



Comparison of Contact Stresses of the test tyres used by the 1/3rd scale Model Mobile Load Simulator (MMLS3) and the full scale tyres of the Heavy Vehicle Simulator (HVS) - A Summary -



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Project Background:



- Project initiated by Gauteng Department of Public Transport, Roads and Works (GDPTRW);
- Accelerated Pavement Testing (APT) Strategy of 2004;
- Full Scale Testing vs 1/3rd Scale Testing;
- Heavy Vehicle Simulator (HVS), and
- 1/3rd Scale Model Mobile Load Simulator (MMLS3).





Project Objectives:

- Quantification of the 3D tyre-pavement contact stresses: HVS and MMLS3 test tyres (using SIM) – 4 Studies;
- Comparison with similar previous Stress-In-Motion (SIM) studies on various HVS tyres – Z Vertical Stress only - in this paper;
- Recommendations for tyre load and inflation pressures of future Accelerated Pavement Testing (APT) on Hot Mix Asphalt (HMA) rutting tests (MMLS3 and HVS);



Heavy Vehicle Simulator (HVS) of Gautrans (GDPTRW) – Full Scale



Model Mobile Load Simulator (MMLS3) – 1/3rd Scale



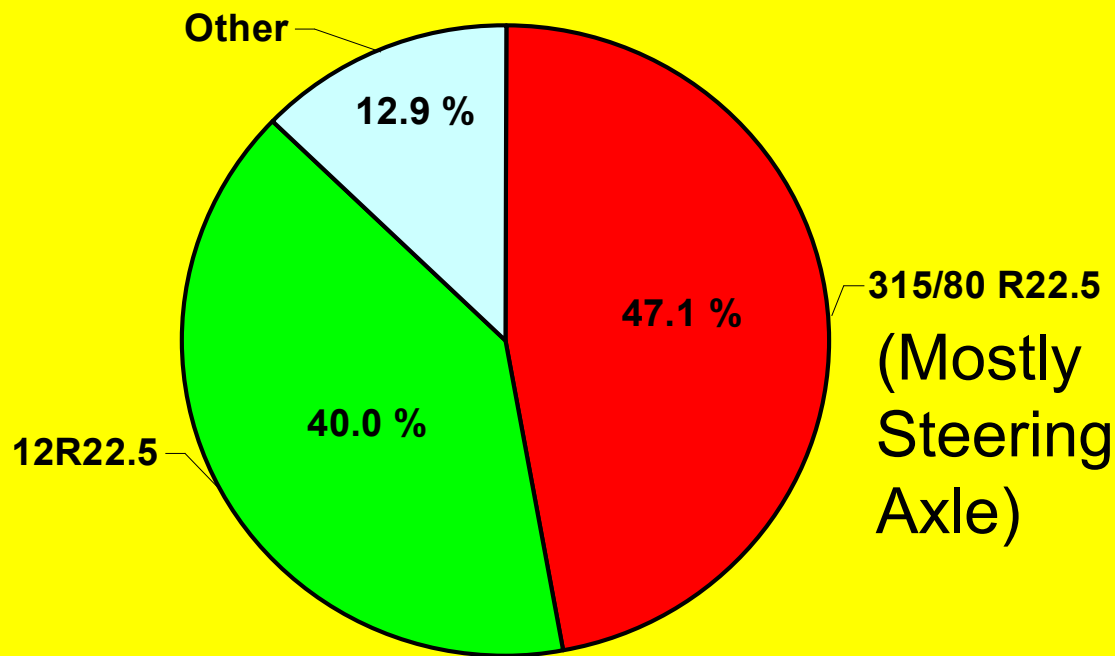
Oct 2004 - HVS –SIM TESTS



Truck Tyres Usage on N3 (2003)



LEFT - 225 STEERING TYRES (N3-26/02/2003-06/03/2003)



HVS Mk IV+ Full Scale Test Tyres



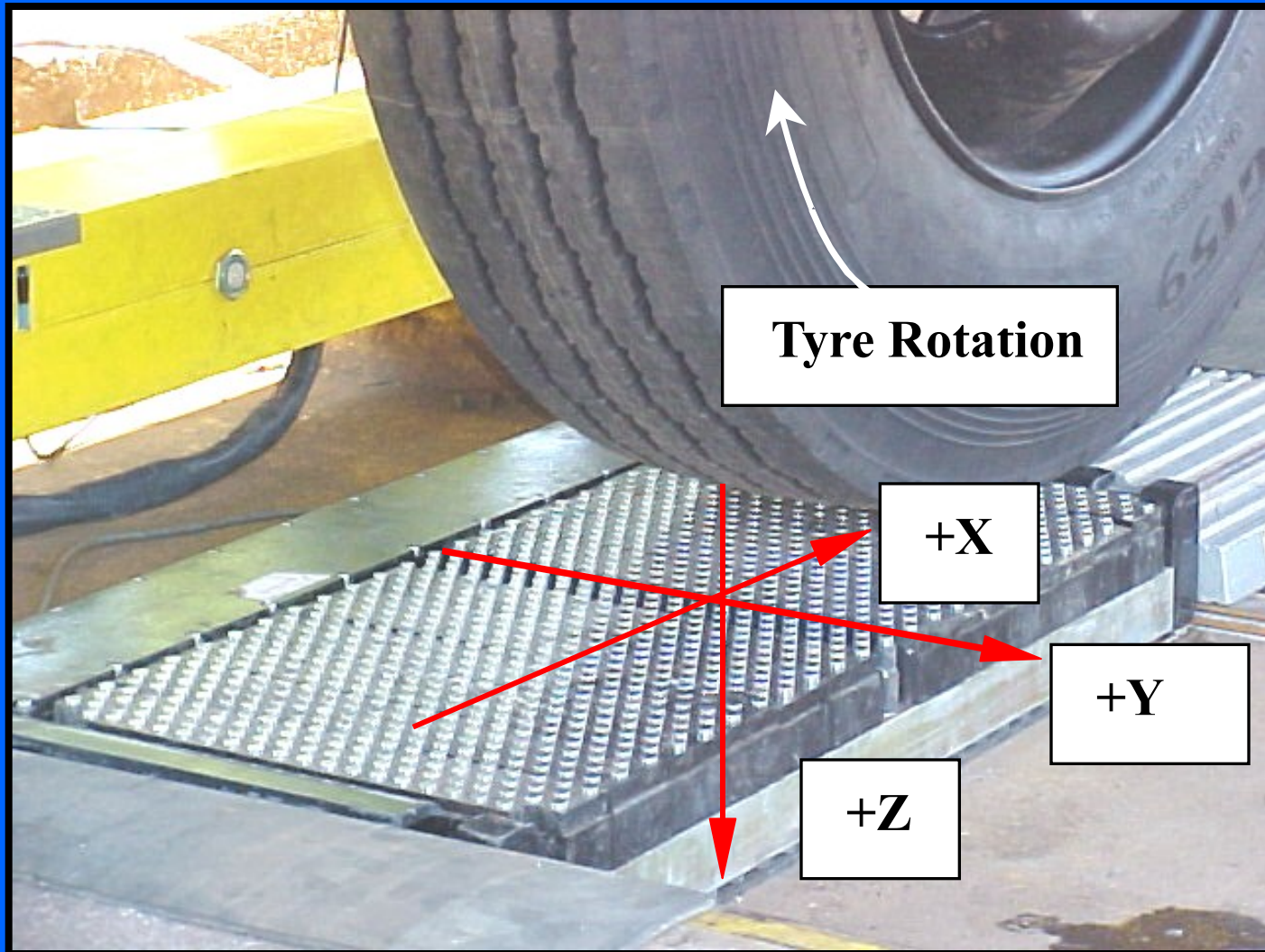
DUAL: 12R22.5



SINGLE: 315/80 R22.5
(Steering Axle)



SAE sign convention used during SIM measurements. X-Longitudinal, Y-Lateral and Z -Vertical loads/stresses.



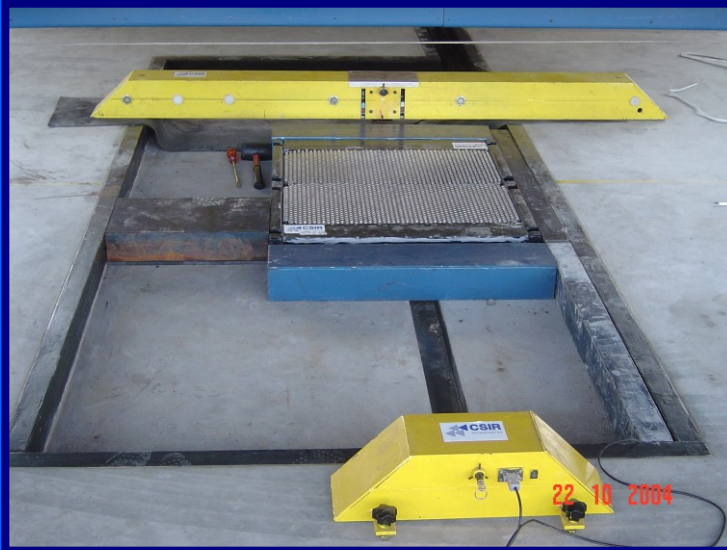
Oct 2004 – Preparation of Test Facility @ Gautrans- KoedoesPoort



September 2004 – 250 mm Concrete slab @ Gautrans- KoedoesPoort



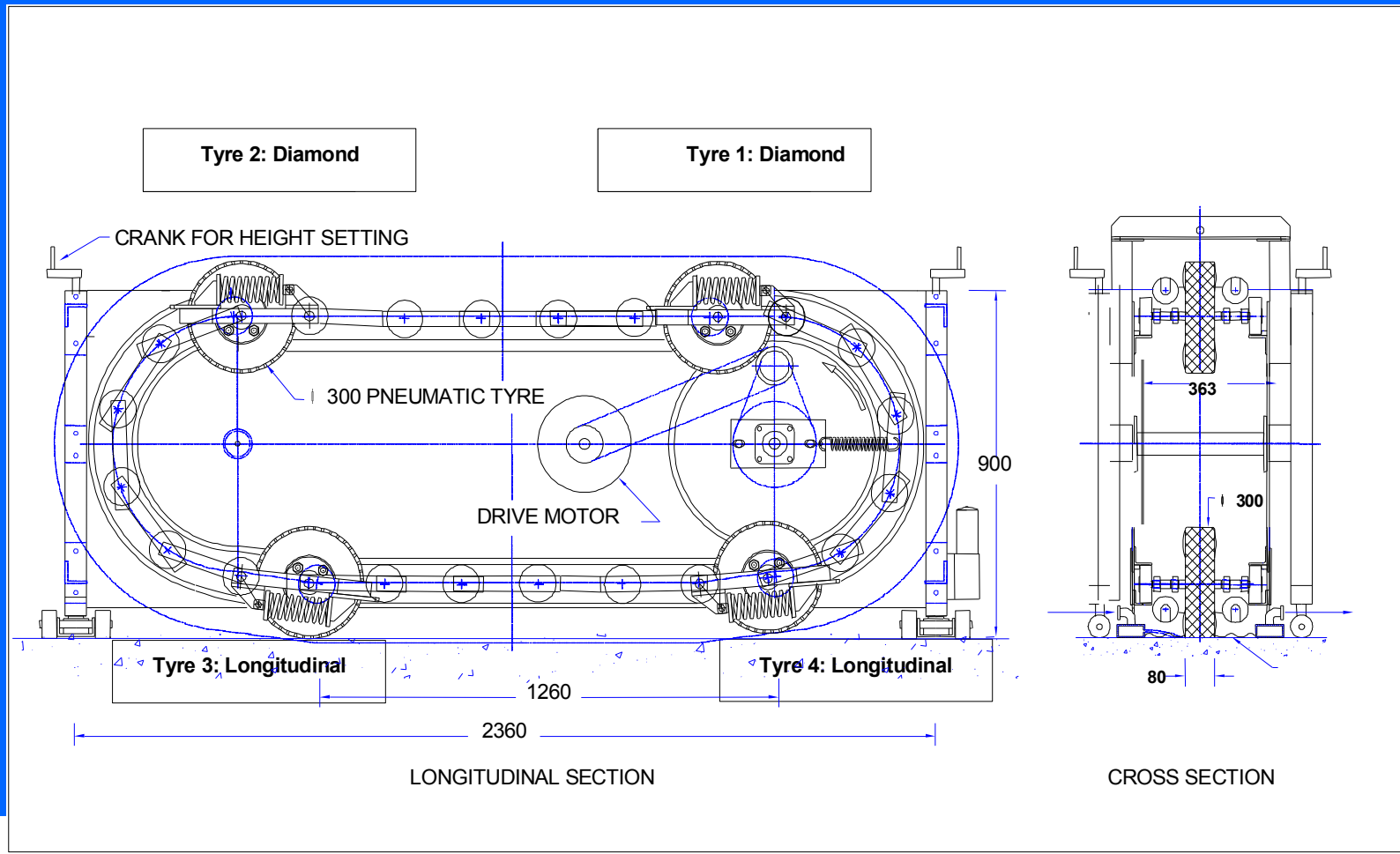
Dual SIM system during HVS tyre testing @ Gautrans



MMLS3 Test Tyres



Model Mobile Load Simulator (MMLS3) – 1/3rd Scale



Characteristics of MMLS3 (highway applications) and HVS Mk IV+



Characteristic	MMLS3 (1/3 rd Scale)	HVS (Full Scale)
Nominal Constant Tyre Loading Range (kN)	1.9 to 2.9	30 to 205 (Dual, Single, Aircraft)
Footprint area (approximately), depending on tyre type, loading and inflation pressure (cm ²)	34 to 45	380 to 881
Inflation pressure (kPa) @ 25 °C	560 to 860	420 to 1 000
Nominal Speed Ranges: (km/h)	Simulated: 3 to 26 (Actual 1 to 8.67)	6 to 12
Approx. wheel load repetitions per hour (rep/hr)	7 200	Uni-directional: 660, and Bi-directional: 1 300

SIM-HVS TEST MATRIX – 12R22.5 TYRES



Table 1: Proposed test matrix for the SIM tests on the 12R22.5 G391 HVS test tyres

HVS DUAL TYRE LOAD (kN)	COLD TYRE INFLATION PRESSURE ² (kPa)					
	520	620	720	800	950	1000
30	√	√	√	√	√	?
40	√	√	√	√	√	?
70	√	√	√	√	√	?
80	√	√	√	√	√	?
100	X	√	√	√	X	?

Approximate rated load and Inflation pressure @ 81 – 95 km/h – Dual tyres:

Shaded areas: 23.9 kN @ 600 kPa to 30.0 kN @ 800 kPa

√: Intend to measure
?: Depend on safety conditions
X : Intend not to measure – safety risk

Model Mobile Load Simulator (MMLS3) – 1/3rd Scale



- 1.8 kN, 2.7 kN, and 2.9 kN;
- For tyre inflation pressures between 400 to 860 kPa, all 4 x tyres loaded and inflated to same values by MMLS3 Team;
- MMLS3 Speeds: 3 km/h, 13 km/h and 26 km/h.



Test Matrices: SIM-MMLS3



Total of Tests (S1/S2)				MMLS3 Load 2.7 kN			MMLS3 Load 2.9 kN			Inflation Pressure (kPa) (S1/S2)
	0.27 8 m/s	1.20 4 m/s	2.40 7 m/s	0.278 m/s	1.20 4 m/s	2.40 7 m/s	0.27 8 m/s	1.20 4 m/s	2.40 7 m/s	
27/26	3*	3	3	3	3	3	3	3	3	400/520
27/27	3	3	3	3	3	3	3	3	3	520/700
27/27	3	3	3	3	3	3	3	3	3	700/800
27/27	3	3	3	3	3	3	3	3	3	800/860
215	Grand total of number of tests completed (S1 & S2)									
1 432	Grand total of number of tests processed (S1 & S2) (Total of all tests on all 4 tyres)									

STATIC TYRE PRINTS (12R22.5)

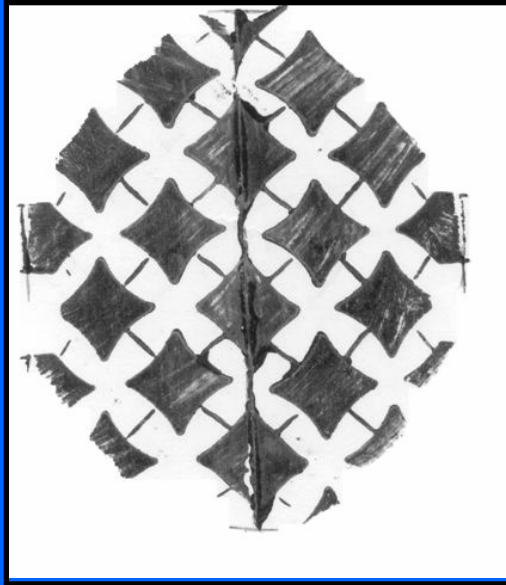


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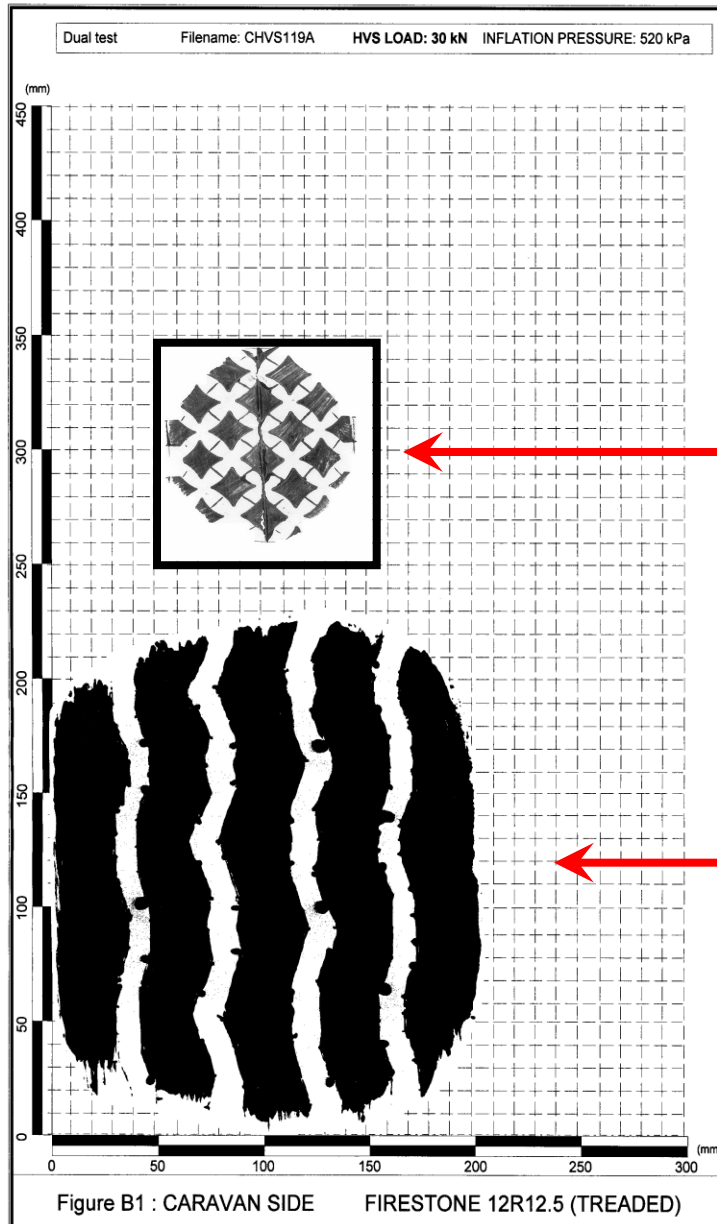
MMLS3 TYRE PRINTS



10 to 26 times smaller than 12R22.5 Full Scale Tyre Prints
–depending on load and inflation pressure level.



Relative Comparison



MMLS3-Square Profile
(2.9 kN @ 700 kPa)

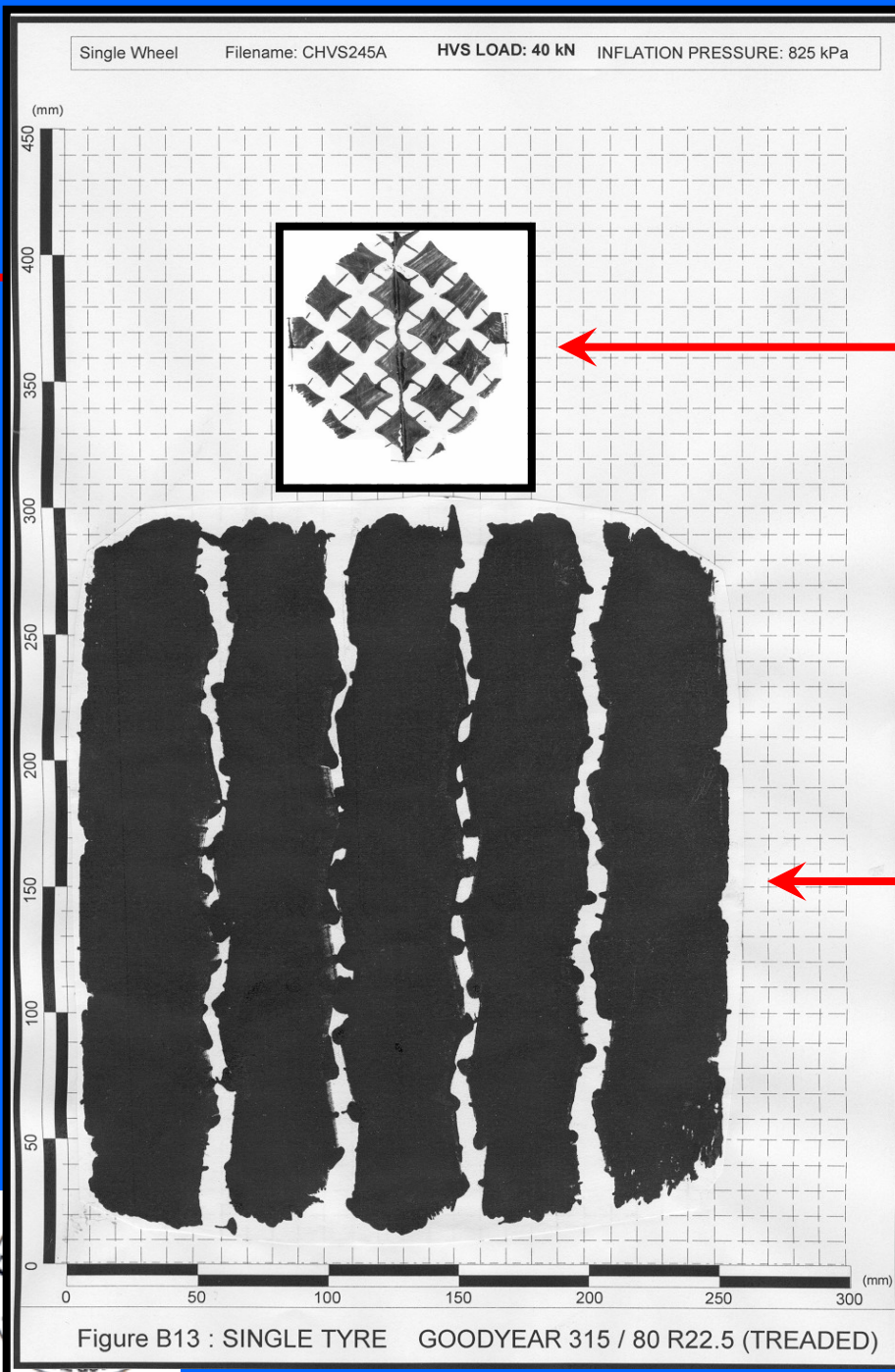
HVS 12R22.5
(30 kN @ 520 kPa)



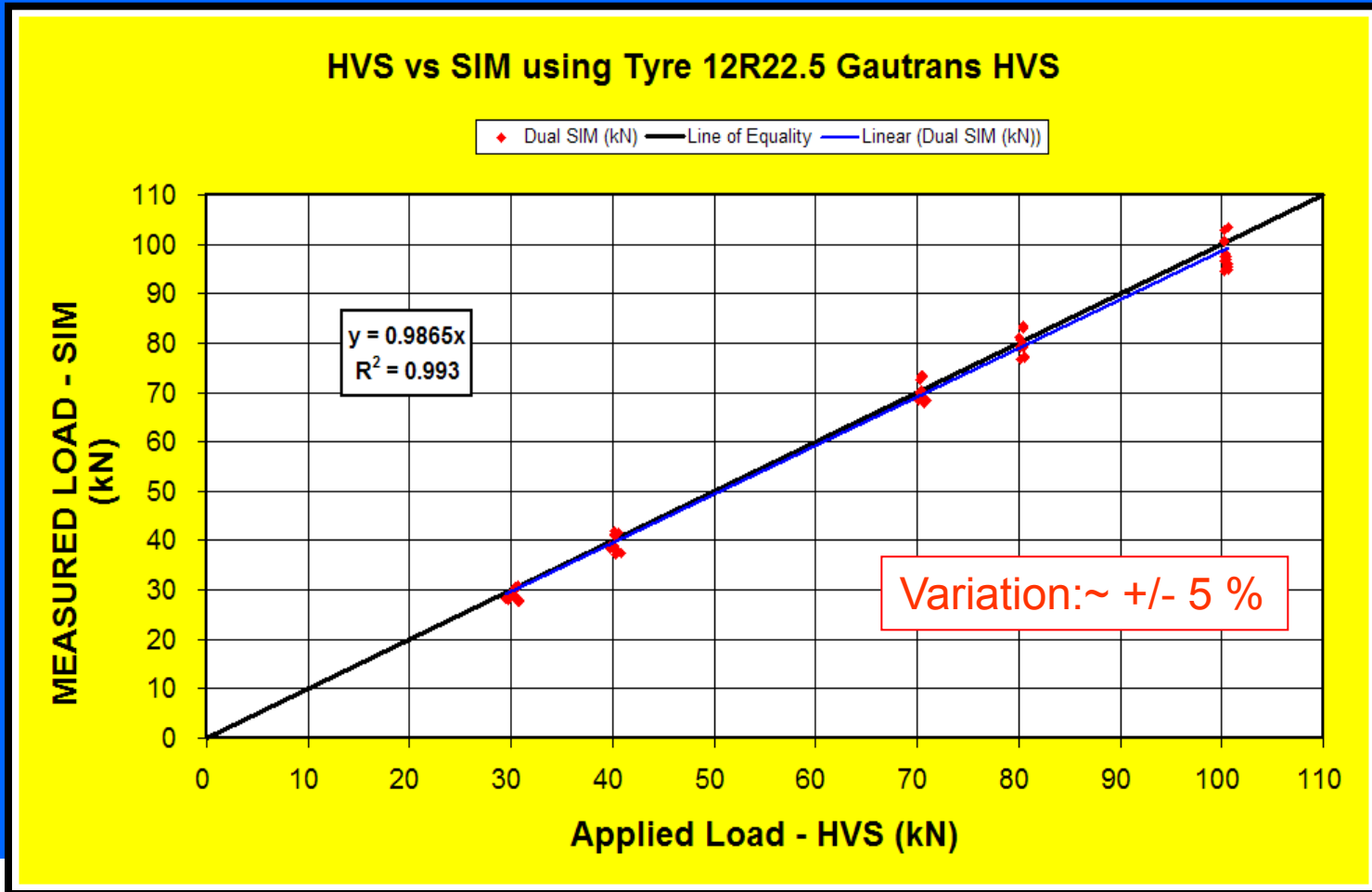
Steering Tyres

MMLS3-Square Profile
(2.9 kN @ 700 kPa)

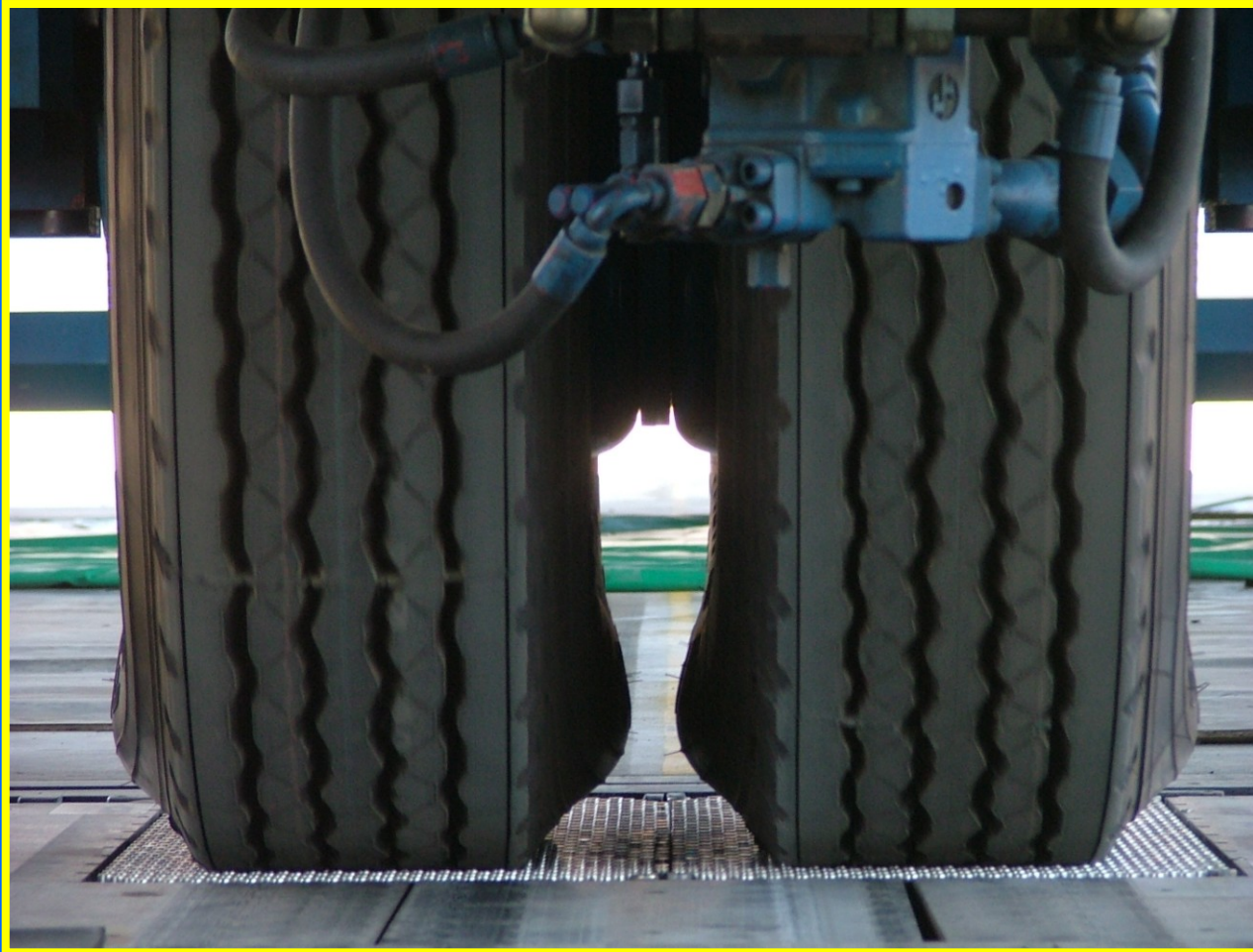
HVS 315/80 R22.5
(Steering Tyre – 40 kN
@ 825 kPa)



TYRE LOAD COMPARISON – HVS-SIM



HEAVY VEHICLE SIMULATOR (HVS) DUAL TEST TYRES (12R22.5)



Smooth Plates – HVS Dual Tyre Tests



22 10 2004

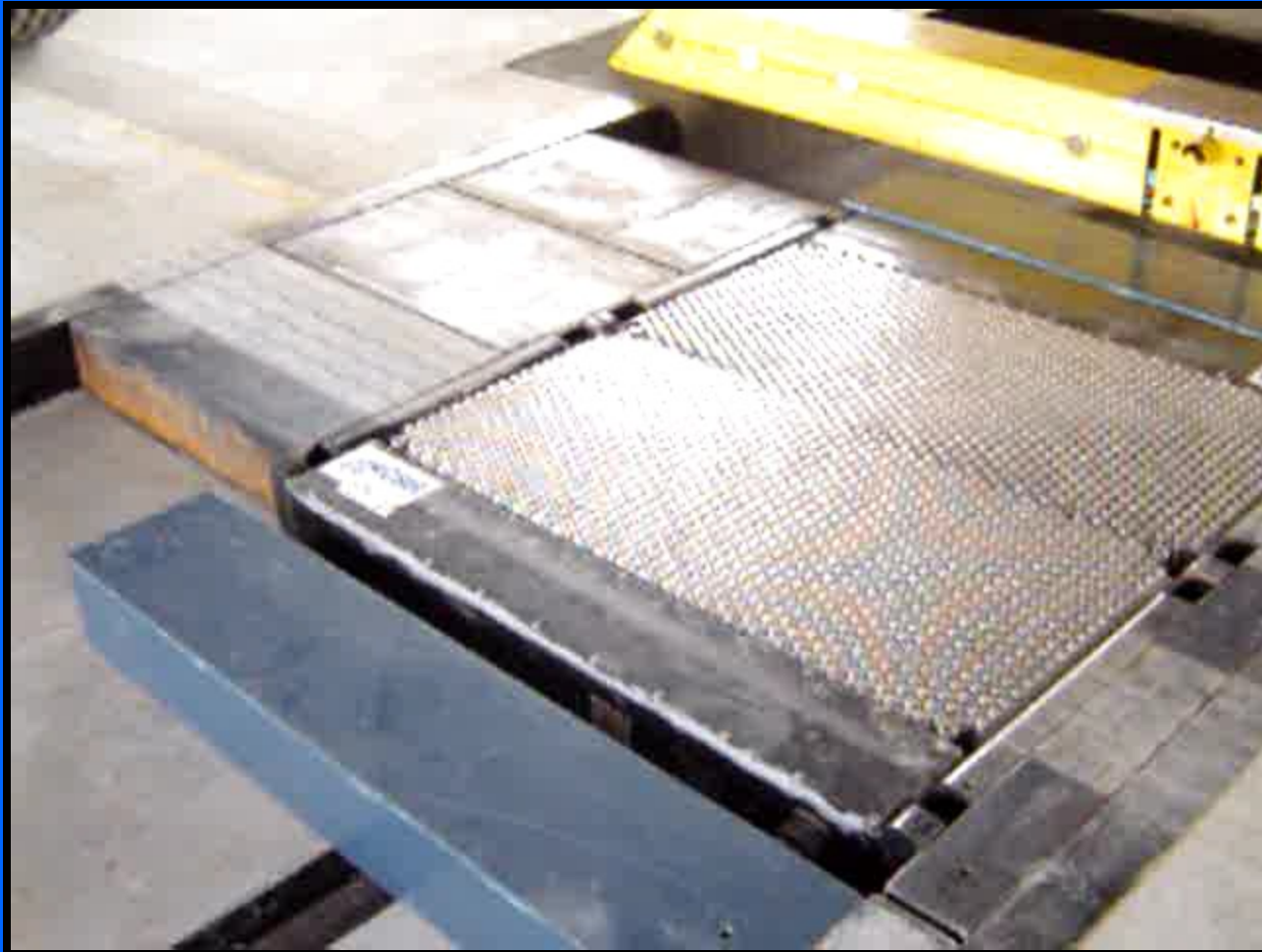


3D Contact Stresses: MMLS3 – Square Tyre





3D Contact Stresses: MMLS3 – Square Tyre



Typical SIM Data – Z - Vertical Contact Stress-Full Scale



Tyre Tested 12R22.5 (HP3000 P.R. 152/148L TREADED)

Inflation Pressure = 1000 kPa

Applied Vertical Dual Load (HVS) = 30.1 kN

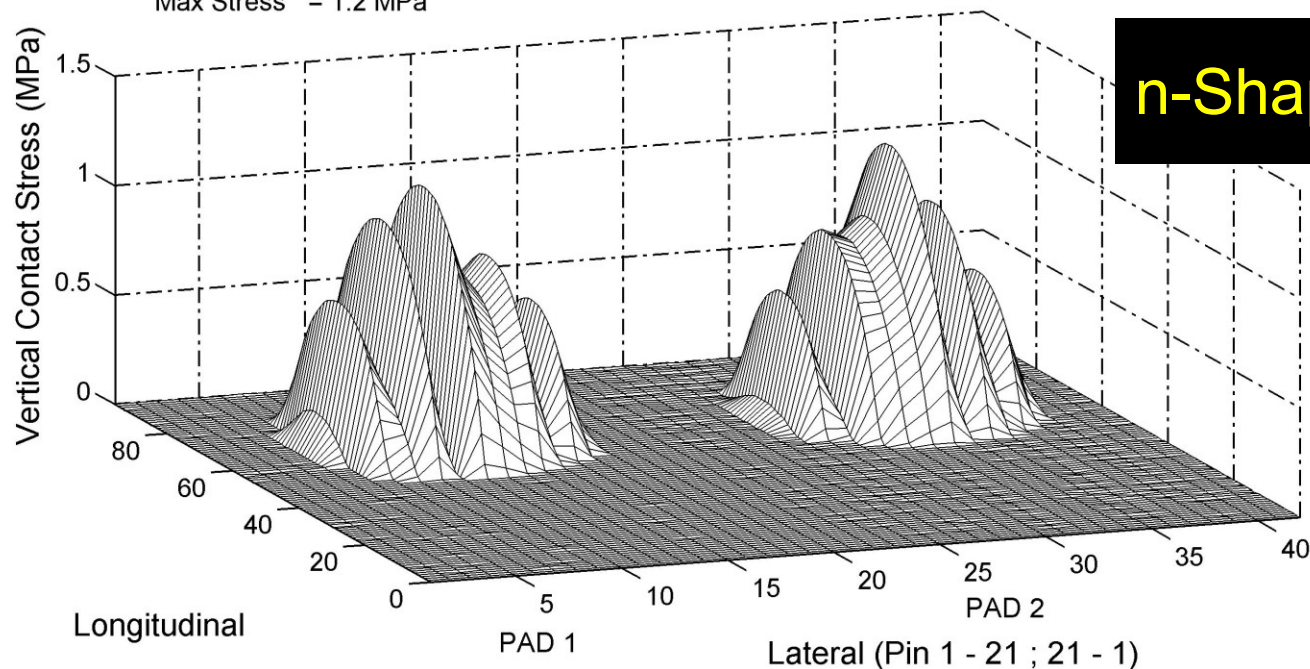
Wheel speed = 1.06 m/s

Max Stress = 1.2 MPa

Measured Vertical Total Load = 29.5 kN

Measured Vertical Load (Pad 1) = 14.8 kN

Measured Vertical Load (Pad 2) = 14.7 kN



Filename : HVS040az (hvsdualbwfig.m)

FIGURE D26Z



STANDARD TYRE LOAD: 40 kN, 520 kPa

Tyre Tested 12R22.5 (HP3000 P.R. 152/148L TREADED)

Inflation Pressure = 520 kPa

Applied Vertical Load (HVS) = 40.3 kN

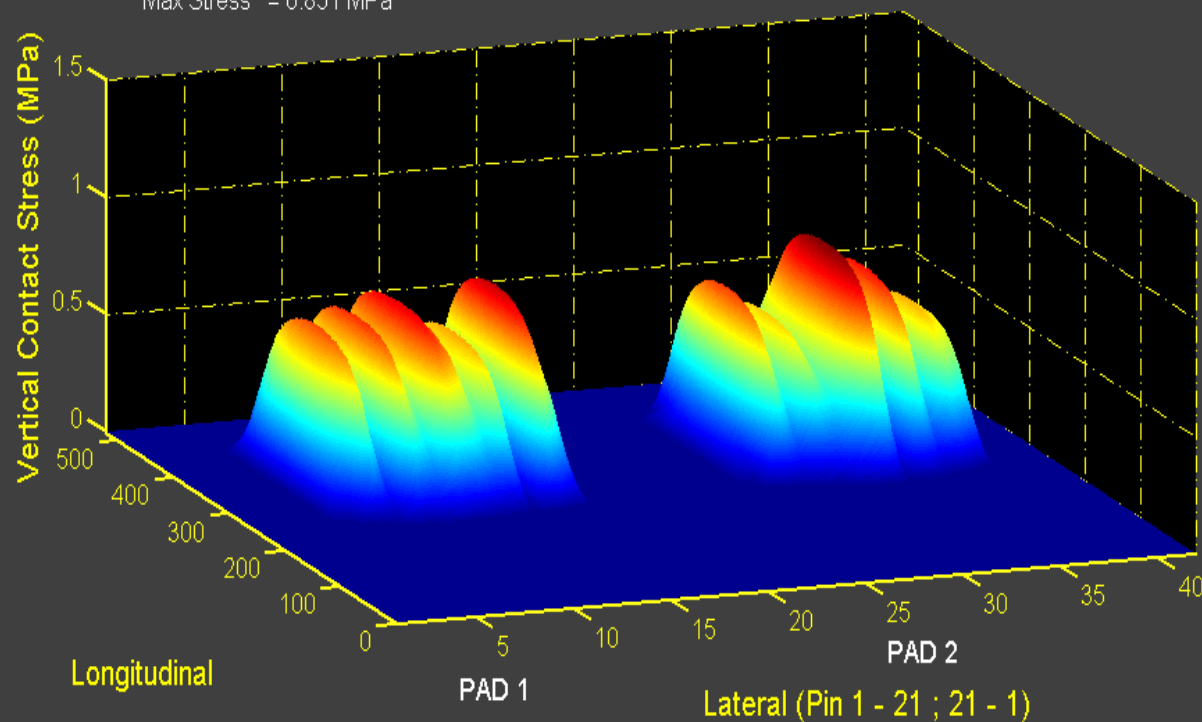
Wheel speed = 1.03 m/s

Max Stress = 0.851 MPa

Measured Vertical Total Load = 37.2 kN

Measured Vertical Load (Pad 1) = 19.6 kN

Measured Vertical Load (Pad 2) = 17.6 kN



Filename : HVS122az (hvsdaul.m)



STANDARD TYRE LOAD: 40 kN, 720 kPa

Tyre Tested 12R22.5 (HP3000 P.R. 152/148L TREADED)

Inflation Pressure = 720 kPa

Applied Vertical Load (HVS) = 40.2 kN

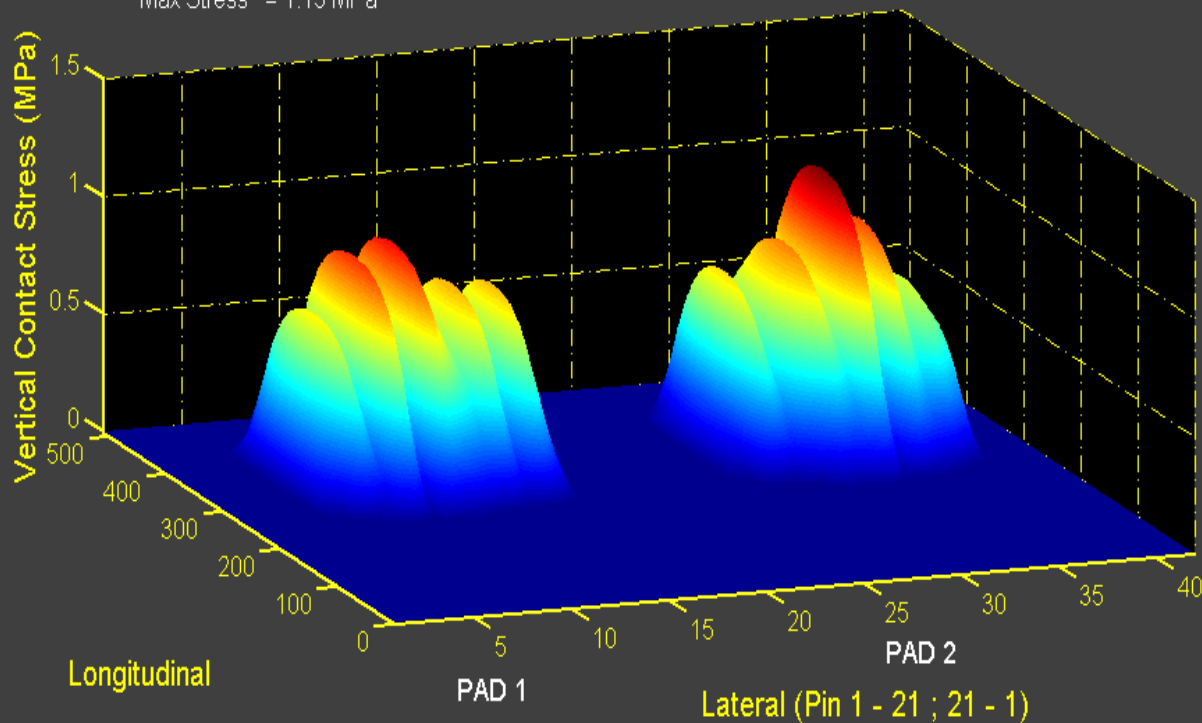
Wheel speed = 1.02 m/s

Max Stress = 1.15 MPa

Measured Vertical Total Load = 40.4 kN

Measured Vertical Load (Pad 1) = 19.8 kN

Measured Vertical Load (Pad 2) = 20.6 kN



Filename : HVS091az (hvsdaul.m)



STANDARD TYRE LOAD: 40 kN, 1000 kPa

Tyre Tested 12R22.5 (HP3000 P.R. 152/148L TREADED)

Inflation Pressure = 1000 kPa

Applied Vertical Load (HVS) = 40.1 kN

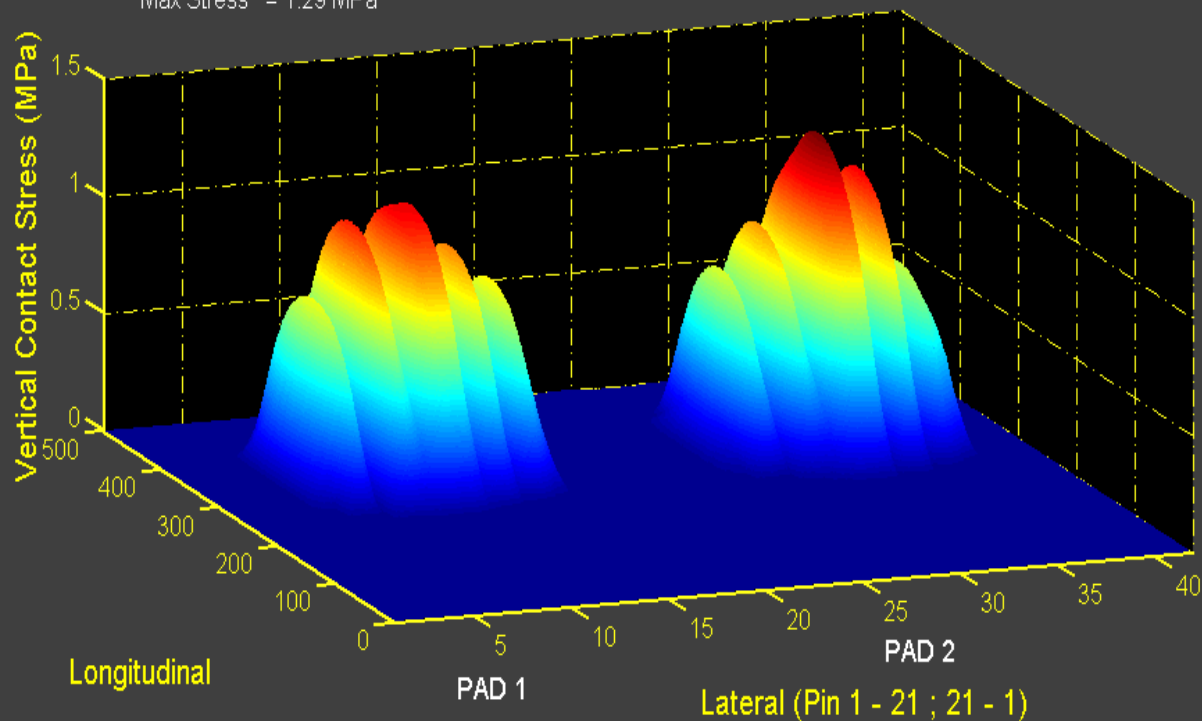
Wheel speed = 1.02 m/s

Max Stress = 1.29 MPa

Measured Vertical Total Load = 37.8 kN

Measured Vertical Load (Pad 1) = 19.3 kN

Measured Vertical Load (Pad 2) = 18.5 kN



Filename : HVS043az (hvsdaul.m)



3D Contact Stresses: HVS – Extreme Loading on SIM – 315/80 R22.5 Tyre



Typical SIM Data – Z-Vertical Stress - Overloading - Full Scale



Tyre Tested 12R22.5 (HP3000 P.R. 152/148L TREADED)

Inflation Pressure = 520 kPa

Applied Vertical Dual Load (HVS) = 100.7 kN

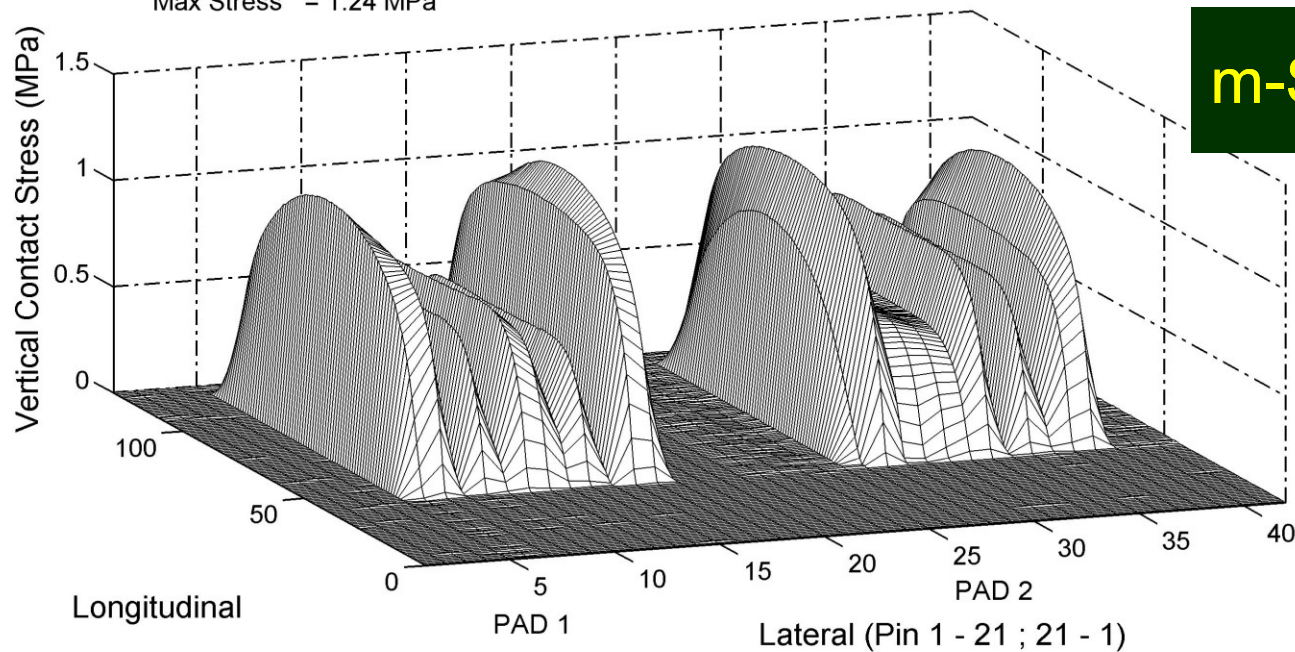
Wheel speed = 1.01 m/s

Max Stress = 1.24 MPa

Measured Vertical Total Load = 94.6 kN

Measured Vertical Load (Pad 1) = 47.1 kN

Measured Vertical Load (Pad 2) = 47.6 kN



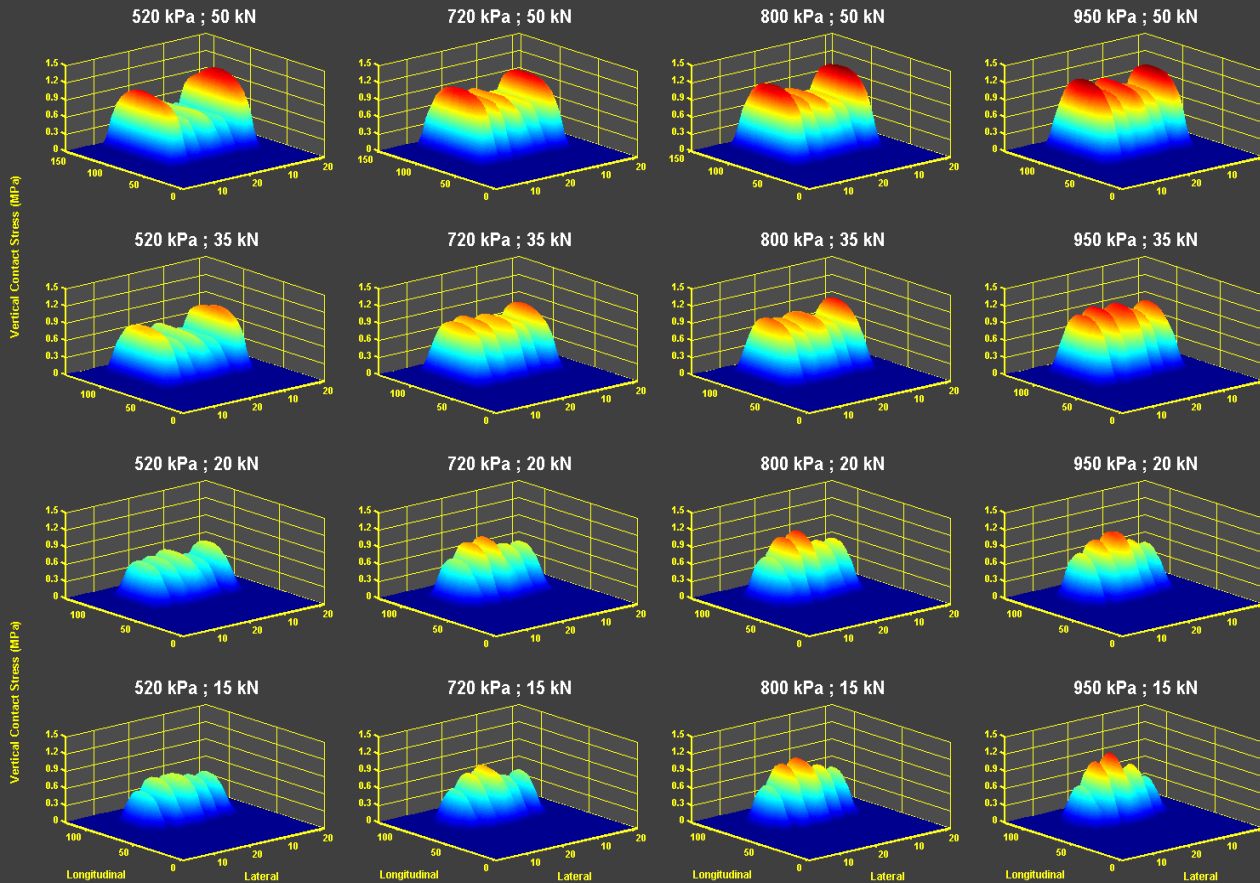
Filename : HVS131az (hvsdualbwfig.m)

FIGURE D5Z



“FINGER PRINTING” - VERTICAL CONTACT STRESS (HVS 12R22.5)

TYRE LOAD



Pad 1 Tyre 12R22.5 (HP 3000) TREADED

INFLATION PRESSURE



Model Mobile Load Simulator (MMLS3) – 1/3rd Scale





Model Mobile Load Simulator (MMLS3) – 1/3rd Scale- on SIM device



Close-up of Square Profile MMLS3 Test Tyre





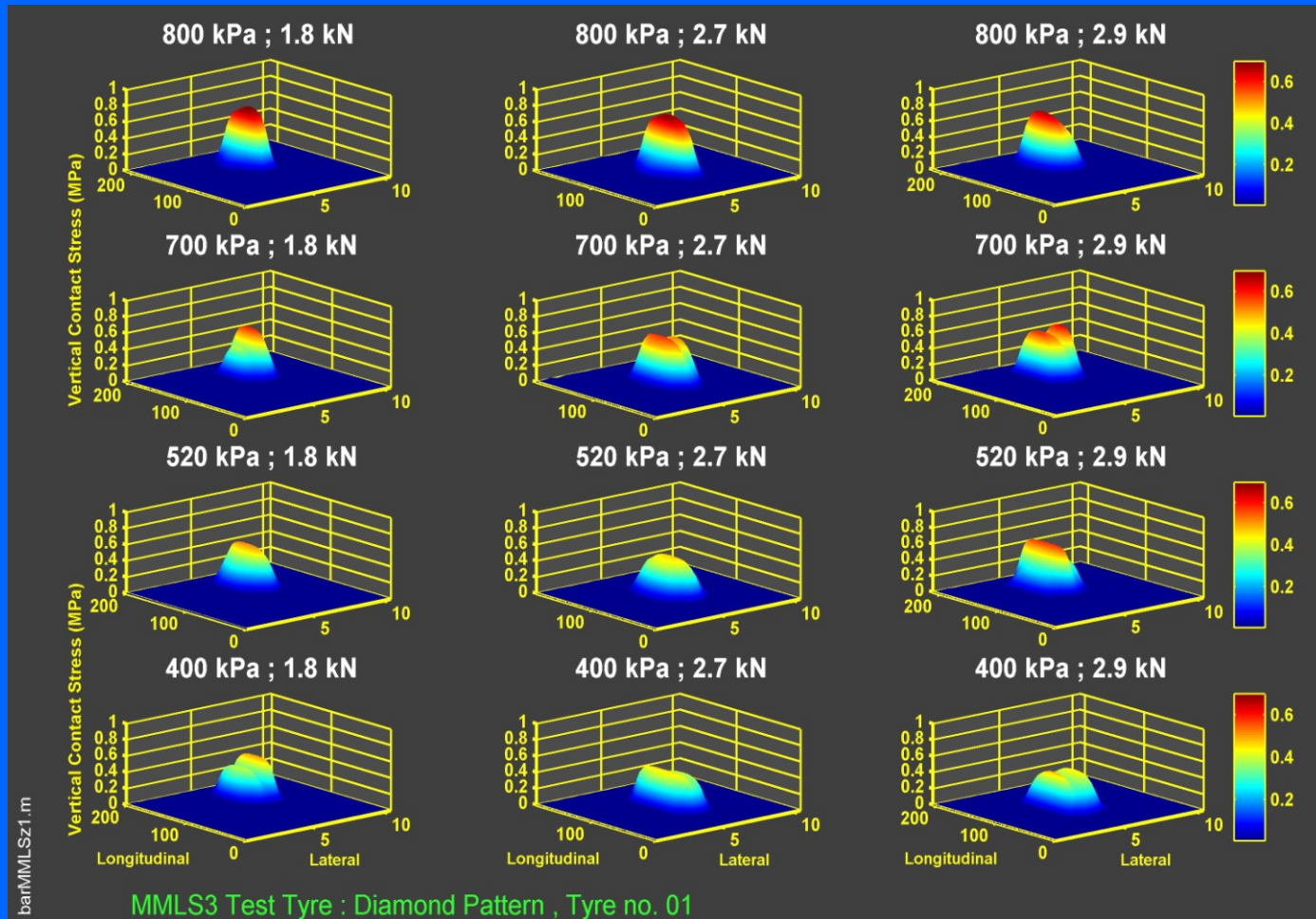
Close-up of Square MMLS3 Test Tyre on SIM Textured (Rough) Surface



"FINGER PRINTING" - VERTICAL CONTACT STRESS (MMLS3)



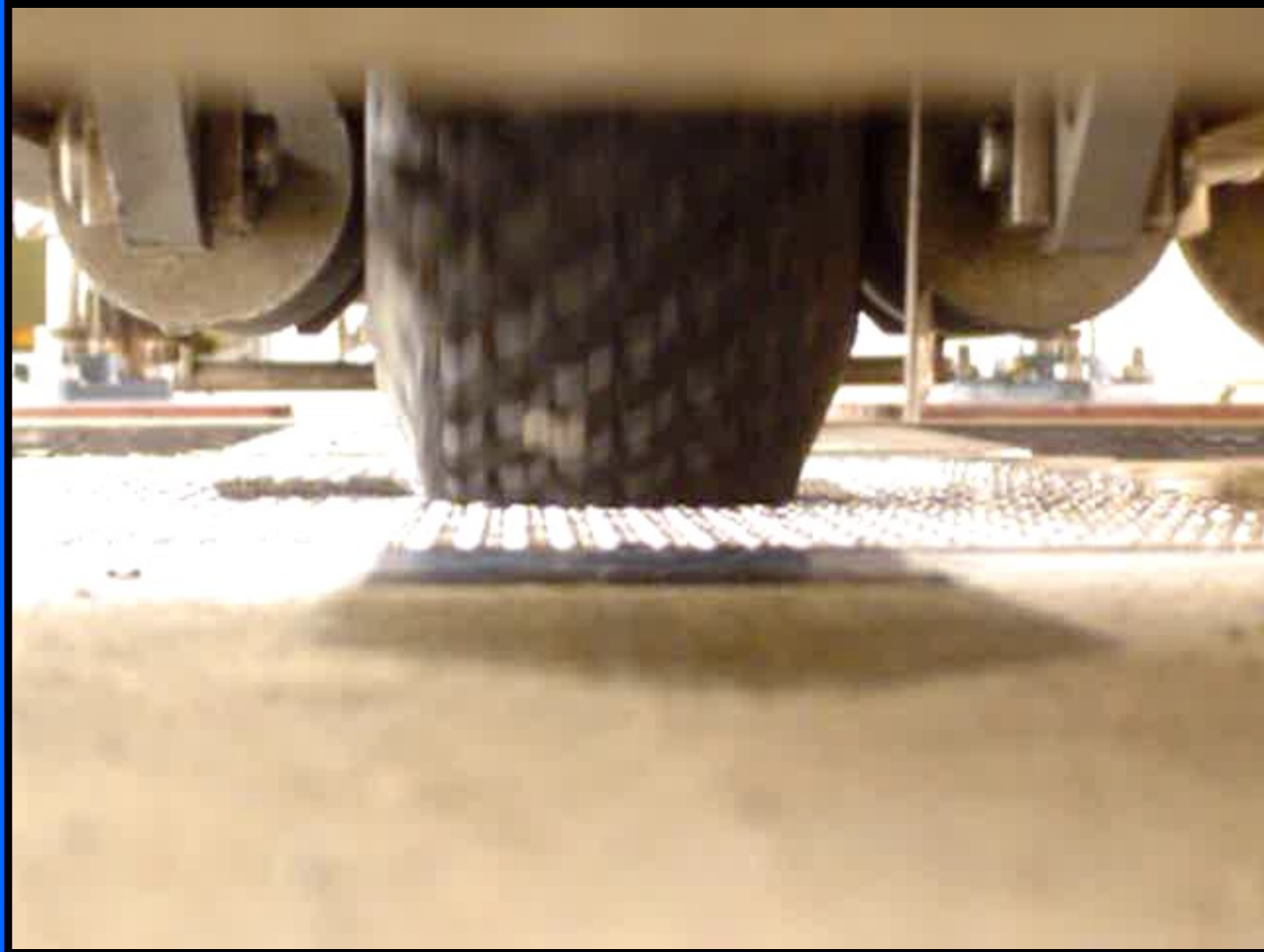
TYRE LOAD



INFLATION PRESSURE



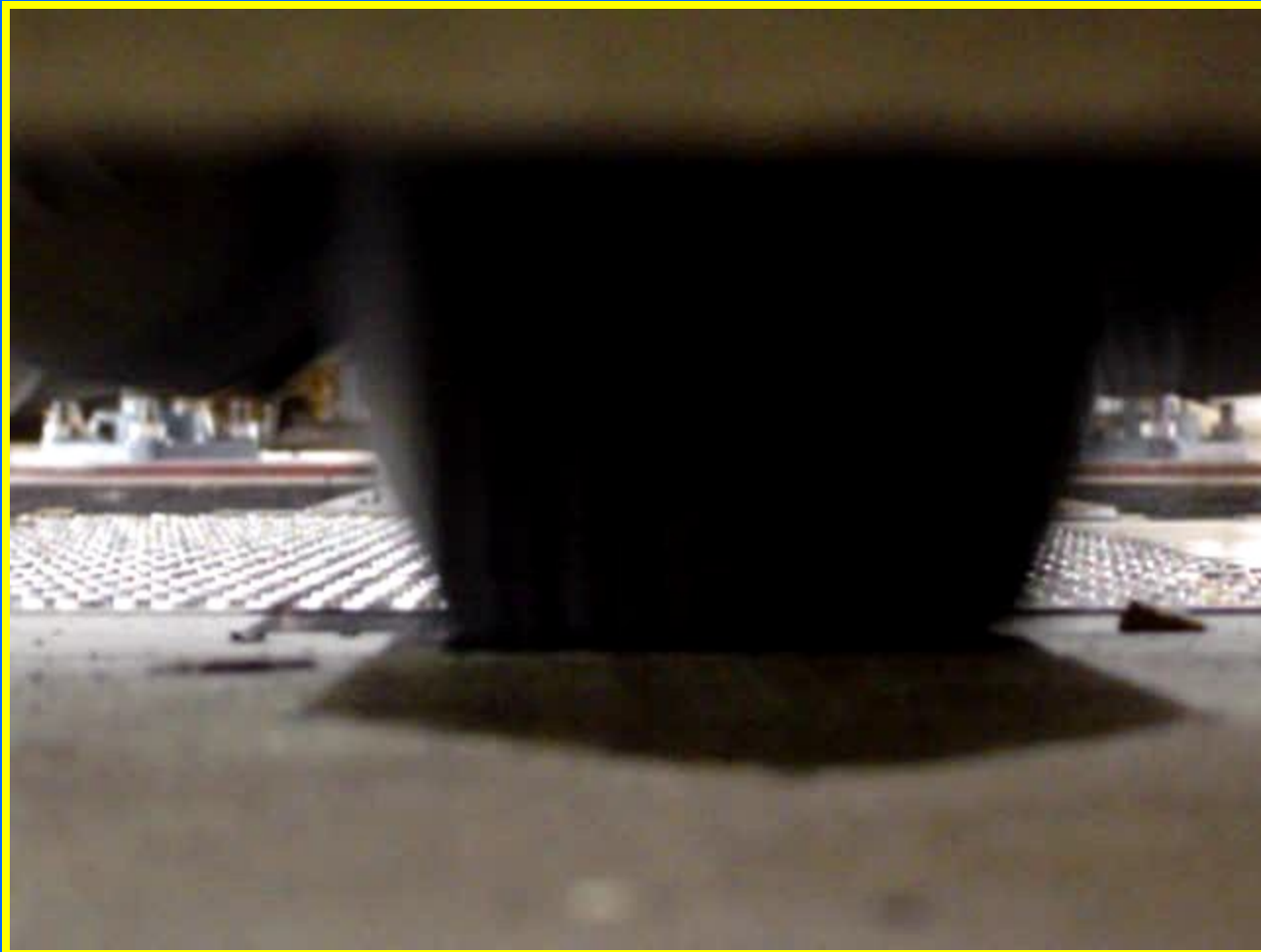
3D Contact Stresses: MMLS3 – Square Profile Tyre



MMLS3 ON SIM:FAST TESTING - 26 km/h

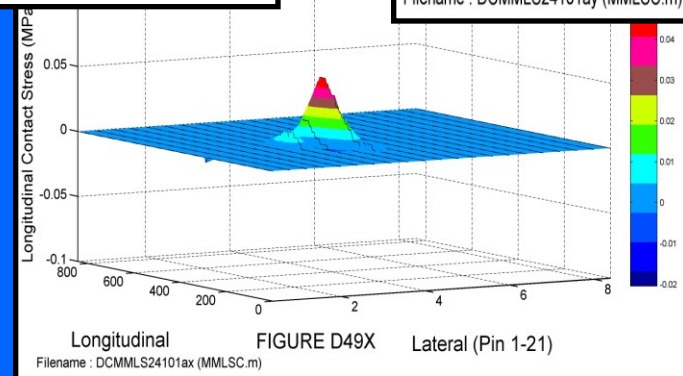
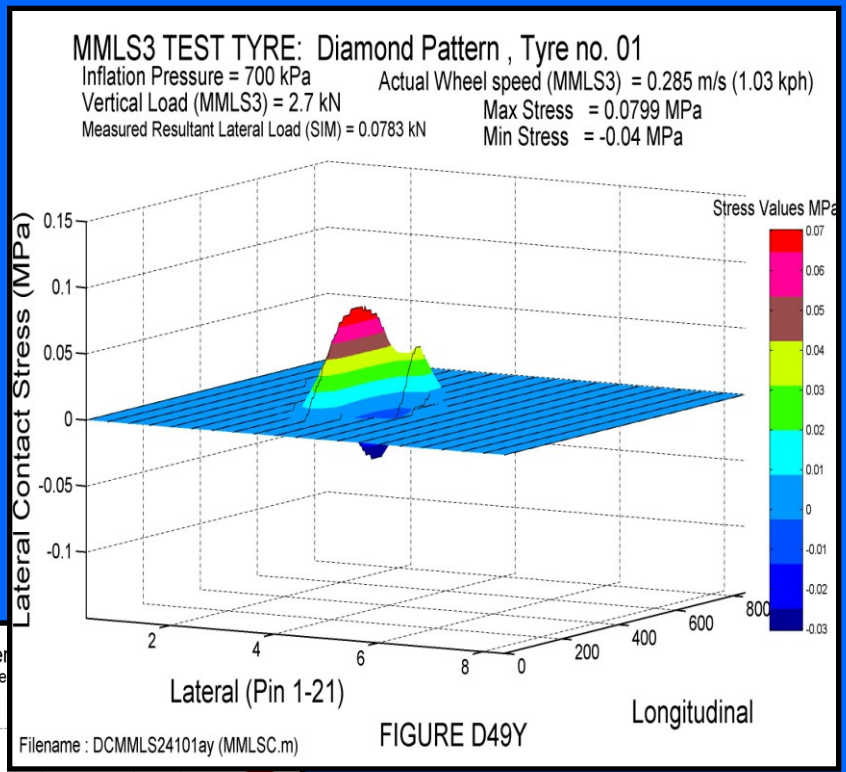
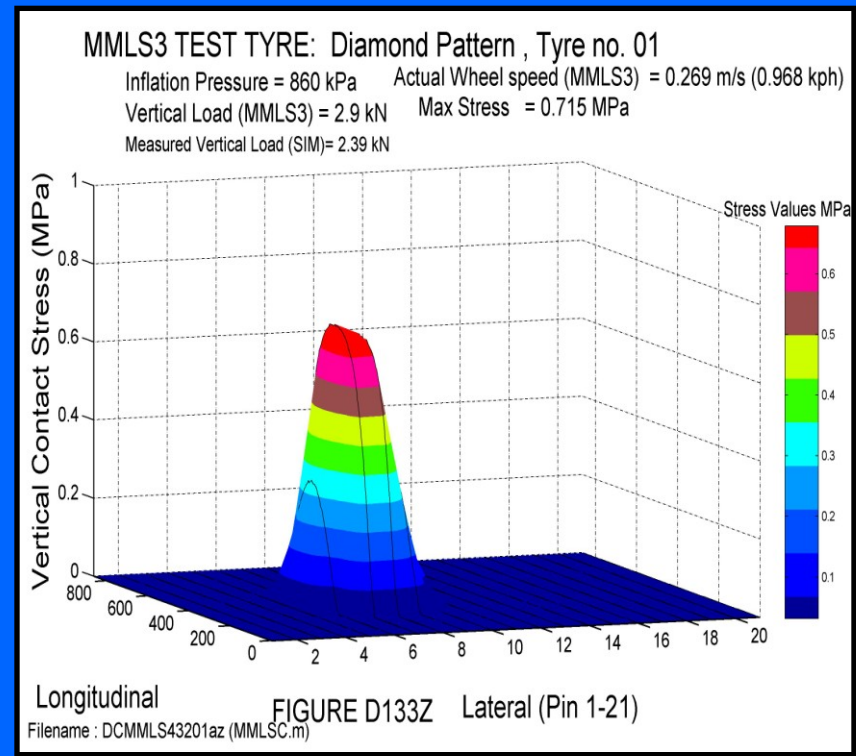


3D Contact Stresses: MMLS3 – Square Profile Tyre





3D Contact Stresses: MMLS3 – SIM Device – This Study





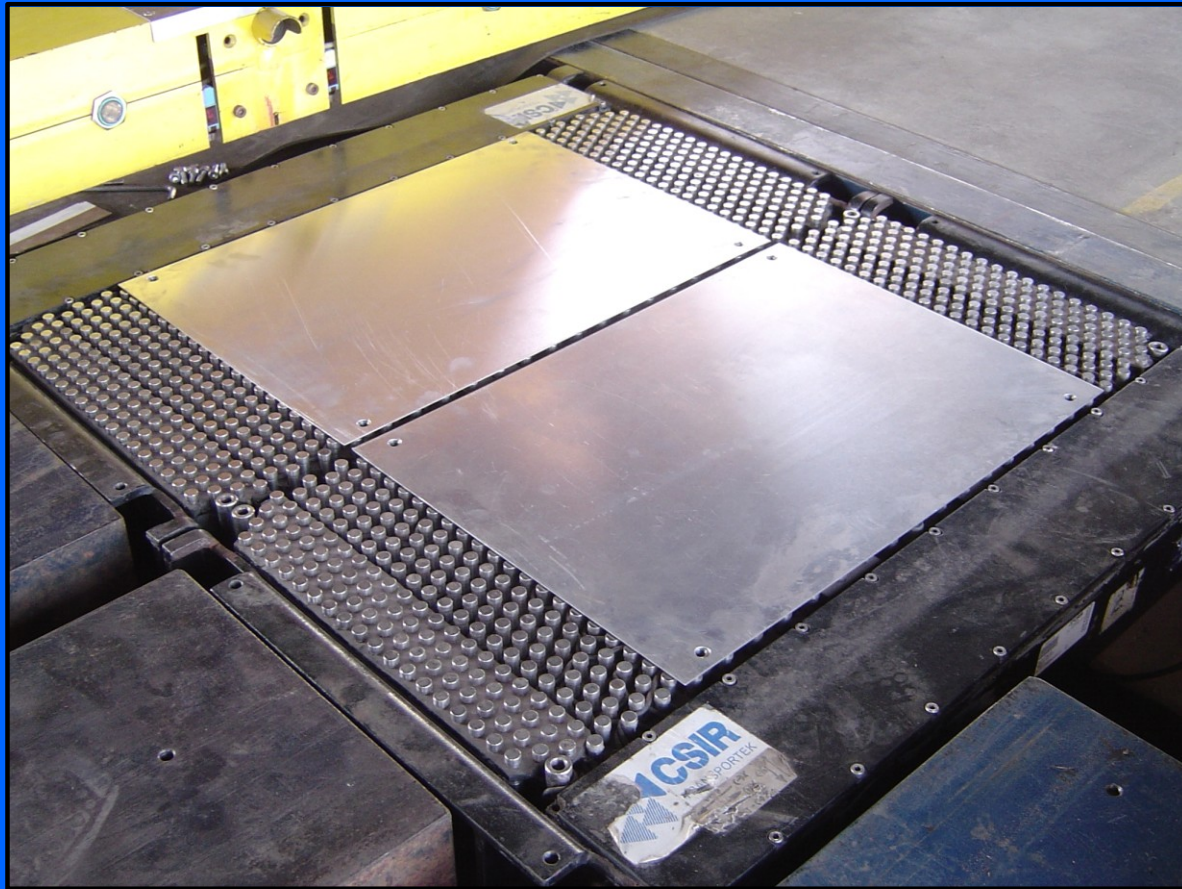
3D Contact Stresses: MMLS3 – Square Profile Tyre – SIM Textured Surface



Close-up of Square MMLS3 Test Tyre on SIM with plate (Smooth) Surface



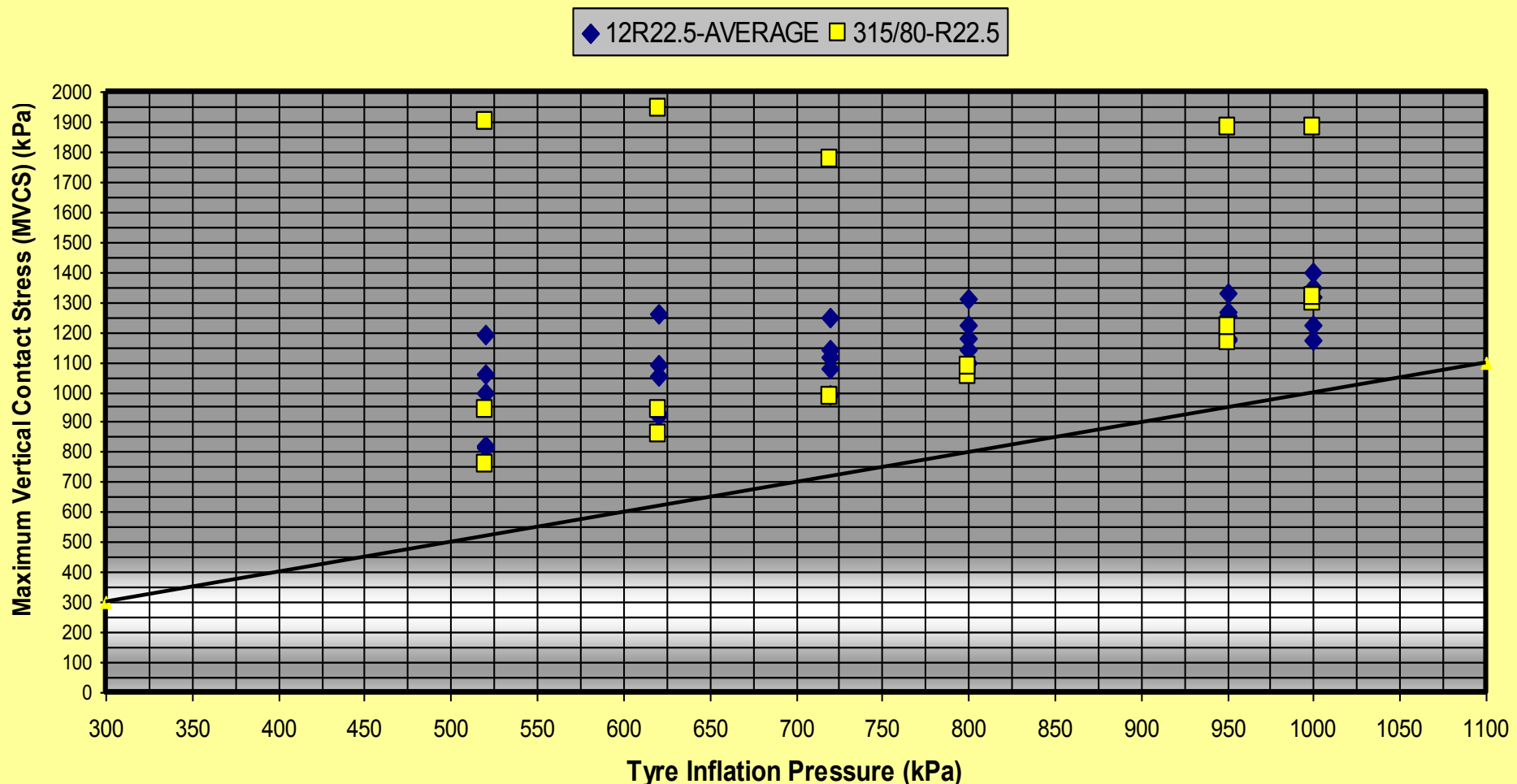
Smooth Plates – HVS Dual Tyre Tests



Detail MVCS results for the HVS and the MMLS3 for both rough and smooth SIM test surface



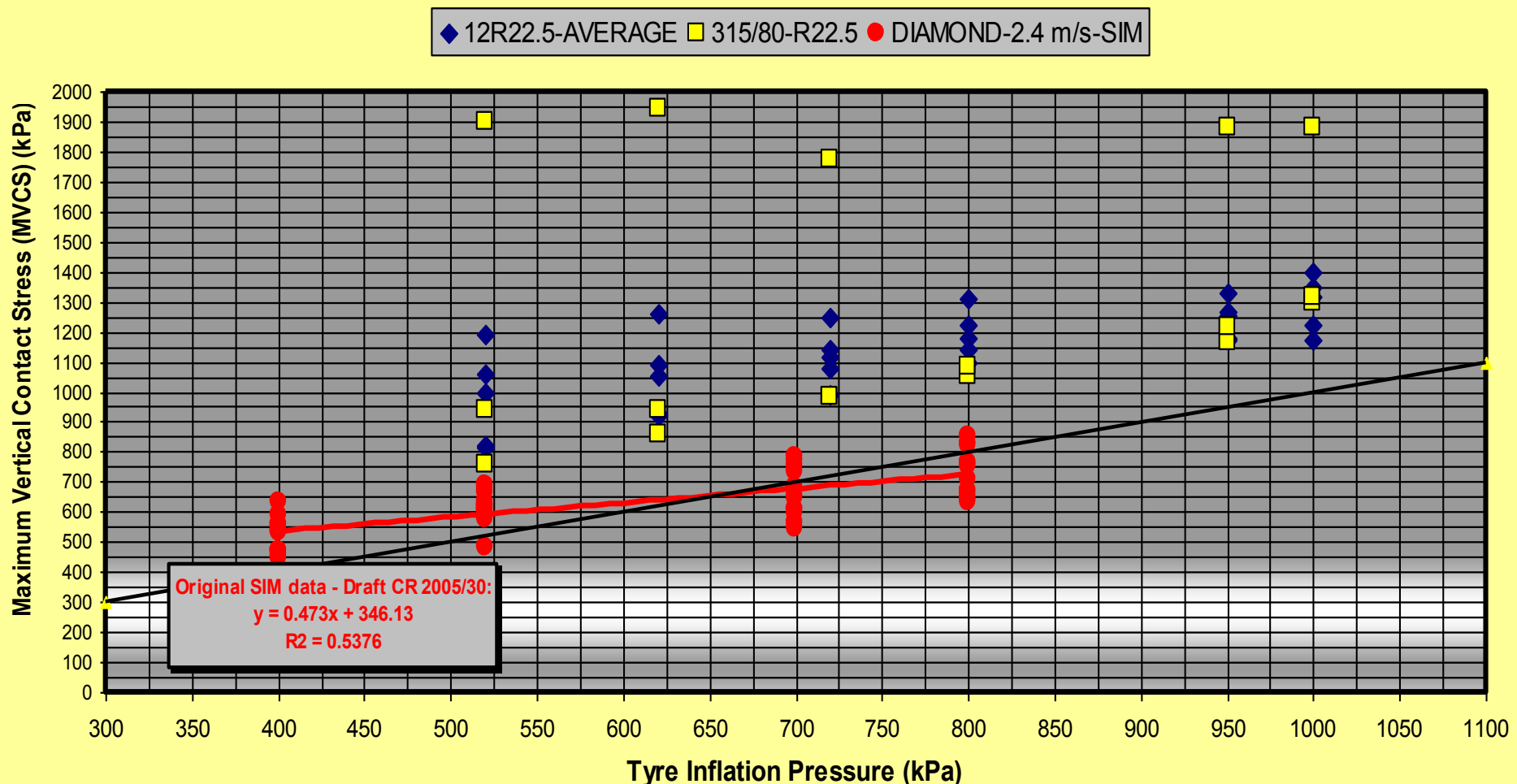
Maximum Vertical Contact Stress (MVCS) (or "PEAK STRESS")
(12R22.5 and 315/80 R22.5 (HVS MK IV+) compared with MMLS3)



Detail MVCS results for the HVS and the MMLS3 for both rough and smooth SIM test surface



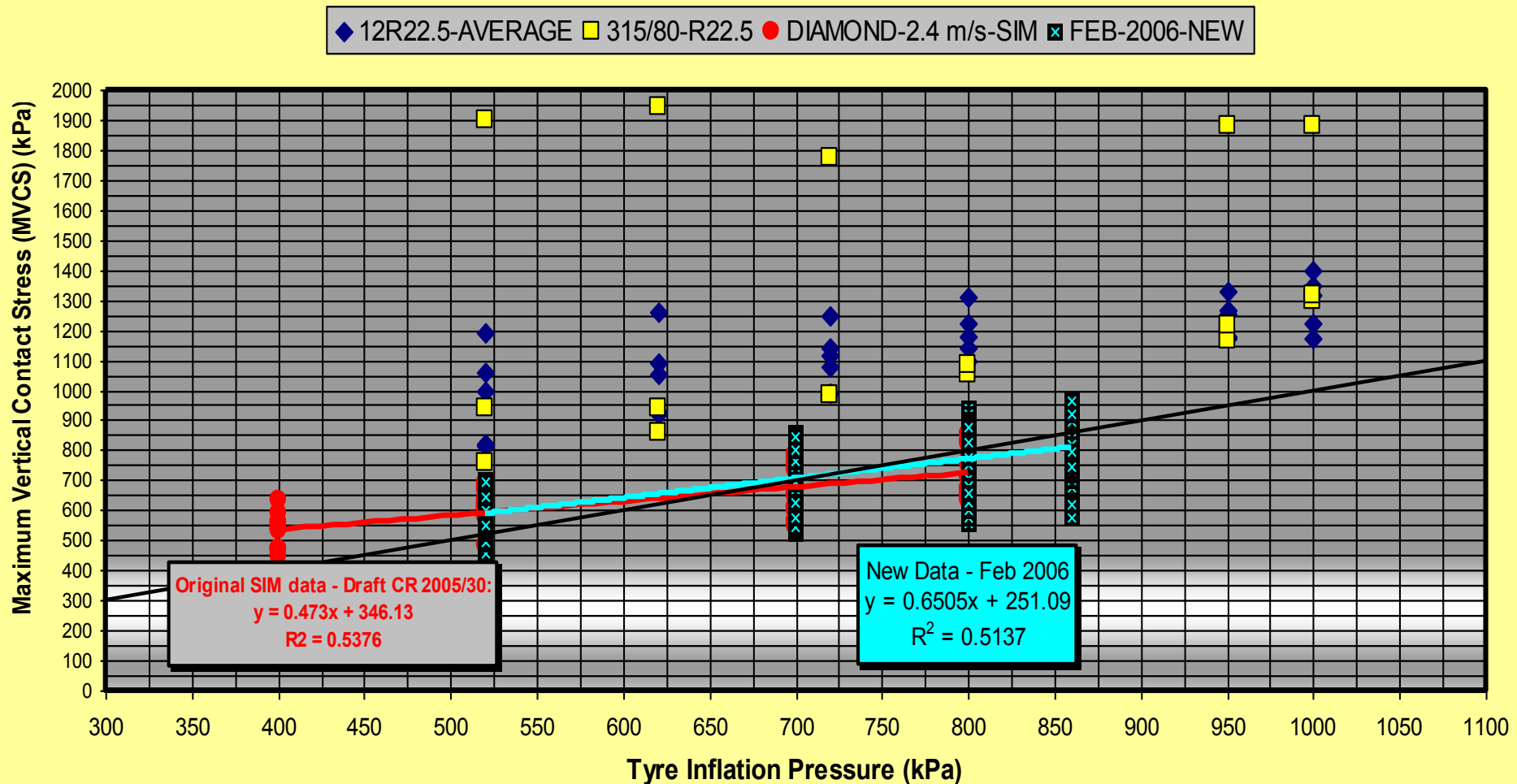
Maximum Vertical Contact Stress (MVCS) (or "PEAK STRESS")
(12R22.5 and 315/80 R22.5 (HVS MK IV+) compared with MMLS3)



Detail MVCS results for the HVS and the MMLS3 for both rough and smooth SIM test surface



Maximum Vertical Contact Stress (MVCS) (or "PEAK STRESS")
(12R22.5 and 315/80 R22.5 (HVS MK IV+) compared with MMLS3)

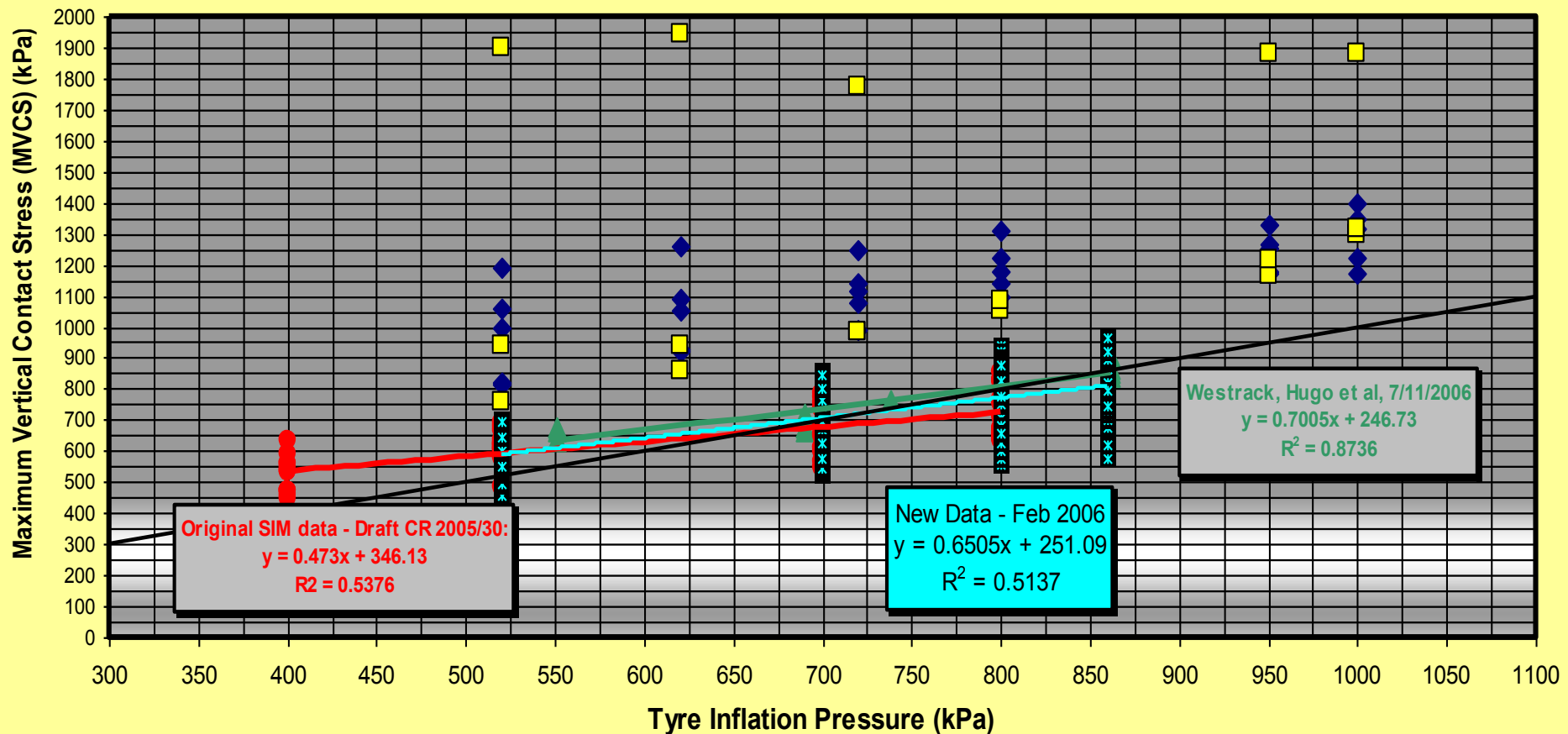


Detail MVCS results for the HVS and the MMLS3 for both rough and smooth SIM test surface



Maximum Vertical Contact Stress (MVCS) (or "PEAK STRESS")
(12R22.5 and 315/80 R22.5 (HVS MK IV+) compared with MMLS3)

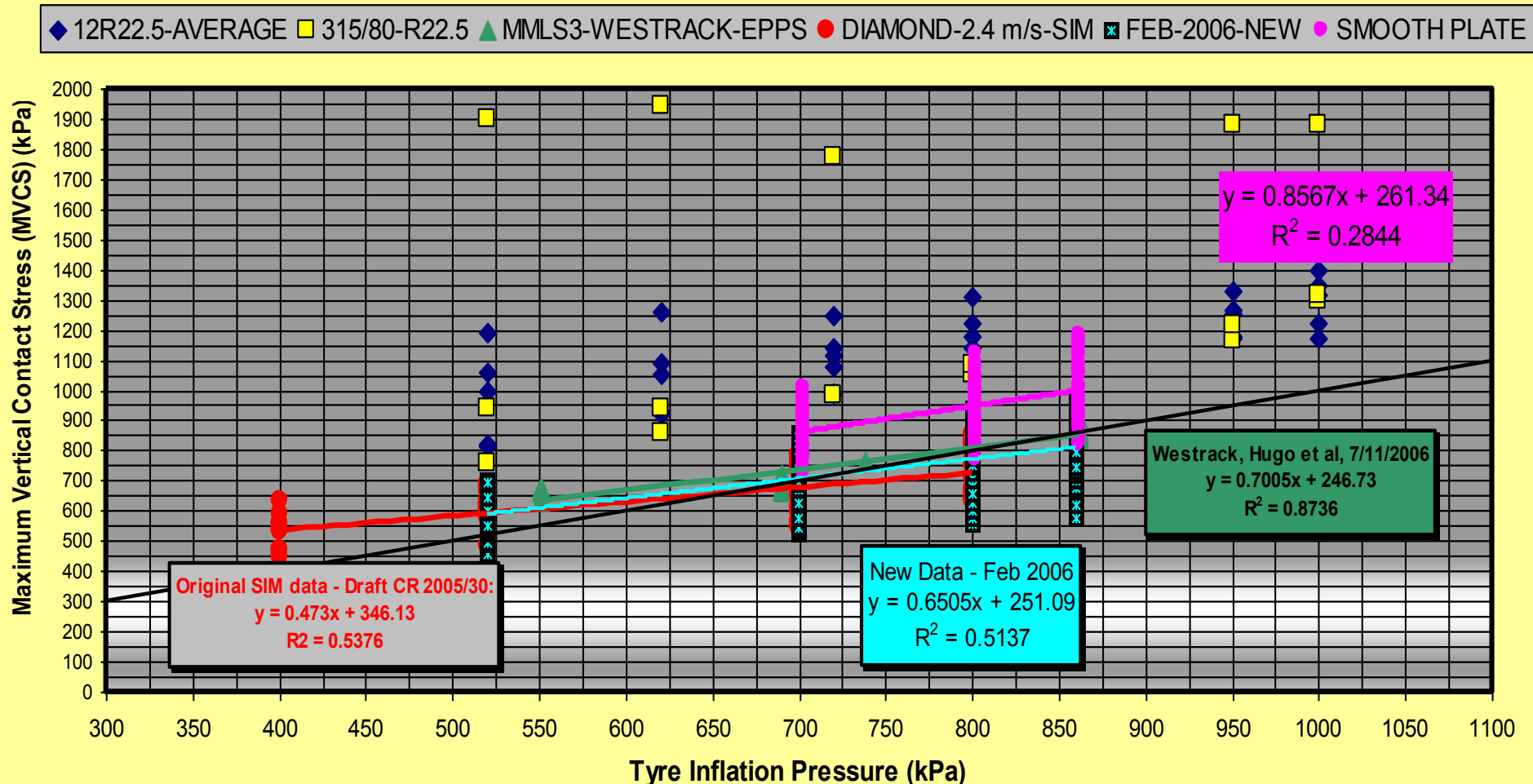
◆ 12R22.5-AVERAGE ■ 315/80-R22.5 ▲ MMLS3-WESTRACK-EPPS ● DIAMOND-2.4 m/s-SIM ✕ FEB-2006-NEW



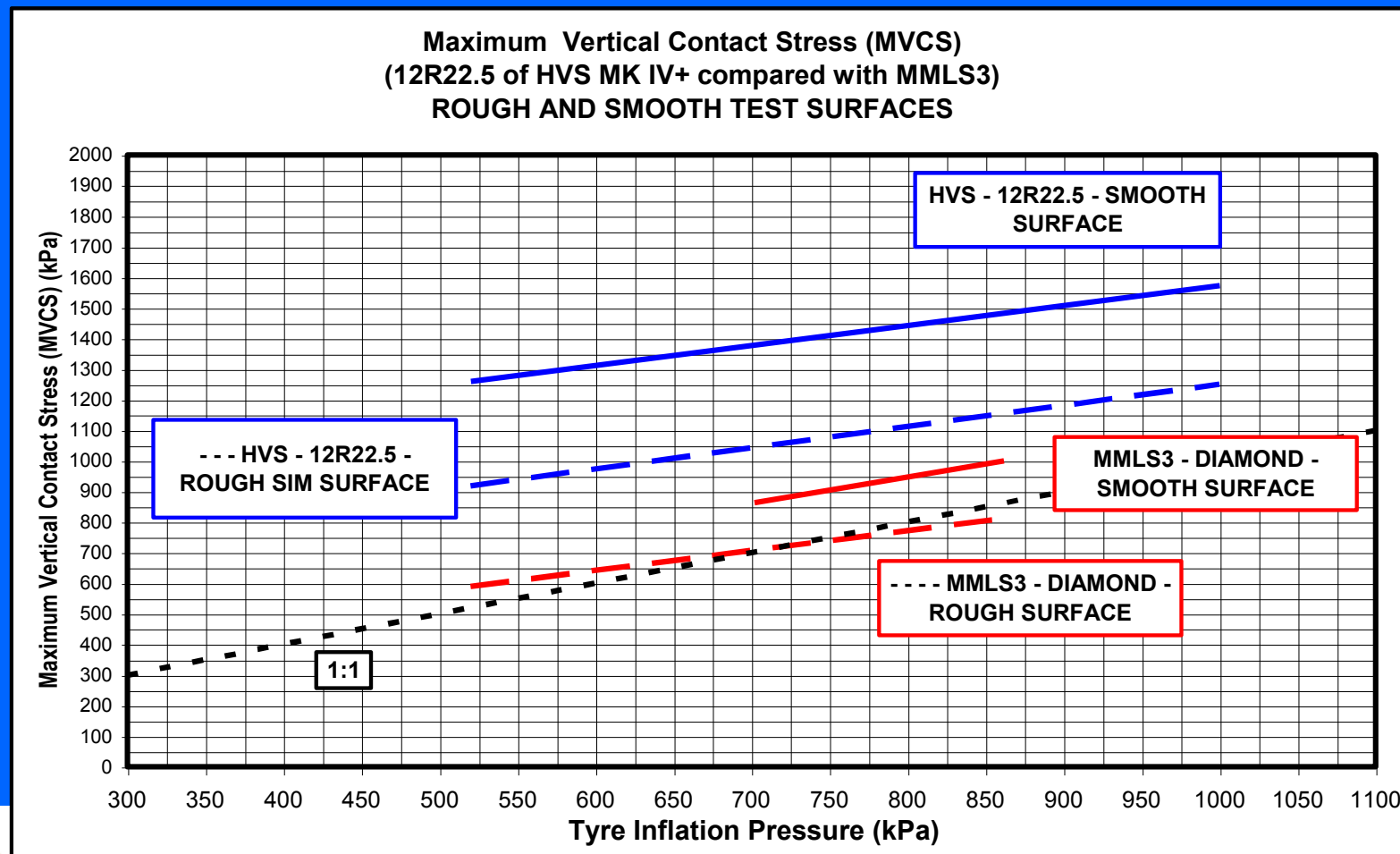
Detail MVCS results for the HVS and the MMLS3 for both rough and smooth SIM test surface



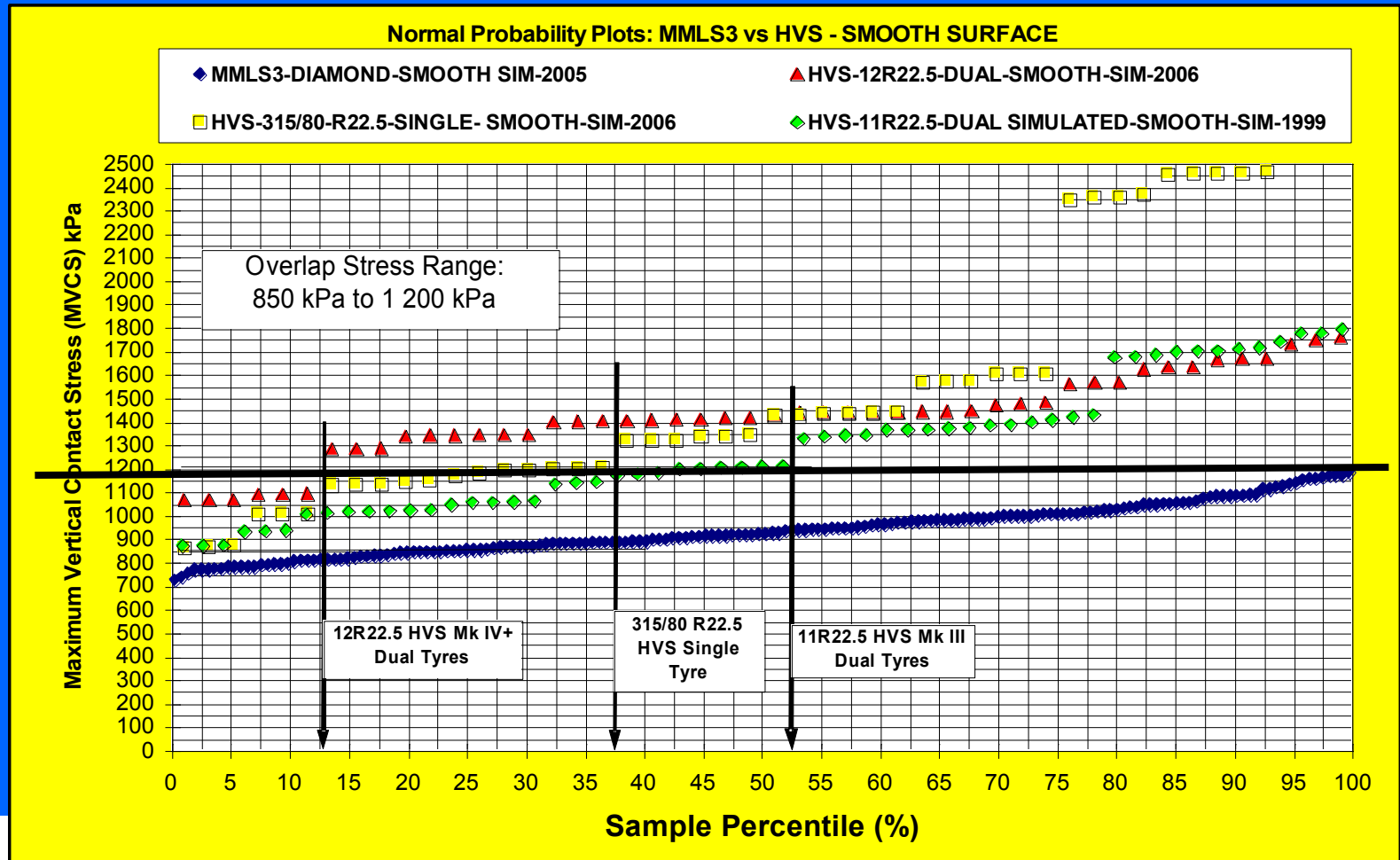
Maximum Vertical Contact Stress (MVCS) (or "PEAK STRESS")
(12R22.5 and 315/80 R22.5 (HVS MK IV+) compared with MMLS3)



Average MVCS results for the HVS and the MMLS3 for both rough and smooth SIM test surface



Per centile plots: MVCS - smooth SIM surface for the MMLS3 Diamond tyres (S2 - this study) relative to three HVS test tyres.



Remember the 3 x Project Objectives:



- Quantification -3D tyre-pavement contact stresses of the HVS and MMLS3 test tyres (using SIM) – 4 x Studies;
- Comparison - similar previous SIM studies on various HVS tyres – Z Vertical Stress only in this paper;
- Recommendations for tyre load and inflation pressures of future Accelerated Pavement Testing (APT) on Hot Mix Asphalt (HMA) rutting tests (MMLS3 and HVS);



Findings:

Z-Contact Stress: At Maximum - Representative Percentile Values (%)



Device Surface	MMLS3-Square Tyre (1/3 rd Scale)
Smooth Surface	12R22.5 Tyre: - 12.5 %; 315/80 R22.5 Tyre:- 37.5 %; 11R22.5 Tyre:- 52.5 %.
Rough Surface	12R22.5 Tyre: - 20 %; 315/80 R22.5 Tyre:- 37.5 %; 11R22.5 Tyre:- 52.5 %.



Findings: Z-Contact Stress Ranges



Device Surface	HVS (kPa)	MMLS3 (kPa)
Smooth Surface	850 to 1 800	850 to 1 200
Rough Surface (~ 30 % Lower)	700 to 1 450	450 to 1 000



Table 3. Recommended Tyre Loading and Inflation Pressure Levels for comparative testing between MMLS3 and HVS Mk IV*

NOMINAL MVCs - Categories - Rough Surface (kPa) *	Dual 11R22.5 - HV8 Mk III tyres (De Beer and Fisher, 2000)			Dual 12R22.5 - HV8 Mk IV tyres (De Beer et al., 2006)			Single - 315-80 R22.5 - HV8 Mk IV (De Beer et al., 2006)			MML83 DIAMOND TREAD TYRE (SQUARE PROFILE) (This Study, 81 and 82)		
	Cold Inflation Pressure	HV8 Dual Load	NOMINAL SHAPE OF VCS**	Cold Inflation Pressure	HV8 Dual Load	NOMINAL SHAPE OF VCS**	Cold Inflation Pressure	HV8 Dual Load	NOMINAL SHAPE OF VCS**	Cold Inflation Pressure	MML83 Load	NOMINAL SHAPE OF VCS**
	(kPa)	(kN)		(kPa)	(kN)		(kPa)	(kN)		(kPa)	(kN)	
700 - 760	420	30	~ Uniform	NO SUCH CASE POSSIBLE			520	20	~n	700	1.80	~n
800 - 860	520	30	~n				520	30	~ Uniform	700	2.70	
	420	40	~M	520	30	~n	520	40	~ Uniform			
	520	40	~ Uniform	520	40	~ Uniform	620	20	~n			
	520	40	~n	520	30	~n	520	30	~n			
	520	30	~n	520	40	~ Uniform	520	40	~ Uniform			
	720	30	~n				650	20	~n			
	720	40	~ Uniform				650	30	~n			
							650	40	~ Uniform			
960 - 1160	420	70	~M	520	70	~M	520	50	~M			NO SUCH CASE POSSIBLE WITH MML83
	520	70	~M	520	80	~M	620	50	~M			
	620	70	~M	620	70	~M	650	50	~M			
	720	70	~M	620	80	~M	720	30	~n			
	800	30	~n	720	30	~n	720	40	~ Uniform			
	800	40	~n	720	40	~n	720	50	~ Uniform			
	800	70	~M	720	70	~ Uniform	825	20	~n			
				720	80	~ Uniform	825	30	~n			
				800	30	~n	825	40	~ Uniform			
				800	40	~n	825	50	~ Uniform			
1160 - 1200	NO SUCH CASE TESTED			520	100	~M	950	30	~n			
				800	70	~ Uniform	950	40	~n			
				950	30	~n						
				950	40	~n						
				1000	30	~n						
1200 - 1280	NO SUCH CASE TESTED			620	100	~M	1000	20	~n			
				720	100	~M	950	50	~ Uniform			
				800	80	~ Uniform						
				950	70	~ Uniform						
				950	80	~ Uniform						
				1000	40	~n						
1300 - 1430	520	100	~M	800	100	~M	1000	30	~n			
	620	100	~M	950	100	~ Uniform	1000	40	~n			
	720	100	~M	1000	70	~n	1000	50	~ Uniform			
	800	100	~M	1000	80	~ Uniform						
				1000	100	~ Uniform						
1770 - 2000	NO SUCH CASE OBTAINED - CONDITIONS NOT SAFE			NO SUCH CASE OBTAINED - CONDITIONS NOT SAFE			520	100	~M			
						620	~M					
						650	~M					
						720	~M					
						825	~M					
						950	~M					
* For relatively smooth test pavement surfaces, the nominal MVCs to be increased by 30 per cent				** ~n = Single bulge or "n"- Shape Vertical Contact Stress (VCS) Distribution across tyre tread width;								
				** ~Uniform = Almost uniform VCS distribution across tyre tread width;								
				** ~M = "M"- Shape double bulge VCS distribution across tyre tread width;								

Major Conclusions (1):



- The contact surface texture directly influences the total load and vertical stress results; and
- Tyre intrusion into the pin surface of the SIM occurs, which may be limited by placing smooth plates on top of the current SIM device, if so desired.



Major Conclusions (2):

The Maximum Vertical Contact Stress (MVCS):



- Increase with increased tyre inflation pressure, for both the 1/3rd scale and full-scale test tyres;
- Average of the HVS test tyres roughly 50 to 88 per cent higher than for the MMLS3 (rough and smooth surface); and
- for the relatively smooth test surface were found to be 25 to 30 per cent higher than those for both the MMLS3 (scaled) and the HVS (Full Scale) tests tyres.;



Major Conclusions (3):



- For the scaled-down MMLS3 tyres the MVCS was roughly equal to inflation pressure, whereas for the full-scale HVS tyres the MVCS was approximately 50 per cent higher;



Recommendations (1):



- The results enables *a more rational interpretation* of APT test data;
- Further studies on different test surfaces;
- Critically important that loading devices such as the HVS and MMLS3 be adequately calibrated before similar studies are done in the future.
- Anchoring of the MMLS3 to the road pavement – NB.





THE END



THANKS FOR
YOUR
ATTENTION



CSIR
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