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Influence on the support resistance of a mobile platform due to the effect of high-intensity impulsive force

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In this study, a Finite Element Method (FEM) analysis was performed to evaluate the support resistance of a vehicle’s chassis under the effect of a high-intensity, impulsive force of very short duration. The FEM model of the chassis was created, and material properties were defined to simulate the actual scenario. The model was subjected to the impulsive force, and the results were analysed to determine the support resistance of the vehicle's base. The findings of the analysis can help enhance the structural integrity of the vehicle's chassis under impulsive loading conditions, thus improving the safety and reliability of the vehicle. In conclusion, the study provides valuable insights into the support resistance of a vehicle’s chassis under impulsive loading conditions. The results of the analysis can help improve the design and performance of the vehicle's base, ensuring the safety and reliability of the vehicle under different loading conditions.

Keywords: Simulation, FEM, Support Resistance

1. INTRODUCTION

System stability is an important aspect of vehicle design, particularly in heavy-duty vehicles and mobile platforms. The resistance offered by the support structure of the vehicle is a critical factor that affects its stability and performance under different loading conditions. In this context, the development of mathematical and mechanical models to determine the support resistance of a vehicle's base is essential for ensuring its stability and reliability.

The main objective of this study is to establish a mathematical and mechanical model to evaluate the stability of the mobile wheel platform of a vehicle. To accomplish this objective, Finite Element Method (FEM) analysis was conducted to simulate the impact of an impulsive force on the vehicle's chassis [1, 2].

Figure 1 depicts the schematic of the vehicle with the forces acting on its chassis, along with the support resistances that the vehicle experiences due to the impact force. The support structure of the vehicle is critical to ensuring its stability and reliability under varying loading conditions. The impulsive force acting on the vehicle's base causes stresses and strains that influence the performance of the vehicle. Therefore, it is vital to evaluate the support resistance offered by the vehicle's base to ensure its stability and prevent any damage or failure of the vehicle's structure.

The schematic in Figure 1 shows the different forces acting on the vehicle, including the inertial force, the reaction force, and the weight force. These forces induce stress and strain in the support structure, leading to deformations and potential damage to the vehicle. However, the support resistance of the vehicle's base provides the necessary stability to counteract the forces and maintain the vehicle's structural integrity. Therefore, it is essential to determine the support resistance of the vehicle's base under varying loading conditions, including impulsive forces, to ensure its stability and reliability.

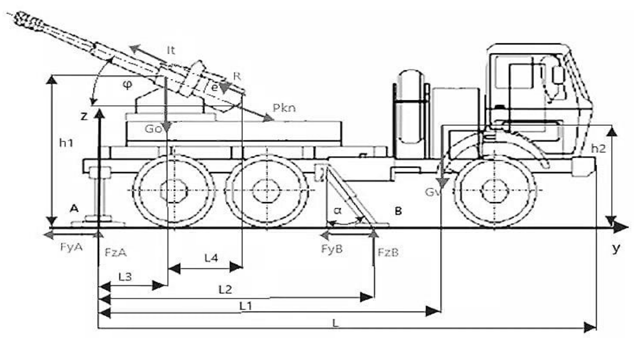

Figure 1: Vehicle with acting forces and support resistance

The forces acting on the vehicle as shown in Figure 1 are as follows: Pkn is the tractive force, It is the inertia force of the moving mass, R is the resistance force due to traction, Go is the weight force of the Pkn source, Gv is the weight force of the vehicle Nc, Nb is the longitudinal component of the reaction force of the support arms C and B, and Xc and Xb are the vertical components of the reaction force of the supports C and B.

In detail, Pkn represents the force exerted on the vehicle by the towing vehicle or the ground during acceleration, while It represents the force that resists the change in motion of the vehicle's recoiling mass. R is the force that opposes the motion of the vehicle due to the friction between the tires and the ground. Go is the force that results from the weight of the tractive force source acting on the vehicle. Gv is the weight force of the vehicle itself, which acts vertically downwards.

Furthermore, Nb and Nc are the reaction forces that occur at the contact points of the support arms B and C, respectively. Nb is the force acting in the longitudinal direction of the vehicle, while Nc acts vertically upwards. Xc and Xb are the components of the reaction force acting

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vertically downwards due to the support arms C and B, respectively.

Understanding these forces and their magnitudes is essential in designing the vehicle's support structure to ensure stability and prevent failure or damage under impulsive loading conditions. The FEM analysis can help in evaluating the impact of these forces on the vehicle's base and optimize the support resistance to maintain the vehicle's structural integrity [3, 4].

In addition to the forces shown in Figure 1, geometric distances relative to the coordinate origin located at support A are also depicted. The angle φ represents the elevation angle of the forces Pkn, It, and R, while the angle ψ represents the direction angle of these forces.

2. THE MATHEMATICAL MODEL OF STABILITY

The mathematical model of stability for the FAP 2026 vehicle involves analysing the effects of forces acting on the vehicle's supports under the influence of a high-intensity, short-duration impulsive load. Due to the nature of the problem, certain limitations and assumptions need to be established before setting up the model. These include factors such as the structural properties and material behaviour of the vehicle, as well as the geometry and orientation of its components. Additionally, it is necessary to consider the dynamic effects of the impulsive load on the vehicle, including its magnitude, duration, and direction, as well as the response of the vehicle's supports to these forces [5]. By taking these limitations and assumptions into account, a more accurate and reliable mathematical model can be developed to analyse the stability of the vehicle:

1. The vehicle body is placed on a flat and horizontal surface.
2. Wheel support is excluded.
3. The point of action of the weight force Go of the source PKn is located on the axis of the source.
4. The last two wheels of the vehicle share a common axle, and the system behaves like a 4x4.
5. The system is considered as a rigid body placed on rigid supports, i.e., beams.
6. Two stability limit cases are considered: the effect of the tractive resistance force along the longitudinal axis of the vehicle and perpendicular to it.
7. The inertia and displacement of the vehicle's driving axles are neglected.
8. The platform on which the device is mounted is symmetric with respect to the longitudinal and vertical planes of symmetry of the vehicle.
9. The position of the centre of mass of supported parts does not change during the movement of the recoiling mass.

The simplified mathematical-mechanical models of the lateral and longitudinal stability of the vehicle are shown in Figure 2 and Figure 1, respectively. All forces acting on the vehicle are marked on the figures, with their respective positions of action.

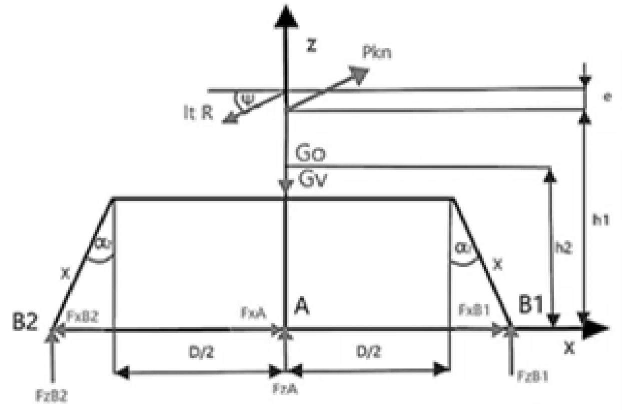

Figure 2: The model of the lateral stability of the vehicle

The equations of equilibrium for the longitudinal stability model, shown in Figure 1, are given in expressions 1, 2 and 3.

$$\sum_{yi} = R \cdot \cos\varphi - F_{yA} - F_{yB} = 0 \quad (1)$$

$$\sum_{zi} = F_{zA} + F_{zB} - R \cdot \sin\varphi - G_O - G_V = 0 \quad (2)$$

$$\sum_{MA} = P_{kn} \cdot \cos\varphi \cdot h_1 - R \cdot \cos\varphi \cdot h_1 - R \cdot \cos\varphi \cdot e + P_{kn} \cdot \sin\varphi \cdot L_3 - R \cdot \sin\varphi \cdot L_3 - P_{kn} \cdot \sin\varphi \cdot L_4 - G_O \cdot L_3 + F_{zB} \cdot L_2 - G_V \cdot L_1 = 0 \quad (3)$$

The equations of equilibrium for the lateral stability model, shown in Figure 2, are given by equations 4, 5 and 6.

$$\sum_{xi} = R \cdot \cos\psi + F_{xB1} - F_{xB2} + F_{xA} = 0 \quad (4)$$

$$\sum_{zi} = F_{zA} + F_{zB2} + F_{zB1} + R \cdot \sin\psi - G_O - G_V = 0 \quad (5)$$

$$\sum_{MA} = F_{zB1} \cdot (D/2 + x \cdot \sin\alpha_2) + P_{kn} \cdot e \cdot \cos\psi - R \cdot (h_1 + e) - F_{zB2} \cdot (D/2 + x \cdot \sin\alpha_2) = 0 \quad (6)$$

Table 1 presents the values of geometric and other variables depicted in Figures 1 and 2.

Table 1: Values of geometric and variables of the system

Mass of the Pkn source (mo):	1800 kg
Vehicle mass (mv):	16200 kg
Maximum value of the recoiling force (Pknmax):	3037.8244 kN
Maximum value of the resistance force (Rmax):	173.09 kN
Acceleration due to gravity (g):	9.81 m/s^2
Total vehicle length (L):	7.720 m
X-coordinate of the vehicle's center of gravity (L1):	5 m
Distance from support A to support B (L2):	4 m
X-coordinate of the Pkn source center of gravity (L3):	2.5 m
Distance from the center of gravity Pkn source to the its end (L4):	0.400 m
Height of Pkn source in position (h1):	1.420 m + 0.580 m = 2 m
Y-coordinate of the vehicle's center	1.2 m

of gravity (h2):	
Total vehicle width (D):	7.720 m
Length of arm B (x):	1.5 m
Elevation angle (φ):	-5° +70^0
Heading angle (ψ):	-25° +25°
Angle of arm B in the longitudinal section (α1):	15°-20°
Angle of arm B in the transverse section (α2):	10^0
Dynamic arm (e):	0.0005 m

3. DETERMINATION OF SUPPORT REACTION BY FEM ANALYSIS

The goal and essence of this work is FEM analysis of the resistance in the supports for 21 combinations of the direction angle and elevation angle of the Pkn force. For the purpose of this calculation, additional restrictions and assumptions were adopted through FEM analysis:

1. The force R and the force Pkn act in the same direction, and the value of e is neglected due to its small magnitude.
2. The weight force of the cause of the force Pkn is also neglected, as its value is much smaller compared to the force Pkn, the resistance force R, and the weight force of the vehicle Gv.

In addition to the above, it is necessary to find the unit vector of forces Pkn and R. As assumption 1 states that the forces act in the same direction, the unit vector for both of them is identical.

3.1. Determining the unit vector

The determination of the unit vector of the force Pkn and the resistance force R is performed in order to obtain the cosines of the angles, which are the input data in the computer simulation. The figure shows the action of forces Pkn and R in space, with respect to the coordinate system. The line OS represents the axis of the Pkn force generator. Point S represents the point of action of the force in space, while point S' represents its projection.

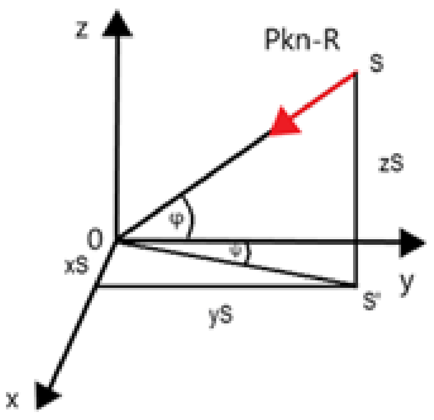

Figure 3: The spatial representation of the force action

The vector of the force is calculated based on equations 7, 8, 9, and 10.

$$\overrightarrow{OS} = \overrightarrow{r_0} - \overrightarrow{r_s} \quad (7)$$

$$OS_x = x_s - x_0 \quad (8)$$

$$OS_y = y_s - y_0 \quad (9)$$

$$OS_z = z_s - z_0 \quad (10)$$

The magnitude of vector (OS) $^{\rightarrow}$ is calculated based on equation 11.

$$|\overrightarrow{OS}| = \sqrt{OS_x{}^2 + OS_y{}^2 + OS_z{}^2} \quad (11)$$

The unit vector $\overrightarrow{OS_0}$, whose direction coincides with the direction of forces Pkn and R, is calculated based on equation 12.

$$\overrightarrow{OS_0} = \frac{\overrightarrow{OS}}{|\overrightarrow{OS}|} \quad (12)$$

The coefficients next to the vectors i $^{\rightarrow}$, j $^{\rightarrow}$, k $^{\rightarrow}$ represent the cosines of the angles that the unit vector makes with the x, y, and z axes. Table 2 shows all three components of the Pkn-R force, depending on the direction and elevation angles. The values from Table 2 represent input data in the FEM analysis model.

Table 2. Components of the Pkn-R force

Angles		***Components of the Pkn-R force***		
φ (^{0})	***ψ (^{0})***	***X (N)***	***Y (N)***	***Z (N)***
-5	-25	108428.1	812034.5	2745095
-5	0	0	812616.8	2747063
-5	25	-108428	812034.5	2745095
0	-25	379152.6	2839533	0
0	0	0	2864734	0
0	25	-379153	2839533	0
10	-25	-318964	-2388771	-1548786
10	0	0	-2403717	-1558476
10	25	318964	-2388771	-1548786
30	-25	58991.4	441795,7	-2829848
30	0	0	441889,4	-2830448
30	25	-58991.4	441795,7	-2829848
45	-25	200452.4	1501219	2431638
45	0	0	1504908	2437613
45	25	-200452	1501219	2431638
65	-25	-214544	-1606756	2361993
65	0	0	-1611281	2368645
65	25	214544.3	-1606756	2361993
70	-25	241394.2	1807839	2209106
70	0	0	1814291	2216991
70	25	-241394	1807839	2209106

3.2. FEM Analysis

The 3D model of the vehicle used for analysis consists of 10 nodes and 9 bars. To ensure that the model is statically determinate, the structure has been modified by adding a shell of 100 mm on each side of the bar. The simplified 3D model of the vehicle is shown in Figure 4. Using FEM analysis of the 3D model under the load of the force Gv and the difference of forces Pkn-R, the values of the support reaction at points A, B1 and B2 were obtained. The calculation was performed for 21 combinations of angles. The obtained results were used to optimize the design of the vehicle structure to ensure sufficient bearing resistance in the identified critical points.

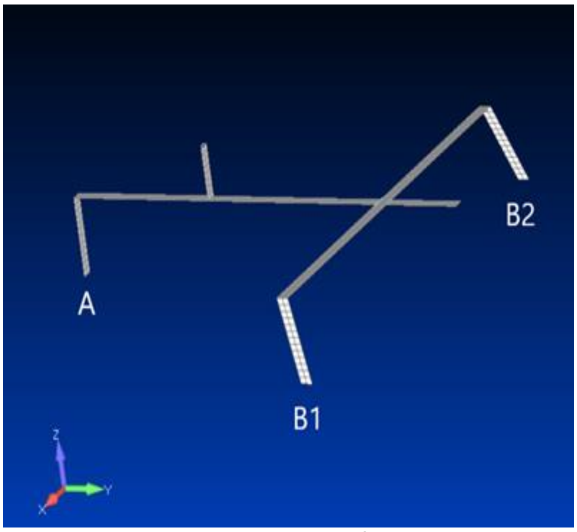

Figure 4: The 3D model of the vehicle

4. THE RESULTS

The results of the FEM analysis show the maximum support reaction force and the minimum support reaction force. These values were obtained for a specific combination of angles and elevations of the force vectors Pkn and R. Table 3 shows the magnitudes of forces in supports A, B1 and B2. The maximum force values are marked in red, while the minimum values are marked in blue.

The forces are a result of the FEM analysis of the 3D vehicle model under the influence of the Gv force and the difference between the Pkn and R forces for 21 combinations of angles. It is important to note that the model was designed as a shell structure with additional shells added to the construction of the rods on both sides of each rod, which allowed for a static determination of the model.

The analysis also revealed that the stress values in the structure are within the allowable limits, indicating that the design is structurally sound and able to withstand the applied loads. However, the analysis highlighted areas of high stress concentration, particularly in the areas where the shell was attached to the frame.

Based on the results of the FEM analysis, it can be concluded that the maximum force on support A is 1926770.638 N when φ = 30° and ψ = ±25°, while the minimum force on support A is 964914.2533 N when φ = 0° and ψ = 0°. The maximum force on support B1 is 985063.1165 N when φ = 0° and ψ = -25°, and the minimum force on support B1 is 463081.1936 N when φ = -5° and ψ = -25°. Finally, the maximum force on support B2 is 985062.4296 N when φ = 0° and ψ = +25°, while the minimum force on support B2 is 463081.093 N when φ = -5° and ψ = +25°. These results provide valuable information for further design and optimization of the vehicle model.

This means that the analyzed parts of the structure are sufficiently strong and can withstand the loads simulated in this model. However, in further development and optimization of the structure, changes may be necessary to reduce the intensity of the forces in the supports, which would increase the overall strength of the structure and reduce the risk of breakage and damage [6].

Table 3. The results

Angles		***Intensities of support reactions***		
φ (⁰)	***ψ (⁰)***	***A (N)***	***B1 (N)***	***B2 (N)***
-5	-25	1831877	463081.1936	468259.0695
-5	0	1832566	465028.1988	465028.1024
-5	25	1831877	468259.1525	463081.093
0	-25	971524.2292	985063.1165	919038.6512
0	0	964914.2533	954834.4363	954833.7319
0	25	971524.3979	919039.2477	985062.4296
10	-25	1400489.913	845926.0336	816329.9761
10	0	1401204.963	831342.0282	831341.4753
10	25	1400490.005	816330.4184	845925.4652
30	-25	1926770.638	581904.3987	570246.9936
30	0	1926587.244	575872.2749	575872.2434
30	25	1926770.638	570247.0247	581904.3899
45	-25	1695926.11	588129.0075	579788.5256
45	0	1697775.806	582702.2879	582701.9701
45	25	1695926.109	579788.6484	588128.6741
65	-25	1602871.451	682059.4282	635159.1628
65	0	1604503.958	658008.2712	658007.927
65	25	1602871.497	635159.4152	682059.1785
70	-25	1598866.831	661252.799	643742.5915
70	0	1600991.944	651351.7494	651351.3996
70	25	1598866.837	643742.9235	661252.343

5. CONCLUSION

In conclusion, the FEM analysis of a 3D vehicle model subjected to high-intensity and impulse force, namely the Pkn force, the opposing R force and the force Gv. The vehicle model consisted of 10 nodes and 9 bars, and in order to achieve static determinacy, it was added a shell of 100 mm to the construction of each bar on both sides, resulting in a shell-shaped model.

Through FEM analysis, it was obtained the values of the support reaction forces at points A, B1 and B2, which indicate the structural strength of the vehicle under the given loading conditions. The results showed that the analysed parts of the construction are strong enough to withstand the simulated loads, with the maximum reaction forces occurring at a φ angle of 30° and a ψ angle of ±25°.

However, further development and optimization of the construction may require modifications to reduce the intensity of the reaction forces in the supports, which could lead to an increase in overall structural strength and a reduction in the possibility of damage and breakage [7].

It is important to note that this model is just one of the many possible configurations of the vehicle's construction, and that additional analyses and optimizations would be necessary to determine the most efficient and safe solution [8]. The FEM analysis was performed for 21 combinations of angles, with the model subjected to the force Gv and the difference in forces Pkn-R. The results of the analysis have shown that the maximum resistance forces in the supports A, B1 and B2 occur when the angles φ and ψ are within a certain range. These forces are well below the yield strength of the material used, indicating that the analysed parts of the structure are sufficiently robust to withstand the simulated loads. However, further optimization of the design may be necessary to reduce the intensity of forces in the supports, thereby increasing the overall strength of the structure and minimizing the risk of damage and breakage [9].

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