Three-Directional Contact Stress Distributions for a Pneumatic Tractor Tire in Soft Soil†

전형규*　　이규승*

정회원

H.G. Jun　　K.S. Lee

1. INTRODUCTION

The importance of protecting soil from soil compaction obliges us to further soil-tire interface studies and improve tractive devices in order to develop better economic and design solutions for use in agriculture. Burt (1993) posed questions regarding future research of soil-tire and soil-track interaction: "How does the rubber track compare with tires with respect to pressures within the soil profile? What is the difference between low pressure tires and crawler tracks with regard to soil compaction?"(Jun et al., 1997a, 1997b and 1997c). He said answers to these questions should give important insight about the compaction process and about the proper selection of equipment for specific tasks.

Burt et al. (1987), in order to try to better understand the soil compaction process and to find a means of reducing soil compaction, initiated research on normal and tangential soil-tire interface stresses. Oida et al. (1991) investigated stress distribution patterns, positions of the maximum stresses, and relations between thrust and side force with parameters of slip and slip angle, the angle between the direction the tire is pointing and the direction it is actually going, during both straight and slant runs which are runs with non-zero slip angles.

A transducer was developed to measure independently and simultaneously three-directional contact stress distributions for a pneumatic tractor tire in soft soil (Jun et al., 1997a). This transducer is expected to be useful in comparisons of rubber tracks and tires with respect to stresses within the soil profile.

A study was undertaken with the following objectives.

1. To determine the effects of dynamic load and inflation pressure on normal, tangential, and lateral contact stresses for a pneumatic tractor tire.
2. To determine if the maximum contact stress varies with a change in the location of the transducer on a lug.

---

† 이 논문은 미국 농공 학회지(Transactions of the ASAE)에 투고된 것임

* 성균관대학교 생명자원과학대학 생물기전공학과

2. EXPERIMENTAL PROCEDURE

A three-directional transducer was used to measure the normal, tangential, and lateral stresses at the soil-tire interface. The construction and characteristics of this transducer were described in detail by Jun et al. (1997a). Mean correlation coefficients for linear regressions of the transducer output as a function of applied load were 0.99964 for the tangential direction and 0.99958 for the lateral direction.

Three transducers were mounted on the lug of a 12.4R28 radial-ply tractor drive tire. The locations of the transducers on a lug were at the lug face near the tire centerline (TC), approximately the center of the lug (LC), and near the outside edge of the lug (LE) (fig.1).

The experiment was designed with two levels of dynamic load (9.3 and 14.2 kN) and two levels of inflation pressure (59 and 157 kPa), and conducted at a constant forward velocity of 0.33 m/s and 20% slip. Tire operating parameters were held constant during a test. One replication of each combination of dynamic load and inflation pressure was used.

The soil used in this study was Eniwa volcanic ash soil (clay 31.0%, silt 12.0%, and sand 57.0%). The soil condition was prepared with a completely soft rotary tilled surface soil overlying a compacted layer (hardpan) about 250 mm below the soil surface.

Each tire was operated at four combinations of dynamic load and inflation pressure (table 1). The initial bulk density of the loose surface soil was 0.9 Mg/m^3 and the water content was 21.5 % wet basis.

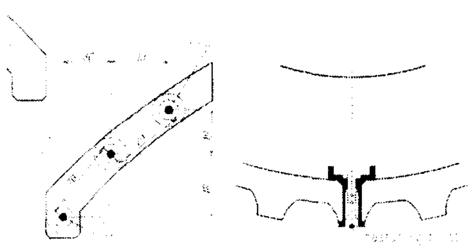

Figure 1 Locations of transducers mounted on a lug(units of dimensions are mm)(left), and side view of a transducer mounted on a lug(right)

Table 1. Dynamic load and inflation pressure combinations

Treatment	Dynamic Load (kN)	Inflation Pressure (kPa)
9.3-59	9.3	59 *
9.3-157	9.3	157 †
14.2-59	14.2	59 ‡
14.2-157	14.2	157 *

* Correct inflation pressure to match load for 12.4R28 tire

† The tire was overinflated in this treatment.

‡ The tire was underinflated in this treatment. This combination of load and inflation pressure is not recommended by the tire manufacturer.

3. RESULTS AND DISCUSSION

Distributions of three-directional contact stresses over a range of angular position of each transducer and each combination of dynamic load and inflation pressure are presented in figures 2 through 5. Each transducer was at the bottom center angular position at a rotational angle of 0 deg. Data at negative angles represent stresses in front of the bottom center position and data at positive angles represent stresses to the rear of the bottom center position.

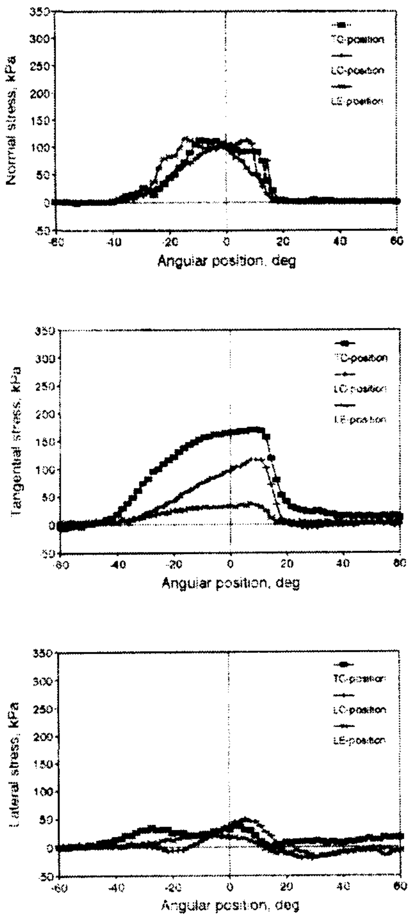

Figure 2 A dynamic load of 9.3 kN and an inflation pressure of 59 kPa at 20% slip.

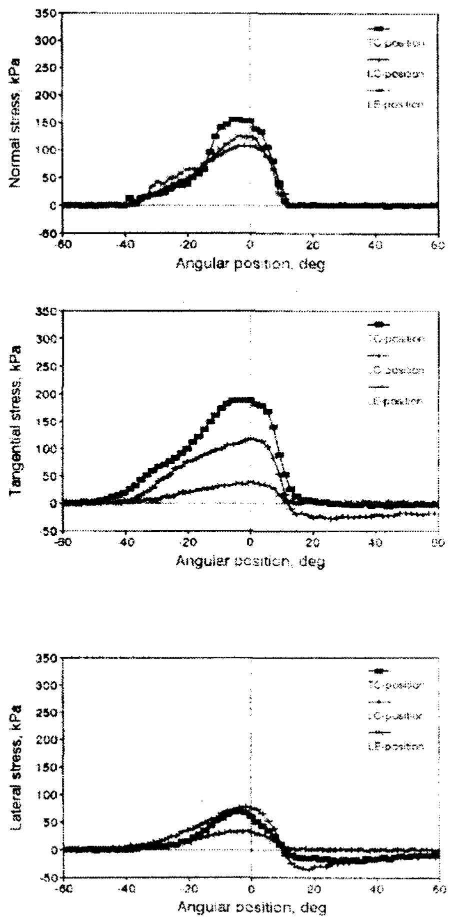

Figure 3 A dynamic load of 9.3 kN and an inflation pressure of 157 kPa at 20% slip.

In figure 2, the distribution of the normal stress measured at the tire centerline (TC) position was relatively constant along the contact length. There was a decrease in the normal stress at the LE position just forward of bottom center, at the -14.5 deg angular position. Maximum normal stresses on each transducer were about 114 kPa, or approximately twice the inflation pressure. The tangential stress distributions are relatively constant along the contact length. The patterns are similar to measurements made under a bias-ply tractor drive tire by Krick (1969). The magnitudes of the tangential stresses increased from a minimum at the edge of the lug to a maximum at the tire centerline. This trend also occurred in the tangential stress distributions in other treatments. This implies that tangential stresses are dependent on transducer position on the lug. The maximum lateral stress occurred at the LC position. The peak values of the three transducer positions were scattered across a wide range of angular positions.

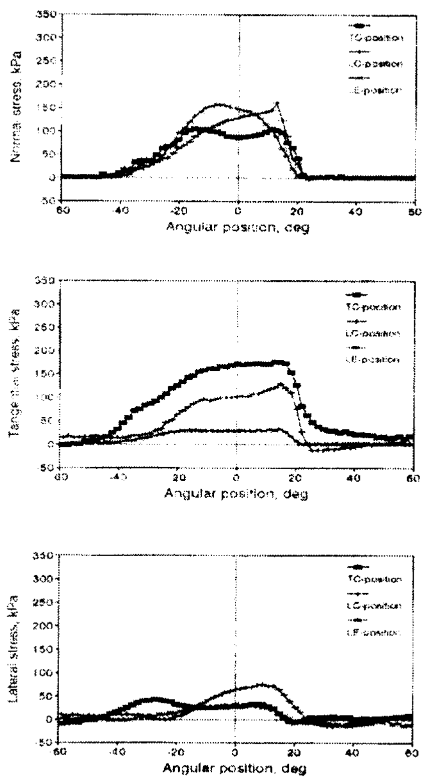

Figure 4 A dynamic load of 14.2 kN and an inflation pressure of 59 kPa at 20% slip.

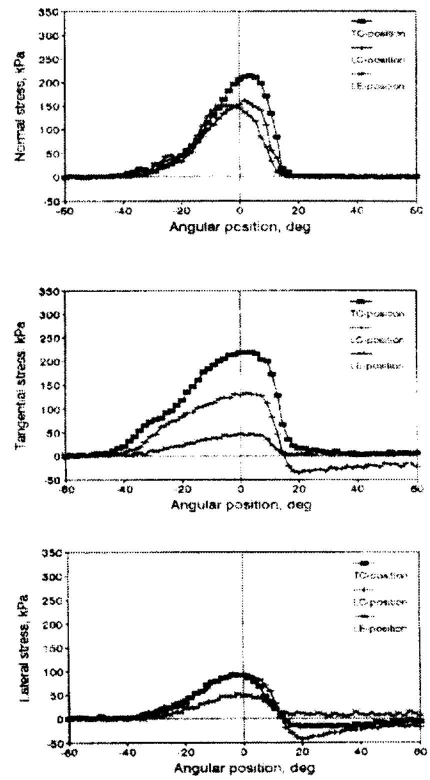

Figure 5 A dynamic load of 14.2 kN and an inflation pressure of 157 kPa at 20% slip.

In figure 3, the tire deformation is less, so the tire behaves more like a rigid wheel in this overinflated treatment than in a correctly inflated treatment. Flexibility and strength are desirable characteristics of a tire carcass. A comparison of the 9.3-59 treatment, in which the tire is relatively flexible (fig. 2), and the 9.3-157 treatment, in which the tire is more rigid (fig. 3), show that increases in inflation pressure result in increases in the maximum values of the contact stresses. The pattern of stress distributions is similar to that obtained on a rigid wheel by Krick (1969). The normal stress exhibited a parabolic distribution along the contact length with stresses concentrated near the bottom center angular position. The maximum normal stress value of 155 kPa, which was approximately the inflation pressure, occurred near the centerline of the tire. Maximum tangential stresses occurred at about 0 deg, which was the bottom center angular position. Maximum normal and lateral stresses occurred at the same angular positions for each transducer.

The shapes of the normal stress distributions in figure 4 are similar to those in figure 2. These distributions show stress concentrations called "edge stresses" at the edge of the contact area. These edge stresses result from the predominance of the sidewall stiffness in this underinflated treatment. The ratio of stress at the centerline to stress at the edge is an important quantity and must be considered in comparisons of rigid wheel and deformable tires (Krick, 1969). The comparisons between the properly inflated tire (fig.2) and the underinflated tire (fig.4) show that a change in dynamic load changes the stress values slightly, but the general pattern of the stress distribution remains unchanged. When the load was increased and inflation pressure was maintained at 59 kPa, the load spreads along the tire contact length. For a given transducer location and a given stress direction, the magnitude of the stress in figure 4 is greater than the stress in figure 2. For each transducer, the lateral stress distributions were more erratic than the normal stress distributions.

In figure 5, the stress distribution patterns were generally similar to those of the overinflated treatment. The magnitudes of stresses in the 14.2-157 correct treatment (fig.5) were generally greater than those in the 9.3-157 overinflated treatment (fig.3).

4. CONCLUSIONS

This experiment showed that:

1. The general trend of stress distributions reflected the effect of tire inflation pressure more than dynamic load in this experiment. Increased dynamic load increased the levels of stresses.
2. The maximum normal stress occurred near the tire centerline at high inflation pressure. The maximum tangential stress occurred near the tire centerline and decreased as the position moved from the tire centerline to the edge of the tire. At the high inflation pressure, the maximum lateral stress was concentrated near the bottom center position for each transducer.

5. REFERENCES

1. Burt, E. C. 1993. Soil-tire/track interaction-current and future research needs. J. Terramech. 30(5):317-323.
2. Burt, E. C., A. C. Bailey and R. K. Wood. 1987. Effects of soil and operational parameters on soil-tire interface stress vectors. J. Terramech. 24(3):235-246.
3. Jun, Hyung-gyu, T. Taniguchi, T. Kishimoto, M. Yoshida and T. Tamari. 1997a. Measurement of tire-lug contact stresses by a three-dimensional stress transducer. J. JSAM (Japanese) 59(6):3-10.
4. Jun, Hyung-gyu, T. Taniguchi, K. Ohtomo, T. Kishimoto and T. Ohyama. 1997b. Determination of the three dimensional contact area between tractor tire and soil. J. JSAM (Japanese) 59(5):3-12.
5. Jun, Hyung-gyu, T. Taniguchi, K. Ohtomo, T. Kishimoto and T. Tamari. 1997c. Measurement and analysis of six direction stresses under tractor tire. J. JSAM (Japanese) 59(1):21-28.
6. Krick, G. 1969. Radial and shear stress distribution under rigid wheels and pneumatic tires operating on yielding soils with consideration of tire deformation. J. Terramech. 6(3):73-98.
7. Oida, A., A. Satoh, H. Itoh and K. Triratanasirichai. 1991. Three-dimensional stress distributions on a tire-sand contact surface. J. Terramech. 28(4):319-330.