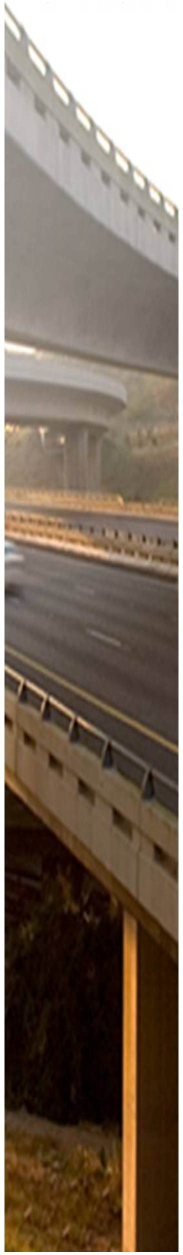

18th RPF

ROAD PAVEMENTS FORUM (RPF)
EIGHTEENTH MEETING
CSIR INTERNATIONAL CONFERENCE CENTRE, PRETORIA
Wednesday NOVEMBER 11, 2009

Integration of Vehicle Tyre - Pavement Contact Stress Data in the South African Pavement Design Method (SAPDM)

Presenter: M De Beer

CSIR
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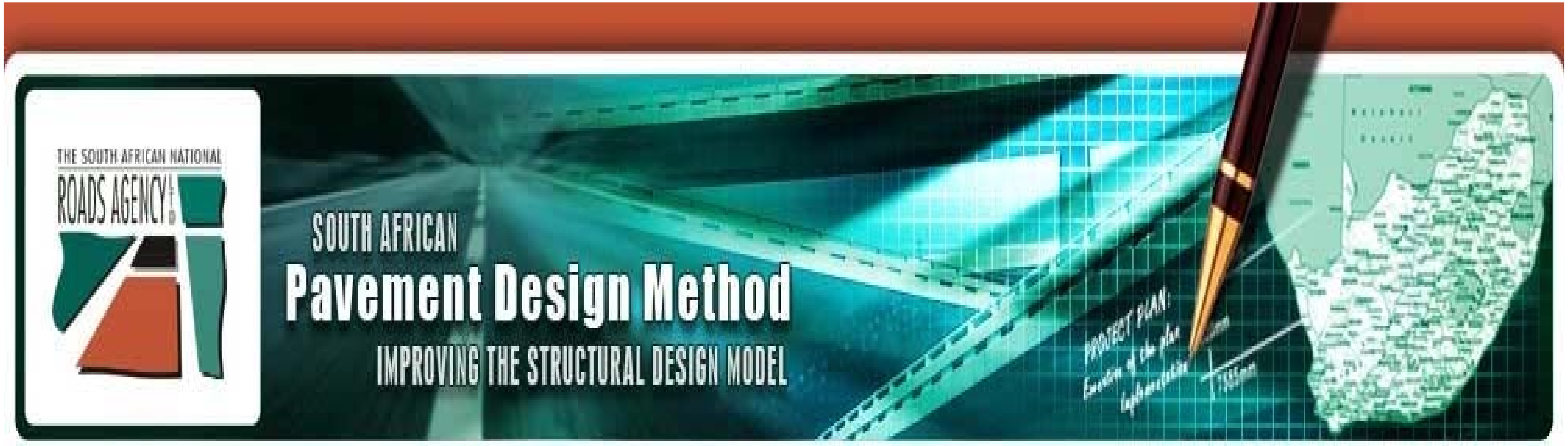

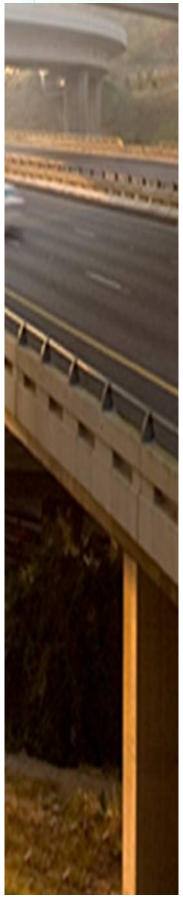

W.I.P on:

Integration of Vehicle-Pavement Contact Stress (Tyre) Data in SAPDM

Tyre-Contact Stress Information System (T-CSIS)

[not SAPEM !]

South African National Roads Agency Ltd. (SANRAL)

Council for Scientific and Industrial Research

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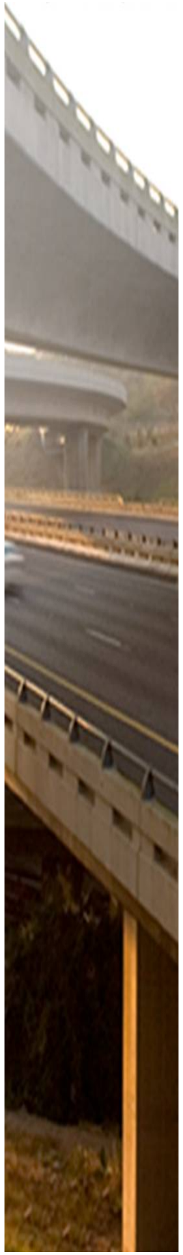

Basic Layout of Presentation:

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- Background on SAPDM-A-1;
  - Part of Probabilistic Design methodology;
  - Project A-1: ...Tyre Contact Stress (..Is not equal to Tyre Inflation Pressure (TiP)) !;
  - New tyre Models;
- Project C-1: Mechanistic Analysis ..improved tyre models..(..."GiGo");
- Tyre Inflation Pressure (TiP) and Tyre Contact Stress;
- Some Conclusions.

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Revision of the Flexible Pavement Design Method – Project A-1: T-CSIS

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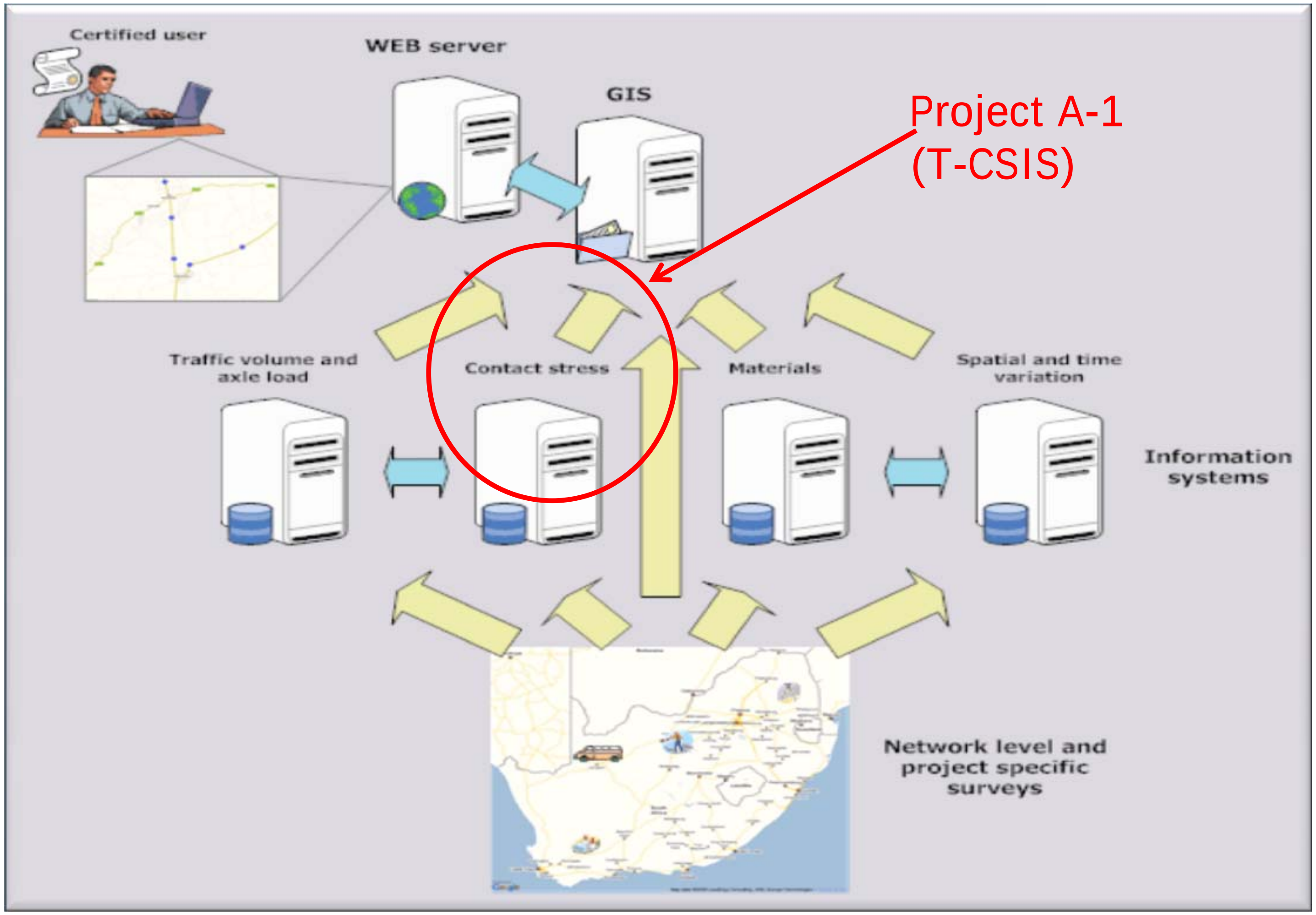
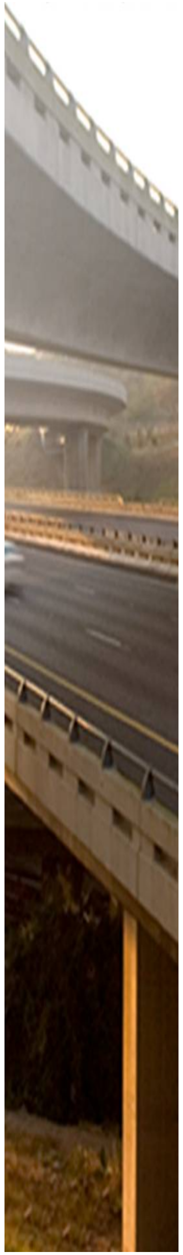
www.sapdm.co.za





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Revision of the Flexible Pavement Design Method – Project A-1: T-CSIS

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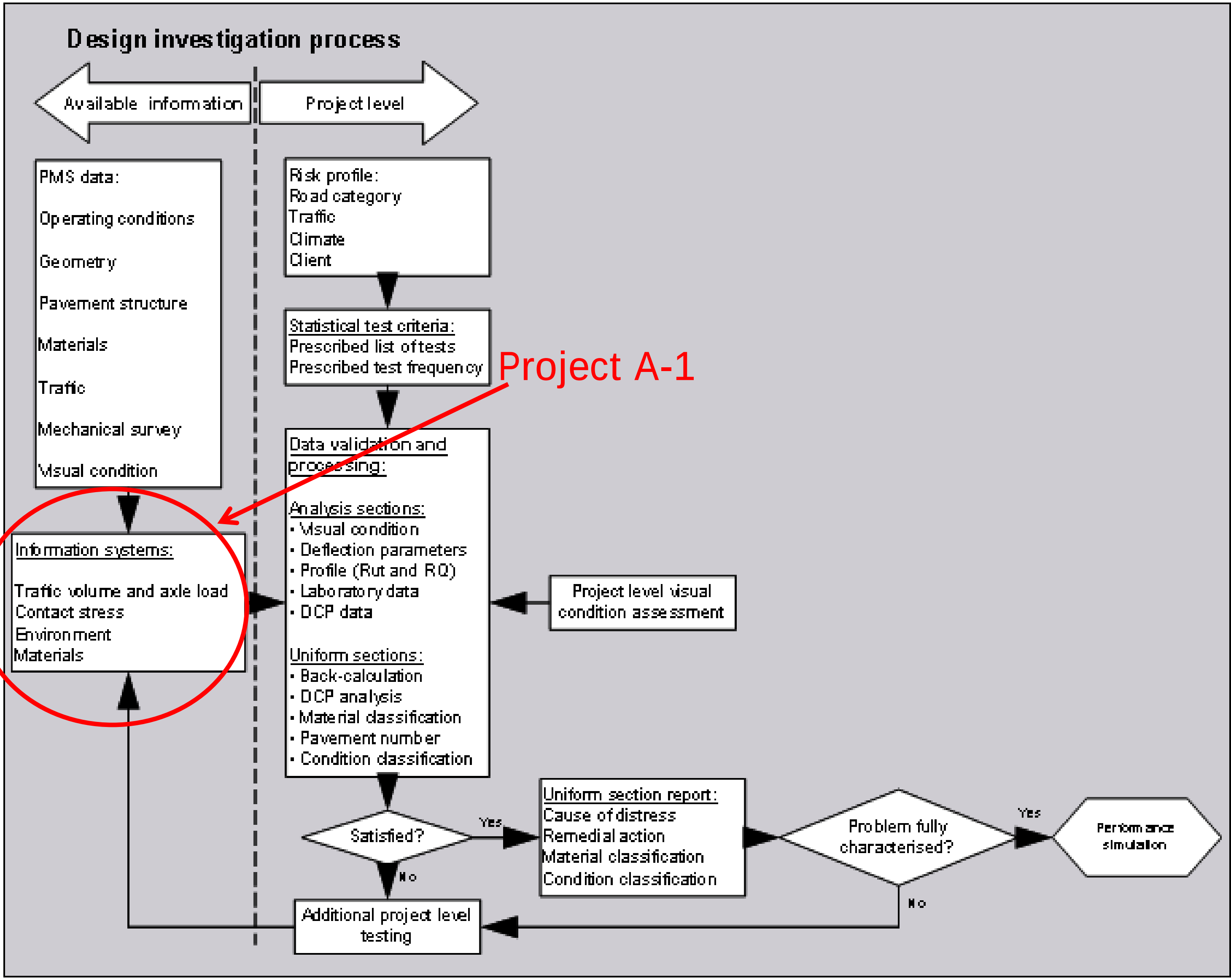

Revision of the Flexible Pavement Design Method – Project A-1: T-CSIS

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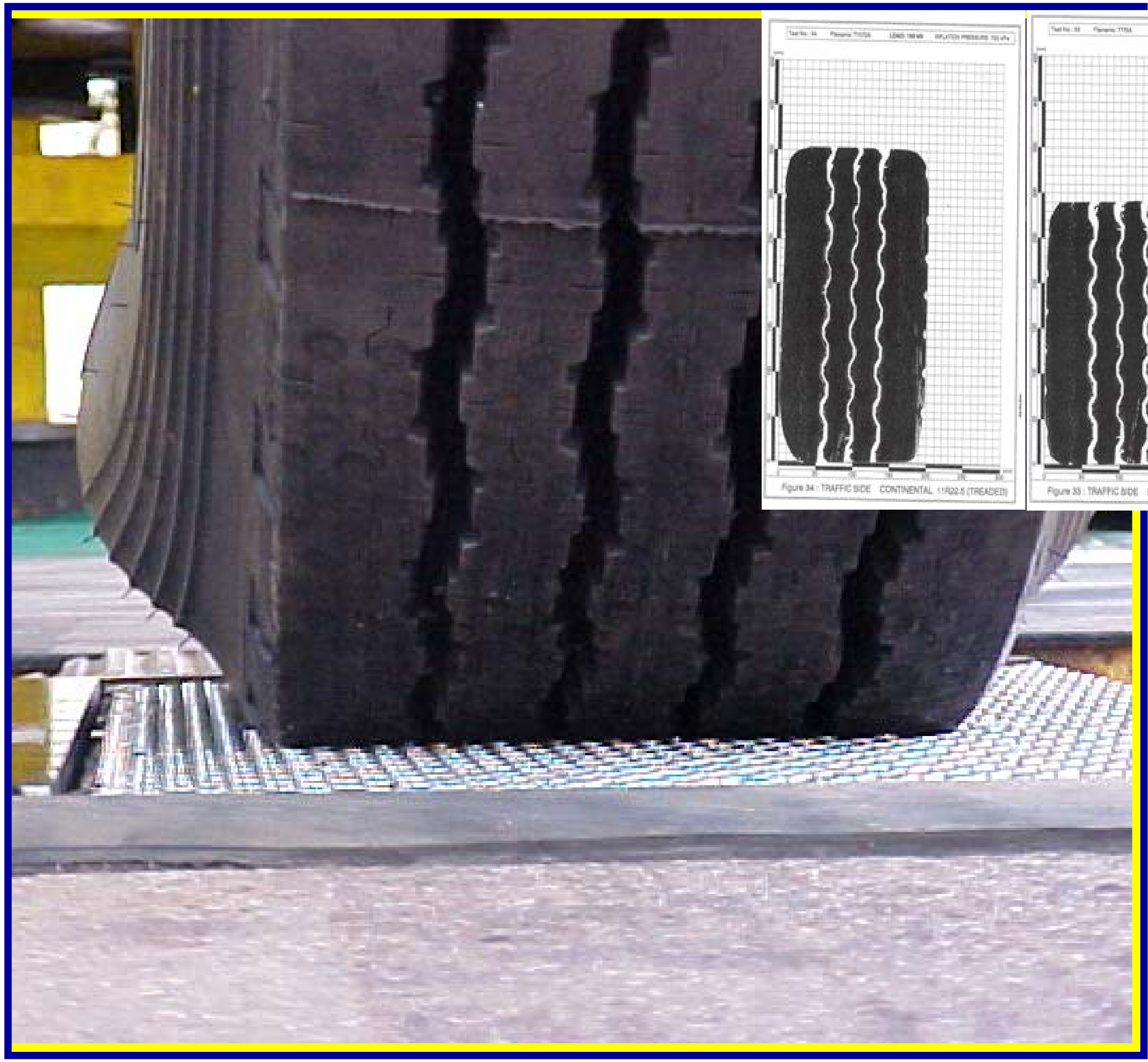
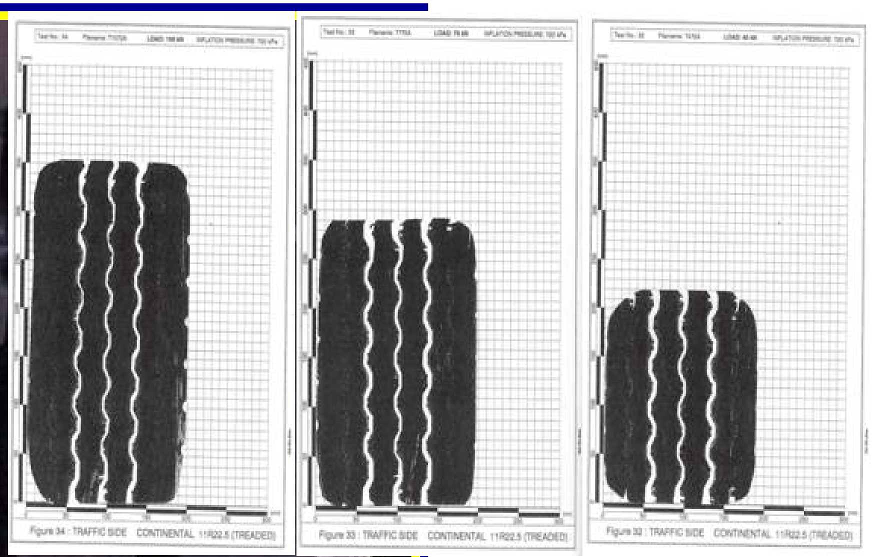
Project Management

Research area	Project title	Project number	Contractor	Project leader
Integration project	Integration of design subsystems and methodologies into an integrated design system	SAPDM/ILP	PMC	Dr H L Theyse
Pavement Performance Information System	The development and population of a pavement performance information system	SAPDM/PPIS	MAS	Dr A Hefer
Traffic demand analysis	A tyre-pavement contact stress information system	SAPDM/A-1	CSIR	Prof M de Beer
	A traffic volume and axle load information system	SAPDM/A-2	TE	Dr S C van As
	Guidelines on conducting traffic surveys and processing the data for the purpose of pavement design	SAPDM/A-3	TE	Dr S C van As
	The effects of vehicle dynamics and vehicle speed on traffic input to the design method	SAPDM/A-4	CSIR	Prof W Steyn
Material resilient response models	Resilient response models for unbound material	SAPDM/B-1a	PMC	Dr H L Theyse
	Resilient response models for bituminous material	SAPDM/B-1b	CSIR	Mr B Verhaeghe
	Resilient response models for stabilised material	SAPDM/B-1c	CSIR	Dr M Mgangi

TYRE LOADING & TYRE PRINTS…





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Dual Tyre: 3D-Contact Stresses

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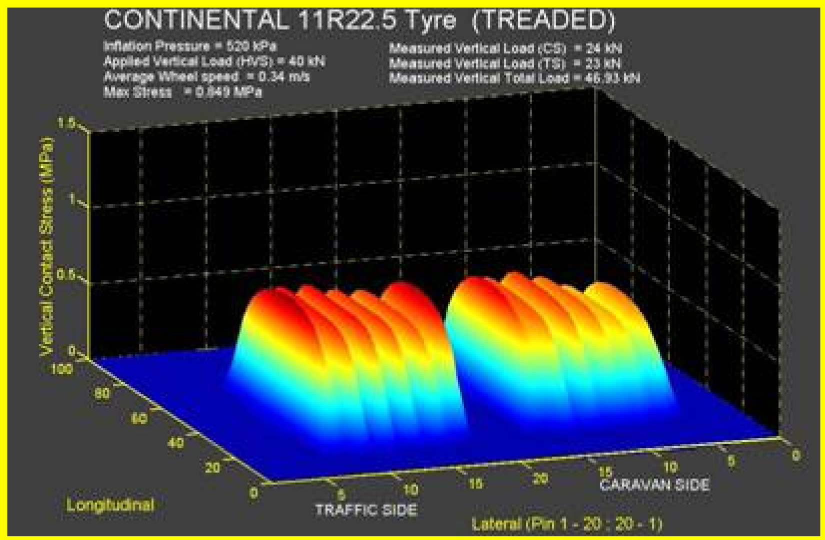
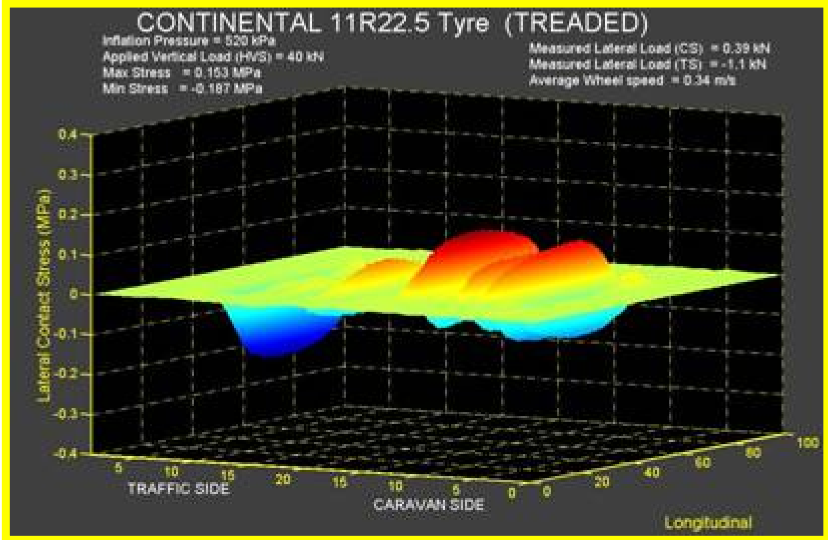
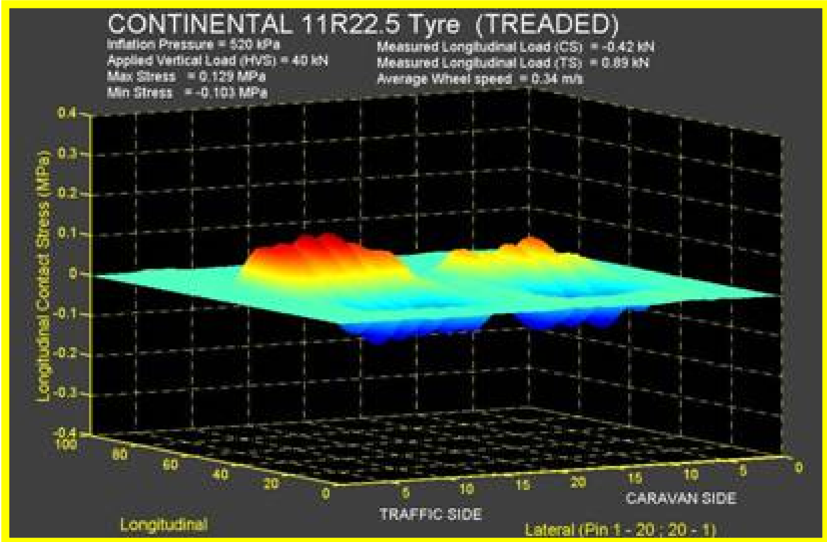




Stress Ratio: 10:3:1



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

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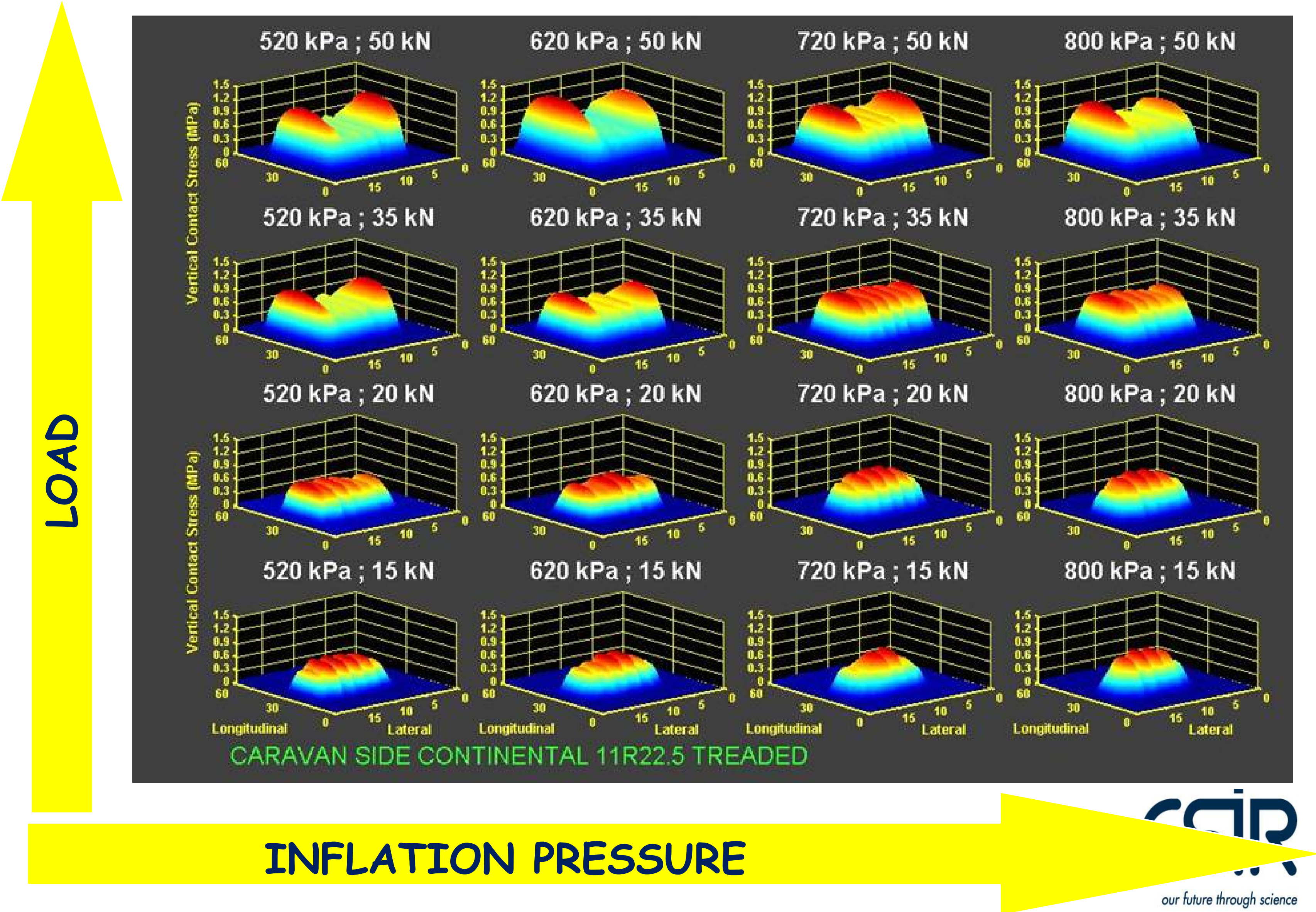

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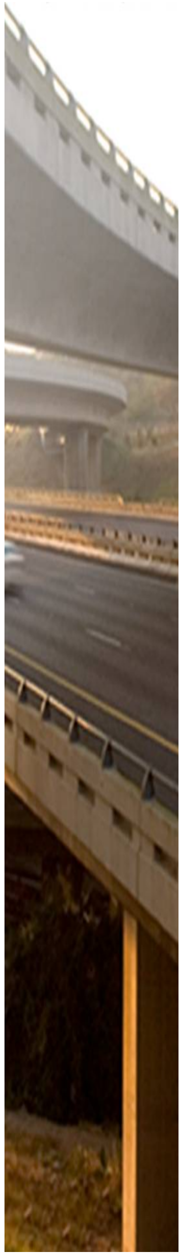

Project SAPDM/A-1: Tyre Contact Stress Information System (T-CSIS)

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..The devil is (always) in the detail…

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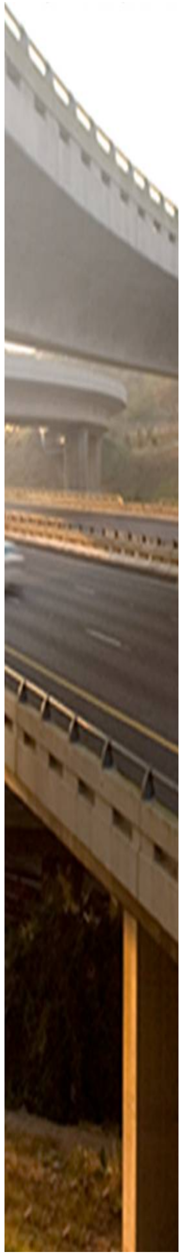
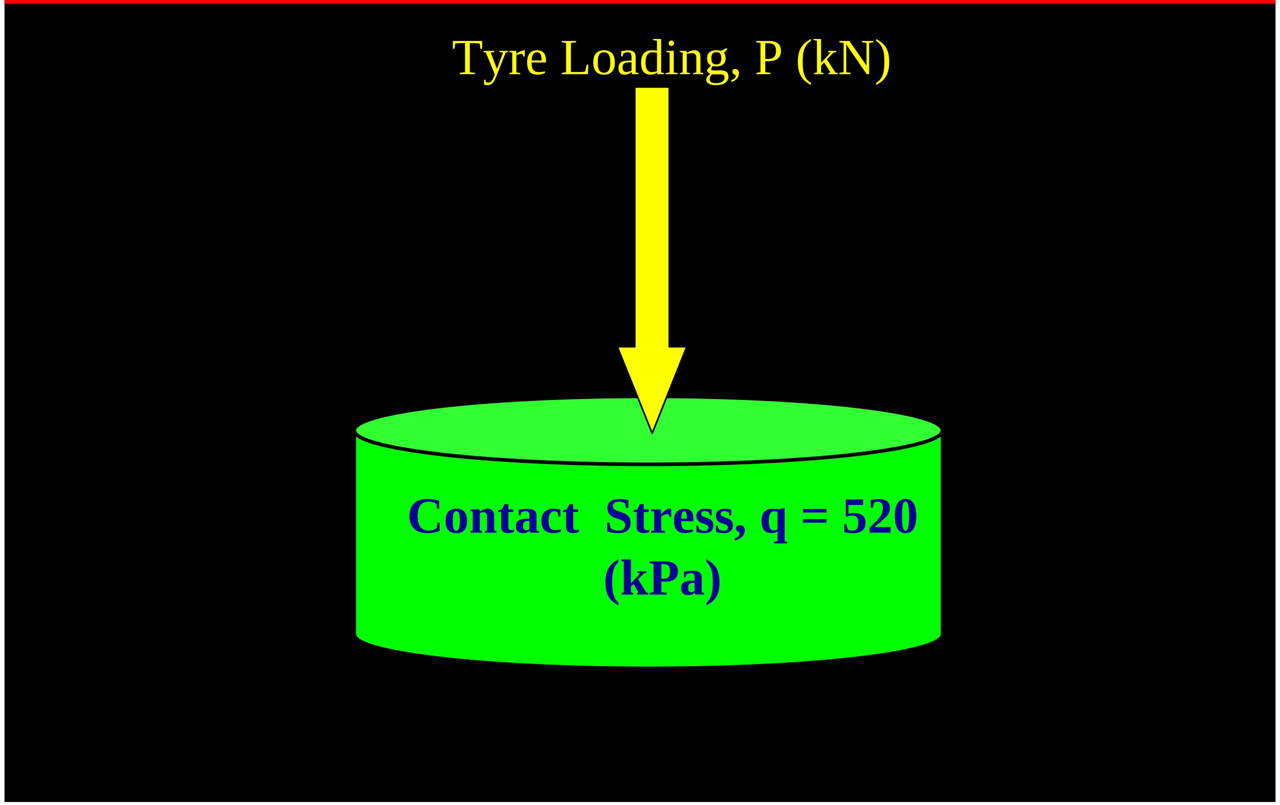
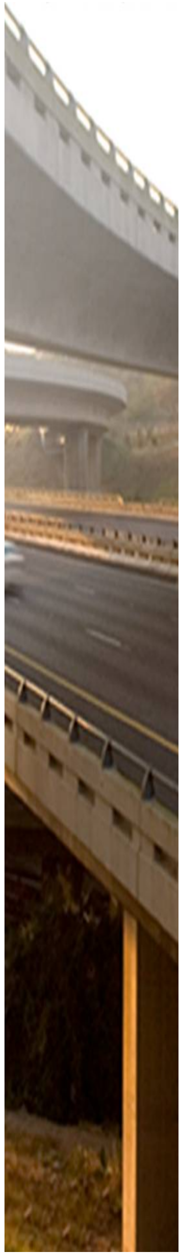
CURRENT ASSUMPTION: Uniform circular disc for tyre….z-stress only



Traditional Design Tyre Loading:
- mePADS, ELSYM, BISAR, etc.



Project SAPDM/A-1: Tyre Contact Stress Information System (T-CSIS)



- Objectives
  - Develop a "TyreStress viewer" which will eventually be the T-CSIS – See Demo;
  - Up to 10 relevant tyre types and conditions included (22 available);
  - SIM Data include measured as well as interpolated data for the non-measured cases- this is done based on a higher order (max 7th) polynomial curve fitting procedure (constants saved & used for interpolation);
  - Output of A-1: T-CSIS = Input for C-1

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Controlled SIM data (10 typical Tyres, SA) for T-CSIS

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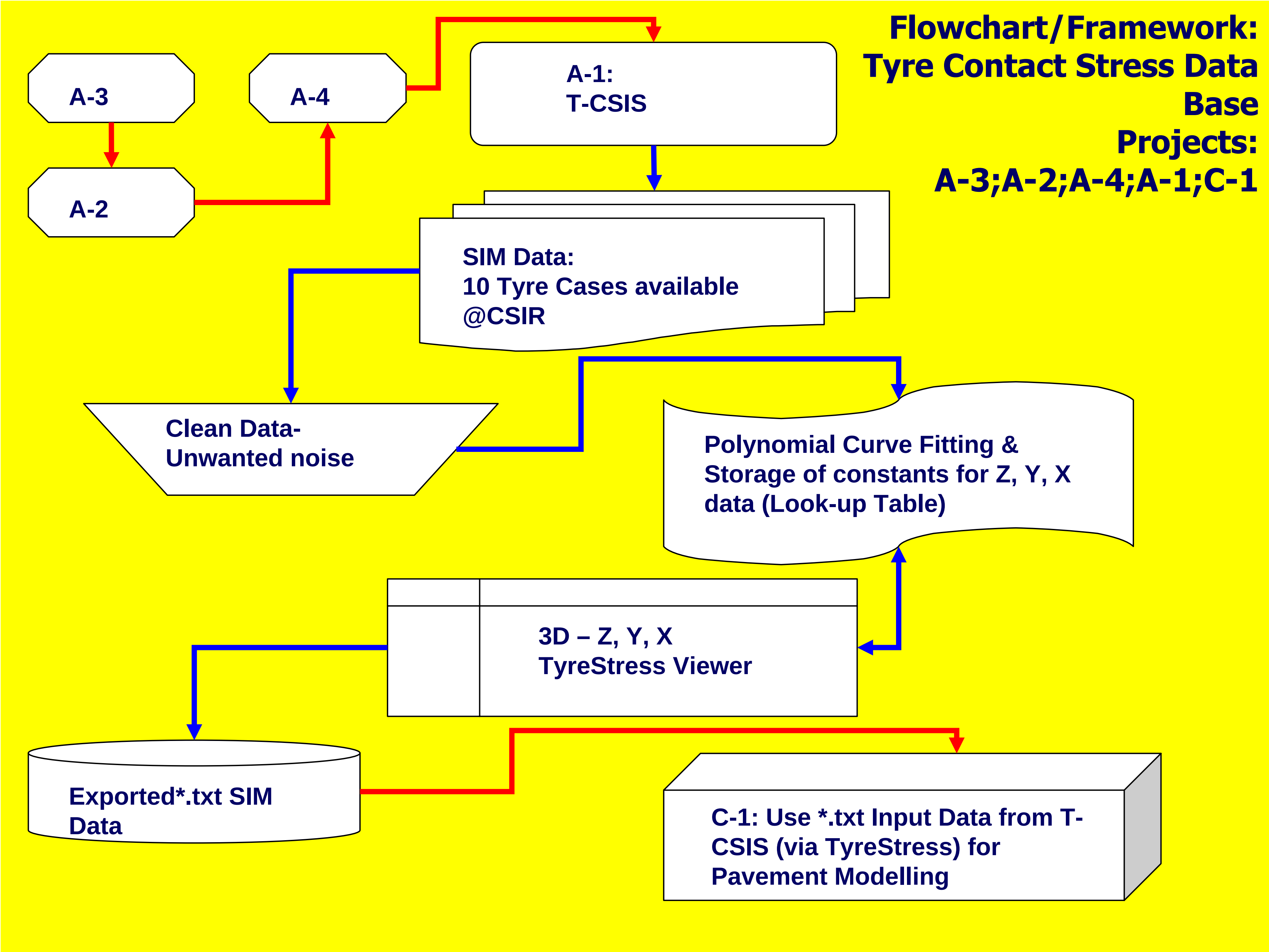
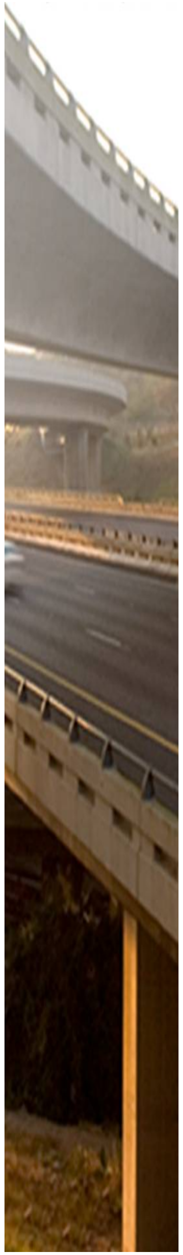
Tyre No.	Tyre Type and usage with SIM device and HVS road testing	Date of measurement	Number of X, Y, Z Data files (with repeats)	Notes
SA 01	HVS-SIM only on smooth tread: Cross-Bias 14 ply Tyre 10 x 20 (HVS up to 1994)	1994	48	SA - HVS Cross-Bias 14 Ply
SA 02	HVS-SIM & tests: Cross-Bias 14 ply Tyre 11 x 20 (HVS since 1995)	1995	357	SA - HVS Cross-Bias Ply
SA 03	HVS-SIM only: Wide Base Tyre: Goodyear 425/65 R22.5 (Radial)	1996	279	SA - HVS Radial
SA 04	HVS-SIM only: Michelin E-22.5 315/80 R22.5 (SA - SIM Only 1996)	1996	270	SA - HVS Radial
SA 05	HVS-SIM & tests: Continental 11 x R22.5 Radial (HVS since 1995)	1999	342	SA - HVS Radial
SA 06	HVS-SIM & tests: Firestone 12R22.5 G391 (Radial) (2004)	2004	546	SA - HVS Radial
SA 07	HVS-SIM & limited tests: Goodyear 315 /0 R22.5 (Radial) G391 (2004)	2004	315	SA - HVS Radial
SA 08	HVS-SIM & tests: Firestone 12R22.5 G391 (Radial) (2006)	2006	329	SA - HVS Radial
SA 09	HVS-SIM & tests: Goodrich Aircraft BF tyre (South Africa)	2006	63	SA - HVS
SA 10	HVS-SIM & limited tests: Goodyear 315/80 R22.5 (Radial) G391 (2006)	2006	609	SA - HVS Radial
			3158	



Flowchart/Framework:
Tyre Contact Stress Data Base
Projects:
A-3;A-2;A-4;A-1;C-1
A-3
A-4
A-1:
T-CSIS
A-2
SIM Data:
10 Tyre Cases available @CSIR
Clean Data-
Unwanted noise
Polynomial Curve Fitting & Storage of constants for Z, Y, X data (Look-up Table)
3D – Z, Y, X
TyreStress Viewer
Exported*.txt SIM Data
C-1: Use *.txt Input Data from T-CSIS (via TyreStress) for Pavement Modelling

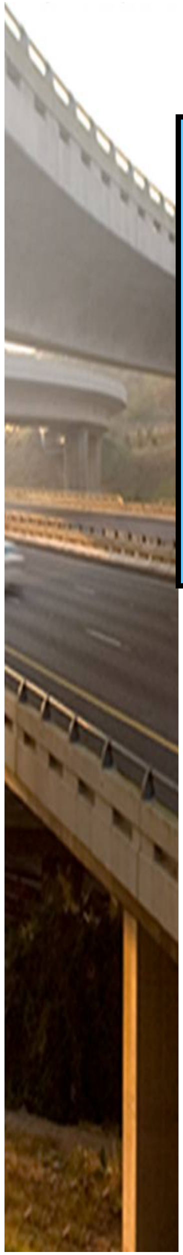


..A-1 needs to link with Project SAPDM/C-1:

Mechanistic Analysis of complex contact stress

Traffic Projects Integration Issues: A to C

18th RPF



A-3
Guidelines for Traffic survey & Processing
TMH 8:
WIM Specs
Traffic Loading
Dynamic/Static

A-2
Traffic Loading & Load Data & Vehicle Classification
TRH 16

A-4
Vehicle Dynamics

A-1
T-CSIS
(TyreStress)

√?

C-1
Modelling
(*.txt Data from TyreStress (T-CSIS)):
Static
Quasi-Dynamic
Dynamic

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Planned Current Tasks (A-1/C-1)

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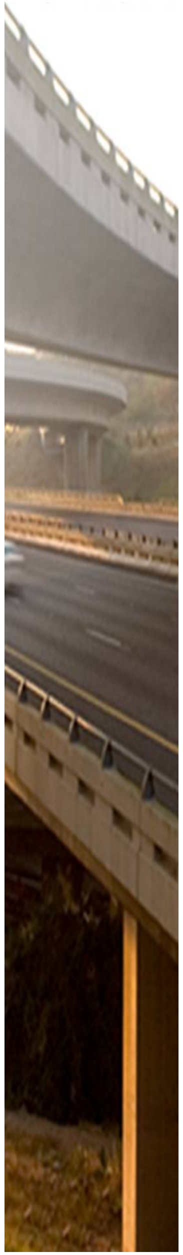
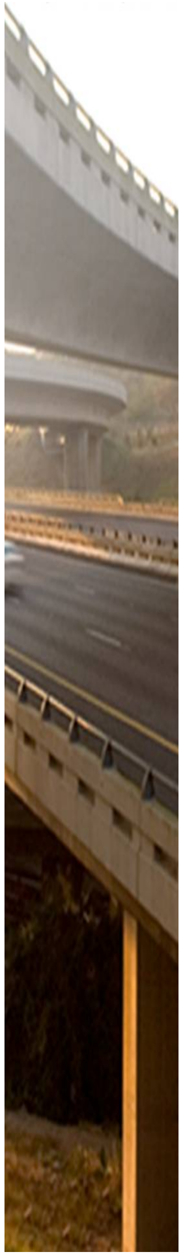


Complex contact stresses

- *Input options for data from Tyre Contact Stress Information System (T-CSIS) - Project A-1*
  - Status
    - Generate equivalent uniformly distributed contact stress using a circular shape for the tyre load – *done (TyreStress)*
    - Generate "staggered" uniformly distributed contact stress to simulate the "n" and "m" shaped contact stresses. – *under development*
    - GAMES to allow for different input options;
    - Report on the input load/stress options.

Complex Contact Stresses: 3D Data: A-1 to C-1



- Objective
  - Input options for data from Tyre Contact Stress Information System (T-CSIS) - Project A-1 *(10 truck tyre types and conditions included in Beta-TyreStress Software)*

TYRE LOADING & TYRE PRINTS…

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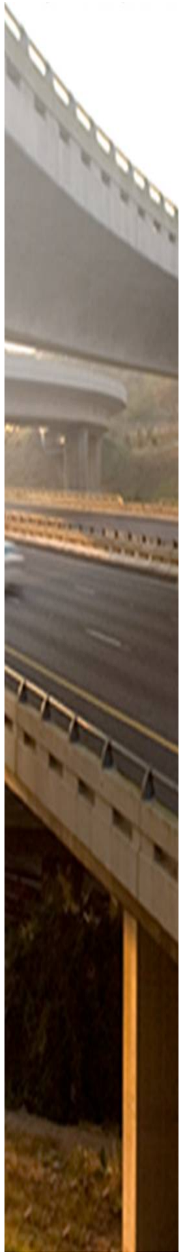

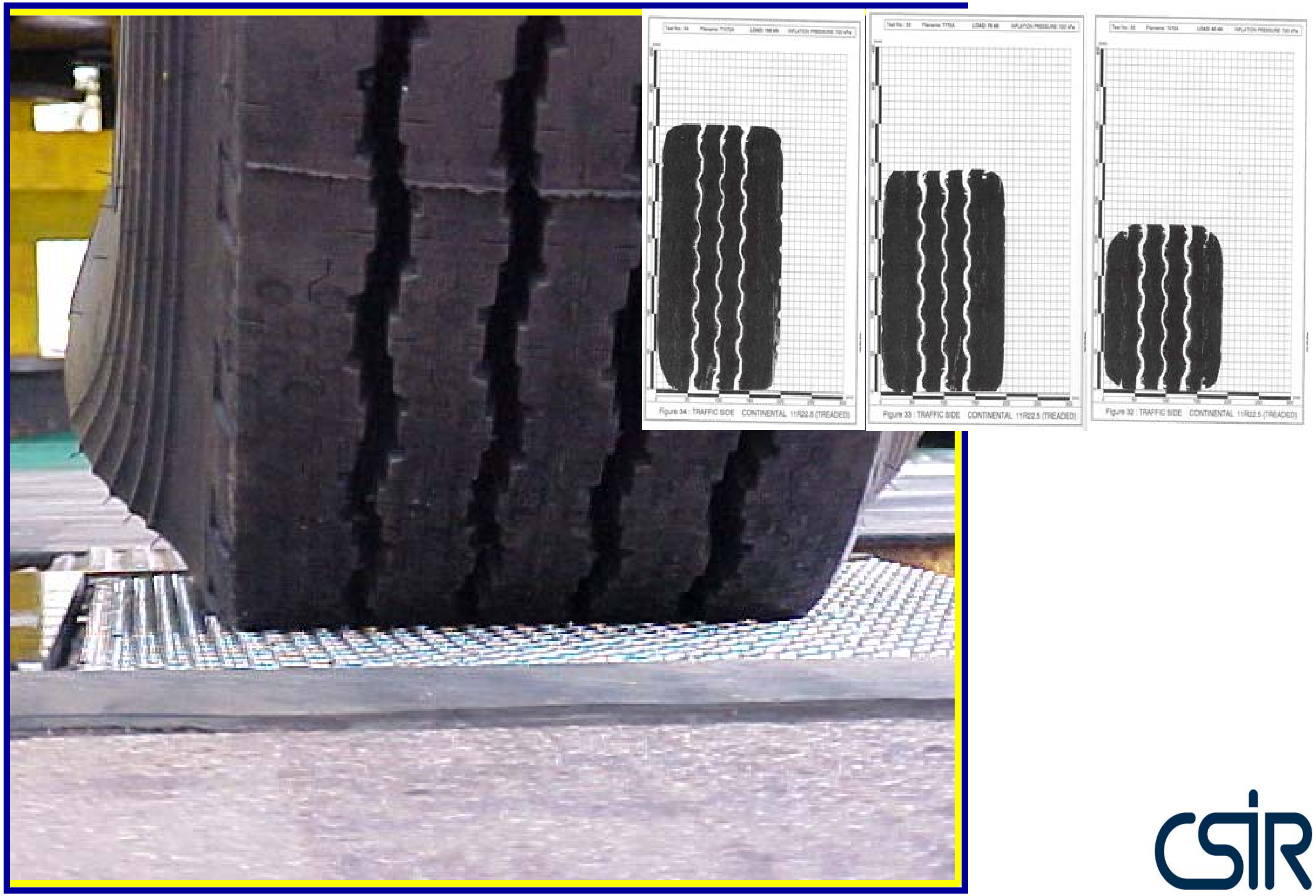

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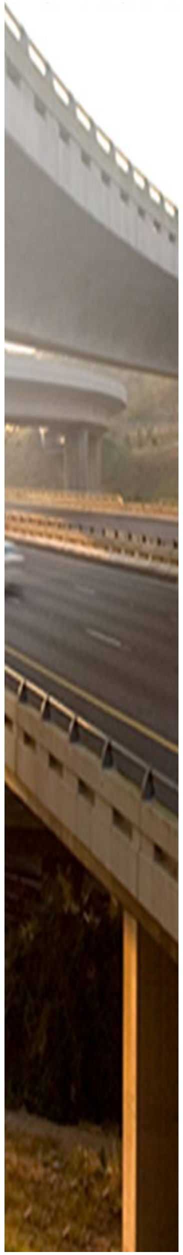
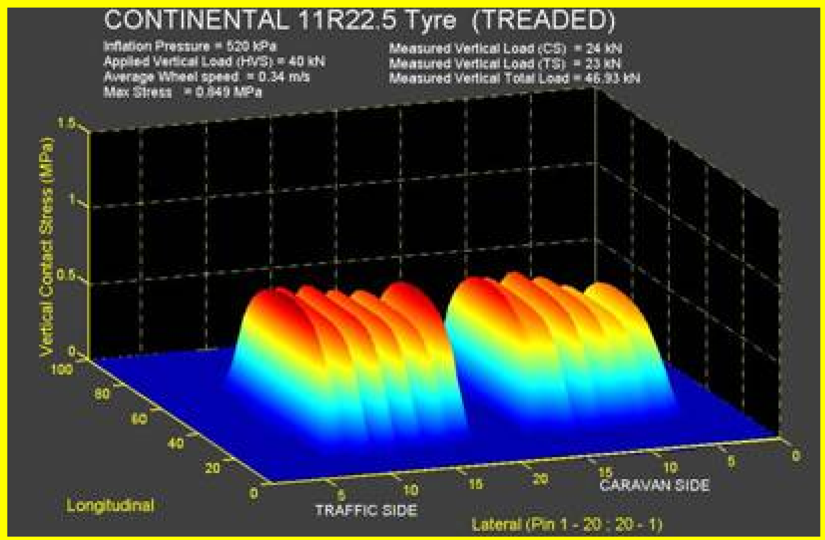
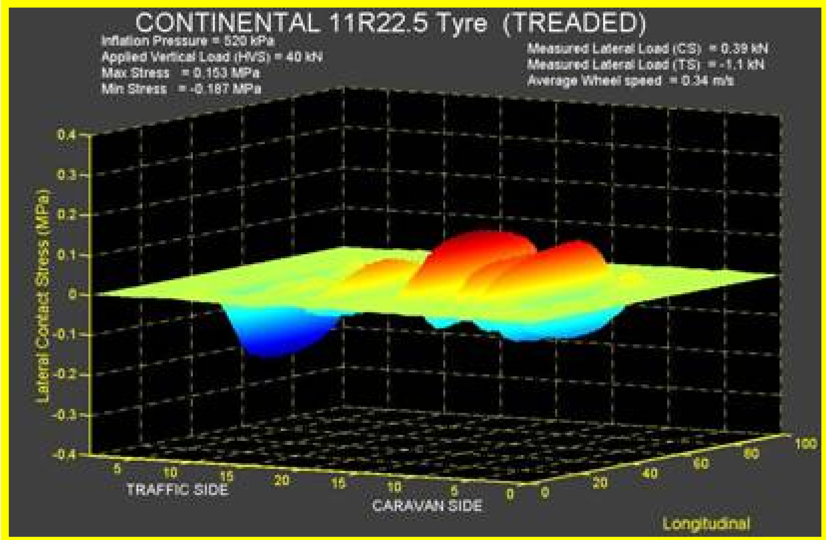
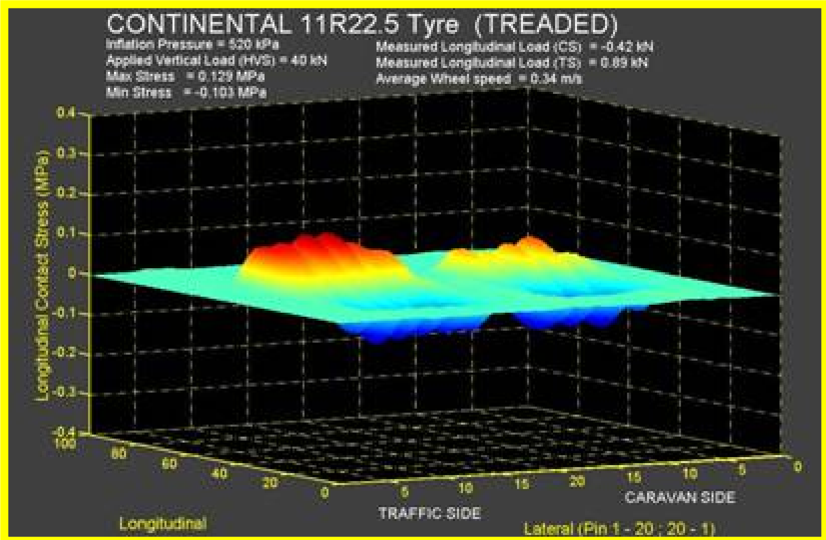
Dual Tyre: 3D-Contact Stresses: Z,Y and X







Stress Ratios: 10:3:1



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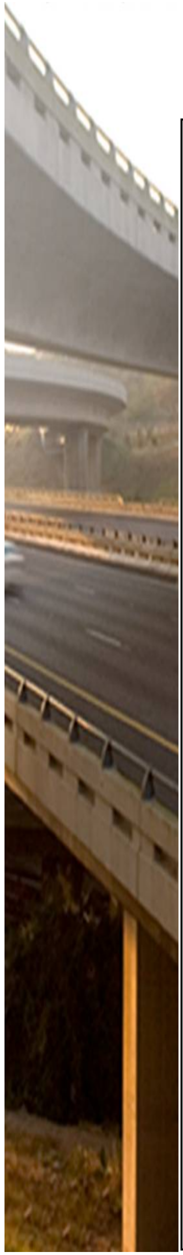


Normal 40 kN loading (80 kN Axle) on Tyres @ 520 kPa:

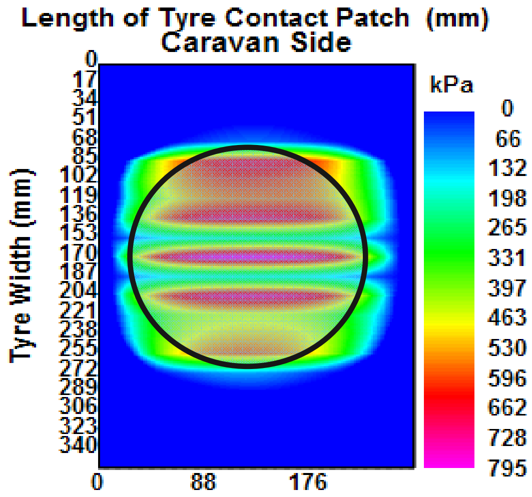
18th RPF

Firestone 12 x R22.5 G391 (SA - HVS)-2006

Direction: [⧄]
Inflation pressure: 520 (kPa)
Load per tyre: 20 (kN)

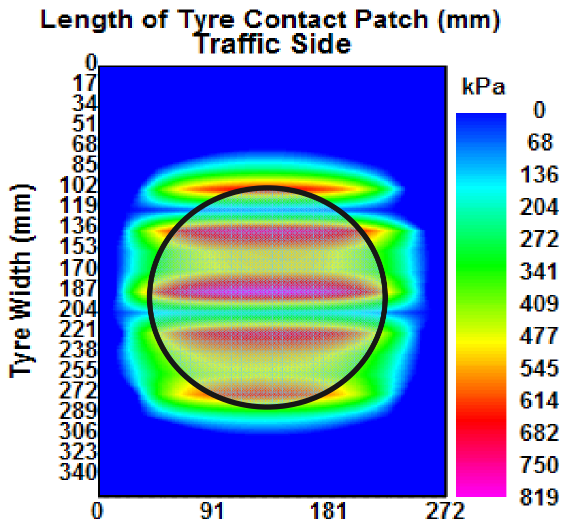
SIM Measured Tyre Load [⧄]: 18.5 (kN)

Estimated contact area: 483.1 (cm²)
Equivalent uniform contact stress: 383.5 (kPa)
Radius of equivalent circular area: 124.0 (mm)



SIM Measured Tyre Load [⧄]: 19.1 (kN)

Estimated contact area: 498.0 (cm²)
Equivalent uniform contact stress: 383.9 (kPa)
Radius of equivalent circular area: 125.9 (mm)



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40 kN - over-loading (160 kN Axle) on Tyres @ 520 kPa:

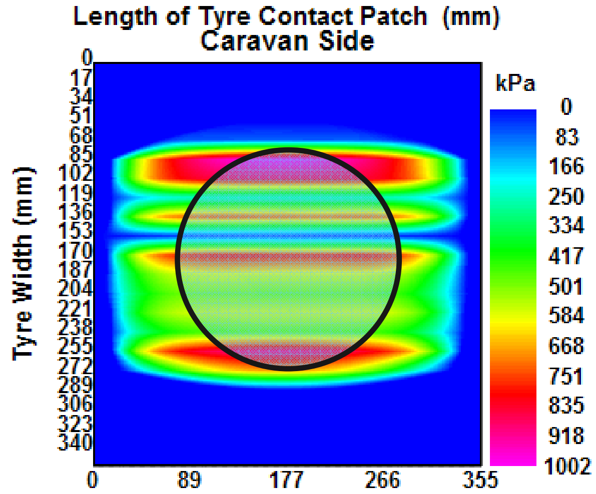
18th RPF

Firestone 12 x R22.5 G391 (SA - HVS)-2006

Direction: [Z]
Inflation pressure: 520 (kPa)
Load per tyre: 40 (kN)

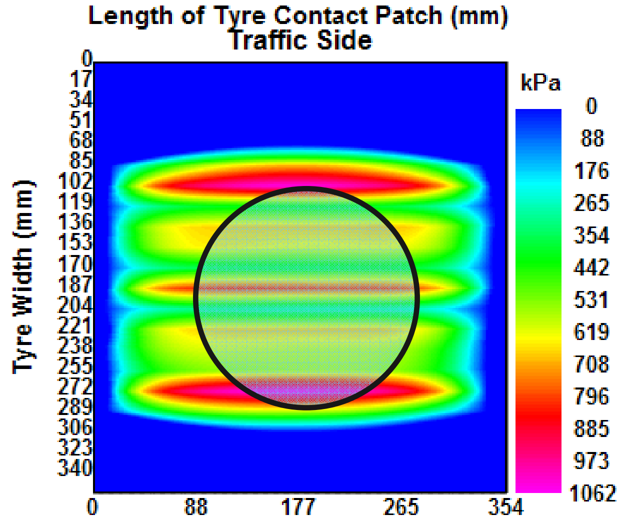
SIM Measured Tyre Load [Z]: 33.8 (kN)

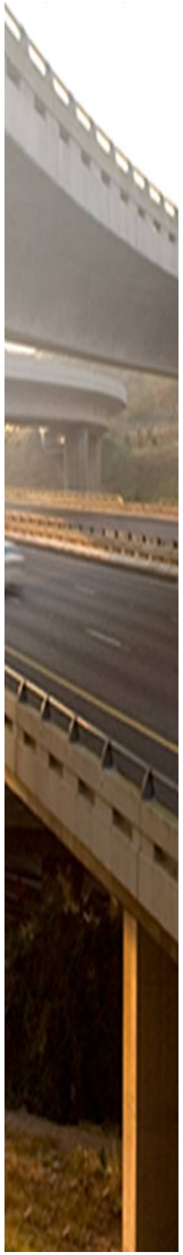
Estimated contact area: 702.6 (cm²)
Equivalent uniform contact stress: 481.3 (kPa)
Radius of equivalent circular area: 149.5 (mm)



SIM Measured Tyre Load [Z]: 38.6 (kN)

Estimated contact area: 723.2 (cm²)
Equivalent uniform contact stress: 533.6 (kPa)
Radius of equivalent circular area: 151.7 (mm)





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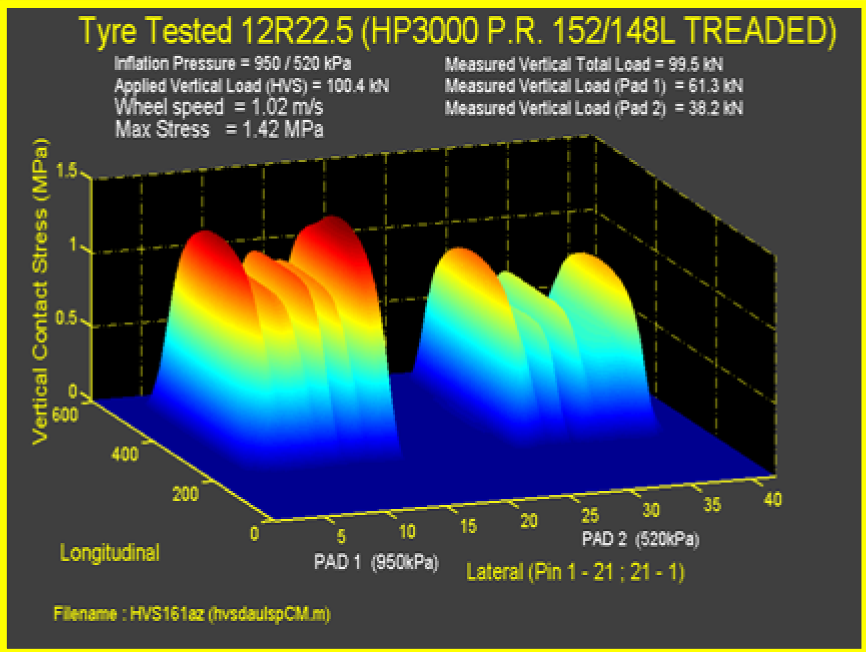
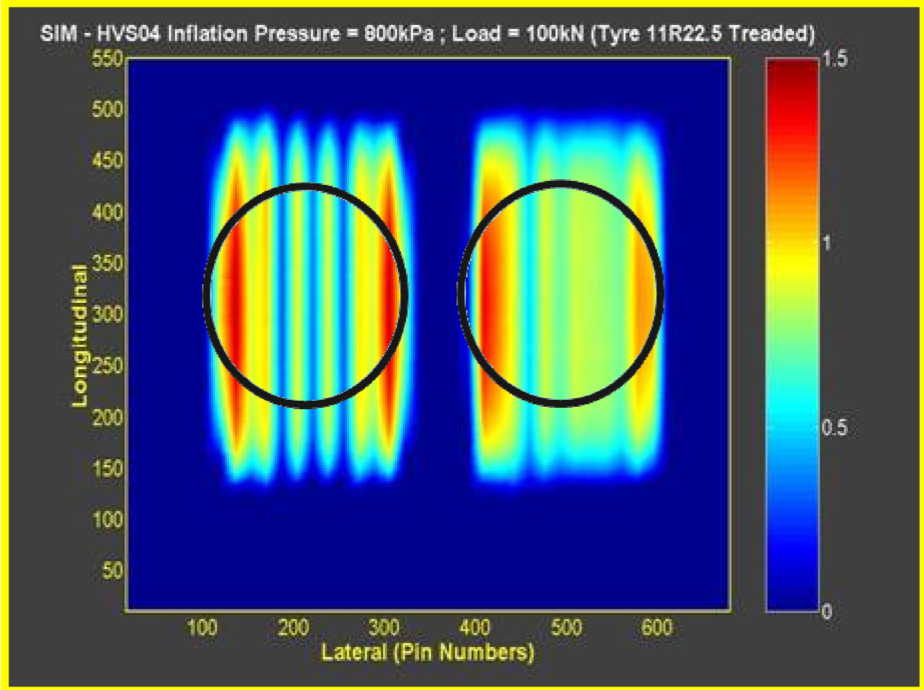
Overloading on Tyres:

18th
RPF



Contact Patches:
(square not circular)



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

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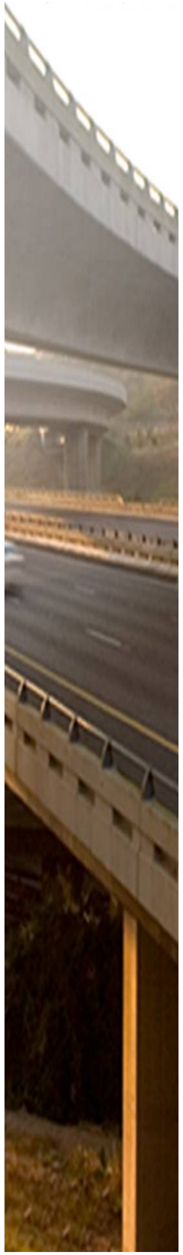
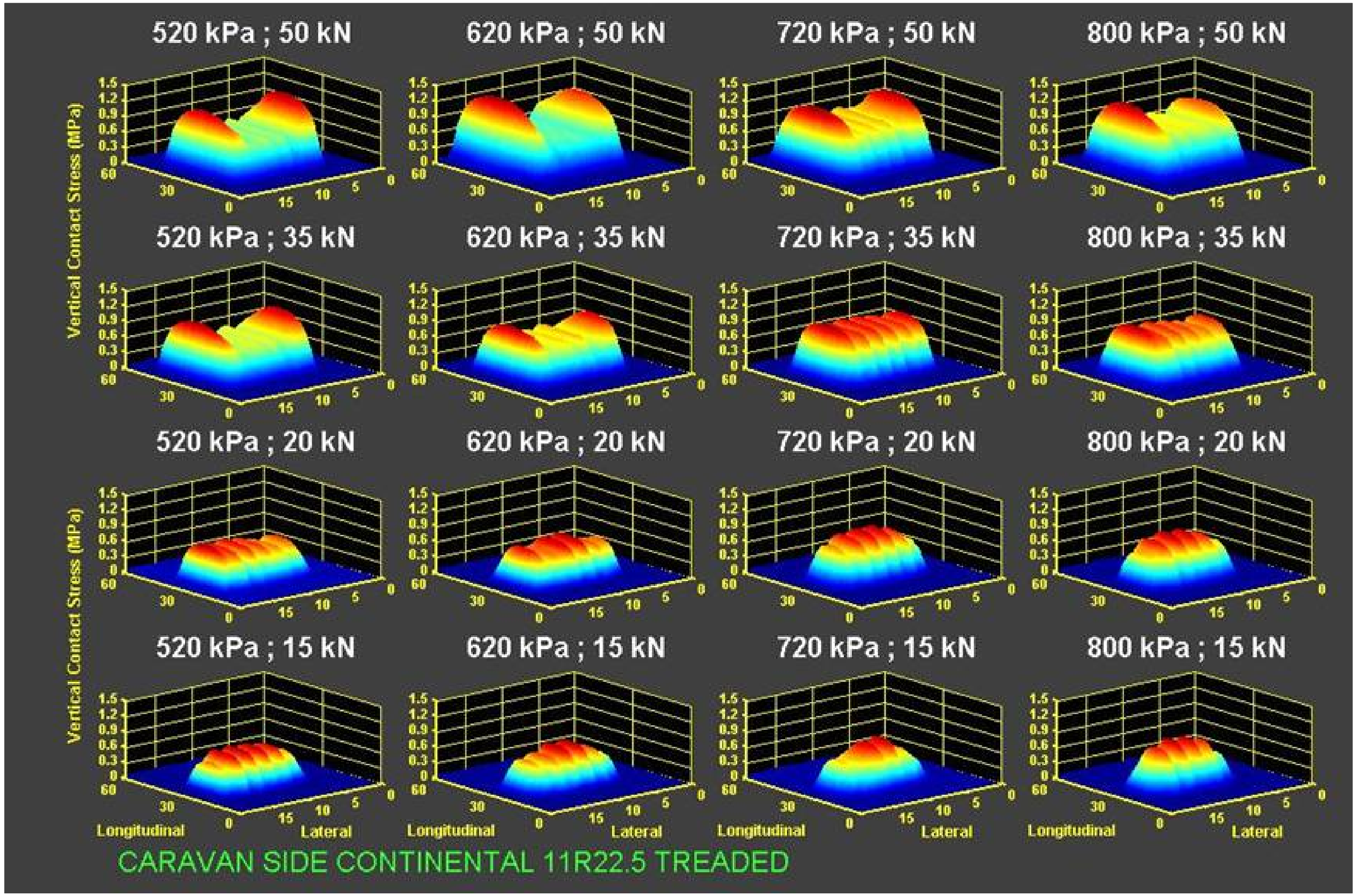


LOAD



INFLATION PRESSURE

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Full Contact Stresses

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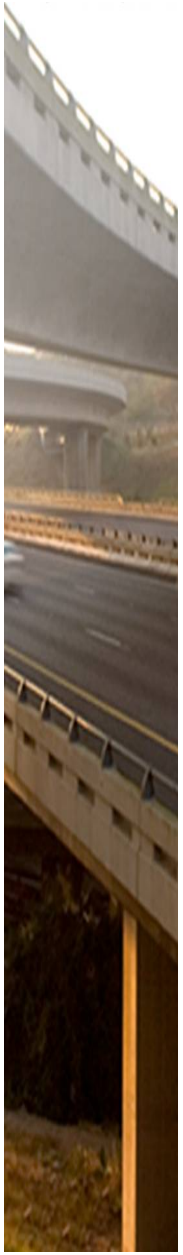
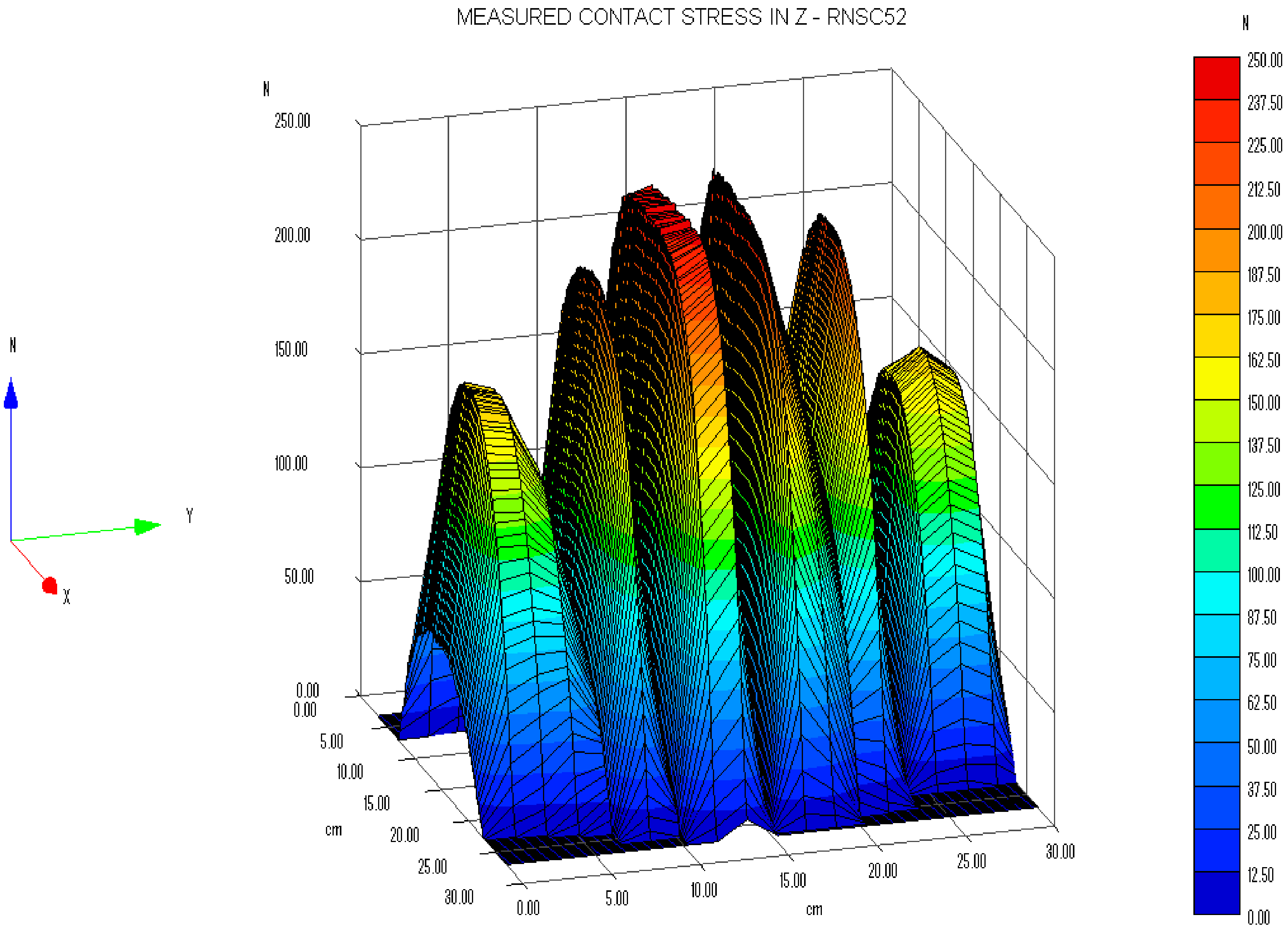
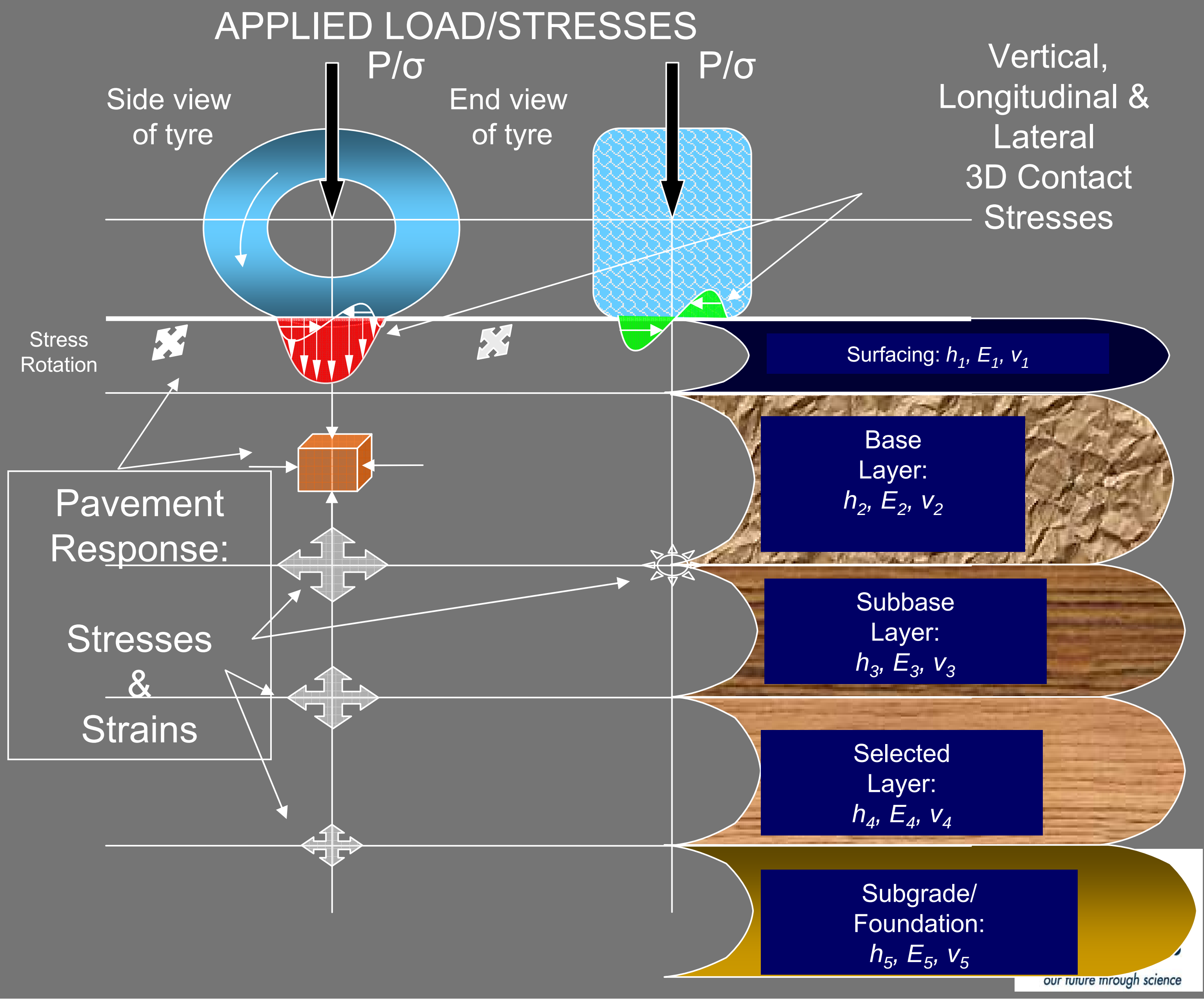




MECHANISTIC APPROACH:



Finite Element Analysis (CSIR):Uniform vs Non-Uniform Stress

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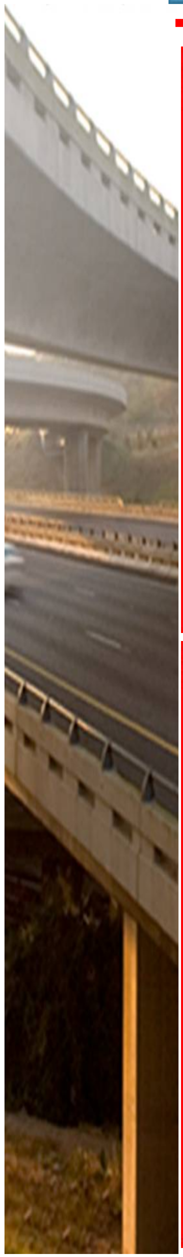

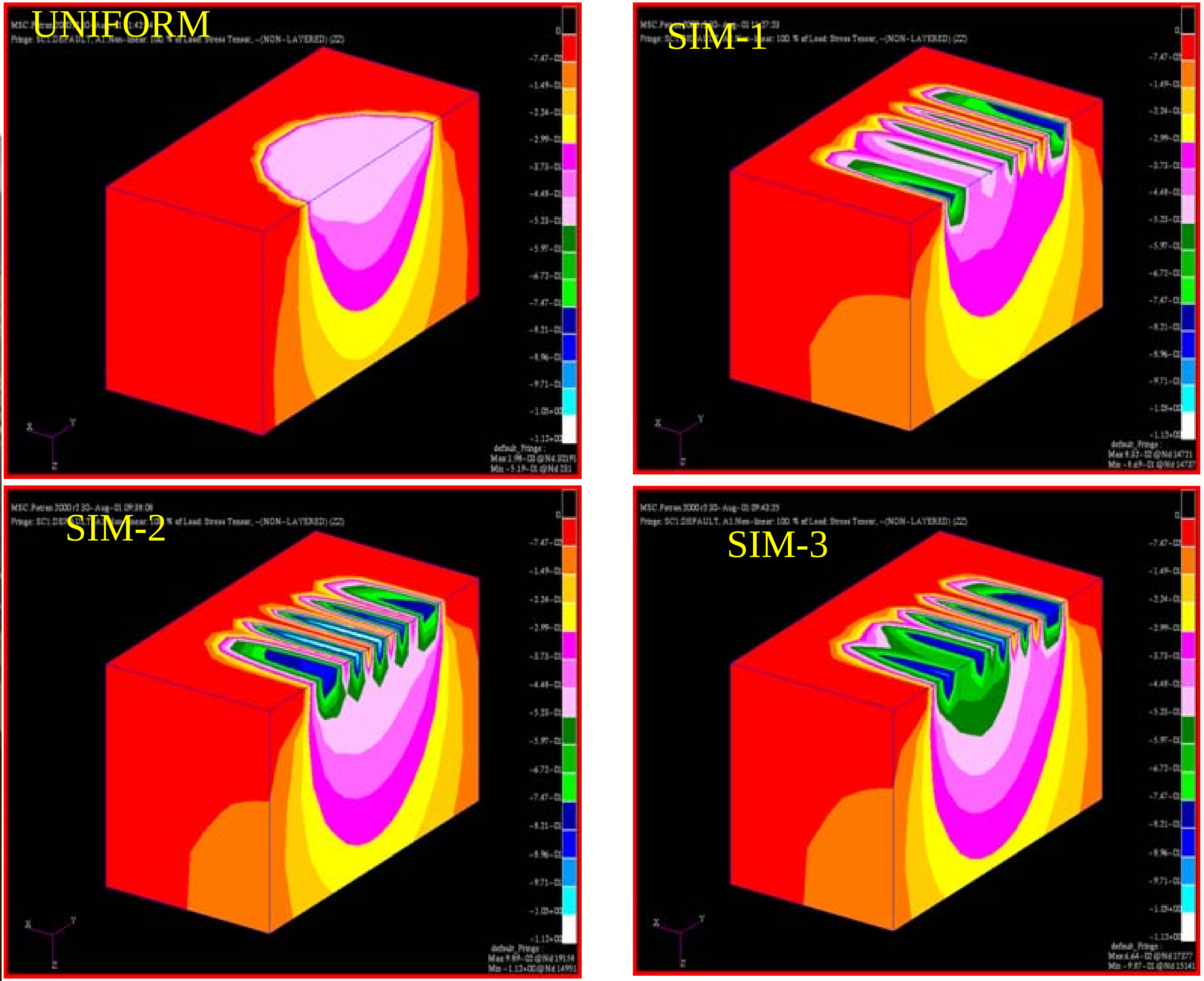

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Equivalent Single Circular Contact Stress(Existing..)

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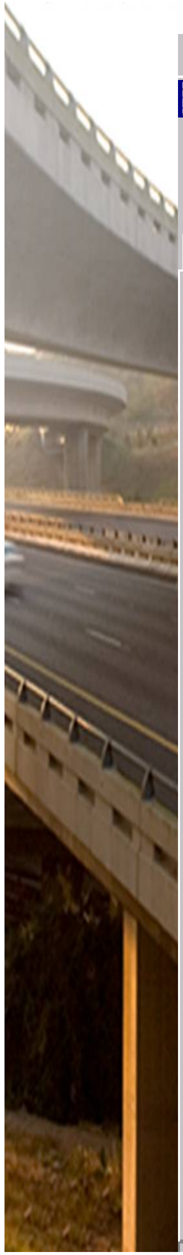

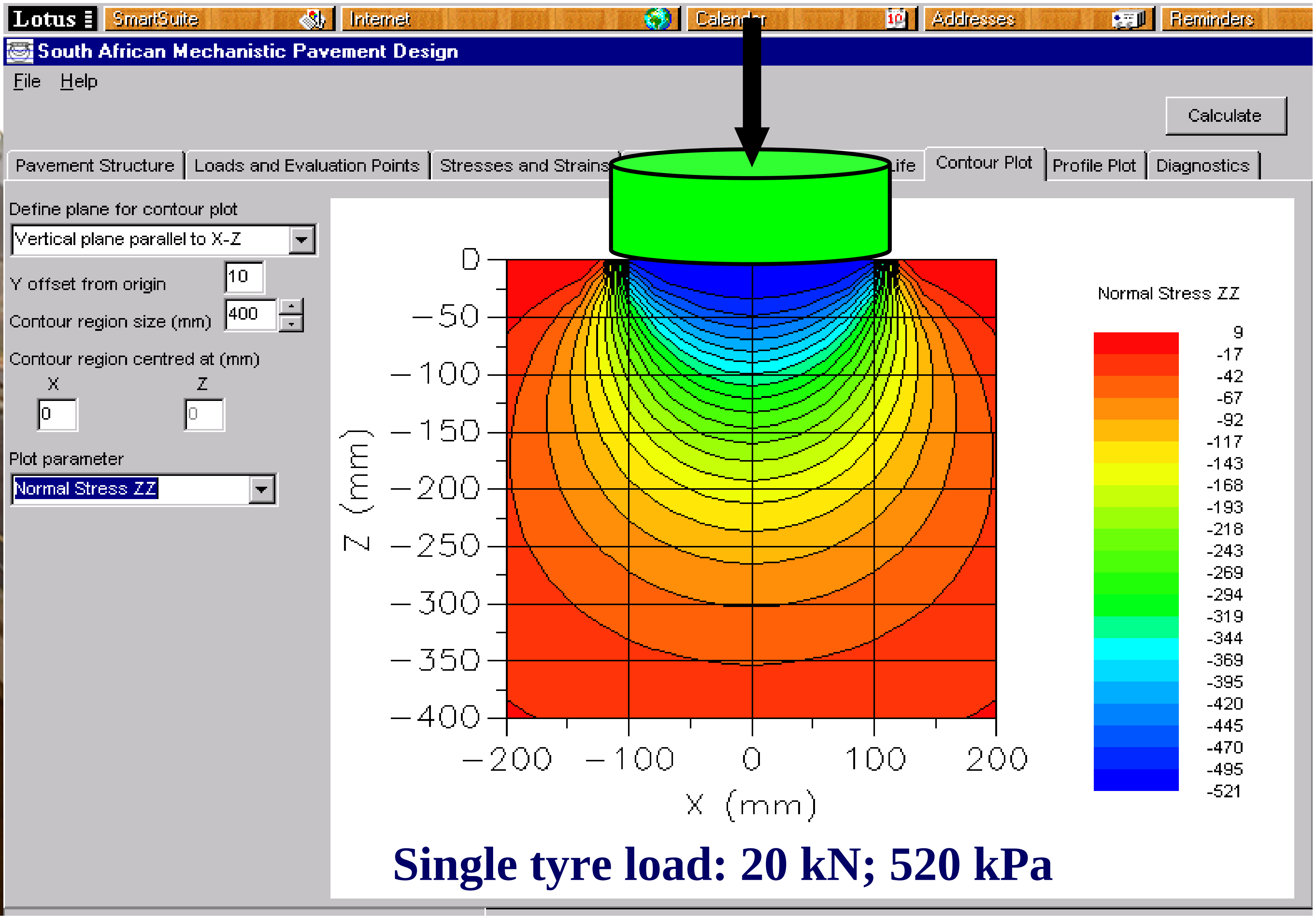

Single tyre load: 20 kN; 520 kPa

n-Shape: Staggered circular modeling (New….)

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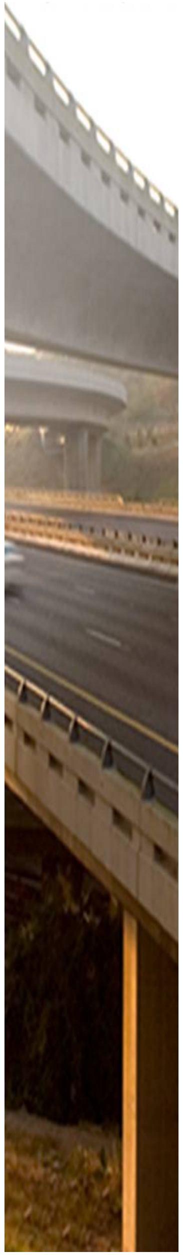
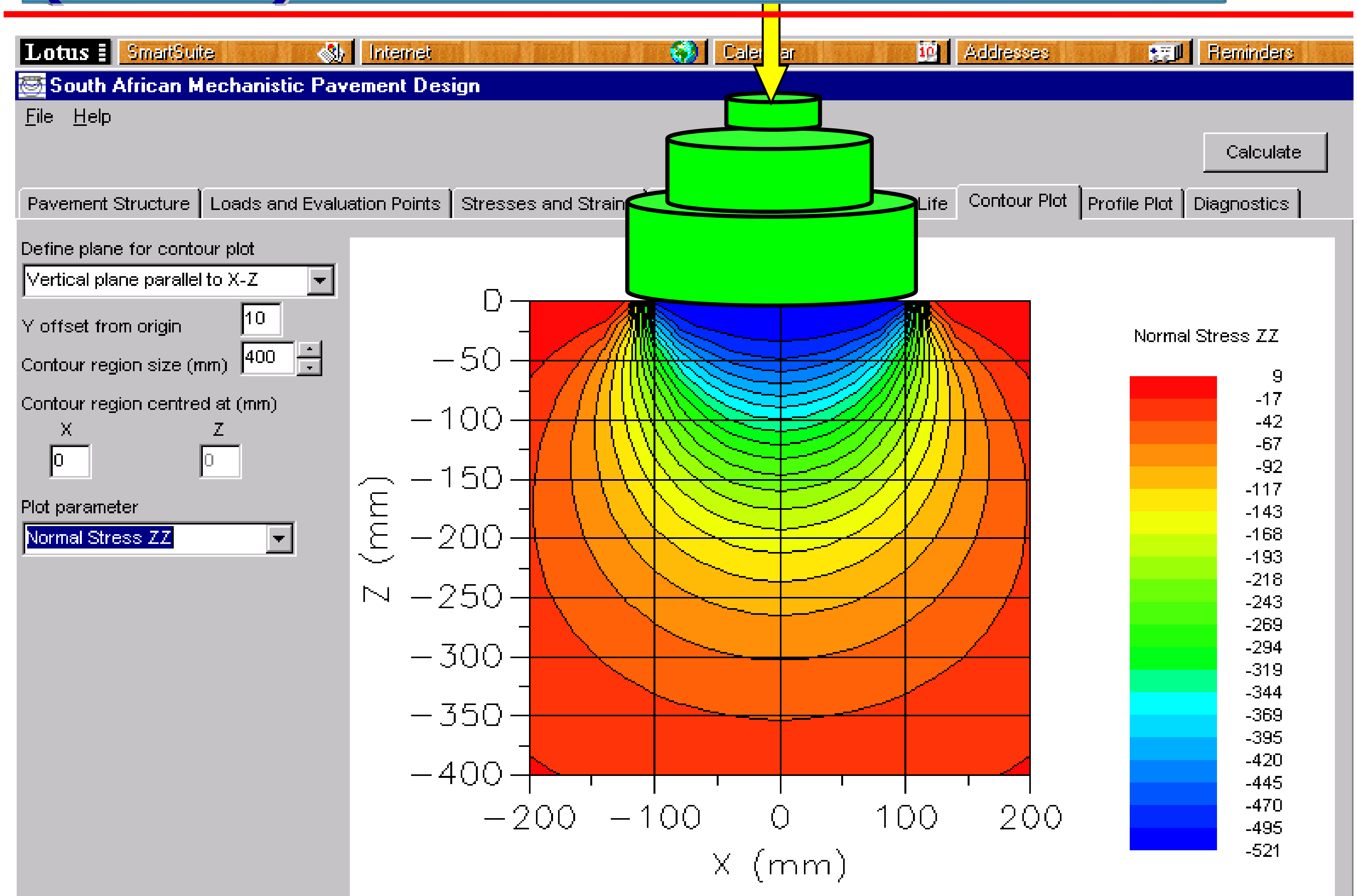
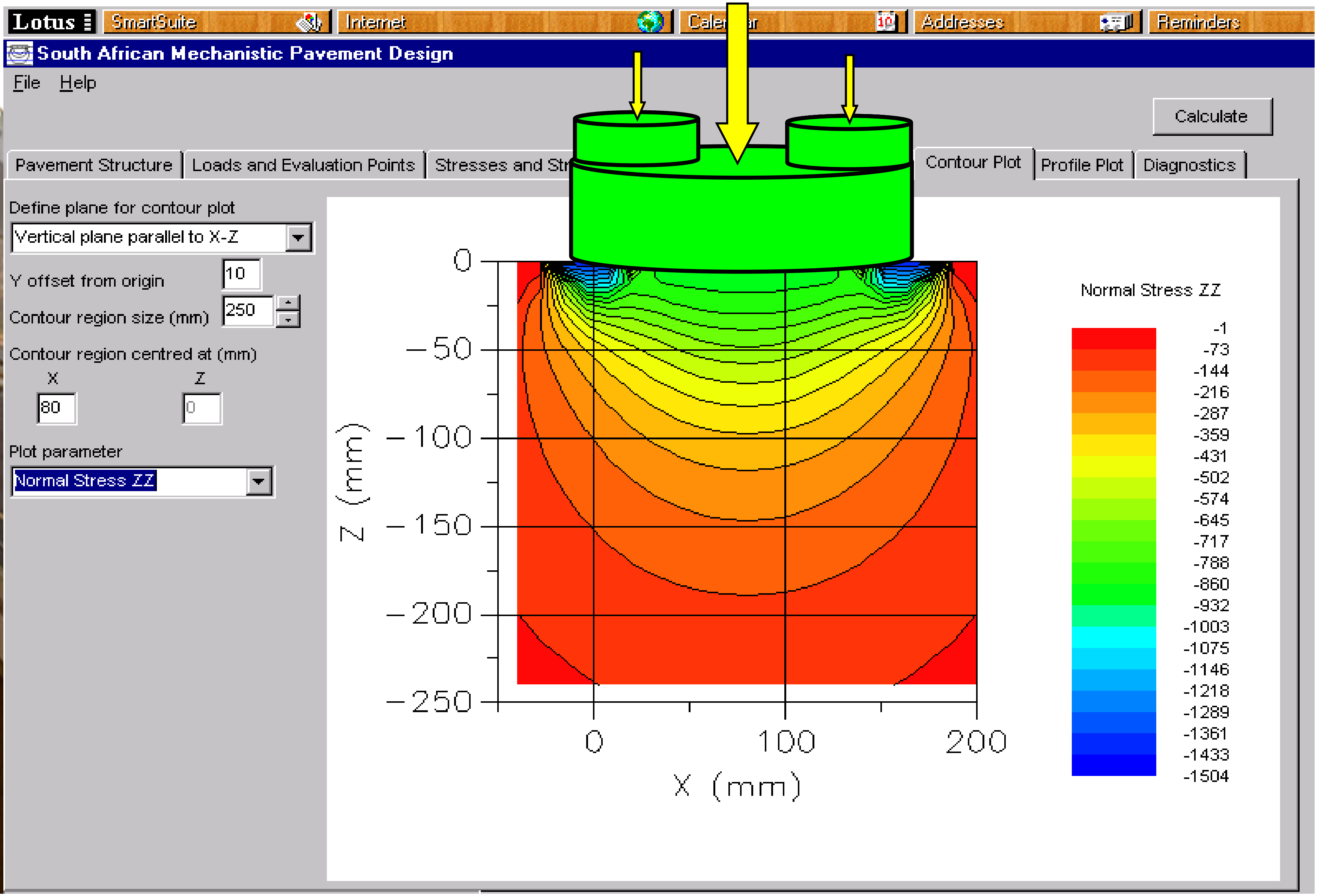


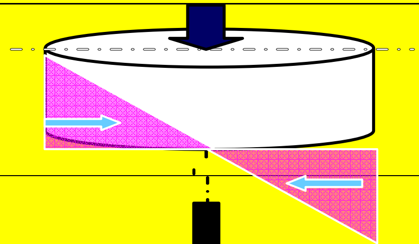
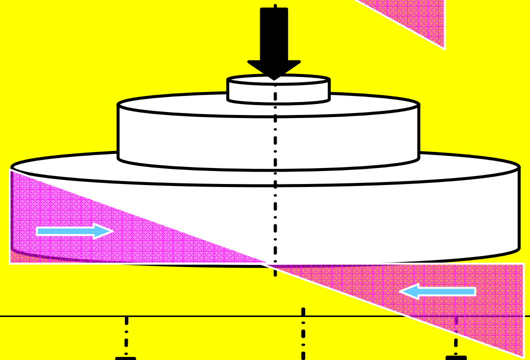
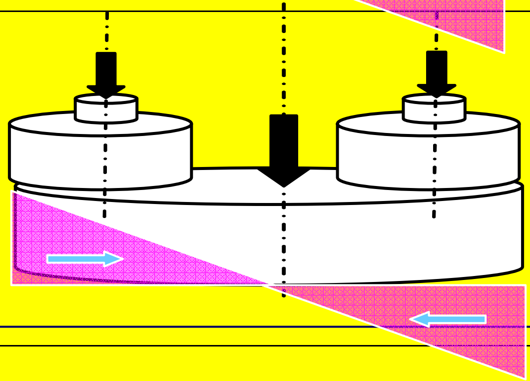
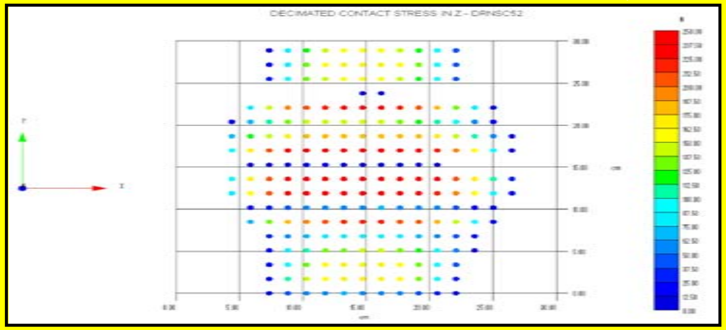


Single tyre load: 20 kN; 520 kPa

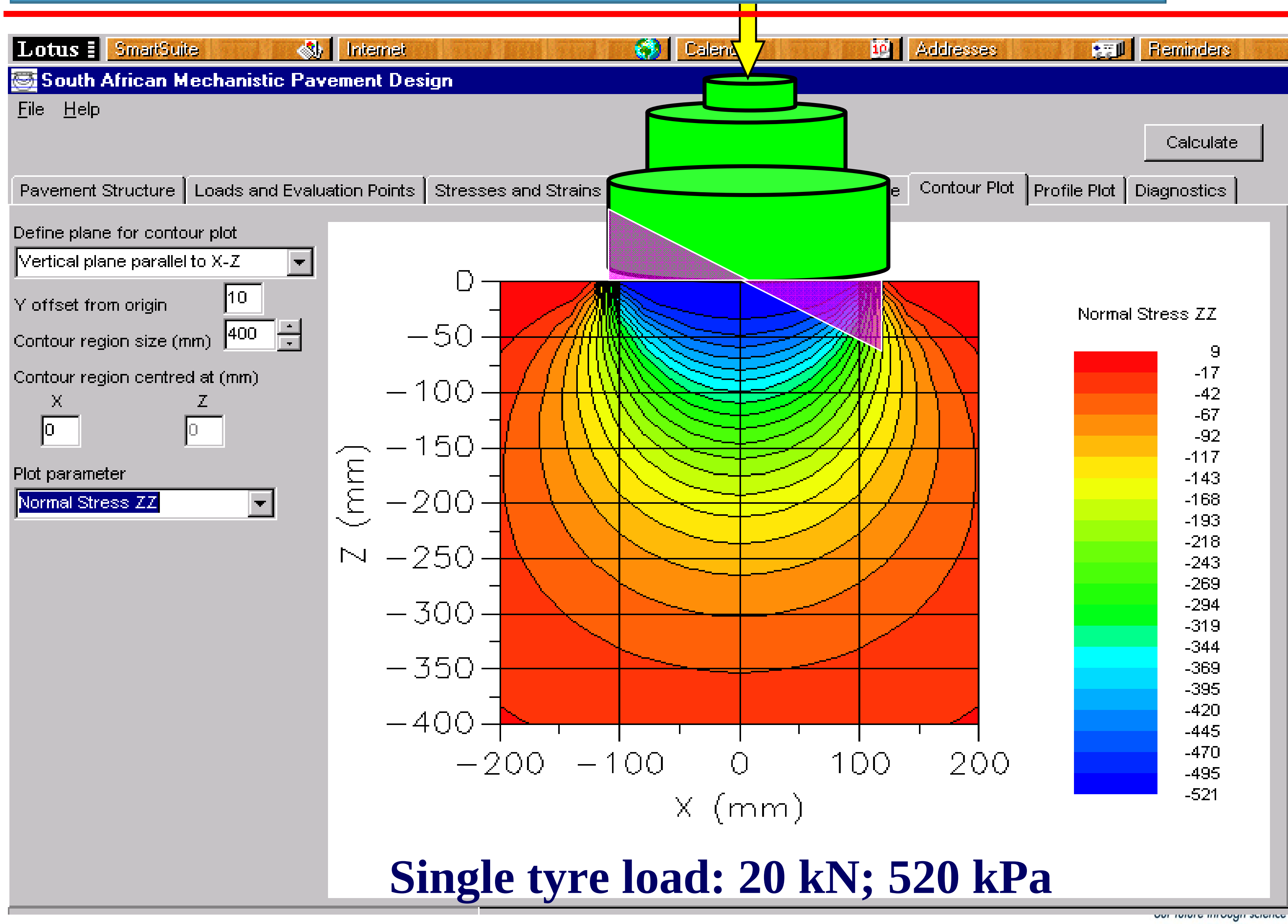
M-Shape: Staggered circular modeling: New….

18th RPF



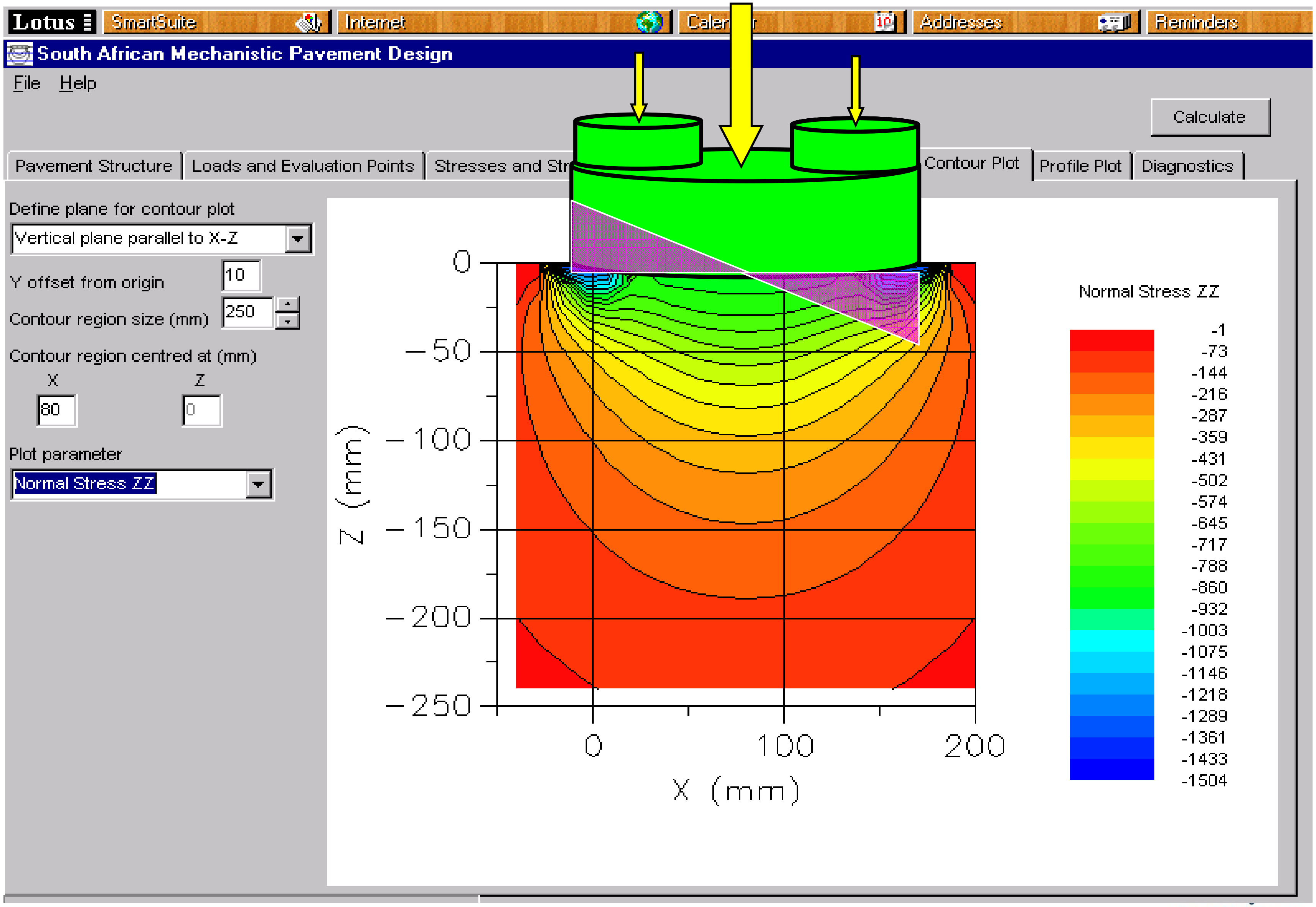
Case		Contact Idealization	Shape of Vertical Contact Stress	Comments
1			Traditional Standard Circular disc	With or without lateral load/stresses (Tri - angular)
2			"n - shape" Staggered Circular disc(s)	With or without lateral load/stresses (Tri - angular)
3			"m - shape" Staggered Circular disc(s)	With or without lateral load/stresses (Tri - angular)
4			Full SIM shape (Decimated) : 1D, 2D and/or 3D shape	With or without lateral load/stresses (Tri - angular)

M-Shape: Vertical Only - staggered circular modeling



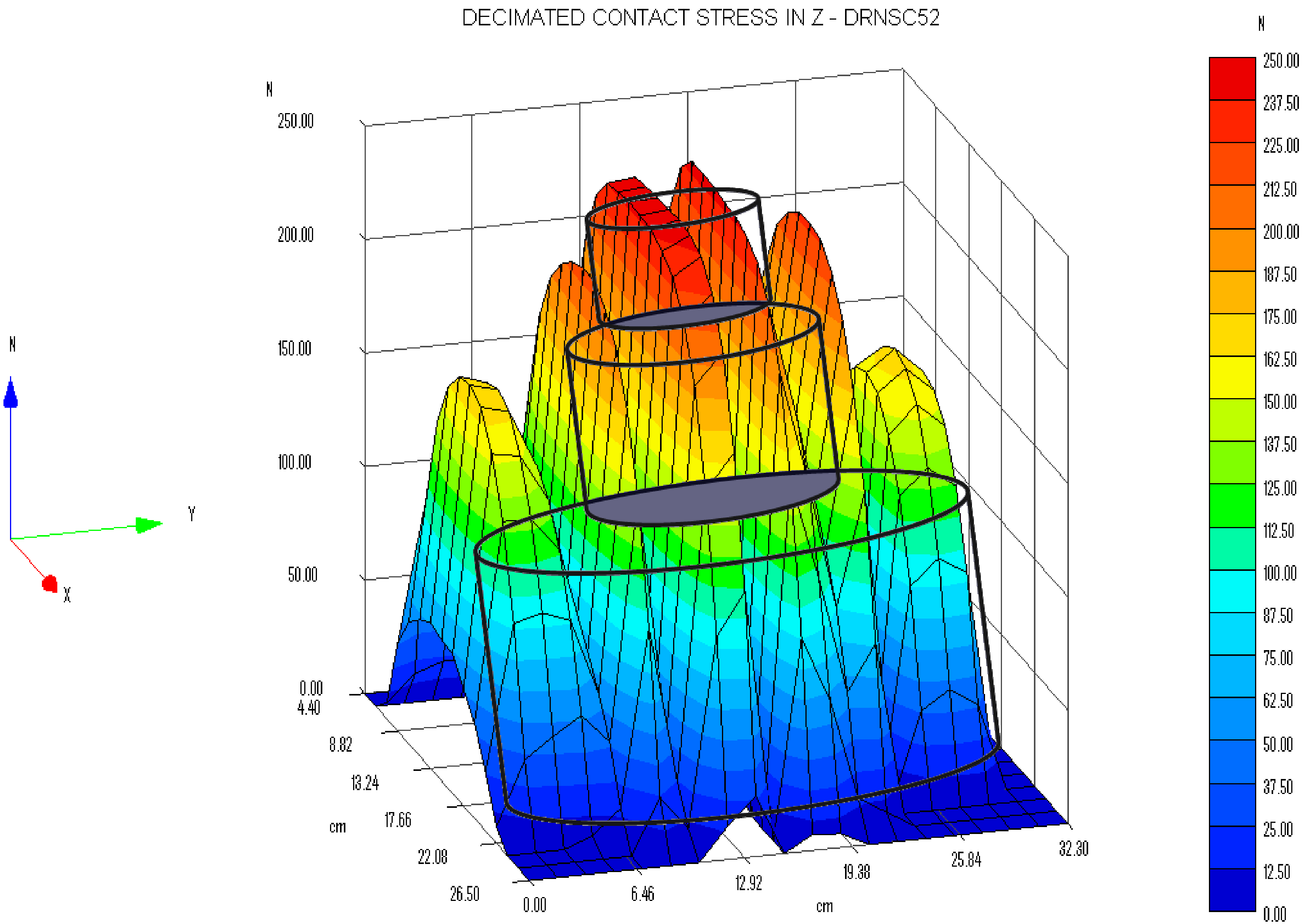
Single tyre load: 20 kN; 520 kPa

M-Shape: Vertical Only - staggered circular modeling



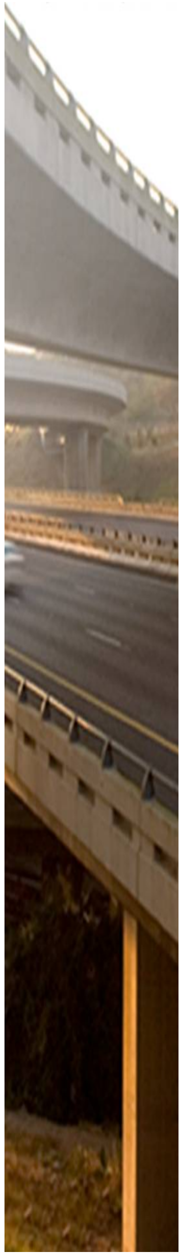
Idealization of measured Contact Stresses using staggered circles..

18th RPF



Project SAPDM/A-1: Tyre Contact Stress Information System (T-CSIS)

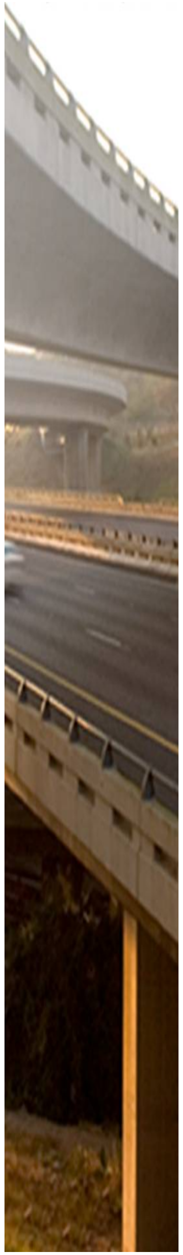
18th RPF



- Objectives
  - New Beta Version of “TyreStress viewer” available on request - eventually be the T-CSIS (See Demo later);
  - New:- Output of A-1: T-CSIS = Input for C-1 (See Demo later);

New Viewer: 2 x Staggered Discs (“n”)

18th RPF



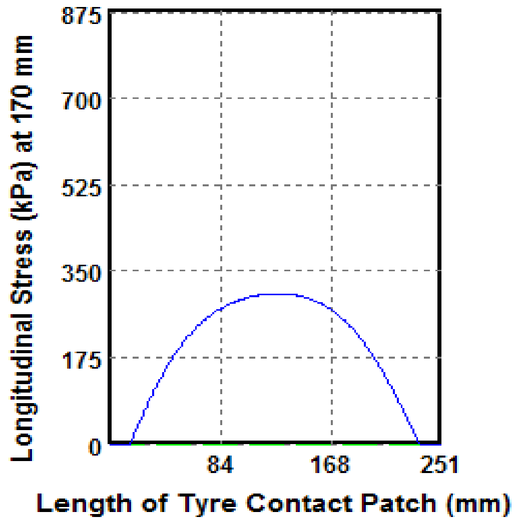
Goodyear 315-80 R22.5 G391 (Steering - SA)-2004

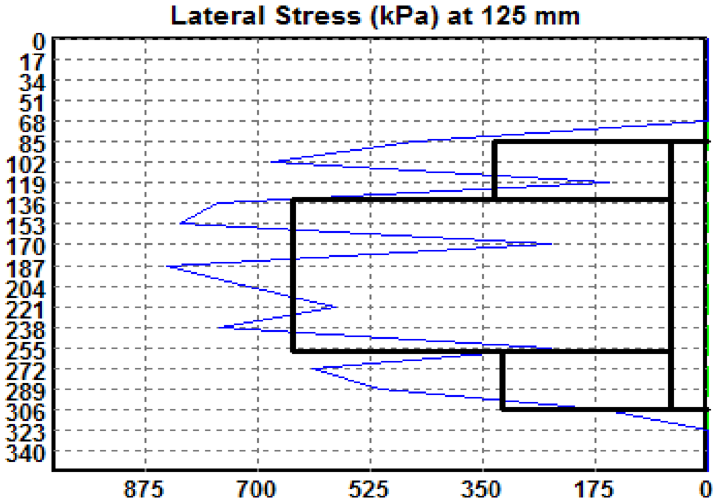
Direction: [Z]
Inflation pressure: 620 (kPa)
Applied Vertical Tyre Load: 20 (kN)

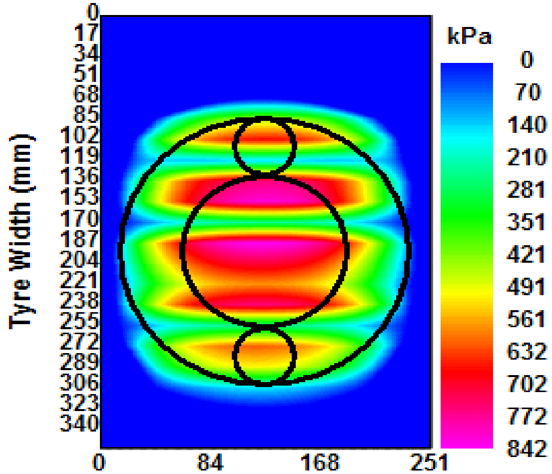
SIM Measured Tyre Load [Z]: 20.0 (kN)

Estimated contact area: 498.0 (cm^2)
Equivalent uniform contact stress: 402.0 (kPa)
Radius of equivalent circular area: 125.9 (mm)
Load (kN)=3.03139,14.1893,2.79634

Stress (kPa)=330.613,444.992,319.886
N Shape







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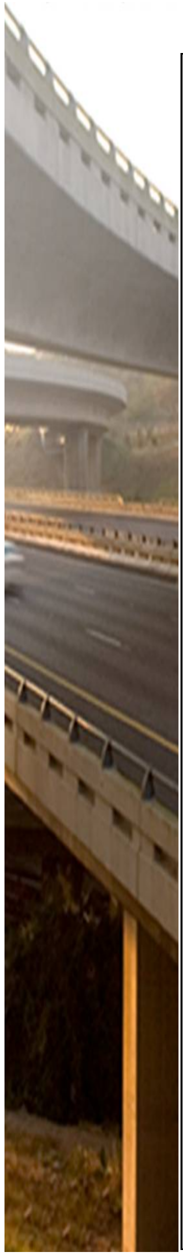
New Viewer: 3 x Staggered Discs ("n")



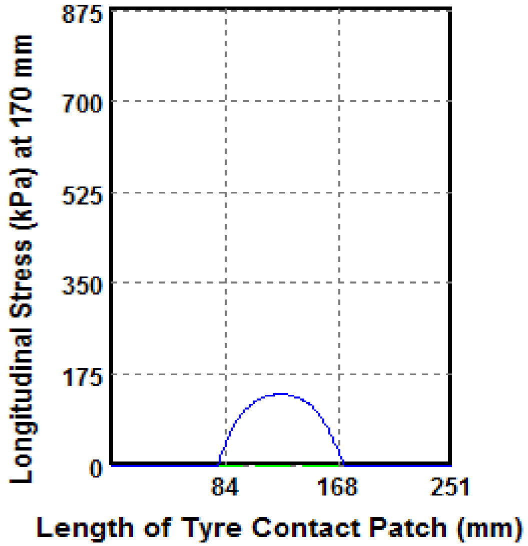
Goodyear 315-80 R22.5 G391 (Steering - SA)-2004

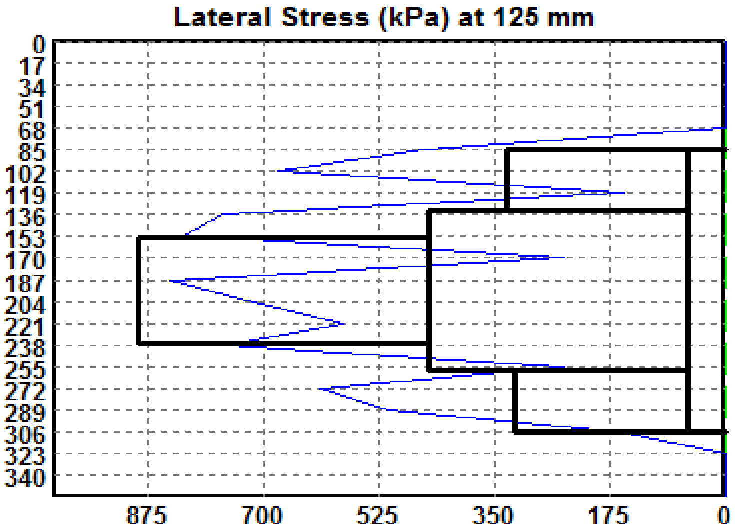
Direction: [∠]
Inflation pressure: 620 (kPa)
Applied Vertical Tyre Load: 20 (kN)

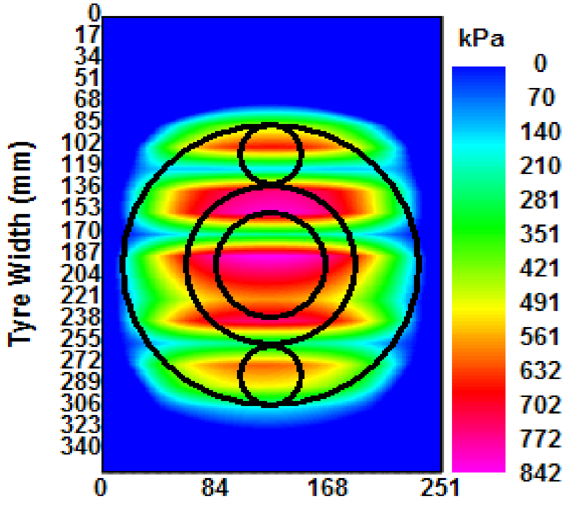
SIM Measured Tyre Load [∠]: 20.0 (kN)

Estimated contact area: 498.0 (cm²)
Equivalent uniform contact stress: 402.0 (kPa)
Radius of equivalent circular area: 125.9 (mm)
Load (kN)=3.03139,14.1893,2.79634

Stress (kPa)=330.613,444.992,319.886
N Shape







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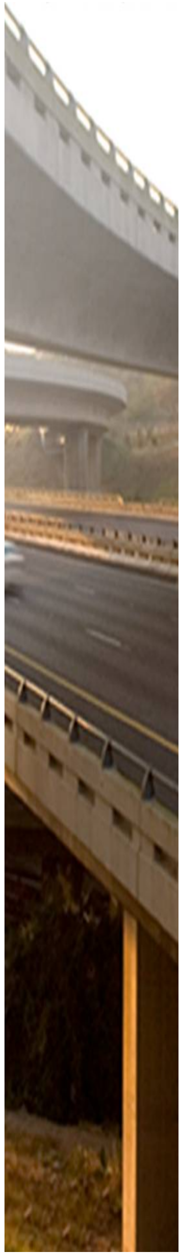
New Viewer: 2 x Staggered Discs (“m”)

18th RPF



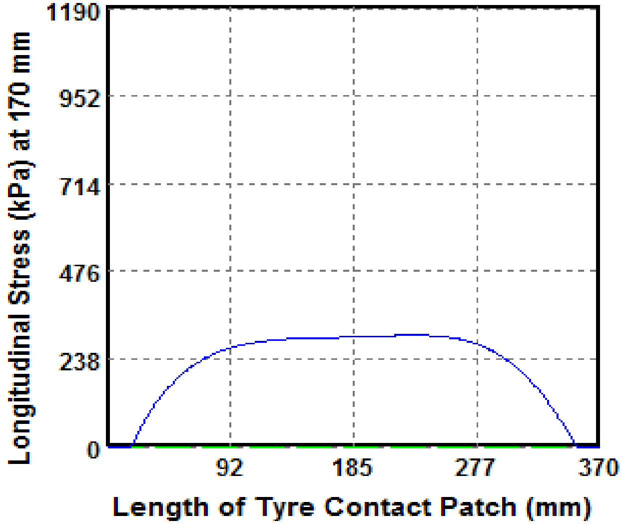
Goodyear 315-80 R22.5 G391 (Steering - SA)-2004

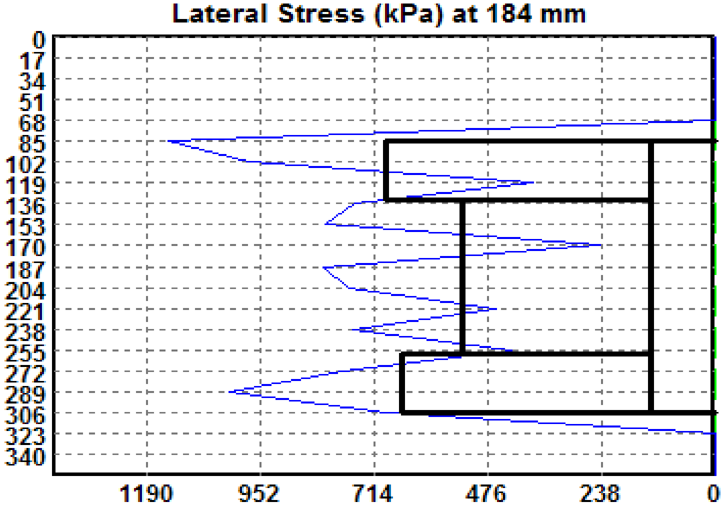
Direction: [Z]
Inflation pressure: 620 (kPa)
Applied Vertical Tyre Load: 50 (kN)

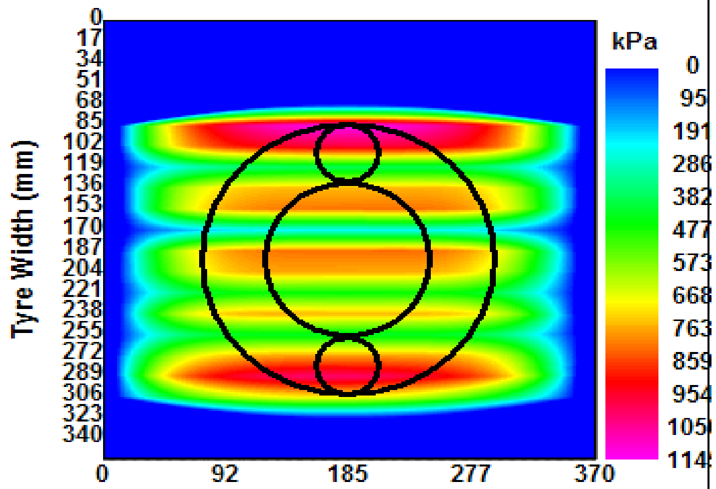
SIM Measured Tyre Load [Z]: 47.4 (kN)

Estimated contact area: 814.7 (cm²)
Equivalent uniform contact stress: 581.6 (kPa)
Radius of equivalent circular area: 161.0 (mm)
Load (kN)=11.2724,25.3581,10.7507

Stress (kPa)=689.125,520.595,655.398
M Shape







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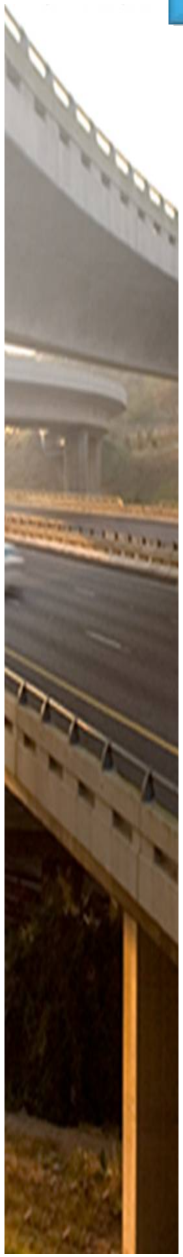
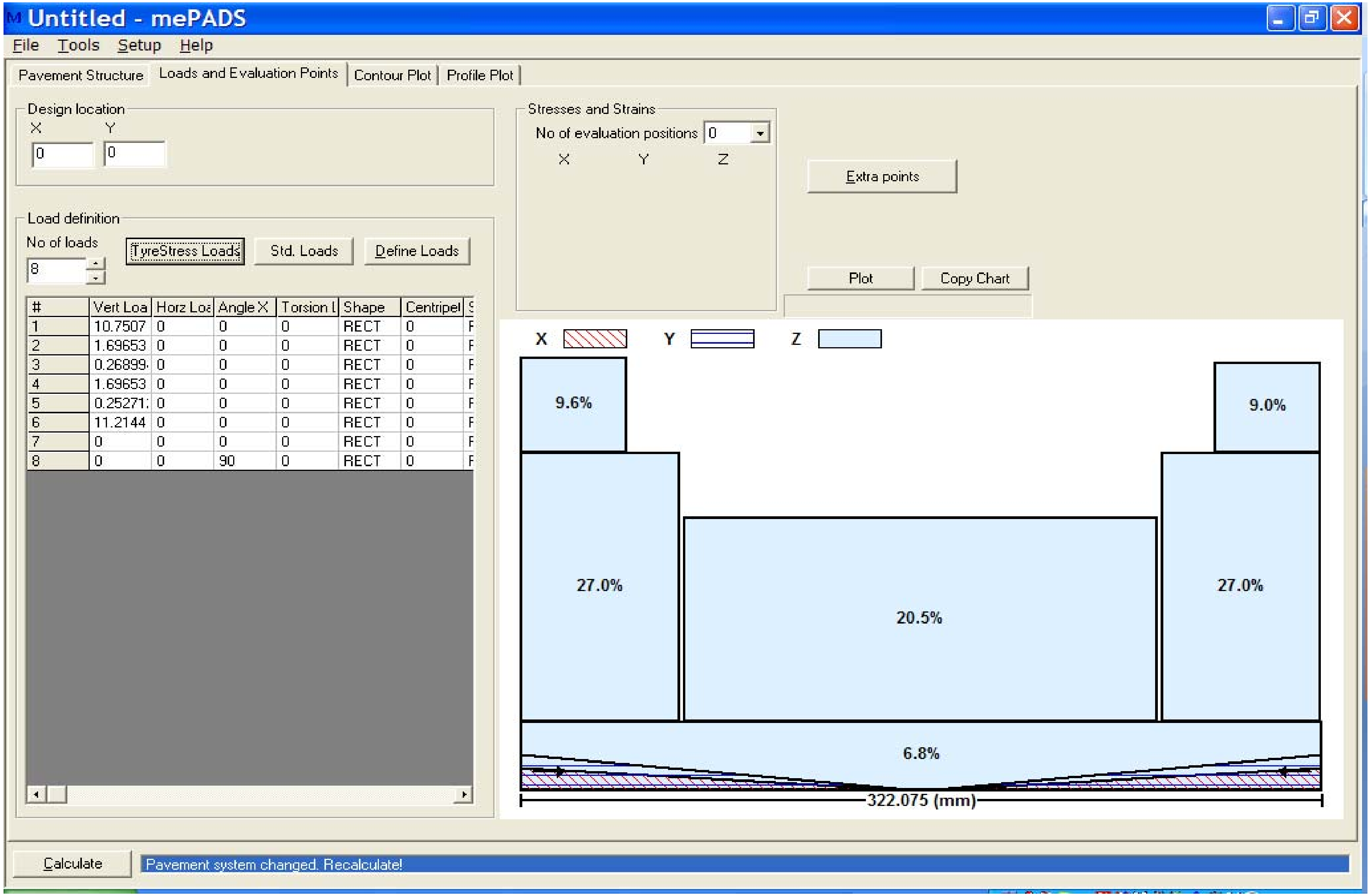
New Viewer Export to me PADS (c-1): 3 x Staggered Discs ("m") - INTERIM

18th RPF

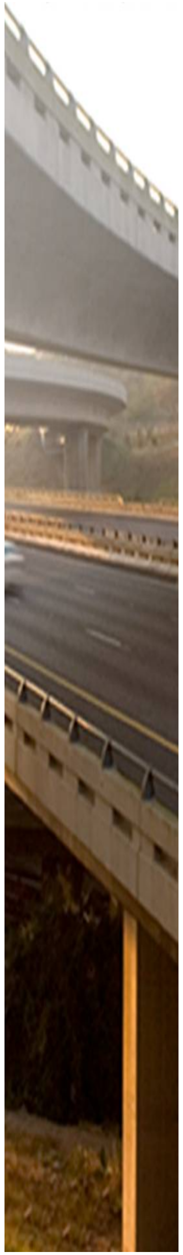


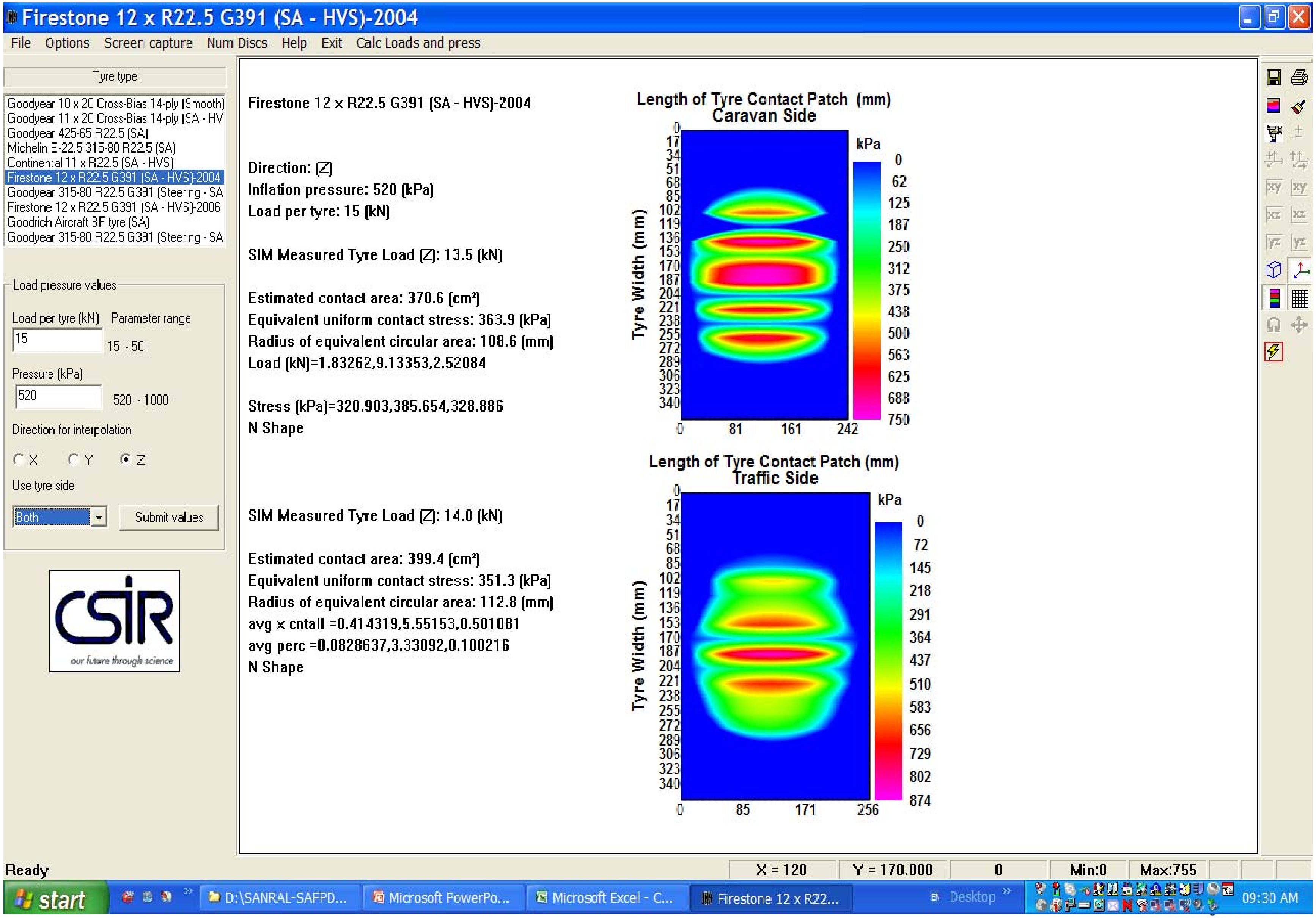


#	Vert Loa	Horz Loa	Angle X	Torsion I	Shape	Centripet	S
1	10.7507	0	0	0	RECT	0	F
2	1.69653	0	0	0	RECT	0	F
3	0.26899	0	0	0	RECT	0	F
4	1.69653	0	0	0	RECT	0	F
5	0.25271	0	0	0	RECT	0	F
6	11.2144	0	0	0	RECT	0	F
7	0	0	0	0	RECT	0	F
8	0	0	90	0	RECT	0	F

New Viewer: Dual Tyres

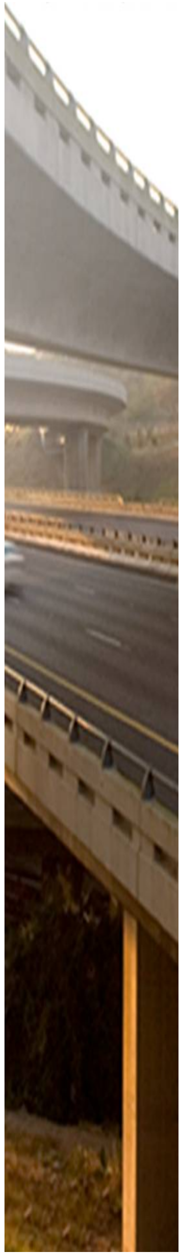
18th RPF





New Tyre Stress Viewer: Dual Tyres

18th RPF



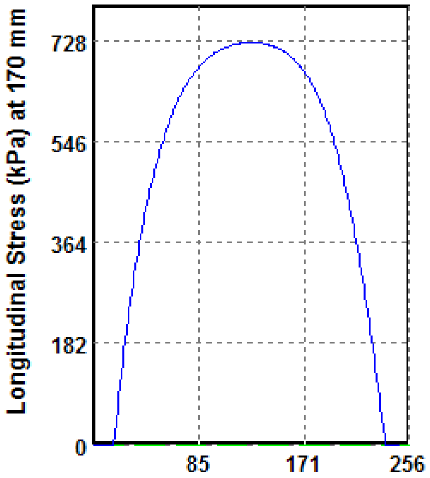
Firestone 12 x R22.5 G391 (SA - HVS)-2004

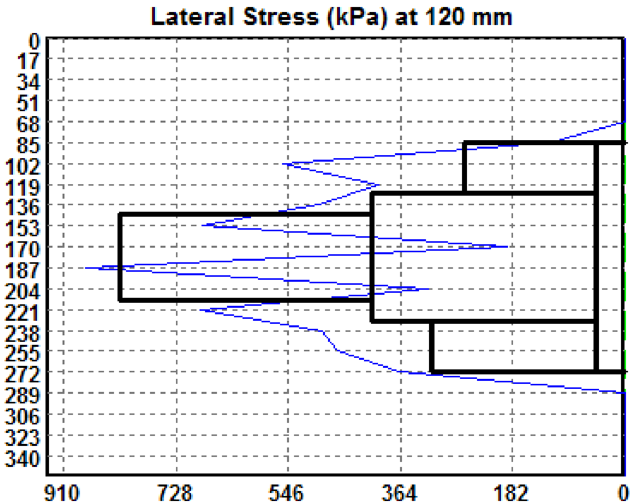
Direction: [Z]
Inflation pressure: 520 (kPa)
Load per tyre: 15 (kN)

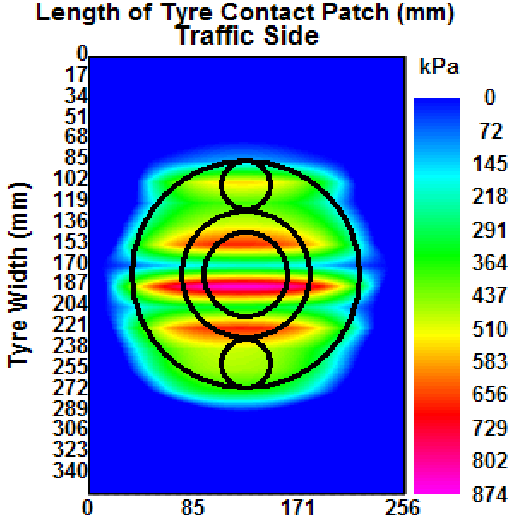
SIM Measured Tyre Load [Z]: 14.0 (kN)

Estimated contact area: 399.4 (cm²)
Equivalent uniform contact stress: 351.3 (kPa)
Radius of equivalent circular area: 112.8 (mm)
Load (kN)=1.80547,10.0287,2.19678

Stress (kPa)=259.334,386.096,313.641
N Shape







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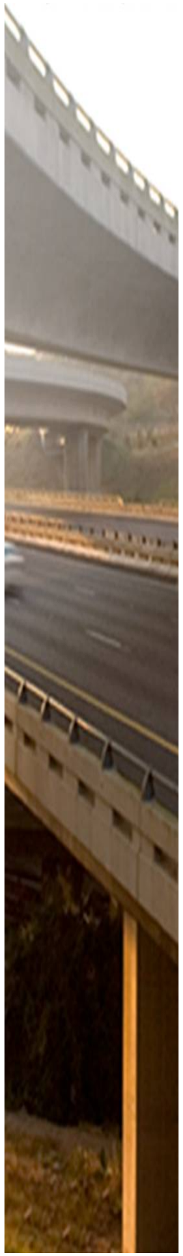
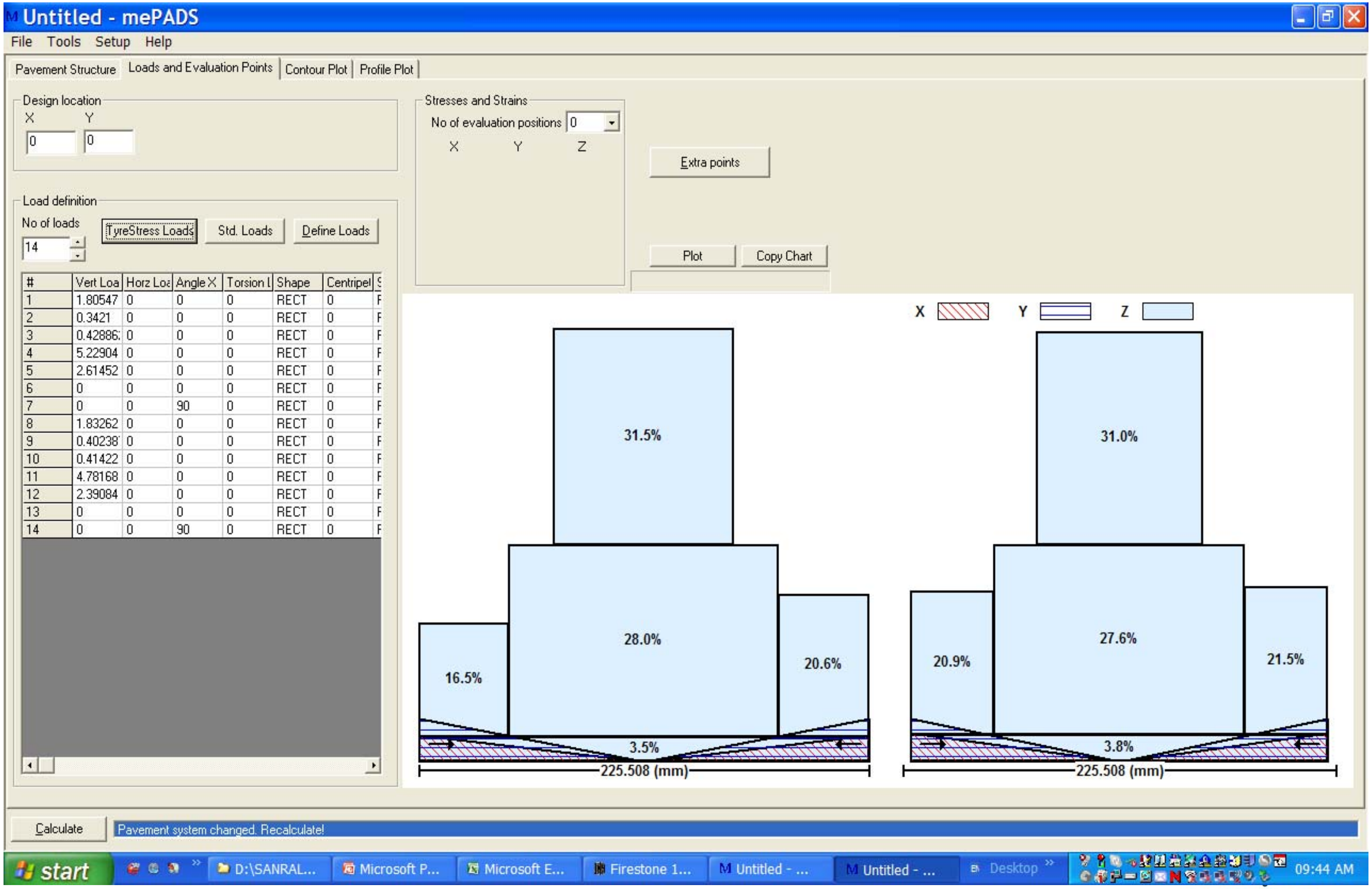
New Viewer: 3 x Staggered Discs ("m")

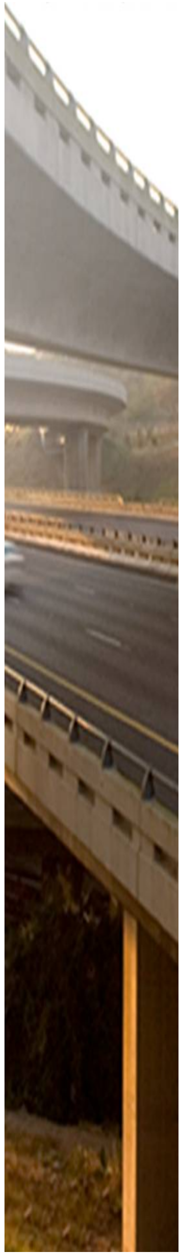
18th RPF





New Viewer Export to me PADS (c-1): 3 x Staggered Discs ("m") - INTERIM

18th RPF



Load Definition

#	Vert Load (kN)	Horz Load	Angle (°)	Torsion Load	Shape	Centripetal	Shape	Moment Vert	Moment Horz	Pressure	Radius (mm)	X Pos (mm)	Y Pos (mm)
1	10.7507	0	0	0	RECT	0	RECT	0	0	131.957	161.038	0	0
2	1.69653	0	0	0	RECT	0	RECT	0	0	520.595	32.2074	-128.83	0
3	0.268994	0	0	0	RECT	0	RECT	0	0	185.722	21.4716	-139.565	0
4	1.69653	0	0	0	RECT	0	RECT	0	0	520.595	32.2074	128.83	0
5	0.252712	0	0	0	RECT	0	RECT	0	0	174.48	21.4716	139.565	0
6	11.2144	0	0	0	RECT	0	RECT	0	0	395.767	94.9715	0	0
7	0	0	0	0	RECT	0	RECT	0	3.56567	43.7662	161.037	0	0
8	0	0	90	0	RECT	0	RECT	0	5.64781	69.3232	161.037	0	0

OK Cancel Copy Paste

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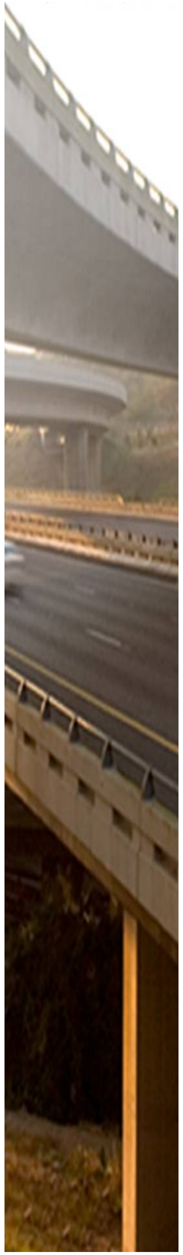
TyreStress Viewer – Example/Demo

18th RPF



TyreStress Viewer:[TyreStress Beta\TyreStress StaggeredDiscs.exe]

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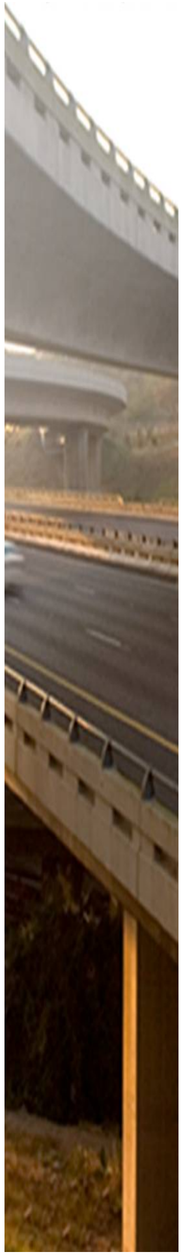
TyreStress Viewer – Example/Demo

18th
RPF



mePADS Mechanistic: Input:TyreStress Beta\mePADS TyreStress.exe

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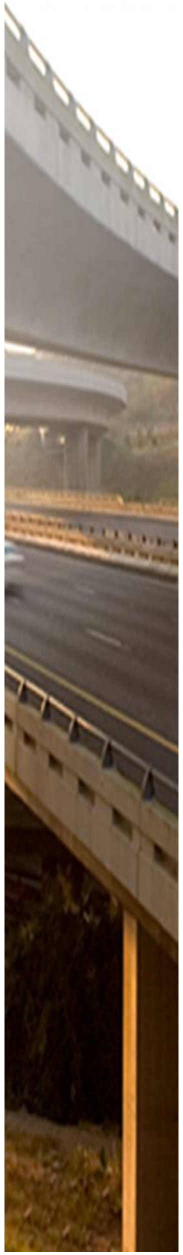
Tyre Inflation Pressure (TiP) and measured Contact Stress….

18th RPF



Seeking for a relationship between TiP and measured contact stresses……

(~ 52 000 tyres measured on N3-TCC) with Stress-In-Motion (SIM) device in 2003/4)

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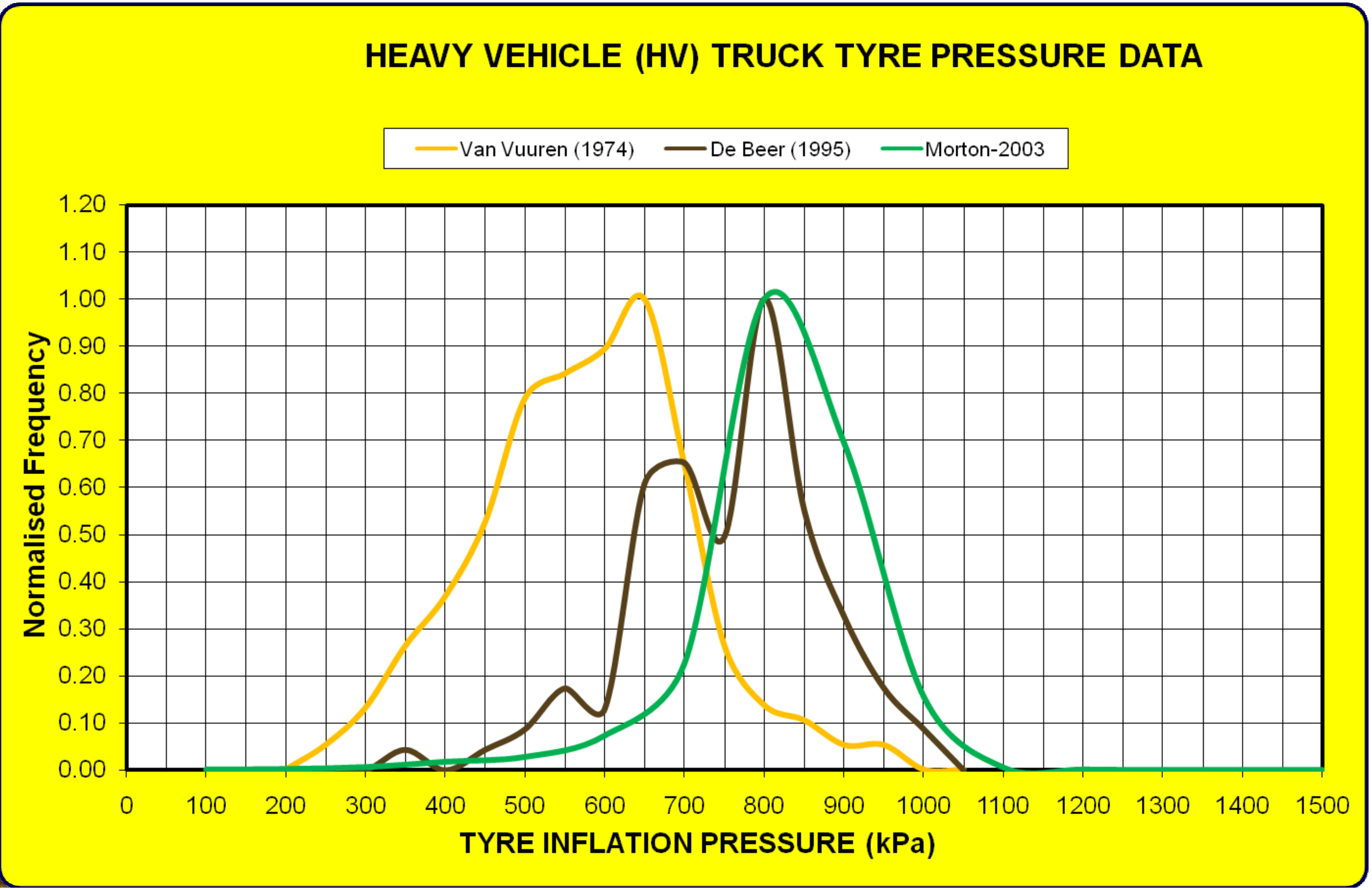
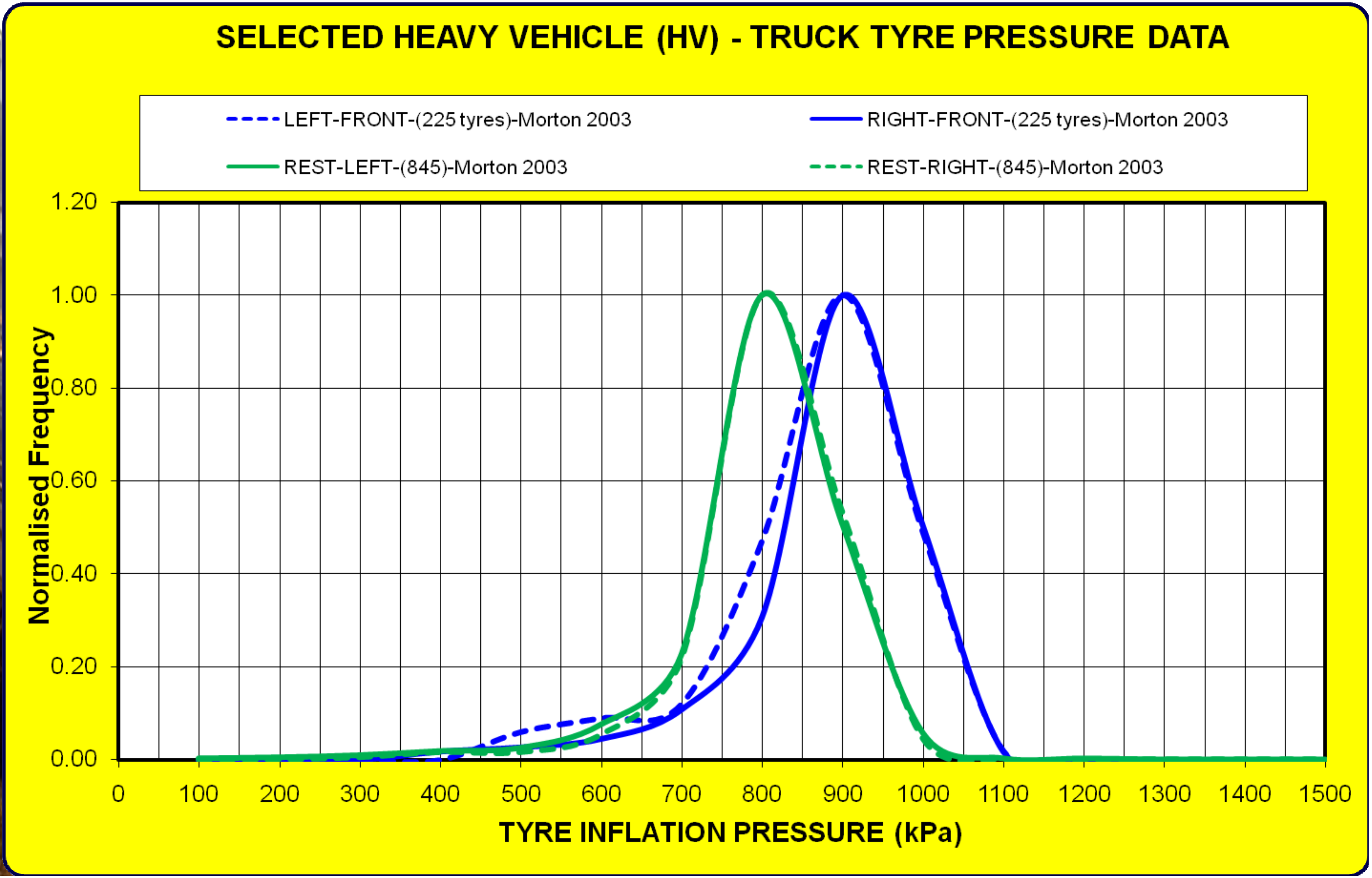
Available (Historical) TiP data sets..

18th RPF



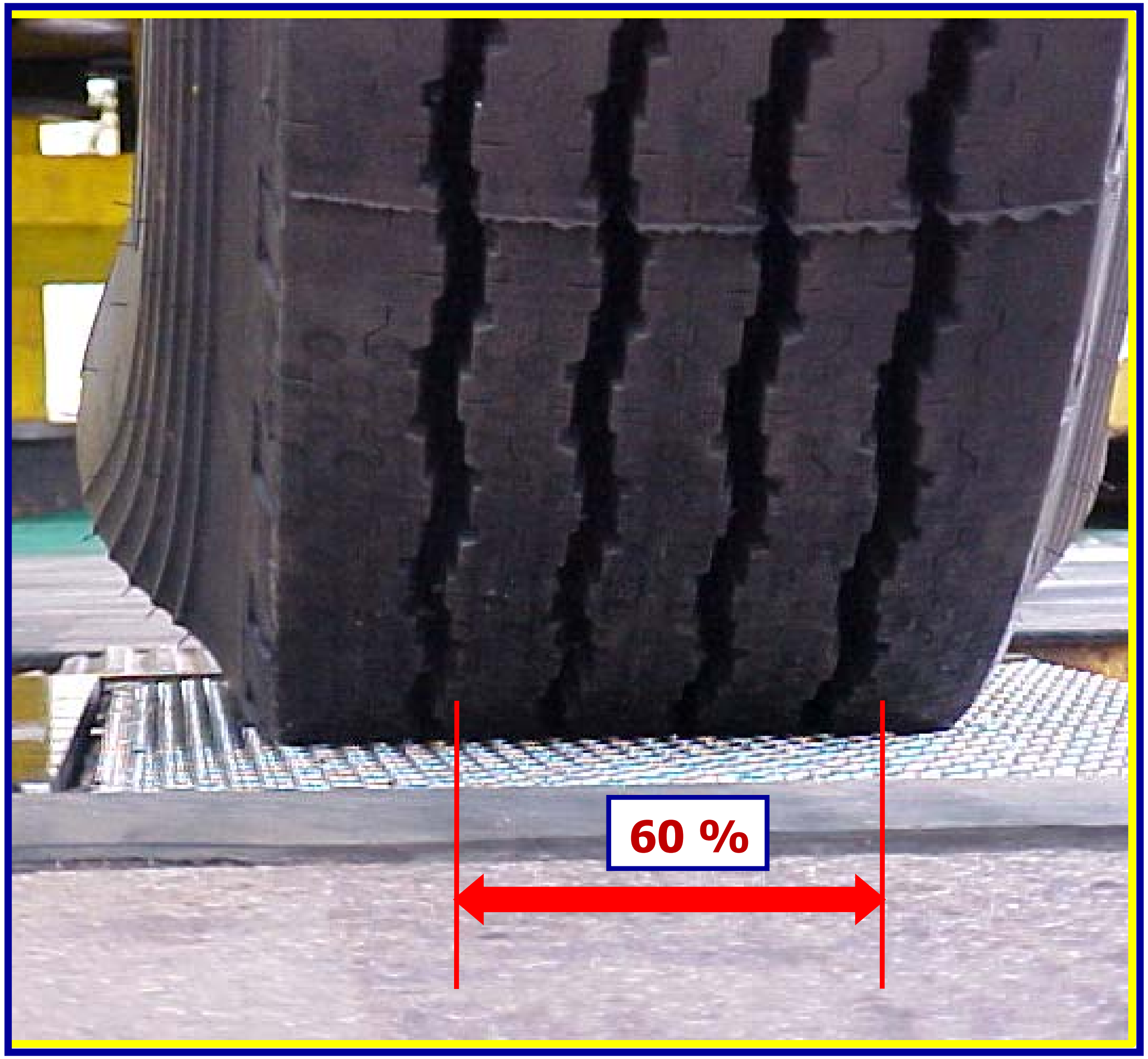
Available (Historical) TiP data sets from N3-TCC (Morton et al, 2003)

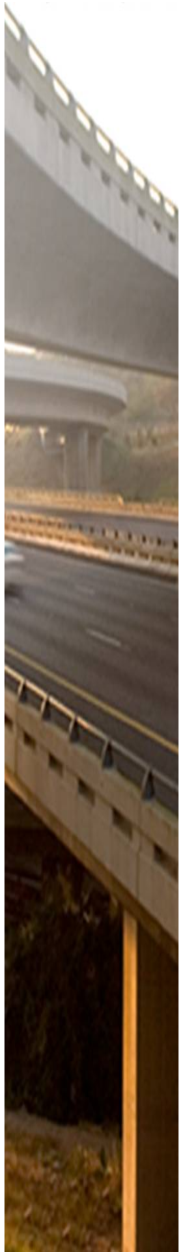
18th RPF



60 % CENTRE PORTION..(AMVCS60)

18th RPF





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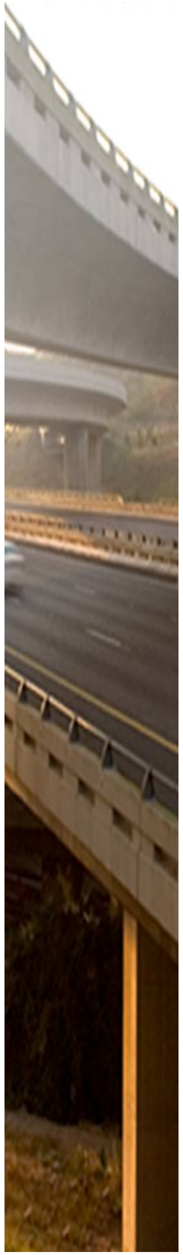
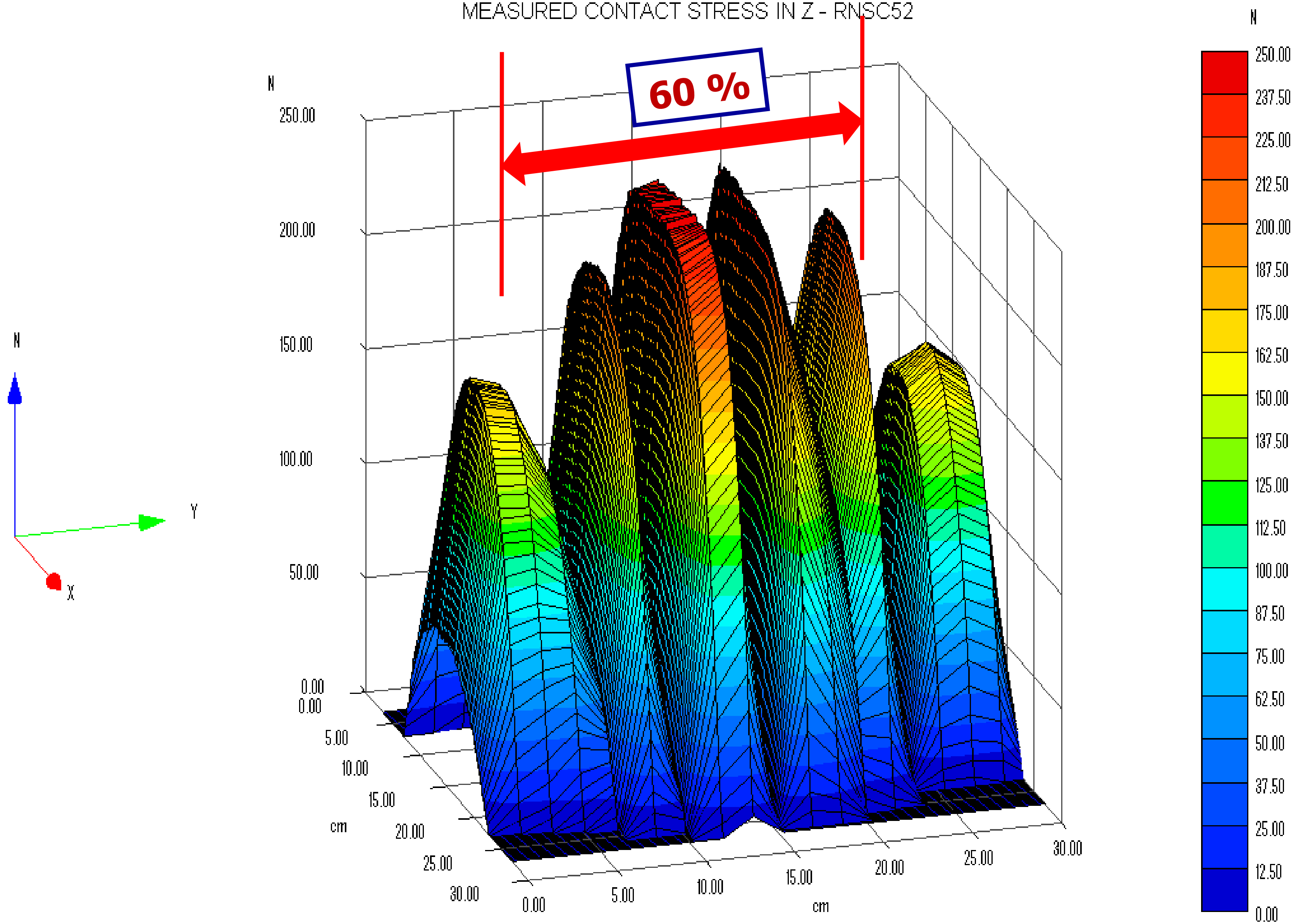
Contact Stresses & TiP (Centre 60 %).....

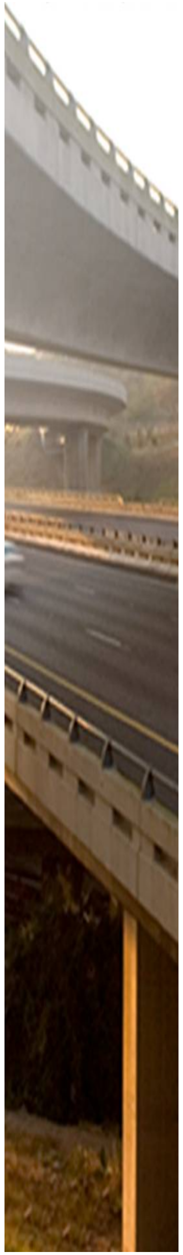
18th RPF





18th
RPF

Tyre Inflation Pressure (TiP) and Contact Stress – from 5049 paired data sets



Ln (TiP) = 2,0855 +0,6973Ln(AMVCS60)

Where:

TiP = Tyre Inflation Pressure (kPa);
AMVCS60 = Average max vertical contact stress in centre 60 % of tyre;

(Best practical relationship form 9 possibilities investigated)

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Linear Regression Analysis

Title	Simple linear Model	
Model	LnTiP ~ LnAMVCS60	
Regr Type	Linear	

Parameters	(Intercept)	LnAMVCS60
Values	2.0855	0.6973

Confidence	(Intercept)	LnAMVCS60
Std. Error	0.0635	0.0097
t value	32.8446	71.8267
Pr(>|t|)	0.0000	0.0000
2.5%	1.9610	0.6783
97.5%	2.2100	0.7163
VIF		

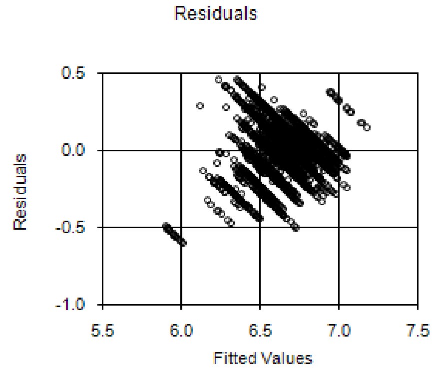
Anova Table	(Intercept)	LnAMVCS60	Residuals
Sum Sq	23.57	1.13E+02	1.10E+02
Df	1	1	5047
F value	1078.8	5159.1	
Pr(>F)	0.0000	0.0000	

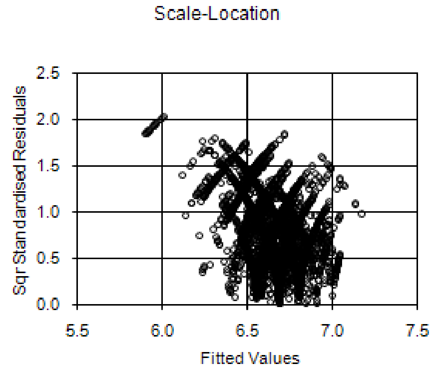
Regression	Statistics	
5049		Number of Observations
0.5055	0.5054	R-squared and Adjusted R-squared
0.1478	0.1478	Standard deviation of residuals and Std Error
-4972.8499	-4953.2690	AIC/BIC

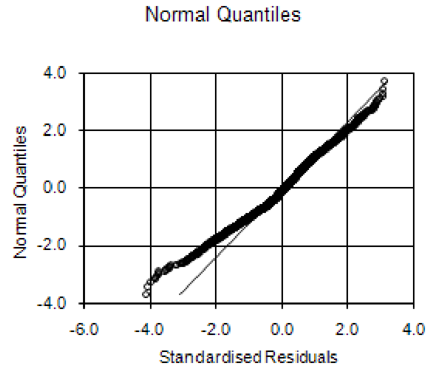
Autocorrelation	Residuals
0.0000	Positive
0.0000	Non-zero
1.0000	Negative

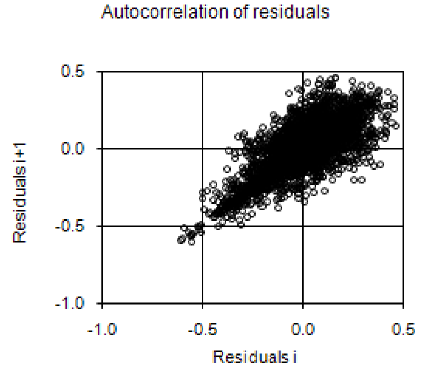
Additional	Tests
	Shapiro-Wilk test not performed
0.0000	Breusch-Pagan Test for Heteroscedasticity
0.1857	Bonferroni Adjustment Test for outliers

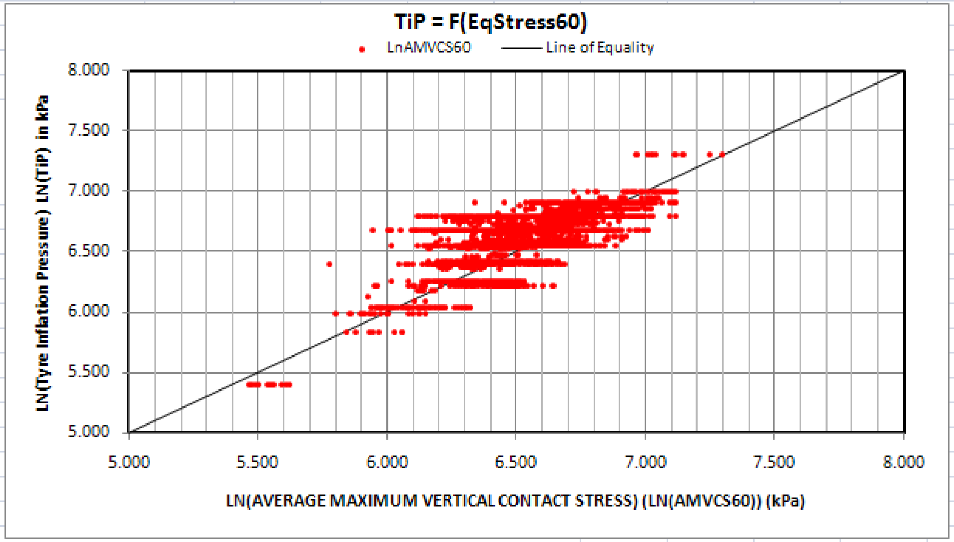
Regr Data	Enter variable names on first line			WEIGHT=	1.0000
Data No	Weight	LnTiP	LnAMVCS60	TiP	AMVCS60
1	1.00	5.394	5.485	220	241
2	1.00	5.394	5.497	220	244
3	1.00	5.394	5.476	220	239
4	1.00	5.394	5.533	220	253
5	1.00	5.394	5.545	220	256
6	1.00	5.394	5.541	220	255
7	1.00	5.394	5.553	220	258
8	1.00	5.394	5.557	220	259
9	1.00	5.394	5.537	220	254
10	1.00	5.394	5.617	220	275
11	1.00	5.394	5.606	220	272
12	1.00	5.394	5.591	220	268
13	1.00	5.394	5.489	220	242
14	1.00	5.394	5.472	220	238
15	1.00	5.394	5.464	220	236





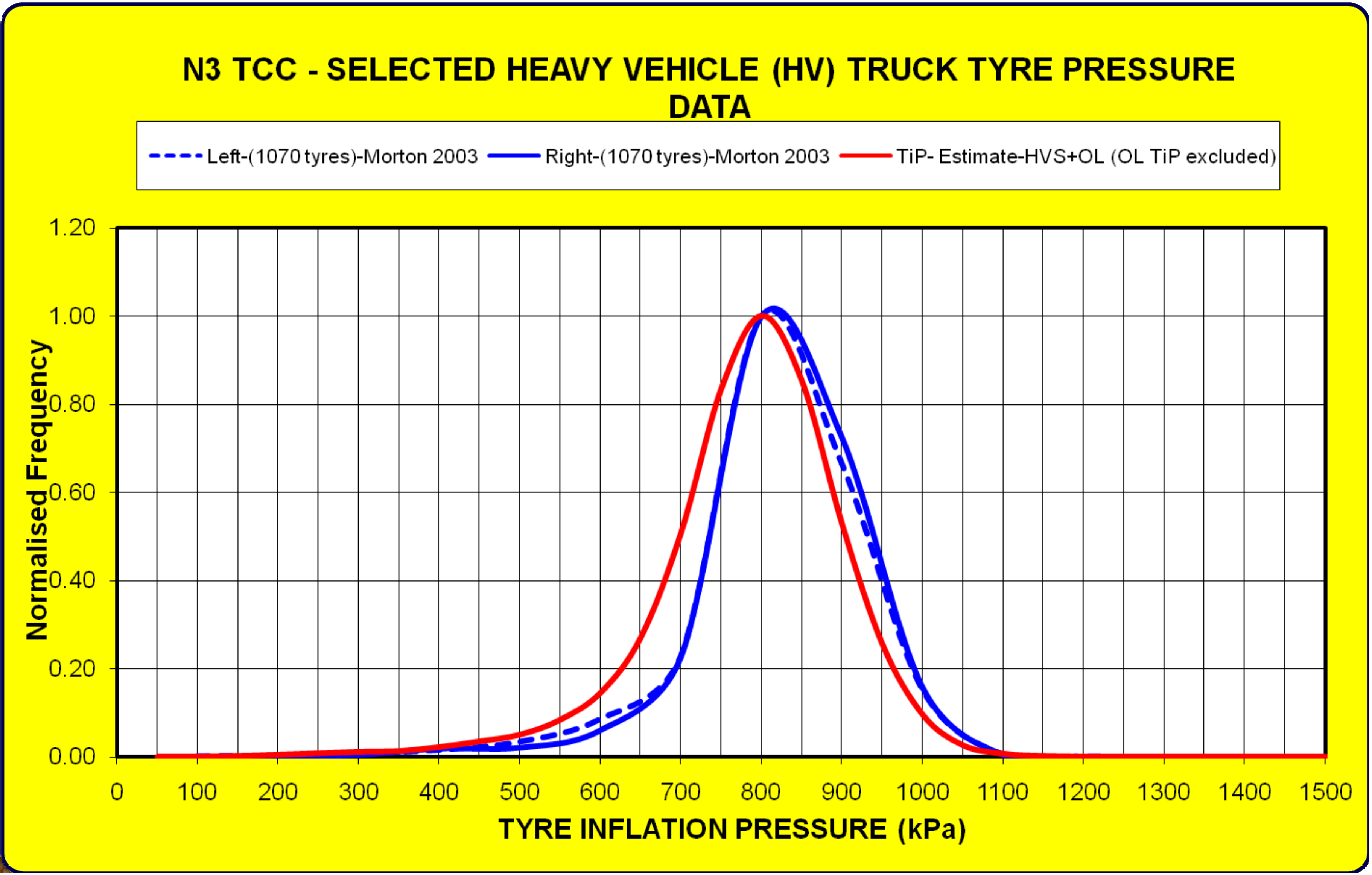






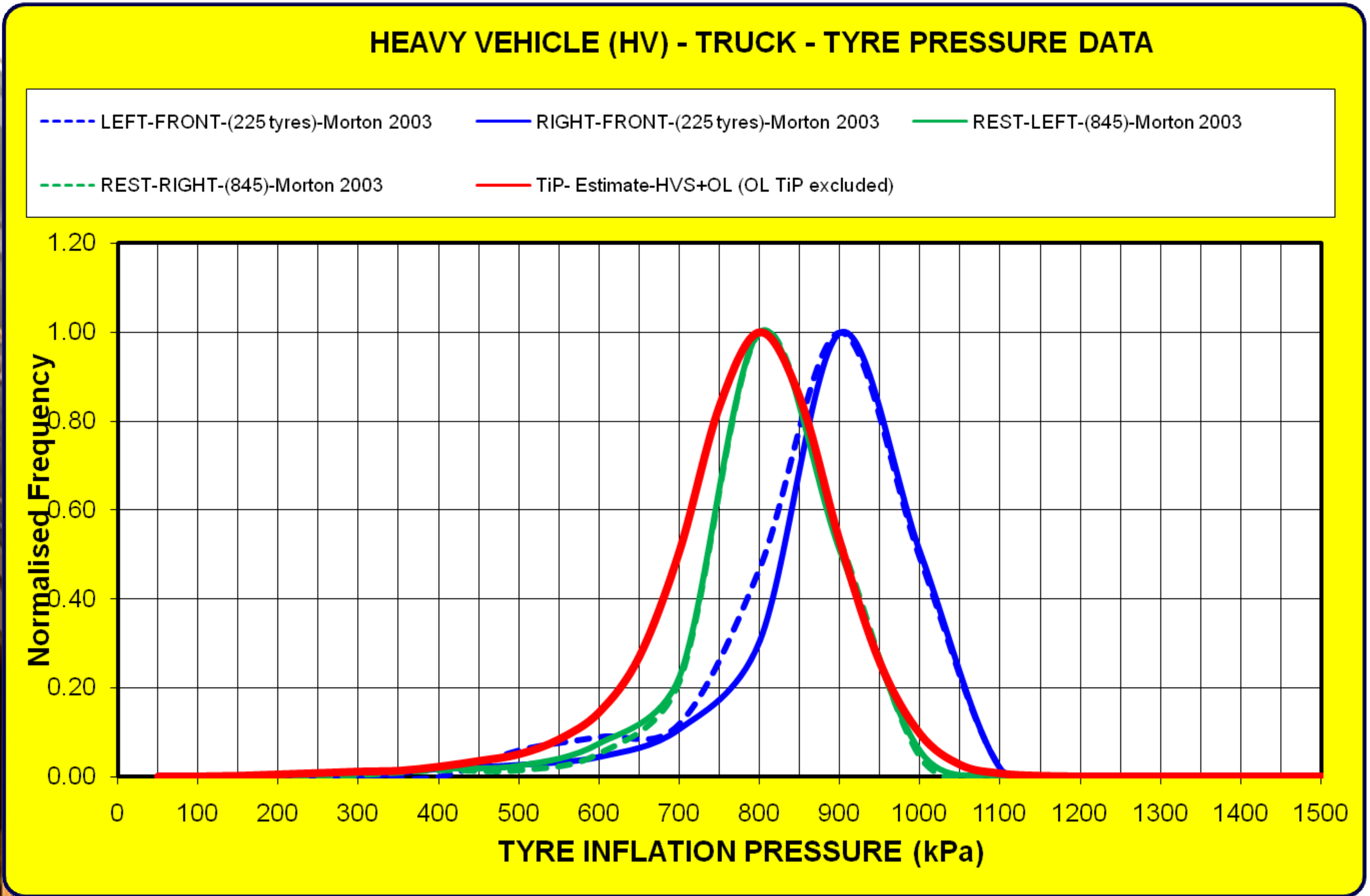
Comparison: Ln (TiP) = k1 +k2 Ln(AMVCS60) with measured TiP AT N3-TCC

18th RPF



Ln (TiP) = k1 +k2 Ln(AMVCS60) Trailing & Steering tyres…Red curve = estimate..

18th RPF



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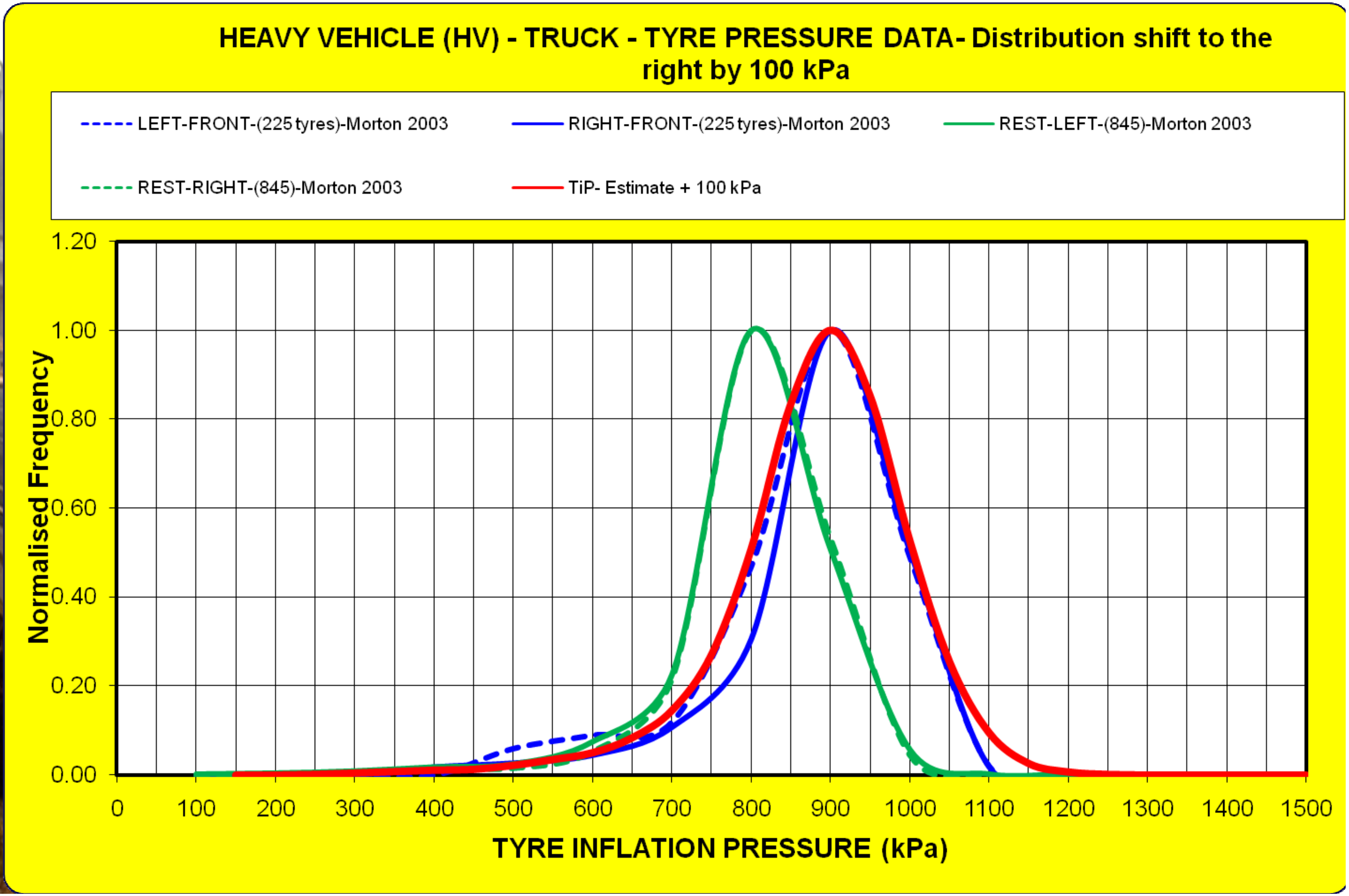
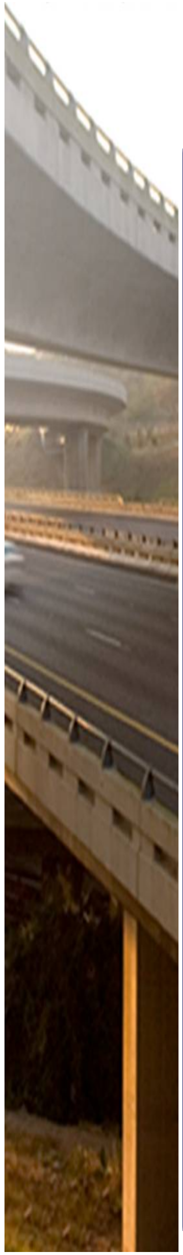
Ln (TiP) = k1 +k2 Ln(AMVCS60) & Steering axles….Red curve moved to the right by 100 kPa

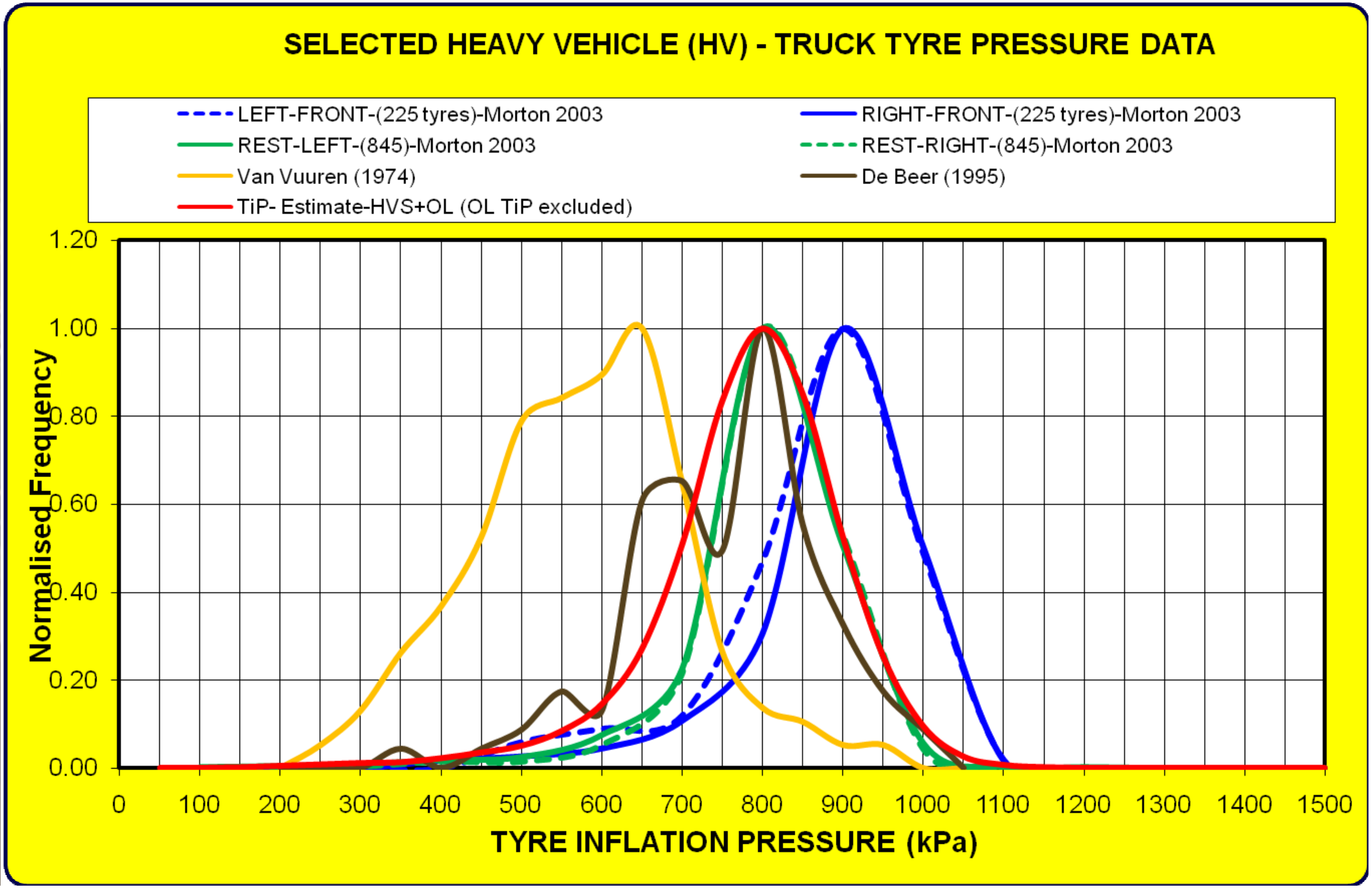
18th RPF



Comparison : With historical TiP Data sets...

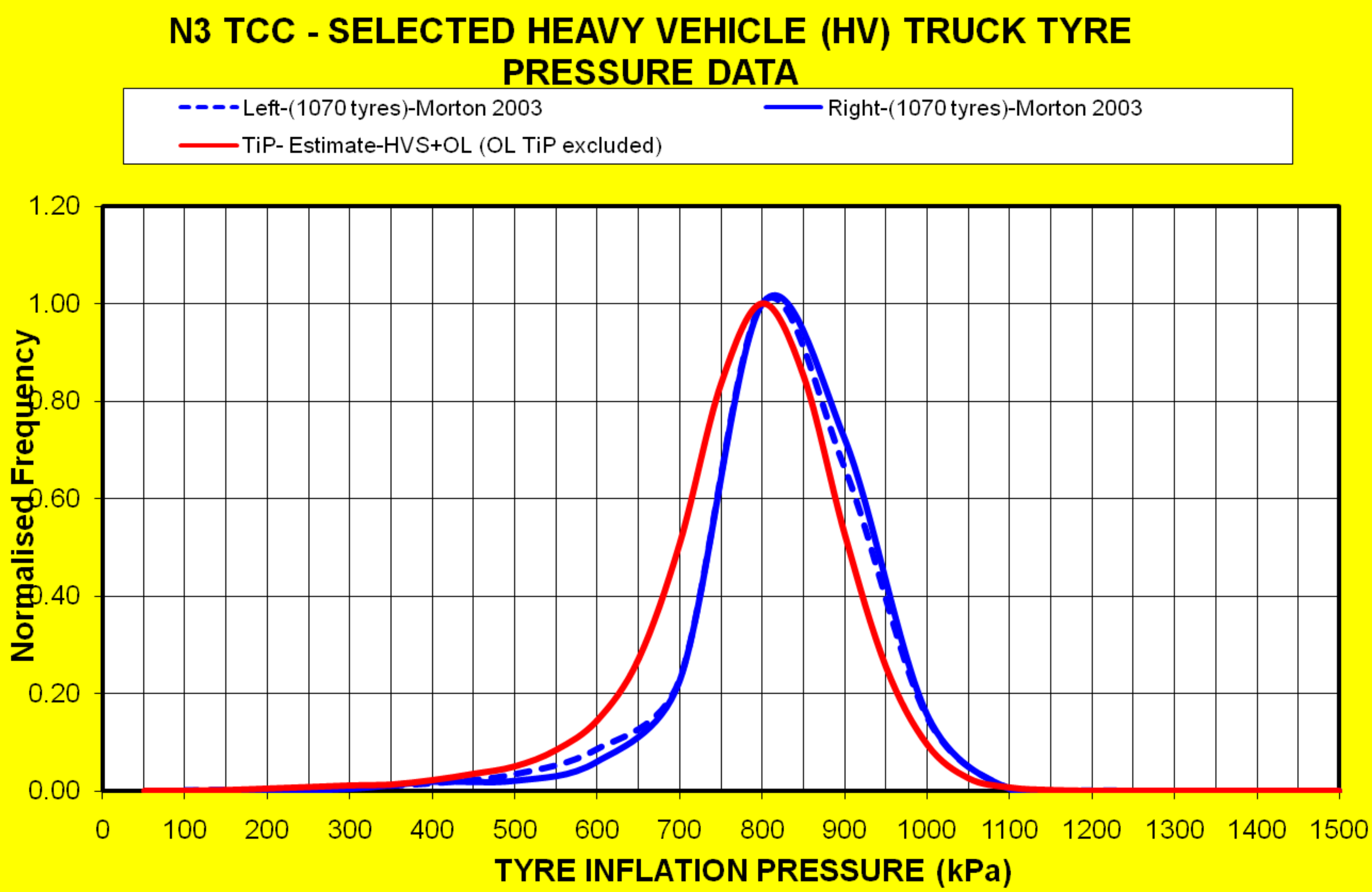
18th RPF





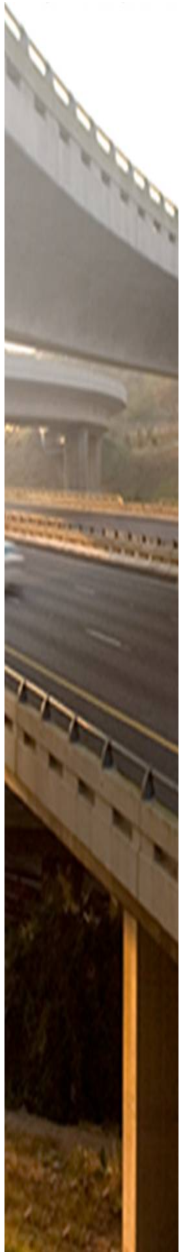
Comparison : With historical TiP Data sets...suggestion for use in SAPDM

18th RPF



Conclusions:

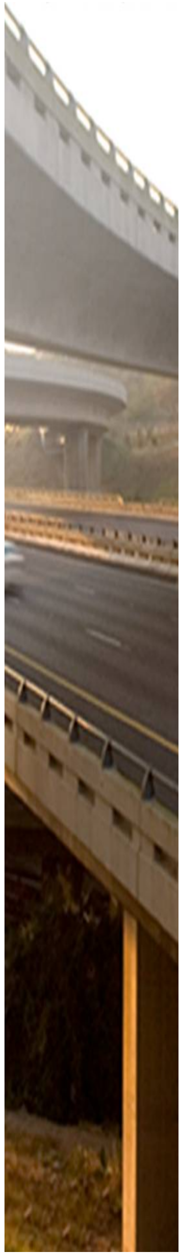
18th RPF



- New Tyre models improved for SAPDM;
- Project A-1: T-CSIS progressing well;
- Tyre Data-Integration into Project C-1 (Mechanistic Design) possible;
- Tyre Inflation Pressure (TiP) – Very promising practical relationship found with contact stress(CS):
  - TiP = exp[k1+k2ln(CS)];
- Over-all progress approx. ~ 65 %;
- Suggest to test/evaluate beta version(s) with practice;

our future through science

Project SAPDM/A-1: Tyre Contact Stress Information System (T-CSIS)



The End…

Thank You