Study of the stresses in the front suspension components of a car passing over speed breakers

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Abstract. To reduce the speed of vehicles before pedestrian crossings or as a warning for lowering the speed, vertical deflection devices or road profiles are placed transversely to the direction of travel. The type of profiles is different – speed bumps and humps with different height and length. Some of the profiles have the task of alerting the driver of changing conditions or potential danger - such are the rumble strips, while others aim to force the driving speed below 30 km/h. The amplitudes of the second profiles are considerably larger than those of the first and can cause significant stresses in the front suspension elements and its connections. The purpose of the study is to obtain information on the load on the front suspension components when passing over speed breakers.

1. Introduction
Speed breakers are divided into several types depending on their dimensions: speed humps, speed bumps and speed tables. They are designed to limit the speed of traffic depending on urban conditions: residential streets, school areas or public areas [1]. The speed at which vehicles approach the breakers decreases with increasing height of the calming devices [2]. This applies for drivers familiar with road specifics or in the case of good road markings [3]. In the absence of these conditions, the driver may approach the calming device with inappropriately high speed, which is perceived as a jolt to the vehicle and its passengers [4]. Also some studies have shown that over time drivers get used to speed breakers and speeds rise again [5]. In this case, the suspension elements are subjected to high dynamic forces which result in increased stresses. In residential areas with high concentration of speed breakers, increased air pollution [6] and noise [7] are observed. Due to the abovementioned disadvantages of the calming devices, the optimal design of speed breakers has been an object of research [8]. Good design slows down the traffic to safety levels without causing any impact on the suspension elements [9] and excessive discomfort in the passengers [10].

This study examines the available speed breakers in an urban road network. Depending on their dimensions and the approaching speed, different vertical and longitudinal accelerations in the hub carrier (wheel axle) are recorded. These accelerations are used as input parameters in a finite element model of a MacPherson strut suspension. The study presents the stresses in the suspension elements obtained when passing over speed breakers and the impact of their dimensions on the dynamic forces in the wheel axle.

2. Experimental determination of wheel axle accelerations
To determine the accelerations in the wheel axle, two accelerometers are mounted on the hub carrier. They are uniaxial – one measuring the accelerations in the vertical and the other in the longitudinal
direction. The accelerometers are piezoelectric and fitted with the suitable “Brüel & Kjær” charge amplifiers. They are connected to the HBM DAQ device 401 and via it the oscillograms are recorded in a computer (figure 1).

The suspension is complete with a 205/55 R16 radial tyre on a steel wheel. The air pressure in the tyre is 2.1 bar. The measurements are conducted on dry pavements at ambient temperature of 25 °C. The speeds of passing over the calming devices are 20, 30 and 40 km/h.

![Figure 1](image1.png)

**Figure 1.** Layout of the measuring system: 1 – DAQ DC module, 2 – charge amplifiers, 3 – piezoelectric accelerometers, 4 – PC.

3. Measuring the profile of the speed breakers

For measuring the profile of the speed breakers, a metric levelling rod and self-levelling laser level shown in figure 2 are used. The levelling rod is placed at the beginning of the speed breaker and it is moved to points, spaced at equal distance of 50 mm between them. The finish point is at the other end of the calming device.

A total of eight different size speed breakers are measured. These include temporary rubber and permanent concrete ones. Some of them are shown in figure 3.

![Figure 2](image2.png)

**Figure 2.** Equipment for measuring the profile of speed breakers:
1 – metric levelling rod;
2 – self-levelling laser level RoboToolz RT-7610-5.

![Figure 3](image3.png)

**Figure 3.** Sample of the measured speed breakers.
4. Processing the experimentally obtained results

To determine the “angle of attack” of a calming device, a drawing consisting of the speed breaker profile and the vehicle pneumatic tyre is made. A tangent line to the speed breaker curve is drawn. This line passes through the common point between the tyre and the speed breaker curve. The angle between this tangent and the pavement surface is the angle of attack – angle $\alpha$ in figure 4. For the specific pneumatic tyre, its static deflection of 16 mm, under the weight of the vehicle, is taken into account.

\[ a_{sum} = \sqrt{a_v^2 + a_h^2} \]

where $a_v$ and $a_h$ are respectively the maximum measured vertical and horizontal accelerations of the hub carrier.

The resulting total accelerations are compared for different passing speed and angles of attack.

5. Suspension modelling

A structural finite element model of the studied MacPherson strut suspension is made. The model is implemented in SolidWorks Simulation software. The coil spring is assumed to be made of steel C60 with elastic modulus $E = 2.1 \times 10^{11} \text{ N/m}^2$, Poisson coefficient $\mu = 0.28$ and density $\rho = 7800 \text{ kg/m}^3$. The hub carrier is assumed to be made of grey cast iron with elastic modulus $E = 6.6 \times 10^{10} \text{ N/m}^2$, Poisson coefficient $\mu = 0.27$ and density $\rho = 7200 \text{ kg/m}^3$. All other metal elements are assumed to be made of mild steel with elastic modulus $E = 2 \times 10^{11} \text{ N/m}^2$, Poisson coefficient $\mu = 0.29$ and density $\rho = 7900 \text{ kg/m}^3$. The rubber mounts of the suspension are presented as distributed springs without their own mass. The rubber mounts of the lower control arm have a radial stiffness of $1.2 \times 10^6 \text{ N/m}$ (position 1 in figure 5). The top mount of the shock absorber has a normal stiffness of $1 \times 10^6 \text{ N/m}$ (position 3 in figure 5). The shock absorber is modelled as a rod system made up of two solid elements: a rigidly connected piston and a piston rod as well as a twin-tube solid element. A spring-damper element connects the piston and the bottom of the inner tube (position 2 in figure 5). The spring-damper connector limits the movement of the piston and piston rod in radial direction by its high tangential stiffness. It also has a damping coefficient of 2000 N.s/m in axial direction.

\[ \text{Figure 4. The angle of attack of a speed breaker and the resultant acceleration which it causes in the axle of the wheel.} \]

\[ \text{Figure 5. Model of the studied MacPherson strut suspension: 1 – rubber mounts of the lower control arm; 2 – spring-damper connector between the piston and the inner tube; 3 – top mount of the shock-absorber.} \]
Input parameters are the vertical and horizontal dynamic forces in the wheel hub (axle) when passing over a speed breaker. The dynamic forces are the product of the measured maximum accelerations with the unsprung mass. The unsprung mass is 45 kg. It includes the mass of the tyre, the steel wheel, the bearing hub, the hub carrier, the brake caliper and disc, the lower arm, and two-thirds of the mass of the coil spring and the shock absorber. Also a static vertical force of 4000 N is applied to the wheel hub.

“Modal Time History Study” available in the SolidWorks Simulation software is used to solve the numerical dynamic study. It allows for the disturbing force to be set as a function of time. The aim of the model is to find the elements of the suspension with the highest stresses caused by passing over a calming device. The resulting stresses estimate the necessary speed of going over a speed breaker to reach the yield strength of material for the endangered suspension element.

6. Results
Table 1 shows the resulting total acceleration and the attack angle for the different speed breakers. The values of the accelerations are measured for three different speeds of motion.

| Number | Angle of attack (degrees) | Resulting acceleration (g) |
|--------|---------------------------|----------------------------|
| №1     | 5.0                       | 1.16 1.41 2.23             |
| №2     | 8.1                       | 1.17 2.05 2.91             |
| №3     | 8.9                       | 1.19 2.12 2.83             |
| №4     | 10.4                      | 1.89 3.18 4.11             |
| №5     | 10.8                      | 1.66 3.05 3.61             |
| №6     | 13.7                      | 2.50 3.81 4.95             |
| №7     | 15.2                      | 2.24 3.37 4.87             |
| №8     | 22.6                      | 2.25 3.81 5.39             |

From the results it can be seen that speed breakers with a larger angle of attack cause even higher accelerations in the wheel axle. Figure 6 shows the resulting total accelerations as a function of the angle of attack and the speed of passing over the speed breakers. The angles of attack correspond to calming devices of different heights. Figure 7 presents the dimensions of calming devices for different angles of attack and a height of 60 mm. The angle of attack decreases proportionally to an increase in length.

The model study is conducted for the highest recorded accelerations at the road measurements. They are registered for speed breaker №8 (Table 1) with the maximum angle of attack. The results show that the suspension elements with highest stresses are the control arm and the piston rod (figure 8). Stresses in the suspension elements increase proportionally to the disturbing forces at the wheel axle. The disturbing forces depend on the speed of passing over the speed breakers. Figure 9 shows the maximum stresses in the control arm and the piston rod as a function of the speed of passing over a speed breaker with 22.6° angle of attack. There is linear dependence between them. This allows us to calculate the estimated speed for which the stresses in one element of the suspension would reach its yield strength. In this case, the estimated speed for the material of the piston rod to reach its yield strength of 350 MPa is 65 km/h.

The mesh is constructed by linear tetrahedral solid elements with a total size of 10 mm and tolerance of 0.5 mm. A numerical solution with smaller size mesh elements (total size of 5 mm and tolerance of 0.25 mm) is performed. The stresses in the endangered elements for the second solution have a deviation less than 5%.
Figure 6. The resulting acceleration in the wheel axle as a function of the angle of attack of a speed breaker and the speed.

Figure 7. Speed breakers with equal height and different angles of attack.

Figure 8. Stresses von Misses in the suspension elements caused by passing over a calming device with an angle of attack of 22.6° at a speed of 40 km/h.

Figure 9. Maximum stresses in the control arm and the piston rod as a function of the speed of passing over a speed breaker with 22.6° angle of attack.

7. Conclusion
The experimental study shows that the angle of attack determines the force of dynamic impact on the wheel axle. The angle of attack depends on the geometric dimensions of the speed breakers such as the height at the midpoint and the length of the base of the cross section.

The dynamic forces are proportional to the speed of passing over the calming devices.
The theoretical FEM study shows that the highest stresses are recorded in the piston rod of the shock absorber and the control arm. At an estimated speed of 65 km/h, possible for urban conditions, the resulting stresses can reach the yield strength of the material. For the purposes of the study the assumed material is mild steel with yield strength of 350 MPa. Stresses higher than this could lead to plastic deformations of the elements and disturbance of the suspension geometry.

From the numerical study, by comparing the stresses caused by the static and the dynamic load, a dynamic coefficient can be calculated. In this case it is $k = 1.82$.

Speed breakers with an angle of attack higher than 20° are not suitable for speeds above 30 km/h. They can only be used in residential areas.

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