The study of the profile passability all-terrain vehicles with a wheel formula 6x6 full mass 0.3, 0.75, 2 tons

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Abstract. The article deals with the issue of overcoming destructible profile obstacles in all-terrain vehicles with a wheel formula of 6x6 with full masses of 0.3, 0.75, 2 tons. It is shown that the most difficult case is overcoming destructible moats. Dependencies are given for calculating the critical value of a pit to be overcome. The calculation method is given. The objects of study are shown - ATVs developed at NSTU named after R.E.Alekseev. The calculations for the four types of soils.

1. Introduction

The mobility of all-terrain vehicles (ATV) when driving over rough terrain will depend on the parameters of the reference and profile cross-country ATV, as well as on the characteristics of the environment. In this paper, attention is paid to the cross-country profile.

Many scientists and researchers were engaged in cross-country issues: Ageikin Ya.S. [1], Antonov A.S. [2], Barakhtanov L.V. [3], Belyakov V.V. [3], Volskaya N.S. [4], Grishkevich A.I. [5], Guskov V.V. [6], Zimelev G.V. [7], Ilarionov V.A. [8], Kravets V.N. [9], Larin V.V. [10], Litvinov A.S. [11], Mamichi G.I. [12], Naumov V.N. [13], Peskov V.I. [14], Selifonov V.V. [9], Skotnikov V.A. [15], Smirnov G.A. [16], Tarasik V.P. [17], Farobin Y.E. [11], Chudakov, EA [18], Bekker M. G. [19] Wong J. [20] et al..

After analyzing these works, it was obtained that the most difficult case of movement in terms of cross-country patency is overcoming ATV barrier obstacles. After analyzing the existing estimates of the cross-country profile, two conclusions were obtained.

1) The parameters of the cross-country profile, such as: front and rear overhangs, the largest angle of climb, the maximum angle of the slope, the flexibility of the train, the axle tilt angle, the coefficient of coincidence of traces of the front and rear wheels, the depth of the ford overcoming is determined by the ATV chassis design.

2) Profile cross-sectional parameters, such as ground clearance, front and rear overhang angles, longitudinal radius of cross-country, cross-sectional radius of the ditch, width of the ditch to be overcome in the transverse direction, height of the vertical wall to be overcome (scarp) will depend on the type and parameters of the soil along which it occurs motion. In the case of the destruction of these obstacles, this will affect the ATV’s core permeability [21].
2. Analysis of the impact of destructible profile obstacles on the ATV permeability

Let us analyze how the destructibility of the obstacles under study affects the profile maneuverability. For convenience and clarity, we summarize all the necessary data in Table 1

Table 1. Influence of destructible profile obstacles on ATV passability.

| All-terrain off-road parameter | Kind of an obstacle to destruction | Kind of an obstacle after destruction | Influence on all-terrain vehicle passability |
|--------------------------------|------------------------------------|--------------------------------------|---------------------------------------------|
| Longitudinal cross-country radius of all-terrain vehicle | ![Image](image1.png) | ![Image](image2.png) | \( R_{np} > R_{npp} \) ATV increases throughput |
| Cross radius of the cross-country vehicle | ![Image](image3.png) | ![Image](image4.png) | \( R_{mp} > R_{mp} \) ATV increases throughput |
| Width of the ditch overcome in the cross direction by the all-terrain vehicle | ![Image](image5.png) | ![Image](image6.png) | \( L_a < L_{np} \) ATV passability decreases |
| Height overcome by all-terrain vehicle vertical wall (escarpment) | ![Image](image7.png) | ![Image](image8.png) | \( H_a < H_{dp} \) ATV increases throughput |

Table 1 in the figures on the left shows movement through rigid profile obstacles. In the figures on the right, the numbers 1 show the areas that are destroyed when interacting with the frame of the ATV.

Thus, from the table above it can be seen that the destructibility of profile obstacles has a positive effect on the permeability in all cases, except overcoming the moat. Therefore, it is this very difficult case that was considered in the paper

3. Calculation of the critical width of the destroyed

Earlier, the authors of the article identified 5 characteristic stages of overcoming the moat by a machine with a 6x6 wheel formula. [21] The last stage determines the critical value of the width of the trench to be destroyed. Figure 1 shows the scheme for calculating the critical value of the width of the destroyed pit.

Figure 1. Scheme for the calculation of the critical value of the width of the destroyed pit [22].
3.1. Calculation of the critical width of the destroyed

The movement of the chassis through the moat is described by a system of equations [22]:

\[
\begin{align*}
X: & \quad F_T \cos \beta - F_T \cos \beta - N \sin \beta + F_{T2} - F_{T2} - F_W - F_{kp} = m \frac{dV}{dt} \\
Y: & \quad F_T \sin \beta - F_T \sin \beta + N \cos \beta + R_z - G_a = m \frac{dV}{dt} \\
M: & \quad -G_a l_a + R_z(l_a + l_b) + (F_{T2} - F_{T2})(h_k - (r_h - r_a \cos \beta)) + \\
& \quad + ma \left( h_g - (r_h - r_a \cos \beta) \right) - F_W \left( h_w - (r_h - r_a \cos \beta) \right) + M_T = J \frac{d\omega}{dt}
\end{align*}
\]

where \( F_T \) – real thrust force on the wheels of the \( i \)-th axis, \( F_{T2} \) – rolling resistance force on the wheels of the \( i \)-th axis, in the calculations can be taken \( F_{T2} = f N_i \), \( N \) – normal reaction to the wheel, \( f \) – wheel rolling resistance; under the conditions considered \( f = 0.02 - 0.05 \), \( M_T \) – total traction moment delivered to the wheels of the chassis.

The calculation of the forward peck of the machine is made in accordance with the equation of rotational motion. In general, it will be determined from the expression:

\[
J\varepsilon = G_a l_b - F_W h_w - F_{kp} h_{kp} - m_a a h_g,
\]

where \( J \) – moment of inertia chassis, \( \varepsilon \) – rotational acceleration, \( G_a \) – machine weight, \( l_b \) – shoulder of force, \( l_b = l_z \cos \alpha \), \( l_z \) – distance from the center of mass to the 2nd chassis axis, \( \alpha \) – peck angle of the machine, \( F_W \) – air resistance force, \( h_w \) – sail center height, \( F_{kp} \) – hook load resistance, \( h_{kp} \) – hook load height, \( m_a \) – machine weight, \( a \) – chassis acceleration, \( h_g \) – center of mass height.

In the case of steady motion at low speed and despite the fact that the values of the peck of the machine are small, one can accept that:

\[
\varepsilon = \frac{G_a l_z}{J}.
\]

The size of the peck can be determined depending on the width of the pit: it will be determined in accordance with the equation of motion.

\[
\alpha = \alpha_0 + \omega_0 t + \frac{et^2}{2},
\]

where \( \alpha_0 \) – starting angle, \( \alpha_0 = 0 \), \( \omega_0 \) – initial angular velocity, \( \omega_0 = 0 \), \( t \) – time of movement through the moat before contact with the wall, \( t = \frac{s}{V} \), \( s \) – width of the moat from the destroyed ledge, to contact with the wall.

Thus, the value of peck can be calculated according to:

\[
h_h = (l_1 + l_2) \sin \alpha,
\]

where \( l_1 \) – the distance from the center of mass to the 1st chassis axis.

The parameters of the relationship in accordance with the scheme in Figure 6.

\[
G_a = R_z 1 + R_z 2, \quad \frac{R_z 1}{R_z 2} = \frac{l_a}{l_b}, \quad l_a = l_1 \cos \alpha + l_2 \sin \beta,
\]

where \( r_a \) – dynamic radius of the wheel.

The angle \( \beta \) will be determined based on the dependence:

\[
\beta = \min\{90 - (\varphi + \gamma); \arccos(1 - h_w r_2^{-1})\},
\]

The maximum width of the overcrowded ditch will be if the thrust force on the wheels of the machine is not less than the adhesion force:

\[
F_T = F_{Tum} + F_{Tr},
\]

where \( F_{Tum} \) – traction force on the friction of the tire material on the ground; \( F_{Tr} \) – traction force on the clutch from the internal friction of the soil material.

\( F_{Tum} \) can be calculated by simplified dependencies:

\[
F_{Tum} = \varphi_p N k_h,
\]

where \( \varphi_p \) – coefficient of rubber friction over the ground; under the conditions considered \( \varphi_p = 0.5 - 0.8 \), \( k_h \) – tread saturation coefficient, for the chassis studied in this work \( k_h = 0.4 - 0.6 \).

\[
F_{Tr} = (cA + N_l \tan \varphi)(1 - k_h).
\]
where \( A \) – contact area of the wheel with the supporting surface, \( c \) and \( \varphi \) - connectivity and angle of internal friction of the soil.

3.2. Calculation method

First, they are defined by the soil type \[22\] and chassis parameters. If necessary, calculate the remaining required parameters for soil heterogeneity \[26\].

Determine \( \beta_{\text{max}} \) – limiting bevel angle of the collapsed wall of the moat, which can overcome the chassis according to the adhesion condition.

Then the condition is checked:
\[
(90 - \beta_{\text{max}}) < (\varphi + \gamma).
\]

If it is executed, then
\[
h_k = L_x \cos(\gamma + \varphi)
\]

From here you can calculate the parameters of the maximum speed and width of the pit using the dependencies given in the work. It is advisable to calculate the parameter \( \zeta \).

\[
\zeta = \left(\frac{S}{V}\right)^2, \quad \zeta = 2 \left(\frac{1}{L_y e_2}\right) \arcsin\left(\frac{L_x \cos(\gamma + \varphi)}{0_1 + L_2}\right).
\]

Knowing the parameter \( \zeta \), we can calculate the ratio \( \frac{S}{V} \).

Using the above method, the ratio of the speed and width of the trench to be overcome was calculated for machines with a 6x6 wheel formula with a total mass of 0.3, 0.75, 2 tons.

4. Objects of study

The objects of research are the development of NNSTU. R.E. Alekseev. Figure 2 shows ATVs with a total weight of 0.3 [23], 0.75 [24], 2 [25] t.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{ATV chassis with 6x6 formula: \(a\) – chassi 0.3 t. [23], \(b\) – ATV «Korsak» [24], \(c\) – AMRS [25]}\end{figure}
For these chassis, theoretical calculations were made to overcome the maximum destructible moat. In the calculations, the chassis parameters were used, and it was also considered how the size of the ditch to be overcome changed with changes in the weight and size of the wheels. The movement was considered on the grounds with the following parameters:

- «Soil-1», $\rho = 1.6$, $E = 10$ MPa, $\varphi = 13^\circ$, $c = 12$ kPa.
- «Soil-2», $\rho = 1.7$, $E = 25$ MPa, $\varphi = 17^\circ$, $c = 18$ kPa.
- «Soil-3», $\rho = 1.8$, $E = 50$ MPa, $\varphi = 23^\circ$, $c = 28$ kPa.
- «Soil-4», $\rho = 1.9$, $E = 100$ MPa, $\varphi = 34^\circ$, $c = 48$ kPa.

Also considered the effect of turf on the profile permeability.

5. Calculation results
For a chassis full weight of 300 kg and a wheel width of 0.2 m obtained that:

- On the «Soil-1», the collapse of the moat walls for the basic chassis is up to 12 cm, the presence of sod reduces collapse to 20% with a sod 3 cm thick and up to 40% with 6 cm sod. 5 cm, weight increase up to 400 - increases collapse up to 15 cm. Decrease wheel width up to 0.16 m increases collapse up to 14 cm, increase up to 0.24 m reduces up to 9 cm.
- On the «Soil-2», the collapse of the moat walls for the basic chassis is up to 7 cm, the presence of sod reduces collapse to 50% with sod 3 cm thick and to 85% with 6 cm turf. Reducing the weight of the machine to 200 reduces the width of the collapse to 5 cm, an increase in mass to 400 increases the collapse to 9 cm. A decrease in the width of the wheel to 0.16 m increases the collapse to 8 cm, an increase to 0.24 m reduces to 6 cm.
- On the «Soil-3», the collapse of the moat walls for the basic chassis is up to 4-5 cm, the presence of sod reduces collapse to 50-60% with a turf 3 cm thick and up to 80-100% with a 6 cm turf. Reduces the width of the collapse up to 3-4 cm, increasing the mass to 400 - increases the collapse to 5.5-6.5 cm. Reducing the width of the wheel to 0.16 m increases the collapse to 5-6 cm, increasing to 0.24 m reduces to 3.5-4.5 cm.
- On the «Soil-4» values of the collapse of the walls of the moat are small.

For a chassis full weight of 750 kg and a wheel width of 0.27 m obtained that:

- On the «Soil-1», the collapse of the walls of the moat for the basic chassis is up to 21 cm, the presence of sod reduces collapse to 12% with a sod 3 cm thick and to 24% with 6 cm sod. cm, increasing the mass to 1000 - increases collapse to 27 cm. Reducing the width of the wheel to 0.2 m increases collapse to 25 cm, increasing to 0.35 m reduces to 19 cm.
- On the «Soil-2», the collapse of the moat walls for the basic chassis is up to 12 cm, the presence of sod reduces the collapse to 28% with a sod 3 cm thick and up to 54% with a sod 6 cm. 9 cm, increasing the mass to 1000 - increases the collapse to 15-16 cm. Reducing the width of the wheel to 0.2 m increases the collapse to 15 cm, increasing to 0.35 m reduces to 11 cm.
- On the «Soil-3», the collapse of the moat walls for the basic chassis is up to 7.5-9 cm, the presence of sod reduces collapse to 30-35% with a sod 3 cm thick and to 57-68% with a sod 6 cm. up to 500 reduces the width of the collapse to 5.5-6.5 cm, increasing the mass to 1000 increases the collapse to 9-12 cm. Reducing the width of the wheel to 0.2 m increases the collapse to 9.5-11.5 cm, increasing to 0.35 m reduces to 7-9 cm.
- On the «Soil-4», the collapse of the walls of the moat for the basic chassis is up to 2-3 cm, the presence of sod reduces collapse to 55-78% with a sod 3 cm thick and up to 100% with a sod 6 cm. collapse width up to 1.5-2.2 cm, weight increase up to 1000 - increases collapse to 2.7-4.2 cm. Decrease wheel width to 0.2 m increases collapse to 2.7-4 cm, increase to 0, 35 m reduces to 2-2.7 cm.

For a chassis full weight of 2000 kg and a wheel width of 0.32 m, it is obtained that:

- On the «Soil-1», the collapse of the moat walls for the basic chassis is up to 40 cm, the presence of sod reduces collapse to 6% with a sod 3 cm thick and up to 13% with a sod 6 cm. Reducing the mass of the machine to 1500 reduces the width of the collapse to 33 cm, increasing the mass to 2500 - increases the collapse to 49 cm. Reducing the width of the wheel to 0.25 m increases the collapse to 46 cm, an increase to 0.4 m reduces to 37 cm.
On the «Soil-2», the collapse of the moat walls for the basic chassis is up to 25 cm, the presence of sod reduces collapse to 14% with a sod 3 cm thick and to 27% with a sod 6 cm. cm, increasing the mass to 2500 - increases the collapse to 30 cm. Reducing the width of the wheel to 0.25 m increases the collapse to 29 cm, increasing to 0.4 m reduces to 22 cm.

On the «Soil-3», the collapse of the walls of the moat for the basic version of the chassis is up to 16-18 cm, the presence of sod reduces collapse to 15-18% with a turf 3 cm thick and up to 30-35% with 6 cm turf. 1500 reduces the collapse width to 12-15 cm, increasing the weight to 2500 - increases the collapse to 18-23 cm. Reducing the width of the wheel to 0.25 m increases the collapse to 18-22 cm, increasing to 0.4 m reduces to 14-17 cm.

On the «Soil-4», the collapse of the walls of the moat for the basic chassis is up to 4.5-6.5 cm, the presence of sod reduces collapse to 27-38% with a sod 3 cm thick and up to 50-71% with a sod 6 cm. Reduction weight of the machine up to 1500 reduces the width of the collapse up to 3.5-5 cm, increasing the weight up to 2500 increases the collapse up to 5-8 cm. Reducing the width of the wheel to 0.25 m increases the collapse up to 5.5-7.7 cm, increasing up to 0.4 m reduces to 4.5-5.5 cm.

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