Determination of the vehicle's carrying capacity taking into account the bearing capacity of the roads

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Abstract. Increasing the efficiency of using the technical parameters of trucks, in order to save resources, remains an urgent task in the operation of vehicles. Maximum vehicle performance is achieved when the vehicle's rated payload capacity is used to its full potential. As practice shows, due to the regulation of weight parameters, the actual carrying capacity, and, consequently, the performance of the vehicle is reduced. The increased load leads to the destruction of the road surface, therefore, for exceeding the standard values of the weight parameters of the car, carriers are subject to administrative punishment in the form of a fine. The actual task is to determine the actual load capacity of the vehicle when the limit value of the axle load according to the regulatory document is ensured. This paper proposes a method for determining the carrying capacity of road trains consisting of a truck tractor and a semi-trailer, taking into account the bearing capacity of highways. When determining the actual mass of the transported cargo, the maximum permissible values of the total mass and axle load of the vehicle were taken into account, which depend on the category of the road, as well as on the design features of the vehicle (type of suspension, wheels, center distance).

1 Introduction

Today in the Russian Federation, according to the Decree of the Government of the Russian Federation of December 21, 2020 No. 2200, there are requirements for the maximum permissible axle loads of vehicles for highways, the design, construction and reconstruction of which were carried out under the standard axle loads of vehicles up to 100 kN / 10 tf and 115 kN/11.5 ts. This regulatory document also regulates the maximum permissible weight of a road train. The influence of wheel type on the road surface is given in the literature.

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In most cases, due to limitations in the load-bearing capacity of highways, it is not possible to use the rated load capacity of a semi-trailer. Therefore, when operating on different routes, it is necessary to determine its actual carrying capacity.

Methods for determining axial loads were studied in the works of the authors [1-7].

2 Research methods

The proposed methodology for determining the carrying capacity of a road train consists of the following points [8]:

- determining the nominal gross weight of the road train and comparing it with the maximum permissible weight of vehicles;
- determination of the actual load on the fifth-wheel coupling device (FDU), taking into account the maximum permissible loads for the axles of the truck tractor;
- determination of the actual load on the semi-trailer bogie, taking into account the maximum permissible axle loads;
- determination of the actual load capacity of the road train.

As an example, road trains consisting of a KAMAZ-5490 truck tractor with a SZAP-9328 and MAZ-975830-3012 semi-trailer are considered [9, 10].

The technical data of the truck tractor and semi-trailers necessary to solve this problem are given in Table 1-3, their overall dimensions are in Figures 1-3.

Table 1. Technical data of the KAMAZ-5490 truck tractor [9].

<table>
<thead>
<tr>
<th>Options</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel formula</td>
<td>4×2</td>
</tr>
<tr>
<td>Rear axle load at full weight, t</td>
<td>11.5</td>
</tr>
<tr>
<td>Curb weight of the tractor m_{тр}, t</td>
<td>7.9</td>
</tr>
<tr>
<td>Weight on the rear axle when in running order m_{2}, t</td>
<td>2.6</td>
</tr>
<tr>
<td>Permissible load on the FWC, t</td>
<td>10.55</td>
</tr>
<tr>
<td>Maximum total weight of the transported semi-trailer, t</td>
<td>36.1</td>
</tr>
</tbody>
</table>

Fig. 1. Overall dimensions of the KAMAZ-5490 truck tractor.
Table 2. Technical data of the semi-trailer SZAP-9328 [10].

<table>
<thead>
<tr>
<th>Options</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of axes</td>
<td>3</td>
</tr>
<tr>
<td>Nominal load capacity, t</td>
<td>26</td>
</tr>
<tr>
<td>Nominal gross weight, t</td>
<td>34</td>
</tr>
<tr>
<td>Weight of semi-trailer in running order, t</td>
<td>8</td>
</tr>
<tr>
<td>Load on the FWC in a loaded state (with a cargo weight of 26 tons), t</td>
<td>11.5</td>
</tr>
<tr>
<td>Load on the trolley when loaded (with a load weight of 26 tons), t</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Table 3. Technical data of the MAZ-975830-3012 semi-trailer.

<table>
<thead>
<tr>
<th>Options</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of axes</td>
<td>3</td>
</tr>
<tr>
<td>Nominal load capacity, t</td>
<td>28</td>
</tr>
<tr>
<td>Nominal gross weight, t</td>
<td>34.6</td>
</tr>
<tr>
<td>Weight of semi-trailer in running order, t</td>
<td>6.7</td>
</tr>
<tr>
<td>Load on the FWC in a loaded state (with a cargo weight of 26 tons), t</td>
<td>10.6</td>
</tr>
<tr>
<td>Load on the trolley when loaded (with a load weight of 26 tons), t</td>
<td>24</td>
</tr>
</tbody>
</table>

Fig. 2. Overall dimensions of the semi-trailer SZAP-9328.

Fig. 3. Overall dimensions of the MAZ-975830-3012 semi-trailer.

The total weight of the road train (at the rated load capacity of the semi-trailer) is determined by the formula:

\[ m_{\text{full}} = q_{\text{nom}} + m_{\text{cur}} + m_{\text{tr}}, \]  

(1)

where \( q_{\text{nom}} \) is the rated load capacity of the semi-trailer, t; \( m_{\text{cur}} \) – curb weight of the semi-trailer, t; \( m_{\text{tr}} \) – curb weight of the truck tractor, t [13, 14].

The diagram of the load action of a 2-axle truck tractor is shown in Figure 4.
Fig. 4. Load diagram of a 2-axle truck tractor.

The actual load on the FWC is determined taking into account the maximum permissible load for the axles of the truck tractor.

An equation is drawn up for the sum of moments about point O:

\[ M(O) = -P_c \times l_c + (P_{2, nor} - m_2) \times L = 0, \]  \hspace{1cm} (2)

where \( P_c \) is the load on the FWC, t; \( L \) – truck tractor base; \( l_c \) – horizontal projection of the distance from the front axle of the truck tractor to the center of the control unit, defined as \( l_c = L - a \); \( P_{2, nor} \) – maximum permissible load on the rear axle of a truck tractor; \( m_2 \) is the mass attributable to the rear axle of a truck tractor when in running order (without a semi-trailer).

Load on FWC:

\[ P_c = \frac{(P_{2, nor} - m_2) \times L}{l_c}. \]  \hspace{1cm} (3)

The actual load capacity of the road train is determined by the formula:

\[ q_{ac} = P_{ul} + P_c - m_{cur} \]  \hspace{1cm} (4)

where \( P_{ul} \) is the maximum permissible load on the semi-trailer bogie, t.

To avoid overloading any axles of the road train, the cargo must be correctly loaded on the platform, taking into account the center of mass of the semi-trailer. The loading diagram of a 3-axle semi-trailer is shown in Figure 5.

To determine the center of mass, an equation of moments of forces is drawn up relative to point A, corresponding to the center of mass of the semi-trailer

\[ M(A) = -P_{c, nom} \times l_{c,g} + P_{lo, nom} \times (L_d - l_{c,g}) = 0, \]  \hspace{1cm} (5)

where \( L_d \) is the distance from the center of the FWC to the center of the semi-trailer bogie; \( P_{c, nom}, P_{lo, nom} \) – respectively, the load on the FWC and the load on the bogie at the full weight of the semi-trailer (according to the semi-trailer manufacturer).

Fig. 5. Loading diagram for a 3-axle semi-trailer.
From equation (5), the distance from the center of the FWC to the center of gravity of the semi-trailer \( l_{c,g} \) is determined.

As an example, a calculation is made for a KAMAZ-5490 road train with a SZAP-9328 semi-trailer for the category of roads with an axle load of 10 t.

### 3 Results and discussion

The total weight of the road train (at the rated load capacity of the semi-trailer) is:

\[
m_{\text{full}} = 26 + 8 + 7.9 = 41.9 \text{ t.}
\]

(6)

For a five-axle road train, the maximum permissible gross weight is 40 tons. Therefore, the rated load capacity of the semi-trailer in this case cannot be fully used.

Horizontal projection of the distance from the front axle of the tractor unit to the center of the FWC:

\[
l_c = 3.580 - 0.565 = 3.015 \text{ m.}
\]

(7)

The load on the FWC is determined by formula (2):

\[
P_c = \frac{(10 - 2.6) \times 3.580}{3.015} = 8.79 \text{ t.}
\]

(8)

The possible load on the semi-trailer bogie is determined depending on the distance between the axles of the semi-trailer: at a distance of 1.31 m, the maximum permissible load on the axle is 7.5 tons.

The actual load on the semi-trailer bogie is:

\[
P_{lo} = 3 \times 7.5 = 22.5 \text{ t.}
\]

(9)

Actual load capacity of the road train:

\[
q_{\text{ac}} = 22.5 + 8.79 - 8 = 23.29 \text{ t.}
\]

(10)

For the SZAP-9328 semi-trailer, we determine the location of the center of gravity. With the total weight of the SZAP-9328 semi-trailer equal to \( Q_{\text{nom}} = 34 \text{ t.} \), the load on the FWC is \( P_{c}^{\text{nom}} = 11.5 \text{ t.} \), on the 3-axle bogie \( P_{lo}^{\text{nom}} = 22.5 \text{ t.} \). Using these data formula (5) determines the distance from the center of the FWC to the center of mass of the semi-trailer.

The center of gravity of the semi-trailer is 5.294 m from the center of the fifth wheel.

### 4 Conclusion

The performance indicators of road trains with different semi-trailers are given in Table 4. The load capacity utilization factor is determined relative to the rated load capacity of the corresponding semi-trailers.

<table>
<thead>
<tr>
<th>Road train</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual load capacity ( q_{\text{ac}} )</td>
</tr>
<tr>
<td>KAMAZ-5490 with semi-trailer SZAP-9328</td>
<td>23.29</td>
</tr>
<tr>
<td>KAMAZ-5490 with semi-trailer MAZ-975830-3012</td>
<td>24.59</td>
</tr>
</tbody>
</table>
Analyzing the indicators, it can be noted that for these conditions it is more expedient to operate a road train consisting of KAMAZ-5490 with a MAZ-975830-3012 semi-trailer [11, 12].

According to the research conducted, it can be said that carrying out calculations using the presented methodology makes it possible to eliminate overloads of trucks and road trains, increase the efficiency of their use, and select rational rolling stock for specific routes. It can be used both for flatbed trucks and curtain-sided platforms, container ships, dump trucks with a constant body section, etc.

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