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EVALUATION OF WHEELED VEHICLE MOBILITY AND PERFORMANCE PREDICTION ON DEFORMABLE SOIL

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ABSTRACT

Mobility is the ability to move freely and rapidly over the terrain of interest to accomplish varied combat objectives. The vehicle weight and its footprint determine the resultant ground pressure that the vehicle imparts on the soil. The soil strength, coupled with the ground pressure, determines vehicle cone index, VCI, which is the key for vehicle mobility. This paper presented a theoretical evaluation of the vehicle mobility and predicts its performance on deformable soil. For this purpose, soil field test was carried out using cone penetrometer in situ to measure the strength of different soils. The vehicle cone index was calculated using vehicle parameters. A comparison of rating cone index with the vehicle cone index indicates whether the vehicle can negotiate the given soil condition for a given number of passes.

KEY WORDS

Vehicle mobility, Soil testing, Vehicle performance, cone penetrometer

NOMENCLATURE

b	Tire width, m
CI	Cone index, N/m^2
d	Tire diameter, m
f	Factor depending on axle load
MI	Mobility Index
n	Number of axles
RCI	Rating Cone Index
RI	Remolding Index
VCI_1	One-pass Vehicle Cone Index
VCI_{50}	50-pass Vehicle Cone Index

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W	Vehicle weight
$\overline{X}$	Axle weight factor
$\overline{Y}$	Weight factor

INTRODUCTION

Vehicle mobility is the overall capability of a vehicle to move from place to place while retaining its ability to perform its primary mission [1]. Terrain trafficability means the ability of terrain to support the passage of vehicles [1]. There are a lot of studies and articles in existence that deal with components related to tractability. Hintze [2], Rounsevell [3] and Earl [4] have set out to predict soil strength with the aid of climatic data. Davis and Laut [5], Saarilahti [6] have estimated the terrain trafficability and soil strength. Birkel [7] took into account the interaction between the terrain and the vehicle. Orava [8] used raster analysis to determine terrain trafficability as needed for planning military activities, but his application included only terrain parameters and did not contain the attributes of the vehicle, and therefore it could not be used to solve routing problems.

The mobility of a vehicle is influenced by three main parameters; vehicle parameters, soil parameters and environmental parameters (Climate conditions and driver's skill). The vehicle parameters; vehicle performance, geometric configuration, vehicle construction and economy of operation have considerable influence on vehicle mobility [9]. The soil parameters affecting vehicle mobility include; behavior under loading, transient and permanent parameters [10-12].

B. Maclaurin [14] compared the available models for predicting the tractive performance of wheeled and tracked vehicles on soft cohesive soils. The author found that there is a major limitation in the development of a reliable empirically vehicle model due to the lack of reliable experimental data, especially in the low traction region. A. Bodin [15] described a tracked vehicle for use in studying the influence of different vehicle parameters on mobility on soft terrain. The author found that the nominal ground pressure has a significant effect on the tractive performance of tracked vehicle. When the nominal ground pressure is increased, the drawbar pull coefficient was decreased.

Jody et al [10] explained how VCI is measured, and compared with different methods of predicting VCI for one-pass performance of wheeled vehicles in fat clay soils. It is further clarified that MMP (mean maximum pressure) should not be compared with VCI. They modified and developed existing relationships for using MMP to predict VCI_1 for wheeled vehicles in clay. Therefore the resulting relationships allow comparison between MMP and MI in terms of their ability to predict VCI. A vehicle cone index is obtained using vehicle parameters. A comparison of the VCI and the soil RCI will result in a prediction of whether the vehicle is mobile or not (GO/NO GO) in a particular soil.

EVALUATION OF SOIL STRENGTH FOR TRAFFICABILITY

The evaluation of soil strength for vehicle mobility is obtained in the field using plate sinkage test or Cohron shear graph test or cone penetrometer test. The cone penetrometer is a simple instrument designed to give a quick and easily obtained index of soil strength [13]. The soil-trafficability test set include cone penetrometer, soil sampler, and remolding equipment as shown in Fig. 1 The cone penetrometer set consists of the following items:

- A 30-degree cone with a 0.5 inch2 (325 mm2) base area.
- A steel shaft 485 mm long and 10 mm diameter.
- Proving ring with dial range from 0-150 Lb or from 0-300 Lb/inch2 (0 - 2.07 N/mm2).
- Micrometers dial.
- A handle.

The cone was pressed into the soil at a uniform speed, 30 mm/sec (approximately 15 seconds in soft soil) and the force required to press the cone through the soil layers was indicated on the dial inside the proving ring in the penetrometer handle. The pressure corresponding to this force was an index of the soil resistance and was called the soil cone index. An assistant should be provided to record the readings taken by the operator. The operator will quickly learn to shift his vision from the rod at the ground to the dial at the proper moment, meanwhile maintaining a constant penetration rate. Five to seven penetrations should be performed to get a good statistical average and an estimate of the variability of the terrain with depth. In this research, the soil strength was measured at different depths as clarified in Table (1) and plotted in Fig. 2, the average CI was calculated. In case of fine-grained soil, a remolding test was used to obtain rating cone index, which was the response to repetitive loads. In this case a sample from the critical layer was ejected into the remolding cylinder and pushed to its bottom with the foot of the drop-hammer shaft. While the cone penetrates the soil sample, the CI readings were recorded for the successive depths of the cone.

Table (1): Soil situ testing

Depth, in	Cone index, Lb/in ^{2}	Average CI
1	22	86.5
2	30	
3	105	
4	130	
5	125	
6	107	

EVALUATION OF VEHICLE MOBILITY

For evaluating MI for wheeled vehicles there are many empirical relationships, some formulae neglect the ground clearance, power/weight ratio and transmission [10]. The vehicle mobility for three vehicles (Gaz 69, Hummer M998 and Zil 131) was calculated using series of equations developed by waterways experiment station, WES [15-17] known as the "Mobility Index". The mobility index is expressed in terms of vehicle parameters; tire load and dimensions, engine and transmission characteristics. The parameters required for mobility evaluation are shown in Table (3). The Mobility Index, MI for all wheel drive vehicle was calculated from equation (1). For a not all-wheel drive vehicle, the MI was computed according to the formula for all wheel drive vehicles, and then multiplied by 1.4. The output results for mobility index for the three vehicles are shown in Tables (4-6).

$$MI = \left(\frac{Contact\ Pressure\ Factor \times Weight\ Factor}{Tire\ Factor \times Grouser\ Factor} + Wheel\ Load\ Factor - Clearance\ Factor \right) \times Engine\ Factor \times Transmission\ Factor \qquad (1)$$

where:

$$Contact\ pressure\ Factor = \frac{Gross\ Weight, Lb}{Nominal\ Tyre\ Width, in. \times Outside\ Radius, in. \times No.\ Of\ Tyres} \qquad (2)$$

Weight Factor, $\overline{Y}$ was calculated according to the weight range, as shown in Table (2).

Table (2): Weight Factor

Weight Range, Lb (KN)	*Weight Factor Equation*
< 2000 (8.9 KN)	$\overline{Y} = 0.553\overline{X}$
2000 - 13,500 (8.9 - 60 KN)	$\overline{Y} = 0.033\overline{X} + 1.050$
13,501 – 20,000 (60 – 88.9 KN)	$\overline{Y} = 0.142\overline{X} - 0.420$
> 20,000 (88.9 KN)	$\overline{Y} = 0.278\overline{X} - 3.115$

where:

$$\overline{X} = \frac{Gross\ Weight, Lb}{No.\ Of\ Axles \times 1000}$$

$$Tire\ Factor = \frac{10 + Tire\ Width, in.}{100}$$

$$Wheel\ Load\ Factor = \frac{Gross\ Weight, Lb}{No.\ Of\ Axles \times 2000}$$

$$Clearance Factor = \frac{Clearance, in.}{10}$$

Engine Factor: ≥ 10 hp/ton of vehicle weight = 1.00

< 10 hp/ton of vehicle weight = 1.05

Transmission Factor: Automatic = 1.00

Manual = 1.05

Grouser Factor: With Chains = 1.05

Without Chains = 1.00

Based on the mobility index (MI), a parameter called the vehicle cone index (VCI) was calculated. The VCI represents the minimum strength of a soil in the critical layer that permits a given vehicle to successfully make a specific number of passes, usually one pass or 50 passes. For instance, the value of VCI for one pass and 50 passes, VCI_1 and VCI_{50}, was obtained either by equations (3-5) [18-19] or using graphs as shown in Fig. 3 [13]. The MI above 40, the VCI_{50} can be obtained from the equation (6) [10]. The evaluation of vehicle mobility module was shown in flow chart shown in Fig. (4)

For one pass, if $MI \leq 115$

$$VCI_1 = 11.48 + 0.2MI - \left(\frac{39.2}{MI + 3.74}\right) \quad (3)$$

And if $MI > 115$

$$VCI_1 = 4.1 \times MI^{0.446} \quad (4)$$

And for 50 passes, for any MI value

$$VCI_{50} = 28.23 + 0.43MI - \left(\frac{92.67}{MI + 3.67}\right) \quad (5)$$

And for $MI > 40$

$$VCI_{50} = 25.2 + (0.454 \text{ x } MI). \quad (6)$$

ANALYSES OF RESULTS

Using Tables (2 through 4), a comparison between VCI_1, VCI_{50} and RCI indicates whether the vehicles can Go / No Go on deformable soil. In the case of going, the performance prediction on deformable soil in terms of rolling resistance, and drawbar pull was investigated using module shown in Fig. (4). the required soil parameters for performance module are shown in Table (6). The drawbar pull of the three tested vehicles is shown in Figs. (5 - 6) on sand and loam. From these figures as the wheel slip increase the drawbar pull increase until it reaches the maximum value corresponding to complete wheel slip. Also these figures display that the vehicle # 2 gives the higher drawbar pull than the others. Therefore, the rolling resistance of the two other vehicles is lower than the vehicle #2 as shown in Figs. (5 - 6) on sand and loam.

CONCLUSIONS

The vehicle mobility evaluations for three different vehicles were carried out and the performance of the tested vehicles in terms of drawbar pull and rolling resistance were predicted. The mobility evaluation was based on vehicle parameters and soil testing in situ, using cone penetrometer. Because the readings must be taken in about 15 seconds with constant penetration rate according to user manual for soft soil, this needs an assistant to record the readings and shift his vision from the rod at the ground to the dial at the proper moment. Therefore, an error with recording the results was anticipated. A good measuring of soil strength using digital electronic cone penetrometer gives accurate results for soil strength and so correct decision for going on deformable soil

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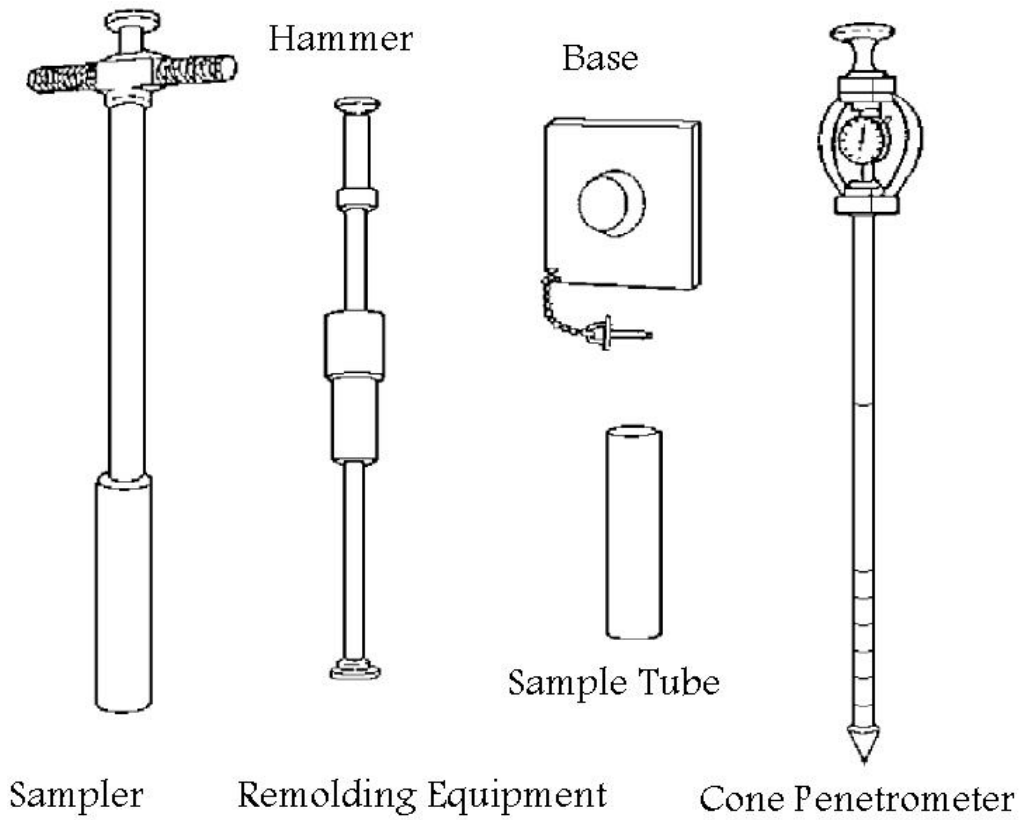

Fig. (1): The soil-trafficability test set [13]

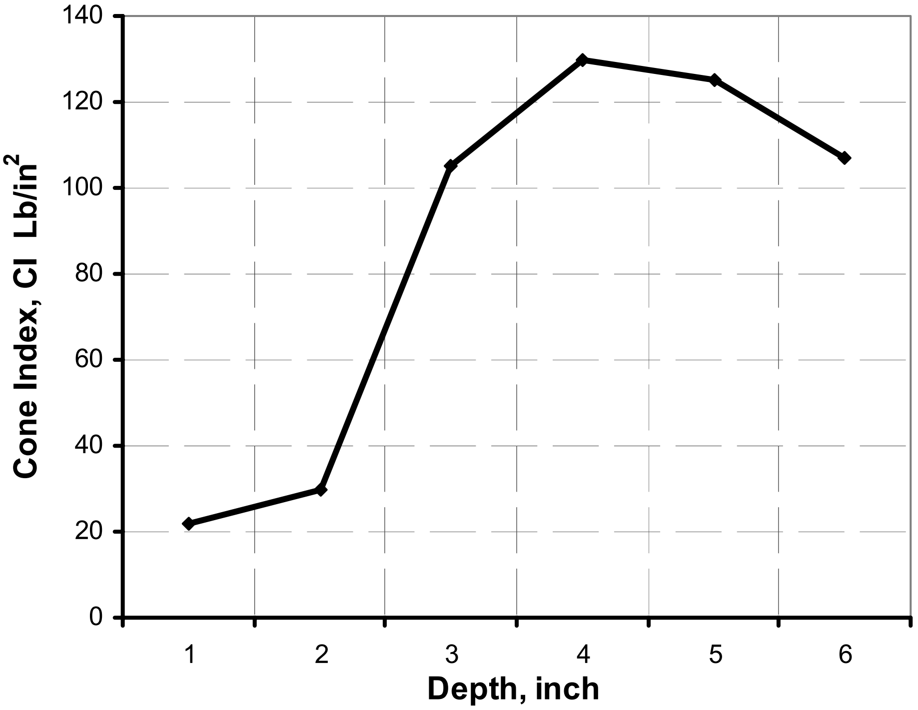

Fig. (2): Variation of soil strength with depth

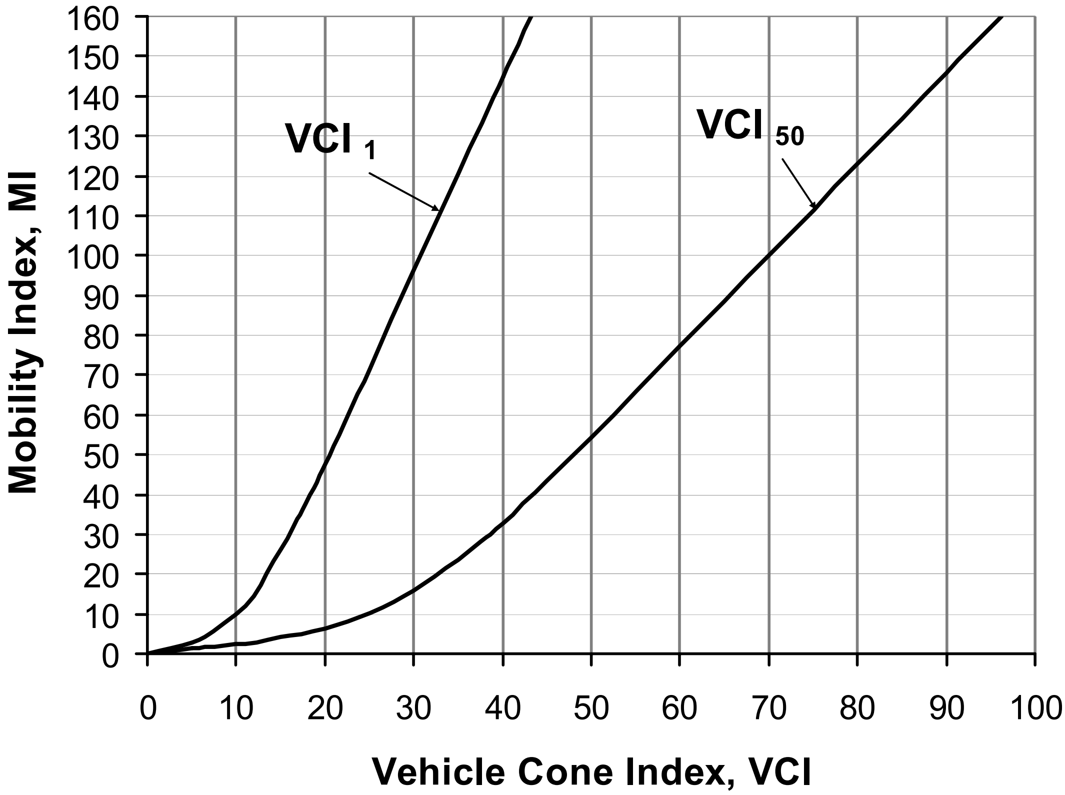

Fig. (3): Estimated relation of MI to VCI [13]

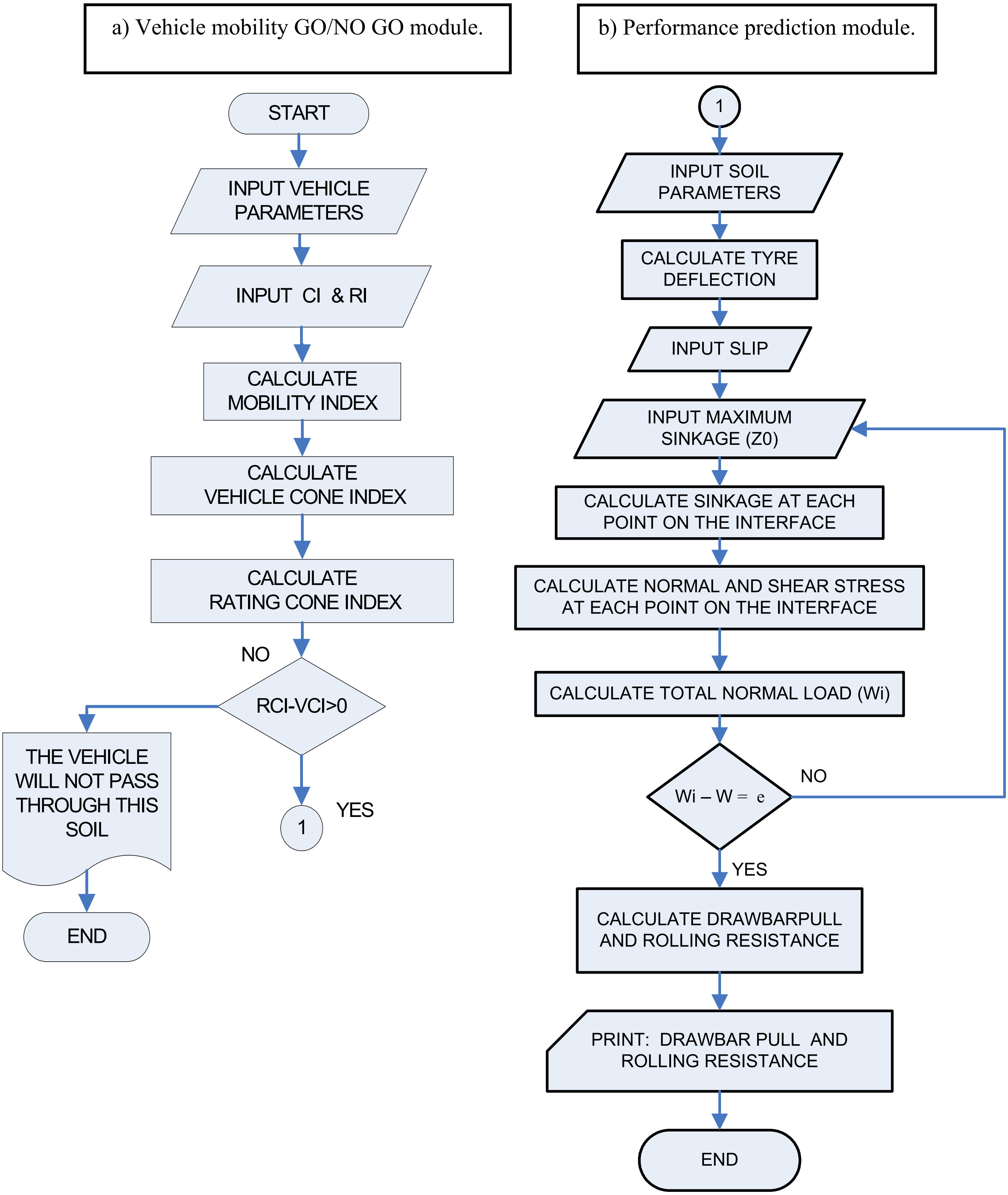

Fig. (4): Flow chart of the computer program

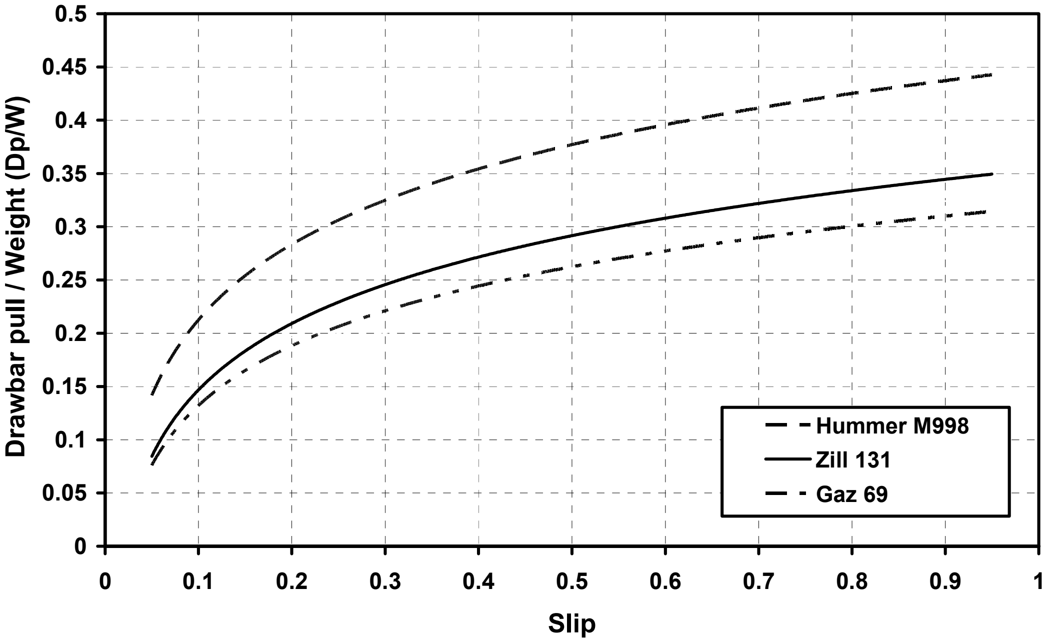

Fig. (5): Drawbar pull / Weight Vs. slip for sand

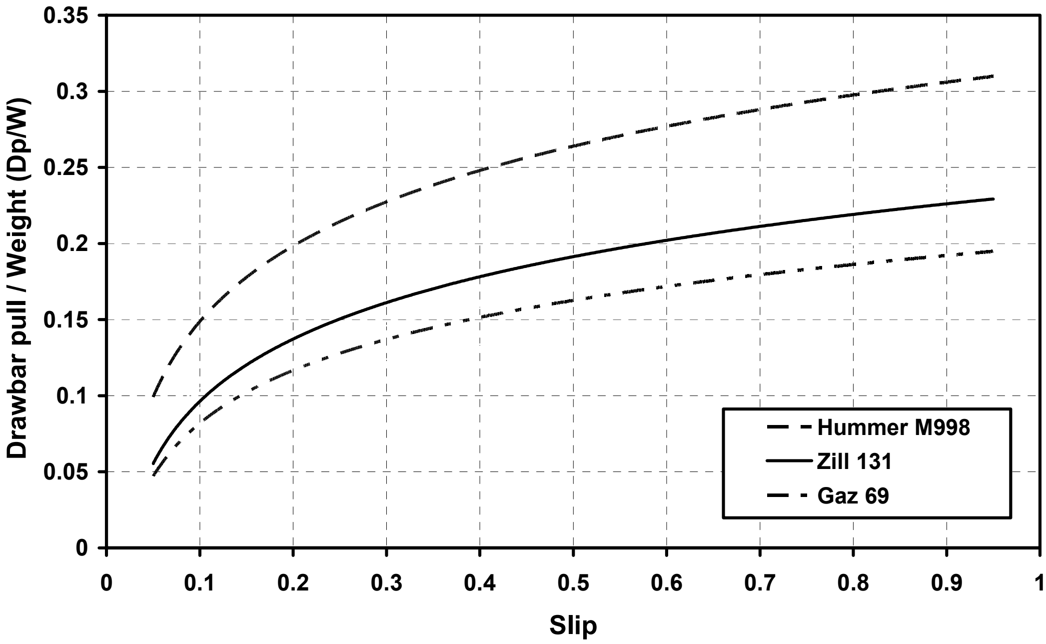

Fig. (6): Drawbar pull / Weight Vs. slip for loam

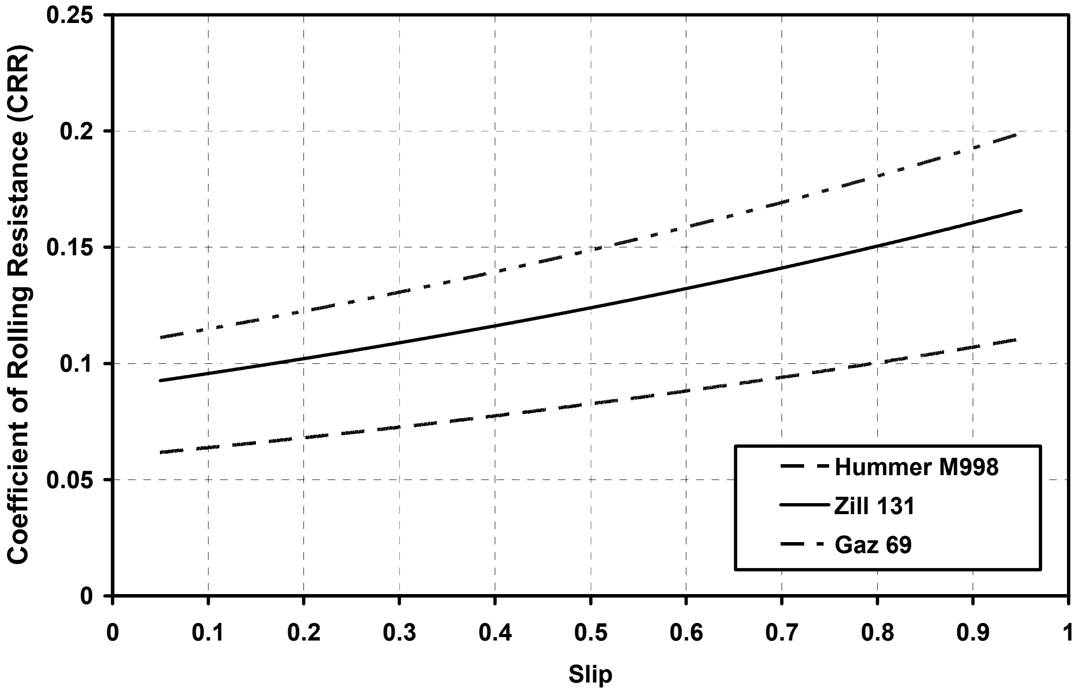

Fig. (7): Coefficient of rolling resistance Vs. slip for sand

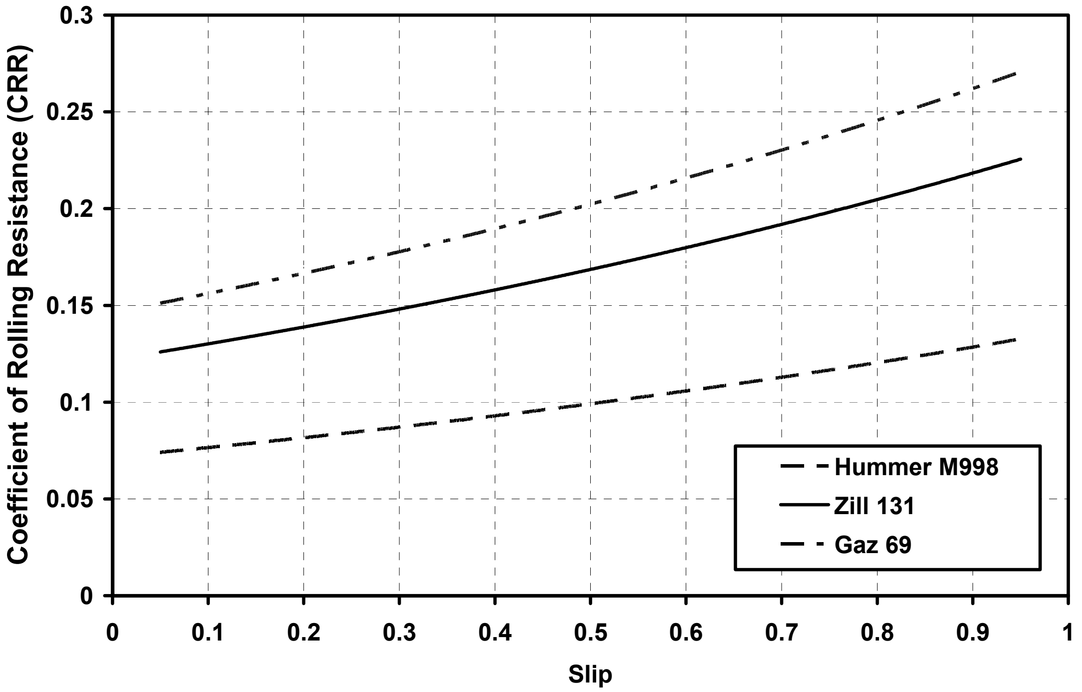

Fig. (8): Coefficient of rolling resistance Vs. slip loam

Table (3): Vehicle parameters required for calculating mobility index

Parameter	vehicle # 1 (Gaz 69)	vehicle # 2 (Hummer M998)	vehicle # 3 (Zil 131)
Specific power: (hp/Ton)	26	43	13.5
Vehicle weight: Lb (kN)	21	35	111
Tire diameter: in (m)	0.6534	0.8952	0.9656
Tire width: in (m)	0.1650	0.3175	0.3050
Ground clearance: in (m)	0.21	0.41	0.38
No. of tires.	4	4	6
No. of axles.	2	2	3
Contact pressure factor	8.709	10.86	12.15
Weight factor	1.128	1.178	0.4147
Tire factor	0.165	0.1839	0.2201
Wheel load factor	1.18	1.938	6.348
Clearance factor	0.7874	0.8661	1.417
Transmission type	Manual	Manual	Manual
Grouser Factor	Without chains	Without chains	Without chains

Table (4): output results for vehicle # 1, Gaz 69

Output parameter	Loam	Sand	Clay
Mobility index, MI	101	101	101
CI	27.18	52.36	86.5
VCI_1	35.32	35.32	35.32
VCI_{50}	70.21	70.21	70.21
RI	0.80	0.85	1
RCI	21.7	44.5	86.5

Table (5): output results for vehicle # 2, Hummer M998

Output parameter	Loam	Sand	Clay
Mobility index, MI	50	50	50
CI	27.18	52.36	86.5
VCI_1	18.5	18.5	18.5
VCI_{50}	43	43	43
RI	0.80	0.85	1
RCI	21.7	44.5	86.5

Table (6) output results for vehicle # 3, Zil 131

Output parameter	Loam	Sand	Clay
Mobility index, MI	90.4	90.4	90.4
CI	27.18	52.36	86.5
VCI_1	32.22	32.22	32.22
VCI_{50}	67.1	67.1	67.1
RI	0.80	0.85	1
RCI	21.7	44.5	86.5

Table (7) Soil parameters required for the model

Soil type	K_c (kN/m^{n+1})	K_φ(kN/m^{n+2})	C(kpa))	Φ (degree)	K (mm)	n
Loam	33.5	615	7.5	37°	25	0.75
Sand	30	500	10	30°	25	0.55
Clay	27.5	175	15	29°	19	0.388