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IMPACT OF ROAD HUMPS ON VEHICLES AND THEIR OCCUPANTS

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A study has been undertaken by TRL and Millbrook Proving Ground for the Charging and Local Transport Division of the Department for Transport (DfT) to examine the impact of road humps on vehicles and their occupants. It involved practical testing of vehicles driven repeatedly over road humps, computer simulation of the road humps and vehicles, and biomechanical modelling of the human spine.

Background

Road humps have been shown in a number of studies to reduce vehicle speeds and accident frequency. They are the most effective traffic calming device currently available and are likely to be in common use for some time. In general, levels of discomfort are higher when humps are traversed at higher speeds and therefore humps cause discomfort to vehicle occupants if their vehicle is travelling too fast. This increased discomfort is the mechanism which persuades drivers to slow down.

The widespread use of road humps has resulted in some members of the public complaining that humps cause long term damage to vehicle components, especially the suspension, and that they can cause damage to the undersides of vehicles with low ground clearance or to exhausts. Concern has also been raised about whether the use of road humps might cause or exacerbate spinal or other injuries.

Trials were undertaken several years ago for the majority of hump profiles used on public roads to ensure that if appropriate speeds are adopted, excessive discomfort to vehicle occupants does not occur. Similarly it was established from trials that damage will not occur to the undersides of vehicles if humps are designed in accordance with the regulations and advice, and are crossed at appropriate speeds.

Bus companies, however, suggest that bus routes with road humps lead to increased maintenance costs. Professional drivers claim that repeatedly driving over road humps does cause or exacerbate back injury. Bus passengers may find the quality of ride is worse on traffic calmed streets and (for a given speed) the discomfort experienced is greater than for car occupants, particularly as they do not have a seat belt. People with a mobility impairment may suffer extreme discomfort or pain when driving over humps even at low speeds.

Improving the safety of vulnerable road users is a primary objective of sustainable transport policies. Complaints concerning increased maintenance for vehicles and/or excessive discomfort for their occupants may inhibit the use of road humps and thus limit the measures available for reducing road accidents.

The study aimed to investigate objectively the possibility that road humps cause increased wear to vehicle components and injury to vehicle occupants, and to suggest how these problems, if they exist, can be ameliorated.

Methodology

The study was based on:

- four different hump types, selected to be representative of those in common use (round top, flat top and sinusoidal humps, and a speed cushion), al175mm high; and
- five different vehicle types, each representative of models currently found in the vehicle fleet (medium saloon car, London taxi, ambulance, single deck bus and minibus).

Practical vehicle testing at Millbrook Proving Ground was undertaken to determine whether repeatedly traversing road humps causes damage to vehicle components. The tests involved instrumenting the vehicles and recording the response of each vehicle when driven over the humps at different speeds, ranging from 10 to 40mph (10 to 25mph for the bus and the minibus), at 5mph intervals. Vehicle components were examined for possible damage after repeated traversing of the humps. The driver and either one or two passengers were asked to rate the discomfort of each hump at each speed for each vehicle.

One of the main outputs from the vehicle testing was the vertical acceleration recorded at different points in the vehicles. The peak vertical acceleration at a particular location in the vehicle (taken in this study as the average of the absolute maximum and minimum values) served as a measure of the discomfort felt by the vehicle occupants. Peak vertical acceleration has been shown to be strongly correlated with discomfort rating: for a given speed, the greater the vertical acceleration, the greater the discomfort. Earlier work has suggested that vehicle occupants are unwilling to accept a peak vertical acceleration greater than about 0.7 g (where g is the force of gravity and equals $9.8m/s^2$).

The data were also used to validate the computer simulation and the biomechanical modelling at TRL. The computer simulation used a vehicle dynamics simulation model- SImulation MOdel Non-linear or SIMON - running within Human Vehicle Environment (HVE). It had three purposes:

- to estimate acceleration values at different positions in the vehicle,
- to provide direct inputs to the biomechanical modelling if required; and
- to investigate the effects on vehicle occupants of a wider range of road hump profiles than was possible with the practical testing at Millbrook, with the potential for improving the situations where discomfort is greatest, without increasing the likely speed of traversal of other vehicles.

The biomechanical modelling was used to investigate the physical effect of road humps on vehicle occupants. TRL' s existing model of the human spine was developed in order to estimate the forces in the spinal ligaments of a vehicle occupant when the vehicle traverses a hump, for a range of hump type / vehicle type / speed combinations.

Effect of humps on the vehicle

The results for the vehicles tested were as follows:

- Visual inspections revealed no damage to any of the vehicles.
- Suspension geometry checks showed 'small changes in the toe (i.e. the difference between front and rear edges of tyres mounted on an axle) following the passes over the humps and these changes were outside the manufacturers' tolerances for the taxi, the ambulance and the minibus. When the tests were repeated at lower speeds, it was found that the changes remained within the tolerances, provided speeds did not exceed 25mph for the minibus or ambulance and l5mph for the taxi.
- Further investigation of the taxi, in which the forces generated when traversing the hump were simulated, showed that repeated traversals caused the toe to go outside the tolerances temporarily, but that subsequent traversals caused it to return within the tolerances. This suggests that the changes were due to deformation in the compliant elements within the suspension system of this particular vehicle (such as suspension arm bushes, control arm bushes, steering rack mounting, track rod ball joints etc), rather than being an early indication of vehicle damage.
- Four out of the five vehicles showed no change in damping performance following the tests. However, the ambulance showed a reduction in the front suspension damping ratios. As no change was seen in the dampers when tested off the vehicle, this result could be attributed to a reduction in the whole system damping, possibly due to minute changes in the rubber bushes. This represents a normal phenomenon in what was a fairly new vehicle rather than damage or accelerated degradation to the suspension.
- The forces generated by driving over humps at the speeds tested were found to be comparable with those sometimes experienced during normal driving activities, such as driving over a very irregular surface or a pothole, or mounting a kerb.

With the exception of the ambulance, the only changes .found in the vehicle components were in the toe angle. The relatively small changes would not be noticeable to the driver in terms of the steering feel or handling, even where the tolerance band was exceeded.

Accelerated tyre wear is a possible effect of toe angle exceeding the tolerance, but it is considered that this would become noticeable to the driver only at greater deviations from specification than those seen during the tests. Since tyres are inspected at the annual MOT test, there is little chance of any defective condition developing that would go unnoticed. Vehicles require periodic adjustment of toe angle during correct maintenance, since driving over normal road features can give gradual toe angle change; that is why tyre centres and garages have the necessary equipment and have routinely carried out such checks during tyre changes for many decades, not just since road humps have become common.

Discomfort experienced by vehicle occupants when traversing humps

For the vehicles tested in this study, the peak vertical acceleration was below 0.7 g for the driver in the car and taxi over the round top, the flat top and the sinusoidal humps at 20mph and in the ambulance and minibus at 15mph, broadly corresponding to subjective ratings in the Mi11brook testing of 'slightly uncomfortable' to 'uncomfortable'. Peak acceleration for the bus driver was slightly above 07g over the flat top and sinusoidal humps at 15mph. Values for the rear seat passenger were similar to those for the driver in the car at 20mph and the minibus and bus at 15mph.

The peak acceleration for the passenger in the rear of the taxi was much greater (and reported discomfort was also substantially higher) than for the driver, even at 15mph. This may be due to the leaf spring suspension in the taxi tested; the latest models are believed to have coil springs. In the ambulance, the peak acceleration was slightly greater for the passenger in the rear crew seat than for the driver at 15mph, with a much greater differential at higher speeds. Of the full width humps, the flat top hump was better than either the round top or the sinusoidal for the passenger.

The peak vertical acceleration over the cushion was well below 0.7 g for both driver and rear seat passenger in most vehicles. For the rear passenger in the taxi and the ambulance, the peak acceleration was higher than for the driver, but still less than for full width humps; straddling the cushion was more comfortable than traversing it with two wheels on. In the trials, the passenger in the ambulance experienced little discomfort when straddling the cushion.

It was concluded that the levels of discomfort associated with measured peak vertical acceleration were generally acceptable if the humps were traversed at appropriate (intended) speeds i.e. not exceeding 15 to 20mph. Although passengers in the rear of taxis suffer considerably more discomfort than drivers, experienced taxi drivers are well aware of this and tend to approach road humps at very low speeds. Ambulance drivers will act in accordance with the situation.

Of the profiles tested, the sinusoidal hump tended to give the highest peak vertical accelerations, but in most cases these were only slightly higher than with the round top hump. Humps with a sinusoidal profile are similar to round top humps but have a shallower initial rise. They were developed in the Netherlands and Denmark to provide a more comfortable ride for cyclists in traffic calmed areas.

Possible alternative hump profiles from HVE computer simulation

From the HVE computer simulation, th6re was no evidence that alternative hump dimensions to those currently recommended could remove any unnecessary discomfort *and* maintain safety objectives. The following hump dimensions were considered optimal of those tested, in the sense of maximising discomfort to car drivers at speeds above 20mph:

- A height of 75mm. This was shown in earlier studies to be a good compromise between effectiveness and possible grounding.
- A round top hump length of 3.7m.
- A flat top hump plateau length of 6m to 9m and a ramp gradient of 1:13 to 1:15.
- A speed cushion length of 3.0m, with 1.8m plateau length, 1:4 side ramp gradient, 1.7m width, 1. 1m plateau width and 1:8 gradient of on/off ramps.

Biomechanical modelling of effect on spine for a vehicle occupant when traversing humps

In terms of possible damage to the spine, the ligament forces were considered appropriate for assessing injury and causation of pain. From the biomechanical modelling, it was found that:

- Predicted spinal ligament forces were almost an order of magnitude smaller than the damage threshold for such ligaments.
- Predicted forces transmitted through the spine as a whole were at least a factor of 4 smaller than those generated in discs by heavy lifting.

Medical opinion was sought to assist in the interpretation of these results. Because the predicted ligament forces were so far below the damage threshold, it was concluded that ligaments are unlikely to be injured by traversing road humps. Although muscle tissue was not modelled explicitly, this fact can also be taken to imply that the muscles would also be very unlikely to be damaged under the predicted loads.

Similarly, the predicted forces on discs were such that a healthy spine is unlikely to be injured by repeated traversing of a road hump and vertebral fractures are very unlikely to occur for those with normal bones.

Based on these predictions, it is considered that vehicle occupants are very unlikely to be injured as a result of single or repeated traversing of road humps. The exceptions to this statement are people with pre-existing conditions that result in either degenerated discs or weak bones, in which case they could be more susceptible to injury depending on the seriousness of their condition.

Recommendations

- Vertical traffic calming measures (road humps and speed cushions) should continue to be used as an effective method of reducing vehicle speeds, preventing injuries and saving lives. The existing guidance on road hump designs should not be altered.
- Where vertical traffic calming measures are required on bus and ambulance routes, speed cushions rather than standard road humps should be used.
- Vehicles should be prevented from parking near to speed cushions to enable buses and ambulances to straddle the cushions (since discomfort is greater when such vehicles are forced to mount the cushion).
- Taxi design needs to be improved to increase comfort in the rear - this is likely to have a general benefit, particularly for elderly people and those with certain disabilities, but would be especially beneficial in areas with road humps.
- Similarly, ambulance design could be improved to increase comfort in the rear. In particular, the use of vehicles with single rather than double rear wheels would be preferable.
- Road humps need to be carefully built to specification as earlier work has shown that quite small deviations can adversely affect the comfort of vehicle occupants. This is particularly true of the profile at the transition from road to hump.
- Careful attention needs to be paid to the signing and marking of road humps to ensure their visibility, especially at night, and to encourage drivers to slow down in good time for them.

Related publications

TRL417 *Traffic calming: passenger and rider discomfort at sinusoidal, round top and flat top humps - a track trial at TRL,* by I A Sayer, D A Nicholls and R E Layfield. 1999 (price £35, code J)

TRL416 *Traffic calming: Vehicle generated noise and ground-borne vibration alongside sinusoidal, round-top and flat-top road humps* by G J Harris, R E Stait, P G Abbott and G R Watts. 1999 (price £35, code J)

TRL215 *Review of traffic calming schemes in 20mph zones* by D C Webster and A M Mackie. 1996 (price £35, code H),

CT1.3 Traffic calming update (2001-2003). *Current Topics in Transport: selected abstracts from TRL Library's database* (price £20)

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