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Effect of Suspension System Stiffness on Dynamic Load Action Chassis Multi-purpose Forest Fire Fighting Vehicle

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ABSTRACT

Multi-purpose forest fire fighting vehicles include a combination of fire fighting equipment such as a high-pressure water pump, create corridor fire insulation cutting machine, vacuum and high wind speed bowling machine, extinguish the fire sandblast apparatus that is mounted on the URAL 4320 active three axles vehicle. When installing fire fighting equipment on vehicles, increases the load, affecting the vehicle's load distribution, angularity, and stability. Therefore, to ensure structural rigidity, the suspension system is redesigned to increase rigidity. However, alteration of the suspension stiffness will change the dynamic load acting on the chassis. This research presents the results of research on the influence of suspension stiffness on dynamic loads acting on the chassis of a multi-purpose forest fire fighting vehicle. The survey results showed that an increasing the suspension stiffness will increase the dynamic load acting on the chassis, and reduce the durability of the chassis in particular and the details of the vehicle in general. The research outcomes are the basis for evaluating the working life of the chassis in subsequent studies.

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1. INTRODUCTION

According to statistics, Vietnam has about 10 million hectares of natural and planted forests. In the dry season, the potential risk is very high, leading to thousands of forest fires, causing great economic losses, and destroying the ecological environment of the country. The main method of forest fire fighting is to use rudimentary equipment such as hoes, consequently, the effectiveness of forest fire fighting is not high [1]. The multi-purpose forest fire fighting vehicle manufactured by Vietnam has improved the effectiveness of forest fire fighting, meeting the requirements in the process of fighting forest fires deep, far from water sources and residential areas (Figure 1). When designing and installing forest firefighting equipment on the vehicle, the vehicle's load increases, so the stiffness of the suspension must be increased so that the vehicle does not bevel compared to the original design. However, when changing the suspension stiffness, will affect the dynamic load acting on the chassis and other details on the vehicle, affecting the durability and working life of the part [1-4].

Automobile loads were studied in early automobile vibration research with the aim of reducing dynamic loads, and improving the destructive strength and long-term durability of automobile assemblies and components [5]. When the car moves on the road, there will be dynamic loads that destroy the road [6, 7], on the contrary, the road surface also reacts, causing dynamic loads to increase, tires to be worn, and dynamic safety is lost [8, 9].

When operating, the driver controls the vehicle by 3 actions: acting on the accelerator, brake, and steering wheel; the parameters shown are longitudinal acceleration, horizontal and vertical accelerations. Together with the weight of the vehicle, the above accelerations act on the wheel vertically through the suspension. From the roadside, activation by the bumpy road will cause the wheel to oscillate vertically, generating a dynamic load [5]. The maximum dynamic load will affect the breaking strength, cyclic dynamic loads will affect fatigue life. Dynamic load depends on

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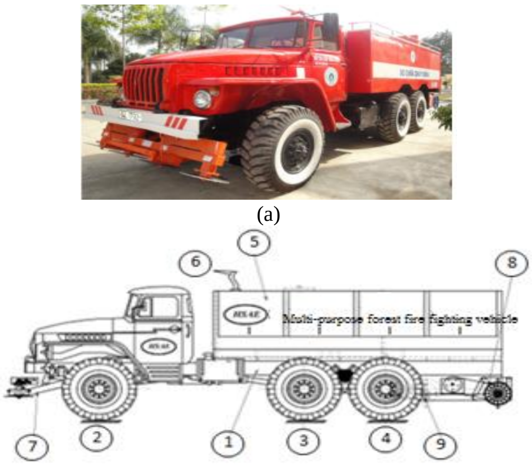

(a)

(b)

Figure 1. (a) Multi-purpose forest fire fighting vehicle (b) Overall multi-purpose forest fire fighting vehicle: 1. Vehicle, 2. front drive axle, 3. middle drive axle, 4. rear drive axle, 5. Water pump equipment, fire water tank, 6. water nozzle, 7. Equipment to cut trees, clean garbage, pave the way to create a fire isolation corridor, 8. Equipment to clean grass on the road, 9. Fire-fighting sandblasting equipment [1-3,5]

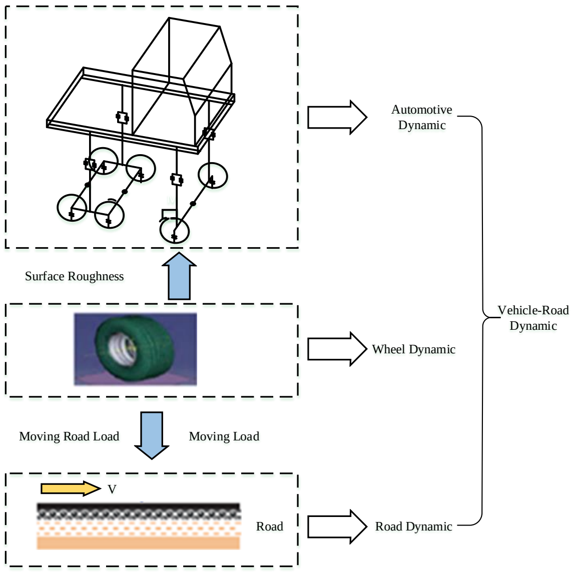

Figure 2. Tire-road interaction

vehicle structure including suspension stiffness, tire stiffness, influence from the roadside, and vehicle speed [10-12]. In order to reduce the dynamic load acting on the car, there are two research directions, namely the study of the suspension system and the study of the influence of the road. The investigtion on the influence of suspension stiffness was studied by the authors [13-16]. Dynamic load studies of multi-purpose forest fire fighting vehicles with research work have experimented to determine the dynamic load when the vehicle goes through the bump [17]. Other research works mainly on conventional vehicles. After being designed, the vehicle's load increases [1]; so to ensure rigidity, the suspension system is designed to increase rigidity to prevent the vehicle from tilting when fully loaded. When changing the suspension stiffness will affect the dynamic load acting on the chassis, Therefore, it is necessary to determine the dynamic load when the vehicle is working in order to serve as a scientific basis for completing the structure of the multi-purpose forest fire fighting vehicle.

2. RESEARCH CONTENT

2. 1. Build a Multi-purpose Forest Fire Fighting Vehicle Model

Applying the object separation method, we build a mechanical model of the vehicle. The objects on the vehicle are defined as follows: Object 1 consists of masses that are not suspended on the front axle, symbol m_1; object 2 consists of masses that are not suspended on the middle axle, symbol m_2; object 3 consists of masses that are not suspended on the rear axle, symbol m3; Object 4 is a vehicle with a mass equal to m4, moments of inertia I4zx and I_{4zy}; Object 5 is a driving water pump with a mass equivalent to m5, moments of inertia I5zx, I_{5zy}; Object 6 is a fire sprinkler with a mass equivalent to m6, moments of inertia I_{6zx}, I_{6zy}; Object 7 includes the masses of the front tree cutting devices, symbol m7; Item 8 includes the mass of the grass cleaning equipment, symbol m_8; Object 9 includes the masses of sandblasting hoe equipment, symbol m_9; Object 0 is the line (background object).

To build the model, we have the following assumptions:

- The mass of the car is distributed symmetrically about the longitudinal plane;
- Since vehicles operating on hilly roads with large undulations are the main sources of oscillation excitation, the excitation source from the engine should be ignored;
- Ignore collisions with the elastic lugs of the suspension and wheel separation of the tires.

From the above analysis and construction of vehicle design drawings, we determine the parameters of the model including:

C_{1L}; C_{1R}; C_{2L}; C_{2R}; C_{3L}; C_{3R}: stiffness of the left and right tires of the front, middle and rear axles;

C_{4L}; C_{4R}; C_{5L}; C_{5R}; C_{6L}; C_{6R}: stiffness of left and right suspension elastic of the front, middle and rear axles;

C_{7L}; C_{7R}; C_{8L}; C_{8R}: stiffness of the left and right elastomers of the front and rear racks;

K_{1L}; K_{1R}; K_{2L}; K_{2R}; K_{3L}; K_{3R}: drag coefficient of left and right tires of the front, middle and rear axles;

K_{4L}; K_{4R}; K_{5L}; K_{5R}; K_{6L}; K_{6R}: drag coefficient of left and right suspension elastic of the front, middle and rear axles;

K_{7L}; K_{7R}; K_{8L}; K_{8R}: drag coefficient of left and right front and rear racks;

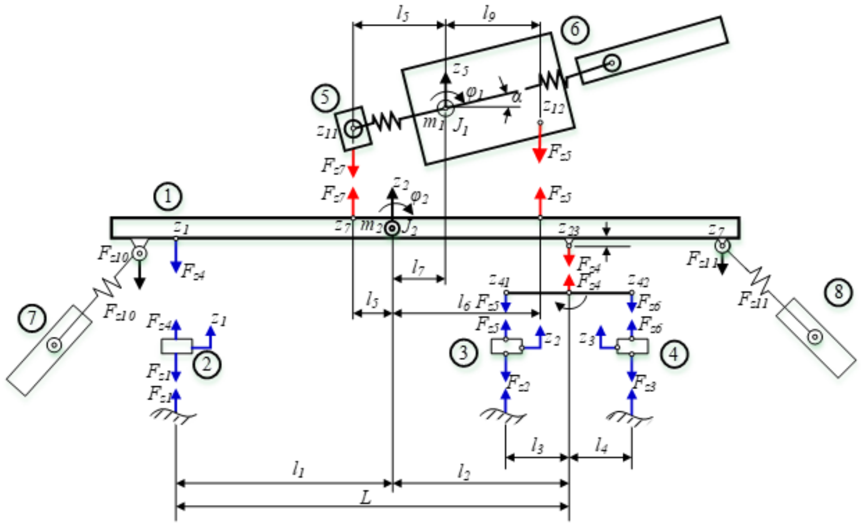

Figure 3. Multi-purpose forest fire fighting vehicle model: 1. Chassis of the vehicle; 2. Front axle; 3. Middle axle; 4. Rear axle; 5. Water pump for fire fighting; 6. Fire sprinkler; 7. Tree cutting structure creates a white corridor; 8. Lawn cleaning machine clears the way

q_{1L}; q_{1R}; q_{2L}; q_{2R}; q_{3L}; q_{3R}: left and right road profiles at the front, middle, and rear wheel;
Mct1: Torque of water pump components and sprinklers;
M_{ct2}: Resistance moment of white tape cutter components;
M_{ct3}: Resistance torque of rear lawn mower components;
M_{ct4}: Resistance moment of sand-generating equipment components.
l_1, l_2: Distance from the center of the vehicle to the center of the front axle and the connection point between the rear springs and the chassis.
l_3, l_4: Distance from the connection point between the rear springs and the chassis to the center of the middle and the rear axle.

2. 2. Set up the System of Equations to Balance the Force on the Vehicle Applying Dalambe's principle to each body whose origin is at the object's static equilibrium position, we have:

2. 2. 1. For the Front Axle The model of separation of objects on the front axle is depicted in Figure 4. Matlab Simulink is applied to solve the front axle force balance equation, the diagram is shown in Figure 5. Matlab Simulink is also applied to solve the force balance equation to determine the dynamic load acting on the chassis through the suspension system (Figure 6).

$$m_1\ddot{z}_1 = -F_{z1L} - F_{z1R} + F_{z4L} + F_{z4R} \quad (1)$$

$$I_{1zy}\ddot{\varphi}_{1zy} = \left(-F_{z1L} + F_{z1R}\right)d_1 + \left(-F_{z4L} + F_{z4R}\right)d_4 \quad (2)$$

2. 2. 2. For The Middle Axle The model of separation of objects on the middle axle is depicted in Figure 6. Matlab Simulink is applied to solve the force

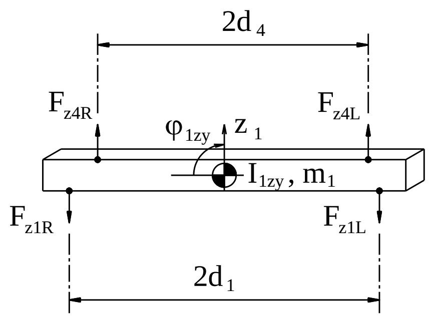

Figure 4. Object separation model of front axle

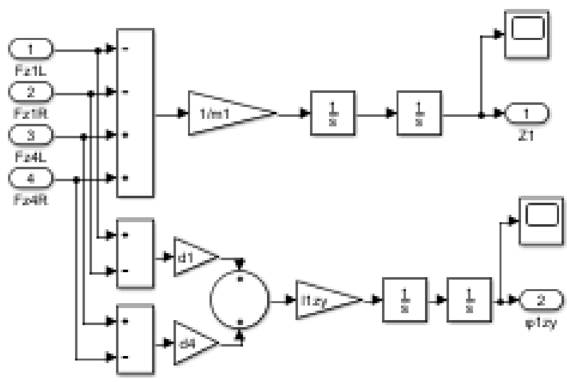

Figure 5. Simulink diagram to solve the front axle force balance equation

balance equation to determine the dynamic load acting on the chassis through the suspension system (Figure 7).

$$m_2\ddot{z}_2 = -F_{z2L} - F_{z2R} + F_{z5L} + F_{z5R} \quad (3)$$

$$I_{2zy}\ddot{\varphi}_{2zy} = \left(-F_{z2L} + F_{z2R}\right)d_2 + \left(-F_{z5L} + F_{z5R}\right)d_5 \quad (4)$$

2. 2. 3. For the Rear Axle The model of separation of objects on the rear axle is depicted in Figure 8. Matlab Simulink is applied to solve the force balance equation to determine the dynamic load acting on the chassis through the suspension system (Figure 9).

$$m_3\ddot{z}_3 = -F_{z3L} - F_{z3R} + F_{z6L} + F_{z6R} \quad (5)$$

$$I_{3zy}\ddot{\varphi}_{3zy} = \left(-F_{z3L} + F_{z3R}\right)d_3 + \left(-F_{z6L} + F_{z6R}\right)d_6 \quad (6)$$

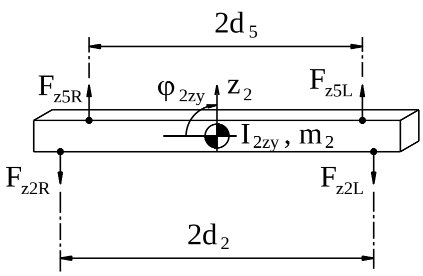

Figure 6. Object separation model of middle axle

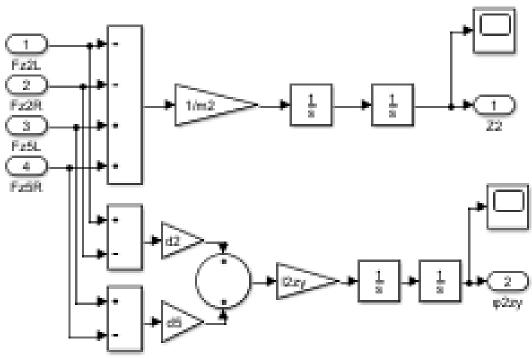

Figure 7. Simulink diagram to solve the middle axle force balance equation

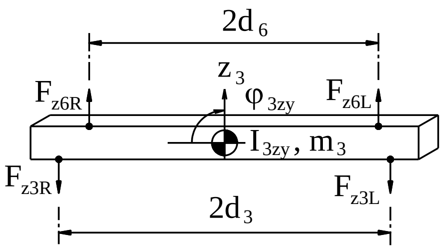

Figure 8. Object separation model of rear axle

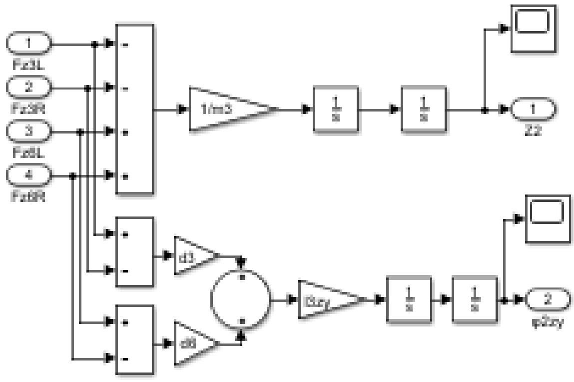

Figure 9. Simulink diagram to solve the rear axle force balance equation

2. 2. 4. For Vehicle Similarly, we can build the object separation model for the vehicle and build the vehicle's force balance equations.

$$m_4\ddot{z}_4 = -F_{z4L} - F_{z4R} + F_{z7L} + F_{z7R} + F_{z8L} + F_{z8R} \quad (7)$$

$$I_{4zx}\ddot{\varphi}_{4zx} = \left(F_{z4L} + F_{z4R}\right)l_1 - \left(F_{z7L} + F_{z7R}\right)l_5 + \left(F_{z8L} + F_{z8R}\right)l_6 \quad (8)$$

$$I_{4zy}\ddot{\varphi}_{4zy} = \left(F_{z4L} - F_{z4R}\right)d_4 + \left(F_{z7L} - F_{z7R}\right)d_6 + \left(F_{z8L} - F_{z8R}\right)d_7 \quad (9)$$

2. 2. 5. For Water Pump Drive Similarly, we can build the object separation model for water pump drive and build the vehicle's force balance equations.

$$m_5\ddot{z}_5 = -F_{z7L} - F_{z7R} + F_{z9} \quad (10)$$

$$I_{5zx}\ddot{\varphi}_{5zx} = \left(F_{z7L} + F_{z7R}\right)l_{12} + F_{z9}l_9 \quad (11)$$

$$I_{5zy}\ddot{\varphi}_{5zy} = \left(-F_{z7L} + F_{z7R}l_{12}\right)d_6 + M_{ct} \quad (12)$$

2 .2. 6. For Sprinklers Similarly, we can build the object separation model for sprinklers and build the vehicle's force balance equations.

$$m_6\ddot{z}_6 = F_{z8L} + F_{z8R} + F_{z9} \quad (13)$$

$$I_{6zx}\ddot{\varphi}_{6zx} = -\left(F_{z8L} + F_{z8R}\right)l_{11} + F_{z9}l_{10} \quad (14)$$

$$I_{6zy}\ddot{\varphi}_{6zy} = \left(-F_{z8L} + F_{z8R}\right)d_7 \quad (15)$$

2. 3. Surveying The Force Balance Model on a Multi-purpose Forest Fire Fighting Vehicle

2. 3. 1. Determine the Parameters of the Model The parameters of the vehicle model are summarized in Table 1 [1, 4].

TABLE 1. Parameters of multi-purpose forest fire fighting vehicle

Order	Technical	Symbol	Unit	Value
1	Front axle mass	m_1	kg	1020
2	Middle axle mass	m_2	kg	1000
3	Rear axle mass	m_3	kg	1000
4	Vehicle mass	m_4	kg	5800
5	Water pump mass	m_5	kg	250
6	Fire sprinkler mass	m_6	kg	1500
7	Stiffness of front wheel tire	C_{L1}	N/m	569964
8	Stiffness of middle wheel tire	C_{L2}	N/m	569964
9	Stiffness of rear wheel tire	C_{L3}	N/m	569964
10	Damping coefficient of front wheel tire	K_{L1}	N.s/m	6497
11	Damping coefficient of middle wheel tire	K_{L2}	N.s/m	6497
12	Damping coefficient of rear wheel tire	K_{L3}	N.s/m	6497
13	The stiffness of front axle suspension without changing stiffness	C_{4B}	N/m	203000
14	The stiffness of middle axle suspension without change stiffness	C_{5B}	N/m	322000
15	The stiffness of rear axle suspension without changing stiffness	C_{6B}	N/m	322000
16	The stiffness of front axle suspension with change stiffness	C_{4A}	N/m	401952
17	The stiffness of middle axle suspension with change stiffness	C_{5A}	N/m	527042
18	The stiffness of rear axle suspension with change stiffness	C_{6A}	N/m	527042
19	Damping coefficient of the front axle	K_4	N.s/m	18900
20	Damping coefficient of middle axle	K_5	N.s/m	18900
21	Damping coefficient of the rear axle	K_6	N.s/m	18900
22	The stiffness of the front bearing	C_7	N/m	203000
23	The stiffness of the rear bearing	C_8	N/m	203000
24	Damping coefficient of the front bearing	K_7	N.s/m	18900
25	Damping coefficient of the rear bearing	K_8	N.s/m	18900

2. 3. 2. Determining the Forest Ground Bump

The purpose of determining the forest ground bump is to serve as an input parameter to determine the dynamic load acting on the chassis. To determine the bump of the forest ground, we must carry out a test. The method of determination is to use the number 2 wheel with an accelerometer sensor to determine the acceleration, then use Dasylab 5.0 software to determine the forest ground elevation.

In order to be able to accurately determine the position of the bumps according to the contour, a Kistler accelerometer must be used, speed sensor V_1, the device that receives and processes measurement data is a computer DEWETRON 3000. During the movement, the vehicle will pull wheel No. 2 rolling on the forest ground, the wheel axle will record the correct forest ground profile and the Kistler sensor will record the acceleration value and transfer it to the computer for processing. Coinstantaneous with the signal of the accelerometer sensor is a signal from the sensor from V_1 to measure the actual moving speed of the vehicle. Thus, at the specified location of the forest ground profile, the bumpy height at that location can be determined.

2. 3. 3. Survey Results of Dynamic Load Assessment

Using Matlab Simulink, we survey and determine the force acting on the chassis when the

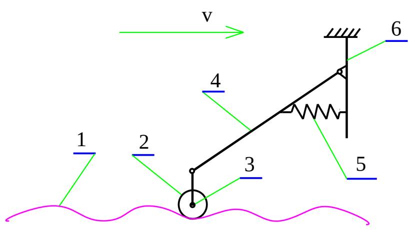

Figure 10. Describe the diagram to determine the bump on the forest ground. *1- Forest ground; 2- wheel 2; 3- Kistler sensor mounting position; 4- link bar; 5- spring; 6- car mount*

Figure 11. Measurement of forest ground bump

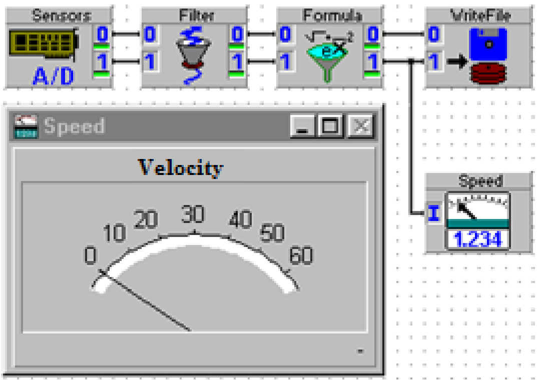

Figure 12. Forest ground measurement program

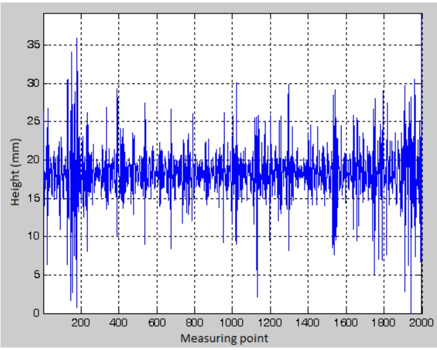

Figure 13. Experimental road surface bump

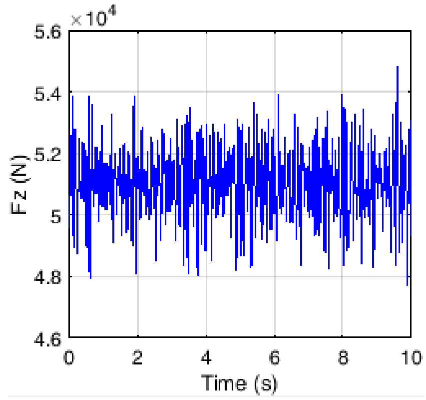

Figure 14. Dynamic load acting on the chassis at the rear axle, v = 10 km/h, C_4 = 203000 N/m, $C_{5,6}$ = 322000 N/m

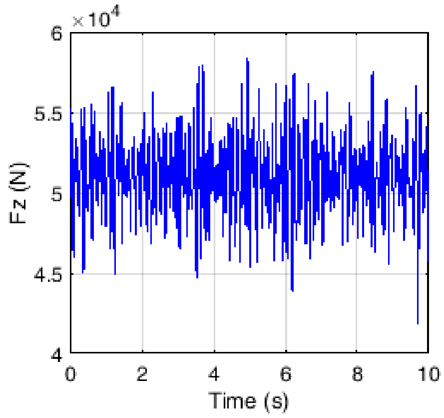

Figure 15. Dynamic load acting on the chassis at the rear axle, v = 10 km/h, C_4 = 401952 N/m, $C_{5,6}$ = 527042 N/m

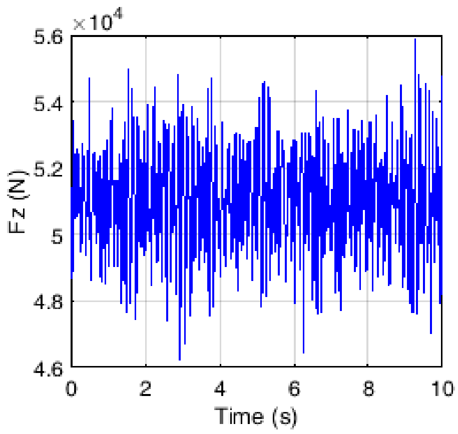

Figure 16. Dynamic load acting on the chassis at the rear axle, v = 15 km/h, C_4 = 203000 N/m, $C_{5,6}$ = 322000 N/m

vehicle moves on the forest road at different moving speeds. In this survey, the author investigates the corresponding suspension stiffness of the base vehicle and the suspension stiffness when it is designed into a forest fire truck to evaluate the dynamic load change. Due to the working characteristics of forest fire trucks with low travel speed [1], the speed of survey vehicles is from 10 km/h to 20 km/h.

When the vehicle is in motion, due to the excitation force of the road surface contour, the dynamic load is applied to the chassis as described in Figures 15 and 16. With a vehicle speed of 10 km/h, the value of the dynamic load acting on the chassis is relatively equal when the suspension stiffness changes. Without changing the suspension stiffness, the maximum dynamic load value on the rear axle is 54833 N, when changing the suspension stiffness, the maximum dynamic load on the rear axle is 58383 N. The maximum dynamic load value when increasing the stiffness is 1.06 times higher than when the hardness is not changed.

When the vehicle speed increases, the excitation force from the road surface causes an increase in dynamic load, making the value of the dynamic load acting on the chassis also increase compared to the case of the vehicle traveling at 10 km/h, described in Figures 16 and 17. With a vehicle speed of 15 km/h, without changing the suspension stiffness, the maximum dynamic load value on the rear axle is 55873 N, with changing the suspension stiffness, the maximum dynamic load on the rear axle is 61912 N. The maximum dynamic load value when increasing the stiffness 1.08 times compared to the original suspension stiffness.

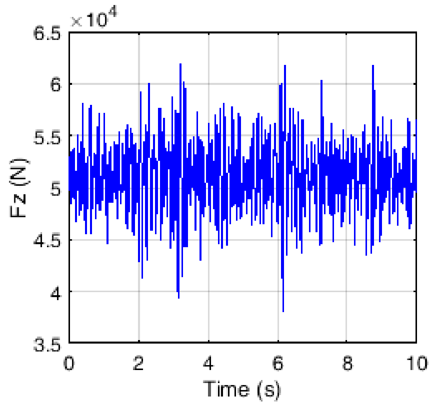

Figure 17. Dynamic load acting on the chassis at the rear axle, v = 15 km/h, C_4 = 401952 N/m, $C_{5,6}$ = 527042 N/m

When the fire fighting vehicle moves at a speed of 20 km/h, without changing the suspension stiffness, the maximum dynamic load value on the rear axle is 58016 N, with changing the suspension stiffness, the maximum dynamic load value on the rear axle is 62225 N. The maximum dynamic load value when increasing the stiffness 1.07 times compared to the original suspension stiffness. The maximum dynamic load acting the chassis without changing and changing the suspension stiffness is summarized in Table 2.

Figures 20 and 21 describe the maximum dynamic load value acting on the chassis at the front and rear axles. The results show that when increasing the suspension stiffness and vehicle movement speed, the dynamic load increases, which is consistent with the laws of physics.

TABLE 2. Maximum dynamic load acting the chassis without changing and changing the suspension stiffness

Vehicle speed	Maximum dynamic load front axle (N)		Maximum dynamic load rear axle (N)	
	C_{1B} = 203000	C_{2B} = 322000	C_{1A} = 401952	C_{2A} = 527042
10 km/h	31960	34109	54833	58383
15 km/h	32603	35654	55873	61912
20 km/h	33405	36251	58016	62225

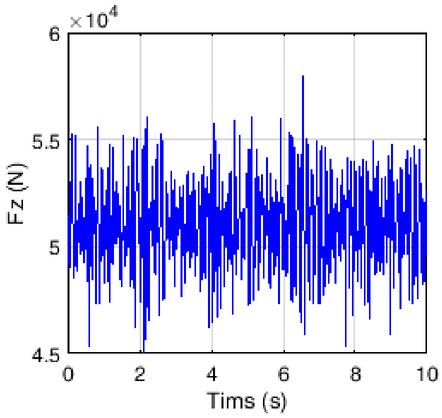

Figure 18. Dynamic load acting on the chassis at the rear axle, v = 20 km/h, C_4 = 203000 N/m, $C_{5,6}$ = 322000 N/m

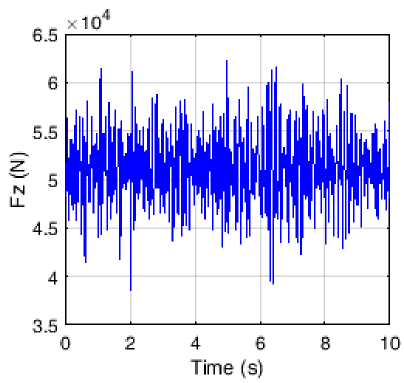

Figure 19. Dynamic load acting on the chassis at the rear axle, v = 20 km/h, C_4 = 401952 N/m, $C_{5,6}$ = 527042 N/m

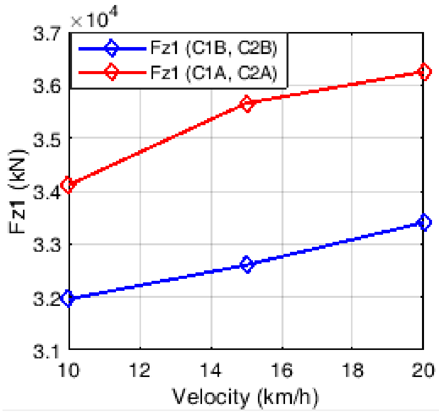

Figure 20. Maximum dynamic load acting on the chassis front axle, v = 10 ÷ 20 km/h

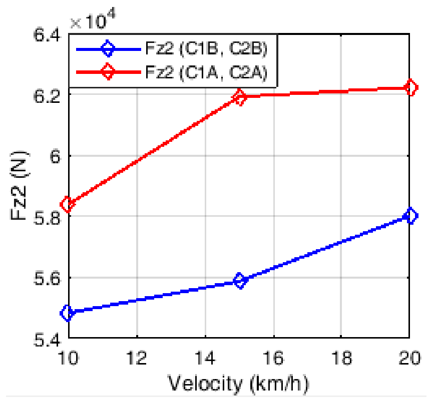

Figure 21. Maximum dynamic load acting on the chassis rear axle, v = 10 ÷ 20 km/h

3. CONCLUSION

The base vehicle URAL 4320 vehicle with permissible payload according to the manufacturer's design is used to make a multi-purpose forest fire truck with enhanced payload, operating on forestry roads with complex terrain. The calculation to determine the force acting on the frame close to the base car to ensure durability when converting the vehicle's features is necessary. The content of the study used the method of separation of objects according to Dalambe's principle and build force balance equations and apply Matlab Simulink to solve. The study will be expanded to fully investigate the operating conditions of the vehicle corresponding to the installation of fire fighting equipment with more uses to improve the effectiveness of forest fire fighting.

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Persian Abstract

چکیده

وسایل نقلیه آتش نشانی جنگلی چند منظوره شامل ترکیبی از تجهیزات آتش نشانی مانند پمپ آب فشار قوی، ایجاد دستگاه برش عایق آتش راهرو، دستگاه بولینگ وکیوم و سرعت باد بالا، اطفاء دستگاه سندبلاست آتش نشانی که بر روی URAL 4320 نصب شده است. وسیله نقلیه سه محور فعال هنگام نصب تجهیزات آتش نشانی بر روی وسایل نقلیه، بار را افزایش می دهد و بر توزیع بار، زاویه و پایداری خودرو تأثیر می گذارد. بنابراین، برای اطمینان از استحکام ساختاری، سیستم تعلیق برای افزایش استحکام دوباره طراحی شده است. با این حال، تغییر سفتی سیستم تعلیق باعث تغییر بار دینامیکی بر روی شاسی می شود. این تحقیق نتایج تحقیق در مورد تأثیر سختی تعلیق بر بارهای دینامیکی وارد بر شاسی یک وسیله نقلیه آتش نشانی جنگلی چند منظوره را ارائه می دهد. نتایج بررسی نشان می دهد که افزایش سفتی سیستم تعلیق باعث افزایش بار دینامیکی وارد بر شاسی و کاهش دوام شاسی به طور خاص و جزئیات خودرو به طور کلی می شود. نتایج تحقیق مبنایی برای ارزیابی عمر کاری شاسی در مطالعات بعدی است.