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DYNAMIC ANALYSIS OF THREE-AXLE SEMI-TRAILER ROAD TANK DRIVING OVER BARRIER

DYNAMICKÁ ANALÝZA TŘÍNÁPRVAVOVÉ CISTERNY PŘI PŘEJEZDU PŘEKÁŽKY

Abstract

This article deals with dynamic analyses of a truck with semi-trailer three-axle road tank for transport of the loose materials (i.e.: corn – barley, wheat, rye, oats, etc.). These articulated vehicles are going over barriers. Calculated forces and reactions of these vehicles are used for the quasi-static analysis of strain and deformation of the road tank. These analyses represent a theoretical preparation of the experimental verification of the road tank. The results of the quasi-static calculation help to define suitable places for strain gauges and accelerometers. Some results of the dynamic simulations will be used for extensive dynamic and fatigue analyses of the road tank and its behaviour in real traffic conditions. Both the dynamic simulations of the simplified truck-tank model and calculation of the separated tank strain-deformation are solved by SolidWorks SIMULATION 2012 [7] which is performed by the finite element method (FEM).

Abstrakt

Tento článek se zabývá dynamickou simulací přejezdu tahače s třínápravovou návěsovou cisternou na sypké hmoty přes překážky. Vypočtené silové zatížení této soupravy je použito pro kvazistatický výpočet stavu napětí a deformace samotné cisterny. Jedná se o teoretickou přípravu experimentálního ověřování skutečné cisterny, kde výsledky simulací napomohou vytipovat vhodná místa pro umístění tenzometrů a akcelerometrů. Získané výsledky poslouží jako základ pro obsáhlou dynamickou a únavovou analýzu chování cisterny ve skutečném provozu. Jak výpočtová analýza chování jednoduchého dynamického modelu celé soustavy, tak i kvazistatická analýza podrobného modelu samotné cisterny jsou provedeny v programu SolidWorks SIMULATION 2012 [7], který je založen na metodě konečných prvků (MKP).

Keywords

FEM, high-cycle fatigue, natural frequency, natural mode, road tank.

1 INTRODUCTION

Road transport is still the most popular and used way of goods and material relocation. At present, it is necessary to produce road transport vehicles (trucks, semi-trailers, etc.) of the best quality. Vibration of vehicles affects road safety and also lifetime of chassis and many other parts. It is important to describe the behaviour of road tank, axles and wheels on road. Next, the right damping and stiffness of the suspension have to be found out. Finally, vibration should be optimized and reduced [3], [6]. The character of behaviour is checked by computer simulations. In this way, it is

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possible to simulate very dangerous situations (i.e.: sharp turning at a high speed, driving on inclined plane, crash with standing or moving objects, etc.). The advantage is low costs of simulations in comparison real prototypes producing but verification between computer simulations and measuring on the real chassis is necessary for reliability of the results. The main aims of this paper can be summarized in a few points:

- to create a computer dynamic model of the truck with semi-trailer three-axle tank,
- to calculate the natural frequencies and modes,
- to perform the computer simulations of going on the special waved road for different speeds.

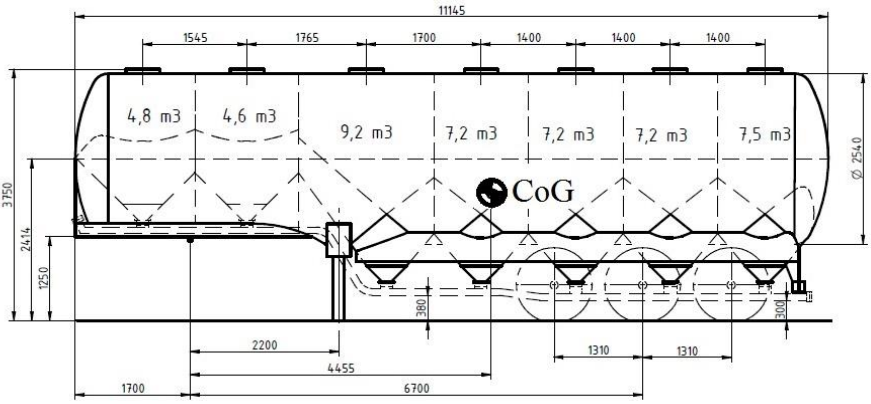

Fig. 1 Dimensions of NKA 46 road tank (with marked Centre of Gravity)

2 SPECIAL WAVED ROAD

This special roadway used for computer simulations is similar to the real road at the test circuit in Kopřivnice (Czech Republic). This road is called as ´´resonance roadway´´ inducing resonant vibration of the tested vehicles. The waves on the roadway have triangular shape. Each wave is about 80 mm wide and 20 mm high. The distance between two waves is 770 mm. The total number of waves is 26 in each computer simulation. During the computational analyses, the profile of roadway is simulated by means of a base excitation under each wheel. The shape of excitation impulse is given by the relationship of wheel position and time. Only kinematic excitation in the vertical direction is considered. All wheels are excited in a suitable phase shift which depends on the simulated speed.

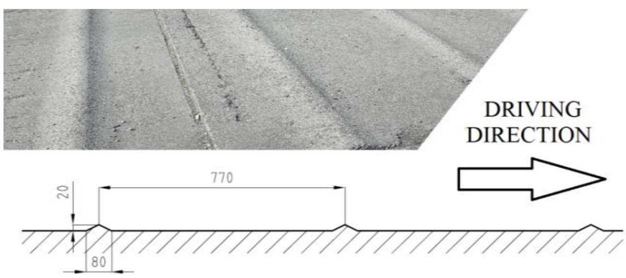

Fig. 2 Profile of roadway

3 DYNAMIC TRUCK-TANK MODEL

This preliminary truck-tank model has to be simplified in comparison with the real truck-tank assembly. The model of the articulated vehicles (truck-tank) consists of several elementary 3-D objects (cylindrical shell and blocks). Main features of the model (mass, dimensions, centre of gravity position) are the same as the real tank [5]. The vehicle is modelled as a rigid body but the cylindrical shell of real bending and torsion stiffness. The grain mass (loose material) is distributed into the front and rear cap of the cylindrical shell. This material is considered a passive mass therefore it moves together with the tank. It also means that the tank is not dampened by movement of grain which is certainly conservative simplification. The global damping is chosen 0.05 which should be appropriate for welded construction. For the purposes of this study, the values of suspension stiffness and damping were adopted from literature [3], [6]. In a first approximation, these values are considered to be linear which simplification is again. A linear model of tires is used. One spring for each wheel represents the stiffness in the vertical, lateral and longitudinal directions. Their values are also used from literature [3], [6]. These linear simplifications are usually used in practice. The influence of results should be minor. The modelled joint between the truck and tank should be similar to the real truck-tank joint (king pin). The king pin allows relative rotation in all directions between the truck and semi-trailer. The mesh of model is quite thin (rough mesh). It should be sufficient for this task because we do not study a strain or deformation but only movements of the tank.

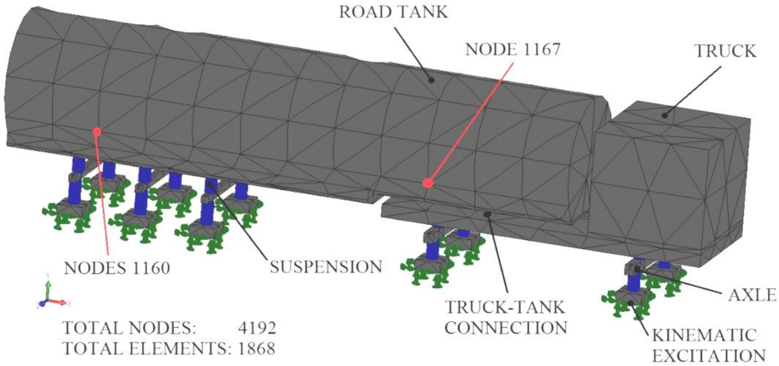

Fig. 3 Model and mesh

4 NATURAL FREQUENCIES

First, it is necessary to find out natural frequencies and natural modes [1], [2]. The frequency analysis is performed by means of the computational software SolidWorks SIMULATION [7]. This analysis enables us to define natural frequencies by modal mass participation. The cumulative mass which is the sum of all modal masses has to be minimal 80% of the total mass in each direction for relevant results. Six natural frequencies and modes are considered. The cumulative mass of six considered natural frequencies in all three directions is about 91% (see Tab. 1).

Tab. 1 Natural frequencies and modal mass participation list

Mode no.	Frequency [Hz]	X direction	Y direction	Z direction
1	0.726	0.000	0.000	**0.582**
2	0.877	**0.889**	0.000	0.000
3	1.518	0.019	0.107	0.000
4	1.568	0.000	0.000	0.002
5	1.581	0.002	**0.809**	0.000
6	2.448	0.000	0.000	**0.333**
$\sum$		*0.910*	*0.916*	*0.917*

It is evident that the first natural frequency affects on 58.2% of the total mass in Z direction (left-right). The second natural frequency affects on 88.9% of the total mass in X direction (front-back). The modal mass of the third and fourth natural frequencies are negligible. But, the fifth natural frequency is significant in Y direction (up-down). The last natural frequency affects on the total mass by only 33.3% in Z direction.

The resulting natural modes of the 1st, 2nd, 5th, and 6th natural frequencies are shown in Fig. 4 - 7. The difference between 1st and 6th mode lies in the fact that 1st mode has the roll centre at the bottom (under axles) and 6th mode has the roll centre at the top of the tank.

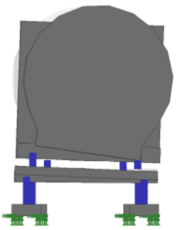

Fig. 4 1st mode – roll

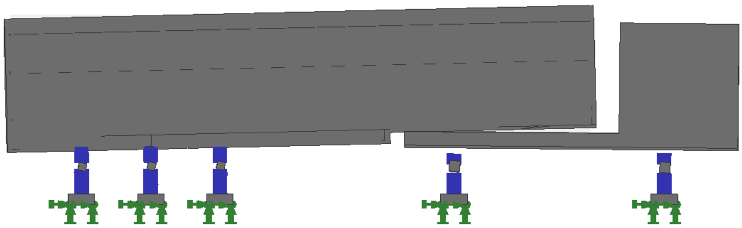

Fig. 5 2nd mode – pitch (tank) & bounce (truck)

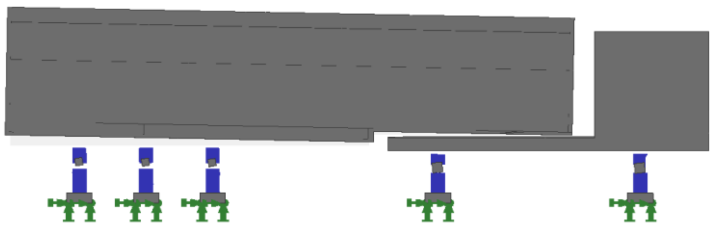

Fig. 6 5th mode – bounce (truck & tank)

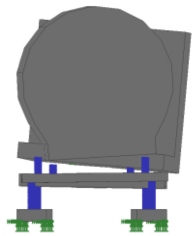

Fig. 7 6th mode – roll

Next, it is necessary to calculate suitable speeds (right excitation frequencies) which correspond with significant natural frequencies. The resonance is achieved if the excitation frequency is in accord with the corresponding natural frequency. Then, it is possible to simulate the most dangerous driving on the waved road. There are also performed simulations for speeds of 8, 10, 13, and 30 km/h for better imagination about the tank behaviour at higher speed.

5 COMPUTER SIMULATIONS OF DRIVING ON SPECIAL WAVED ROAD

In this chapter, the behaviour of semi-trailer tank going on the special waved road is studied. The response of the tank is studied in two nodes. The first node (no. 1167) is near the truck-tank connection. The front part of the tank is depended on a movement of the truck. The second node (no. 1160) is placed at the rear part of the tank (near the second and third tank axle). Both of nodes are on the right side of the cylindrical shell. The rear part of the tank is not affected so much by the truck. The response of this part is depended on damping and stiffness of the tank suspension [4]. The articulated vehicles move over 26 triangular waves. For each speed is used appropriate phase shift. Simulations are performed for speeds – 2, 2.4, 4.4, 6.8, 8, 10, 13, and 30 km/h.

Tab. 2 Response – maximal displacements

Natural frequency	Velocity	|UX| max	|UY| max (1167)	|UY| max (1160)	|UZ| max
[Hz]	[km/h]	[mm]	[mm]	[mm]	[mm]
0.726	2	2.230	**5.461**	**5.087**	**0.069**
0.877	2.4	**3.880**	4.565	3.870	0.060
1.581	4.4	0.858	5.040	2.631	0.029
2.448	6.8	0.469	1.957	2.379	0.031
-	8	0.469	1.445	2.118	0.034
-	10	0.549	1.759	2.336	0.029
-	13	0.543	2.289	2.876	0.028

It is obvious that the first natural frequency (0.726 Hz) really generates the maximal displacement in Z direction as well as the second natural frequency (0.877 Hz) generates the maximal displacement in X direction. The maximal displacement in Y direction was expected because of the fifth natural frequency excitation (1.581 Hz) but this premise is wrong. The largest displacement is found at the first natural frequency. The next step in evaluating of responses is transform signals by the Fast Fourier Transformation (FFT).

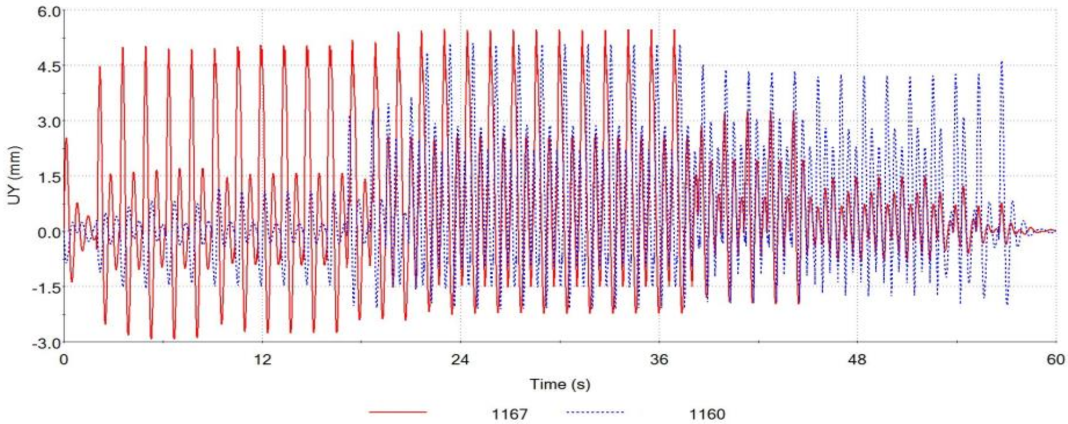

Fig. 8 Maximal Y displacement – 2 km/h ($UYmax_{1167}$ = 5.461mm, $UYmax_{1160}$ = 5.087mm)

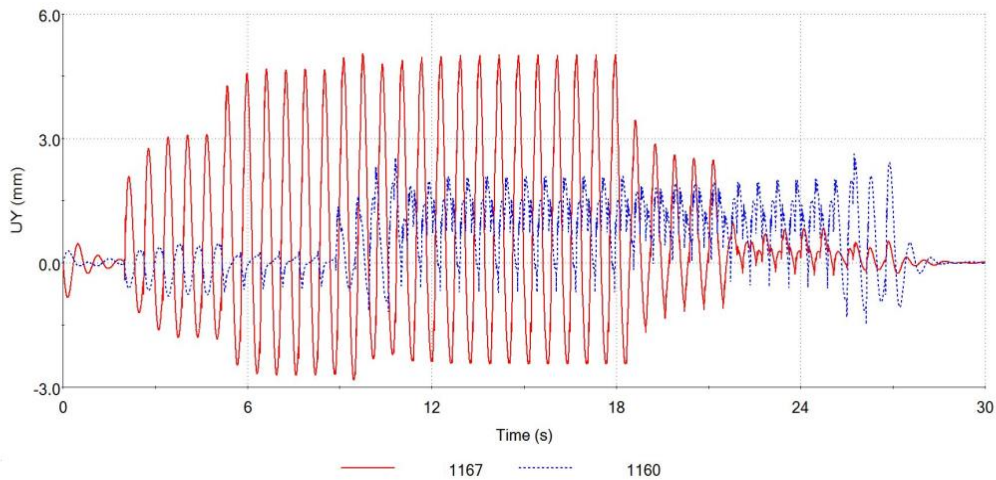

Fig. 9 Maximal Y displacement – 4.4 km/h ($UYmax_{1167}$ = 5.040mm, $UYmax_{1160}$ = 2.631mm)

The most interesting results are shown at speeds 2 km/h and 4.4 km/h in Y direction (Fig. 8 and 9). The maximal displacement was expected at speed 4.4 km/h but the front part of road tank and rear part of tank are completely out of phase from 10 s until 19 s. Especially, this situation affects displacement amplitudes of the real part (no. 1160). The maximal amplitude is only 2.63 mm.

It is possible to compare the effect between natural frequencies and other ones. In this case, Fast Fourier Transformation is used. The highest peaks are visible at natural frequencies or their harmonic components in all directions.

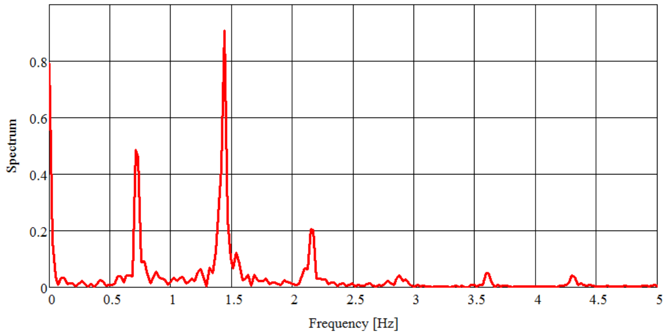

Fig. 10 FFT result – Y direction (node 1167) – 2 km/h (fmax = 1.44 Hz)

From investigated speeds (2, 2.4, 4.4, 6.8, 8, 10, 13, 30 km/h) is the worst situation in Y direction – node 1167 (up-down) at 2 km/h. In this picture the first peak corresponds with the first natural frequency (0.73 Hz). The highest peak corresponds with frequency approximately 1.44 Hz. Probably, it is the second harmonic components of natural frequency. Other frequencies are insignificant in Y direction.

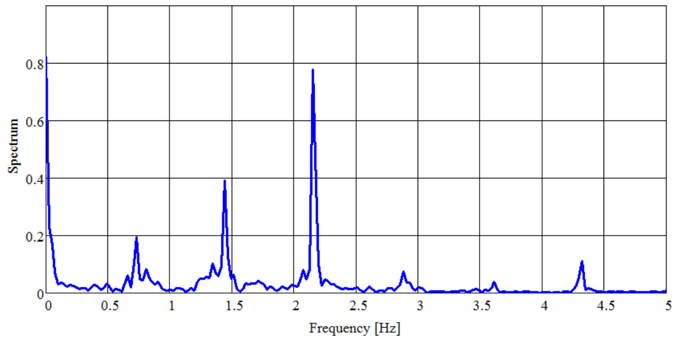

Fig. 11 FFT result – Y direction (node 1160) – 2 km/h (fmax = 2.15 Hz)

From investigated speeds is the worst situation in Y direction – node 1160 (up-down) at 2 km/h. In this picture the first peak corresponds with the first natural frequency (0.73 Hz). This frequency is also excitation frequency. In this case the highest peak corresponds with frequency 2.15 Hz. It is the third harmonic components of natural frequency. Other frequencies are insignificant in Y direction.

CONCLUSIONS

The major attention was dedicated driving on the special waved roadway. Values of main natural frequencies were found – 0.73 Hz, 0.88 Hz, and 1.58 Hz. Each of these frequencies is important for movements in different direction (X, Y,Z). Critical speeds of driving were calculated – 2 km/h, 2.4 km/h, and 4.4 km/h. The articulated vehicles hardly ever go slower than 10 km/h. These slow speeds are reached only when the truck starts or stops. Computer simulation for these and several other speeds were performed. Maximal displacements for eight speeds were found in X, Y, Z directions. The driving on the special waved roadway gave us a good imagination about overall damping and suspension stiffness. Results of all simulations were evaluated by FFT. Especially, the excitation frequencies and their harmonic components were discovered. For simulation, several simplifications were used (shape of articulated vehicle, linear damping a stiffness of suspension) so it would be good to verify results by the real tank test. The strain gauges and accelerometer measuring would give us the best imaginations about the behaviour of the tank. This article will be used for extensive dynamic and fatigue analysis of the road tank and its behaviour in real traffic conditions.

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