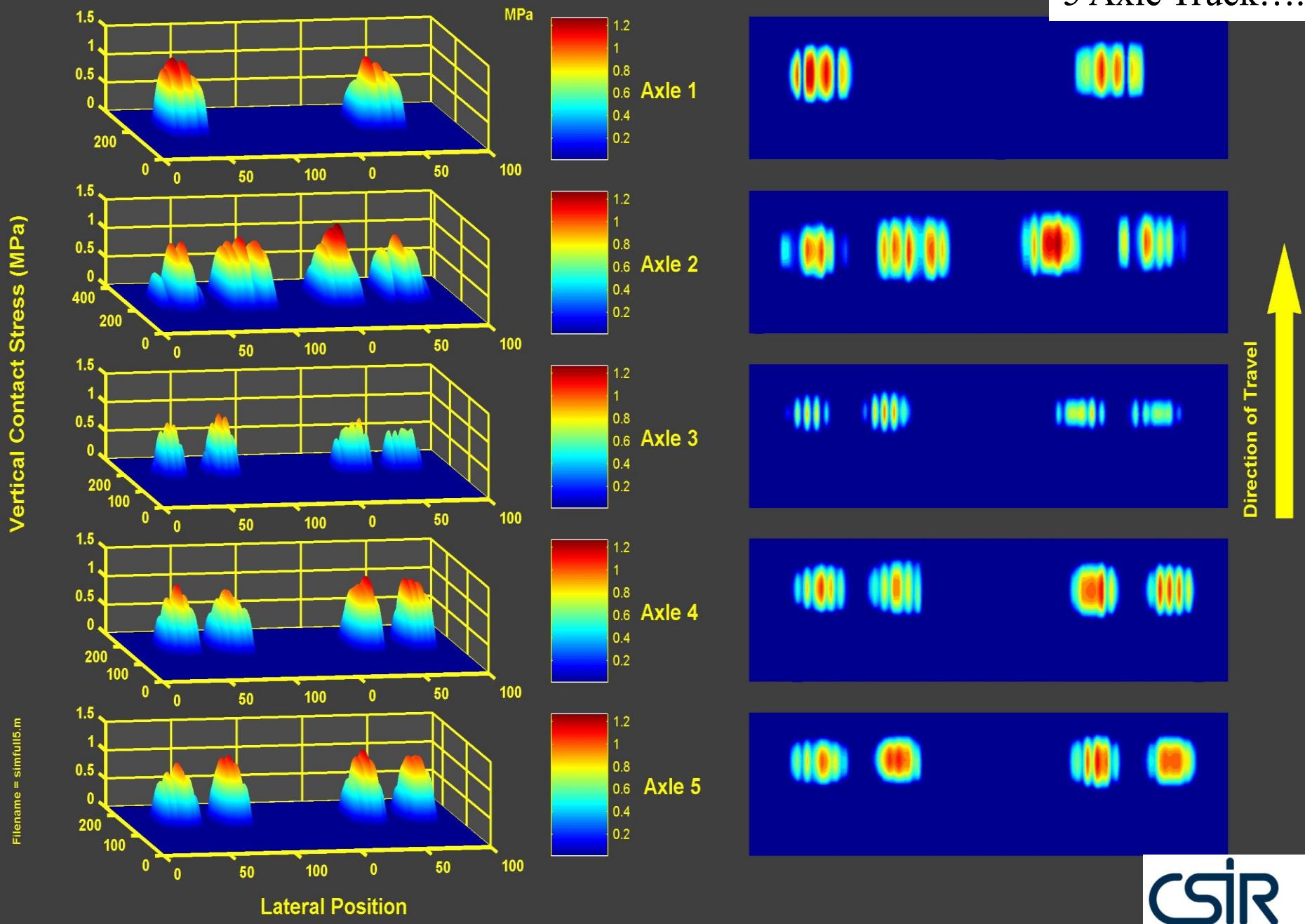
Test H833 done at Heidelberg : Date 09/09/2003



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

5 Axle Truck….



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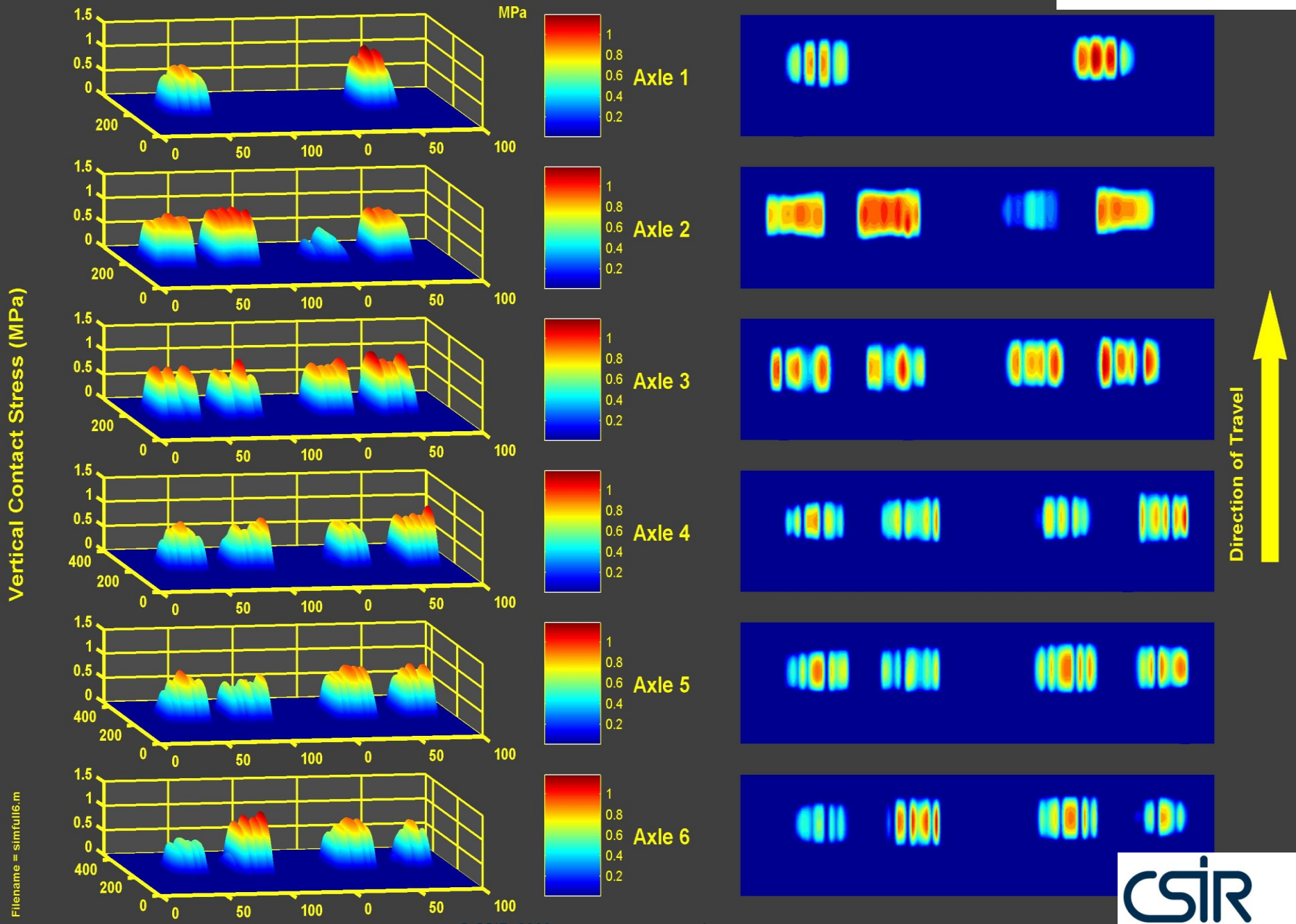
Test 174 done at Heidelberg : Date 10/09/2003 (overload)

6 Axle Truck….



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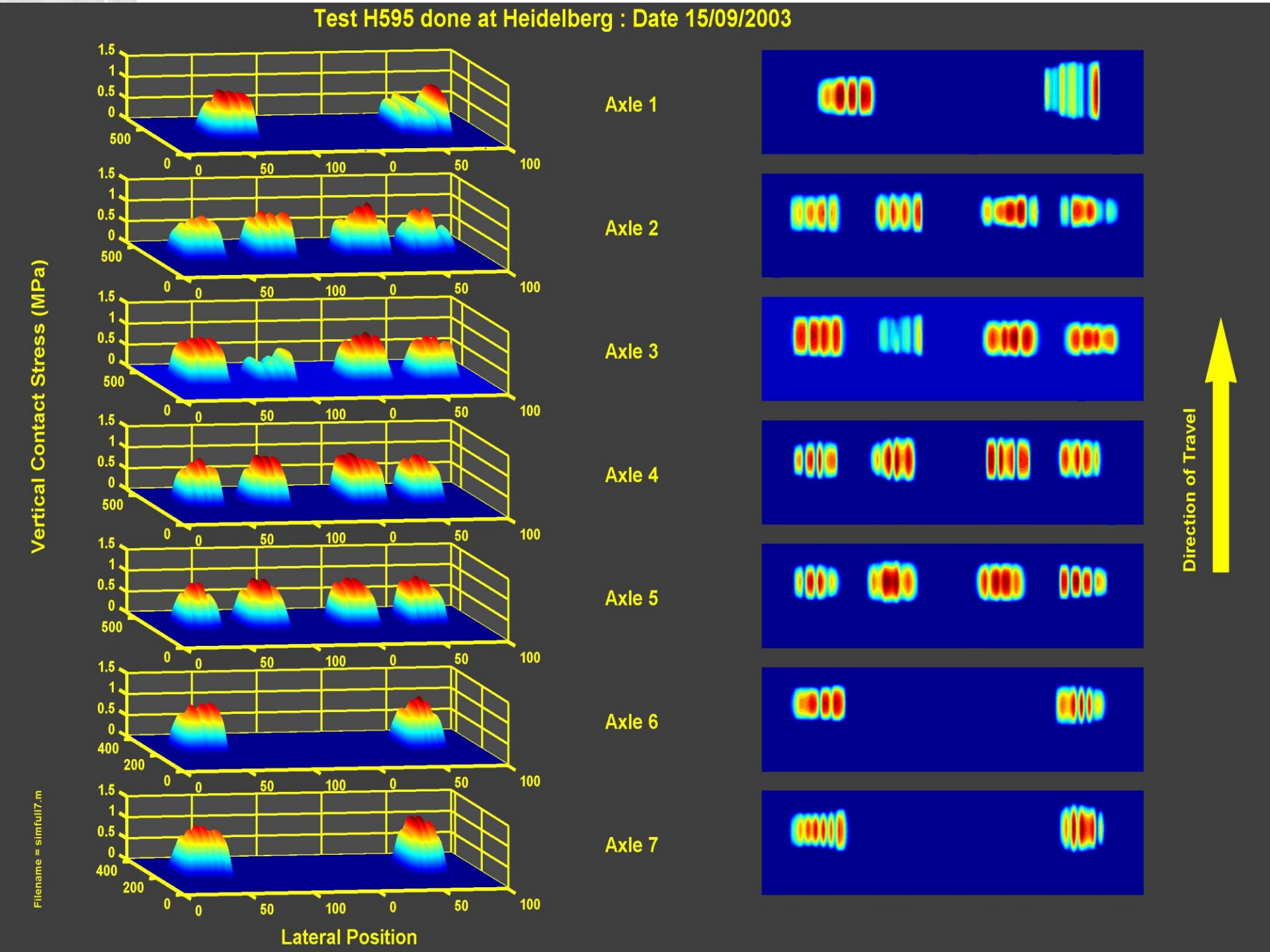
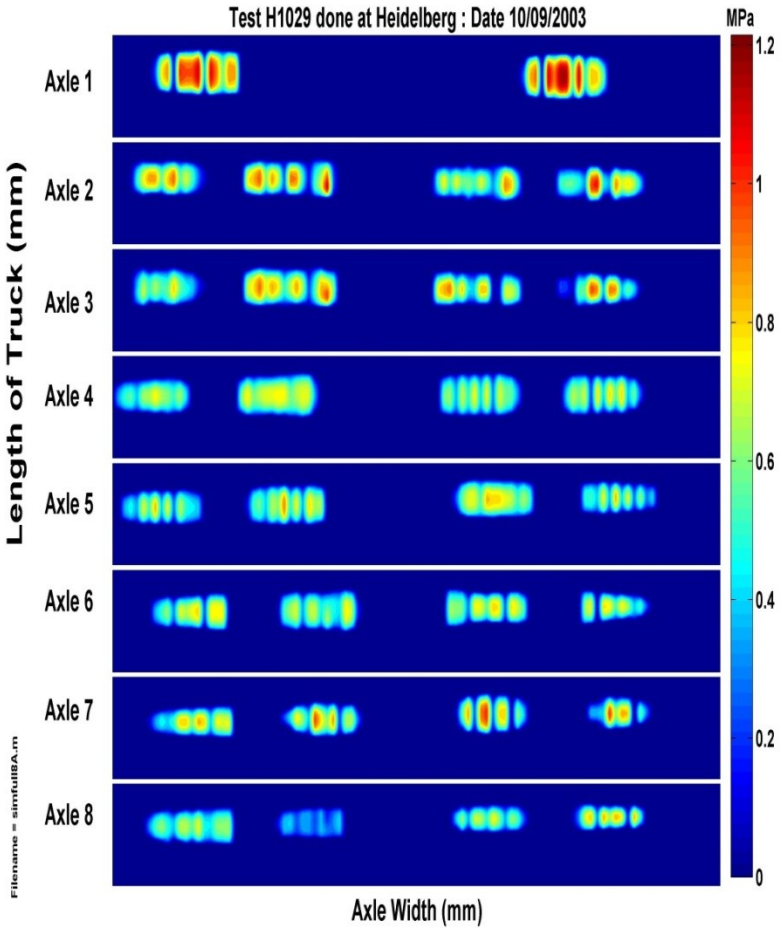
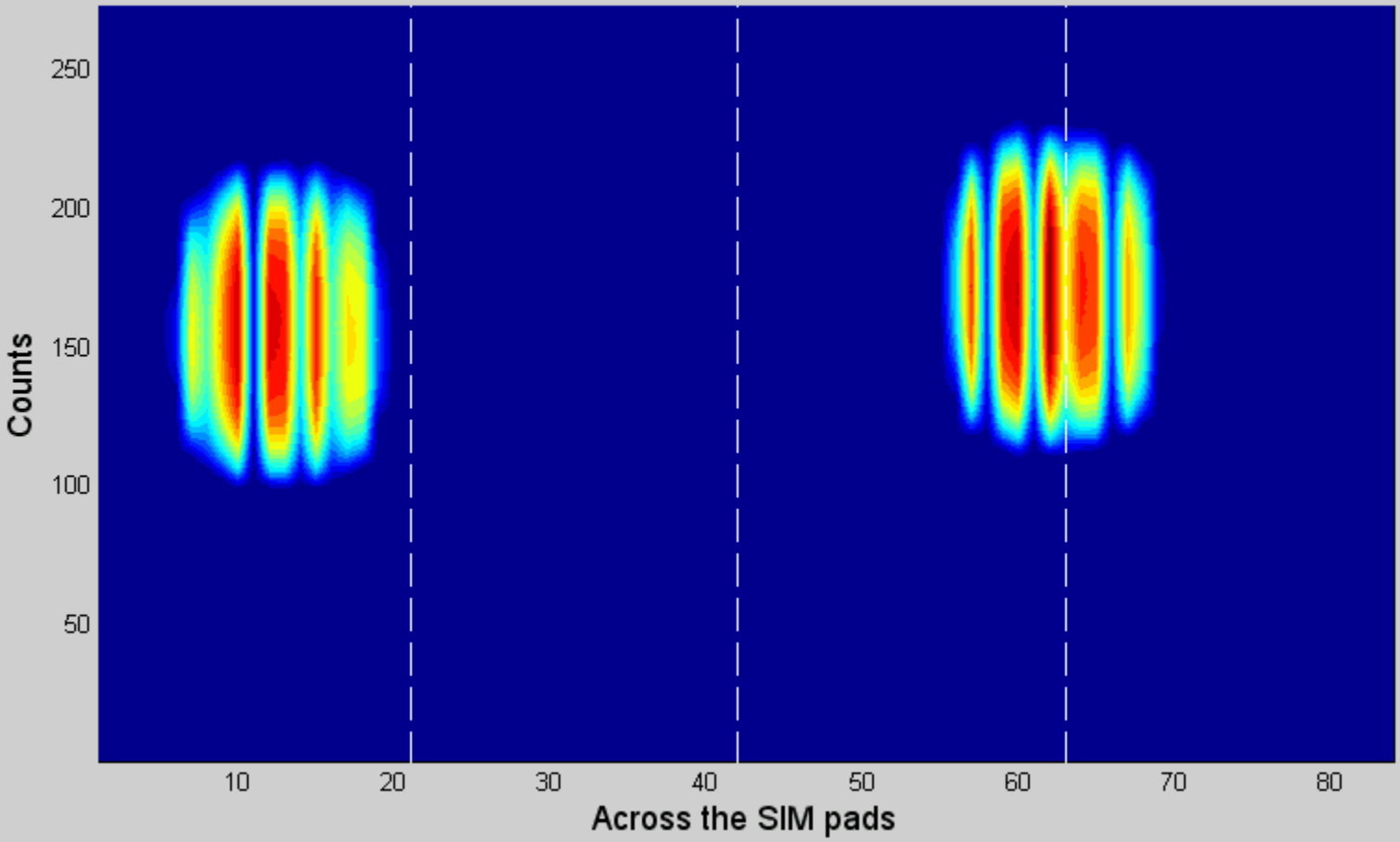

Test H595 done at Heidelberg : Date 15/09/2003
Vertical Contact Stress (MPa)
Lateral Position
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Axle 7
Direction of Travel
Filename = simfull7.m

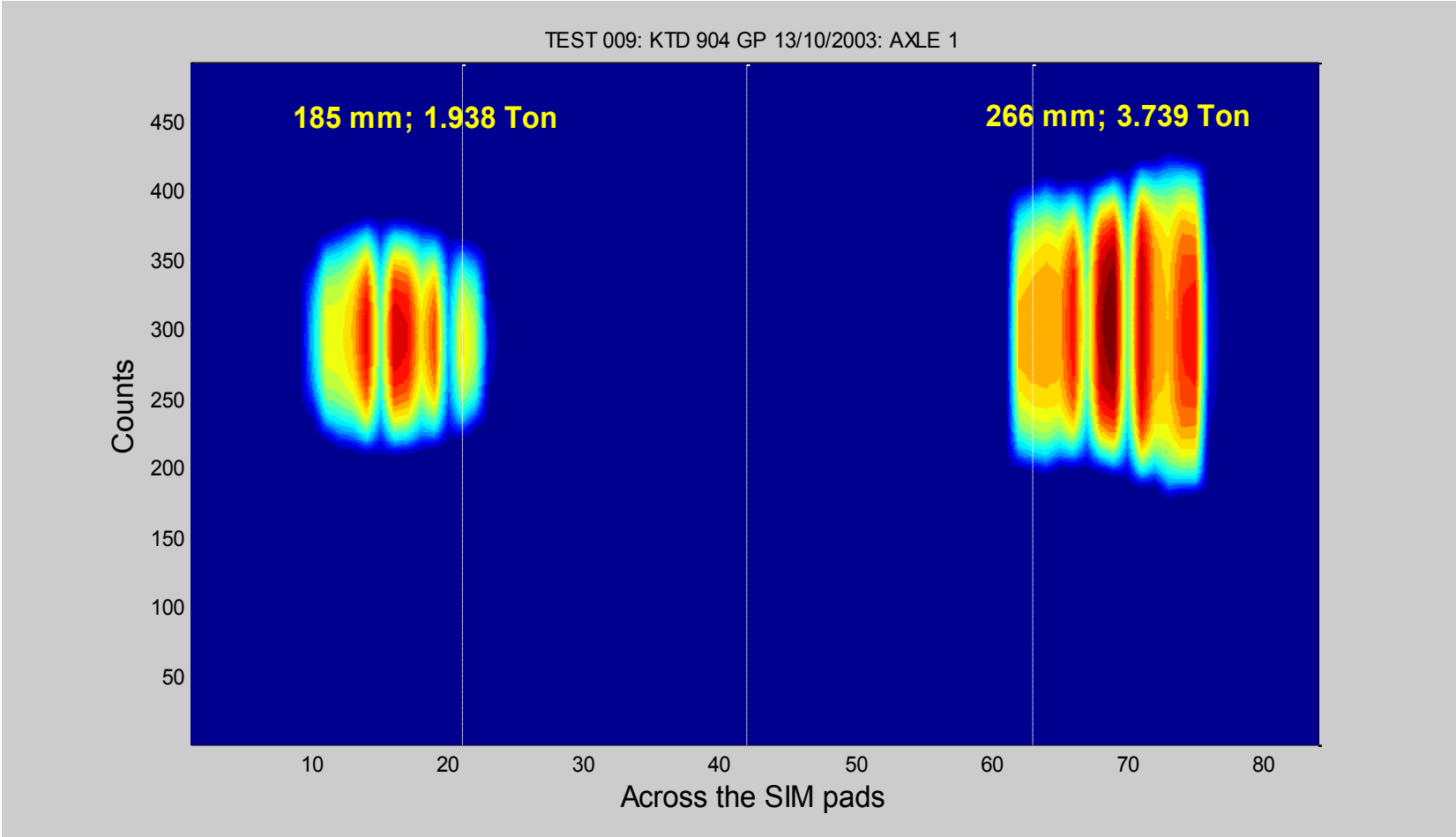
Eight (8) Axle Truck – Vertical Contact Stress - Foot Prints….



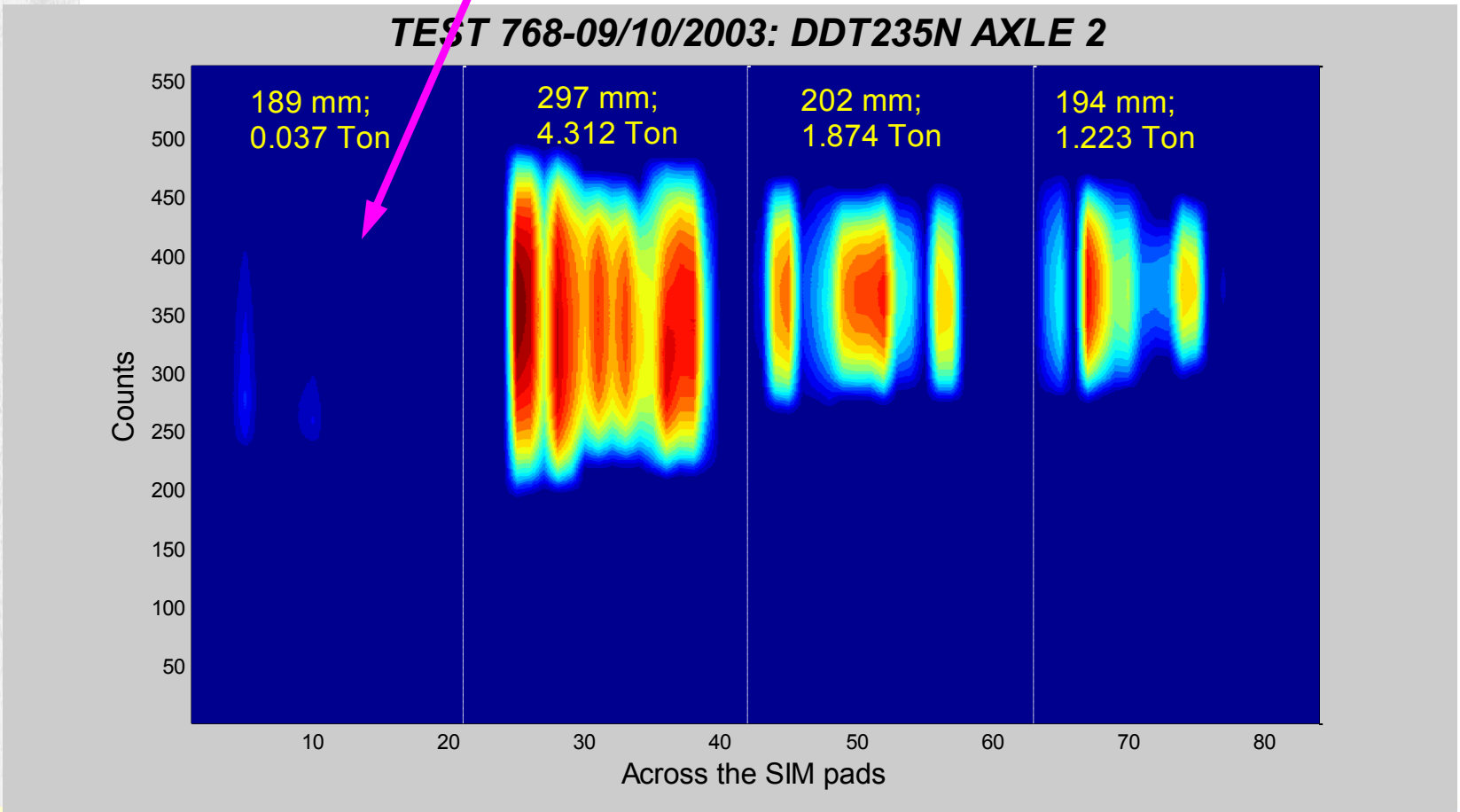
TYPICAL STEERING AXLE: VERTICAL STRESS



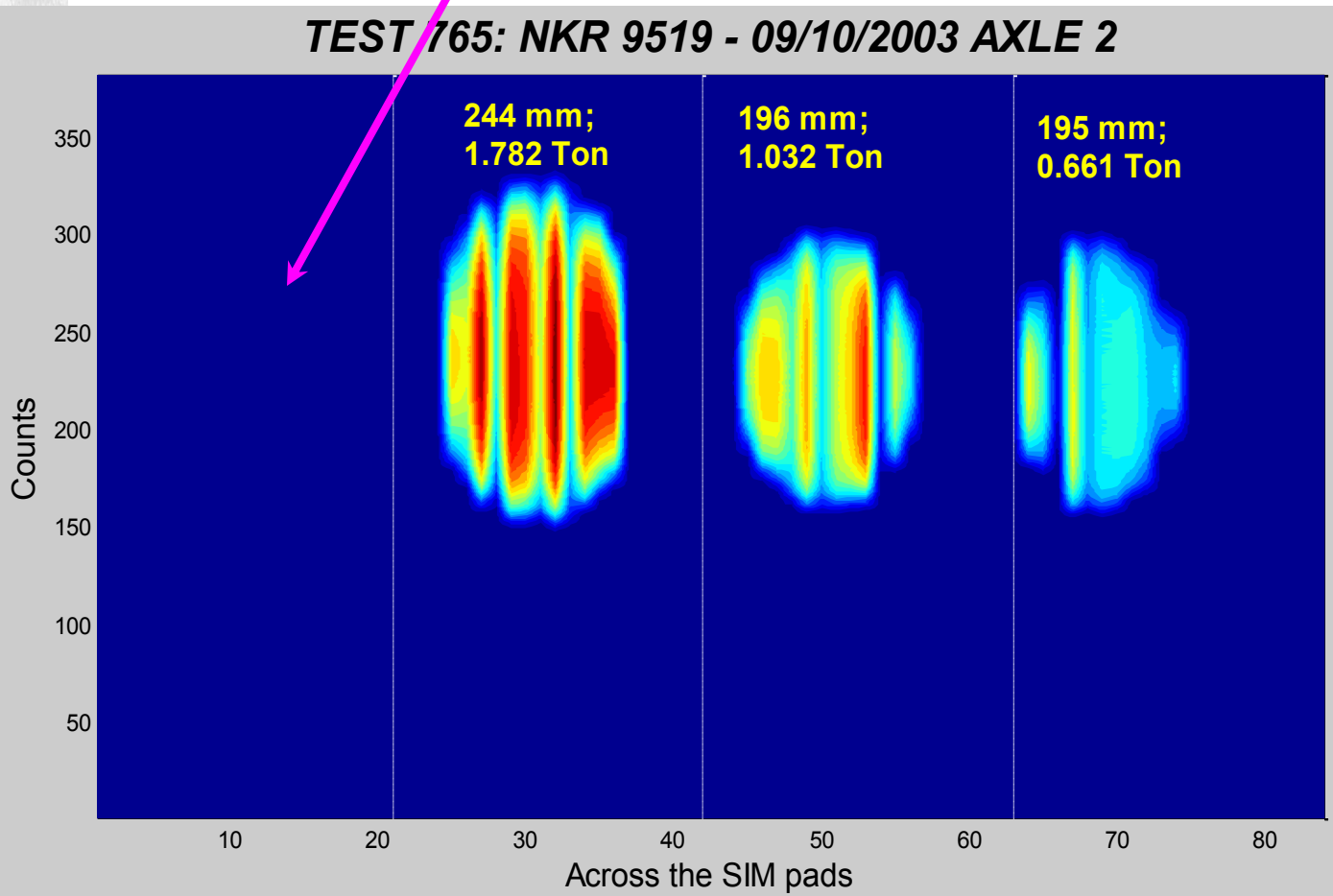
STEERING AXLE – UNEQUAL LOADING……



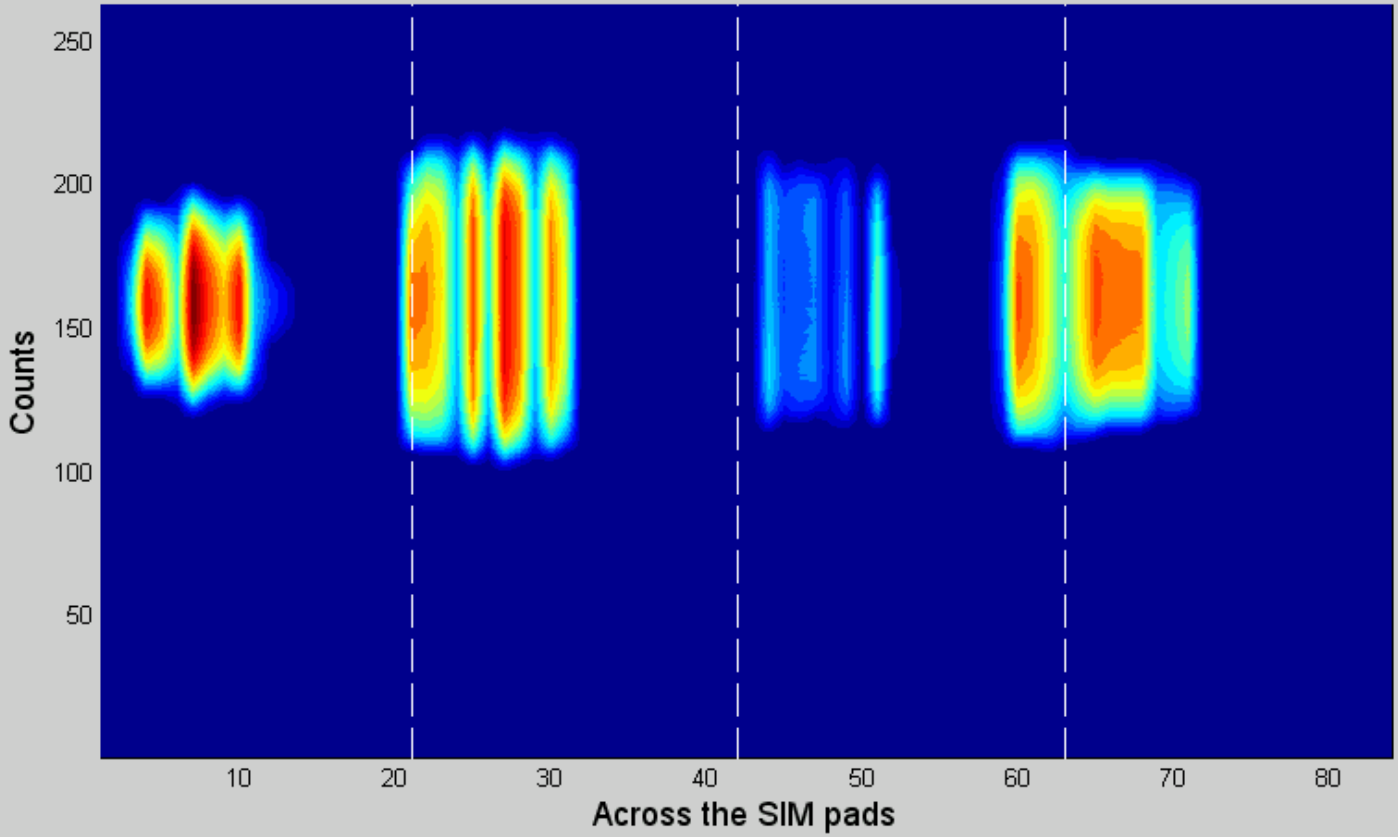
TYRE BARELY IN CONTACT WITH SURFACE…



AXLE 2: MISSING TYRE…… !!

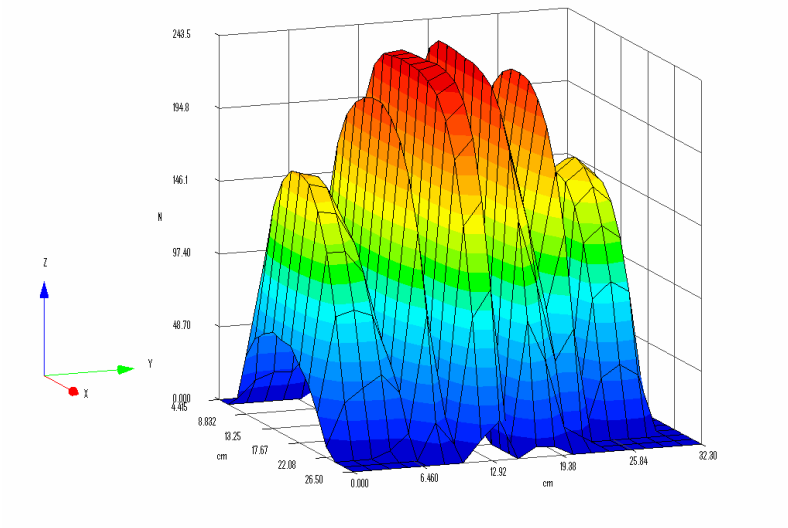


AXLE 2- DRIVING AXLE

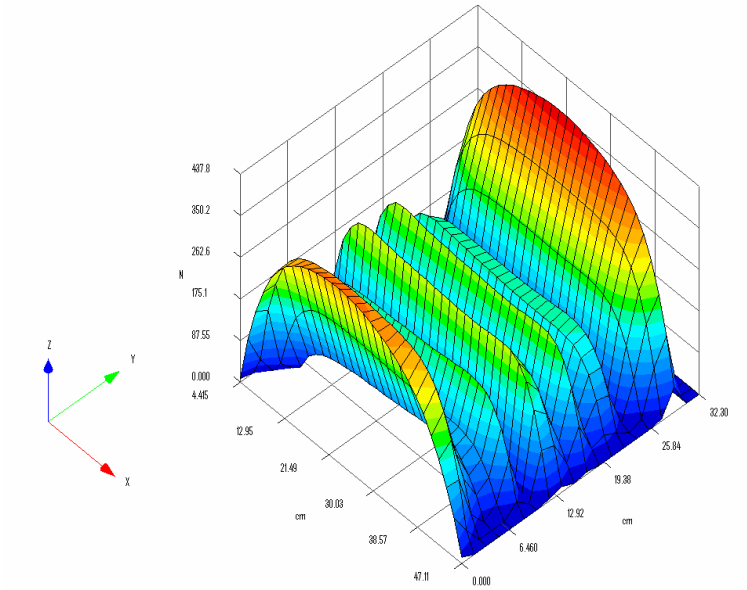


Tyres Damage……

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

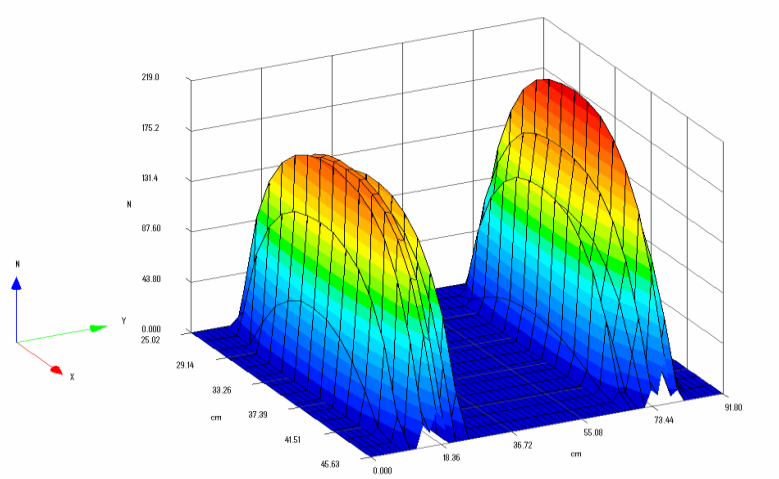


Typical “n – Shape”

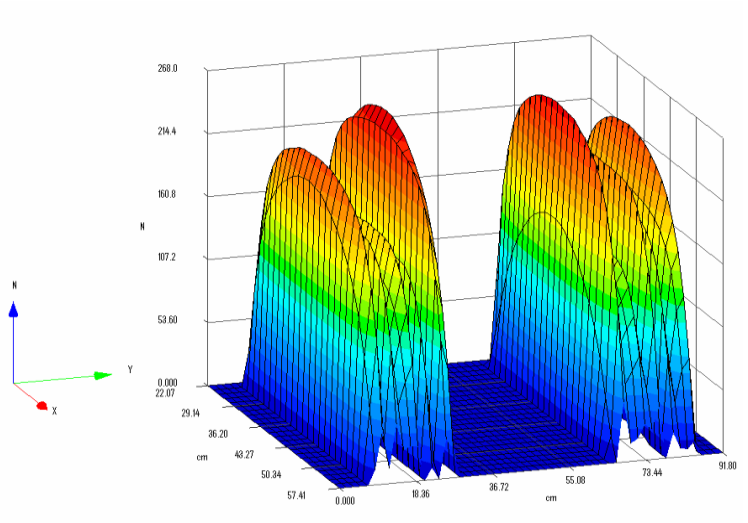


Typical “m – Shape”

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



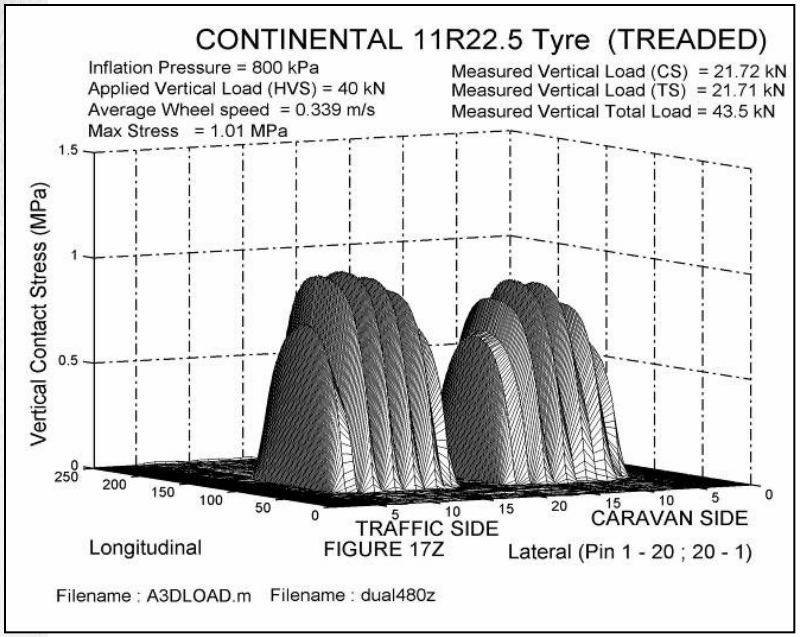
"n – Shape"



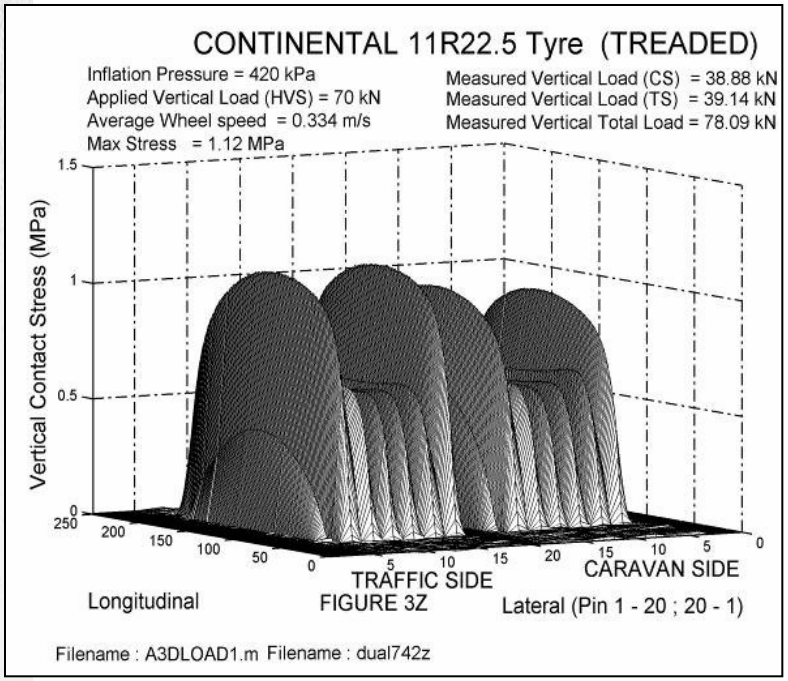
"m – Shape"- Heavily overloaded..

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

Vertical Tyre Stress: "n-Shape" tyre stress results in "n-Shape" rutting in asphalt overlay..

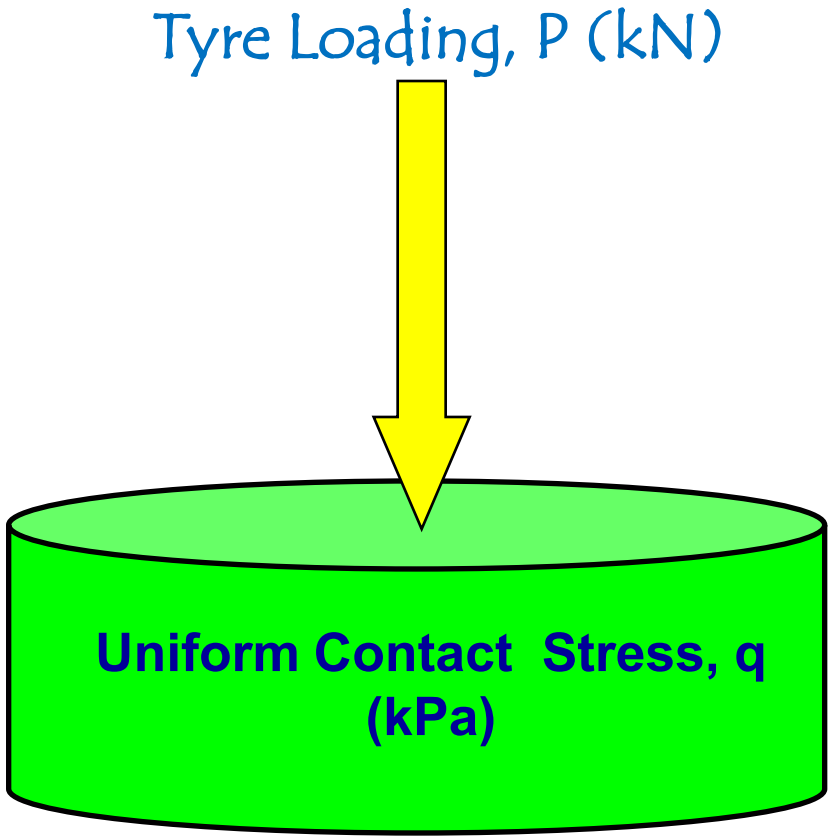


Vertical Tyre Stress: “m-Shape” stress result in “m-Shape” rutting in asphalt overlay..

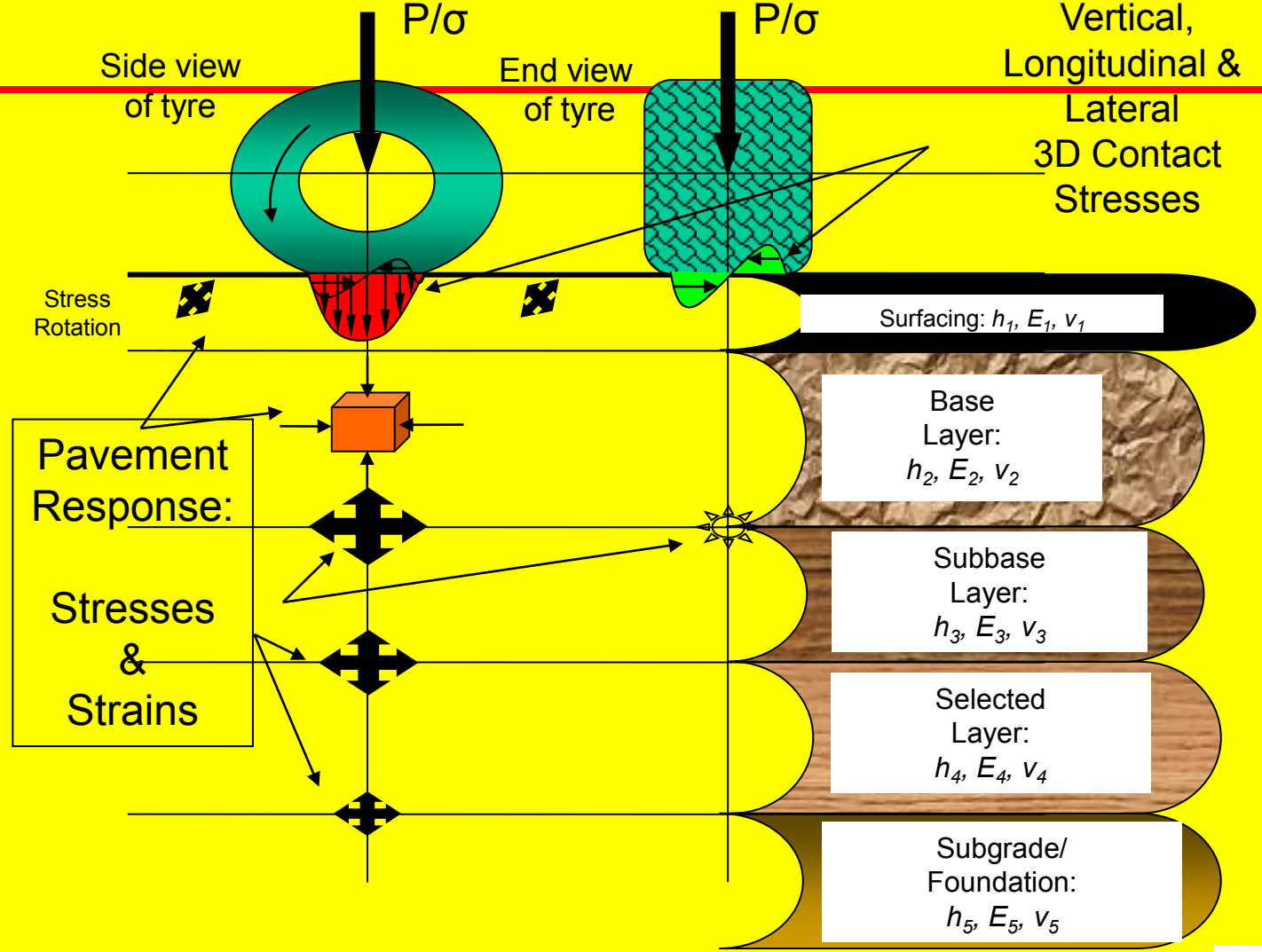


Assumption of Tyre Loading - Pavement Design Modeling:

- Circular;
- Variable load;
- Variable pressure, but Uniform…..



APPLIED LOAD/STRESSES



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

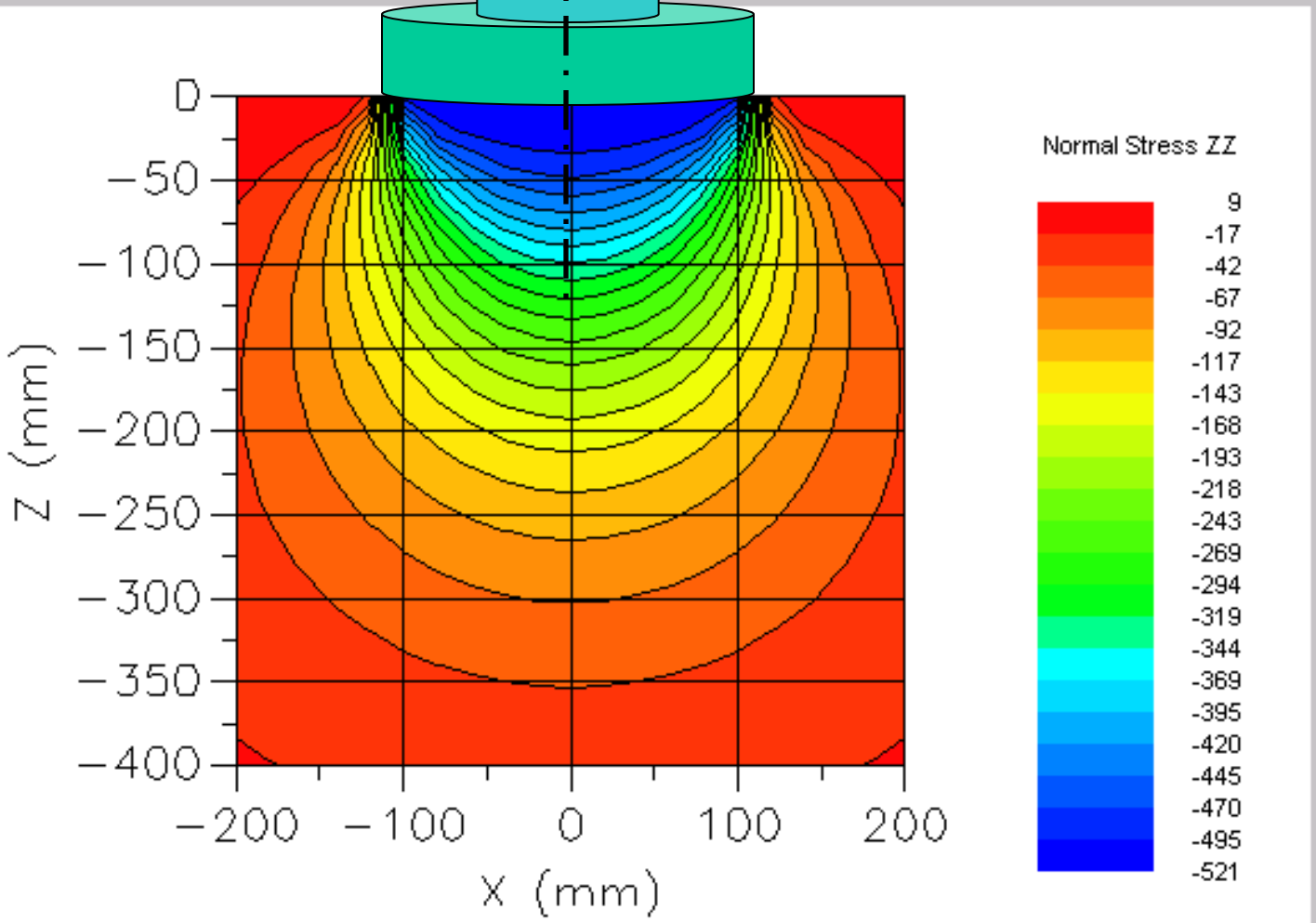
Contour region size (mm): 400

Contour region centred at (mm)

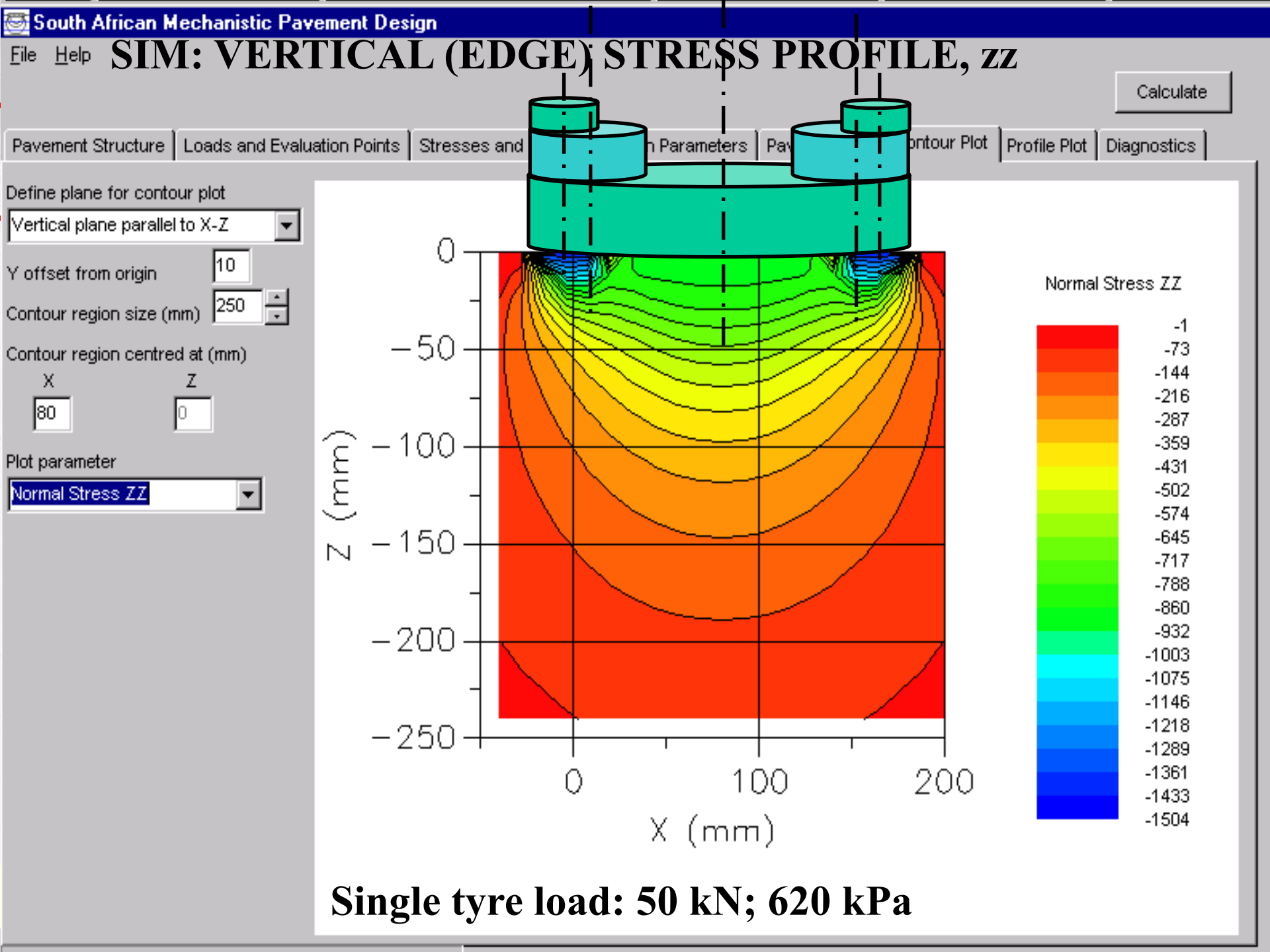
X: 0 Z: 0

Plot parameter

Normal Stress ZZ



Single tyre load: 20 kN; 520 kPa

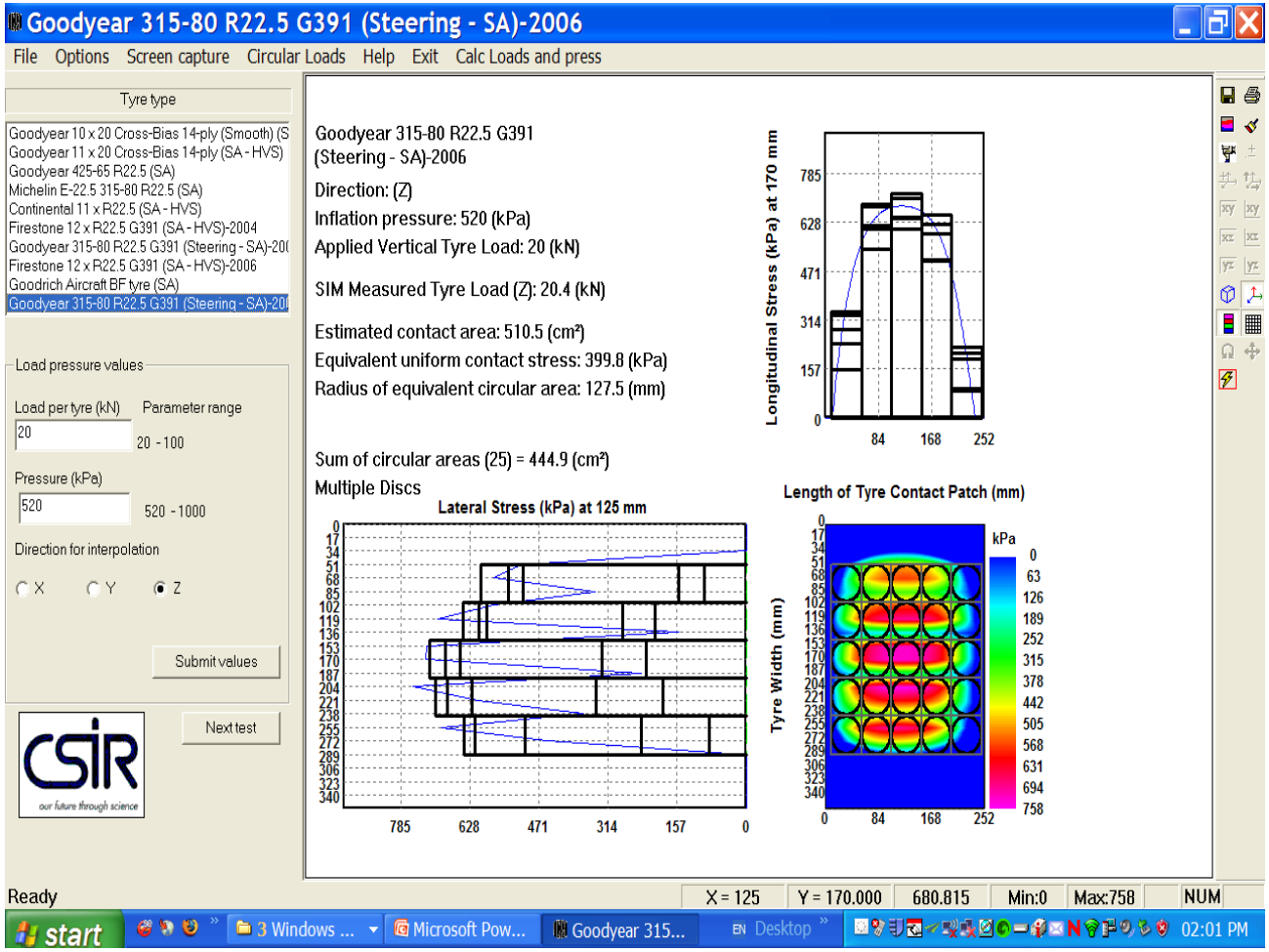

South African Mechanistic Pavement Design
File Help
SIM: VERTICAL (EDGE) STRESS PROFILE, zz
Calculate
Pavement Structure
Loads and Evaluation Points
Stresses and
Parameters
Contour Plot
Profile Plot
Diagnostics
Define plane for contour plot
Vertical plane parallel to X-Z
Y offset from origin
10
Contour 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

Mechanistic - Road Pavement Analysis-Multi-Layer

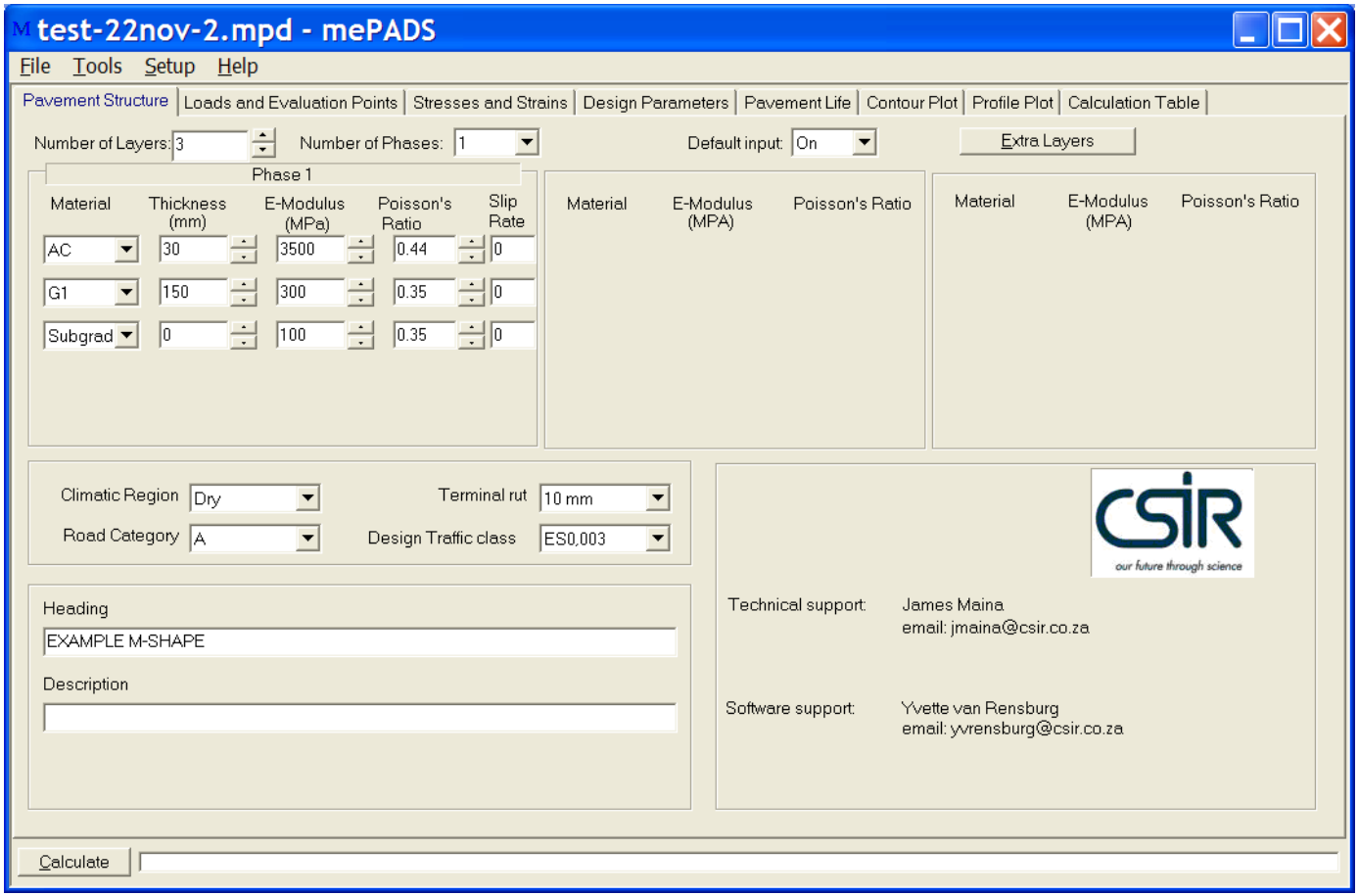
TyreStress Software Result passed onto Pavement Design Software:

"mePADS"
(Multi-Layer Linear Elastic)

From TyreStress to Pavement Design…..



Mechanistic - Road Pavement Analysis-Multi-Layer



Multiple Discs: 50kN 520kPa

Goodyear 315-80 R22.5 G391 (Steering - SA)-2006

Direction: [Z]

Inflation pressure: 520 (kPa)

Applied Vertical Tyre Load: 50 (kN)

SIM Measured Tyre Load [Z]: 47.7 (kN)

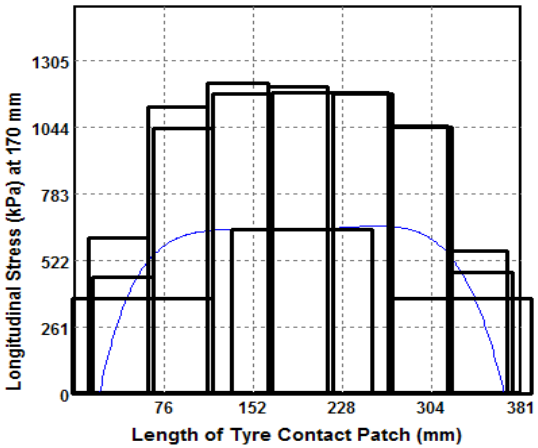
Estimated contact area: 818.6 (cm²)

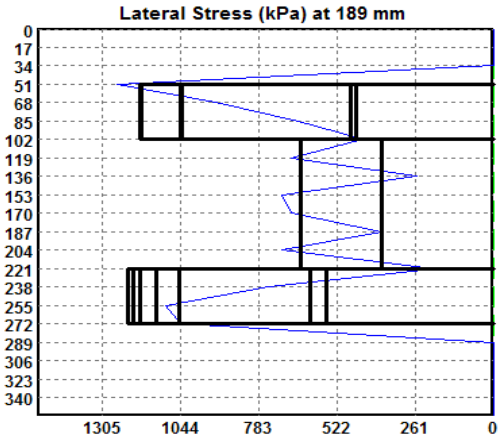
Equivalent uniform contact stress: 582.4 (kPa)

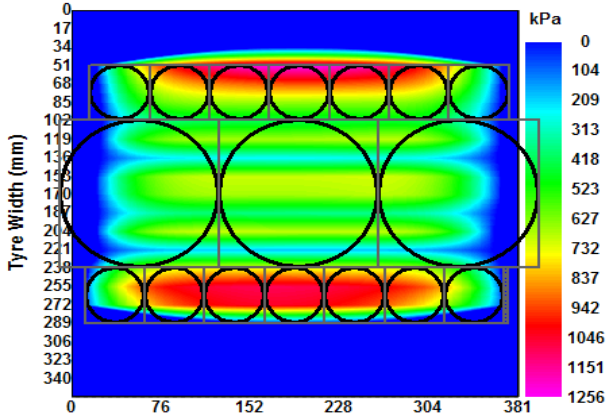
Radius of equivalent circular area: 161.4 (mm)

Load (kN)=12.7187,21.5405,13.4146

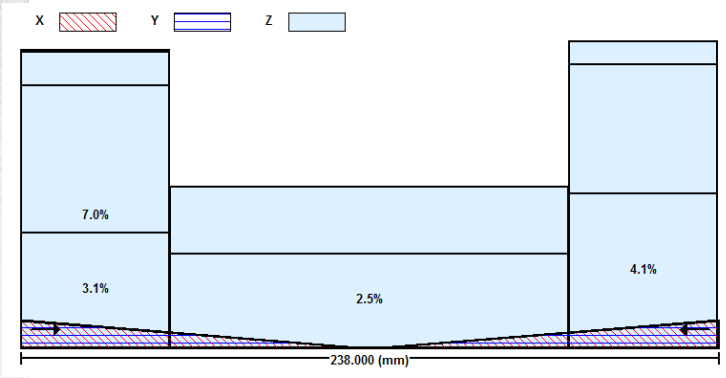
Stress (kPa)=777.69,443.945,789.903

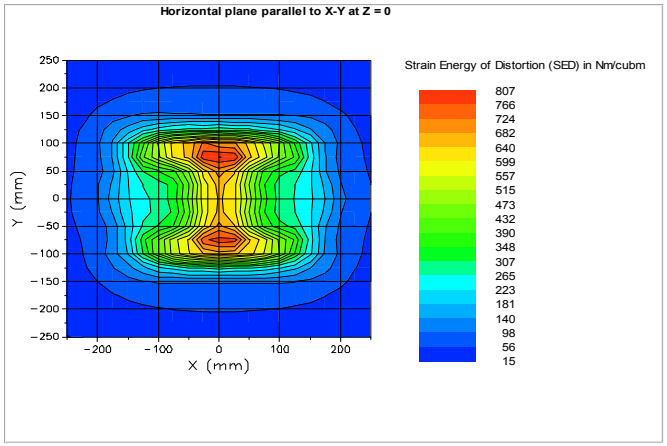


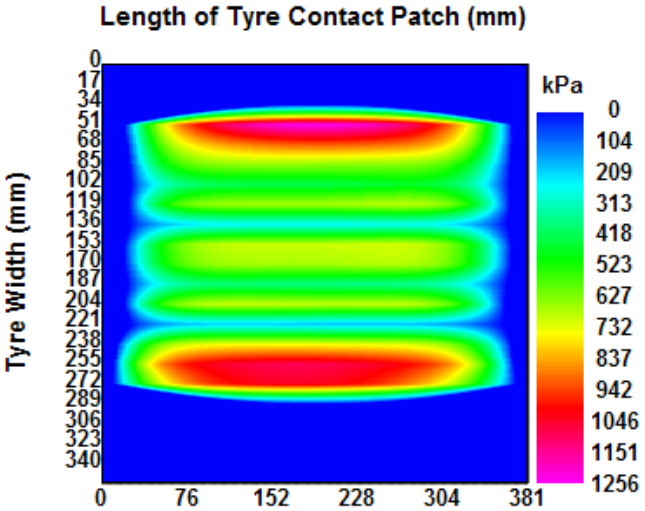


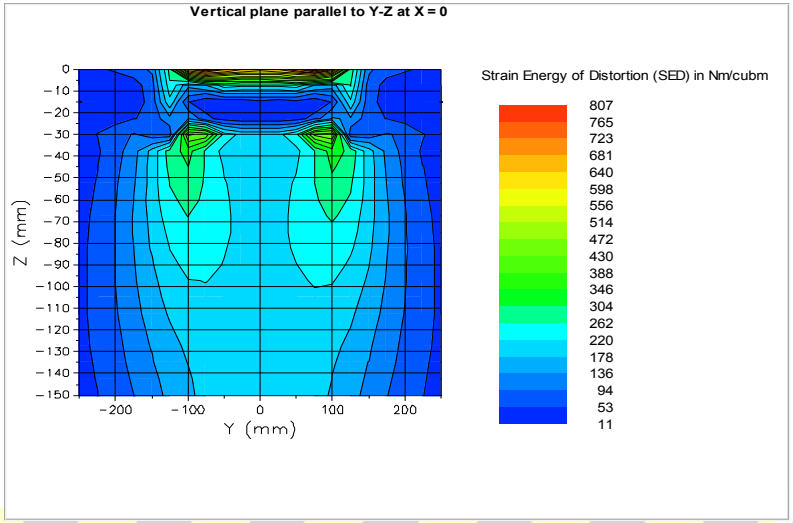


MePADS Outputs……



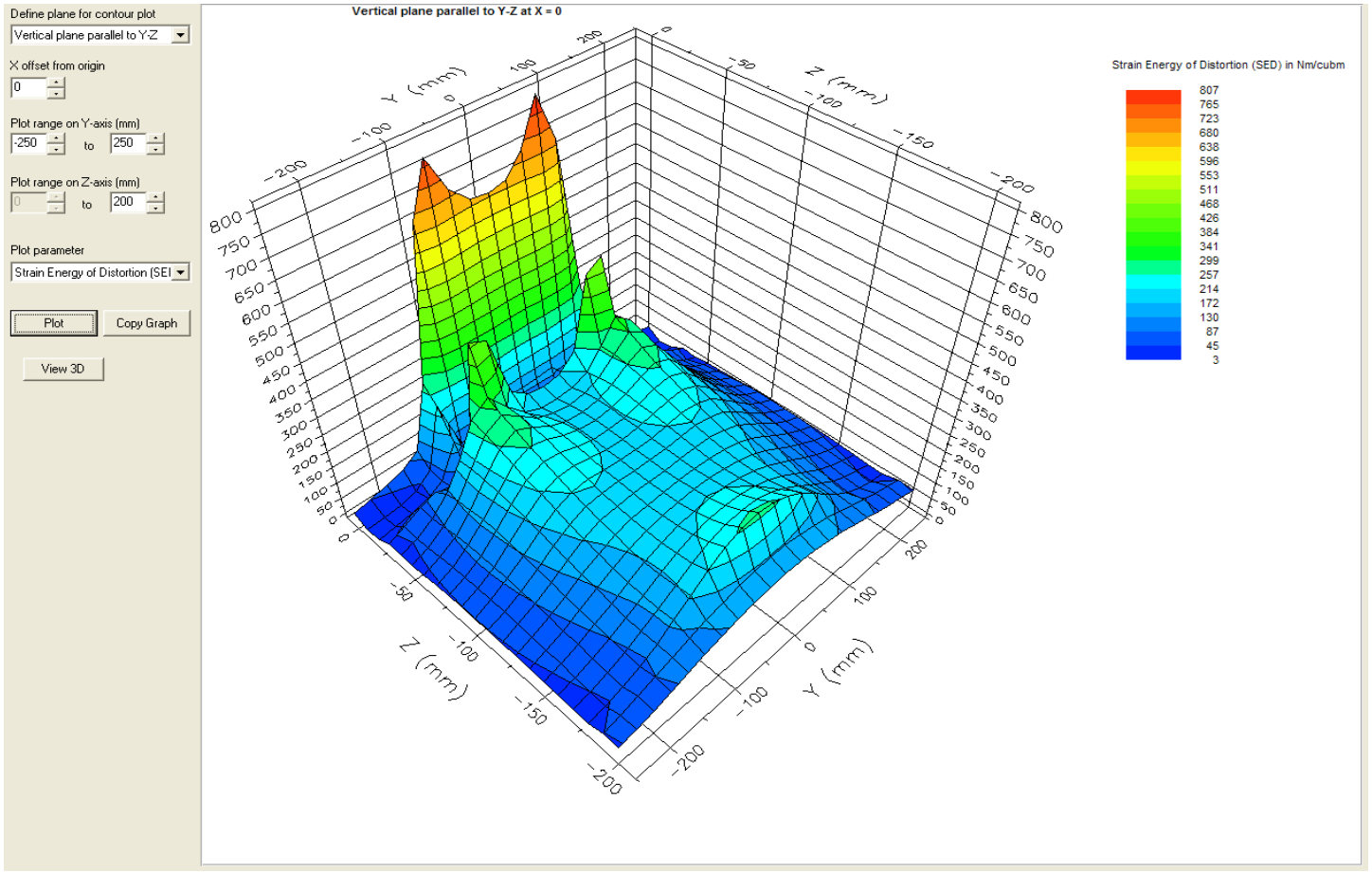






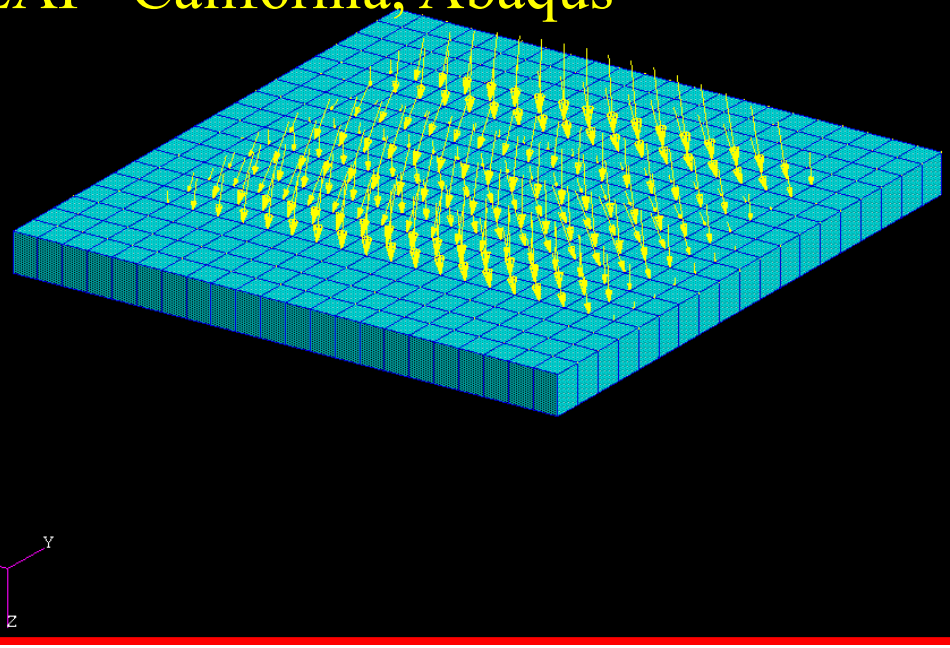
CSIR our future through science

Strain-Energy of Distortion (SED)

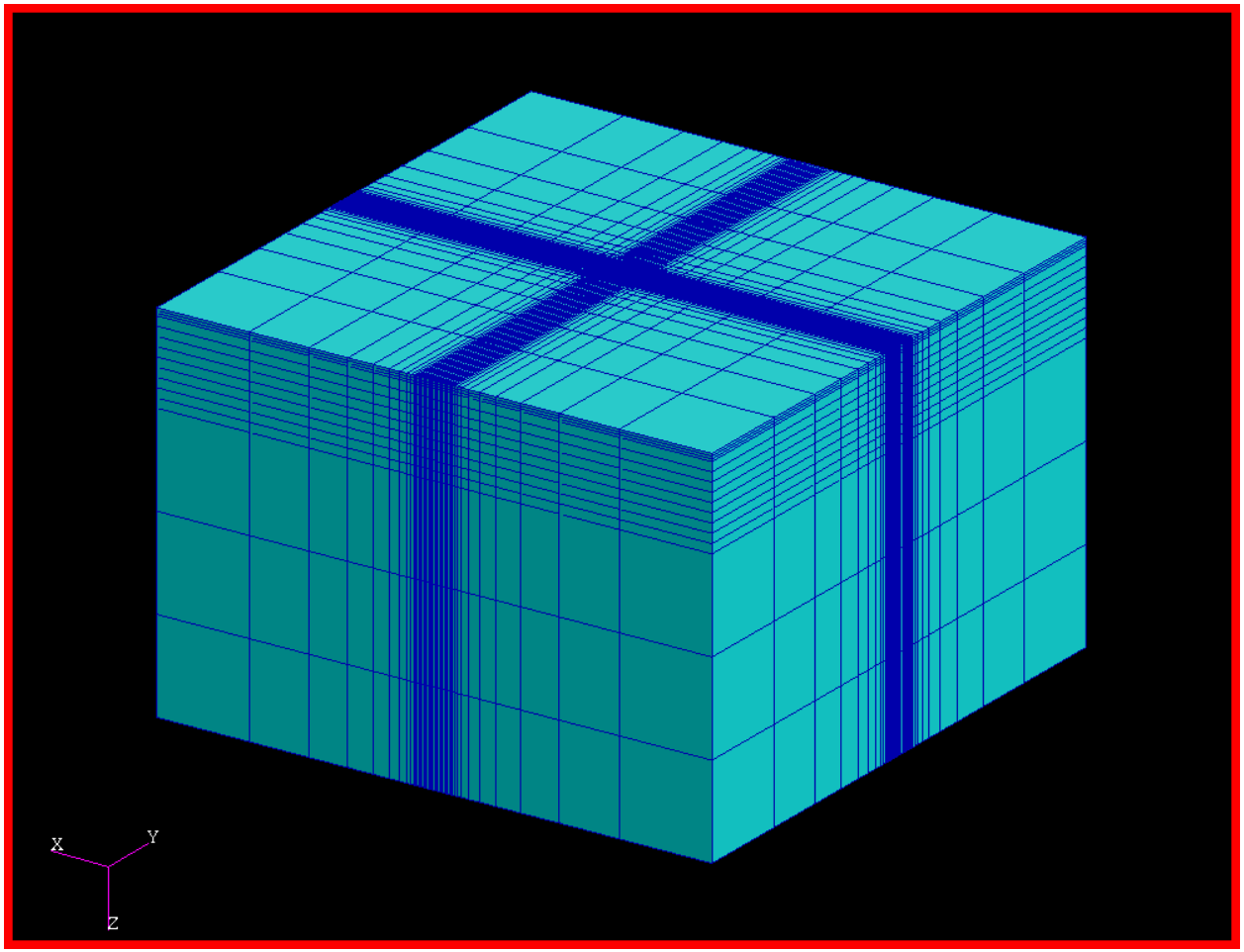


Application of non-uniform tyre loading:

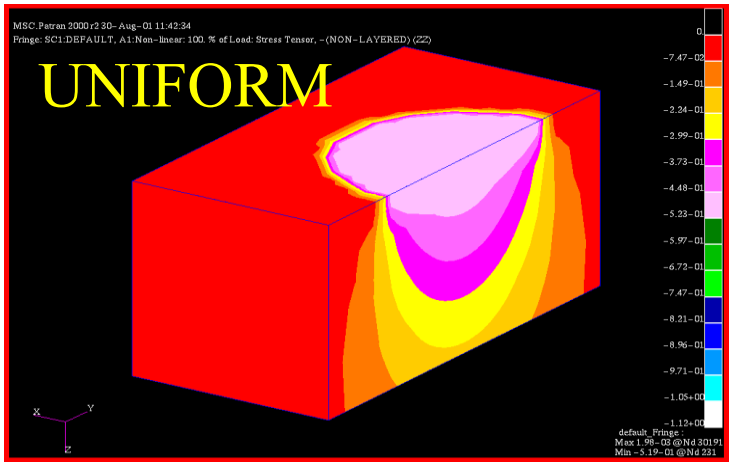
Finite Element Analyses (FEA),(NASTRAN; FEAP- California, Abaqus

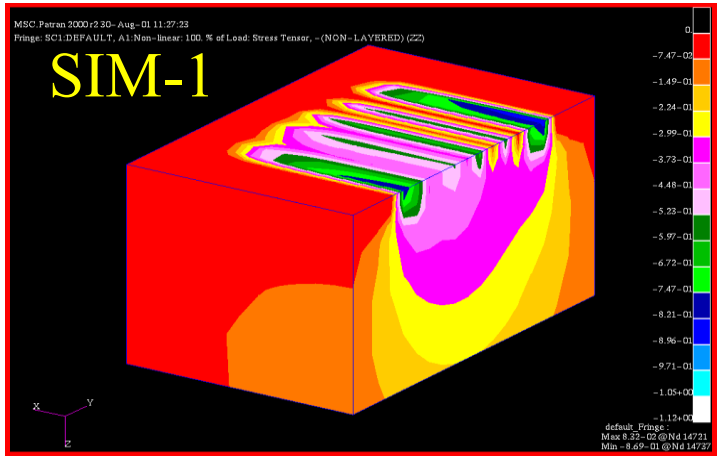


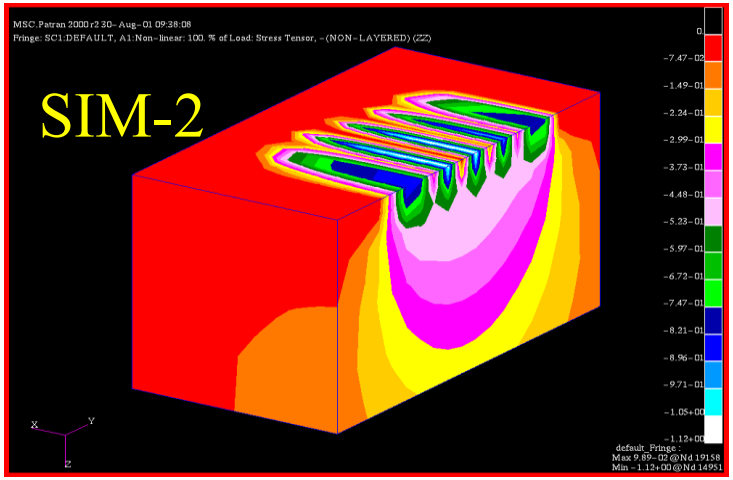
3D - Finite Element Analyses (FEM): CSIR

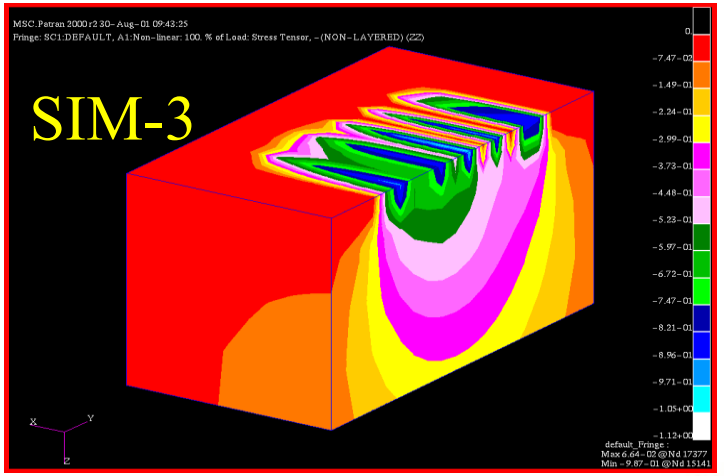


Finite Element Analysis (CSIR)



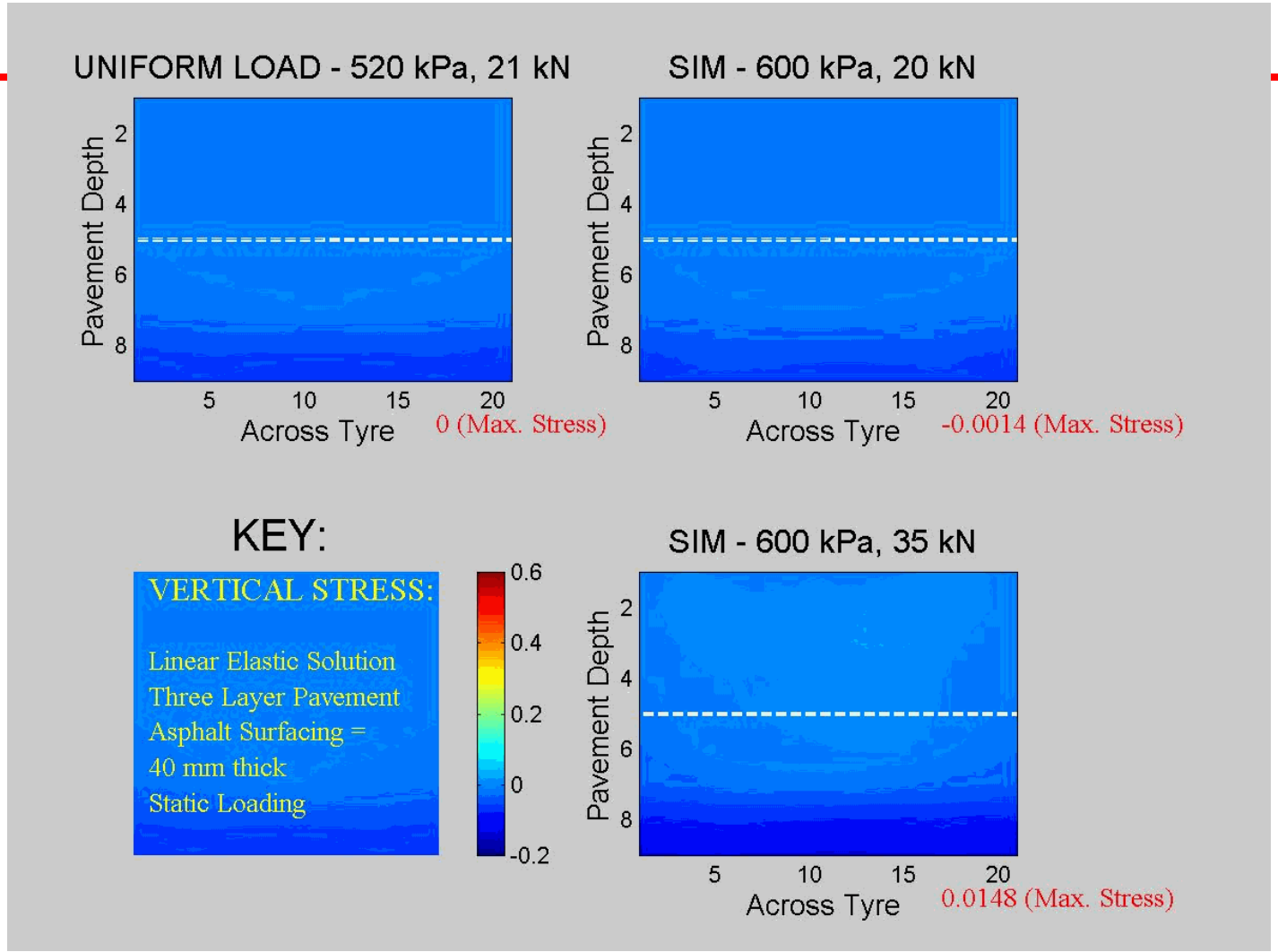




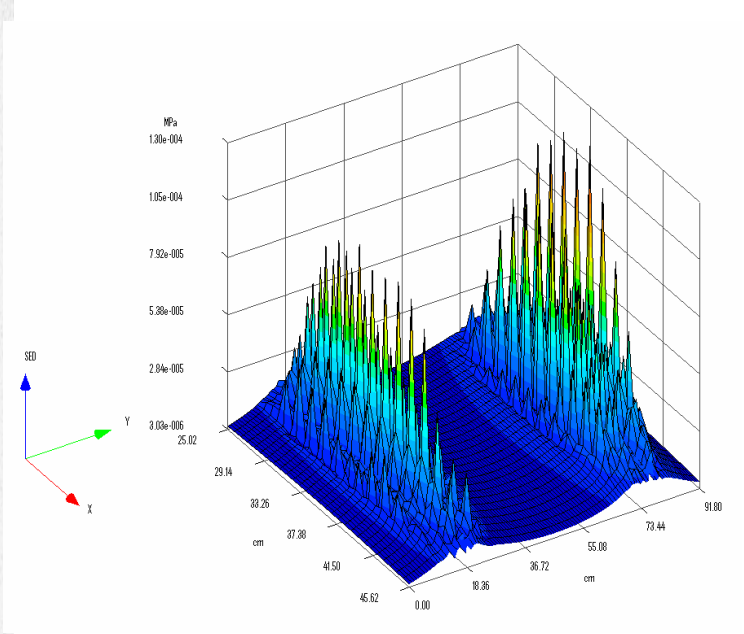


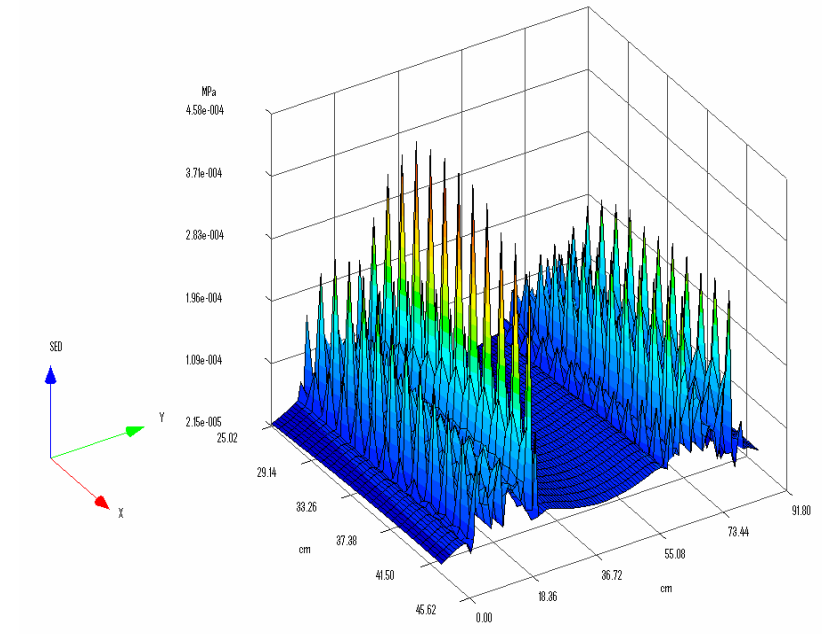
MODELED TYRE

"REAL"-TYRE-SIM Data



Strain Energy of Distortion (SED)- “n” and ”m – Shape” - dual tyres……





SUMMARY, CONCLUSIONS AND RECOMMENDATIONS (1)

- Tyre-pavement contact stresses can be quantified in 3D – using Stress-In-Motion (SIM) technology ;
- Results considered acceptable for *advanced* mechanistic pavement analysis ;
- Current data suggest that 3D Contact Stresses are complex, and may assist with advanced structural road pavement analysis;

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS (2)

- Functional performance, such as rolling resistance not investigated yet, but may be done in near future ;
- Not treated in this presentation, but: *"X,Y Stress Excursion"* plots may also largely assist with above ;

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS (3)

- Effects on pavement infrastructure to be researched, also in economical terms for each Country/State ;
- Use of Cost/Benefit studies recommended ;
- Road Authorities to plan maintenance and rehabilitation accordingly;
- More *Collaboration* needed – Tyre/Tire Industry…..?;

I thank you for your attention.