

Using tire-road contact

stresses in road pavement design and analysis

Simple tire-pavement contact analysis reveals that higher contact stresses

from truck tires could result in increased potential for road pavement failures

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Road pavements worldwide are one of the most important infrastructure elements which should be maintained in good to excellent condition in order to service the economy of any progressive nation. Most of the time, however, road pavement failures initiate within the pavement structural or subgrade layers long before they are visible on the surface of the pavement.

There are two main basic classes of pavement failures: traffic-associated and non-traffic-associated failures. Non-traffic-associated failures are those associated with the environment, mainly through variations in temperature and water (moisture) over time. Traffic-associated failures are due to tire-road contact, where tire (or vehicle) loading is transferred to the structural layers of the pavement, which is usually covered with a functional surfacing layer. This means the structural importance of the final layer of a paved road system should not be underestimated, both from a safety perspective and because it serves as a protective layer for the structural layers of the pavement system. Roque *et al.*,^{21,22} Myers *et al.* in 2001¹⁹ and Novak *et al.* (2003)²⁰, among others, all indicated potential road failures (rutting/cracking)

“Never underestimate the final layer of a paved road system, both in terms of safety and because it acts as a protective layer”

originating at the near surface of the pavement due to, among other factors, the Poisson's effect under the ribs of pneumatic truck tires causing some peak strains in the near surface of the pavement next to the tire edge.

The aim of this paper is to discuss aspects of measured tire-road contact stresses (in three dimensions: 3D) within the tire contact patch (footprint) of typical



Figure 1: An aerial photograph of a high-quality thin surfaced divided freeway located near Pretoria, South Africa

truck tires. It is shown by relatively simple tire-pavement contact analysis that higher (or different) contact stresses could result in increased potential for road pavement failures, mostly visible within the final surfacing layer, or near the surface of pavement layers.

Observations of road pavement failures

In South Africa, most flexible paved road pavement structures consist of a relatively thin asphalt surfacing layer covering the base layer, which is often a 150mm

high-quality unbound crushed rock material, compacted to a solid density of 86 to 88% material specification.² The thickness of these asphalt surfacing layers varies between 25mm and 30mm, and the vast majority of primary roads are covered with an asphalt seal layer (chip stones, or chip seal), with a thickness of approximately 12mm to 20mm (see Figure 1). In the wetter coastal regions

of South Africa, however, the crushed stone layer is replaced by an asphalt base layer of approximately 120mm or thicker. It is therefore of critical importance to quantify and also improve the understanding of the actual tire-road contact stresses (or forces), and, if possible, also to quantify them in 3D, in order to optimize road layer 'life' (or bearing capacity) by means of effective road design and associated maintenance schedules, often with limited budgets and resources.

The failures of these functional surfacing layers include both plastic deformation such as 'rutting' and/or shoving/horizontal plastic flow often resulting in standing water in the wheel paths during rain, and fatigue cracking, delamination, and disintegration leading to the formation of potholes. The typical 'wiggling yellow line' indicative of shear failure in the unbound base layer caused by substandard base layer quality is another sign of potential pothole formation on flexible road pavements. Most of these failures are somehow related to tire-road interaction and are therefore considered 'traffic associated'. In this paper it is postulated that an improved understanding of the 3D tire-road

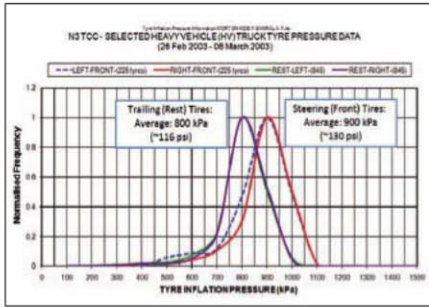


Figure 2: Inflation pressure differences of steering and trailing tires of heavy vehicles. Data from Ref. 8

interaction forces (or contact stresses) could serve as a sound platform for the formulation of improved pavement design rules. The traditional assumption of one-dimensional (1D) uniformly distributed tire loading on a circular area for pavement design as discussed by Huang in 1993¹⁵ is therefore questioned.

Tire inflation pressure of heavy vehicles

A major assumption in road pavement design is that the vertical tire-pavement contact stress is assumed to be equal to the tire inflation pressure, and to be uniformly distributed on a circular area.¹⁵ With regard to tire inflation pressure trends, several studies since 1974 have shown an increase in the inflation pressure of the tires of heavy vehicles.

In South Africa, tire inflation pressure data from 1974 compared with those of 2003 shows that there was a 30-40% increase in average inflation pressure over 30 years. A study by De Beer¹¹ showed an increase in average inflation pressure (cold) from 633kPa in 1974 to 733kPa in 1995, and that the pressures are currently approaching an average of 800kPa (116psi), with maximum pressures exceeding 1,000kPa (145psi). Figure 2 illustrates the results of a more recent study in which a difference in tire inflation pressure was observed between steering tires and trailing tires of approximately 100kPa (14.5psi) (cold). The average inflation pressure was approximately 900kPa (131psi) for the steering tires, and 800kPa (116psi) for the trailing tires of a selection of heavy vehicles.

It should be noted that back in the 1970s, Van Vuuren²⁴ recommended a value of 520kPa (75.4psi) for circular uniform contact stress for pavement design in South Africa.

Contact stress measurements

Based on the increasing trend of truck tire inflation pressures found in South

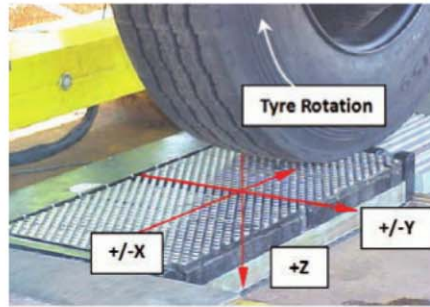


Figure 3: The flat bed Stress-In-Motion (SIM) device with SAE coordinate system, as was used in this study

Africa, in association with numerous road surface failures (also demonstrated by Heavy Vehicle Simulator (HVS) accelerated pavement testing and research),¹⁰ it was decided to further study tire contact stress measurements, which dated back to 1965.¹ During the 1990s a rigid flatbed device with a textured surface was successfully developed and used to measure the tire-pavement contact stresses of a range of pneumatic truck tires. The single pad of the device, referred to as the Stress-In-Motion (SIM) device (earlier versions were referred to as Vehicle Road Surface Transducer Array,

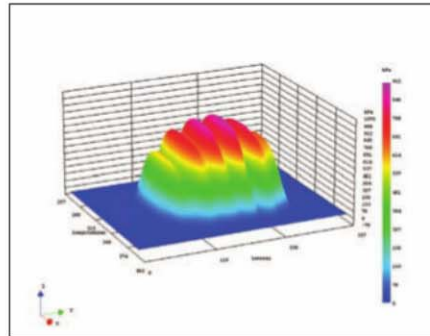


Figure 5a: 3D Footprint of vertical contact stress of the 11 x R22.5 HVS tire at 20kN load at 800kPa inflation



Figure 4: Dual SIM device under dual tire loading using the Heavy Vehicle Simulator (HVS) for testing

or VRSPATA),^{5,6} is shown in Figure 3 (single SIM pad), and Figure 4 (dual SIM pad configuration).

The SIM system is modular and a test bed configuration of up to 2,100mm wide is possible with this setup (more information is available at http://www.csir.co.za/Built_environment/brochures.html). For controlled tire loading and tire inflation pressure the HVS was used for tire-pavement contact stress measurements in association with the SIM device. The first typical SIM data were published by De Beer in 1996,⁵ and a comprehensive summary was presented in 1997.⁶ An

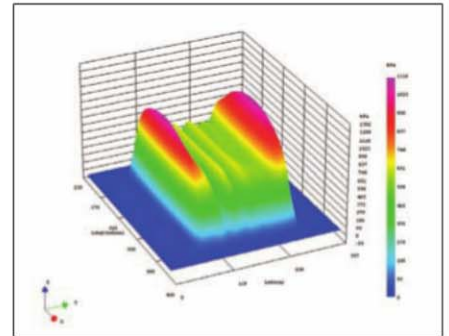


Figure 6a: 3D Footprint of vertical contact stress of the 11 x R22.5 HVS tire at 40kN load at 420kPa inflation



Figure 5b: This road sample displays rutting or plastic deformation in asphalt surfacing. Heavy Vehicle Simulator (HVS) tire loading of 20kN, and inflation pressure of 800kPa (with typical "n-shape" vertical stress distribution), resulting in typical "n-shape" plastic deformation in a thin asphalt surfacing layer – only one HVS tire traffic lane is shown here²³



Figure 6b: This road sample displays rutting or plastic deformation in asphalt surfacing. Heavy Vehicle Simulator (HVS) tire (over) loading of 40 kN, and inflation pressure of 420kPa (with typical "m-shape" vertical stress distribution), resulting in typical "m-shape" plastic deformation in a thin asphalt surfacing layer – only one tire HVS traffic lane is shown here²³

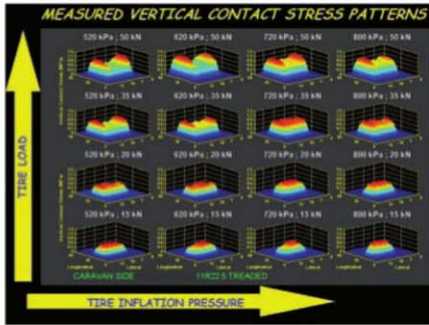


Figure 7: Typical tire ‘fingerprint’ of the vertical stress variation with tire loading and inflation pressure

article in the *Tire Technology International* Annual Review of 2000 also discussed this system and associated results.⁷ This was followed by several presentations relating SIM data with mechanistic analyses of road pavements in 2006,⁸ and 2008,⁹ and a recent paper.¹²

Typical tire contact stress results from the SIM system

The SIM device was developed mainly for the measurement of slow-moving pneumatic truck tires at speed of approximately 3mph (5km/h). A single SIM pad consists of 21 instrumented conically shaped hollow cylindrical pins with a surface contact area of approximately 94mm² (diameter of 9.7mm) at a fixed lateral resolution of 17mm c/c, each pin being a five-axial load cell based on strain gauge technology, calibrated against a high-precision miniature load cell, which in turn is calibrated against dead weight.^{5,6}

In the longitudinal direction the resolution is a function of the test speed

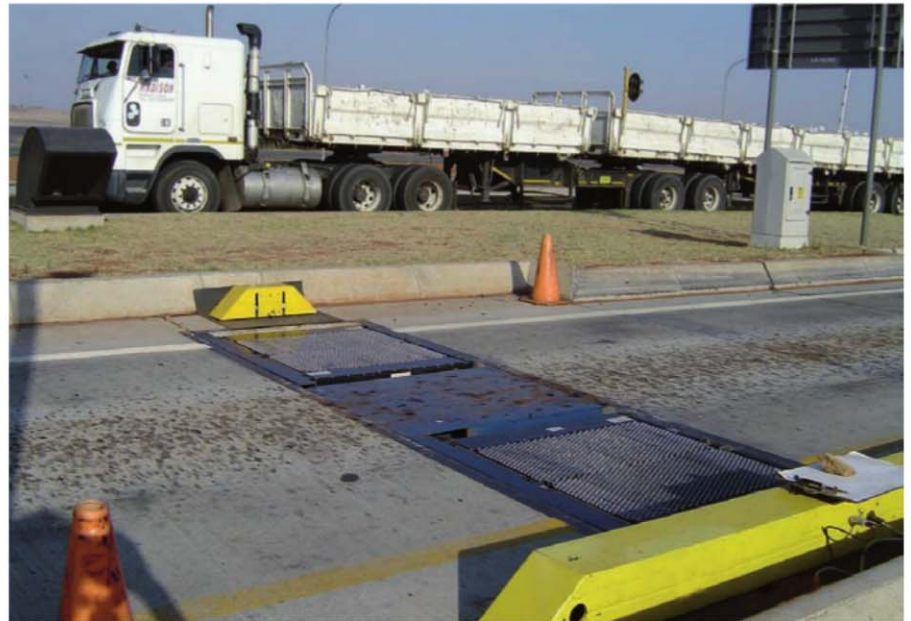


Figure 8: Shows a typical field configuration during a special test series with a quad SIM system, conducted in 2003

(V in m/s) of the tire divided by the sampling rate (usually 1,000Hz per channel). For typical HVS testing with the SIM device, the longitudinal increment is approximately 0.3mm. The fore and aft sections of the SIM pad (which is 350mm-wide and 750mm in length) also consist of a number of conically shaped supporting pins (totalling more than 1,000) of similar shape and size to the instrumented pins. This configuration results in a textured measuring surface with friction values approximating those of a dry asphalt surface,⁶ which means that the tire is approaching the textured surface of the SIM device (or the measuring pad).

Measurement is made in the center portion of the SIM pad after the front part of the tire contact patch has been ‘conditioned’ by the textured surface, after which the aft part of the contact patch is measured. A 3D contact stress pattern is obtained in one measurement cycle. Typical contact stress results under a standard dual 11 x R22.5 tire load of 40kN and inflation pressure of 520kPa (typical standard axle of 80kN). Note that higher test speeds can be achieved with the SIM system, and are dependent mainly on the

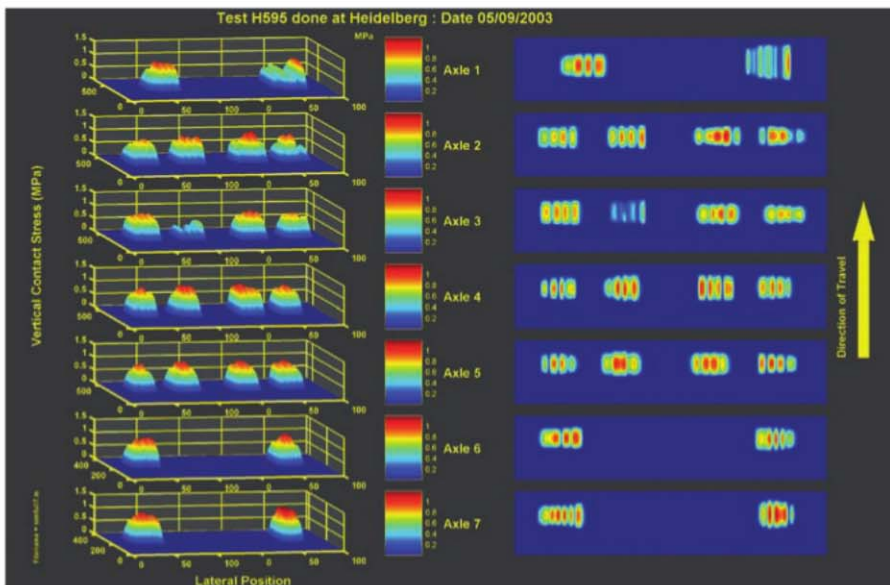


Figure 9: Typical vertical contact stress footprint of a seven-axle heavy vehicle captured with the SIM system in 2003

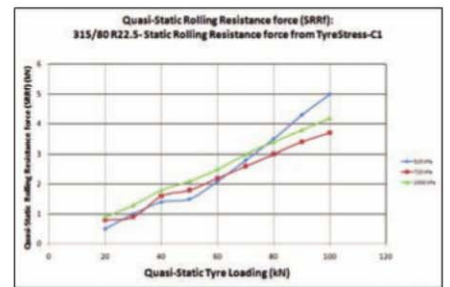


Figure 10: Quasi-static rolling resistance force data

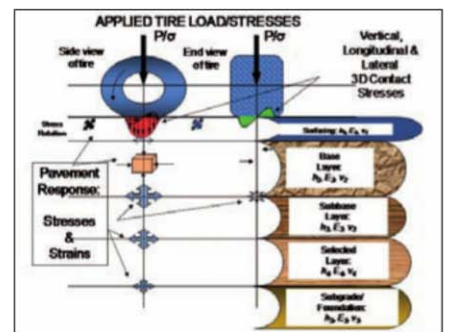


Figure 11: Typical schematic of a multilayer road pavement structural design problem with tire loading

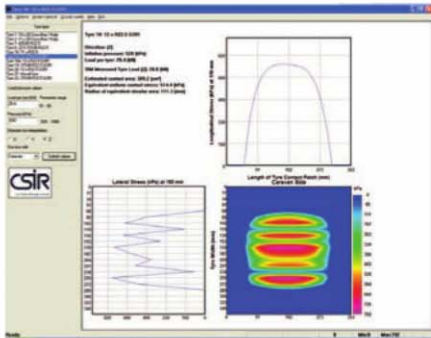


Figure 12: Interpolated data for Tire 18 at 20kN and 520kPa. Average vertical contact stress of 613kPa

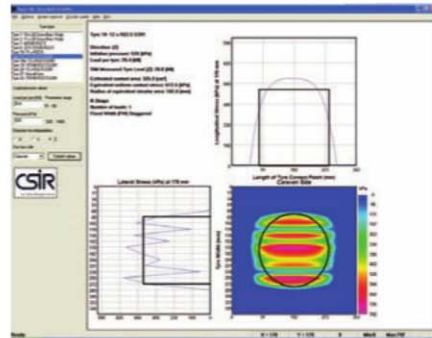


Figure 13: Data for Tire Model 2. SIM-measured tire loading/stress. Vertical load 20kN, vertical stress 613kPa

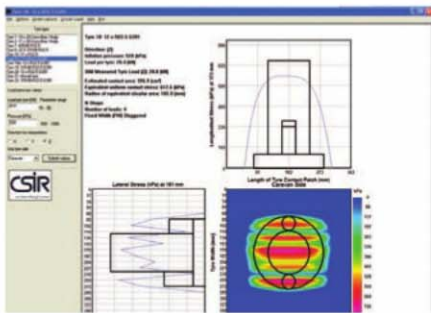


Figure 14: Measured data for Tire Model 3: Representing Tire Model 2 but with four discs staggered in two layers

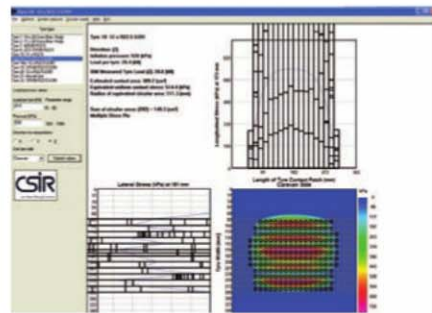


Figure 15: Measured data for Tire Model 4. Representing Tire Model 2 but with multiple (202) smaller discs

data acquisition system. The natural frequency of the instrumented pins (or sensors) is approximately 3,700Hz. A typical truck tire, with contact patch length (L) with the tire contact patch of 250mm traveling at a speed (V) of 50mph (80km/h), will result in a total data count of approximately $[250\text{mm}]/[80,000\text{m} / (60 \times 60)] = 11$, with increments between the data points of 22.2mm. However, most of the measurements so far were made at a speed of approximately 0.3m/s, resulting in data counts varying between 200 and 1,000, depending on the length of the tire

contact patch (L), the speed (V) and the sampling frequency (f). Currently the sampling frequency is 1,000Hz. In Figures 5 and 6, some measured HVS tire test results are shown with a tire loading case of 20kN/800kPa, resulting in 'n-shape' rutting (or plastic/permanent deformation), and an overloaded/ underinflated case of a tire at 40kN/420kPa, resulting in 'm-shape' rutting. The resulting shapes of the road surface rutting mimicking the shape of the n-shape and m-shape vertical tire contact stress (Z), respectively.

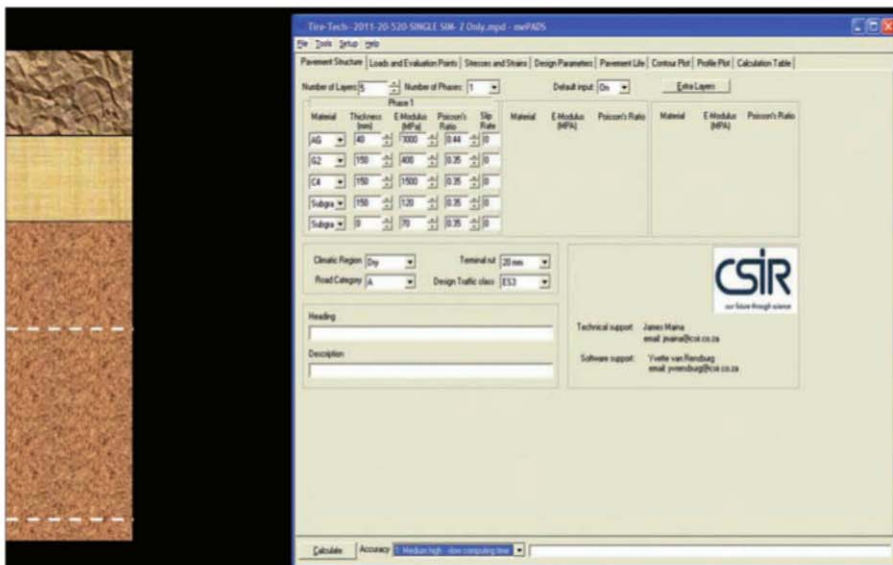


Figure 16: Definition of five-layer road pavement structure used for the various analyses. Screen clip from mePADS

In Figure 7, typical tire footprints (collectively referred to as tire 'fingerprint') of the vertical contact stress variation with tire loading (vertical axis from 15kN to 50kN loading) and with variation in tire inflation pressure (horizontal axis from 520kPa to 800kPa) is illustrated. Similar data can be presented for the measured +/- lateral and +/- longitudinal contact stresses. Figure 7 illustrates the effect of tire loading at constant tire inflation pressure and clearly shows the changes in the contact stress pattern from a relatively light load, where the maximum stress is towards the tire center (typical bell or n-shape), to the typical dual bell, or m-shape, where the load is carried mostly by the tire sidewalls, resulting in the highest contact stresses at the tire edges, as originally described in 1997.⁶ The ideal (and often rated load/inflation pressure condition) is shown here at a rated tire load of 20kN and a rated inflation pressure of 720kPa. In the latter case a more uniform pressure (or vertical contact stress) distribution is observed (see also Figure 7).

SIM field testing next to a freeway in South Africa

During 2003, a special study was conducted in which a selection of real truck traffic was diverted over a quad SIM system at the relatively slow speed of ~3mph (5km/h). The test configuration is illustrated in Figure 8. During this test series lasting for a period of six weeks, a total of about 2,900 heavy vehicles, representing approximately 45,000 tires, were measured with the SIM system.^{8,9} In Figure 9 a typical vertical contact stress footprint of a seven-axle heavy vehicle (with 22 tires) captured with the SIM system in 2003 is illustrated. Note the non-uniformity of especially the tires on the steering axle, as well as the tires on drive axle number three.

Rolling resistance

Although the SIM system was developed mainly to get an indication of 3D tire-road contact force (or stress) distributions across the tire contact patch for the purposes of improved road pavement design, closer inspection of the data of a 315/80 R22.5 tire showed some promise for estimating a 'quasi-static' rolling resistance force (SRRF) on a textured measuring surface. Data of three tire loading cases were extracted and are shown in Figure 10. The figure indicates the measured total resultant longitudinal

force (for example, SRRf) during SIM measurement on the sample tire, as a function of vertical tire loading on the horizontal axis.

On average, the highest f_x was found to be at a tire inflation pressure of 1,000kPa, but the highest value was obtained at the lowest inflation pressure at 0.05. This case also yielded the highest range in values (and CoV) as a function of vertical load, F_z . However, further work is needed to assess whether this procedure (and hence the method of measurement) could indeed be used to measure the rolling resistance of tires.

The preliminary findings for the SIM measured data on a 315/80 R22.5 tire for slow-moving (< 6mph (10km/h)) free-rolling conditions include:

- There was a linear increase in SRRf with increased vertical tire loading at a rate of:
- ~3kN per 80kN @ 750kPa to 1,000kPa to
- ~4kN per 80kN @ 520kPa cold inflation pressure;
- There was an increase in SRRf with increased loading and decreased inflation pressure (see 520kPa result);
- The highest average rolling resistance coefficient ($f_x = 0.043$) was obtained at an inflation pressure of 1,000kPa;
- The highest single value of the rolling resistance coefficient ($f_x = 0.050$) was obtained at the lowest inflation pressure (520kPa) at the highest load investigated here. This case also resulted in the highest range of coefficients ($f_x = 0.025$ to 0.050), compared with those at inflation pressures at 720kPa and 1,000kPa.

The above data should be confirmed through more research on a wider range of tires and a wider range of operating conditions with the aid of the SIM system.

Road pavement analyses: a simplistic evaluation

In Figure 11 a schematic is shown defining a multilayer road pavement structural design problem with 'real' tire loading. The figure is self-explanatory. Real tire loading is defined here as that measured with the SIM system, as opposed to the general pavement engineering assumption of a uniformly distributed vertical loading/stress of circular shape for the tire loading. This modeling problem was also addressed by the development of the first worldwide tire/pavement contact-stress model based on artificial neural networks by El-Gindy and Lewis in 2001,¹³ as well as by a study by Fernando *et al.* in 2006,¹⁴ also based on SIM tire contact loading/stress

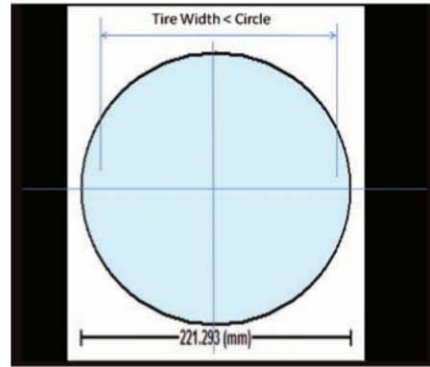


Figure 17: Tire Model 1, with no limit on radius

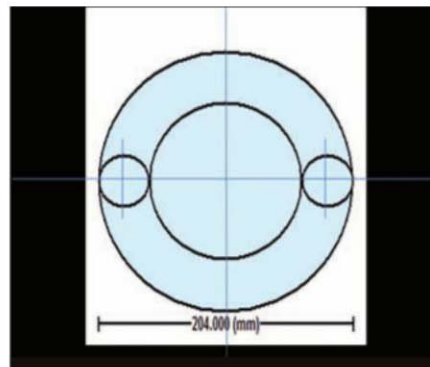


Figure 19: Model 3 (four discs, radius limited to FW)

measurements. For the present study pavement analyses were done using the normal linear elastic multilayer approach,¹⁵ with measured vertical loading/stress as input, using four different tire models.

Tire models used for pavement analyses in this study

The four tire models used for pavement analyses in this study are:

- Tire Model 1: Assumed vertical loading of 20kN and uniformly distributed vertical contact stress of 520kPa of circular shape (for example, disk) without restriction on the diameter of the disk (traditional method);
- Tire Model 2: SIM measured tire loading/stress – Uniformly distributed vertical loading (20kN) and average vertical contact stress of 613kPa, assumed to be of circular shape (for example, disk) with restriction on the diameter of the disk, for example, diameter not exceeding the tire width;
- Tire Model 3: Representing Tire Model 2 but with four circular discs staggered in two layers (to mimic the measured shape of vertical contact stress in the tire patch);
- Tire Model 4: Representing data measured for Tire Model 2 but with multiple (202) smaller circular disks with a radius of 4.85mm (to mimic the

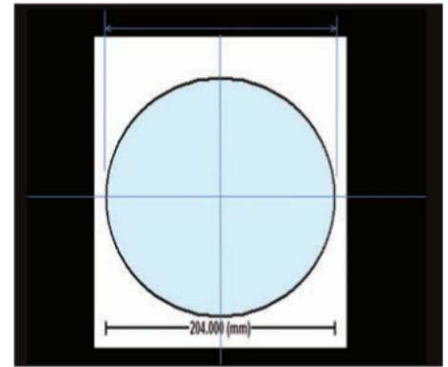


Figure 18: Model 2 (radius limited to Fixed Tire Width)

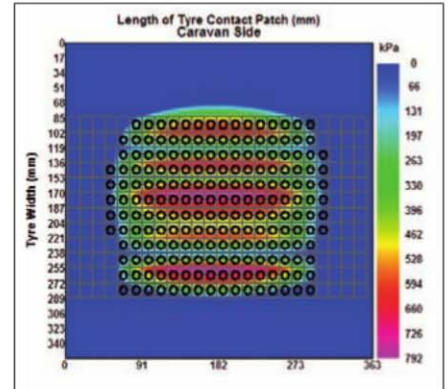


Figure 20: Model 4 (202 discs, all with 4.85mm radius)

measured shape of vertical contact stress in the tire patch).

The purpose of the various analyses that follow here is to demonstrate the effect of different tire models on pavement responses, as obtained from the vertical stress reaction, and the Strain Energy of Distortion (SED). Software dubbed 'TyreStress' was developed to interpolate and also export the SIM measured contact load/stress in the format of the above different tire models for the purpose of pavement analyses (TyreStress is the so-called 'delivery system' for tire contact stress/load for pavement design).⁴ The mechanistic-empirical pavement analyses were done using general (optimized) multilayer linear elastic methodology with the possibility of multiple circular 3D tire loadings.^{16,17,18}

For the case investigated in this paper, for example, 'Tire 18: 12 R22.5' at load of 20kN and inflation pressure of 520kPa, an image of the measured vertical contact stress (Z) footprint is shown at the bottom right of Figure 12. An average vertical contact stress of 613kPa (over the contact patch of 326cm²) is estimated from the measured data for this tire at 20kN load and 520kPa inflation pressure. The calculated radius of the equivalent circular area for this case is 102mm.

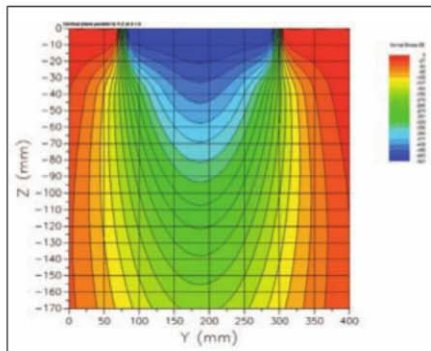


Figure 21: Vertical stress reaction through pavement (top 170mm): Model 1. Max. stress = 520kPa on surface

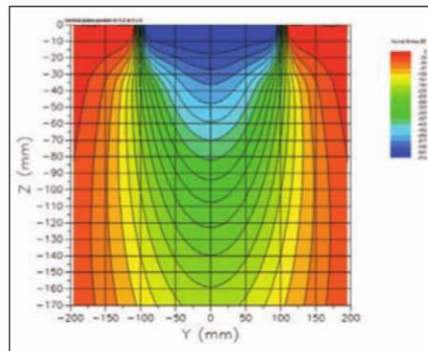


Figure 22: Vertical stress reaction through pavement (top 170mm): Model 2. Max. stress = 614kPa on surface

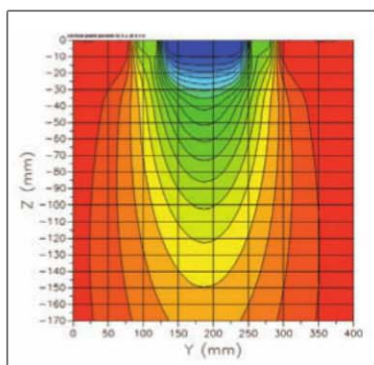


Figure 23: Vertical stress reaction through pavement (top 170mm): Model 1. Max. stress = 863kPa on surface

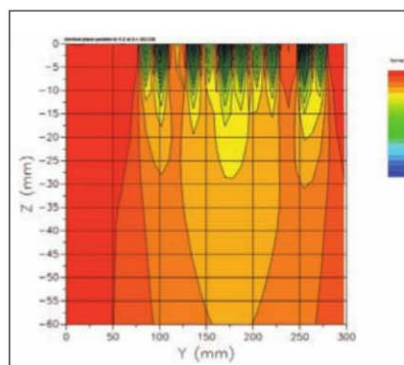


Figure 24: Vertical stress reaction through pavement (top 170mm): Model 1. Max. stress = 2490kPa on surface

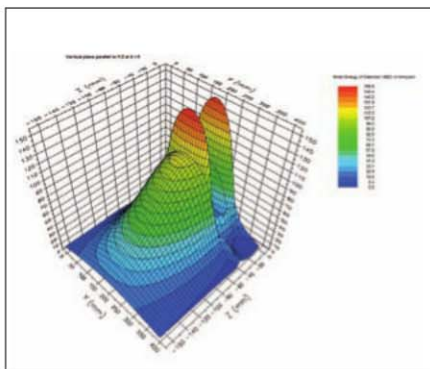


Figure 25: Strain energy of distortion (SED) through pavement (top 170mm): Tire Model 1. Maximum SED = 157Nm/m³ at 40mm depth

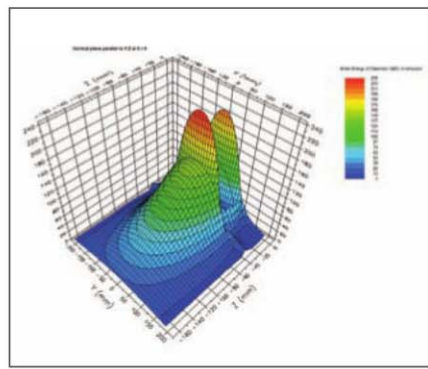


Figure 26: Strain energy of distortion (SED) through pavement (top 170mm): Tire Model 2. Maximum SED = 236Nm/m³ at 40mm depth

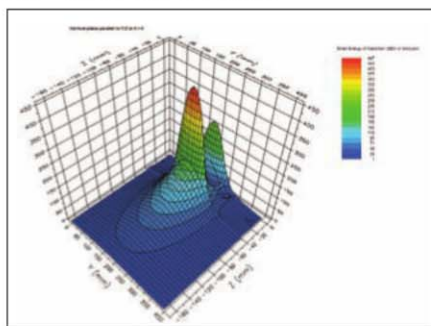


Figure 27: Strain energy of distortion (SED) through pavement (top 170mm): Tire Model 3. Maximum SED = 337Nm/m³ at 40mm depth

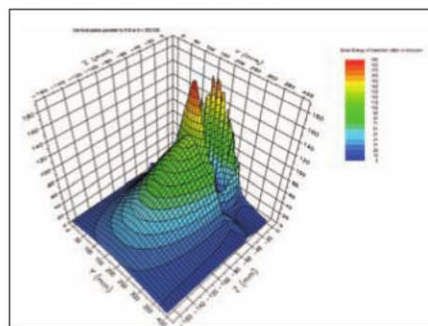


Figure 28: Strain energy of distortion (SED) through pavement (top 170mm): Tire Model 4. Maximum SED = 193Nm/m³ at 40mm depth

The maximum contact stress within the footprint area in this case is given as 792kPa.

It should be noted that the images in Figures 12 to 15 are constructed from data obtained by pentic-order polynomial fitting and topological interpolation from measured tire data (see various examples of measured data given in Figures 5, 6, 7, and 9), similar to what was reported by Fernando *et al.* in 2006,¹⁴ but for South African tire data. Further, cross-sections of the interpolated contact stress data are shown above and toward the left of the footprint images in Figures 12 to 15. The stress values are in kPa units. A further functionality of TyreStress software is to enable the exporting of tire contact stress (or load) data in idealized format or as raw interpolated data. Figures 13, 14 and 15 illustrate Tire Models 2, 3 and 4 respectively, for which the data were exported for the pavement analyses used in this study.

The definition of the five-layer flexible road pavement investigated in this study is given in Figure 16. The pavement analyses were done with multilayer linear elastic methodology using the basic mPADS software²³ available in South Africa.

The images of the four tire models discussed above are also summarized in Figures 17, 18, 19, and 20, respectively. The vertical stress distribution through the pavement depth under the four tire models is illustrated in Figures 21, 22, 23, and 24. The maximum vertical stress (Normal Stress ZZ) was found to be on the surface of the pavement, in the center area of the tire patch. The computed vertical stresses ranged from 520kPa to 2,490kPa for the four tire models. Note the rather irregular pattern of vertical stress in Figure 24 for Tire Model 4, compared with the results of the other three tire models.

The four different SED distributions through the pavement are illustrated in Figures 25, 26, 27 and 28. These figures indicated two nominal peak values of SED through the pavement structure, one on the surface of the 40mm asphalt layer near the center of the tire patch, and the second at the bottom of the asphalt layer at a depth of 40mm, also near the center of the tire patch. The maximum SED values at the bottom of the 40mm asphalt layer ranged between 157Nm/m³ and

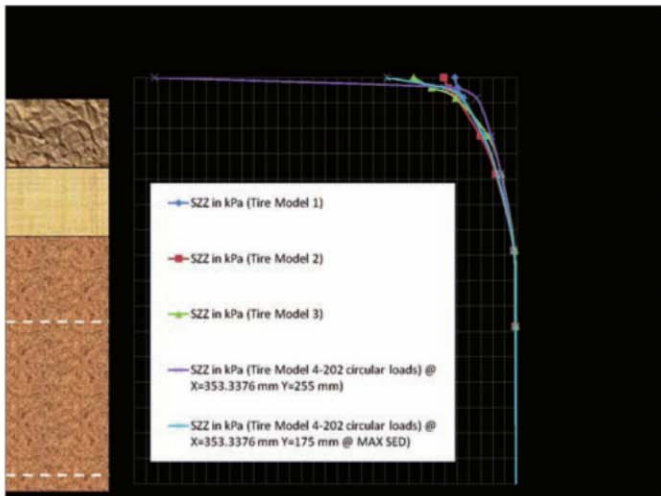


Figure 29: Summary of computed vertical stress through pavement depth for models

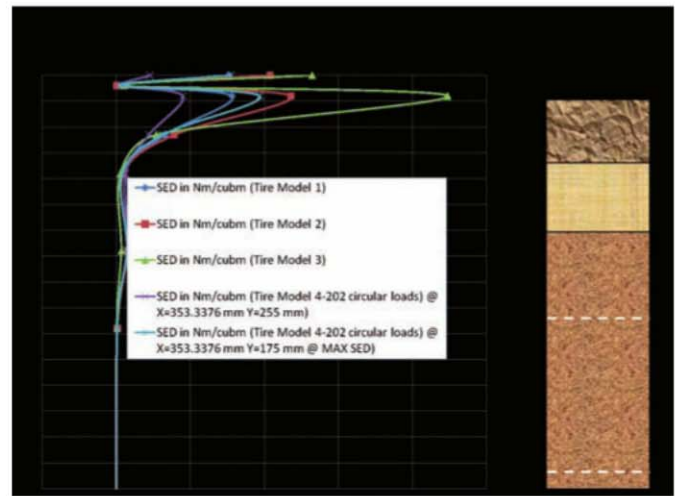


Figure 30: Summary of computed SED through pavement depth for the four models

337Nm/m³. The positions of the peak SED values can be interpreted as 'hot spots' for potential road layer failure, as was discussed by De Beer *et al.* in 1997.⁶

Discussion of pavement response

The two selected pavement response parameters, for example, vertical stress through the pavement as well as the SED, clearly indicate different maximum peak values, depending on the tire model used. In this case a surface contact stress difference of up to 4.5 times was computed between the standard assumption (Tire Model 1) and the 'close-to-ideal' case where the tire was modeled as 202 multiple circular disks (Tire Model 4). Also, a change in SED was obtained,

expected potential failure mechanism in this structure (probably fatigue cracking to be initiated at the bottom of the asphalt layer), in addition to potential rutting from the surface, indicated by the peak SED at $z = 0$ mm in the center of the tire contact patch, under the various tire models (see summary of the pavement response data (for example, computed vertical stress and SED) shown in Figures 29 and 30).

An attempt was also made to compute expected pavement life (or bearing capacity in terms of standard 80kN axle repetitions) for the pavement and the various tire models investigated here. For the layer bearing capacities in terms of standard 80kN axles, existing fatigue and layer damage models available in the

example, Tire Model 1) is changed to Tire Model 2 (for example, with SIM measured tire data and fixed width – FW – limitation).

Similarly, the layer 'life' of the asphalt (AG layer) is reduced by approximately 94%, and that of the unbound base (G2 layer) by approximately 6% when the results of Tire Model 1 are compared with those of Tire Model 3. Interestingly, according to Theyse *et al.*,²³ the 'life' or bearing capacity of the lightly cementitious subbase layer (C4 layer) with regard to both fatigue and rushing failure associated with these layers improved by approximately 70%, owing to a slightly reduced vertical stress on the top of this cementitious subbase (C4 layer) – see Figure 29 at a depth of 190mm. The layer life estimations discussed above are in accordance with layer damage laws for mechanistic-empirical pavement analyses discussed by Theyse *et al.*²³

The above results are interpreted (as with the computed vertical stress) to be dictated by the geometry and characteristics (for example, tire contact stress patch and its contact shape) of the tire model used for pavement modeling. The importance, therefore, of using a realistic (and hopefully a more rational) tire model for pavement design cannot be overemphasized. More research and analyses are, however, needed to validate the theoretical behavior discussed here, and the results should be updated on the basis of future appropriate research on a wider range of tires and road pavement types.

“An attempt was also made to compute expected pavement life for the pavement and the various tire models investigated”

peaking under Tire Model 3, and then reducing again in the case of Tire Model 4.

These peak SED values occurred both at zero depth (pavement surface) and at the bottom of the 40mm thin asphalt surfacing layer, with the maximum always at the bottom of the asphalt surfacing layer. It is interesting to note that the SED peaks at the bottom of this relatively stiffer asphalt layer (modeled with linear elastic modulus (E_t) of 3,000kPa and Poisson's Ratio $\nu_1 = 0.44$). These peaks of SED are considered to be indicative of the

South Africa were used for the quantitative analyses.

The calculated results from Tire Model 1 compared to those from Tire Model 2, Tire Model 3 and Tire Model 4 indicated that the layer life (or bearing capacity) of the 40mm asphalt layer (AG layer) is reduced by approximately 64%, and that the bearing capacity of the unbound granular base (G2 layer) is reduced by approximately 6%, and that of the lightly cementitious subbase layer (C4 layer) by 74% when the tire model from the traditional assumption (for

Conclusions and recommendations

It is concluded that:

- Tire-pavement contact stresses can be quantified in 3D, using Stress-In-Motion (SIM) technology;
- Tire rolling resistance could potentially be defined by the Static Rolling Resistance force (SRRF) and associated rolling resistance coefficients obtained from the SIM type of testing;
- The tire contact stress/loading results are considered acceptable for advanced mechanistic pavement analysis;
- Current data show that 3D tire pavement contact stresses are complex, and may assist with advanced structural road pavement analysis;
- More sophisticated tire models appear to result in a more realistic road pavement response;
- Current analyses show that 'road surfacing layer life' is reduced by as much as ~94% by changing the tire model used for mechanistic road pavement design;
- Tire models idealized by several multiple circular loadings could result in different pavement layer 'lives' being computed within a single tire contact patch.

It is therefore postulated that: 'The better the representation of the 'real/actual tire-contact stress' regime, the better the road response and hence the design of road pavements – especially near the road surface.' It is believed that an improved understanding of the surface pavement failure mechanisms illustrated in this paper will be possible with the incorporation of improved understanding and quantification of the tire-road interaction mechanisms at the near road surface.

It is recommended that 3D tire road pavement contact stresses be quantified on a wider range of tires, and their effect be incorporated into modern-day road pavement analyses. Ideally, 3D tire pavement contact stresses should be used for the mechanistic design of road pavement structures, as measured, with minimal idealization of shape and magnitude. **tire**

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