A CONTROL SYSTEM OF THE TIRE INFLATION PRESSURE FOR RUNNING OF A WHEEL SYSTEM VEHICLE ON SOFT TERRAIN

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Abstract: The purpose of this study is to inquire into the primary factor closely for running of a wheel system vehicle on soft terrain. So far the inflation pressure of an off-the-road tire was used as in constant under operation, and when the equivalent elastic modulus of a tire was higher than that of terrain the tire was regarded as a rigid wheel. The object of the test is 1000-R20 off-the-road tire to be set an initial inflation pressure of 550kPa. The experiments on pure rolling were made running tests on soft terrain for 3-pattern inflation pressure (550kPa, 450kPa, and 350kPa).

The sinkage, the deflection of tire and the stress distribution were measured. It was observed that the sinkage is accompanied by the set of the inflation pressure of the tire. Furthermore, it was clarified that even though the equivalent elastic modulus of a tire was higher than that of terrain, the tire shows the behavior of elastic wheel. As a result, the running performance of vehicle could be controlled by using the set of inflation pressure.

Keywords: inflation pressure, elastic wheel, sinkage

1. INTRODUCTION

Recently, construction vehicles have become bigger and bigger in size. Consequently, off-the-road pneumatic tires for wheel system vehicles become larger in size too. In spite of a lack of research on large sized pneumatic tires in fields it prompted us to start an investigation on them.

For constructional and agricultural vehicles and mobile machinery, which frequently operate in soft terrain, the optimization of design and of system functions is difficult.

So far the inflation pressure of an off-the-road pneumatic tire was used as in constant under operation, and when the equivalent elastic modulus of a pneumatic tire was higher than that of terrain the tire was regarded as a rigid wheel.

Due to the automation, a control system of the tire inflation pressure for running of a wheel system vehicle on soft terrain have become unavoidable tools for planning, for design, for development and for manufacturing.

Here, some fundamental laboratory experiments were executed to investegate the relationship between the inflation pressure of off-the-road pneumatic tire and the equivalent elastic modulus of soft terrain under a pure rolling state. The object of the test is 10.00-R20 off-the-road tire to be set an initial inflation pressure of 550kPa. The experiments on pure rolling were made running tests on soft terrain for 3-pattern inflation pressure (550kPa, 450kPa, and 350kPa).

This paper examines possible relations between equivalent elastic moduli of off-the-road tire and soil. The implications of this study and suggestions for control system of the inflation pressure of off-the-road pneumatic tire are discussd.

2. PURE ROLLING TEST

2.1 Specifications for off –the-road tire

The growth of off-road operations has brought about a great diversification in tires to meet all service requirements. Pneumatic tires have become larger both in cross-section and in rim diameter. Large sized tires permit higher loads per tire without sacrificing flotation. With the same tire loading, inflation

Figure 1. Test apparatus

pressures on the wide-base tire can be reduced. The wider cross-section gives improved traction and flotation and the lower unit ground pressure can improve the resistance to damage from stones and other object [1].

Table 1 shows the specifications of the off-the-road pneumatic tire. The standard inflation pressure of a large sized pneumatic tire recommended by manufacturers is 700kPa. To maintain the rolling of the off-the-road pneumatic tire without large sinkage, the initial inflation pressure was set to be 550kPa at this test. The tread pattern of this tire is rock type for construction field.

2.2 Test apparatus

The sandy soil adjusted to an optimal water content of 12.8 % was filled up uniformly in the depth of 700 mm in a soil bin of size of 1000 ×900 ×2200(mm^3). A soil sample of the decomposed granite soil of size below 4.75 mm was used. The specific gravity of the soil was measured as 2.66 and the average grain size was 0.78 mm, the coefficient of uniformity was 12.0. The initial bulk density of the test terrain was observed to be 1.33 ±0.08 g/cm^3.

Figure 1 shows the view of the test apparatus for pure rolling state. The test apparatus is composed

Table 1. Specifications for the off-the-road pneumatic tire dimensions

Size	10.00-20-14PR
Outer diameter (mm)	1055
Tire width (mm)	296
Standard pressure (kPa)	700
Capacity (kN) At 10km/h	52.1

of a main frame, an air cylinder for loading, a loading frame, a soil bin and a transferring device. The height of the test apparatus is about 3.5m.

The contact pressure at the centre, the shearing stress and the normal stress were measured using a memorizer. Stress state transducer were used to measure the stress distribution in a soil.

To get rid of initial uncertainty for measurments, a new tire for test was pressed at between 10kN and 15kN load per rotation of 15 degrees.

2.3 Experimental method

In order to study closely the primary factor for running of a wheel system vehicle on soft terrain, the following experiments and tests on the behavior of the off-the-road pneumatic tire were made:

1. To carry out triaxial compression tests to determine the equivalent elastic modulus of the sandy soil.
2. To carry out loading tests to determine the equivalent elastic modulus of the off-the-road pneumatic tire.
3. To measure the contact pressure at the centre, the shearing stress and the normal stress of the off-the-road pneumatic tire.
4. To measure the stress distribution in a soil.
5. To collect the tire footprint and to measure contact pressure distribution on rigid plate.

The experiments on pure rolling were made running tests on soft terrain for 3-pattern inflation pressure:550kPa, 450kPa, and 350kPa. The operator was required to assemble rim and tire carefully to avoid corrosion of the valve by damp air which might brings about air leakage on measurement.

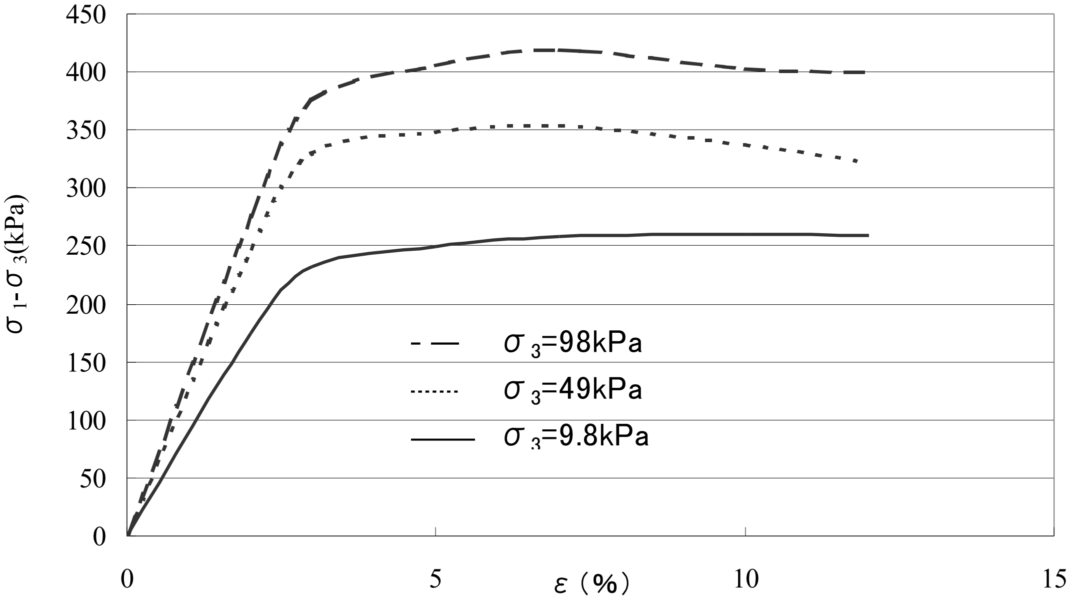

Figure 2. Results of triaxial compression tests

3. RESULTS AND DISCUSSION

3.1 Equivalent elastic moduli of off-the-road pneumatic tire and sandy soil

In order to determine equivalent elastic moduli of the off-the-road pneumatic tire and the sandy soil, loading tests and triaxial compression tests were carried out. Figure 2 shows the result of triaxial compression tests for sandy soil. The linear part at the rising was used to decide the equivalent modulus of the sandy soil. The equivalent elastic modulus of the sandy soil was calculated using the following equation.

$$E_B = \frac{\sigma_1 - \sigma_3}{\varepsilon} \tag{1}$$

here, E_B : equivalent elastic modulus of the sandy soil, $\sigma_1 - \sigma_3$: deviate stress, ε : strain.

The value of calculation E_B was 14.5MPa.

Next, we determined the equivalent elastic moduli of the off-the-road pneumatic tire for 3-pattern inflation pressure: 550kPa, 450kPa, 350kPa. Yong et al. [2] suggested the following equations to express the equivalent elastic modulus of the off-the-road pneumatic tire.

$$\frac{1}{R_A} + \frac{1}{R_B} = \frac{16W}{\pi L^2}\left(\frac{1-\nu_B^2}{E_A} + \frac{1-\nu_A^2}{E_B}\right) \Bigg/ \left(1 + \frac{k_B^2}{k_A^2}\right)$$

$$k_A = \frac{2}{\pi}\left(\frac{1-\nu_A}{G_A} + \frac{1-\nu_B}{G_B}\right)$$

$$k_B = \frac{1-2\nu_A}{G_A} - \frac{1-2\nu_B}{G_B}$$

$$G_A = \frac{E_A}{2(1+\nu_A)} \tag{2}$$

$$G_B = \frac{E_B}{2(1+\nu_B)}$$

here, R_A: radius of the tire, R_B: radius of the road bed(=∞,on rigid plate), E_A: equivalent elastic modulus of the tire, E_B: equivalent elastic modulus of the road bed(=∞,on rigid plate), G_A: elastic shear coefficient of the tire, G_B: elastic shear coefficient of the road bed(=∞,on rigid plate), ν_A: Poisson's ratio of the tire(=0.5), ν_B: Poisson's ratio of the road bed(=0.284), W: load, L: contact length.

Figure 3 shows the relationship between equivalent elastic modulus of the off the road pneumatic tire and inflation pressure.

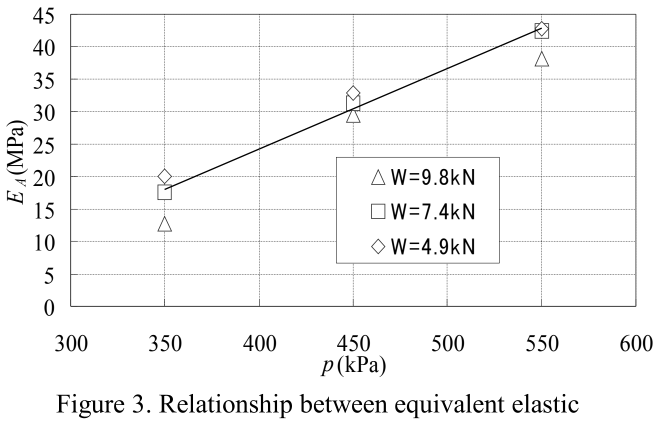

Figure 3. Relationship between equivalent elastic modulus of the tire E_A and inflation pressure p

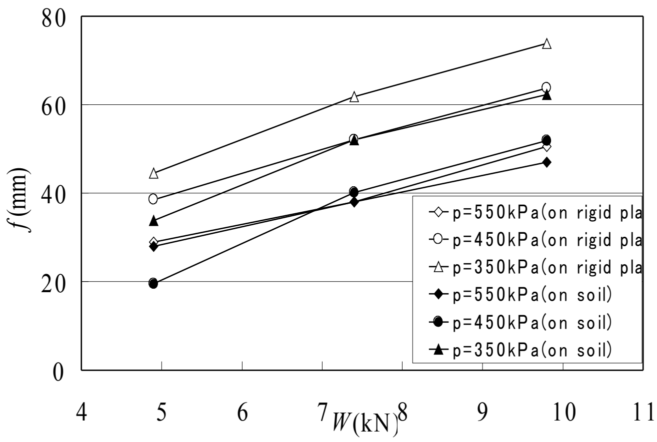

Figure 4. Relationship between load W and deflection of the tire f

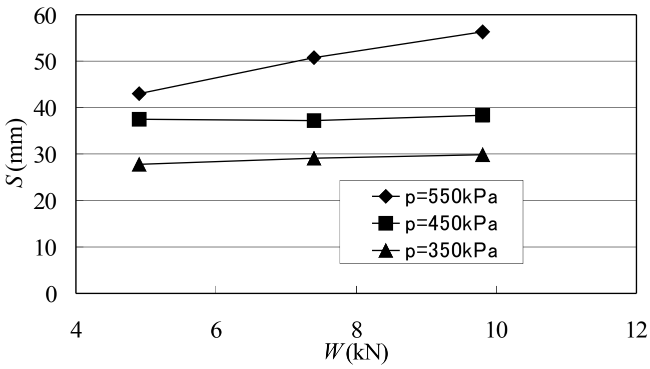

Figure 5. Relationship between load W and sinkage S at static load state

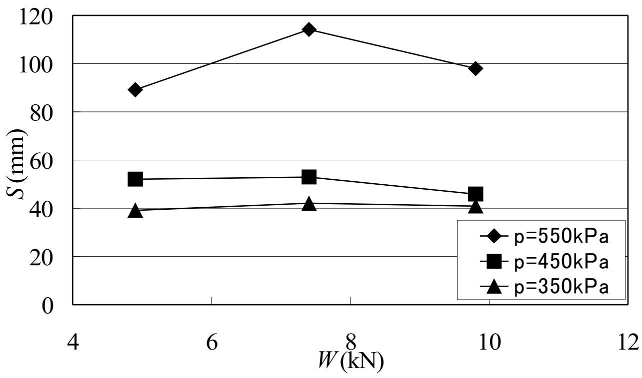

Figure 6. Relationship between load W and sinkage S at pure rolling state

The relationship indicates that equivalent elastic modulus shows a linear increment with inflation pressure.

3.2 Evaluation of Equivalent elastic modulus of off-the-road pneumatic tire

The deflection of the off-the-road pneumatic tire was investegated on a rigid plate and a mass of sandy soil. Figure 4 shows the relationship between load and deflection of the off-the-road pneumatic tire. The off-the-road pneumatic tire had a deflection for all ptterns of inflation pressure. On the other hand, equivalent elastic moduli of the off-the-road pneumatic tire were compared to that of the sandy soil. Equivalent elastic moduli E_A of off-the-road pneumatic tire were higher than those of sandy soil except inflation pressure of 350kPa, load of 9.8kN because E_B of sandy soil was 14.5MPa. E_B/E_A=1.0 as the boundary value had been used to define rigid wheel or elastic wheel. So far when the equivalent elastic modulus of a tire was higher than that of terrain the tire was regarded as a rigid wheel.

However as mentioned above, the off-the-road pneumatic tire has a deformation on a mass of sandy soil and the behavior of it is different from a rigid wheel.

3.3 Sinkage, contact pressure, shearing stress, stresses in a soil

We are interested in the effect of inflation pressure of off-the-road pneumatic tire in running on soft terrain.

Sinkages were measured to investigate the influence of inflation pressure at static state and at pure rolling state. Figures 5 and 6 show the relationship between load and sinkage for sets of inflation pressure at each state. Clearly, there is a large sinkage in set when moving from lower to higher inflation pressure. In lower set of inflation pressure(450kPa, 350kPa), there is a little fluctuation of sinkage when moving from smaller to larger loads. Observations made during pure rolling tests revealed that the effect of inflation pressure of the off-the-road tire was higher than that of load for the sinkage of the terrain surface.

Contact pressure and shearing stress on the tire surface were measured. Figure 7 shows the maximum contact pressure at the centre of tread. Small change of the contact pressure was found when moving from smaller to larger loads. This fact expresses the contact pressure becomes the phenomenon close to the inflation pressure of the pneumatic tire. Figure 8 shows the relationship between the load and the maximum shearing stress on the surface of tread. There is a increament of maximum shearing stress when moving from smaller to larger loads and there is a hard tendency of that when moving from higher to lower inflation pressure of the pneumatic tire.

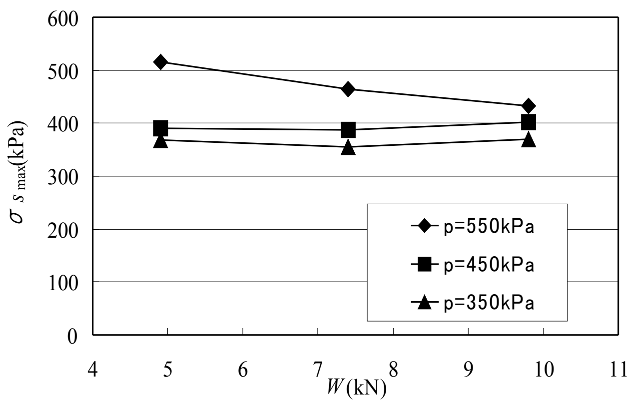

Figure 7. Relationship between load W and maximum contact pressure $\sigma_{s\,max}$

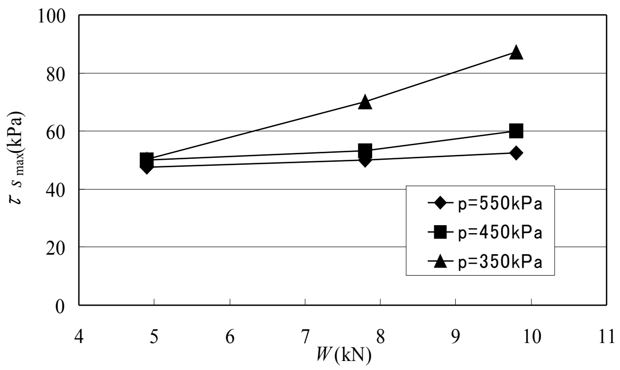

Figure 8. Relationship between load W and maximum shearing stress on the surface $\tau_{s\,max}$

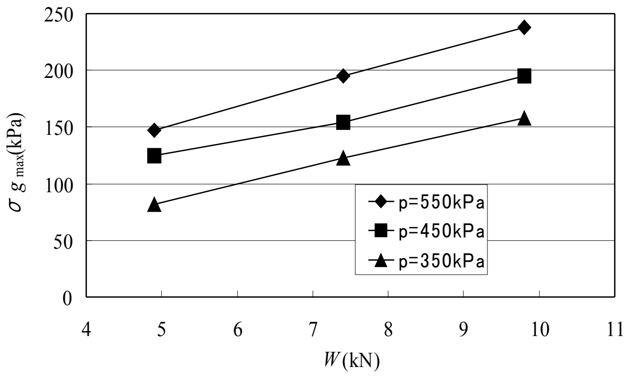

Figure 9. Relationship between load W and maximum normal stress in a soil $\sigma_{g\,max}$

As described above, the inflation pressure of the pneumatic tire causes the change of contact pressure,

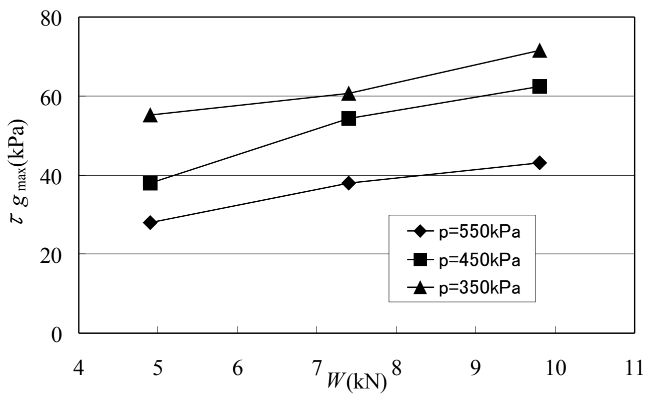

Figure 10. Relationship between load W and maximum shearing stress in a soil $\tau_{g\,max}$

and the inflation pressure of the pneumatic tire and the load cause the variation in the shearing stress on the surface.

Stresses in a soil were measured by use of a stress state transducer embeded at depth 30cm. Figure 9 shows the relationship between the load and the maximum normal stress in a soil. There is aincreament of the maximum normal stress in a soil in this pure rolling tests when moving from smaller to larger loads for all sets.

Figure 10 shows the relationship between the load and the maximum shearing stress in a soil. There is an increment of the maximum shearing stress in a soil in this pure rolling tests when moving from higher to lower inflation pressures. The veracity of the result is doubtful.

3.4 Suggestion for control system of tire inflation pressure

From the afore mentioned point of view, we would like to suggest a control system of the inflation pressre of the off-the-road pneumatic tire for running of a wheel system vehicle on soft terrain.

The system is composed as follows:

1. Off-the-road pneumatic tire with changeable inflation pressure
2. Air compressor
3. Valve with slip ring tube
4. Exhaust instrument
5. Detecting device for sinkage or elasticy

The model is shown in figure 11. Points to which special attention should be paid are that even though the equivalent elastic modulus of a tire was higher than that of terrain, the tire shows the behavior of elastic wheel.

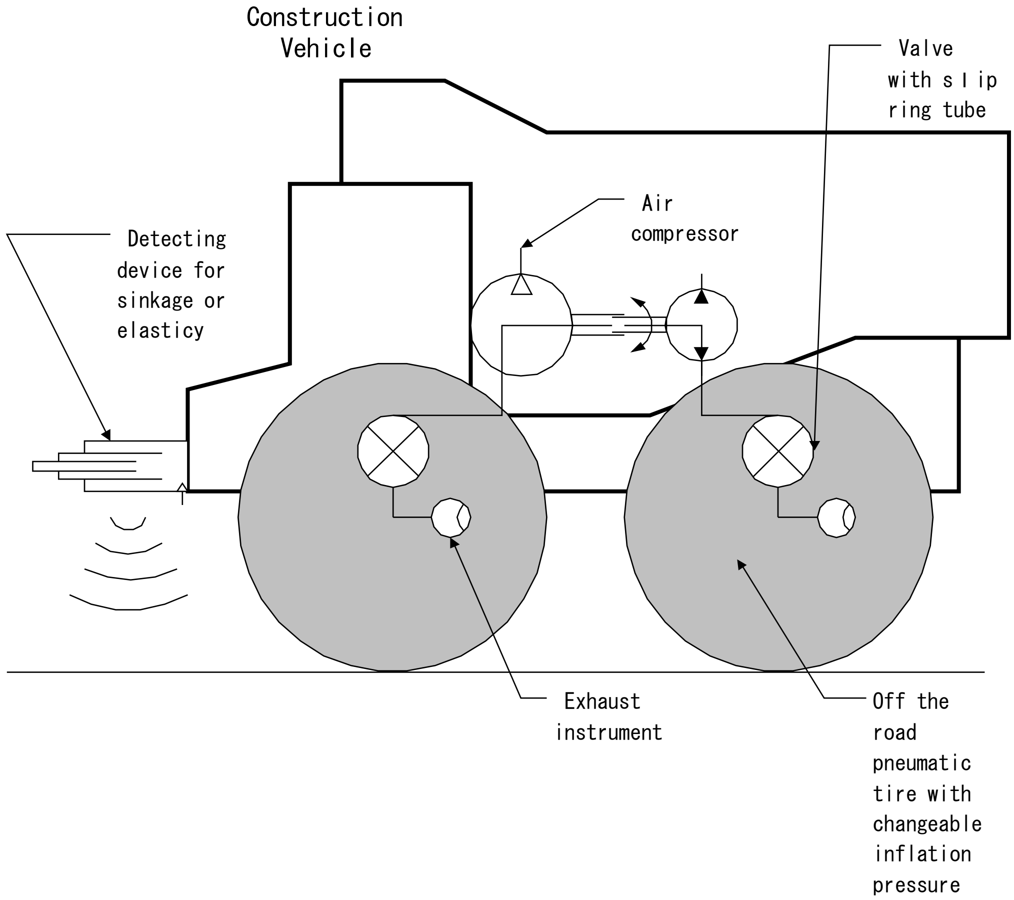

Figure 11 A model of construction vehicle

4. CONCLUSION

This study has explored the effects of the inflation pressure of the off-the-road pneumatic tire for running construction vehicle on soft terrain. The result of the investigation shows that:

1. So far when the equivalent elastic modulus of a tire was higher than that of terrain the tire was regarded as a rigid wheel. The off-the-road pneumatic tire has a deformation on a mass of sandy soil and the behavior of it is different from a rigid wheel.
2. Observations made during pure rolling tests revealed that the effect of inflation pressure of the off-the-road tire on the sinkage of terrain surface was higher than that of load.
3. A control system of tire inflation pressure for running of a wheel system vehicle on soft terrain could be suggested.

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