Influence of speed bumps on braking distance

A Maftei, A I Dontu, L Gaiginschi and I Agape
Gheorghe Asachi Technical University of Iasi, Faculty of Mechanical Engineering, Blvd. Mangeron, No. 61-63, 700050, Iasi, Romania
E-mail: alexandru.maftei90@gmail.com

Abstract. This paper aims to dismiss the popular belief that speed bumps reduce the vehicle speeds or reduce the braking distance. In recent years, the implementation of speed bumps on public roads in Romania has increased. The correct understanding of the role of the speed bump has been misunderstood by the Romanian authorities who use them to slow down traffic on highly used roads. More advanced countries in the segment of traffic controlling and traffic safety have special rules for speed humps and speed bumps. This paper is concerned with the theoretical and experimental study of the performance of the vehicle in emergency braking when passing over such a speed bump. The theoretical study is done by using mathematic formulas and the experimental study is done by using a real car and testing it’s braking distance in normal weather on a dry road that has a speed bump implemented. The study shows the influence of the induced forces from the speed bump in the car dynamics, once because of the low adhesion surface of a worn out speed bump and secondly because of the changes in normal force on the wheel after passing over the hump, the influence of the suspension loading is also backed up by the Tr. Ori study.

1. Model

1.1 Braking Dynamics
Braking dynamics refer to all the physical processes that act upon a car when decelerating. Theoretical vehicle braking dynamics are addressed in many papers, the main influences on the deceleration of the vehicle are taking into account the following parameters:
- Adhesion coefficient;
- Mass;
- Temperature;
- Braking system efficiency.

Knowing the enumerated parameters and applying theoretical approach, the following parameters can be calculated:
- Braking/Stopping distance;
- Braking/Stopping Time;
- Braking Stabilty.

Deceleration is the process through which a body travelling at a certain speed starts to reduce the speed. Deceleration is a negative value. In the ideal case of vehicles, when all wheels are at the limit of adhesion, deceleration can be calculated using the following formula:
\[ a' = \frac{g}{\delta^1} (\varphi + p) \]  

(1)

Where:  
\( g \): gravitational acceleration.  
\( \delta^1 \): coefficient for the influence of the wheels in rotation regarding the vehicle translation.  
\( \varphi \): adhesion coefficient.  
\( p \): the gradient of the road.  

For studying the deceleration of a vehicle when passing over a speed bump, the conventional formula is not sufficient, for this case, we need to introduce in the formula the influence induced by the impact with the speed bump.

For the influence of the speed bump, we can try to apply Burg’s theory of impact, from this we can derive formula (1) and bring it to the form of formula (2).

\[ a' = \varphi \cdot g \cdot \left[ f_h + (1 - f_h) \cdot \sin \alpha_m \right] \text{m/s}^2 \]  

(2)

Where:  
\( \alpha_m \): is the medium angle of post collision rotation, which can be calculated formula (3) that can apply for speed bumps.

\[ \alpha_m = \frac{|\Delta \alpha|}{2} \text{ for } |\Delta \alpha| < 60^\circ \]  

(3)

\( f_h \): the braking distribution on wheels coefficient. (values 0,1 \leq f_h \leq 1).

Braking distance is the distance traveled by a vehicle from the moments it’s starts decelerating until it comes to a lover speed or until it comes to a stop. In the ideal case of vehicle braking, with all the wheels and efficient braking system, the braking distance can be calculated using the simplified formula:

\[ S_{f \text{ min}} = \frac{\delta^1}{26 \cdot g \cdot \varphi + f + p} \left( v_{a1}^2 - v_{a2}^2 \right) \]  

(4)

Where:  
\( v_{a1}^2 \): speed at which braking starts;  
\( v_{a2}^2 \): speed at which braking has stopped (If the car comes to a stop, \( v_{a2}^2 = 0 \text{ [km/h]} \))  
\( f \): road resistance coefficient;

For determining the braking distance when passing over the speed bumper, formula (4) is not sufficient, as well as applied in the deceleration, Burg’s theory regarding impact can be adapted here, as shown in formula (5).

\[ S_{f \text{ min}} = \frac{1}{26 \cdot g \cdot \varphi \cdot \left[ f_h + (1 - f_h) \cdot \sin \alpha_m \right]} \left( v_{a1}^2 - v_{a2}^2 \right) \]  

(5)

1.2 Analysed Vehicle
The considered vehicle for the theoretical calculations was a 2001 Opel Astra Coupe with a 1.8 Gas engine. The dimensional characteristics are shown in Figure 1.
Figure 1. Dimensional characteristics of the analysed vehicle.

Dimensional characteristics that influence the braking capabilities of the vehicle:
Wheel dimensions: 195/60 R15 88V - DOT 3513
Wheel pressure: front - 2.3 (bar) - 0.23 MPa, rear - 2.3 (bar) - 0.23 MPa
Mass: 1345 [kg];
Front area dimension: 2.01 [m²];
Drag coefficient: 0.2

1.3 Calculated values
Using the values provided from the producer of the analysed vehicle and applying the dynamic formulas for deceleration (1) we obtained the results shown in Table 1, the values are calculated for dry asphalt when braking from the speed of 50 [km/h]. Applying Burg’s theory on the deceleration formula (2), we obtain the values from Table 2.

| Adhesion coefficient $\phi$ | Deceleration [m/s²] |
|-----------------------------|----------------------|
| Dry Asphalt                 | 0.7                  | 6.341                |

Table 1. Calculated deceleration values with normal deceleration formula.

| Adhesion coefficient $\phi$ | Deceleration [m/s²] |
|-----------------------------|----------------------|
| Dry Asphalt                 | 0.7                  | 6.227                |

Table 2. Calculated deceleration values with Burg’s theory implemented.

For calculating braking distance of the analysed vehicle, the normal formula for such ideal cases was used (4), the values are presented in Table (3). In Table (4) the values for braking distance after applying Burg’s theory (5) are presented. As in the case of deceleration, the calculations where done for all 3 types of conditions.

| Adhesion coefficient $\phi$ | Deceleration [m/s²] |
|-----------------------------|----------------------|
| Dry Asphalt                 | 0.7                  | 6.227                |

Table 3. Calculated braking distance values with normal formula.

| Adhesion coefficient $\phi$ | Deceleration [m/s²] |
|-----------------------------|----------------------|
| Dry Asphalt                 | 0.7                  | 6.227                |

Table 4. Calculated braking distance with Burg’s theory implemented.
2. Experiment
For demonstrating the influence of speed bumps on braking distance, test studies have been conducted in the enclosed campus location.

The selected street for conducting the tests was sufficiently long that the car could accelerate to a speed of 50 [km/h] before reaching the speed bumps.

For the measurements the same vehicle as in the calculated analyse was used, an Opel Astra Coupe 1.8L gasoline engine. A radar gun was used to verify that the instrument panel cluster indicated the correct speed of the vehicle. Also an LSM6DS accelerometer was used to monitor the vibrations on X direction (for braking) and on Z direction (for Z displacement when going over the speed bump), pin-out configuration of the accelerometer is seen in Figure 2.

![Figure 2. Accelerometer pin-out configuration.](image)

**Location** - The exact location of measurement is seen in Figure 3, this is “Professor Vasile Petrescu Alley, Iași” (GSP Coordination: 47.154392, 27.609449).

![Figure 3. Image from the test location.](image)
“Tudor Vladimirescu” student campus from Iasi where the test was conducted, has implemented seven speed bumps around the streets that pass through it. Traffic on this campus it’s about of 13,000 cars on a weekly basis. So in one week a lot of cars transit the campus, and being a residential neighbourhood the presence of speed bumps do not have a high influence in the traffic flow.

2.1 Conditions
The weather conditions on the day of measurements:
- Temperature from that day: 22.5°C
- Asphalt condition: dry

2.1.1 Speed Bump. The speed bump is usually a road calming construction applied in parking lots. The dimensions of the speed bumps are usually from 30 to 100 mm in height and 500 mm length. They are not recommended for applications on public roads, but the understanding of the Romanian authorities in these cases is wrong. These traffic bumps are usually made from recycled rubber and are designed to reduce vehicle speeds to 16 km/h.

The dimensions for the speed bump used in the test is shown in Figure 4, it is a small height speed bump that is found implemented on a lot of streets in Romania.

![Figure 4. Dimensional characteristics of the speed bump.](image)

2.1.2. Measured results and test method. A number of three test runs were done for control, in this case the vehicle was breaking on the road with no speed bump influences, this set a benchmark for the measurements and a way to see if the theoretical values match.

The three test runs with the speed bump implemented on the road, were conducted on the same section of road so as to maintain the same coefficient of adhesion for braking.

Each of the two cases of braking, with and without speed bumps, was conducted from marked points for each case of study. Also, the stopping point of the car was clearly marked on each run. The distance between these two points were afterwards measured.

For the test case of braking over the speed bump, the braking is started at approximately 1.5 [m] before the bump as seen in Figure 5.
Figure 5. Captured image from collecting data, point were braking started.

All the data collected from the test runs are shown in Table 5. Also, the vehicle speed registered by the radar gun is mentioned.

| No. | Car speed [Km/h] | Car braking distance [m] | No. | Car speed [Km/h] | Car braking distance [m] |
|-----|------------------|--------------------------|-----|------------------|--------------------------|
| 1   | 49               | 10.85                    | 1   | 53               | 12.97                    |
| 2   | 48               | 12.10                    | 2   | 47               | 13.37                    |
| 3   | 53               | 11.45                    | 3   | 50               | 12.73                    |
|     | Medium values    | 50                       |     | Medium values    | 50                       |
|     | Influence of distance | 11.46               |     | Braking difference in distance | 1.55                  |

The accelerometer readings have also produced valuable data regarding the accelerations on the vehicle on X and Z directions, we can see an example of one of the readings while braking from 50km/h to a complete stop in Figure 6 and in Figure 7 we see these forces when braking from 50km/h to a complete stop while going over a speed bump.

Figure 6. Accelerometer reading when braking from 50km/h to a complete stop.
Figure 7. Accelerometer reading when braking from 50km/h to a complete stop going over a speed bump.

3. Conclusions
Although implementation of speed bumps on the roads has significantly reduced the speed of the vehicles and also the number of accidents, we must not forget the disruption produced by such traffic calming tools in the flow of traffic.

Another thing to take into account is that the speed bumps are not responsible for reducing vehicle speeds, the driver is the main controller of the vehicle speed in any case, if he chooses to ignore the speed bump and drive fast, in the eventuality of hard braking over it, the speed bump will influence the braking distance.

Based on the conducted test runs and measurements, correlated with the theoretical model, we can observe that these traffic calming tools have a drawback regarding safety in braking distance. From the theoretical formula we see a difference of 2.24 [m] in braking distance, at a speed of 50 [km/h] this means that braking over the speed bump will increase the braking distance with approximately 18%, whereas in the practical measurements we have a difference of 1.55 [m], meaning that in the real case and with the chosen test vehicle, the braking distance was with approximately 14% longer.

The differences of 4% between the two cases, theoretical and physical, can be explain either through driver error, driver reaction time, vehicle braking stability or error in measuring. In any case, a longer distance is shown, from this we can conclude that the speed bump leads to an increase in vehicle stopping distance.

The theoretical formula needs refinement, because in the present status it does not take into consideration the influenced induced in braking from a worn out suspension. Also the test needs to be conducted at different speeds to see exactly the difference in influence of these speed bumps on the braking distance in different conditions and through utilizing specialized measuring equipment.

Acceleration forces measurement shows a clear relation between the influence of the Z acceleration versus the X deceleration force.

The additional length of stopping distance in cases in which such traffic calming tools are used near pedestrian crossings can be the difference that leads to an accident.

4. References
[1] Ori T R, Gbaha P, Asseu O and Le Bot A 2011 Asian Journal of Scientific Research 4(1) 28-41
[2] Jazar N R 2008 Vehicle Dynamics: Theory and Applications (New York: Springer-Verlag) XXII
[3] Wong J Y 2001 Theory of Ground Vehicles (Illinois: John Wiley & Sons)
[4] Rajamani R 2006 Vehicle Dynamics and Control (New York: Springer-Verlag)
[5] Burg H and Rau H 1981 Handbuch der Verkehrsunfallrekonstruktion (Verlag: Information Ambs GmbH)
[6] Gaiginschi R 2006 Siguranța circulației rutiere (Iasi: Tehnica) II
[7] Accelerometer datasheet : http://www.datasheetcafe.com/LSM6DS-PDF-datasheet-inertial-module/