Dr Morris De Beer is a Project Manager and research engineer at the Division for Roads Transport Technology of the *Council for Scientific and Industrial Research (CSIR)* in South Africa.

He is a Civil Engineer (Ph. D), working in the field of research towards the structural behavior of road pavements and road materials under Accelerated Pavement Testing (APT) since 1976.

Since 1993, he is actively involved in the tire/pavement contact stresses for the purposes of more effective road pavement design.

He has published more than 50 international papers and pavement research reports.

The Maintenance Council (TMC) - ATA:
Fall Meeting, Tampa, Florida, USA
October 11, 1999

Session 2. Tire and Wheel:

Tire Impact on Pavement Damage

Morris De Beer (Ph. D, Civil Engineering)
Transportek, CSIR
(Council of Scientific and Industrial Research)
SOUTH AFRICA

Well known statements:

- *"Without Trucks America Stops" (WTAS)*
  -- American Trucking Associations (ATA);
- *IT'S NOT OUR STRONG ECONOMY THAT GAVE US GOOD ROADS -- IT'S OUR GOOD ROADS THAT GAVE US A STRONG ECONOMY !!*
  -- J.F. KENNEDY, former US President
- *Roads & Trucks = Multi - Billion US$ business !! – Without Roads Truckers Stop !*

GOOD ROADS LEAD TO PROSPERITY..

..motto of the South African Road Federation

PAVEMENT DAMAGE…

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Fatigue Cracking and aging


SURFACE DISINTEGRATION


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Job & Job...

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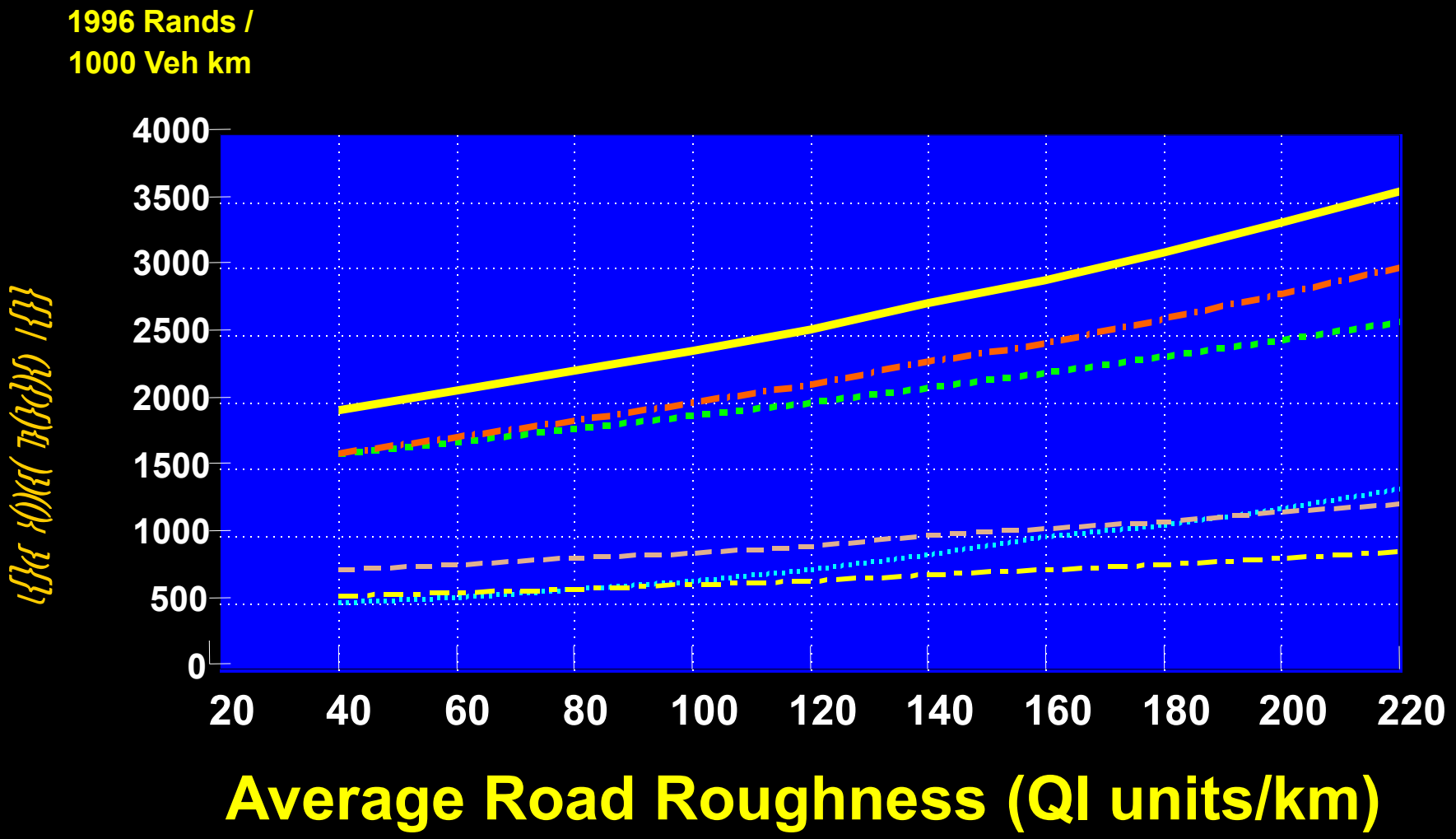
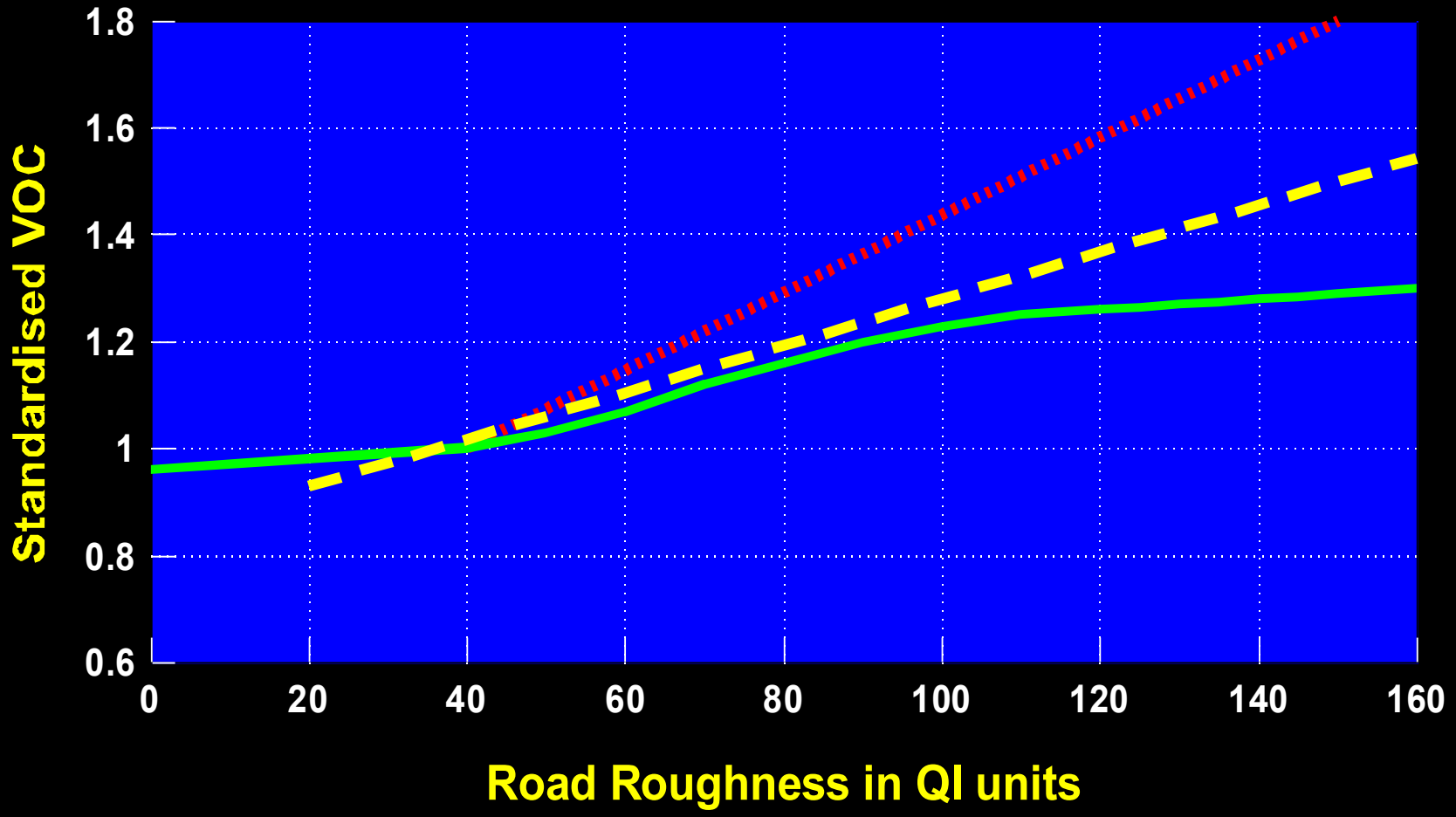
VEHICLE OPERATING COST

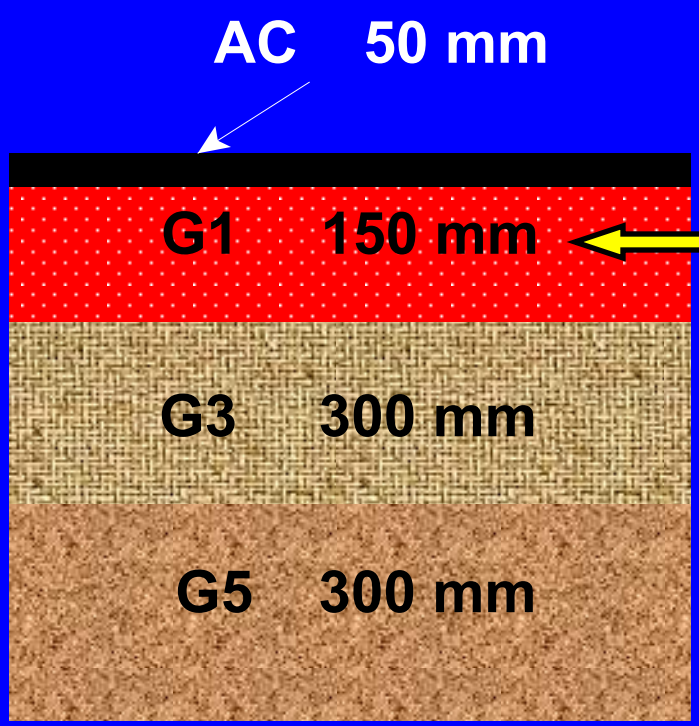


VOC OF HEAVY TRUCKS AS AFFECTED BY ROAD ROUGHNESS



Typical SA Pavement Design

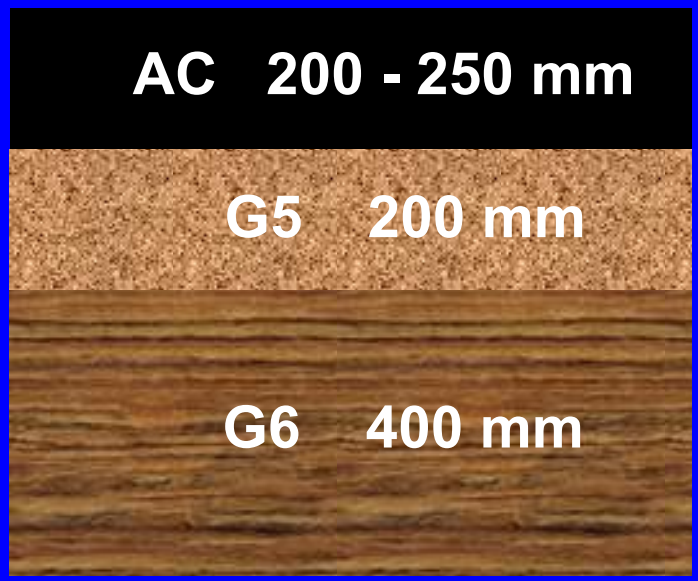
30 million ESALS :
Weak sub-grade, CBR = 5 %



Cost $12.75/ sq.m

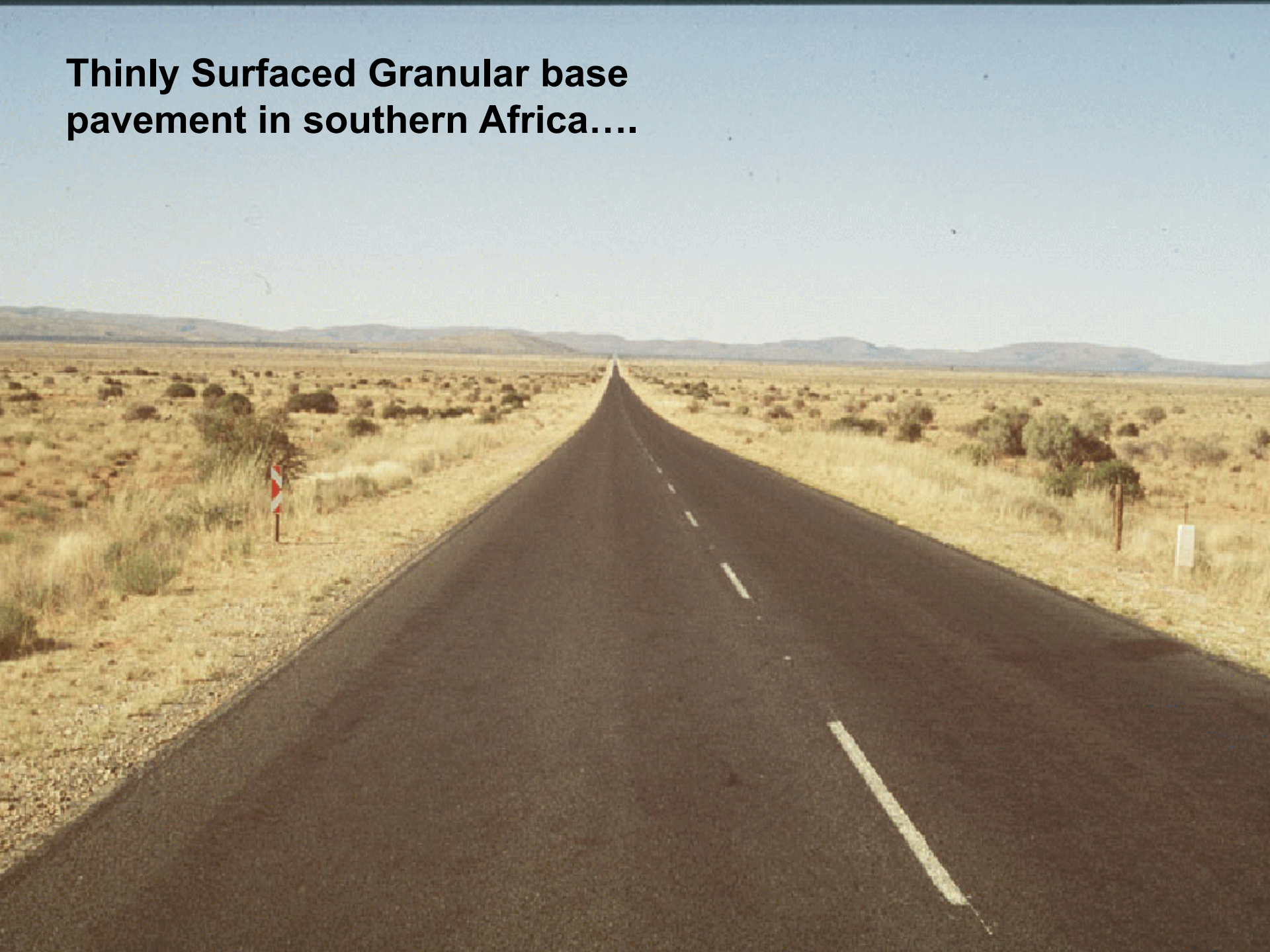
Typical US (Caltrans) Pavement Design

26 - 35 million ESALS :
Weak sub-grade, CBR = 5 %



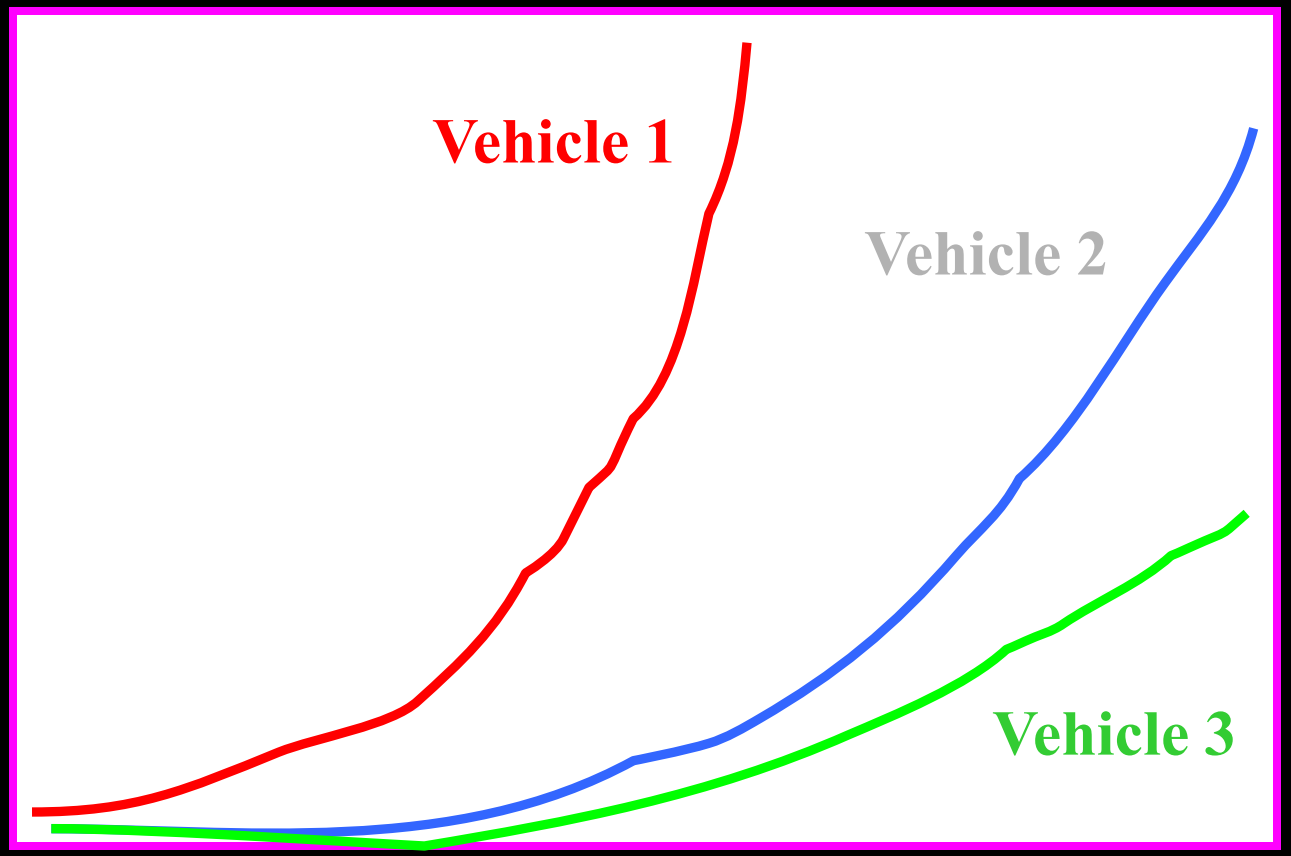
Cost $20.60/ sq.m

Thinly Surfaced Granular base pavement in southern Africa….



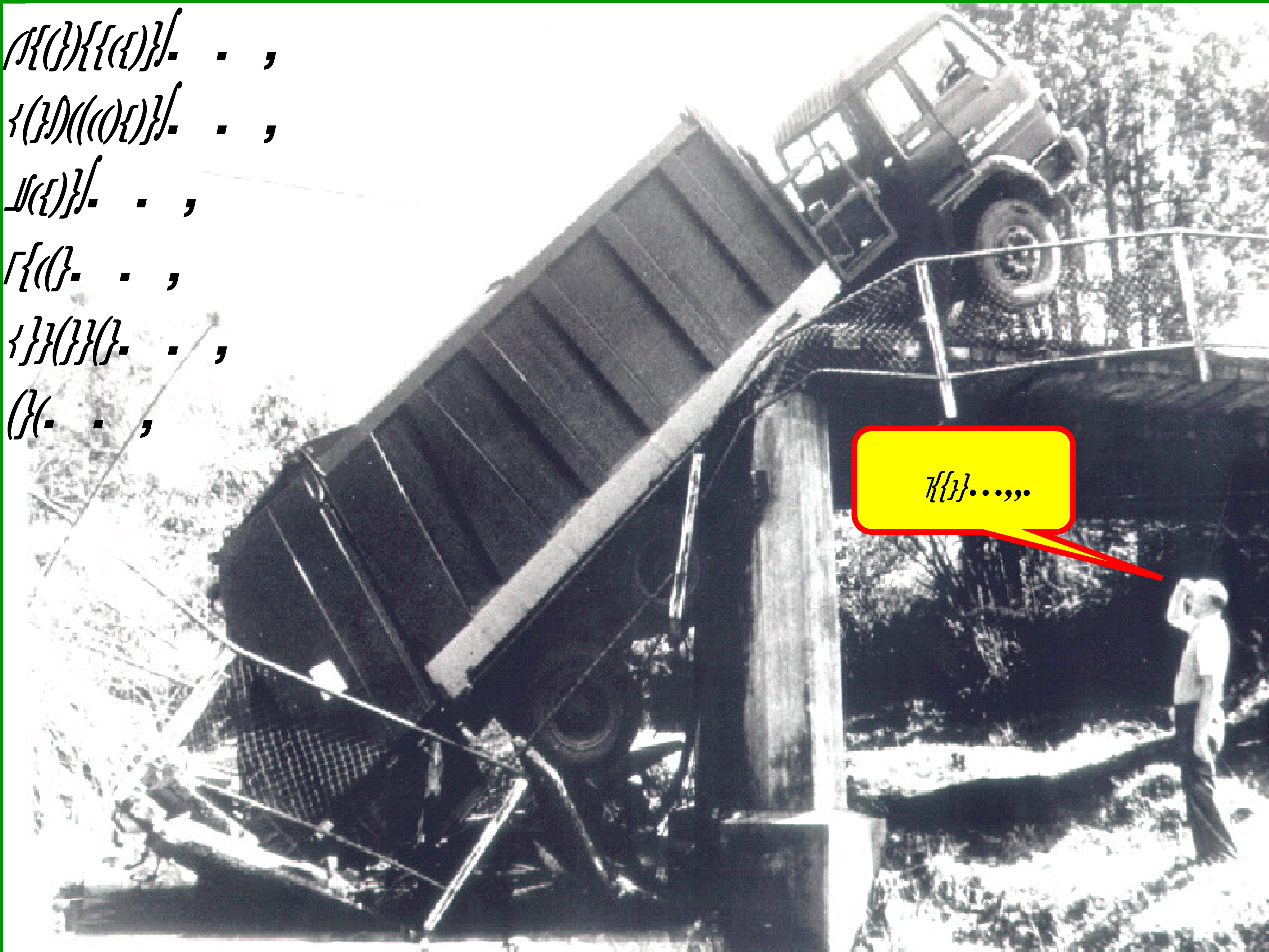

TRUCKS NEAR RENO, NEVADA (USA)…
3 3'97

TRUCK DYNAMICS vs ROAD ROUGHNESS



Traditional Approach for Pavement Damage based primarily on :

AXLE LOADS

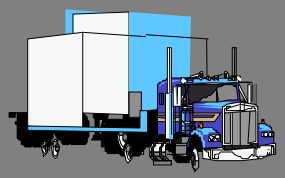


EQUIVALENT STANDARD AXLE LOADS (E80)

1 E80 = 80 kN = 8 200 kg per axle

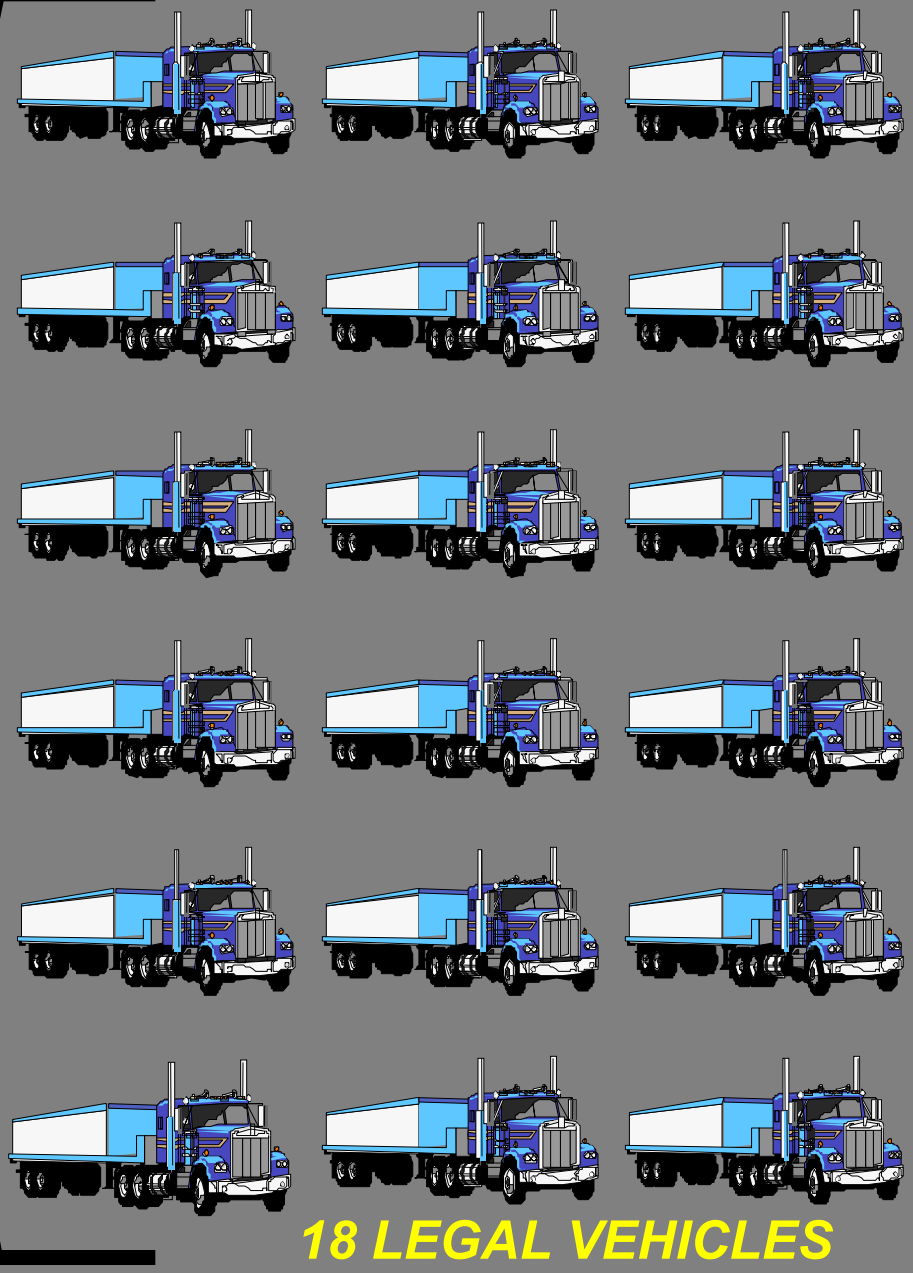
$$\text{Equivalency Factor (F)} = \left(\frac{\text{Actual axle load (P ton)}}{\text{Standard axle load (8,2 ton)}} \right)^{d}$$

d = 4,2 but can vary from 2 to 20, based on AASHO test & Heavy Vehicle Simulator (HVS) research in SA



One OVERLOADED VEHICLE

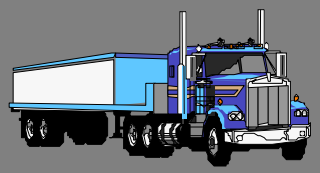
(100% OVERLOAD)



18 LEGAL VEHICLES

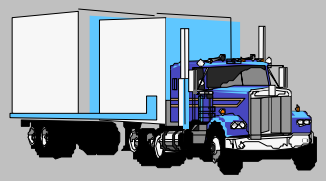
EFFECT OF OVERLOADED VEHICLES..

Cars



Heavy Vehicles

80 - 85 % are legally loaded



Heavy Vehicles

15 - 20 % are overloaded

% Damage Result

40 %

60 %

COMPUTER ANALYSES OF ROAD PAVEMENT STRUCTURES

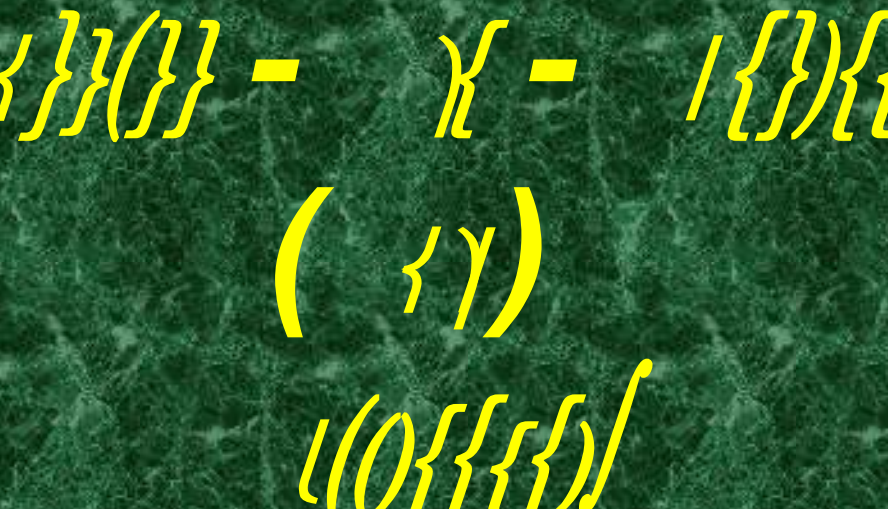
- ✓ *SYMPLISTIC ANALYSIS: MULTI-LAYER - LINEAR - ELASTIC THEORY -- Loads are represented as a uniform disc;*

- ✓ *COMPLEX: FINITE ELEMENT METHOD + NON – LINEAR - ELASTIC THEORIES – Loads & Pavement Materials;*

This Presentation, however, focus on:

3D - Tire/Pavement Contact Stresses

This TMC-Meeting:



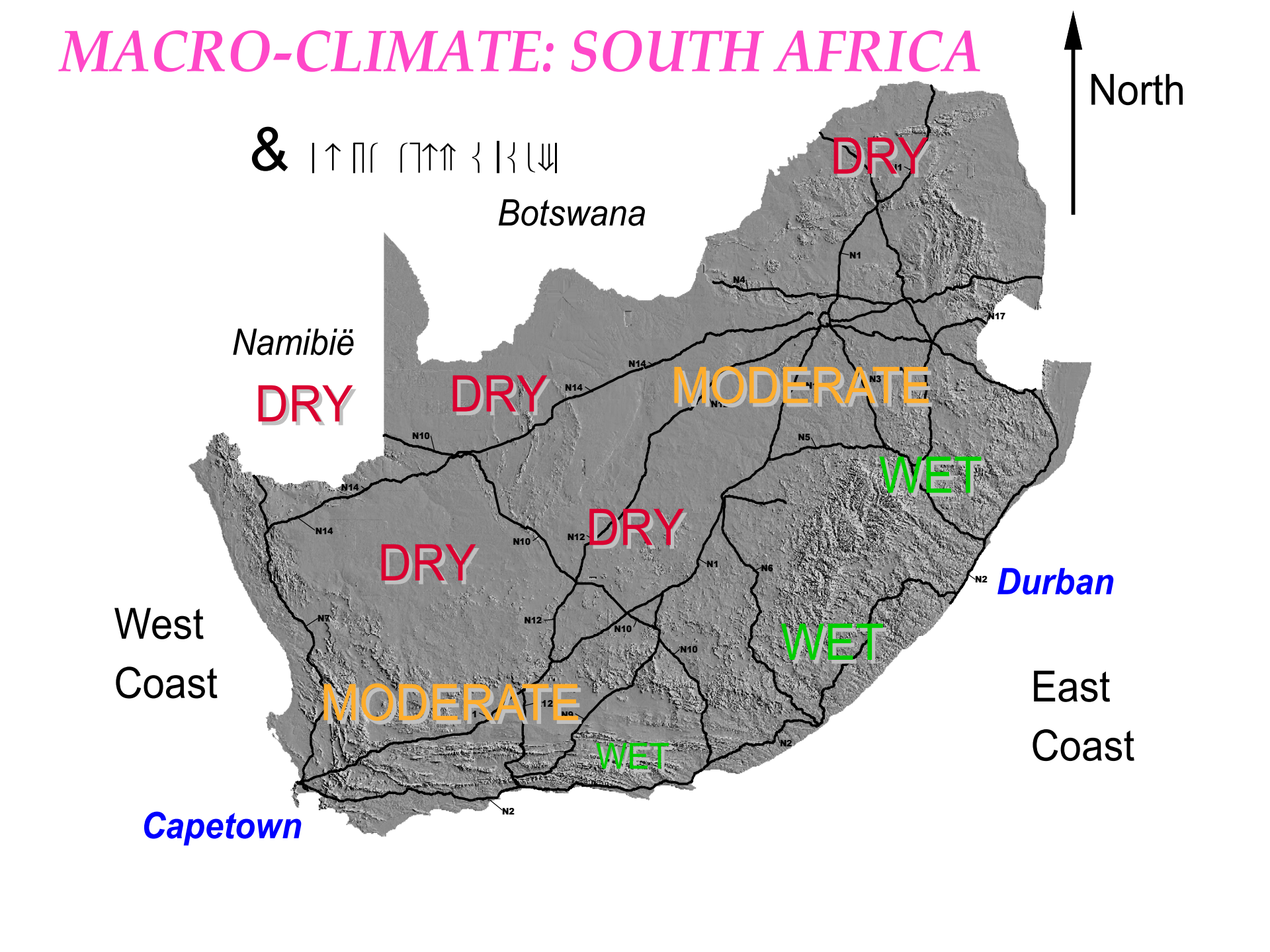
$$\left(\frac{1}{x} \right)' = -\frac{1}{x^2}$$

$$\left(\frac{1}{f(x)} \right)' = -\frac{f'(x)}{f(x)^2}$$

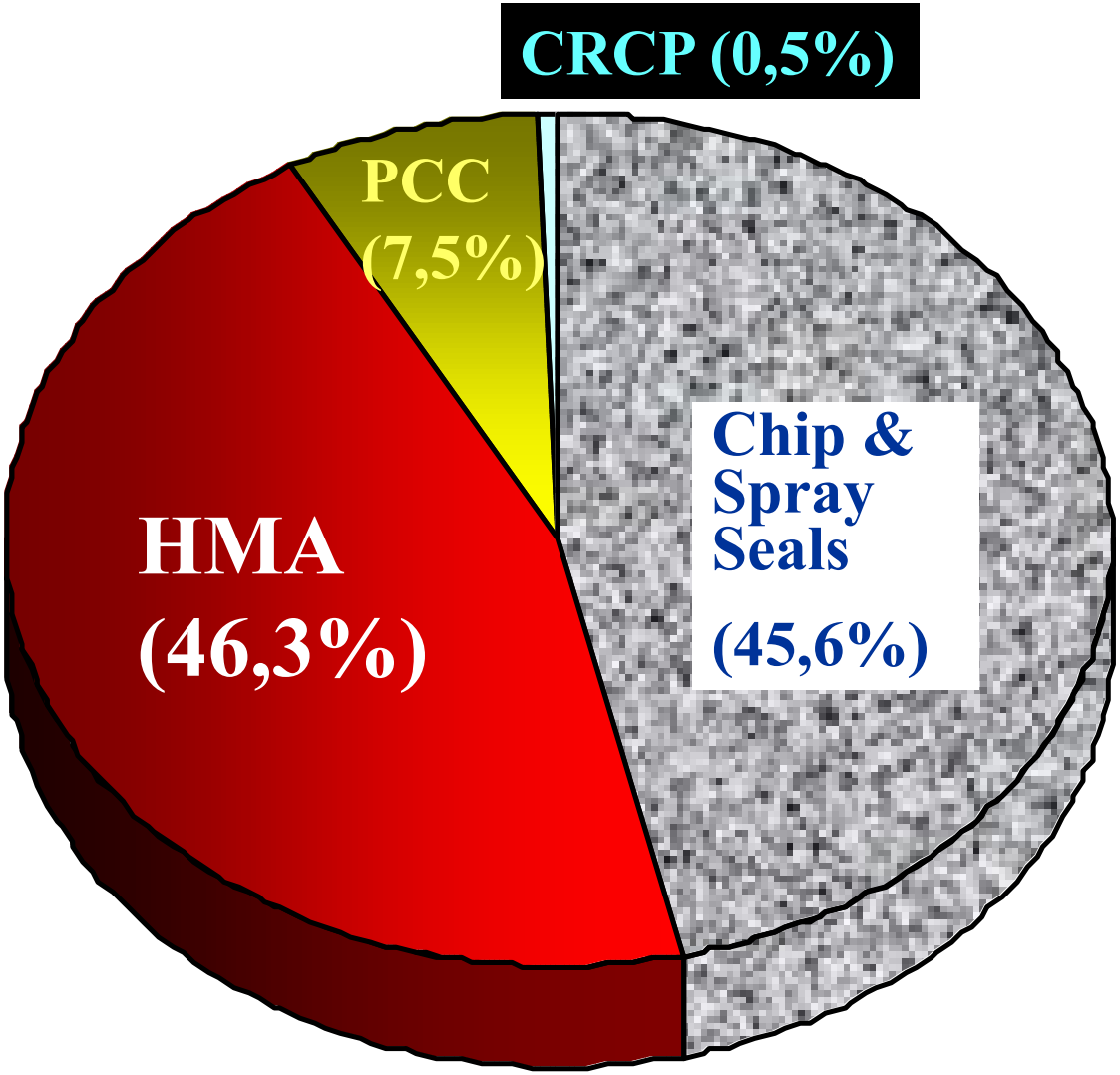
$$\left(\frac{f(x)}{g(x)} \right)' = \frac{f'(x)g(x) - f(x)g'(x)}{g(x)^2}$$

$$\left(\frac{f(x)}{g(x)} \right)' = f'(x)\frac{1}{g(x)} + f(x)\left(-\frac{g'(x)}{g(x)^2} \right)$$

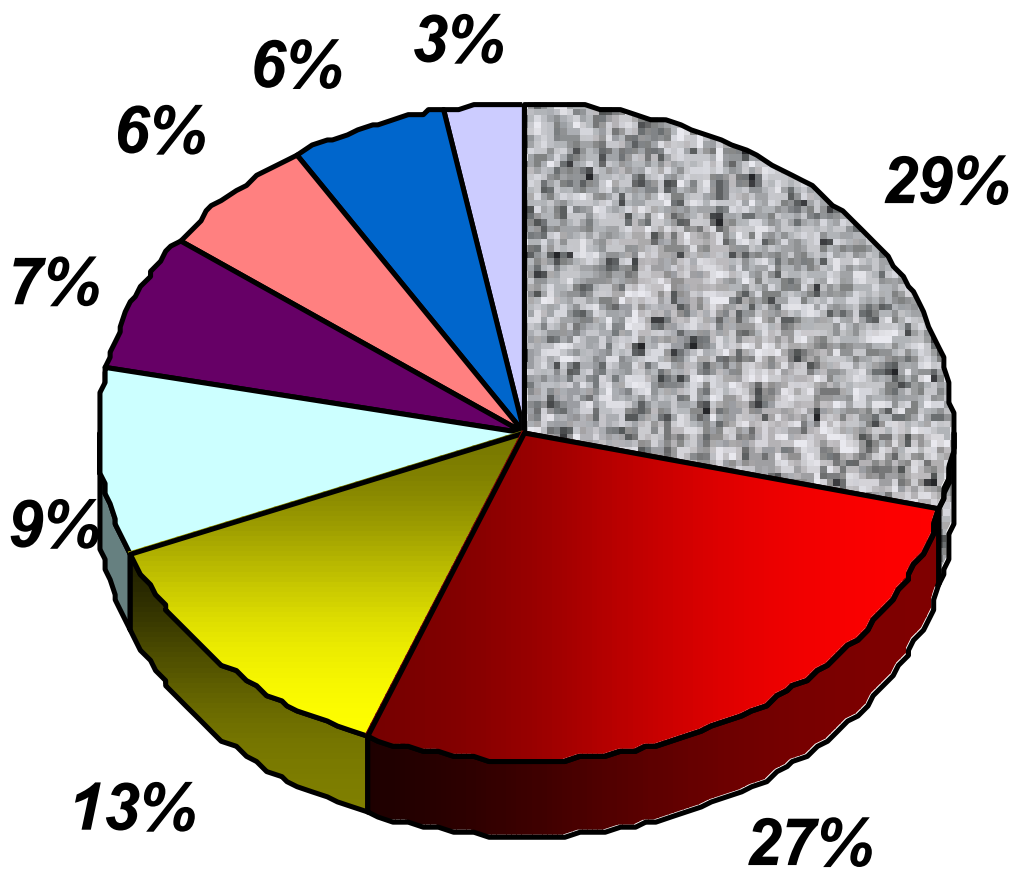
MACRO-CLIMATE: SOUTH AFRICA



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

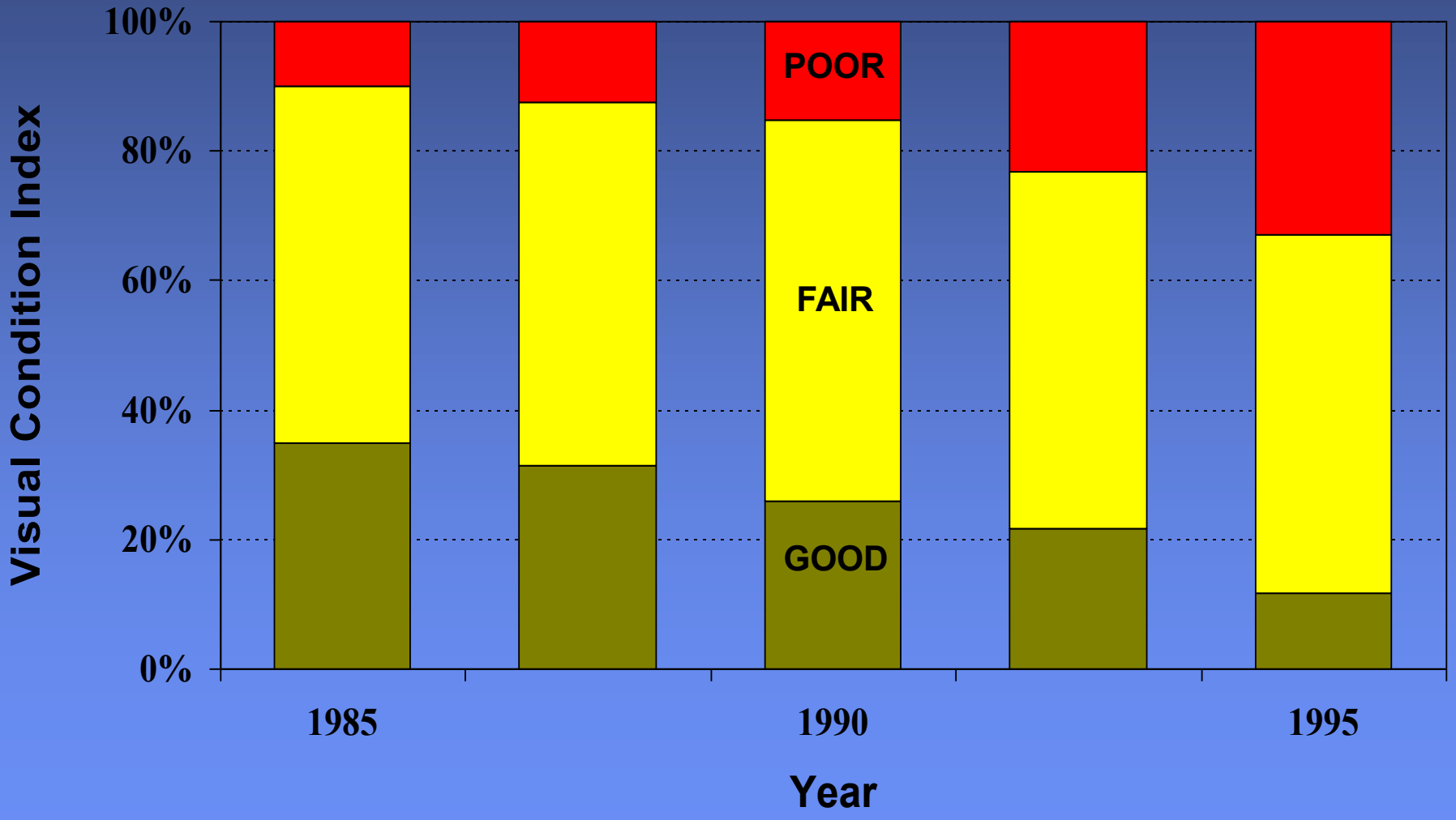


Base and Subbase Types of National Roads in South Africa (1997/8)

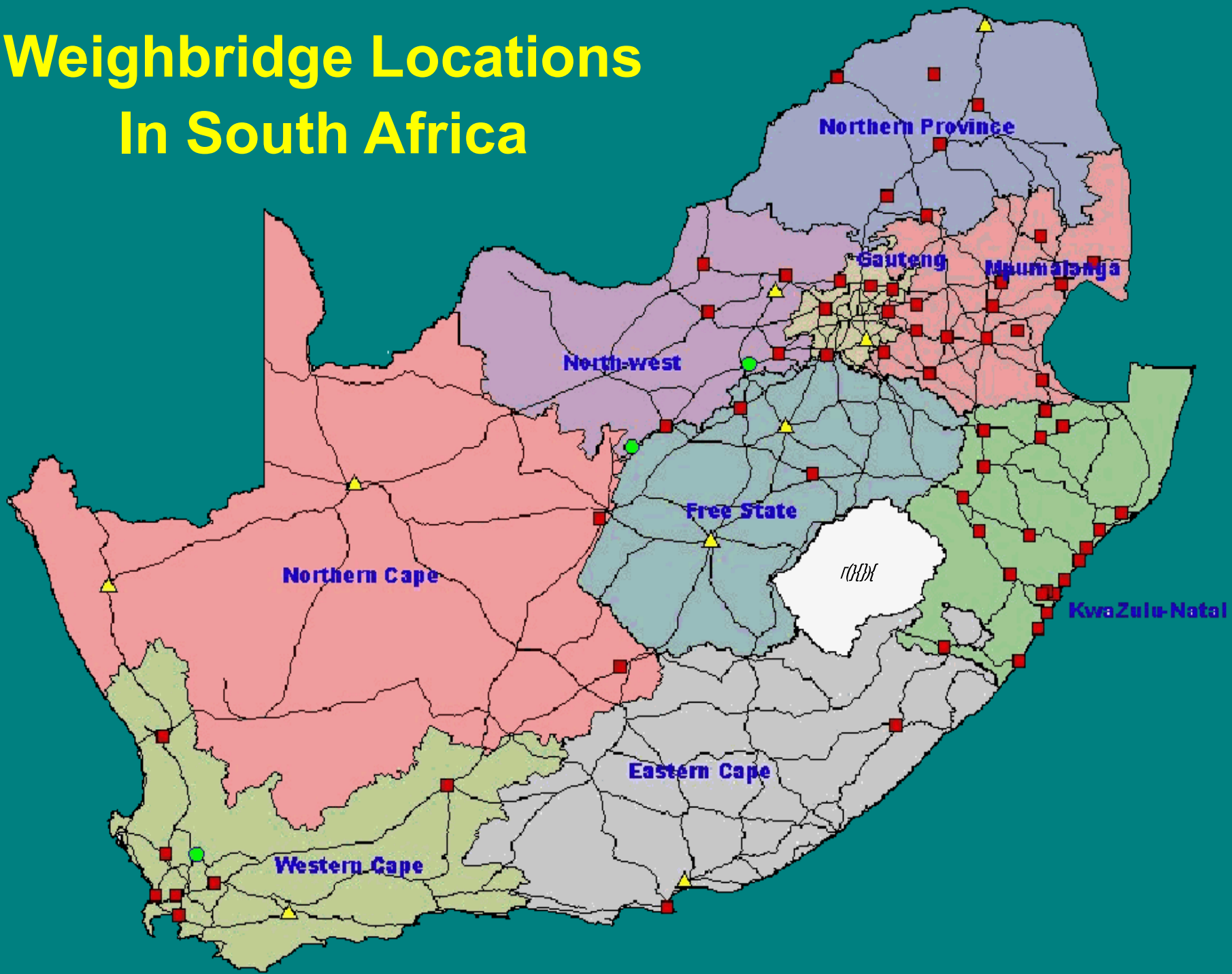


- G1/G2 Base on Stab Subbase (29%)
- G1/G2 Base on Nat gravel Subbase (27 %)
- HMA (13 %)
- PCC (9 %)
- C3/C4 Base on Nat gravel Subbase (7 %)
- C3/C4 Base on Stab gravel Subbase (6%)
- G3/G4/G5 Base on Nat Gravel Subbase (6%)
- G3/G4/G5 on Stab Subbase (3%)

CHANGE IN ROAD CONDITION FOR THE NETWORK IN SA



Weighbridge Locations In South Africa



How to address the problem of Pavement Damage ??

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

315/80 R22.5 HVS TIRE ON VRSPTA

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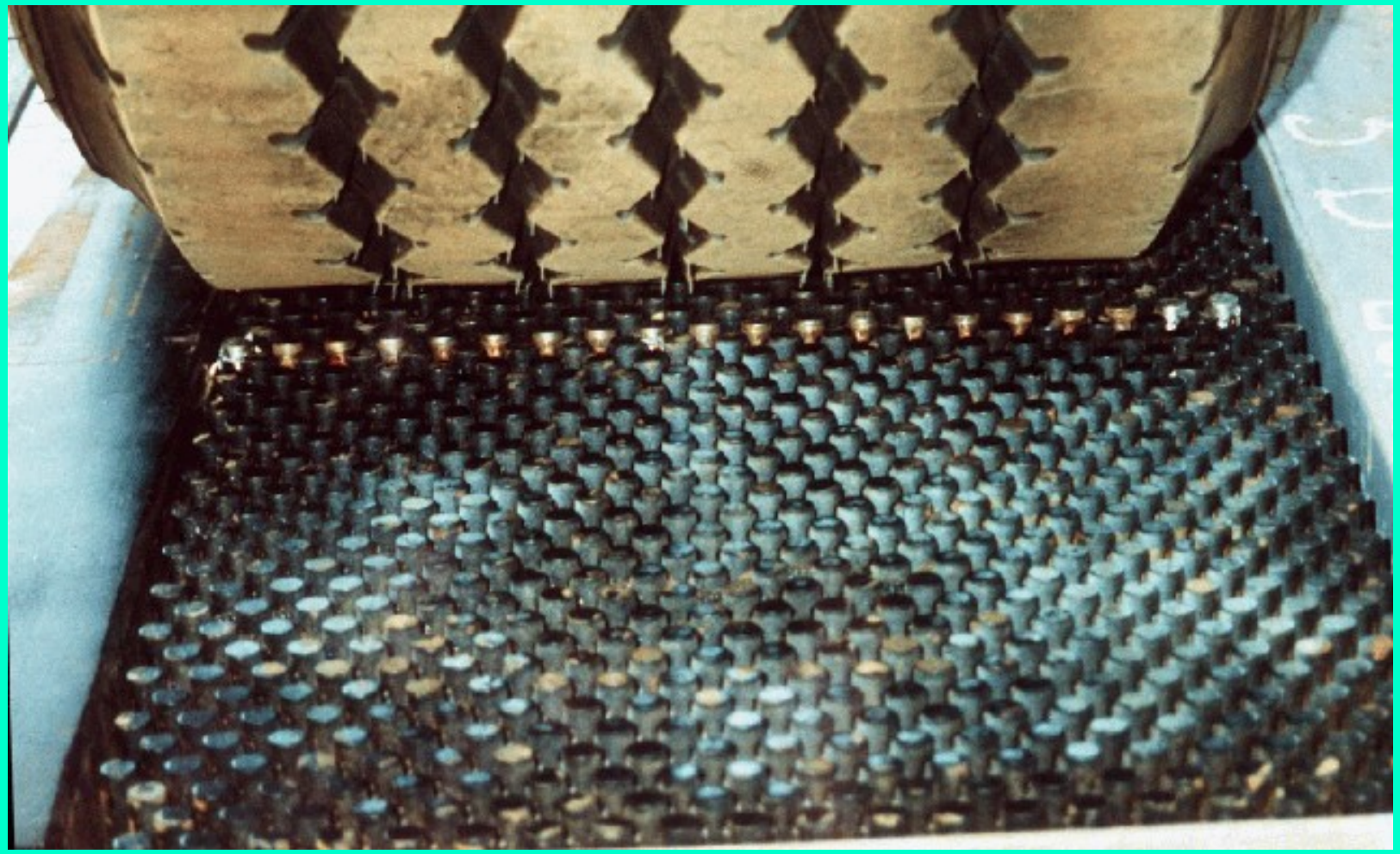
(HVS) Heavy Vehicle Simulator - - Mobile Unit



425 /65 R22.5 HVS TIRE ON VRSPTA

CONTACT STRESS DATA (BOLD TIRE)

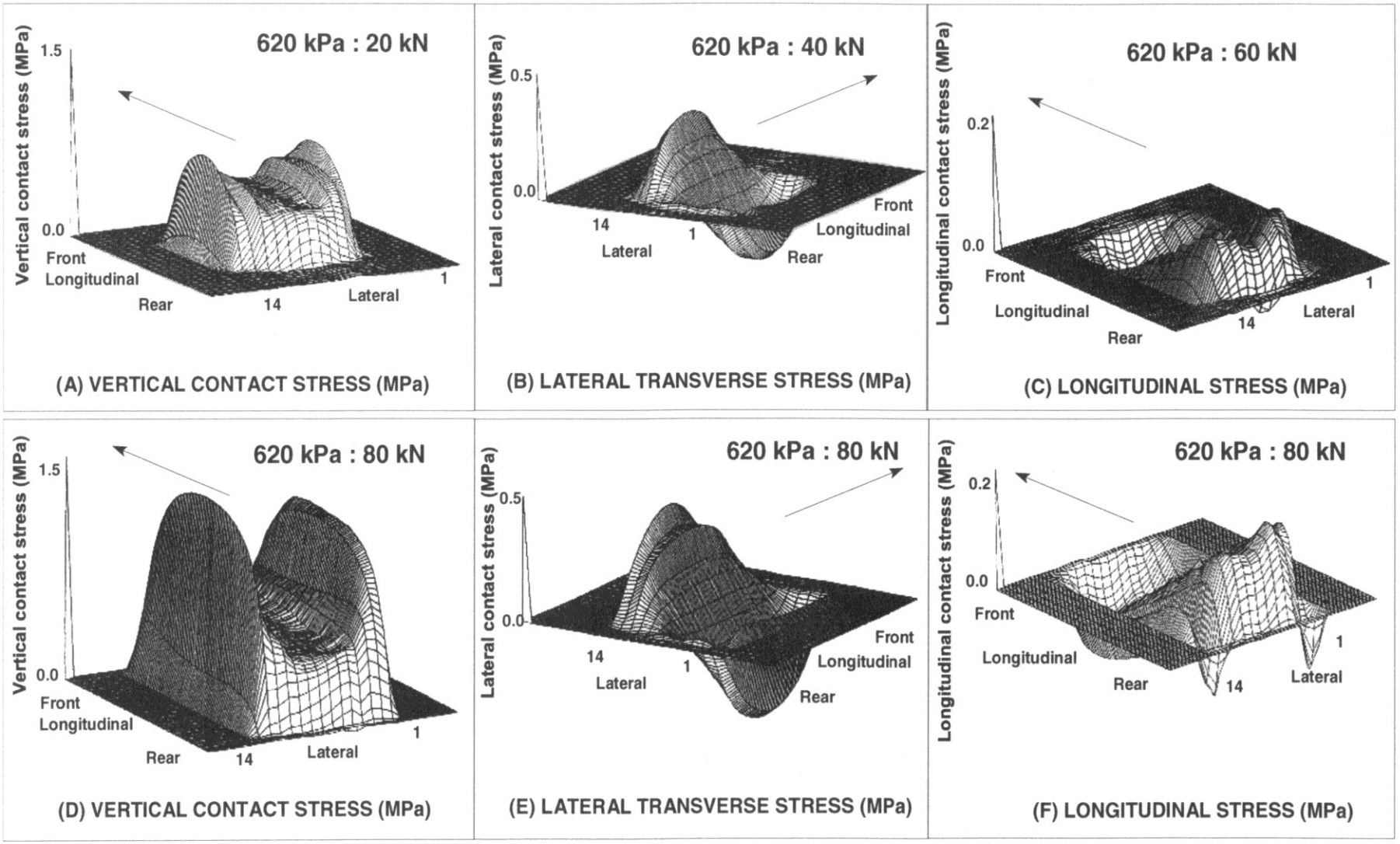
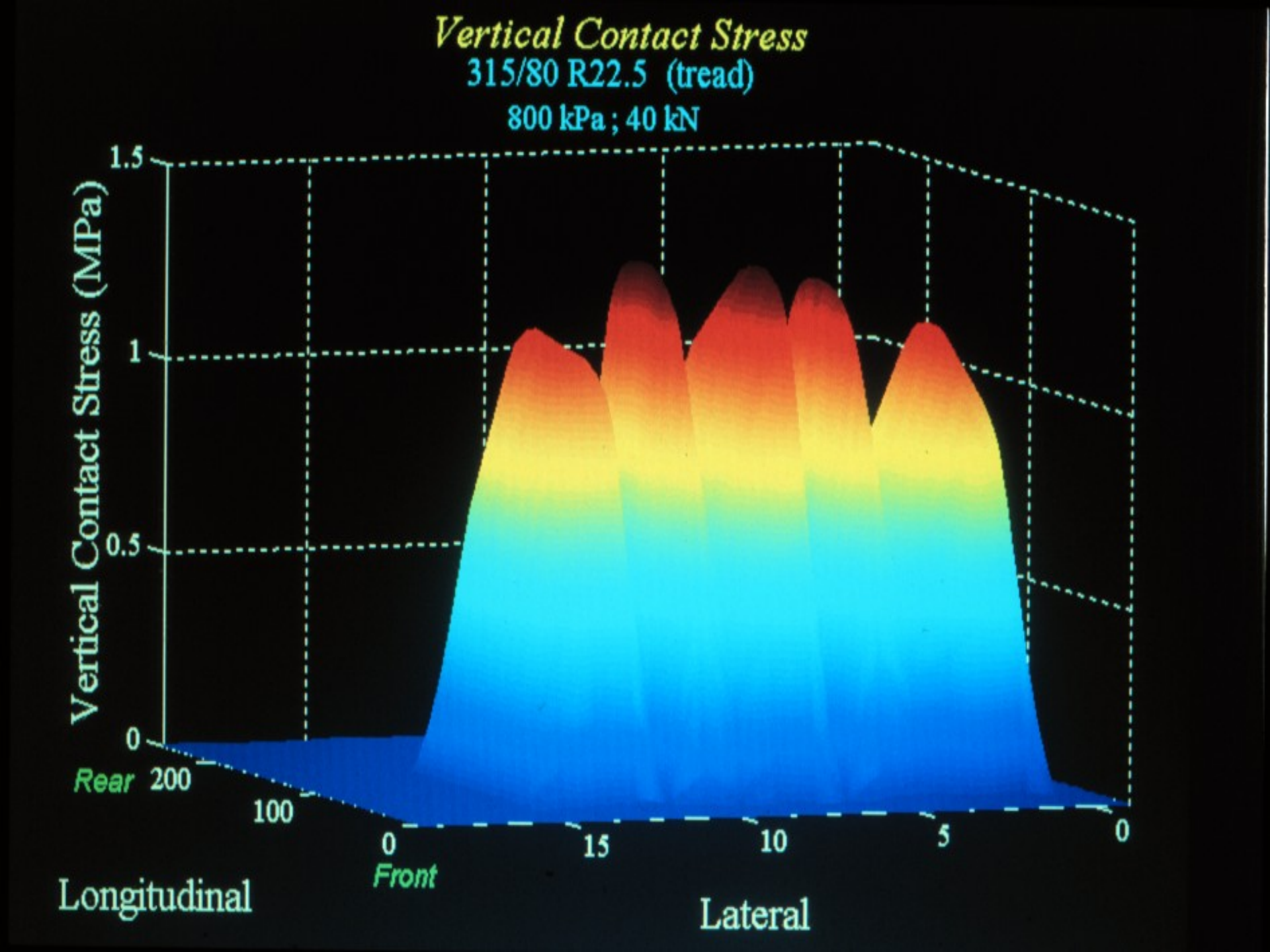
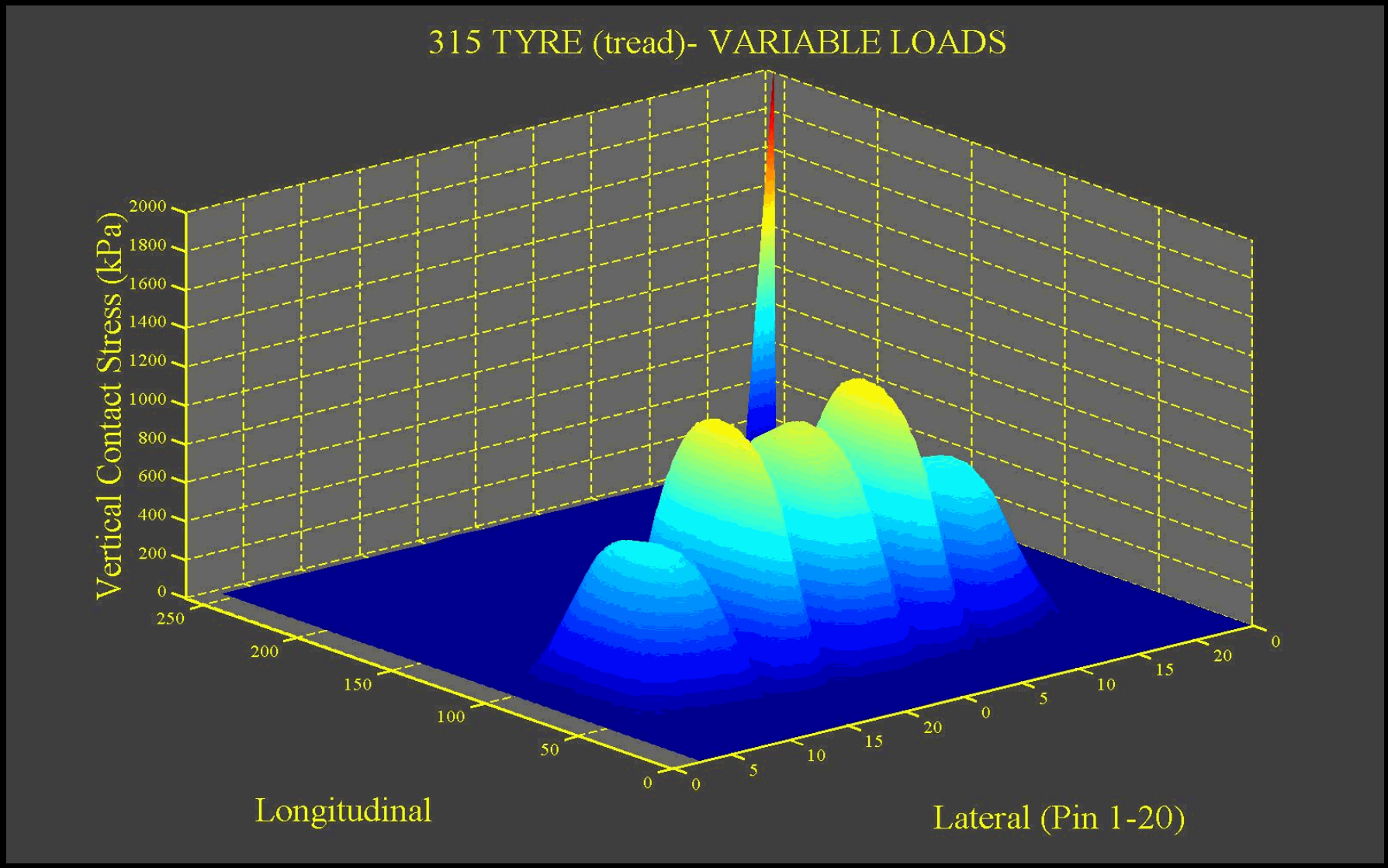


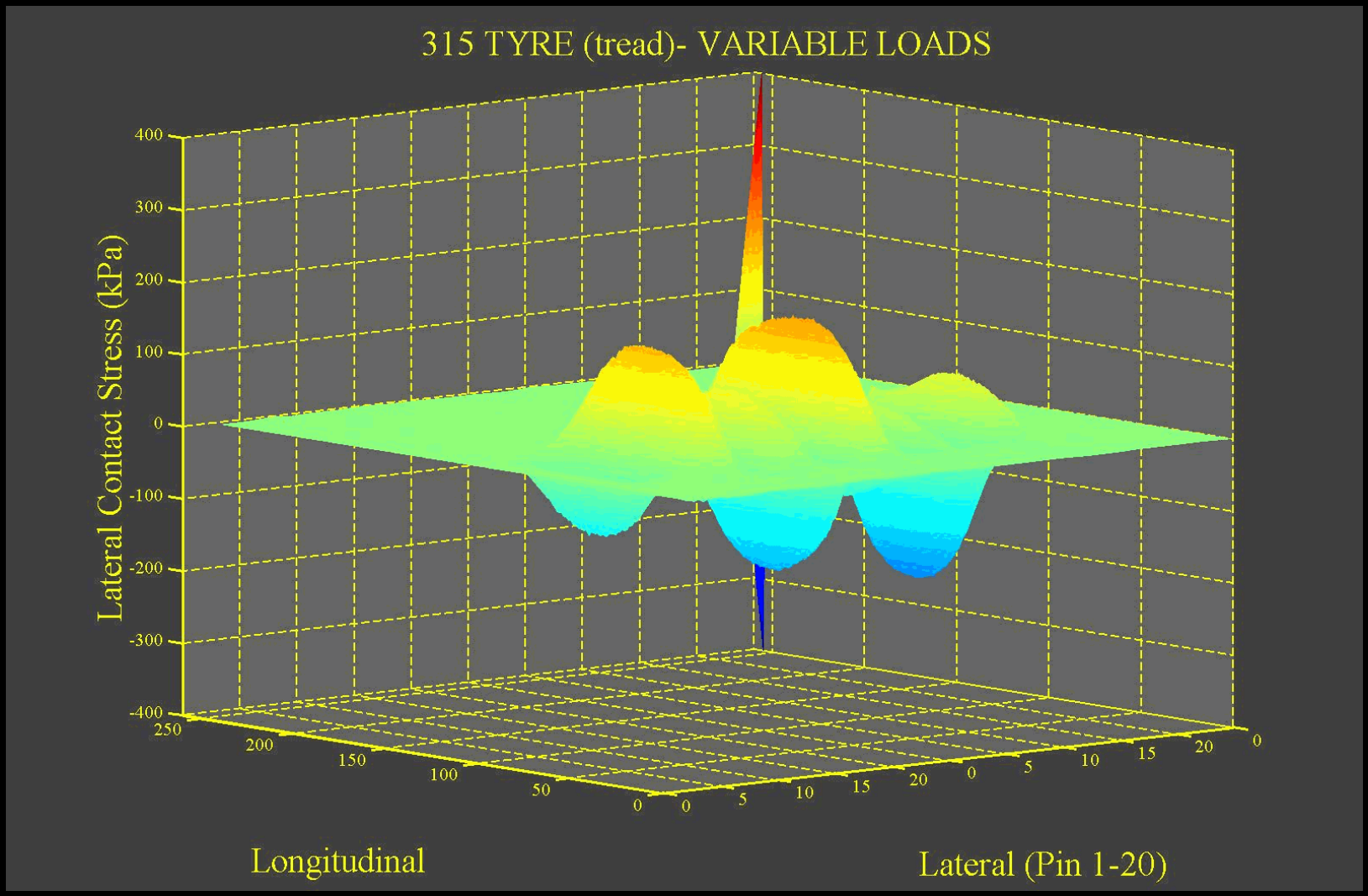
FIGURE 6 : Typical contact stress distributions measured with the VRSPTA system for a slow moving (1,2 km/h) free rolling smooth single truck tyre (Goodyear 11.00 X 20, 14 Ply rating)


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

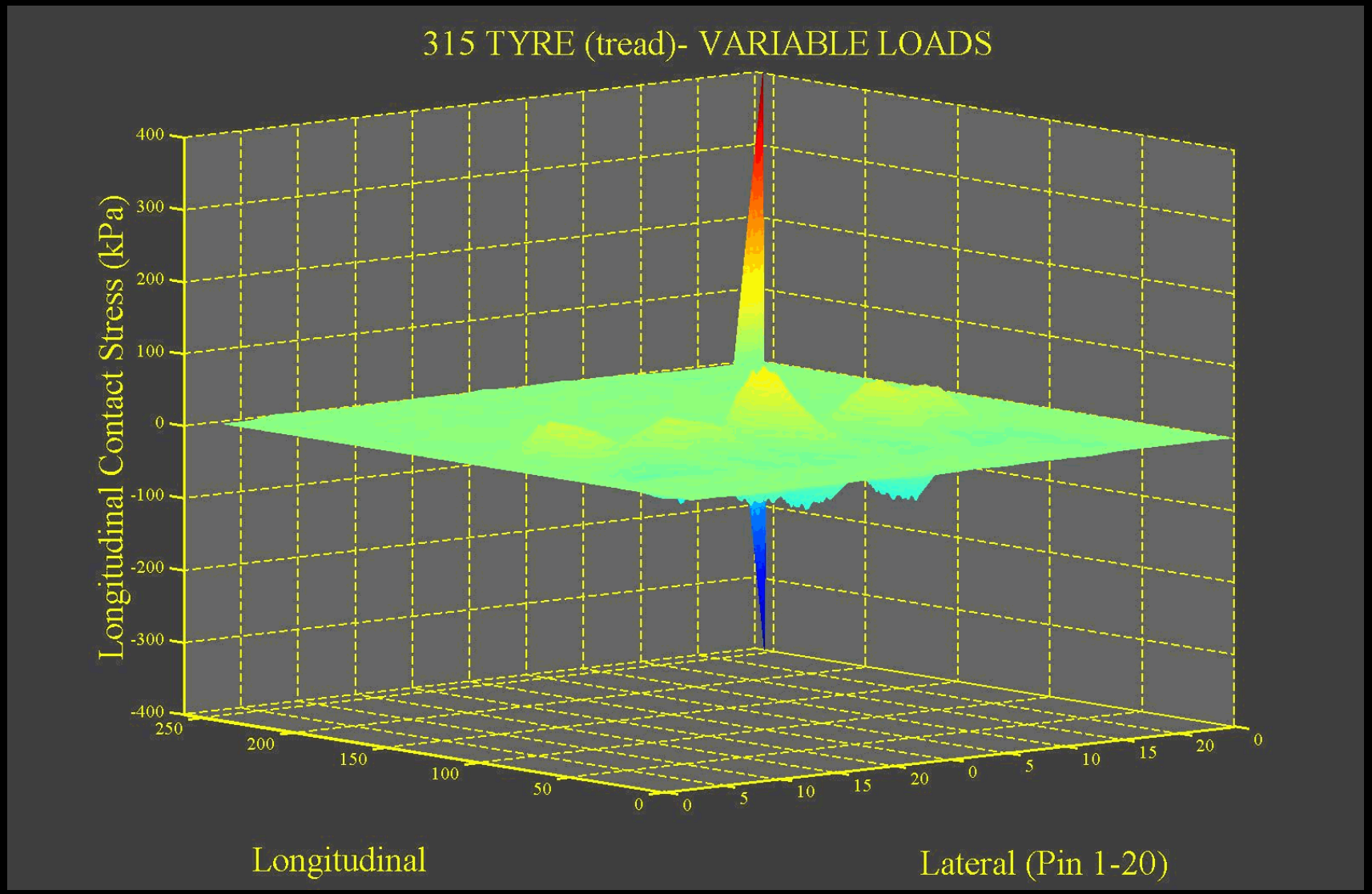
Vertical Contact Stress:
Variable loads: 315/80 R22.5 Tire



Lateral Contact Stress:
Variable loads: 315/80 R22.5 Tire



Longitudinal Contact Stress:
Variable Loads: 315/80 R22.5 Tire



TIRES
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Truck Tire Inflation Pressure in South Africa:

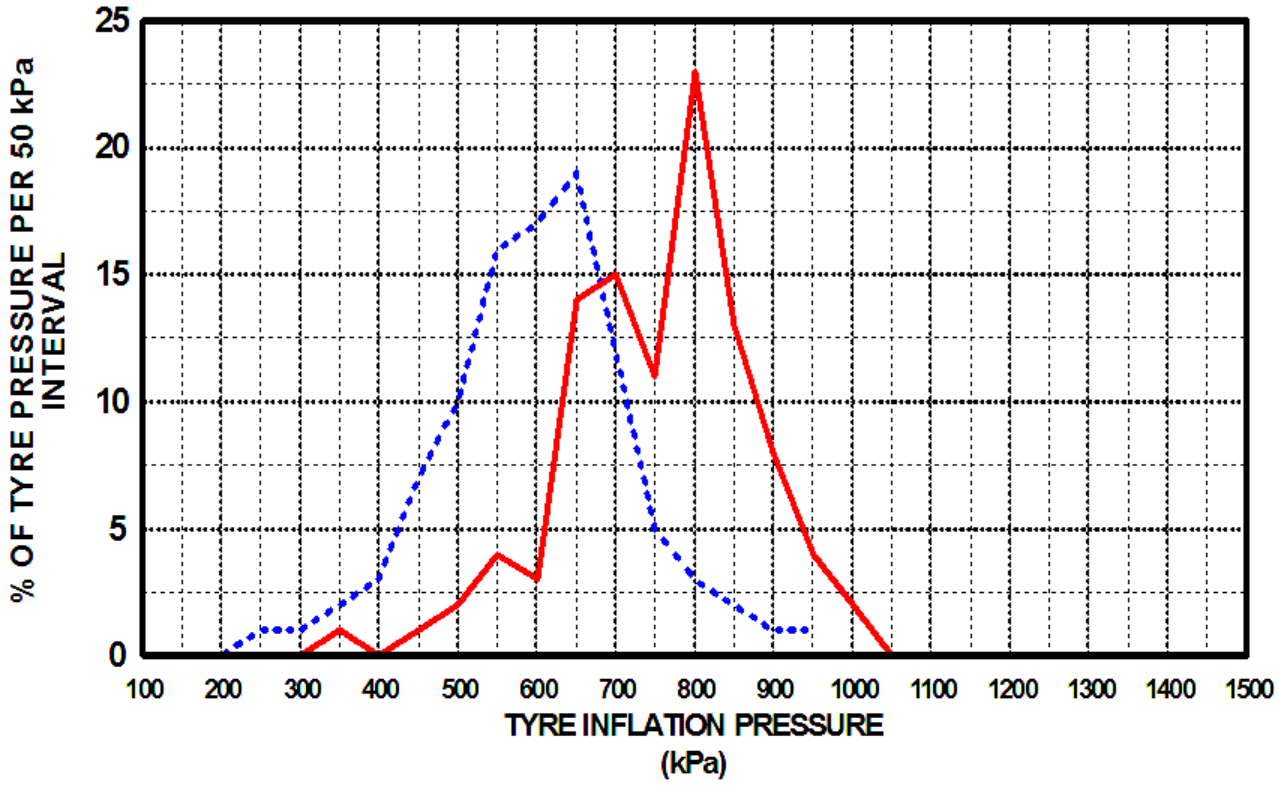


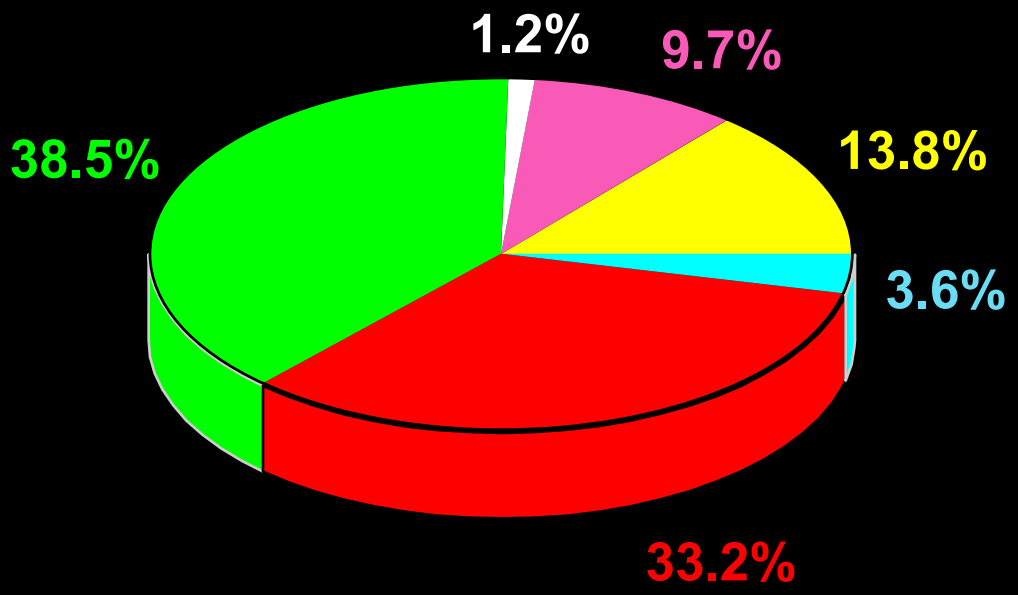
FIGURE 1

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

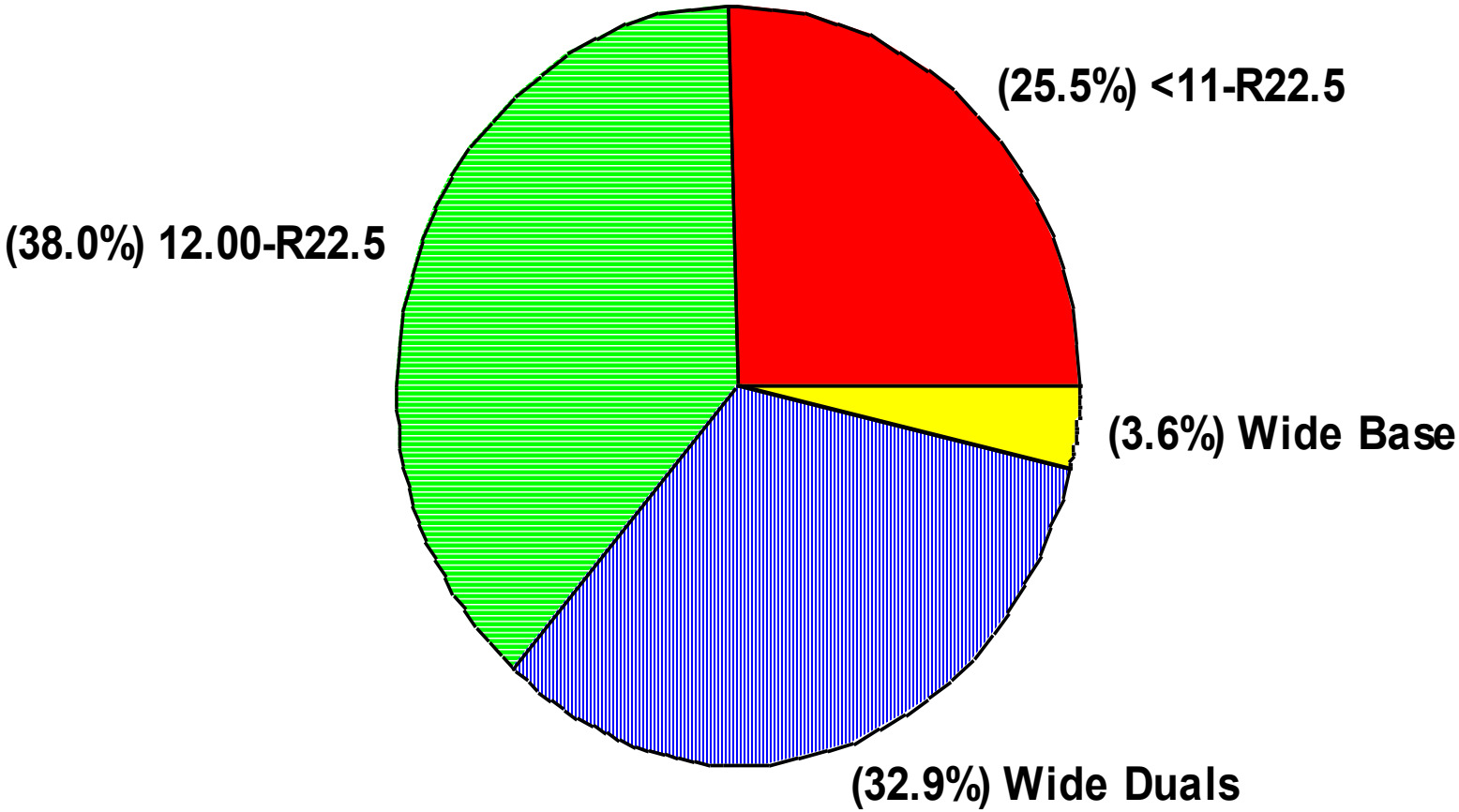
~ 20 % Increase in 20 Years

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)



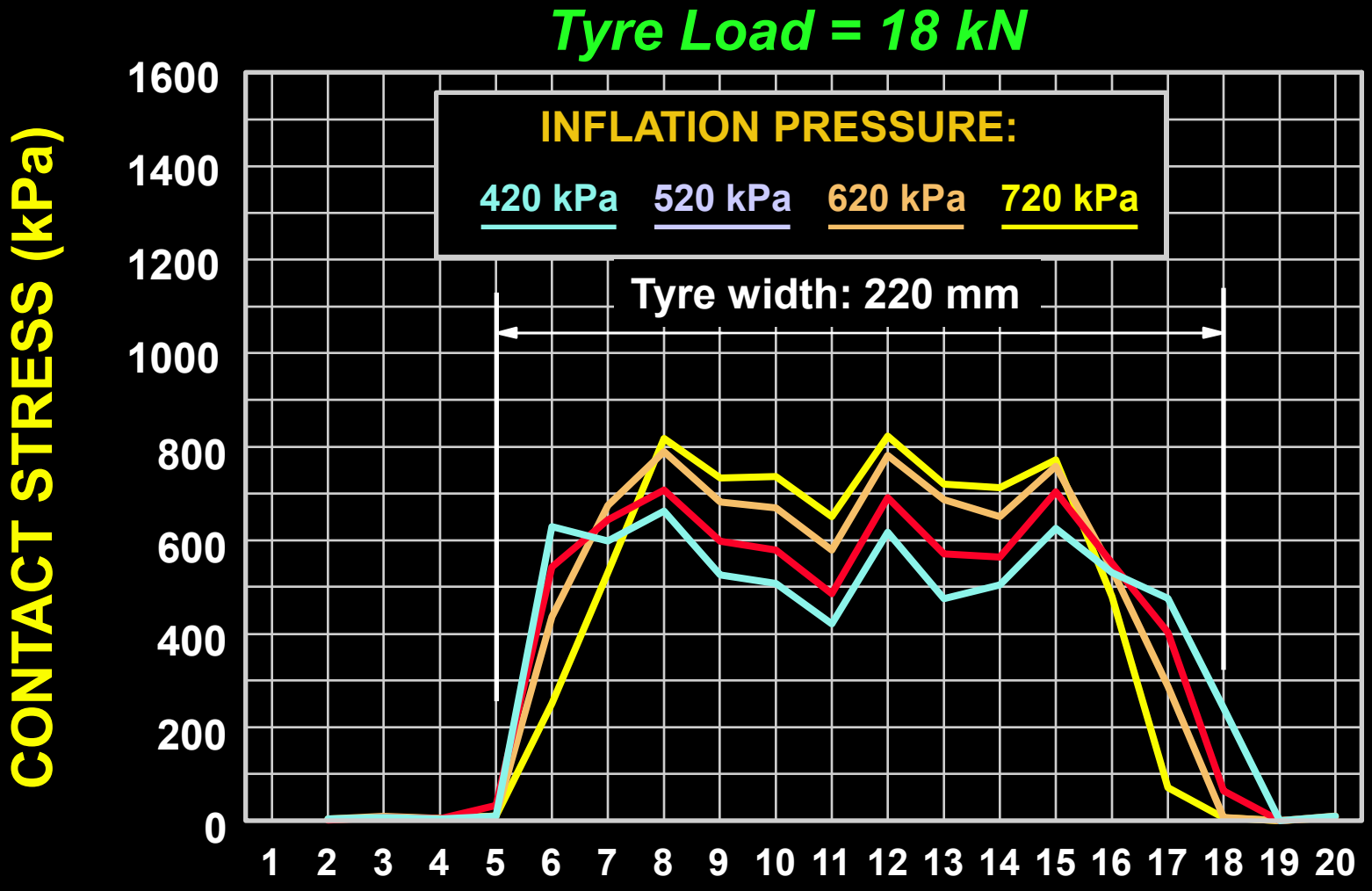


FIGURE 11

Maximum vertical stress at CONSTANT LOAD and various inflation pressures

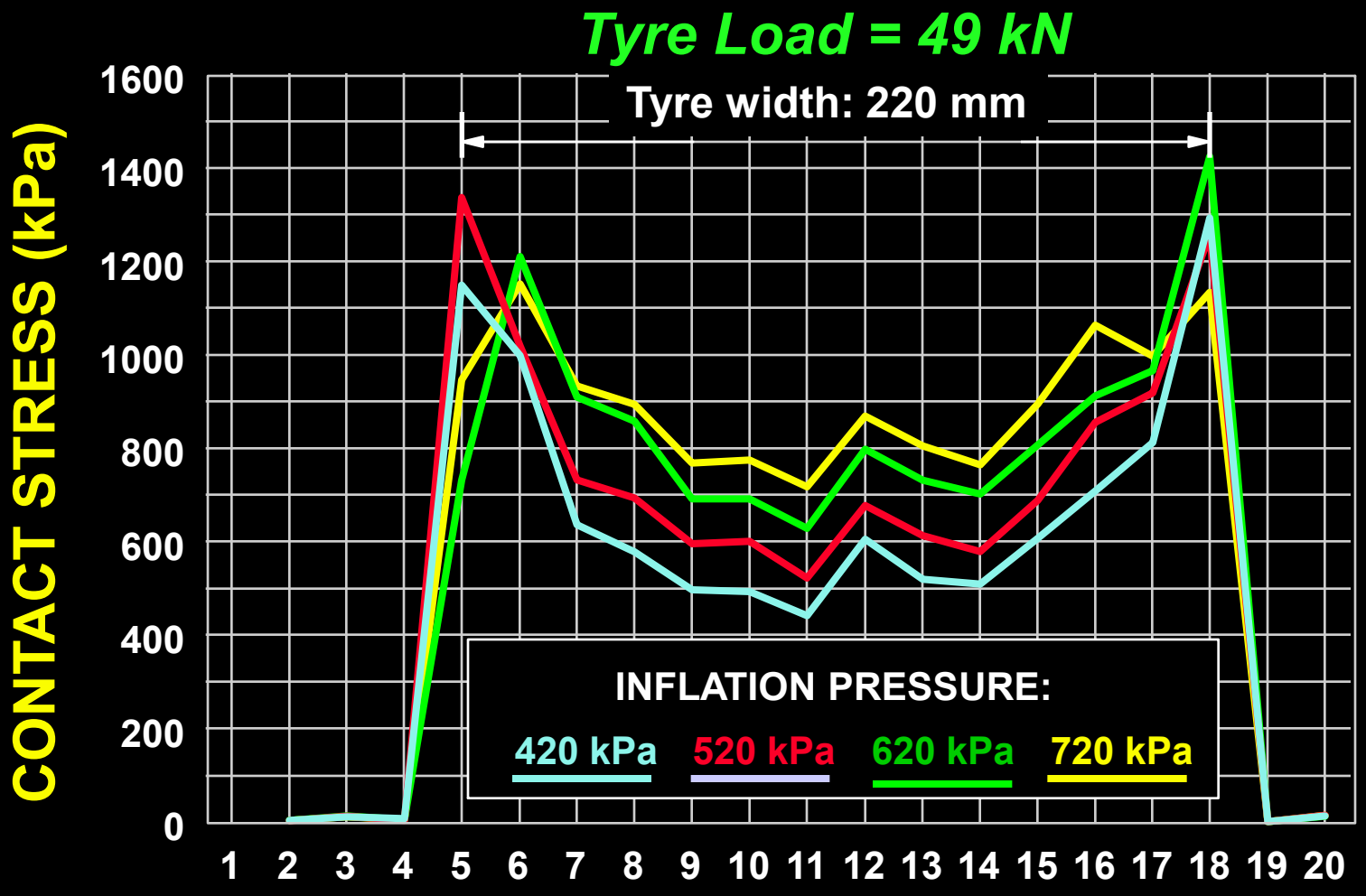


FIGURE 12

Maximum vertical stress at CONSTANT LOAD and various inflation pressures

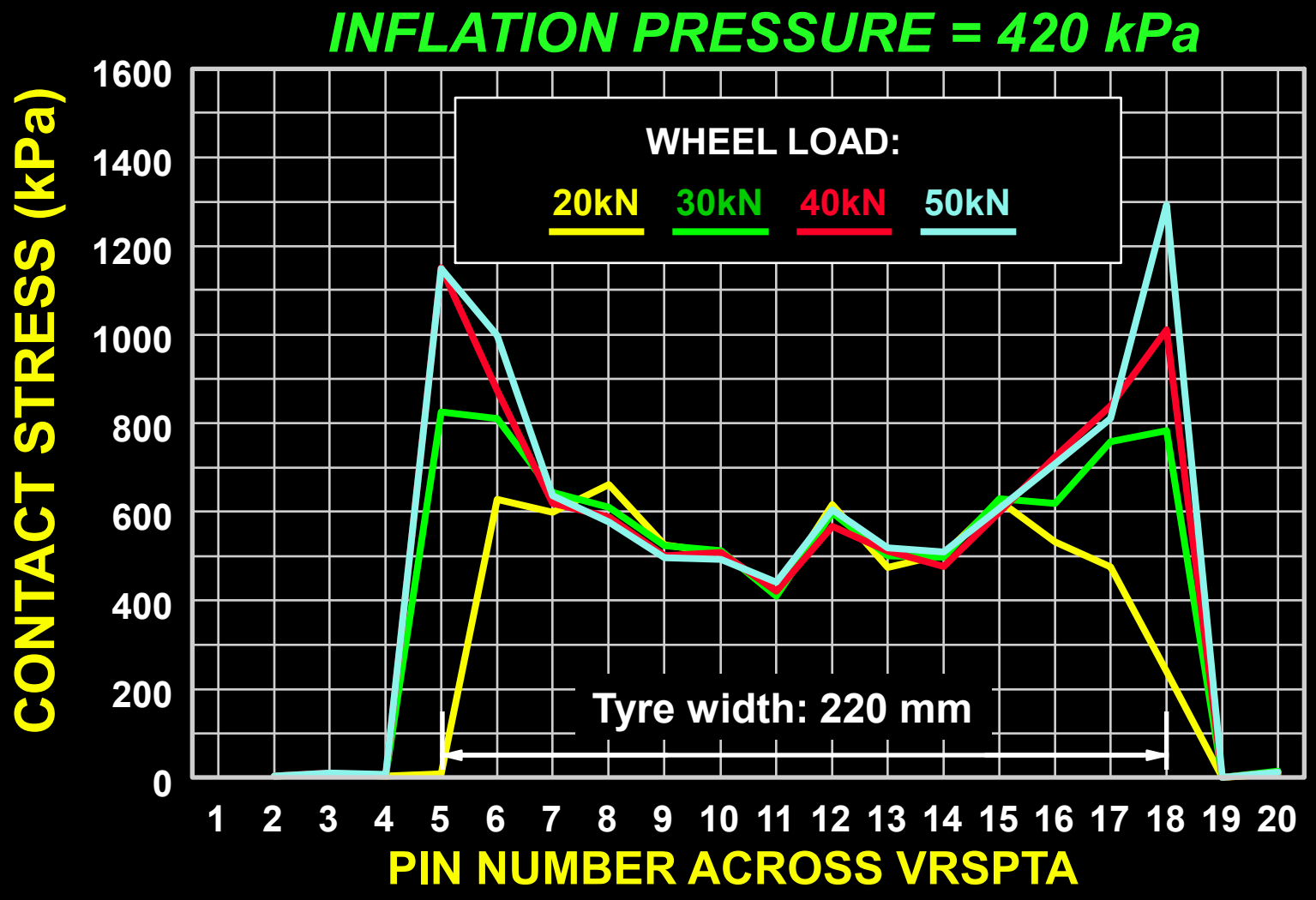


FIGURE 13

Maximum vertical stress at CONSTANT INFLATION PRESSURE at various loads

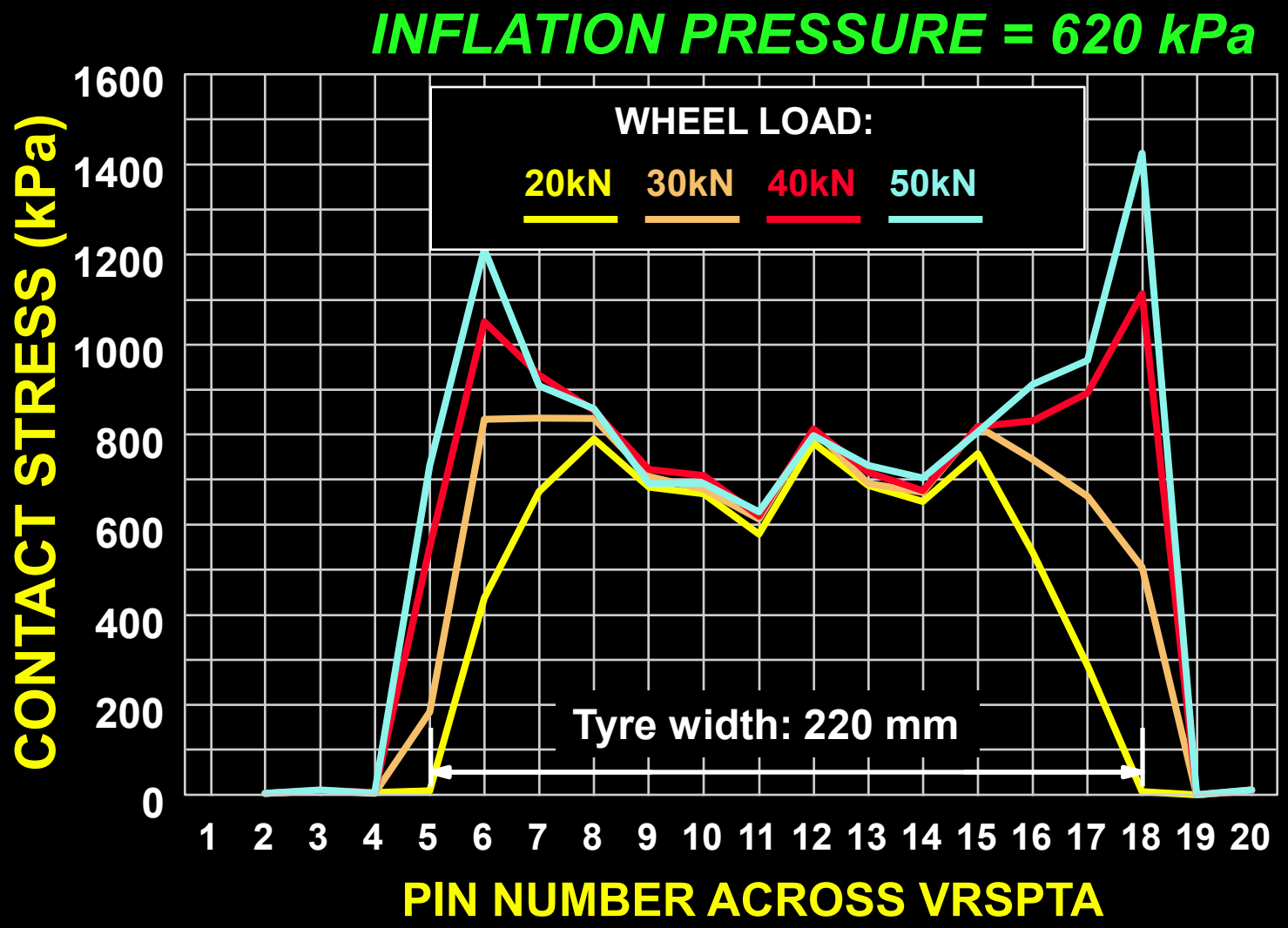
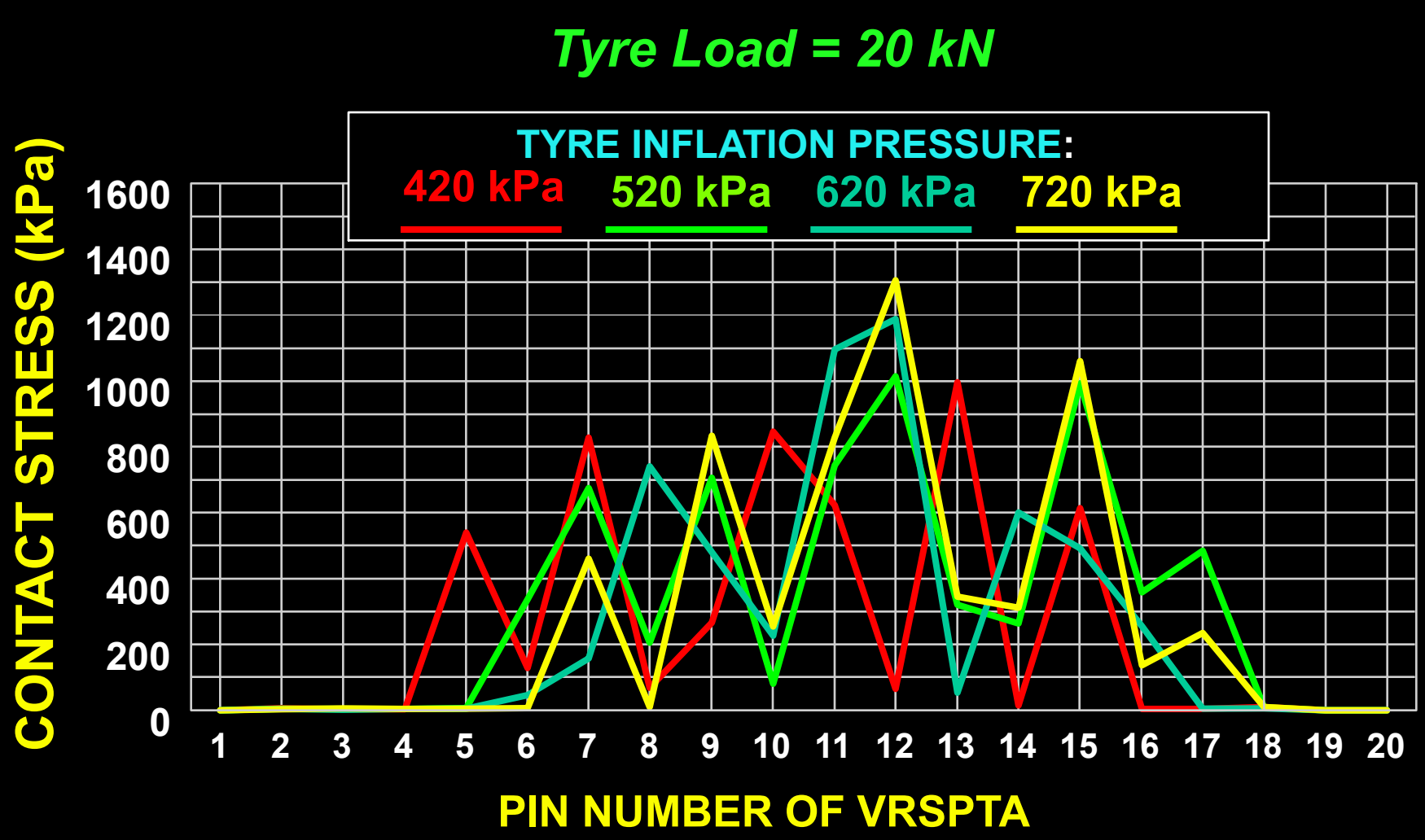
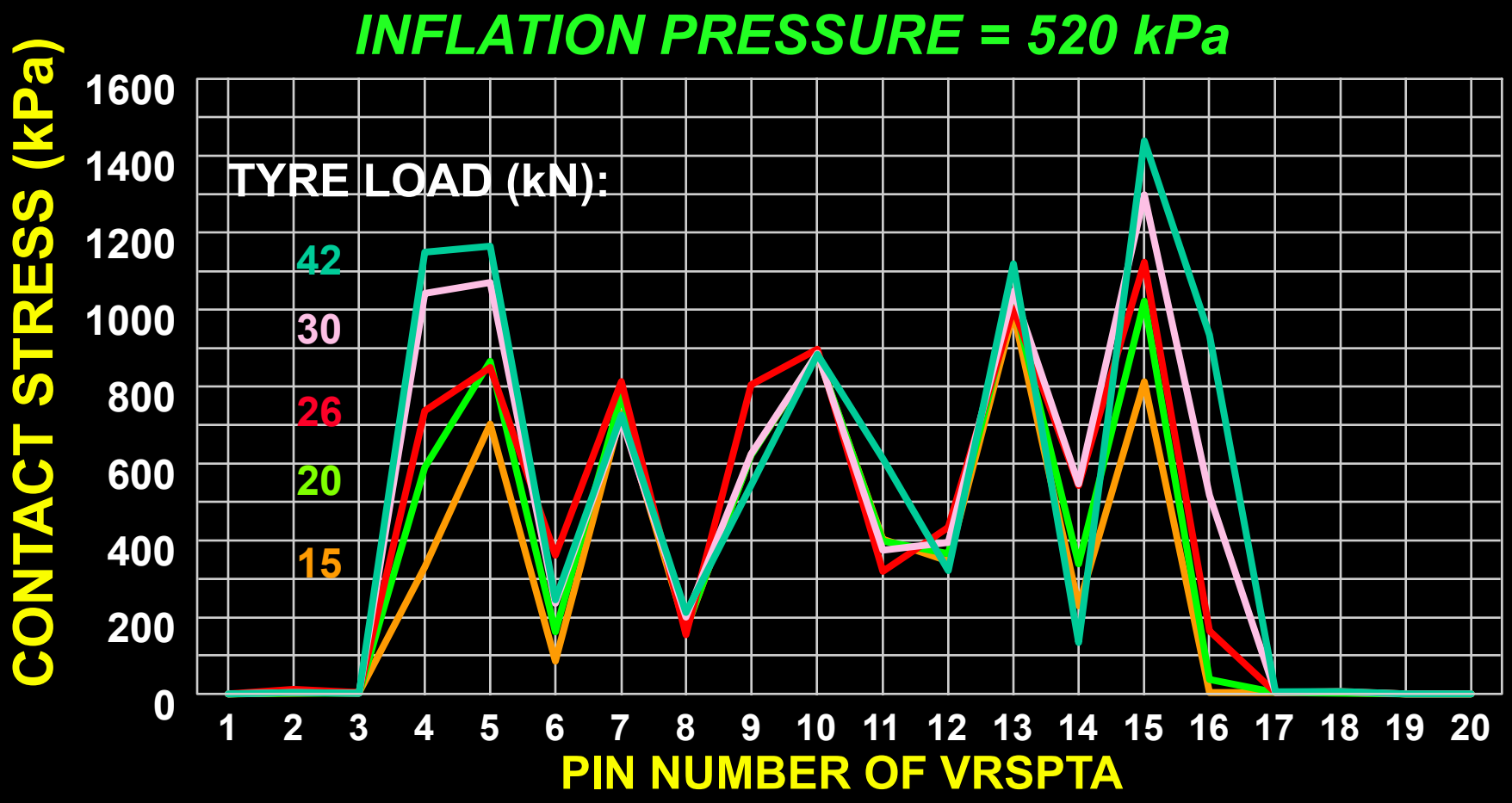


FIGURE 14

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

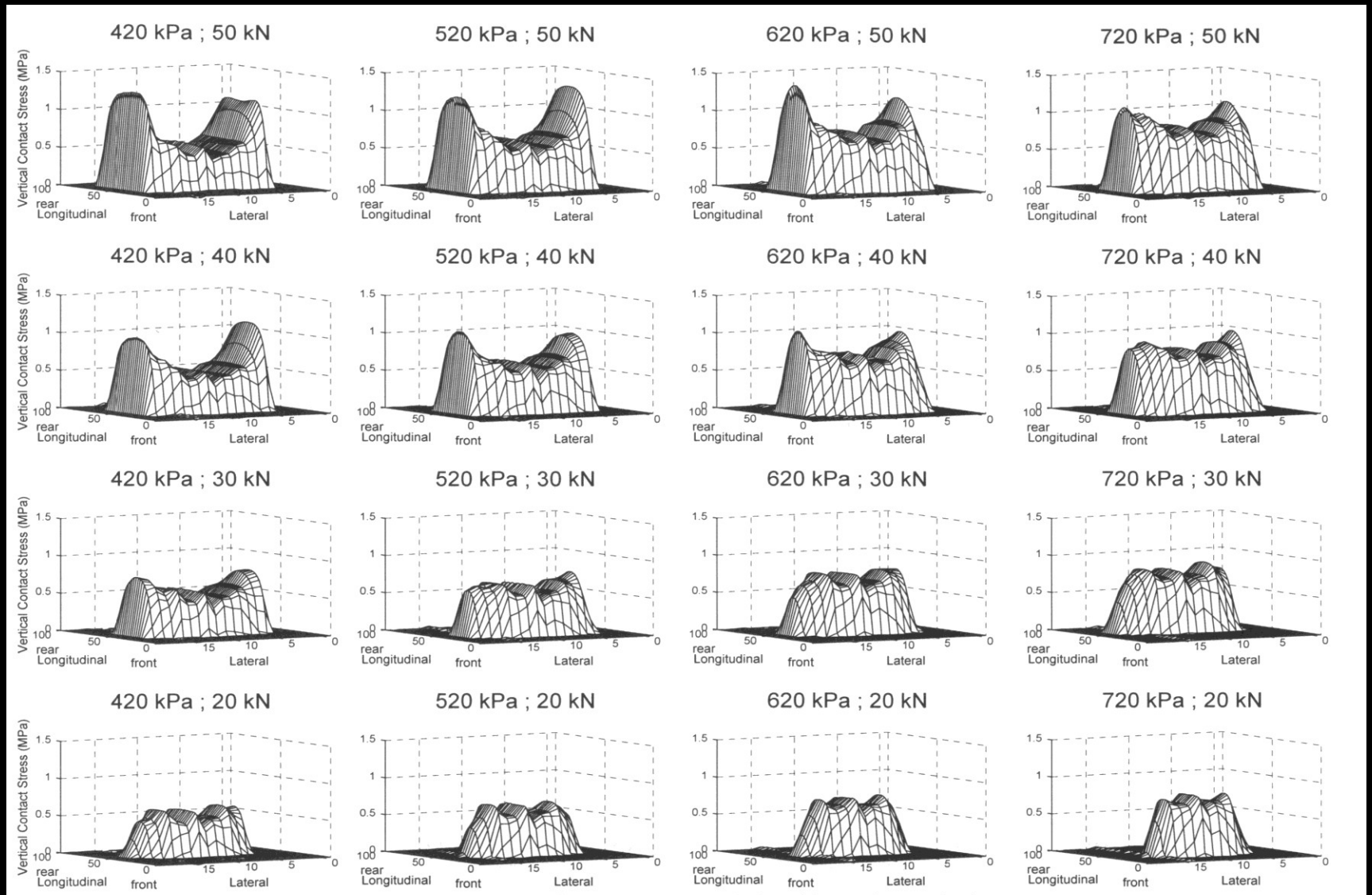


Figure 7: Graphic illustrations of the tyre load/inflation pressure relationship on the vertical contact stress distributions of a slow moving (1,2km/h) single bias/cross ply HVS tyre with tread grooves:
Tyre TYPE I, Table 1 (Inflation Pressure:420kPa to 720kPa, Tyre Load: 20kN to 50kN)

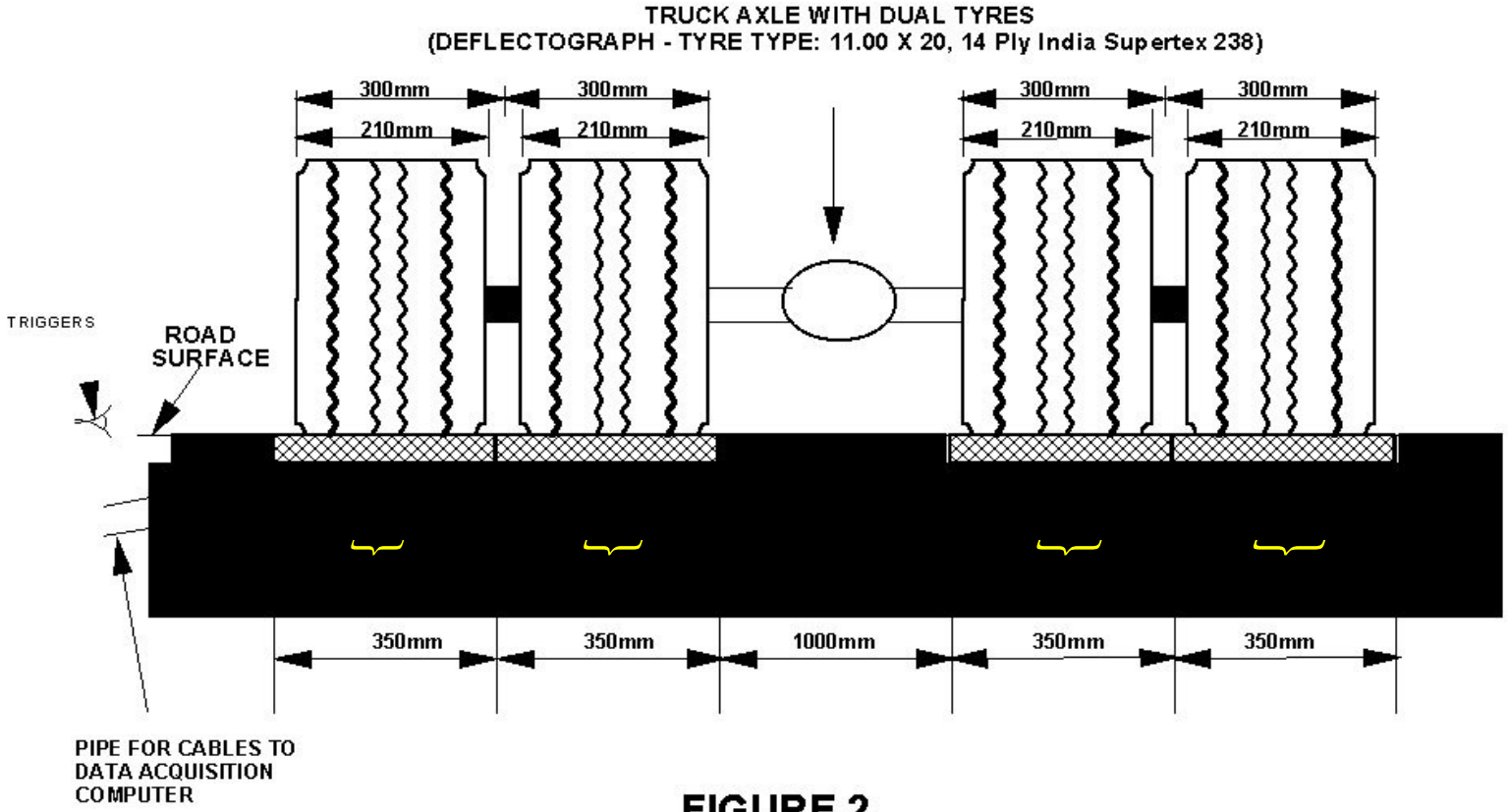


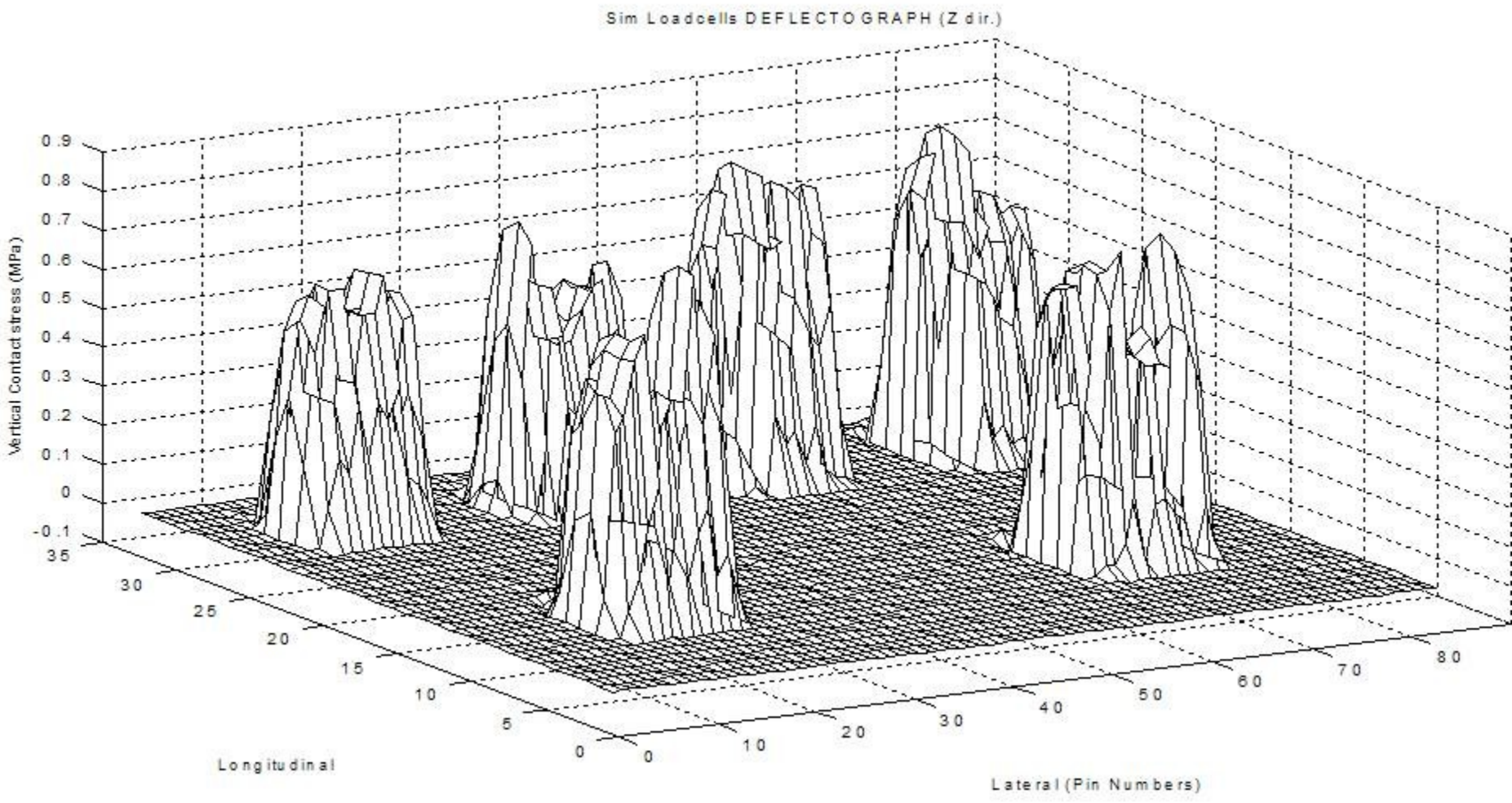
FIGURE 2

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

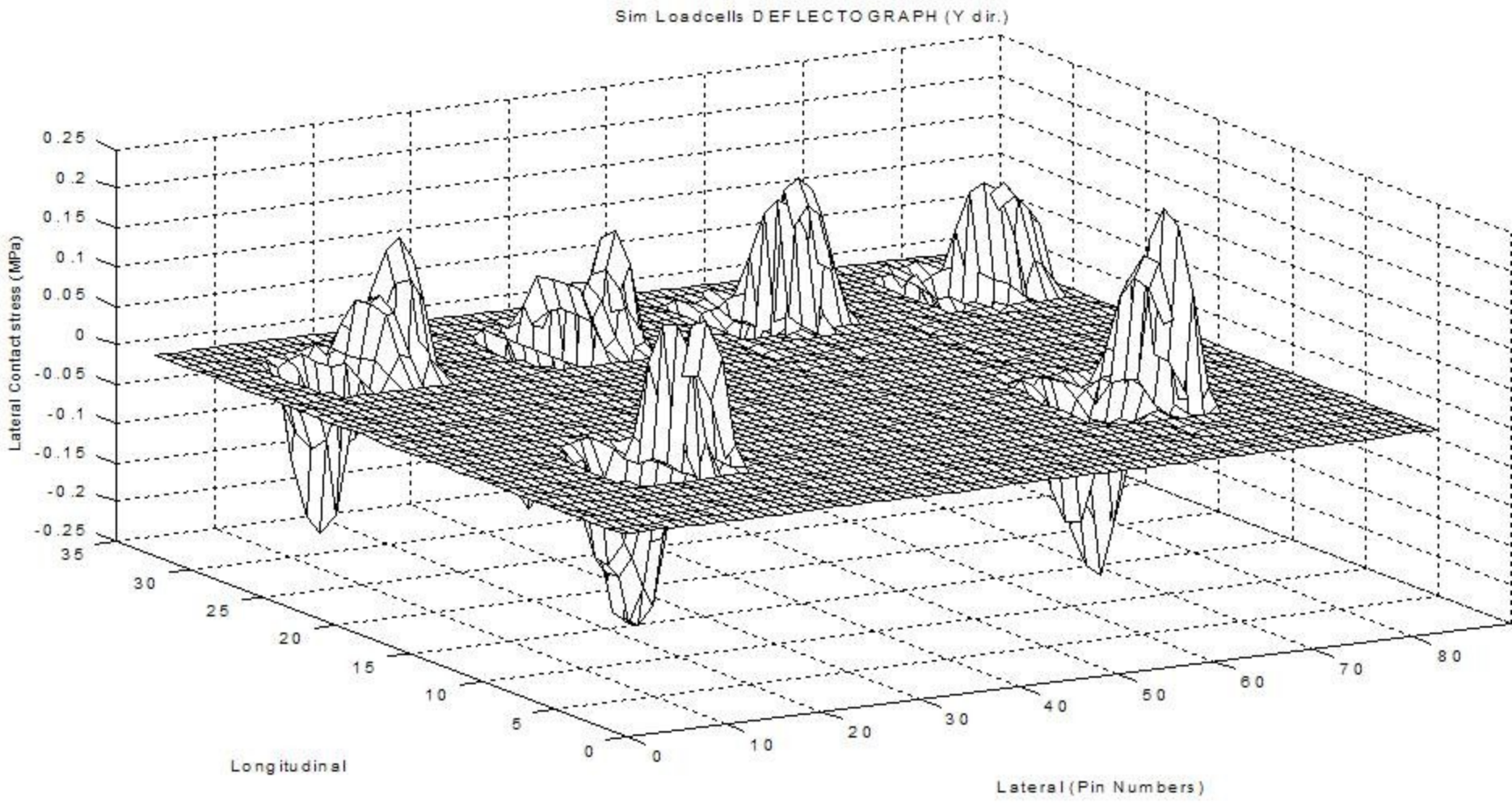
SIM3.DRW


WARNING
PASOP
STADIGE
TOETS
VOERTUIG
CAUTION
SLOW
TEST
VEHICLE
80
KMP270T

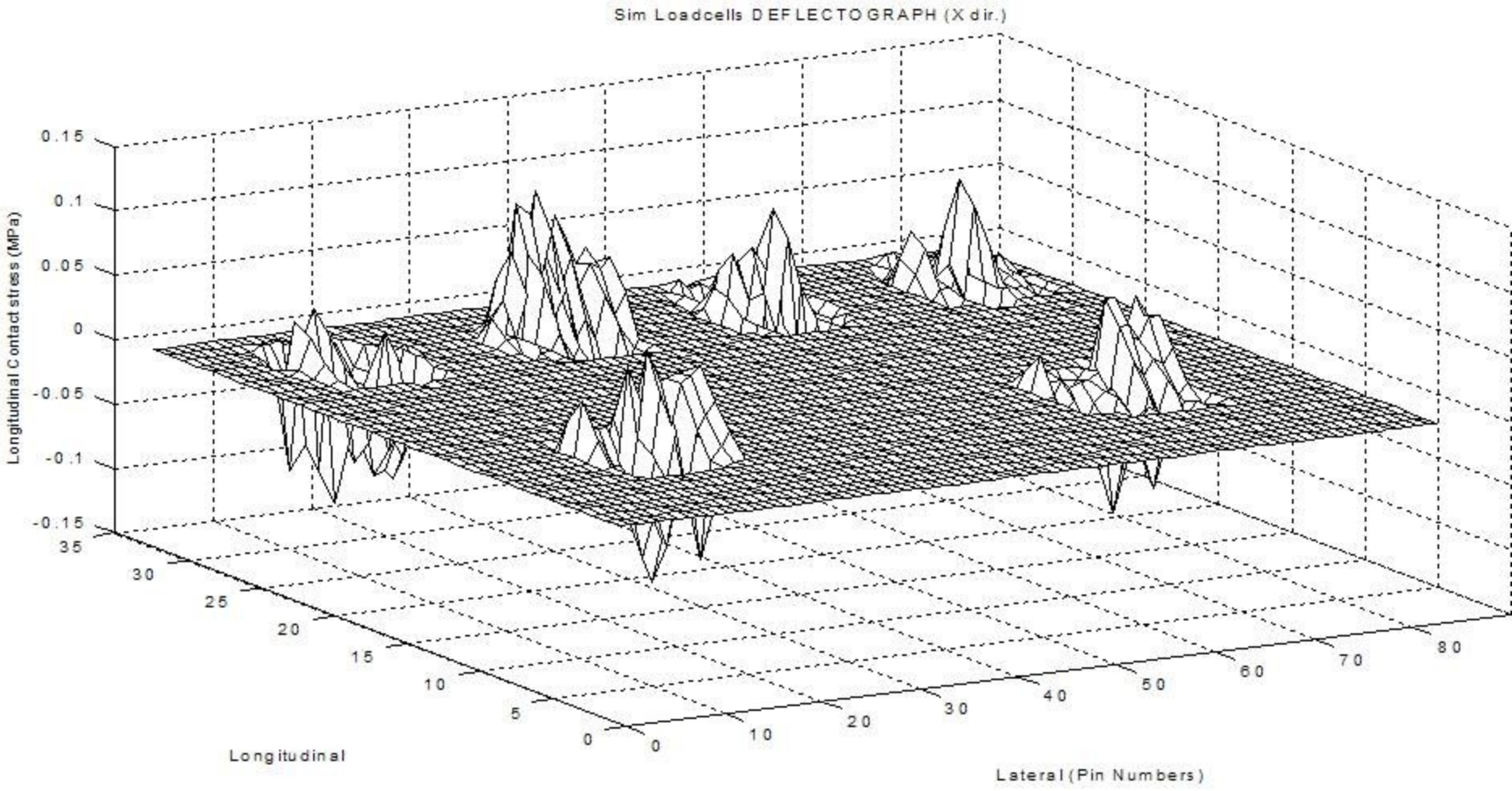
Deflectograph Truck (80kN, 650 kPa): Vertical Contact Stress

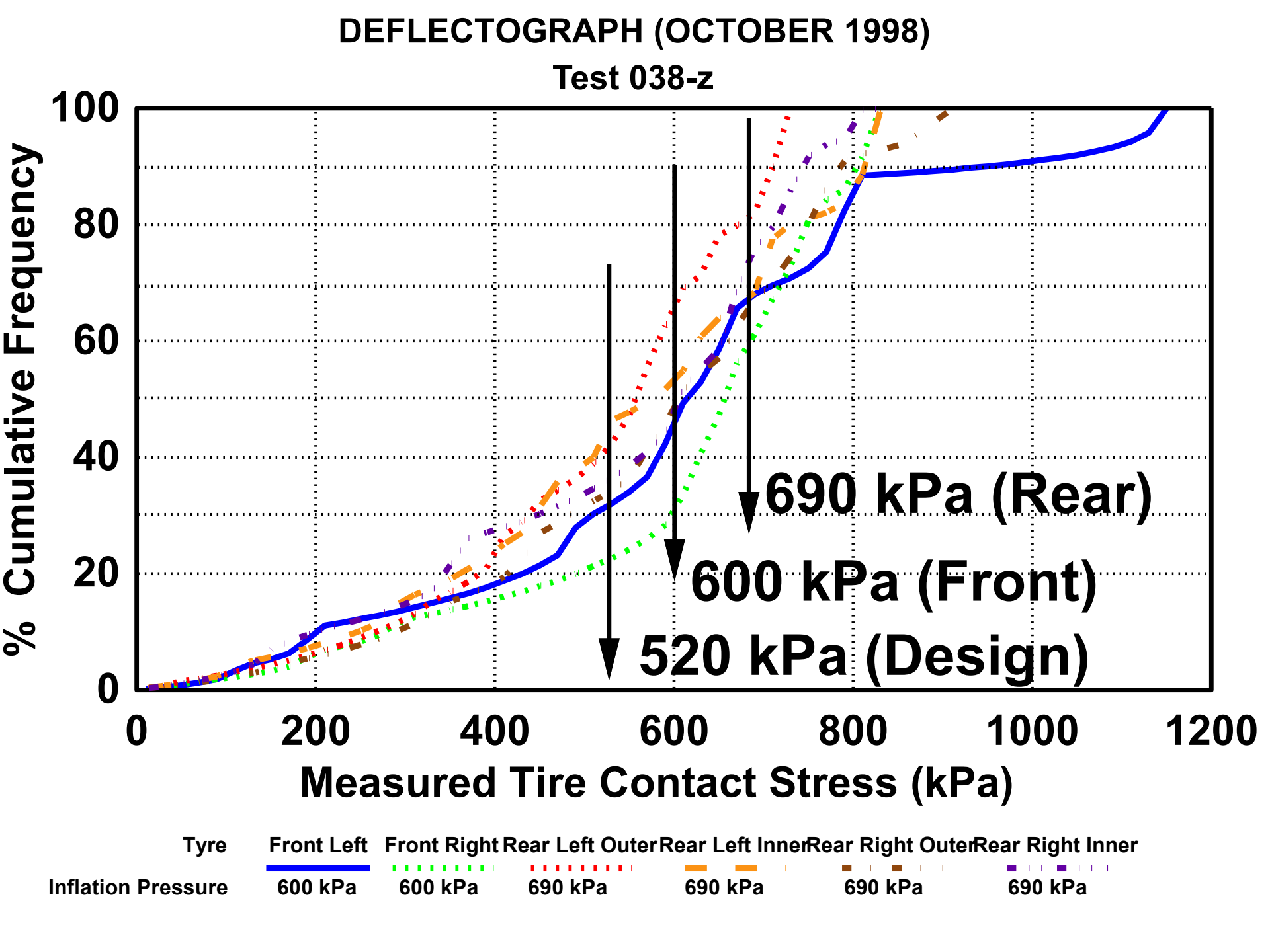


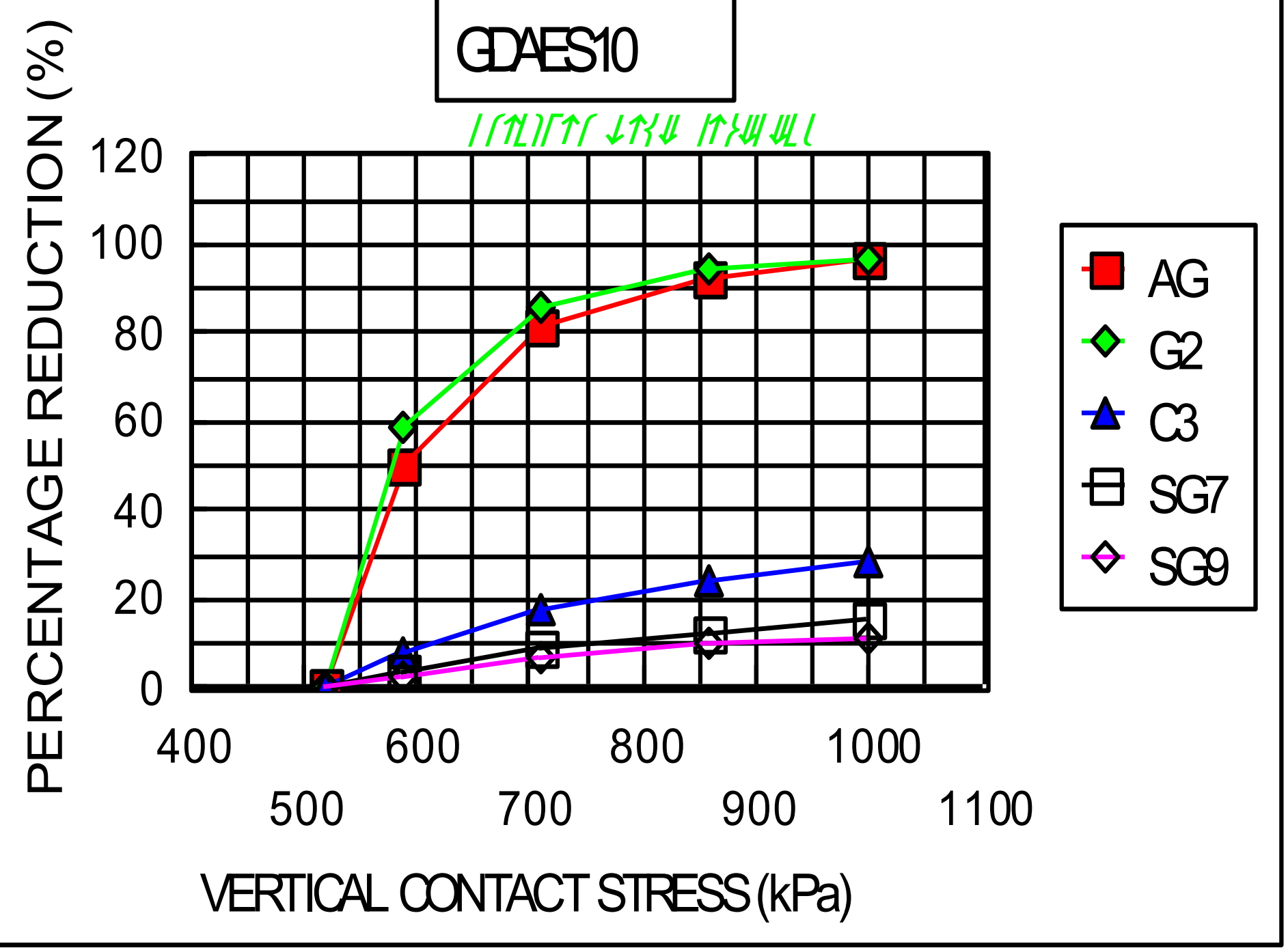
Deflectograph Truck (80kN,650 kPa): Lateral Contact Stress

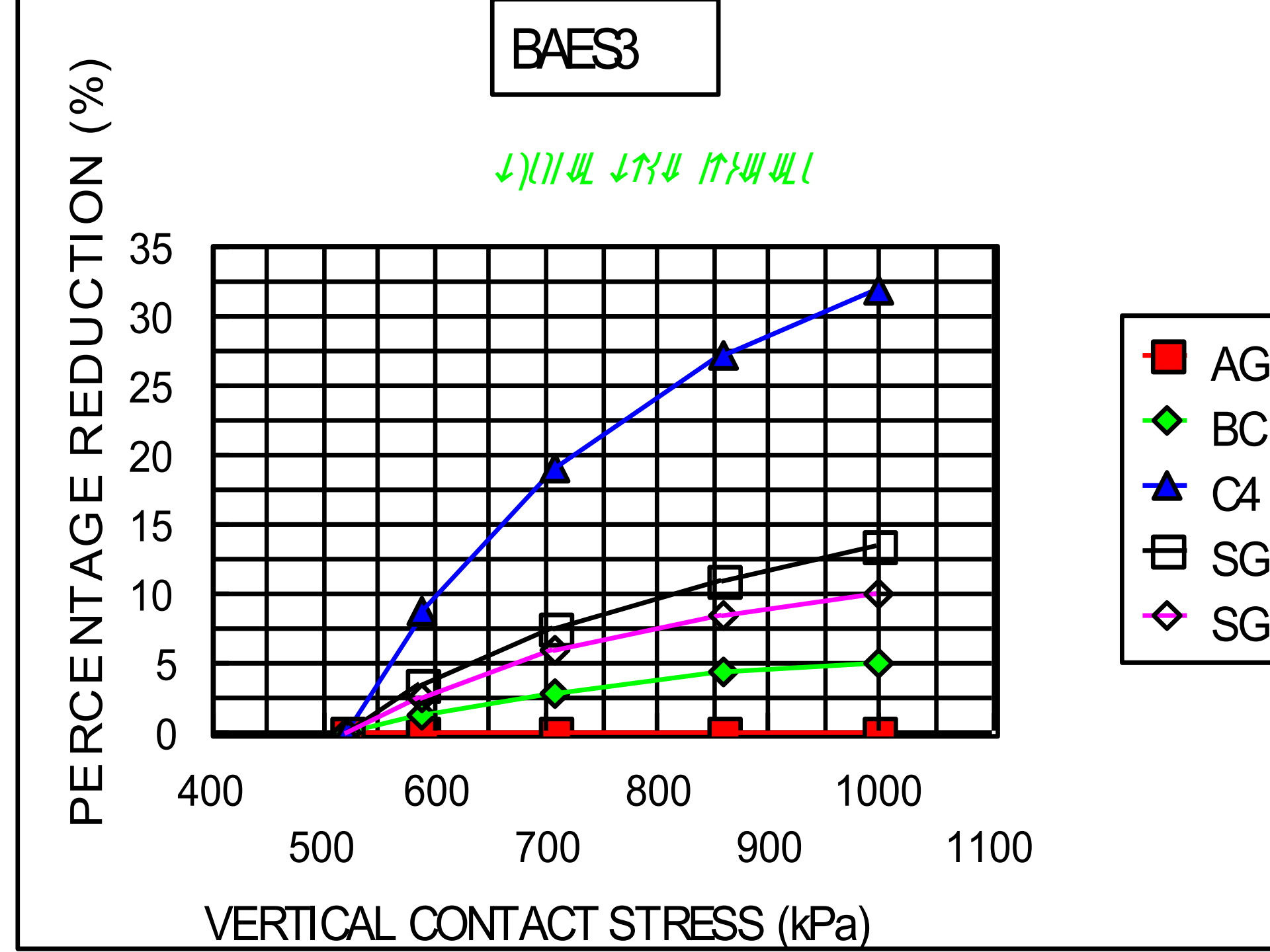


Deflectograph Truck (80kN,650 kPa): Longitudinal Contact Stress




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:

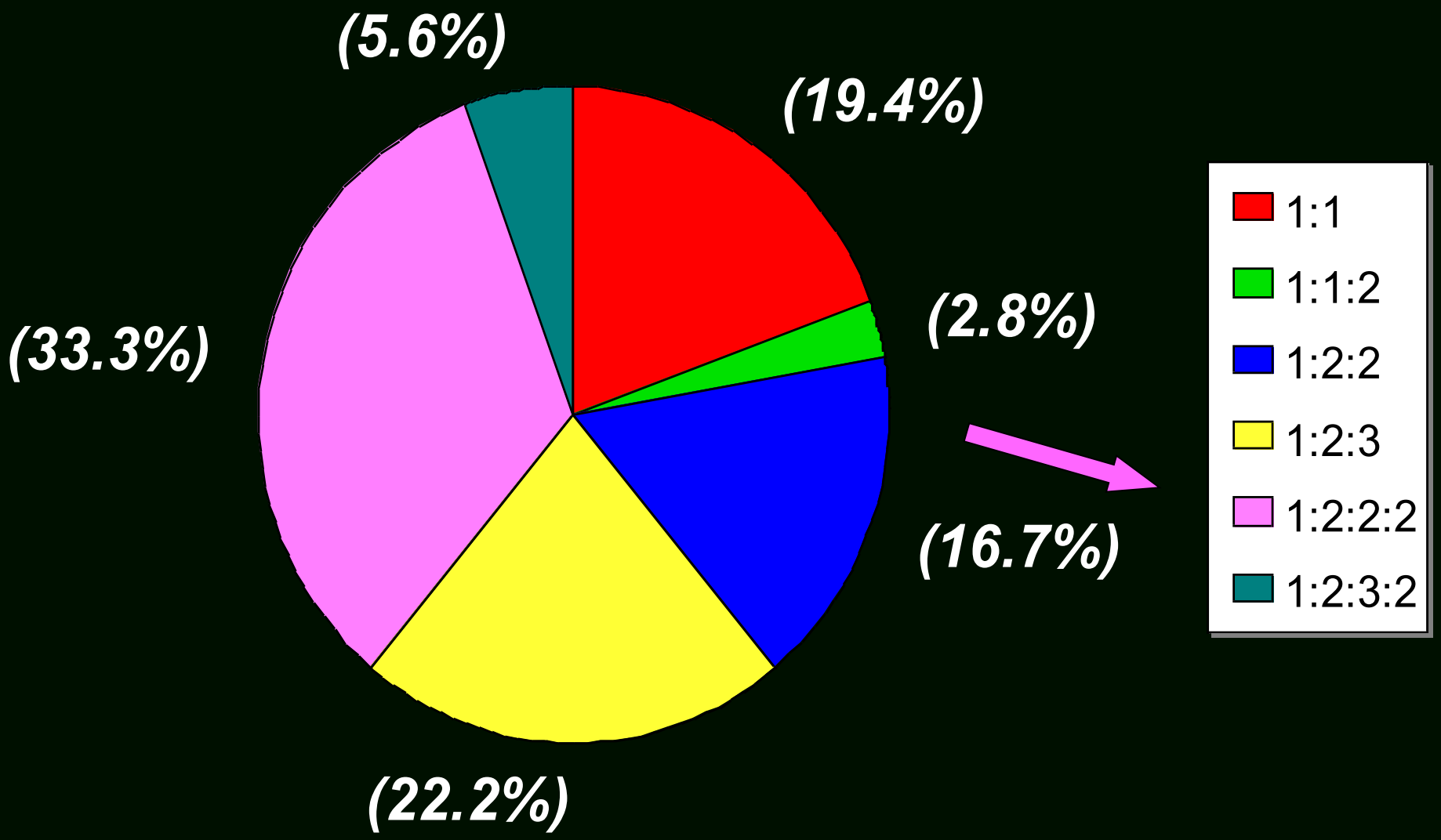
- ✓ *Vehicle Registration number;*
- ✓ *Date of measurement;*
- ✓ *Time of measurement;*
- ✓ *Vehicle classification (i.e 1:2:2:2)*

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

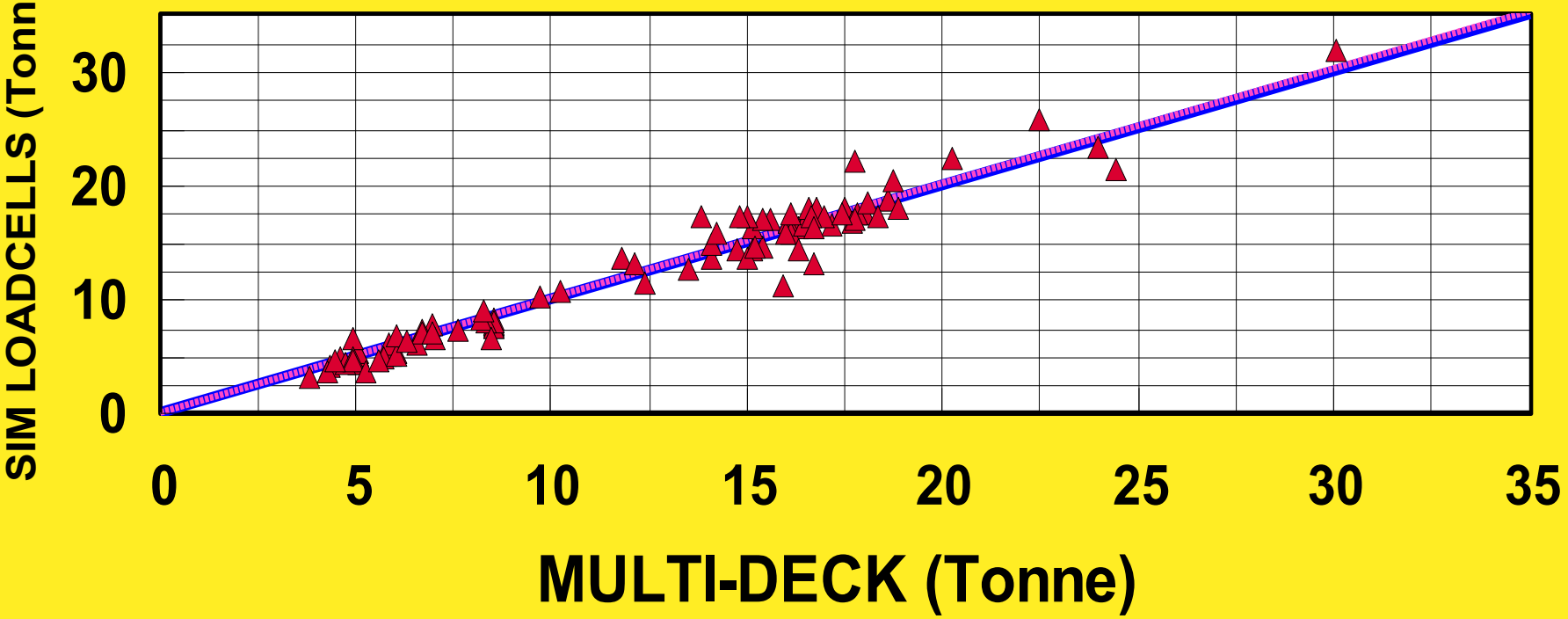
The following items are obtained with the SIM:

- ✓ *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)



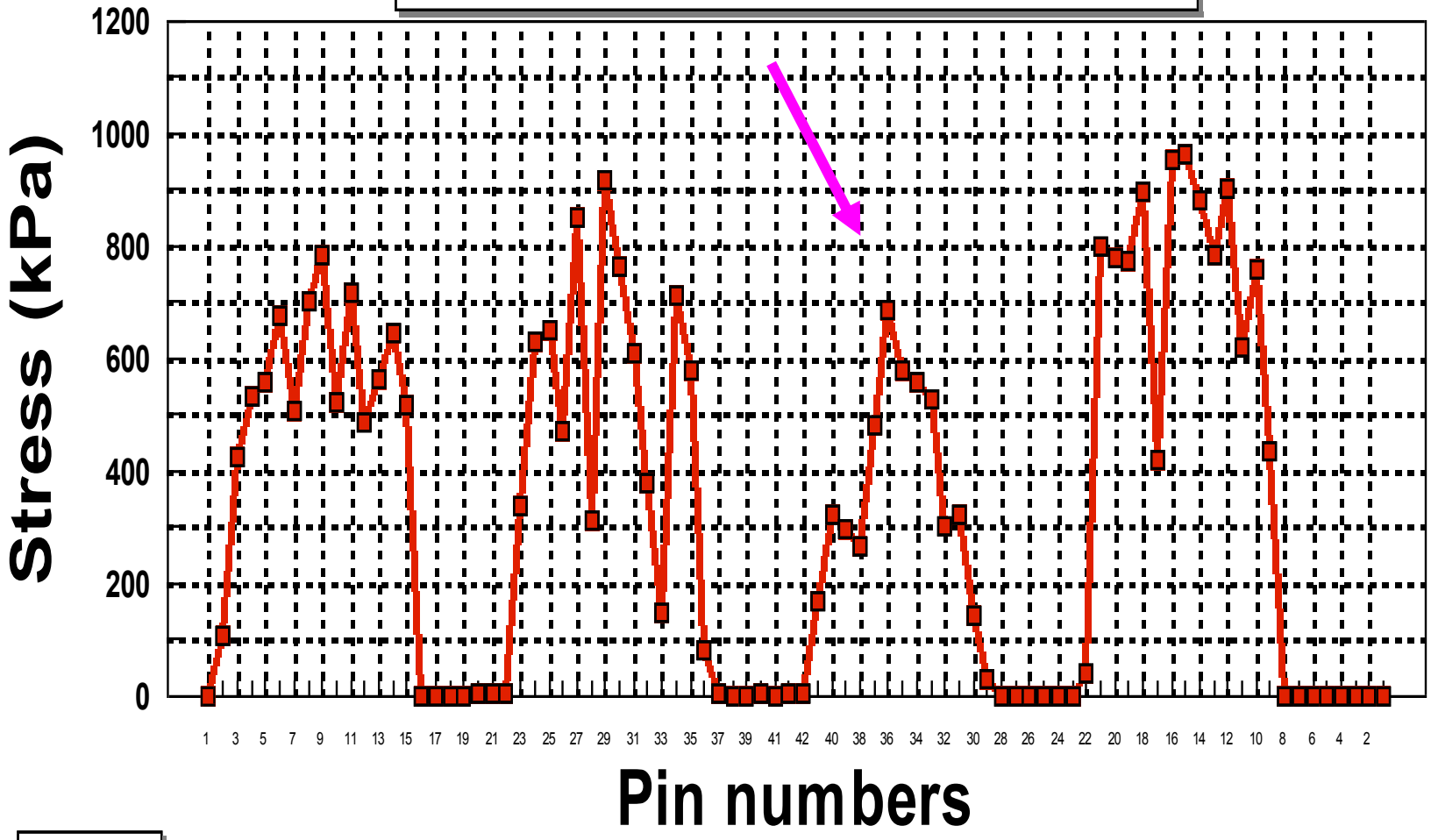
MANTSOLE WEIGHBRIDGE (TCC)
SIM TESTS NOV. & DEC. 1998 & FEB 1999



MAN1.WK4

AXLE 5

Vertical Maximum Contact Stress (kPa)



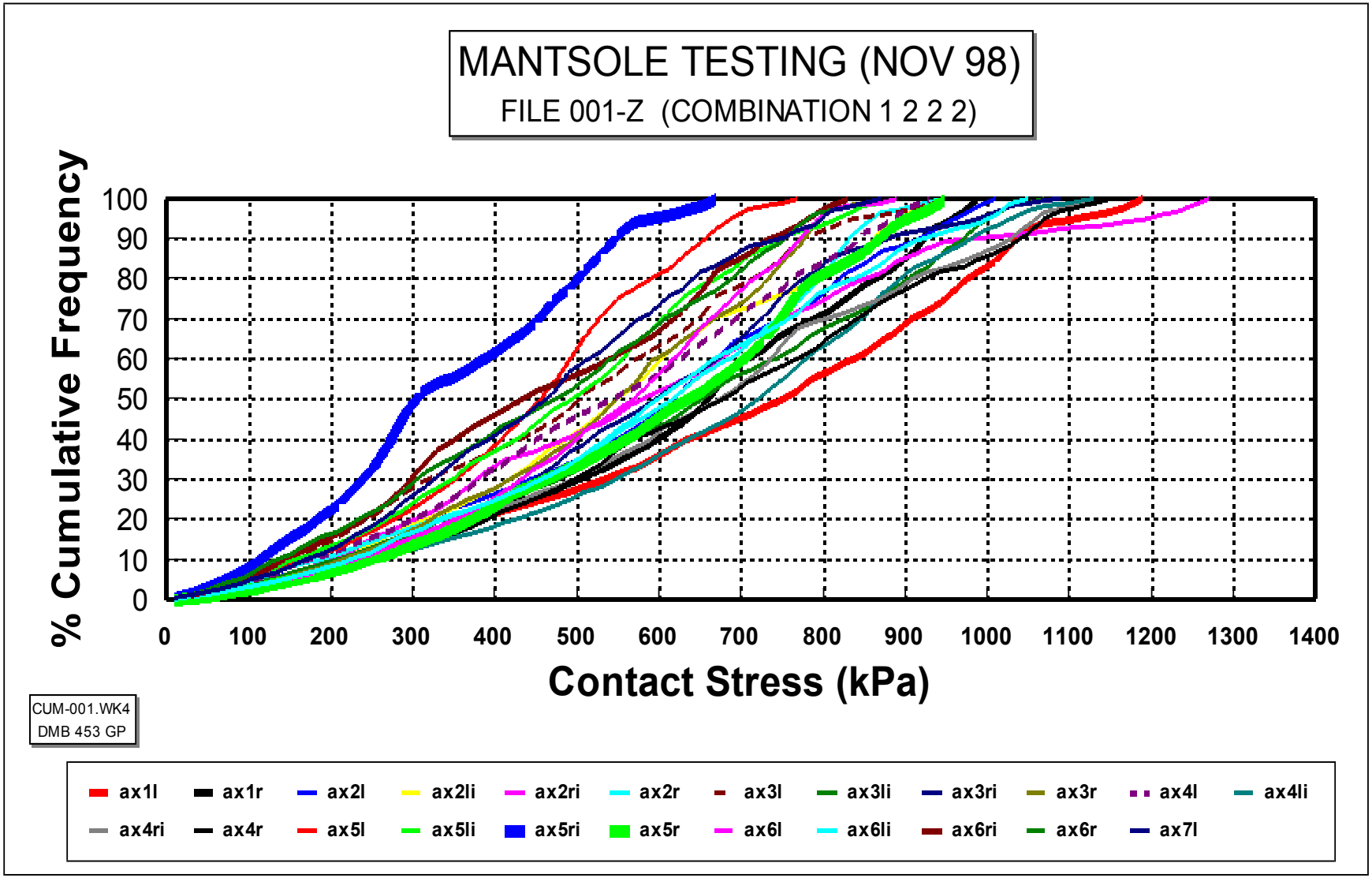
001-z
DMB 453 GP

Left Outer Tyre

Left Inner Tyre

Right Inner Tyre

Right Outer Tyre


MANTSOLE TESTING (NOV 98)
FILE 001-Z (COMBINATION 1 2 2 2)
% Cumulative Frequency
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
Contact Stress (kPa)
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:

- **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: 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;**

COMPUTER ANALYSES OF ROAD PAVEMENT STRUCTURES

- ✓ *SYMPLISTIC ANALYSIS: MULTI-LAYER - LINEAR - ELASTIC THEORY;*

- ✓ *COMPLEX: FINITE ELEMENT METHOD + NON – LINEAR - ELASTIC THEORIES;*

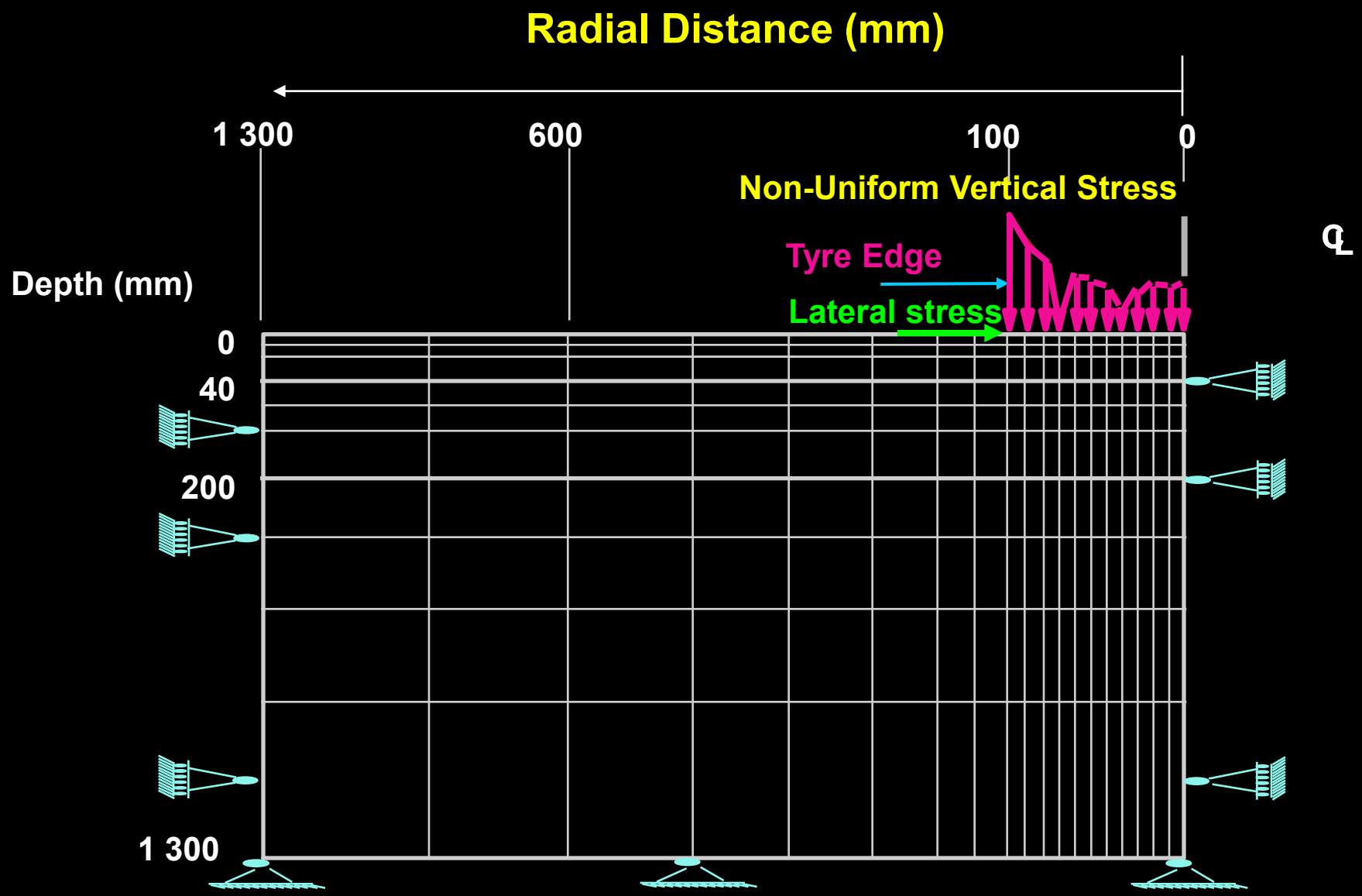
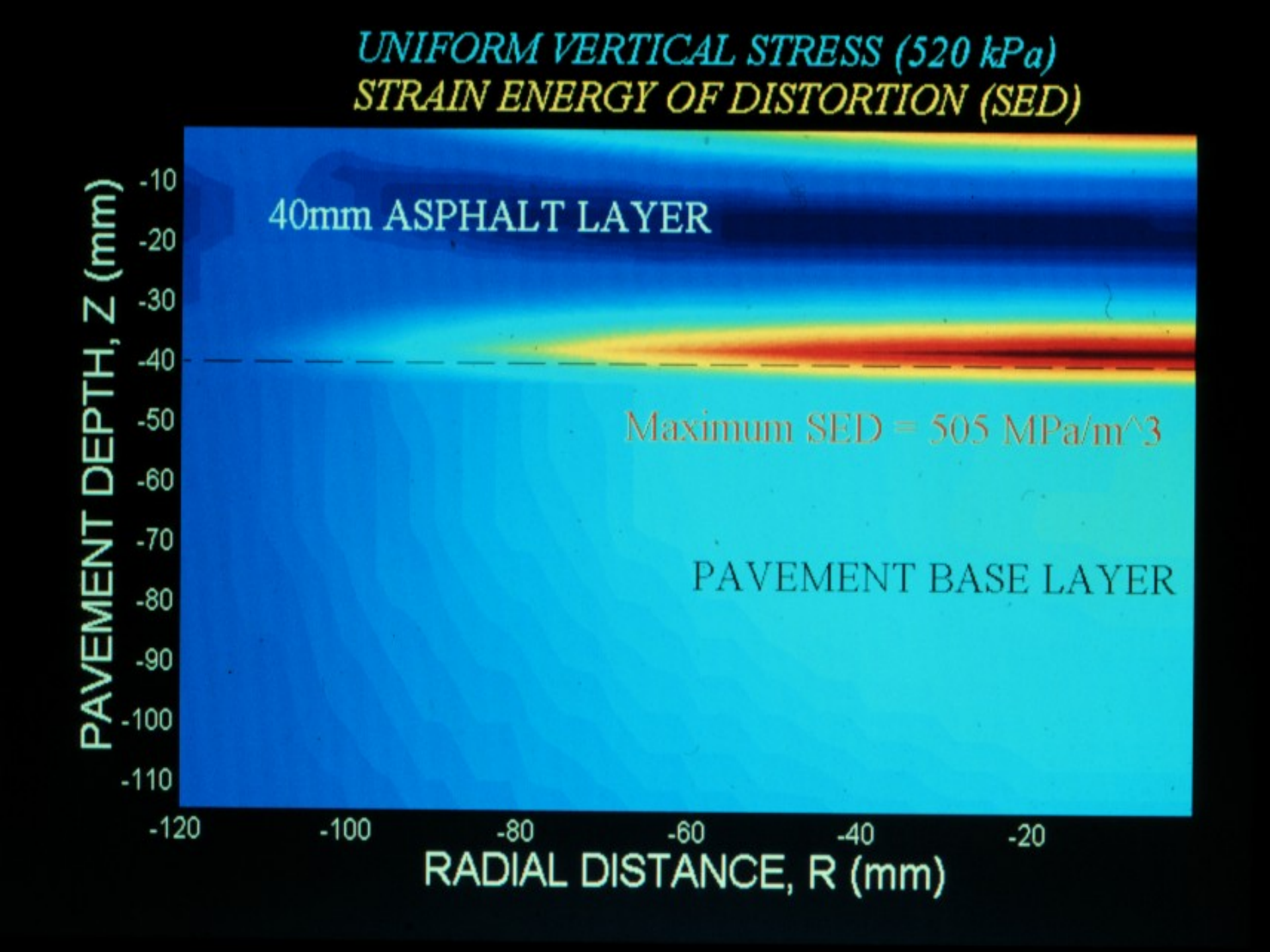
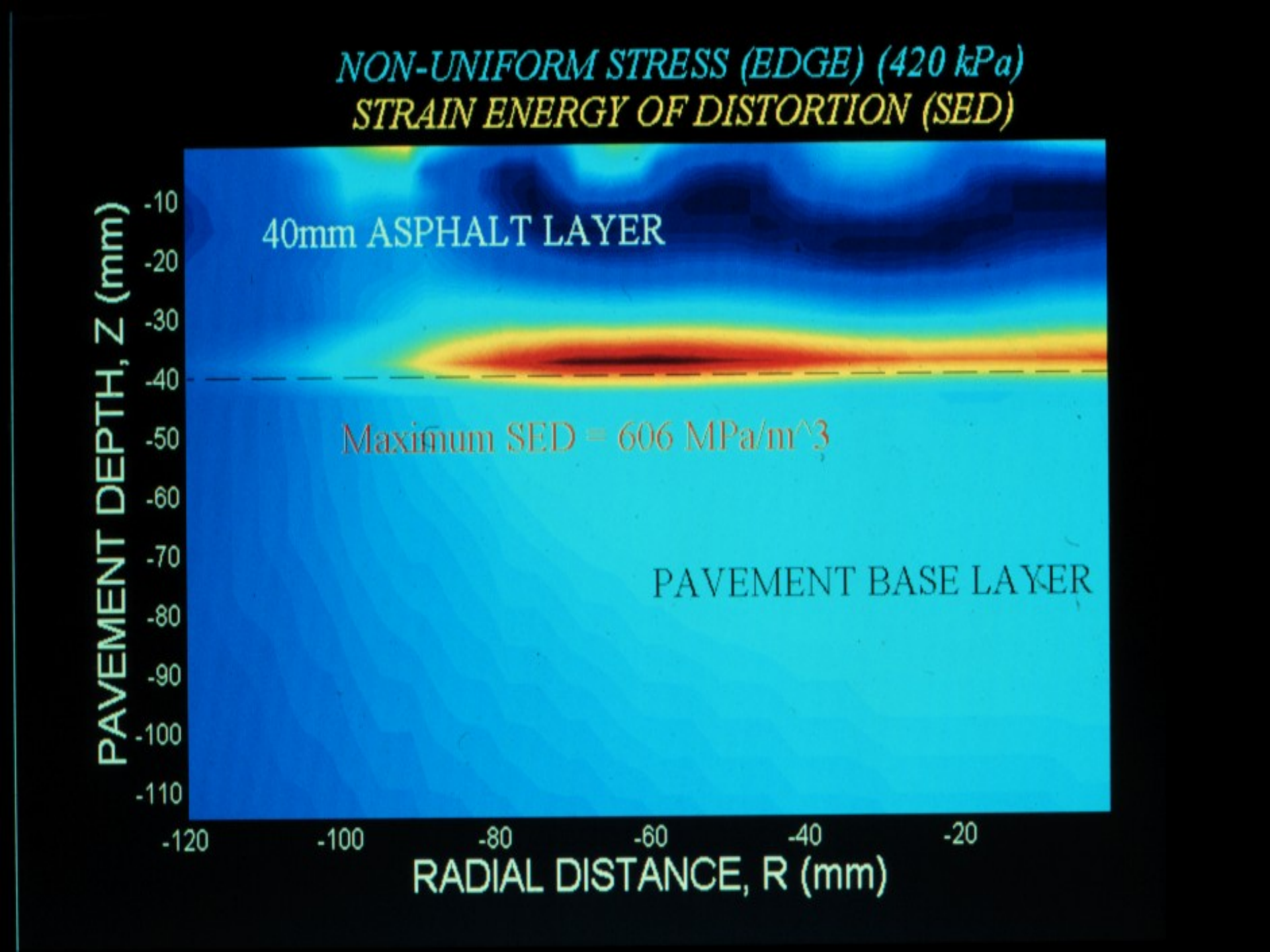


FIGURE: 29

Axi-symmetrical Finite Element Model used in this study

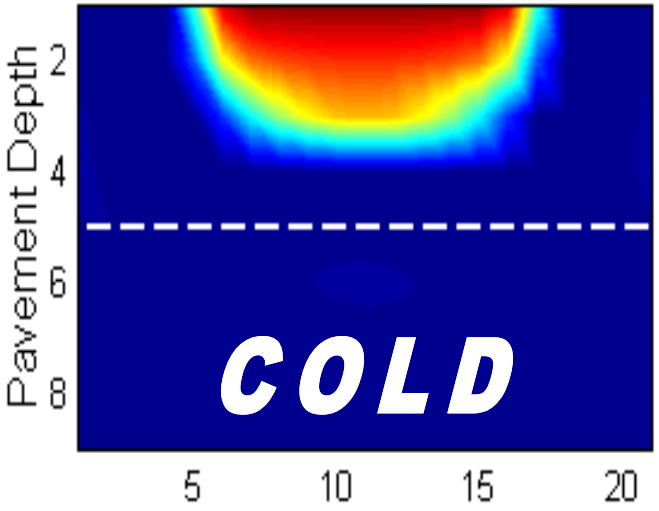

UNIFORM VERTICAL STRESS (520 kPa)
STRAIN ENERGY OF DISTORTION (SED)
40mm ASPHALT LAYER
Maximum SED = 505 MPa/m^3
PAVEMENT BASE LAYER
PAVEMENT DEPTH, Z (mm)
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-100
-80
-60
-40
-20
RADIAL DISTANCE, R (mm)


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)

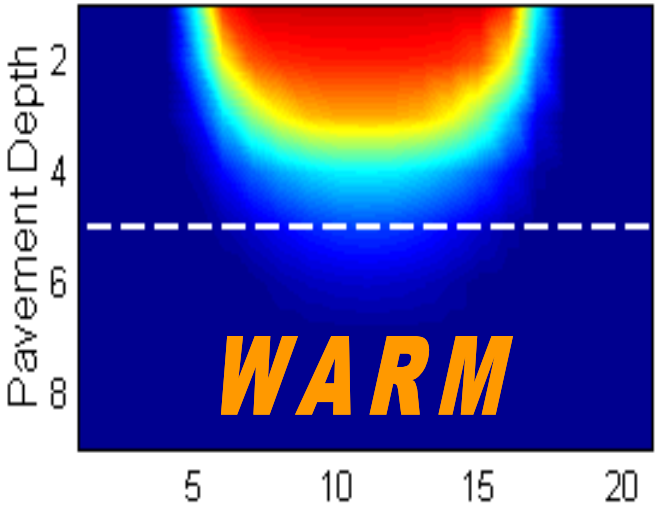
Colour maps of Shape distortion (Symplectic Engineering Corporation)

UNIFORM LOAD - COLD (Eac = 3000 MPa)



0.63 (Max. Vertical Stress)

UNIFORM LOAD - WARM (Eac = 1000 MPa)



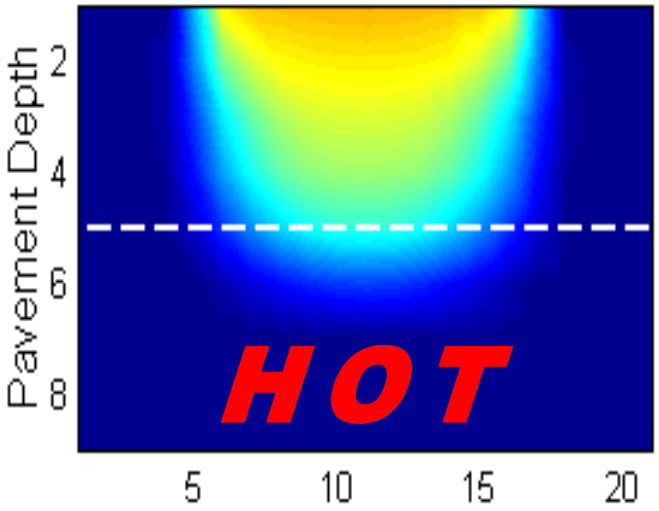
0.562 (Max. Vertical Stress)

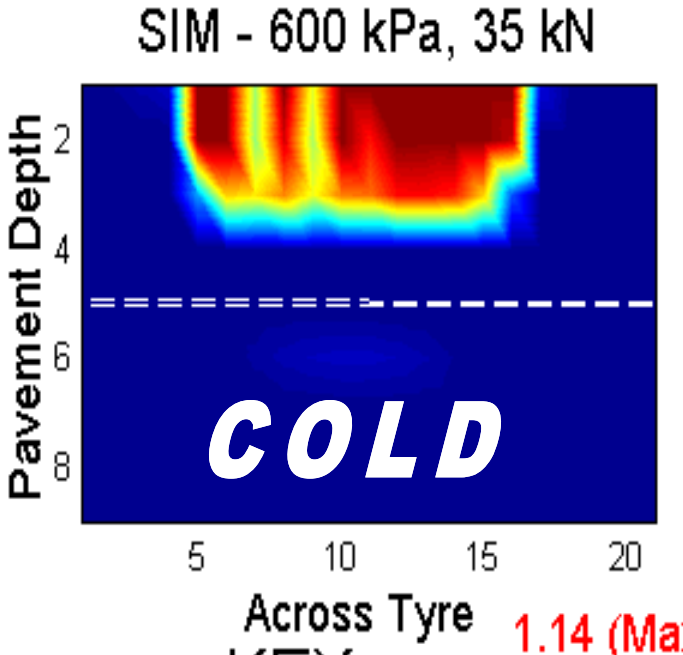
KEY:

VERTICAL STRESS:

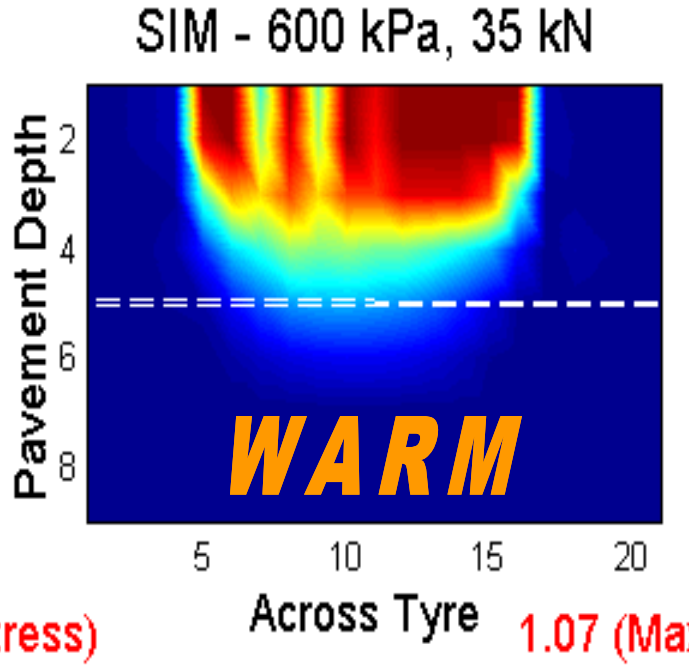
C(kPa) = 2000, 1150, 150
Theta = 43 degrees
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing = 40 mm thick
Static Loading

UNIFORM LOAD - HOT (Eac = 200 MPa)





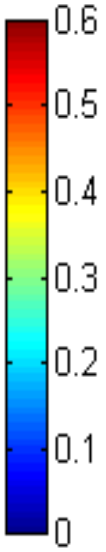
1.14 (Max. Stress)

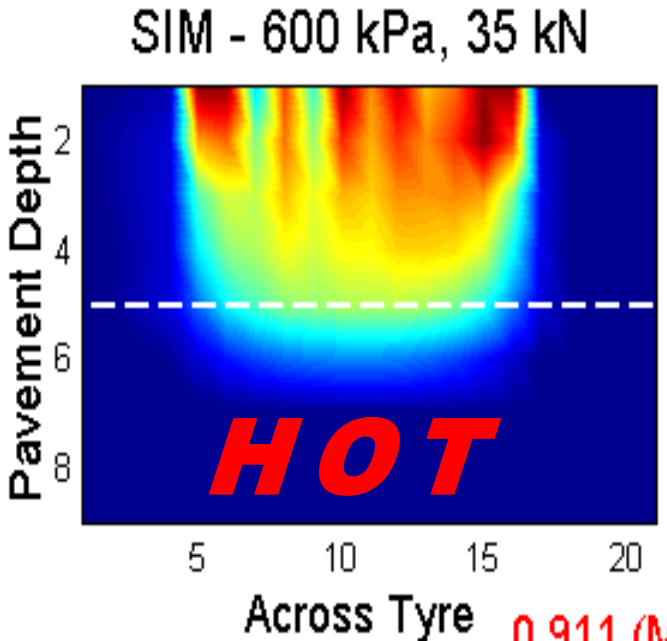


1.07 (Max. Stress)

KEY:

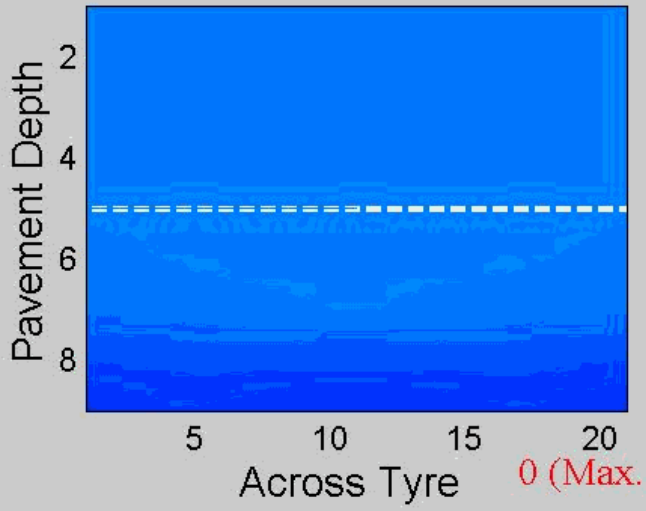
VERTICAL STRESS
C(kPa) = 2000, 1150, 150
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading





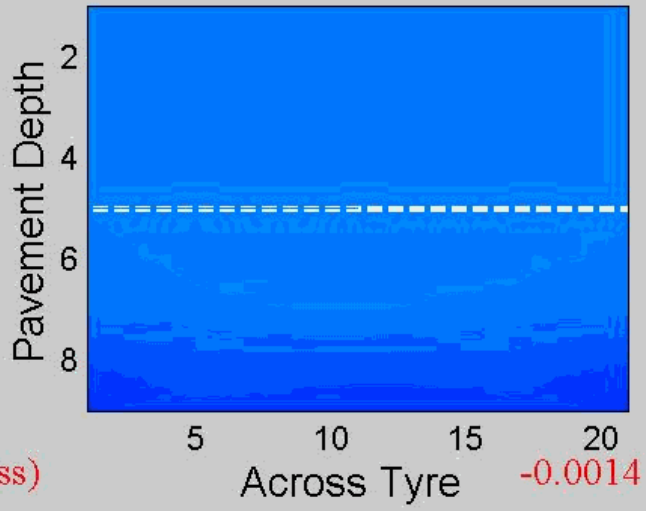
0.911 (Max. Stress)

UNIFORM LOAD - 520 kPa, 21 kN



0 (Max. Stress)

SIM - 600 kPa, 20 kN

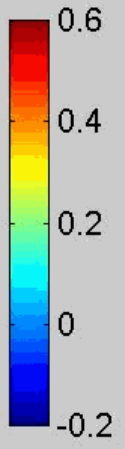


-0.0014 (Max. Stress)

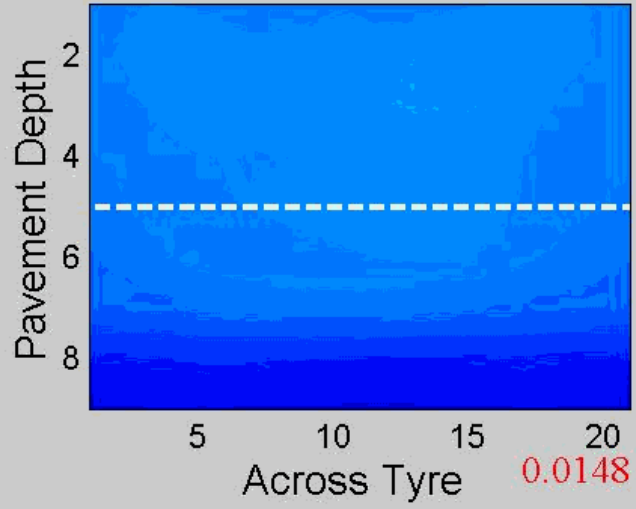
KEY:

VERTICAL STRESS:

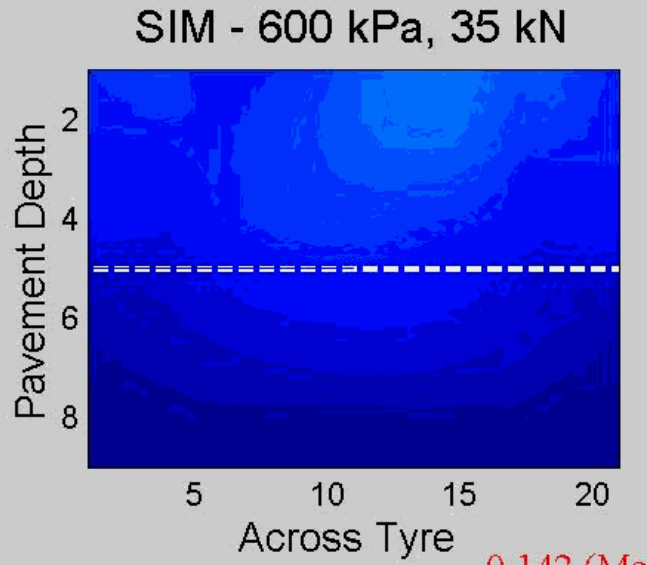
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading



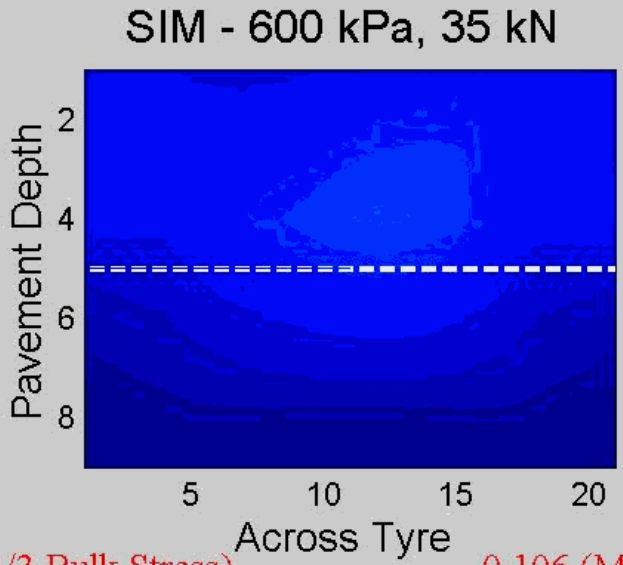
SIM - 600 kPa, 35 kN



0.0148 (Max. Stress)



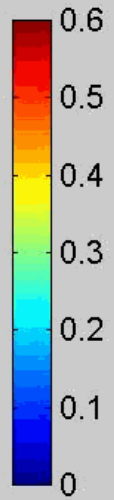
0.142 (Max. I1/3 Bulk Stress)

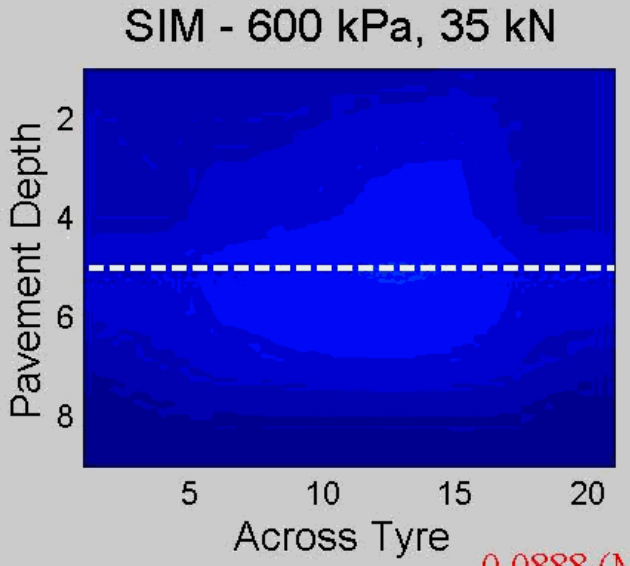


0.106 (Max. I1/3 Bulk Stress)

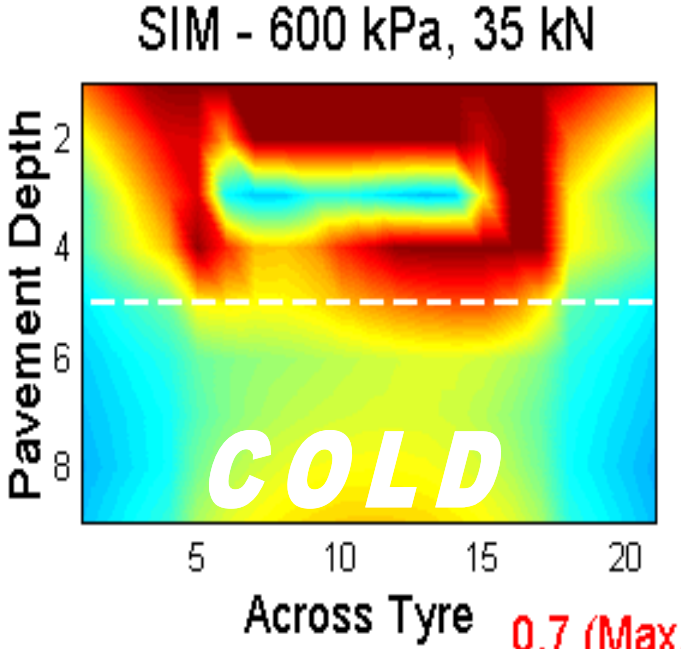
KEY:

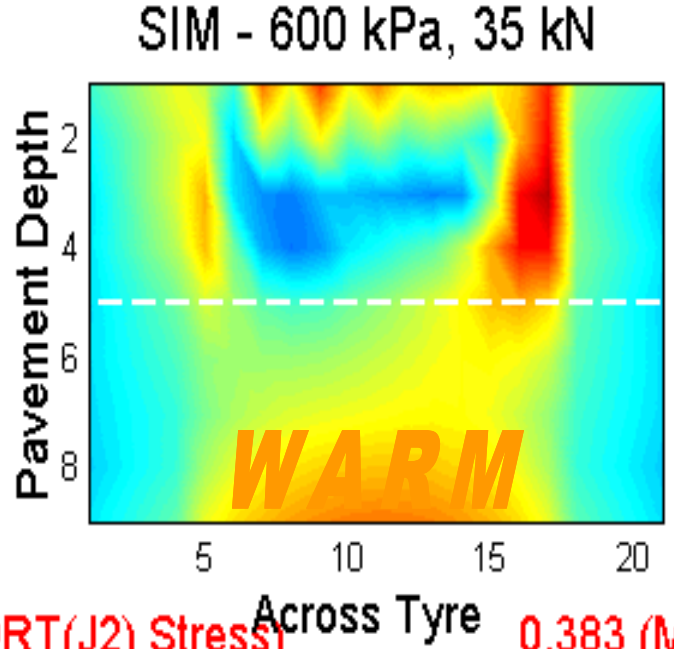
(I1/3) BULK STRESS:
C(kPa) = 2000, 1150, 150
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading





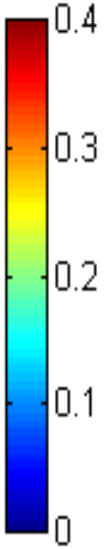
0.0888 (Max. I1/3 Bulk Stress)

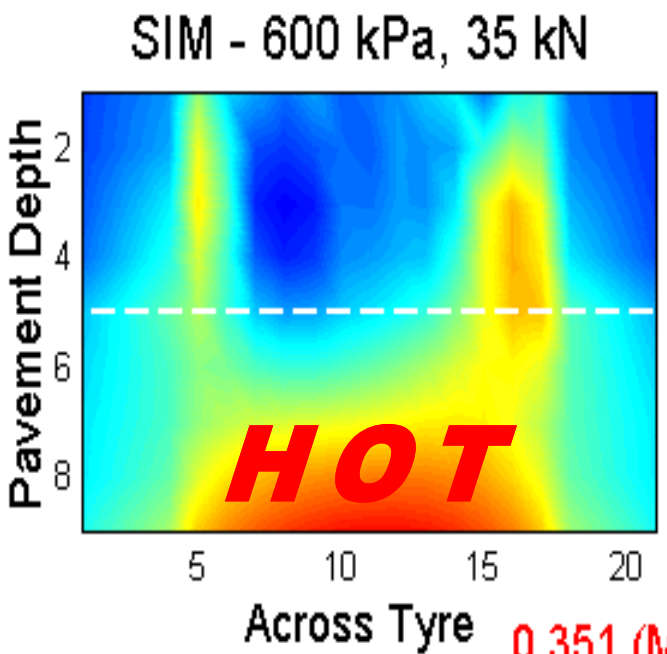


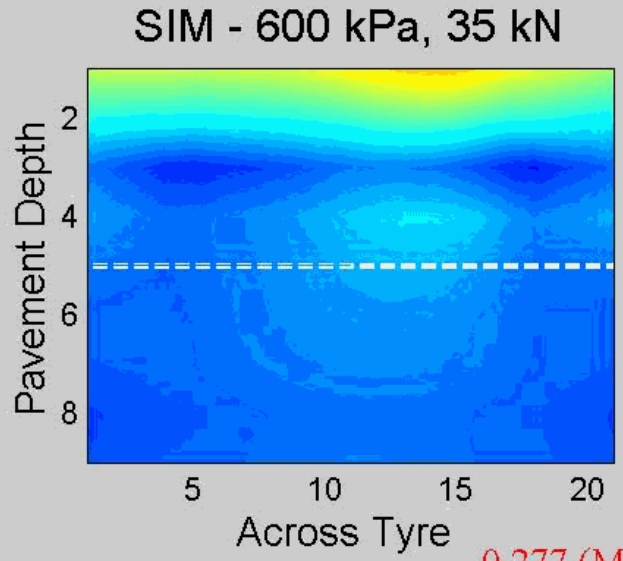


KEY:

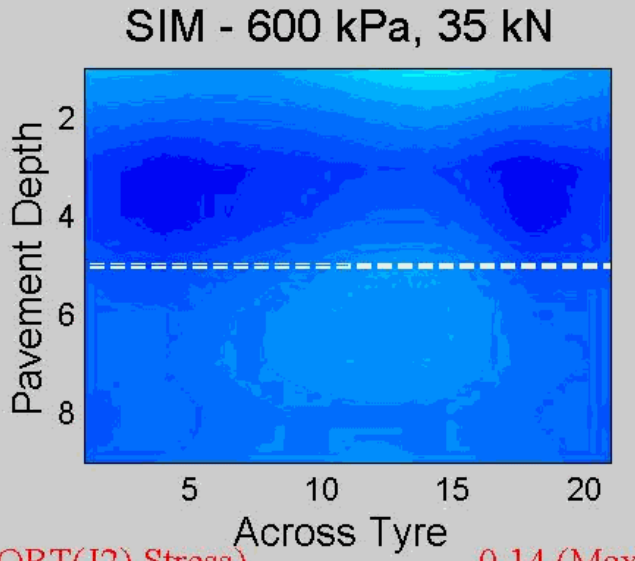
SQRT (J2) STRESS:
C(kPa) = 2000,1150,150
Linear Elastic Solution
Three Layer Pavement
Asphalt Surfacing =
40 mm thick
Static Loading





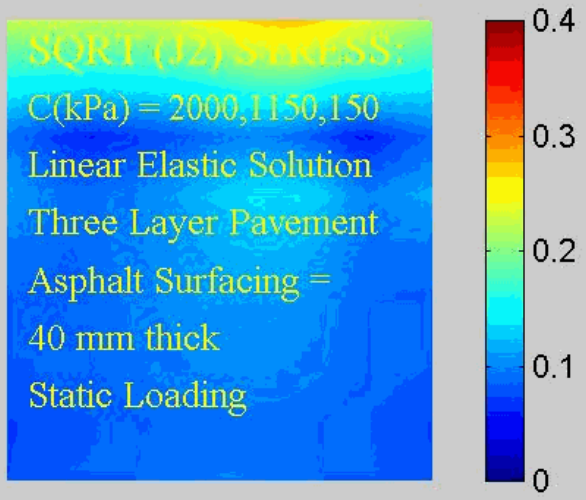


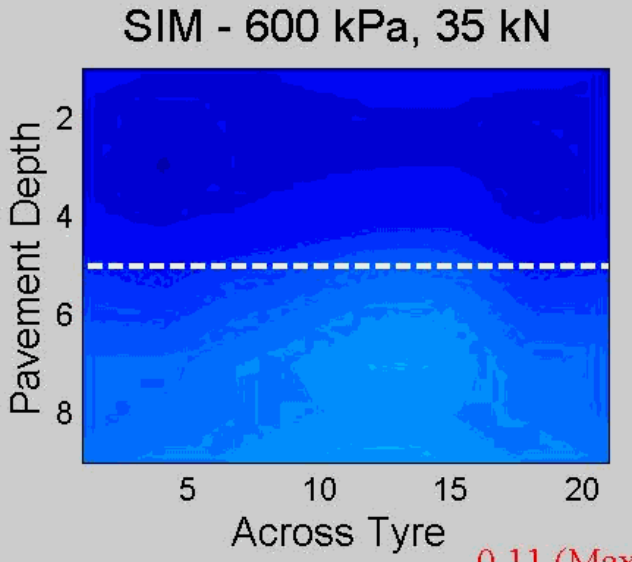
0.277 (Max. SQRT(J2) Stress)



0.14 (Max. SQRT(J2) Stress)

KEY:





0.11 (Max. SQRT(J2) Stress)

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";**


80
Potholes
....TO BE AVOIDED !!


I Thank You all !!