PAVEMENT SHEAR FORCES PRODUCED BY TRUCK TIRES

by

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PREFACE

This document originally appeared as a memorandum from the author to Dr. William W. Crockford of the Texas Transportation Institute (TTI). It is essentially a summary of current knowledge of the pavement shear forces produced by free-rolling tires. As this material may be of interest to other researchers working in the area of tire-pavement interaction it is herewith placed in the TTI archives for convenience in accession and reference.

REFERENCE: Tielking, J.T., Pavement Shear Forces Produced by Truck Tires, Texas Transportation Institute, College Station, TX 77843-3135, February 1991.

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MEMORANDUM February 25, 1991

TO: W.W. Crockford

FROM: J.T. Tielking J.T.T.

SUBJECT: Pavement Shear Forces Produced by Truck Tires

The information provided here is relevant to a single truck tire in free-rolling, straight-ahead motion.

The Texas A&M tire model, which is capable of calculating pavement shear forces for tires in vehicle braking and steering [1], is unable to calculate pavement shear forces produced by free-rolling tires. The reason for this is due to (a) tire footprint kinematics are more complicated in free-rolling, and (b) tire-pavement friction force levels are much smaller for a free-rolling tire than for a tire responding to braking and/or steering control inputs.

As nearly all of the load history on a highway pavement is produced by free-rolling tires, it may be assumed that any shear force contribution to pavement fatigue and distress comes from tires in the free-rolling mode of operation. Some experimental studies have been made of the shear stresses in the free-rolling tire footprint. References [2-7], at the end of this memo, describe the major findings. Most of this work was done in the 1960's and early 1970's. I am not aware of further research of this type since Lippmann and Oblizajek [2] presented their highly regarded SAE paper on passenger car tire shear forces in 1974. The rest of this memo contains a review of what is known about free-rolling tire shear forces, followed by some empirical relationships that I believe can be used to calculate, approximately, the two-dimensional distribution of pavement shear force produced by a free-rolling truck tire.

The three components of interfacial pressure in the free-rolling tire footprint are essentially distributed as shown in Fig. 1, taken from Ref. [3]. Although the pressures in Fig. 1 were measured for a small radial passenger car tire (size 165 SR 13) the distributions are similiar to those found for a truck tire. Since truck tire treads are compounded to be long wearing, at the expense of traction, one may expect the peak values of pavement shear force to be lower for a truck tire than for a passenger car tire. Figure 2, from [4], shows the distribution of longitudinal shear force, measured on a highway, for a free-rolling truck tire (size not given). The peak pressure in Fig. 2 is about 14 psi. This surprisingly low level is confirmed by the work of Bonse & Kuhn [5] who found the peak longitudinal pressure for a free-rolling truck tire (size 9.00-20) to be 22 psi, also measured on a highway. Although the data in [4] and [5] were obtained for a tire rolling on a highway pavement, the shear forces were actually measured by an instrumented stud embedded in the pavement. In [4], the stud surface area is 1 cm^2 and in [5] it is 1 in^2.

The experimental studies of free-rolling tire shear forces have all found the effect of speed to be insignificant (traveling speed has a significant effect when the tire is generating braking and steering forces [6]). References [3] and [5] also report that inflation pressure has a minor effect. The effect of tire load on free-rolling shear stresses does not appear to have been investigated. However, as load and pressure have similiar effects on tire behavior, the load effect may be assumed negligible also.

Although none of the available data, described here, were measured specifically for a modern wire-reinforced radial truck tire, these data provide guidelines in making a realistic estimate of the pavement shear forces being produced by truck tires today. The following assumptions are believed to be reasonable.

1. Tire size, inflation pressure, and load determine the size and shape of the footprint. These parameters have negligible effect on the general shape of the distributions of pavement shear forces.

2. The shape of the shear force distributions is determined by the kinematics of rolling shell contact. The shape is modified somewhat by tire construction, the longitudinal shear force peak being nearly equal to the transverse shear force peak for a radial tire. Speed has negligible influence on pavement shear forces.

3. The amplitude of the shear force distributions is controlled by the friction coefficient. On dry pavement, the friction coefficient is determined by (a) tread compound, and (b) pavement texture.

Let τ_M be the maximum pavement shear stress in the free-rolling truck tire footprint. From the available data, τ_M is the same for the longitudinal and the transverse distributions. The data suggest that τ_M = 25 psi is a realistic value for dry pavement.

Neglecting tire hysteresis effects, the longitudinal and transverse shear distributions may both be modeled as being antisymmetric. The following equations are for the distributions along the footprint medians, sketched in Fig. 3.

Longitudinal Shear Force, τ_ℓ

The analysis given in [7] results in the expression

$$\tau_\ell = K[\frac{\theta}{\theta_o}\sin 2\theta_o - \sin 2\theta] \quad (1)$$

where

$$K = \frac{\tau_M}{\max[\,]}\ ,\quad \theta_o = \frac{a}{R}\ ,\quad \theta = \frac{x}{R}$$

R = axle to pavement distance (loaded radius)

The distribution modeled by Eq. (1) is repeated to sweep out the transverse distribution of longitudinal shear force. An example is given in Fig. 4 where the longitudinal distributions measured along the five ribs of a radial passenger car tire are shown. These data show that the transverse distribution is approximately uniform.

Transverse Shear Force, τ_t

The transverse distribution of the transverse shear force may be calculated from

$$\tau_t = \tau_M \sin\frac{\pi y}{b} \quad (2)$$

where b is the half-width of the tire footprint. This distribution is repeated to sweep out the longitudinal distribution of transverse shear force. Laboratory data, such as shown in Fig. 5(b), indicate that the transverse (lateral) shear force is approximately uniform over most of the length of the footprint.

The distributions given by Eqs. (1) and (2) give the pavement shear force components as being directed toward the medians of the tire footprint. The resultant of τ_ℓ and τ_t will not necessarily be always directed toward the center of the footprint. However, the integral of each distribution will give zero longitudinal and lateral net shear forces on the pavement. This is a good approximation for the free-rolling tire.

I realize that two-dimensional pavement force distributions need to be refined and further approximated for use in pavement structural analysis by the finite element method. Please confer with me regarding this or any questions on the information in this memo.

References

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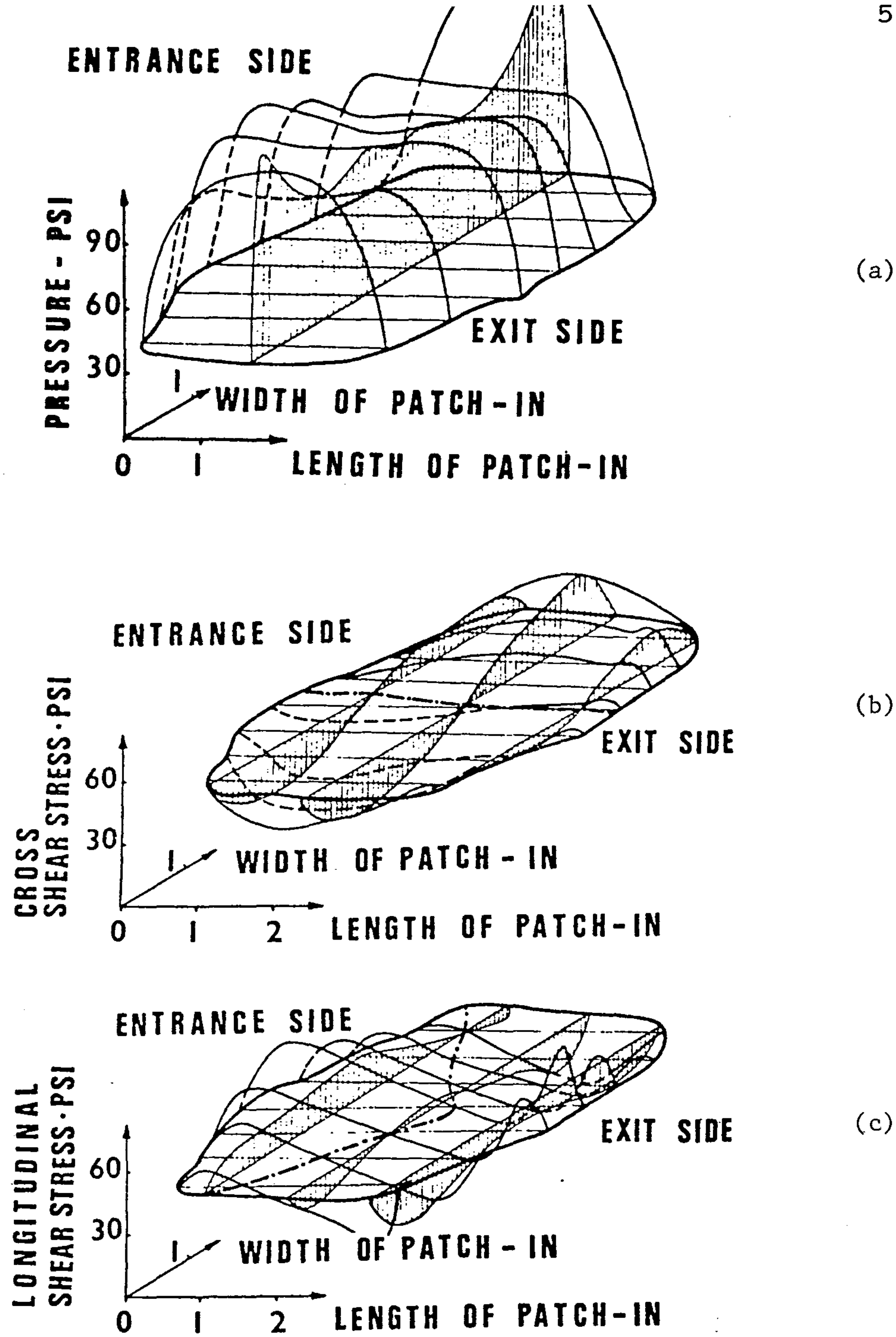

Figure 1. Laboratory measurement of passenger car radial tire contact pressure components. (a) normal pressure, (b) transverse shear pressure, (c) longitudinal (direction of travel) shear pressure.

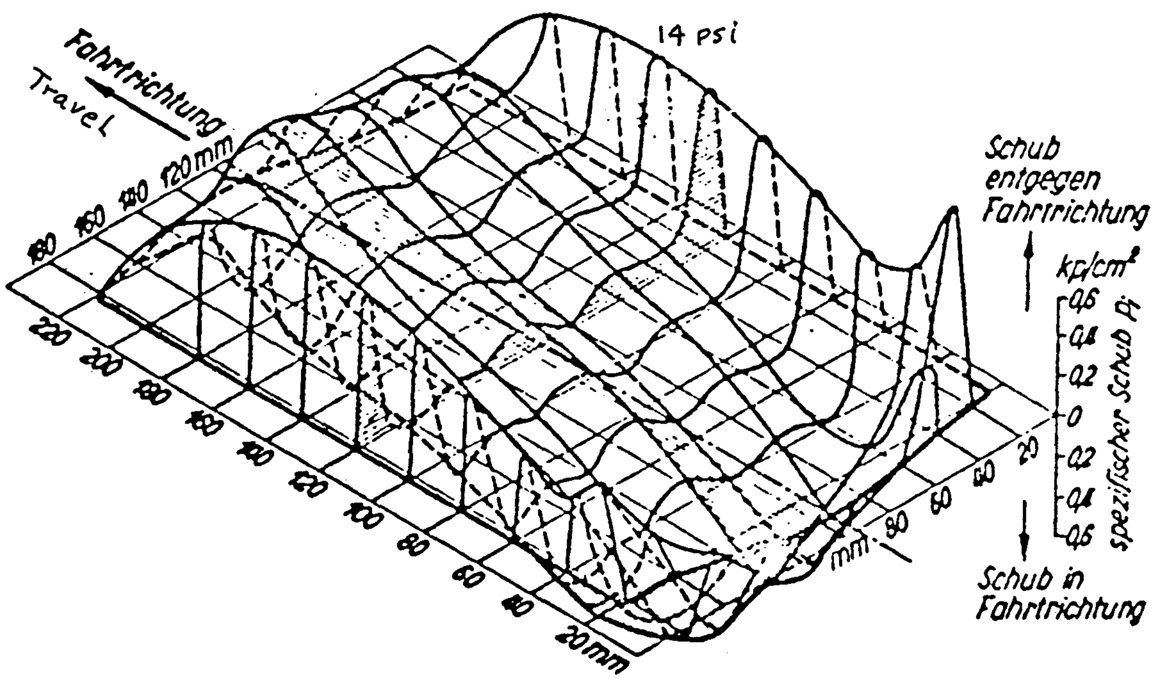

Figure 2. Truck tire longitudinal shear force measured by highway instrumentation. The maximum shear force here is about 14 psi.

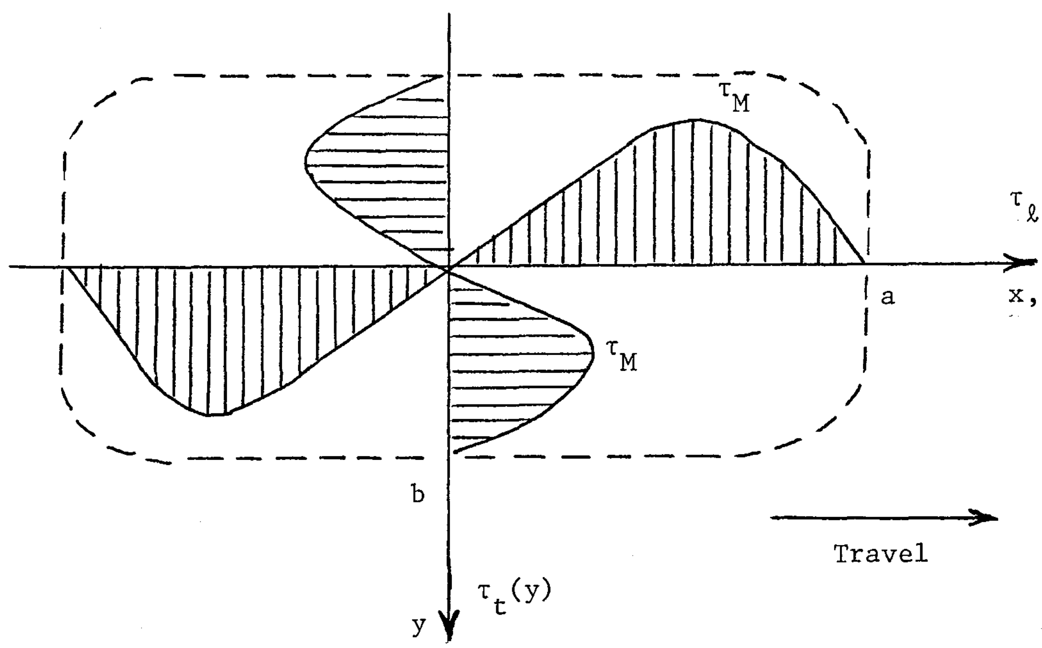

Figure 3. Longitudinal and transverse distributions of pavement shear stress produced by a free-rolling tire. Equations (1) and (2) model these distributions along the footprint medians. The shear forces are directed toward the medians.

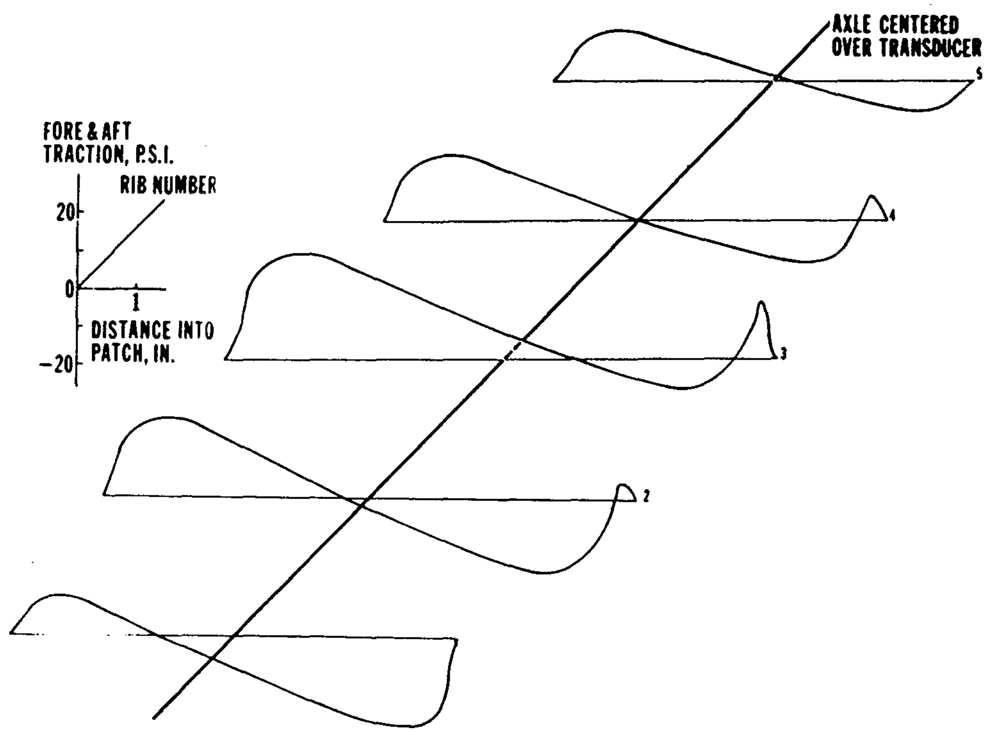

Figure 4. Longitudinal distributions of the longitudinal component of pavement shear stress [2]. Free-rolling radial passenger car tire, design load and inflation pressure.

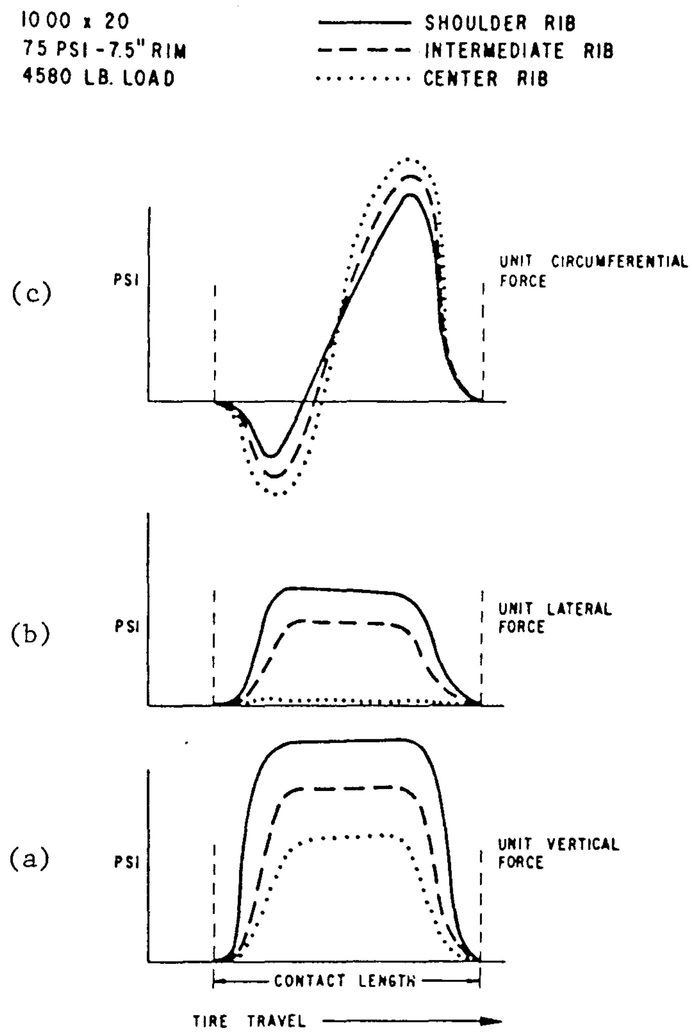

Figure 5. Typical plots of footprint force analyzer results [6]. Longitudinal distributions. Free-rolling bias-ply truck tire, design load and inflation pressure.