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SHOCK ABSORBER CHARACTERISTICS REPRESENTATIONS AND VEHICLE PERFORMANCE EVALUATION

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ABSTRACT

The main objective of the present work is to study theoretically and experimentally how the ride performance is affected by shock absorber representation. To achieve this goal, mathematical modeling of vehicle suspension system is introduced, and the MATLAB/ SIMULINK and ADAMS software are used for numerical simulation.

The shock absorber characteristics are measured experimentally. An advanced test rig for measurement, recording, and computer analyzing the readings is used. The time history of force applied, the force versus displacement and force versus velocity are given in sheet and also in graphs.

An analysis of the obtained results considering the actual measured characteristics has been carried out. For the considered vehicle, it is concluded that, the actual shock absorber representation improve the response of sprung mass acceleration up to (37 %), pitch acceleration up to (74.3 %), vehicle ride index up to (58.4 %), and vehicle road holding up to (-4.25 %) compared to the results obtained using linear shock absorber approximation.

KEY WORDS

Shock absorber, Vehicle ride, Vehicle handling, Vehicle performance

NOMENCLATURE

a, b:	Distance of c.g. from front and rear axles
B2, B4:	Front and rear damping rates.
f1,f3:	Dynamic tire forces.
f2,f4:	Dynamic body forces.
K1,K3:	Front, rear tire radial rates.
K2, K4:	Front & rear suspension spring rates.
K:	Body pitch radius of gyration about the c.g.
L:	Wheel base (a+b)
M:	Half the total body mass
M1, M3:	Un-sprung masses at front and rear.

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1. INTRODUCTION

Suspension system designs are mostly based on ride and control analysis. The simplest and most common types of suspensions are passive suspensions in the sense that no external source of energy is required. With the development of modern control theory and the extraordinary development of inexpensive and reliable electronic devices, the active suspension system in which the actuator can generate forces to compensate for the bounce and the pitching is being considered. However; this type of suspension is under debate because it still consumes large amount of energy with comparatively high cost. In passive suspension systems, the ride and control are two contradictory design objectives. There is a wealth in the references [1 – 8], which discuss the ride and control performance. There are some design numbers for suspension specifications of passenger cars useful in ride comfort and handling these are reviewed by Barak [3]. These numbers are helpful for mathematical models, which describe the dynamic motion of vehicle on the road. In spite of the fact that these numbers may not be correct for all vehicles, it can give a guide to the designer, for that it is called magic numbers in design. Example of these magic numbers in ride: ride comfort criteria=1Hz, transmissibility= $\sqrt{2}$ and wheel hop frequency = 10. For handling: lateral acceleration = 0.3g , steady state lateral acceleration= (0.6-0.9) g.

In this paper, the shock absorber characteristic as a part of a passive suspension system is studied with the objective of measuring actual shock absorber characteristics to be used in simulation. In order to carry out this objective, different existing vehicle mathematical models representing the vehicle dynamics is checked, choosing a suitable software tool (Matlab/Simulink) and (ADAMS) Automatic Dynamic Analysis of Mechanical Systems for numerical simulation, and experimentally measurements of the actual characteristics of different shock absorbers using an advanced test rig found in the Egyptian army. The results of measurements of the shock absorber characteristics are used for the numerical simulation.

2. VEHICLE MATHEMATICAL MODEL:

The model being used is the half car model, shown in Fig. 1. This model has 4 degrees of freedom (DOF) [5 &6]. The 4 DOF, are bounce and pitch of the sprung mass, and the bounce of the two un-sprung masses. The model is simple enough that it lets the user keep track of the variables considered. However; its degree of sophistication is enough to obtain the required accuracy.

Referring to the model in Fig. 1 and for small deflections, the following set of equations may be derived according to the nomenclature and Fig.1.

$$x_2 = x + a\,\Phi \quad (1)$$

$$x_4 = x - b\,\Phi \quad (2)$$

$$M\,(d2x/dt^2) = f_2 + f_4 \quad (3)$$

$$J\,(d2\Phi/dt^2) = af_2 - bf_4 \quad (4)$$

$$f_2 = k_2\,(x_1 - x_2) + B_2\,(\,(d2x_1/dt^2) - (d2x_2/dt^2)\,) \quad (5)$$

$f_4 = k_4 (x_3 - x_4) + B_4 ((d2x_3/dt^2) - (d2x_4/dt^2))$ (6)

$M_1 (d2x_1/dt^2) = f_1 - f_2$ (7)

$M_3 (d2x_3/dt^2) = f_3 - f_4$ (8)

$f_1 = K_1(x_a - x_1)$ (9)

$f_3 = K_3(x_b - x_3)$ (10)

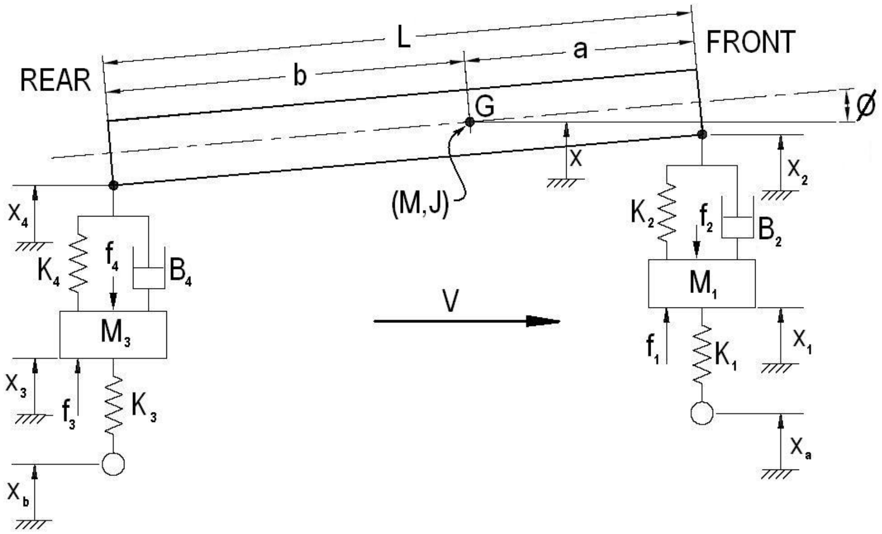


Fig. 1 The Half Car Model

The Matlab/ Simulink and ADAMS program tools are used in simulation. Fig. 2(a) and Fig.2(b) show the Simulink and ADAMS representation of the model; respectively. The results of the half car model are compared with those given by Thompson [5]. Table 1 shows the sum of the integral-squared values (PI) of the front and rear tire deflections, calculated by the different simulation programs compared to those obtained from reference [5]. Fig.3 (a) and Fig.3 (b) show sample results of the simulation model (time history for the pitch displacement, and sprung mass acceleration.). It should be noted that PI is calculated as follows [5, 6 & 9]:

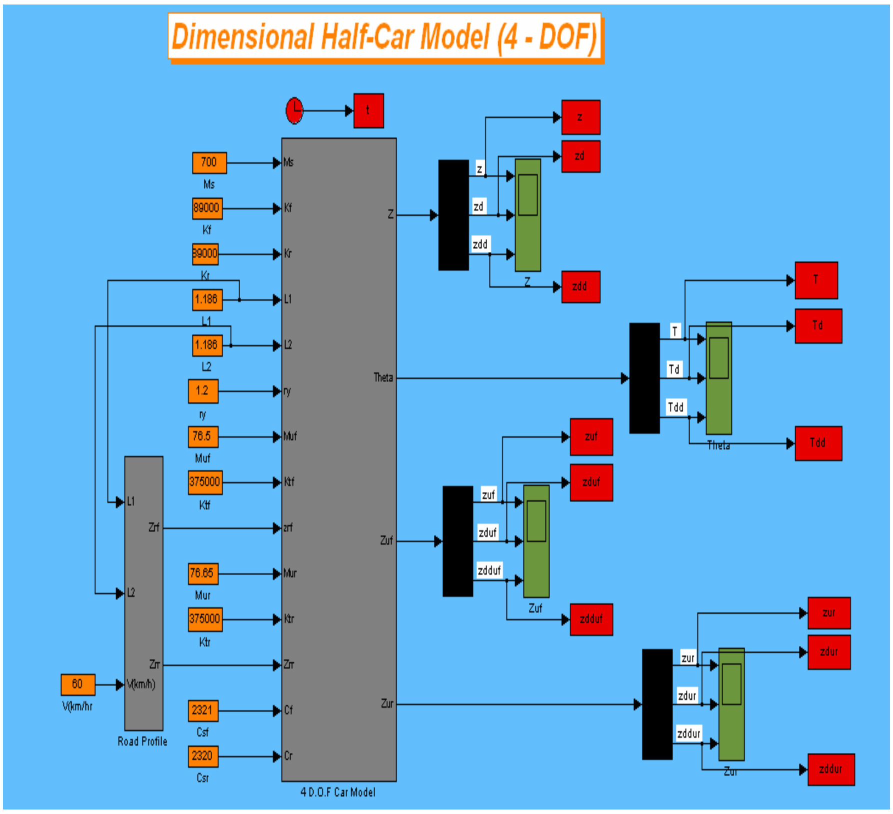


Fig. 2 (a) The half car model using Simulink

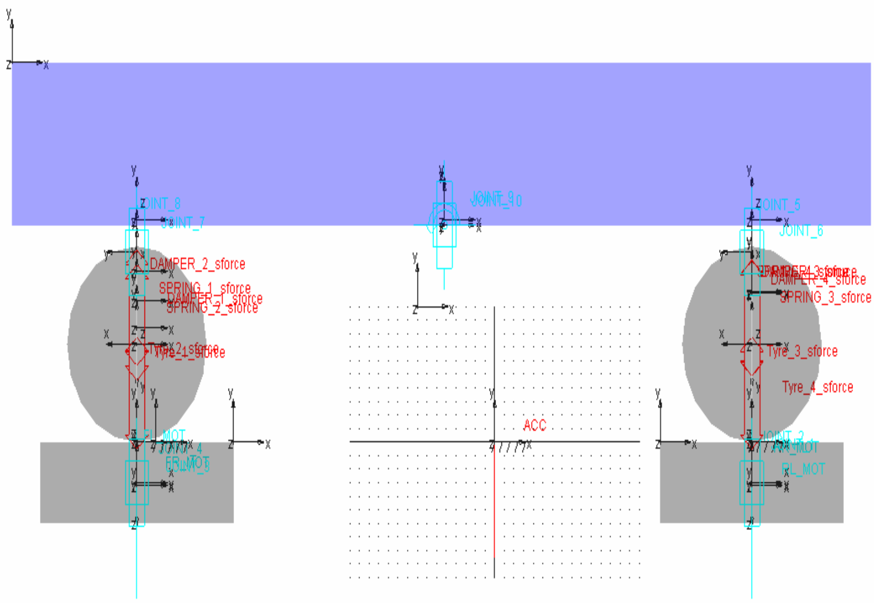


Fig. 2(b): Half car model using ADAMS

$$PI = \int_0^T (X^2{}_{1a} + X^2{}_{3b}).dt \quad (11)$$

$$X_{1a} = x_{uf} - x_{rf} \quad (12)$$

$$X_{3b} = x_{ur} - x_{rr} \quad (13)$$

Where;

x_{uf} : the front un-sprung mass displacement

x_{rf} : road input on the front tire

x_{ur} : the rear un-sprung mass displacement

x_{rr} : road input on the rear tire

T : the settling time in seconds

Table 1: Comparison of PI from the simulation programs with that given by Thompson [5]

Model	Outputs	Vehicle speed (m/s)			
		10	20	30	40
Thompson	PI	0.038026	0.039090	0.040010	0.040029
Matlab / Simulink	PI	0.039090	0.03895	0.03722	0.03717
ADAMS	PI	0.039090	0.03895	0.03722	0.03717
Difference	%	-1.3 %	0.17 %	3.6 %	3.7 %

3. EXPERIMENTAL TESTING OF SHOCK ABSORBER:

The experimental testing is carried out to measure the actual characteristics of the shock absorber. The variation of force in the damper piston, its displacement and velocity are measured at different displacement amplitudes with different speeds.

A-Testing equipment: The MTS850 damper test system is used. It is composed of two major units, which are the loading unit, Fig. 4, and the hydraulic power supply. The characteristics are measured by subjecting the shock absorber unit to input displacement in different frequencies (similar to road input). In this work, the shock absorber is tested with input sinusoidal road with frequencies (1, 4, 6 Hz) and amplitude 40 mm.

B- Sample Results:

The dynamic characteristics (Force vs. time, Force vs. displacement, and Force vs. velocity) of the tested shock absorber with input frequency of 1 Hz are given in Fig. 5.

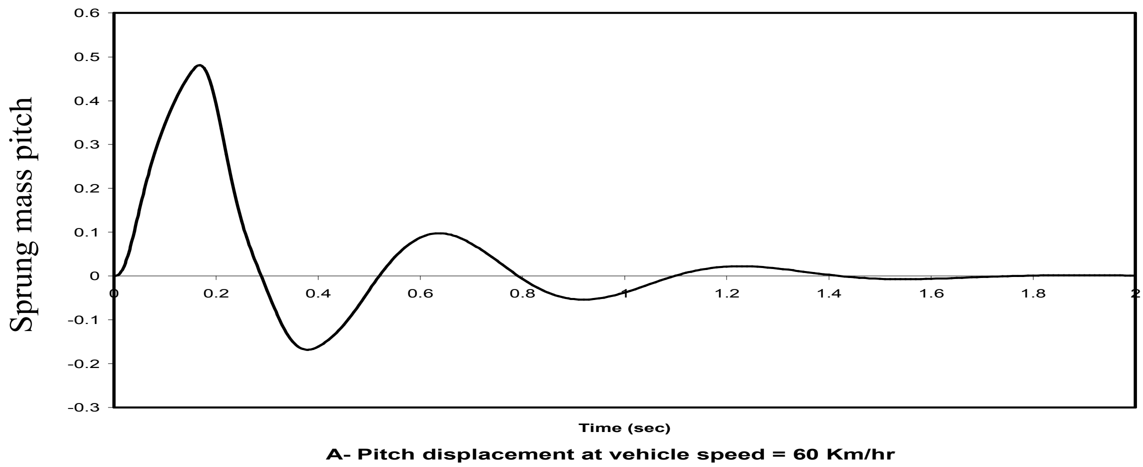


Fig. 3 (a): Sprung mass pitch motions at speed = 60 km/hr

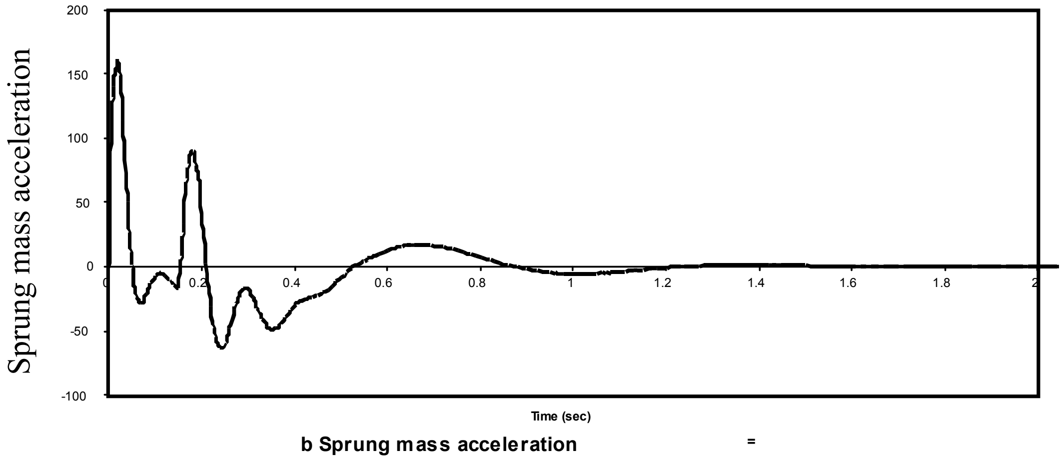
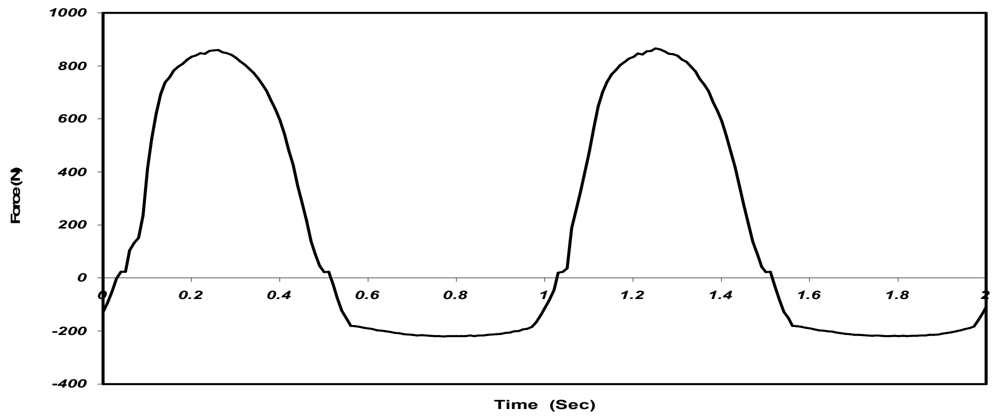
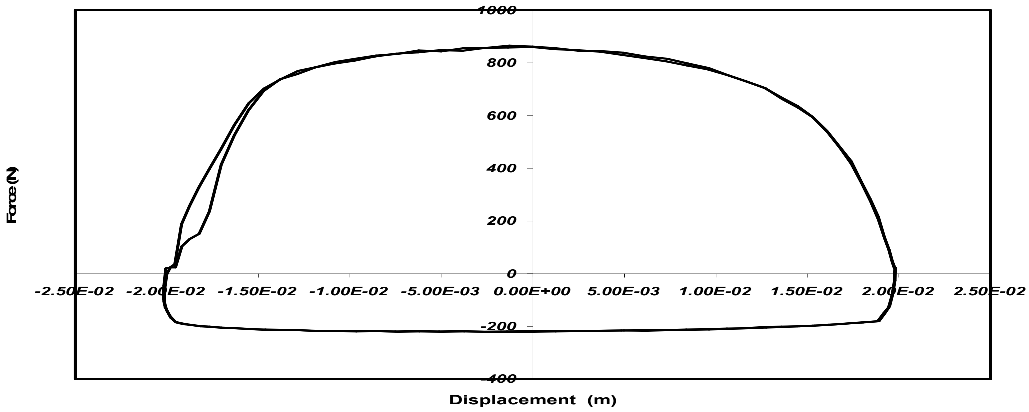


Fig. 3 (b): Rear un-sprung mass velocity at vehicle speed = 60 km/hr

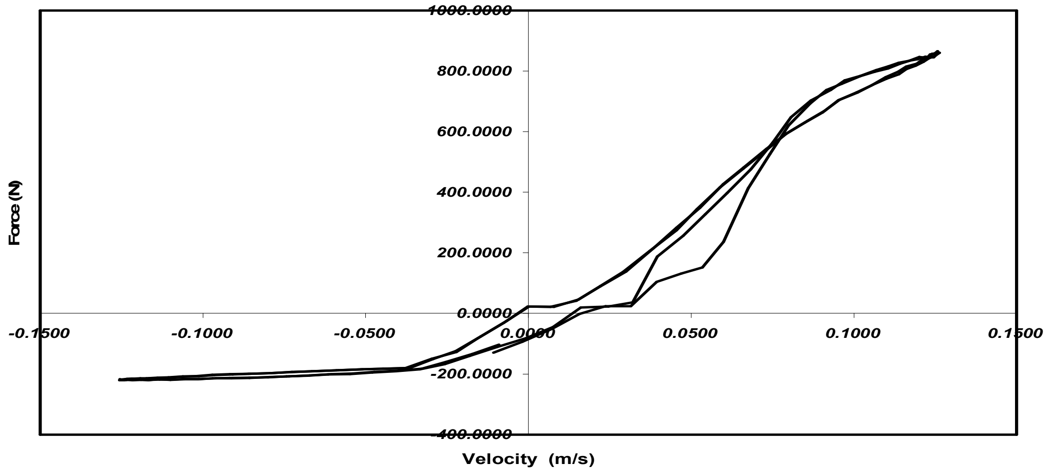
Fig. 4: The loading unit



A- Force vs Time characterstics with input of frequency 1 Hz



B- Force vs Displacement characterstics with input of frequency 1 Hz



C- Force vs Velocity characterstics with input of frequency 1 Hz

Fig. 5: The shock absorber dynamic characteristics

4. ANALYSIS OF RESULTS

Using the half car model, the effect of representation of the shock absorber characteristics has been studied considering the following:

1. The linear rebound and compression strokes with same slopes
2. The linear rebound and compression strokes with different slopes
3. The actual measurements

Two road inputs are considered on evaluating vehicle dynamic performance, which are: sinusoidal, and step road input. The vehicle parameters needed for simulation are given in Table 2.

Table 2: Vehicles data used for simulations [9]

Vehicle specification	Vehicle type		
	1	2	3
Sprung mass (kg)	1718	914.7	700
Un-sprung mass (kg)	164	96.3	78
Front suspension stiffness (KN/m)	89	22.67	15.6
Rear suspension stiffness (KN/m)	89	22.67	15.6
Front tire stiffness (KN/m)	375	180	160
Rear tire stiffness (KN/m)	375	180	160
Distance from front axle to centre of gravity (m)	1.1	1.26	1.17
Distance from centre of gravity to rear axle (m)	1.272	1.26	1.17
Radius of gyration (m)	1.2	1.2	1.2

4.1 Linear Approximation Of Shock Absorber Characteristics

This is done by taking the slope of the complete Force-Velocity curve obtained from experimental test. A sample of the slope taking to get the linear damping factor for one vehicle is shown in Fig. 6. Table 3 shows the linear damping factor of the three tested vehicles.

4.2 Linear Rebound And Compression Stroke Approximation Of Shock Absorber Characteristics:

The representation of the damping factor depending on the relative speed (V) between the two ends of the shock absorber is done, where:

- If $V < 0$, compression damping factor is considered.
- If $V > 0$, rebound damping factor is considered.

Table 4 shows the damping factor in compression and rebound for the vehicles dampers tested experimentally.

4.3 THE ACTUAL SHOCK ABSORBER CHARACTERISTICS

The actual shock absorber characteristics, the force versus velocity is given in computer sheet. Table 5 shows the actual shock absorber characteristics used in this study.

Table 3 Linear damping coefficients

Vehicle Type No.		1	2	3
Linear damping Coefficient (N.s/m)	Front	2321.1	1309.3	759.78
	Rear	2320.9	1581	N.A*

* Not available.

Table 4 Damping coefficients in rebound and compression stroke approximation

Vehicle Type No.		1		2		3	
State		Reb.	Comp.	Reb.	Comp.	Reb.	Comp.
Damping Coefficient (N.s/m)	Front	3790.7	842	1929.3	689.52	1056.7	460.84
	Rear	3704.5	927.5	2524	630.86	N.A*	N.A*

* Not available

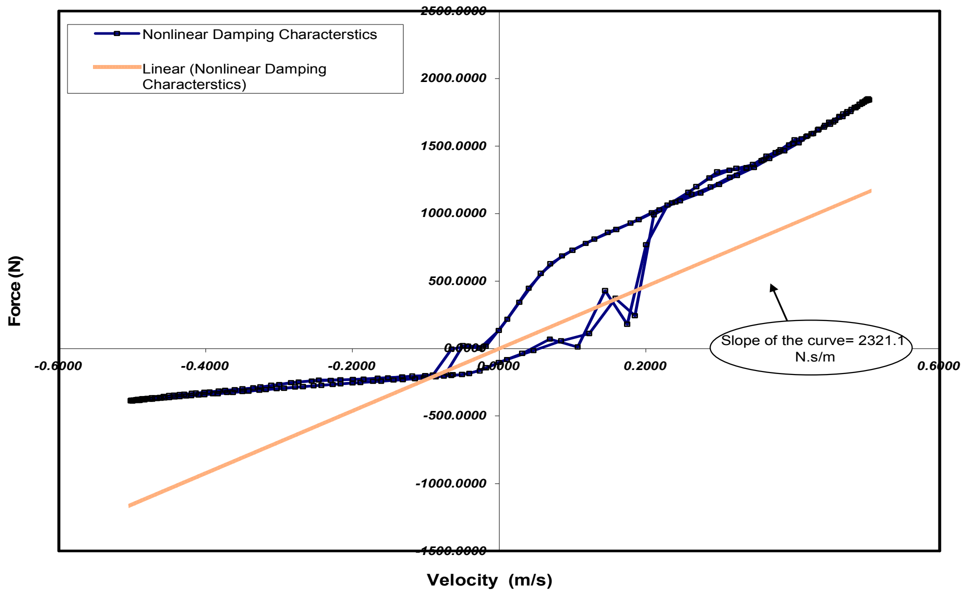


Fig. 6: Vehicle front linear damping approximation

Table 5: Actual measured shock absorber characteristics for the tested vehicles

Vehicle No.	Velocity (m/s)		-0.5	-0.3	-0.12	-0.06	0	0.020	0.059	0.12	0.30	0.50
1	Force (N)	Front	375	270	-234	-151	0	77	209	495	1255	1847
		Rear	426	276	-254	-170	0	89	244	581	1378	1658
2	Force (N)	Front	328	225	-107	-57	0	26	69	169	600	912
		Rear	293	203	-103	-58	0	28	77	196	699	1275
3	Force (N)	Front	217	157	-113	-71	0	34	91	207	388	462

4.4 Effect Of Shock Absorber Characteristics On Vehicle Performance

An analysis study is done by varying the damping factor using the three representations and comparing the peaks of vehicle response output. Half car model form is used to simulate the vehicle with vehicle speed of 60 km/hr and step road input. Fig 7 through 10 shows a comparison of the vehicle outputs using the half car model simulation with input data given in Table 2

It is clear from the above figures that by using actual measured non-linear characteristics, an improvement (reduction of peak values in the sprung mass acceleration, pitch acceleration, and vehicle ride) achieved. In addition, an increase on ground force (control) achieved by using actual measured non-linear characteristics. Table 6 summarizes the improvement in vehicle dynamic response using different representations of shock absorber characteristics. It is clear that, compression and rebound representation shows good improvement in the design output like for the sprung mass acceleration improvement reaches 8.91 %. On the other hand using the actual measured nonlinear representation gives a better improvement that on the case of sprung mass acceleration, it reaches 37 %. Also for the measure of road holding (control), an increase on control (ground force) reaches 3.01 % using rebound and compression stroke representation and 4.25 % using actual measured non-linear shock absorber characteristics. This yields to an increase on the tire-road contact patch, which means better road holding. This leads to the fact that linear representation (constant damping factor) may give a misleading response in vehicle simulation. The use of the rebound and compression stroke representation is still may give a misleading results (even it is better than the linear representation). The use of actual measured shock absorber characteristics gives the best result, as it is the actual. Fig 11 shows comparison of the vehicle performance using different damper approximations with respect to the linear approximation.

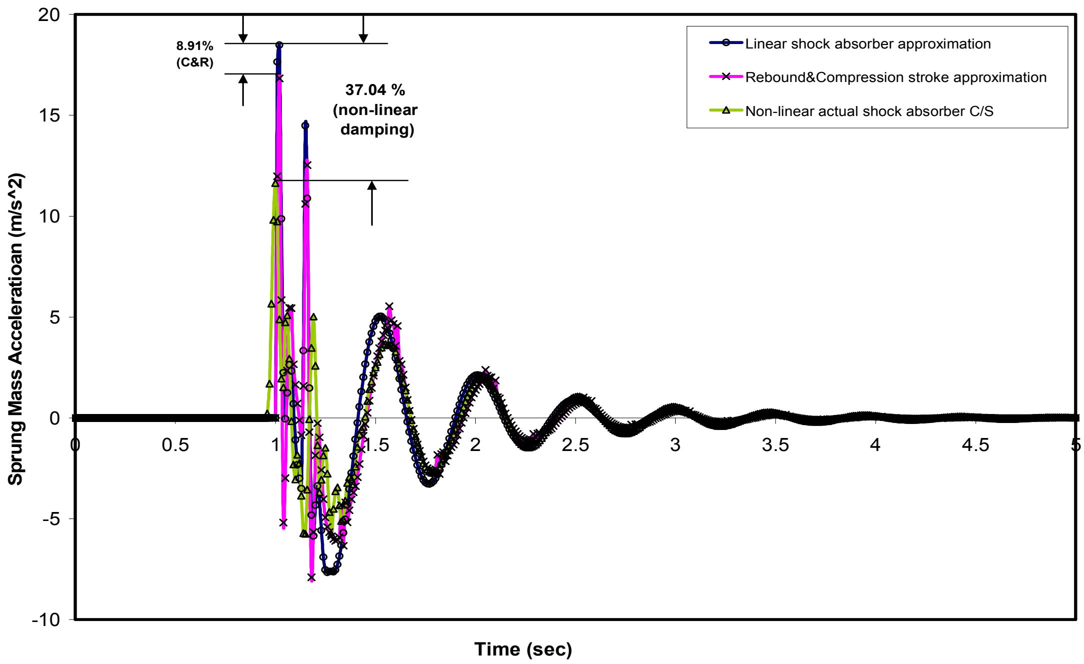


Fig. 7 Vehicle sprung mass acceleration

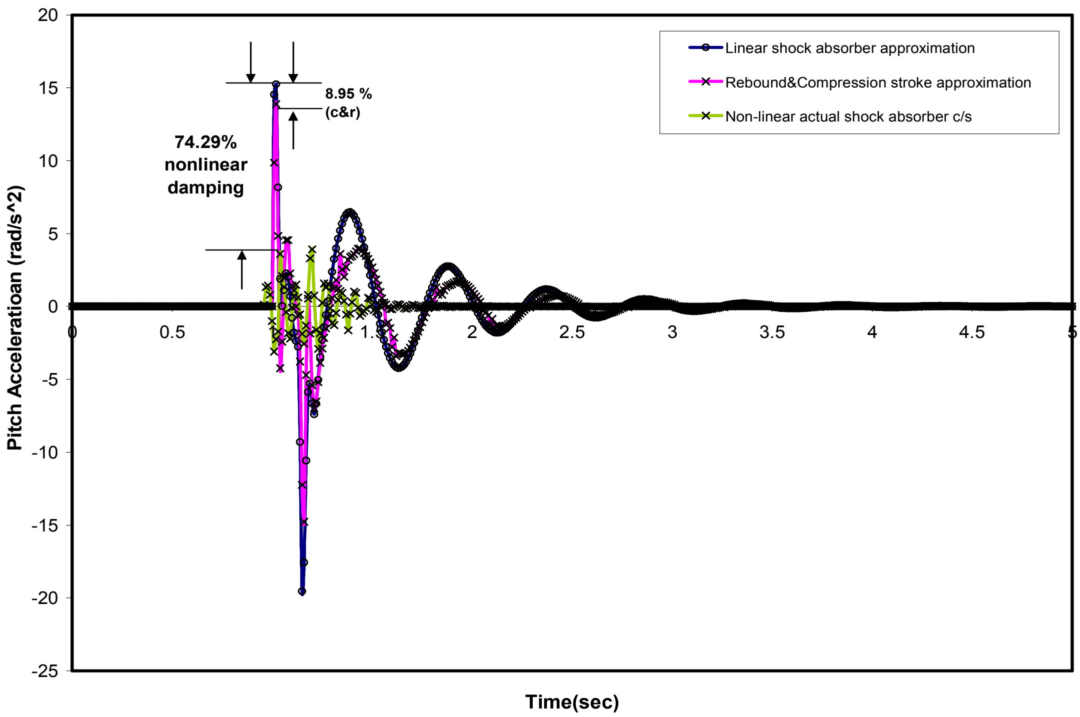


Fig. 8 Vehicle pitch acceleration

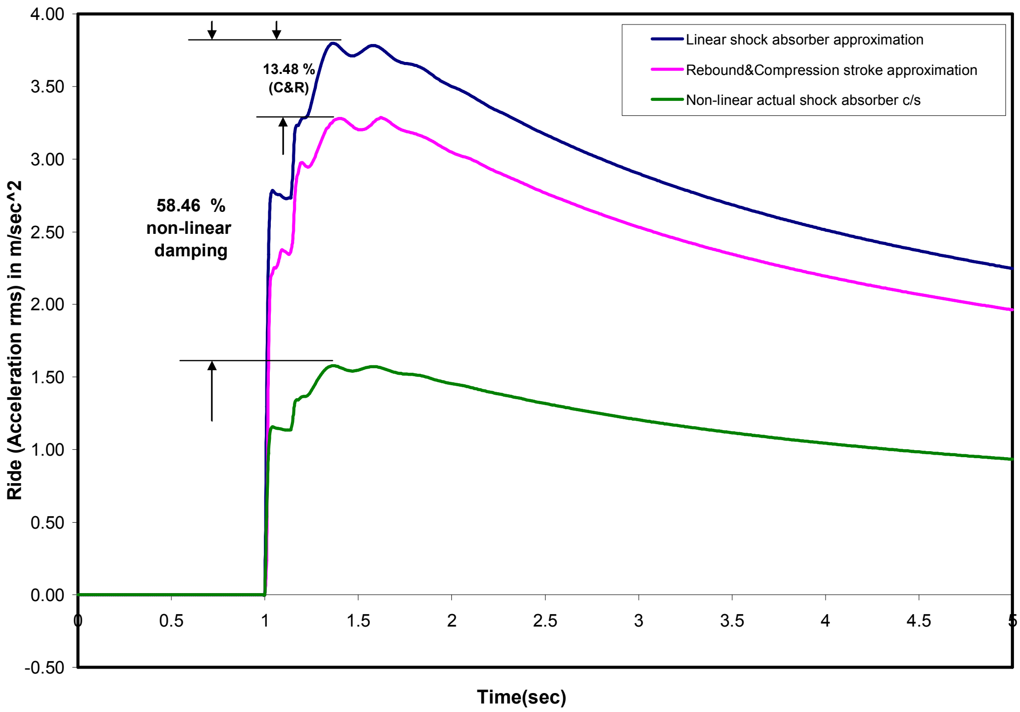


Fig. 9 Vehicle body acceleration for step road input

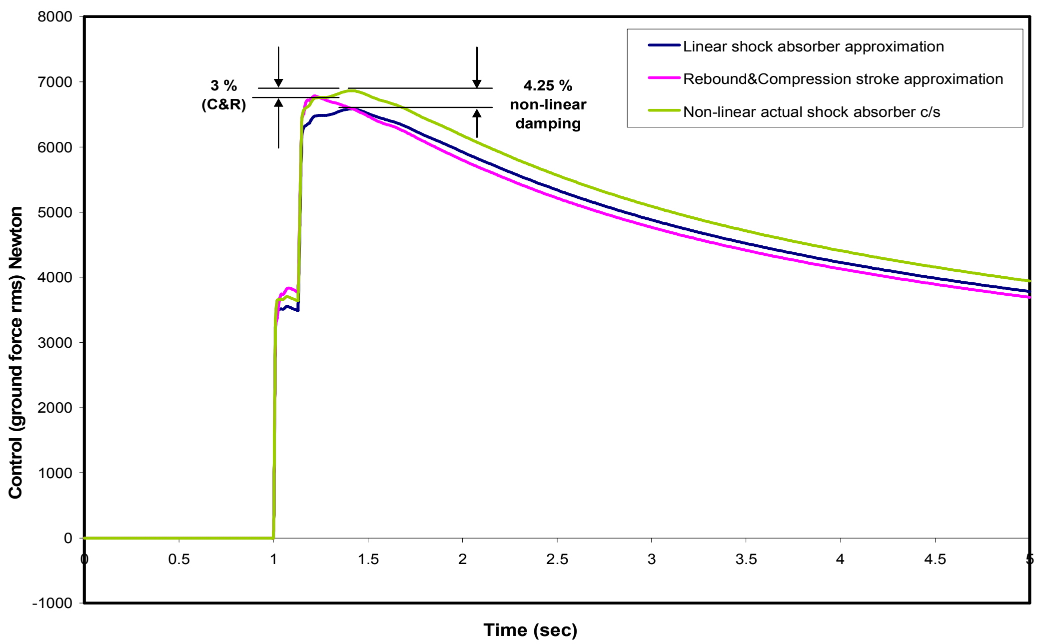


Fig. 10: Vehicle dynamic tire force (control)

Table 6: Vehicle dynamic response using different representation of shock absorber characteristics.

Design Vehicle Output	Shock Absorber Representations	
	Rebound& Compression Stroke	Non-linear (actual measured)
Sprung Mass Acceleration	8.91%	37%
Pitch Acceleration	8.95%	74.3%
Ride	13.48%	58.4%
Control	-3.01%	-4.25%

Note: (negative percentage values means increase on peak relative to the linear representation).

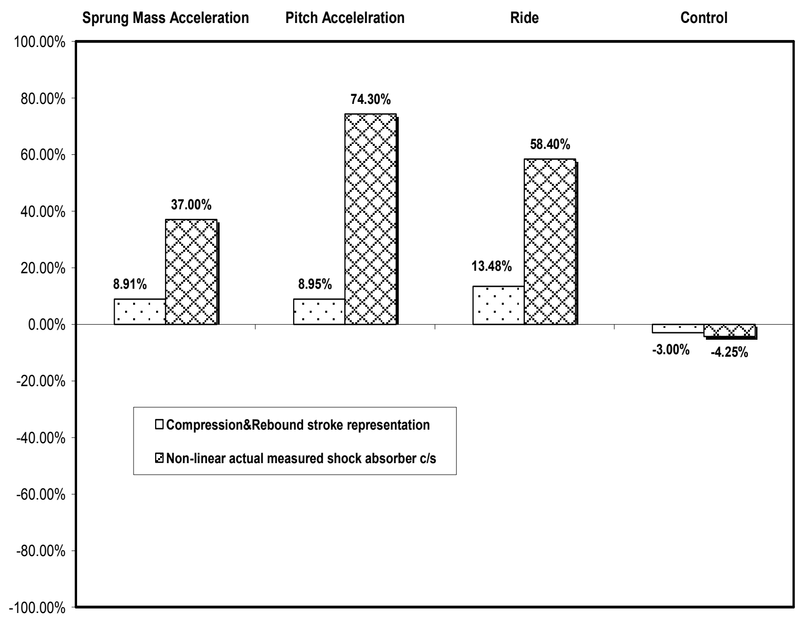


Fig. 11 comparison of vehicle performance using different representation of shock absorber characteristics

5. CONCLUSIONS

Different shock absorber characteristics representations have been introduced. These are; the linear, the rebound and compression stroke representation, and the actual shock absorber characteristics. These different characteristics have been considered and measured experimentally.

From the present study and for the vehicles considered in testing, the following conclusions can be stated: Using actual shock absorber characteristics measured experimentally gives the most accurate simulation results (compared to the linear and the rebound and compression stroke representation.). For the considered vehicle, it is concluded that, the actual characteristics improve the response of sprung mass acceleration up to (37 %), pitch acceleration up to (74.3%), vehicle ride index up to (58.4 %), and vehicle road holding up to (-4.25 %) compared to the results obtained using linear shock absorber approximation.

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