

RSA/US Pavement Technology Workshop: Session 9:

Pavement Instrumentation and Applications

Presenter: Morris De Beer

Stress - In - Motion (SIM) Technology

**Morris De Beer,
Transportek**



Gautrans



...Courtesy: <http://www.AfriCam.co.za..>

It's all to do with footprints.....

Layout of Presentation:



- **Introduction**
- **SIM Equipment**
- **Results**
- ***Conclusions***

***GOOD ROADS LEAD TO
PROSPERITY..***

..motto of the South African Road Federation

PAVEMENT DAMAGE...



RUTTING



Surface Disintegration...



Fatigue Cracking and aging



Delamination..



Longitudinal Flow of Asphalt



SURFACE DISINTEGRATION



**POTHOLES :
Water & Loads ...**



Potholes & Patching...

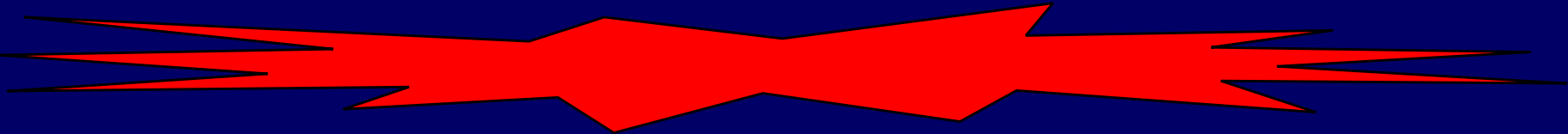


Sub-grade Failures... .



Water & Safety...

The General Problem Statement:

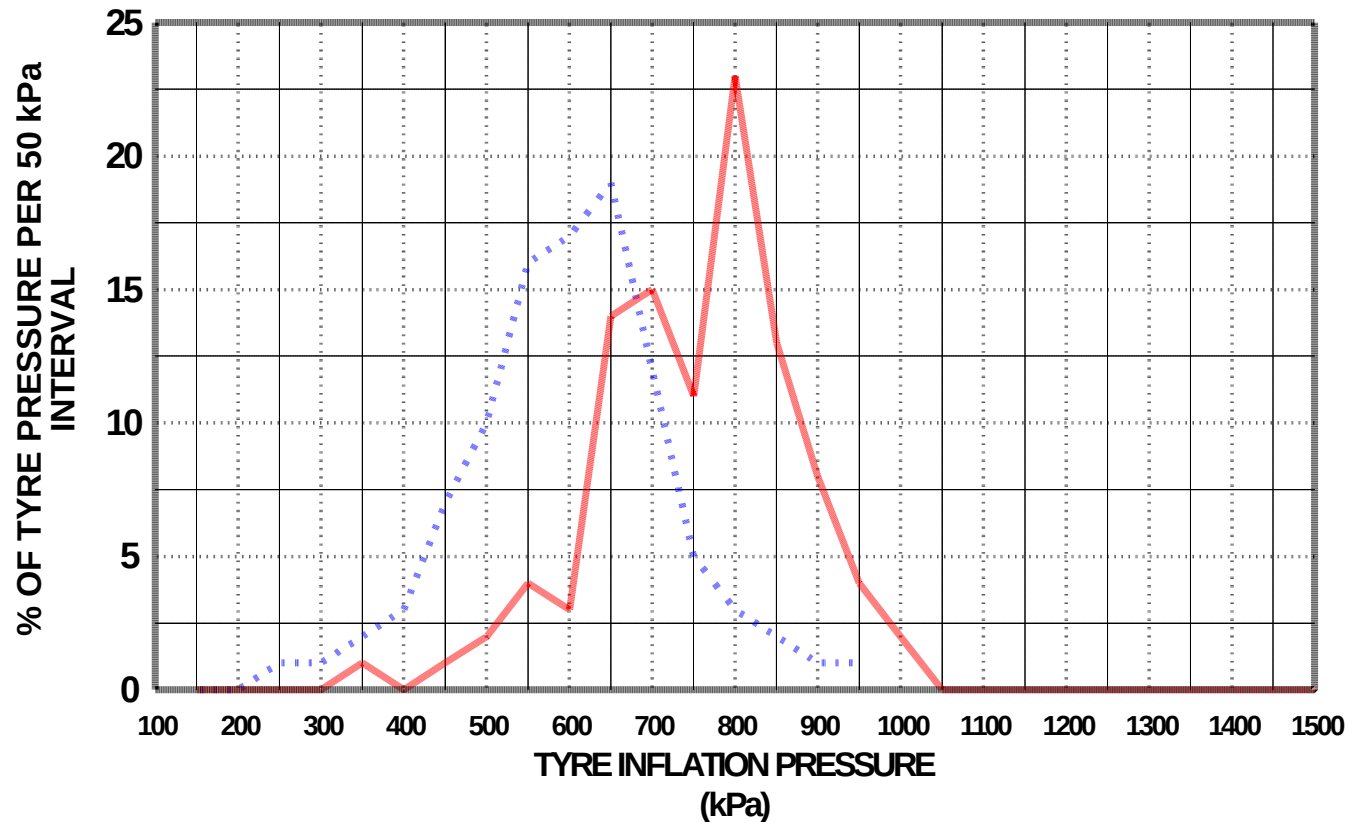


“..there exist very little commonality between *pavement surface distress types* such as rutting, cracking, disintegration, debonding, crushing, ravelling, bleeding, potholes, etc., and current pavement design, performance and analysis methods...
..therefore the impact on maintenance and rehabilitation on paved roads is very difficult to quantify.....

TYRES



Truck Tire Inflation Pressure in South Africa:



Van Vuuren (1974)

Average: 620 kPa

De Beer (1995)

Average: 733 kPa

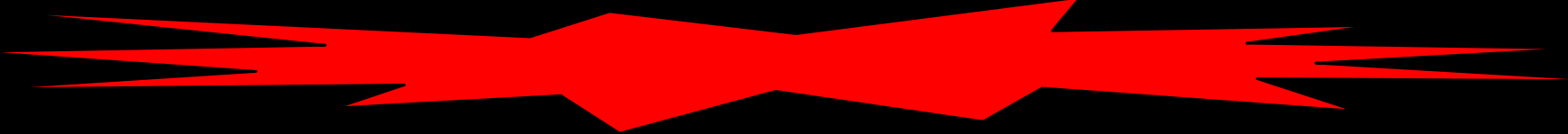
FIGURE 1

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

**~ 20 %
Increase
in
20 Years**



**I believe that part of
the problem is that :**



**“In Pavement Engineering, worldwide today,
the representation of pneumatic
tyre/pavement contact stresses is
oversimplified by using a circular disc
of uniformly distributed pressure,
equal or less than the tyre inflation
pressure”.**

***..Strong indications suggests that this
may be far from real - world conditions....***

HVS-SIM Project

Objective:



**..To obtain a more realistic
tyre/pavement contact stress
representation under
the pneumatic tyres of the
Heavy Vehicle Simulator (HVS)...**

***..This is to improve pavement tests and
analysis, in general....***

Confidential Contract Report
CR - 99/012 (March 2000)

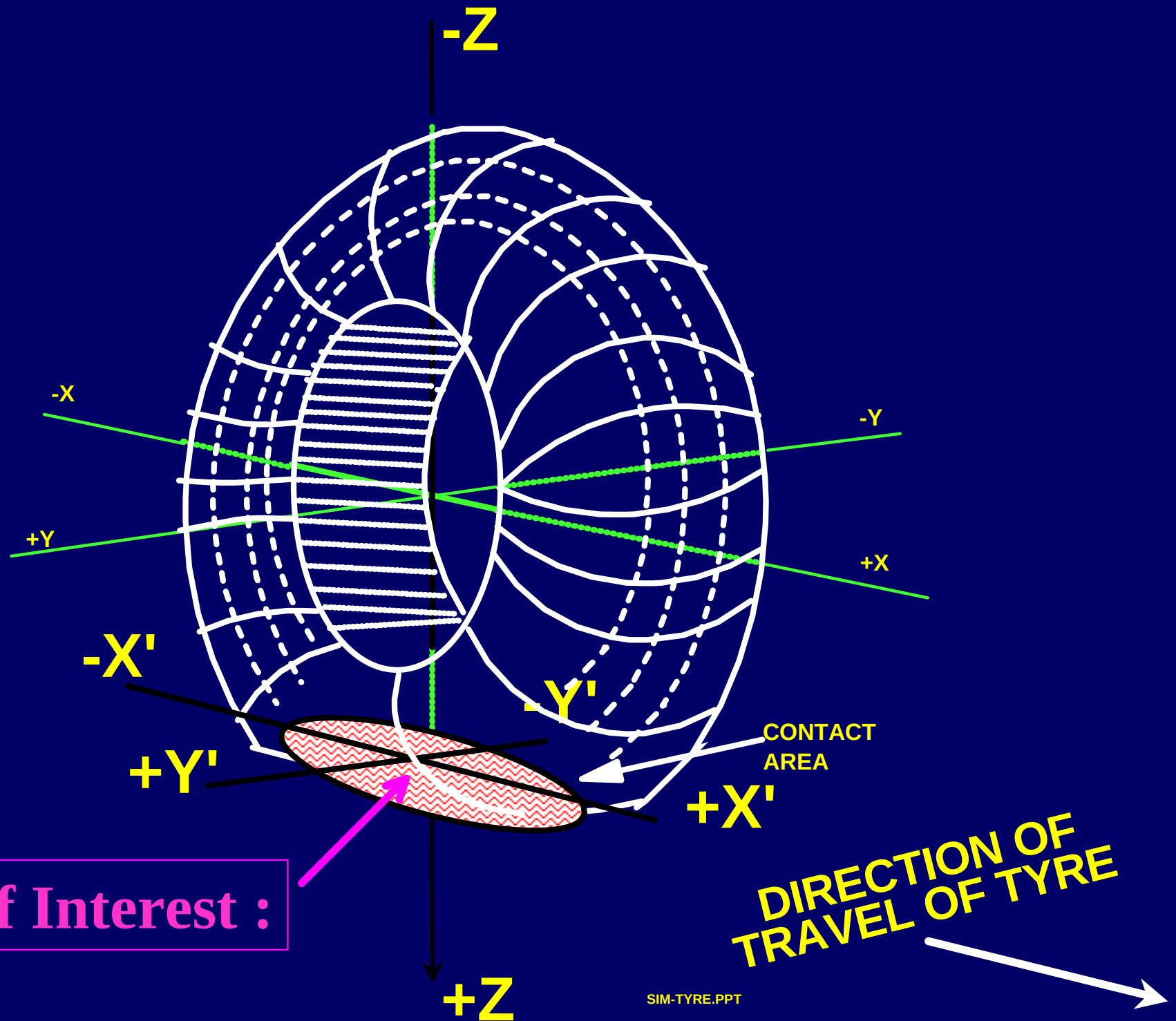
**Contact stresses of the 11.00 -
R22.5 pneumatic radial tyres on
the Gautrans Heavy Vehicle
Simulator (HVS) measured with
the Vehicle-Road Surface
Pressure Transducer Array
(VRSPTA) system**

HEAVY VEHICLE SIMULATOR (HVS)

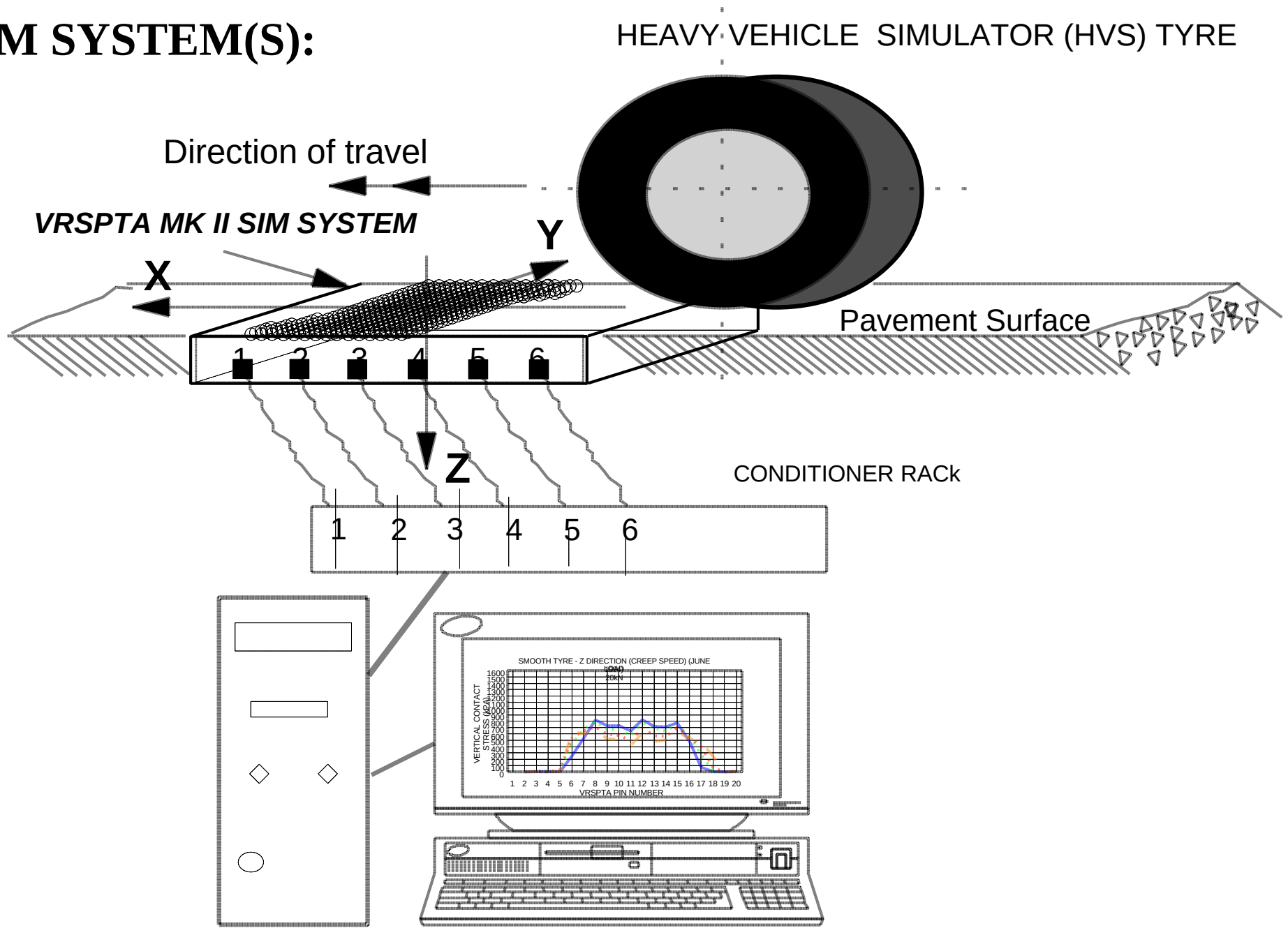




**11.00 - R22.5 RADIAL HVS TYRES
(AFTER CULLINAN ROAD 2388 TESTS)**

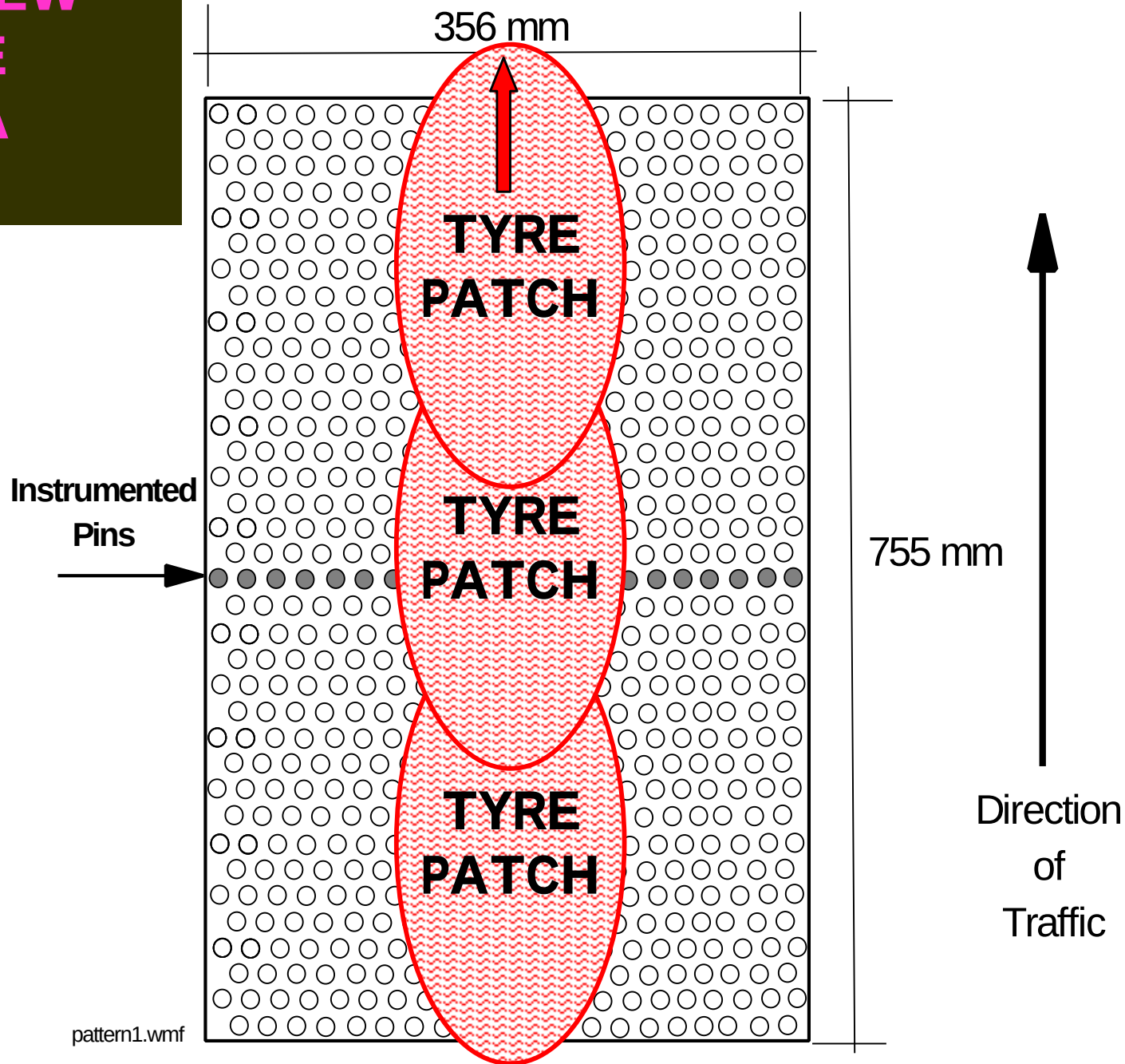


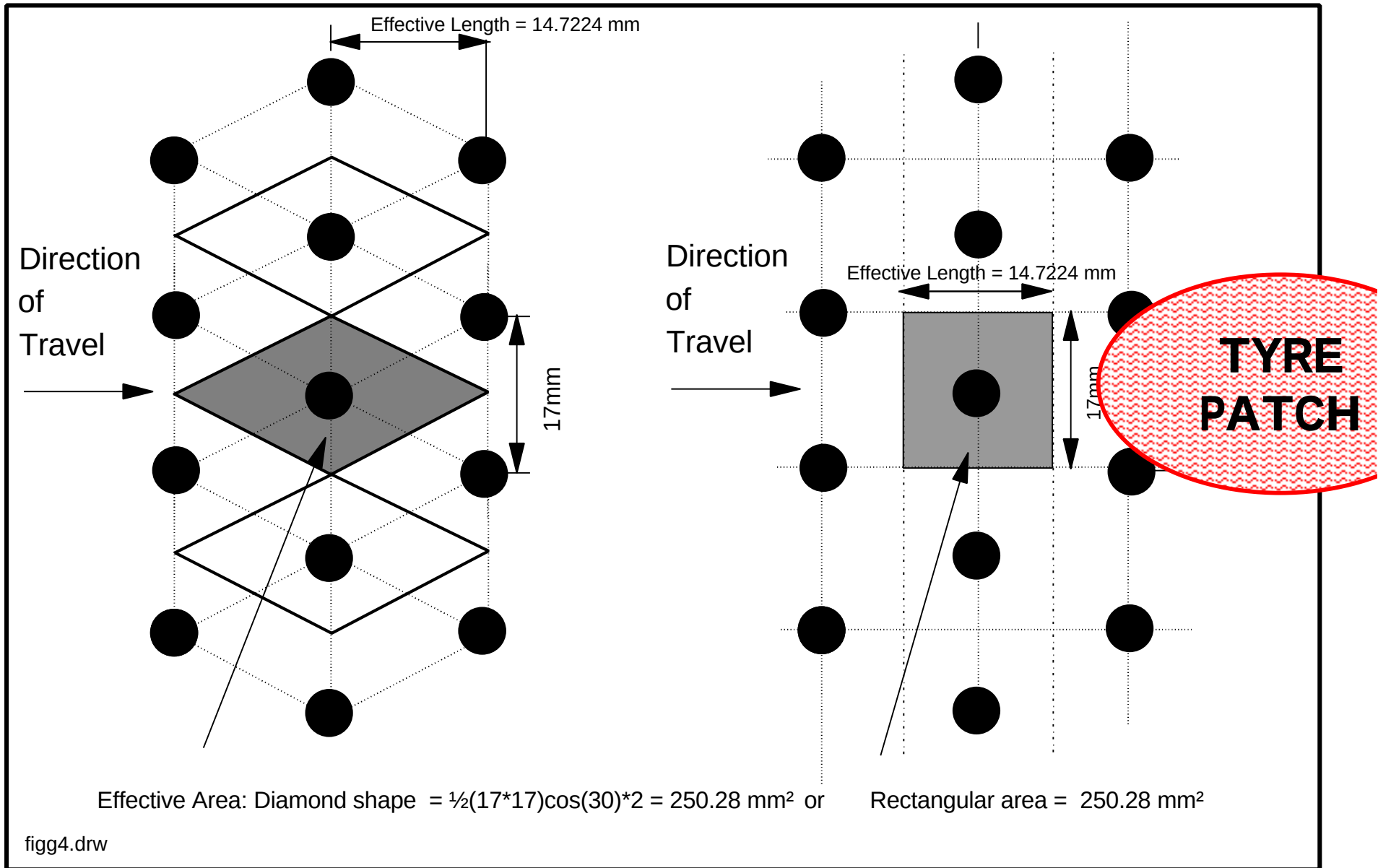
SIM SYSTEM(S):

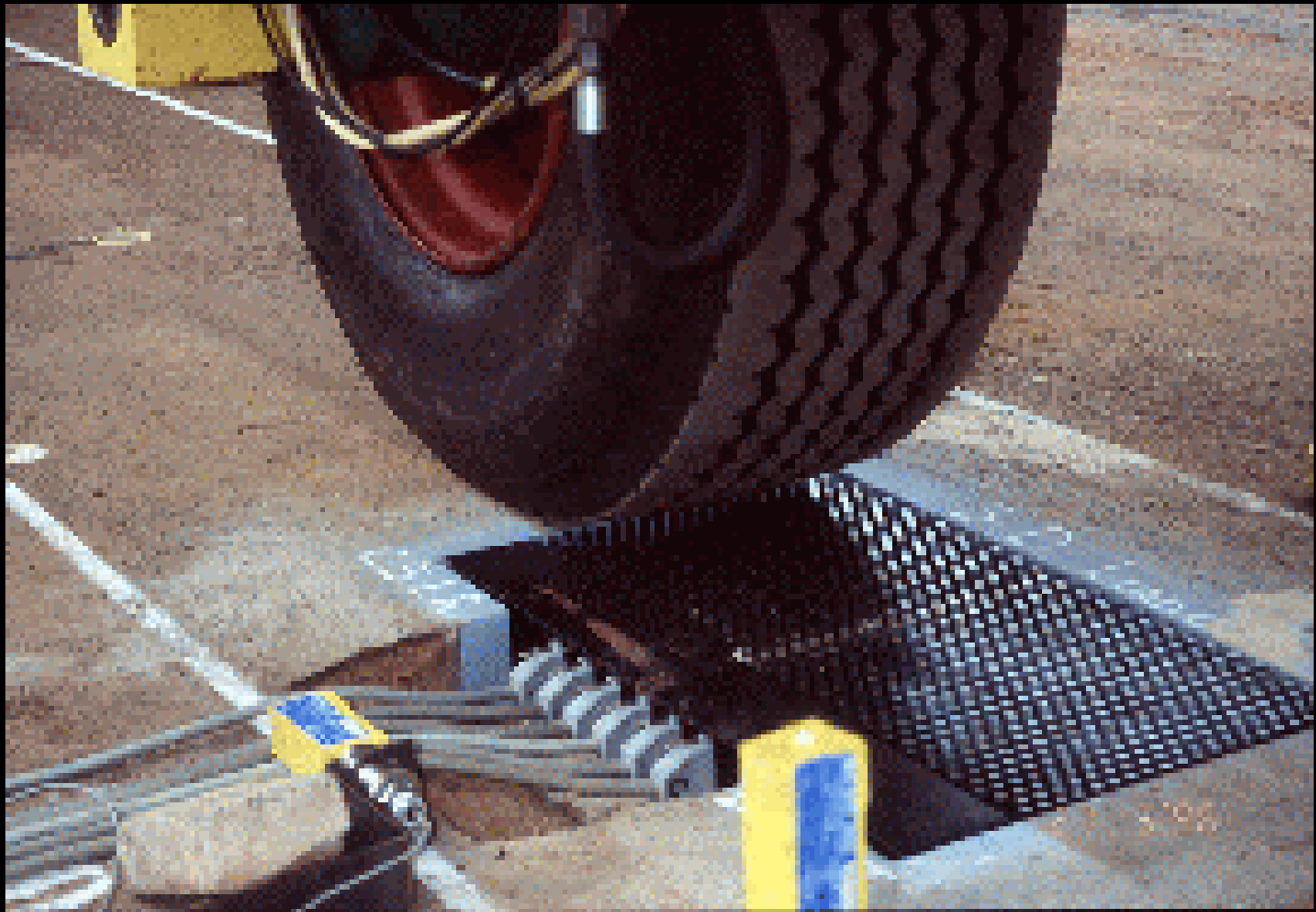


Data Acquisition and Computer set-up

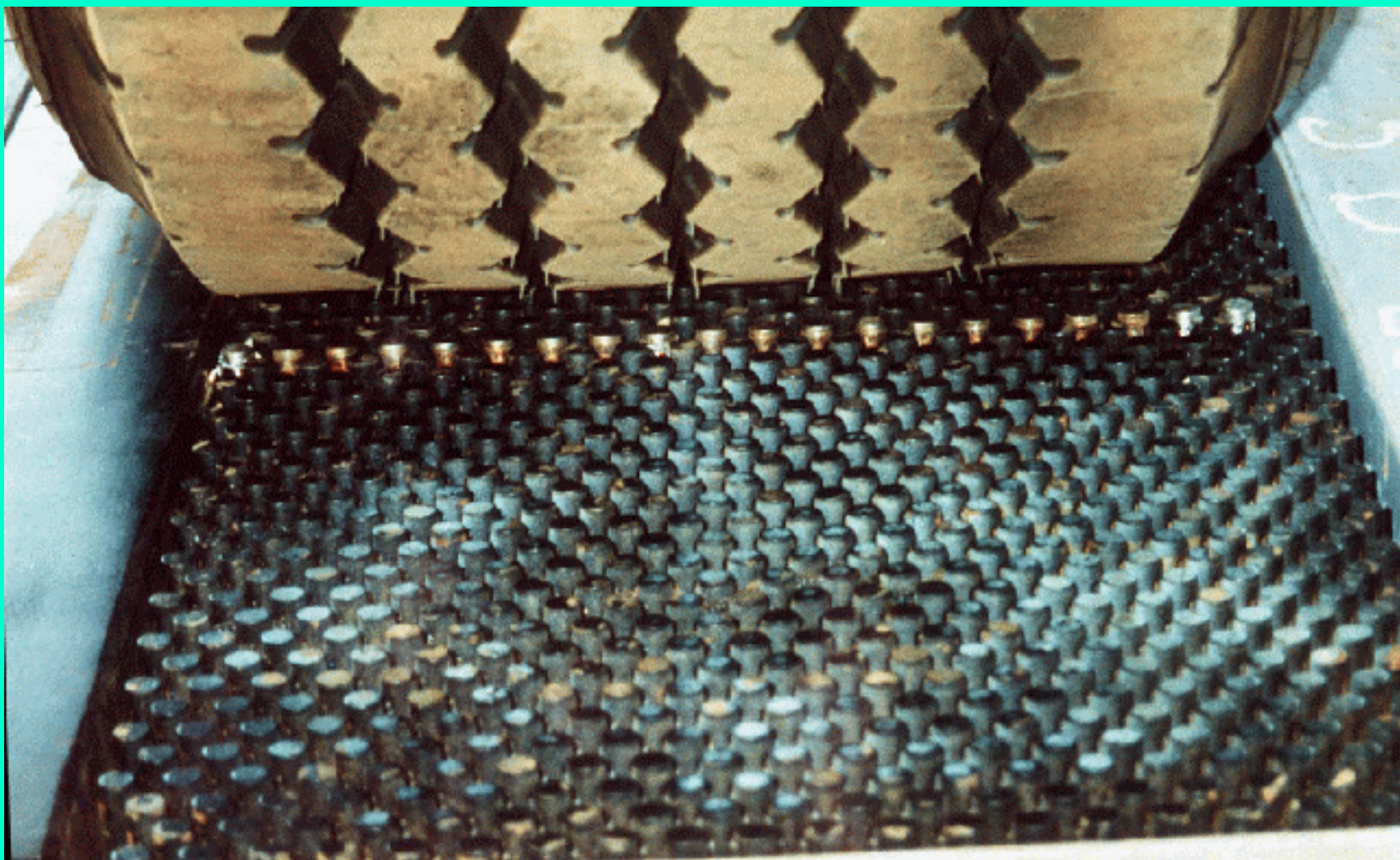
**TOP VIEW
OF THE
VRSPTA
MK II**



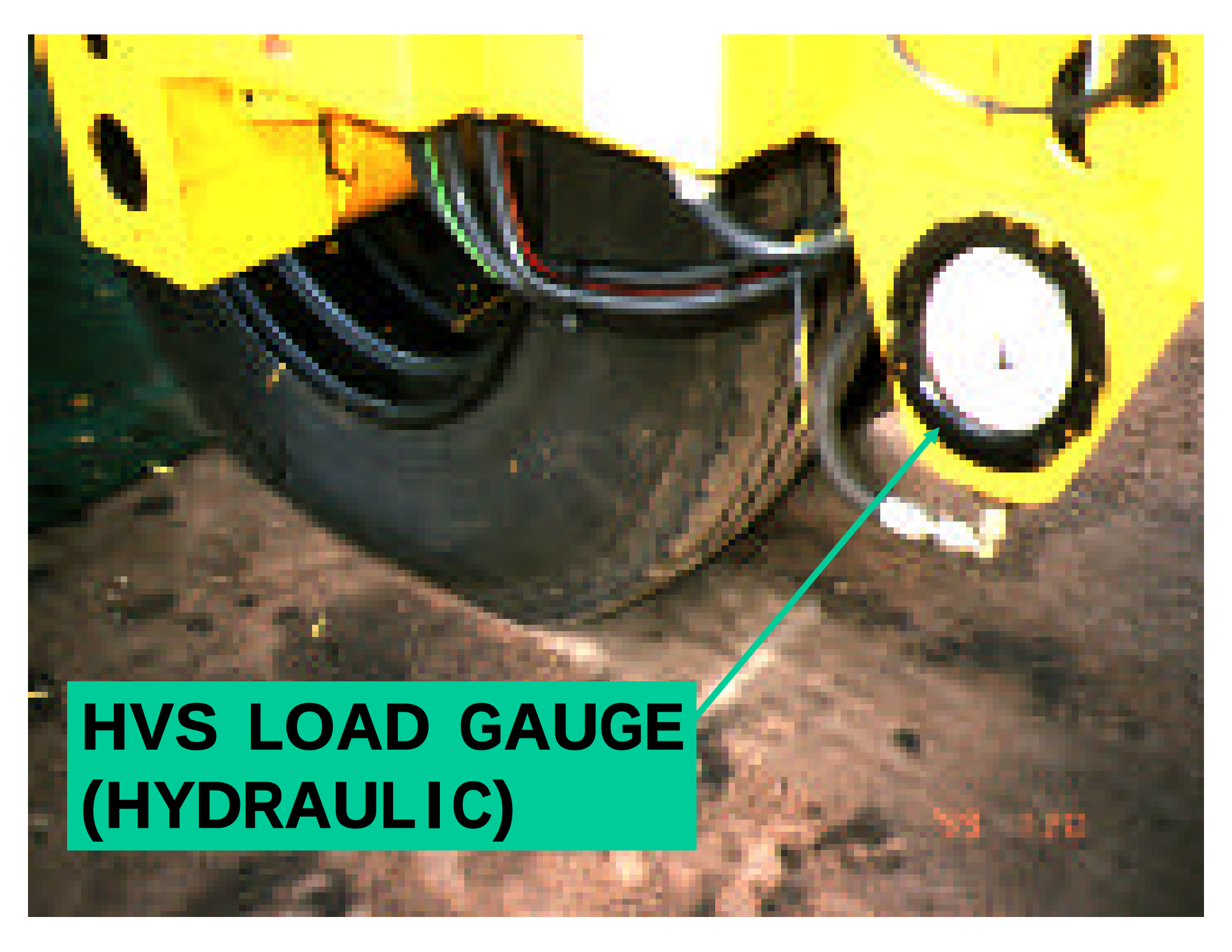




315/80 R22.5 HVS TIRE ON VRSPTA



425 /65 R22.5 HVS TIRE ON SIM SYSTEM:
EXAMPLE OF FOOTPRINT TO FOLLOW.....

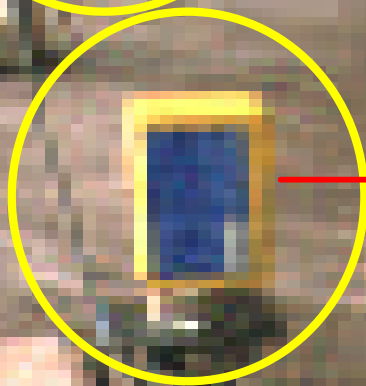
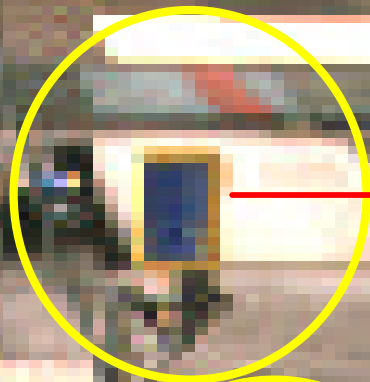


**HVS LOAD GAUGE
(HYDRAULIC)**

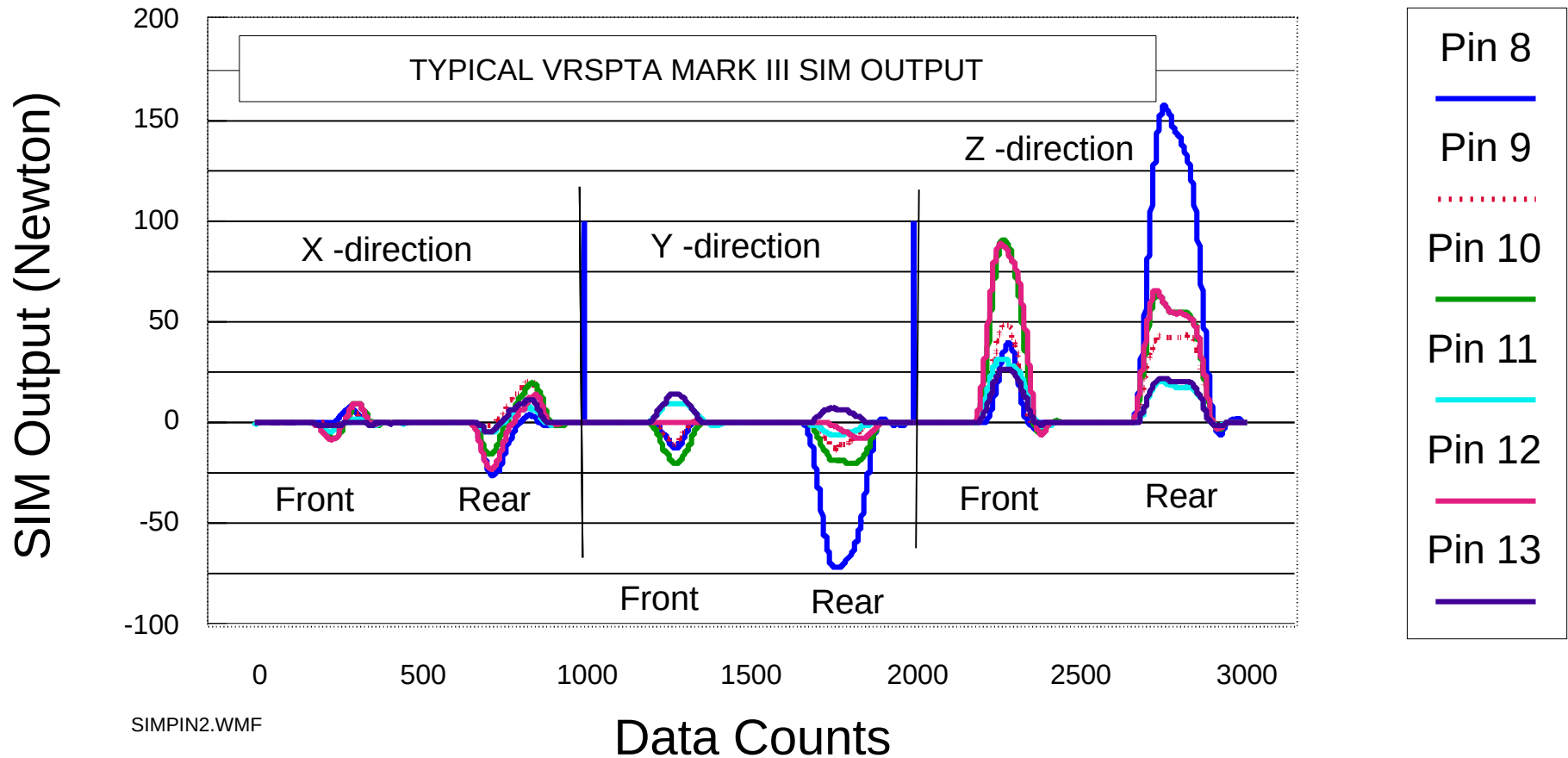


***VRSPTA Mk II SYSTEM USED
FOR THE SIM MEASUREMENTS
UNDER THIS CONTRACT***

SIM Optic Triggers..



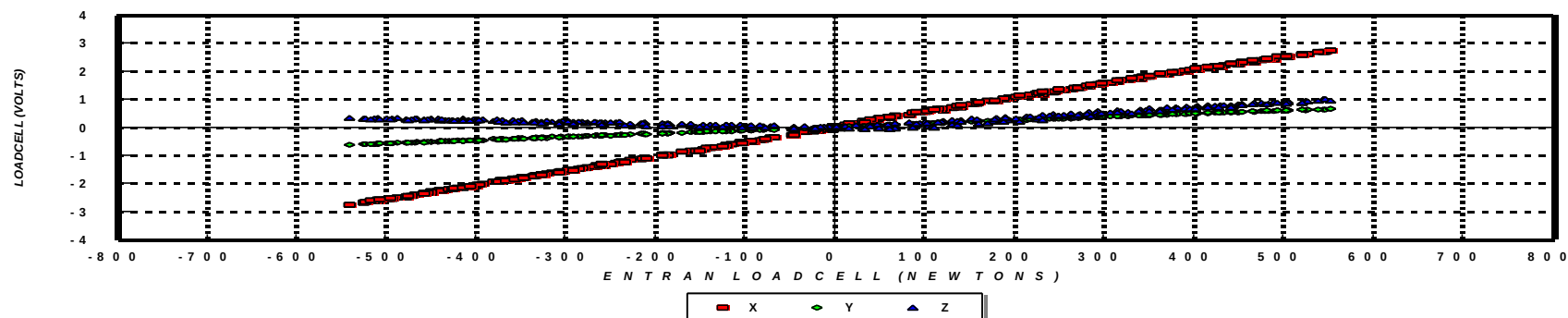
SIM OUTPUT LOADS FOR QUALITY CHECK



SIM PIN CALIBRATIONS..

L P I N 1 0

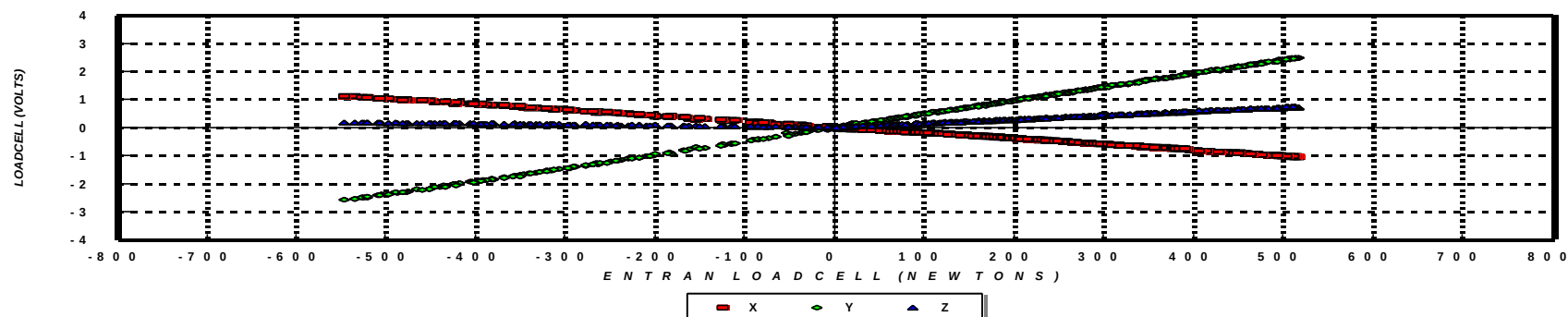
LOADING IN "X" DIRECTION



3D-CELL X/Y/Z.WK3
11/01/1999

3 D L O A D C E L L P I N 1 0

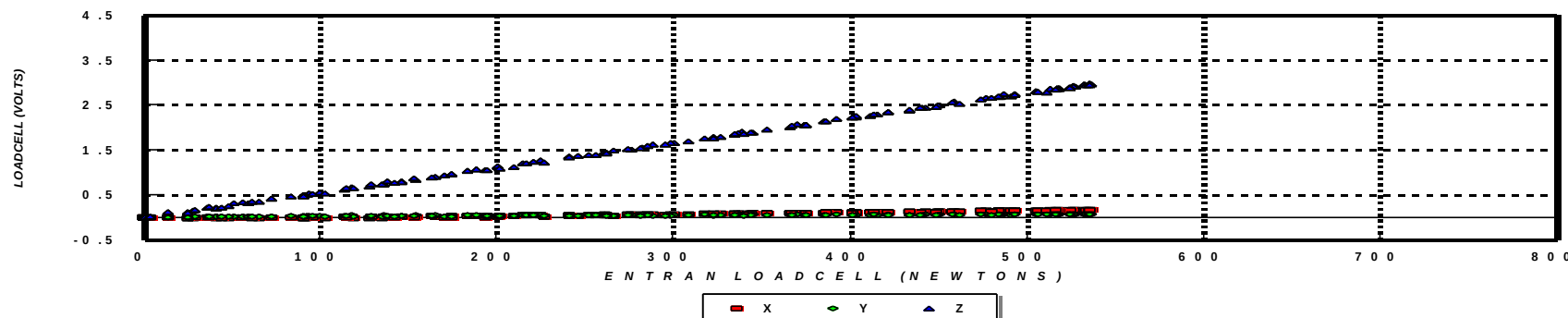
LOADING IN "Y" DIRECTION



3D-CELL X/Y/Z.WK3
11/01/1999

3 D L O A D C E L L P I N 1 0

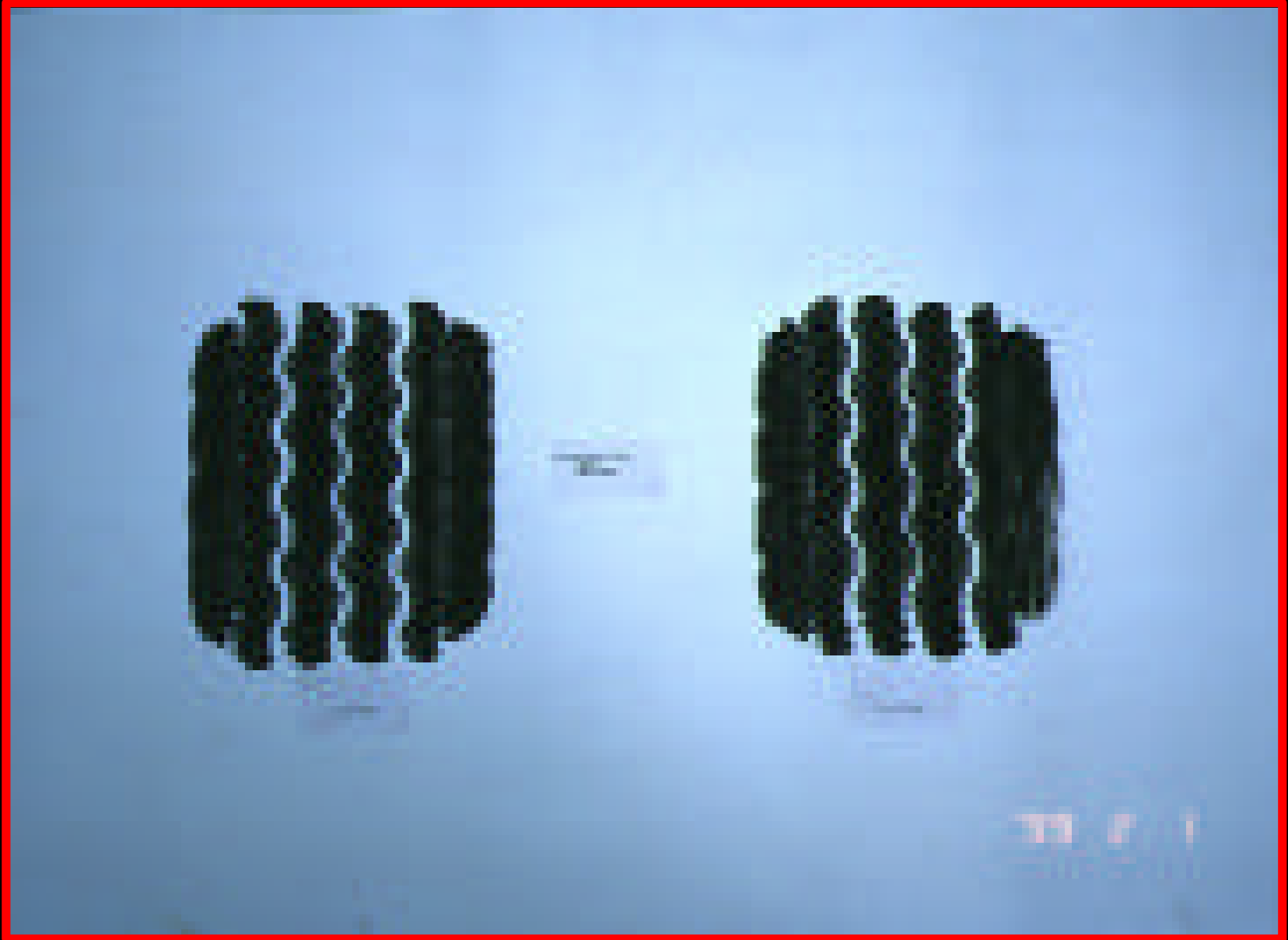
LOADING IN "Z" DIRECTION



3D-CELL X/Y/Z.WK3
11/01/1999



**11.00 - R22.5 RADIAL HVS TYRES
(AFTER CULLINAN ROAD 2388 TESTS)
--TYRE PRINTS--**



HVS DUAL TYRE FOOTPRINT @ 30 kN
& 420 kPa, USING PAINT

**11.00-R22.5
HVS04
TYRES
UNDER
HIGH
LOADING -**

**Note the
“bulging” of
both tyres**





HVS DUAL TYRE FOOTPRINT @ 70 kN
& 420 kPa, USING PAINT



SIM DATA ACQUISITION SYSTEM DURING HVS04 SIM PROJECT

THE HVS-SIM DATA.....

HVS-SIM TEST MATRIX

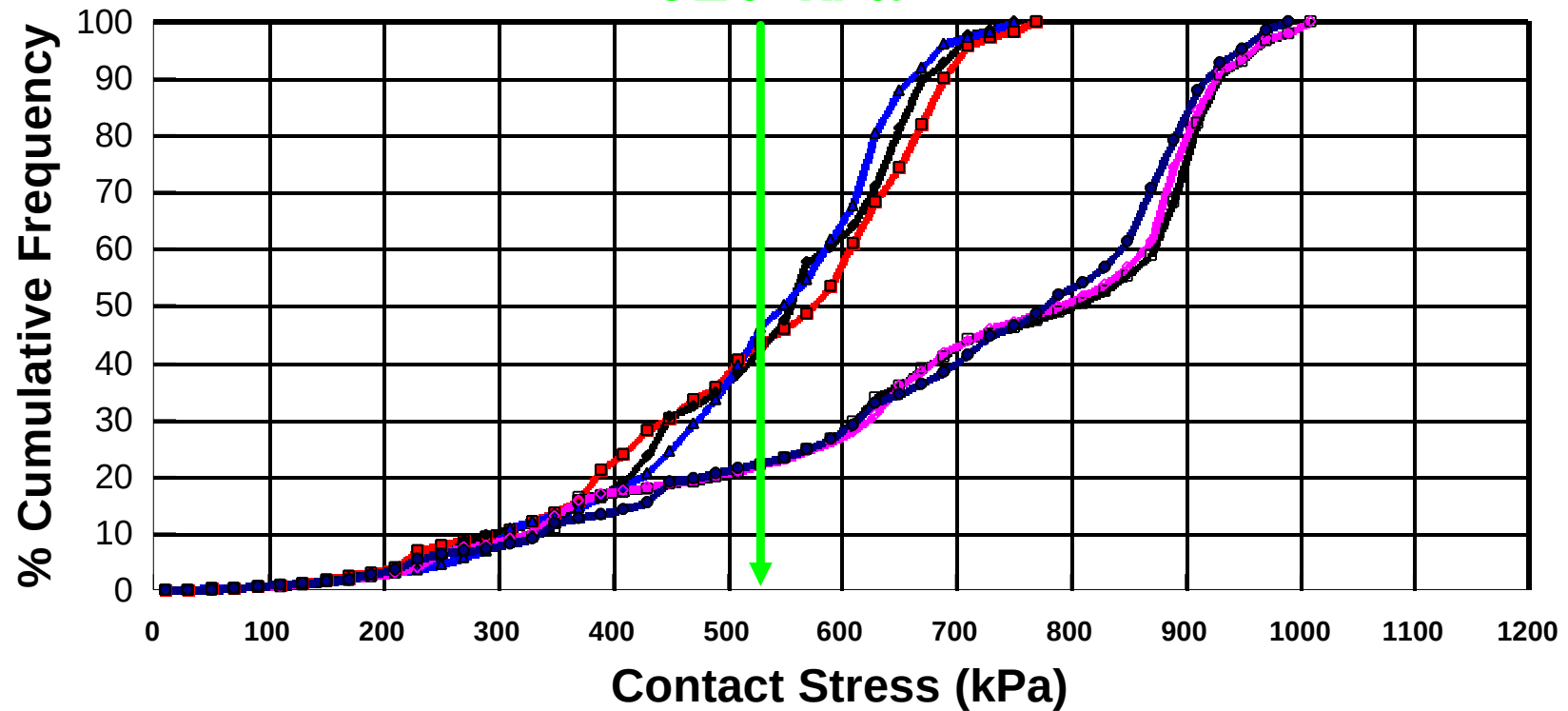
Dual Tyre Load (kN)	TYRE INFLATION PRESSURE (kPa)				
	19 X 3 = 57 Tests per tyre				
	420	520	620	720	800
30					
40					
70					
100	 UNSAFE				

Within Tyre Manufacturer specifications

CARAVAN SIDE (CSIR SITE)

VRSPTA Mk II

520 kPa 40 kN 70 kN

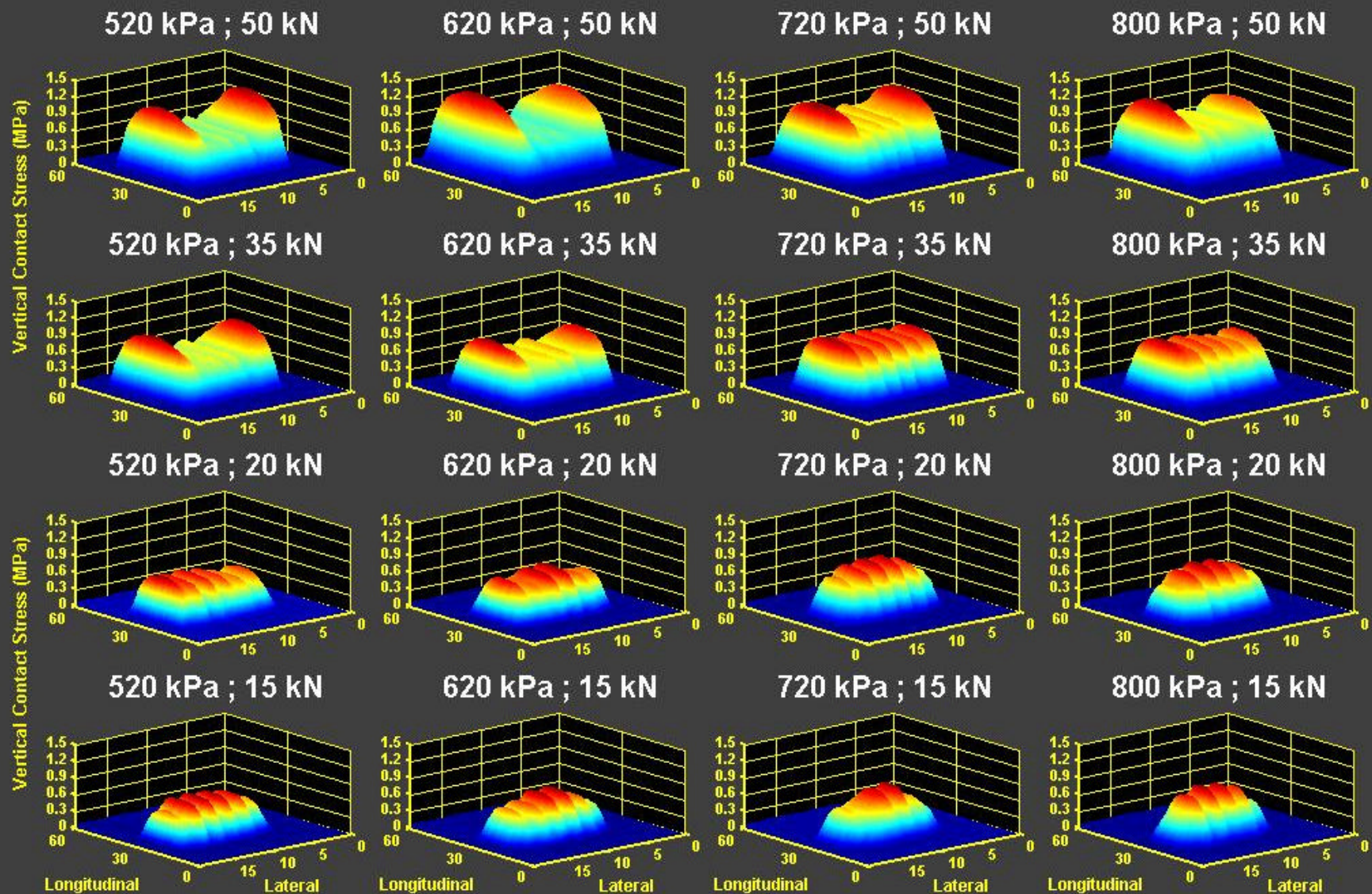


24.36kN ; 520kPa 24.57kN ; 520kPa 24.75kN ; 520kPa
37.35kN ; 720kPa 37.60kN ; 720kPa 37.94kN ; 720kPa

3d-cum.wk4
20/01/99

HVS 04 SIM MEASUREMENTS OF 11R22.5 TYRE

LOAD



CARAVAN SIDE CONTINENTAL 11R22.5 TREADED

INFLATION PRESSURE

CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 520 kPa

Applied Vertical Load (HVS) = 40 kN

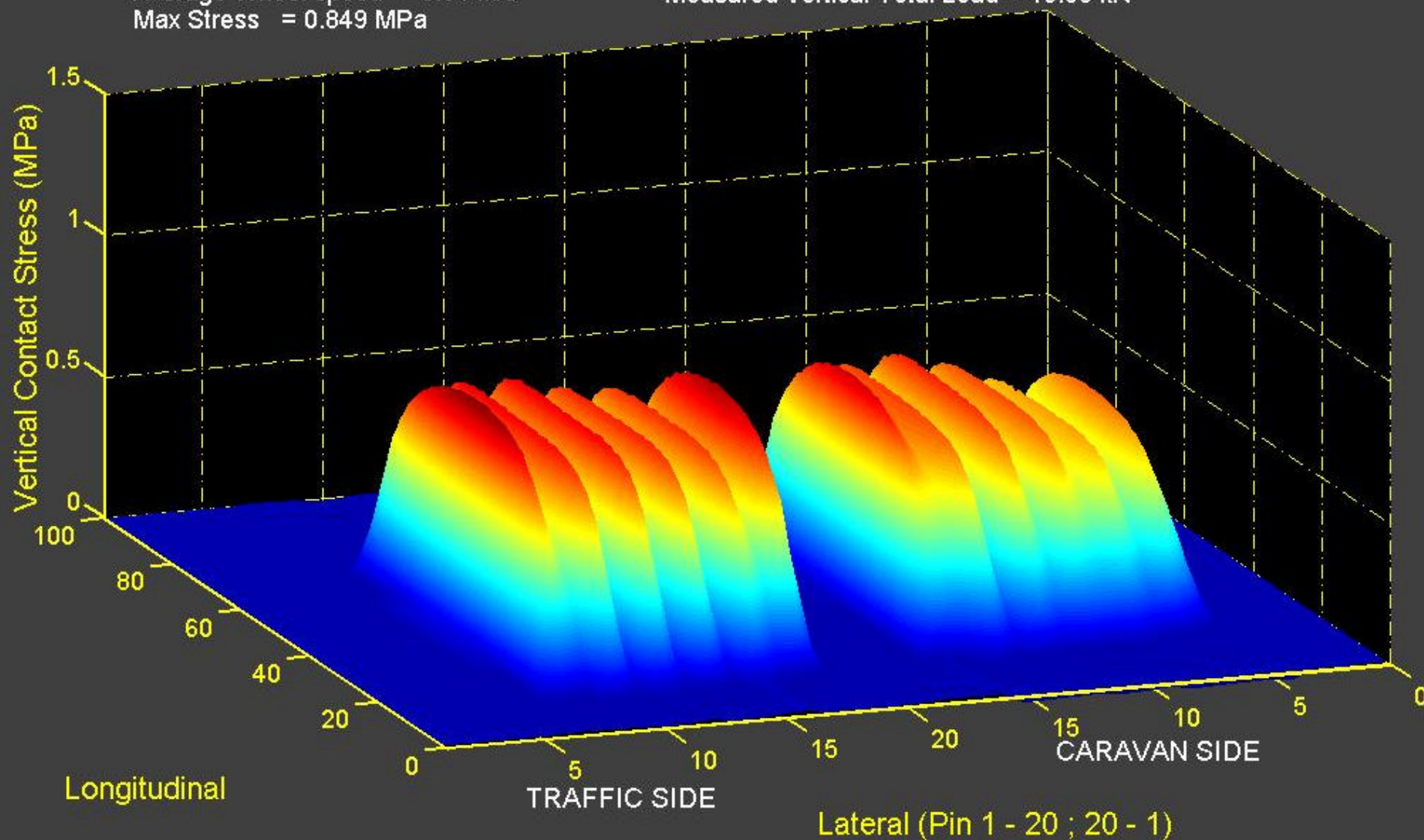
Average Wheel speed = 0.34 m/s

Max Stress = 0.849 MPa

Measured Vertical Load (CS) = 24 kN

Measured Vertical Load (TS) = 23 kN

Measured Vertical Total Load = 46.93 kN



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 520 kPa

Applied Vertical Load (HVS) = 40 kN

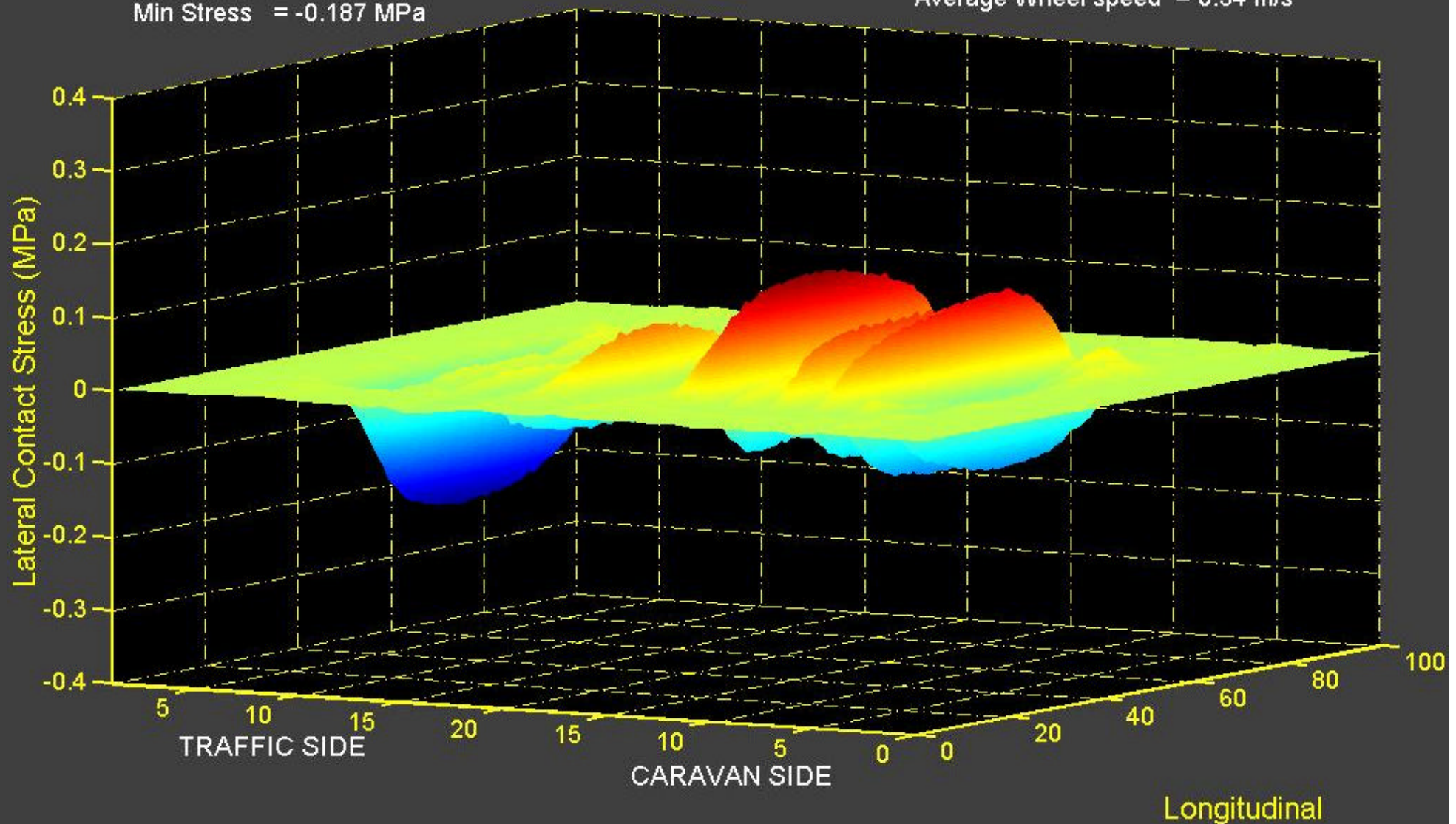
Max Stress = 0.153 MPa

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



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 520 kPa

Applied Vertical Load (HVS) = 40 kN

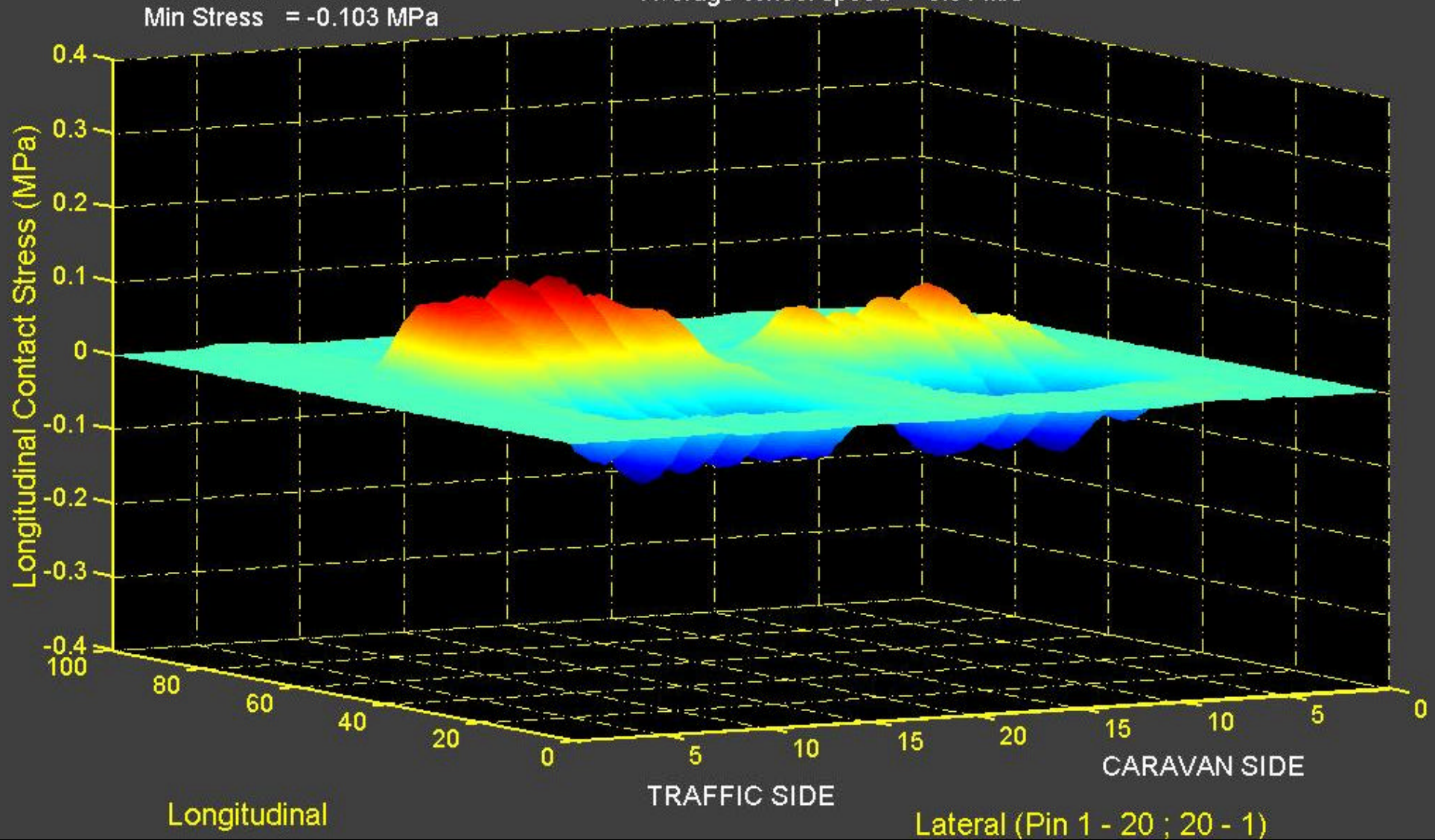
Max Stress = 0.129 MPa

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



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 520 kPa

Applied Vertical Load (HVS) = 100 kN

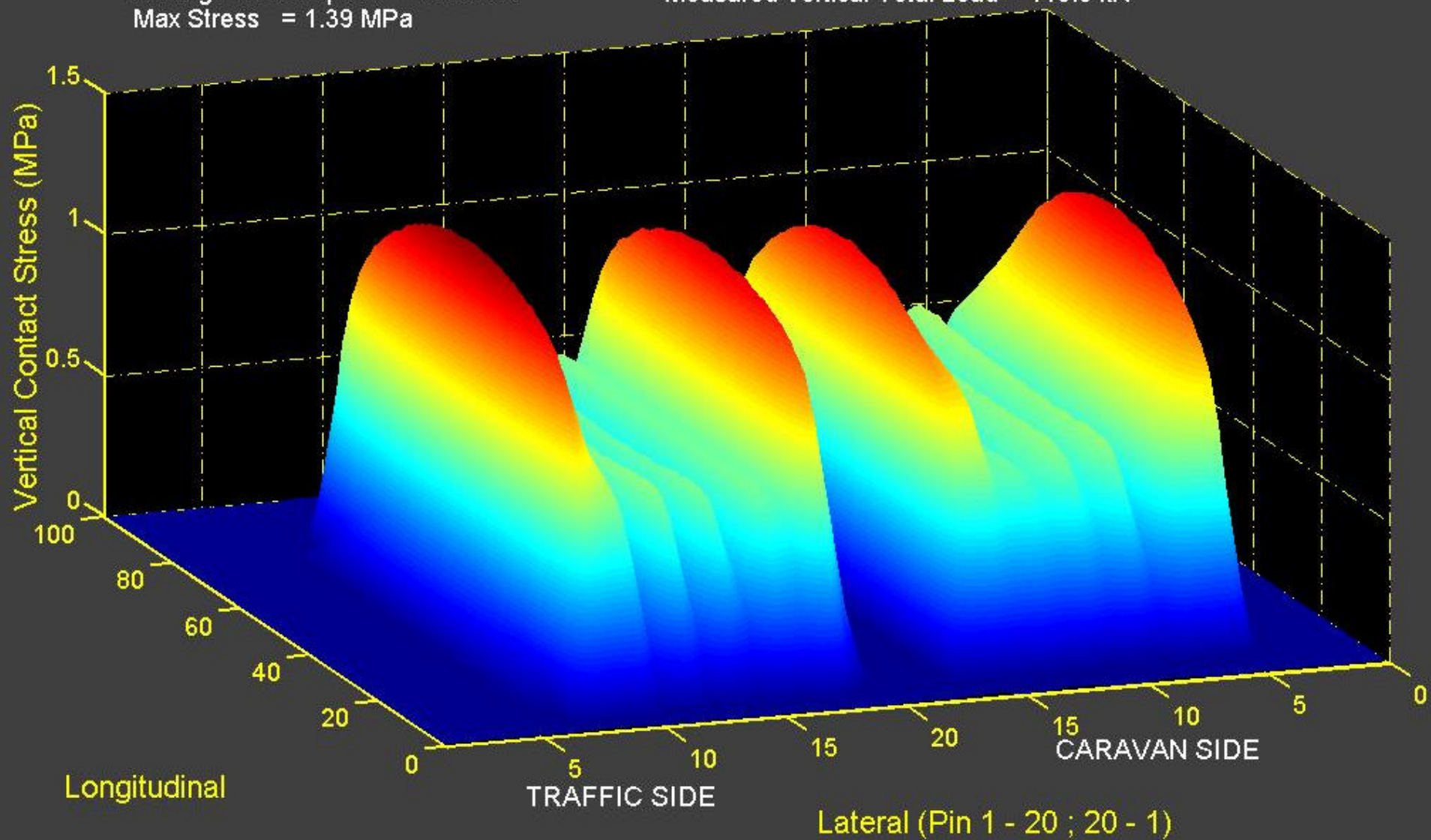
Average Wheel speed = 0.34 m/s

Max Stress = 1.39 MPa

Measured Vertical Load (CS) = 61 kN

Measured Vertical Load (TS) = 58 kN

Measured Vertical Total Load = 119.5 kN



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 520 kPa

Applied Vertical Load (HVS) = 100 kN

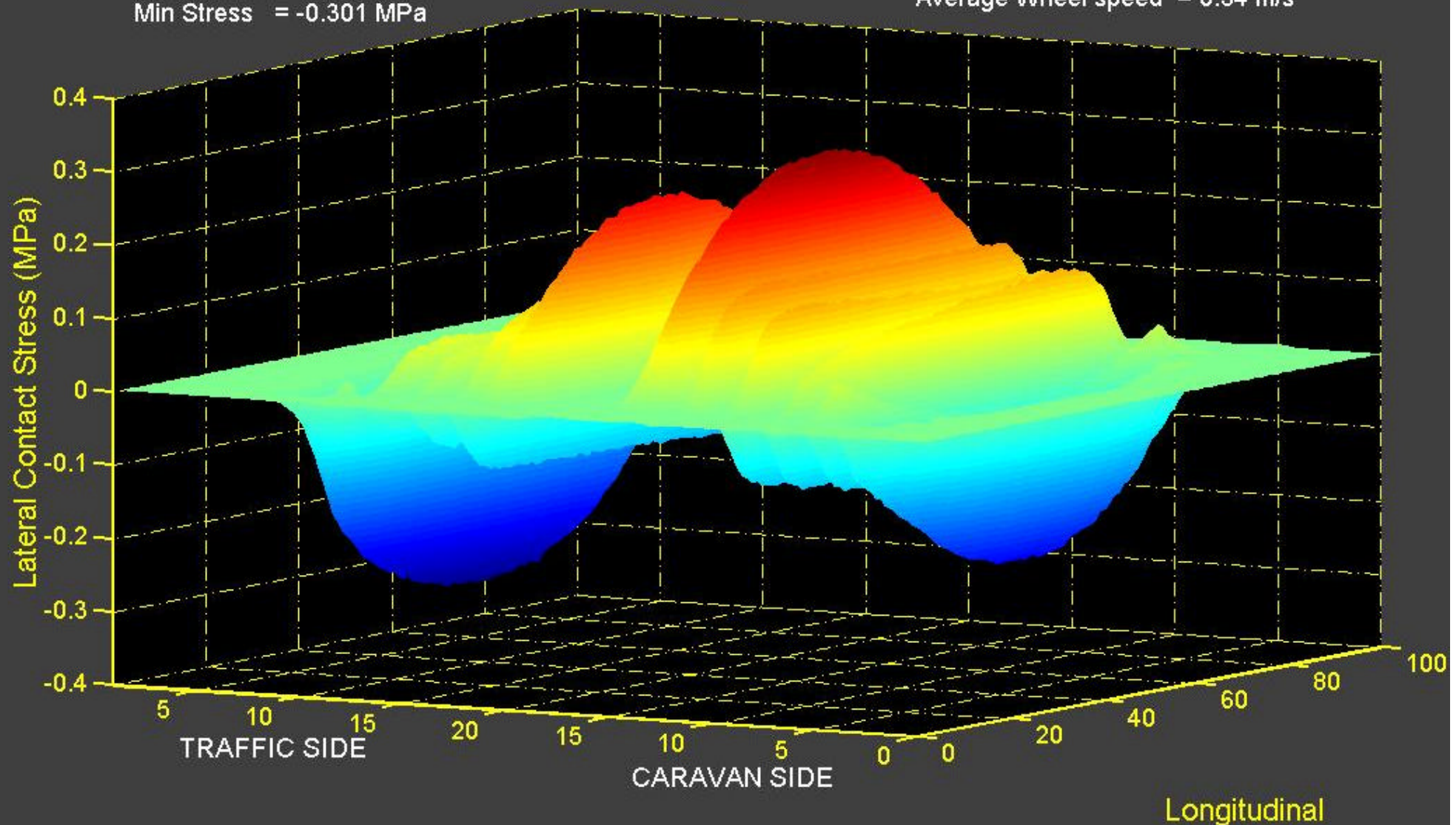
Max Stress = 0.316 MPa

Min Stress = -0.301 MPa

Measured Lateral Load (CS) = 1.8 kN

Measured Lateral Load (TS) = -2.2 kN

Average Wheel speed = 0.34 m/s



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 520 kPa

Applied Vertical Load (HVS) = 100 kN

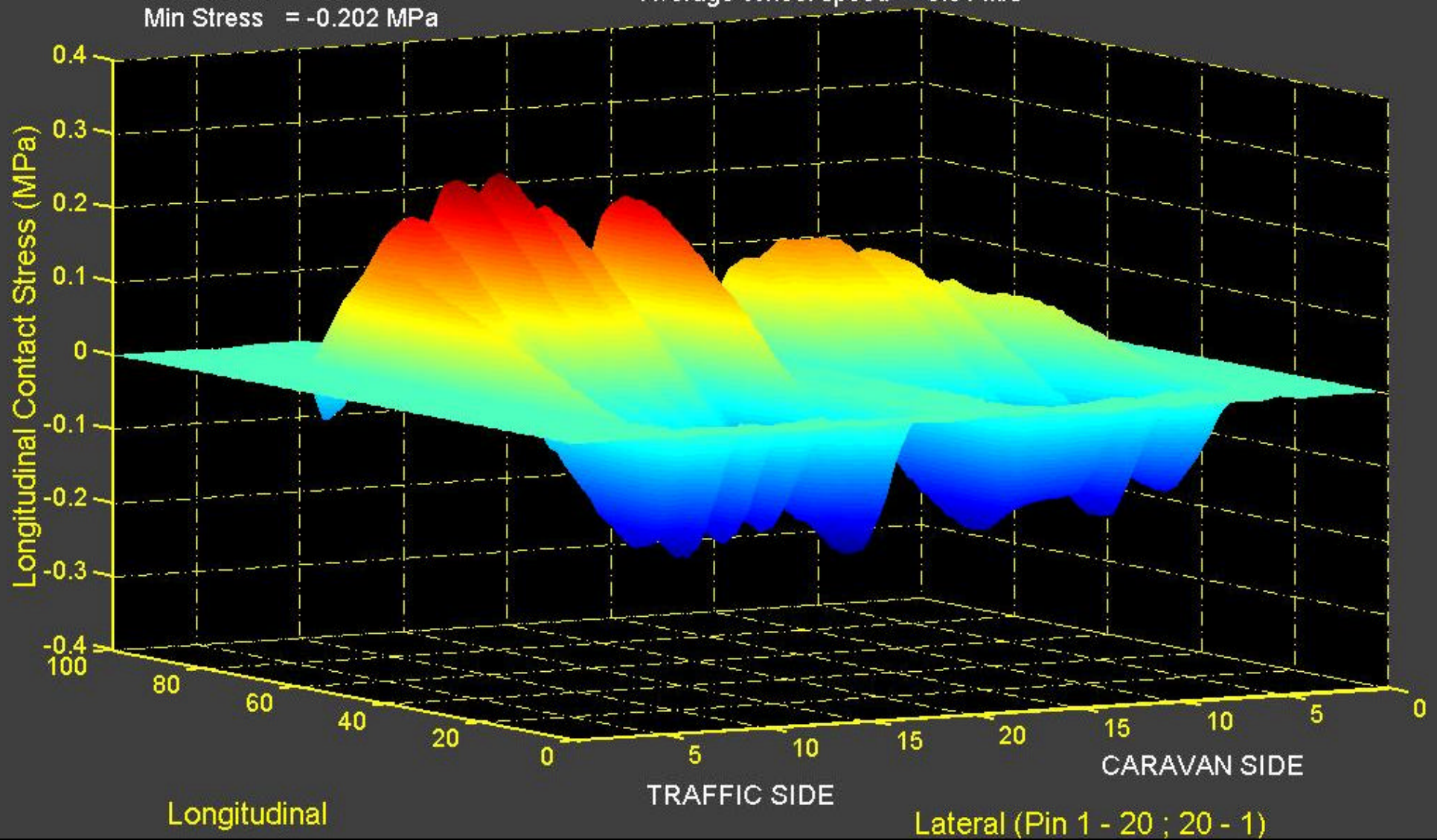
Max Stress = 0.253 MPa

Min Stress = -0.202 MPa

Measured Longitudinal Load (CS) = -1.3 kN

Measured Longitudinal Load (TS) = 2.4 kN

Average Wheel speed = 0.34 m/s



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 800 kPa

Applied Vertical Load (HVS) = 70 kN

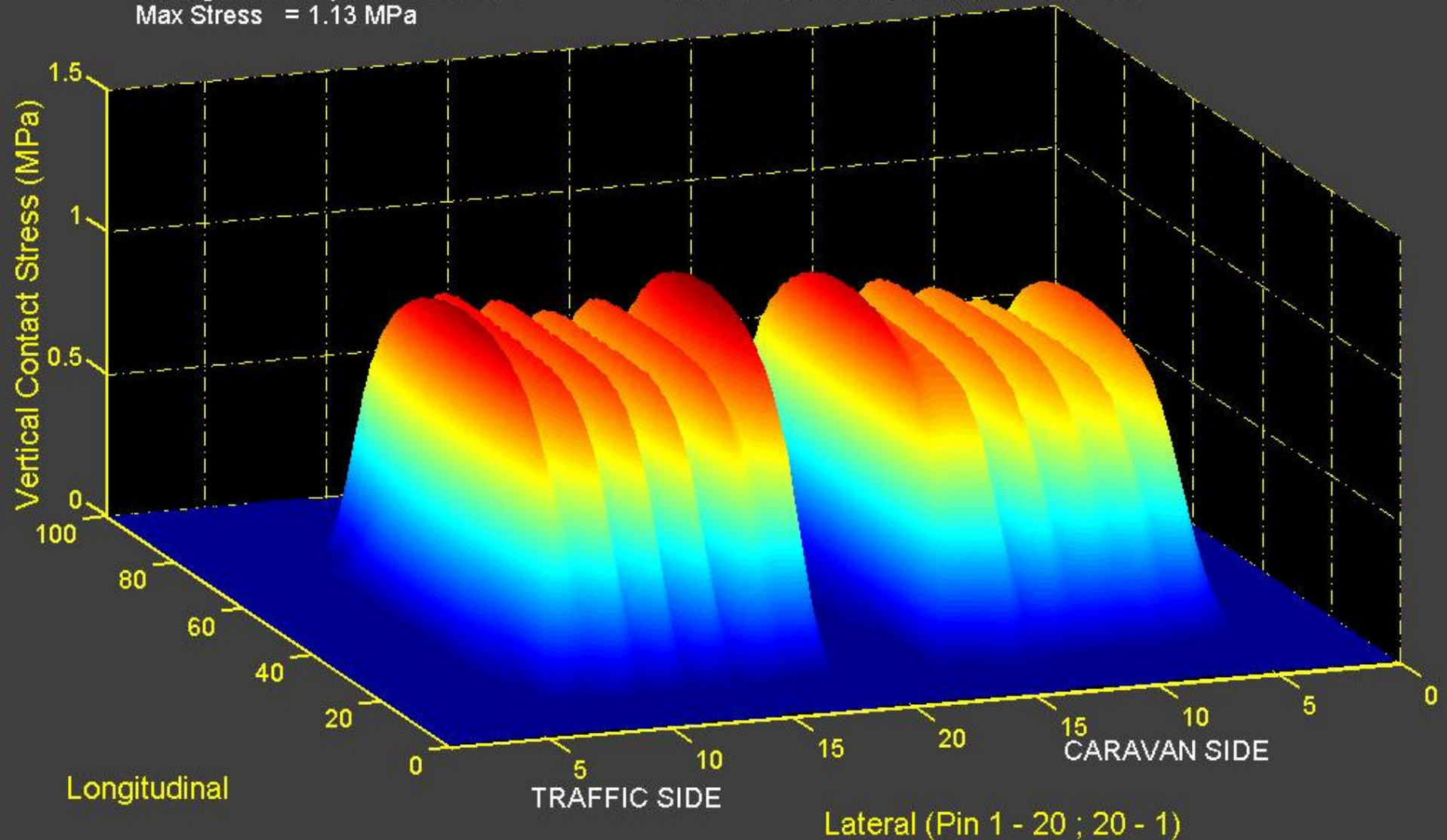
Average Wheel speed = 0.33 m/s

Max Stress = 1.13 MPa

Measured Vertical Load (CS) = 39 kN

Measured Vertical Load (TS) = 37 kN

Measured Vertical Total Load = 76.07 kN



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 800 kPa

Applied Vertical Load (HVS) = 70 kN

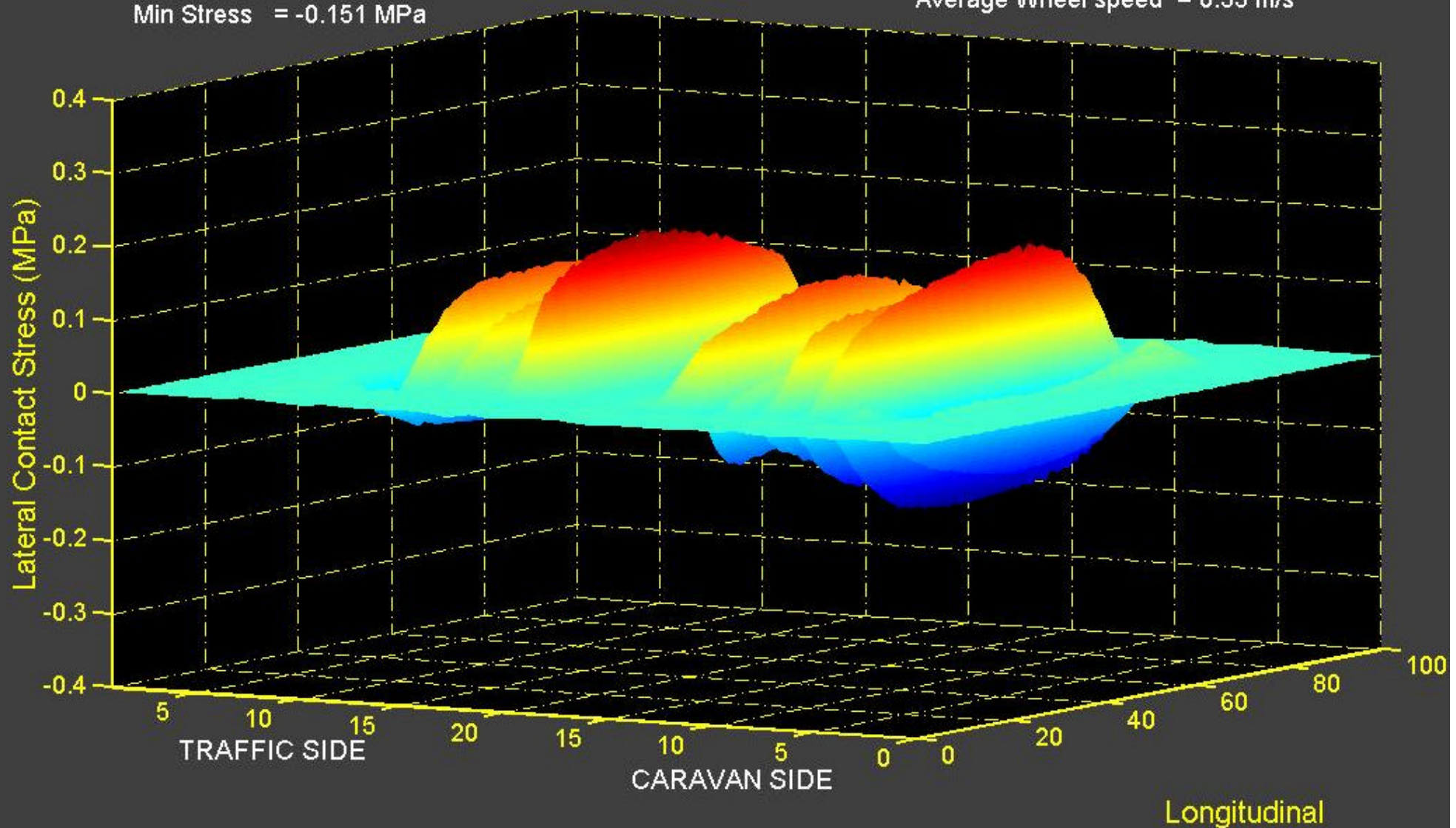
Max Stress = 0.199 MPa

Min Stress = -0.151 MPa

Measured Lateral Load (CS) = 0.063 kN

Measured Lateral Load (TS) = 1.4 kN

Average Wheel speed = 0.33 m/s



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 800 kPa

Applied Vertical Load (HVS) = 70 kN

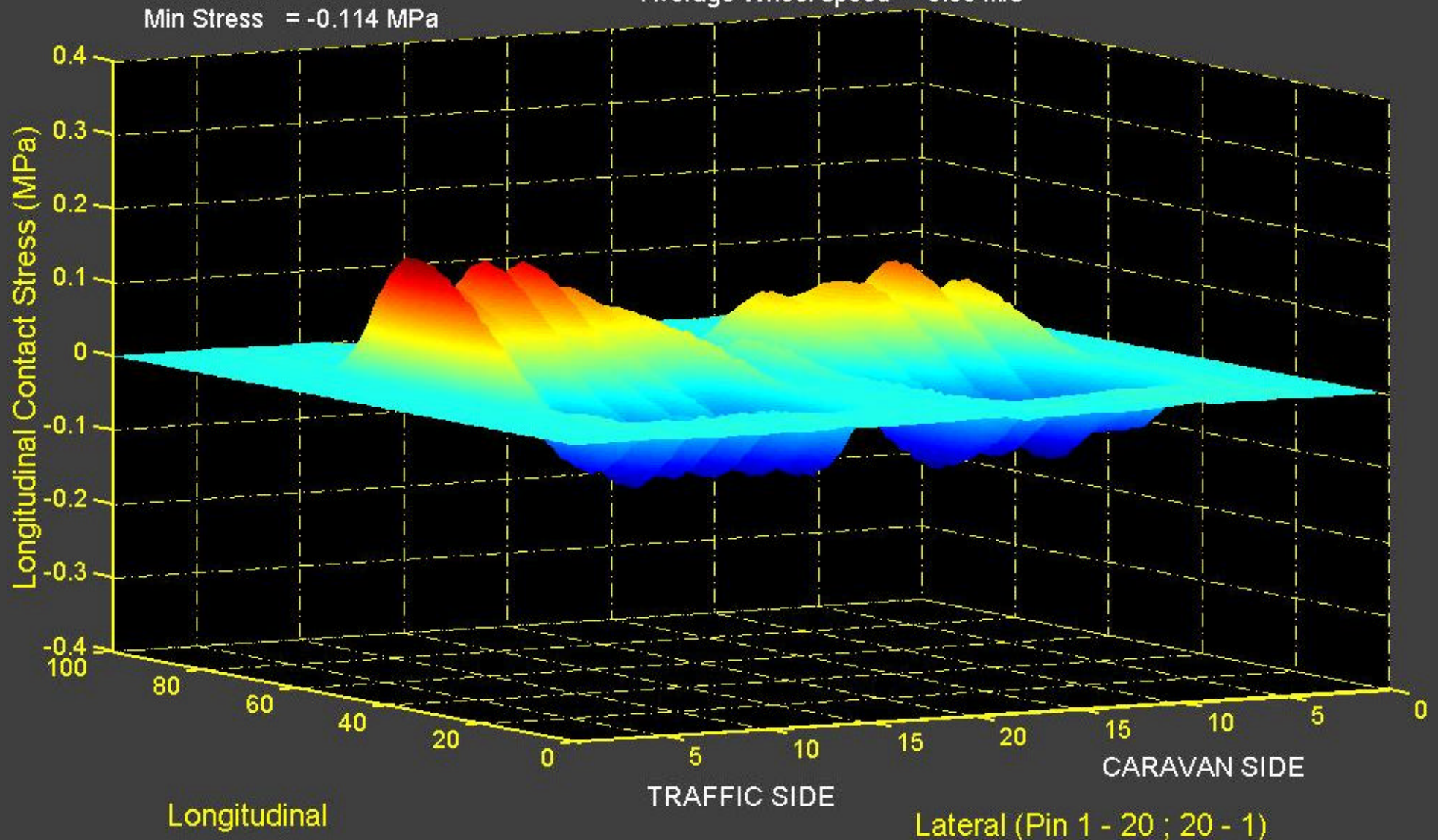
Max Stress = 0.17 MPa

Min Stress = -0.114 MPa

Measured Longitudinal Load (CS) = -0.34 kN

Measured Longitudinal Load (TS) = 0.97 kN

Average Wheel speed = 0.33 m/s



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 800 kPa

Applied Vertical Load (HVS) = 100 kN

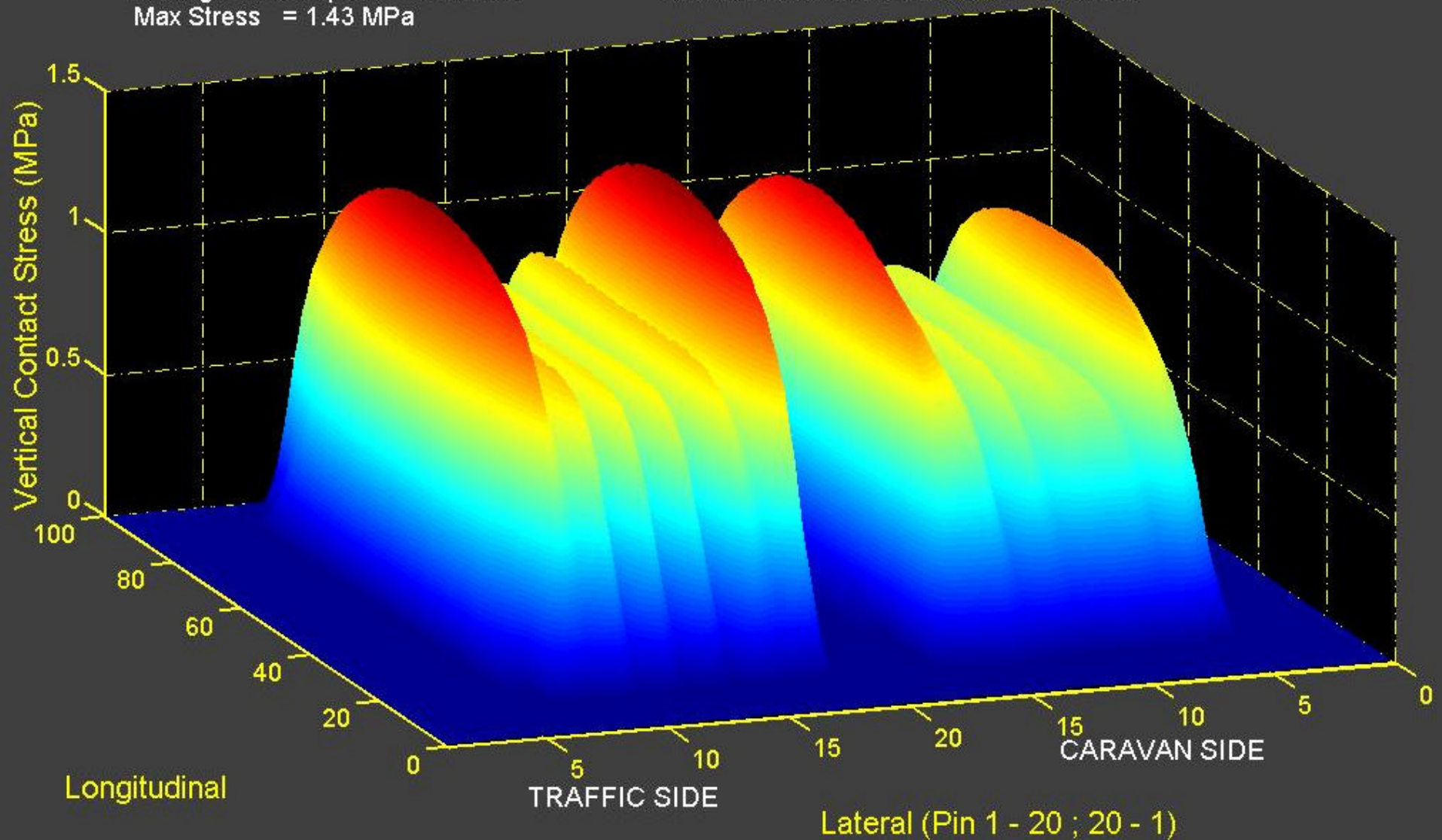
Average Wheel speed = 0.33 m/s

Max Stress = 1.43 MPa

Measured Vertical Load (CS) = 57 kN

Measured Vertical Load (TS) = 56 kN

Measured Vertical Total Load = 112.3 kN



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 800 kPa

Applied Vertical Load (HVS) = 100 kN

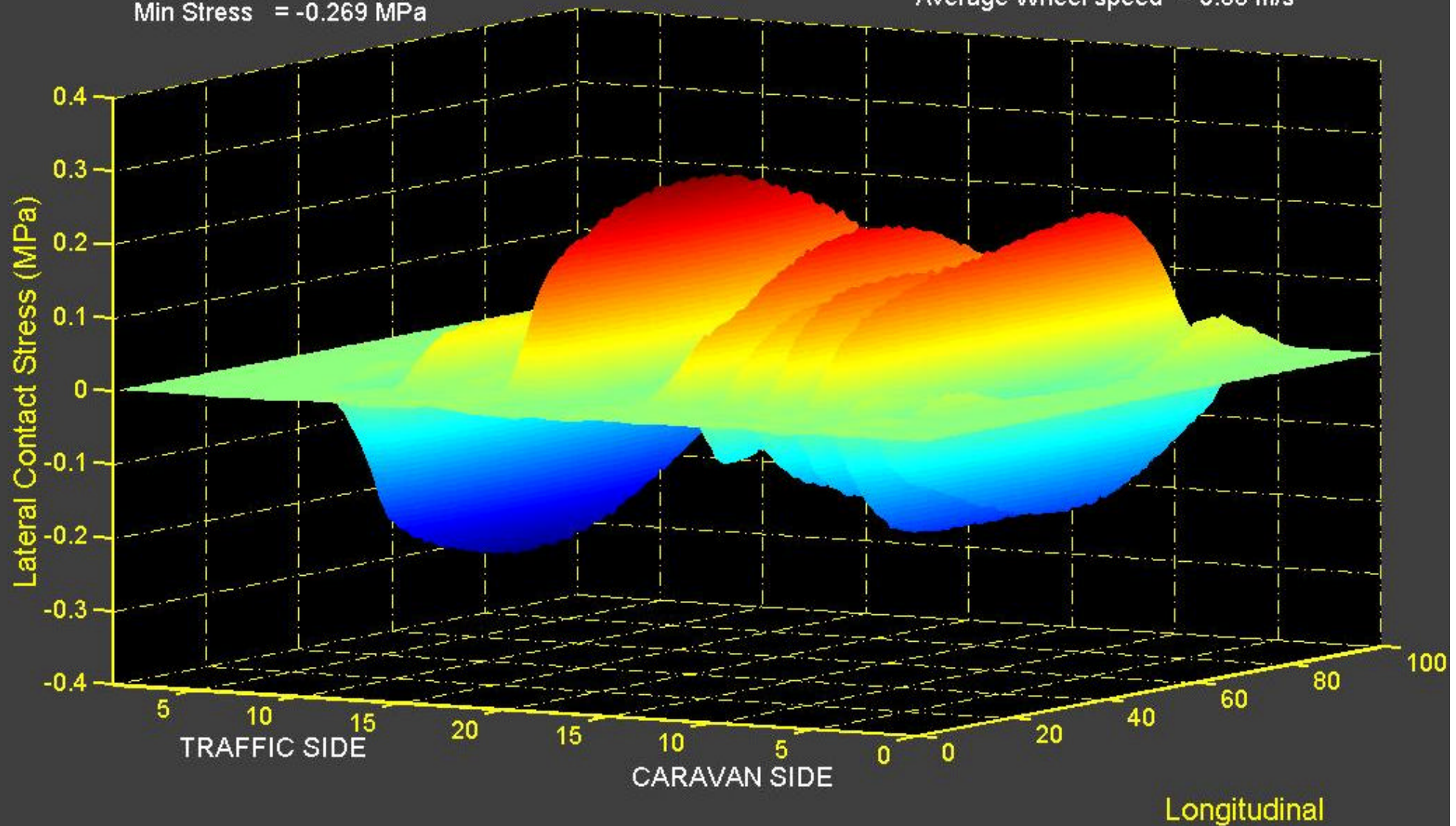
Max Stress = 0.255 MPa

Min Stress = -0.269 MPa

Measured Lateral Load (CS) = 0.59 kN

Measured Lateral Load (TS) = -0.55 kN

Average Wheel speed = 0.33 m/s



CONTINENTAL 11R22.5 Tyre (TREADED)

Inflation Pressure = 800 kPa

Applied Vertical Load (HVS) = 100 kN

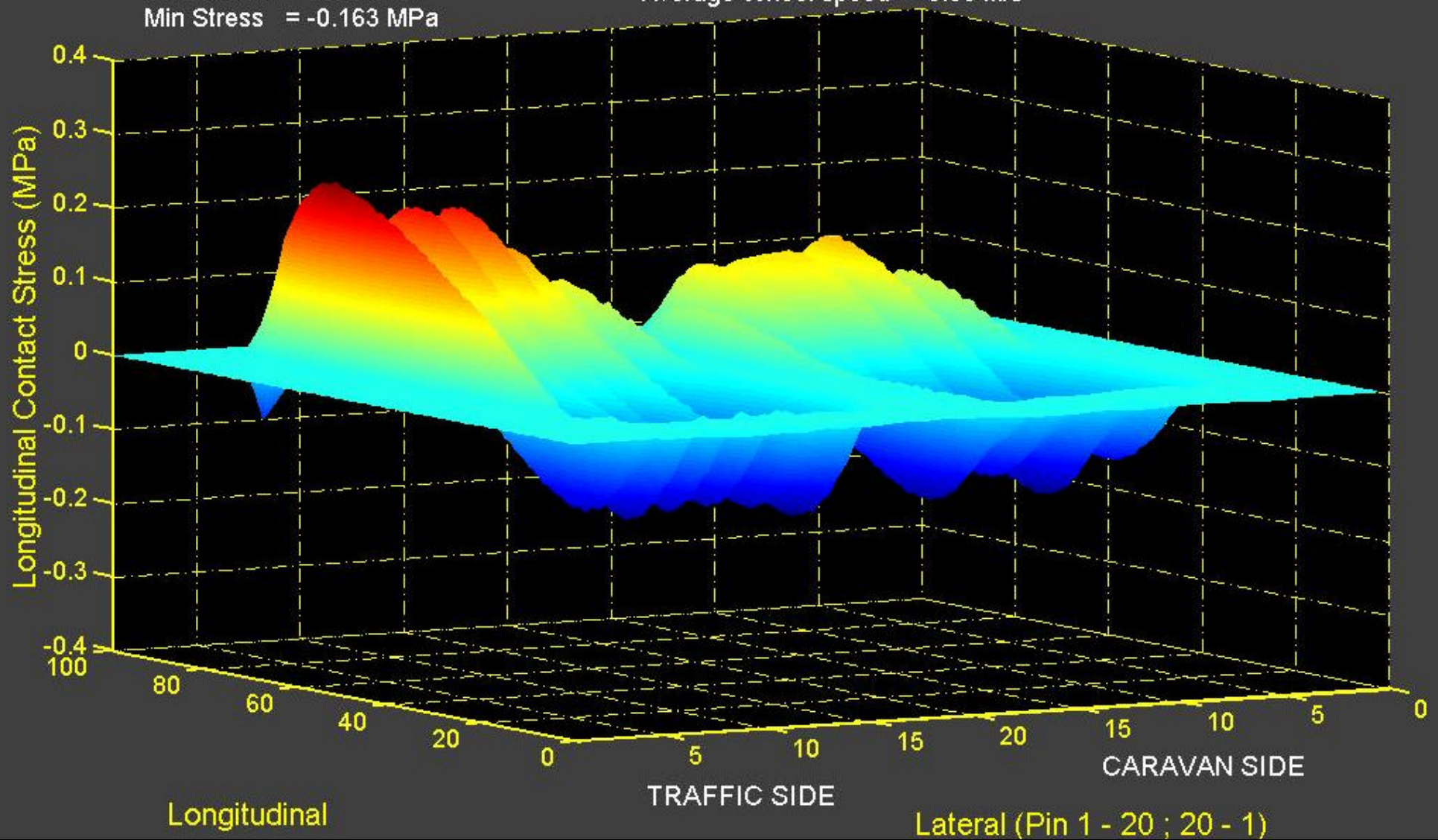
Max Stress = 0.25 MPa

Min Stress = -0.163 MPa

Measured Longitudinal Load (CS) = -0.99 kN

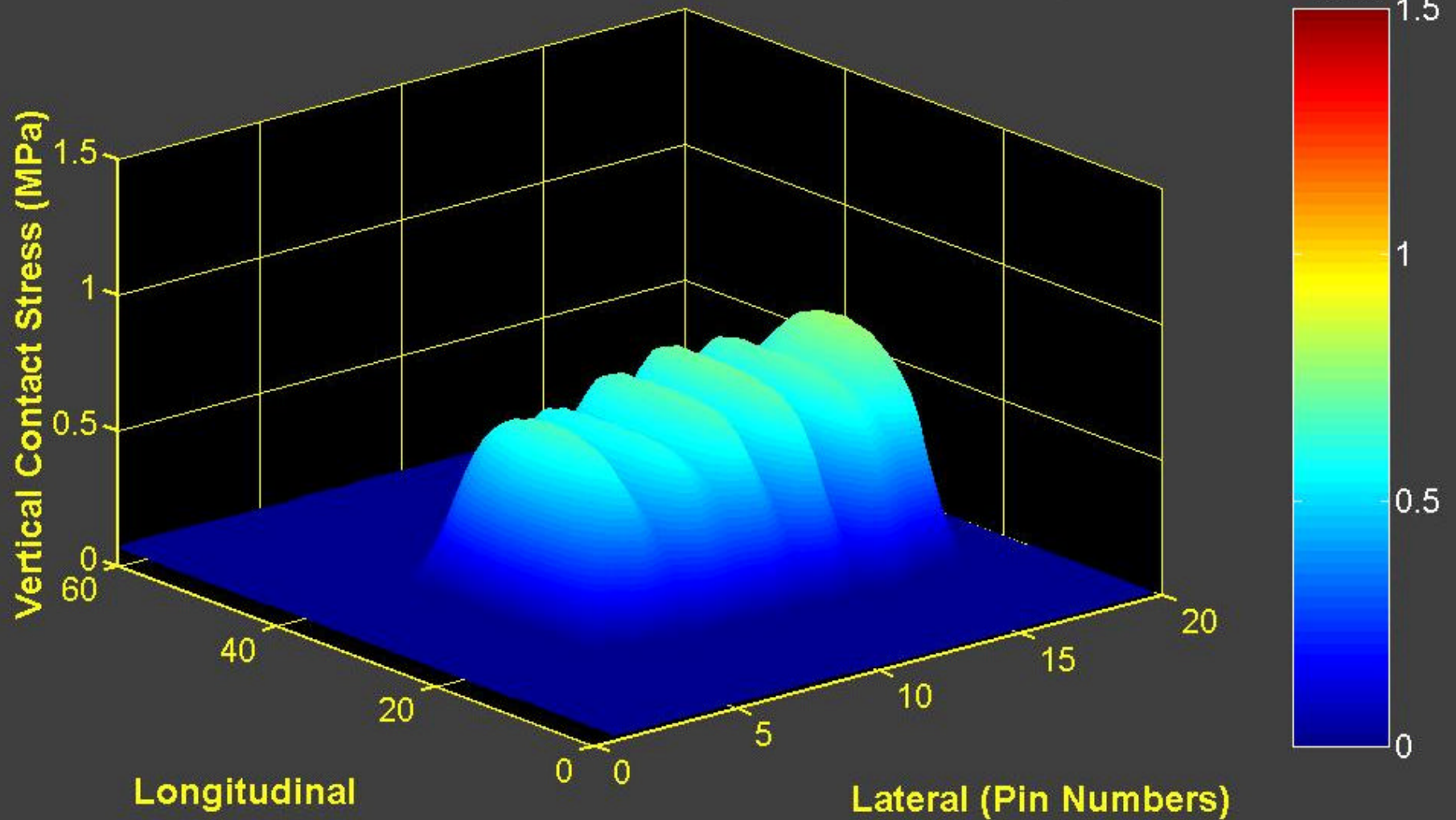
Measured Longitudinal Load (TS) = 1.3 kN

Average Wheel speed = 0.33 m/s



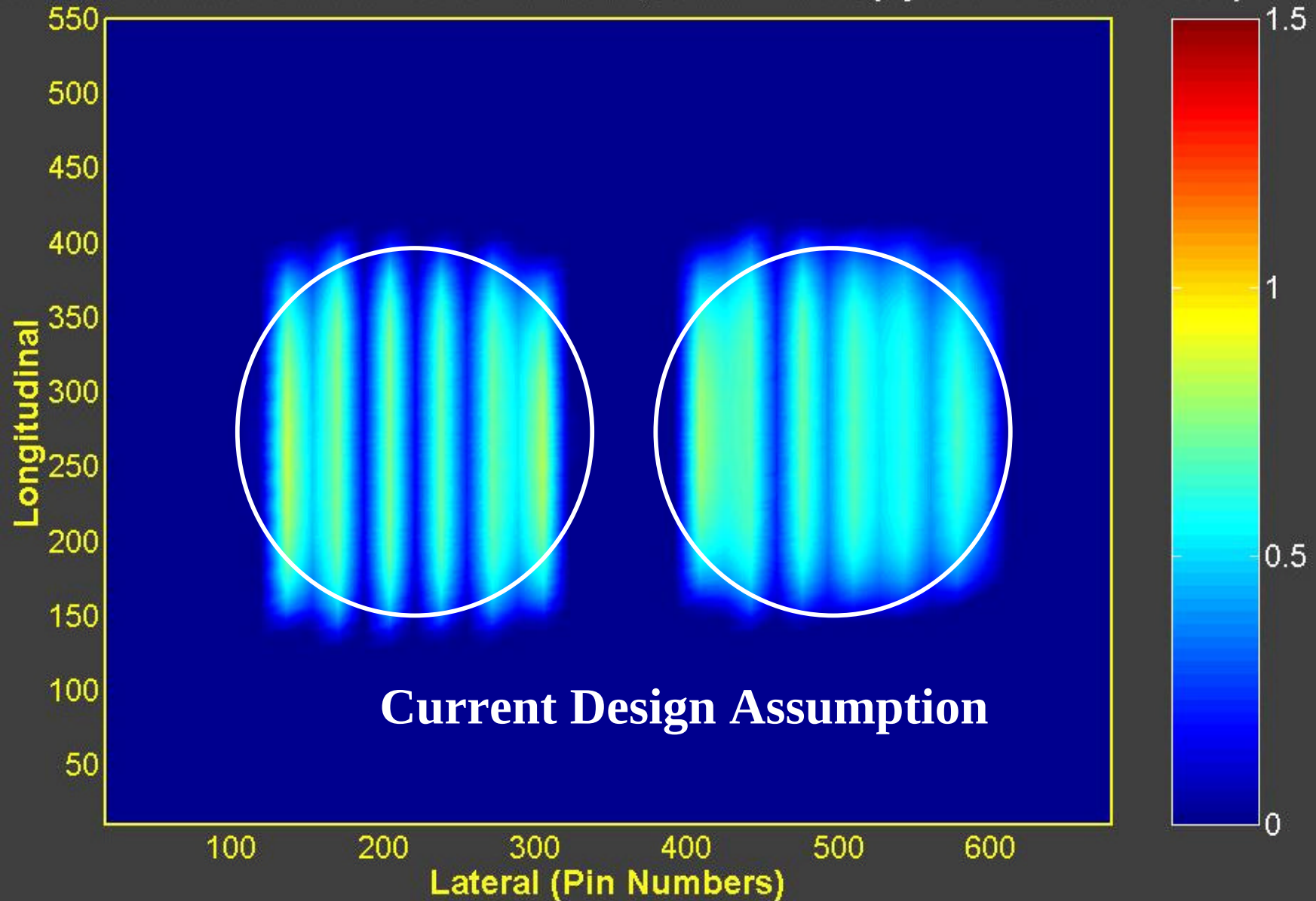
Inflation Pressure 520 kPa at a Load of 20 kN

SIM - HVS04 Caravan Side (Tyre 11R22.5 Treaded)



(80 kN Axle)

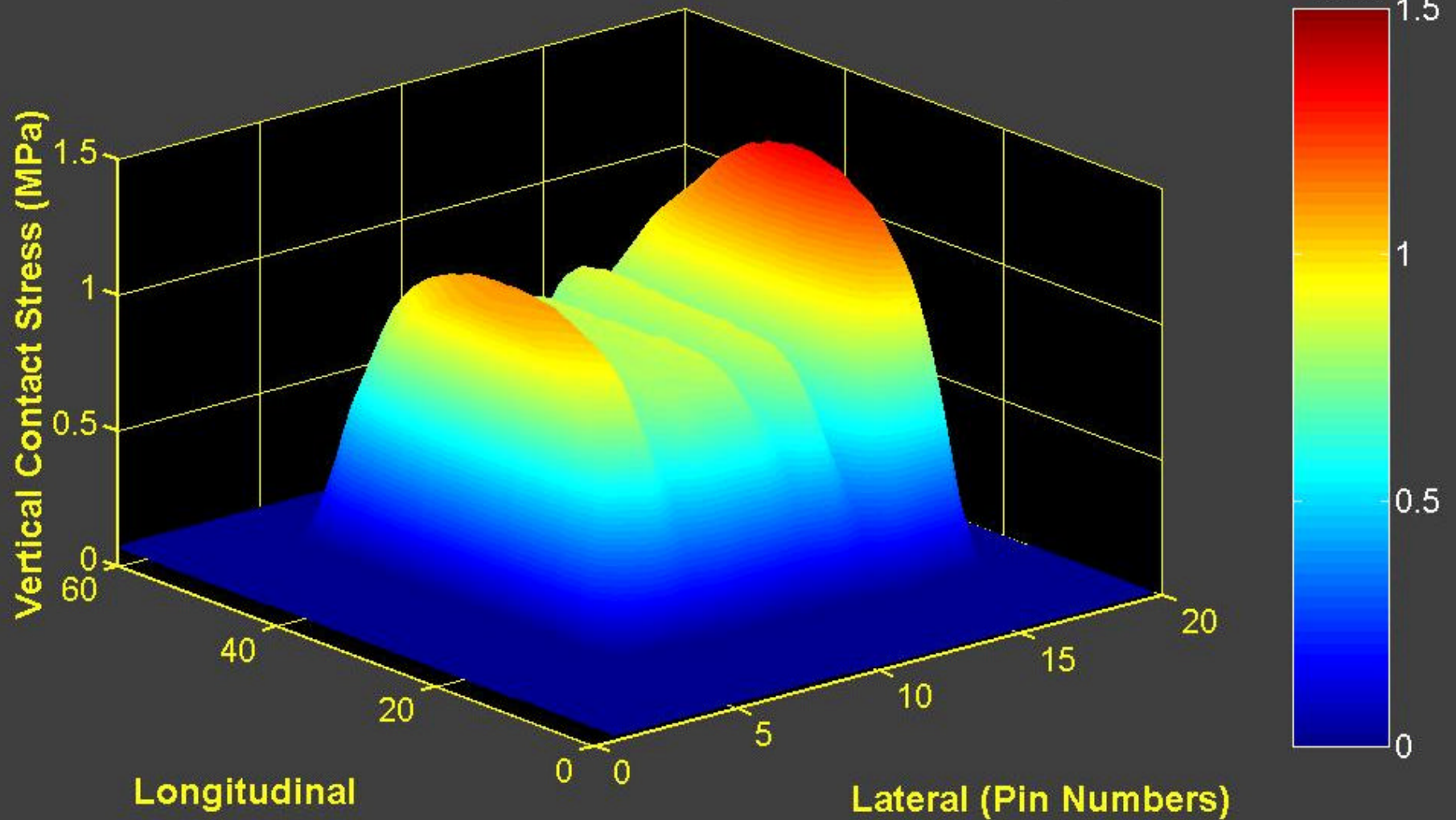
SIM - HVS04 Inflation Pressure = 520kPa ; Load = 40kN (Tyre 11R22.5 Treaded)



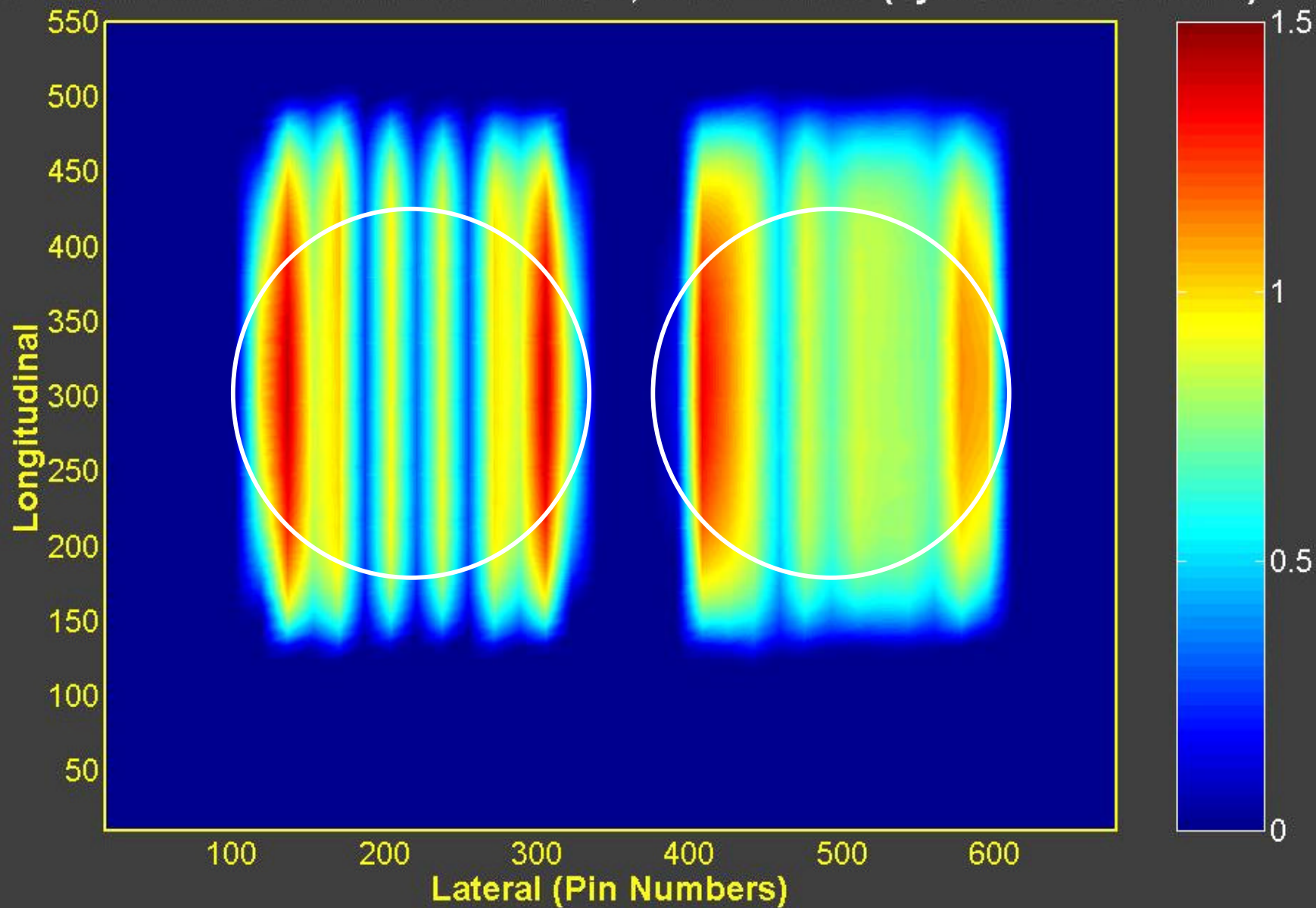
(80 kN Axle)

Inflation Pressure 800 kPa at a Load of 50 kN

SIM - HVS04 Caravan Side (Tyre 11R22.5 Treaded)

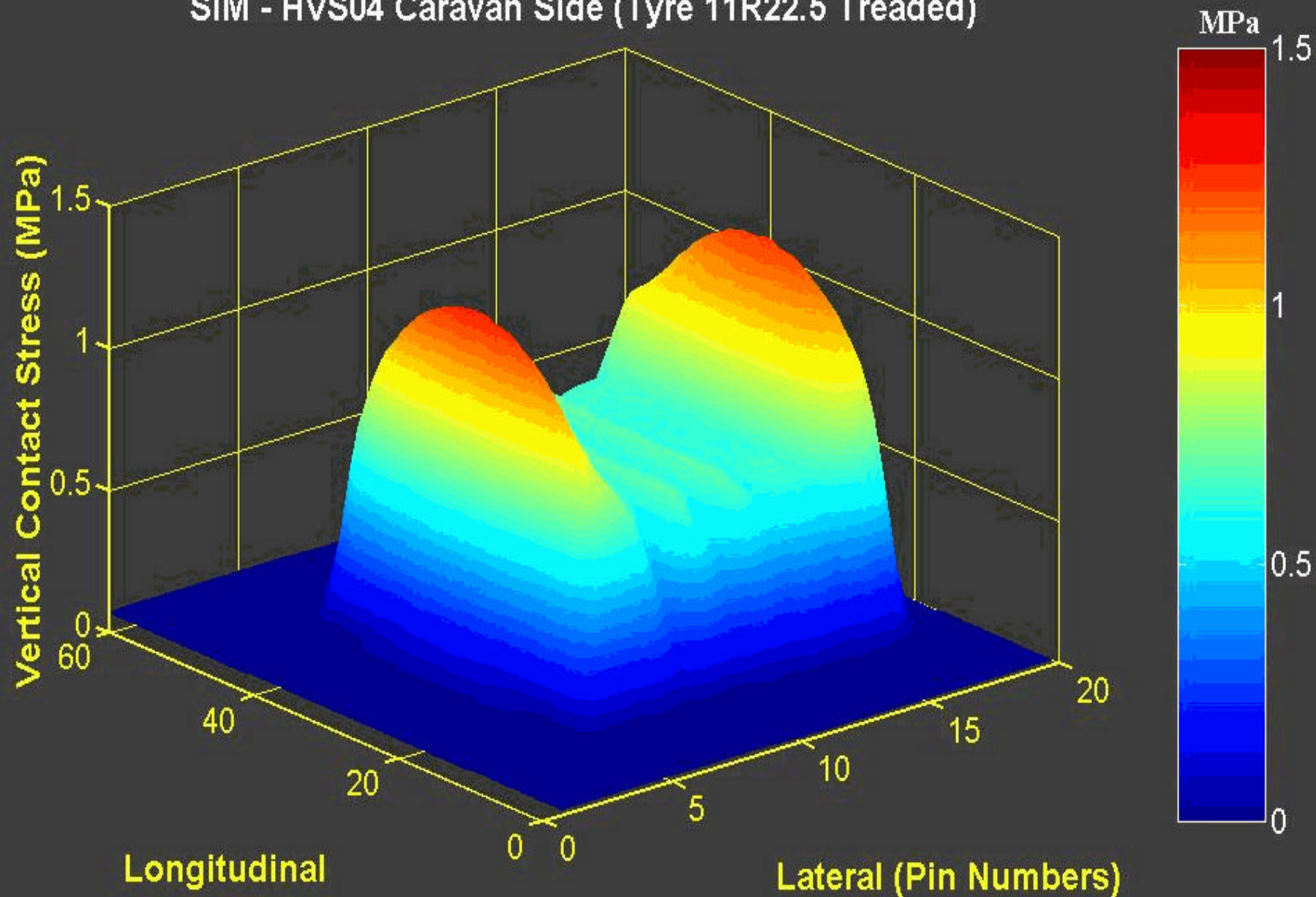


SIM - HVS04 Inflation Pressure = 800kPa ; Load = 100kN (Tyre 11R22.5 Treaded)



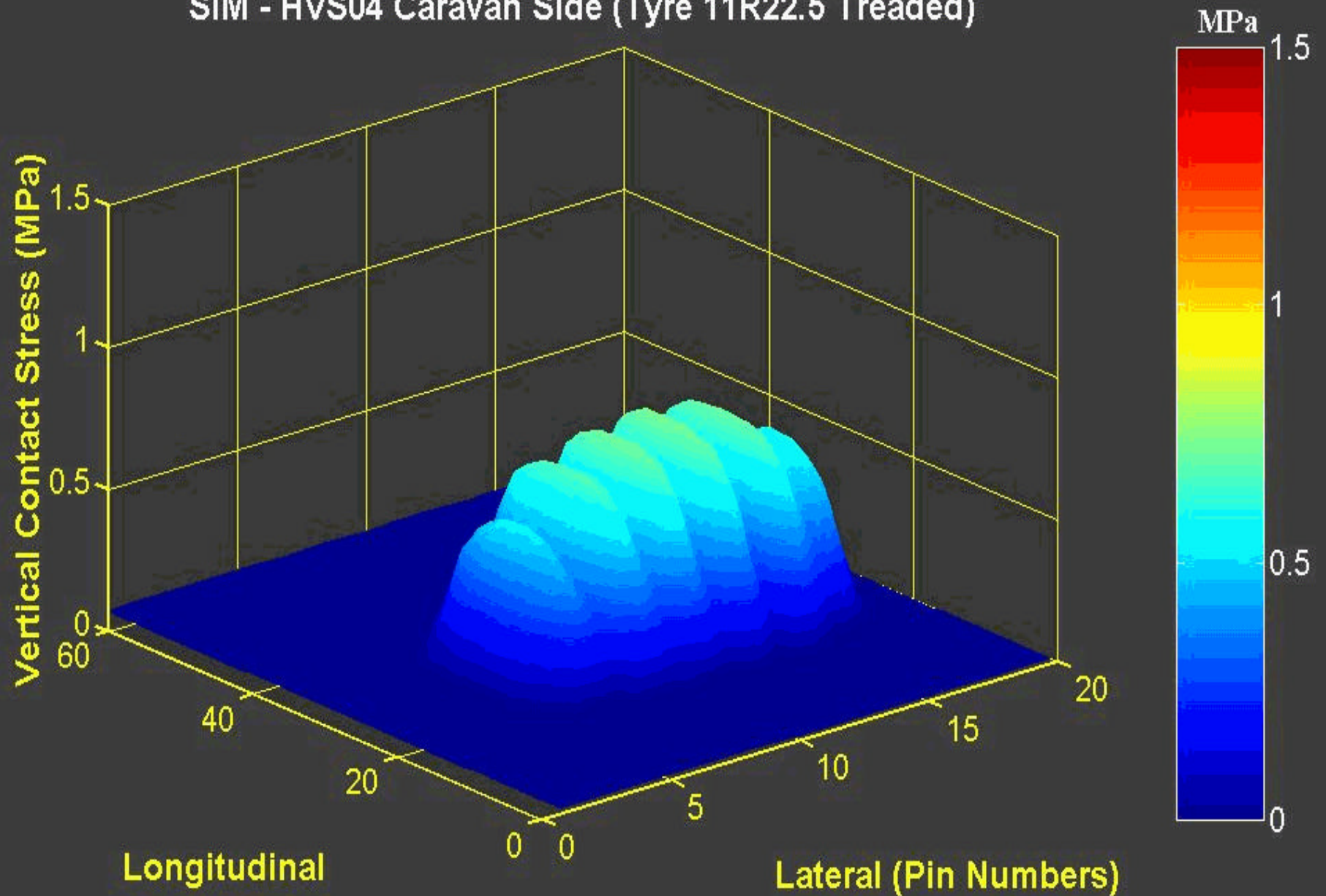
Applied Load 50 kN at Variable Inflation Pressures 520 - 800 kPa

SIM - HVS04 Caravan Side (Tyre 11R22.5 Treaded)

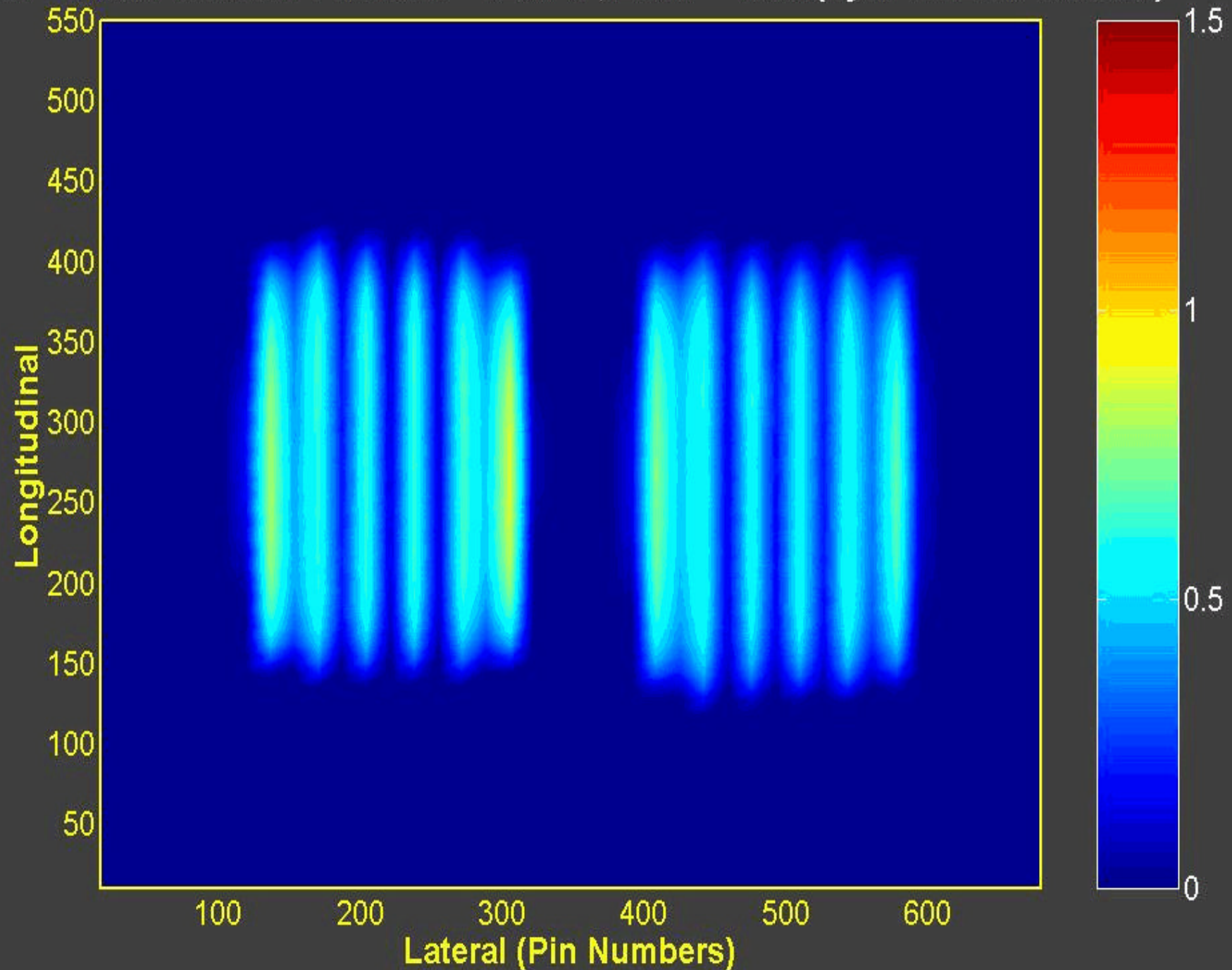


Inflation Pressure 520 kPa at Variable Loads of 15 kN - 50 kN

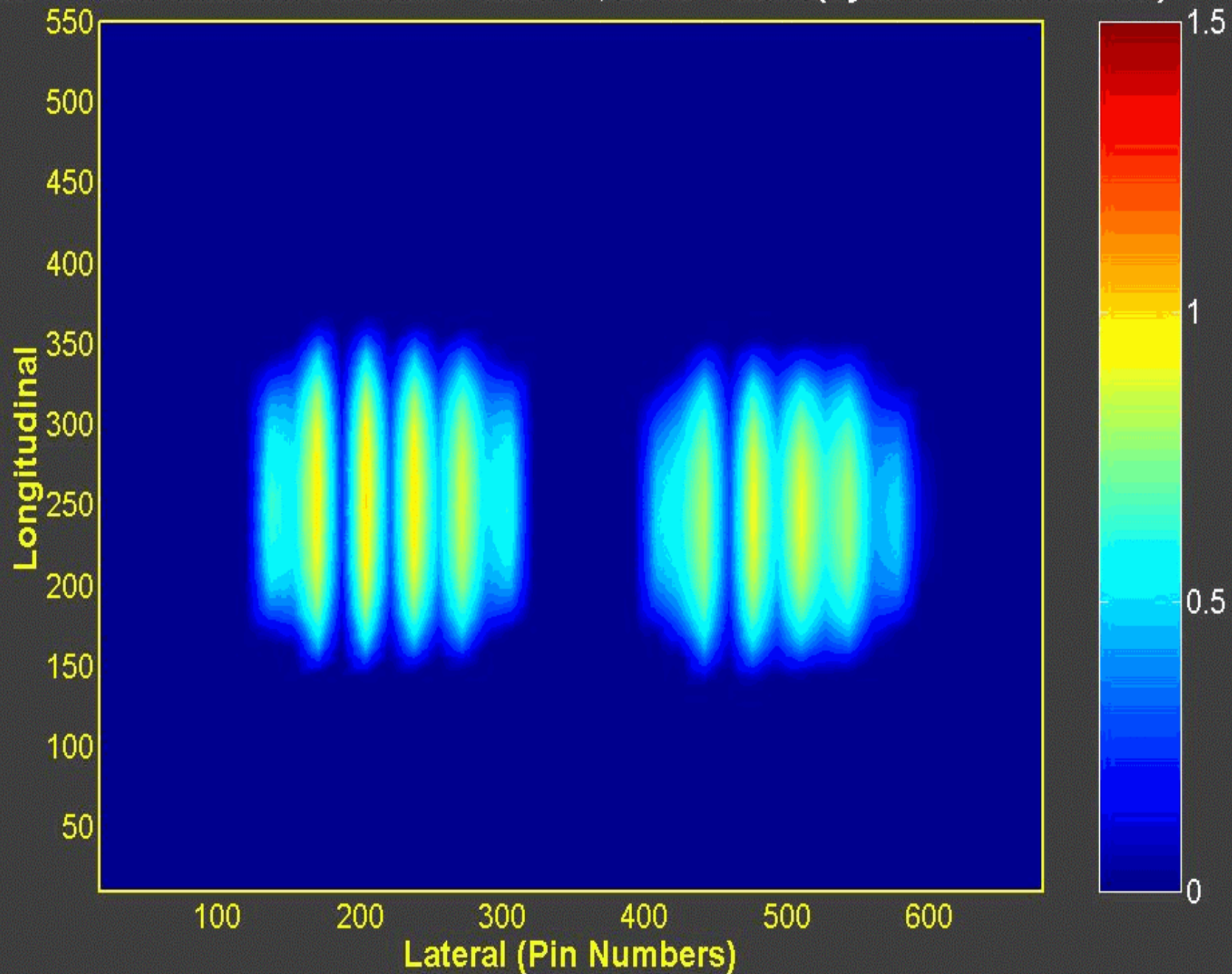
SIM - HVS04 Caravan Side (Tyre 11R22.5 Treaded)



SIM - HVS04 Inflation Pressure = 420kPa ; Load = 40kN (Tyre 11R22.5 Treaded)

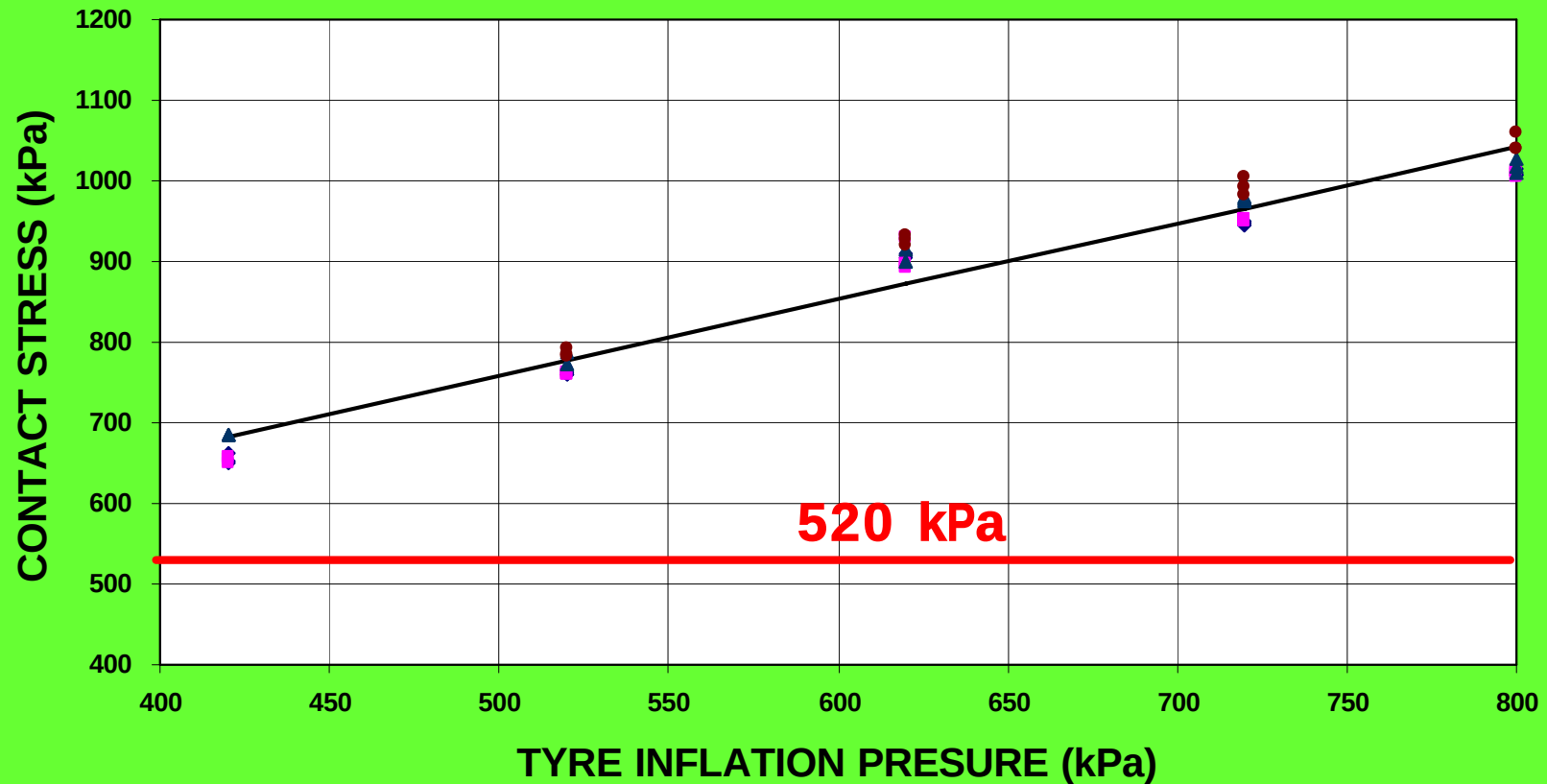


SIM - HVS04 Inflation Pressure = 800kPa ; Load = 30kN (Tyre 11R22.5 Treaded)



PRACTICAL APPLICATIONS: tyre center stress....

TRAFFIC SIDE CONTACT STRESS (CENTRE)

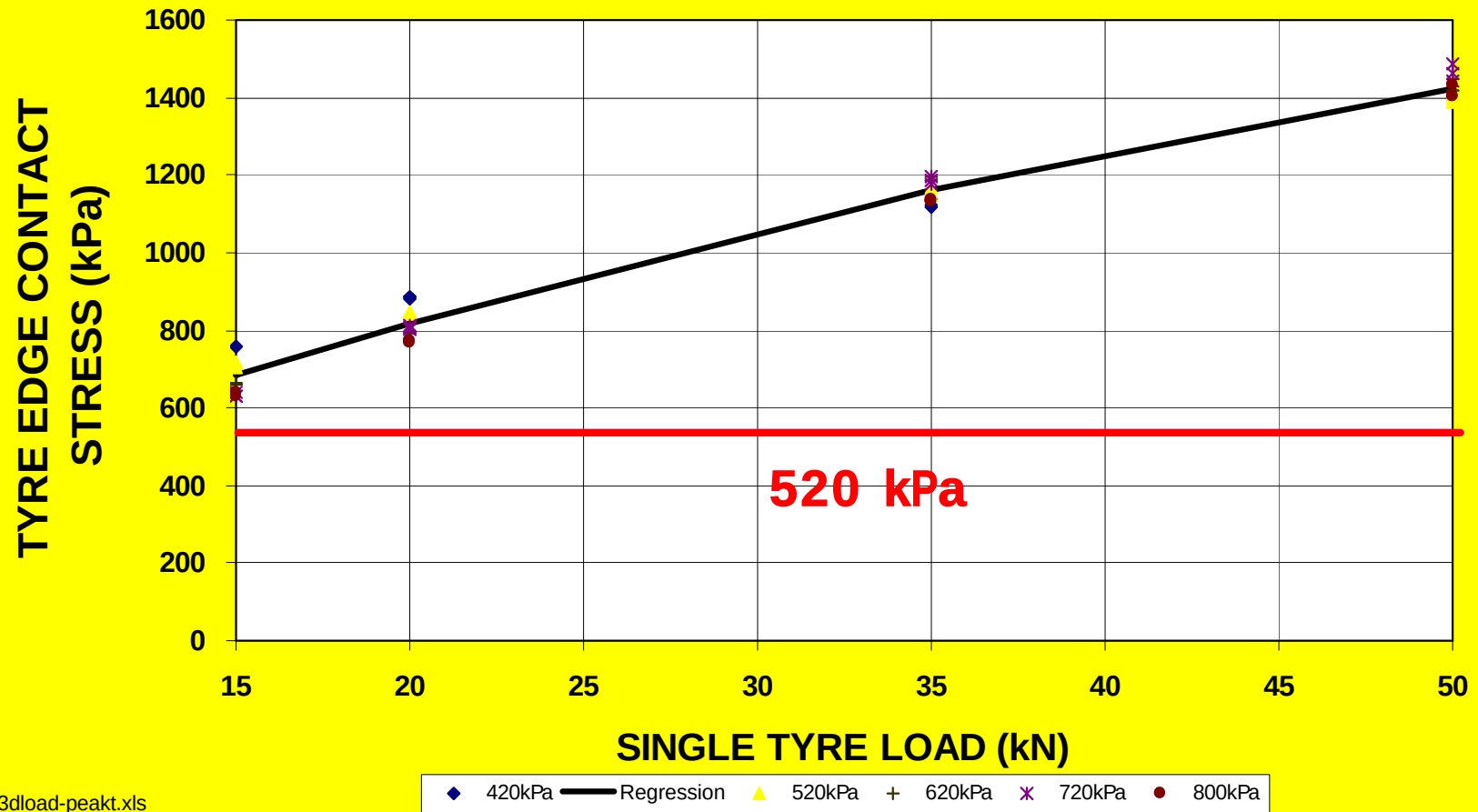


3dload-peakt.xls

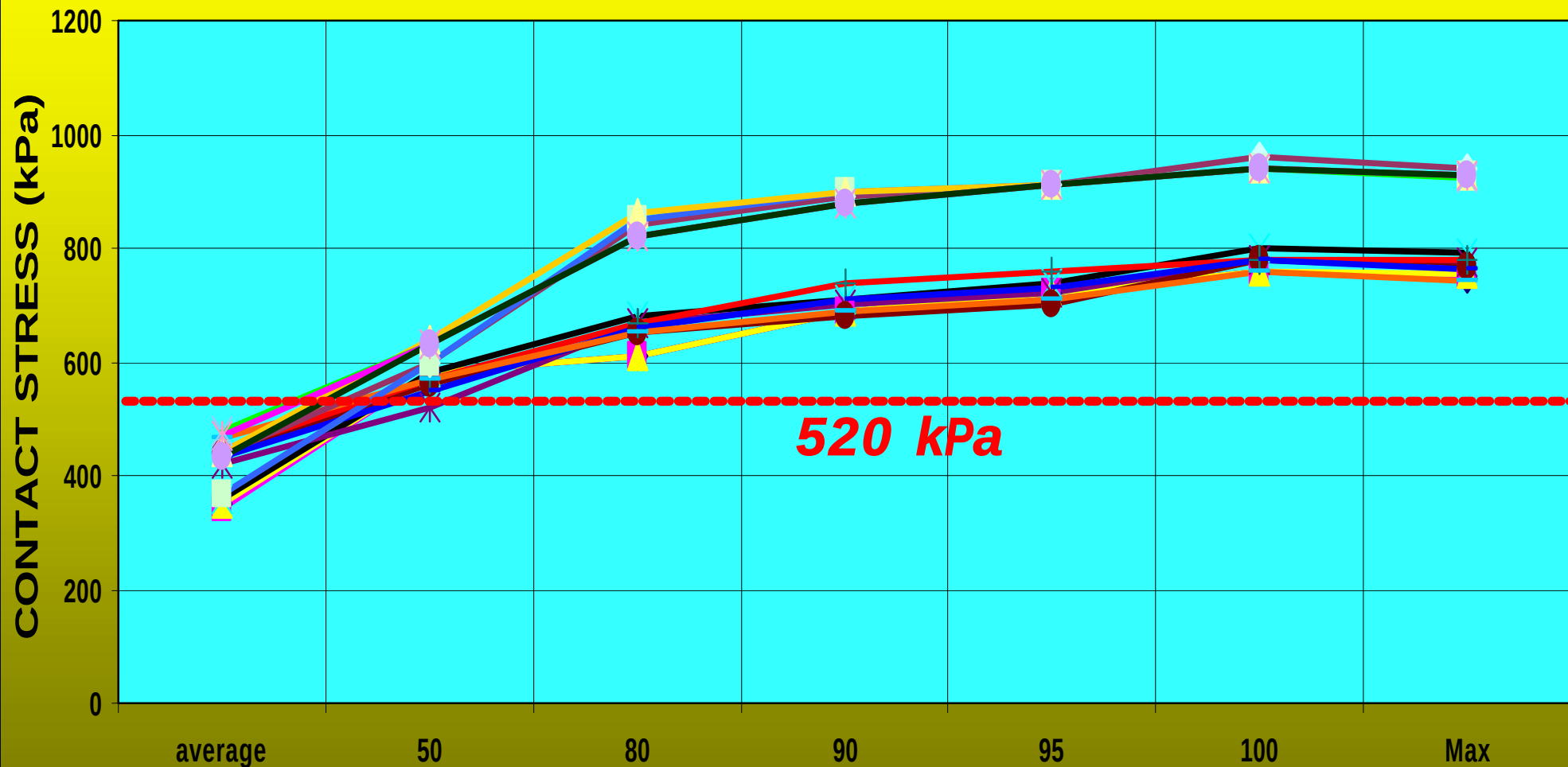
◆ Single load 15 kN ■ Single load 20 kN ▲ Single load 35 kN ● Single load 100 kN — Regression

PRACTICAL APPLICATIONS: tyre edge stresses....

TRAFFIC SIDE : TYRE EDGE CONTACT STRESS



CARAVAN SIDE - DUAL TYRE LOAD 40kN, @ INFLATION PRESSURES OF 420, 520, 620, 720 and 800kPa



PERCENTILE VALUES (%)



SUMMARY OF SIM RESULTS FOR ELSYM5M

PERCENTILE VALUE (%)	UNIFORM CONTACT STRESS (kPa)		LOAD RADIUS (mm)	
TYRE LOAD; INF.PRES.	20 kN; 520 kPa	35 kN; 720 kPa	20 kN; 520 kPa	35 kN; 720 kPa
Average	369	547	130	145
50	617	843	100	115
80	708	937	95	110
90	748	1017	90	105
95	770	1057	90	105
Max	812	1105	90	100

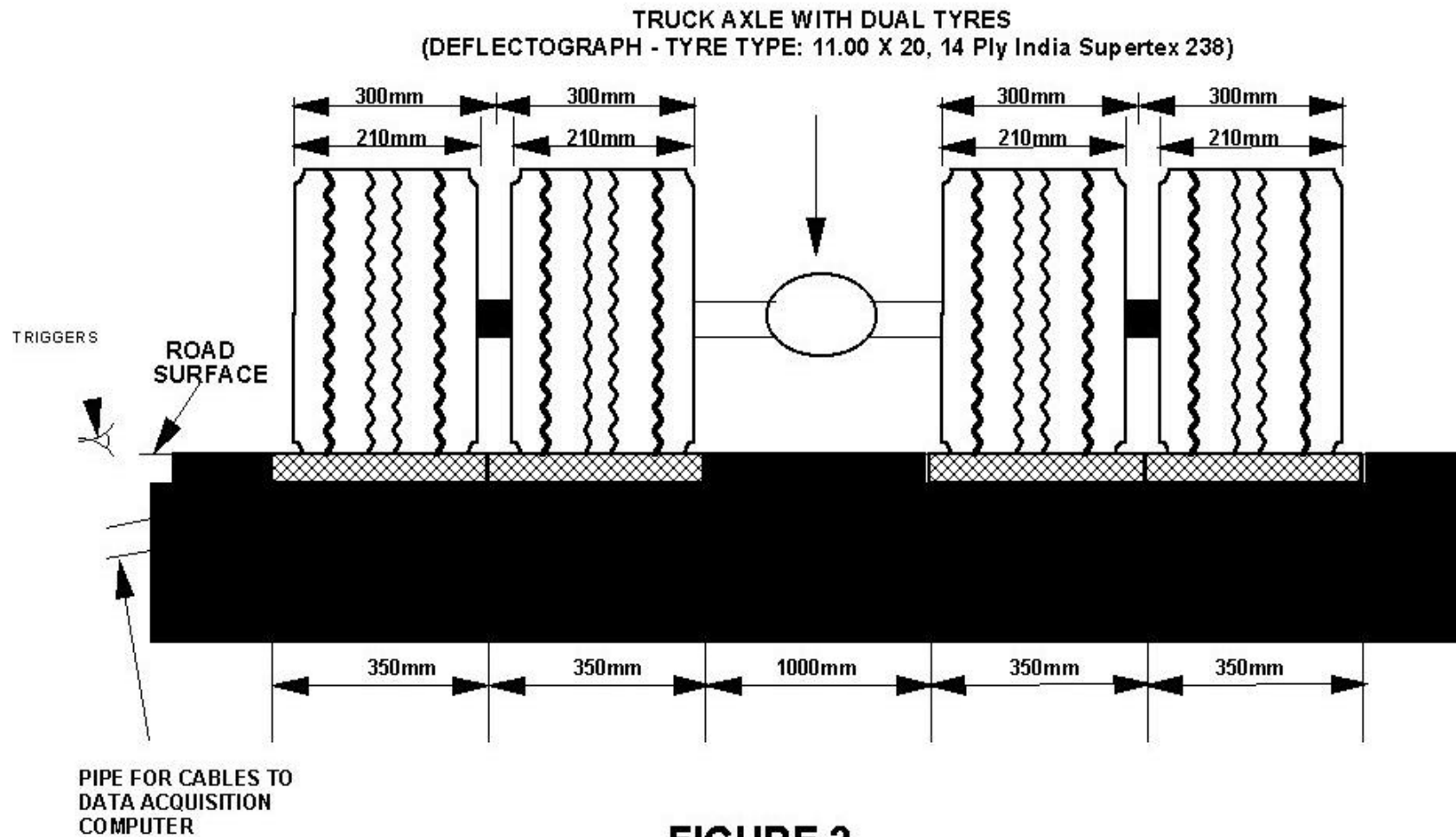


FIGURE 2

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

SIM3.DRW

4 PAD SIM SYSTEM

VRSPTA Mark III



4 PAD SIM SYSTEM – *most advanced*





WARNING



PASOP
STADIGE
TOETS
VOERTUIG



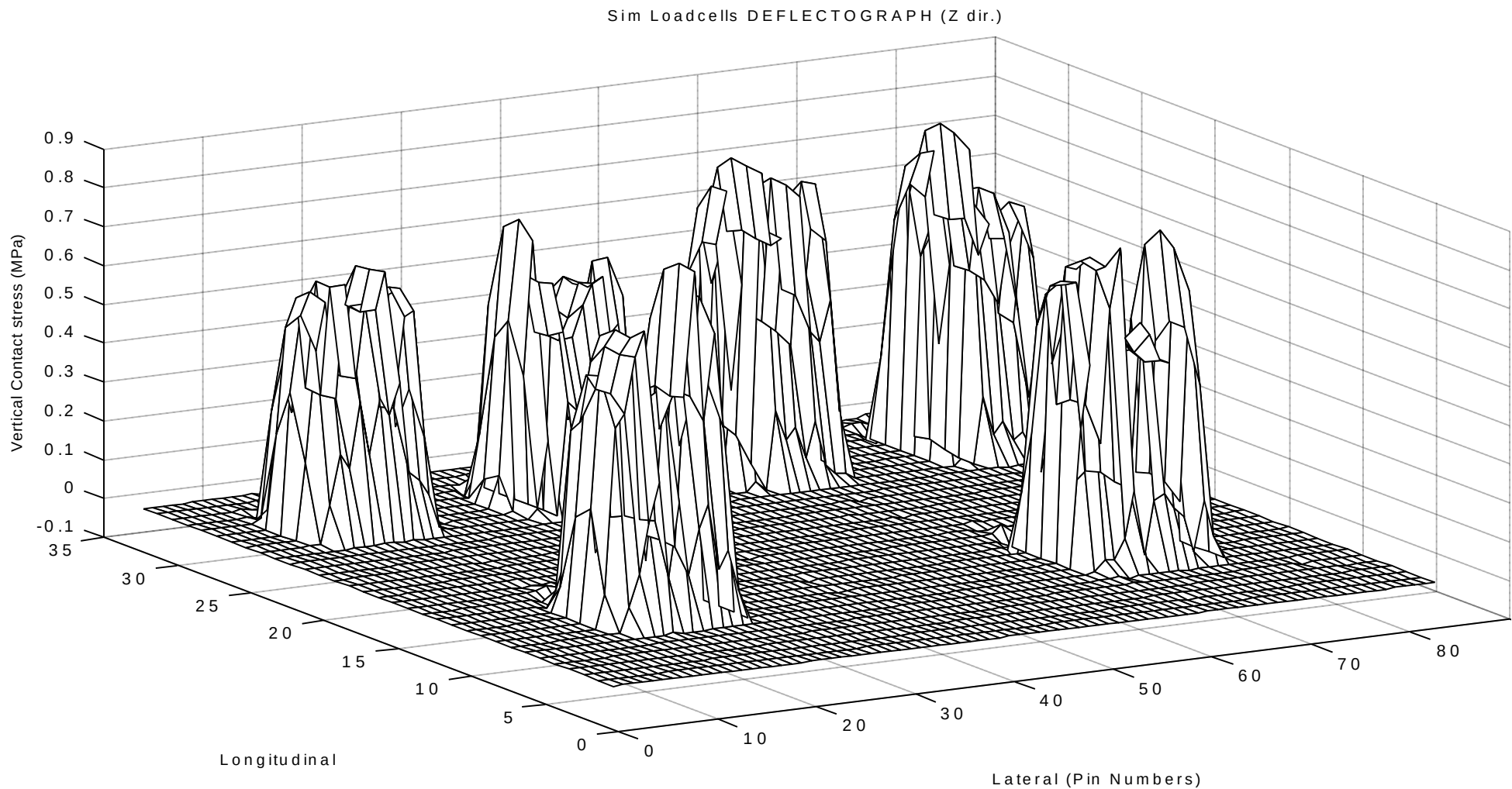
CAUTION
SLOW
TEST
VEHICLE

80

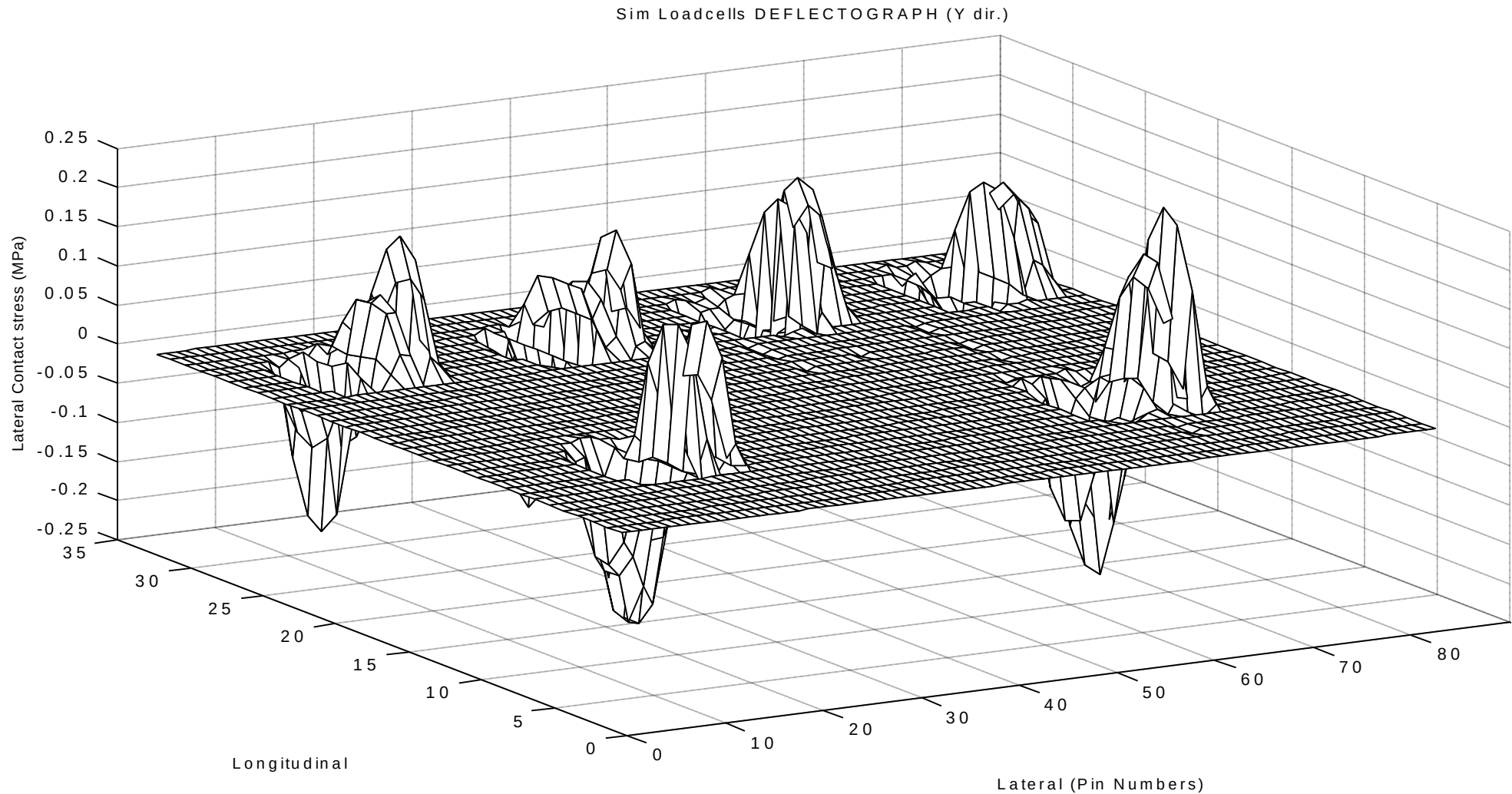
KMP270T



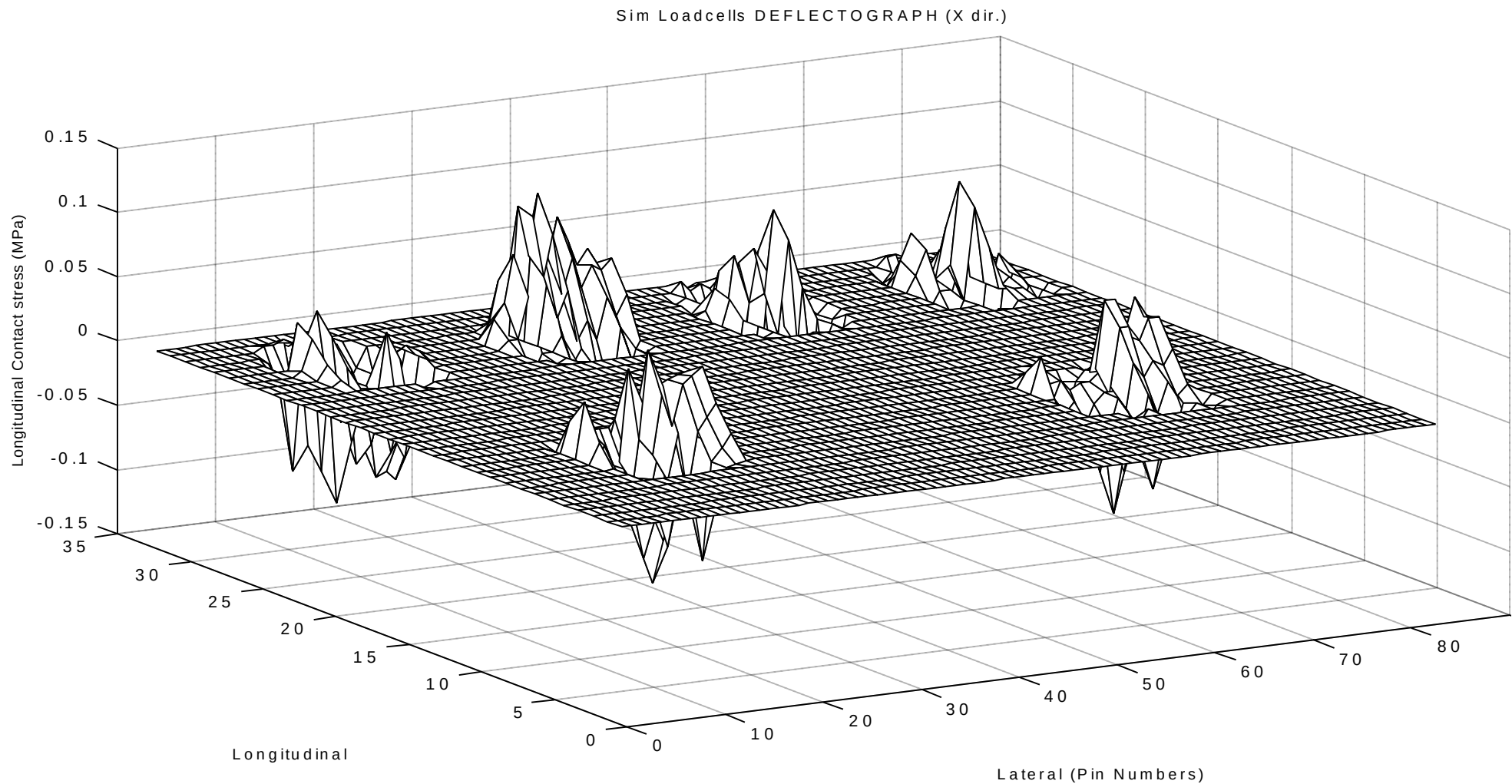
Deflectograph Truck (80kN, 650 kPa): Vertical Contact Stress



Deflectograph Truck (80kN, 650 kPa): Lateral Contact Stress

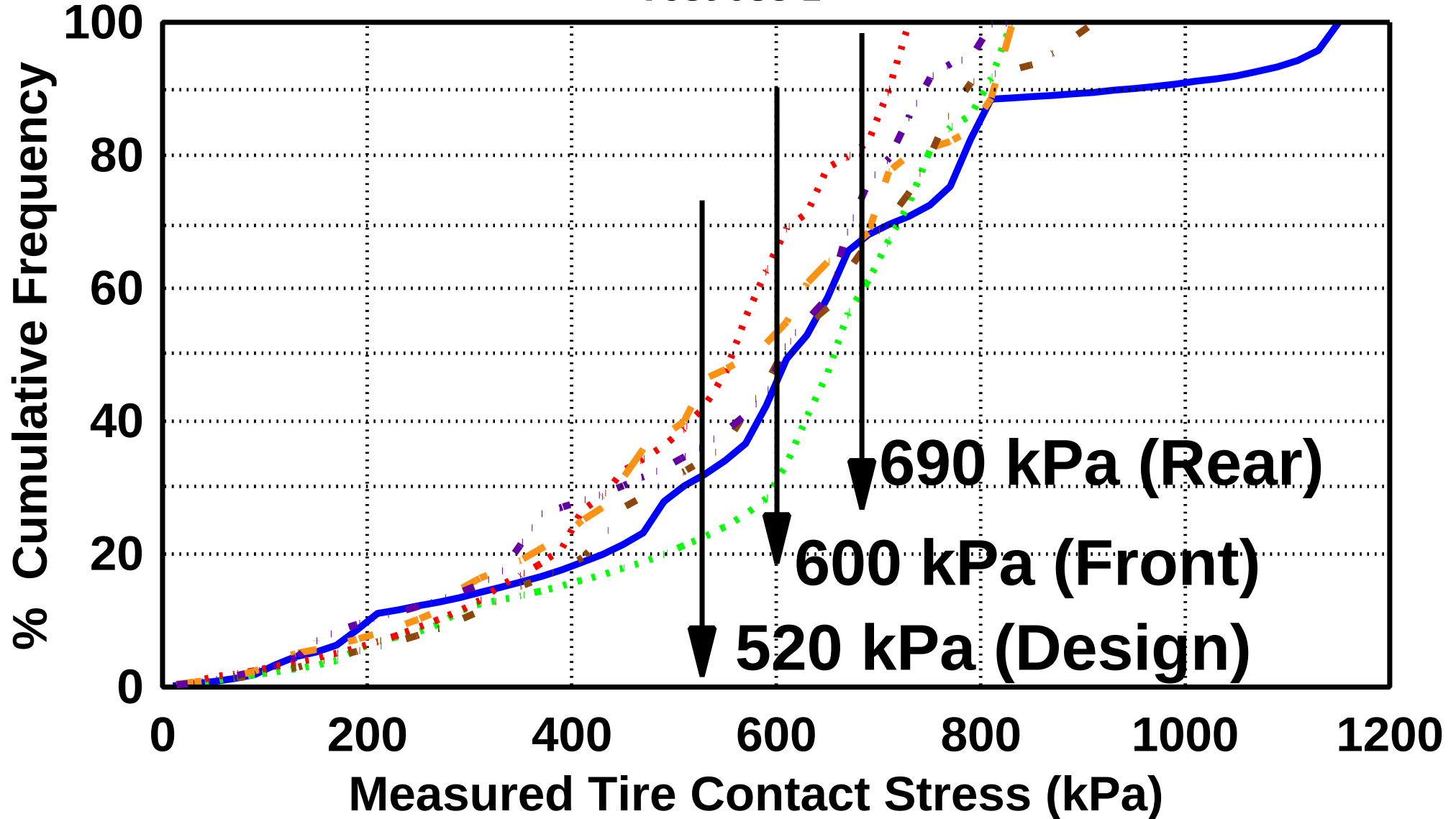


Deflectograph Truck (80kN, 650 kPa): Longitudinal Contact Stress



DEFLECTOGRAPH (OCTOBER 1998)

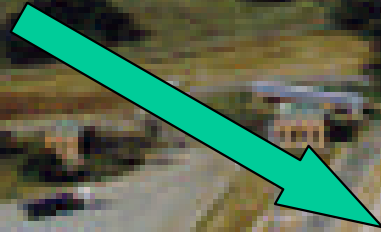
Test 038-z



Tyre	Front Left	Front Right	Rear Left	Rear Left Outer	Rear Left Inner	Rear Right Outer	Rear Right Inner
Inflation Pressure	600 kPa	600 kPa	690 kPa	690 kPa	690 kPa	690 kPa	690 kPa

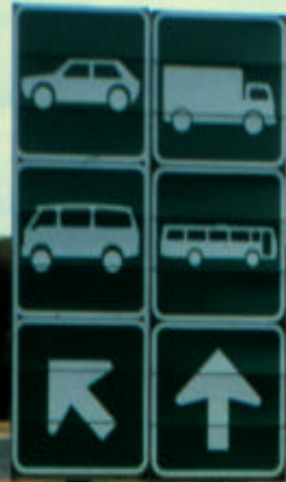
MANTSOLE TRAFFIC CONTROLL CENTRE (TCC) ON NATIONAL ROAD NR 1 (N1)

Full Axle SIM



North





WEIGH-BRIDGE SITE FOR SIM AT
MANTSOLE ON THE N1

12 11'97

A photograph of a concrete road, likely a test track or a newly constructed road. The road surface is light-colored concrete with visible aggregate. A bright orange line runs diagonally from the bottom left towards the center. A blue rectangular area is painted on the road surface in the middle ground. To the right of the road is a metal guardrail. In the background, there is a building with a red roof and some trees. The sky is blue with some clouds.

MANTSOLE TCC

12 11'97







TRUCK IDENTIFICATION INCLUDES:

- ✓ *Vehicle Registration number;*
- ✓ *Date of measurement;*
- ✓ *Time of measurement;*
- ✓ *Vehicle classification (i.e 1:2:2:2)*
- ✓ *Tyre inflation pressure and tyre temp only on selected trucks at the TCC.*

The following items are obtained with the SIM:

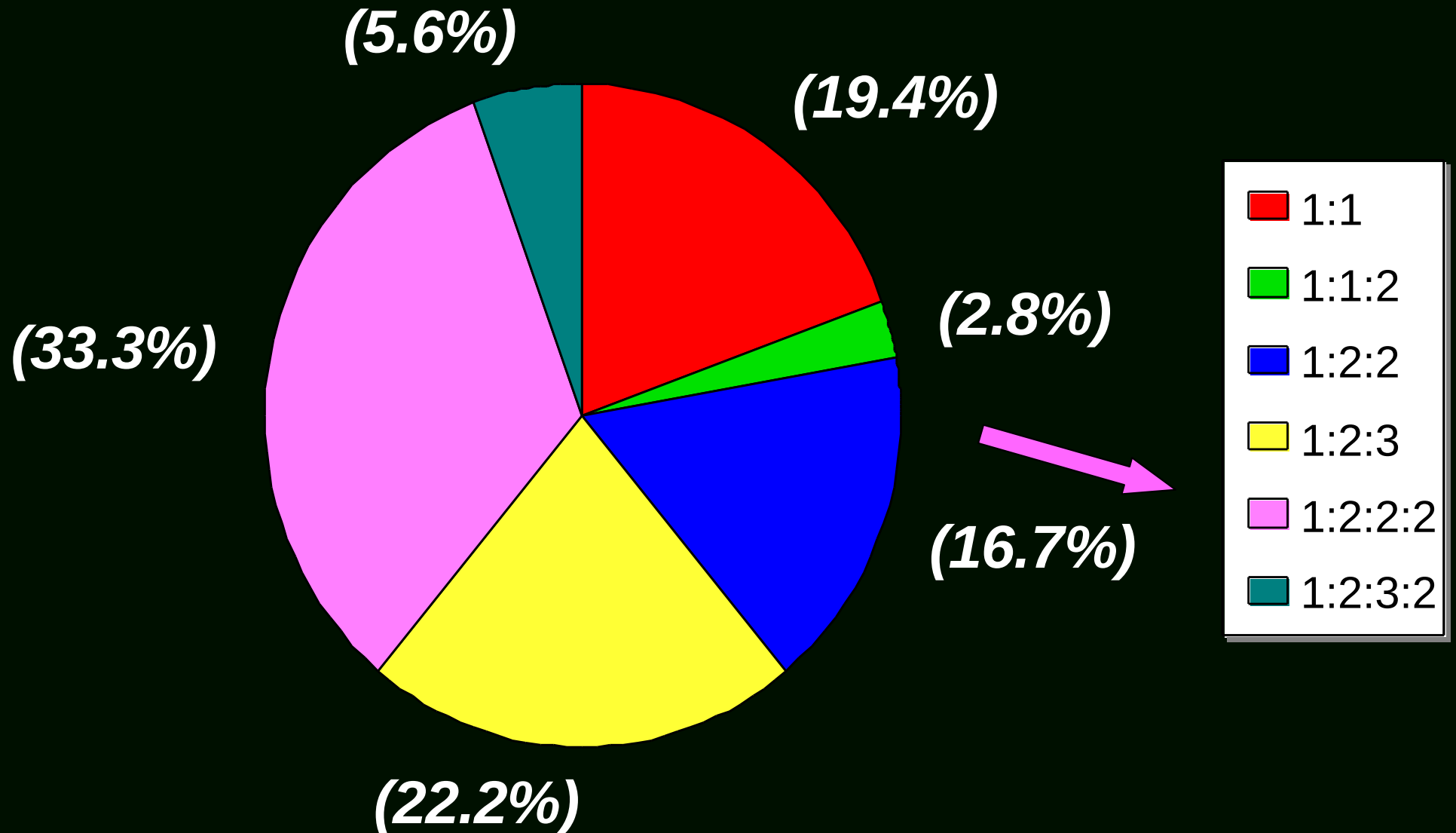
- ✓ *Axle Speed;*
- ✓ *Axle Distance;*
- ✓ *Axle weights;*
- ✓ *Axle Group weights;*
- ✓ *Tyre width;*
- ✓ *Tyre contact area;*
- ✓ *Tyre patch length (TPL);*
- ✓ *Tyre weights;*
- ✓ *3D Vertical, Lateral & Longitudinal Stresses*
- ✓ *Stress Ratios;*





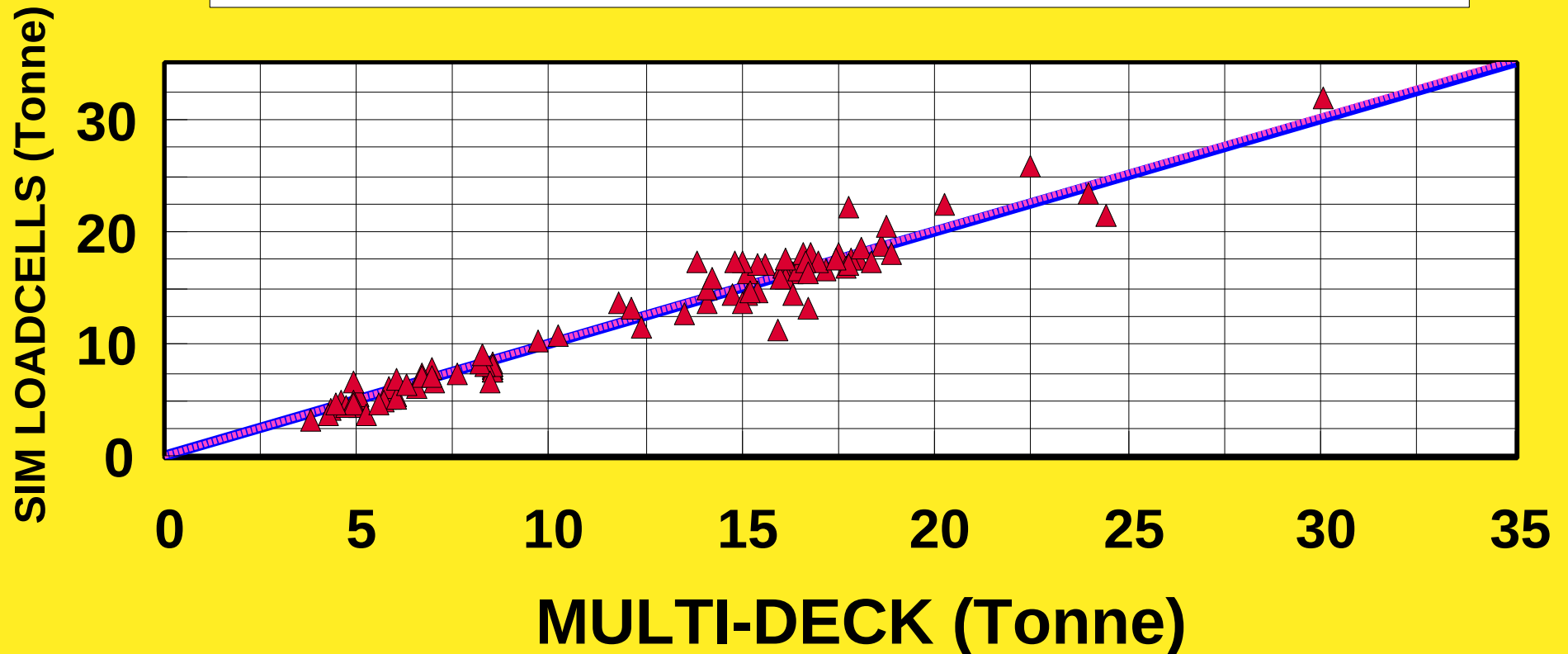


SIM TESTS: BREAK DOWN OF VEHICLE CLASSES MEASURED (MANTSOLE, N1)



MANTSOLE WEIGHBRIDGE (TCC)

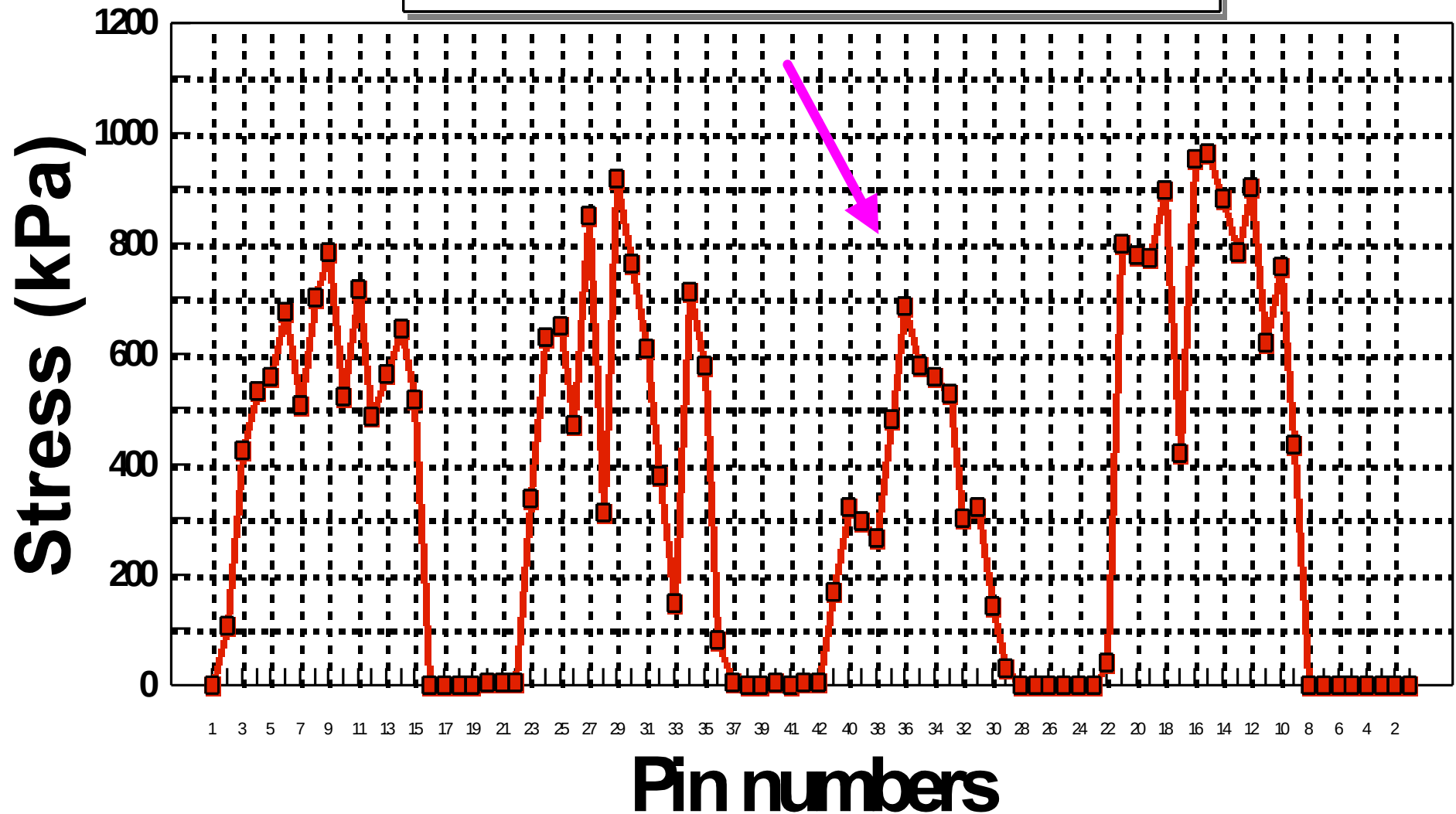
SIM TESTS NOV. & DEC. 1998 & FEB 1999



- 1 to 1
- ◆ Regression line ($R^2 = 0.956$)
- ▲ Validated Data (26 Trucks)

AXLE 5

Vertical Maximum Contact Stress (kPa)



001-z
DMB453 GP

Left Outer
Tyre

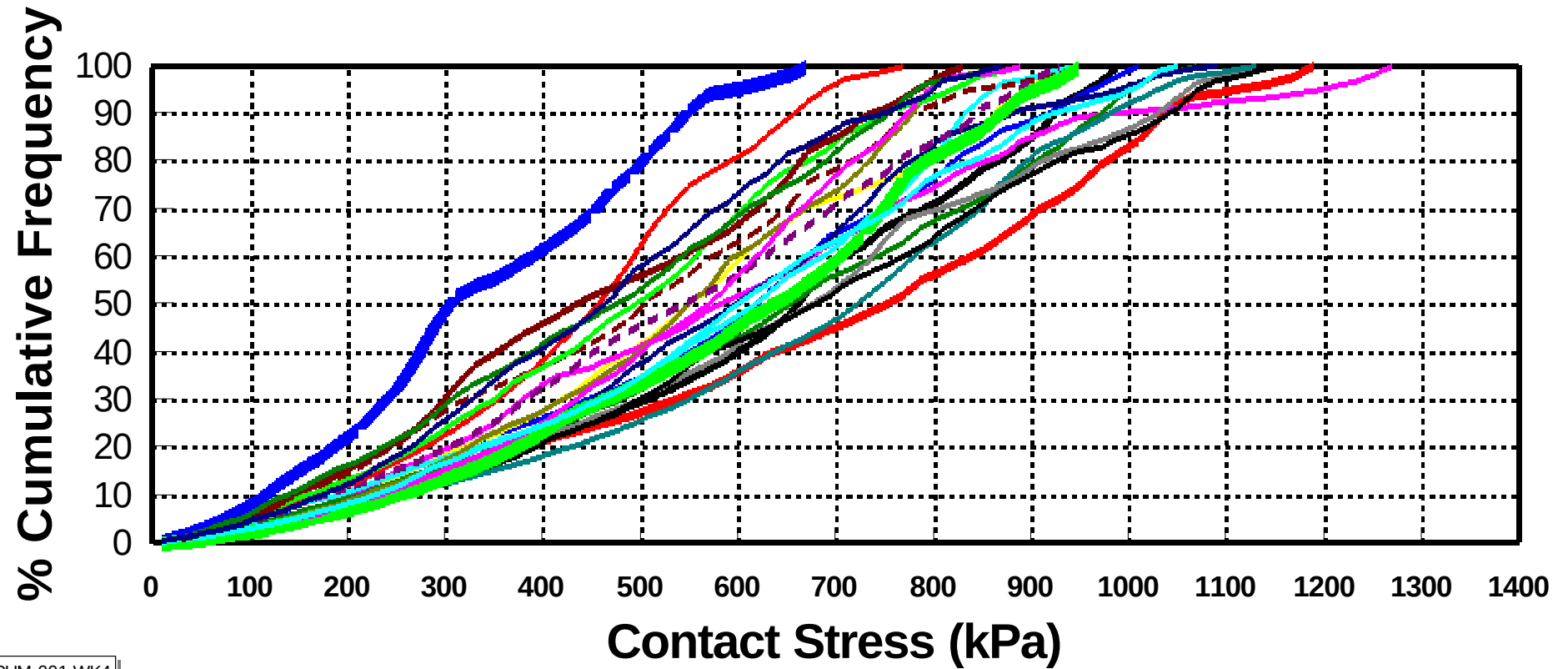
Left Inner
Tyre

Right Inner
Tyre

Right Outer
Tyre

MANTSOLE TESTING (NOV 98)

FILE 001-Z (COMBINATION 1 2 2 2)



CUM-001.WK4
DMB 453 GP

ax1l	ax1r	ax2l	ax2li	ax2ri	ax2r	ax3l	ax3li	ax3ri	ax3r	ax4l	ax4li
ax4ri	ax4r	ax5l	ax5li	ax5ri	ax5r	ax6l	ax6li	ax6ri	ax6r	ax7l	

Summary of SIM data: Mantsole, TCC on N1:

- **SIM Data of 36 trucks - 704 tyres analyzed;**
- **SIM Accuracy vs Multi-deck Scale: within 2,5 %;**
- **SIM Precision @ 95 % = 2,6 tonne /Axle Group**
- **Vertical Stress: 577 – 1149 (Ave. = 903 kPa);**
- **Lateral Stress: 89 – 233 (Ave. = 170 kPa);**
- **Longitudinal Stress: 52 – 237 (Ave. = 124 kPa);**

Summary of SIM data: Mantsole, TCC on N1

Continue:

- **Stress Ratios: 10:1,88:1,38**
- **Average Max Vertical > 1,59 x Inflation Pressure;**
- **Max Vertical Stress/520 kPa : 1,37 to 2,75 (NCP);**
- **Vertical Stress Patterns of approx. 22 % of tyres show “abnormal” patterns;**

ELSYM5M PAVEMENT ANALYSIS

UNIFORM: VERTICAL (NORMAL) STRESS, zz

Calculate

Pavement Structure

Loads and Evaluation Points

Stresses and Strains

Design Parameters

Pavement Life

Contour Plot

Profile Plot

Diagnostics

Define plane for contour plot

Vertical plane parallel to X-Z

Y offset from origin

10

Contour region size (mm)

400

Contour region centred at (mm)

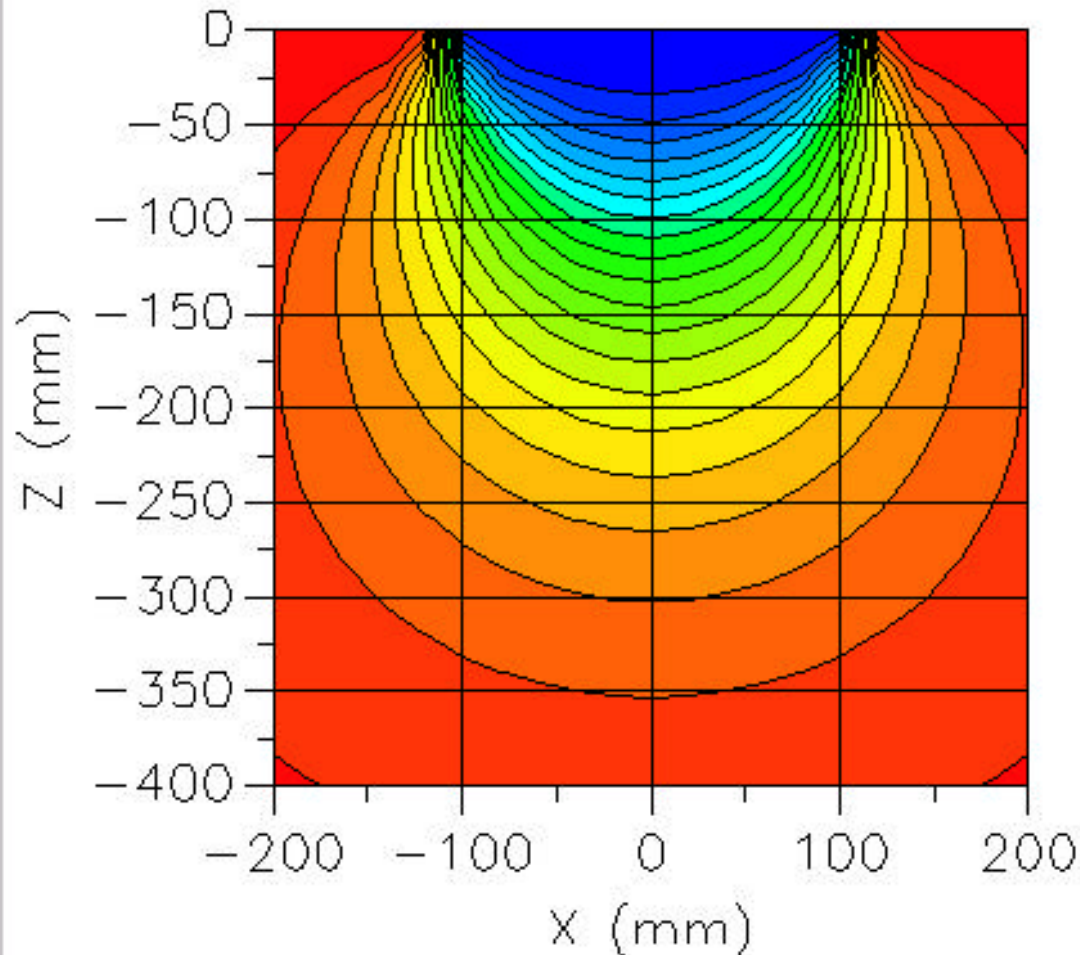
X

0

Z

0

Plot parameter

Normal Stress zz 

Single tyre load: 20 kN; 520 kPa

SIM: VERTICAL (NORMAL) STRESS, zz

Calculate

Pavement Structure | Loads and Evaluation Points | Stresses and Strains | Design Parameters | 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)

250

Contour region centred at (mm)

X

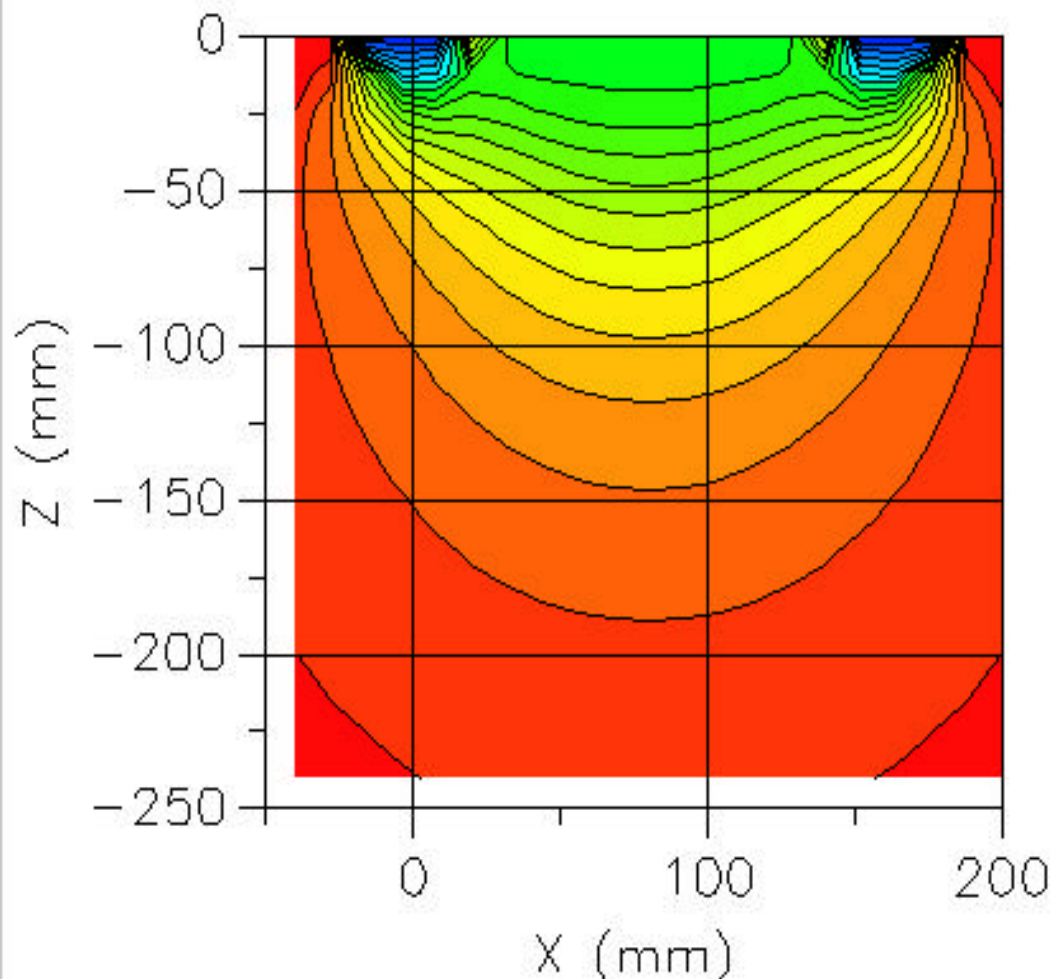
80

Z

0

Plot parameter

Normal Stress zz



Single tyre load: 50 kN; 620 kPa

UNIFORM LOAD: SHEAR STRESS, xz

Calculate

Pavement Structure | Loads and Evaluation Points | Stresses and Strains | Design Parameters | 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

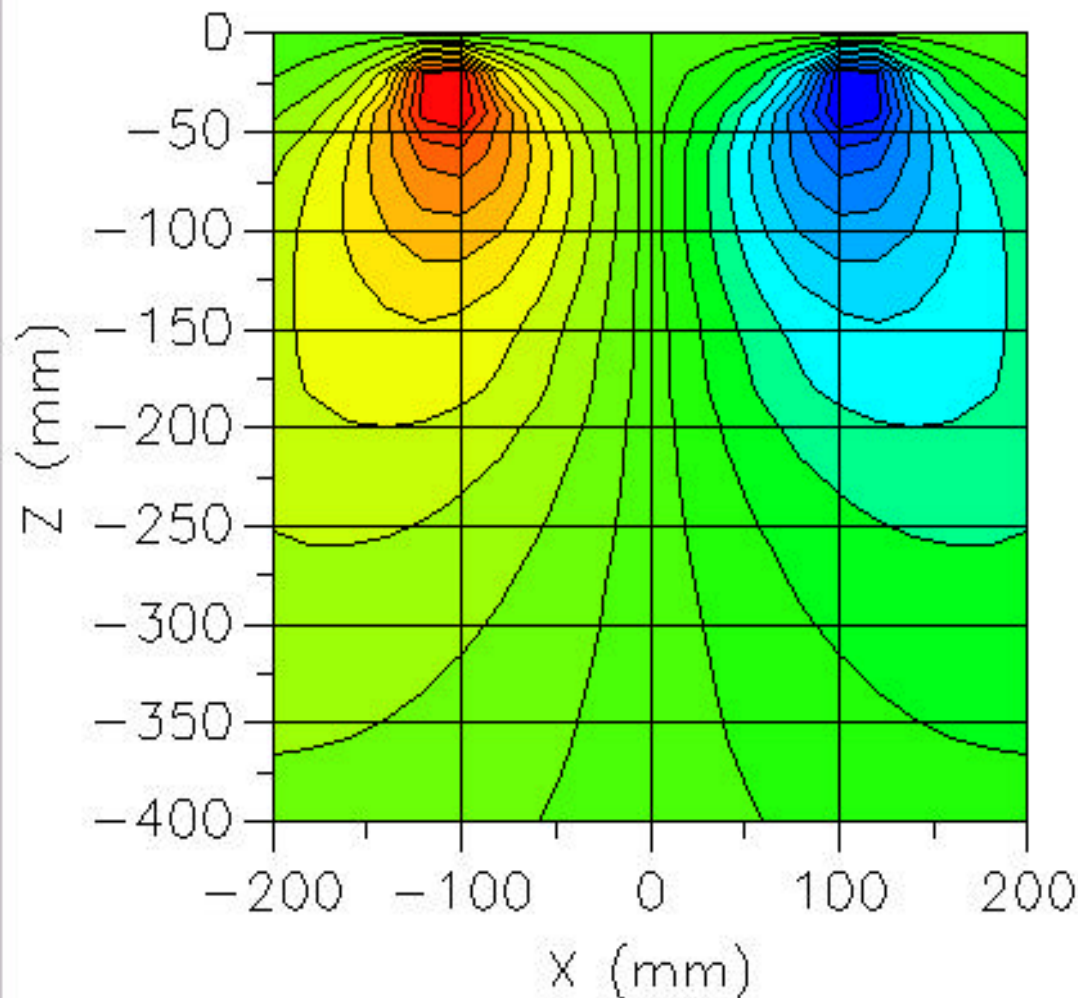
Z

0

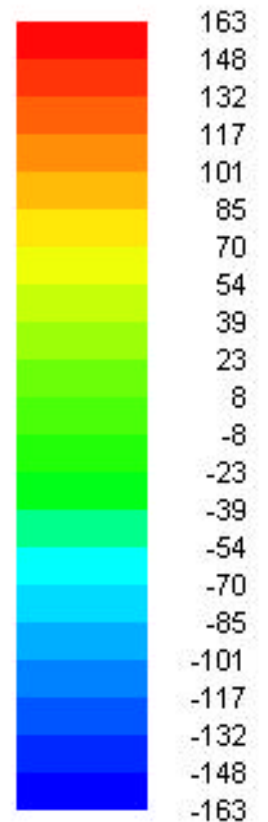
0

Plot parameter

Shear Stress XZ



Shear Stress XZ



Single tyre load: 20 kN; 520 kPa

FINITE ELEMENT METHOD (FEM) FOR PAVEMENT ANALYSIS

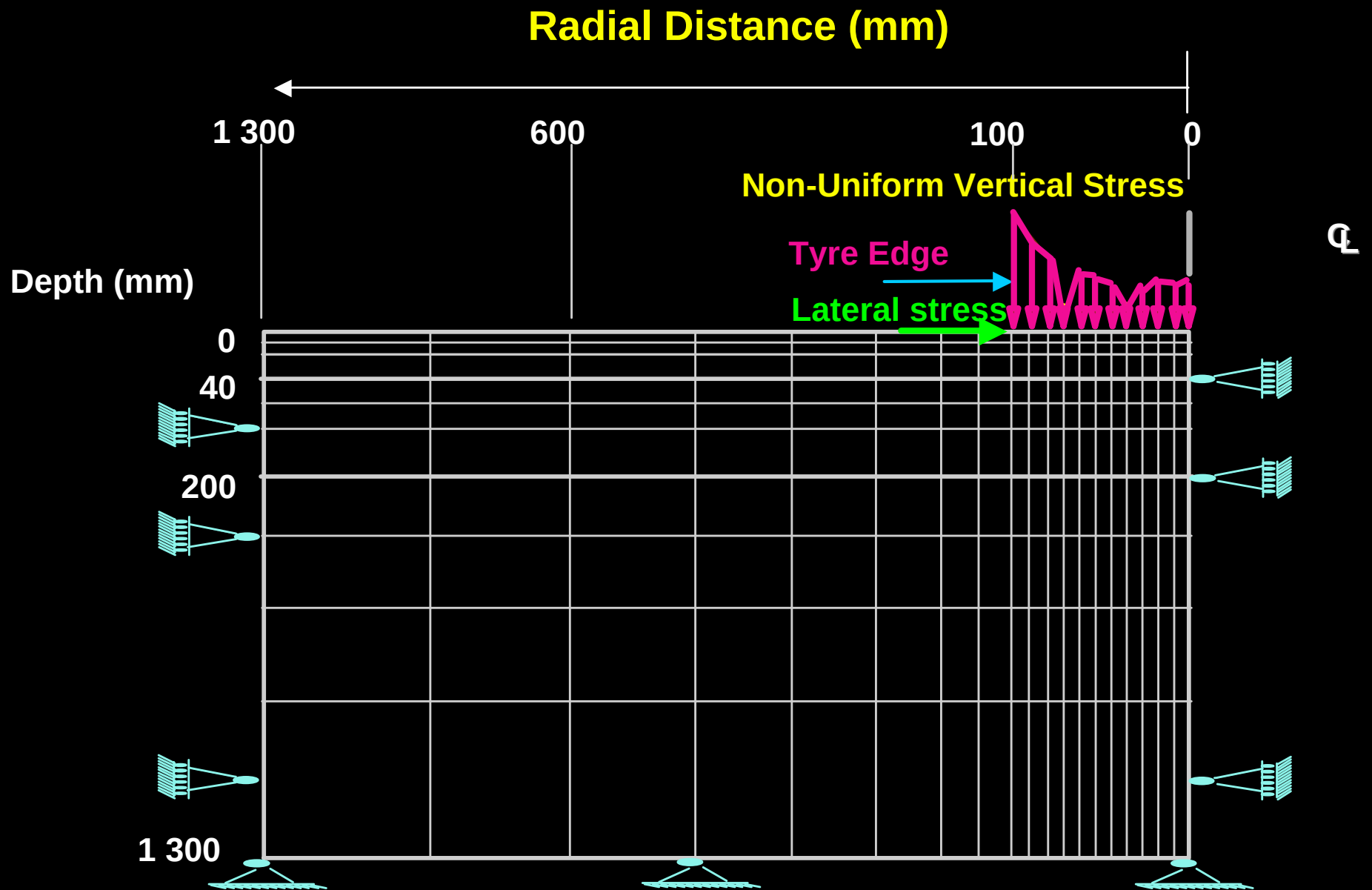
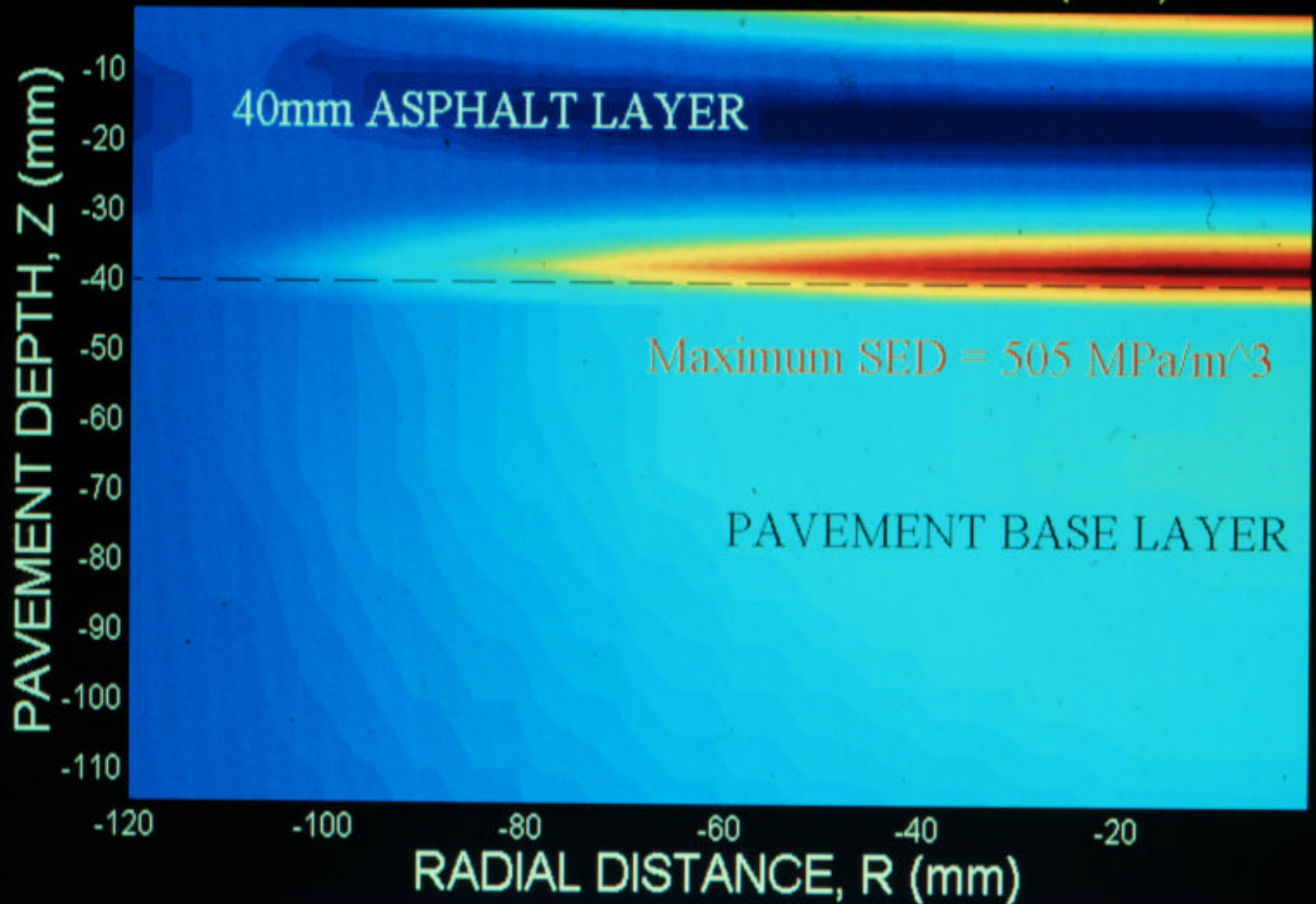


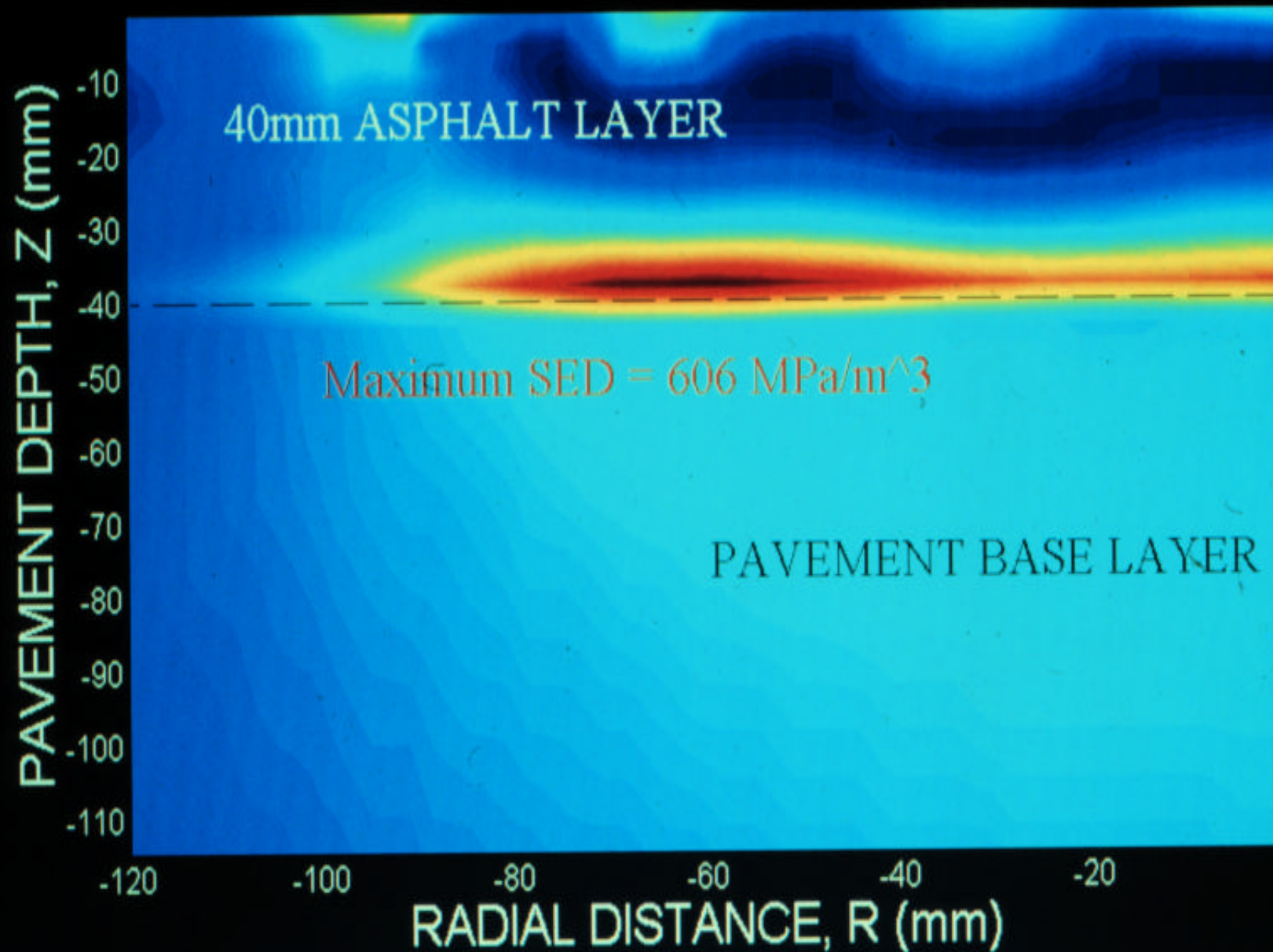
FIGURE: 29

**Axi-symmetrical Finite Element Model
used in this study**

UNIFORM VERTICAL STRESS (520 kPa)
STRAIN ENERGY OF DISTORTION (SED)

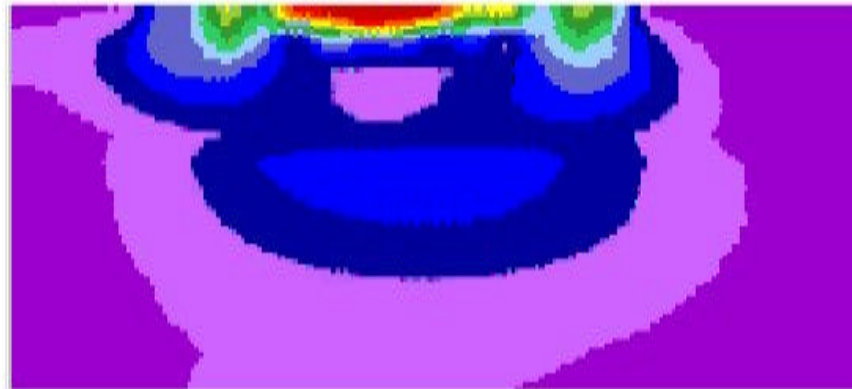


NON-UNIFORM STRESS (EDGE) (420 kPa)
STRAIN ENERGY OF DISTORTION (SED)



Pseudo-Energy under non-uniform contact stress conditions

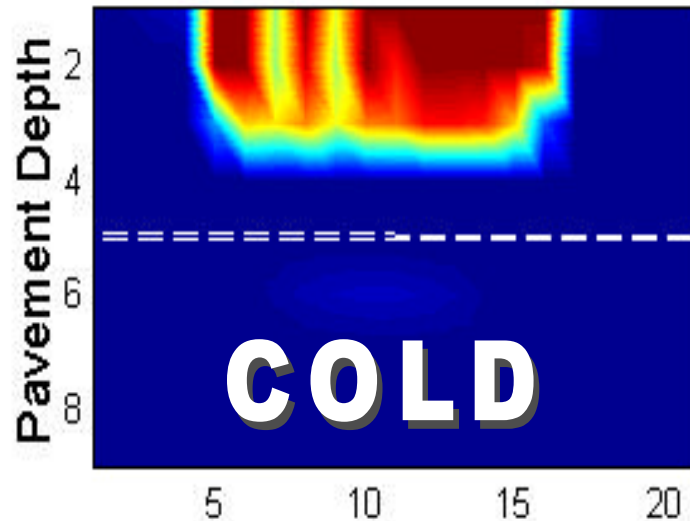
(Symplectic Engineering Corporation, USA)



Colour maps of (Symplectic Engineering Corporation)



SIM - 600 kPa, 35 kN

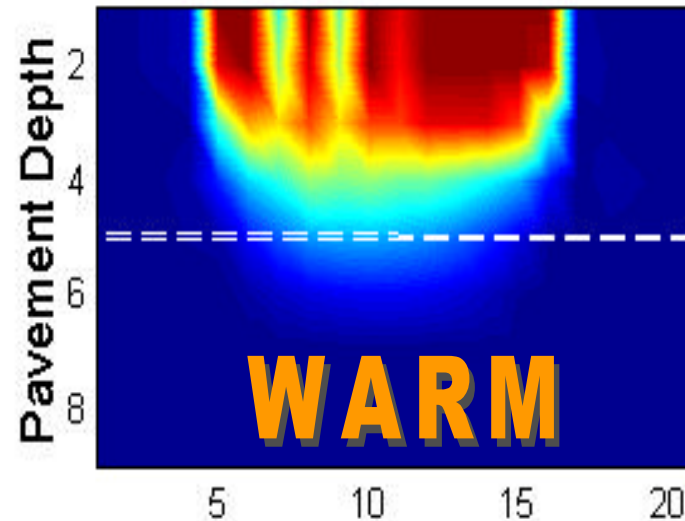


Across Tyre 1.14 (Max. Stress)
KEY:

VERTICAL STRESS:
C(kPa) = 2000, 1150, 150
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading

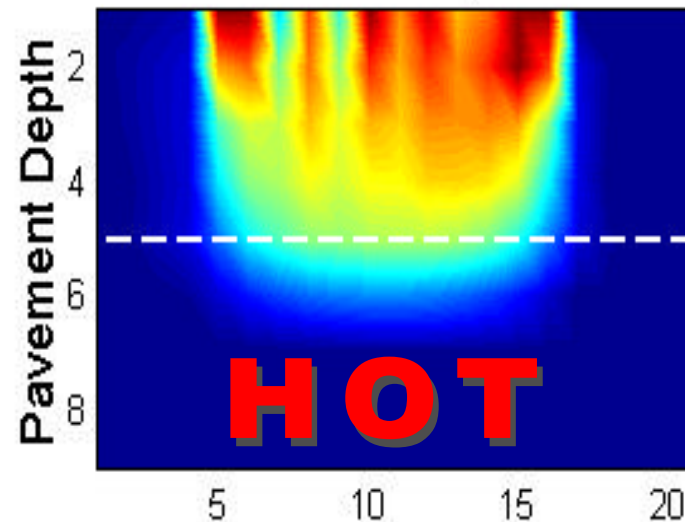


SIM - 600 kPa, 35 kN



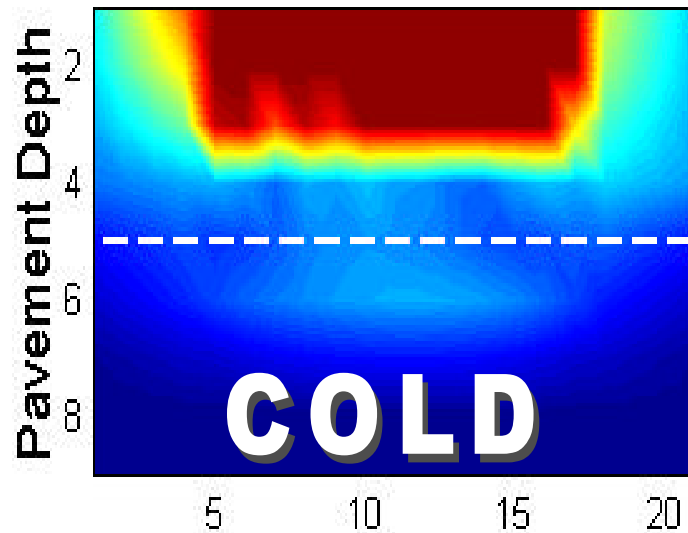
Across Tyre 1.07 (Max. Stress)

SIM - 600 kPa, 35 kN

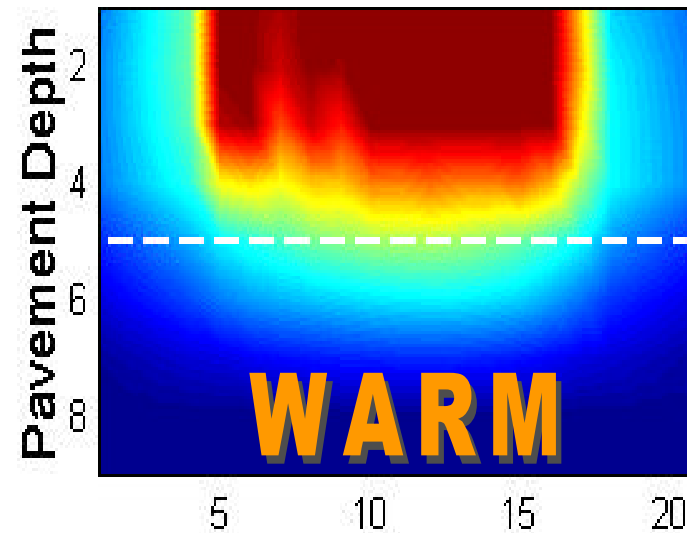


Across Tyre 0.911 (Max. Stress)

SIM - 600 kPa, 35 kN



SIM - 600 kPa, 35 kN

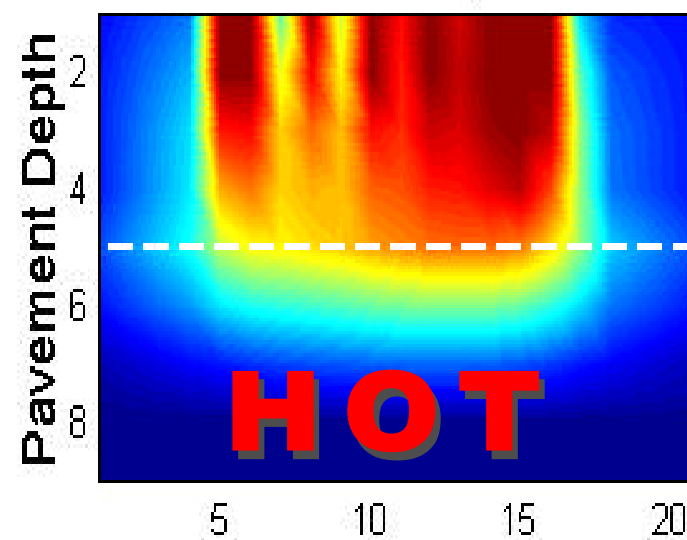


KEY: Across Tyre 1.87 (Max. 1/3 Bulk Stress) Across Tyre 1.36 (Max. 1/3 Bulk Stress)

(1/3) BULK STRESS:
C(kPa) = 2000, 1150, 150
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading

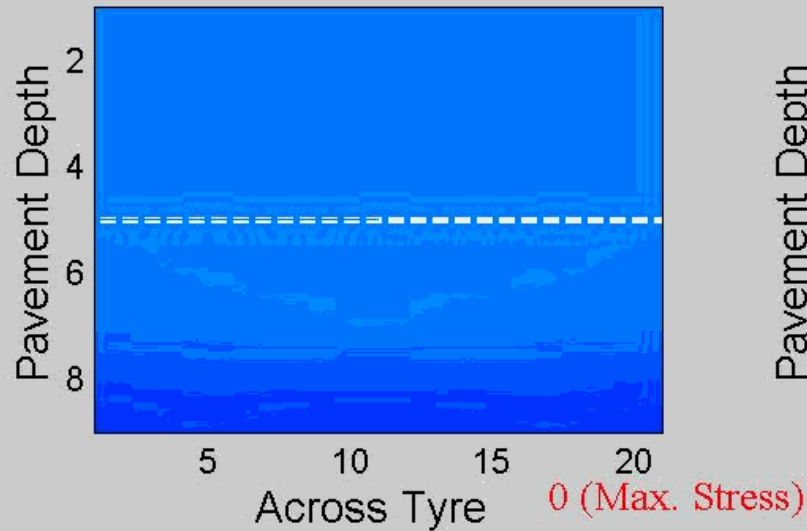


SIM - 600 kPa, 35 kN

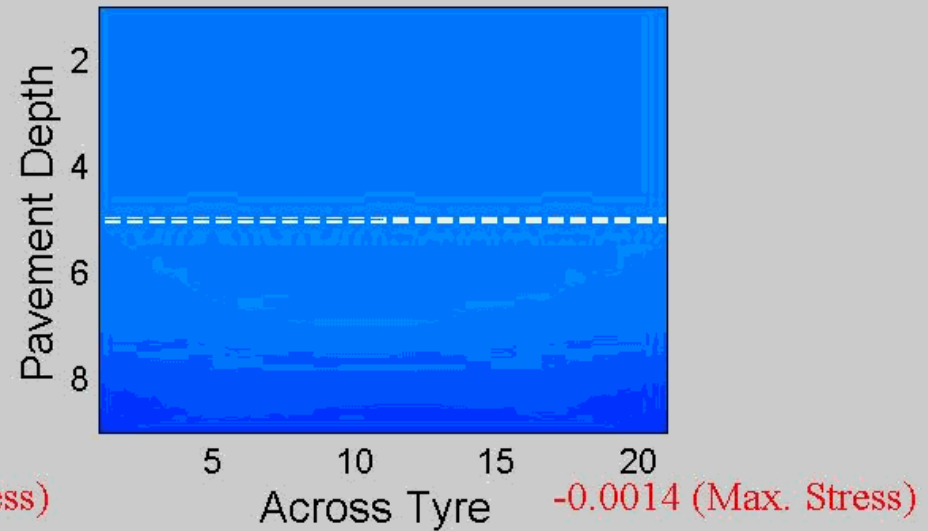


Across Tyre 0.998 (Max. 1/3 Bulk Stress)

UNIFORM LOAD - 520 kPa, 21 kN



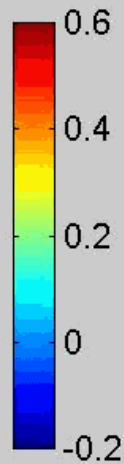
SIM - 600 kPa, 20 kN



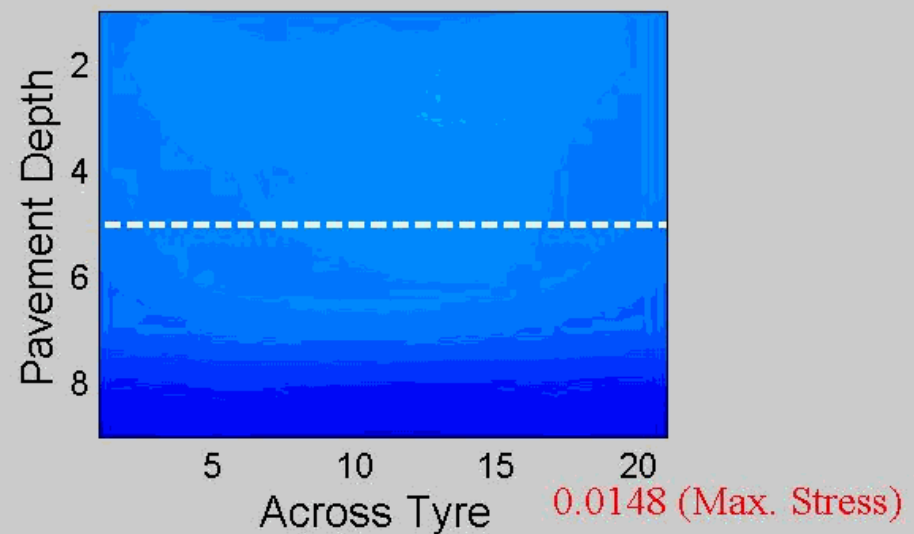
KEY:

VERTICAL STRESS:

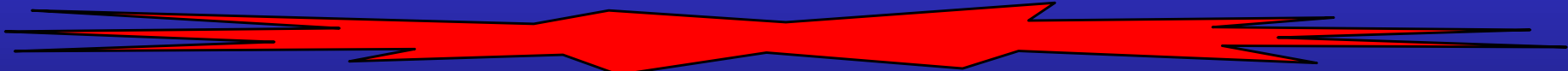
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading



SIM - 600 kPa, 35 kN



CONCLUSIONS.....

- 
- SIM Technology resulted in improved pneumatic tyre/pavement contact stress definitions;
 - Improved selection of HVS *tyre and inflation pressure* levels;
 - Improved potential for *more rational* pavement design, performance and analysis methods;
 - Potential savings of Rmillions, if effectively employed...

A total solar eclipse is shown, with a bright, glowing ring of fire (the corona) surrounding the dark, circular disk of the Moon. The background is a deep black, and the light from the corona creates a soft, yellowish-green glow around the central dark area.

..the end..,

I Thank You all !