Effect of Speed Breaks on Vehicle Dynamics and Ride Comfort

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ABSTRACT: *The primary objective of the ride comfort analysis is to study the response behavior of the sprung mass systems subject to different road excitation forces. Speed Bumps are a traffic calming tool designed to slow traffic. They are widely used and gradually increasing on the roads year by year. A Speed Bump is a bump on a roadway that may be circular, parabolic, or sinusoidal. The speed hump design parameters such as height, width, and space as well as the vehicle's speed are the important factors that affect safety and comfort of passengers. In this paper, the effect of speed hump design parameters at different speeds on vehicle dynamics and ride comfort are experimentally investigated. Throughout this study, a quarter car test rig of Toyota Hiace microbus, which one of the most favorite on the Egyptian roadway is prepared and used. The experimental results show that the vehicle vibration increases with the increasing of bump height, and vehicle speed, while it can be possibly reduced by reducing the tire inflation pressure, and increasing the vehicle weight. Experimental investigation of the effect of a speed bump on the car noise emission level is also presented.*

I.   INTRODUCTION

Road speed control humps are a kind of forced road traffic safety facilities, which play an important role in curbing the occurrence of traffic accidents [1, 2]. At present, all various speed control bumps are paved on the road; in addition to the common entrance, community and school road install rubber speed control bumps and the accident black spot on the highway, such as highway curve, ramp, and tunnel entrances, generally setting up consecutive speed bumps to force the vehicle deceleration. When the car passes the uneven speed control bumps, severe vibration through the body and the seat is passed from tire to the driver, which makes the driver feel uncomfortable. Thus, the driver will be forced to reduce speed to achieve the goal of speed limit [3–5].

The automobile suspension system is necessary equipment, which can reduce the vibration generated by the SCHs, improve the vehicle's driving smoothness and comfort, and reduce the damage of the vehicle and road surface.

Because of the nonlinearities of automobile suspension system and wheels, the nonlinear characteristics existing in the automobile suspension system can lead to suspension system producing complicated dynamic behaviors under uneven road surface excitation, such as chaotic vibration and quasi periodic vibration. When the vibration becomes severe, it will lead the vehicle to jump or overturn [3, 6-7].

Chaotic vibration and quasi periodic vibration may cause shock vibration to the road surface, thus influencing the lifetime of road surface, safety of driving, and the comfort of the driver [8–13].

Research has shown that speed humps, when designed and installed properly, reduce vehicle speeds to 20-30 km/h when travelling over speed humps and 30-40 km/h in between properly spaced speed humps. When travelling over a speed hump, the vehicle experiences a gentle rocking motion that increases with speed. This enables the speed humps to be self-enforced because the vehicle occupants will experience discomfort when passing over a hump at higher speeds and a jolting when passing over at excessive speeds [14]. It is also shown that although speed humps have been proven to be effective at reducing speeds, they also come with their own drawbacks. Installed speed humps have actually been removed in response to resident complaints. The major complaints have been aesthetics of having speed humps and the increased noise level at each hump, although the net noise change throughout the controlled strip is insignificant. Speed humps are not the best thing to have own ones road. Also, if people are not happy, the council has to hear the complaints of the residents [15]. It would not be nice to be living on a road where you can hear cars going over speed humps and scratching the humps as well as their car. It is not aesthetically pleasing when you leave your front door and see scratches on your road.

Although they are the most important group, more than just the residents are affected by the installation of speed humps. Other groups such as emergency service providers, street maintenance providers, school districts, transit operators, refuse collection agencies will be affected and should, therefore, be informed and

consulted concerning the installation of speed humps. Emergency providers may have casualties in their vehicles and going over the humps may affect the injuries which the casualties have. Especially if they are in a life threatening situation, they may need to move as far as possible.

Hessling [16] showed that the comfort changes with car speed and the improper design of road humps leading to a risk of injury. He listed the tools of dynamic measurement systems used in the measurements when the vehicle crossing a speed hump.

Kanjanavapastit and Thitinaruemit [17] stated that a road speed hump can cause an accident, and they proposed a technique to estimate the speed hump profile using a quarter car model. They used accelerometers located on the unsprung mass to measure the axial and vertical accelerations and used MATLAB Simulink to estimate the speed hump profile. Silva and Vasconcelos [18] emphasized that the use of speed humps for their ease of construction / installation and their efficiency in reducing vehicle speeds. They developed a speed profile model using a database and hierarchical multiple regression techniques, providing speeds on the approach and exit of isolated speed humps.

Hassan [19-20] presented a novel simple harmonic speed hump and studied the car dynamics during crossing this hump using a quarter car model. He covers a car hump crossing speed in the range 5-30 km/h, hump length 3-9 m and hump height 60-120 mm. He set a ride comfort diagram to assist simple harmonic hump design for any desired crossing speed between 5 and 30 km/h.

With the reference to the used published list [1-20] and other publish papers have been checked by the authors on the internet, there is no research results in dynamic performance of a torsion bar suspension system, which mainly used in light weight trucks and Microbuses, which are the most used vehicles on the Egyptian roads. A torsion bar suspension, also known as a torsion spring suspension (but not to be confused with torsion beam rear suspension), is a general term for any vehicle suspension that uses a torsion bar as its main weight bearing spring. One end of a long metal bar is attached firmly to the vehicle chassis; the opposite end terminates in a lever, the torsion key, mounted perpendicular to the bar, that is attached to a suspension arm, a spindle, or the axle. The vertical motion of the wheel causes the bar to twist around its axis and is resisted by the bar's torsion resistance. The effective spring rate of the bar is determined by its length, cross section, shape, material, and manufacturing process.

This study mainly focuses on the experimental investigation of chaotic vibration induced by road excitation due to speed humps on laboratory test model for Toyota Hiace microbus, which one of the most favorite on the Egyptian roadway. This study includes the effect of all design and operating parameters on the sprung mass vibration.

II. EXPERIMENTAL SETUP

To analyze the behavior of the torsion bar suspension system; double-wishbone type of suspension with upper torsion bar was used during the experimental tests. Figure (1) illustrates the arrangement of the quarter car suspension with torsion bar. The experimental setup is composed of electrical motor fitted with a drum has diameter 0.38 m used to rotating the tire has diameter 0.7 m via a belt. Electric motor speed can be controlled by an inverter device to change the drum speed.

To simulate the hump road effect, the drum tire (3) has the freedom to move up and down direction by using a 5 hp electric motor via connecting rod attached to the drum tire. Electric motor speed can be controlled by the inverter device, to change the hump position.

The height of the hump can be changed by using disc has some holes in certain position and rotates by the electric motor as shown in Figure 2. The big end of the connecting rod connects to disc hole and the other attached to the drum. The height of the hump is controlled by changing the position of the contact point of the connecting rod end to the holes in the disc.

The vibrations were measured at two different positions by ICP accelerometer (model 333B32) which has a frequency range from 0.5 to 3000 Hz. The accelerometer signals are post-processed by LMS pimento a multi-channel device (model Asp 424). All the measured data were directly collected to PC computer, and analyzed using the MATLAB [21]. The tire speed was measured using digital tachometer, and the tire noise was measured using the RO-line precision sound level meter, type 1350 fixed at 1 meter perpendicular to tire rolling direction.

Figure (1). Torsion bar test rig.
1. Electrical motor for hump, 2. Electrical motor for drum, 3. Drum, 4. Hump system, 5. Tire, 6. Torsion bar, 7. Quarter car suspension assembly, 8. Vibration sensor position, 9. Bolt of the torsion bar.
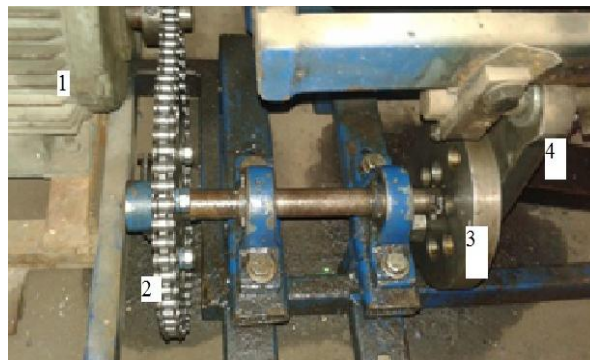

Figure (2) Photo of the drive motor and the hump height mechanism.
1. Electrical motor, 2. Chain, 3. Drum, 4. Connecting rod.

During the measurements, the road is considered as cam which will give harmonic road excitation to the suspension system. The road profile is approximated by a sine wave with 50mm amplitude, the wavelength of road surface is 1.57 m, angular velocity (ω) is 8.33 rad/s and frequency (f) of 1.32 Hz at 7.5 km/hr. Both angular velocity and frequency are varied during the measurements according to vehicle speed.

III. RESULTS AND DISCUSSIONS

Through this study different design; hump height and space, tire air pressure as well as operating parameters; vehicle weight and speeds on the vehicle dynamics and ride comfort are studied. A summary of this study will be presented here.

3.1 Effect of vehicle load on the ride comfort.

The effect of vehicle load on the ride comfort at tire speed of 7.5 km/hr is presented in figure 3. It can be seen that the sprung mass acceleration are reduced with the increasing of vehicle load in both cases without and with speed humps. Without speed hump (h=0), the RMS value of the body acceleration decreases by 13 % with the increase of sprung mass weight from 400 kg to 480 kg and decreases by 29 % when it increases from 480 kg to 530 kg. It can be seen, the sprung mass acceleration reduction is not linear with vehicle speed due to the non linear damping of the suspension system. With speed humps with height (h=50 mm), the RMS value of the body acceleration decreases by 4 % with the increase of sprung mass weight from 400 kg to 480 kg and decreases by 19 % when it increases from 480 kg to 530 kg. It can be concluded that the ride comfort can be improved by 42% without hump and 23% with hump when the vehicle full load is presented.
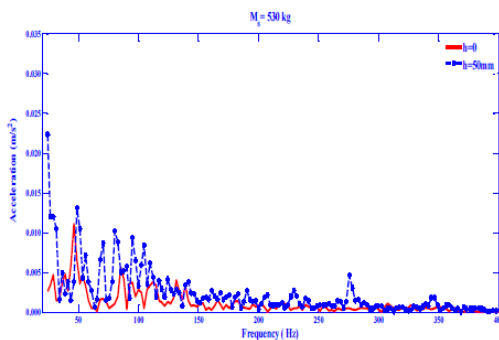
These values are changed with vehicle speed as shown in Appendix (A).
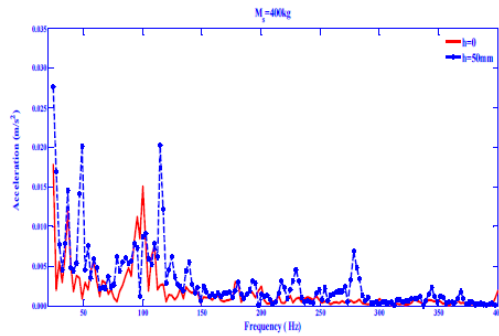
(a) Vehicle acceleration versus frequency without/with a speed hump, the tire speed is 7.5 km/hr, and the sprung mass is 400 kg.
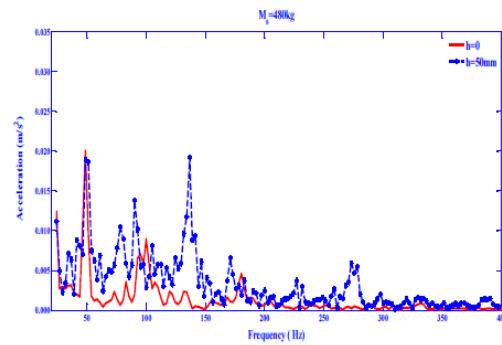
(b) Vehicle acceleration versus frequency without/with a speed hump, the tire speed is 7.5 km/hr, and the sprung mass is 480 kg.

(c) Vehicle acceleration versus frequency without/with a speed hump, the tire speed is 7.5 km/hr, and the sprung mass is 530 kg.
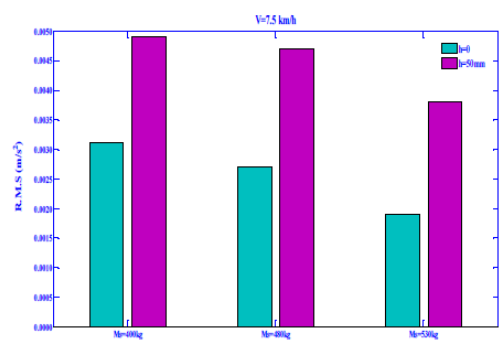
(d) Summary of RMS versus sprung mass weight without/with a speed hump at the tire speed of 7.5 km/hr.

Figure (3) Vehicle acceleration versus sprung mass weight without/with a speed hump at tire speed of 7.5km/hr.

3.2 Effect of tire speed on the vehicle vibration.

The effect of tire speed on the vehicle vibration at sprung mass weight of 530 kg is presented in Figure 4. It can be seen that the sprung mass acceleration has increased with the increasing of vehicle speed in both cases without and with speed humps. Without speed hump, the RMS value of the body acceleration increases 25 % with the increase of tire speed from 2.5 km/hr to 5 km/hr and 25 % when it increases from 5 km/hr to 7.5 km/hr. With speed humps height 50 mm, the RMS value of the body acceleration increases 8.8 % with the increase of tire speed from 2.5 km/hr to 5 km/hr and 2.7 % when it increases from 5 km/hr to 7.5 km/hr. The variation of RMS values at different loads can be found in Appendix (B).
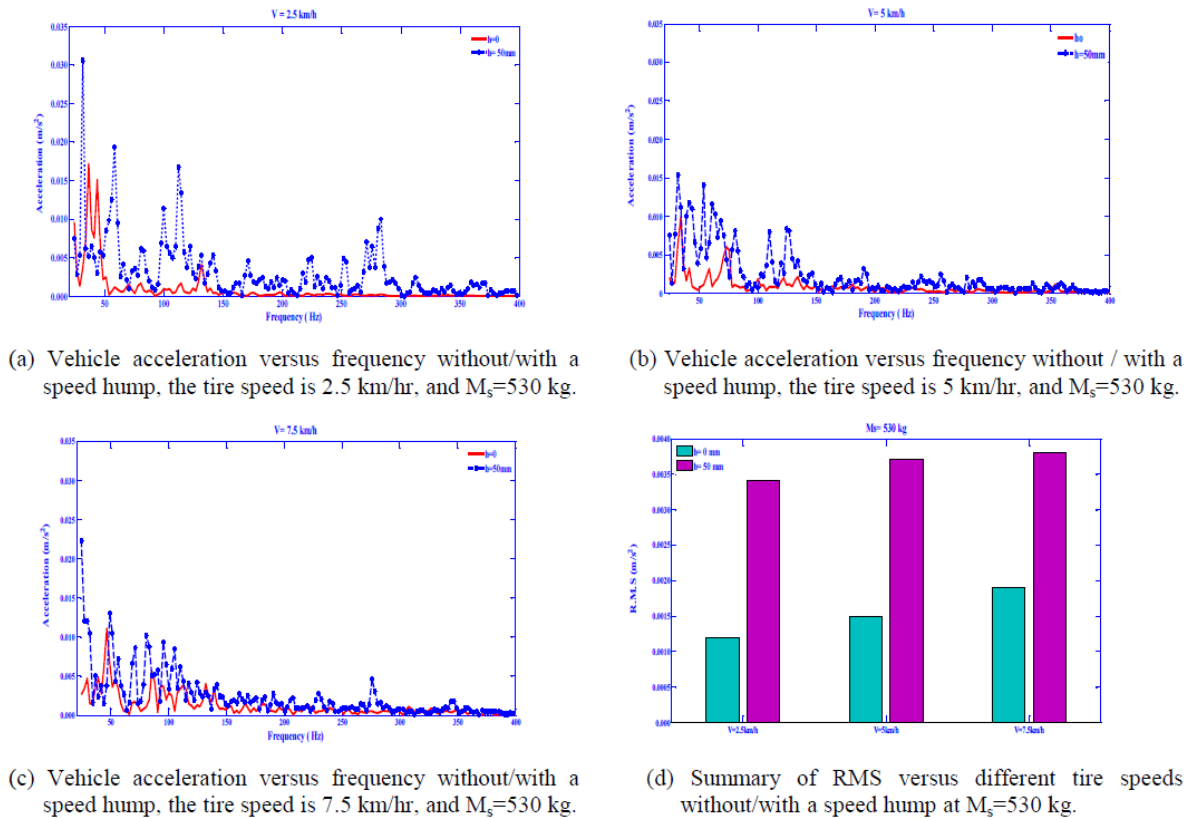
(a) Vehicle acceleration versus frequency without/with a speed hump, the tire speed is 2.5 km/hr, and M_s=530 kg.

(b) Vehicle acceleration versus frequency without / with a speed hump, the tire speed is 5 km/hr, and M_s=530 kg.

(c) Vehicle acceleration versus frequency without/with a speed hump, the tire speed is 7.5 km/hr, and M_s=530 kg.

(d) Summary of RMS versus different tire speeds without/with a speed hump at M_s=530 kg.

Figure (4) Vehicle acceleration versus tire speed without / with a speed hump at different tire speeds.

3.3 Effect of the tire inflation pressure on vehicle vibration.

The effect of the tire inflation pressure on the ride comfort at tire speed of 7.5 km/hr and sprung mass weight of 480 kg is presented in figure 5. Without speed hump, the RMS value of the body acceleration is increased by 4.2 % when the tire inflation pressure is changed from 55 psi to 60 psi, while, the RMS value is increased by 3.7 % when the tire inflation pressure is changed from 55 psi to 60 psi with speed humps height of 50 mm as shown in Figure (5-b).

The effect of the speed hump on the ride comfort can be seen in Figure (5.b). It can be notice that the RMS value is increased by 74 % when the tire inflation pressure is 55 psi, while it has increased about 75 % when the tire inflation pressure 60 psi, the tire speed is 7.5 km/hr and sprung mass weight is 480 kg. The variation of RMS values at different loads can be found in Appendix (C).
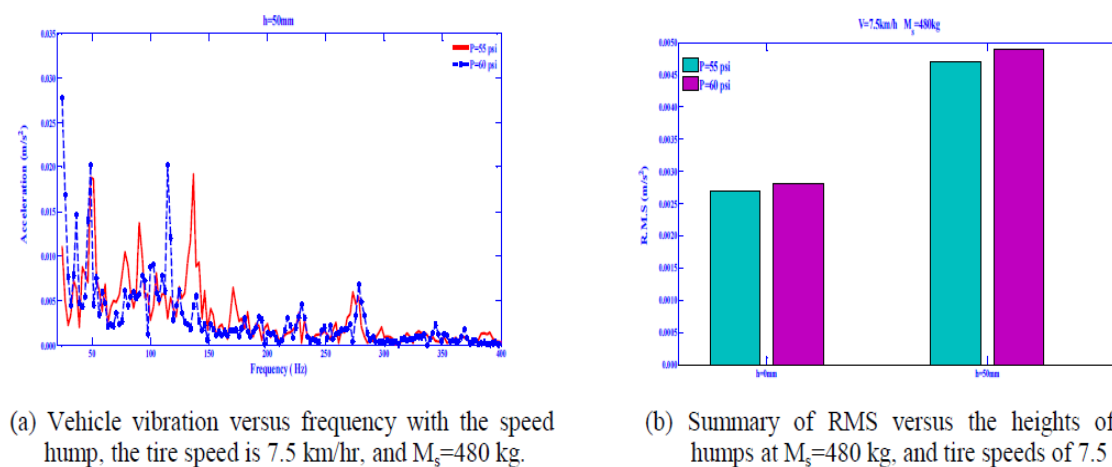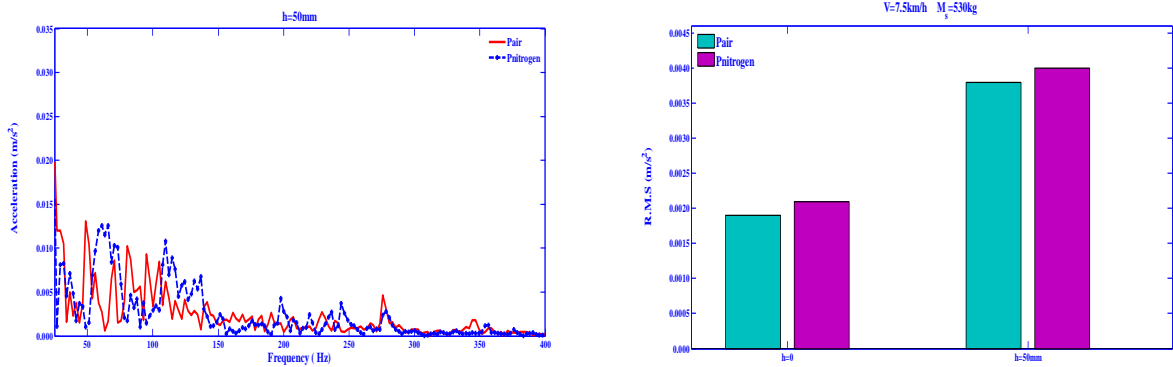

(a) Vehicle vibration versus frequency with the speed hump, the tire speed is 7.5 km/hr, and M_s=480 kg.

(b) Summary of RMS versus the heights of speed humps at M_s=480 kg, and tire speeds of 7.5 km/hr.

Figure (5) Variation of vehicle vibration with tire inflation pressure without/with a speed hump at the tire speeds of 7.5 km/hr.

3.4 Effect of type of gas filling tire on the ride comfort.

The effect of the type of gas filling tire on the ride comfort is presented in figure (6). It can be seen that the type of gas has also clear effect on vehicle vibration. The difference between the RMS values with air filling tire and nitrogen filling tire at without speed hump is 10 %, while with speed hump of 50 mm height, it has increased 5% respectively as shown Figure (6-b).


(a) Vehicle acceleration versus frequency with speed hump, the tire speed of 7.5 km/hr, and M_s=530 kg.

(b) Summary of RMS versus air filling the tire and gas filling tire, and different tire speeds without/with a speed hump at M_s=530 kg.

Figure (6) Effect of gas filling tire on vehicle acceleration without/with a speed hump at M_s=530 kg.

3.5 Effect of height of the hump on the vehicle vibration

The effects of hump's height on vehicle noise at different speeds are shown in Figure (7). It can be seen that the RMS increases linearly by 8.5% when the height of humps increased 10mm at different speeds. The effect of speed variation on the increasing of RMS is small around 2% at each hump.
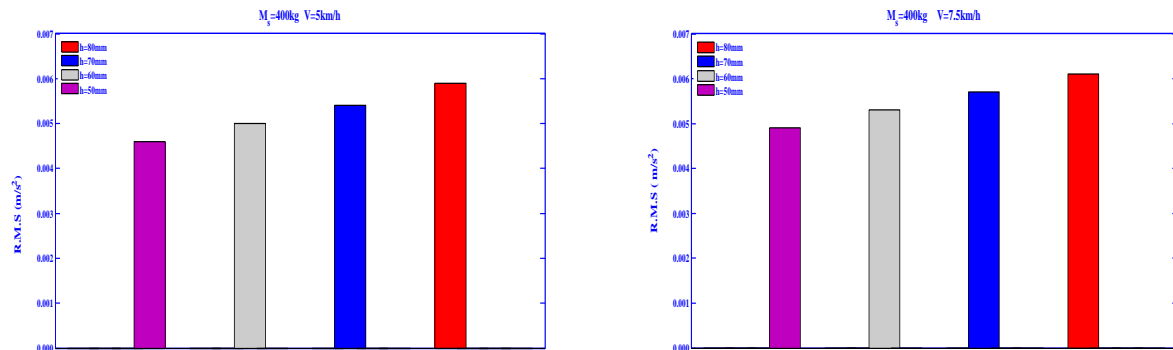

(a) RMS versus the height of speed hump at M_s=400 kg and the tire speed of 5 km/hr .

(b) RMS versus the height of speed hump at M_s=400 kg and the tire speed of 7.5 km/hr.

Figure (7) RMS versus the height of speed hump at sprung mass weight 400 kg at different speeds.

### 3.6 Effect of load and speed on vehicle noise

The effect of humps on vehicle noise at different loads and speeds are shown in Figure (8). The average increases in RMS values are around 13% at different loads and speeds. Using the speed hump, the average load effect on the increasing of RMS is about 6% at different speeds, while the average speed effect is about 2% at different loads.
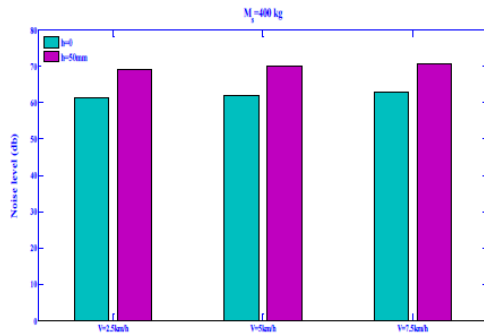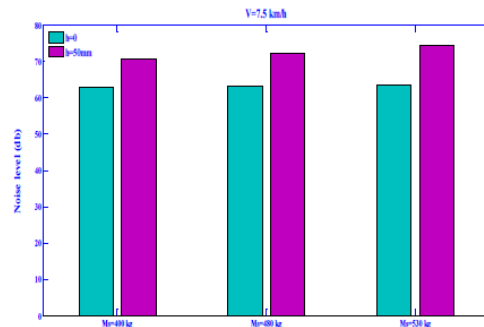
(a) Vehicle noise versus speed without / with a speed hump at the tire Ms of 400 kg.
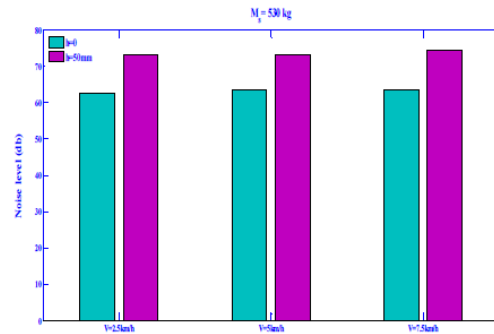
(b) Vehicle noise versus speed without / with a speed hump at the tire Ms of 530 kg.
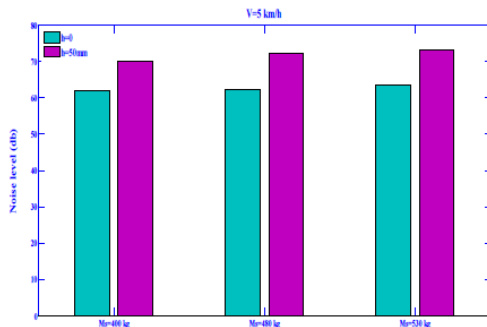
(c) Vehicle noise versus sprung mass without / with a speed hump at the tire speed of 5 km/hr.

(d) Vehicle noise versus sprung mass without / with a speed hump at the tire speed of 7.5 km/hr.

Figure (8) Vehicle noise versus sprung mass weight at different tire speeds without/with a speed hump.

IV. CONCLUSIONS AND FUTURE WORK

A quarter-car test rig with torsion bar, passive elements was used in this study to investigate the car dynamics during passing a speed hump and the following conclusion can be drawn:

- The increase of vehicle load decreases vehicle vibration due to the increasing in the damping of the suspension system.
- For tire speed 7.5 km/hr with a speed hump by increasing the vehicle load from (unload to quarter load), the vehicle vibration decreases 6 %, and 19 % from (quarter load to half load),also by increasing the vehicle load from (half load to 3/4 load), the vehicle vibration decreases 22 % , and 23% from (3/4 load to full load).
- For half vehicle load by increasing the tire speed from 5 to 7.5 km/hr, the vehicle vibration increases 6 % without speed hump, and 6.5 % with speed humps. Also the vehicle vibration increases 13.6 % by increasing the tire speed from 10 to 15 km/hr, without speed hump, and 12.7 % with speed humps.
- The increasing of tire pressure by 10% for half load vehicle increased vehicle vibration by 4.2% without speed hump and 3.7% with speed humps at tire speed 7.5 km/hr.
- By using the nitrogen filling tire, it increases the vehicle vibration at full load from 6% to 10% without speed hump and from 3% to 6 % with speed humps at different speeds.
- Using the speed hump increases the vehicle noise about 13%.
- Vehicle vibration increases linearly with the height of the speed humps.
- Using the speed humps, the increasing of the vehicle loads increases the vehicle noise 6% at different speeds while the increasing in vehicle speed only increases vehicle noise 2%.

Conflict of Interests
The authors declare that there is no conflict of interests regarding the published results of this article.

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Appendix (A) Effect of load vehicle on the ride comfort

Height speed hump (mm) Body vertical acceleration (m/s²)		0	50
Tire speed 2.5 km/h	Body vertical acceleration (m/s²) at M_s= 400 kg	0.0024	0.0045
	Body vertical acceleration (m/s²) at M_s= 480 kg	0.0015	0.0042
	Body vertical acceleration (m/s²) at M_s =530 kg	0.0012	0.0034
Tire speed 5 km/h	Body vertical acceleration (m/s²) at M_s= 400 kg	0.0029	0.0046
	Body vertical acceleration (m/s²) at M_s= 480 kg	0.0025	0.0043
	Body vertical acceleration (m/s²) at M_s =530 kg	0.0015	0.0037
Tire speed 7.5 km/h	Body vertical acceleration (m/s²) at M_s= 400 kg	0.0031	0.0049
	Body vertical acceleration (m/s²) at M_s= 480 kg	0.0027	0.0047
	Body vertical acceleration (m/s²) at M_s =530 kg	0.0019	0.0038

Appendix (B) Effect of tire speed on the ride comfort

Height speed hump (mm) Body vertical acceleration (m/s^2)		0	50
Load vehicle 400 kg	Body vertical acceleration (m/s^2) at V= 2.5 km/h	0.0024	0.0045
	Body vertical acceleration (m/s2) at V= 5 km/h	0.0029	0.0046
	Body vertical acceleration (m/s2) at V= 7.5 km/h	0.0031	0.0049
Load vehicle 480 kg	Body vertical acceleration (m/s^2) at V= 2.5 km/h	0.0015	0.0042
	Body vertical acceleration (m/s2) at V= 5 km/h	0.0025	0.0043
	Body vertical acceleration (m/s2) at V= 7.5 km/h	0.0027	0.0047
Load vehicle 530 kg	Body vertical acceleration (m/s^2) at V= 2.5 km/h	0.0012	0.0034
	Body vertical acceleration (m/s2) at V= 5 km/h	0.0015	0.0037
	Body vertical acceleration (m/s2) at V= 7.5 km/h	0.0019	0.0038

Appendix (C)

Effect of the tire inflation pressure on the ride comfort (Without speed hump)

The tire inflation pressure (psi) Body vertical acceleration (m/s^2)		55	60
Load vehicle 400 kg	Body vertical acceleration (m/s^2) at V= 2.5 km/h	0.0024	0.0026
	Body vertical acceleration (m/s2) at V= 5 km/h	0.0029	0.0031
	Body vertical acceleration (m/s2) at V= 7.5 km/h	0.0031	0.0033
Load vehicle 480 kg	Body vertical acceleration (m/s^2) at V= 2.5 km/h	0.0015	0.0016
	Body vertical acceleration (m/s2) at V= 5 km/h	0.0025	0.0026
	Body vertical acceleration (m/s2) at V= 7.5 km/h	0.0027	0.0028

Effect of the tire inflation pressure on the ride comfort (With a speed hump)

The tire inflation pressure (psi) Body vertical acceleration (m/s^2)		55	60
Load vehicle 400 kg	Body vertical acceleration (m/s^2) at V= 2.5 km/h	0.0045	0.0047
	Body vertical acceleration (m/s2) at V= 5 km/h	0.0046	0.0047
	Body vertical acceleration (m/s2) at V= 7.5 km/h	0.0048	0.0049
Load vehicle 480 kg	Body vertical acceleration (m/s^2) at V= 2.5 km/h	0.0042	0.0043
	Body vertical acceleration (m/s2) at V= 5 km/h	0.0043	0.0045
	Body vertical acceleration (m/s2) at V= 7.5 km/h	0.0047	0.0049

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