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APPLICATION HEIGHT CONTROL SYSTEM OF A WHEELED VEHICLE RUNNING ON A LOOSE SANDY SOIL

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Abstract

In earth moving sites, several wheeled vehicles are used to excavate a sandy soil, or to pull another construction machinery.

Here, the mechanism of land locomotion of a 5.88 kN weight, two axles and four wheel vehicle running on a loose sandy soil is analysed theoretically. The optimum height of application force and the optimum eccentricity of gravity center to obtain the largest value of the maximum effective tractive effort can be clarified by means of an analytical simulation program. As the results, it is clarified that the optimum height of application force is 30 cm and the optimum eccentricity of gravity center is 0.05.

1. INTRODUCTION

The motor scraper tyres are forced to drive forward to penetrate a cutting blade into sandy soil. For a hard soil terrain, the axle load of the rear tyre is often decreased due to the occurrence of large vertical excavation resistance acting on the cutting blade. Then, the effective driving force reduces suddenly due to the excessive slippage of the rear tyre.

When the cutting blade can not excavate the hard soil terrain any more, another motor scraper is necessary to help the excavation. At that time, the position of pulling force to the scraper should be controlled to set automatically on the optimum application height to obtain the largest value of the maximum effective tractive effort.

Here, the mechanism of two axles and four wheel vehicle is considered as the combination of an effective braking force of the front wheel during pure rolling state and an effective driving force of the rear wheel during driving action. For a given dimensions of 5.88 kN weight, four wheel vehicle and a given terrain-wheel system constants, the relations among tractive effort of the vehicle, amount of sinkage of front and rear wheel and slip ratio, etc. have been analysed by use of a simulation program.

The maximum tractive effort of the vehicle varies with the position of gravity center and the height of application force. So, the optimum height of application force and the optimum eccentricity of gravity center to obtain the largest value of the maximum effective tractive effort should be determined.

After that, the application height control system and the gravity center position control system of the wheeled vehicle running on a loose sandy soil will be robotized soon.

2. TRAFFIC PERFORMANCE OF A FOUR WHEEL VEHICLE

Two axles and four wheel vehicles are divided into rear–wheel drive vehicle, front–wheel drive vehicle and four–wheel drive vehicle.

Here, the mechanism of traffic performance of a four wheel and rear–wheel drive vehicle running on a loose sandy flat terrain is analysed. **Fig.1** shows the vehicle dimensions and several forces acting on the rear–wheel drive vehicle. The vehicle weight W acts vertically on the gravity center **G** of the vehicle, and the front axle load W_f and the rear axle load W_r acts vertically on the front axle $\mathbf{O}_f$ and the rear axle $\mathbf{O}_r$, respectively. The position of gravity center **G** is located on the amount of eccentricity $\overline{eD}$ from the central axis of the vehicle and on the height h_g perpendicular to the line $\overline{\mathbf{O}_f\mathbf{O}_r}$. D is the distance from front to rear wheel axle, R_f and R_r is the radius of front and rear wheel respectively. The driving torque Q_d acts around the rear axle $\mathbf{O}_r$. The position of the application point **F** of the effective tractive effort T is located on the distance L from the central axis of the vehicle and on the application height H from the surface of terrain just after passing the rear wheel. The pure rolling resistance i.e. compaction resistance L_{cb} acts horizontally on the front axle $\mathbf{O}_f$, and the effective driving force T_d acts horizontally on the rear axle $\mathbf{O}_r$, as shown in this figure. The vehicle trim angle θ_t is defined as the angle between the line $\overline{\mathbf{O}_f\mathbf{O}_r}$ and horizontal surface. For the amount of sinkage s_f at the bottom–dead–center $\mathbf{M}_f$ of the front wheel and for the amount of sinkage s_r at the bottom–dead–center $\mathbf{M}_r$ of the rear wheel, the vehicle trim angle θ_t is calculated as follows ;

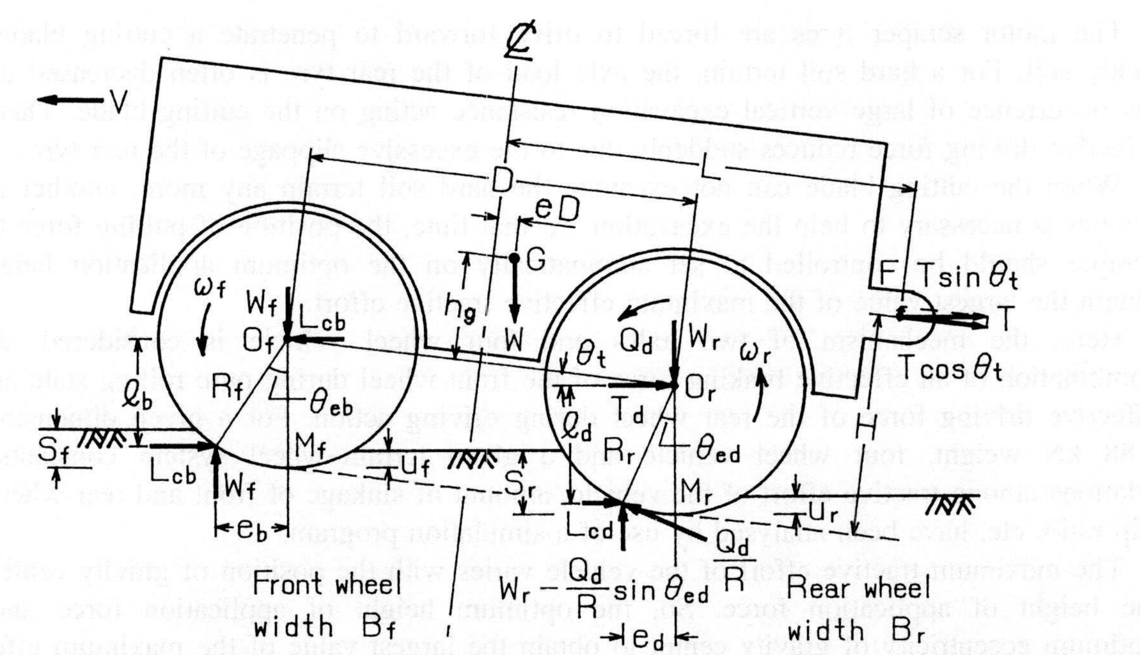

Fig.1 Vehicle dimensions and several forces acting on rear–wheel drive vehicle

$$\theta_t = \sin^{-1} \frac{R_f - u_f + s_r - R_r}{D} \tag{1}$$

where u_f is the amount of rebound of the terrain at the front wheel.

On the forward contact part of the front wheel, the horizontal compaction resistance L_{cb} and the vertical ground reaction W_f acts in the distance of eccentricity $e_b = R_f \sin \theta_{eb}$ and $\ell_b = R_f \cos \theta_{eb}$. On the forward contact part of the rear wheel, the compaction resistance L_{cd}, the tangential driving force Q_d / R_r, and the vertical ground reaction $W_r - Q_d \sin \theta_{ed} / R_r$ acts in the distance of eccentricity $e_d = R_r \sin \theta_{ed}$ and $\ell_d = R_r \cos \theta_{ed}$. B_f and B_r is the front and the rear wheel width respectively.

For the vehicle speed V, the angular velocity ω_f and ω_r of the front and the rear wheel, the skid i_b of the front wheel and the slip ratio i_d of the rear wheel are expressed as follows ;

$$i_b = \frac{R_f \omega_f}{V} - 1 \tag{2}$$

$$i_d = 1 - \frac{V}{R_r \omega_r} \tag{3}$$

From the horizontal and the vertical force balances,

$$T = \frac{Q_d}{R_r} \cos \theta_{ed} - L_{cd} - L_{cb} = T_d - L_{cb} \tag{4}$$

$$W = W_f + W_r \tag{5}$$

are obtained.

From the moment balance around the rear axle O_r,

$$W_f D \cos \theta_t + L_{cb} D \sin \theta_t - W\{\frac{D}{2} - (eD + h_g \tan \theta_t)\} \cos \theta_t$$

$$+ (H - R_r) T \cos \theta_t - (L - \frac{D}{2}) T \sin \theta_t = 0 \tag{6}$$

is obtained.

The effective tractive effort T given in Eq.(4) can be calculated from the compaction resistance L_{cb} and the effective driving force T_d.

The relation between T and i_d, T_d and i_d, L_{cb} and i_d, the relation between Q_d and i_d, and the relation between s_f, s_r and i_d are determined by means of the analytical simulation program.

3. GRAVITY CENTER POSITION CONTROL SYSTEM

When a two axles and four wheel vehicle is operating on a loose sandy flat terrain to pull another construction machinery, the effect of the position of the gravity center of the vehicle eD on the effective tractive effort T has been analysed. The optimum amount of

Table 1 Dimensions of two axles and four wheel vehicle

Vehicle weight	W	5.88 kN
Distance from front to rear wheel axle	D	50 cm
Radius of front wheel	R_f	16 cm
Radius of rear wheel	R_r	16 cm
Width of front wheel	B_f	10 cm
Width of rear wheel	B_r	10 cm
Line pressure of front wheel	$W/4B_f$	14.7 kN/m
Line pressure of rear wheel	$W/4B_r$	14.7 kN/m
Eccentricity of gravity center of vehicle	e	$-$ 0.05 ~ 0.05
Height of gravity center **G** of vehicle	h_g	50 cm
Distance between central axis of vehicle and point **F** acting effective tractive effort	L	30 cm
Application height of effective tractive effort	H	20 cm
Circumferential speed of rear wheel	$R_r\omega_r$	7.07 cm/s

Table 2 Terrain–wheel system constants

Plate loading and unloading test	
Front wheel	Rear wheel
k_{c1} = 28.93 N/cm^{n1+1}	k_{c1} = 28.93 N/cm^{n1+1}
$k_{\phi 1}$ = 8.41 N/cm^{n1+2}	$k_{\phi 1}$ = 9.68 N/cm^{n1+2}
n_1 = 0.450	n_1 = 0.445
k_{c2} = 48.10 N/cm^{n2+1}	k_{c2} = 48.10 N/cm^{n2+1}
$k_{\phi 2}$ = 31.12 N/cm^{n2+2}	$k_{\phi 2}$ = 35.83 N/cm^{n2+2}
n_2 = 0.394	n_2 = 0.389
λ = 0.35	λ = 0.40
κ = 1.55	κ = 1.60
V_0 = 0.035 cm/s	V_0 = 0.035 cm/s
Plate traction and sinkage test	
Front wheel	Rear wheel
c_a = 0 kPa	c_a = 0 kPa
$\tan\phi$ = 0.442	$\tan\phi$ = 0.444
a = 2.05 1/cm	a = 2.51 1/cm
c_0 = 5.275 × 10^{-3}	c_0 = 2.035 × 10^{-3}
c_1 = 0.887	c_1 = 0.984
c_2 = 0.523	c_2 = 0.500

eccentricity of the gravity center to obtain the largest value of the maximum effective tractive effort can be determined for the four wheel vehicle, of which the front wheel is in a pure rolling state and the rear wheel is in a driving state.

As an example, the traffic performance of a 5.88 kN weight, four wheel vehicle has been simulated. The vehicle dimensions are shown in **Table 1**, and the terrain–wheel system constants at the site of front and rear wheel are shown in **Table 2**, respectively. The average line pressure of the wheel is 14.7 kN/m. To determine the terrain–wheel system

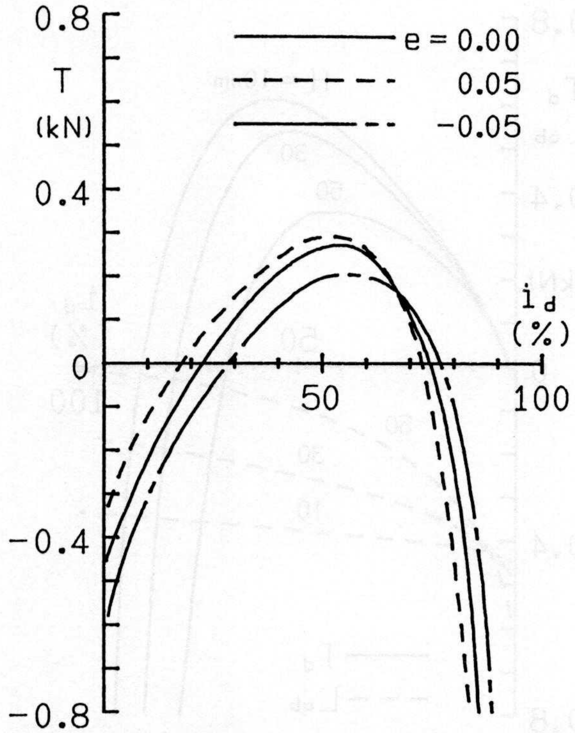

Fig.2 Relations between effective tractive effort T and slip ratio i_d for three kinds of eccentricity e (H = 20 cm)

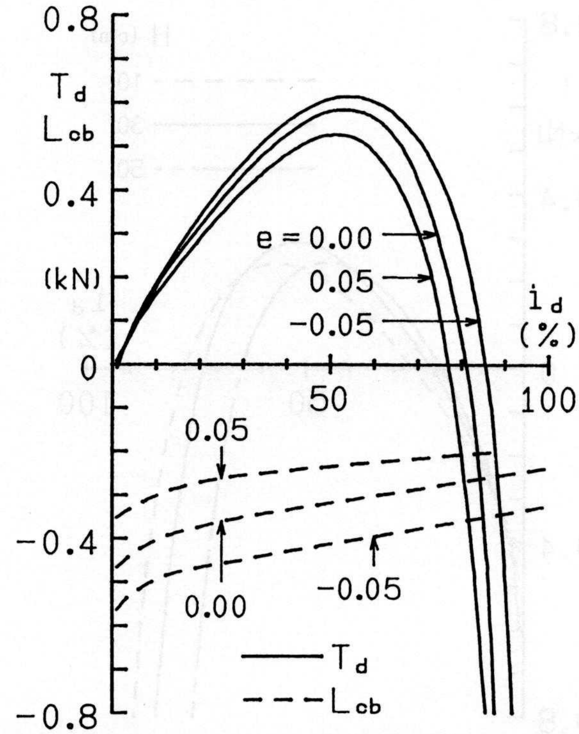

Fig.3 Relations among effective driving force T_d, compaction resistance L_{cb} and slip ratio i_d for three kinds of eccentricity e (H = 20 cm)

constants at the front wheel site and the rear wheel site, the plate loading and unloading test, the plate traction and sinkage test have been executed for the fresh loose sandy soil and for the compacted sandy soil after one pass of the roller having the same line pressure, respectively.

For three kinds of eccentricity $e = -0.05$, 0.00 and 0.05, the analytical simulation results are presented. **Fig.2** shows the relations between effective tractive effort T and slip ratio i_d for $e = 0.00$ and ± 0.05, and $H = 20$ cm. **Fig.3** shows the relations among effective driving force T_d, compaction resistance L_{cb} and slip ratio i_d for $e = 0.00$ and ± 0.05, and $H = 20$ cm. In these cases, the skid i_b of the front wheel is maitained from -3 to -4 % for the pure rolling state.

As a result, the largest value of the maximum effective tractive effort is obtained at $e = 0.05$ in this case. And it is clarified that the maximum effective tractive effort T increases with the increment of the eccentricity e for the range of $e \leqq 1/6$, and there is an optimum eccentricity e_{opt} of the gravity center to obtain the largest value of the maximum effective tractive effort.

Establishing a position control system of the eccentricity of gravity center e of the vehicle which is set up to the optimum eccentricity e_{opt}, the maximum effective tractive effort of the vehicle can be automatically controlled to maintain the largest value of the maximum effective tractive effort.

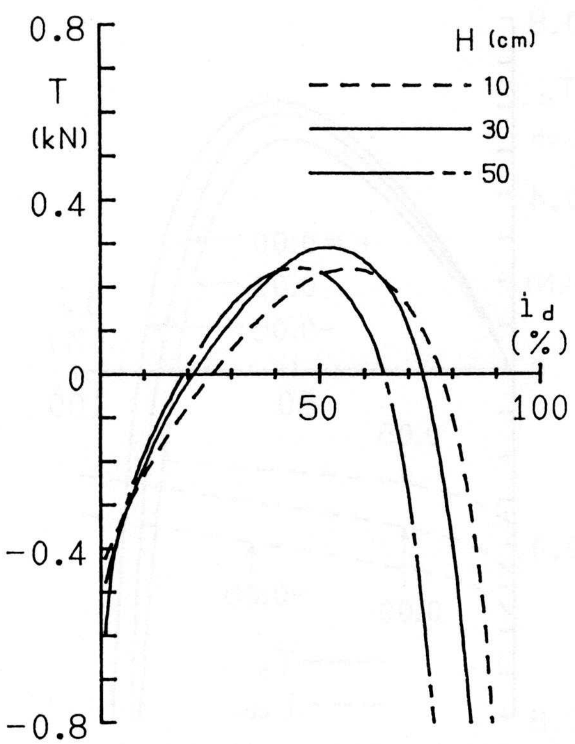

Fig.4 Relations between effective tractive effort T and slip ratio i_d for three kinds of application height H (e = 0.00)

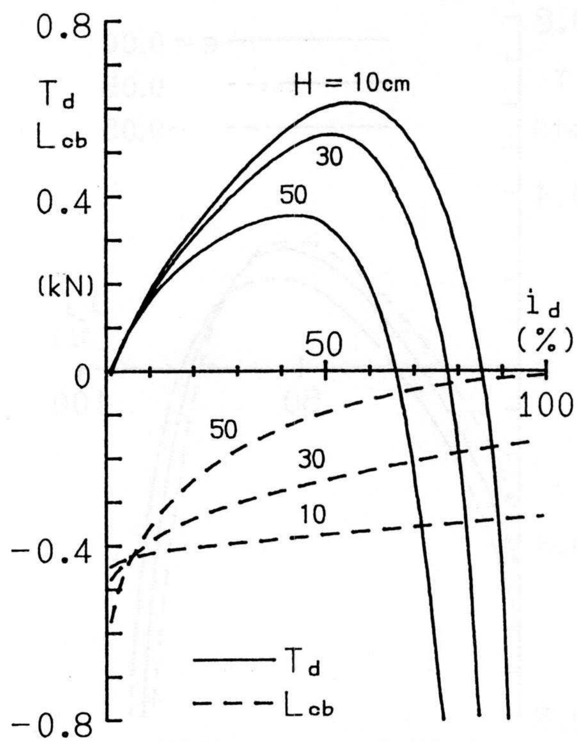

Fig.5 Relations among effective driving force T_d, compaction resistance L_{cb} and slip ratio i_d for three kinds of application height H (e = 0.00)

4. APPLICATION HEIGHT CONTROL SYSTEM

When the two axles and four wheel vehicle is operating on the loose sandy flat terrain to pull another construction machinery, the effect of the application height H on the effective tractive effort T has been analysed. The optimum application height to obtain the largest value of the maximum effective tractive effort can be determined for the four wheel vehicle, of which the front wheel is a pure rolling state and the rear wheel is in a driving state.

As an example, the traffic performance of the same 5.88 kN weight, four wheel vehicle as mentioned before has been simulated. As the analytical simulation results, **Fig.4** shows the relations between effective tractive effort T and slip ratio i_d for H = 10, 30 and 50 cm and e = 0.00. It is clarified that, for H = 10 cm, T_{max} = 0.242 kN is obtained at i_d = 55 %, for H = 30 cm, T_{max} = 0.291 kN is obtained at i_d = 51 %, and for H = 50 cm, T_{max} = 0.243 kN is obtained at i_d = 45 %. As a result, the largest value of the maximum effective tractive effort T_{max} is obtained at H = 30 cm in this case.

Fig.5 shows the relations among effective driving force T_d, compaction resistance L_{cb} and slip ratio i_d for H = 10, 30 and 50 cm and e = 0.00. It is clarified that, for H = 10 cm, the maximum effective driving force T_{dmax} = 0.612 kN and L_{cb} = − 0.370 kN is obtained at i_d = 55 %, for H = 30 cm, T_{dmax} = 0.539 kN and L_{cb} = − 0.248 kN is obtained at i_d = 51 %, and for H = 50 cm, T_{dmax} = 0.355 kN and L_{cb} = − 0.112 kN is obtained at i_d = 45 %. As a result, both T_{dmax} and $|L_{cb}|$ tends to decrease with the increment of H.

Fig.6 shows the relations among maximum effective tractive effort T_{max}, corresponding effective driving force T_d and compaction resistance L_{cb}, and application height H for the eccentricity e = 0.00.

As a result, it is clarified that the maximum effective tractive effort T_{max} reaches the largest value 0.291 kN at H = 30 cm, and the effective driving force T_d and the absolute value of compaction resistance $|L_{cb}|$ decreases with the increment of application height H.

The amount of sinkage of rear wheel s_r increases gradually with the increment of H, corresponding with the increment of compaction resistance of the rear wheel L_{cd}, and with the decrement of effective driving force T_d.

Establishing a control system of the application height H which is set up to the optimum application height H_{opt}, the maximum effective tractive effort of the vehicle can be expected to be automatically controlled to maintain the largest value of the maximum effective tractive effort.

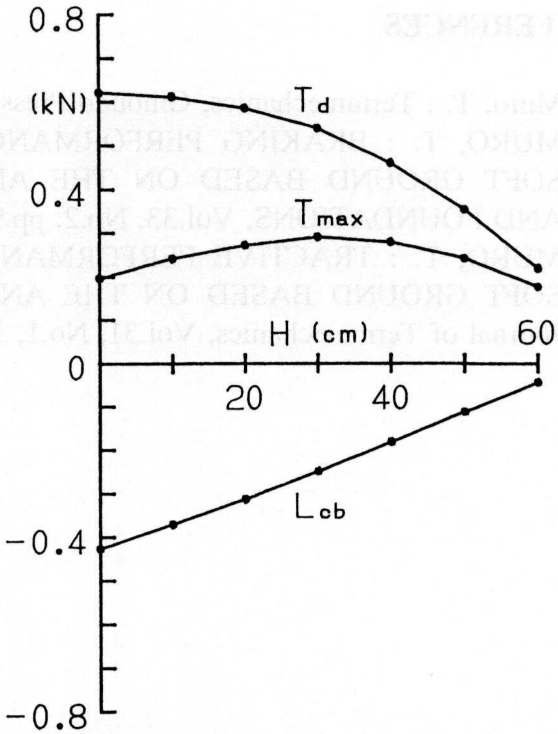

Fig.6 Relations among maximum effective tractive effort T_{max}, effective driving force T_d, compaction resistance L_{cb} and application height H (e = 0.00)

5. CONCLUSION

The maximum effective tractive effort of a two axles, four wheel, and rear–wheel drive vehicle varies with the position of gravity center and the height of application force. So, the optimum height of application force and the optimum eccentricity of gravity center to obtain the largest value of the maximum effective tractive effort should be robotized. Several new analytical results obtained are summarized as follows :

(1) For a given four wheel vehicle, the optimum eccentricity e_{opt} = 0.05 is obtained to get the largest value of the maximum effective tractive effort.

(2) The optimum application height H_{opt} = 30 cm is obtained for the four wheel vehicle of the eccentricity e = 0.00. The largest value of maximum effective tractive effort is 0.291 kN. The effective driving force and the absolute value of the compaction resistance of the front wheel decrease with the increment of the application height.

(3) The amount of sinkage of rear wheel increases gradually with the increment of application height, corresponding with the decrement of effective driving force.

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