Determine the dynamic load acting on the chassis of multi-purpose forest fire fighting vehicle

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Abstract. Multi-purpose forest fire fighting vehicle is produced in Viet Nam include a combination of fire fighting equipment such as high-pressure water pump, create corridor fire insulation cutting machine, vacuum and high wind speed bowling machine, extinguish the fire sand blast apparatus that is mounted active three axles vehicle. The paper presents how to determine the dynamic load acting on the chassis by 3D modeling method. The results of this study are the input parameters for assessing the durability of the chassis of multi-purpose forest fire fighting vehicle.

Keywords: dynamic load, chassis, multi-purpose forest fire fighting vehicle, 3D vehicle model

1. Introduction
Multi-purpose forest fire fighting vehicle was designed on the basic URAL 4320, three active axle, used mainly in the military to increase mobility on the road surface. Shape of base vehicle Ural 4320 and multifunction forest fire fighting vehicle shown in Figure 1 [1,2].

Figure 1. Multi-purpose forest fire fighting vehicle.

The main equipment of multi-purpose forest fire fighting vehicle are shown in Figure 2 [3,4]
Figure 2. General design multifunction forest fire fighting vehicle.

2. Mathematical modelling

2.1. Some initial assumptions

To building modelling, there are some assumptions:
- The wheels always contact the road surface;
- The modelling includes front axle, middle axle, rear axle are considered absolute solids;
- The resistance of tire is linear elastic;
- Mass of cab and container are distributed symmetry around the longitudinal and transverse planes;
- Speed of vehicle on the road is low, constant; therefore, inertial and air resistance low and considered zero [2].

2.2. Survey modeling

Figure 3. Full car suspension model
By applying Newton’s second law of motion, we establish the differential oscillation system as follows [2]:

\[
m\ddot{Z} + K \left[ 4\ddot{Z} + 2\dot{\theta}_n (c_1 - c_3) + \dot{\theta}_n (c_1 - c_3) - 4\ddot{Z} + 2\dot{\theta}_n (c_2 - c_1) - 2\dot{\theta}_n (l_1 + l_1 - c_1 - c_3) \right] = 0
\]

(1)

\[
C \left[ 4\ddot{Z} + 2\theta_n (c_1 - c_3) + \theta_n (c_1 - c_3) - 4\ddot{Z} + 2\theta_n (c_2 - c_1) - 2\theta_n (l_1 + l_1 - c_1 - c_3) \right] = 0
\]

(2)

\[
J_n \ddot{\theta}_n + Kc_1 \left[ 2\ddot{Z} + 2\dot{\theta}_n (c_1 - c_3) + \dot{\theta}_n (c_1 - c_3) - 2\ddot{Z} - 2\dot{\theta}_n c_1 - \dot{\theta}_n (2l_1 + 2l_1 + c_1 + c_3) \right] = 0
\]

(3)

\[
-C_c c_1 \left[ 2\ddot{Z} + 2\dot{\theta}_n c_1 + \dot{\theta}_n (c_1 - c_3) - 2\ddot{Z} + 2\dot{\theta}_n c_1 - \dot{\theta}_n (2l_1 + 2l_1 + c_1 + c_3) \right] = 0
\]

(4)

\[
-C_c c_1 \left[ 2\ddot{Z} + 2\dot{\theta}_n c_1 + \dot{\theta}_n (c_1 - c_3) - 2\ddot{Z} + 2\dot{\theta}_n c_1 - \dot{\theta}_n (2l_1 + 2l_1 + c_1 + c_3) \right] = 0
\]

(5)

\[
C_c c_1 \left[ 2\ddot{Z} + 2\dot{\theta}_n c_1 + \dot{\theta}_n (c_1 - c_3) - 2\ddot{Z} + 2\dot{\theta}_n c_1 - \dot{\theta}_n (2l_1 + 2l_1 + c_1 + c_3) \right] = 0
\]

(6)

\[
m\ddot{Z} + K \left[ 4\ddot{Z} + 2\dot{\theta}_n (c_1 - c_3) + \dot{\theta}_n (c_1 - c_3) - 4\ddot{Z} + 2\dot{\theta}_n (c_2 - c_1) - 2\dot{\theta}_n (l_1 + l_1 - c_1 - c_3) \right] = 0
\]

(7)
\begin{align}
J_{\alpha\beta} + K_{\alpha\beta} & \left[ 2Z_{\alpha} + 2\theta_{\alpha} c_{\beta} + \theta_{\alpha} (c_{\beta} + c_{\beta}) - 2Z_{\beta} - 2\theta_{\beta} c_{\alpha} - \theta_{\beta} (c_{\alpha} + c_{\alpha}) \right] \\
- K_{\alpha\beta} & \left[ 2Z_{\alpha} + 2\theta_{\alpha} c_{\beta} + \theta_{\alpha} (c_{\beta} + c_{\beta}) - 2Z_{\beta} - 2\theta_{\beta} c_{\alpha} - \theta_{\beta} (c_{\alpha} + c_{\alpha}) \right] \\
+ K_{\alpha\beta} & \left[ 2Z_{\alpha} + 2\theta_{\alpha} c_{\beta} + \theta_{\alpha} (c_{\beta} + c_{\beta}) - 2Z_{\beta} - 2\theta_{\beta} c_{\alpha} - \theta_{\beta} (c_{\alpha} + c_{\alpha}) \right] \\
- K_{\alpha\beta} & \left[ 2Z_{\alpha} + 2\theta_{\alpha} c_{\beta} + \theta_{\alpha} (c_{\beta} + c_{\beta}) - 2Z_{\beta} - 2\theta_{\beta} c_{\alpha} - \theta_{\beta} (c_{\alpha} + c_{\alpha}) \right] \\
+ K_{\alpha\beta} & d \left[ 2\theta_{\alpha} d - 2\theta_{\alpha} d \right] + K_{\beta\gamma} d \left[ 2\theta_{\beta} d - 2\theta_{\beta} d \right] \\
+ K_{\alpha\beta} & d \left[ 2\theta_{\alpha} d - 2\theta_{\alpha} d \right] + K_{\alpha\beta} d \left[ 2\theta_{\alpha} d - 2\theta_{\alpha} d \right] \\
+ C_{\alpha\beta} & \left[ 2Z_{\alpha} + 2\theta_{\alpha} c_{\beta} + \theta_{\alpha} (c_{\beta} + c_{\beta}) - 2Z_{\beta} - 2\theta_{\beta} c_{\alpha} - \theta_{\beta} (c_{\alpha} + c_{\alpha}) \right] \\
- C_{\alpha\beta} & \left[ 2Z_{\alpha} + 2\theta_{\alpha} c_{\beta} + \theta_{\alpha} (c_{\beta} + c_{\beta}) - 2Z_{\beta} - 2\theta_{\beta} c_{\alpha} - \theta_{\beta} (c_{\alpha} + c_{\alpha}) \right] \\
+ C_{\alpha\beta} & \left[ 2Z_{\alpha} + 2\theta_{\alpha} c_{\beta} + \theta_{\alpha} (c_{\beta} + c_{\beta}) - 2Z_{\beta} - 2\theta_{\beta} c_{\alpha} - \theta_{\beta} (c_{\alpha} + c_{\alpha}) \right] \\
- C_{\alpha\beta} & \left[ 2Z_{\alpha} + 2\theta_{\alpha} c_{\beta} + \theta_{\alpha} (c_{\beta} + c_{\beta}) - 2Z_{\beta} - 2\theta_{\beta} c_{\alpha} - \theta_{\beta} (c_{\alpha} + c_{\alpha}) \right] \\
+ C_{\alpha\beta} & d \left[ 2\theta_{\alpha} d - 2\theta_{\alpha} d \right] + C_{\alpha\beta} d \left[ 2\theta_{\alpha} d - 2\theta_{\alpha} d \right] \\
+ C_{\alpha\beta} & d \left[ 2\theta_{\alpha} d - 2\theta_{\alpha} d \right] + C_{\alpha\beta} d \left[ 2\theta_{\alpha} d - 2\theta_{\alpha} d \right] \\
= 0
\end{align}
The values of the geometry and dynamic parameters of multi-purpose forest fire fighting vehicle are given in Table 1 [1,3].

### Table 1. Technical of multi-purpose forest fire fighting vehicle.

| Symbol | Value        | Symbol | Value        | Symbol | Value       |
|--------|--------------|--------|--------------|--------|-------------|
| $m_c$  | 850 kg       | $m_5$  | 1000 kg      | $K_{11}, K_{12}$ | 2800 Ns/m  |
| $J_{cx}$ | 200 kgm²    | $J_{3}$ | 1277 kgm²    | $K_{21}, K_{22}$ | 2800 Ns/m  |
| $J_{cy}$ | 150 kgm²    | $C_{c1}, C_{c2}, C_{c3}, C_{c4}$ | 100000 N/m | $c_1$  | 0.7 m       |
| $m_t$  | 8500 kg      | $K_{c11}, K_{c12}, K_{c21}, K_{c22}$ | 750 Ns/m | $c_2$  | 0.6 m       |
| $J_{tx}$ | 48700 kgm²  | $C_{t1}, C_{t2}, C_{t3}, C_{t4}$ | 500000 N/m | $c_3$  | 0.8 m       |
| $J_{ty}$ | 13819 kgm²  | $K_{t11}, K_{t12}, K_{t21}, K_{t22}$ | 4000 N/m  | $c_4$  | 0.7 m       |
| $m_s$  | 14310 kg     | $C_{s11}, C_{s12}$ | 401952 N/m | $c_1$  | 0.8 m       |
| $J_{sx}$ | 1020 kg      | $K_{s11}, K_{s12}$ | 3248 Ns/m  | $c_2$  | 2.5 m       |
| $m_u$  | 1000 kg      | $C_{l11}, C_{l12}$ | 569964 Ns/m | $c_3$  | 2.5 m       |
| $J_{su}$ | 1320 kgm²    | $C_{l21}, C_{l22}$ | 569964 Ns/m | $c_4$  | 2.5 m       |
| $m_u$  | 1227 kgm²    | $K_{l11}, K_{l12}$ | 6497 Ns/m  | $l_2$  | 1.687 m     |
| $J_{uu}$ | 1227 kgm²    | $K_{l21}, K_{l22}$ | 6497 Ns/m  | $l_3$  | 1.847 m     |
| $m_s$  | 800 kg       | $K_{l31}, K_{l32}$ | 6497 Ns/m  | $l_4$  | 1.9 m       |
| $J_{us}$ | 1105 kgm²   | $C_{l11}, C_{l22}$ | 80000 N/m | $l_5$  | 0.55 m      |

### 3. Determination of dynamic load

In this survey, the author uses a simple sinusoidal shape is used because of its simple structure and easy to predict the results [2].

The height of the bump is determined by the formula:

$$h(x) = \begin{cases} 
\frac{1}{2} H \left[ 1 - \cos \left( 2\pi \frac{x}{L} \right) \right] & \text{when } 0 < x < L \\
0 & \text{when } x \leq 0 \quad , \quad x \geq L 
\end{cases}$$

With a constant velocity of the car ($v$) is the height of the bump in time ($h$) calculated according to the formula:

$$h(t) = \begin{cases} 
\frac{1}{2} H \left[ 1 - \cos \left( 2\pi \frac{vt}{L} \right) \right] & \text{when } 0 < vt < L \\
0 & \text{when } vt \leq 0 \quad , \quad vt \geq L 
\end{cases}$$

Inside: $H$ - maximum bump height (m); $L$ - bump length (m); $v$ - movement velocity of the vehicle (m/s); $t$ - Last time was bumpy (s).
Figure 4. Description of the pavement according to the length.

Apply $F_{z11}$, $F_{z12}$, $F_{z21}$, $F_{z22}$, $F_{z31}$, $F_{z32}$ is the dynamic load from the road surface acting alternately of the left front wheel, front right, left middle, right middle, rear left, right rear in verticality. Due to the high level of the forest road, sometimes the height of the road is over 0.35 m, and the movement velocity of the vehicle is about 25 km/h. Therefore, the survey when the wheels pass through the bump has a length of $L = 0.5$m and the height of the bump ($H$) varies from 0.1 to 0.4m, the vehicle velocity varies from 5 to 25 km/h, the vehicle is moving straight, not subject to horizontal forces.

3.1. Rough evenly two front wheels

Because two front wheels are evenly spaced, the vertical dynamic load acting the left and right wheels must be equal to the front and rear axles ($F_{z11} = F_{z12}$, $F_{z31} = F_{z32}$). On the car, the rear suspension design is balanced, to simply calculate whether vertical dynamic load acting on the middle wheel is equal to vertical dynamic load acting on the rear wheel in all moving conditions.

The results in Figures 5 and 6 describe the vertical dynamic load at one side of the leaf spring at a speed $v = 20$ km/h when bumpy height of road surface 0.4 m in the front and rear axles, Figures 7 and 8 describe the change of maximum value of vertical dynamic load with different velocities, different heights on the front and rear axles. The results show that the law of physics: When the speed of
movement of the vehicle increases, the vertical dynamic load will increase. With the speed \( v = 20 \text{ km/h} \), \( H = 0.4 \text{ m} \), the maximum value of vertical force \( F_{z1} = 170394 \text{N} \) and \( F_{z3} = 56752 \text{N} \). Maximum vertical dynamic load is 5.62 times greater than in the case of static load (stationary vehicle) for front axle and 2.22 times greater for rear axle.

3.2. Single bump front wheel
In this case, the front right wheel must pass through the bump. The survey results will determine the dynamic load acting on the chassis through the axle and suspension. Because the two front wheels are not equal, the dynamic load on the left and right wheels is different \( (F_{z11} < F_{z12}) \).

When the speed of movement of the vehicle increases, the vertical dynamic load will increase. With the speed \( v = 20 \text{ km/h} \), the maximum value of vertical force \( F_{z12} = 68150.6 \text{N} \). Maximum vertical dynamic load is 6.004 times greater than in the case of static load.

3.3. Rough evenly two wheels cross (left front and right rear)
When moving at different speeds, rear wheel time contact with the surface roughness from the left front wheel contact road surface is different.
When the speed of movement of the vehicle increases, the velocity $v = 20$ km/h, $H = 0.4$ m, the maximum value of vertical force $F_{z1} = 181783$ N (Figure 14). Maximum vertical dynamic load is 6.004 times greater than in the case of static load. The maximum value of vertical force $F_{z3} = 207840$ N (Figure 15), larger than 8.14 in the case of static load.

4. Conclusion
Multi-purpose forest fire fighting vehicle was designed on the basic URAL 4320, was installed specialized fire fighting to increase weight as well as change the center of gravity of the vehicle. Because of the factor makes it become unstable while moving, at time reduce details when the vehicle has a large
load, especially the chassis. The result of the study are the basic for stability of chassis to perfect the
design of the multi-purpose forest fire fighting vehicle. However, this study only determines the dynamic
load when the vehicle through sine-wave form. Therefore, further study is need to determine dynamic
loads when vehicles are traveling on forest roads or on roads according to ISO 8608:1995.

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