7th CAPSA '99: General Session 5: Innovation in Asphalt Pavement Design

Towards Improved Mechanistic Design of Thin Asphalt Layer Surfacings based on Actual Tyre/Pavement Contact Stress - In - Motion (SIM) data in South Africa

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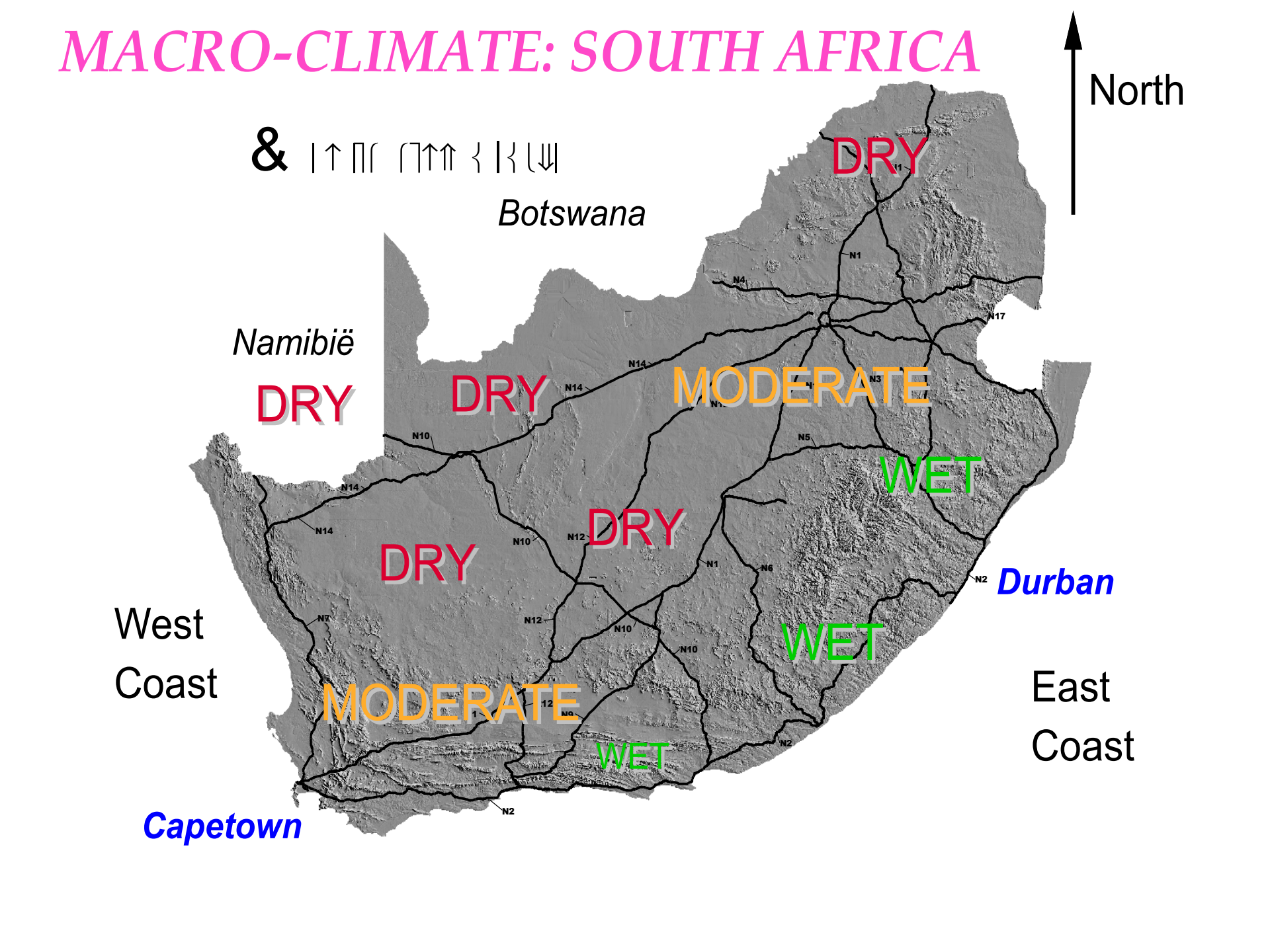
7th CAPSA: '99

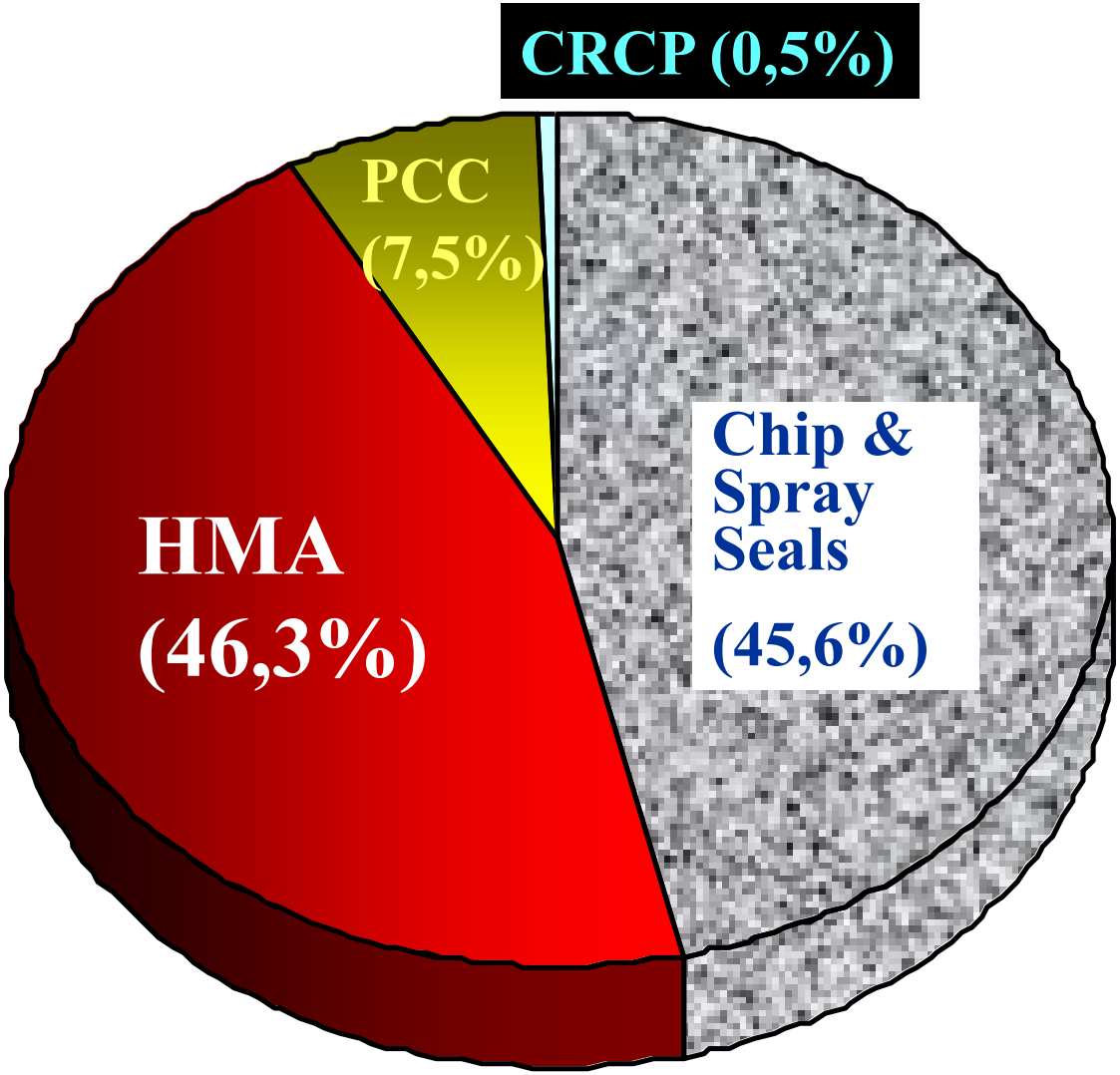
Stress - In - Motion (SIM) Technology

Stress – In – Motion (SIM) Technology = The measurement of 3D tyre/pavement contact stresses from moving vehicles

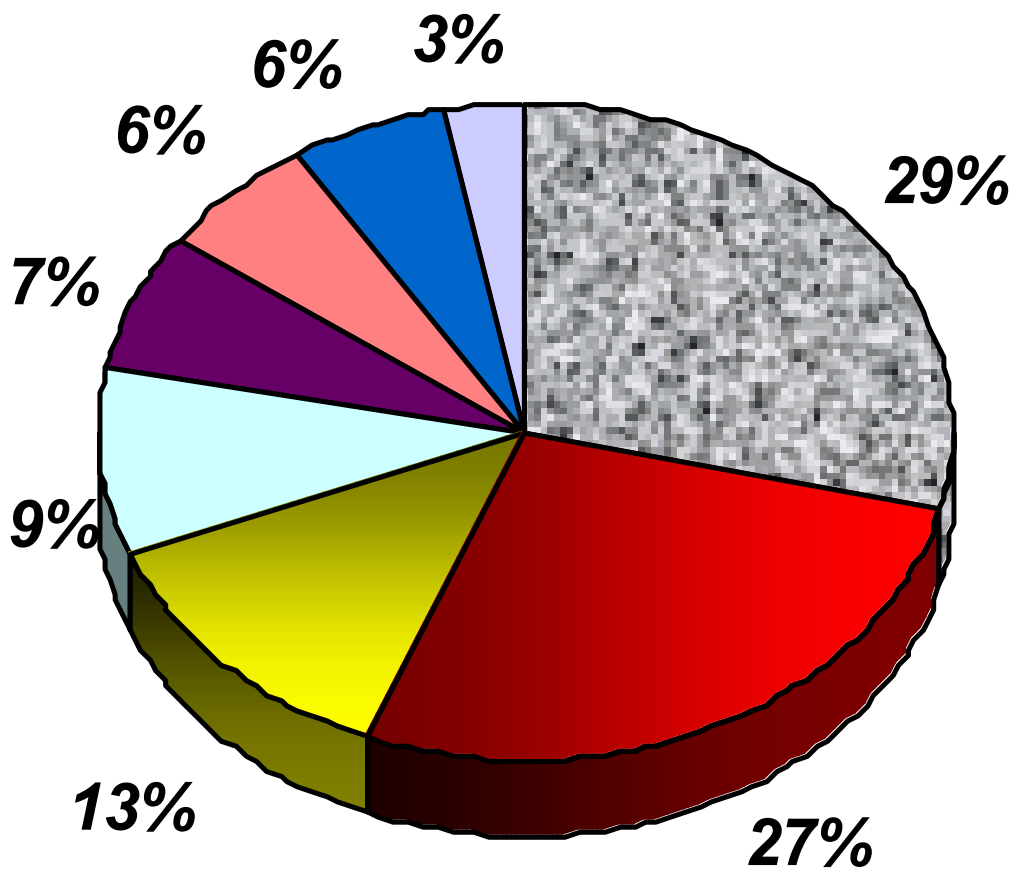
MACRO-CLIMATE: SOUTH AFRICA



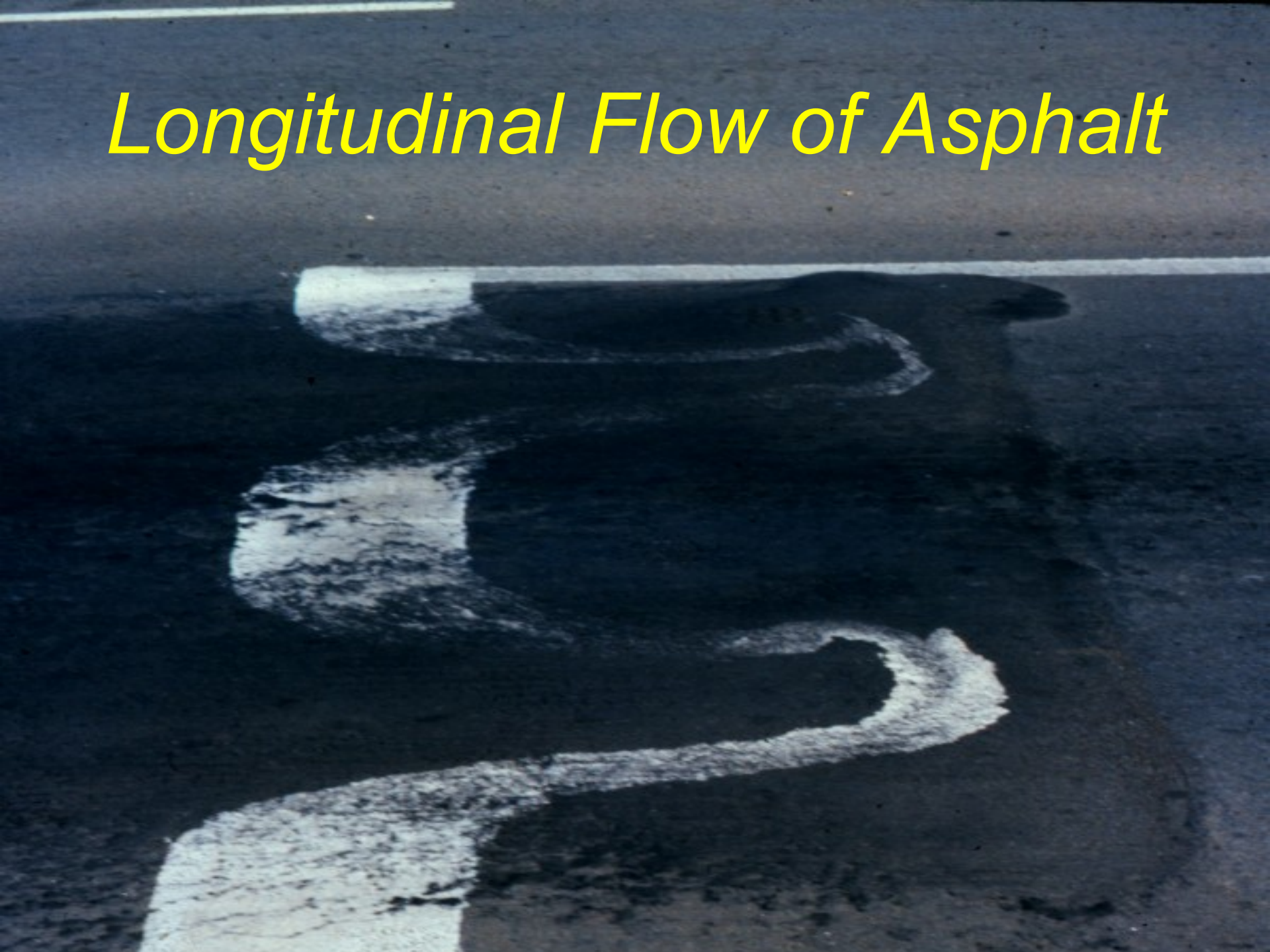
Surfacing Types of National Roads in South Africa (1997/8)



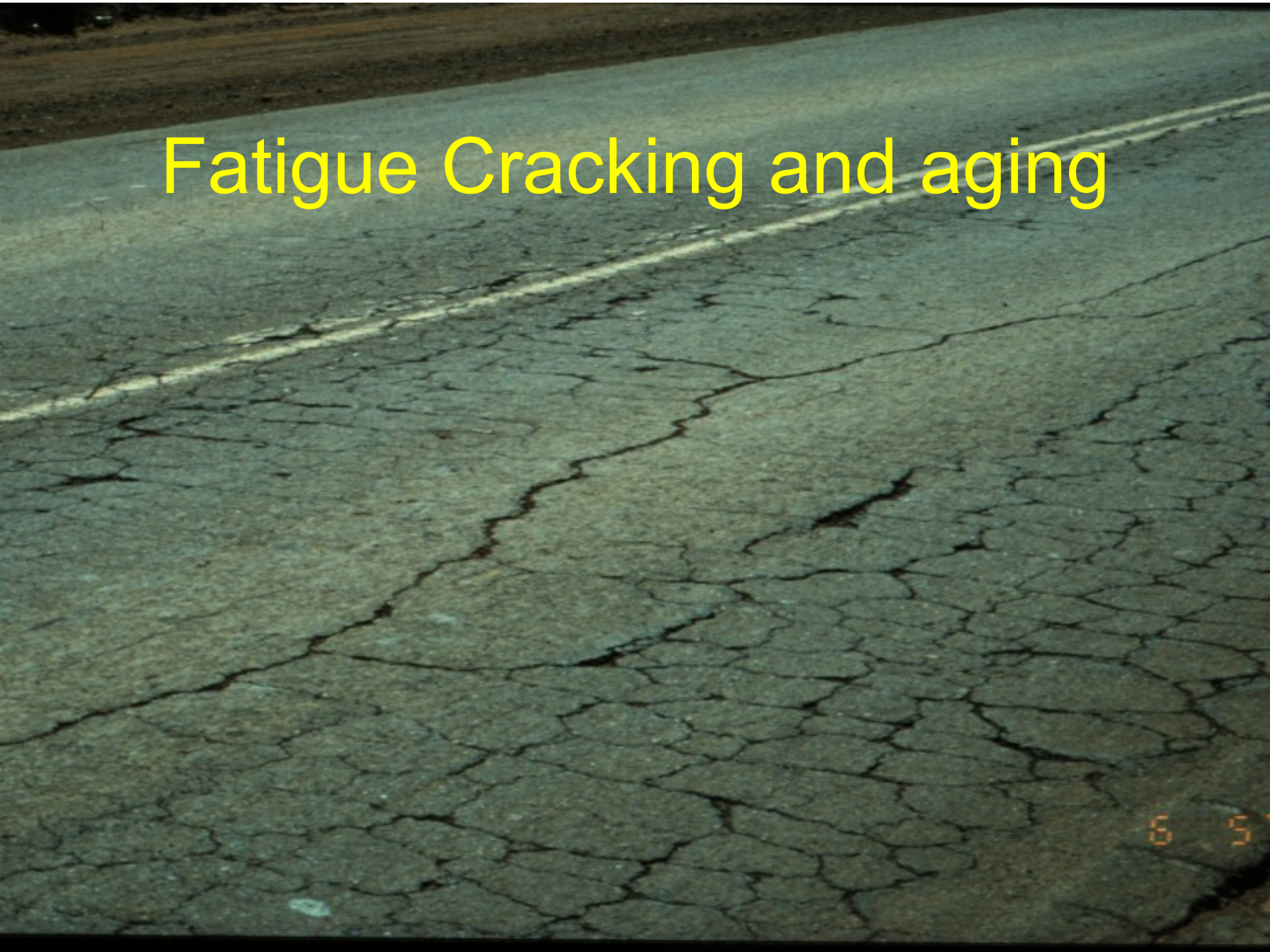
Base and Subbase Types of National Roads in South Africa (1997/8)



- G1/G2 Base on Stab Subbase (29%)
- G1/G2 Base on Nat gravel Subbase (27 %)
- HMA (13 %)
- PCC (9 %)
- C3/C4 Base on Nat gravel Subbase (7 %)
- C3/C4 Base on Stab gravel Subbase (6%)
- G3/G4/G5 Base on Nat Gravel Subbase (6%)
- G3/G4/G5 on Stab Subbase (3%)


Longitudinal Flow of Asphalt


Longitudinal Flow of Asphalt

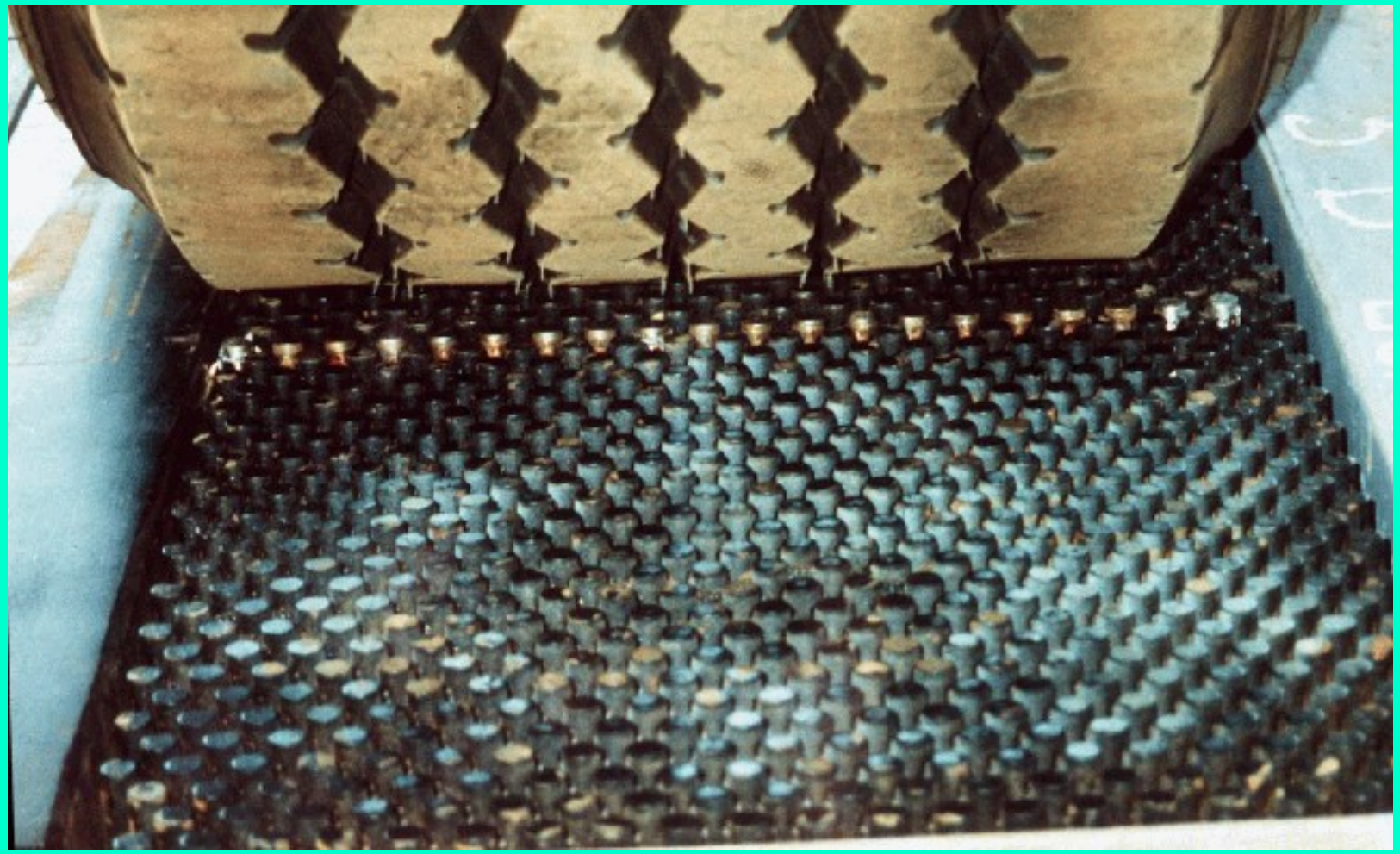

Fatigue Cracking and aging


SURFACE DISINTEGRATION

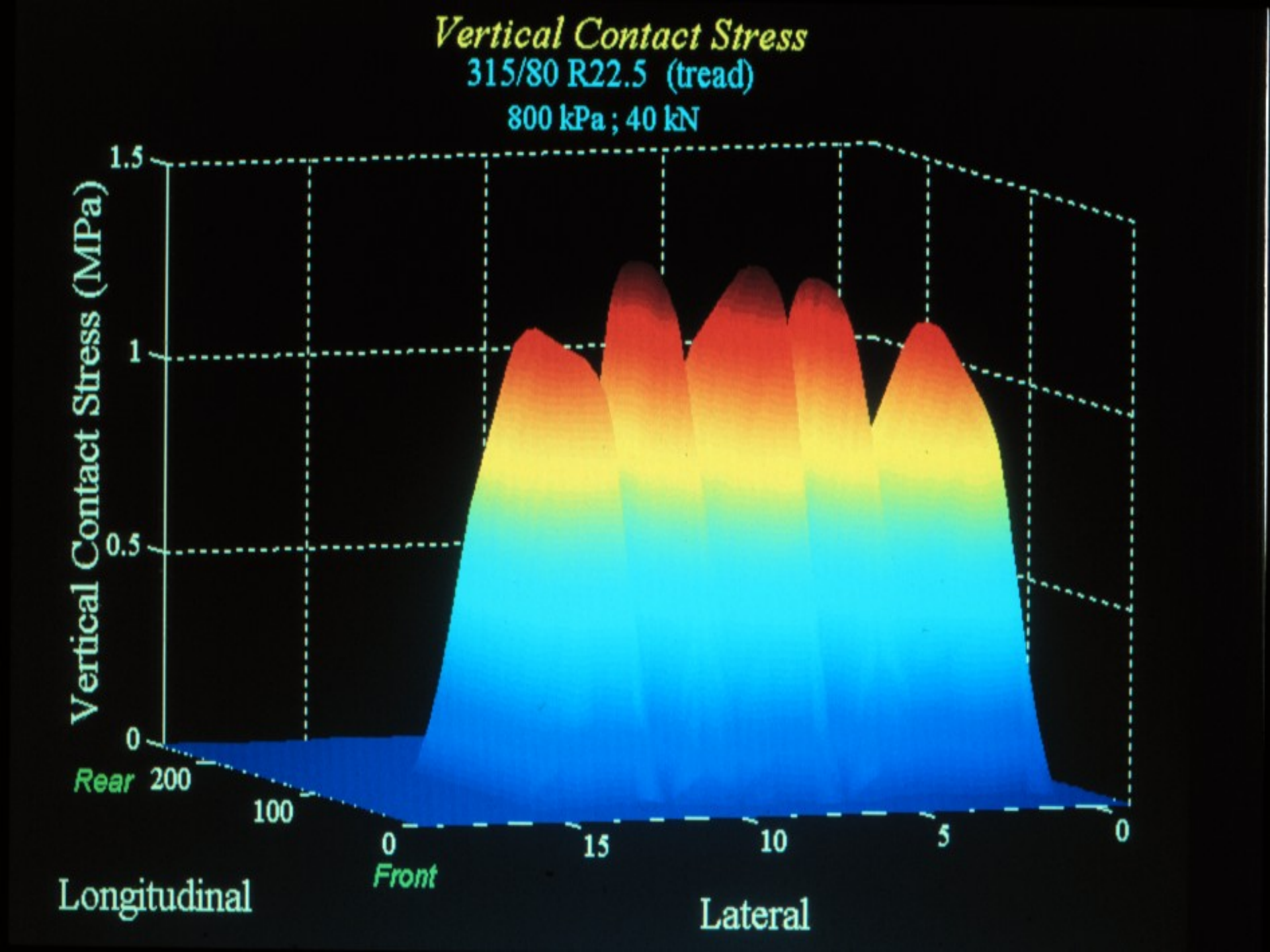
How to address the problem??

SIM Technology: Vehicle-Road Surface Pressure Transducer Array (VRSPTA)

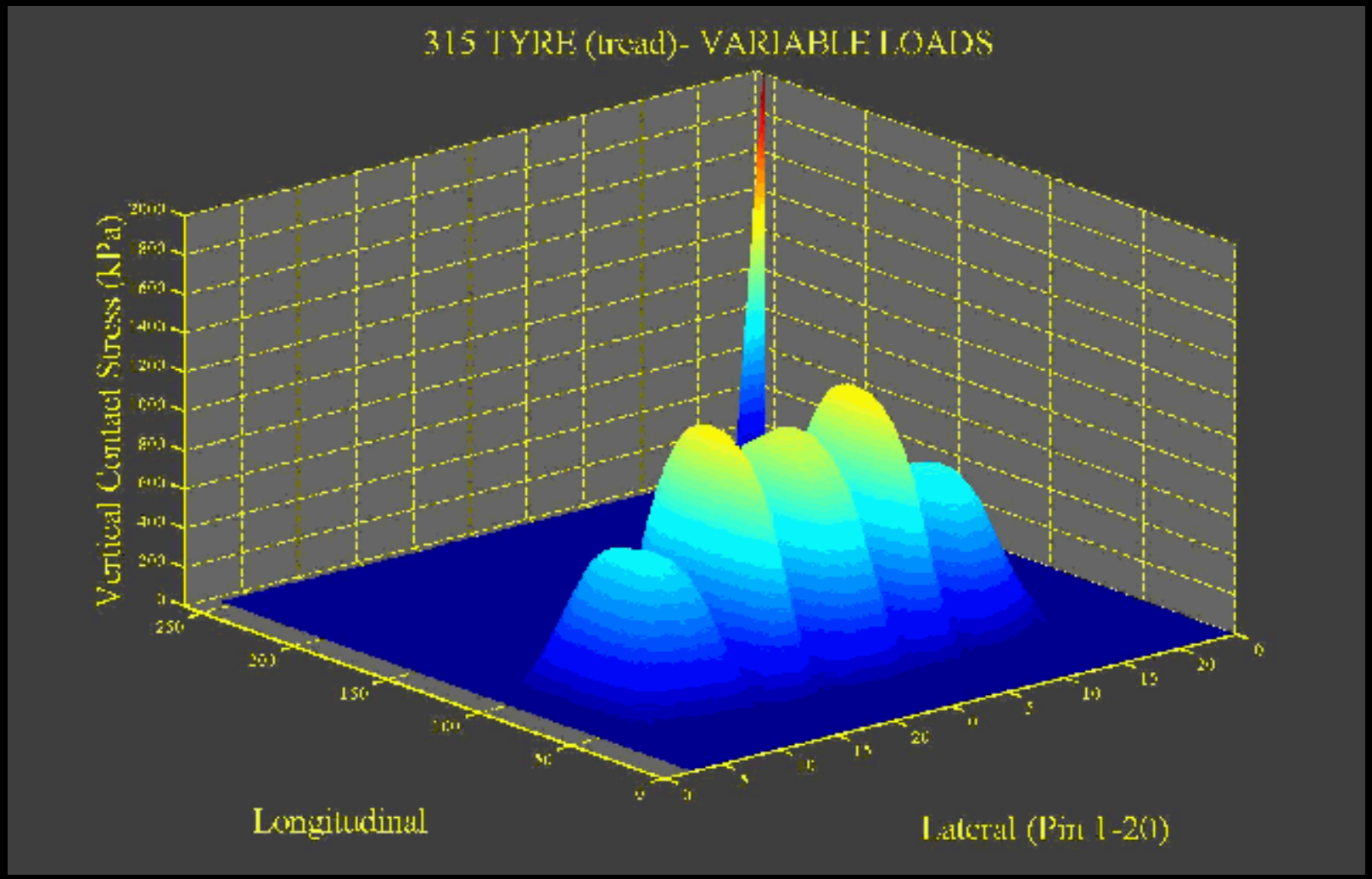
315/80 R22.5 HVS TYRE ON VRSPTA



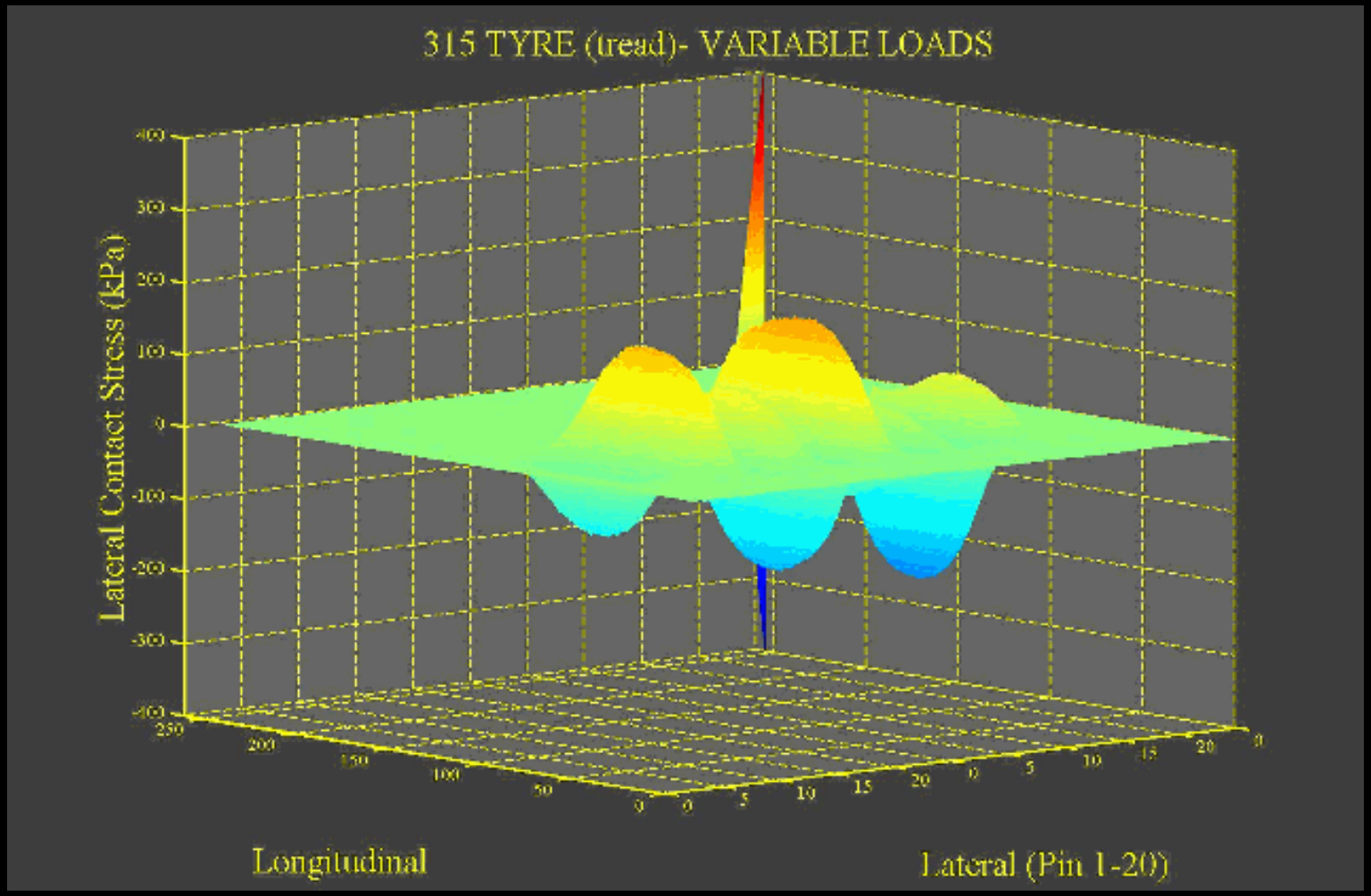
425 /65 R22.5 HVS TYRE ON VRSPTA


Vertical Contact Stress
315/80 R22.5 (tread)
800 kPa ; 40 kN
Vertical Contact Stress (MPa)
1.5
1
0.5
0
Rear
200
100
0
Front
Longitudinal
15
10
5
0
Lateral

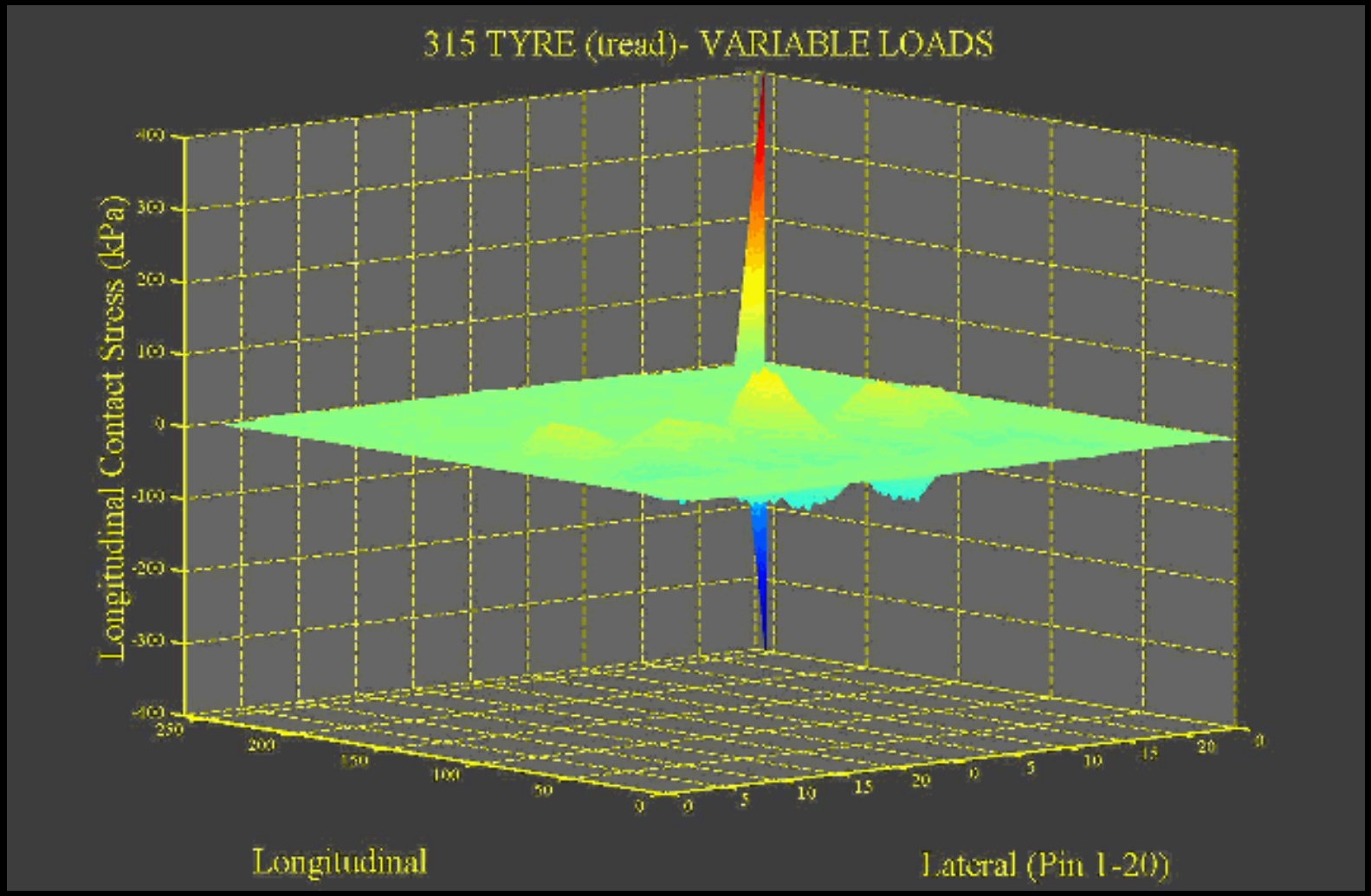
VERTICAL CONTACT STRESS: VARIABLE LOADING (315 TIRE)



LATERAL CONTACT STRESS: (Across 315 TIRE)



LONGITUDINAL CONTACT STRESS: (Along 315 Tire)



TYRES


17 7'96

Tyre Inflation Pressure in South Africa:

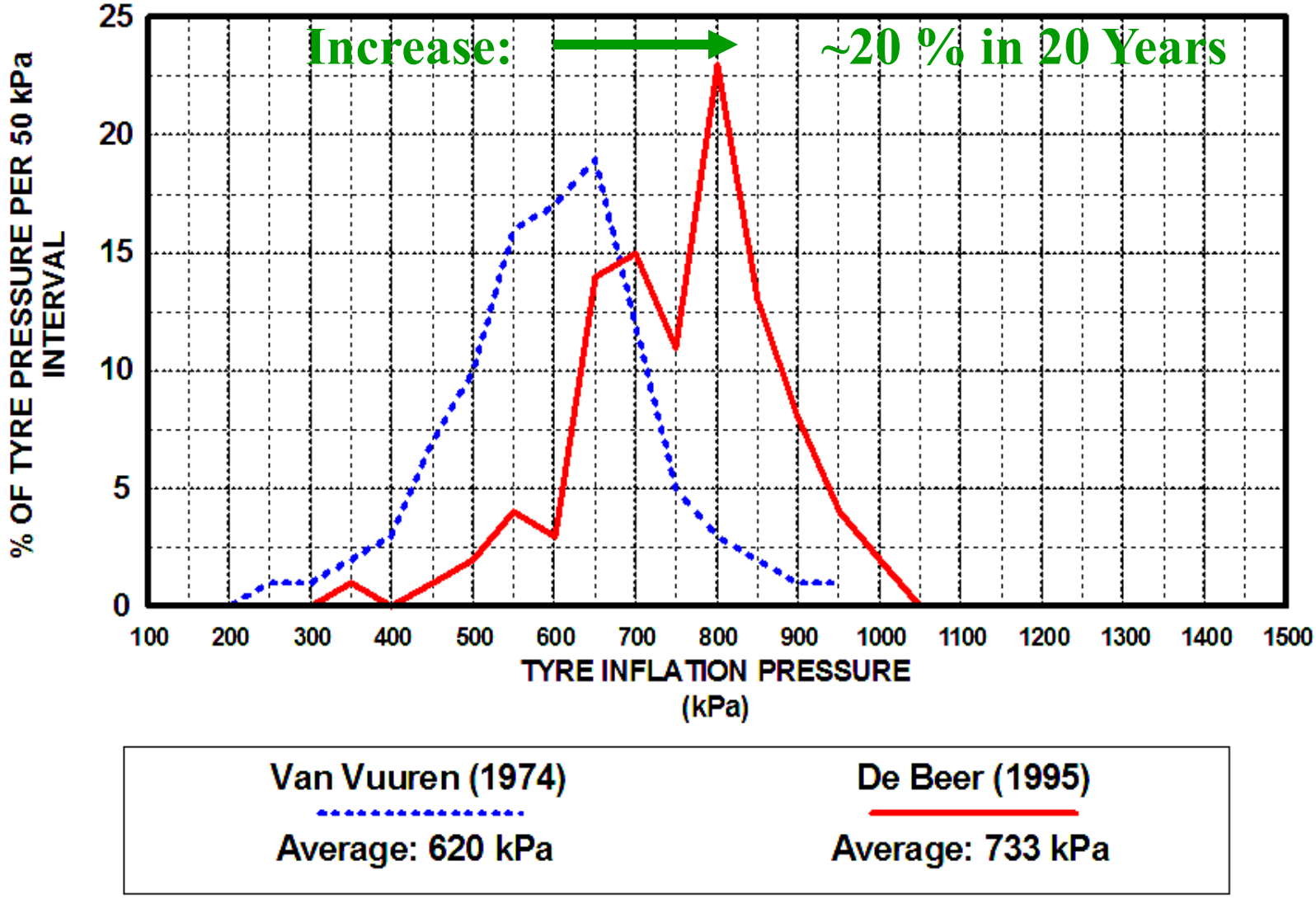
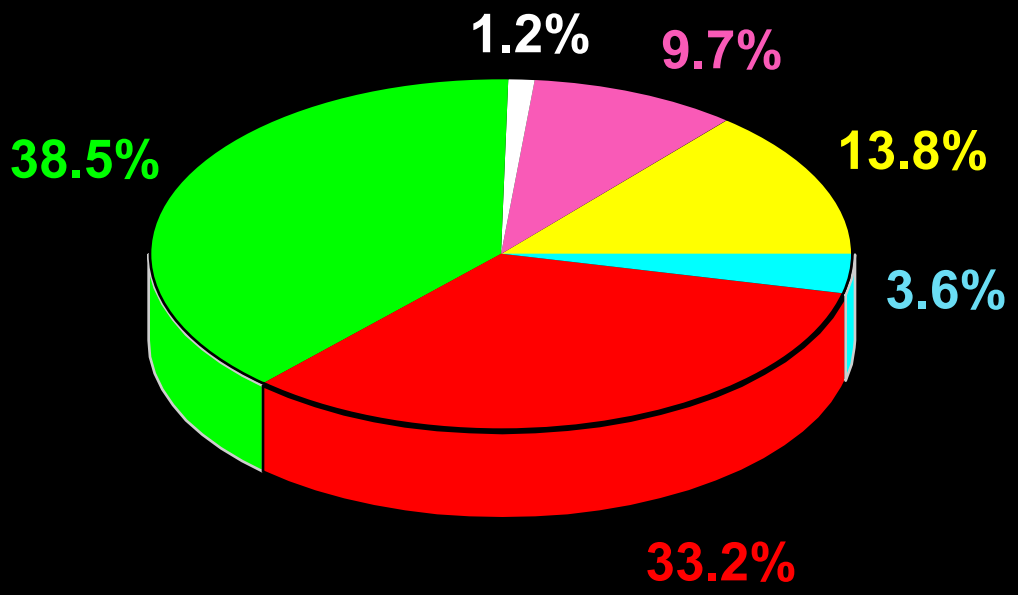


FIGURE 1

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

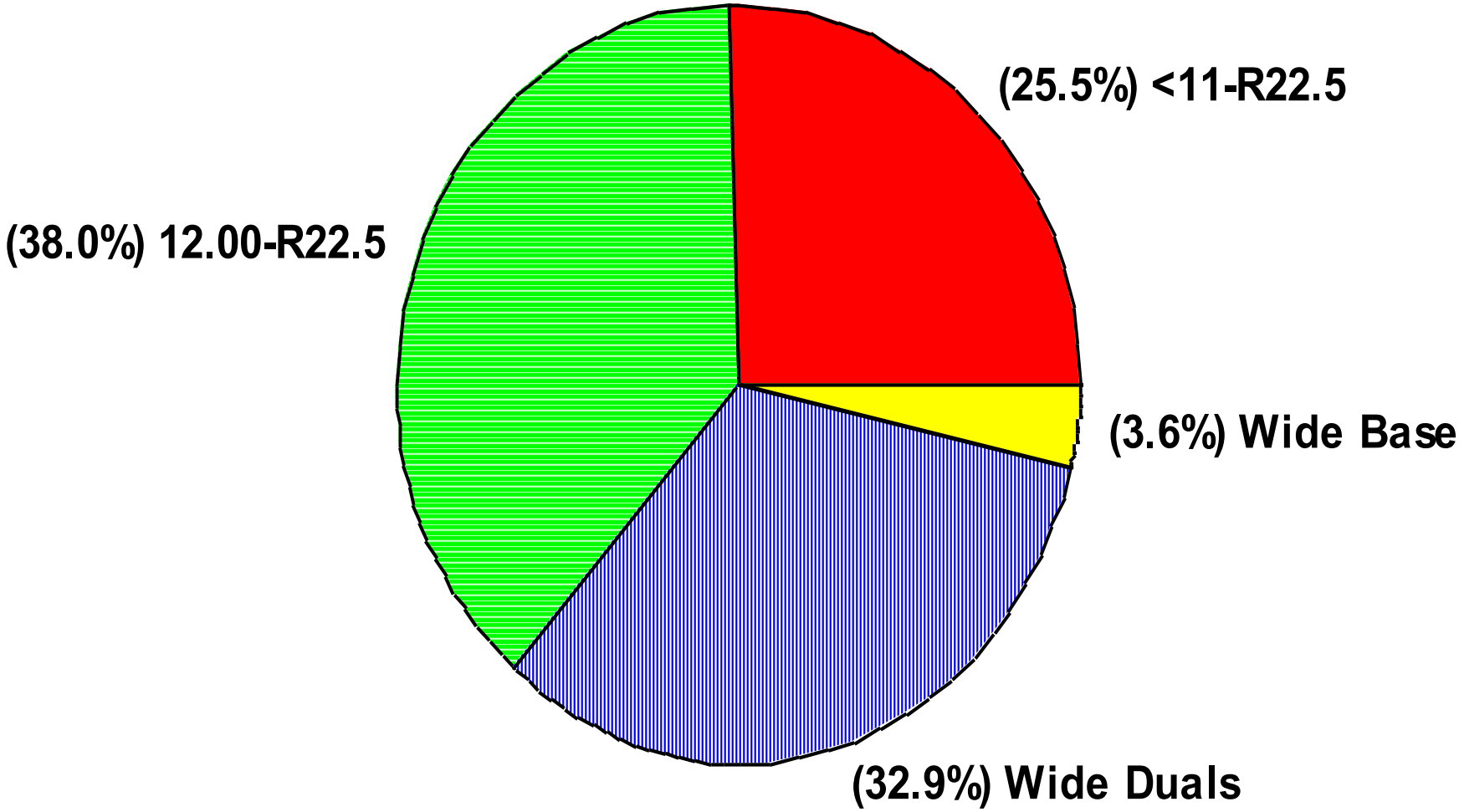
c:/capsaf1.wmf

Tyres: Heavy vehicles: Axle Loads > 7 000 kg
Survey: 1995



Distribution of heavy truck tyre types in South Africa

NOMINAL DISTRIBUTION OF TRUCK TYRE TYPES IN SOUTH AFRICA (1995/6)



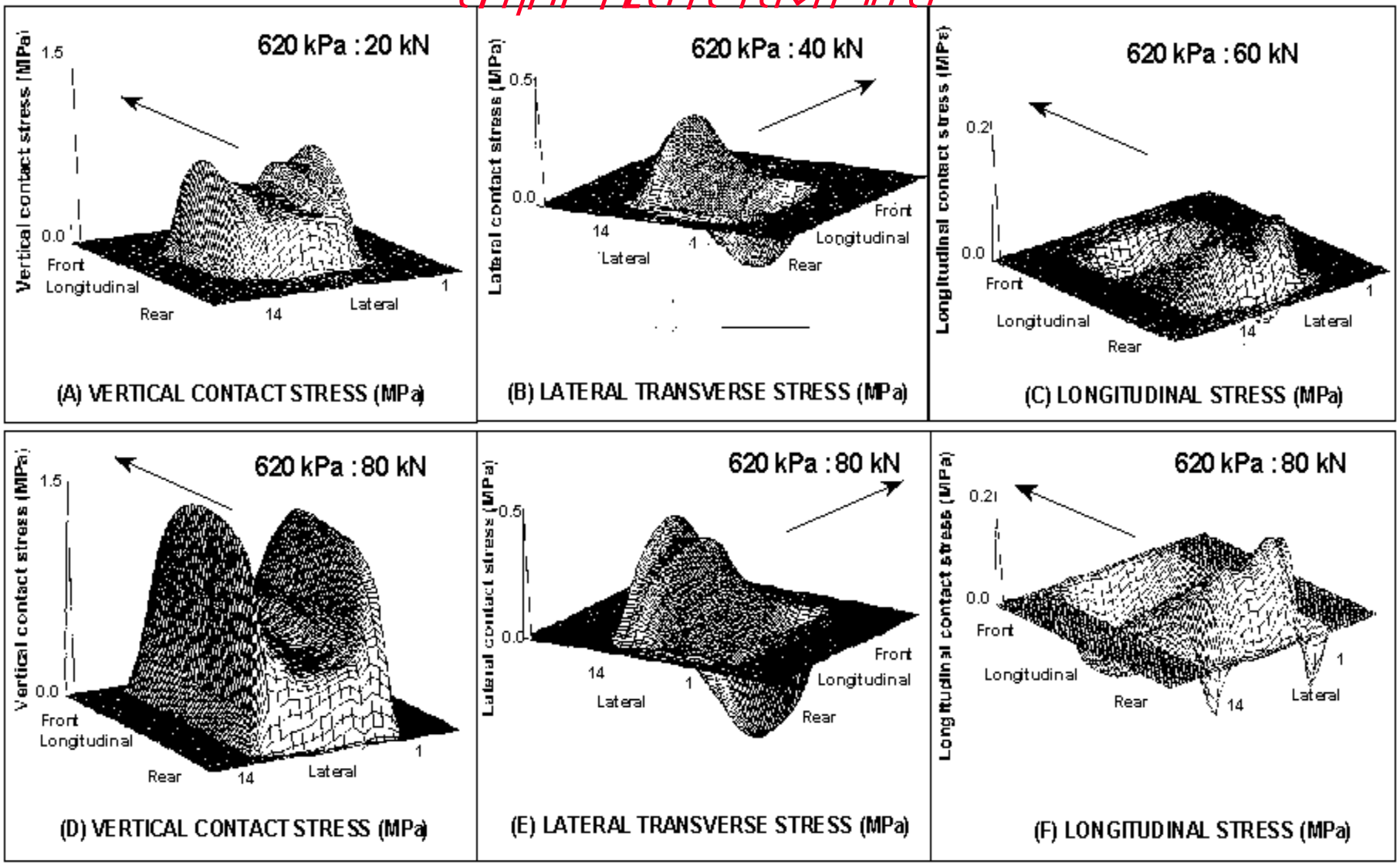


FIGURE 1a : Typical contact stress distributions measured with the VRSPTA system for a slow moving (1,2 km/h) free rolling smooth single truck tyre (Goodyear 11.00 X 20, 14 Ply rating) . The arrows indicate the direction of the rolling tyre during measrement. (After De Beer et al, 1997)

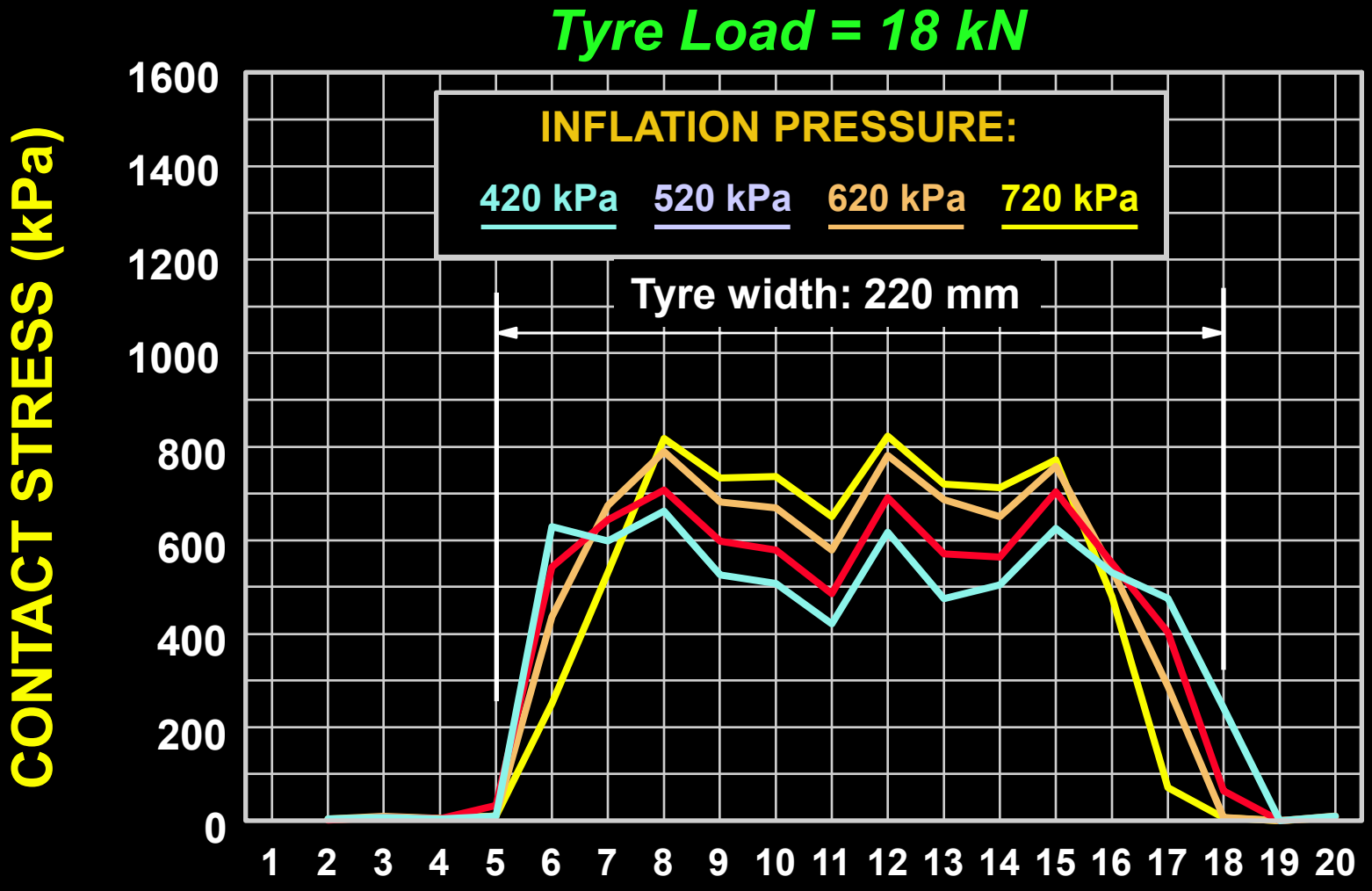


FIGURE 11

Maximum vertical stress at CONSTANT LOAD and various inflation pressures

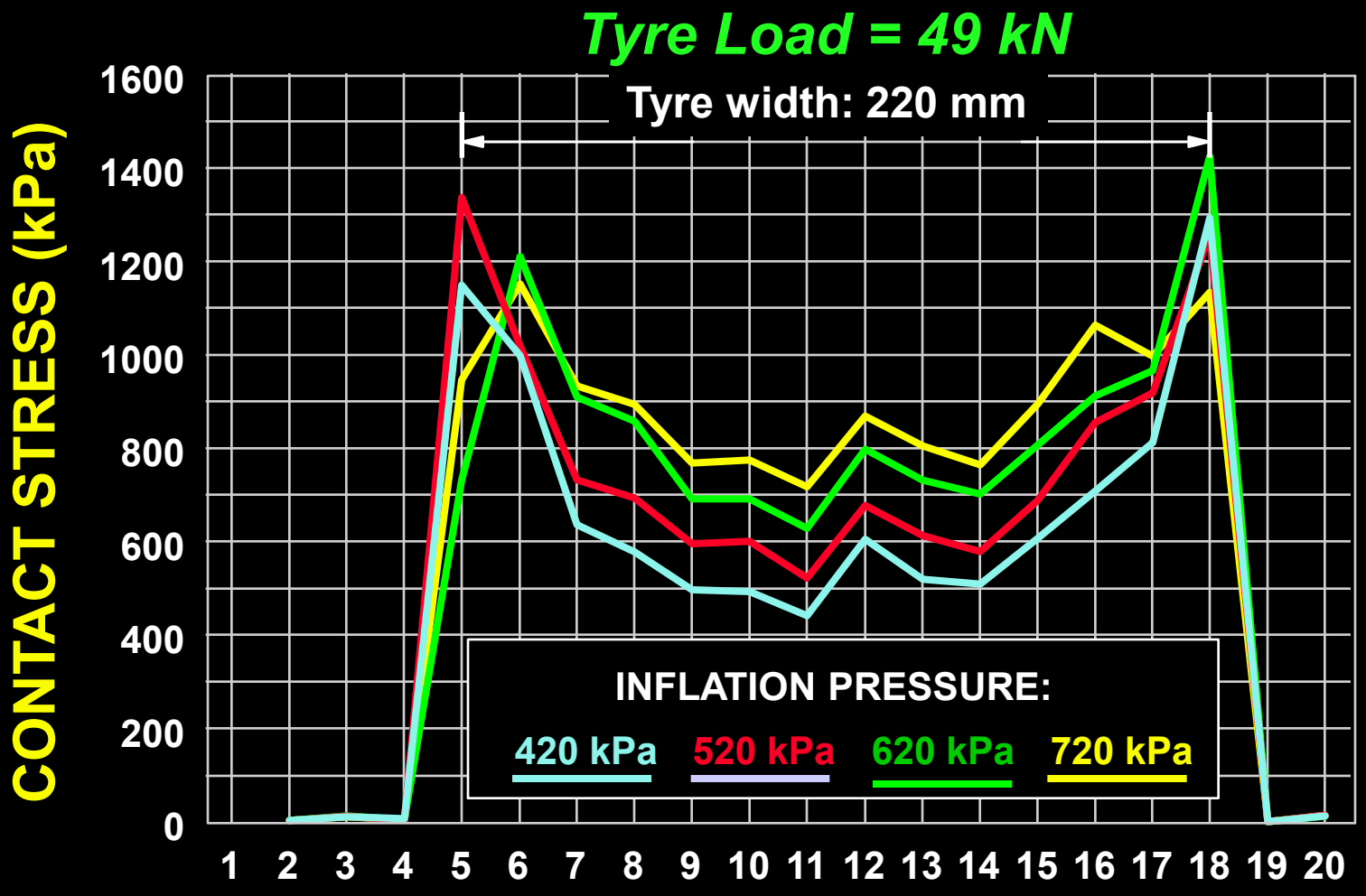


FIGURE 12

Maximum vertical stress at CONSTANT LOAD and various inflation pressures

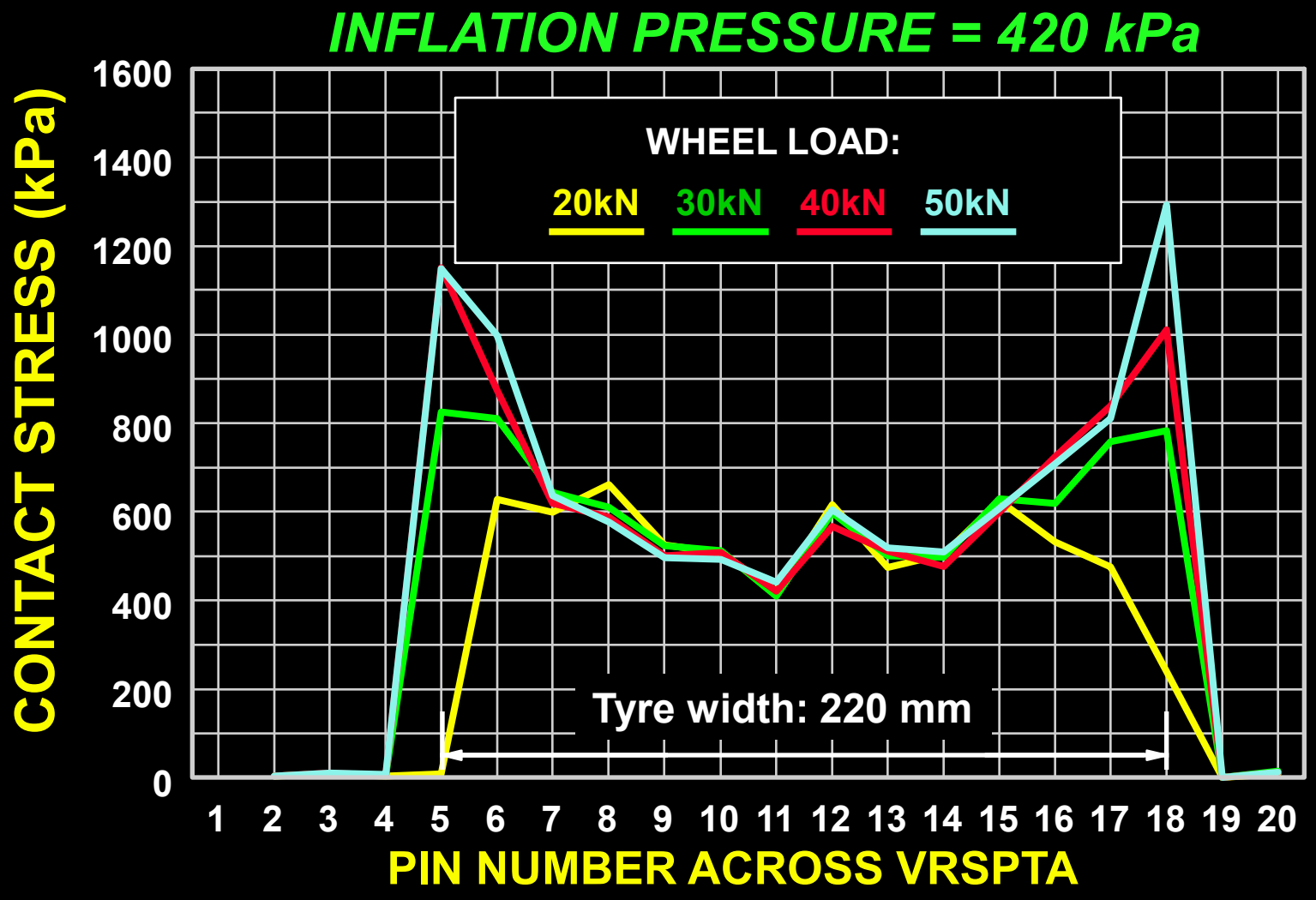


FIGURE 13

Maximum vertical stress at CONSTANT INFLATION PRESSURE at various loads

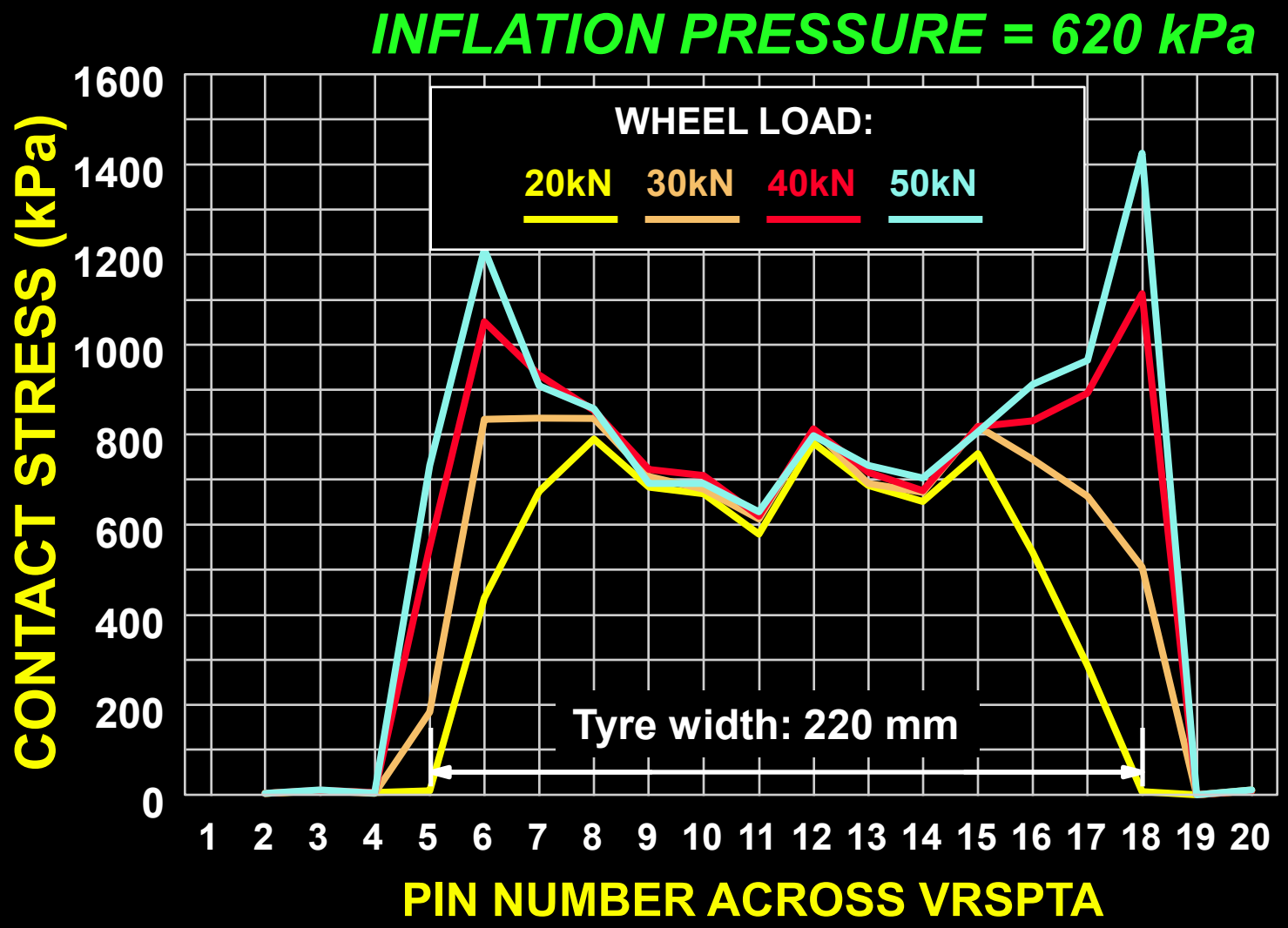
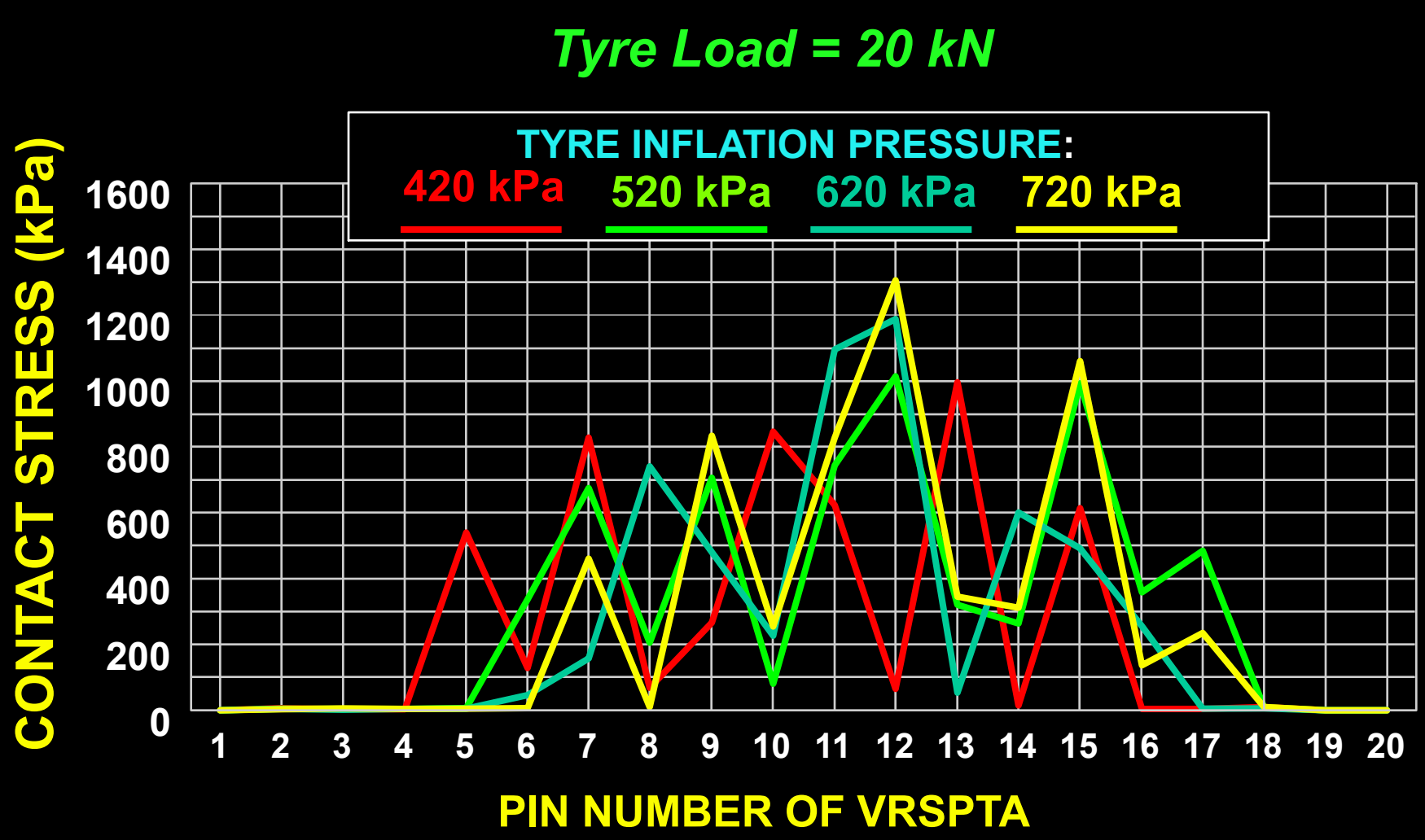
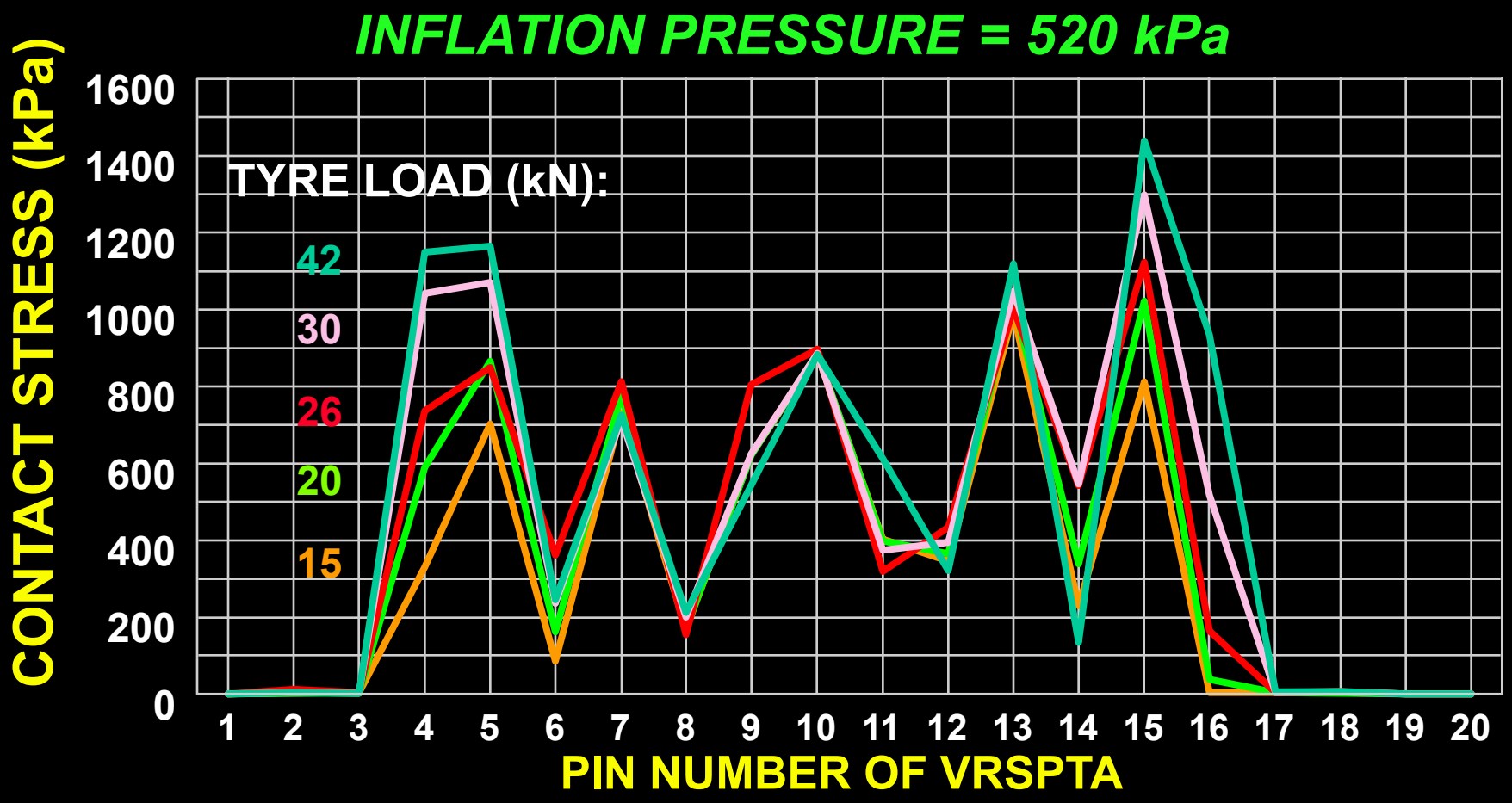


FIGURE 14

Maximum vertical stress at CONSTANT INFLATION PRESSURE and various loads



Maximum vertical stress of tyre with tread grooves at CONSTANT LOAD and various inflation pressures



Vertical stress of tyre with tread grooves at CONSTANT INFLATION PRESSURE and various loads

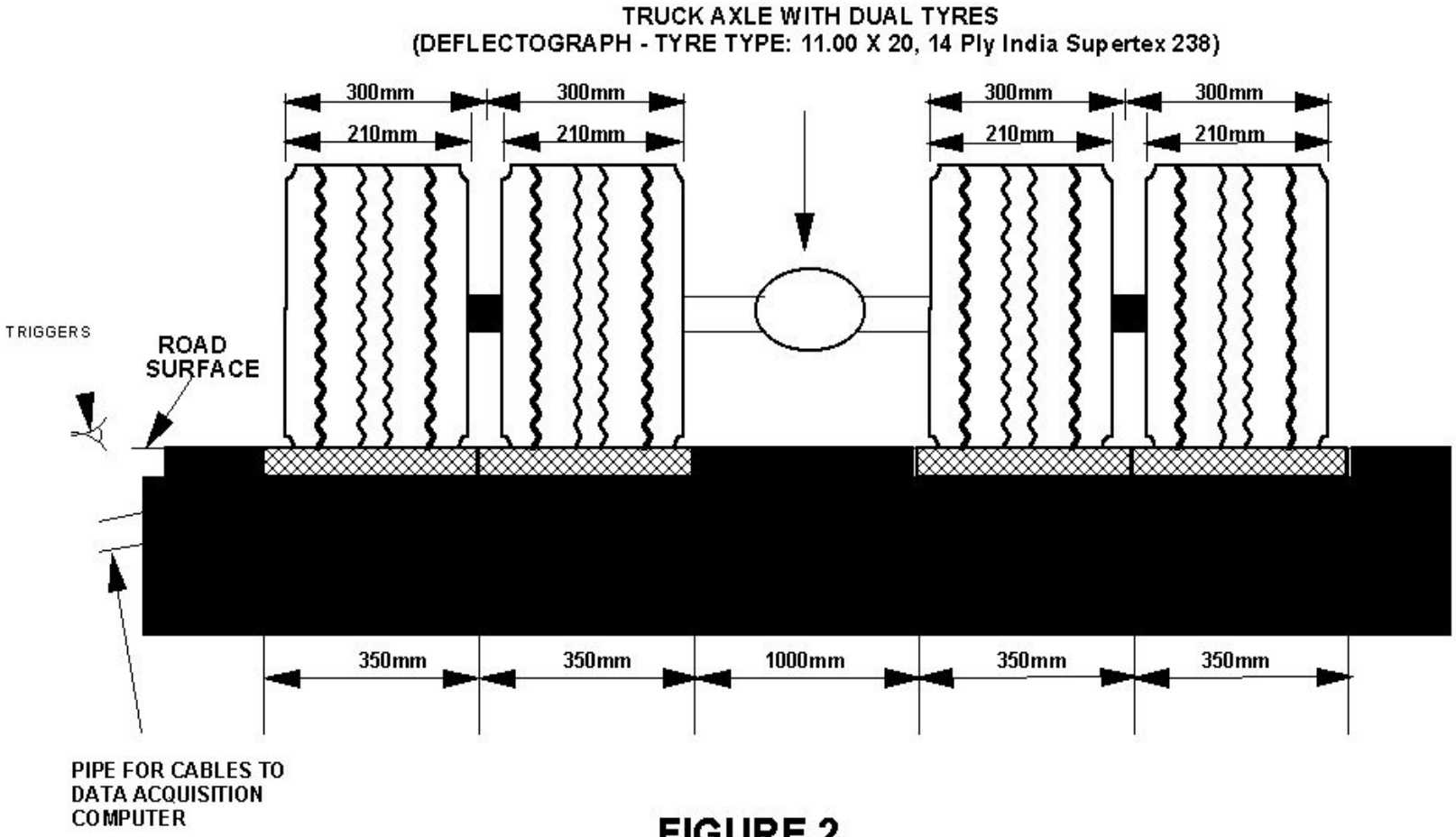


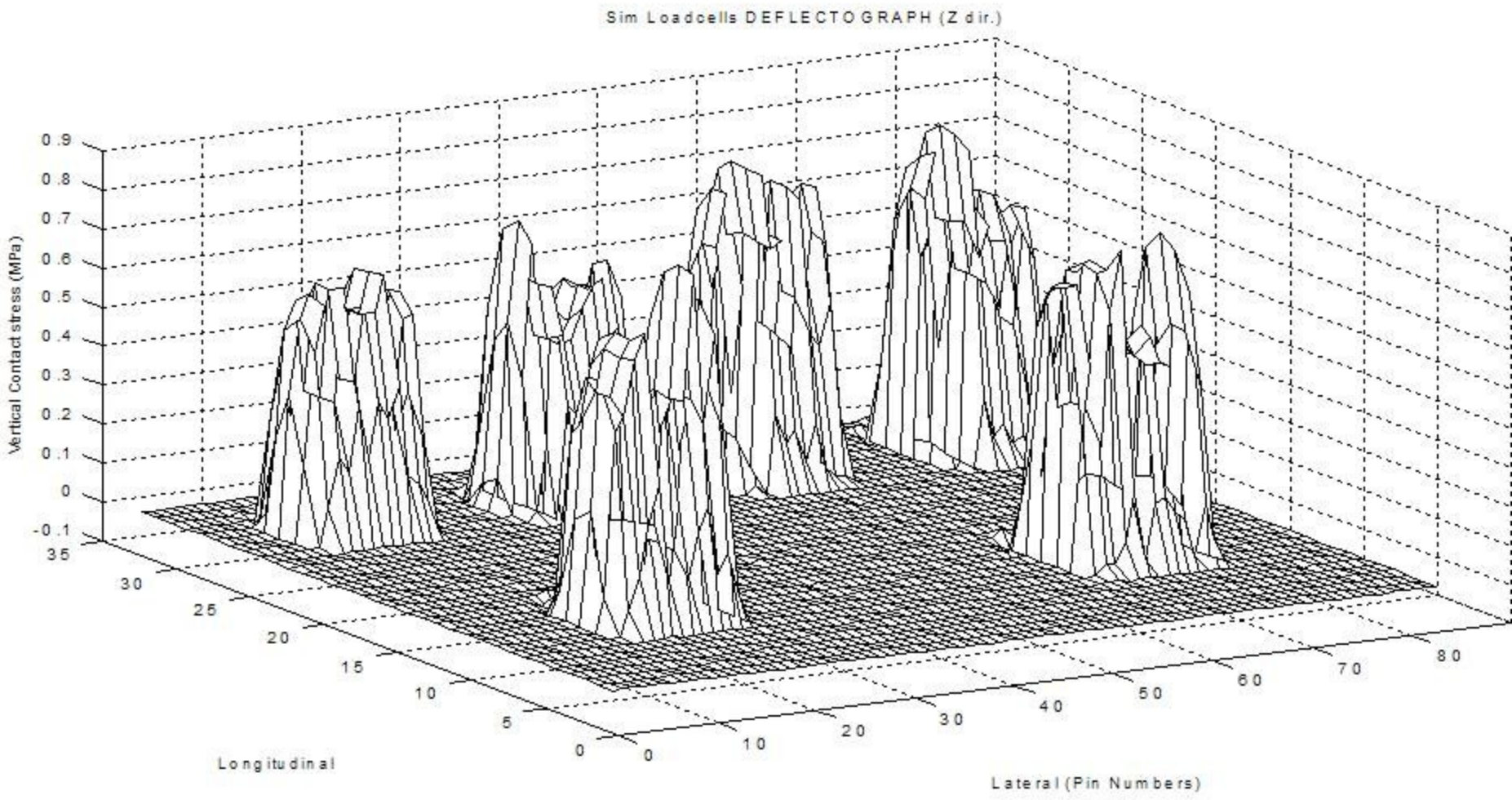
FIGURE 2

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

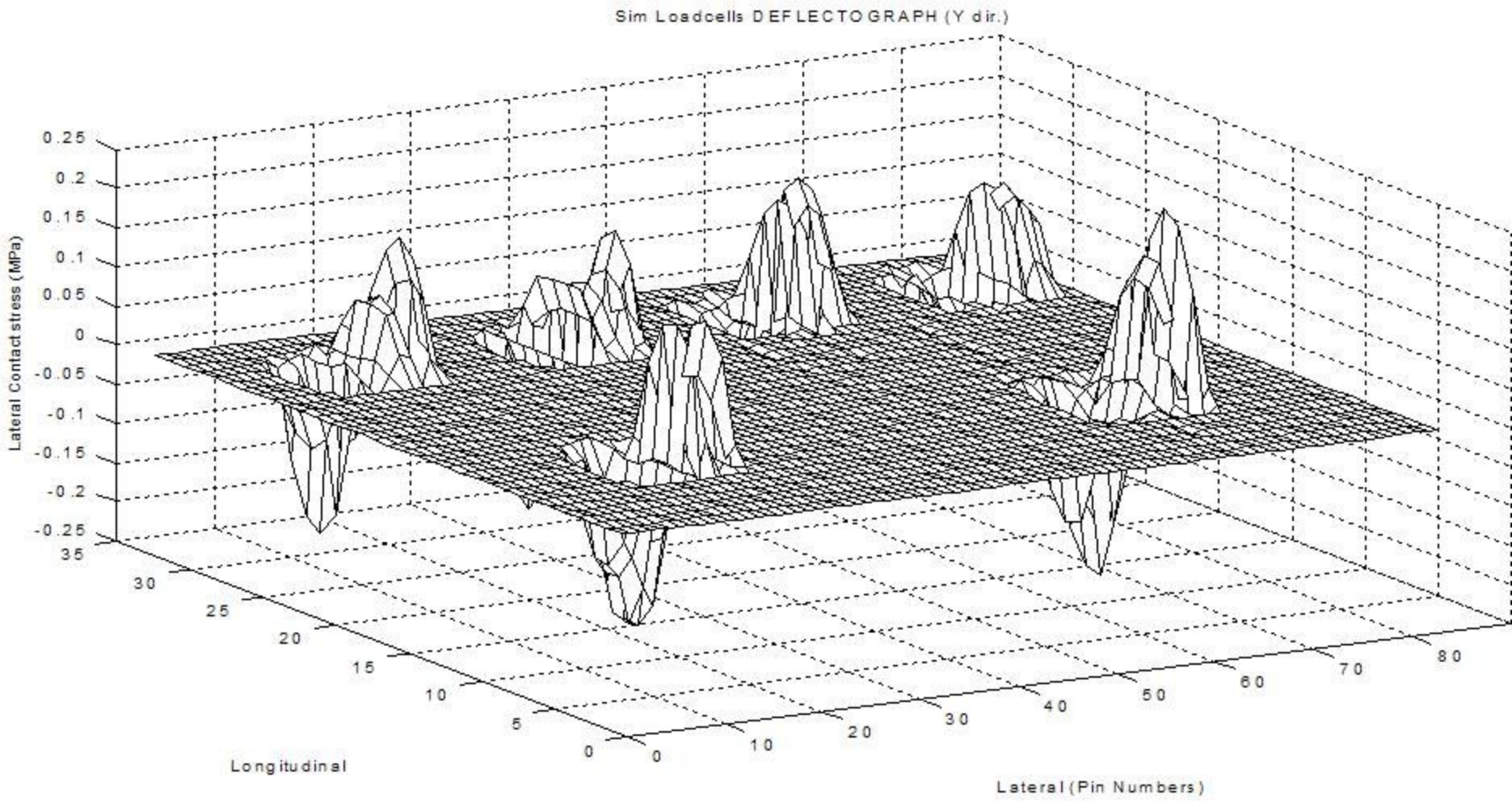
SIM3.DRW


WARNING
PASOP
STADIGE
TOETS
VOERTUIG
CAUTION
SLOW
TEST
VEHICLE
80
KMP270T

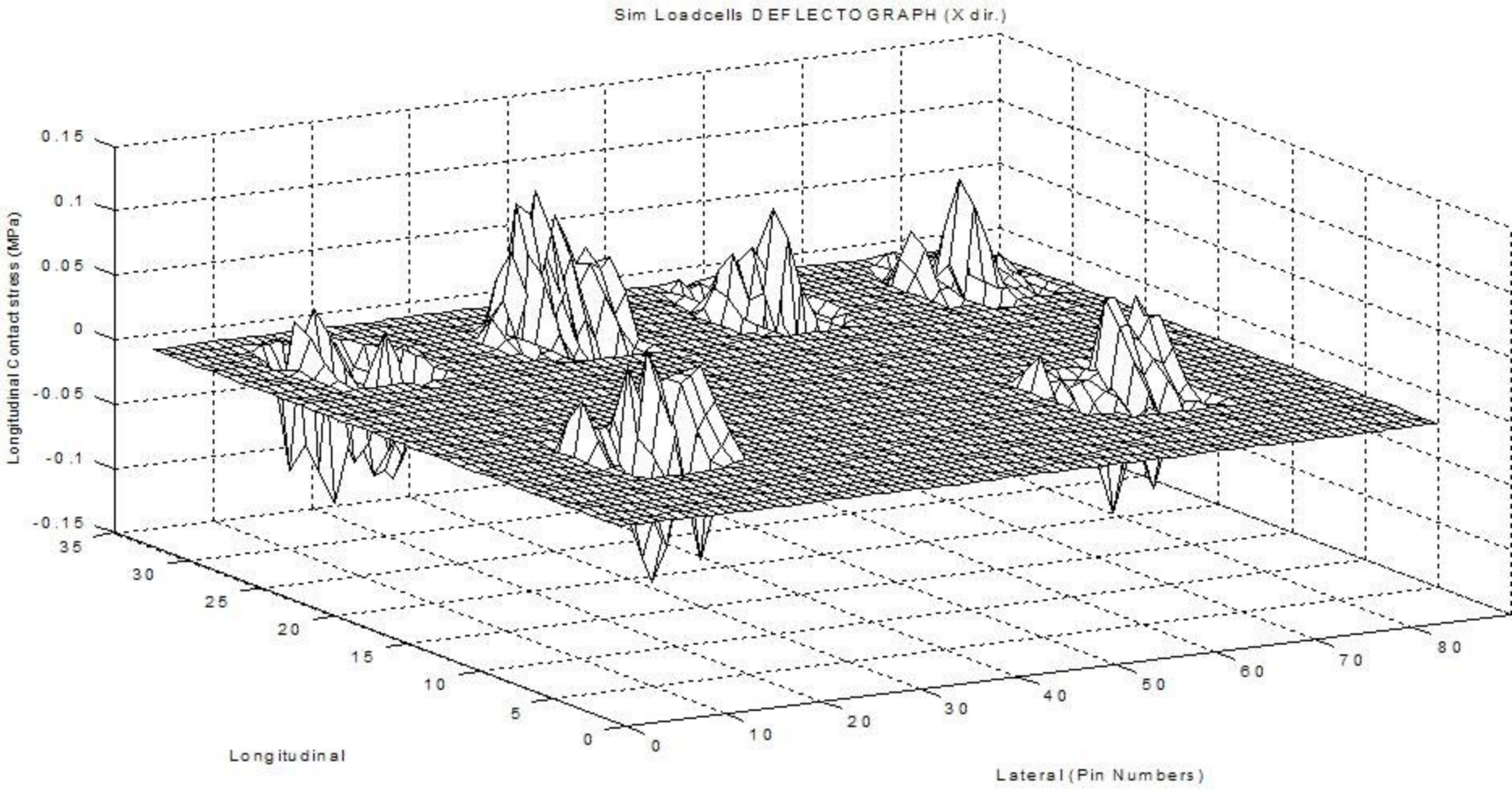
Deflectograph Truck (80kN, 650 kPa): Vertical Contact Stress

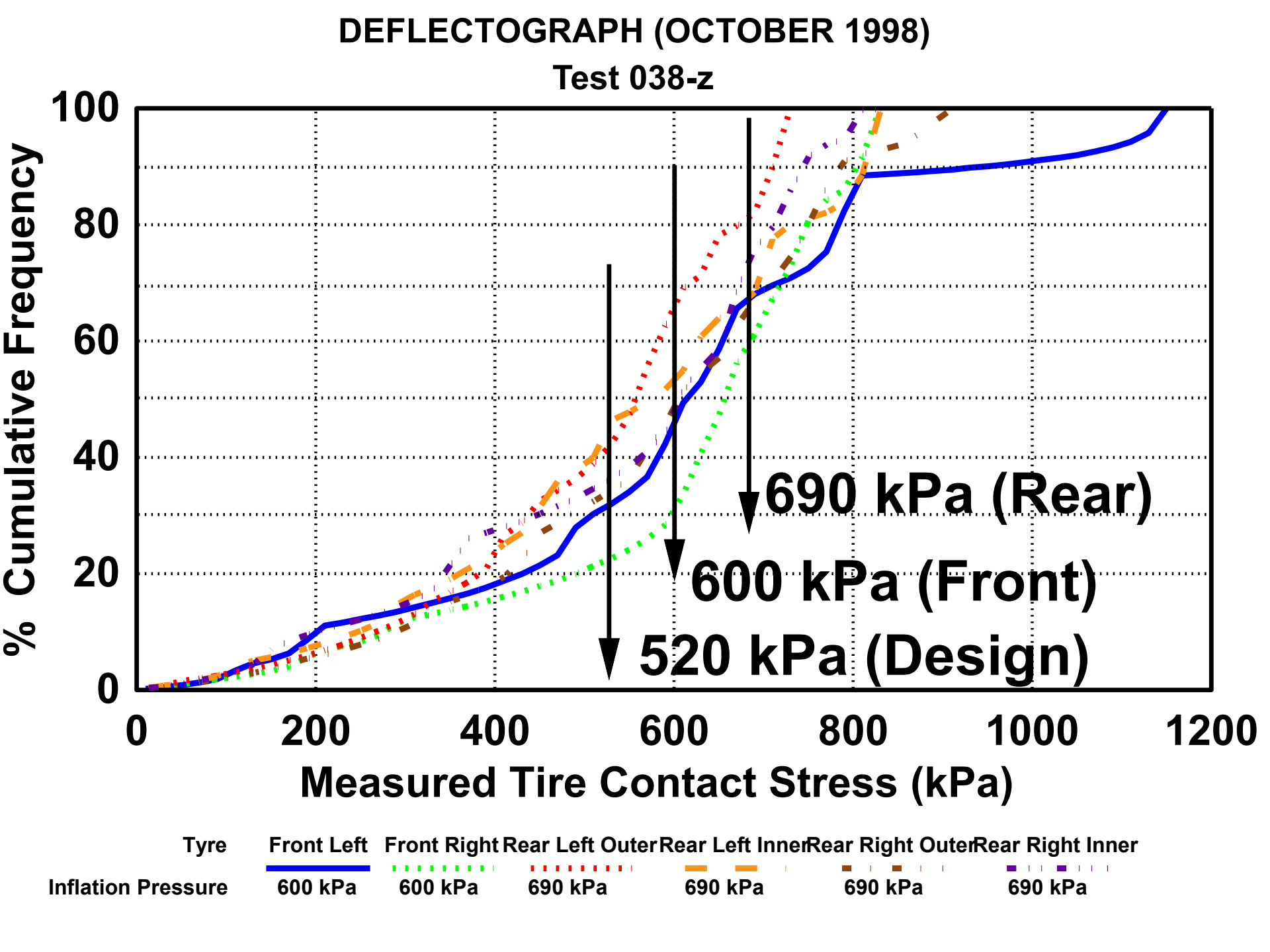


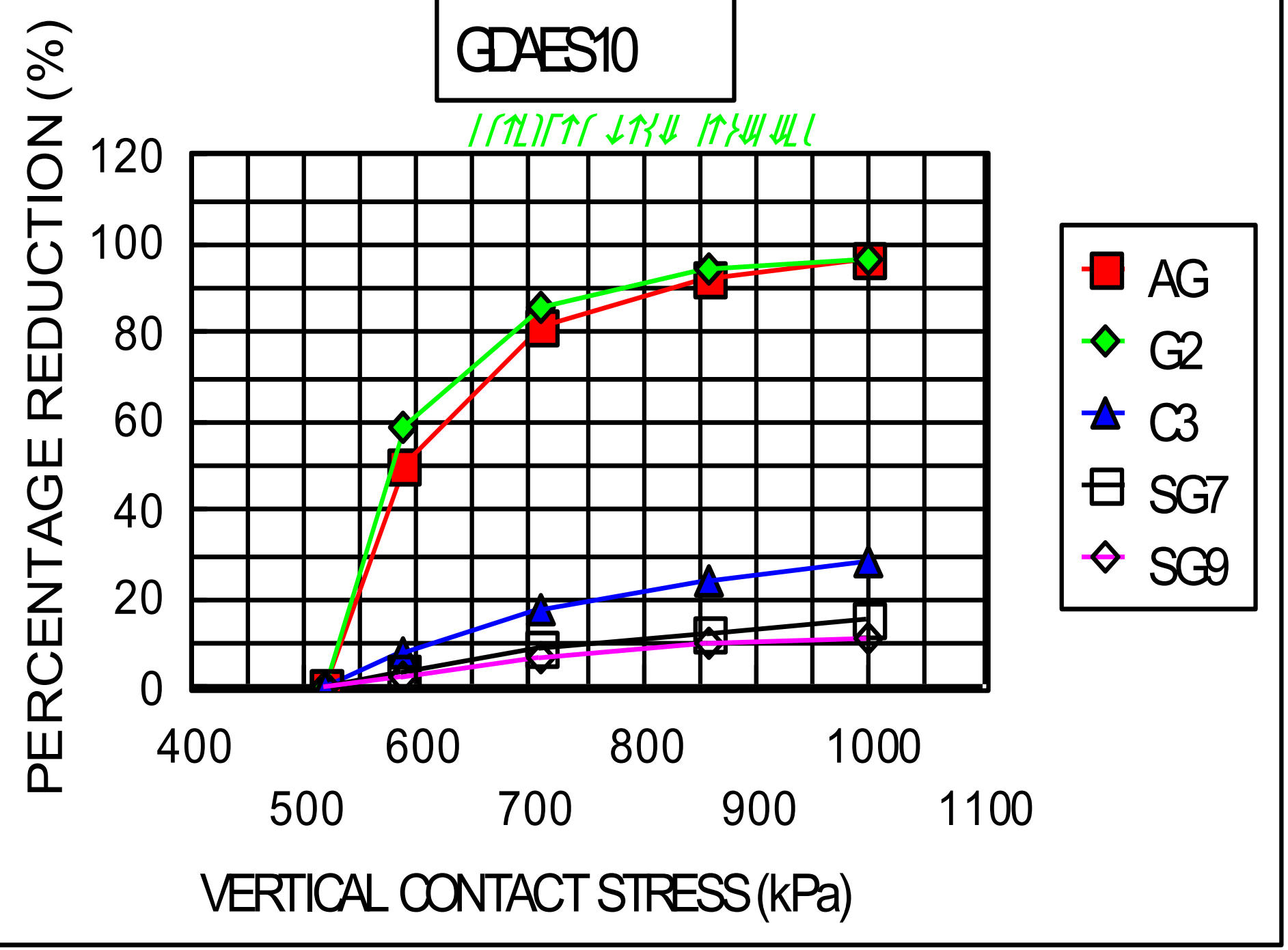
Deflectograph Truck (80kN,650 kPa): Lateral Contact Stress

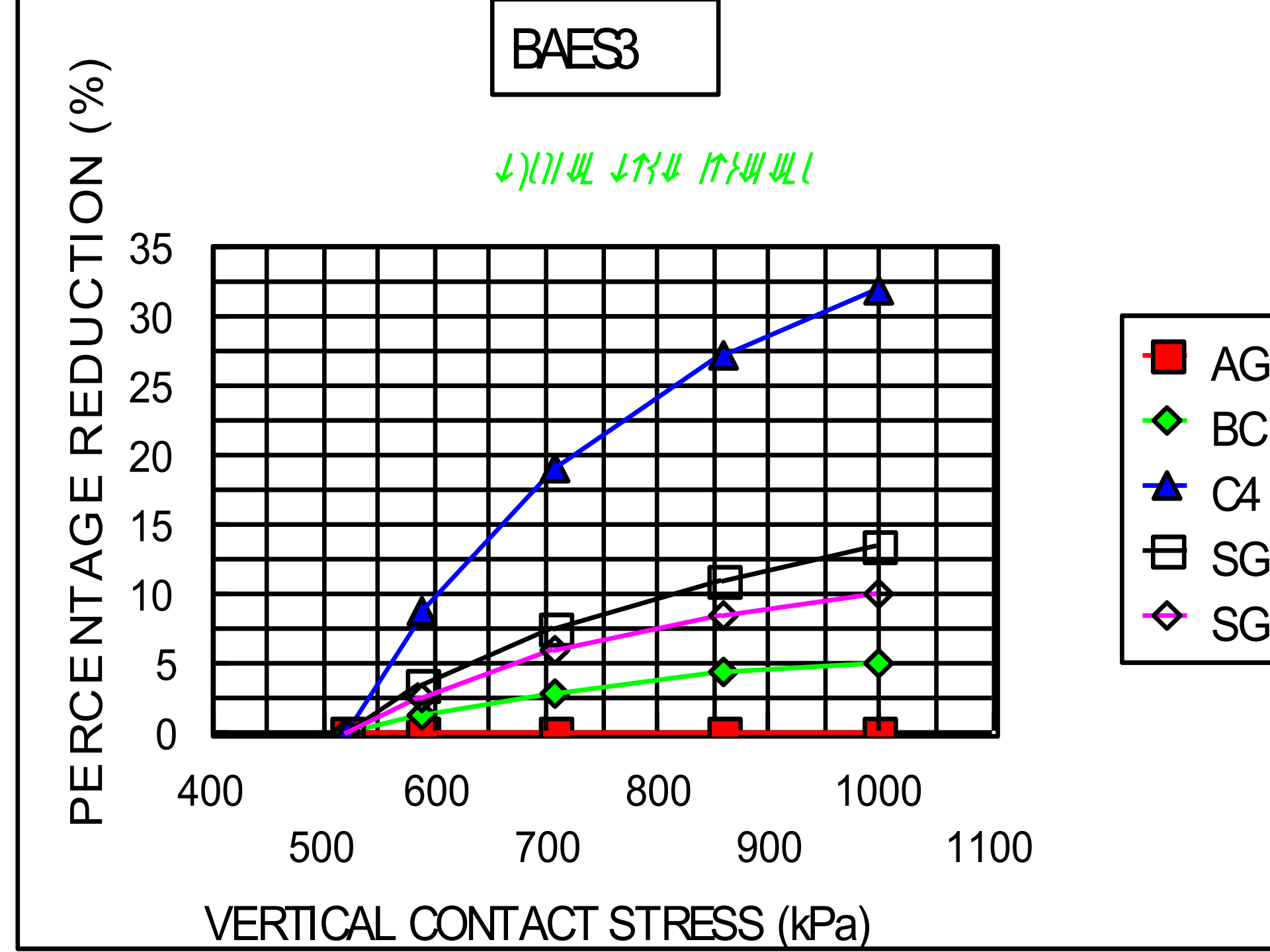


Deflectograph Truck (80kN,650 kPa): Longitudinal Contact Stress




DEFLECTOGRAPH (OCTOBER 1998)
Test 038-z
% Cumulative Frequency
100
80
60
40
20
0
690 kPa (Rear)
600 kPa (Front)
520 kPa (Design)
0
200
400
600
800
1000
1200
Measured Tire Contact Stress (kPa)
Tyre
Front Left
Front Right
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


GDAES10
PERCENTAGE REDUCTION (%)
120
100
80
60
40
20
0
400
600
800
1000
500
700
900
1100
VERTICAL CONTACT STRESS (kPa)
AG
G2
C3
SG7
SG9


BAES3
PERCENTAGE REDUCTION (%)
35
30
25
20
15
10
5
0
400
500
600
700
800
900
1000
1100
VERTICAL CONTACT STRESS (kPa)
AG
BC
C4
SG
SG


MANTSOLE TRAFFIC CONTROLL CENTRE
(TCC) ON NATIONAL ROAD NR 1 (N1)
Full Axle SIM
North


STOP
50 m
12 11'97


MANTSOLE TCC
12 11'97

TRUCK IDENTIFICATION INCLUDES:

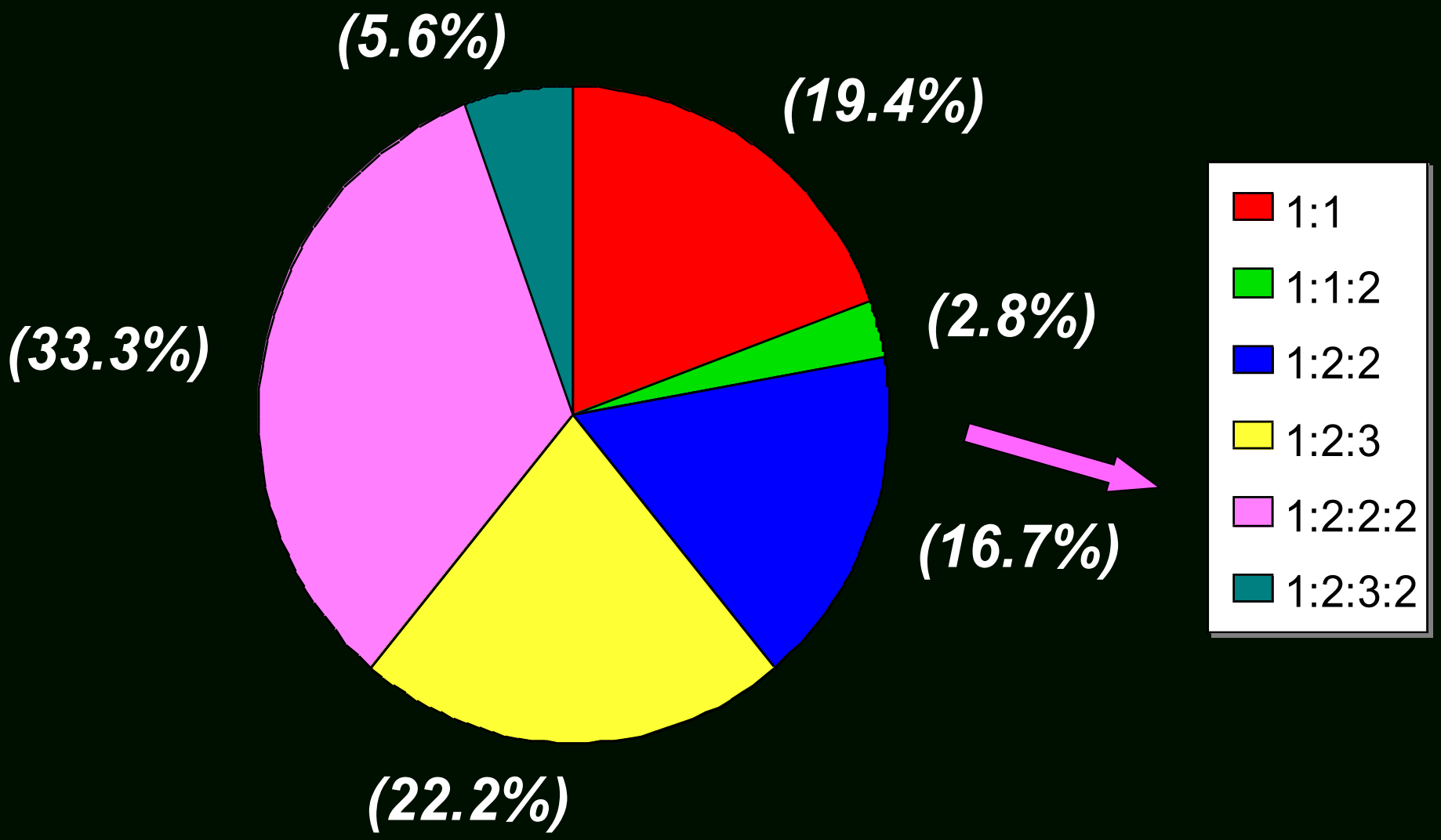
- ✓ *Vehicle Registration number;*
- ✓ *Date of measurement;*
- ✓ *Time of measurement;*
- ✓ *Vehicle classification (i.e 1:2:2:2)*

- ✓ *Tyre inflation pressure and tyre temp only on selected trucks at the TCC.*

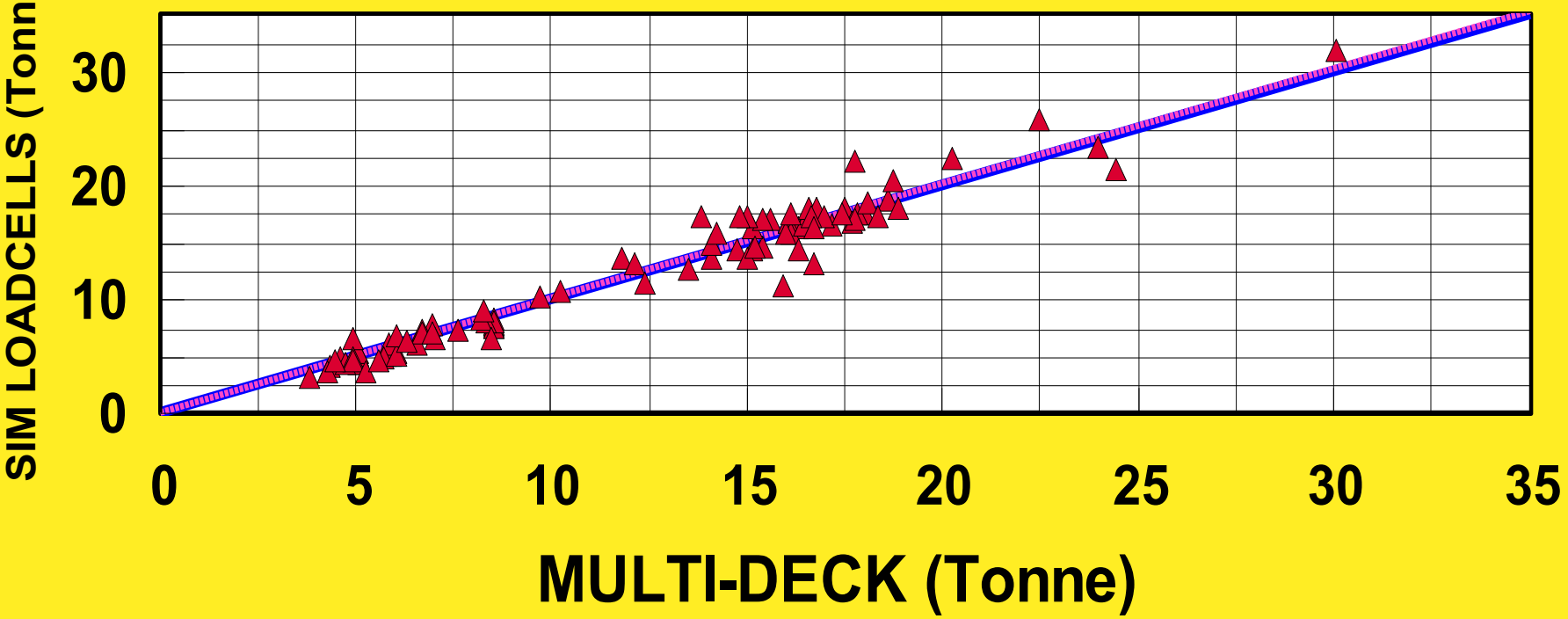
The following items are obtained with the SIM:

- ✓ *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)



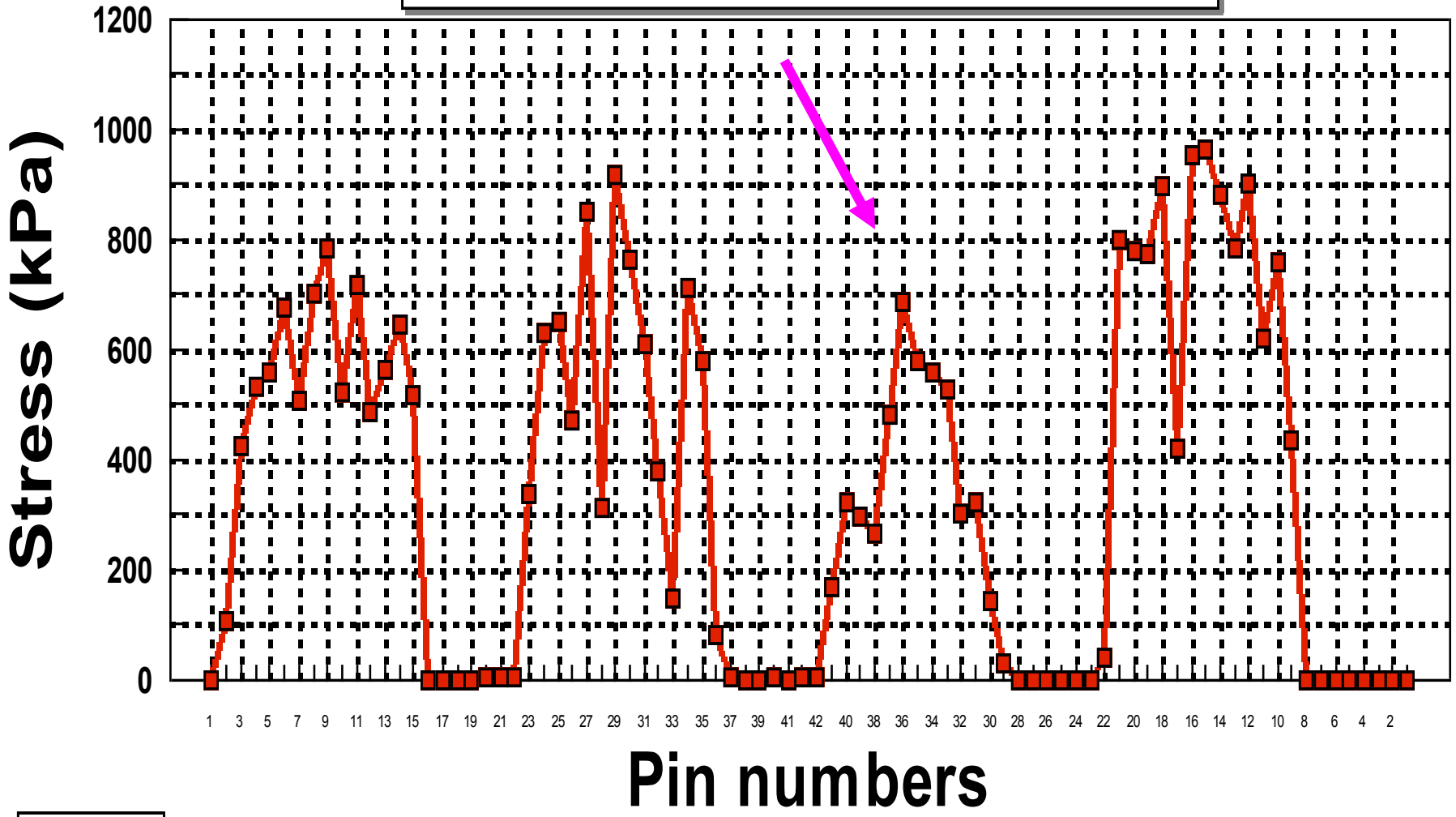
MANTSOLE WEIGHBRIDGE (TCC)
SIM TESTS NOV. & DEC. 1998 & FEB 1999



MAN1.WK4

AXLE 5

Vertical Maximum Contact Stress (kPa)



001-z
DMB 453 GP

Left Outer Tyre

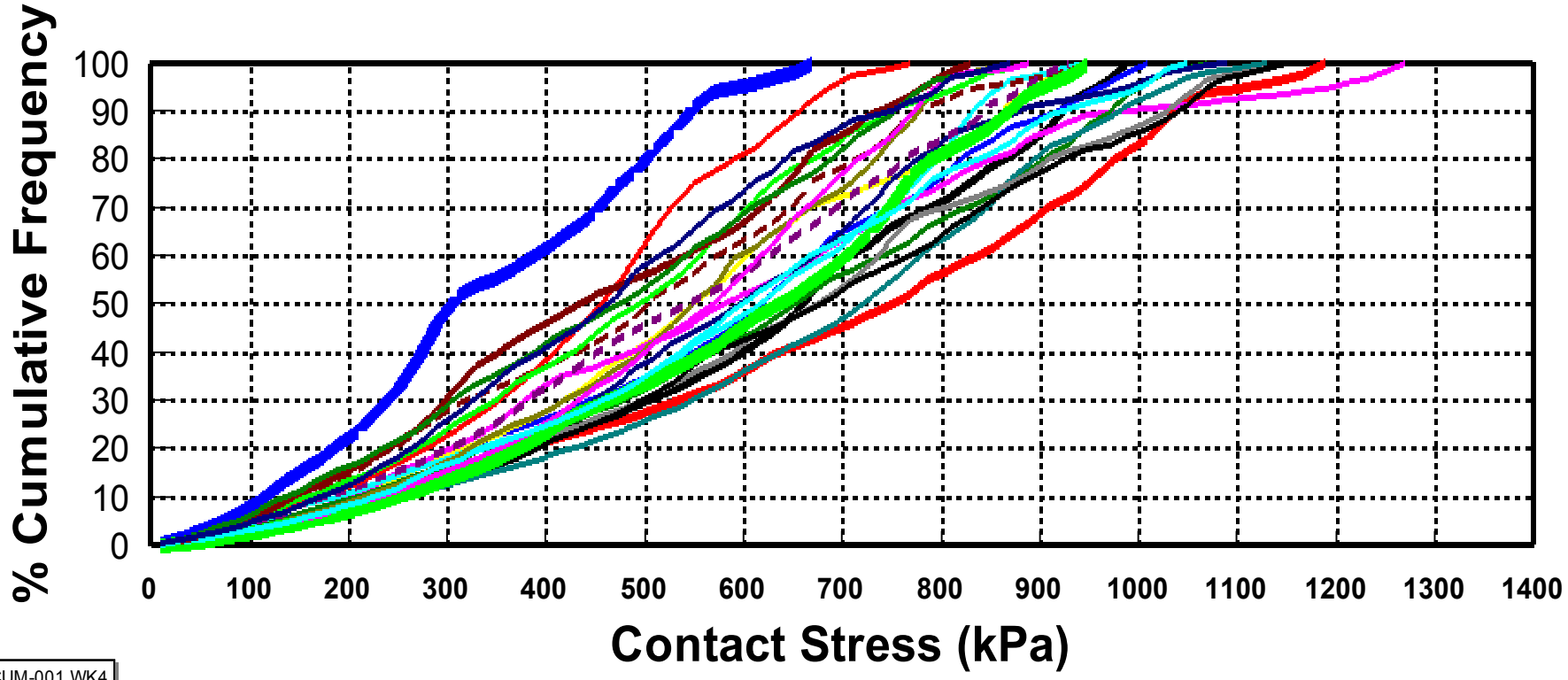
Left Inner Tyre

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;**

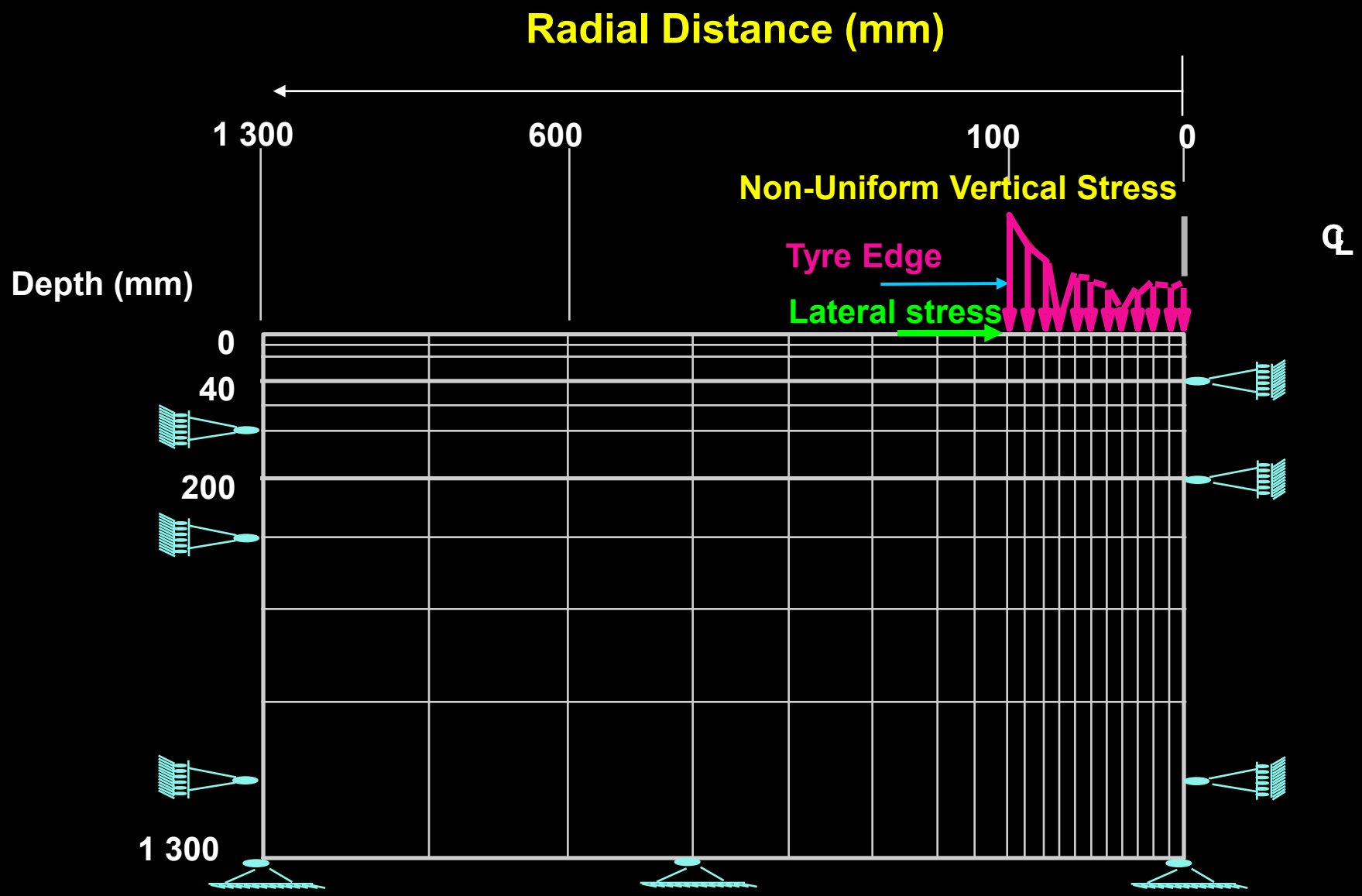
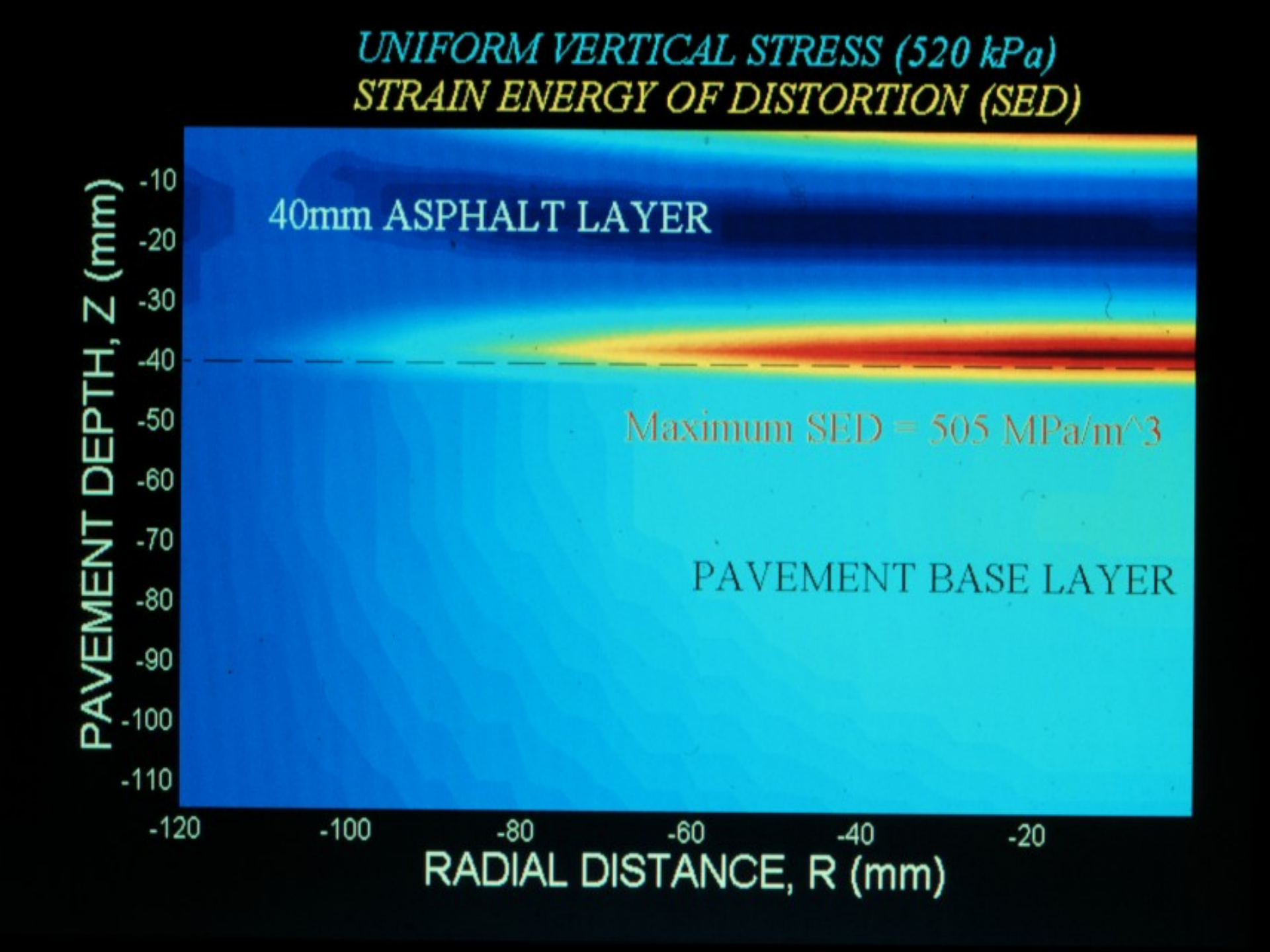
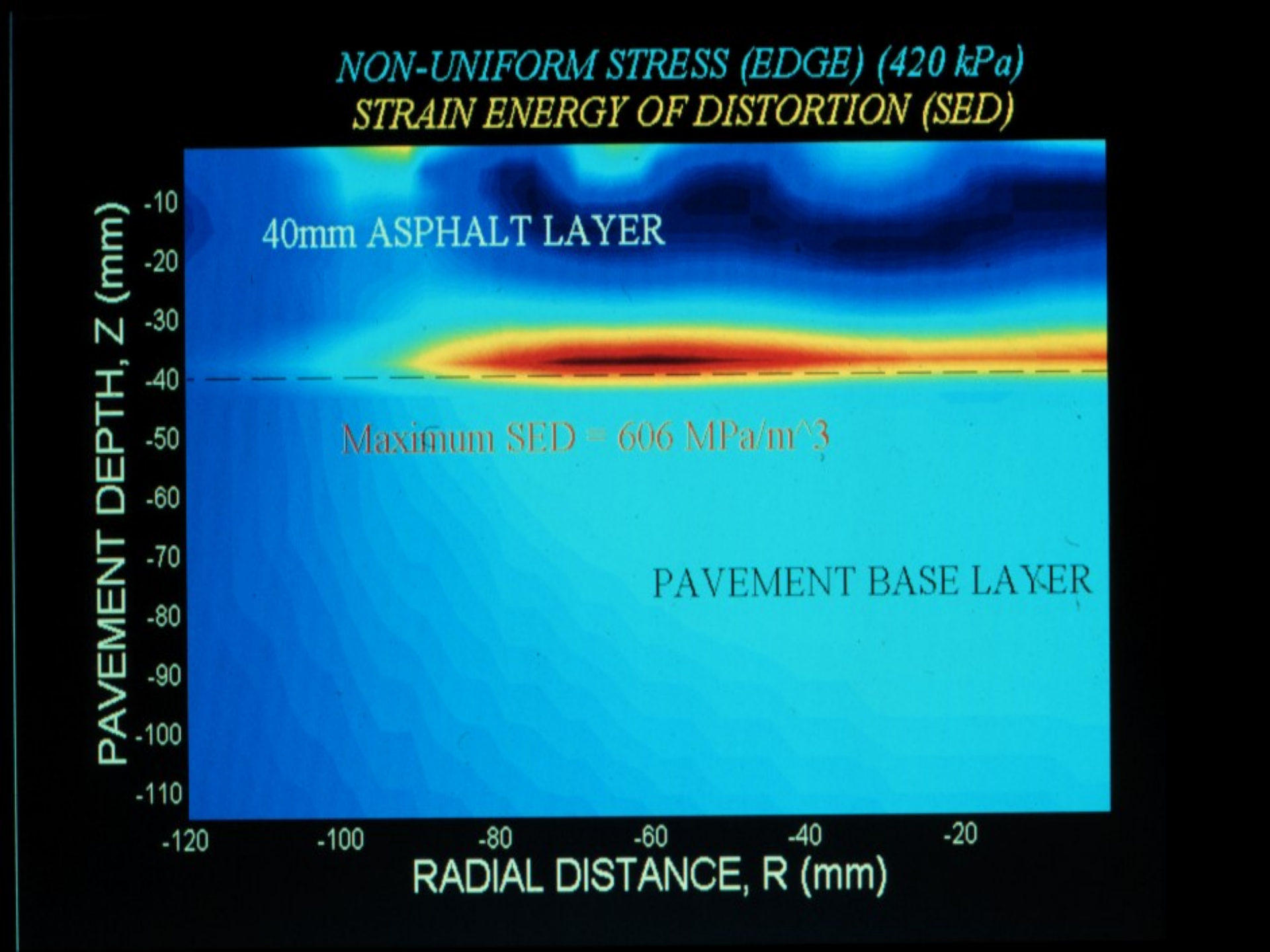


FIGURE: 29

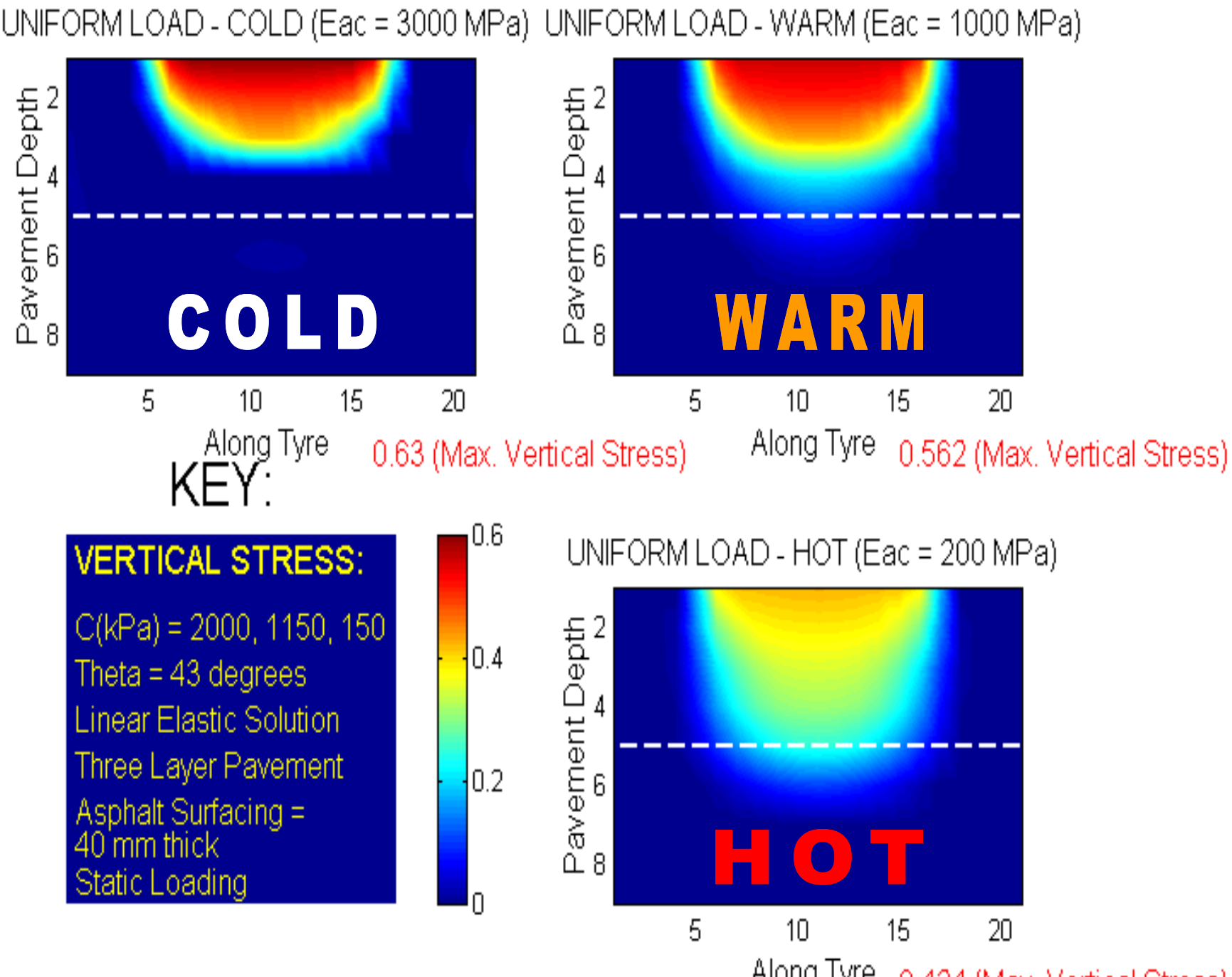
Axi-symmetrical Finite Element Model used in this study

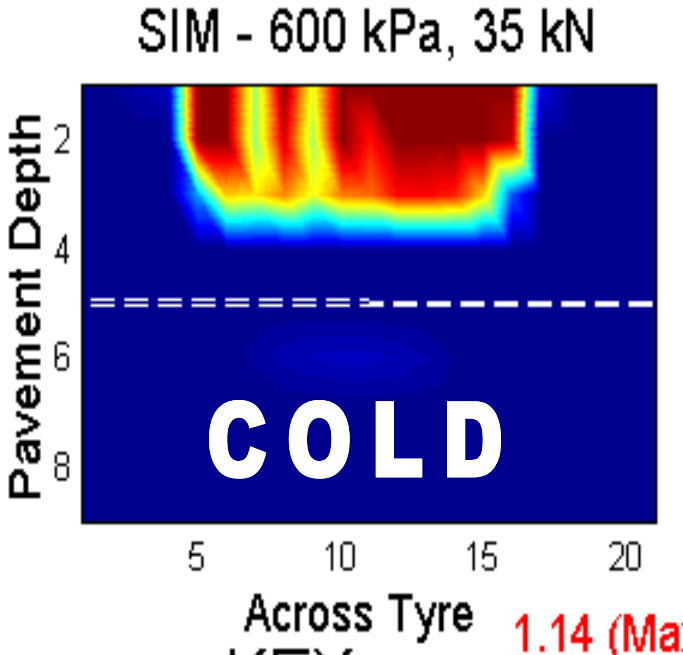

UNIFORM VERTICAL STRESS (520 kPa)
STRAIN ENERGY OF DISTORTION (SED)
40mm ASPHALT LAYER
Maximum SED = 505 MPa/m^3
PAVEMENT BASE LAYER
PAVEMENT DEPTH, Z (mm)
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-100
-80
-60
-40
-20
RADIAL DISTANCE, R (mm)


NON-UNIFORM STRESS (EDGE) (420 kPa)
STRAIN ENERGY OF DISTORTION (SED)
40mm ASPHALT LAYER
Maximum SED = 606 MPa/m^3
PAVEMENT BASE LAYER
PAVEMENT DEPTH, Z (mm)
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-100
-80
-60
-40
-20
RADIAL DISTANCE, R (mm)

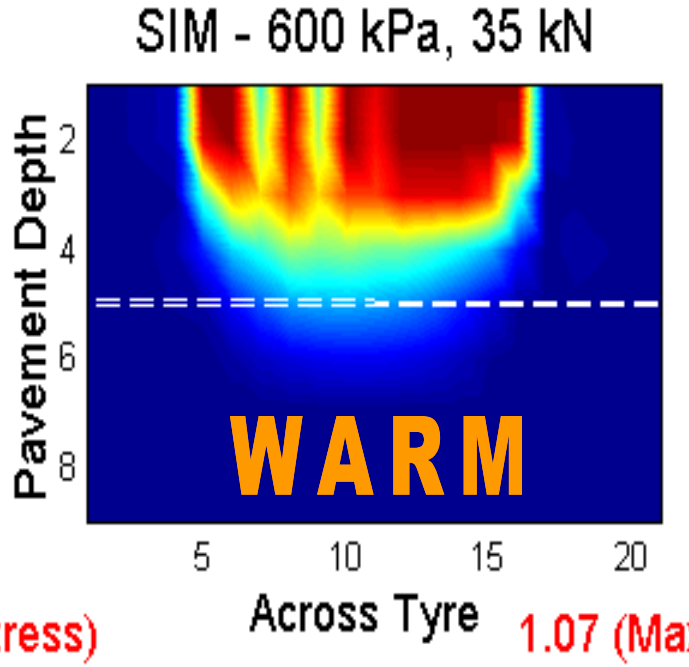
Pseudo-Energy under non-uniform contact stress conditions
(Symplectic Engineering Corporation, USA)

Colour maps of Shape distortion (Symplectic Engineering Corporation)


UNIFORM LOAD - COLD (Eac = 3000 MPa)
UNIFORM LOAD - WARM (Eac = 1000 MPa)
Pavement Depth
2
4
6
8
COLD
WARM
5
10
15
20
Along Tyre
0.63 (Max. Vertical Stress)
0.562 (Max. Vertical Stress)
KEY:
VERTICAL STRESS:
C(kPa) = 2000, 1150, 150
Theta = 43 degrees
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing = 40 mm thick
Static Loading
0.6
0.4
0.2
0
UNIFORM LOAD - HOT (Eac = 200 MPa)
HOT



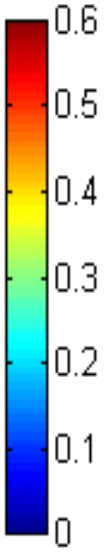
1.14 (Max. Stress)

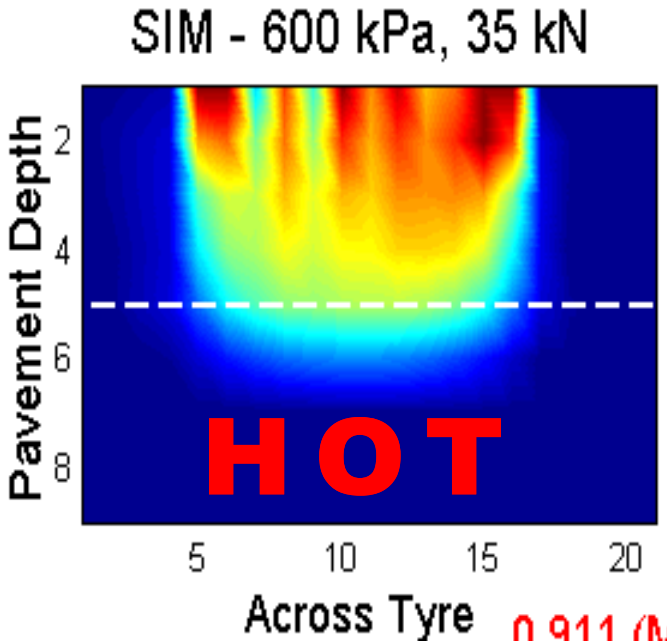


1.07 (Max. Stress)

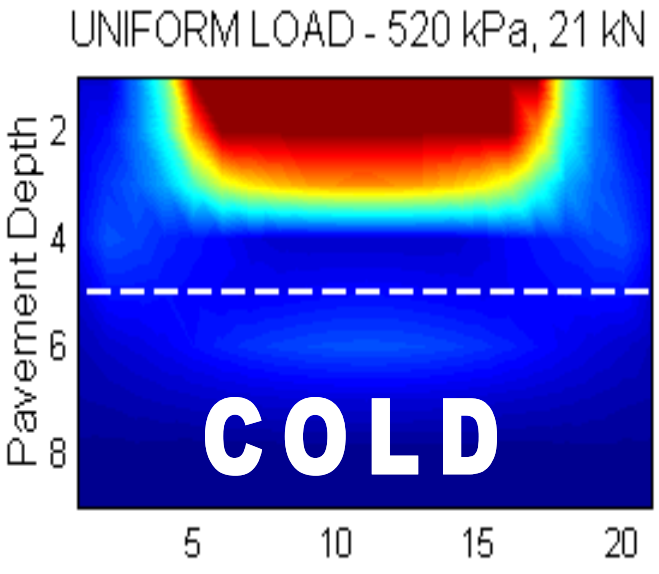
KEY:

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

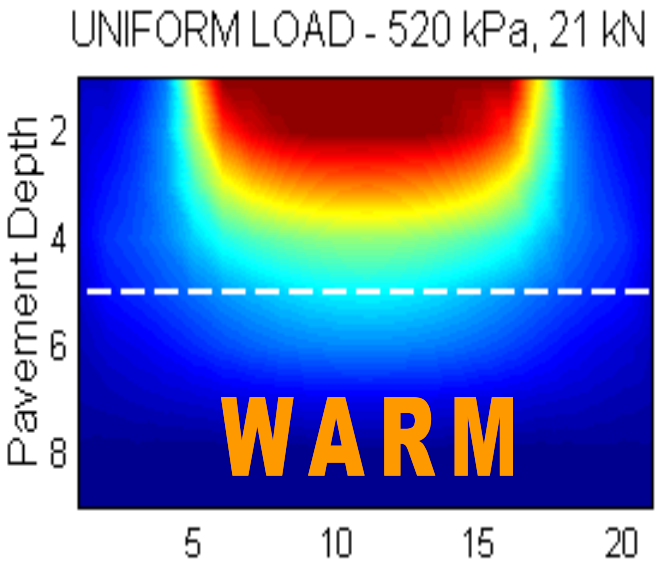




0.911 (Max. Stress)



1.21 (Max. I1/3 Bulk Stress)

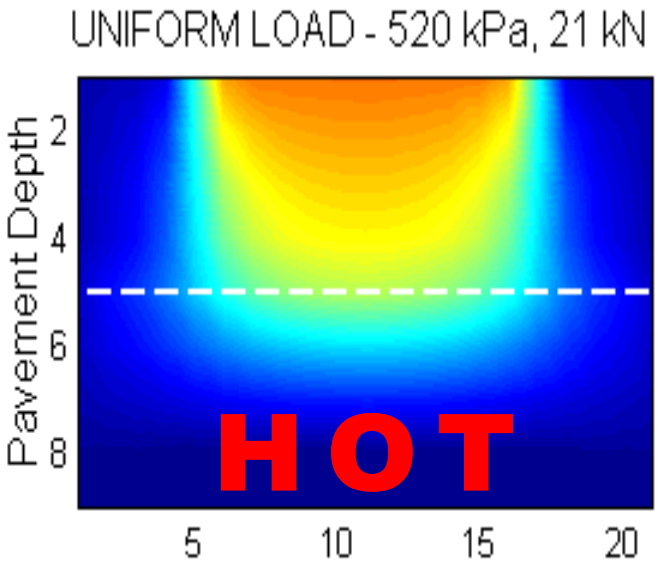


0.748 (Max. I1/3 Bulk Stress)

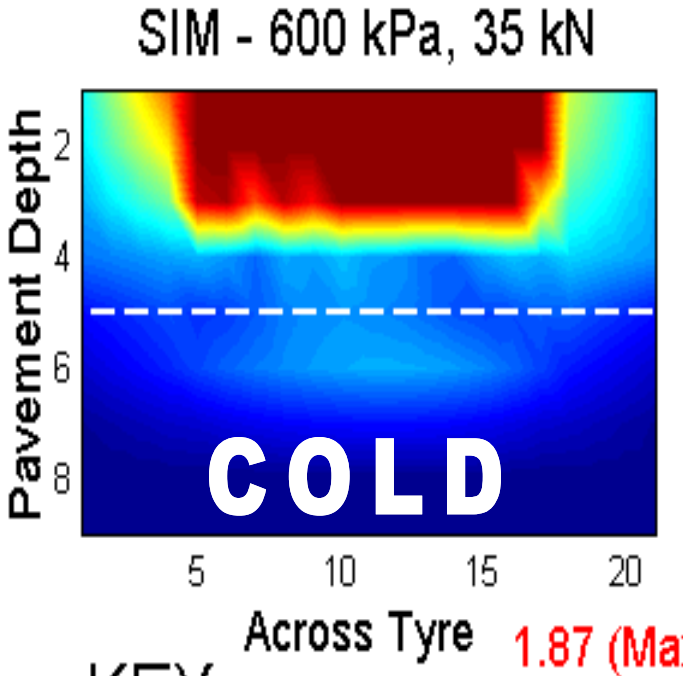
KEY:

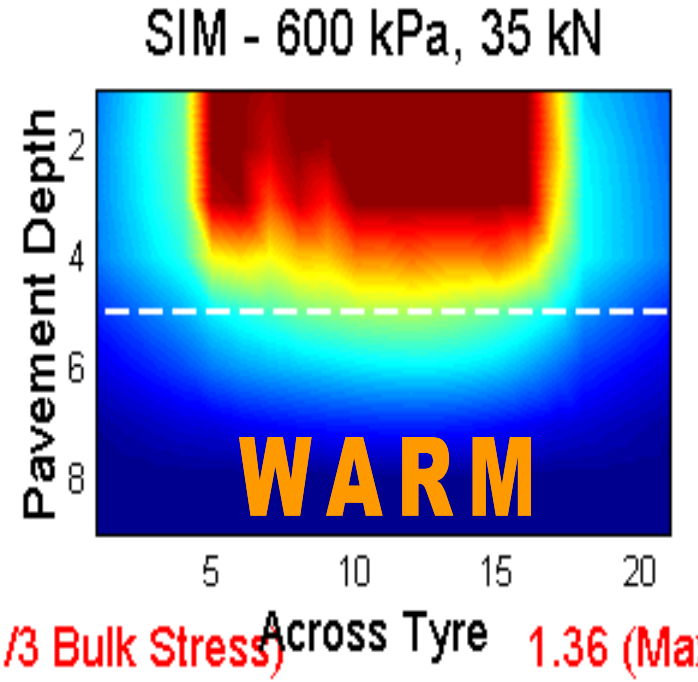
(I1/3) BULK STRESS:

C(kPa) = 2000, 1150, 150
Theta = 43 degrees
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing = 40 mm thick
Static Loading



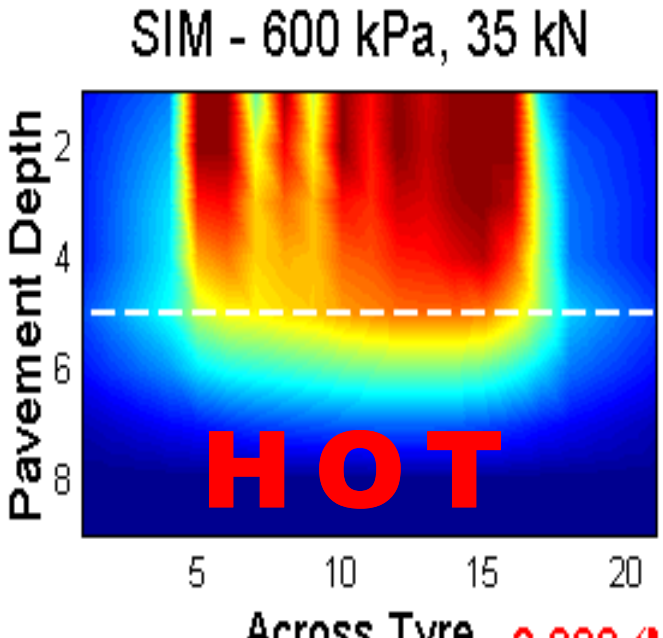
0.462 (Max. I1/3 Bulk Stress)

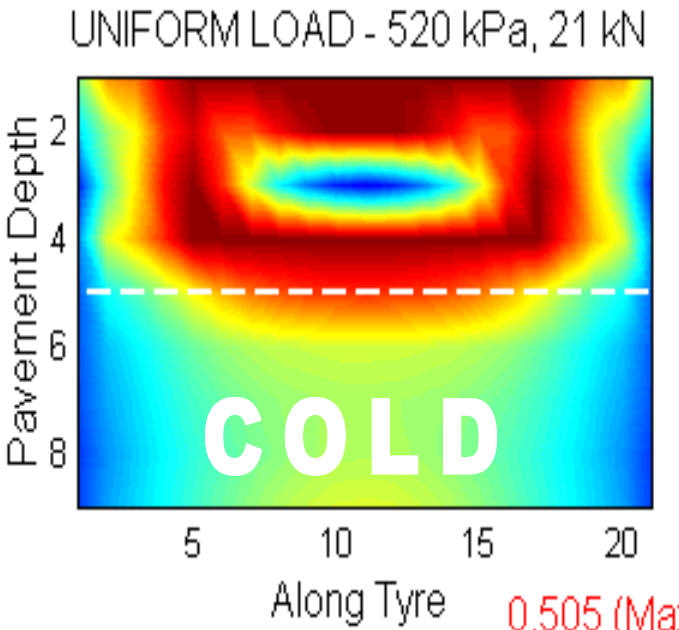


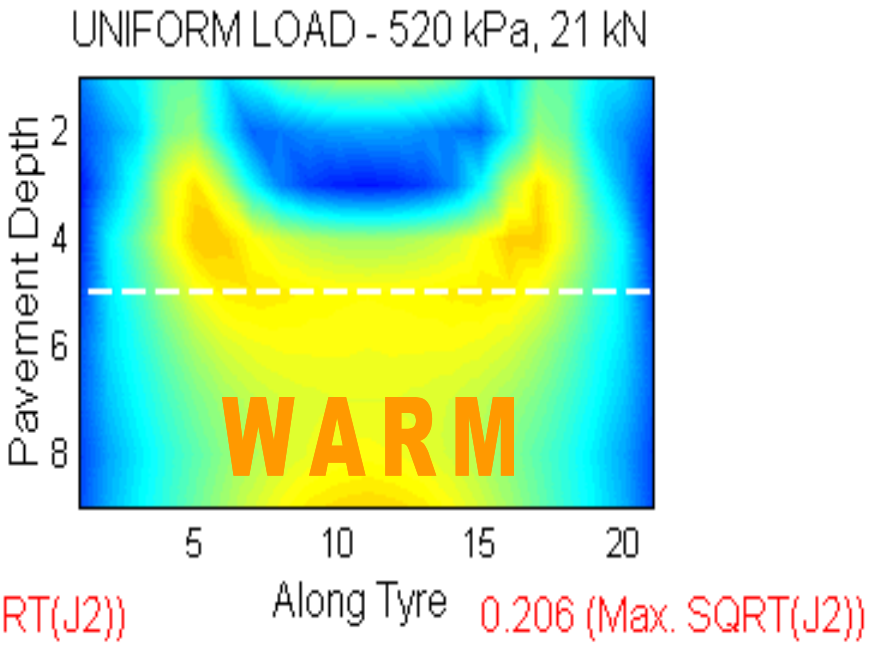


KEY:

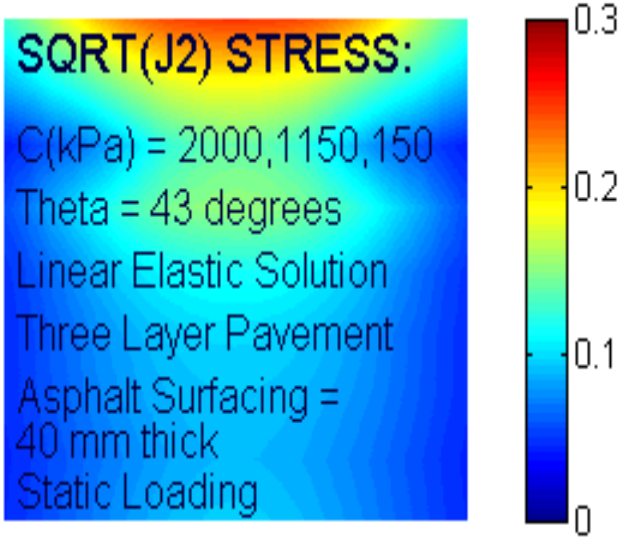
(I1/3) BULK STRESS:
C(kPa) = 2000, 1150, 150
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading

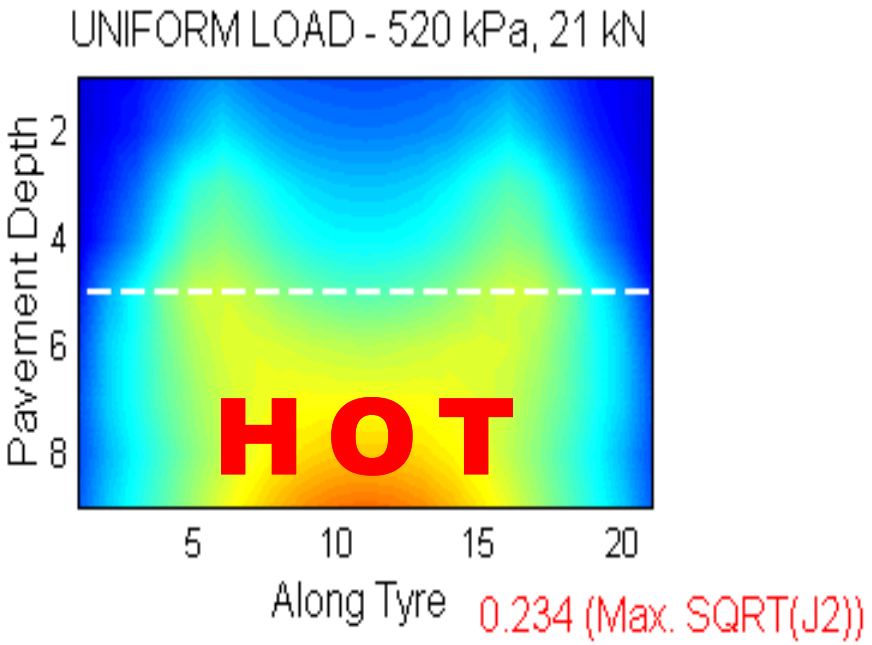


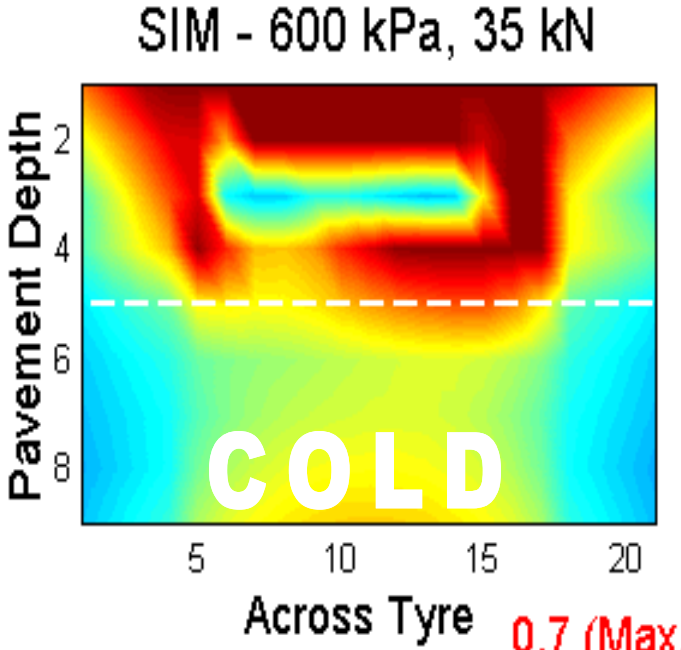

UNIFORM LOAD - 520 kPa, 21 kN
Pavement Depth
2
4
6
8
COLD
5
10
15
20
Along Tyre
0.505 (Max. SQRT(J2))

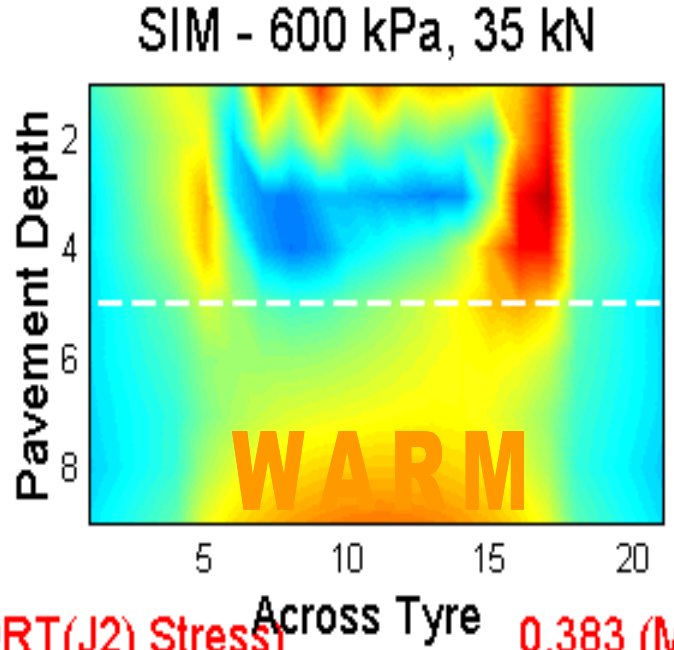

UNIFORM LOAD - 520 kPa, 21 kN
Pavement Depth
2
4
6
8
WARM
5
10
15
20
Along Tyre
0.206 (Max. SQRT(J2))

KEY:


SQRT(J2) STRESS:
C(kPa) = 2000,1150,150
Theta = 43 degrees
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading
0.3
0.2
0.1
0

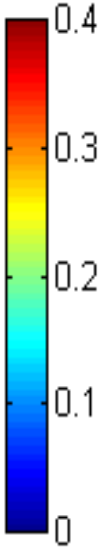

UNIFORM LOAD - 520 kPa, 21 kN
Pavement Depth
2
4
6
8
HOT
5
10
15
20
Along Tyre
0.234 (Max. SQRT(J2))

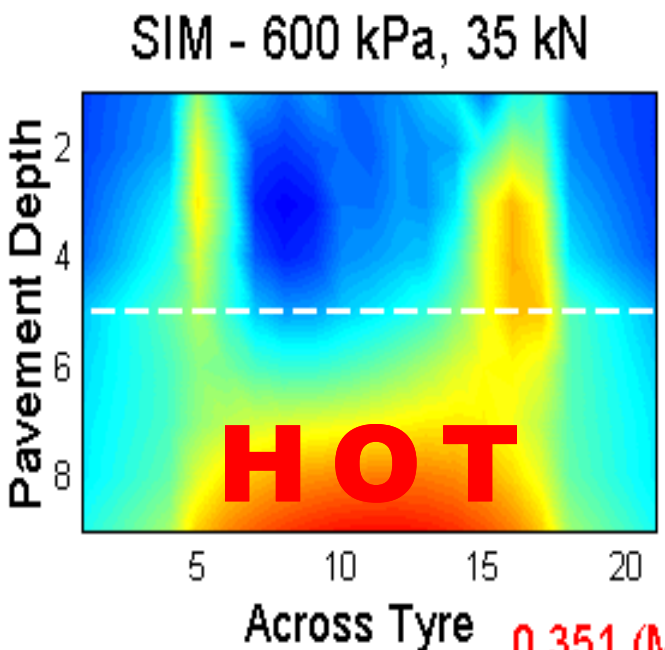


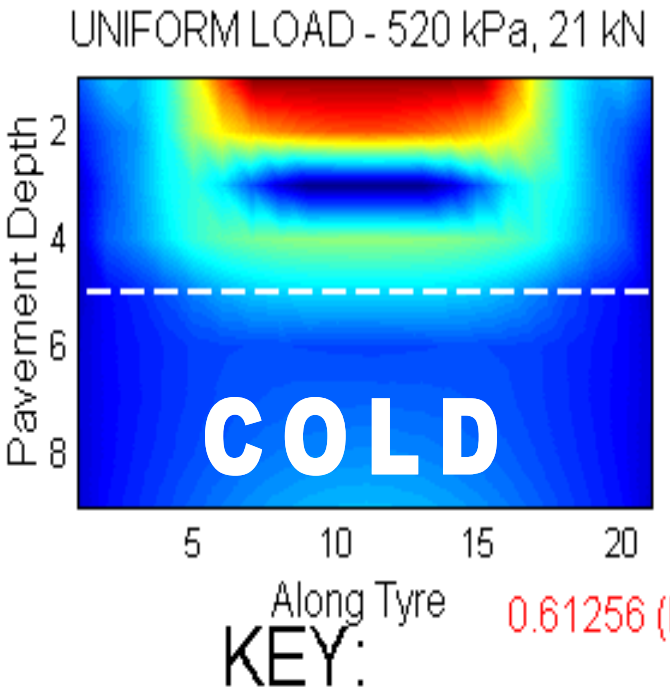


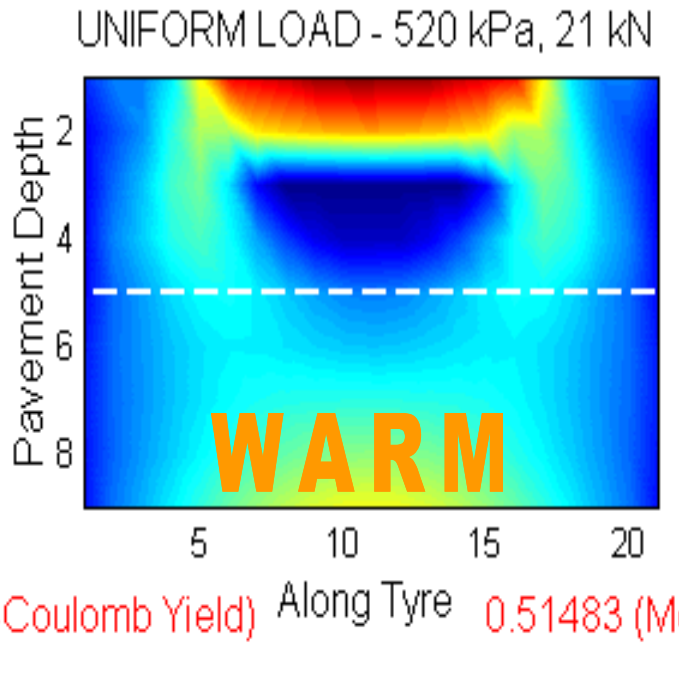
KEY:

SQRT (J2) STRESS:
C(kPa) = 2000,1150,150
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading



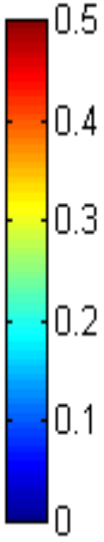


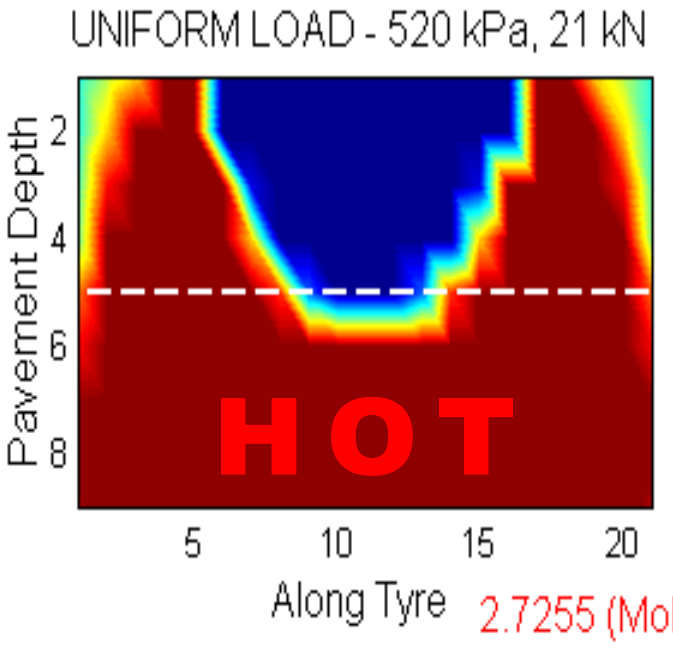


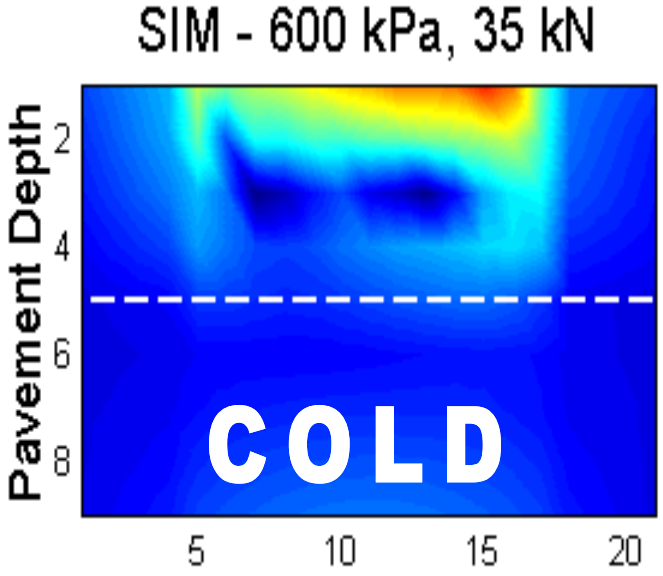


KEY:

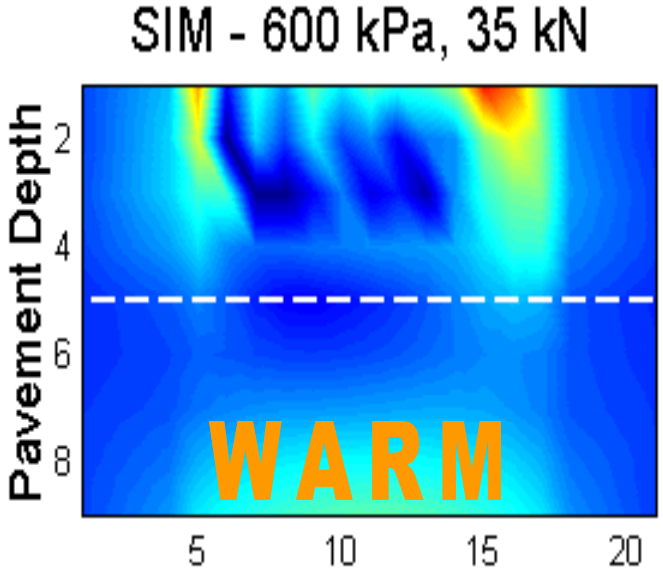
MOHR-COULOMB YIELD FUNCTION:
C(kPa) = 2000, 1150, 150
Theta = 43 degrees
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing = 40 mm thick
Static Loading







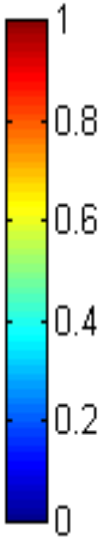
0.86141 (Max. Yield)

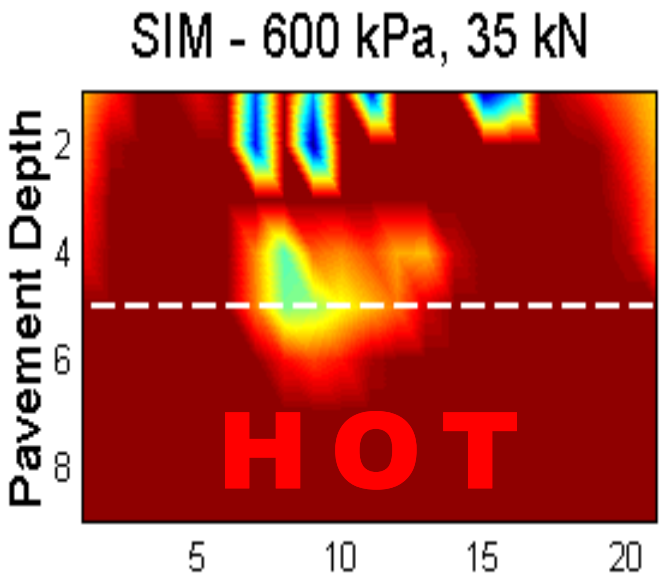


0.87271 (Max. Yield)

KEY:

MOHR-COULOMB YIELD FUNCTION:
C(kPa) = 2000,1150,150
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing = 40 mm thick
Static Loading





4.0929 (Max. Yield)

Summary & Conclusions:

- **SIM Technology proven to be successful locally and overseas;**
- **Ratio of Stresses: Vert : Lat : Long = 10 : 2 : 1,5**
- **SIM results useful to Civil Engineers and road building;**
- **Challenge to develop detailed design and analyses methods utilizing SIM data;**
- **Finite Element Analysis Methods (FEM) to be used more widely with SIM data in road design;**
- **SIM systems should be improved for wider use such as "WIM";**


I Thank You all !!

Thank you !!