COMPONENT PART NOTICE

THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT:

(TITLE): Proceedings of the International Conference on the Performance of Off-Road Vehicles and Machines (8th) Volume 1 Held at Cambridge, England on August 5-11, 1984

(SOURCE): International Society for Terrain-Veihcle Systems

TO ORDER THE COMPLETE COMPILATION REPORT USE AD-148 643.

THE COMPONENT PART IS PROVIDED HERE TO ALLOW USERS ACCESS TO INDIVIDUALLY AUTHORED SECTIONS OF PROCEEDINGS, ANNALS, SYMPOSIA, ETC. HOWEVER, THE COMPONENT SHOULD BE CONSIDERED WITHIN THE CONTEXT OF THE OVERALL COMPILATION REPORT AND NOT AS A STAND-ALONE TECHNICAL REPORT.

THE FOLLOWING COMPONENT PART NUMBERS COMPRISE THE COMPILATION REPORT:

COMPONENT PART NOTICE (CON'T)

AD#:	TITLE:
AD-P004 269	Leistungssteigerung und Verbesserung des Fahrkomforts Bei Selbstfahrenden Baumaschienen Durch Reduzierung Einsatbedingter Nick- und Hubschwingungen (Increase in Performance and Improvement of Ride Comfort of Self-Propelled Construction Machinery by Reducing Pitch and Vertical Vibration)
AD-P004 270	Stresses in Situ Generating by Bulldozers
AD-P004 271	Finite Element Analysis of Ground Deformation Beneath Moving Track Loads
AD-P004 271	A Rig for Testing the Soft Soil Performance of Track Systems
AD-P004 273	Die Abhaengigkeit der Bodentragfaehigkeit und der Zugkraft von der Abstandgroesse der Bodenplatten (The Dependence of Soil Bearing Capacity and Drawbar Pull on the Spacing between Track Plates)
AD-P004 274	The Dynamic Interaction between Track and Soil
AD-P004 275	Analysis of Ground Pressure Distribution Beneath Tracked Model with Respect to External Loading
AD-P004 276	A Comparison between a Conventional Method and an Improved Method for Predicting Tracked Vehicle Performance
AD-P004 277	Effect of Hitch Positions on the Performance of Track/Grouser Systems
AD-P004 278	Grouser Effect Studies
AD-P004 279	Ride Comfort of Off-Road Vehicles
AD-P004 280	Further Development in Ride Quality Assessment
AD-P004 281	Comparison of Measured and Simulated Ride Comfort for an Agricultural Tractor and Influence of Travel Speed and Tyre-Inflation Pressure on Dynamic Response
AD-P004 282	Characteristics of Fram Field Profiles as Sources of Tractor Vibration

Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

THE ROLLING RESISTANCE AND SINKAGE OF TOWED DUAL WHEEL COMBINATIONS IN SAND

J.G. HETHERINGTON and I. LITTLETON

ROYAL MILITARY COLLEGE OF SCIENCE, SHRIVENHAM, SWINDON, WILTS. SN6 8LA

INTRODUCTION

The ability to predict the performance of wheeled vehicles across country is of paramount importance in both the design of military vehicles and assessing their effectiveness within a specified theatre of operation. In a previous paper by the authors (1) a predictive formula was developed which effected the prediction of the rolling resistance and sinkage of towed wheels on sand. The advantage of the form of the equation was that, where other workers had employed the cone index gradient as a measure of sand strength for mobility studies, this prediction used only the soil bulk unit weight and the angle of friction of the soil. The predictive equation was shown to correlate well with experiments on a wide range of wheel geometries, loads and granular soils.

It has been shown, Rowland (2), that the typical peak pressures beneath an armoured, wheeled vehicle are generally very high, and certainly much higher than their tracked counterpart. In general it is assumed that high pressure equates to poor performance. This is certainly so on fine grained soils, where increased pressure produces no benefit in traction, but incurs the penalty of extra sinkage and rolling resistance. For this reason the draw-bar pull reduces and the mobility suffers. However, on coarse grained soils, increased pressure both increases traction and resistance, with the result that draw-bar pull can actually increase with increased vehicle weight. For vehicle designers attempting to improve mobility, it has commonly been a tempting solution to consider dualling the wheels on a particular axle. The effect of this action has proved difficult to understand and often disappointing in outcome. Melzer and Knight in their paper on this subject (3) quote examples of field tests on both agricultural and military vehicles in which the single wheeled version out-performed the dual wheeled on certain soil conditions.

Tests performed by Rouch, Liljedahl and Clark (4, 5) on a cohesive soil showed that, whilst dual-wheels consistently out-performed single wheels, the magnitude of the improvement decreased with soil strength. Melzer and Knight (3) performed a comprehensive series of tests on driven dual wheel combinations and presented their results within the system of mobility numerics developed by Freitag (6). They found that the draw bar pull mobilised with a dual wheel system, with zero separation between wheels, coincided with that which would be obtained from a single wheel of the same overall dimensions. The total draw bar pull from the pair of wheels decreased with increased separation and they confirmed the findings of references 4 and 5 that the benefit of dual wheels was greatest on weak soils. Gee Clough (7) has observed that the reduction in rolling resistance with separation found by Melzer and Knight, and confirmed himself experimentally, contradicted the prediction from mobility numeric analysis.

Whilst the work of Gee Clough examined wheel separation ratios (a/b Figure 1) in the range of 0 to 0.33, Melzer examined ratios of 0 and 1 to where z_s is the sinkage of single wheel

and z_d is the sinkage of dual wheel system carrying the same load.

Thus these parameters are simply the percentage improvement derived from doubling up the wheels.

By considering a dual combination with zero spacing ($a/b = 0$) values of F_R and F_S can be obtained from equations (1):

$$\text{For } a/b = 0, \quad F_R = \frac{\left(\frac{2W^4}{bd^2\gamma N_q}\right)^{1/3} - \left(\frac{2W^4}{2bd^2\gamma N_q}\right)^{1/3}}{\left(\frac{2W^4}{bd^2\gamma N_q}\right)^{1/3}} \times 100 = 20.6\%$$

$$\text{and } F_S = \frac{d\left(\frac{2W}{b\gamma N_q d^2}\right)^{2/3} - d\left(\frac{2W}{2b\gamma N_q d^2}\right)^{2/3}}{d\left(\frac{2W}{2b\gamma N_q d^2}\right)^{2/3}} \times 100 = 37\%$$

For small separations, the soil will be unable to perceive the wheels as discrete and therefore the performance of a pair of wheels, each of width b, separated by an amount 'a', can be represented by a single wheel of breadth (2b+a). Thus

$$F_R = \frac{\left(\frac{2W^4}{b\gamma N_q d^2}\right)^{1/3} - \left(\frac{2W^4}{(2b+a)\gamma N_q d^2}\right)^{1/3}}{\left(\frac{2W^4}{b\gamma N_q d^2}\right)^{1/3}} \times 100\%$$

$$= 100\left\{1 - \left(\frac{b}{2b+a}\right)^{1/3}\right\} = 100\left\{1 - \left(\frac{1}{2}\right)^{1/3}(1 + a/2b)^{-1/3}\right\}$$

$$= 100\left\{1 - 0.794\left(1 - \frac{a}{6b} + \ldots\right)\right\}$$

$$\simeq 20.6\% + 13.2\ a/b\%.$$

Similarly $F_S \simeq 37\% + 21\ a/b\%$.

These expressions predict that, for small values of a/b, the improvement derived from dualling will increase linearly with wheel separation.

EXPERIMENTAL WORK

A programme of tests was carried out on model scale, rigid wheels in single and dual configurations. The wheels were towed at a slow, constant speed on a uniform bed of dry Calne sand, the details of which are contained in reference 7. The wheels used were 0.047 m wide, with diameters of 0.25 m and 0.3 m, and 0.072 m wide with a diameter of 0.3 m. For each wheel combination, both axle load and wheel spacing were varied, and the rolling resistance and sinkage of the combination recorded. The results of the experimental tests are presented in Figures 2 and 3.

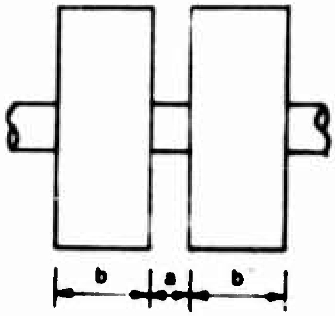

Figure 1

8. Thus the findings and anomalies could be attributable to the different ranges examined. Clearly there is a complex interaction between traction and rolling resistance in the case of driven wheels as investigated by Melzer and Knight. The aim of this work is to isolate the parameters of sinkage and rolling resistance by studying the towed case. By taking experimental results for a range of ratios between 0 and 5, and comparing these with the predictions from the formula of reference 1, this paper seeks to quantify and explain the reductions in sinkage and rolling resistance which accrue from dualling towed wheels.

THEORY

Reference (1) gives the following expressions for the rolling resistance and sinkage of a towed rigid wheel in sand:

$$\left.\begin{aligned} R &= \left(\frac{2W^4}{bd^2\gamma N_q}\right)^{1/3} \\ z &= d\left(\frac{2W}{b\gamma N_q d^2}\right)^{2/3} \end{aligned}\right\} \qquad (1)$$

where R is rolling resistance
W is vertical axle load on wheel
b is wheel breadth
d is wheel diameter
γ is soil bulk unit weight
N_q is a Terzaghi bearing capacity factor

These expressions were shown to predict, within tolerable limits of accuracy, performance parameters for a wide range of wheels on several sands of widely differing properties. The advantages of these equations over other systems lies in their ease of use, and in their dependence only on soil bulk unit weight and angle of friction in defining soil properties. An informative method of describing the performance of dual wheel systems is to examine the benefit which accrues from replacing a single wheel with a double wheel unit. In this paper this benefit will be characterised by a "resistance improvement factor" (F_R) and a sinkage improvement factor (F_S) defined as follows:

$$F_R = \frac{R_s - R_d}{R_s} \times 100\%$$

where R_s is the resistance of single wheel
and R_d is the resistance of dual wheel system carrying the same load

$$F_S = \frac{z_s - z_d}{z_s} \times 100\%$$

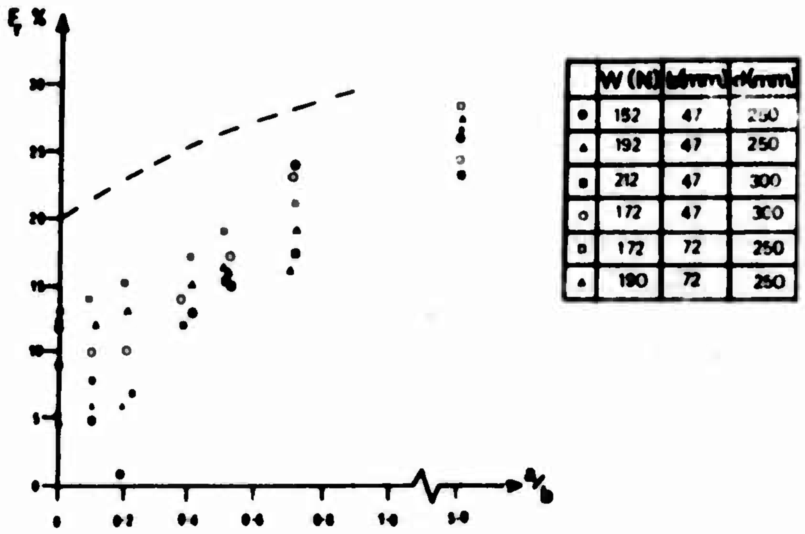

Figure 2

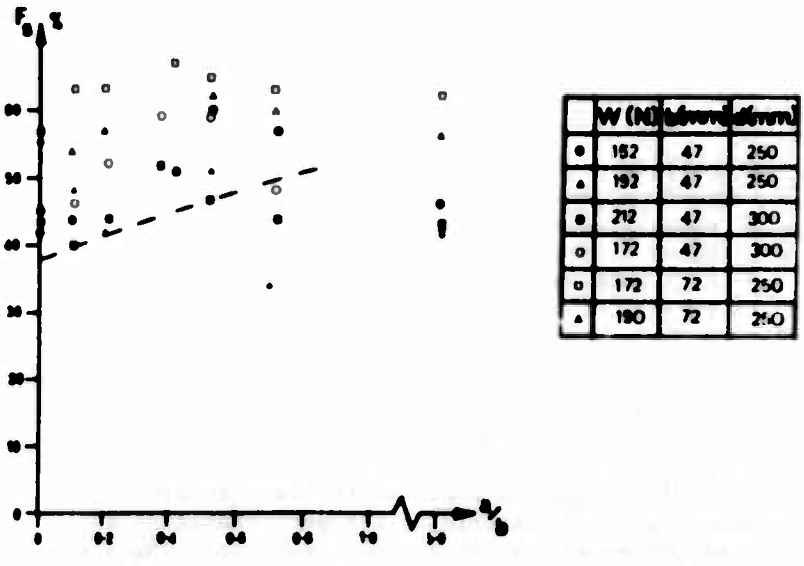

Figure 3

DISCUSSION

One advantage of assessing dual wheel performance by comparison with a single wheel carrying the same load is that the major source of error, which comes from soil property measurement, is eliminated. The only significant sources of error in this work were in the measurement of rolling resistance and sinkage. It is estimated that the determination of both sinkage and rolling resistance could be subject to errors of up to ± 10%.

Since both single and dual wheel measurements are subject to errors, their quotient will be subject to errors of up to ± 20%. The experimental results indicate the following characteristics of behaviour:

1) Replacing a single wheel with a dual wheel combination will reduce both sinkage and rolling resistance.

2) The improvement derived from dualling wheels increases with wheel spacing, until the wheels act as separate entities.

3) As a rule of thumb, the percentage improvement derived varies from 10 to 25% for resistance and about 50% for sinkage.

The dotted lines added to the figures represent the theoretical predictions. In the case of rolling resistance, the predicted benefit is considerably more than that actually observed, although the variation with separation is comparable. In the case of sinkage, both the levels of benefit derived and their dependence on a/b show some correlation.

It is interesting to observe that the presentation of Figures 2 and 3 apparently removes the distinction between different families of tests. Differences in axle load, wheel breadth and wheel diameter do not manifest themselves in data grouping when the results are analysed in this way. Thus both the sinkage and the rolling resistance improvement factors appear to be independent of mobility numeric. This is consistent with the findings of previous workers who observed that the magnitude of the benefit derived diminished with increased numeric value since, for towed wheels, both sinkage and resistance also diminish with increased numeric value.

Finally, it is worth making an observation on the case of driven dual wheel systems. In both sands and clays reductions will be observed in sinkage and rolling resistance through dualling wheels. The increased contact area will improve traction significantly in cohesive soils but not in frictional soils. It is probable therefore that there will be more to be gained from dualling wheels for applications on clays than there will be on sand. There is clearly a need for more information on the performance of driven dual wheel combinations on clay soils.

CONCLUSIONS

1) A programme of tests on towed, rigid wheels on sand has shown that replacing a single wheel with a dual wheel unit will reduce both sinkage and rolling resistance.

2) The improvement derived from dualling wheels increases with spacing, until the wheels act as separate entities.

3) As a rule of thumb, a 50% reduction in sinkage and between 10 and 25% reduction in rolling resistance derives from dualling wheels.

4) By modelling the dual wheel unit with a single wheel of the same external dimensions, some trends of behaviour can be predicted.

REFERENCES

1. Hetherington, J.G. and Littleton, I., "The Rolling Resistance of Towed Rigid Wheels in Sand", Journal of Terramechanics, Vol 15, No 2. 1978.
2. Rowland, D., "Tracked Vehicle Ground Pressure", Report No 72043. MVEE Chertsey, U.K., September 1972.

3. Melzer, K.-J., "Dual Wheel Performance in Sand", A.S.A.E. Paper No 71-132 presented at 1971 Annual Meeting of A.S.A.E., June 1971, Washington State University.
4. Rouch, K.E. and Liljedahl, J.B., "The Effect of Dual Tire Spacing on Tractive Performance in Soil", Paper presented at 1967 Annual Meeting of A.S.A.E., Saskatoon, Saskatchewan, Canada, June 1967.
5. Clark, S.J. and Liljedahl, J.B., "Model Studies of Single, Dual and Tandem Wheels", Transactions of the A.S.A.E. Vol 12, No 2, 1969.
6. Freitag, D.R., "A Dimensional Analysis of the Performance of Pneumatic Tires on Soft Soils", Technical Report No 3-688, Aug 1965, U.S. Army Engineer Waterways Experimental Station, Vicksburg, Mass.
7. Gee-Clough, D., "The Effect of Separation on the Rolling Resistance of Dual Rigid Wheels in Sand", Departmental Note DN/T/935/01002 January 1979 (Internal report of NIAE, Silsoe, Beds, UK).
8. Littleton, I., "Some Observations on the Mechanical Properties of Frictional Soils used at RMCS". Technical Note MAT/14 RMCS, Shrivenham, Swindon, UK.