

Turning Characteristics of a Model Tracked Vehicle Running on Fresh Concrete

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Research objective: The objective of the research is to establish numerical analysis to predict turning characteristics of tracked vehicles. Especial attention was paid to vehicle running on weak terrain where the sinkage of the vehicle is relatively large. In this report, the turning characteristics of tracked vehicle running on fresh concrete will be reported based on results of numerical analysis and experiment carried out for a model tracked vehicle running on fresh concrete with steering ratio of 1.6.

Numerical analysis and experimental conditions:

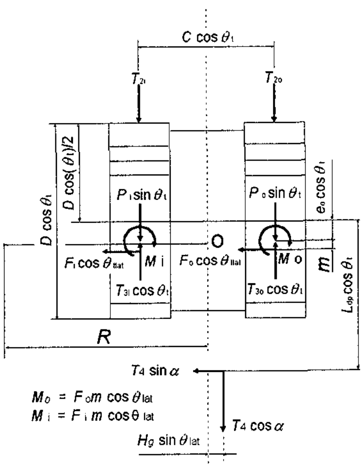

Fig. 1. a

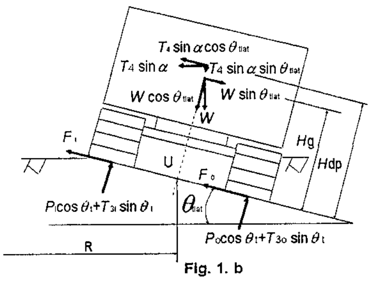

Fig. 1. b

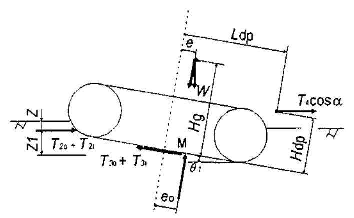

Fig. 1. c

Fig. 1 Forces and moment acting to turning vehicle

Vehicle weight (N) W			638
Height of hitch point (cm) H_{dp}			15
Dist. from grav.cent. to hitch point(cm) L_{dp}			30
Initial tract tension (N) Ho			196
Height of gravity center (cm) Hg			10
Contact length (cm) D			33
Track width (cm) B			10
Track gauge (cm) C			23
Grouser height (cm) H			1.7
Grouser pitch (cm)			2.55
Grouser thickness (cm)			0.3
Maximum track extension (cm)			1
Rad. of front idler and rear sprock. (cm) R_f R_r			6.5
Radius of road rollers (cm) R_m			1.9
Number of road rollers			3
Road roller interval (cm)			6
k_1 (kgf/cm^{n1+2})	0.023	m_{clon}(kgf/cm^2)	0.002
n_1	1.213	M_{flon}	1.017
k_2 (kgf/cm^{n1+2})	0.871	a_{lon}(cm)	0.153
n_2	0.801	m_{clat}(kgf/cm^2)	0.013
c_0(cm$^{1+2c1-c2}$/kgf^{c1})	7.485	m_{flon}	1.017
c_1	0.915	a_{lat}(cm)	0.123
c_2	0.601		

Table 1 Vehicle specifications and terrain-track system constants

The numerical analysis is established based on a numerical method to solve a set of 5 equilibrium equations written for steady turning state of tracked vehicles[1]. From fig. 1 the equilibrium equations can be written as:

$$(T_{3o}+T_{3i})\cos\theta_t - (T_{2o}+T_{2i}) - (P_o+P_i)\sin\theta_t - T_4\cos\alpha = 0 \qquad (1)$$

$$W-[(P_o+P_i)\cos\theta_t+(T_{3o}+T_{31})\sin\theta_t]\cos\theta_{tlat}-(F_o+F_i)\sin\theta_{tlat} = 0 \qquad (2)$$

$$T_4\sin\alpha + (F_o+F_i)\cos\theta_{tlat} - (P_o+P_i)\cos\theta_t\sin\theta_{tlat} = 0 \qquad (3)$$

$$(C/2)[(P_o-P_i)+(T_{20}-T_{2i})\sin\theta_t]-WH_g\sin\theta_{tlat}\cos\theta_t+T4H_{dp}\sin\alpha\cos\theta_{tlat} = 0 \qquad (4)$$

$$M+(T_{20}+P_o\sin\theta_t-T_{3o}\cos\theta_t)(C/2)\cos\theta_{tlat} - (T_{2i}+P_i\sin\theta_t-T_{3i}\cos\theta_t)(C/2)\cos\theta_{tlat} + T_4\sin\alpha\cos\theta_t(L_{dp}-d(e_o+e_i)/2)+T_4\cos\alpha H_{dp}\sin\theta_{tlat} = 0 \qquad (5)$$

The group of 5 independent unknown characteristics could be established. These characteristics are sinkage of front idler and rear sprocket s_{fi}, s_{ri}, lateral trim angle θ_{tlat}, slip ratio of outer and inner track i_o and i_i. The thrusts T_{3o}, T_{3i}, running resistances T_{2o}, T_{2i}, ground reaction forces P_o, P_i, effective tractive effort T_4, lateral shear resistances F_o, F_i, longitudinal trim angle θ_t, eccentricity of center of ground reaction force e_o, e_i in the above equilibriums can be expressed as function of the 5 independent unknowns using basic terra-mechanical relationship such as Janosi-Hanamoto's equations, Bekker's pressure sinkage relationship and other geometrical relationships. The problem can then be expressed as which combination of vehicle position and running condition specified by 5 independent unknowns would satisfy 5 equilibrium equations. Solving this set of 5 equilibrium equations for 5 above mentioned independent unknowns solves the problem. The set of equations is solved based on Newton-Raphson method [2].

[1] Turning Characteristics of a Model Tracked Vehicle Running on Fresh Concrete, Tatsuro Muro, Tran Dang Thai (Ehime Univ.), Hirakawa Manabu (Hitachi Kenki Co., Ltd)

The equations are established based on various assumptions. The vehicle is considered to be in steady turning state, or in other word, in a turning motion with constant velocity. The turning pole of the vehicle is considered to be in the longitudinal centerline of vehicle and at the center of the ground reaction force. The turning center is the center of the path of this turning pole. Turning moment was considered to overcome lateral shear resistance and lateral bulldozing resistance. The lateral shear resistance was computed based on a consideration to determine lateral amount of slippage[1]. The pressure is considered to be uniformly distributed in lateral direction and centrifugal force was ignored.
The simulation was applied for a model vehicle turning on fresh concrete. The experiment was carried out to verify the simulation. The input to the simulation is the vehicle design characteristics and its running conditions. Table 1 shows dimension of the model vehicle as an input to the simulation. Running conditions are characterized by terrain-track system constants, steering ratio (defined as ratio of circumferential speed of outer and inner track), value of effective tractive effort and its traction angle. Table 2 shows terrain-track system constants for the given vehicle and fresh concrete of slump of 55 cm as the input to the simulation. The vehicle is the scaled model of a bulldozer and is driven by two electric motors. The vehicle is turned with steering ratio of 1.6. It has a rigid suspension system and three road rollers support each of its tracks. The experiment was carried with effective tractive effort of 0, 69 and 147 N. The traction angle was zero for all the cases of effective tractive effort. The measured values are sinkage of front idler, rear sprocket of both tracks, slip ratios and turning radius.

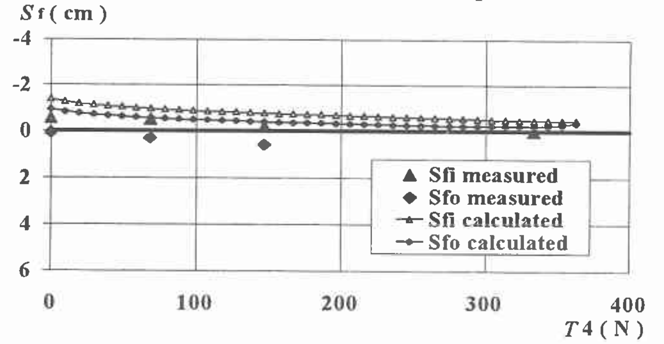

Fig. 2 Comparison between measured and calculated sinkage *Sf* of front idlers relating to effective tractive effort *T4*

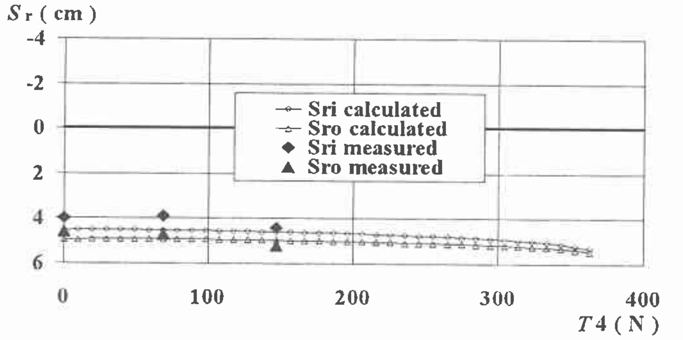

Fig. 3 Comparison between measured and calculated sinkage *Sr* of rear sprocket relating to effective tractive effort *T4*

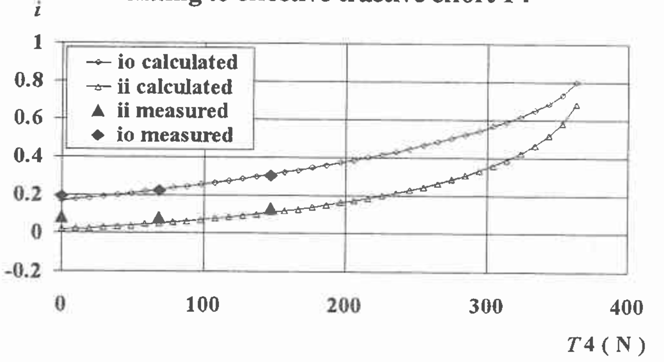

Fig. 4 Comparison between measured and calculated slip ratio *i* relating to effective tractive effort *T4*

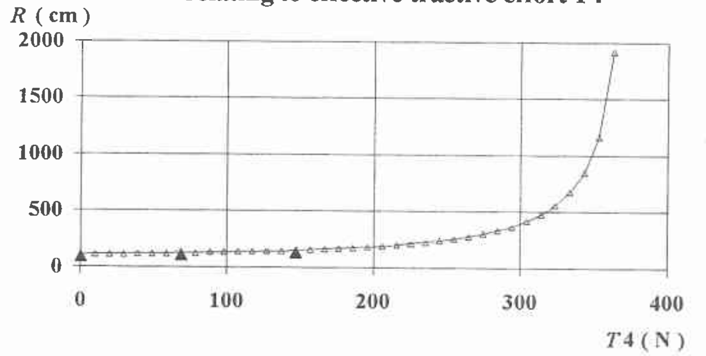

Fig. 5 Comparison between measured and calculated turning radius *R* relating to effective tractive effort *T4*

Numerical and experimental results: Fig. 2 and 3 show the comparison between measured and calculated values of sinkage of front idler and rear sprocket respectively for different effective tractive effort. The values of the sinkage in the figures are the sinkage of the beginning and end point of the track theoretical contact length and at the centerline of each track. Fig. 4 and 5 shows the comparison between measured and calculated slip ratios i_o and i_i of both tracks and turning radius respectively for different effective tractive effort. The slip ratios are the values at the centerline of each track. The figures show that good match can be observed between measured and calculated values.
Conclusion: The simulation analysis was established and applied for a model of rigid suspension tracked vehicle turning on fresh concrete. The experiment was also carried out and the results were compared. The comparison shows that the simulation has high accuracy and can be used to predict turning characteristics of tracked vehicle or to analyze the effect of design characteristics to turning characteristics of tracked vehicle.
References: 1) T. Muro, T. D. Thai, Turning Characteristics of a Bulldozer under Traction on a Weak Sandy Terrain, Proceedings of 7th European ISTVS Conference, pp. 102-109, 1997.
2) William H. Press, Saul A. Teukoisky, William T. Vetterling, Brian P. Flannery, Numerical Recipes in C, the art of scientific computing- second edition, Cambridge Univeristy Press pp 379-393, 1995.