Improved Performance Evaluation of Road Pavements by Using Measured Tyre Loading

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CSIR Built Environment, South Africa

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Paper today: "Improved Performance Evaluation of Road Pavements by Using Measured Tyre Loading"

- Part 1:
- General introduction;
- Quality and importance of road infrastructure in SA;
- Trucks on our road infrastructure;
- Truck tyre loading and stresses;
- Stress-In-Motion (SIM) Technology;
- Typical Stress-In-Motion (SIM) Data;
- Part 2:
- Equations for mechanistic road analysis;
- Analysis for multiple loading;
- Strain Energy of Distortion (SED);
- Worked Examples and Analytical Results;
- Summary of research findings;
- Recommendations.

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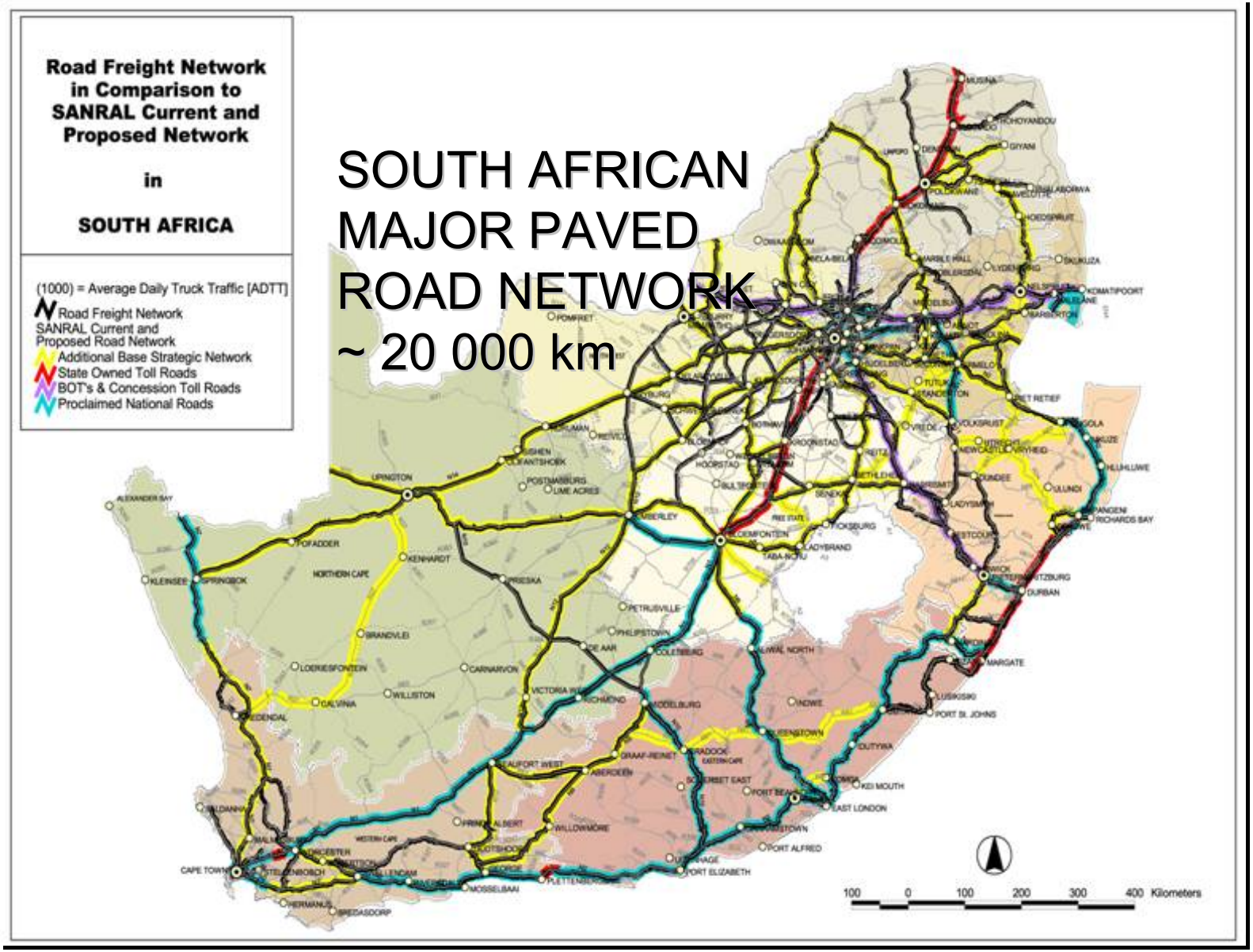
SOUTH AFRICAN MAJOR PAVED ROAD NETWORK ~ 20 000 km



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Background…

- SA: 750 000 km of roads - 20 % paved;
- Road Pavement Engineering critical for upgrade & sustainability of road infrastructure;
- Locally developed Stress-In-Motion (SIM) study part of this process;
- Analytical: Strain Energies of Distortion (SEDs) at various sections within the road pavement structure were determined – good promise !;

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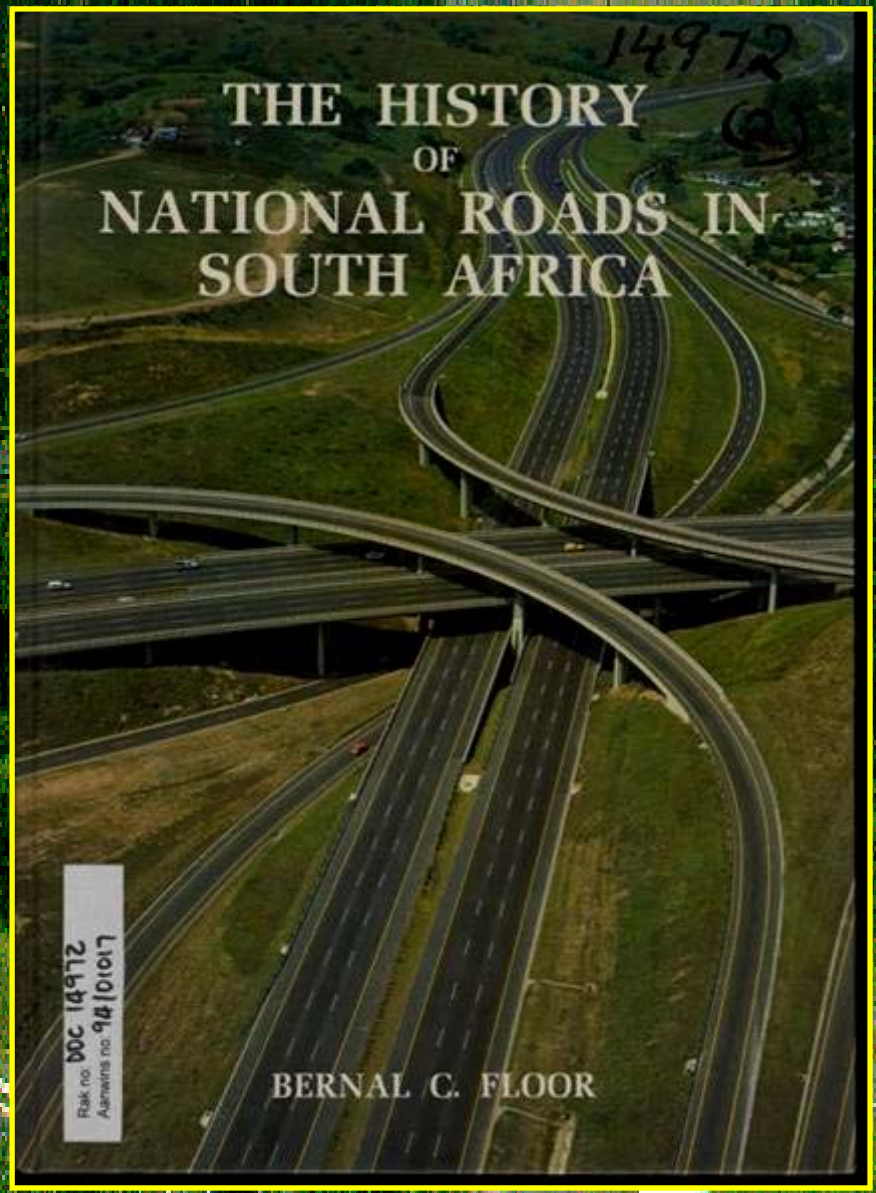

7 700 km National Roads in SA of Freeway/Expressway standard



Freight Transport in SA….(CSIR - 4th SA Logistics Report, 2007).

- The 4th annual State of Logistics Survey for SA indicated that total land transport accounted for 1,5 billion tonnes, with recent growth of higher than 5 per cent, mainly captured by the road transport sector, as opposed to the rail sector carrying only 0.2 billion tonnes.

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Freight Transport in SA….(CSIR - 4th SA Logistics Report, 2007).

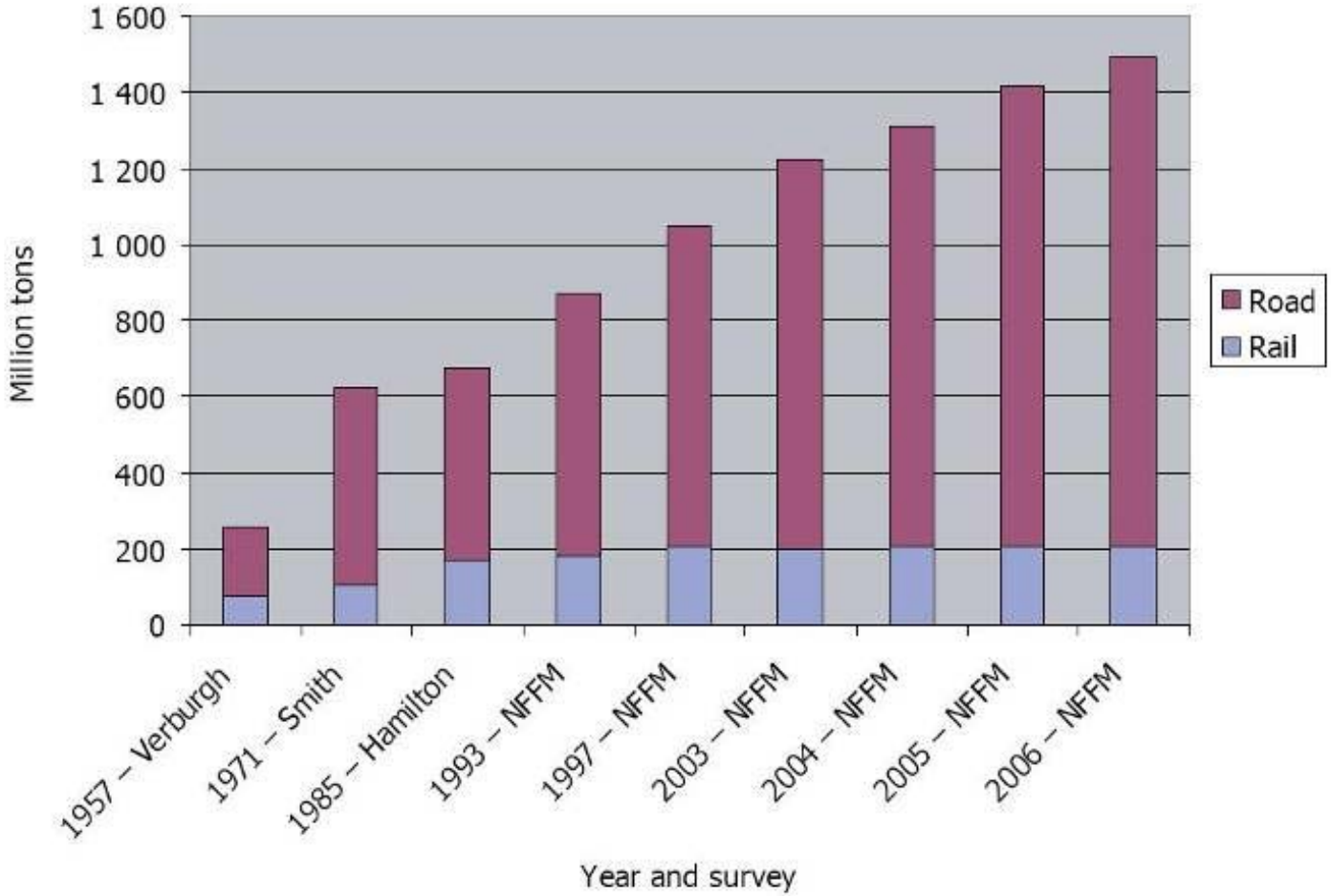

Figure 1. Historical freight transport data (CSIR, 2007).

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Traffic Volumes and Road Damage….

- Traffic volumes on our national highways are at all time highs, for example, N3 has already carried the equivalence of 20 years of traffic over the last two years. (..2007..)
- Daily, newspapers carry articles on potholes and other road shortcomings which cost motorists in excess of R200 billion a year (News24, 2008).

It is therefore not surprising that there have been numerous calls for extensive revision of important parts of the SA road pavement design method in order to cope with the new traffic realities, amongst other factors.

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Heavy Vehicles….

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Growth in Heavy Vehicle (HV) Traffic…

- In terms of growth in HVs on the toll portion of the road, the rate was approximately 8 per cent since 2002-2007, 20 per cent 2006-2007, and almost 40 per cent between February and October 2007.

- The N3 is therefore the national road with the highest growth and HV composition in SA (Le Roux, 2007).

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More Specific issues in Paper today…

- South African Roads, Trucks @ Road Damage;
- Introduction into Stress-In-Motion (SIM) technology;
- Tyre Studies with Heavy Vehicle Simulator (HVS);
- Full Scale SIM Testing @ N3-Traffic Control Centre (TCC) -Heidelberg, SA @ typical SIM Results;
- Implications for Road Surface Design and Road Preservation/Protection – Analytical Evaluations..

- Summary, Conclusions and Recommendations

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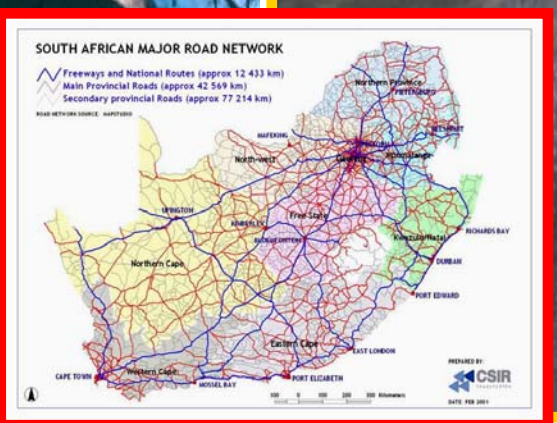
Vehicle-Tyre-Pavement Interaction:

STRESS-IN-MOTION (SIM) Technology



Thin Asphalt Surfacings (30 mm to 50 mm) on crushed rock: Economical in dry regions.

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From: http://www.i-traffic.co.za/index.php?q=cameras

At Buccleuch
2008/11/13; 17:05:40

North of Buccleuch facing South
2008/11/13; 17:05:40

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Truck Tyre Inflation Pressure in South Africa

~ 20 % Increase in 20 Years

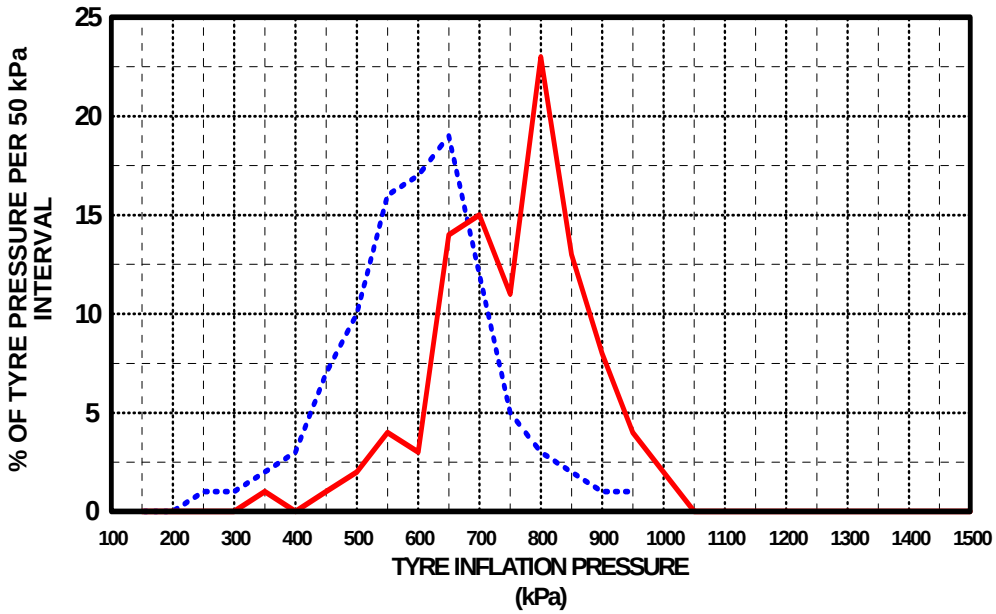

FIGURE 1

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

c:/capsaf1.wmf

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Road Damage….

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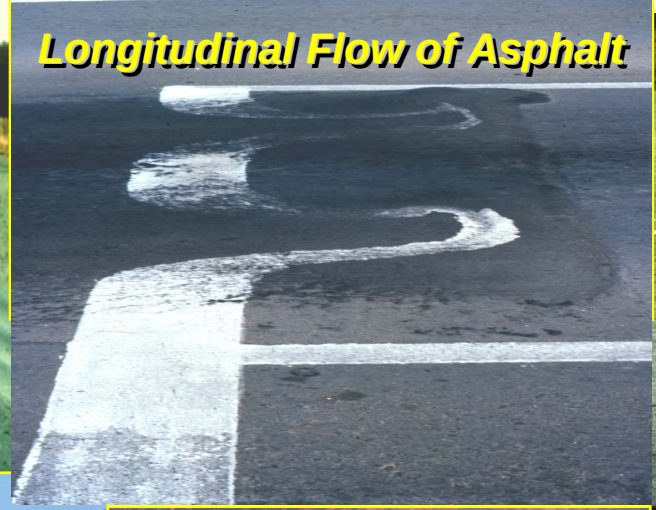
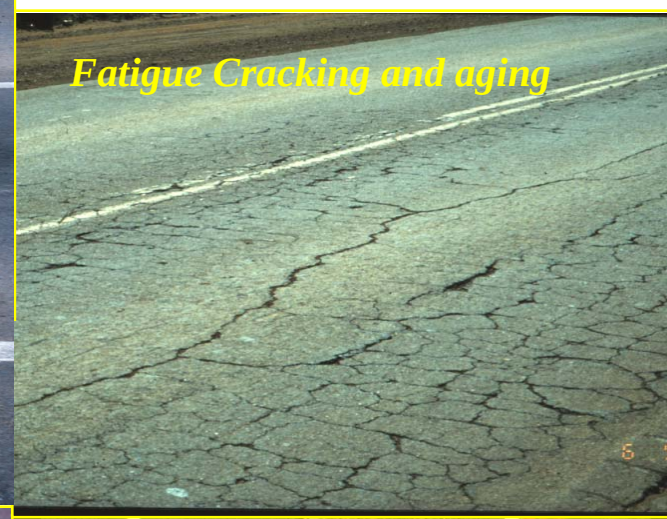
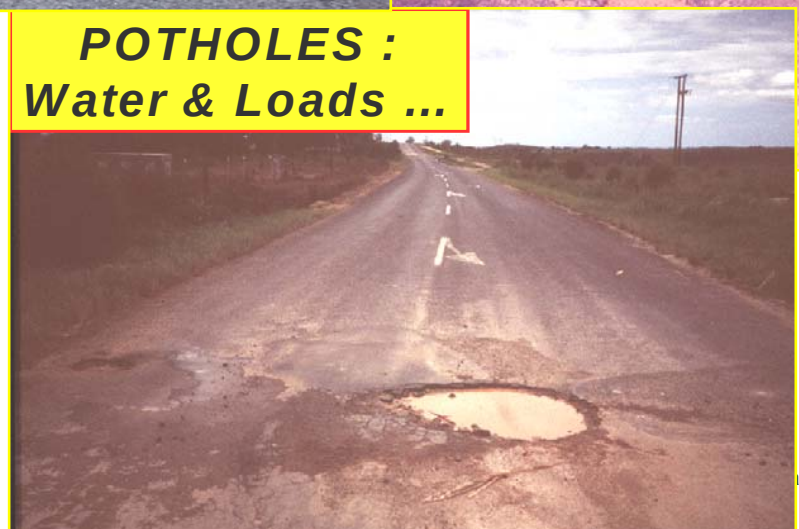
RUTTING


Longitudinal Flow of Asphalt


Fatigue Cracking and aging

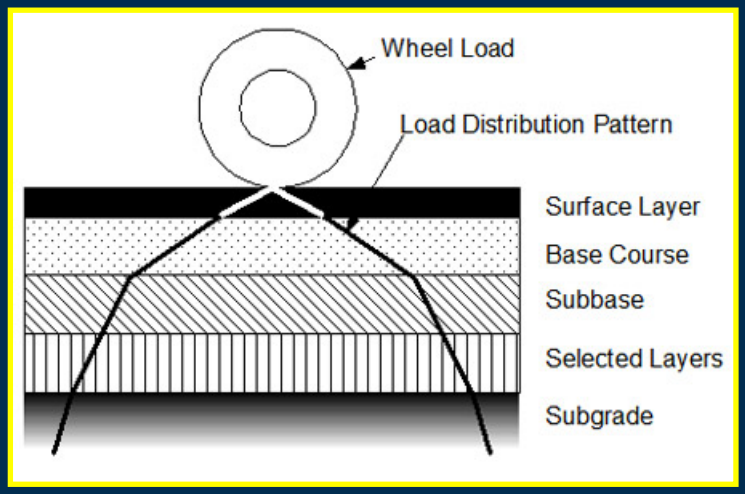

Delamination..

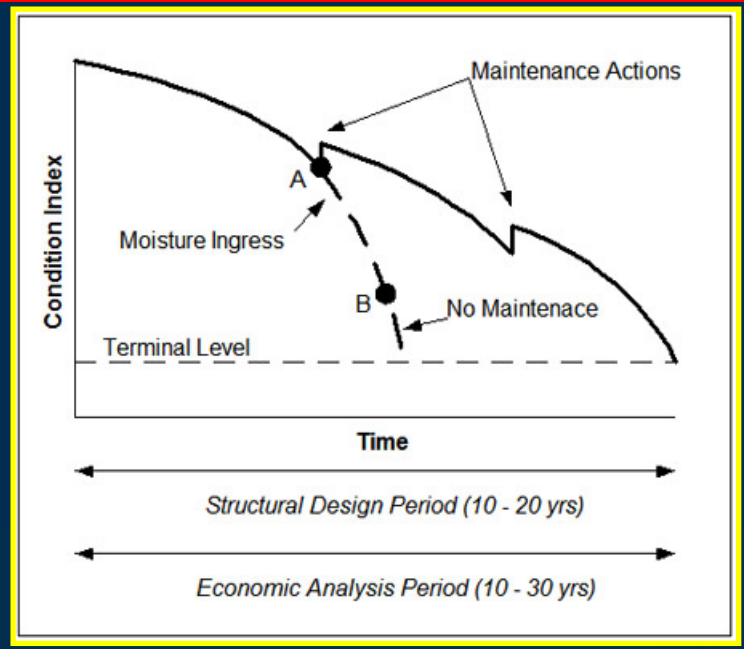

Surface Disintegration…

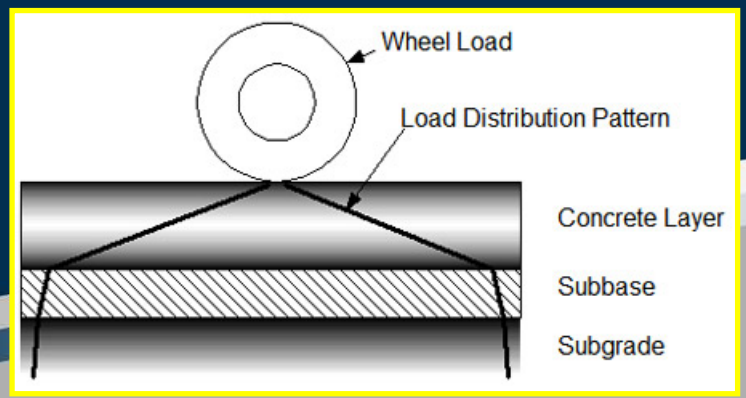

POTHOLES :
Water & Loads …


Water & Safety…

Tyres and Road Structures…..







…from SANRAL: www.nra.co.za

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Modern Tyre science…

”Sectometer”
S. Eckens, 1928

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

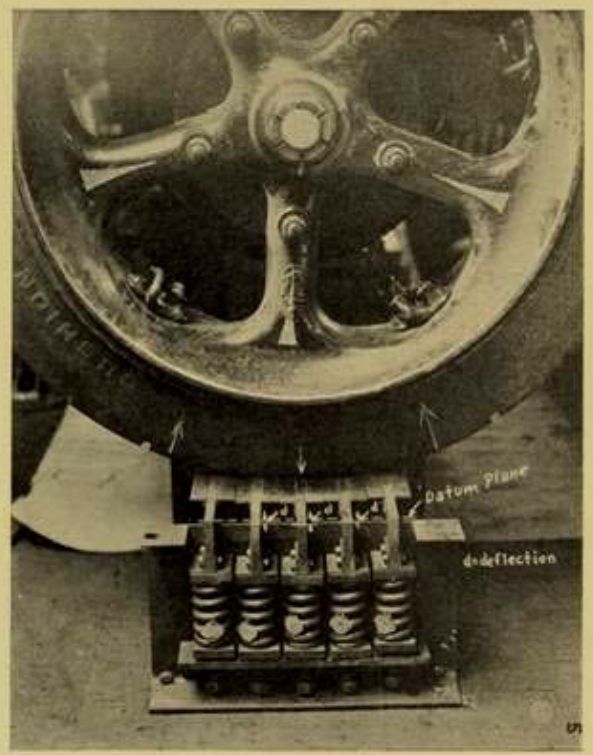
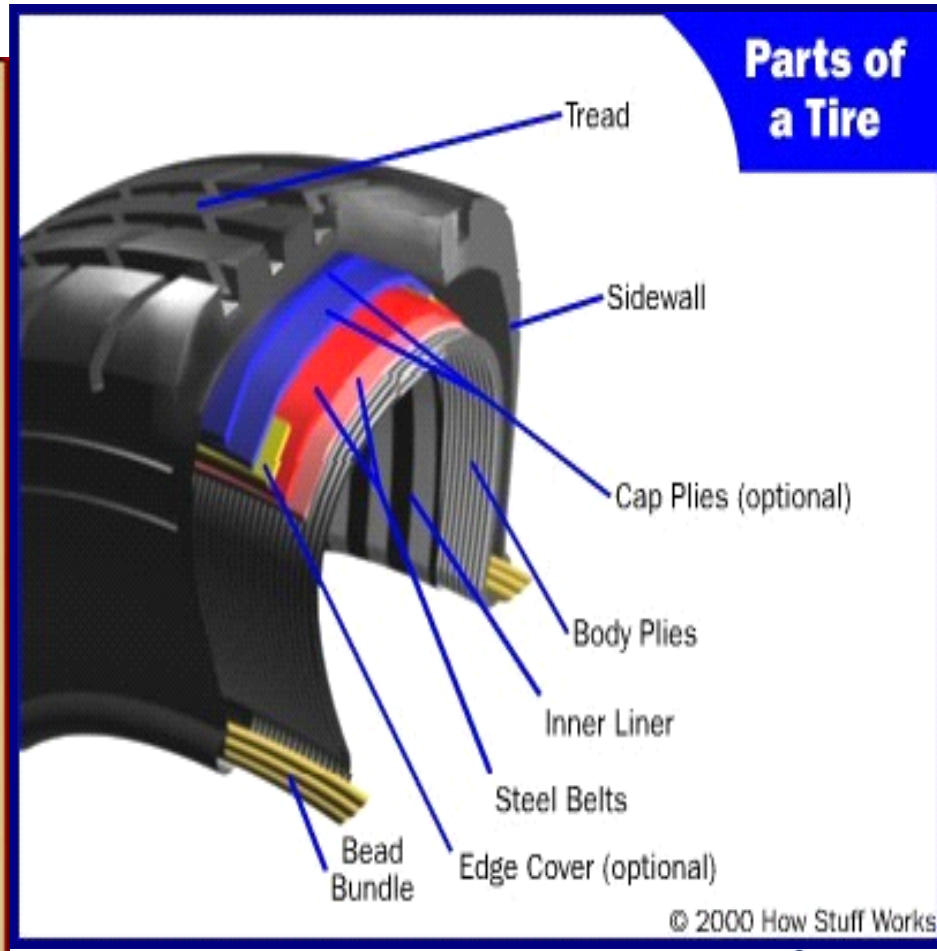


Figure 5

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



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Gautrans Heavy Vehicle Simulator (HVS) Mark IV+: Loading Device for Controlled loading tests on roads..

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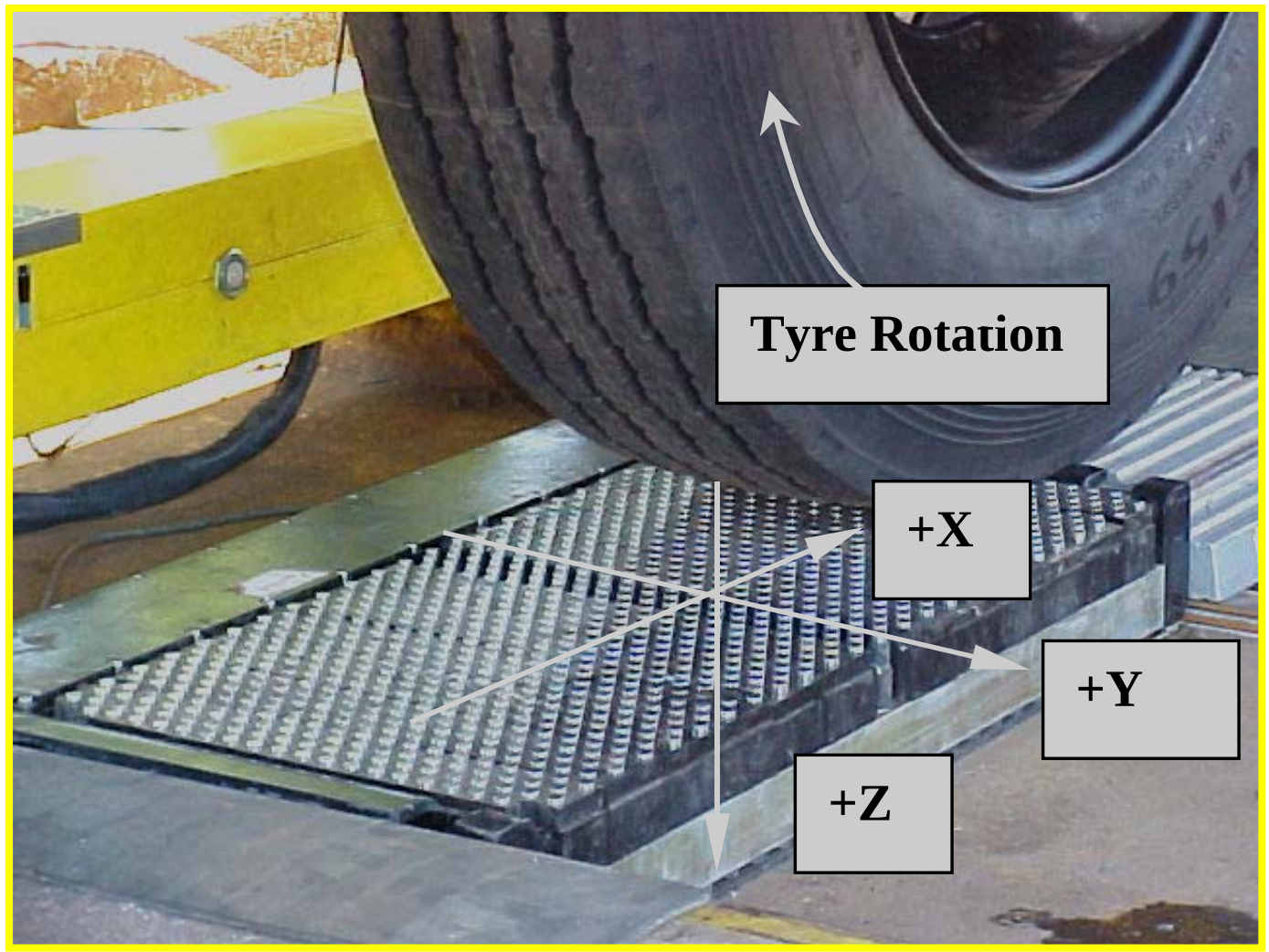
LOADS & STRESSES FROM TYRES:



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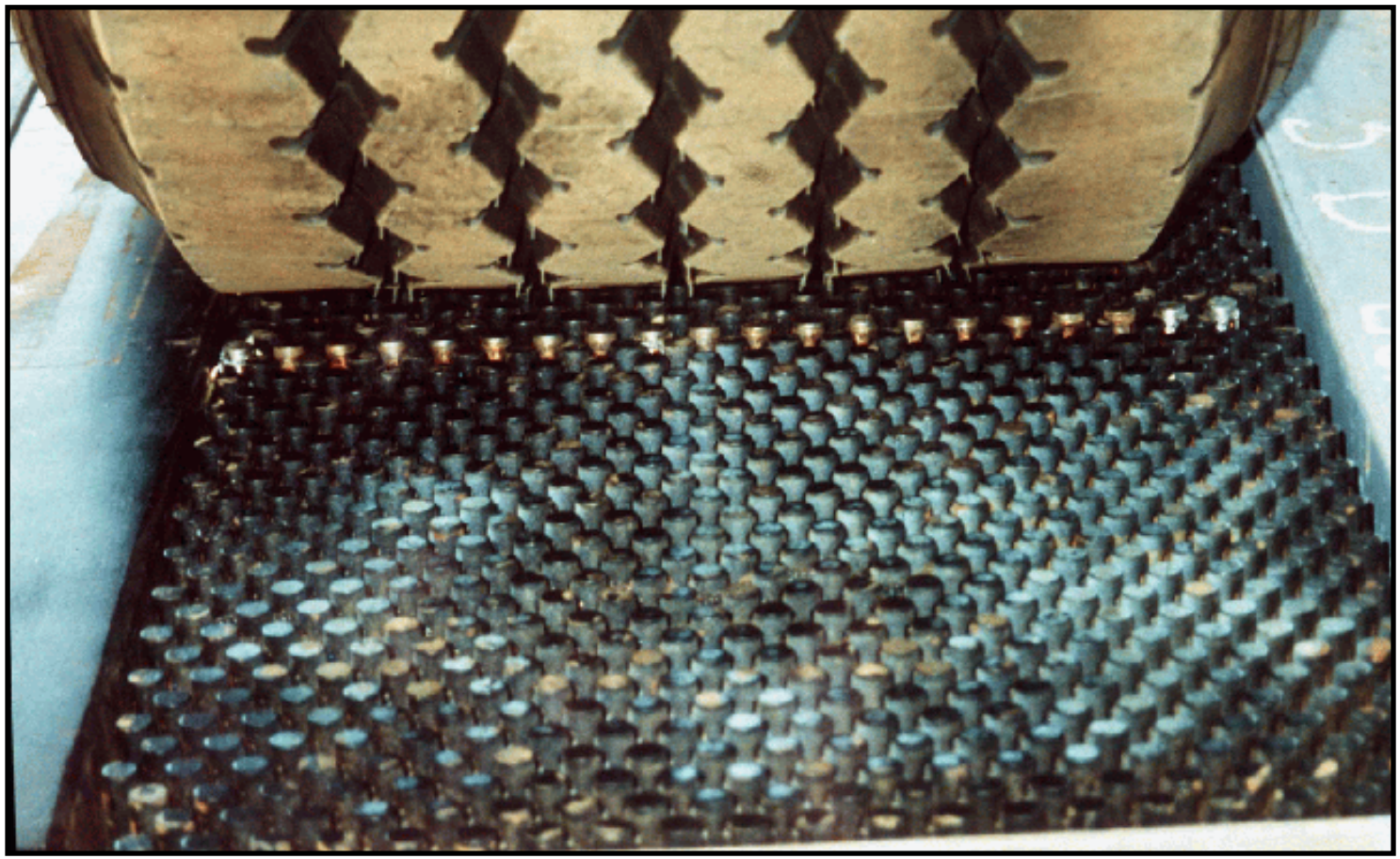
425 /65 R22.5 HVS TYRE ON SIM SYSTEM



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Stress-In-Motion testing with HVS
Dual Load Configuration – Twin SIM pads

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STRESS-IN-MOTION TESTING USING THE HVS

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TYRE DEFLECTION & TYRE PRINTS…

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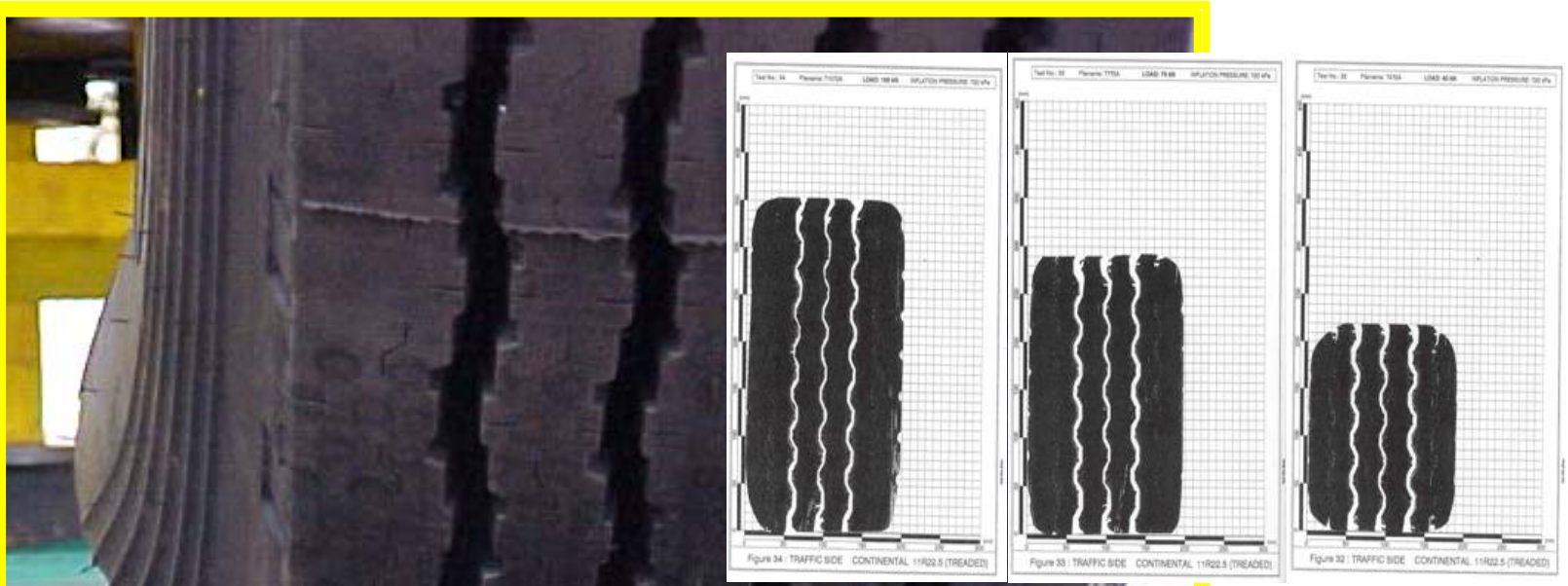
TYRE DEFLECTION & TYRE PRINTS…



315/80 R22.5 HVS Tyre:
Overloaded

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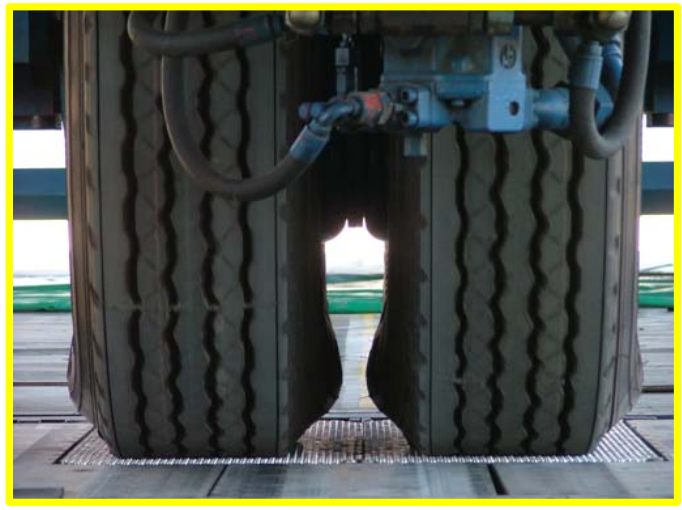
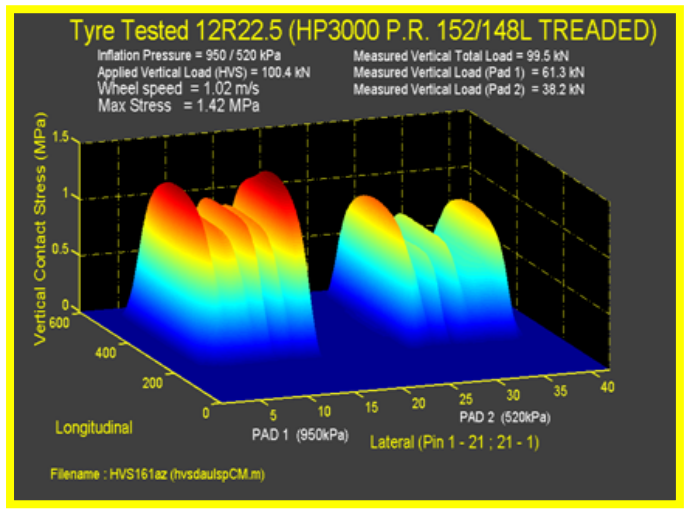
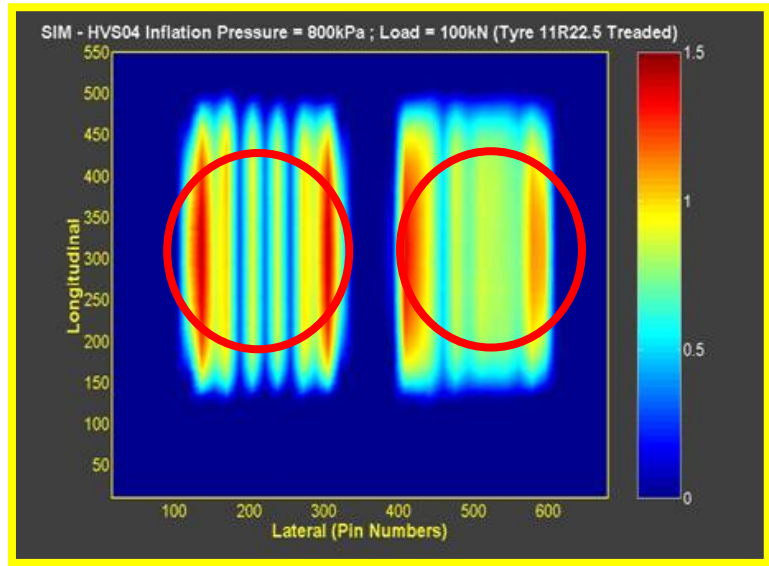
Overloading on Tyres….and contact with road..





Tyre Contact Patches: (square not circular)…



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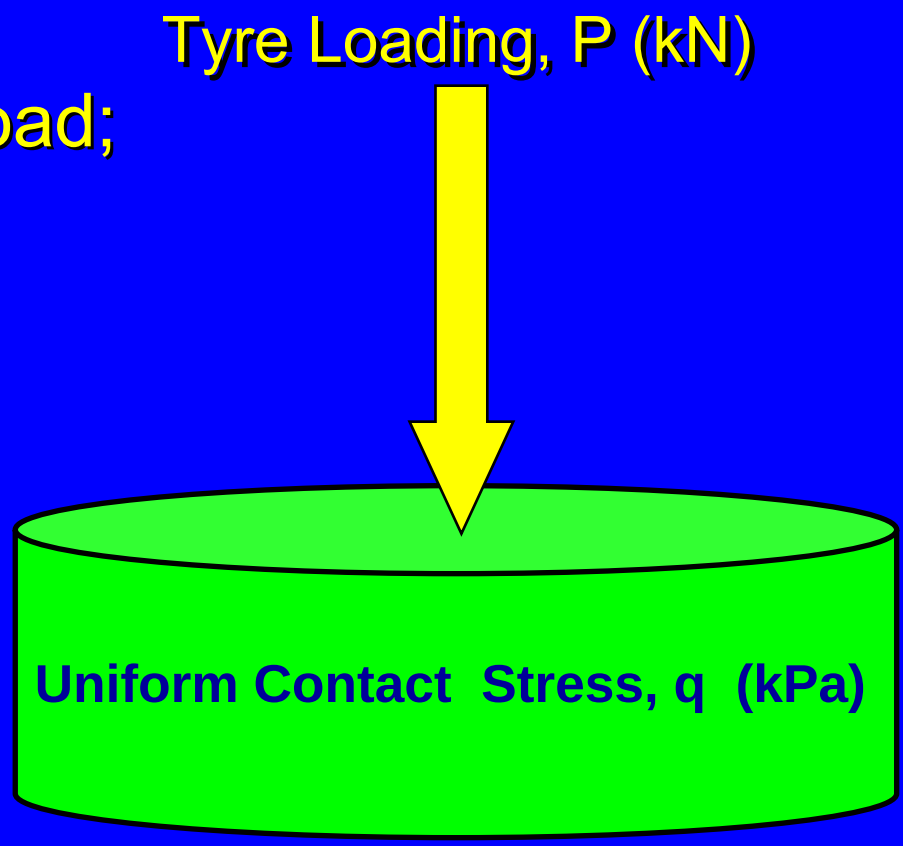
Assumption of Tyre Loading - Pavement Design Modeling:

- Circular;
- Variable Vertical load;
- Variable pressure,

but UNIFORM &
No Shear Forces
included.



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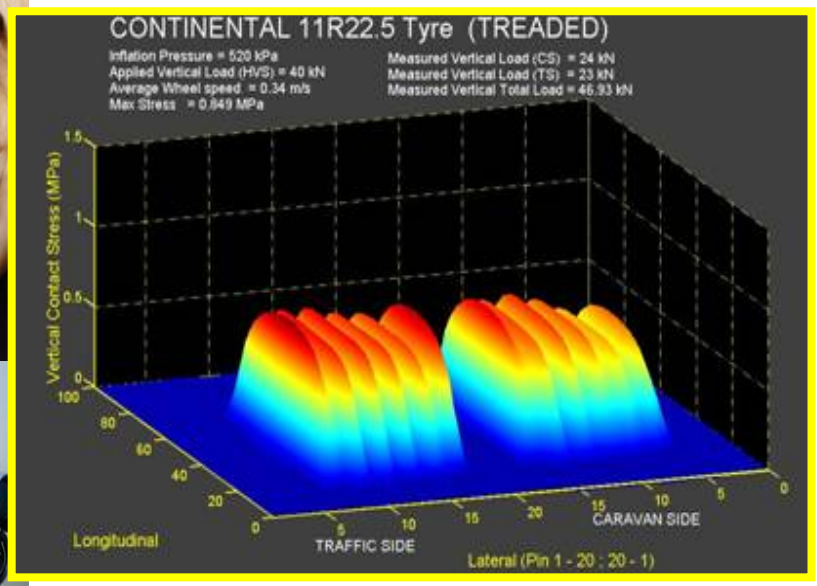
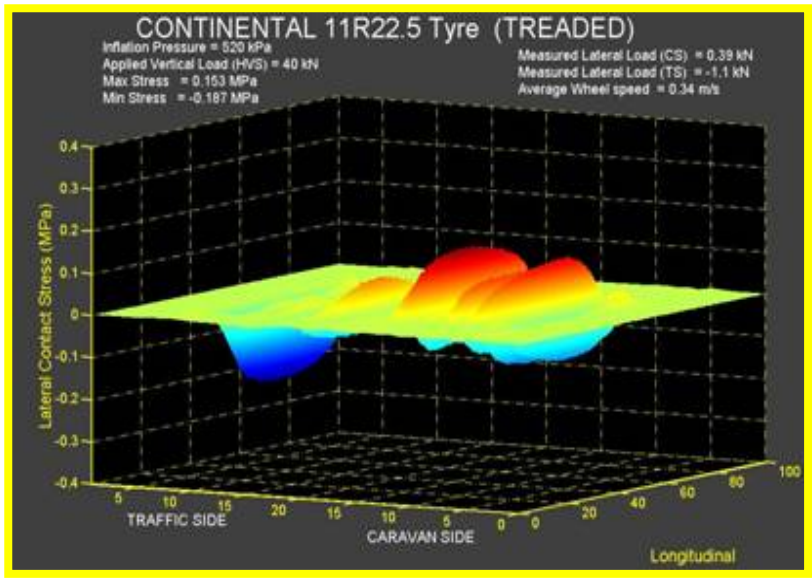
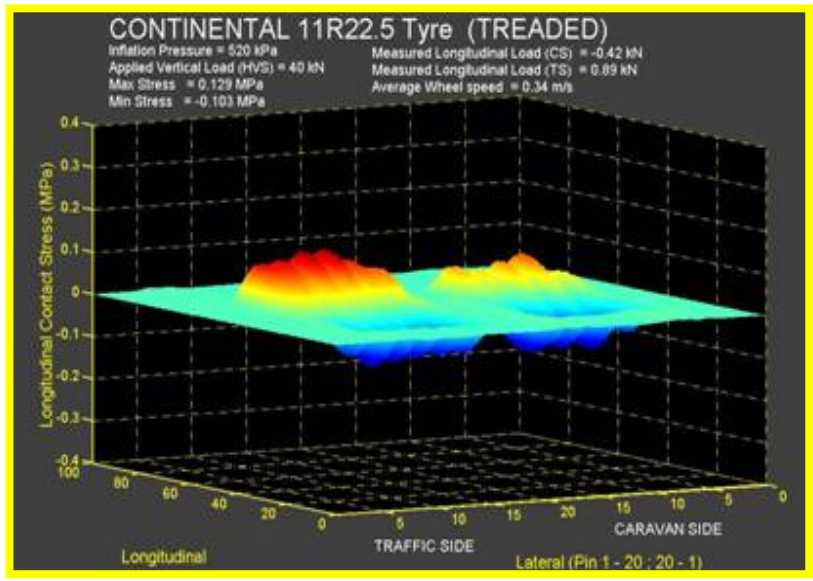
Dual Tyre: 3D-Contact Stresses (Pressure)…





Stress Ratio: 10:3:1



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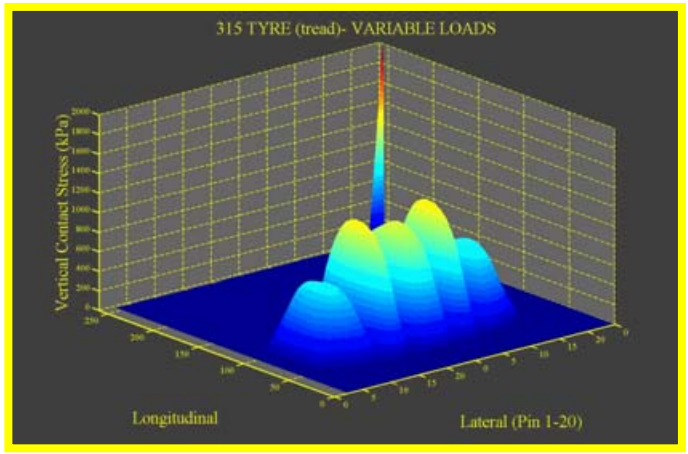
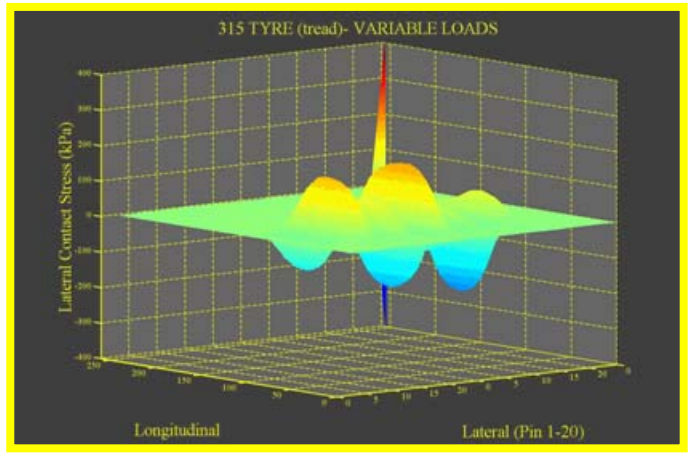
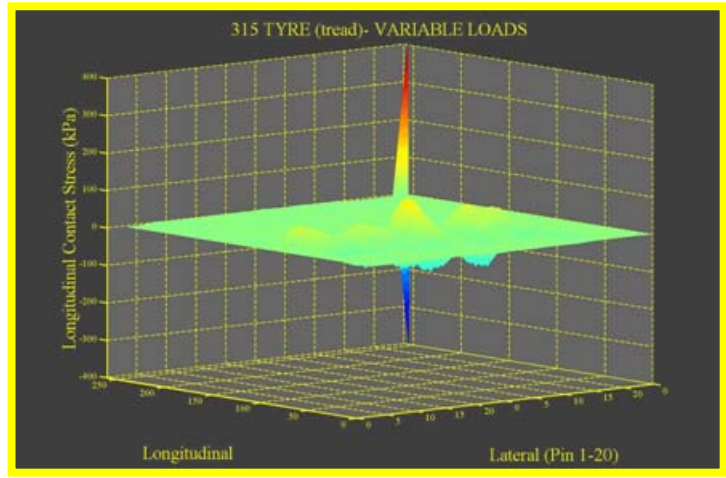
Typical SIM 3D Data Sets - Variable loading:





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



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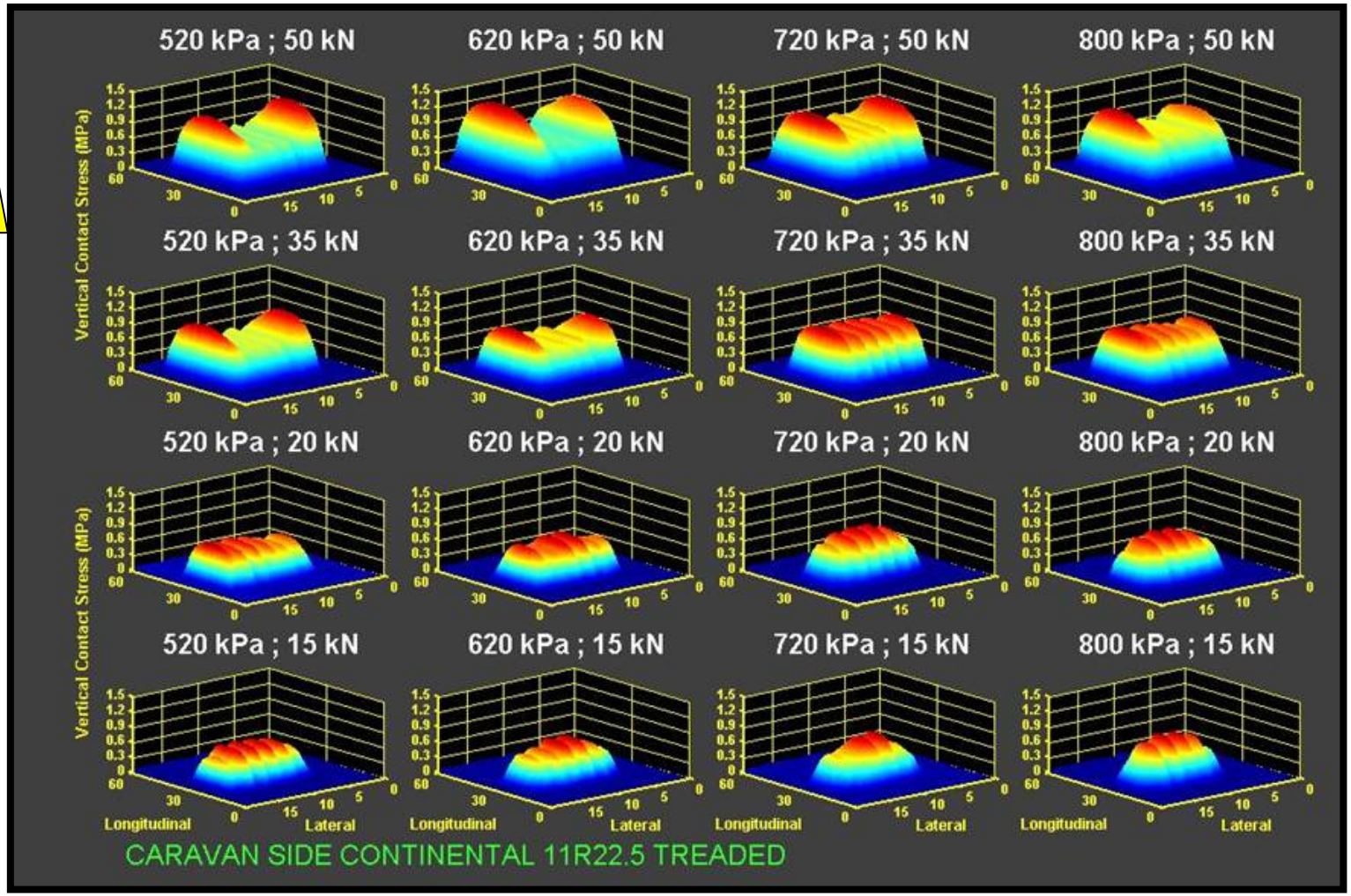
TYRE "FINGER PRINTING": (11R22.5 TYRE)…

TYRE LOAD



TYRE INFLATION PRESSURE

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Truck Weighing - National Road 3 (N3), near Heidelberg in Gauteng….

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

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

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Examples of Stress-In-Motion (SIM) Testing on the N3 – Freeway near Heidelberg….

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

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Quad (full) SIM Scale on National Road 3 (N3), near Heidelberg in Gauteng ….

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SIM Measurement: N3- “1232” Tanker…

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SIM In operation – N3-TCC …….

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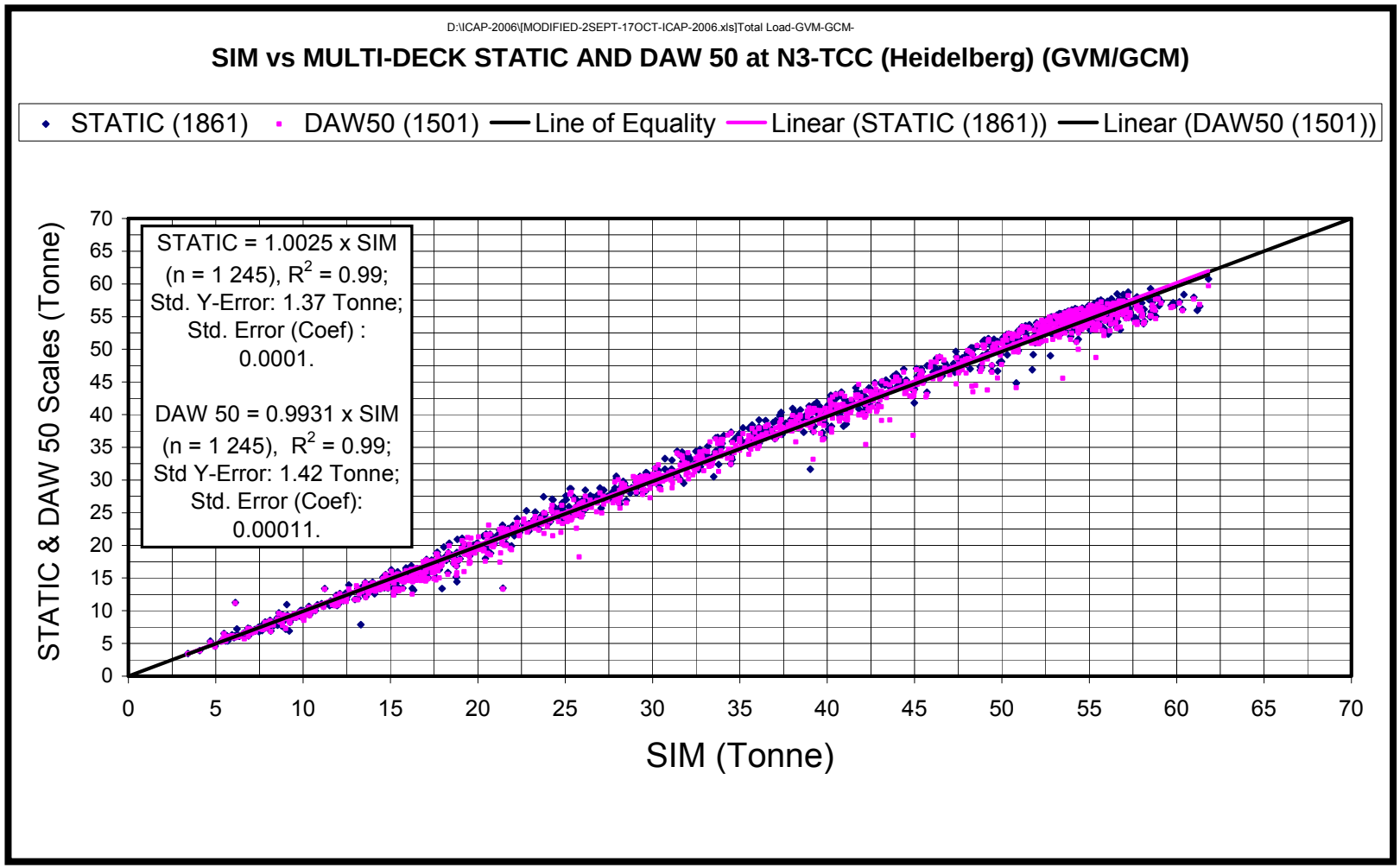
SIM Scales: Accuracy checking @ N3-TCC…



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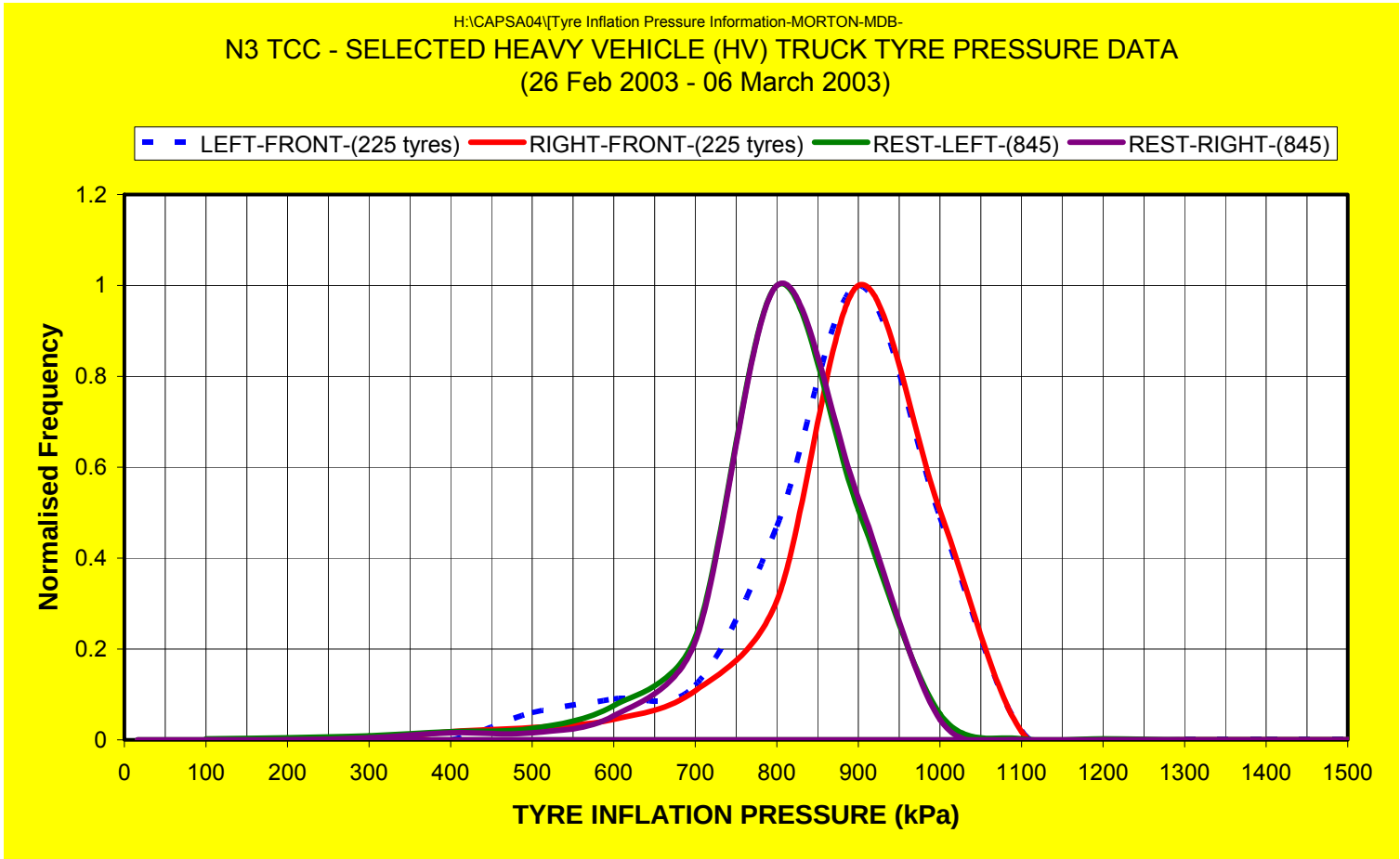
Tyre Inflation Pressure Distributions – N3- 2003



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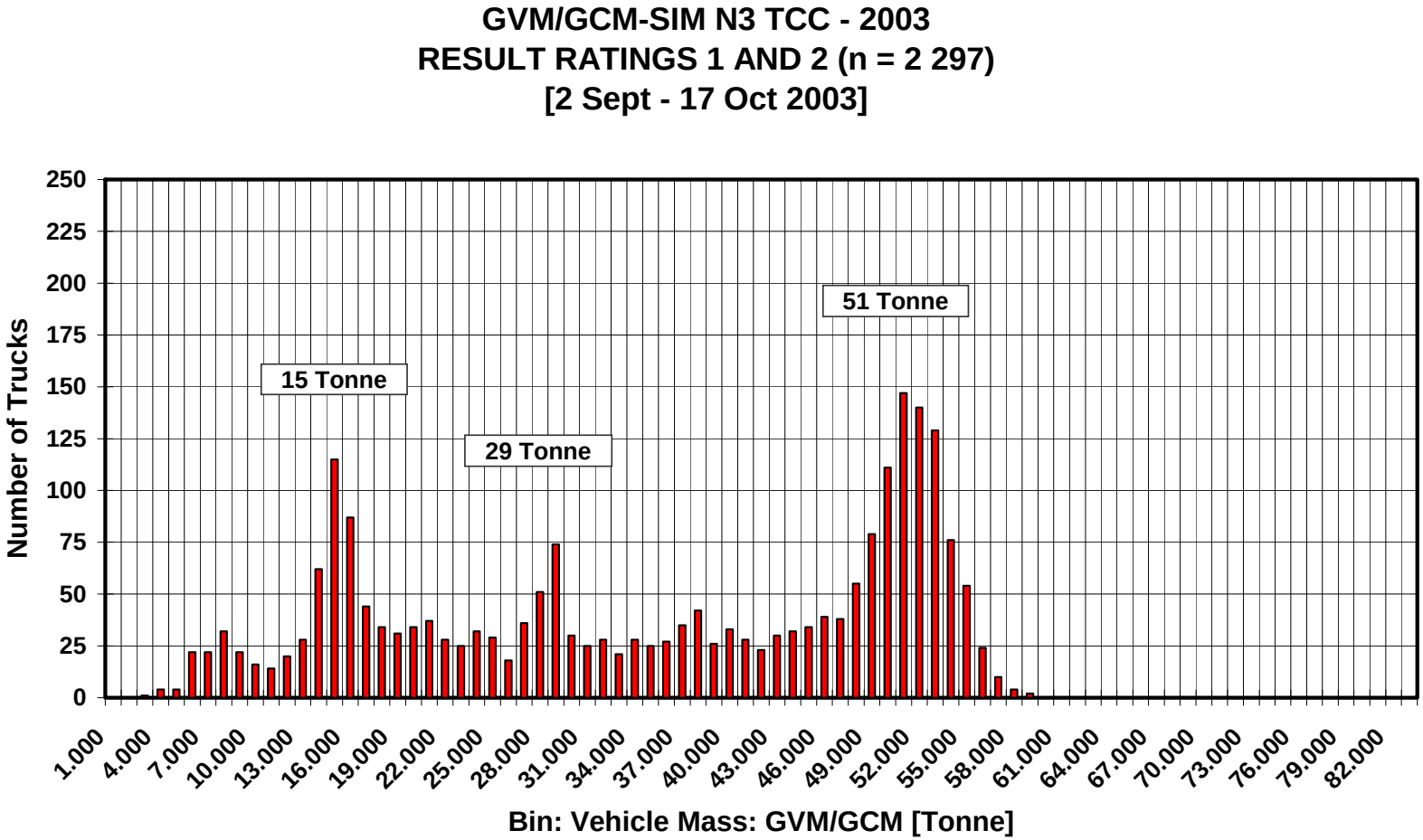
Gross Vehicle Mass (GVMs).....



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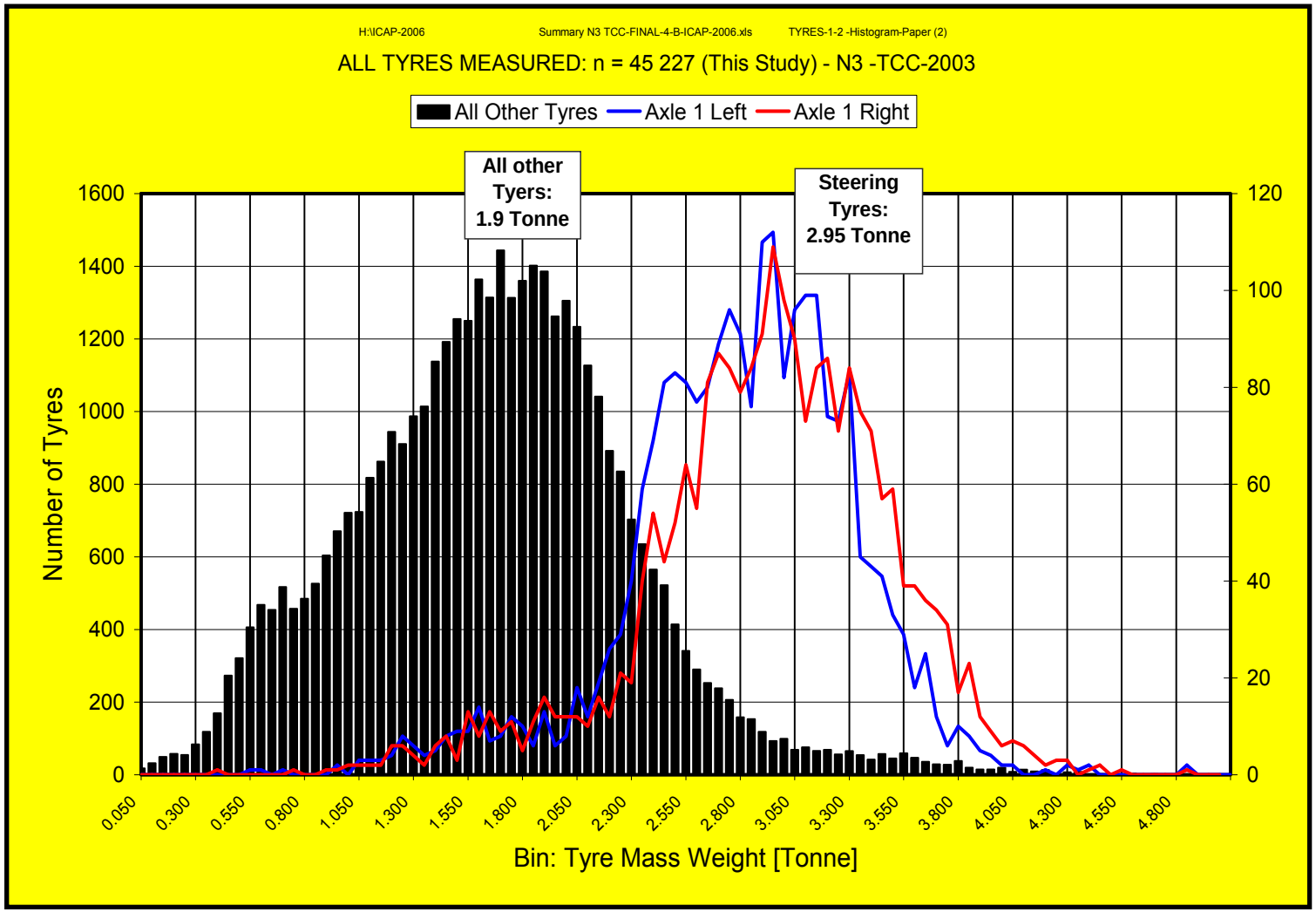
Axle Mass Distributions – N3- 2003



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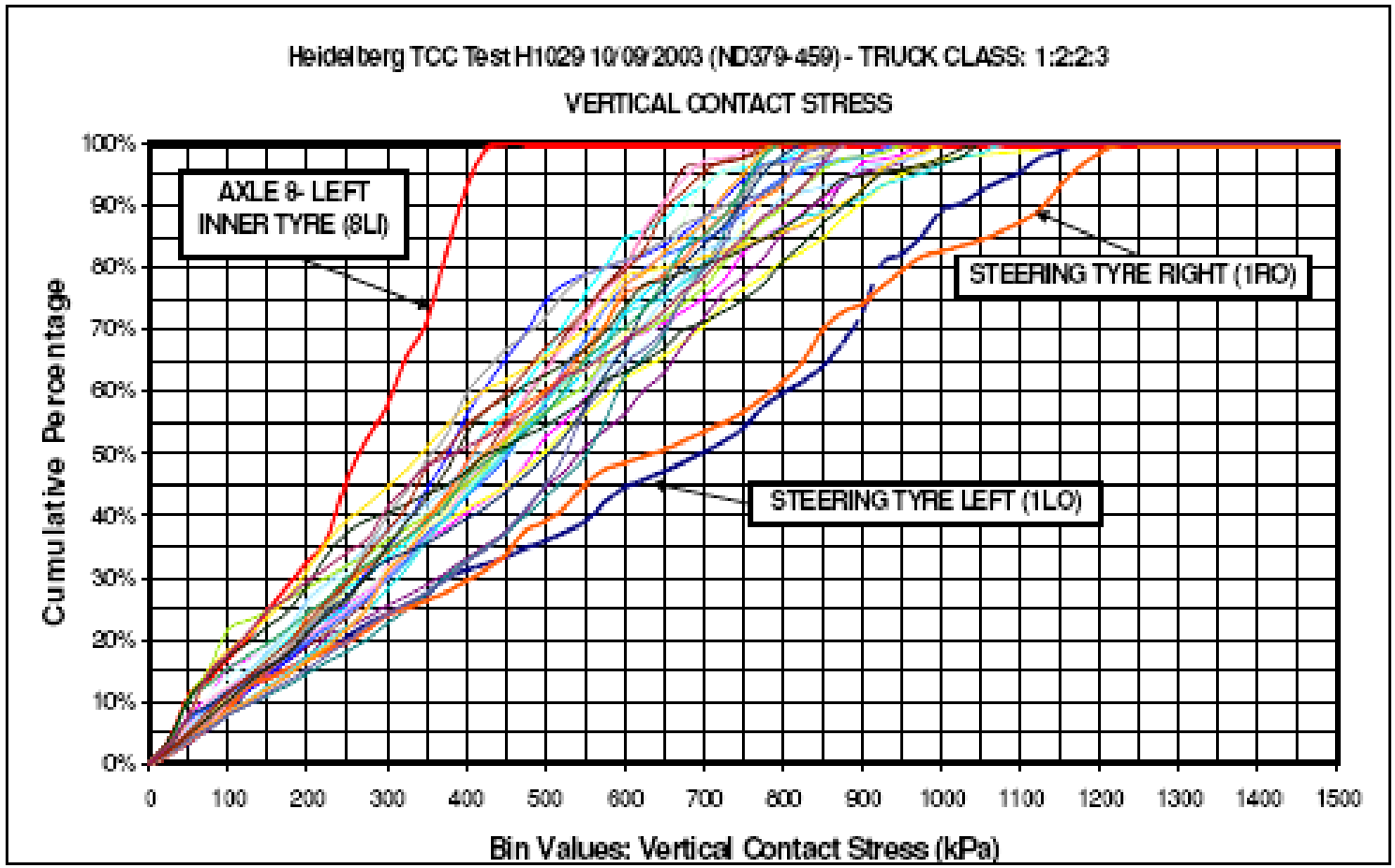
Vertical Stress Cumulative Frequency – N3- 2003



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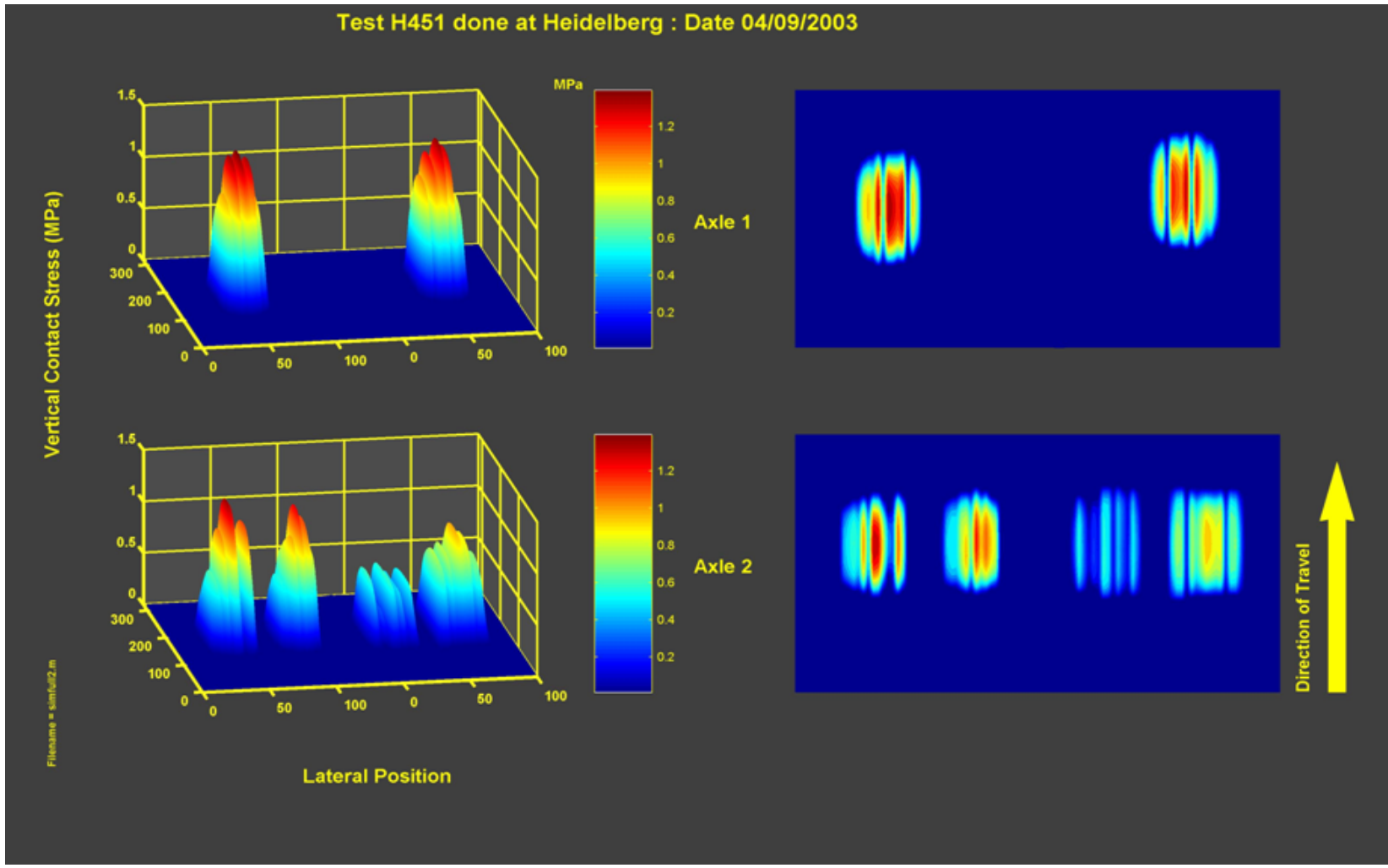
Measured Tyre Foot Prints :Two Axle Truck – Vertical Contact Stress –…..



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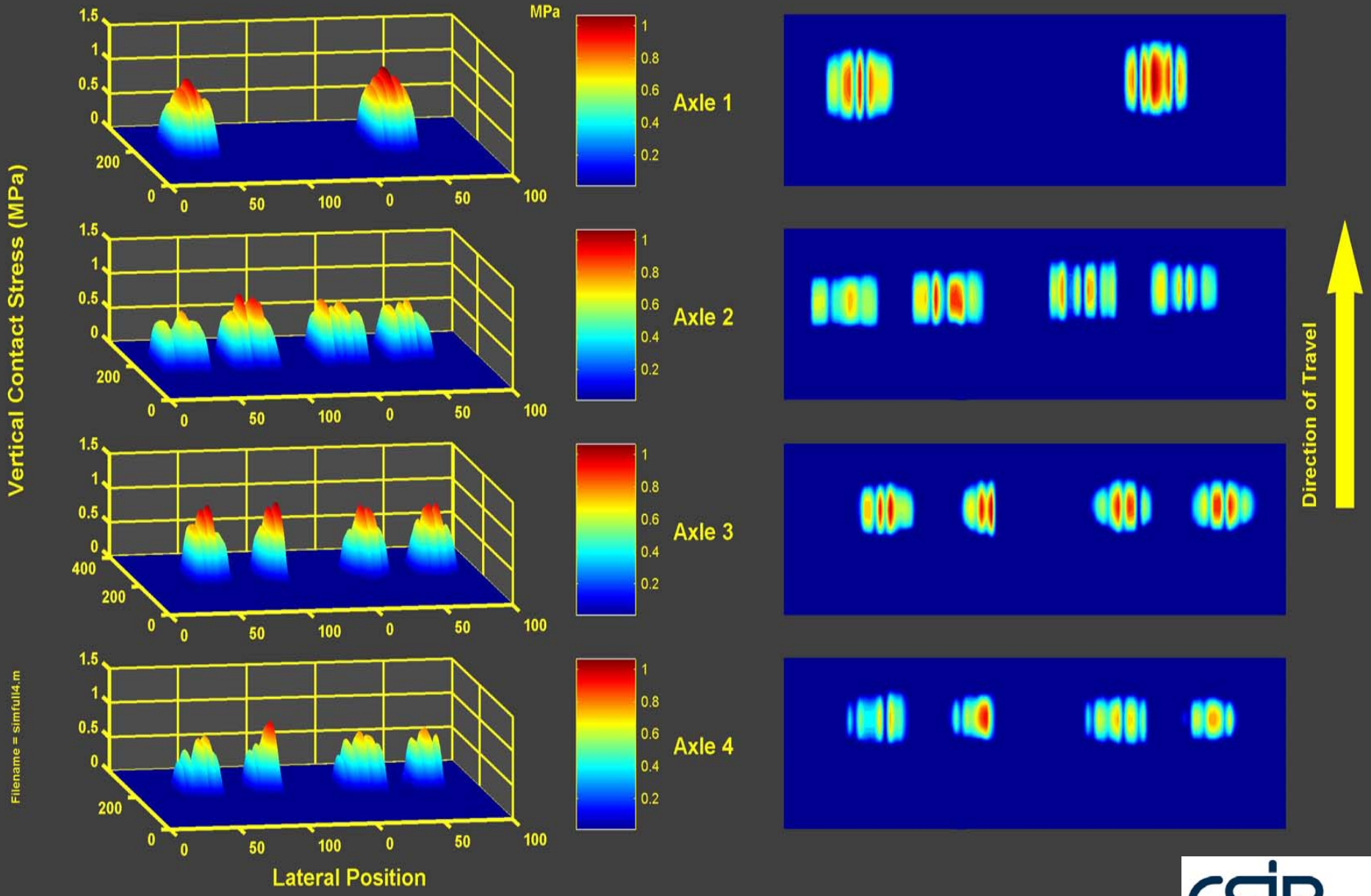
Test H1070 done at Heidelberg : Date 10/09/2003

4 Axle Truck….



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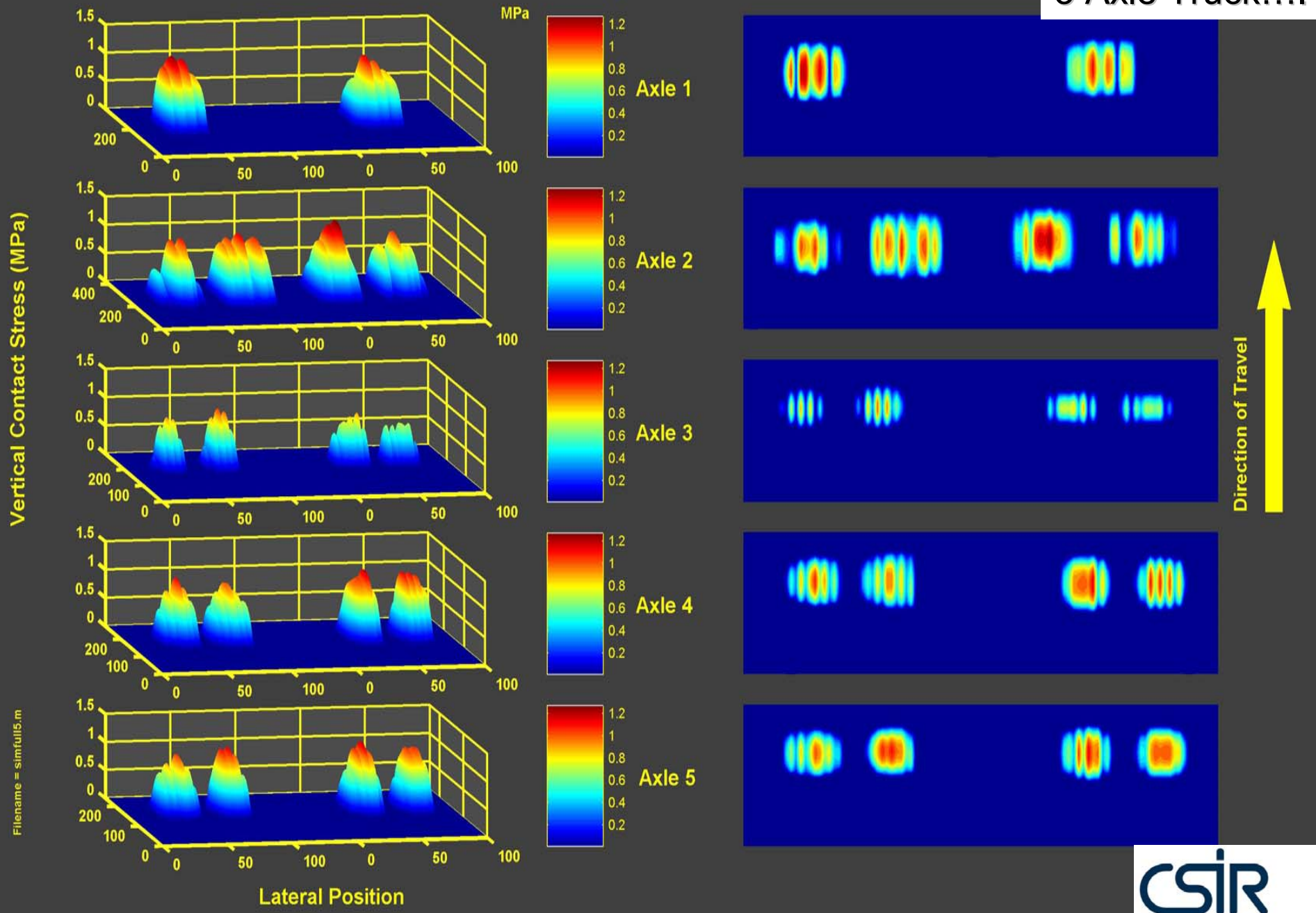
Test H1077 done at Heidelberg : Date 10/09/2003

5 Axle Truck….



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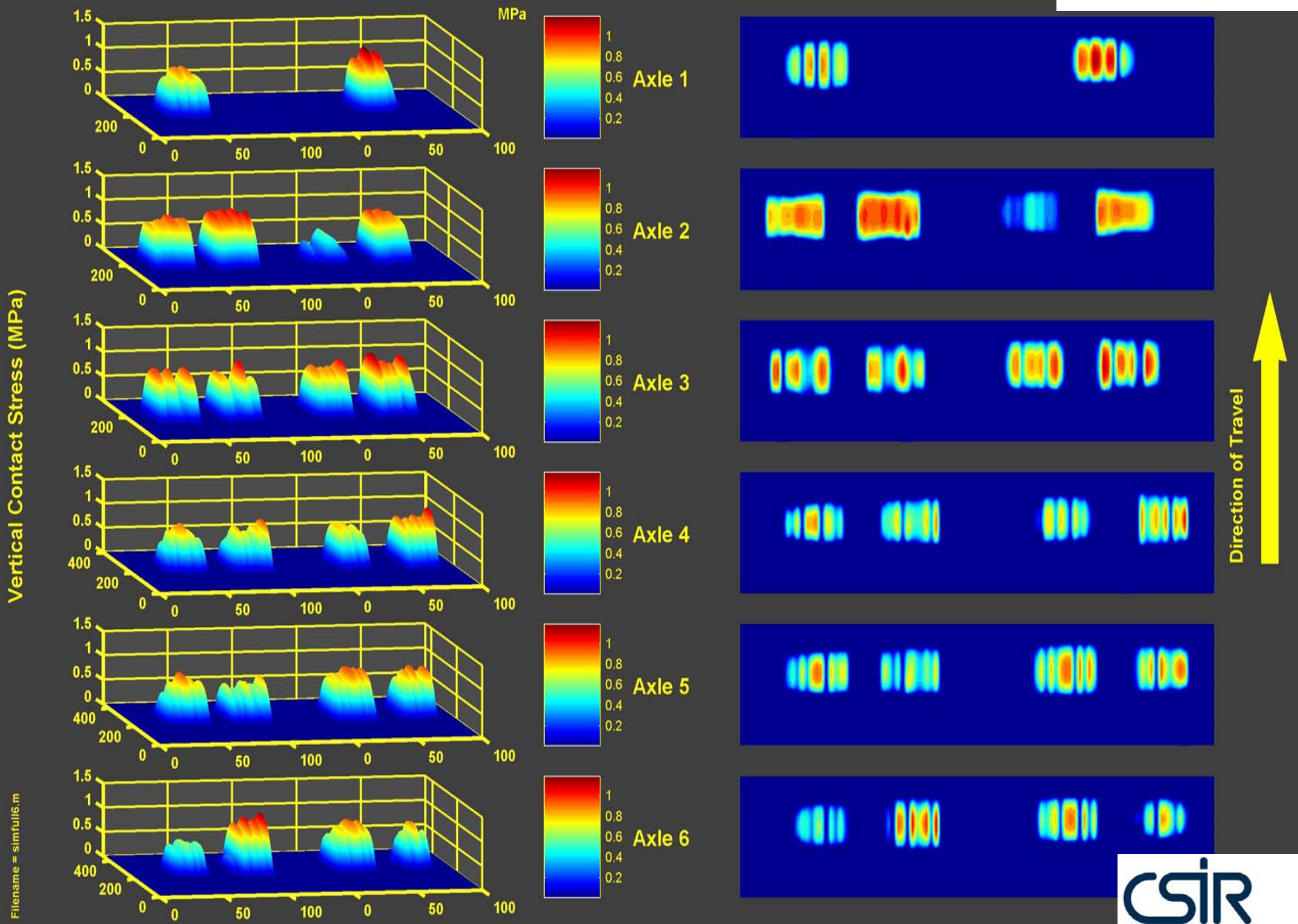
Test 174 done at Heidelberg : Date 10/09/2003 (overload)

6 Axle Truck….



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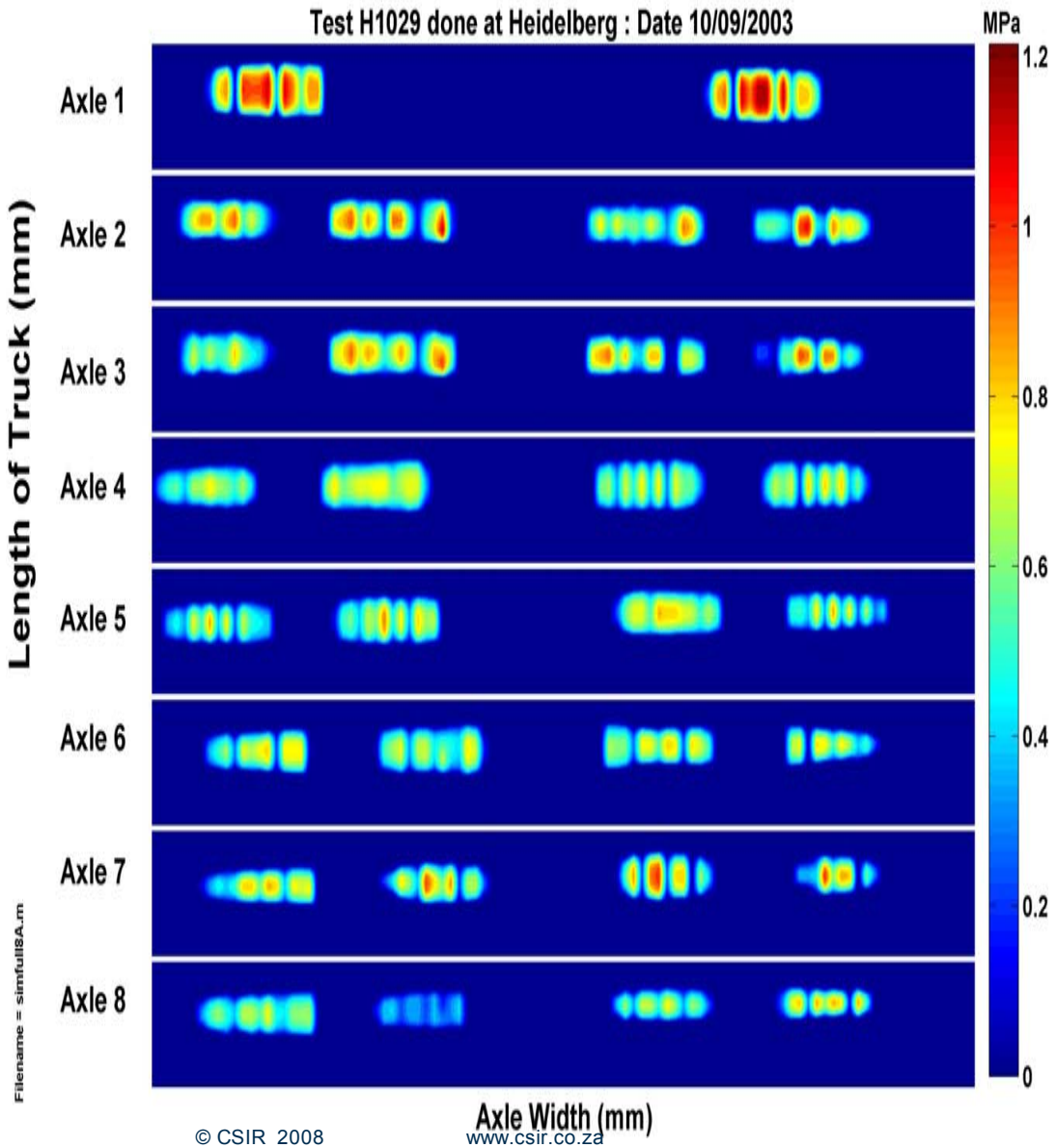
Eight (8) Axle Truck – Vertical Contact Stress - Foot Prints….



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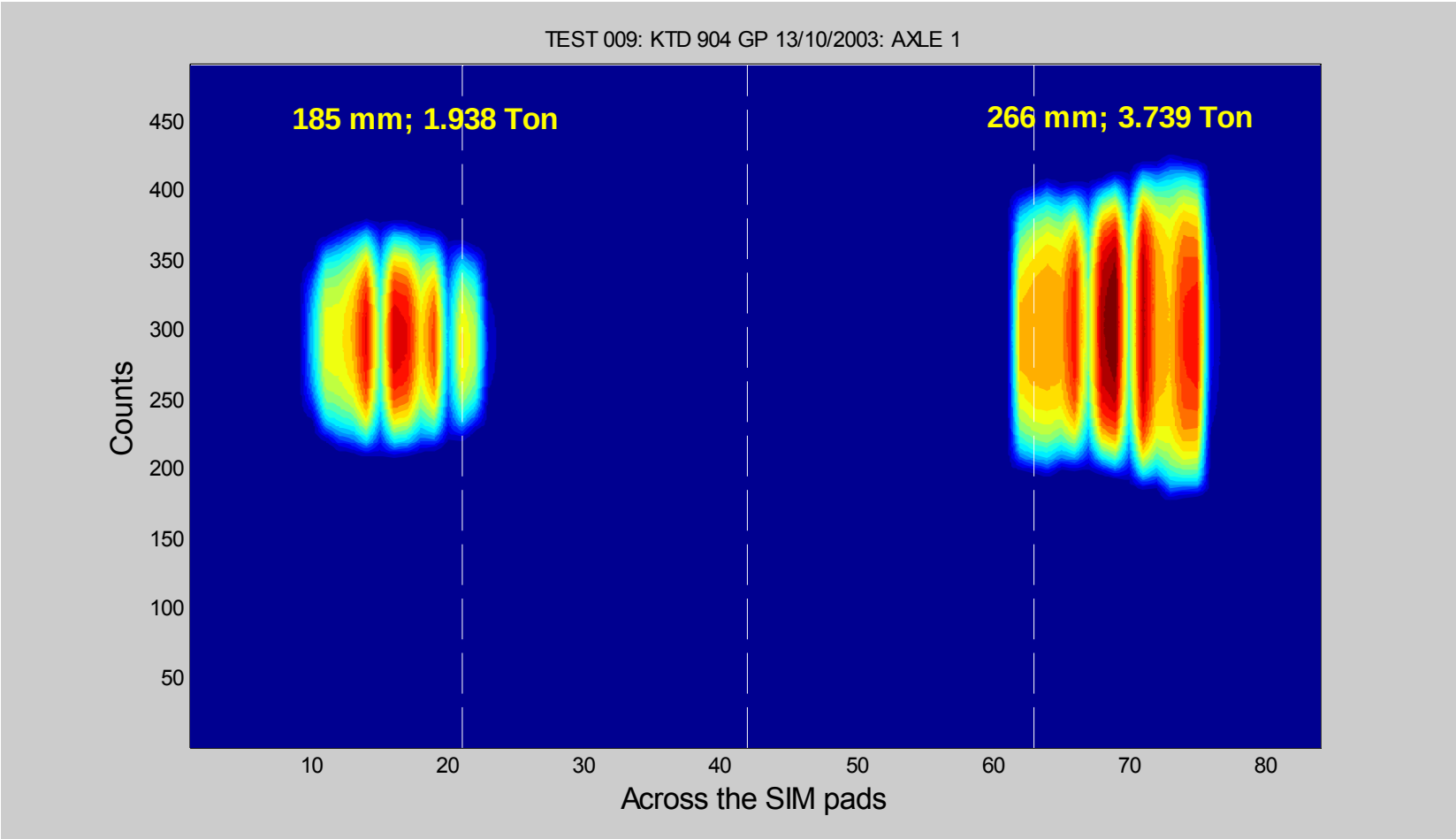
STEERING AXLE – UNEQUAL LOADING……



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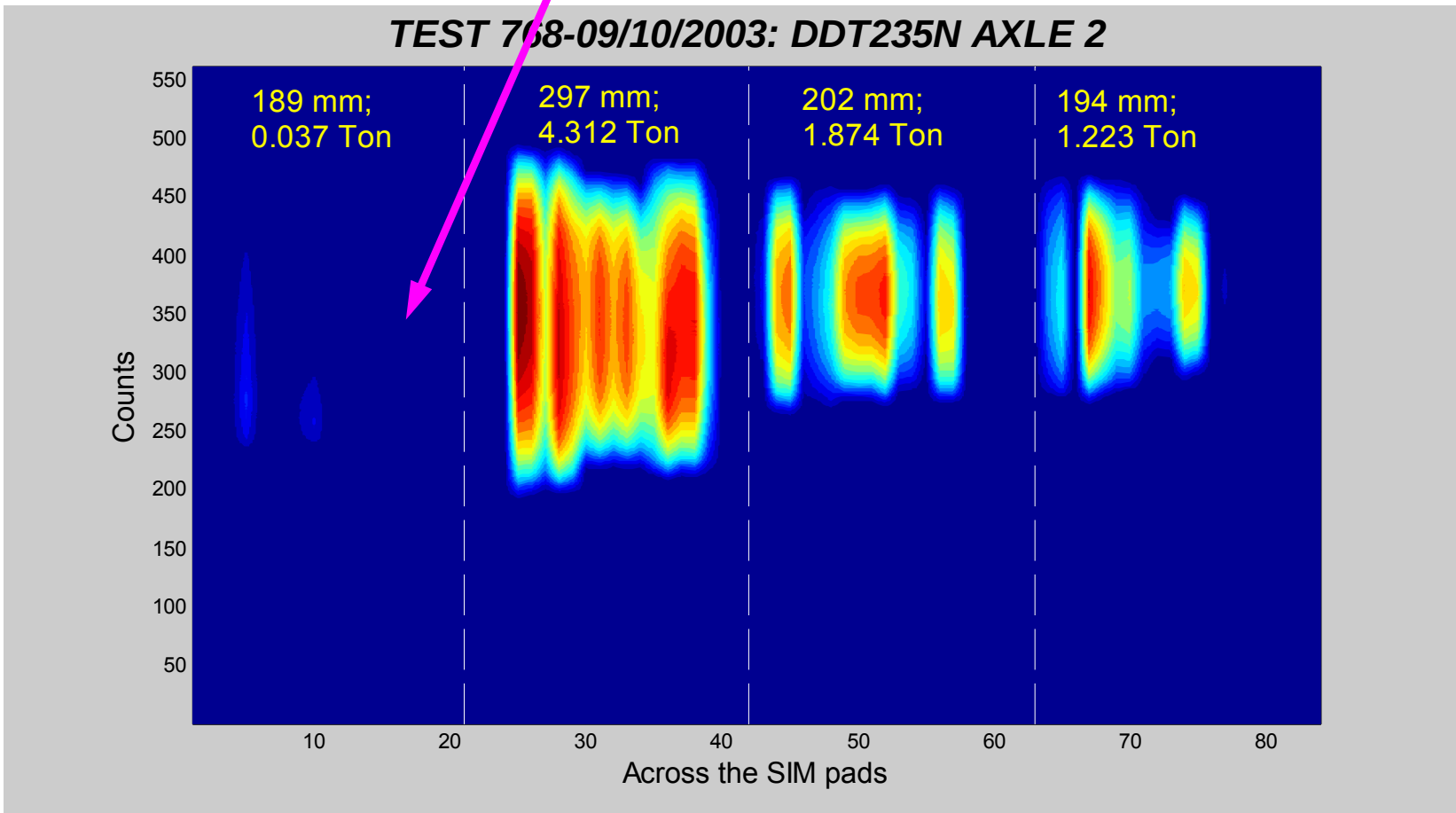
UNEQUAL LOADING ON TRUCK TYRES….

TYRE BARELY IN CONTACT WITH SURFACE



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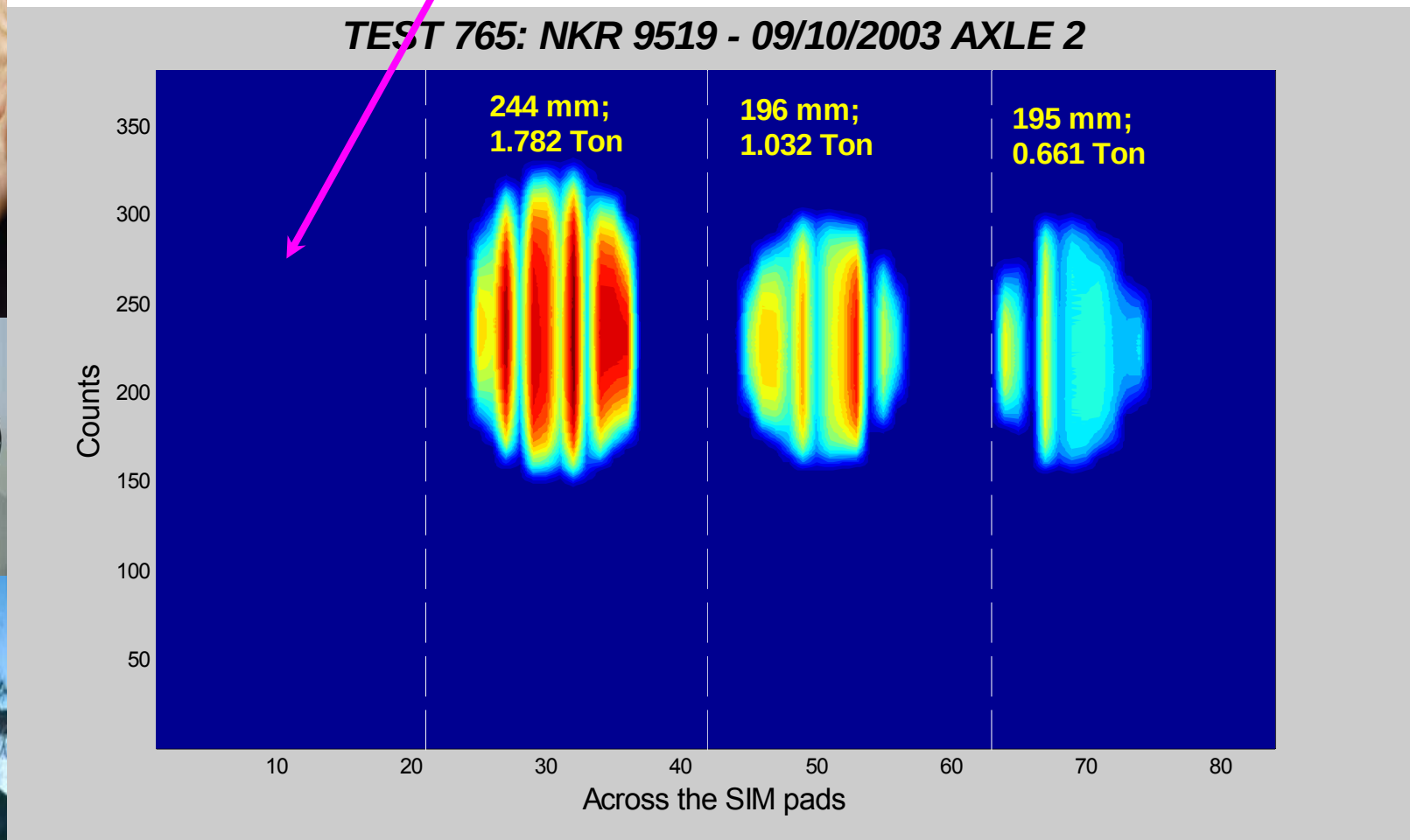
AXLE 2: MISSING TYRE !!



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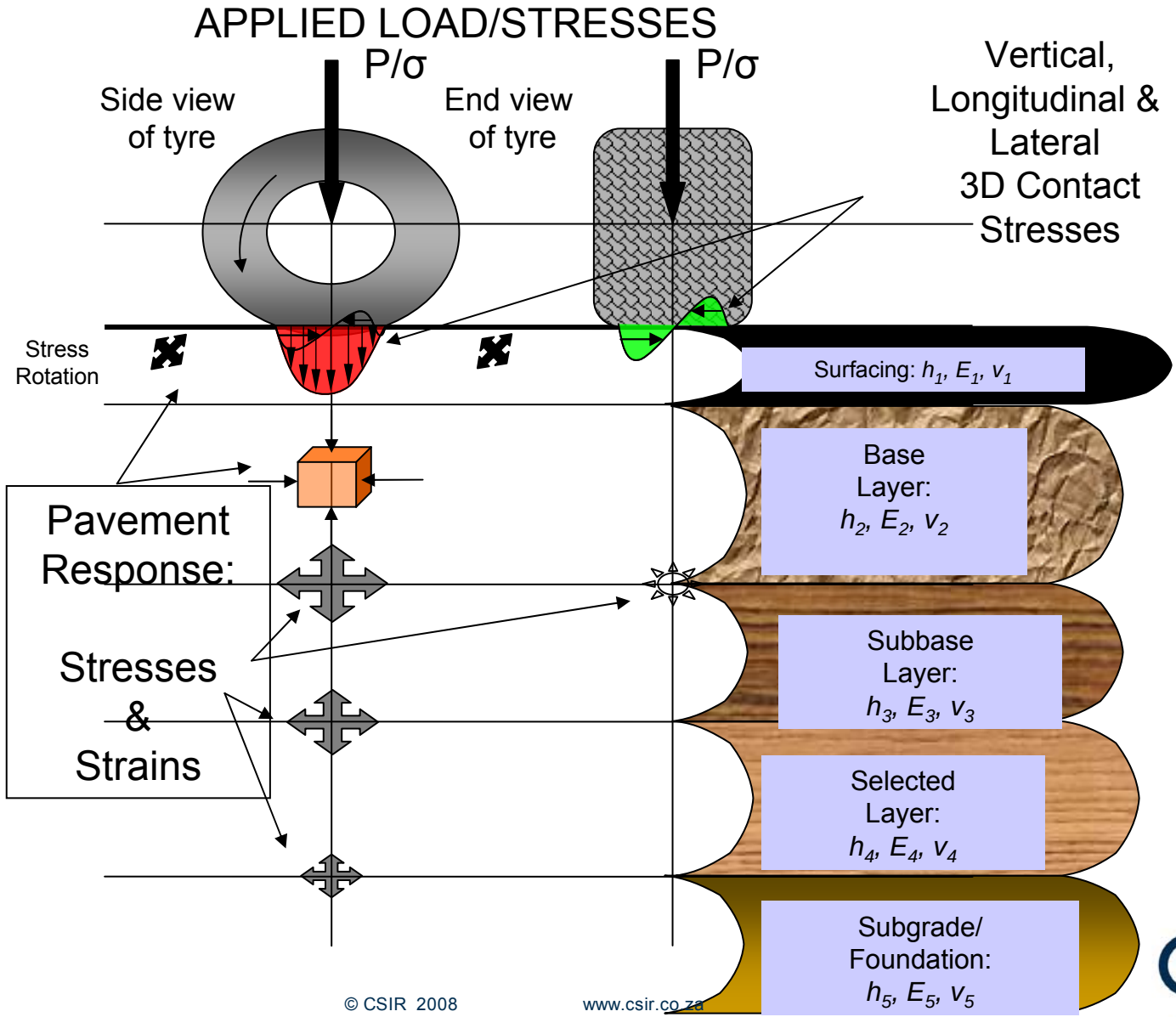
ANALYTICAL ROAD PAVEMENT MODEL….



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General Features & Assumption

- **Pavement:** Multilayer elastic system with a possibility of interface slip.
- **Surface load:** Single/Multiple circular loads.
- **Analysis:** Single/Multiple points of interest.
- **Response:** Stresses, strains, and displacements

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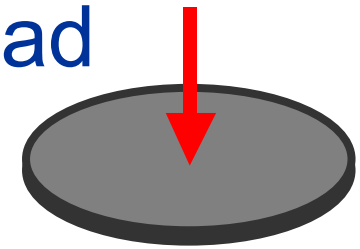
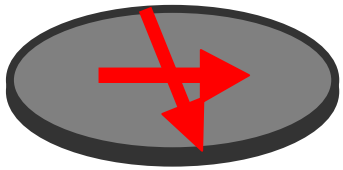
Uniformly distributed circular load

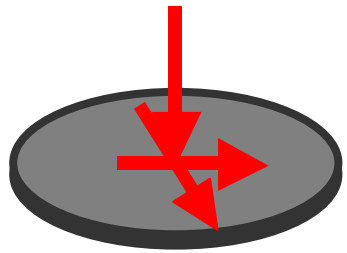
Vertical load

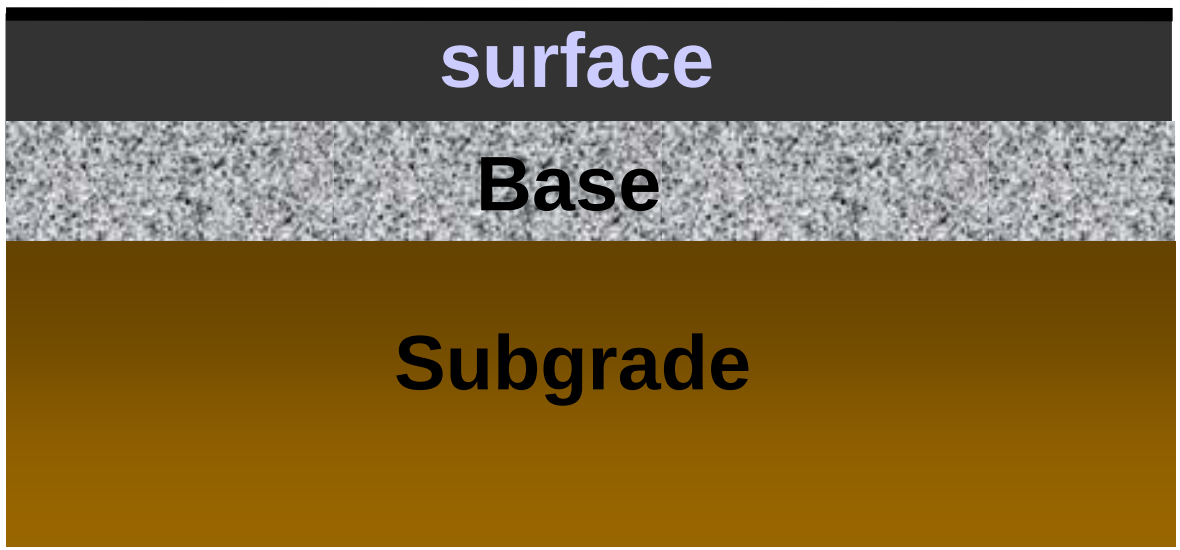


Horizontal load



vertical + horizontal loads





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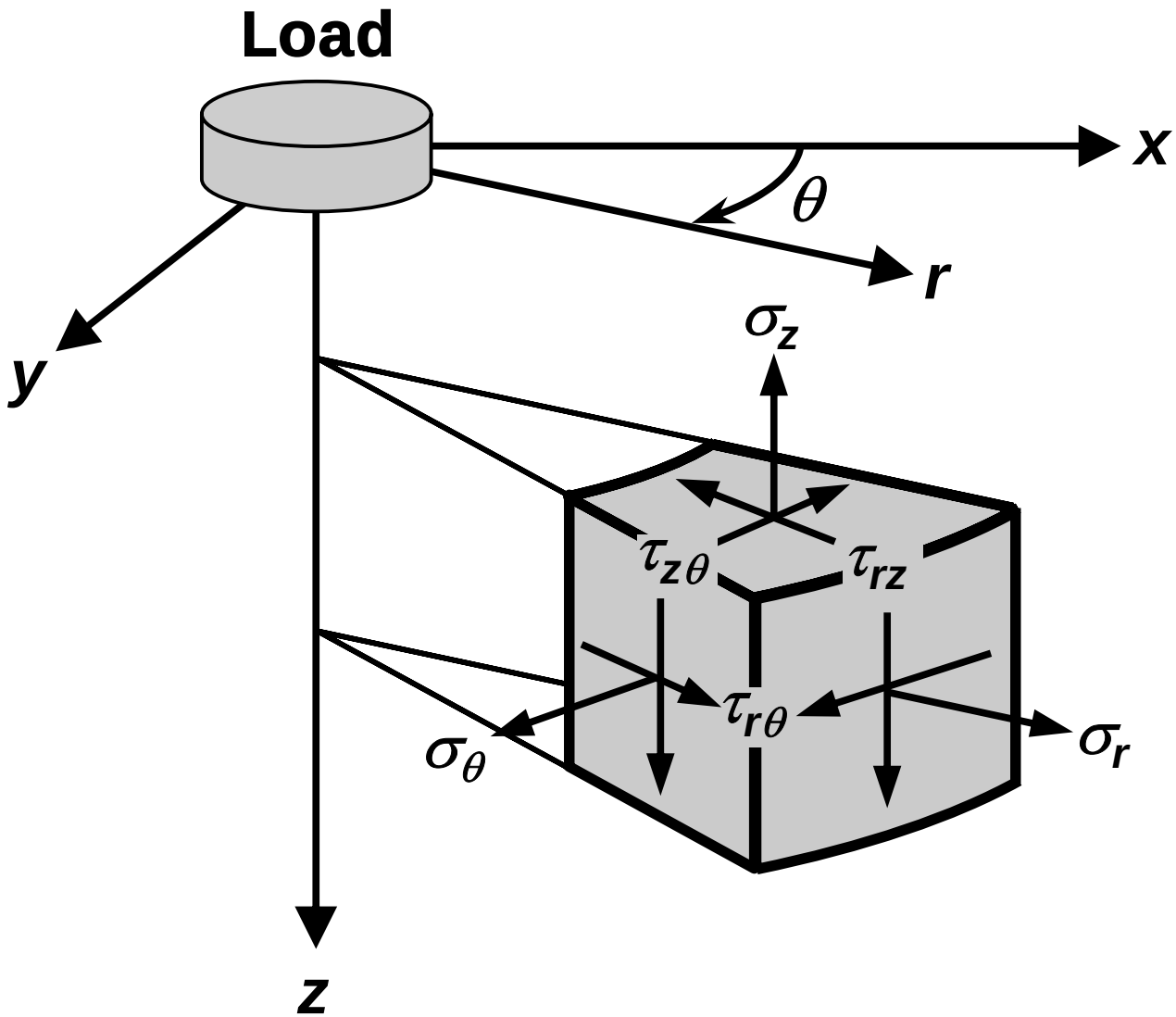
Stresses within a Road Pavement Structure
- $r\theta z$ Axes -



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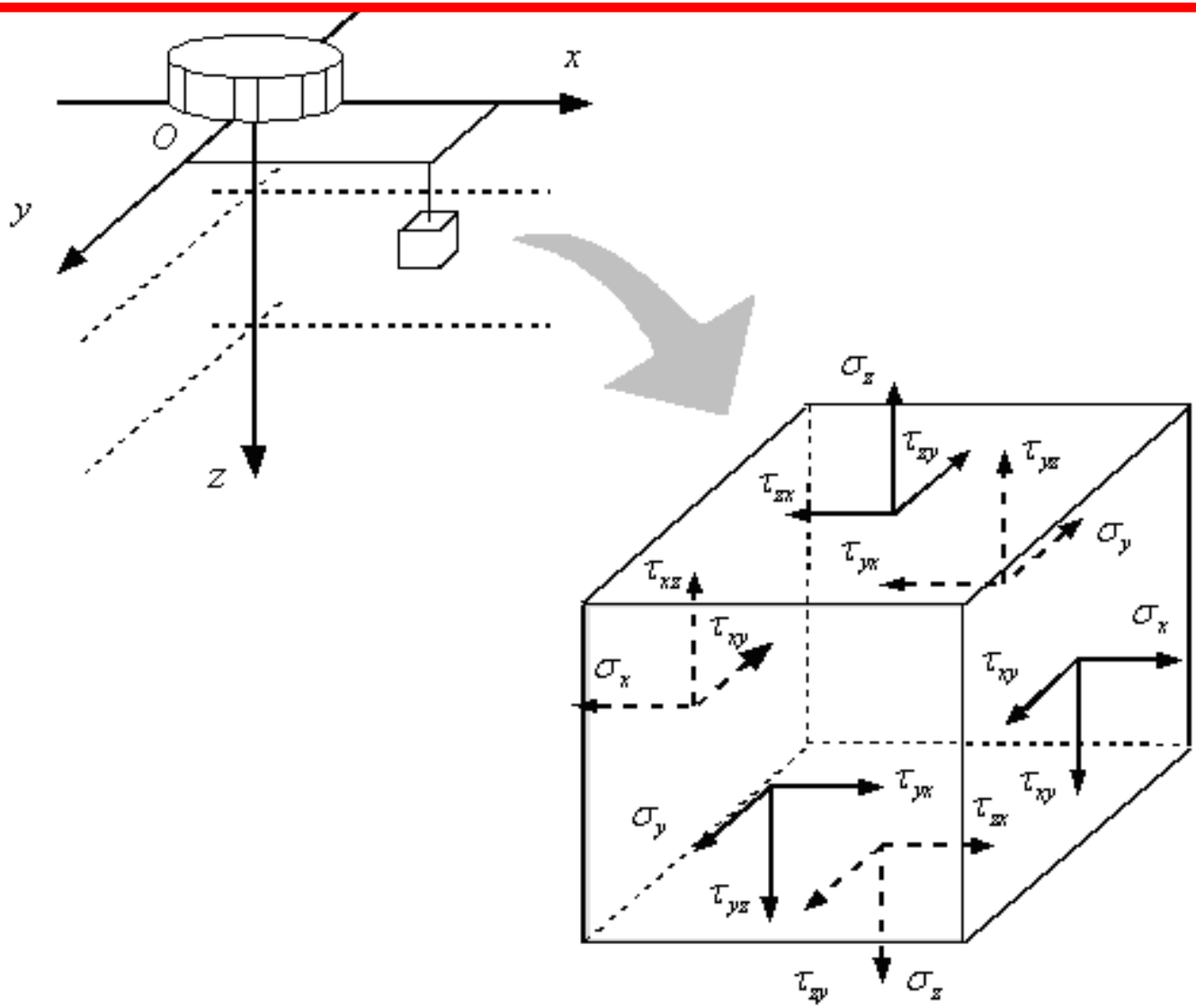
Stresses within a Road Pavement Structure..



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Global Cartesian coordinate system

Local Cartesian and cylindrical coordinates

load

X

Y

Z

x

y

z

r

θ

α

Stress acting on an element

σ_z

$\tau_{rz} = \tau_{zr}$

$\tau_{z\theta} = \tau_{\theta z}$

σ_r

σ_θ

$\tau_{r\theta} = \tau_{\theta r}$

Arrows give directions for positive sign

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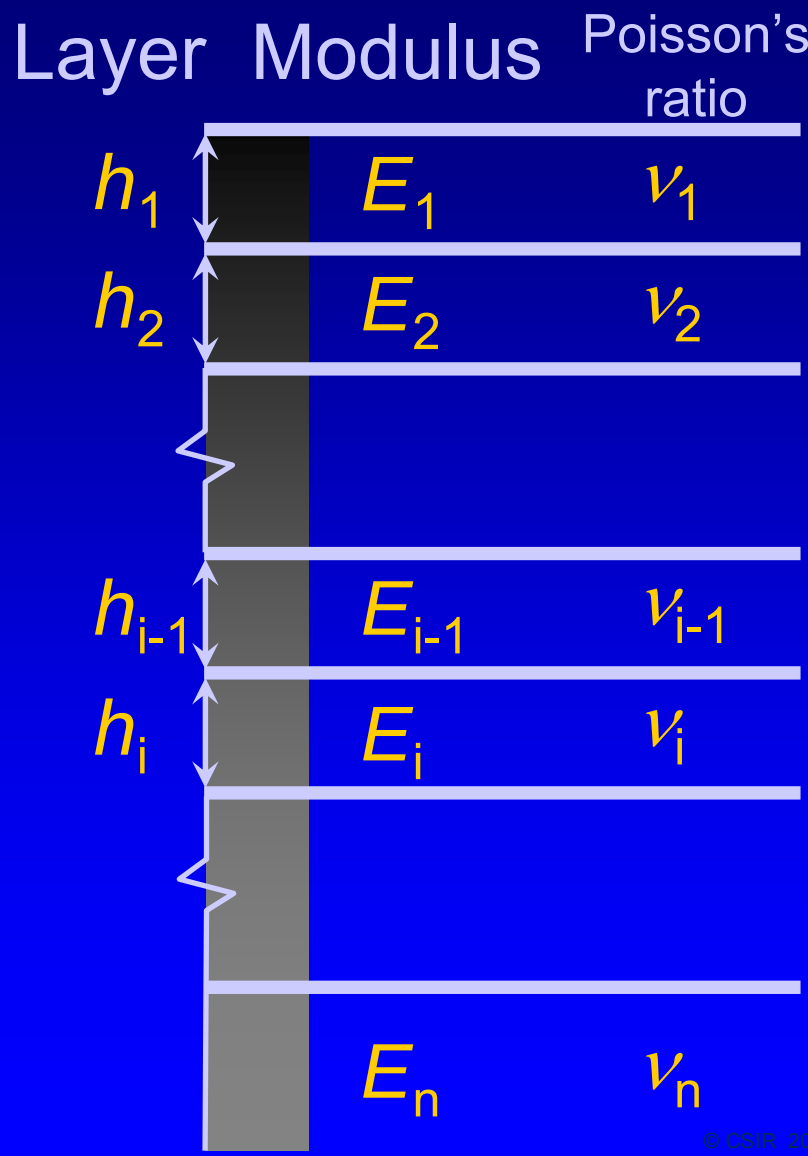
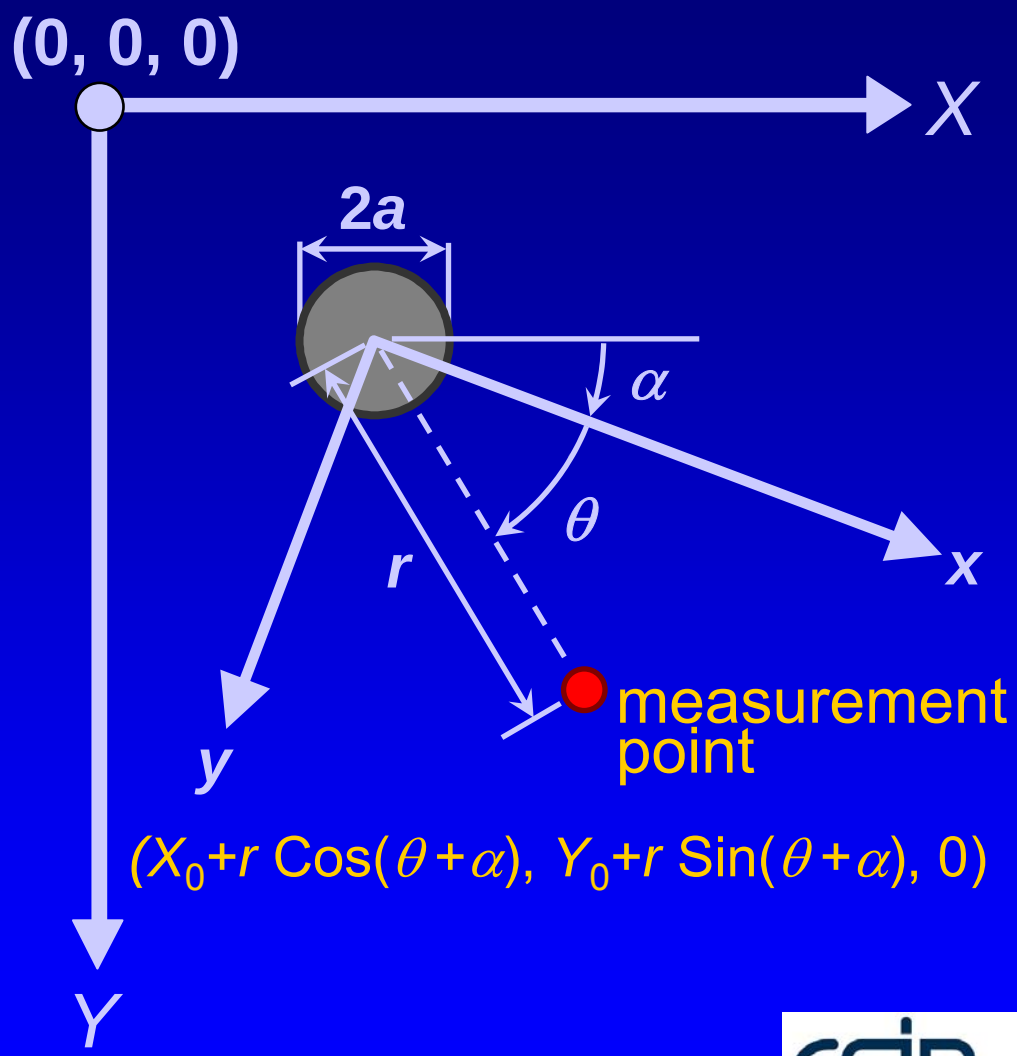
Multilayer Structural Model:





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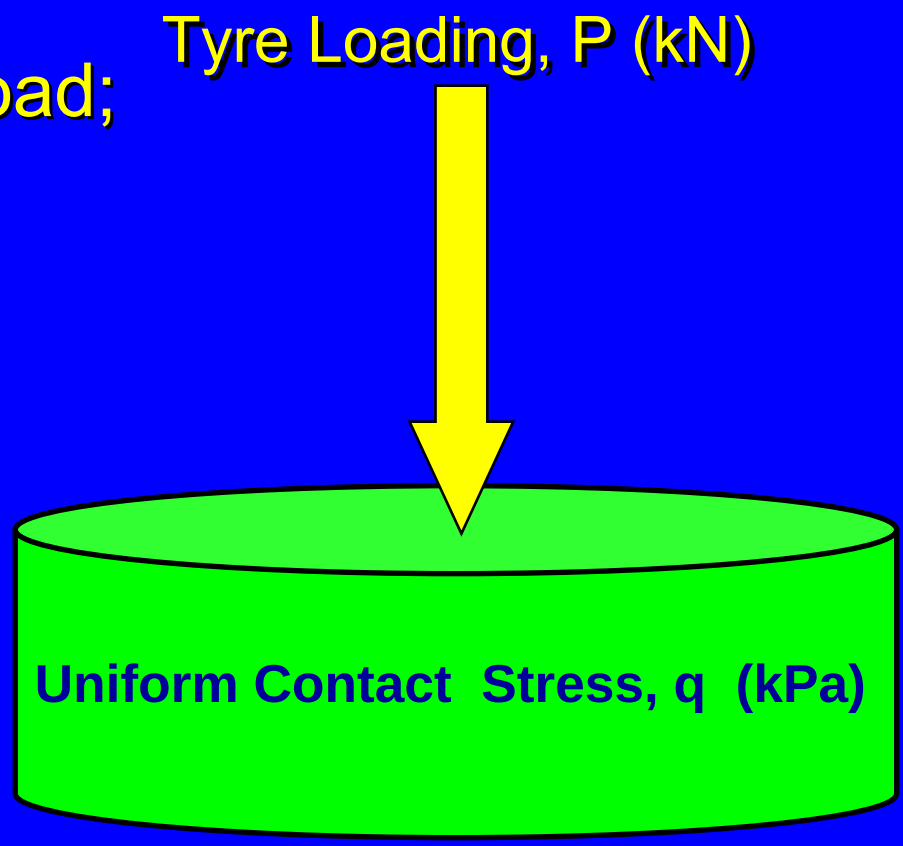
Assumption of Tyre Loading - Pavement Design Modeling:

- Circular;
- Variable Vertical load;
- Variable pressure,

but UNIFORM &
No Shear Forces
included.



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SIM systems..

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

Controlled Field Tests with HVS…on R80 route.

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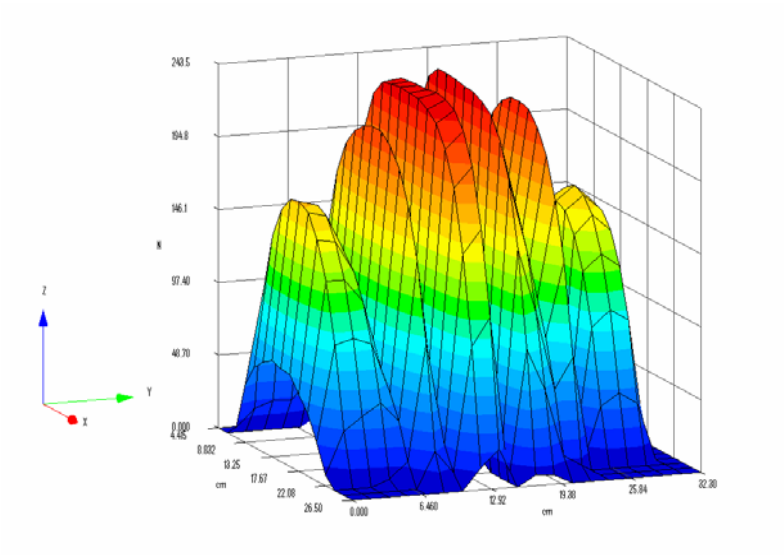
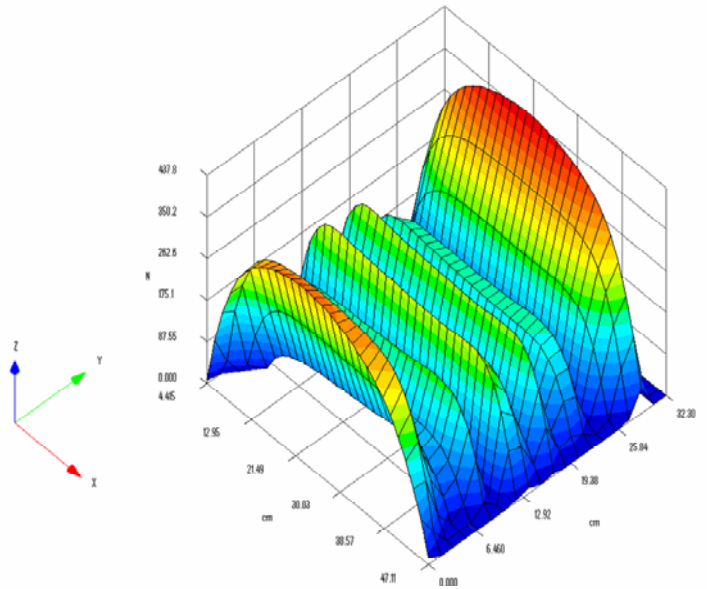
Wide Base Single Tyre- Input Data: Vertical Stress Patterns: “n” and “m” – Shapes…



“n – Shape”



“m – Shape”

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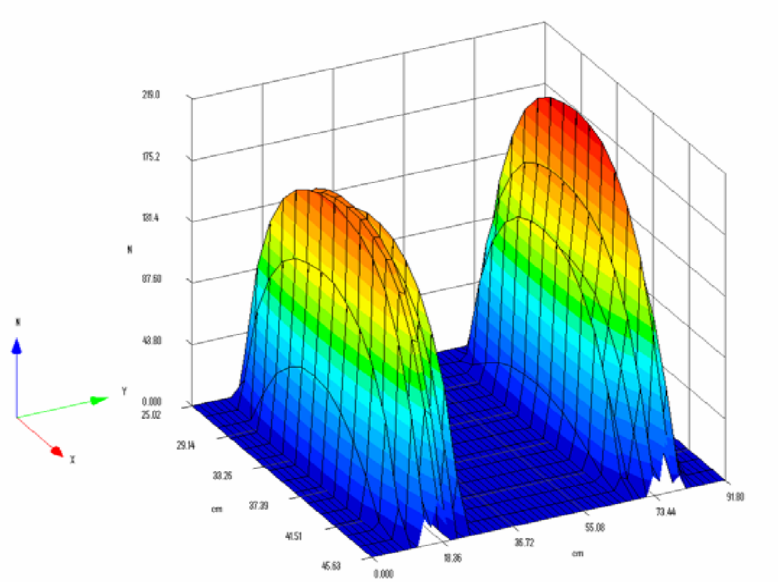
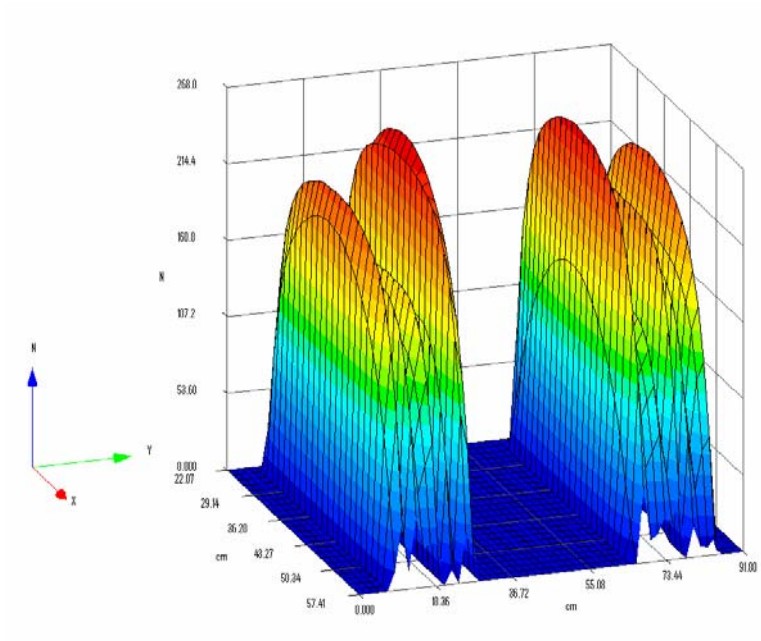
Wide Base Single Tyre- Input Data: Vertical Stress Patterns: “n” and “m” – Shapes…



“n – Shape”



“m – Shape”

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

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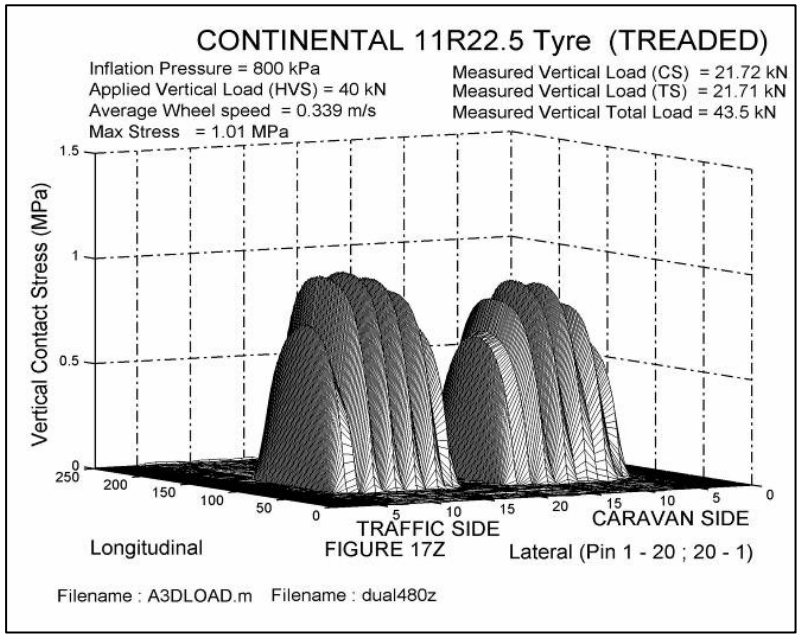
Vertical Tyre Stress: “n-Shape” tyre stress results in “n-Shape” rutting in asphalt overlay..



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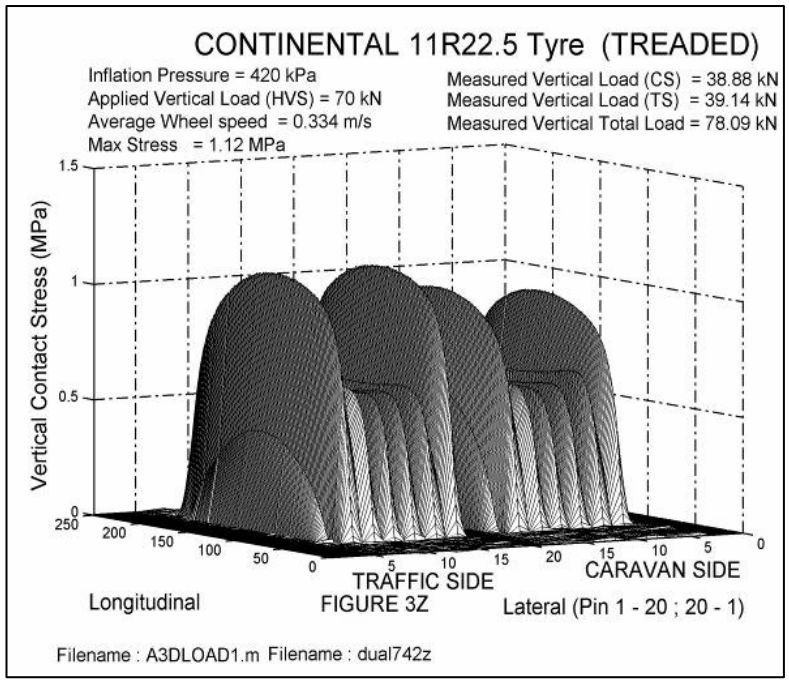
Vertical Tyre Stress: “m-Shape” stress result in “m-Shape” rutting in asphalt overlay..



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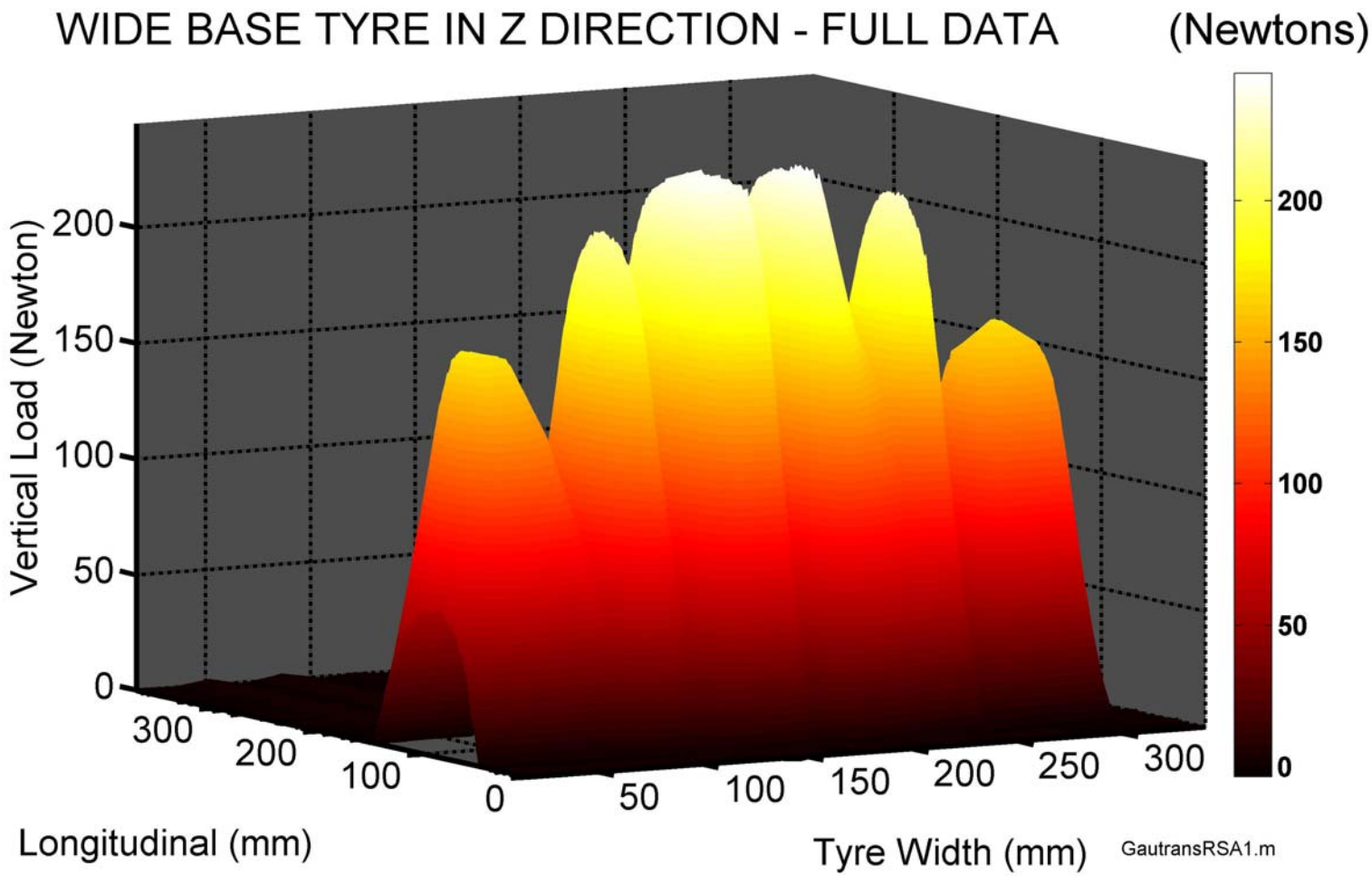
Vertical Tyre Stress: “n-Shape” tyre stress distribution



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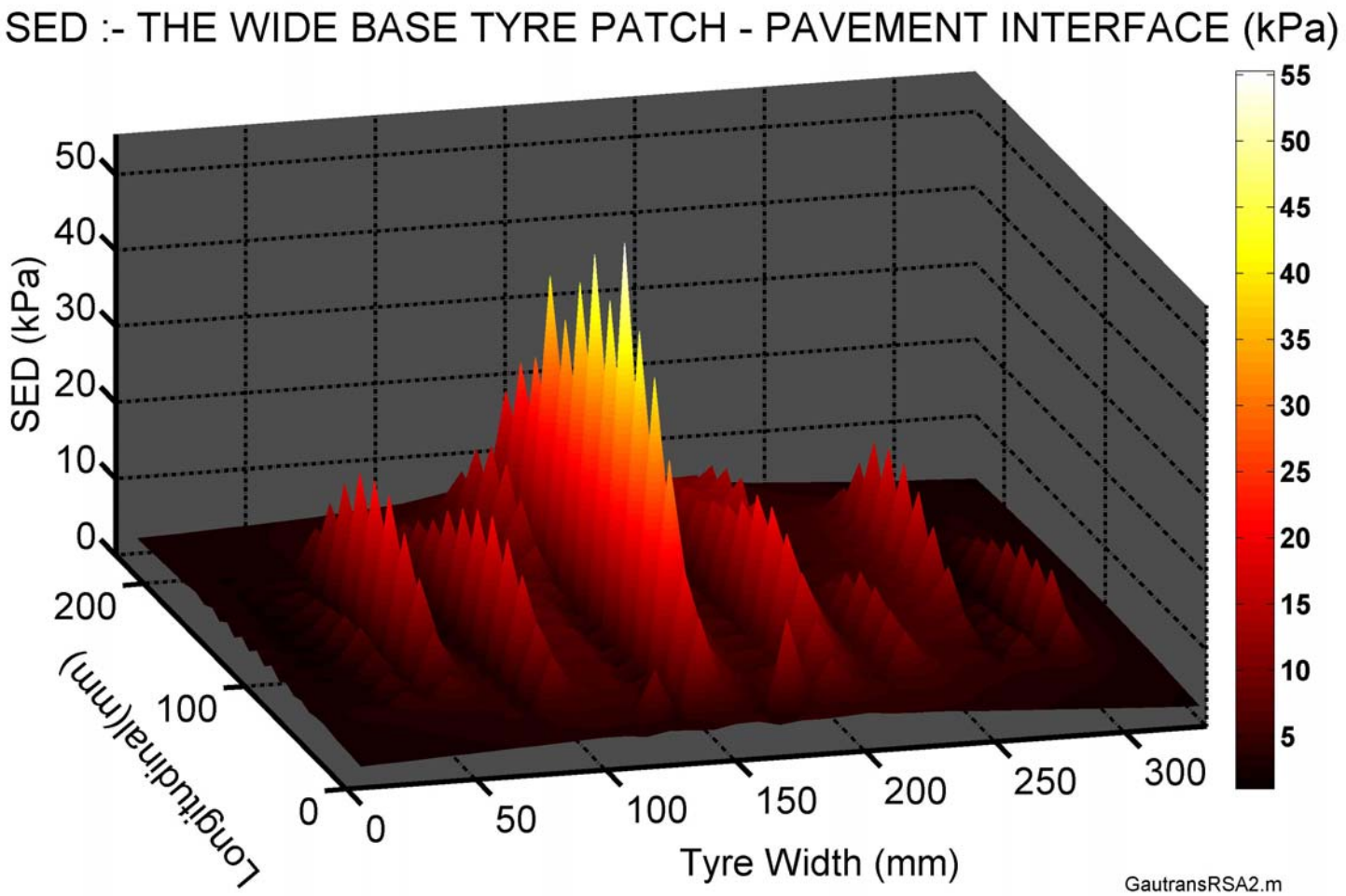
Strain Energy of Distortion (SED) on road surface: From “n” – Shape single tyre stress…



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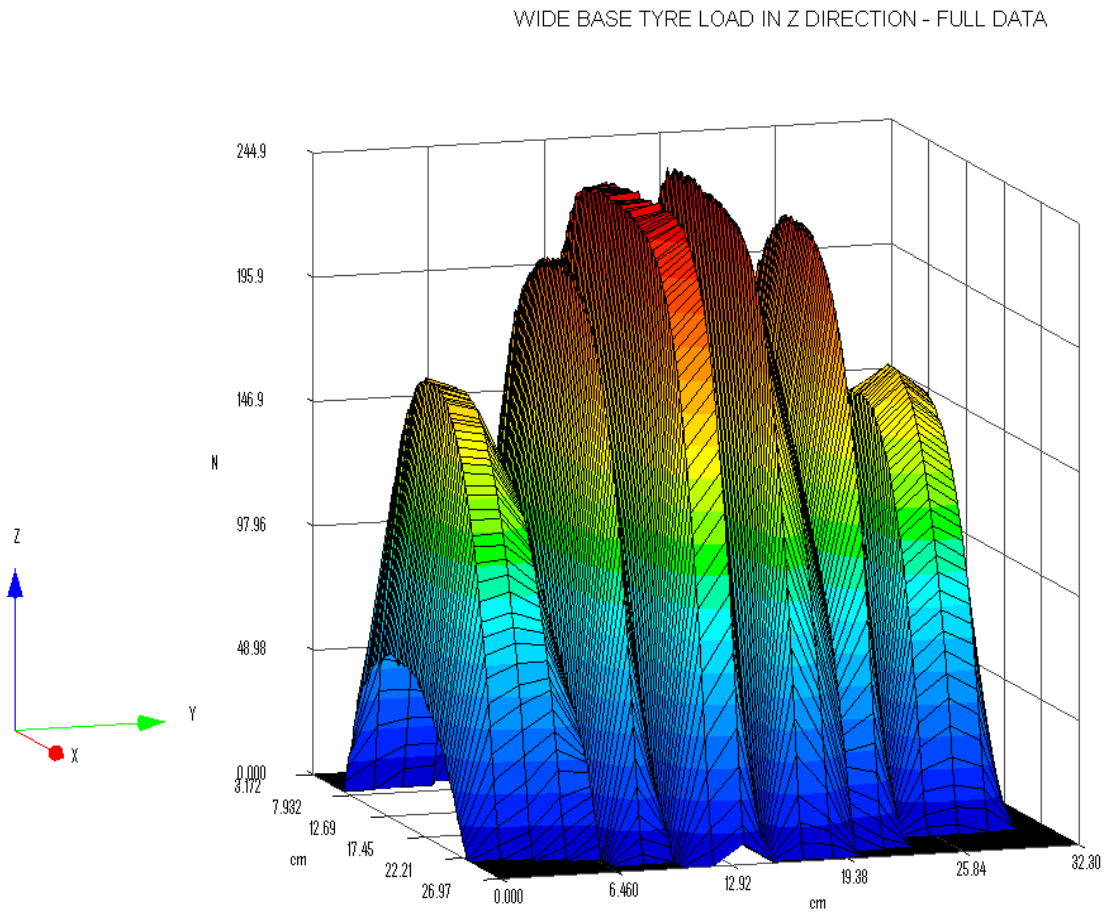
Vertical Tyre Stress: “n-Shape” tyre stress distribution.



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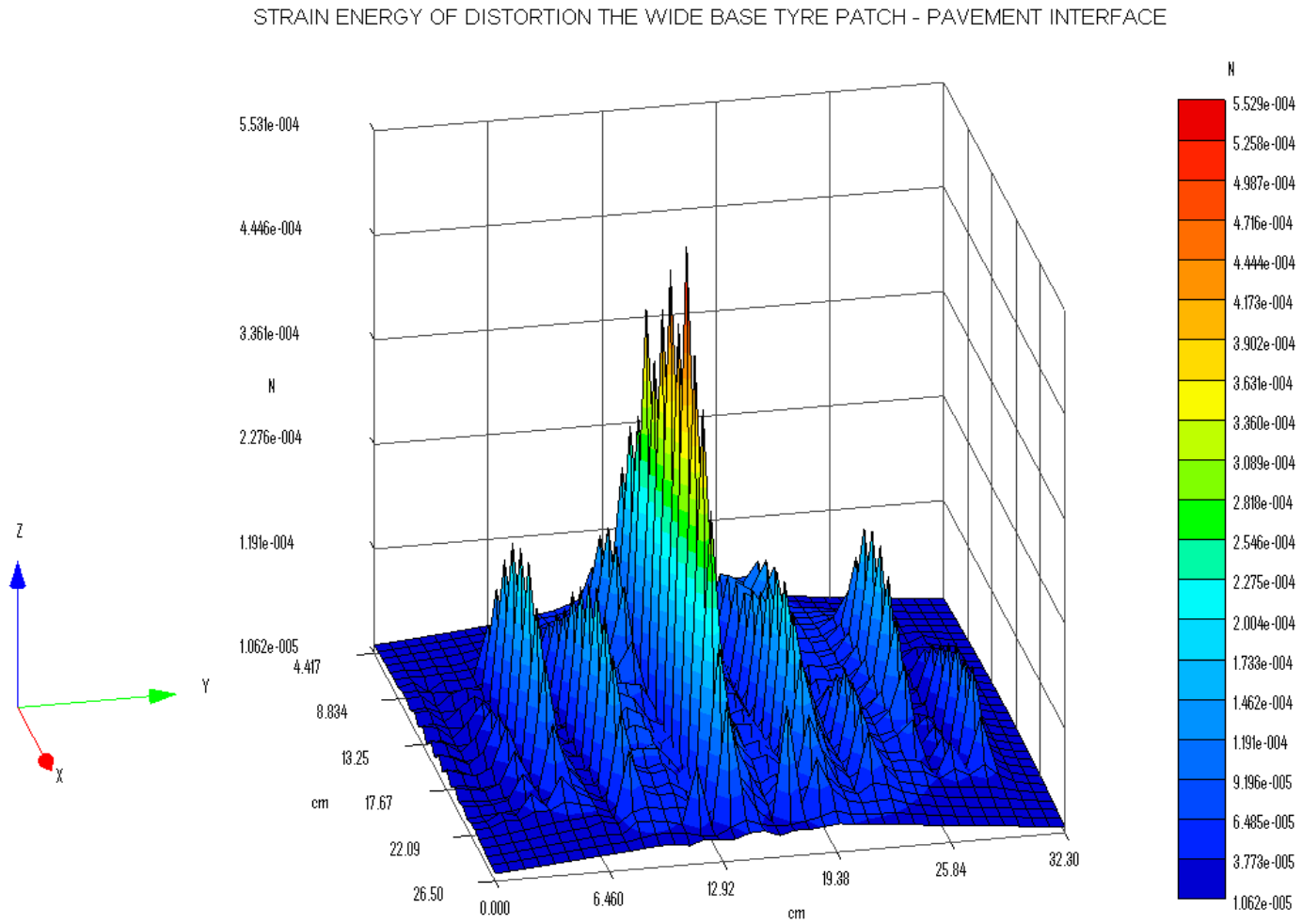
Road Surface: Strain Energy of Distortion (SED) – from "n – Shape" single tyre stress…



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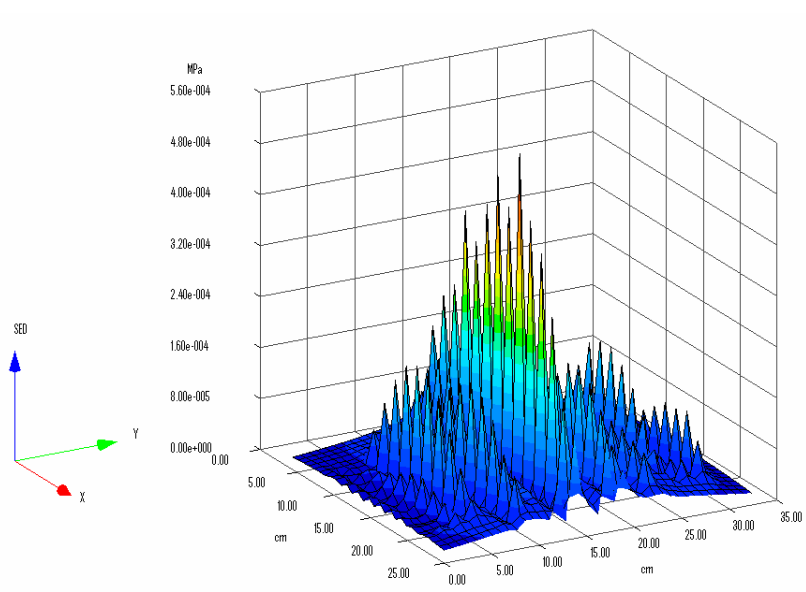
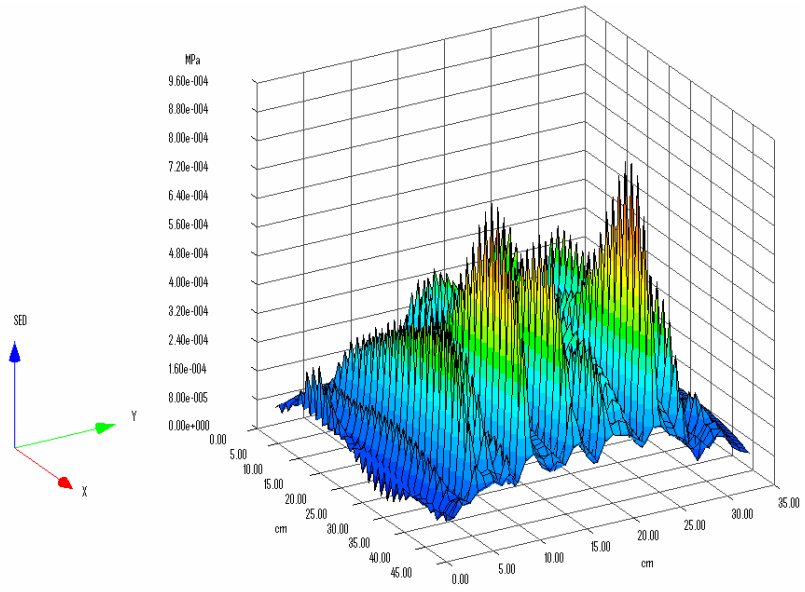
Road Surface: Strain Energy of Distortion (SED) – from “n – Shape” single tyre stress…





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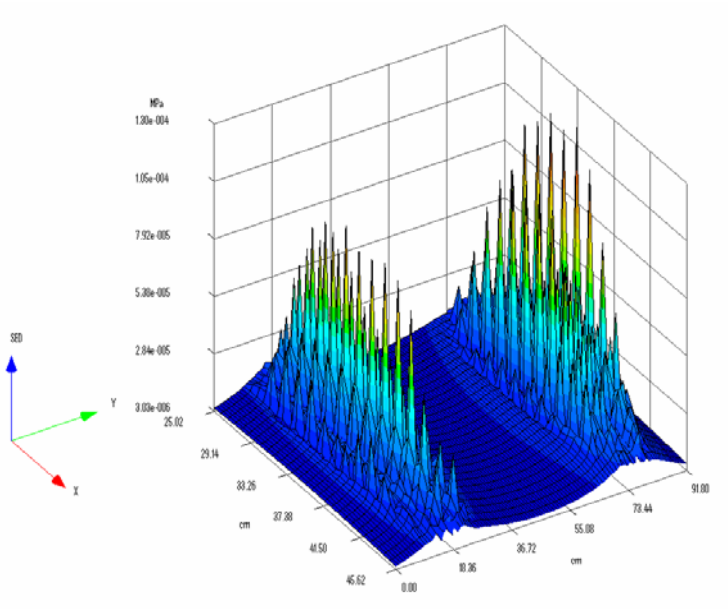
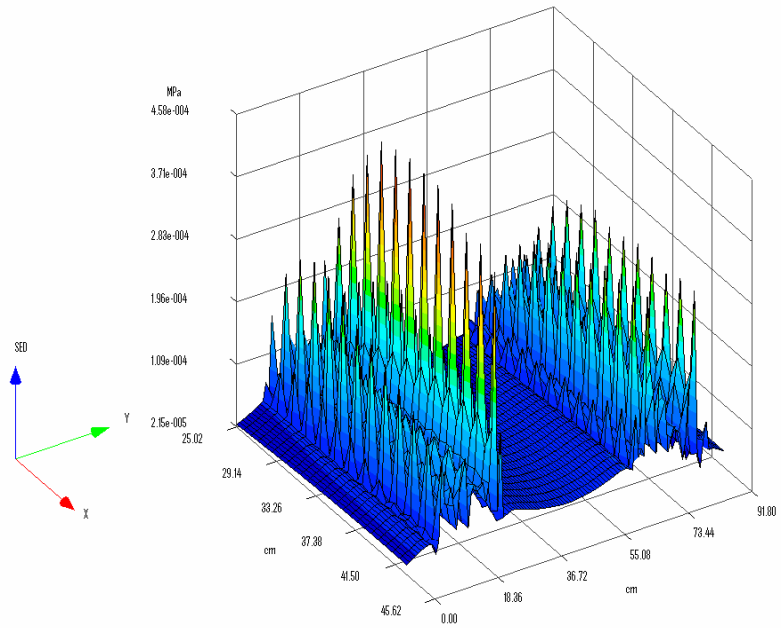
Strain Energy of Distortion (SED)- “n” and ”m – Shape” - dual tyres……





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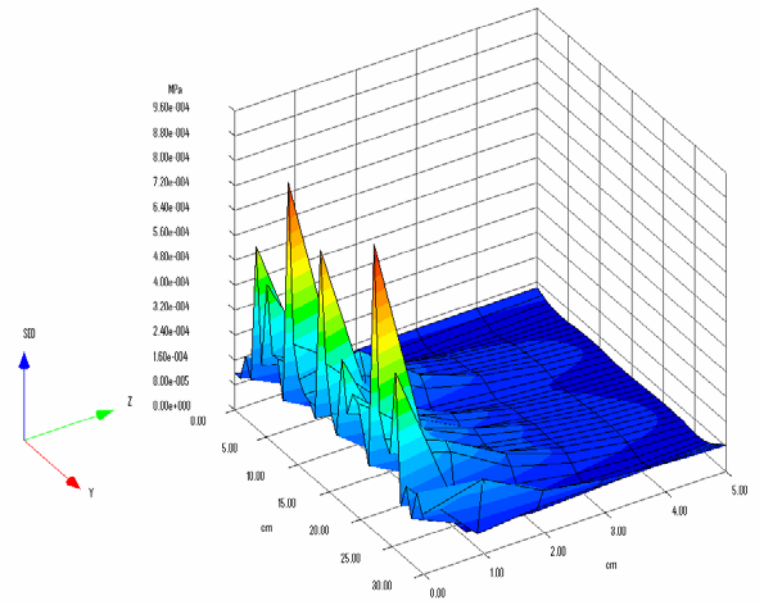
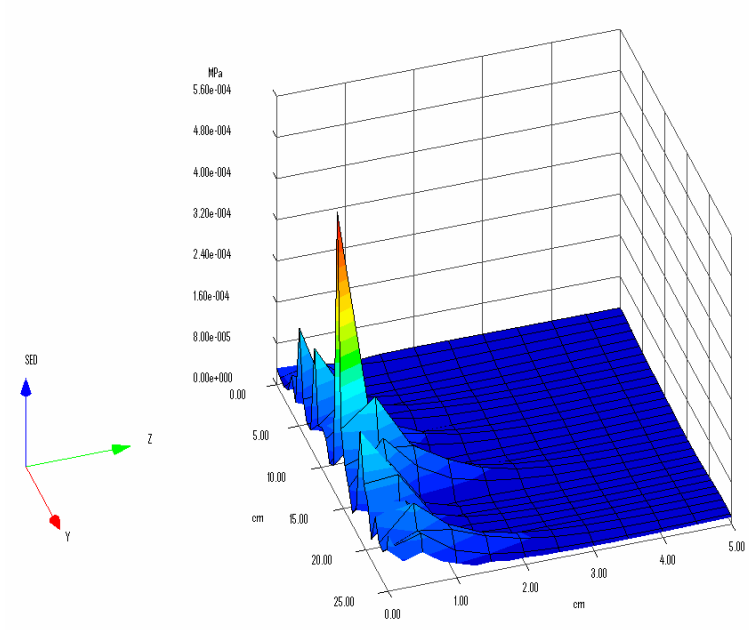
Strain Energy of Distortion (SED) – Dissipation with road pavement depth…





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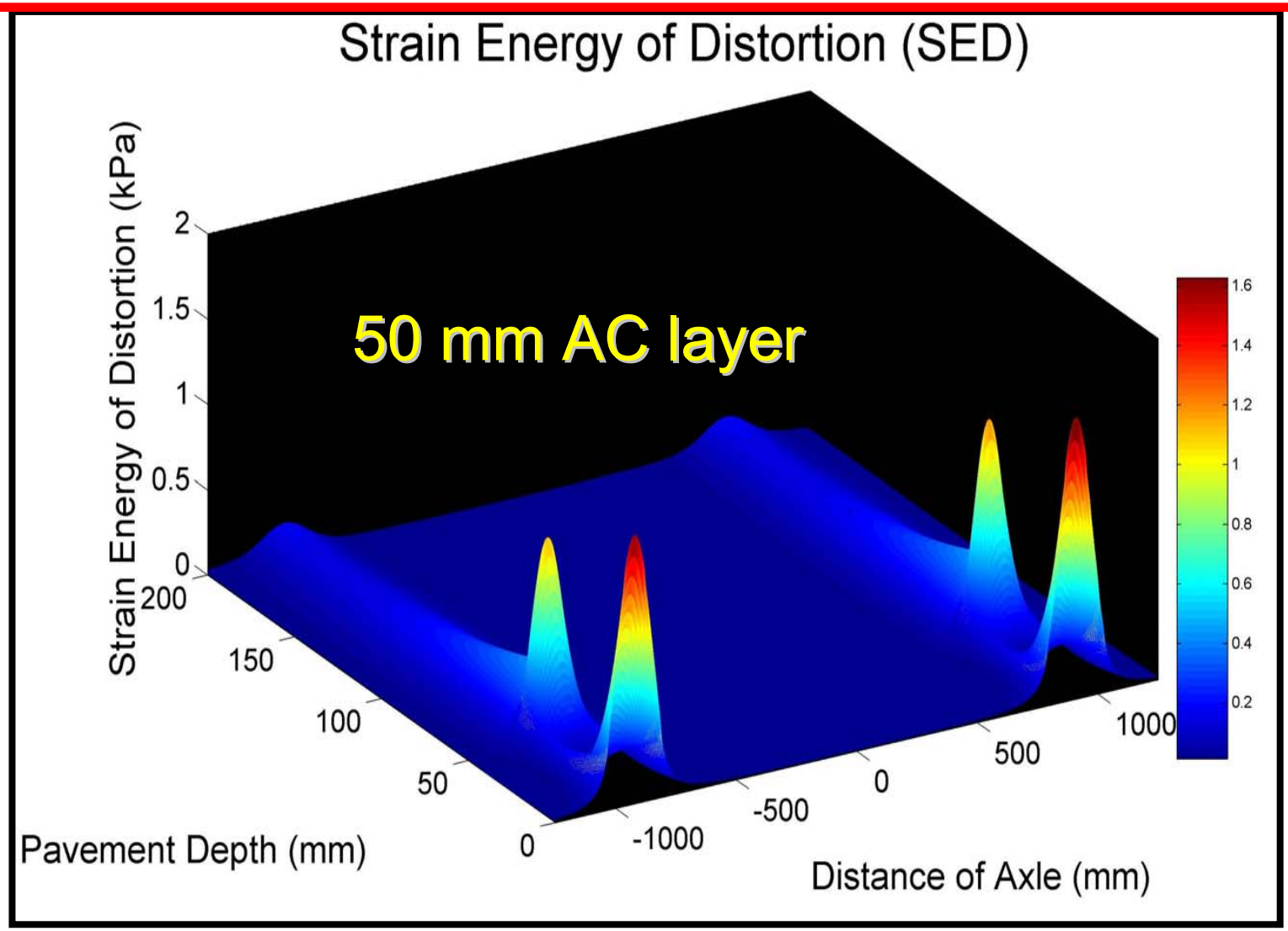
1 x Truck - 30 Tyres: 1 mm x 1 mm resolution – 500k points – SED under Steering Axle ……



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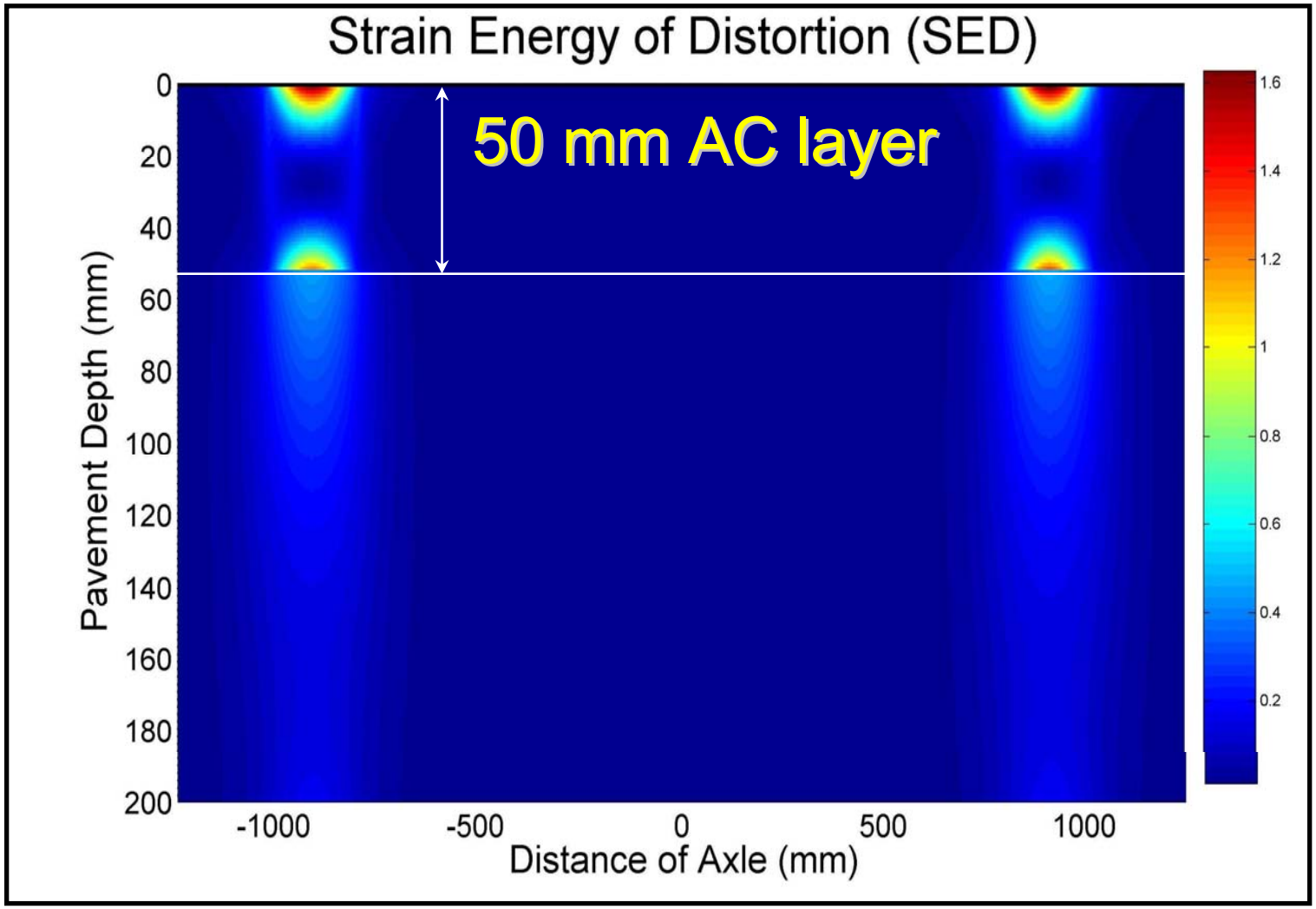
…SED under Steering Axle



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Summary, Conclusions (1):

- South African Roads, Trucks @ Road Damage – real cause of concern;
- Tyre Studies with Heavy Vehicle Simulator (HVS);
- Successful Demonstration - Stress-In-Motion (SIM) technology;
- Analytic approach - SED shows good promise for further implementation;
- Implications for Road Surface Design and Road Preservation/Protection – Important to be implemented;
- SIM future of existing Weigh-In-Motion (WIM) ??.

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Summary, Conclusions (2):

- The concept of SED as a response parameter that quantifies road pavement's "potential for failure": seems to resonate well with the applied tyre stresses and its different shapes.
- Single wide base tyres induce more than double the potential for failure compared with the dual tyre configuration on the same road pavement.
- Under-inflated-heavily-loaded tyres may cause more damage on the surface of the road compared to correctly inflated tyres.
- The combination of SIM technology and SED from numerical modelling may be used to identify areas of high potential for failure on the road pavement system.

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Conclusions- based on SED Evaluation:…

- Depending on the shape of the vertical contact stress distribution, the damaging effect in terms of SED of the single tyre appears to be 2.0 to 4.3 times higher than dual tyres under the same total loading.
- For both tyres, the damaging effect appears to be between 1.7 and 3.5 higher for the m-shape contact stress distribution.
- The top 5 mm to 10 mm of road pavements is potentially more prone to failure (top-down cracking or rutting) than was perhaps realised in the past.

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Recommendations:

- Further research work is needed to establish if this trend of tyre type is similar for all road pavement structures in South Africa before it is safe to argue against the use of single tyres vs dual tyres or make recommendation on tyre inflation pressure for HVs.
- Implementing concept of SED in road design;

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Thank You for listening today……any Questions ?

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