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Contact stresses of pneumatic tires measured with the Vehicle-Road Surface Pressure Transducer Array (VRSPTA) system for the University of California at Berkeley (UCB) and the Nevada Automotive Test Center (NATC)

VOLUME 1:

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Abstract: This contract report gives a description of a comprehensive test programme of research measurements that were made for the Soil Mechanics and Bituminous Materials Research Laboratory, Institute of Transportation Studies, University of California at Berkeley (UCB) in association with the Californian Highway Department (Caltrans) and the Nevada Automotive Test Center (NATC), in the USA. The measurements were made with the Vehicle-Road Surface Pressure Transducer Array (VRSPTA), more commonly known as the "3-D Stress Sensor", using the Heavy Vehicle Simulator (Cal-HVS 1) belonging to Caltrans at UCB to apply the vertical loading to a slow-moving wheel. This report contains a detailed description and operation of the VRSPTA system that was used for this study. The study includes the contact stress measurements in the vertical, lateral and longitudinal direction of "free-rolling" tires. A total of six tires and several load and inflation pressure conditions were measured with the VRSPTA at a relatively slow speed of approximately 0,3 m/s. Graphical representations of typical measured contact stress data in 3-D as well as tire prints in black and white are given in the Appendices.

The individual data sets are given separately on 16 (sixteen) 3,5" diskettes, which form the *raw data base* for this study.

Volume 1 contains the main report and Appendices A to D. **Volume 2** contains only Appendices E to Q.

Keywords: Measured contact stresses, wide base single tires, Vehicle-Surface Pressure Transducer Array (VRSPTA), tire load, tire inflation pressure, Stress-In-Motion (SIM).

Proposals for implementation:
Integration with existing Accelerated Pavement Testing (APT) research programs at UCB and for use by NATC.

Related documents (eg software, interim or other reports, working drawings etc):
Measured data on diskettes (See Table 9).

Signatures:

CM Mac Carron Language editor	Dr S V Kekwick Technical Reviewer	F C Rust Programme Manager	A van der Merwe Info Centre

PREFACE

This report contains quantitative measurements that were made of the three dimensional (3-D) contact-stresses occurring between the road (pavement) surface and relatively slow-moving, free-rolling pneumatic bias/cross ply and radial tires.

The measurements discussed in this report were done for the Soil Mechanics and Bituminous Materials Research Laboratory, Institute of Transportation Studies, University of California at Berkeley (UCB) in association with the California Department of Transportation (Caltrans) and the Nevada Automotive Test Center (NATC).

The measurements were made with the Vehicle-Road Surface Pressure Transducer Array (VRSPTA), more commonly known as the "3-D Stress Sensor", using the Heavy Vehicle Simulator (CAL-HVSI) belonging to Caltrans at UCB to apply the loading to a slow moving wheel (see Plate 1). The VRSPTA system was developed between 1991-1995 by the Division of Roads and Transport Technology, CSIR, Pretoria, South Africa [De Beer, 1995a]. The HVS was developed between 1970-l 978 by the Division of Roads and Transport Technology, CSIR in South Africa and is extensively described elsewhere [Walker et al, 1977; Freeme et al, 1981; Maree, et al, 1982; Freeme et al, 1982a; Freeme et al, 1982b; Freeme et al, 1984; Freeme et al, 1987; De Beer et al, 1987; De Beer et al, 1988; De Beer, 1991; Horak et al, 1992].

The VRSPTA work was executed during February 1997 at the Richmond Field Station of the University of California at Berkeley (UCB), USA. Six different tire types and several load/inflation pressure configurations were used in this test series.

The information given here is considered an important step in the search for improved quantification and characterization of the principal contact stresses acting between moving pneumatic tires and the surface of the pavement to serve as inputs towards enhanced modelling and analysis of the behavior of particularly flexible pavement structures.

All reasonable care was taken in doing the measurements given in this report, and the results were validated for possible errors. However, no responsibility can be accepted for the consequences of any inaccuracy which may be contained therein in the use and application of the results given.

Neither Transportek of the CSIR, nor UCB/NATC make any claims and do not assume responsibility for correcting all errors; nor can they be held responsible for any damages which may be incurred as a result of the application of the results given.

The views expressed in this report are those of the authors and do not necessarily reflect those of the Soil Mechanics and Bituminous Materials

Research Laboratory, Institute of Transportation Studies, University of California at Berkeley (UCB) or the Nevada Automotive Test Center (NATC) or Transportek of the CSIR in South Africa.

Any person wishing to make use of the results presented in this report is invited to do so on application to UCB or NATC. The only restriction that is imposed on such use, is the full and correct citation of the findings to be given (after permission is granted to use the information given).

The purpose of this report is to give a representative description of the VRSPTA system used for the tire contact stress measurements given here. In addition, one 3-D graphical representation of the vertical (Z), transverse (Y) and longitudinal (X) contact stress is given for the first *one* of three measurements per test condition. These graphics are given in the various appendices of this report in both Volumes 1 and 2.

The data sets generated with this study are given separately on sixteen (16) 3,5" diskettes as summarized in Table 3 in Section 6.

Detailed analysis of the test results was *outside* the scope of this report. However the stress ratios based on the maximum positive or negative stresses were calculated and are also given in the various appendices. The stress ratios are given in the following format:

Vertical Stress (σ_{zz}):Transverse (or Lateral) Stress (τ_{zy}): Longitudinal Stress (τ_{zx}),

with the vertical stress being given a relative value of 10 (ten). The tables containing the stress ratios of the maximum stresses for the tests described in this report are given in the various appendices (Volumes 1 and 2).

PLATE 1: Images of the Vehicle-Road Surface Pressure Transducer Array (VRSPTA) SIM MK II system during the UCB/NATC tests

1. INTRODUCTION AND BACKGROUND

Since the late 1960s it has been common practice to assume a uniform circular vertical contact stress (generally equal to or somewhat *lower* than the tire inflation pressure) for modelling the tire/pavement interface stress condition on both flexible and rigid pavements. Although a wealth of information already exists to prove that the vertical stress components at the moving tire/pavement interface are not uniformly distributed and that some shear stresses are also present, both in the lateral (or transverse) direction as well as in the longitudinal direction, it remains difficult to quantify accurately these stresses under moving truck tires. In addition, it is difficult to model multi-layered pavements taking these non-uniform contact stress distributions into full consideration.

This report concentrates on the measurements of the three-dimensional (3-D) tire/pavement contact stress distributions for several pneumatic bias (or cross ply) and radial type tires used for Accelerated Pavement Testing (APT) at UCB and radial tires used by NATC at its Westrack test facility. The 3-D contact stress measurements were conducted with the Vehicle-Road Surface Pressure Transducer Array (VRSPTA) system.

The VRSPTA system is in essence a “Stress-In-Motion” (SIM) system because it was developed to quantify the contact stresses between the tire and the pavement surface. As the VRSPTA system used for this study is the second prototype, it is referred to in this study as the “VRSPTA SIM Mark II” system. It was originally developed in South Africa for use in Accelerated Pavement Testing (APT) with the South African Heavy Vehicle Simulator (HVS).

The VRSPTA SIM MK II system incorporates some improvements relative to the first system (VRSPTA SIM MK I)’ developed during 1992/3 and which are reported elsewhere [De Beer, 1994-1996]. The VRSPTA SIM MK I system was originally developed to prove the concept of the measurements of the 3-D stress components at the moving tire/pavement interface. The stresses that were measured simultaneously and the sign convention used in this study are similar

[1] The VRSPTA SIM MK I suffered inaccuracies of up to 25 per cent concerning the total load measured after integration of the vertical stress volume [De Beer, 1994], but this was largely corrected by improvements to the design of the current VRSPTA SIM MK II system used for the measurements given in this report [De Beer 1995a, 1995b].

to those of the *SAE* tire *axis system* (Gillespie, 1992), and are as follows:

- The Vertical contact stress *positive* in the Z - direction, σ_{zz};

- The Lateral (or Transverse) shear stress across the contact area *negative* in the Y - direction (i.e. from Pin 1 to Pin 21 on the VRSPTA), τ_{zy} and the

- Longitudinal shear stress, τ_{zx} (*Positive* in the X - direction, i.e. in the direction of the moving wheel).

2. DESCRIPTION OF THE VRSPTA SIM MK II SYSTEM

The VRSPTA SIM MK II system (hereafter referred to as "VRSPTA") used in this study consists of 1041 flat topped cone shaped hollow steel pins mounted in 51 rows on a 50 mm steel base plate. Twenty (20) pins in the centre row (array) are instrumented with strain gauges, thus forming 20 small individual tri-axial load cells transversely distributed across the base plate.

The VRSPTA is set within a steel pan embedded in the pavement such that the VRSPTA surface is flush with the pavement surface. The basic principle of the VRSPTA is that the loads on each tri-axial load cell pin across the tire contact patch are measured directly. The contact stresses imposed on the road (or, in this case, on the VRSPTA surface), are then calculated during post-processing of the data. The vertical, transverse (or lateral) and longitudinal forces (loads) are therefore measured in one line across the tire contact patch in real time by the array of instrumented pins. The rolling wheel load is moved across the instrumented pins with a known measured speed and the loads measured with a fixed sampling frequency until the total contact area has traversed the surface of the VRSPTA. The remainder of the pins (all of equal geometric shape and height, approximately 50 mm) are supporting pins with the same shape, contact area and all-direction stiffness (rigidity) as the instrumented pins.

There are 60 active channels (20 pins x 3 directions) which simultaneously scan all the strain gauges when the wheel moves over the array of instrumented pins in the centre portion of the VRSPTA. Data acquisition is automatically triggered by coaxial cables and/or optical beams on the approach side of the VRSPTA. Separate micro switches on both sides of the VRSPTA in the longitudinal direction serve to measure the speed of the moving wheel across the instrumented pins.

The present VRSPTA SIM MK II system is considered adequate for research purposes, particularly when used with current Accelerated Pavement Testing (APT) devices. It can potentially be used as a "Stress-In-Motion" (SIM) system on highways, especially at weighbridge stations, but needs further improvement to be more user- and production-friendly for use as a potential replacement for current "Weigh-In-Motion" (WIM) systems.

A schematic layout of the VRSPTA used in this study is given in Figures 1 and *2.*

The electronic system consists of the following main components:

- Topward Laboratory Power supply (TPS-4000), capable of supplying 20V at four (4) Amps, and

- a rack of strain gauge conditioners with excitation voltage of 7,0 volts for the vertical gauges (Z) and 3.5 volt for the horizontal gauges (X,Y). The cut-off frequency is 1 kHz and the gain is set at 1000 times.

- The VRSPTA SIM MK II Data Acquisition System (DAS) consists of four 386SX computers, four PC30 DS A/D (Analog to Digital) cards and the DAS software.

One computer is used as the “master”. This has a VGA screen and a large hard disk. It is able to run the software and controls the three other slave computers. These slave computers serve mainly as a housing for the A/D cards. The DAS software produces three files, one for the results of each load direction (Y = Transverse (or Lateral), X = Longitudinal, Z = Vertical). In each file, the data are arranged in table format, with one column for each measuring channel.

A maximum sampling rate of up to 12.5 kHz per channel is possible with the current system. However, at a wheel speed of approximately 0.3 m/s (“creep speed”) sampling rates of 120 Hz, 130 Hz and 150 Hz are appropriate and, at approximately 4,0 m/s, a rate of 1000 or 1500 Hz is normally used.

Typically, a sampling rate of 150 Hz for a total of 256 samples were used for each channel during the testing described in this report.

The strain gauge conditioner rack interfaces with the VRSPTA and the data acquisition computers (Figure 1). As discussed earlier, the VRSPTA SIM MK II system is designed to measure directly the *three-dimensional load* acting on each pin (i.e. the sensor) during the movement of the tire over the instrumented pins. The contact stresses are then calculated from the load measurements using a *diamond shaped effective area* covered or represented by each of the pins. The diamond shaped area is a direct result of the diagonal pattern of all the pins fixed to the base plate. The detail of the layout of the *effective area* is given in Figure 4. It should however, be noted that this diamond shaped area is transformed to an equivalent rectangular area (or width equal to 17 mm) in order to obtain the "effective length over which the loads are measured *per pin."*

The resultant effective length in the direction of tire movement is, therefore equal to 250.28/17=14.7224 mm and is used to obtain the total load during the integration process See later in Section 3.4.

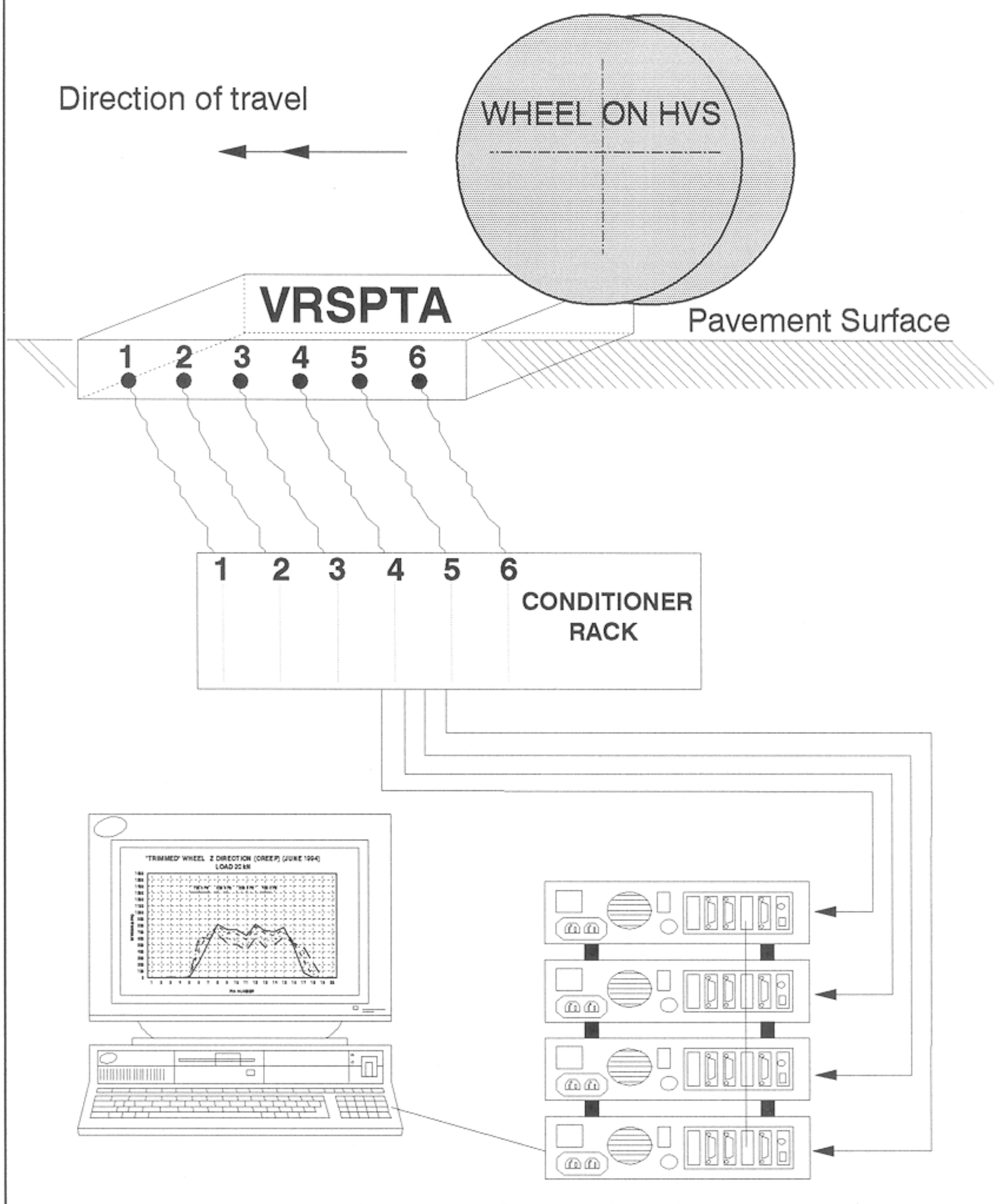

FIGURE 1
LAYOUT OF THE VEHICLE-ROAD SURFACE PRESSURE TRANSDUCER ARRAY (VRSPTA) SYSTEM

C:\UCBNATC\FIGURE1.DRW

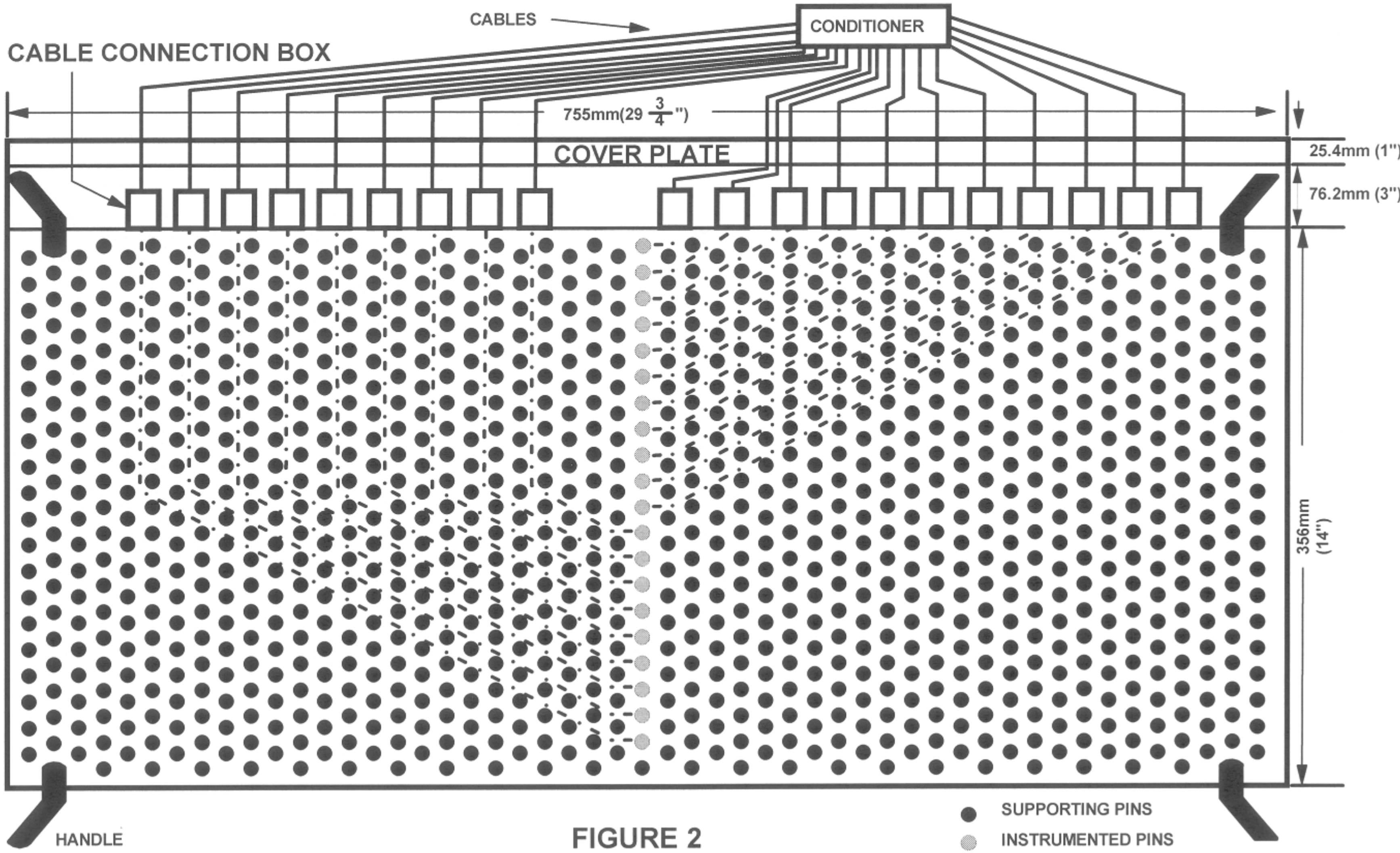

FIGURE 2

TOP VIEW OF THE VEHICLE-ROAD SURFACE PRESSURE TRANSDUCER ARRAY (VRSPTA SIM MK II)