Overcoming of high escarp by an all-wheel drive machine 8x8

V I Peskov
Nizhny Novgorod State Technical University n.a. R.E. Alekseev, 24 Minin Street, Nizhny Novgorod, Russia

Abstract. In our research there has already been expressed the idea that from the point of view of overcoming big obstacles like escarpments, multi-axial all-wheel vehicles should have advantages over biaxial vehicles with 4x4 wheel arrangement. A thorough analysis of the movement process of a 8x8 wheeled vehicle on the escarpment which height exceeds the radius of the wheel is made. It was proved that such a vehicle can overcome the escarpment that almost twofold exceeds height of similar obstacles that a 4x4 wheeled vehicle overcomes.

Multi-axial vehicles with more than four driving wheels have the improved potential of overcoming big obstacles. For example, if an all-wheel vehicle drive with wheel formula 4x4 has a possibility to overcome the escarp by all axles, the height of which is equivalent of 0,8 wheel radius, in that case, as preliminary calculations showed, an all-wheel drive machine with a wheel formula 8x8 can overcome such an obstacle by all axles in height even more than a wheel radius [1]. It is necessary to underline only, that essential importance on these possibilities must influence the pull up of the wheels of one of the driving axles, which is inevitable in such conditions during the machine movement with a very rigid body. The matter is if the wheels of one of the axles are pulled up, then the vertical load is redistributed on other driving wheels, influencing their possibility to overcome a big obstacle seriously.

An attempt is made to study overcoming the escarp in detail, with the height being more than a wheel radius. A special armoured vehicle with an 8x8 wheel formula created by General Dynamic in Great Britain was used as a prototype. Wheel radiuses of 0,6 m, the height of escarp of 0,9 m are worked out, special attention being paid to design data of the calculations schemes (in accordance with the scale). The geometrical parameters of the machine body and distances between wheel axles are also similar to the real construction (2,5 is a wheel radius between two forward axles and two rear axles; 3,5 is wheel radius between second and third axles).

Vertical reactions on the single wheels of such vehicles usually are similar, that is \( R_1 = R_2 = R_3 = R_4 = 0,25 \ G_a \). The distinctions do not usually exceed 5-10 %. It is necessary to consider the effect on the static weight distribution of the location of the front power unit which is more demanded now, and the absence of the troops in the compartment at the moment of overcoming obstacles, the total weight of them reaches 1000 kg (10 people equipped with military equipment, 100 kg each), the final distribution of the static vertical loads on the axles (curb weight of the machine is 12 tons) is taken:

\[
R_{1c} = 0,27 \ G_a \ ; \quad R_{2c} = 0,26 \ G_a \ ; \quad R_{3c} = 0,24 \ G_a \ ; \quad R_{4c} = 0,23 \ G_a .
\]

The first stage of the machine movement with small velocity through the escarp, the height of which is 0,9 m, is starting on the contact of the top edge of the bow part of the body with the top of the escarp. The armoured bow, which usually has corresponding inclination of the lower front part for rising protective properties under action of draft forces \( F_{t1}, F_{t2}, F_{t3} \) and \( F_{t4} \) provides sliding of the front part of the body on top of the escarp while touching the vertical wall of the escarp by the front wheels (figure 1). The total force \( F_{x1} \) of pressing the first axle wheels to the wall at that moment is equivalent to

\[
F_{x1} = F_{x1} + F_{x2} + F_{x3} + F_{x4} = (R_1 + R_2 + R_3 + R_4) \ \varphi_a = \varphi_a \ G_a ,
\]
where $R_1, R_2, R_3, R_4$ – vertical reactions of the support surface on wheels of the corresponding axle of the machine with consideration of their redistribution from reactive moments on the body from driving axles (wheels); $\varphi_x$ – coefficient of adhesion of the wheels with the support surface.

Reactive momentum from forces $F_{a1}, F_{a2}, F_{a3}$ and $F_{a4}$ forms unload action for wheels of two front axles, and the sum of reactive momentum $T_p$ from that forces in the first approach is equal to

$$T_p = (F_{a1} + F_{a2} + F_{a3} + F_{a4}) \varphi_x (R_{a1} + R_{a2} + R_{a3} + R_{a4}) \Delta r_3 = \varphi_x G_a r_4 . \quad (2)$$

![Image](scheme.png)

**Figure 1.** Scheme of the forces on machine with wheel formula 8x8 at the moment of starting to overcome the escarp (the first driving axle wheels start an upward movement; pair of the forces for calculation the reactive momentum are applied on axles)

It is possible to consider with sufficient accuracy, that it gives the reduction of vertical reactions on wheels of the front axle on $\Delta R_{a1}$ on wheels of the second axle – on $0,5 \Delta R_1$. Accordingly, on wheels of the rear axle it gives the increase of vertical reactions on $\Delta R_3$ on wheels of the third axle – increase is $0,5 \Delta R_1$. That is why the size $\Delta R_1$ may be determined for this calculation scheme from such dependences:

$$T_p = 8,5 \Delta R_1 \varphi_x \Delta r_3 + 3,5 \Delta R_2 \varphi_2 \Delta r_2 = 8,5 \Delta R_1 \varphi_x \Delta r_3 + 1,75 \Delta R_2 \varphi_2 \Delta r_2 + 10 \Delta R_1 \varphi_x \Delta r_3$$

$$T_p = \varphi_4 G_4 \varphi_2 \Delta r_2; \quad \Delta R_1 = 0,1 \varphi_4 G_4 . \quad (3)$$

In case of asphalt surface $\varphi_4 = 0,8$, we get $\Delta R_1 = 0,08 G_4$. Accordingly, the dynamic distribution of vertical load on machine axles during of overcoming of escarp will be the following:

$R_1 = 0,19 G_4; \quad R_2 = 0,22 G_4; \quad R_3 = 0,28 G_4; \quad R_4 = 0,31 G_4.$

With the total force of pressing to the front wheels to the wall of escarp $F_{a1} = \varphi_4 G_4$ (2), on the front wheels it $F_{a1} = \varphi^2 G_4 = 0,64 G_4$ is guaranteed, vertical force that is enough for beginning its moving upwards ($F_{a1} = 0,64 G_4 \varphi_x > R_1 = 0,19 G_4$). After the front wheels come onto the horizontal surface, the total force $F_{a1}$ will be reduced because the forward pushing force from the wheels of the front axle disappears (figure 1). But the pushing force from the driving wheels of the second, the third and the forth axles is enough for reliable pressing the wheels of the front axle to the vertical wall of the escarp and its continuation for confident moving upwards:

$F_{a1} = (0,22 G_a + 0,28 G_a + 0,31 G_a) \varphi_x^2 = 0,64 \cdot 0,81 G_a = 0,52 G_a \varphi_x > 0,19 G_a = R_1$.

Then hanging out of the second axle wheels takes place (figure 2), which leads to the redistribution of the vertical load $0,22 G_a$ on the stay for supporting the three other axles. This redistribution according to the geometry axles arrangement on the machine length may be taken as following:

$\Delta R_1 = 0,12 G_4; \quad \Delta R_3 = 0,06 G_4; \quad \Delta R_4 = 0,04 G_4$.

Accordingly, the real vertical loads on the wheels of the machine at that moment are the following:

$R_1 = 0,31 G_4; \quad R_2 = 0; \quad R_3 = 0,34 G_4; \quad R_4 = 0,35 G_4.$

Moving of the front driving wheels upwards along the vertical wall of the escarp and then forward will continue during such hanging out because the necessary condition should be fulfilled:
$F_{a1} = (0.34 \ G_a + 0.35 \ G_a) \phi^2 = 0.64 \times 0.69 \ G_a = 0.442 \ G_a > 0.31 \ G_a = R_1$.

At the final moment of moving the front axle driving wheels up the vertical wall of the escarp (figure 2) the front wheels by the grousers engage on the rib of the escarp, thus leading to 20-30\% increase of its adhesion coefficient [2, 3]. Momentum $T_1$, which acts on these wheels, and forces inertia $F_j$ (because of some decrease of the speed moving of the machine) in combination with forces $F_{t3}$ and $F_{t4}$ leads to confident moving of the machine forward.

The next stage of overcoming a big escarp by machine 8x8 is moving along its vertical wall of the second axle driving wheels. To this moment the front axle driving wheels are already situated on the upper horizontal ground of the escarp and create draft force $F_{t1}$. The wheels of the second axle hung out at maximum, the vertical reaction on them is absent (figure 3).

FIGURE 3. Scheme of the forces on the machine with wheel formula 8x8 at the moment of leaning of the second axle wheels to the vertical wall of the escarp

In these conditions the vertical movement of the second axle wheels on the escarp wall is performed without any difficulties because even on their maximum upwards moving the load on them does not exceed 0,25-0,4 $G_a$ and force $F_{sz}$ of pressing to the wall by these wheels is

$F_{sz} = F_{t1} + F_{t3} + F_{t4} = \phi \ G_a = 0.8 \ G_a$.

Accordingly, force $F_{s2}$, which moves them up, at maximum is able to reach of the size $F_{s2} = \phi \ F_{sz} = 0.64 \ G_a > 0.4 \ G_a$, that is more than enough.

The second axle wheels moving upwards are over with the situation, which is similar to fig. 2 for the front axle, when the wheels rest on the escape edge. In that position it is possible to hang the front axle wheels because the bow part of the machine is raised upwards strongly. That means approaching the vertical load of the second axle wheels to 0,4-0,5 $G_a$ level. At the final moment of moving the
second axle wheels upwards on the wall of the escarp the grouser of the tires catch on the rib of escarp, what leads to increasing their adhesion coefficient. Momentum $T_2$, which acts on these wheels, and force of inertia $F_j$ (because of some decrease of the speed moving of the machine) in combination with pushing forces $F_{t3}$ and $F_{t4}$ assist to confident moving of the machine forward.

With the third axle wheels pressing to the vertical wall of the escarp it starts the third stage of the process, which scheme is introduced in figure 4. Very likely, the third axle wheels will be hanging also how it was during overcoming the escarp with the second axle. At the initial stage of moving the third axle wheels upwards it is no of any difficulties. Practical absence of the essential vertical load on them leads to its moving upwards on the wall easily because of pressing force $F_\Sigma 3$ from drag forces $F_{t1}$, $F_{t2}$ and $F_{t4}$ (as it was illustrated in the example of the second axle) is more than enough, so force $F_\Sigma 3 >> R_3$.

![Figure 4. Scheme of the forces which act on the machine with wheel formula 8x8 at the moment of leaning the third axle wheels against the vertical wall of the escarp](image)

Problems arise when lifting the third axle wheels to the stop in the vertical suspension travel limiter due to the beginning of hanging the rear axle wheels (figure 5). The vertical load on the wheels of the third axle is thus approaching its possible maximum: 0.5 Ga. In this position crucial influence to overcome obstacles exerts a torque on the wheels of the third axis, which is due to the high grip of these wheels with the edge of the escarpment provide a significant increase in push force to the pull force $F_{t1}$ and $F_{t2}$ from the front axles. Some additive also gives an inertial effect of $F_j$ which will be the result of small decrease in the speed of horizontal movement along the obstacle at this moment.

![Figure 5. The scheme of forces acting on the machine with a wheel formula 8x8 when lifting the wheels of the third axis until it stops in the vertical suspension travel limiter (one of the most difficult modes of movement on the escarpment)](image)
After the entry of the third axis wheels on the upper platform of the escarp, the entry of the rear (fourth) axis wheels on it is not particularly difficult. It is because in this situation machine, the amount of tractive effort $F_t1, F_t2$ and $F_t3$ on wheels three front axles located at the top of the escarpment, significant, and the drive wheels of the fourth axle, which is in the posted state when substantially horizontal position of the machine frame, to enter onto a ledge, the height of which will actually be significantly smaller than the radius of the wheel. At the same time, at the initial moment of entry to the escarp edge, the vertical loads on the rear axle wheels are minimal, since they are posted.

The obtained theoretical results are confirmed by the relevant experiments of foreign researchers. It should be noted that the presence of the foreign all-wheel drive eight-Wheeler hydropneumatic suspension allowed in the process of moving along the obstacle to reduce the longitudinal rolls of the machine, but this practically did not affect the course of the process in terms of facilitating the overcoming of the escarp, the height of which, as follows from official publications, during the tests was 0.9 m (figure 6 – figure 9), which corresponds to the taken basis for the analysis of the calculation scheme of the situation.

The theoretical analysis and the experimental data obtained from the literature allow us to draw the following conclusions:

1. It is confirmed that an all-wheel drive machine 8x8 have improved capabilities to overcome the biggest obstacles of rectangular type of the escarp compared to machines with wheel formula 4x4. To overcome escarpment of height of 1.5-1.7 radius of the wheel by such machines, which is almost twice as high for cars with a wheel formula 4x4 is real.

2. Geometrical parameters of the bow part of an all-wheel drive machine 8x8 can have a significant impact on the success of overcoming obstacles exceeding the radius of the wheel. From this position, the placement of protruding elements such as towing devices or lighting devices on the lower panel of the bow is undesirable, as they may prevent (see figure 1) sliding of the front of the machine on the top edge of the escarpment.
References

[1] Peskov V I, Serduk V I and Serdiuk A E 2009 Improving of exploitation qualities of automobile (Nizhny Novgorod: Nizhny Novgorod State Technical University n.a. R.E. Alekseev) p 135

[2] Ageikin J S, Volskaya N S and Chichekin I V 2000 Passability of automobile (Moscow: Moscow State Industrial University) p 141

[3] Ageikin J S and Volskaya N S 2008 Theory of automobile (Moscow: Moscow State Industrial University) p 318