

TYRE-PAVEMENT CONTACT STRESS PATTERNS FROM THE TEST TYRES OF THE GAUTRANS HEAVY VEHICLE SIMULATOR (HVS) MK IV+

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ABSTRACT

This paper addresses the measurement (i.e. “fingerprinting”) of tyre loading and contact stress patterns associated with slow moving test tyres on the new Heavy Vehicle Simulator (HVS Mk IV⁺) of Gautrans. The two test tyres used on the HVS are a dual set of 12R22.5 and a single 315/80 R22.5 radial tyres, which represents typical tyres used on heavy vehicles (HV) in South Africa. The aim of this study was to quantify the three-dimensional tyre-road pavement contact stresses for these two types of truck tyres, which is currently employed for accelerated pavement testing (APT) in South Africa. Using the local Stress-In-Motion (SIM) technology, the measurements were done using a specially constructed concrete test facility at Gautrans Koedoespoort premises. A test matrix of five load levels and six inflation pressures was used on both HVS test tyres at creep speed conditions (<6 km/hr). The results indicated that at constant inflation pressure the vertical tyre contact pattern (“fingerprint”) is highly non-uniform, and changes from the well known “n”-shape to the “m-shape” with increased tyre loading. In addition the finger printing of the lateral and longitudinal stresses also appear to be highly non-uniform, but are relatively lower than the associated vertical stresses. In practice these load/stress data sets are crucial, firstly to understand the complex nature of forces within the tyre road contact patch, and secondly, to be used in the planning of loading/inflation pressure conditions for future HVS and APT testing. This is especially critical on roads incorporating thin asphalt surfacings especially during hot and also during wet climates. Finally, the results in this paper can be used to enhance future modelling of tyre-pavement loading in mechanistic-empirical (M-E) pavement design technologies.

1. BACKGROUND AND MOTIVATION

After many years of owning and operating the HVS Mk III (“Yellow HVS”), Gautrans recently acquired a new HVS Mk IV⁺. In addition to the advanced features of this machine compared to the HVS Mk III, the Mk IV⁺ has certain operational advantages as well that it is more efficient than the Mk III (Steyn, et al, 1999). In the light of the foregoing, it is necessary to ensure quality outputs from the new HVS Mk IV⁺. In this context the SIM technology can assist greatly in defining load/contact stress patterns of the applied loading of the test tyre(s) of the HVS, which was identified as an area of further APT research in South Africa (Sampson and Sadzik, 2004). This knowledge is used for enhanced understanding of the applied loading/stress regimes of the HVS test tyres, which could assist greatly in the effective experimental planning of future HVS testing scenarios, and mechanistic-empirical (M-E) pavement design and analysis. Currently the selection of HVS

Mk IV⁺ test tyres consist of a dual set of 12R22.5 tyres (see Figure 1) and a single tyre 315/80 R22.5 (see Figure 2). These tyres are representative of currently used truck tyres in South Africa.



Figure 1: Image of the type 12R22.5 HVS Mk IV⁺ single test tyre (Normally, the HVS test use a dual tyre set)



Figure 2: Image of the type 315/80 R22.5 HVS Mk IV⁺ single test tyre (Used mainly on steering axles of trucks).

2. PROBLEM STATEMENT

Gautrans are using the new HVS Mk IV⁺ machine on several APT projects since 2003. Previously the HVS Mk III was used. In addition to differences in the type of test tyres and physical sizes of these machines, differences in load application during testing may also lead to differences in pavement response and hence the test results. Although there are many mechanical differences between the machines, the variables that could influence the HVS test results are:

- The accuracies of the total load applied with the HVS Mk III and the HVS Mk IV⁺ test machines. Although this should not be a problem if both machines are properly calibrated, the load control system of the Mk III machine is not as accurate as that of the Mk IV⁺. The load of the Mk III HVS is manually set

- based on a hydraulic oil pressure reading while for the Mk IV⁺, the load is constantly monitored electronically and adjusted by a hydraulic servo-valve;
- The speed of operation and number of loads applied per time period of the Mk IV⁺ is significantly higher than that of the Mk III. The maximum speed for the Mk III HVS was 6,5 km/h and that of the Mk IV⁺ is 12,8 km/h. Currently for operational efficiency HVS Mk IV⁺ is operating at 10 km/h;
- The tyre-pavement contact stress distribution differs between the two machines as the tyres that are used are also different. This is considered as one of the most important issues for future APT, assuming that the HVS is properly calibrated for applied loading;

The first two items were partly addressed during comparative testing on Road D2388 using HVS Mk III and HVS IV+ HVS (Morton and Theyse, 2003). Currently, a protocol will be introduced to further improve on HVS load calibration during HVS testing with static scales (Sampson and Sadzik, 2004). During 1999 SIM measurements were done on the test tyres 11R22.5 of HVS Mk III (De Beer and Fisher, 2000). This paper addresses the contact stresses of the previous 11R22.5 tyres (on HVS Mk III), the new 12R22.5 and the new single 315/80 R22.5 test tyres¹ used on the new HVS Mk IV+. An attempt is also be made to check if there are differences in the tyre contact stresses that could assist in explaining some of the differences observed during the comparative testing by the two HVSs reported by Morton and Theyse (2003).

The information contained in this paper is complimentary to two other papers at this SATC 2005 conference, where the accuracy of the SIM system is described (Mkhize and De Beer, 2005) and also to a paper by Steyn and Haw (2005) where the amongst others, the effects of uneven road surfaces on truck tyres are discussed.

3. METHODOLOGY

The methodology for this test series included the following preparations and actions:

- The design and construction of a rigid 5.5 m x 22.8 m x 250 mm thick heavily re-inforced concrete test slab incorporating a test pit for the SIM device at the premises of Gautrans in Koedoespoort, Pretoria (Tender No 9430/2004/1);
- Provision of the HVS Mk IV⁺ and test tyres by Gautrans;
- Provision of two of the four SIM measuring pads by CSIR Transportek. [This system was recently compared with independent scales. See paper by Mkhize and De Beer (2005), this conference];
- Measurements of applied tyre loads, inflation pressures and 3-dimensional contact stresses;
- Measurement of SIM data (3-D contact stresses) at slow (< 6 km/hr) creep speed and non-driven free rolling tyre conditions at ambient temperatures (varying between 23 °C to 29 °C);
- Measurement of concrete slab deflections under 40 kN and 100 kN using the Road Surface Deflectometer (RSD) with the HVS loading. These measurements confirmed a rigid support, with maximum resilient deflections within the noise range of the RSD instrument (in this case less than 50 µm at 100 kN loading);
- Data reduction, basic analysis and report (De Beer et al, 2005);

¹ Recent investigations on tyre types used by Heavy Vehicles on the N3 North at Heidelberg Traffic Control Centre indicated that approximately **50 per cent** of steering tyres are of the **315/80 R22.5** type, and approximately **40 per cent** are of the **12R22.5** type (De Beer et al, 2005).

3.1 Field Measurements at Gautrans test slab - Koedoespoort

3.1.1 HVS test tyres 12R22.5

The 12R22.5 HVS test tyre shown in Figure 1, which is normally used in a single or dual configuration on the HVS, were tested according to the test matrix set out in Table 1. The two-pad SIM system was used to measure the 3-dimensional contact stress distributions at the dual load and inflation pressure combinations given in Table 1. Note that most inflation pressure/load combinations given in Table 1 are outside the specifications of the tyres, but is typical of what are being used for APT testing in South Africa. A total of 90 tests were done on these tyres.

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

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

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.

√ - 3 repeat measurements taken.

3.2 HVS test tyres 315/80 R22.5

The 315/80 R22.5 HVS test tyre shown in Figure 2, which is normally used in a single or dual configuration on the HVS, was tested according to the matrix given in Table 2. A total of 114 tests were done on this tyre.

Table 2: Test matrix used for the SIM tests on the 315/80 R22.5 HVS test tyre (114 tests)

HVS SINGLE TYRE LOAD (kN)	COLD TYRE INFLATION PRESSURE (kPa)						
	520	620	650*	720	825	950	1000
20	√	√	√	√	√	√	√
30	√	√	√	√√	√	√	√
40	√	√	√	√	√√	√√	√
50	√	√	√	√	√	√	√
100	√	√	√	√	√	√	√

Approximate rated load and Inflation pressure @ 81 – 95 km/h – Single tyre:

Shaded areas: 31 kN @ 650 kPa to 37.5 kN @ 825 kPa

√ - 3 repeat measurements taken (SIM Pad 1).

√√ - 6 repeat measurements taken (3 on SIM Pad1, and 3 on SIM Pad 2).

4. MEASUREMENTS AND DISCUSSION

4.1 Results for the 12R22.5 test tyres

The measured contact stress patterns of an extraction of load/inflation pressure from the matrix of tests defined in Table 1 are illustrated in Figures 3, 4 and 5. Note that the load values in these figures are given for a single 12R22.5 tyre, whilst the loading in Table 1 are for a dual set of tyres.

Figure 3, 4 and 5 illustrate the SIM measured Vertical (Z), Lateral (Y) and Longitudinal (X) contact stresses, and clearly illustrates the change in of shape and magnitude in all the patterns (i.e. "fingerprinting") as a function of both loading (vertical axis) and inflation pressure (horizontal axis).

For the vertical contact stress the shapes typically change from the well-known "n - shape" to the "m - shape" as a function of increased load. These typical shapes are described in De Beer et al (2004). For changes in inflation pressure, the increase in contact stresses occurs towards the centre of the tyre tread. These patterns are typical for most pneumatic truck tyres evaluated with the SIM system (see De Beer, 1996; De Beer et al, 1997, 1999, 2000). Similar patterns were obtained for the previous 11R22.5 test tyres used by HVS Mk III.

4.1.1 Comparison of the average maximum vertical contact stresses (AMVCS) between the right and left tyres (12R22.5) on HVS Mk IV⁺

In Figure 6 a comparison of the average maximum vertical contact stresses (AMVCS) between the right and left tyres of the 12R22.5 tyres from new HVS Mk IV⁺ are illustrated (90 tests). The data are given for the full test matrix defined in Table 1, for a range of 30 kN to 100 kN load and 520 kPa to 1000 kPa inflation pressure. In general, the figure indicates an increase in the AMVCS with applied loading. In addition, the relative increase reduces with increased inflation pressure. The AMVCS ranged between 756 kPa to 1388 kPa (average 1107 kPa, standard deviation 154 kPa) for the right hand tyre, and 851 kPa to 1444 kPa (average 1182 kPa, standard deviation 151 kPa) for the left tyre. Comparison between the AMVCS results of the right and left tyre indicated differences up to 18 per cent. The reasons for this difference are believed to include possible unequal loading through the HVS Mk IV⁺ (minute tolerance on the rigid axle under load) and tyre factors such as manufacturing tolerances, tyre "out-of-roundness", tyre condition, tread patterns, etc. Very little can be done on the current HVS Mk IV⁺ (or the tyres itself) to improve the situation, since the dual tyre loading is applied through a rigid axle with oil pressure cylinders on each side. It is therefore postulated that this difference in AMVCS *may* cause spatially non-uniform surface defects on test pavements during HVS-APT testing. Detailed research on this specific issue is recommended within the context of HVS-APT testing on thin surfaced flexible pavements. It should, however, be noted that similar differences in stresses (if not worse) were noted on real trucks from the N3 - Traffic Control Centre at Heidelberg (N3-TCC) (De Beer et al, 2004, 2005).

4.1.2 Comparison of the AMVCS between the previous 11R22.5 and the new 12R22.5 HVS test tyres

In Figure 7 a comparison between the AMVCS results of the two tyre types 11R22.5 and 12R22.5 are given (48 tests). The figure indicates that for the range of inflation pressures and loads studied (420 kPa to 800 kPa, at 30 kN to 100 kN) the AMVCS from the 12R22.5 tyres are higher (approx. 1 to 18 per cent) compared with the 11R22.5 tyre for dual loads up to 40 kN. For the extremely overloaded dual loads at 70 kN and 100 kN, the AMVCS of

the 11R22.5 tyre appears to be higher (up to approximately 11 per cent) compared to those from the 12R22.5 tyre. For the 11R22.5 tyre the AMVCS ranged between 749 kPa and 1427 kPa (average 1071 kPa, standard deviation 151 kPa), and for the 12R22.5 the range was 817 kPa to 1312 kPa (average 1060 kPa, standard deviation 220 kPa). It is postulated that the implications for HVS-APT is that, depending on the degree of loading (and overloading) of the test tyre for the associated tyre inflation pressure, slightly more surface damage are expected for the new 12R22.5 HVS test tyre for dual loads up to 40 kN, maybe 50 kN. However, in the case of *extreme* overloading (say from 70 kN to 100 kN), the AMVCS data suggests *lower* surface damage from these new 12R22.5 tyres compared with the 11R22.5 tyres. It is believed that this condition is a direct result of potentially less stiff tyre walls for the new 12R22.5 tyres. It should be noted that these findings need to be treated with utmost care (also by normal tyre users) since the tyre loadings used for HVS-APT far exceeds those recommended by the tyre manufactures, even considering the slow moving speed of these HVS test tyres (1 to 10 km/hr).

For the mentioned case in Section 2, where HVS Mk III was compared with HVS Mk IV⁺

(Morton and Theyse, 2003) the 11R22.5 tyres (HVS Mk III) were at a lower load level (62 kN vs 66 kN), but at a higher inflation pressure level (i.e. 690 kPa vs 646 kPa). Based on the contact stress information the only conclusion is that *marginally higher* tyre wall edge stresses occurred with the new 12R22.5 tyres compared to the 11R22.5 tyres. It is believed that these higher tyre contact stresses, together with a higher load level are responsible for a) the slightly higher resilient deflections obtained (loading effects from subgrade), and b) directly related to the relatively higher plastic deformation observed (higher contact stresses at the tyre edges) with the HVS Mk IV⁺ using the 12R22.5 tyres.

4.1.3 Normalized Contact Pressures (NCP) for the 11R22.5 and the 12R22.5 test tyres

The “normalized contact pressure” (NCP) is a dimensionless parameter defined as the ratio between the AMVCS and the associated tyre inflation pressure (De Beer et al, 1997). For the two 11R22.5 tyres, the NCP range is from 1.20 to 2.58, and for the new 12R22.5 the range is found to be 1.37 to 2.29. This data suggest (as was also discussed in section 4.3.3) that at lower loads the 11R22.5 tyre seem to result in lower AMVCSs compared to those from the 12R22.5 tyre, which, in turn, seems to be more beneficial at the higher load levels compared with the 11R22.5 test tyre (De Beer et al, 2005).

4.1.4 Lateral and Longitudinal Contact Stresses for the 12R22.5 tyres

The lateral and longitudinal contact stresses (associated with the vertical stresses) are illustrated in Figures 4 and 5 for the 12R22.5 tyre. It is clear that these horizontal stresses are much smaller than the associated vertical stresses. For the 12R22.5 tyres the maximum lateral stresses (Y) are approximately 17 per cent (+/- 3 per cent) of the associated maximum vertical stresses, and the longitudinal stresses (X) are approximately 12 per cent (+/- 3.5 per cent) of the associated maximum vertical stresses (from 90 tests). Although these stresses seem to indicate relatively low percentages of the maximum vertical stress, typical ranges are between 116 kPa to 295 kPa for the lateral (Y) stresses (average approximately 195 kPa, standard deviation 37 kPa), and 64 kPa to 251 kPa (average approximately 136 kPa, standard deviation 71 kPa) for the longitudinal (X) stresses of the various load cases investigated. For more rational design and analysis of thin surfaced flexible pavements, it is the opinion that these transverse stresses ideally to be incorporated in addition to the vertical stresses (De Beer et al, 1997, 1999, 2002, 2004).

4.2 Results for the single 315/80 R22.5 test tyre

The measured contact stress patterns of an extraction of load/inflation pressure from the matrix of tests defined in Table 2 are illustrated in Figures 8, 9 and 10. Note that the load values in these figures are given for a *single* 315/80 R22.5 tyre on the HVS Mk IV⁺. In a recent study it was found that almost 50 per cent this type of tyre is also used on the steering axle of heavy vehicles (De Beer et al, 2005).

The figures illustrate the SIM measured Vertical (Z), Lateral (Y) and Longitudinal (X), contact stresses, and (similar to the 12R22.5 tyres) also clearly illustrates the change of shape and magnitude in all the patterns (i.e. "fingerprinting") as a function of both loading (vertical axis) and inflation pressure (horizontal axis). For the vertical stress patterns, the typical "n-shape" and the "m-shape" (as a function of increased load) are clearly visible for this type of tyre².

4.2.1 Comparison of the AMVCS between the previous 11R22.5, the new 12R22.5 and the new 12R22.5 HVS test tyres

Figure 11 illustrates a summary of the AMVCS of the 11R22.5, 12R22.5 and the 315/80 R22.5 single tyre for a range of loads (30 kN to 100 kN), and tyre inflation pressures (520 kPa to 1 000 kPa). Note that not enough data was available to compare all loads and inflation pressures up to 100 kN and 1000 kPa, especially for the old 11R22.5 tyre set. However, the available data indicated in Figure 11 suggests the following:

- The average maximum vertical contact stresses (AMVCSs) ranging between 817 kPa to 1 312 kPa for the new 12R22.5 tyre and between 760 kPa to 2 004 kPa for the 315/80 R22.5 single tyre for the load and inflation pressure levels studied here;
- For inflation pressures up to 800 kPa and total load at approximately 30 kN (~manufactures rating) it is interesting to note that the AMVCS of the 315/80 R22.5 single tyre is marginally *lower* than that of the 11R22.5 tyre, and marginally *higher* than that of the 12R22.5 tyre;
- At 30 kN and 950 kPa the AMVCS of the 315/80 R22.5 tyre *equals* that of the 12R22.5 tyre, and at a 1000 kPa the AMVCS of the 315/80 R22.5 tyre is marginally *higher* than that of the 12R22.5 tyre;
- At 40 kN and 950 kPa to 1 000 kPa, the AMVCS of the 315/80 R22.5 tyre marginally exceeds those of the 12R22.5 tyre;
- For the full range of inflation pressures investigated (520 kPa to 1 000 kPa) and load at approximately 100 kN, the AMVCS of the 315/80 R22.5 single tyre *far exceeds* those of the dual 11R22.5 and 12R22.5 test tyres, with a typical range of 30 per cent to 60 per cent. This is primarily a result of the excessive tyre wall edge stresses under these extreme loading conditions (tyre *extremely* overloaded by approximately 166 per cent). This condition is normally only used for APT in very limit tests;

4.2.2 Normalized Contact Pressures (NCP) for the 315/80 R22.5 tyre

For the 315/80 R22.5 single tyre the NCP ranges from 1.17 to 3.68 for the load and inflation pressures studied here. The lower end of the NCP for this tyre is comparable to the both those of the 11R22.5 and 12R22.5 test tyres, but the higher end far exceeds

² The "n-shape" and "m-shape" typifying vertical contact stress patterns where defined in De Beer et al (2004a).

those of the other two test tyres. This is primarily a direct result of the high vertical contact stresses at the tyre walls, as was discussed in the previous section.

This data suggests that under these extremely high loading conditions (> 35 per cent overloading), more potential spatial damage is expected on the HVS test section (or normal road surface) compared to the other two tyre types. It is generally accepted (and can be mechanistically proven) that the damage on the road surface is in direct proportion to the level of applied contact stress (De Beer et al, 1997). Therefore this single 315/80 R22.5 tyre will potentially be much more damaging on rough road surfaces (high roughness indices) together with poorly maintained suspension systems, compared to the 11R22.5 and 12R22.5 dual tyre set.

Based on this finding, unless more effective policing of overloading is done and the roads kept at an acceptable level of riding quality, these single 315/80 R22.5 tyres should preferably not be used as single tyres on non-steering axles. On the steering axles the loads should however be limited to the current legal limit of 7 700 kg, at the prescribed inflation pressure levels.

4.2.3 Lateral and Longitudinal Contact Stresses for the 315/80 R22.5 tyre

For the 315/80 R22.5 test tyre, the lateral and longitudinal contact stresses (associated with the vertical stresses) are illustrated in Figures 9 and 10. It is clear that these horizontal stresses are also much smaller than the associated vertical stresses. For the 315/80 R22.5 tyre the maximum lateral stresses (Y) are approximately 18 per cent (+/- 1.3 per cent) of the associated maximum vertical stresses, and the longitudinal stresses (X) are approximately 12 per cent (+/- 2.7 per cent) of the associated maximum vertical stresses (from 114 tests). Although these stresses seem to indicate relatively low percentages of the maximum vertical stress (as for the 11R22.5 and 12R22.5 tyres), typical ranges are between 120 kPa to 400 kPa for the lateral (Y) stresses (average approximately 221 kPa, standard deviation 67 kPa), and 64 kPa to 336 kPa (average approximately 147 kPa, standard deviation 60 kPa) for the longitudinal (X) stresses of the various load cases investigated.

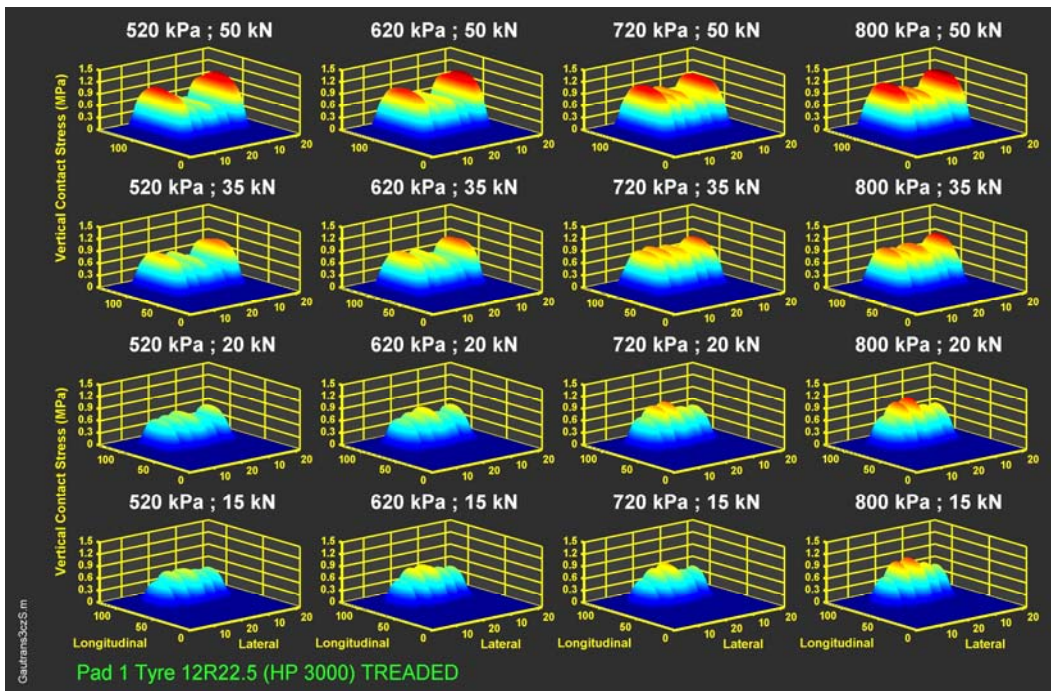


Figure 3: Matrix of tyre “fingerprinting” patterns of the measured Vertical Contact Stresses of the 12R22.5 HVS test tyre

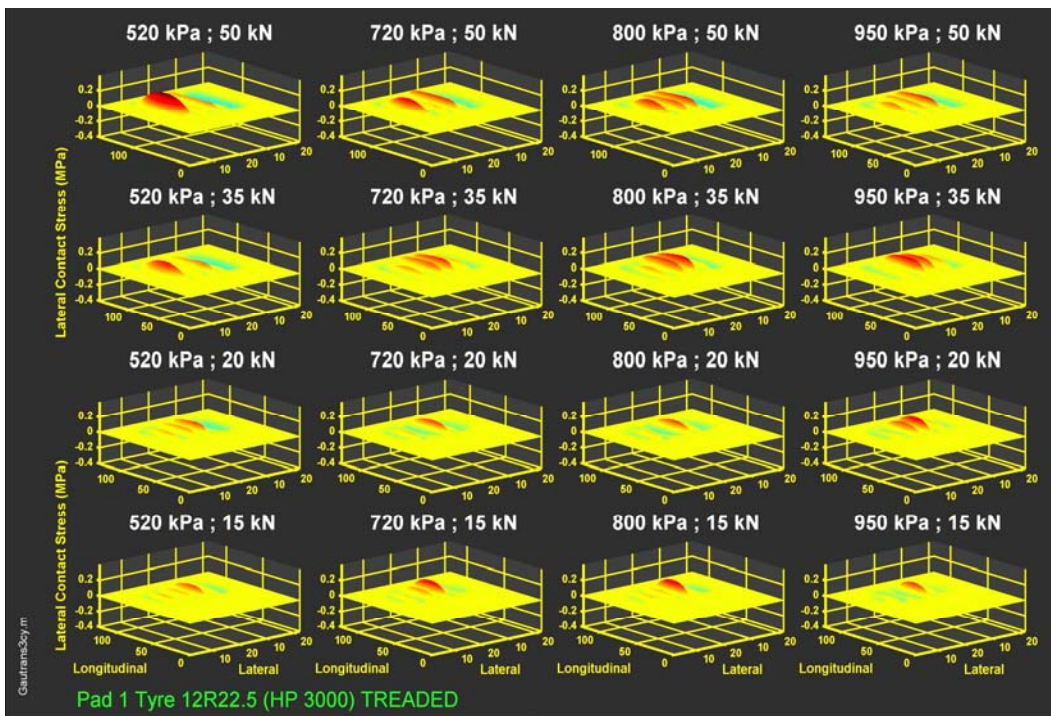


Figure 4: Matrix of tyre “fingerprinting” patterns of the measured Lateral Contact Stresses of the 12R22.5 HVS test tyre

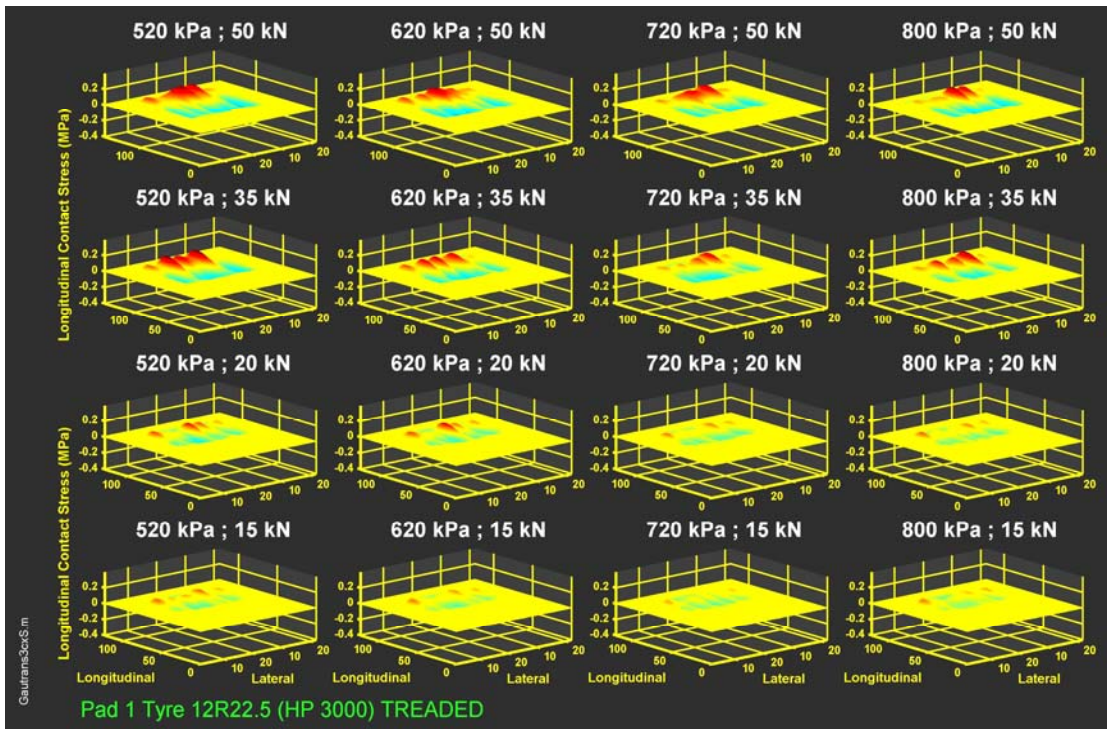


Figure 5: Matrix of tyre “fingerprinting” patterns of the measured Longitudinal Contact Stresses of the 12R22.5 HVS test tyre

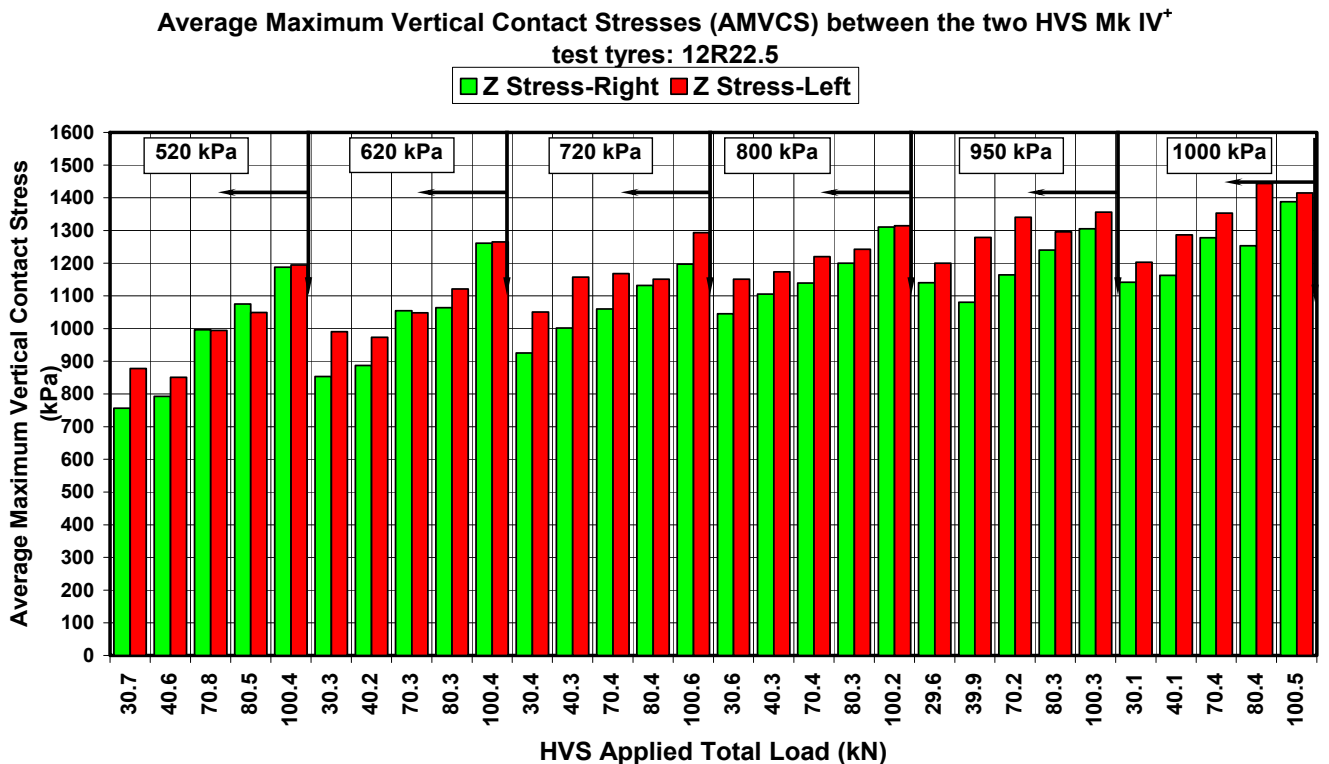


Figure 6: Comparison between the average maximum vertical contact stresses (AMVCS) between the dual HVS Mk IV⁺ test tyres: 12R22.5

Average Maximum Vertical Contact Stresses (AMVCS) between the 12R22.5 and the 11R22.5 HVS test tyres

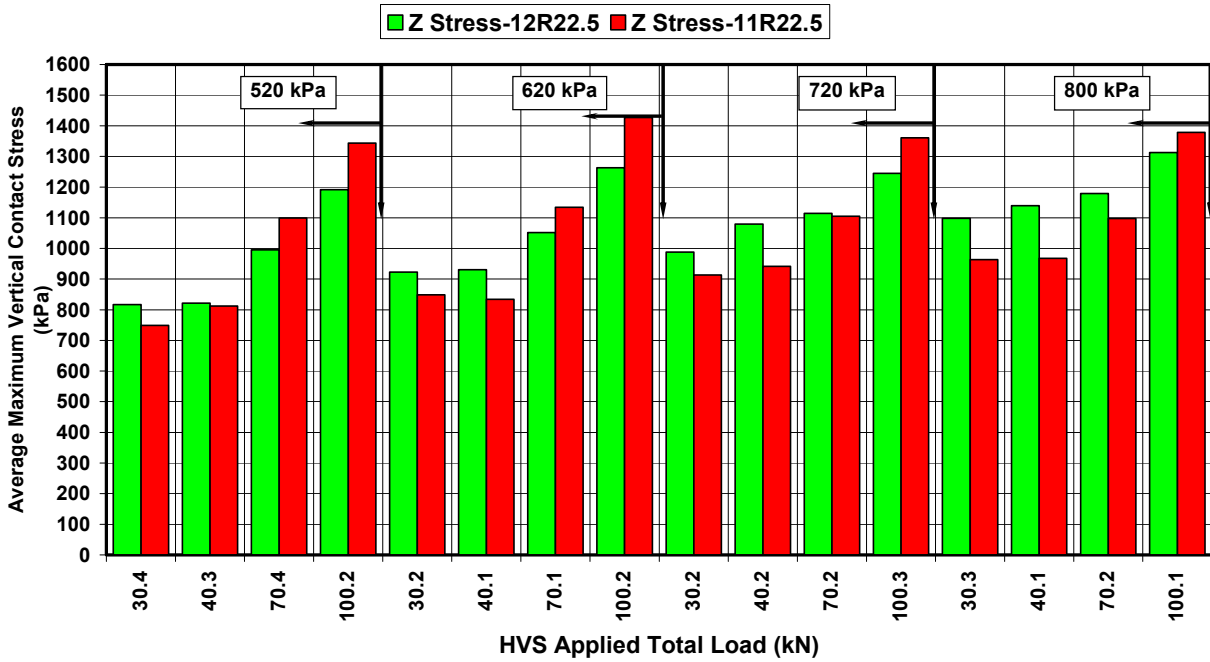


Figure 7: Comparison between the average maximum vertical contact stresses (AMVCS) of the 12R22.5 and 11R22.5 HVS test tyres

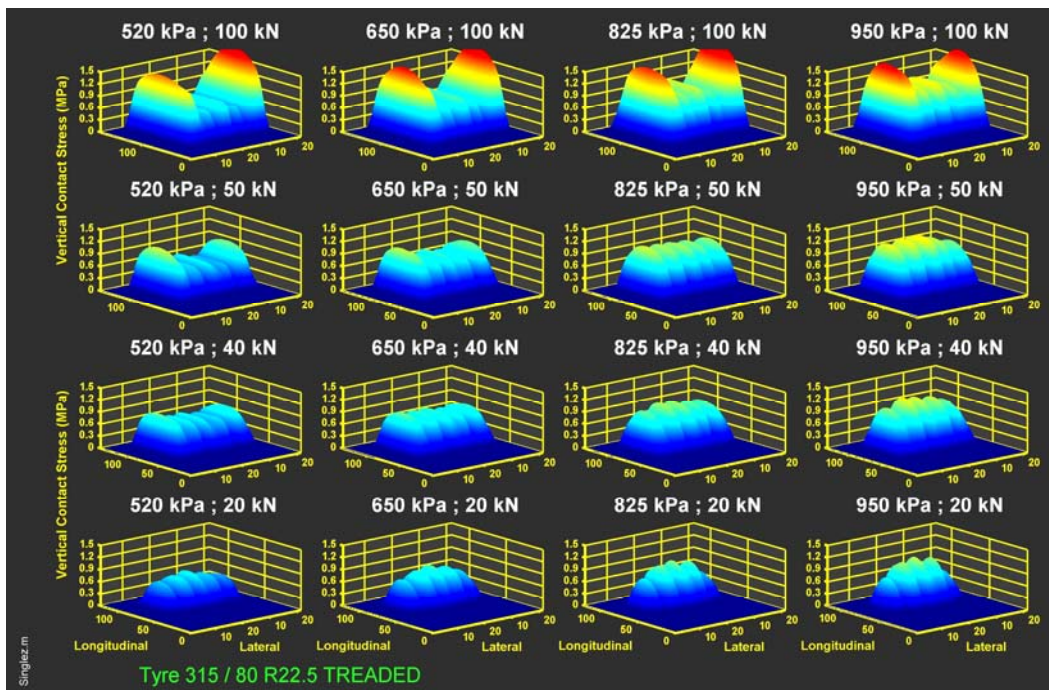


Figure 8: Matrix of tyre “fingerprinting” patterns of the measured Vertical Contact Stresses of the 315/80 R22.5 HVS test tyre

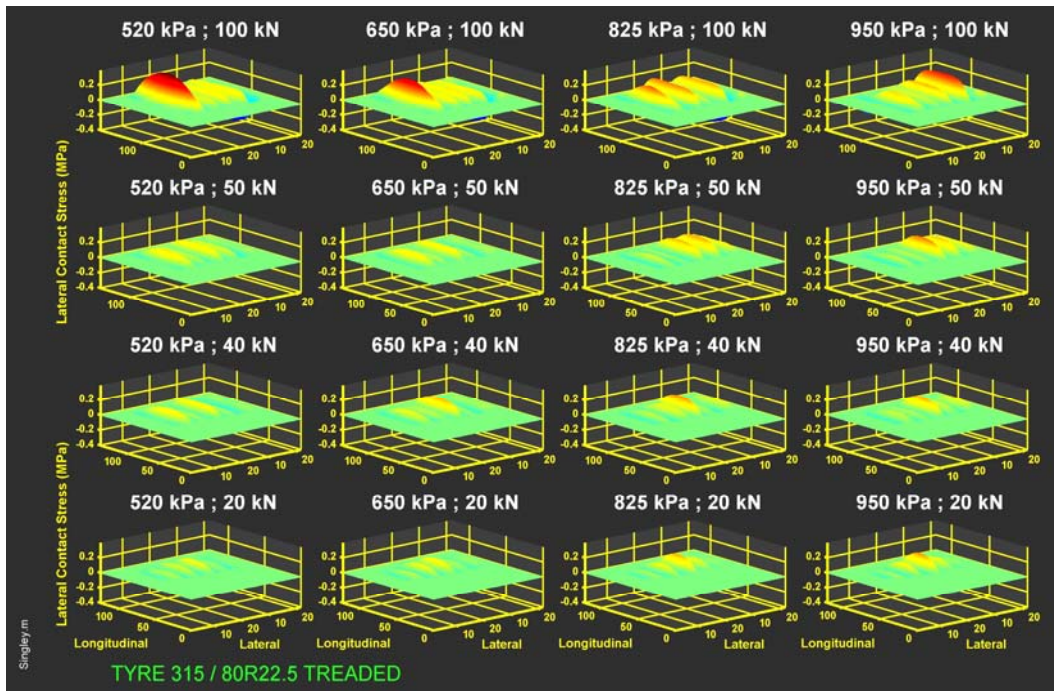


Figure 9: Matrix of tyre “fingerprinting” patterns of the measured Lateral Contact Stresses of the 315/80 R22.5 HVS test tyre

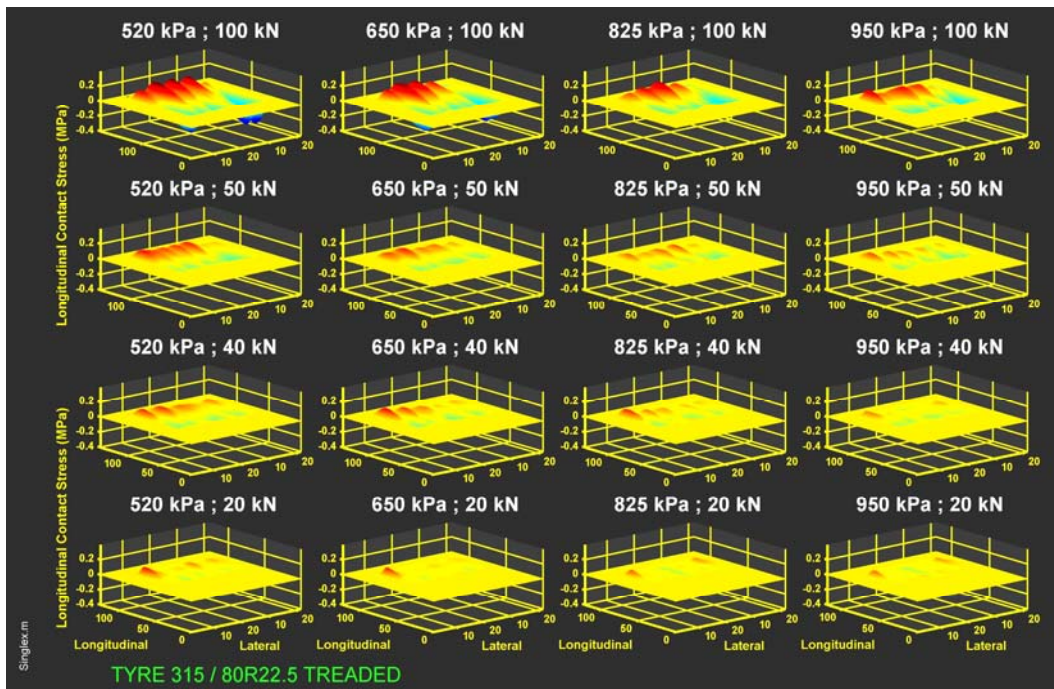


Figure 10: Matrix of tyre “fingerprinting” patterns of the measured Longitudinal Contact Stresses of the 315/80 R22.5 HVS test tyre

Average Maximum Vertical Contact Stresses (AMVCS) between the 11R22.5, 12R22.5 and the 315/80 R22.5 HVS test tyres

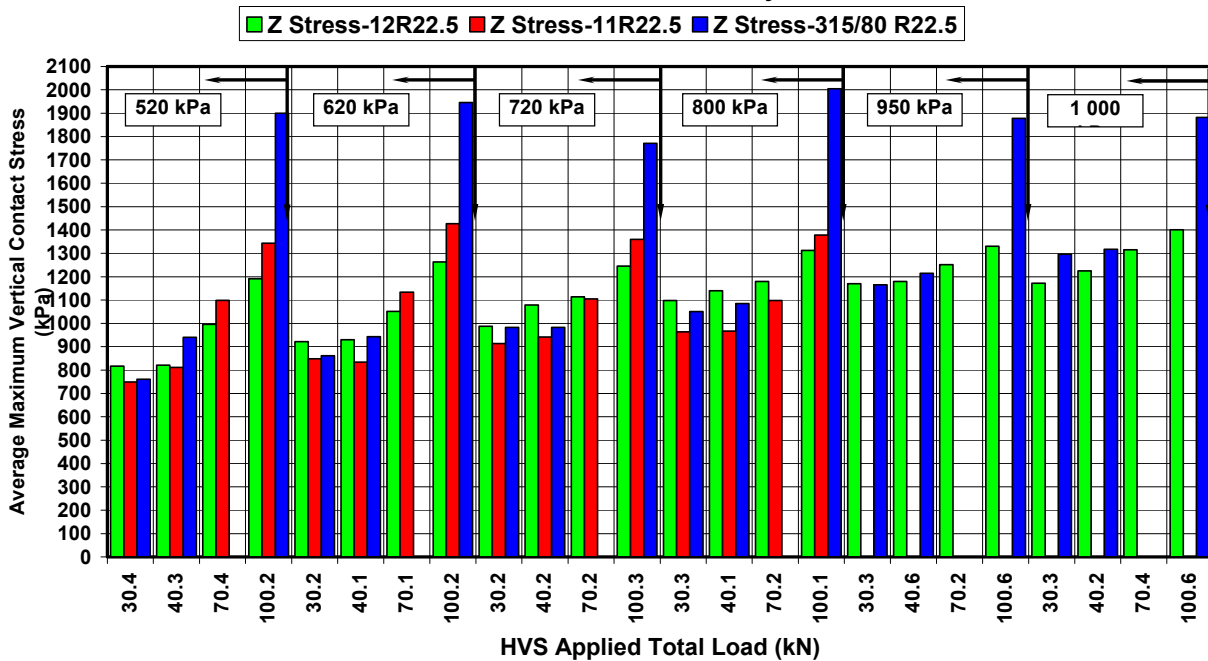


Figure 11: Comparison between the average maximum vertical contact stresses (AMVCS) of the 11R22.5, 12R22.5 and 315/80 R22.5 HVS test tyres at comparable load and inflation pressure levels

5. DISCUSSION ON RELEVANCE OF TEST RESULTS

Accelerated Pavement Testing (APT) worldwide is relatively expensive, but a very important technology platform from which remarkable knowledge can be gained in a relative short period. This knowledge is gained and studied in a phenomenological way, and constitute the very basis of the South African pavement design and pavement behaviour intelligence. One of the main input parameters into the design of pavements is the design loading, loading intensity (i.e contact stress) and its shape. Various studies have shown the importance of the correct modeling of tyre loading in pavement design and analysis, especially for thin surfaced pavements, common in southern Africa (Blab 1999, Blab and Harvey 2000; De Beer et al, 1997, 1999, 2002, 2004a, b; Milne et al, 2004).

Not only is the correct modelling of the load/pavement interface important, but it is believed that the area of tyre-pavement contact needs much more research attention in APT than what was done until recently. With the 3-dimensional contact stresses known, using available technology such as the SIM device, APT testing can now be optimized for a particular load/inflation pressure condition for a specific tyre and test environment. It is not enough to accelerate pavement testing by simply increasing the load without increasing inflation pressure, or even keeping inflation pressure constant. The spatial surface defects of APT test pavements are directly related to the applied contact stresses. This is also true for normal road pavements. A stage has now been reached where these contact stresses are very closely approximated to the actual stress regimes between rolling pneumatic tyres and pavement surfaces. This knowledge can also be applied to test configurations in the laboratory for optimization of surfacing mixes for known stress conditions.

Therefore, if the above new knowledge is applied properly it should lead to a more rational understanding of tyre-pavement interface behaviour, which could optimize the choice of a

specific surfacing for a specific condition much better than perhaps done in the past. The ultimate objective of tyre-pavement contact stress information is to assist in the Governments mandate to ensure quality delivery and sustainable road infrastructure systems.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

This paper discusses the measurement (quantification) of 3-dimensional tyre-pavement contact stresses for different pneumatic tyres used in the Gautrans accelerated pavement testing (APT) program. Two new tyres were tested (in addition to previous tests on 11R22.5 tyres) including the new 12R22.5 and the new 315/80 R22.5 tyres used by the Gautrans Heavy Vehicle Simulator (HVS Mk IV⁺). The measured data from the Stress-In-Motion (SIM) system indicate rather well known non-uniformities of the contact stress regime at the tyre-road surface interface, and can now be used to optimize APT in South Africa. These non-uniformities are a function of both tyre loading and tyre inflation pressure for a specific tyre carcass and tread pattern.

The measured data suggest that at lower loads the 11R22.5 tyre seem to result in lower contact stresses compared to those from the 12R22.5 tyre, which, in turn, seems to be more beneficial (lower stresses) at the higher load levels. In the case where HVS Mk III was compared with HVS Mk IV⁺ during parallel testing (reported by Morton and Theyse, 2003), it is believed that different load and inflation pressure levels between the two sets of dual test tyres caused the observed differences in the resilient deflection and also the permanent deformation.

For the 12R22.5 and the 11R22.5 tyres, the relative order of magnitude of the maximum contact stresses is vertical (100 per cent), lateral (approximately 17 percent) and lastly longitudinal (approximately 12 per cent) for a *non-driven free rolling slow moving tyre*. In addition, measured data on the 315/80 R22.5 tyre suggests comparable stresses and stress ratios as the 11R22.5 and the 12R22.5 tyre sets for non-overloading conditions. However, in cases of overloading and severe overloading the 315/80 R22.5 tyre type indicates extremely high tyre wall contact stresses which should be avoided at all costs.

For the 315/80 R22.5 tyre, the ascending order of magnitude of average maximum contact stresses is vertical (100 per cent), lateral (approximately 18 percent) and lastly longitudinal (approximately 12 per cent) for a *free rolling slow moving tyre*. These values are highly comparable to the other two tyre types studied in this paper.

6.2 Conclusions

For non-driven free rolling slow moving tyres, the following is concluded from this study:

- The complex nature the tyre-pavement contact stress regime of slow moving and free rolling pneumatic tyres can be approximated by measurement with the Stress-In-Motion (SIM) technology;
- Differences exist between the stresses from the 11R22.5 tyre and the new 12R22.5 test tyres on the HVS, depending on the inflation pressure and loading level (even at the same load and inflation pressure, see Figure 7);
- The average maximum vertical contact stresses (AMVCSs) ranging between 749 kPa to 1 427 kPa for the 11R22.5 tyre, and 817 kPa to 1 312 kPa for the new 12R22.5 tyre for the same load in inflation pressure levels studied;

- For these tyres the average maximum vertical contact stresses (AMVCSs) exceed the inflation pressure by 1.2 to 2.58 times, as was quantified by the Normalized Contact Pressure (NCP) parameter. This indicates that it is incorrect to assume the vertical contact stresses to be equal (or lower) than inflation pressure for road pavement studies. This assumption may lead to premature pavement surface distress;
- Lateral and Longitudinal stresses are approximately 17 per cent and 12 per cent of the associated vertical maximum stress. Typical ranges are 116 kPa to 295 kPa for the lateral (Y) stresses, and 64 kPa to 251 kPa for the longitudinal (X) stresses for the range of load and inflation pressure levels studied here;
- Differences also exist between the stresses from the 11R22.5, 12R22.5 tyre and the new 315/80 R22.5 test tyres on the HVS, depending on the inflation pressure and loading level;
- The average maximum vertical contact stresses (AMVCSs) ranging between 817 kPa to 1 312 kPa for the new 12R22.5 tyre and between 760 kPa to 2004 kPa for the 315/80 R22.5 single tyre;
- For the 315/80 R22.5 tyre the average maximum vertical contact stresses (AMVCSs) exceeds the inflation pressure by 1.17 to 3.68 times, as was quantified by the Normalized Contact Pressure (NCP) parameter. Again, it can be seen that the assumption of inflation pressure being equal (or less) the vertical contact stress is a gross under estimation for the purposes of pavement design and analysis of this tyre type;
- The Lateral and Longitudinal stresses of the 315/80 R22.5 tyre ranging between 120 kPa to 400 kPa for the lateral (Y) stresses, and 64 kPa to 336 kPa for the longitudinal (X) stresses, for the range of load and inflation pressure levels studied here;

6.3 Recommendations

Based on the findings of this study and its interpretations, the following are recommended:

- Immediate implementation of the findings of this study by the APT steering committee in future HVS Mk IV⁺ testing – i.e. study the contact stress patterns *before* any test commences in order to rule out undesirable tyre edge and side wall effects, which are difficult to quantify with current mechanistic design and analysis methods;
- HVS-APT testing should preferably always include a period of testing at the “Standard Load” and the associated inflation pressure levels (80 kN axles). These levels are different for different tyre types. *For the 12R22.5 tyres these testing levels are: 720 kPa at a total load of 40 kN per dual set of tyres (tyre side wall vertical stresses < than stresses at tyre centre). For the single 315/80 R22.5 tyre these levels are: 825 kPa to 950 kPa at a total load of 40 kN.* This condition should *exclude* undesirable tyre edge stresses which is higher than the maximum stress at the tyre centre;
- For future HVS testing it is strongly recommended that care should be exercised in selecting a higher load level (with or without an associated inflation pressure level) in order to “accelerate” the test purely because of restricted time or funding;
- During HVS-APT on flexible pavements with “sensitive” thin asphalt (or seal) surfacings, it is critical to apply *comparable* contact stresses during HVS-APT to the test pavement to those expected from normal truck traffic. Therefore, it is recommended that the existing (or expected) traffic for the road intended to be

- tested with the HVS, be defined correctly *before* any HVS testing commences;
- Road Authorities and pavement design consultants to be aware of this work in the APT field in order to enhance general pavement design practice. It is strongly suggested that sensitivity analyses to be done at various contact stress levels using current mechanistic design principles. It is recommended to use the following ranges for design purposes: *Inflation pressure from 520 kPa to 1 000 kPa (100 kPa increments) at load levels ranging from 15 kN per tyre to 30 kN per dual tyre types (in 5 kN increments), and 15 kN to 60 kN for the single tyre types, also in 5 kN increments;*
- Design protocols for pavement surfacing and seals to be rationalized - taking the new contact stress data into consideration during the design and analysis phase of new or rehabilitated facilities;
- Local and international tyre manufacturers to be made aware of the use of this tyre of tyre data in road design and road perseverance;
- Road authorities and designers to take cognisance of the *actual traffic loading/stressing demands* on flexible pavements in South Africa.

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