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Research Paper

The Effect of Dolly Suspension Parameters to the European Modular System Vehicle Combination

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Abstract

The European Modular System (EMS) is introduced to allow increased vehicle length and weight for road freight transport. Directive 96/53EC defines the types of combinations for this modular concept. This study concentrates on the Type-3 EMS so called "road train" including truck, dolly and semi-trailer combination. To get an idea about the effect of this long module combination over the valuable goods transportation, three cases are defined for the dolly's front and rear suspension parameters, than 14-degree of freedom (DOF) half vehicle models are generated in order to observe the dynamic characteristics of the road-train for these three cases. Modal and transient analyses are performed and vertical displacement responses are obtained from front , middle and the end of the semi-trailer's nodal points. Pitch angles of the semi-trailer body are also demonstrated. The change in the bounce responses and the pitch angles are interpreted for all three cases. It is observed that the middle of the body is affected less by vertical displacement.

Key Words : European Modular System, Road Train, Dolly, Half Vehicle Model, Modal Analysis, , Transient Analysis

1.INTRODUCTION

The participation of Sweden and Finland required a new definition for the road freight transport in European Union. As the longer and heavier vehicle combination (LHV) usage is a majority in these two countries, a new modular system is defined with the combination of a 7.82m long swap body and 13.6m long semi-trailer with a total length of 25.25 m called European Modular System (EMS). EMS consists of three modules according to 95/53 EC directive as given in Figure 1. In order to get a 25.25 m long combination, Module A uses a truck/dolly/semi-trailer, Module B uses a tractor/semi-trailer/central axle trailer, Module C uses a tractor/B-train (or B-double) containing swap body/semi-trailer combination.

Several studies have been done to see the advantages and disadvantages of this modular system. In the study of Larsson [1], the benefits of EMS is defined as positive environmental impact over CO_2 emissions, reduced congestion, co-modality & inter-modality, improved traffic safety, supporting logistics efficiently and flexible use of existing vehicle units. Akerman et al. [2] published a study to evaluate the Swedish and Finnish hauliers' experiences. They demonstrate less fuel consumption, reduced transport costs, less vehicles carrying the same amount of properties as the advantages of this concept. They also comment the possibility of increment in the market share of road transports and accident rate as the disadvantages. Whereas Grislis [3] declares that there is not a proven evidence that shows LHVs are more dangerous than an ordinary truck/trailer or truck/semi-trailer combinations. Aurell et al. [4] also mentions LHVs' have better dynamic stability than shorter vehicle combinations. The other benefit of this concept is the intersection with the railway transportation as swap body usage is more popular in road trains. Eom at al. [5] shows shift toward railway from truck presents a sizable opportunity to reduce freight CO_2 emissions.

The aim of the study given in this article is to see the impacts of dolly's suspension system parameters to the general vehicle dynamics for a Module A type combination. In order to see the vehicle responses, a considerable amount of computer simulations are performed. In his Master thesis Lundberg [6] pointed out the importance of the simulation results to understand deeply how several attributes affect the vehicle response as per a particular road excitation.

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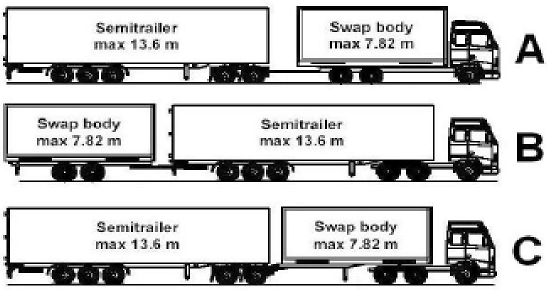

Figure 1. EMS Combinations

to perform modal and transient analyses to see the vertical and pitch responses of the complete vehicle structure. Past literature studies include modal analysis of trailer frames to observe the mode shapes of the complete body [10,11,12]. It can be strongly supported that considering the change in the mode shapes is one of the important design criteria.

Gillespie comments as there are not separate bounce and pitch modes as most vehicles move through the vertical and pitch directions synchronously [13]. Karmiadji [14] performed an analysis including bounce and pitch motions through X-Z body motion algorithm. Penaz et al. [15] made a modal analysis for a three axle semi-trailer, and they also found several pitch-bounce modes. Spivey [16] and Walhekar et al. [17] configured a 15 and 17-DOF half vehicle truck-semi-trailer models respectively to see the dynamic response on several locations of the vehicle combination.

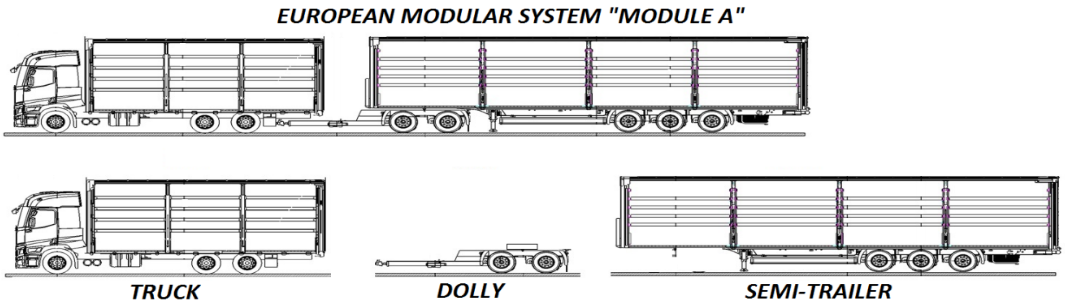

Figure 2. EMS Module A Vehicle Definition

Patil [7] shows the importance of vehicle dynamics models for automotive research and development studies. Several models such as quarter, half and full vehicle models can be used to examine the dynamic behavior of a vehicle. Malgaca et al. [8] uses half vehicle model to observe the bounce-pitch dynamics of a bus, while Philipson et al. [9] mentions using a full vehicle model to see the roll characteristics of a truck-trailer combination.

Figure 3. Dolly Suspension System

In this study three different cases are defined including different suspension parameters and 14-DOF half vehicle models are created for each cases. Half vehicle model is used

2.METHODS

2.1 EMS "Module A" Vehicle Definition

Complete vehicle combination consists of a three axle truck, two axle dolly and semi-trailer is given in Figure 2. The dolly vehicle includes a telescopic draw bar to supply the connection between the dolly and the truck. The fifth wheel over the dolly let the semi-trailer couples them to each other. Both axles are rigid while the front one is force-steer. Both front and rear suspension systems include an air bellow, trailing arm and hydraulic-telescopic shock absorbers as given in Figure 3.

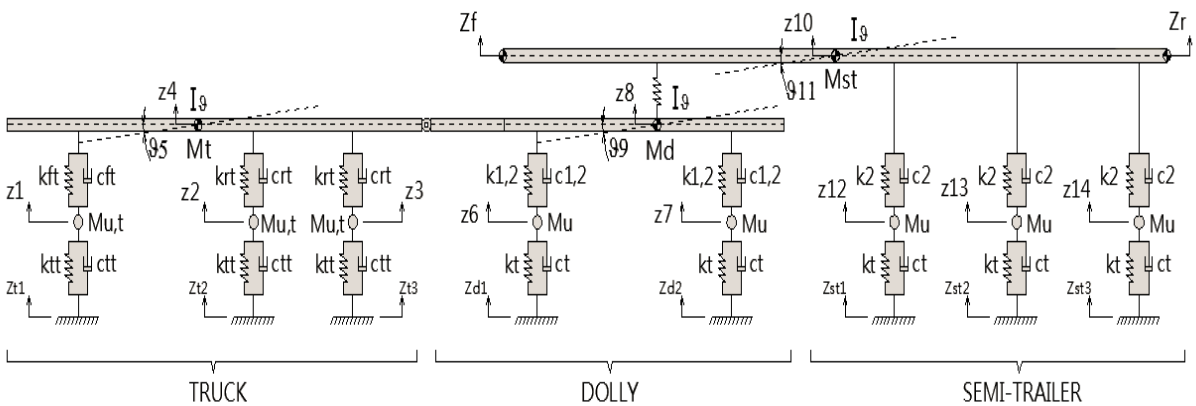

Figure 4. Half Vehicle Model

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2.2 Half Vehicle Model and Case Definition

14 degree of freedom half vehicle model is configured as given in Figure 4. System inputs are seen as base excitations zt_n, zd_n and zst_n. System coordinates consists of 11 displacement z_n and 3 angle ϑ_n values. Truck frame, dolly frame and semi-trailer frames are modeled as the solid beam. Unsprung masses are lumped into the wheel centers, $M_{u,t}$ represents the truck unsprung mass and M_u represents the dolly and semi-trailer unsprung masses. Both primary suspension system and tires are modeled with spring-damper couples, spring rate and damping ratios are reduced to wheel axis. There are two different spring and damper characteristics for dolly as given $k_{1,2}$ means k_1 or k_2 which is subjected to soft and harsh springing that will show how the semi-trailer is affected from this parameter changes. Z_f is the front end and Z_r is the rear end vertical displacements of the semi-trailer, Z_{10} is the center of gravity location displacement of the semi-trailer body which is more less in the middle of the frame structure. Continue on of this paper, displacement-time graphics will be demonstrated from Z_f, Z_r and Z_{10} locations for each cases to observe the effect of the suspension parameter change.

As mentioned above there will be 3 different cases as the mixture of two vertical ride frequency values. k_1 and k_2 spring rates will create 1.62 Hz and 2.1 Hz vertical ride frequency, respectively. Table 1 defines the three cases for different front and rear ride frequencies.

Table 1. Case Definition

Case #	Front Vertical Frequency	Rear Vertical Frequency
1	2.1	1.62
2	2.1	2.1
3	1.62	2.1

Table 1 shows that Case 1 represents a harsh front axle springing and a soft rear axle springing, Case 2 represents a harsh springing for both of the axles and Case 3 represents a soft front axle springing and a harsh rear axle springing.

2.3 Modal Analysis

Modal Analyses are performed for all three cases and natural frequency values are given in Table 2. First four mode shapes are belongs to pitch-bounce modes. Malgaca et al. [8] remarked that since the road inputs excide the front wheels of the vehicle first, pitch motions occur even during small obstacle transitions. As a matter of fact it can not be seen a pure bounce or pitch mode in any mode shapes.

In the first mode shape the whole vehicle combination moves together, while the truck and the dolly perform a pitch motion together as a couple, the semi-trailer travels in vertical axis with a very limited pitch motion.

In the second mode shape, the truck and the trailer perform a pitching motion at the same direction but the dolly sweeps a bigger pitch angle. The semi-trailer also pitches harmoniously with the truck and the dolly couple.

Table 2. Natural Frequency Values

Mode Shape #	Case 1	Case 2	Case 3
1	1.49	1.42	1.50
2	1.53	1.53	1.54
3	1.69	1.65	1.71
4	1.78	1.77	1.84
5		10.90	
6		10.94	
7		10.94	
8		10.96	
9		10.97	
10		11.23	
11		11.27	
12		11.77	
13		1640	
14		4947.3	

In the third mode shape, this time dolly and the semi-trailer act as a couple and perform a pitching motion together, while the truck pitches to the other angular direction.

In the forth mode shape, the combined structures move relatively to each other, where the truck and the dolly perform pitch motions to the different angular directions, the situation is the same for the dolly and the semi-trailer, they also pitch to the opposite angular side.

Mode shapes between the fifth mode and the twelfth mode demonstrates the natural frequency modes of unsprung masses of the truck, the dolly and the semi-trailer. Table 2 shows that they are not affected from dolly suspension parameter change.

Thirteenth and fourteenth mode shapes are related with the natural frequency modes of the draw bar coupling and the fifth-wheel coupling respectively. They are also the same for all cases.

2.4 Transient Analysis

Analyses are carried out in ANSYS software including all three cases for the vehicle combination travels over a 0.1m height bump with 54 km/h velocity. Displacement-time graphics are demonstrated in Figures 5, 6 and 7 respectively for three cases including the front end, rear end and center nodal points of the semi-trailer.

3 RESULTS

3.1 Displacement-Time Responses of the Semi-Trailer

Table 3 shows the peak points of the curves for the nodal points according to Figures 5, 6, 7. The maximum displacement values are as given in below table.

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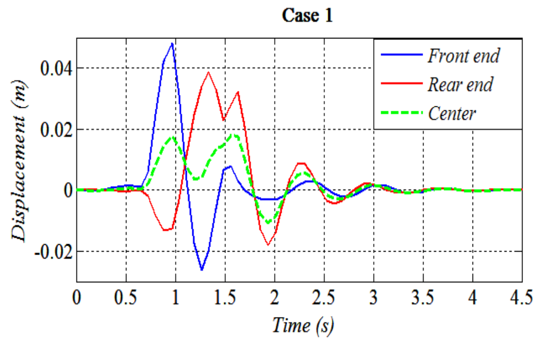

Figure 5. Case 1, Displacement-Time Graphic

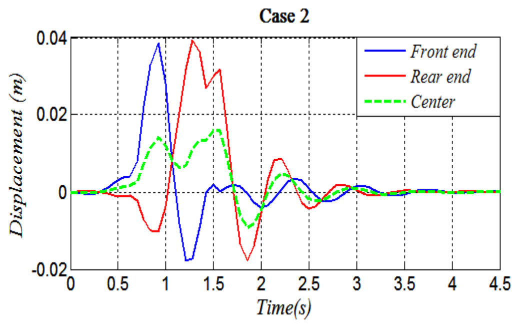

Figure 6. Case 2, Displacement-Time Graphic

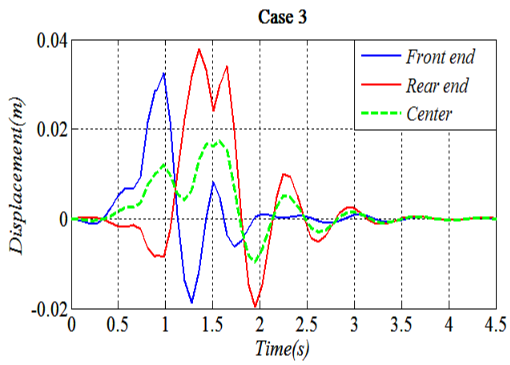

Figure 7. Case 3, Displacement-Time Graphic

Table 3. Maximum Displacement Values

Case #	Travel	Displacement (m)		
		Front end	Rear end	Center
Case 1	Bump	- 0.026	- 0.018	- 0.010
	Rebound	+ 0.048	+ 0.038	+ 0.018
Case 2	Bump	- 0.018	- 0.018	- 0.009
	Rebound	+ 0.039	+ 0.039	+ 0.016
Case 3	Bump	- 0.019	- 0.019	- 0.009
	Rebound	+ 0.032	+ 0.037	+ 0.017

3.2 Pitch Angle-Time Responses of the Semi-Trailer Body

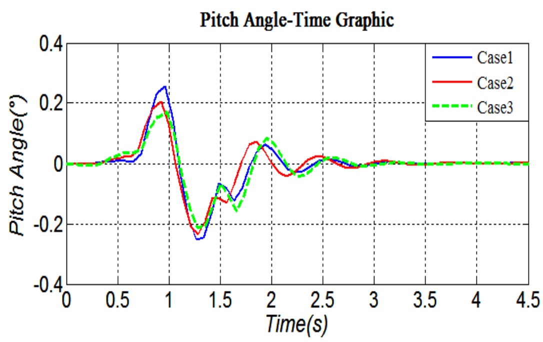

Figure 8. Pitch Angle-Time Graphic

Table 4 shows the peak points of the curves given in Figure 8. The maximum pitch angle values are calculated by the summation of top and bottom angle values.

Table 4. Maximum Pitch Angle Values

Case #	Travel	Pitch Angle (°)
Case 1	Top	0.2548
	Bottom	-0.2518
	Total	0.5066
Case 2	Top	0.2053
	Bottom	-0.2371
	Total	0.4424
Case 3	Top	0.1720
	Bottom	-0.2112
	Total	0.3832

4 CONCLUSIONS

This study analyzed the effect of the suspension parameters change in a dolly to the freight transportation in a semi-trailer.

Modal analysis results show that four mode shapes are effected due to suspension parameter change and all of these mode shapes belongs to pitch-bounce modes. It can be said that there are not a significant change in the natural frequency values with the selected ride frequency cases, but the lowest natural frequency values exist in Case 2 on which both axles have the harsh springing characteristics. Results demonstrate that the increment in the vertical frequency of a suspension system creates a drop in the natural frequency values of the pitch-bounce modes. According to the values given in Table 2, it can be interpreted that if the difference in the vertical frequency values increase between front and rear axles from soft springing through harsh springing, the difference will be more significant in the natural frequency values.

Section 3 demonstrates the nodal responses of the semi-trailer according to the defined cases. Transient analysis results show that maximum front end displacement value occurs in Case 1 which represents a harsh front springing and soft rear springing. Rear end and center nodes seem does not been affected too much from suspension parameters change.

Results given in Table 4 shows that pitch angle is mostly affected from Case 1, harsh front springing and soft rear springing. There is a significant drop in the pitch angle in the semi-trailer body as the springing starts from soft to harsh in the front axle, but the situation is opposite for rear axle springing, if pitch angle is requested to decrease than the rear axle vertical frequency should be increased.

According to the results presented in this study, if a fragile furniture is transported in a semi-trailer of Module A type European Modular System, it will be suggested to be located through the center of the trailer frame as much as possible.

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