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Forecasting Vehicle Mobility in Remote Areas -an Aid to Military Vehicle Design

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Abstract. Military vehicles are designed for off the road mobility. These are liable for deployment on varying ground conditions. Terrain parameters effecting vehicle systems design are listed. To avoid large scale measurement of terrain parameters, use of physiographic maps in forecasting these parameters has been suggested. Field tests to ascertain the similarity of soil strength parameter between the similar physiographic terrain units, called land facets were conducted and the tests confirmed the usefulness of the technique.

Introduction

Military vehicles, be these armoured tanks, logistic carriers, self propelled or towed guns, are often required to operate on pieces of land quite different in characteristics, and yet a high degree of mobility is expected out of these on all types of terrain. Soil, one of the terrain attributes, which provides the bearing surface/floatation and the thrust for the move of vehicle, is variable from location to location and so is the soil strength. The soil strength also varies from season to season. The terrain factors which affect the design of a cross country vehicle are, surface composition (nature of soil), surface profile and roughness, vegetation, and weather surface hydrology.

To design the various systems of a vehicle, data based characteristics of terrain must be known for ready use in the vehicle performance/design equations. To obtain these terrain characteristics it shall need measurement over the entire area where the military vehicle is intended to operate. Terrain trafficability maps, based on actual measurement of these parameters, should be prepared to predict vehicle trafficability. However, such large scale measurements will consume unspecified resources as for example, to measure empirical soil strength parameter by a cone penetrometer, soil within a radius of 0.15 m around it is only disturbed, thus for a country like India with approx

3.29×10^6 sq km surface area, which is quite a moderate one for which a vehicle should be designed, 4.65×10^{13} measurements of soil strength are possible. Moreover, military vehicle design caters for its effective deployment in enemy land for offensive operations of war. It may not be possible to obtain ground conditions data by actual measurements on such land.

Keeping these difficulties in view, an attempt has been made in this investigation to obtain such information from the physiographic maps and avoid large scale measurements.

2. Ground Parameters for Vehicle Design

It has been identified through various researches* that for design of various vehicle assemblies/systems, the terrain factors which interact predominantly with vehicle equations are :

Vehicle system	Predominant terrain factor	Terrain parameter
Running gear (tyres, track system)	Surface composition (type of soil)	Soil strength (dry/wet) kPa
Suspension (transmissibility)	Surface roughness	Ground disturbance to suspension $m^2/c/m$
Transmission (torque multiplication)	Surface profile	Slopes encountered (Degree)
Steering (turning circle diameter)	Vegetation, surface profile	Spacing of growth, rocky defiles, inter visibility
Angle of approach/departure	Surface profile	Obstacles (size frequency)

(Weather affects the terrain parameters of soil strength over a yearly cycle)

This listing by no means indicates that a terrain factor listed against a particular vehicle system does not influence the design of the other vehicle systems. To a modern vehicle system, all these terrain factors are inputs for design.

The land attributes vary from one geographical area to another, and the variations are extremely wide, if one has to design a military vehicle for global application. As an illustration, if a cross section of the soil strength of the world areas trafficable by land vehicles is taken, the ground parameter value say Rating Cone Index* can vary from less than 70 kPa to more than 2,000 kPa[1] and G* value[2] can vary from 1 MN/m^3 to more than 30 MN/m^3. It is obvious that a vehicle designed to operate in either of

Rating Cone Index (RCI), Cone Index (CI) and G 'Penetration Resistance Gradient' are empirical soil strength parameters used in vehicle mobility models.

the extreme condition of soil will suffer in performance on the other soil condition. The same is true with other terrain factors. Hence a designer must identify a set of ground parameters for which a vehicle is to be designed and for this he must know or has to measure these parameters world wide to arrive at a most appropriate value of parameters for the desired trafficability.

3. Terrain Classification Techniques

To avoid large scale measurements of terrain parameter over a region/area for which a vehicle is being designed or is required to operate, techniques such as soil identification, terrain evaluation and classification are proposed to be applied such that measurements taken at a few selected accessible terrain units can be taken as representative for predicting terrain parameters for similar terrain units occurring elsewhere in the region/remote areas. In this investigation the use of terrain evaluation and classification techniques for the said use shall be examined.

Terrain evaluation techniques commonly used for various purposes of terrain use are

Parametric

Mapping areas based on some pre-selected parameters affecting vehicle mobility such as surface geometry, surface composition etc. Prediction of ground parameters for an un-surveyed area, needs knowledge of soil type, topography and moisture state throughout the year for soil strength. Similarly a number of such factors for the other terrain parameters. A parametric map for soil type of an area in SE Asia[3] is shown at Fig. 1. Parametric maps for the other terrain factors for this area are also made in the similar way.

3.2 *Landscape or Physiographic*

Mapping areas into physiographic units based on visible factors on ground such as physical features. A basic terrain unit described as land facet[4] recur in a land system** and can be recognised and delimited on aerial photographs with the aid of available geological maps. Description of a land facet is shown in Fig. 2. A land facet by field measurements can be given values of soil strength (CI or G) and other terrain factors. To be more accurate in prediction, land facets can be further sub-divided into land elements.

A field test programme was undertaken to establish the usefulness of the physiographic maps in predicting the soil strength.

** Land System : A recurrent pattern of genetically linked land facets. Approx mapping scale 1 : 250,000 to 1 : 1 million.

Land Facet : Part of Landscape which is reasonably homogeneous and fairly distinct from surrounding terrain. Approx mapping scale 1 : 10,000 to 1 : 80,000.

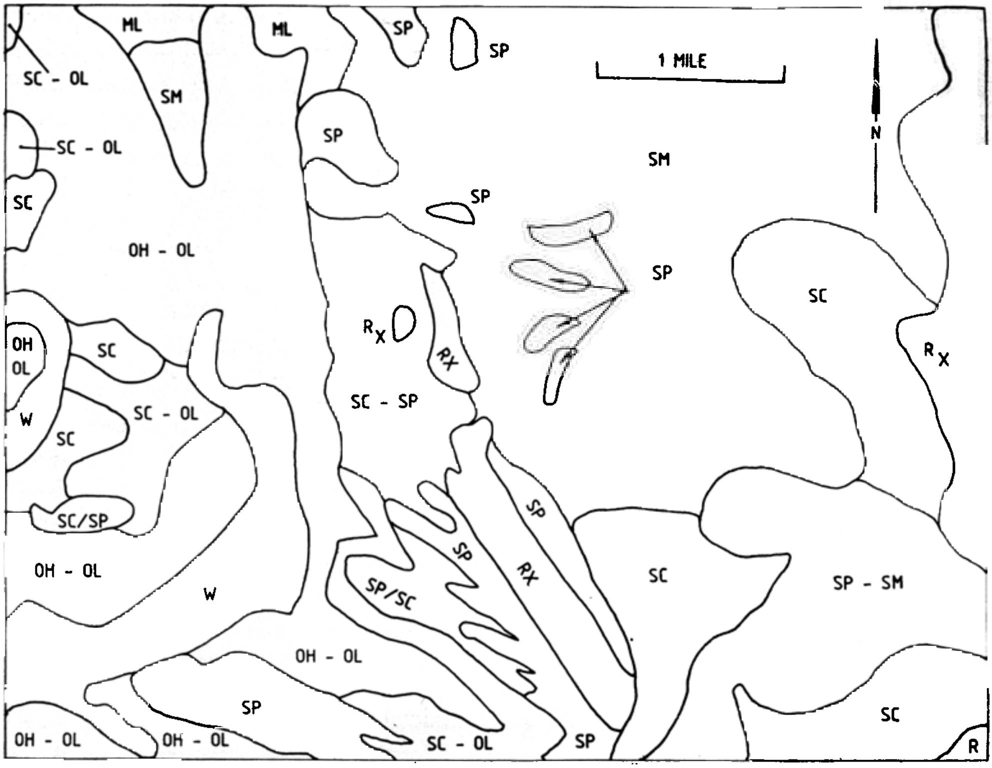

Figure 1 Parametric map of an area in South East Asia showing soil types.

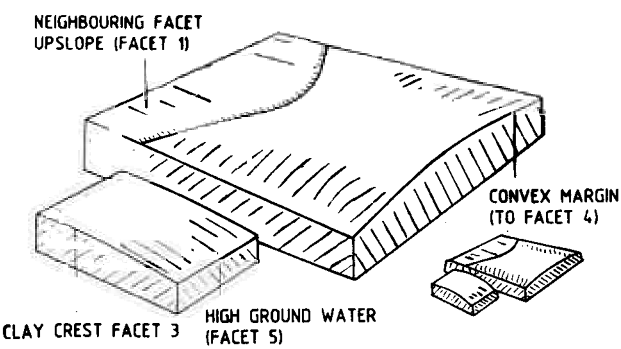

Figure 2. Land facet description from physiographic map of Oxford region (facet-3 clay crest, country rockclay).

4. Field Test Programme

Field test programme for measurement of soil strength in the Oxford region† of U.K. was undertaken in May 1978. Physiographic map of the area was obtained and the following test sites were selected :

Map details : GSGS (Misc) 2036, A Physiographic Map of the Oxford Region published by D. Survey, Ministry of Defence, U.K., 1965.

Land facet local form	Location	General grid reference	
13d	Stanford in the vale	433000	194000
13d	Longcot-Watchfield	426000	191000
3k	Bower Green	425700	190500

The soil strength was measured in terms of cone index (CI) values with the soil penetrometer, hand operated. Brief specifications of the equipment are given at Fig. 3, The tests were conducted on the same day (22 May 1978) to avoid seasonal variation. The following field tests were conducted :

(a) Similarity between land facets 13d separated about 8 km apart.

(b) Mutual exclusiveness of land facets 13d and 3k.

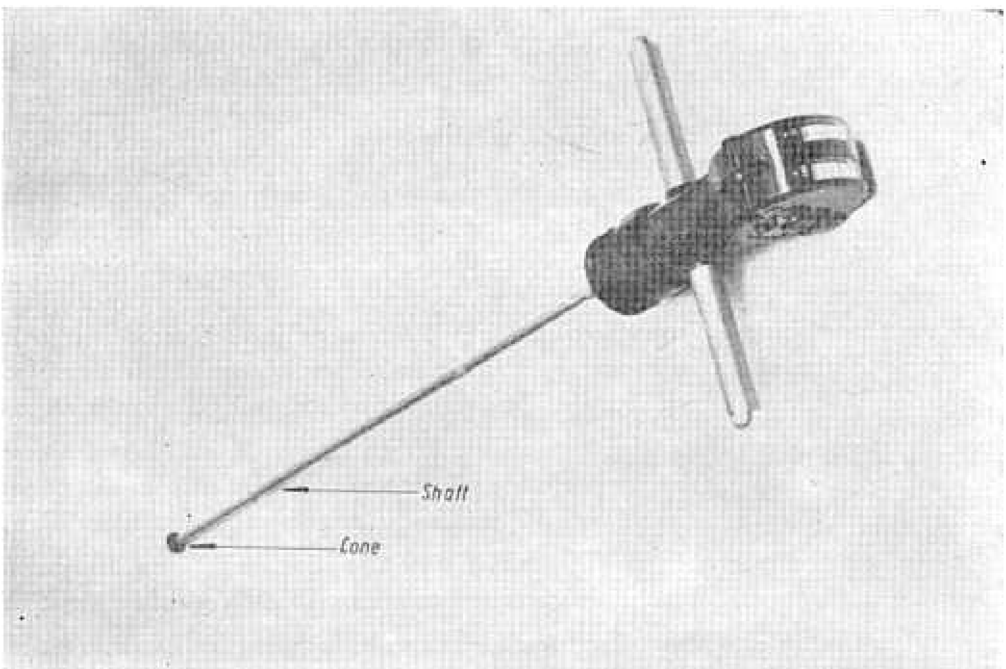

Figure 3. Hand operated soil penetrometer

Specifications :

Cone base area	= 0.5 in²	(3.23 cm²)
Shaft dia	= 0.625 in	(1.588 cm)
Shaft extended length	= 24 inches (4 shaft sections of 6 inches each)	
Dial for cone index values	= 0-300	(0-2070 kPa)
Recommended rate of penetration	= 6 ft/min	(0.03m/s)

The cone index value of the soil was measured at 150 and 300 mm of depth and averaged on all three facets. Cone index readings at 45 sites each were taken in the land facets 13d and at 3k at 20 sites, land facet 3k being smaller in size than 13d. Soil strength measurements for these facets are given in Tables 1-3.

5. Field Test Results

Statistical mean of the cone index and co-efficient of variation for the land facets were calculated and are given below :

Land facet	Location	Mean cone index $\bar{x}$ kPa	Co-efficient of variation CV %
13d	Stanford in the vale	1710	2.3
13d	Longcot-watch field	1717	1.81
3k	Bower Green	896	18.2

6. Discussion of Test Results and Recommendations

It can be seen that the two identical land facets 13d, though separated by about 8 km have identical values of empirical soil strength parameter, cone index 1710 kPa and 1717 kPa, respectively. The land facets 13d, 4260000, 191000) and 3k (425700, 190500) though very close geographically (adjoining land facets) show wide difference in the empirical soil strength parameter, 1717 kPa against 896 kPa. The difference in soil strength can be inferred by examination of the drainage and topographical situation of the two land facets. These are described on the physiographic maps as follows :

6, *Land Facet Local Form 13d- -Dip Slope Plateau*

Level to gently sloping (slope 0-7° down dip, 0-5° against dip), even topography, usually extensive and usually with convex margins. Freely drained. Vegetation characteristic of dry land.

6.2 *Land Facet Local Form 3k—Clay Crest*

Level to very gently sloping (slope 0-2°) topography with convex margins. Surface drainage sluggish, very slow internal drainage. Ditches common.

Within the land facet itself, the coefficient of variation of 2 to 18 per cent is considered sufficiently small for making useful generalisation of this terrain factor.

From the foregoing field tests, it can be seen that with the help of physiographic maps it is possible to predict within a reasonable accuracy the soil strength parameters of remote areas. It shall, however, need further test programmes to confirm the

Table 1. Soil strength measurement at test sites ofland facets (13d)

Map Ref : Physiographic Map Oxford RegionGSCS (MISC) 2036 Date : 22 May 1978
Facet Local Form : 13d Area : Stanford in the Vale,
General Grid Ref : 433000194000 Shellingford

Test site	Cone index (psi) at depth in inches			Remarks
number	6	12	Average 6-12	
1	250	250	250	
2	250	250	250	
3	200	250	225	
4	250	250	250	
5	250	250	250	
6	250	250	250	
7	250	250	250	
8	250	250	250	
9	250	250	250	
10	220	250	235	
11	240	250	245	
12	250	250	250	
13	250	250	250	
14	250	250	250	
15	250	250	250	
16	250	250	250	
17	250	250	250	Statistical
18	250	250	250	mean CI $\bar{x}$ = 248 psi
19	250	250	250	= 1710 kPa
20	250	250	250	
21	250	250	250	
22	250	250	250	Standard
23	250	250	250	deviation = 6 psi
24	250	250	250	= 41 kpa
25	250	250	250	
26	250	250	250	
27	250	250	250	Coeff of
28	250	250	250	variation
29	250	250	250	CV% = 2.31
30	250	250	250	
31	250	250	250	
32	250	250	250	
33	200	250	225	
34	240	250	245	
	250	250	250	
	250	250	250	
	250	250	250	
	245	235	240	
39	250	250	250	
40	250	250	250	
41	250	250	250	
42	250	250	250	
43	250	250	250	
44	250	250	250	
45	250	250	250	

Table 2. Soil strength measurement at test sites of land facets (13d)

Map Ref : Physiographic Map Oxford region GSGS (MISC) 2036 — Date : 22 May 1978
Facet Local Form : 13d — Area : Longcot, Watchfield
General Grid Ref : 426000191000

Test site number	Cone Index (psi) at depth in inches			Remarks
	6	12	Average 6-12	
	250	250	250	
2	250	250	250	
3	250	250	250	
4	250	250	250	
5	250	250	250	
6	250	250	250	
7	250	250	250	
8	240	250	245	
9	245	250	247	
10	250	250	250	
11	250	250	250	
12	250	250	250	
13	250	250	250	
14	250	250	250	
15	250	250	250	
16	250	250	250	
17	250	250	250	Statistical
18	250	250	250	mean CI $\bar{x}$ = 249 psi
19	250	250	250	= 1717 psi
20	220	250	235	
21	240	250	245	
22	200	250	225	Standard
23	250	250	250	deviation = 4.5 psi
24	250	250	250	= 31 kPa
25	250	250	250	
26	240	250	245	
27	250	250	250	Coeff of
28	250	250	250	variation
29	250	250	250	CV% =1.81
30	250	250	250	
31	250	250	250	
32	250	250	250	
33	250	250	250	
34	250	250	250	
35	250	250	250	
36	250	250	250	
37	250	250	250	
38	250	250	250	
39	235	250	243	
40	250	250	250	
41	240	250	245	
42	245	250	247	
43	250	250	250	
44	250	250	250	
45	250	250	250	

Table 3. Soil strength measurement at test sites of land facet 3 k

Facet Local Form : 3k Date : 22 May 1978

Oxford Region Area : Bower Green

Test site number	Cone Index (psi) at depth in inches			Remarks
	6	12	Average 6-12	
	140	150	145	
2	110	150	130	
3	150	120	135	
4	130	170	150	Mean Cl, $\bar{x}$ = 130 psi
5	120	120	120	= 896 kPa
6	90	90	90	
7	90	90	90	Standard
8	140	150	145	deviation
9	190	180	185	= 163 kPa
10	120	130	125	
11	130	190	160	Coeff of
12	140	140	140	variation
13	150	140	145	CV% = 18.2
14	100	170	135	
15	120	110	115	
16	80	150	115	
17	140	160	150	
18	80	160	120	
19	120	110	115	
20	90	90	90	

usefulness of this technique in forecasting the other terrain factors and the forecasting accuracy in the far flung areas. It is also desirable that similarity between land facets with respect to these terrain factors for vehicular mobility be established under different weather conditions like dry season, wet season or high moisture state condition.

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