RESEARCH TO PROPOSE THE MAXIMUM LONGITUDINAL GRADE FOR MILITARY ROADS

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Abstract

In order to serve coaching and combat readiness in the new situations, in recent years, our Army has been invested and equipped with many innovative and modern weapons and armaments. Many types of them are placed on military vehicles which have peculiar sizes, loads and dynamic characteristics. Therefore, military ways whould have been designed separate geometric elements, especially in the difficult conditions: craggy terrain conditions, or on military routes that are quickly built without pavement. In this article, the authors studied the theoretical basis and applied it to build dynamic factor diagrams of some special military vehicles by analytically method as a basis of offering the maximum longitudinal grade for specific military roads of the Vietnam People's Army.

Keywords: *Military roads; military vehicles; longitudinal grade; dynamical factor; traction.*

1. Introduction

The system of military roads includes: roads that combine economic - defense designed according to [1, 2] and specific military routes designed according to [3]. However, in the above documents, there is a lack of the recommendations about designing geometric elements which are suitable for the size, weight and dynamic characteristics of special military vehicles, especially recently fitted ones.

The maximum longitudinal grade is the most important geometrical element of the military routes. It is usually determined only on the basis of the dynamic characteristics of the military vehicle, the type of pavement and the designing velocity. Here, the design speed is the desired marching speed which is decided follow the commander's combat intentions, but the type of pavement is usually selected according to the local material conditions.

The dynamical factor, denoted *D*, is an important dynamic characteristic of the vehicle, that serves as the basis for determining the maximum longitudinal grade that

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DOI: 10.56651/lqdtu.jst.v5.n02.548.sce

the vehicle can overcome in a given road condition. Starting from the force balance equation of a motor vehicle [4-6]:

$$P_k - (P_f + P_w \pm P_i + P_j) = 0 \quad (1)$$

with P_k, P_f, P_w, P_i, P_j are respectively the tractive force of driving vehicle, the rolling resistance force, the aerodynamic drag force, the uphill resistance force and the inertial resistance force acting on the vehicle when the vehicle is in motion.

We have the dynamical factor of a motor vehicle (traction per a weight unit of the vehicle) determined by the formula [4, 6]:

$$D = \frac{\frac{M.i_0.i_i}{r_k}\eta - K_B.F.v^2}{G} = f \pm i + \frac{\delta}{g}\frac{dv}{dt} \quad (2)$$

where M is the tractive moment of the vehicle engine (kG.m); i_i is the gear transmission ratio, at the gear number i; i_0 is the overall gear transmission ratio, which remains constant for each specific vehicle; r_k is the radius of master wheel, included its deformation; η is the transmission efficiency factor; K_B is aerodynamical drag coefficient (kG.s^2/m^4); F is frontal area of vehicle (m^2); G is total weight of the motor vehicle (kG); f is the rolling resistance coefficient and dimensionless, i is the longitudinal grade of the road; δ is the rotational inertia coefficient; g is the gravitational constant and v is the vehicle velocity (m/s^2).

We can see that D depends on the rotational rate of the crankshaft and the vehicle velocity corresponding to each gear.

In order of convenient using, the D-V dependency graphs (D - chart) are often built by experiments on the vehicles working with maximum engine capacity [6-8]. In the geometric design of road and highway, D - chart has the following effects:

- Determine the maximum longitudinal grade of the road to ensure the required speed;

- Determine the vehicle speed in a specified road condition;

- Determine the vehicle's ability to start at the foot of a slope;

- Determine the acceleration or deceleration lengths as the basis for designing acceleration or deceleration lanes and auxiliary climbing lanes when necessary.

However, at present, the technical profiles of many military vehicles still lack their D - chart. That’s making difficult for proposing the designing standards of military roads. When there are no conditions to conduct experiments, it is possible to build the graphs of dynamic factors for military vehicles by analytical method on the basis of current data in their technical profiles.

2. Building D - chart for some specific military vehicles by 3-point method

The vehicle's diagram of dynamical factor is depicted in Fig. 1 [5].

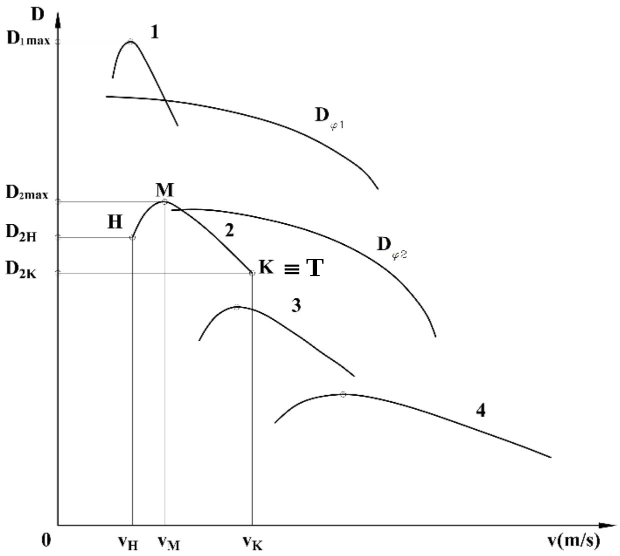

Fig. 1. D - chart of a vehicle [5]

In Fig. 1, there are the following special points:

H - starting point;

M - score corresponding to D_{max} (corresponding to M_{emax} score);

T - point corresponding to N_{emax} (often called calculation point);

K - end of the curve.

Usually the point K ≡ T [5]. Within the scope of this paper, the authors propose to use the 3-point method to establish a drive factor chart according to the following steps [5]:

2.1. Determine the power of the engine (N_{ev}) corresponding to the maximum speed of the car (v_{max})

When the car is moving uniformly at speed v_{max}, the acceleration $j = \frac{dv}{dt} = 0.$ So we have the following power balance equation [5, 6]:

$$N_{ev} = N_f + N_w + N_{th} \tag{3}$$

where N_{ev}, N_f, N_w, N_{th} in turn are the power of the engine when the vehicle is moving at $v_{\max}$, rolling resistance power, aerodynamical resistance power, power loss in the transmission system.

Written in expanded form (3) has the form [5, 7]:

$$N_{ev} = \frac{G.\psi_v.v_{\max} + K_B.F.v^3{}_{\max}}{1000.\eta_{tl}.K_p} \tag{4}$$

where ψ_v is calculated overall drag coefficient of the road: $\psi_v = f(v)$. An approximation can be obtained:

- For passenger cars and vans: $\psi_v = 0.01 + 5 \cdot 10^{-6} \cdot v_{\max}^2$

- For trucks: $\psi_v = (0.015 + 0.02) + 6 \cdot 10^{-6} \cdot v_{\max}^2$

K_B, F, G are as in equation (2); K_p is the coefficient taking into account the power loss in the transmission system; η_{tl} is transmission efficiency factor; $v_{\max}$ is the maximum speed of the car (m/s).

2.2. Determine the maximum power of the engine and construct the motor's external speed curves

Normally, the rotation rate of the engine crankshaft at $v_{\max}$ (n_{ev}) is different from the rotation rate corresponding to the maximum power ($N_{e\max}$).

When determining N_{ev} according to the rotation rate of the crankshaft n_{ev}, that is, on the characteristic $N_e = f(n_e)$, we have a point.

The Engine's external characteristic curves are those showing the relationship of M_e, N_e, g_e with n_e corresponding to the maximum fuel supply mode.

We can determine $N_{e\max}$ on the basis of the empirical formula S.R. Laydecman [6]:

$$N_{e\max} = \frac{N_{ev}}{\left[a.(\frac{n_{ev}}{n_{eN}}) + b.(\frac{n_{ev}}{n_{eN}})^2 - c.(\frac{n_{ev}}{n_{eN}})^3 \right]} \tag{5}$$

where a, b, c are the empirical coefficients depending on the engine type. We can choose the coefficients a, b, c as follows:

- For gasoline engines: $a = b = c = 1$

- For 2-stroke diesel engines: $a = 0.87$, $b = 1.13$, $c = 1$

- For 4-stroke diesel engines: $a = 0.53$, $b = 1.56$, $c = 1.09$

- Or you can choose according to existing similar engines.

We can rewrite it as follows [7]:

$$N_{e\max} = \frac{N_{ev}}{a.\lambda + b.\lambda^2 - c.\lambda^3} \quad (6)$$

with $\lambda = \frac{n_{ev}}{n_{eN}}$ is the ratio between the rotation rate of the engine corresponding to the maximum speed (n_{ev}) of the vehicle and corresponding to the maximum power of the engine (n_{eN}).

- For gasoline engines with unlimited rotational rate: $\lambda = 1.1 \div 1.3$

- For gasoline engines with rotational rate limiter set: $\lambda = 0.8 \div 0.9$

- For diesel engines (usually with limiters): $\lambda = 1$

Substituting known or selected values in (6) we will determine the value $N_{e\max}$.

To determine the rotation rate of the engine crankshaft corresponding to $N_{e\max}$, we can determine it in one of two ways:

- Reference n_{eN} in existing analog engines.

- Based on the value of the maximum angular velocity ($\omega_{\max}$) of the modern engines below and the value λ to calculate.

+ For tourist cars: $\omega_{\max}$ = 523 ÷ 575 (rad/s);

+ For trucks and buses with gasoline engines: $\omega_{\max}$ = 272 ÷ 366 (rad/s);

+ For diesel trucks and buses: $\omega_{\max}$ = 209 ÷ 334 (rad/s).

with $N_{e\max}$ and n_{eN}, the empirical formula Deerman was introduced to determine the values of engine power according to the rotation rate of the crankshaft [7].

$$N_e = N_{e\max} \cdot \left[a.\left(\frac{n_e}{n_{eN}}\right) + b.\left(\frac{n_e}{n_{eN}}\right)^2 - c.\left(\frac{n_e}{n_{eN}}\right)^3 \right] \quad (7)$$

From this, the power curve $N_e = f(n_e)$ is obtained and that is the torque curve:

$$M_e = 716.2 \cdot \frac{N_e}{n_e} \text{ (KG.m)} \quad (8)$$

where N_e is engine power (horsepower).

On that basis, we have calculated and built a dynamical factor chart for some of military vehicles based on their tactical parameters [9] as follows:

** Dynamical characteristics of motor vehicle УРАЛ-4320-31*

- Determine T-point: Based on the maximum power

Gear	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Gear transmission ratio	5.22	2.90	1.52	1.00	0.66
Ne max, W	176,000.00				
Rotation rate, rps	35.00				
Angular velocity, rad/s	27.32				
Radius of the master wheel, m	0.58				
Velocity, m/s	3.03	5.46	10.41	15.82	23.97
Velocity, km/h	10.91	19.64	37.47	56.95	86.29
Tractive force, kG	5,034.79	2,797.11	1,466.07	964.52	636.58

- Determine point M: Based on maximum tractive moment

Gear	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Overall trasmission ratio	8.05				
Gear transmission ratio	5.22	2.90	1.52	1.00	0.66
Maximum tractive moment Me, kG.m	90.00				
Rotation rate, rps	22.50				
Angular velocity, rad/s	17.56				
Radius of the master wheel, m	0.58				
Velocity, m/s	1.95	3.51	6.69	10.17	15.41
Velocity, km/h	7.01	12.63	24.09	36.61	55.47
Tractive force, kG	5,550.85	3,083.80	1,616.34	1,063.38	701.83

- Determine point H: Based on ω_{max}

Gear	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Overall trasmission ratio	8.05				
Gear transmission ratio	5.22	2.90	1.52	1.00	0.66
Ne max, W	176,000.00				
Maximum rotation rate, rps	37.92				
Maximum angular velocity, rad/s	29.59				
Radius of the master wheel, m	0.58				
Velocity, m/s	4.21	7.57	14.45	21.96	24.95
Velocity, km/h	15.14	27.26	52.01	79.05	89.83
Lamda	1.08				
Ne, W	179,372.31				
Me, kG.m	79.06				
Tractive force, kG	4,875.88	2,708.82	1,419.80	934.08	616.49

1st Gear			
Velocity, km/h	15.14	7.01	6.00
Tractive force, kG	4,875.88	5,550.85	5,034.79
Aerodynamical resistance force, kG	6.31	1.35	0.99
Dynamical factor D	0.304	0.347	0.314
2nd Gear			
Velocity, km/h	27.26	12.63	10.00
Tractive force, kG	2,708.82	3,083.80	2,797.11
Aerodynamical resistance force, kG	20.44	4.39	2.75
Dynamical factor D	0.168	0.192	0.174
3rd Gear			
Velocity, km/h	52.01	24.09	18.00
Tractive force, kG	1,419.80	1,616.34	1,466.07
Aerodynamical resistance force, kG	74.41	15.96	8.91
Dynamical factor D	0.084	0.100	0.091
4th Gear			
Velocity, km/h	79.05	36.61	25.00
Tractive force, kG	934.08	1,063.38	964.52
Aerodynamical resistance force, kG	171.91	36.88	17.19
Dynamical factor D	0.048	0.064	0.059
5th Gear			
Velocity, km/h	89.83	55.47	86.29
Tractive force, kG	616.49	701.83	636.58
Aerodynamical resistance force, kG	221.99	84.66	204.86
Dynamical factor D	0.025	0.039	0.027

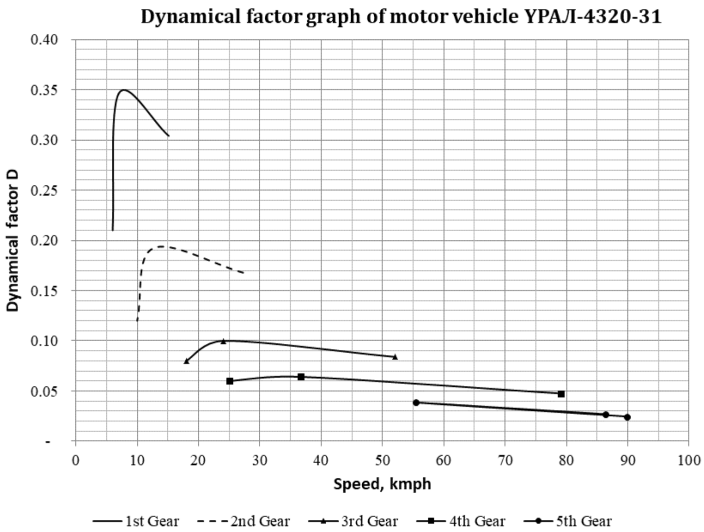

Fig. 2. D - chart for motor vehicle УРАЛ-4320-31.

** Dynamical characteristics of motor vehicle УРАЛ-55571-30*

- Determine T-point: Based on the maximum power

Gear	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Gear transmission ratio	5.26	2.90	1.52	1.00	0.66
Ne max, W	176,000.00				
Rotation rate, rps	35.00				
Angular velocity, rad/s	30.04				
Radius of the master wheel, m	0.53				
Velocity, m/s	3.03	5.50	10.49	15.95	24.16
Velocity, km/h	10.92	19.80	37.77	57.41	86.99
Tractive force, kG	5,032.70	2,774.68	1,454.32	956.79	631.48

- Determine point M: Based on maximum torque

Gear	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Overall trasmission ratio	7.32				
Gear transmission ratio	5.26	2.90	1.52	1.00	0.66
Maximum torque Me, kG.m	90.00				
Rotation rate, rps	22.50				
Angular velocity, rad/s	19.31				
Radius of the master wheel, m	0.53				
Velocity, m/s	1.95	3.54	6.75	10.25	15.53
Velocity, km/h	7.02	12.73	24.28	36.91	55.92
Tractive force, kG	5,548.53	3,059.08	1,603.38	1,054.85	696.20

- Determine point H: Based on ω_{max}

Gear	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Overall trasmission ratio	7,32				
Gear transmission ratio	5,26	2,90	1,52	1,00	0,66
Ne max, W	176,000.00				
Maximum rotation rate, rps	37.92				
Maximum angular velocity, rad/s	32.55				
Radius of the master wheel, m	0.53				
Velocity, m/s	3.83	6.94	13.24	20.13	22.87
Velocity, km/h	13.78	24.99	47.67	72.46	82.34
Lamda	1.08				
Ne, W	179,372.31				
Me, kG.m	79.06				
Tractive force, kG	4,873.85	2,687.10	1,408.41	926.59	611.55

1st Gear			
Velocity, km/h	13.78	7.02	5.00
Tractive force, kG Aerodynamical resistance force, kG	4,873.85 5.10	5,548.53 1.32	5,032.70 0.67
Dynamical factor D	0.235	0.268	0.243
2nd Gear			
Velocity, km/h	24.99	12.73	9.00
Tractive force, kG	2,687.10	3,059.08	2,774.68
Aerodynamical resistance force, kG	16.78	4.35	2.18
Dynamical factor D	0.129	0.147	0.134
3rd Gear			
Velocity, km/h	47.67	24.28	16.00
Tractive force, kG	1,408.41	1,603.38	1,454.32
Aerodynamical resistance force, kG	61.07	15.85	6.88
Drive factor D	0.065	0.077	0.070
4th Gear			
Velocity, km/h	72.46	36.91	24.00
Tractive force, kG	926.59	1,054.85	956.79
Aerodynamical resistance force, kG	141.11	36.61	15.48
Drive factor D	0.038	0.049	0.045
5th Gear			
Velocity, km/h	82.34	55.92	86.99
Tractive force, kG	611.55	696.20	631.48
Aerodynamical resistance force, kG	182.21	84.04	203.36
Dynamical factor D	0.021	0.030	0.021

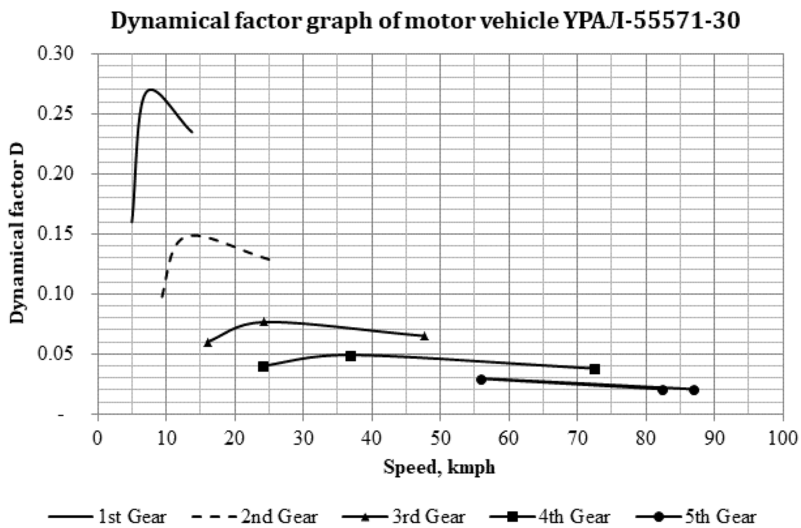

Fig. 3. D - chart of YPAJI-55571-30.

** Dynamical characteristics of motor vehicle KPA3-257*

- Determine T-point: Based on the maximum power

Gear	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Gear transmission ratio	5.26	2.90	1.52	1.00	0.66
Ne max, W	176,519.52				
Rotation rate, rps	35.00				
Angular velocity, rad/s	28.45				
Radius of the master wheel, m	0.53				
Velocity, m/s	2.87	5.21	9.94	15.10	22.88
Velocity, km/h	10.34	18.75	35.77	54.37	82.38
Tractive force, kG	5,330.27	2,938.74	1,540.31	1,013.36	668.82

- Determine point M: Based on maximum torque

Gear	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Overall trasmission ratio	7.73				
Gear transmission ratio	5.26	2.90	1.52	1.00	0.66
Maximum torque Me, kG.m	90.00				
Rotation rate, rps	25.00				
Angular velocity, rad/s	20.32				
Radius of the master wheel, m	0.53				
Velocity, m/s	2.05	3.72	7.10	10.79	16.34
Velocity, km/h	7.38	13.39	25.55	38.83	58.84
Tractive force, kG	5,859.31	3,230.42	1,693.19	1,113.94	735.20

- Determine point H: Based on ω_{max}

Gear	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Overall trasmission ratio	7.73				
Gear transmission ratio	5.26	2.90	1.52	1.00	0.66
Ne max, W	176,519.52				
Maximum rotation rate, rps	37.92				
Maximum angular velocity, rad/s	30.82				
Radius of the master wheel, m	0.53				
Velocity, m/s	3.83	6.94	13.24	20.13	22.87
Velocity, km/h	13.78	24.99	47.67	72.46	82.34
Lamda	1.08				
Ne, W	179,901.79				
Me, kG.m	79.29				
Tractive force, kG	5,162.03	2,845.99	1,491.69	981.37	647.71

1st Gear			
Velocity, km/h	13.78	7.38	5.00
Tractive force, kG	5,162.03	5,859.31	5,330.27
Aerodynamical resistance force, kG	5.27	1.51	0.69
Dynamical factor D	0.228	0.259	0.236
2nd Gear			
Velocity, km/h	24.99	13.39	10.00
Tractive force, kG	2,845.99	3,230.42	2,938.74
Aerodynamical resistance force, kG	17.33	4.98	2.78
Dynamical factor D	0.125	0.143	0.130
3rd Gear			
Velocity, km/h	47.67	25.55	18.00
Tractive force, kG	1,491.69	1,693.19	1,540.31
Aerodynamical resistance force, kG	63.08	18.12	8.99
Dynamical factor D	0.063	0.074	0.068
4th Gear			
Velocity, km/h	72.46	38.83	26.00
Tractive force, kG	981.37	1,113.94	1,013.36
Aerodynamical resistance force, kG	145.75	41.86	18.76
Dynamical factor D	0.037	0.047	0.044
5th Gear			
Velocity, km/h	82.34	58.84	82.38
Tractive force, kG	647.71	735.20	668.82
Aerodynamical resistance force, kG	188.21	96.10	188.36
Dynamical factor D	0.020	0.028	0.021

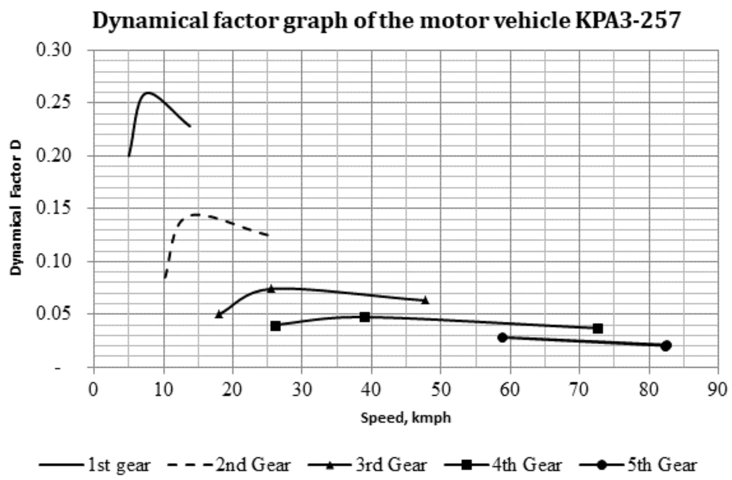

Fig. 4. D - chart of motor viehicle KPA3-257.

3. Proposal of longitudinal grade for specific military road for maneuvering of some special military vehicles

Starting from the condition of the vehicle's movement in terms of traction (2), the most unfavorable case, when the vehicle goes uphill i_{max}, the vehicle can still run at a certain marching speed, so we have [4, 6]:

$$D_{max} = f + i_{max} \quad \text{or} \quad i_{max} = D_{max} - f \tag{9}$$

Using the dynamical characteristics of some military vehicles built in section 2, the authors have calculated the maximum longitudinal grade that the vehicle can overcome corresponding to different marching speeds. Calculation results when excluding pavement deformation are shown in Tab. 1 ÷ 3.

Tab. 1. Maximum longitudinal grade of the manoeuvre according to УРАЛ-4320-31

Moving speed, km/h	Maximum longitudinal grade each pavement type, %				
	Cement Concrete or asphalt Concrete (f = 0.015)	Black macadam (f = 0.022)	Macadam or aggregate (f = 0.04)	Dry flat subgrade (f = 0.045)	Wet rough subgrade (f = 0.12)
15	17.50	16.80	15.00	14.50	7.00
24	8.5	7.80	6.00	5.50	-
36	5.00	4.30	2.50	2.00	-
55	2.50	1.80	0.00	-	-
75	1.50	0.80	-	-	-
90	1.00	0.30	-	-	-

Table 2. Maximum longitudinal grade of the manoeuvre according to УРАЛ-55571-30

Moving speed, km/h	Maximum longitudinal grade each pavement type, %				
	Cement Concrete or asphalt Concrete (f = 0.015)	Black macadam (f = 0.022)	Macadam or aggregate (f = 0.04)	Dry flat subgrade (f = 0.045)	Wet rough subgrade (f = 0.12)
7.5	25.50	24.80	23.00	22.50	15.00
14	13.50	12.80	11.00	10.50	3.00
24	6.50	5.80	4.00	3.50	-
36	3.50	2.80	1.00	0.50	-
56	2.50	1.80	0.00	-	-
85	0.50	-	-	-	-

Tab. 3. Maximum longitudinal grade of the manoeuvre according to KPA3-257

Moving speed, km/h	**Maximum longitudinal grade each pavement type, %**				
	Cement Concrete or asphalt Concrete (f = 0.015)	**Black macadam (f = 0.022)**	**Macadam or aggregate (f = 0.04)**	**Dry flat subgrade (f = 0.045)**	**Wet rough subgrade (f = 0.12)**
7.5	24.5	23.80	22.00	21.50	14.00
15	12.5	11.80	10.00	9.50	2.00
25	5.80	5.10	3.30	2.80	-
38	3.50	2.80	1.00	0.50	-
58	1.50	0.80	-	-	-
80	0.5	-	-	-	-

In addition, using the D - charts of military vehicles, we can calculate and build the graphs of the acceleration and deceleration segments for military vehicles according to the road's longitudinal grade as a basis for designing speed change lanes, and also can establish the velocity graphs of the military convoy when there is a task requirement. In these contents, the authors would like to mention in future researches.

4. Conclusions

- When there is no document about the dynamical factor graphs of military motor vehicles and there are no conditions to conduct experiments to establish the chart, using the theoretical method proposed by the authors, it is possible to build a D - chart of military vehicles based on their tactical specifications;

- From the D - charts of military vehicles, the authors have calculated the maximum longitudinal grades that the vehicles can overcome according to the vehicle's maneuvering speed, as a basis for designing the maneuvering road and calculating the travel time troops on the military road network for different combat options.

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NGHIÊN CỨU ĐỀ XUẤT ĐỘ DỐC TRÊN TRẮC DỌC CHO MỘT SỐ TUYẾN ĐƯỜNG QUÂN SỰ ĐẶC THÙ

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Tóm tắt: *Để phục vụ công tác huấn luyện và sẵn sàng chiến đấu trong tình hình mới, vài năm gần đây, Quân đội ta đã được đầu tư trang bị nhiều vũ khí, khí tài mới, hiện đại. Trong đó, nhiều loại đặt trên các xe quân sự có kích thước, tải trọng và đặc tính động lực đặc thù nên cần có các thiết kế yếu tố hình học riêng cho đường cơ động của chúng, nhất là trong các điều kiện khó khăn về địa hình, hay trên các tuyến quân sự đặc thù xây dựng nhanh không có kết cấu mặt đường. Trong bài báo này, các tác giả đã nghiên cứu cơ sở lý thuyết và vận dụng để xây dựng biểu đồ nhân tố động lực của một số loại xe quân sự đặc chủng bằng phương pháp giải tích, làm cơ sở đề xuất độ dốc dọc tối đa cho các tuyến đường quân sự đặc thù của Quân đội Nhân dân Việt Nam.*

Từ khóa: Đường quân sự; xe quân sự; độ dốc dọc lớn nhất; nhân tố động lực học; lực kéo.

Received: 19/09/2022; *Revised:* 16/12/2022; *Accepted for publication:* 30/12/2022

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