Towards a North American Geometric Design Standard for Speed Humps

THE PURPOSE OF THIS STUDY IS TO CONTRIBUTE TO THE DEVELOPMENT OF SPEED-HUMP GEOMETRIC DESIGN STANDARDS FOR NORTH AMERICA, WHERE VEHICLE CHARACTERISTICS, ENVIRONMENTAL CONDITIONS AND MOTORIST EXPECTATIONS MAY BE DIFFERENT FROM THOSE IN OTHER COUNTRIES.

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SPEED HUMPS ARE A VERY EFFECTIVE means of calming traffic. The most common design is the Watts Profile or circular hump. It is a section of a cylinder 3.7-meters (m) long and 75- to 100-millimeters (mm) high extending over the width of a street.[1] Most vehicles can traverse them safely at 25 to 30 kilometers per hour (km/h).

These speeds are often considered unrealistically low for many streets in North America that could benefit from traffic calming. Also, Watts Profile and similar humps are too abrupt for most heavy vehicles. Other less-severe designs are considered more suitable under these conditions. One such design developed in the United States is the Seminole Profile or "flat top" hump. The design features the addition of a 3-m flat section into a Watts Profile hump for an overall length of 6.7 m.[2] Both are illustrated in Figure 1.

Research in Europe and elsewhere has led to designs with many different lengths, heights and profiles. This has allowed their use on bus and truck routes, and streets with posted speeds up to 50 km/h. They are designed so that most vehicles will cross them at 5 km/h lower than the posted speed and are spaced so that over the length of a given street actual speeds will fluctuate around a predetermined desired speed.

The purpose of this study is to contribute to the development of speed-hump geometric design standards for North America, where vehicle characteristics, environmental conditions and motorist expectations may be different from those in other countries. It is one of the first attempts at a scientific examination of speed-hump design in North America and will hopefully serve to stimulate further research. In this study emphasis is placed on length as a critical design parameter. The goal is to suggest variations in Watts and Seminole Profile designs suitable for bus routes and non-bus routes having posted speeds of 30, 40 and 50 km/h.

SPEED-HUMP THEORY

A speed hump works by transferring an upward force to a vehicle, and its occupants, as it traverses the hump. The force induces a front-to-back pitching acceleration in vehicles having a wheelbase similar to the length of the hump that increases as the vehicle travels faster. This differs from a speed bump, which induces a high vertical acceleration at low speeds because it is significantly shorter than the wheelbase of a vehicle. The acceleration decreases with higher speeds due to absorption of the impact by the vehicle suspension.

For this reason length is a critical geometric-design parameter. Experiments have shown that as lengths increase peak accelerations tend to occur at higher speeds, and more linear dynamic effects are created. In general, longer humps exhibit better characteristics for speed reduction.[3,4]

In Denmark, circular humps up to 9.5 m long are used to reduce speeds to 50 km/h for automobiles and 35 km/h for buses.[5] Trapezoidal humps as much as 12-m long are used in the Netherlands and Australia.[6]

EXPERIMENTAL DESIGN AND PROCEDURE

The study consists of a two-phase experiment using variations of Watts and Seminole Profile speed humps. Several Watts Profile humps exist in Ottawa, Ontario, Canada, while Montgomery County, Md., USA, employs both humps on many of its local and collector streets.

In the first phase of the experiment, speeds for vehicles traveling over several of these on-road speed humps were recorded using a radar gun. It was thought that motorists, being free to choose their own speeds, would keep discomfort at a relatively constant level by traveling faster over the less-abrupt humps.

Oxnard's style 3700 mm x 100 mm = 12 feet x 4 inches

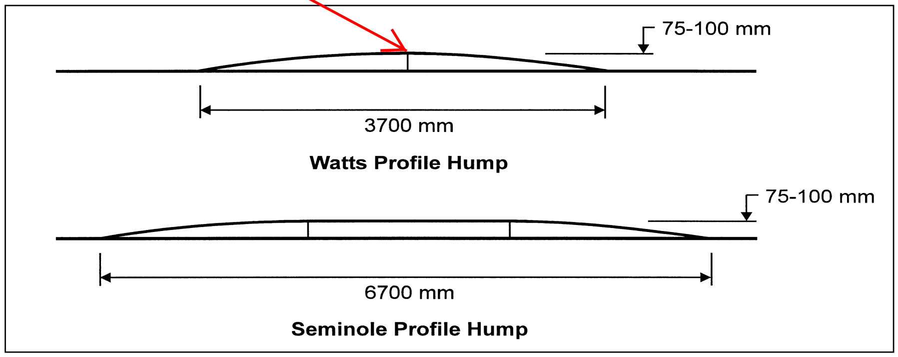

Figure 1. Watts and Seminole Profile Speed Humps.

Oxnards Style of speed humps, .621 x KM/H= MPH

Table 1. Observed hump-crossing speeds.

Speed-hump design	Automobile 85% speed (km/h)	Transit-bus mean speed (km/h)
100 mm Watts Profile	25	–
75 mm Watts Profile	29	–
100 mm Seminole Profile	40	–
75 mm Seminole Profile	44	30

25 Km/h=15.5MPH

Six on-road speed humps were selected:

- One 100-mm-high Watts Profile hump on a campus road with a posted speed of 25 km/h at Algonquin College in Ottawa;
- Three 75-mm-high Watts Profile humps on local streets with posted speeds of 20 miles per hour (mph) (30 km/h) in Rockville, Silver Spring and Gaithersburg, Md.;
- One 100-mm-high Seminole Profile hump on a collector road with a posted speed of 25 mph (40 km/h) in Bethesda, Md.; and
- One 75-mm-high Seminole Profile hump on a collector road and bus route with a posted speed of 25 mph (40 km/h) in Rockville.

In all instances the humps had been in place for at least one year. This ensured that motorists driving over them were familiar with their effects. Speeds were recorded for automobiles, and in the case of the Seminole Profile hump in Rockville, transit buses as well. The vehicles had to cross the humps under free-flow conditions and not be slowing for turns or stops. Readings were not taken for minivans, pickup trucks, sport utilities or other vehicles, as they were not used in later tests.

The calculated speeds are listed in Table 1. Thirty readings were obtained in each direction to obtain the 85th percentile speeds for automobiles. A mean speed was used for transit buses to reflect their greater impact on the perceptions of residents and vulnerable street users and because only ten bus crossings were recorded.

Off-road field tests were then carried out at the Central Experimental Farm in Ottawa using speed humps constructed out of wood to the same dimensions as the existing on-road humps. To simulate discomfort, horizontal and vertical accelerations were measured on a test subject as the duplicate humps were traversed at the observed speeds by two automobiles and a regular transit bus.

The automobiles were a 1989 Suzuki Swift GTi and a 1997 Chevrolet Monte Carlo LS, taken to be representative of the range of automobiles currently in common use in North America. The transit bus was a 1991 GM Classic on loan from OC Transpo, the Ottawa regional transit company. The bus was assumed to be representative of other heavy vehicles such as fire trucks and commercial vehicles.

In the second phase of the experiment, further tests were performed using Watts and Seminole Profile humps and two additional designs with lengths of 4.9 and 9.1 m. Again heights of 75 and 100 mm were used. The same test vehicles traveled over all the humps at design speeds of 25, 35 and 45 km/h, which correspond to desired speeds of 30, 40 and 50 km/h. To reduce the size of the experiment, a portion of all the possible tests was selected using a factorial design. All test runs were carried out twice.

Accelerations were measured at the interface between the vehicle seat and a test subject using an accelerometer housed in a Society of Automotive Engineers' pad. This method has been used in most studies of human vibration, which have established that accelerations are primarily interpreted by seated subjects through the lower parts of the hip bone.[7]

DISCOMFORT CRITERIA

It was found that the lowest standard deviations among the results from the first phase of the experiment came from examining root sum of square (RSS) accelerations along the horizontal and vertical axes of the test subject. Although many previous speed-hump tests have represented discomfort through peak vertical acceleration, other studies of human vibration often use RSS accelerations because they combine root-mean-square accelerations along different axes and take into account their duration.[7]

The peak vertical and RSS accelerations (averaged between identical test runs) for the two test automobiles are shown in Table 2. The peak vertical accelerations had a much higher standard deviation over the range of designs and speeds tested. The baseline acceleration level, or discomfort criterion for the automobiles, was therefore taken to be an RSS acceleration of 0.17g.

A much less rigorous treatment of discomfort was possible with buses since only ten speeds were recorded over one existing hump. Accelerations were measured at the driver and rear seats as the transit bus traversed the 75-mm-high Seminole Profile test hump at 30 km/h. The discomfort criterion at the driver seat of the bus was an RSS acceleration of 0.20g, and the discomfort criterion at the rear seat was an RSS acceleration of 0.23g.

Interestingly enough, the mean peak vertical acceleration of 0.57g is lower than the average of 0.7g usually used to

Table 2. Automobile accelerations at observed 85th percentile speeds.

Speed-hump design	Observed 85% speed (km/h)	Test vehicle	Peak vertical acceleration (g)	RSS acceleration (g)
100 mm Watts Profile	25	Suzuki	0.67	0.17
100 mm Watts Profile	25	Chevrolet	0.57	0.18
75 mm Watts Profile	29	Suzuki	0.56	0.15
75 mm Watts Profile	29	Chevrolet	0.33	0.12
100 mm Seminole Profile	40	Suzuki	0.70	0.20
100 mm Seminole Profile	40	Chevrolet	0.62	0.18
75 mm Seminole Profile	44	Suzuki	0.61	0.18
75 mm Seminole Profile	44	Chevrolet	0.52	0.14
Mean			**0.57**	**0.17**
Standard deviation			**0.11**	**0.03**

Table 3. Optimal speed-hump dimensions.

Vehicle type	Hump-crossing speed (km/h)	Speed-hump dimensions (m, mm)
Automobile	25	5.2 x 100
Automobile	35	7.9 x 100
Automobile	45	9.1 x 75
Transit bus	25	7.9 x 100
Transit bus	35	5.7 x 75
Transit bus	45	Not found

STATISTICAL SIDEBAR

The variables used in the multiple regression analysis were those of experimental interest, the main effects of speed-hump length and height, hump-crossing speed and vehicle type, and the two-factor interactions. Since vehicle type was a qualitative factor, it was represented by three dummy variables.

The full details of the regression analysis are presented elsewhere.[10] A stepwise regression model was ultimately developed, and centered data was used to reduce multicollinearity. The model proved to be a very good fit of the experimental data, with an adjusted R^2 of 97 percent, and a global F-statistic of 165.8 at a significance level of 0.00.

The regression model was split into a separate equation for each vehicle type by substituting for the dummy variables. These four equations were used to estimate the RSS accelerations measured in the experiment and predict additional accelerations. The equations were not used for lengths below 3.7 m or above 9.1 m, as these were outside the range of designs tested.

model discomfort in other speed-hump studies.[4,8,9] This suggests that compared to other countries lower discomfort levels are tolerated by motorists traveling over humps in North America.

REGRESSION ANALYSIS

Using a multiple regression model, lengths were selected at each height and hump-crossing speed that produced RSS accelerations equal to the discomfort criteria for each vehicle type. The optimal lengths for both automobiles and the two positions on the transit bus were then averaged. For example, at a height of 100 mm and a speed of 25 km/h, the length that produced an RSS acceleration of 0.17g for the Chevrolet Monte Carlo was 3.7 m and for the Suzuki Swift, it was 6.7 m. Therefore, the average of the two, 5.2 m, was selected as the optimal length for automobiles under these conditions.

The optimal speed humps for automobiles and transit buses are summarized in Table 3. Only one length and height was found to be suitable at each hump-crossing speed. Others always produced accelerations above or below the appropriate discomfort criteria. The regression model suggests that humps designed for transit buses at 25 km/h will allow automobiles to traverse them at 35 km/h.

The model was sensitive to small changes in accelerations, and each optimal design could encompass a range of lengths. This seems logical, as small differences in length are unlikely to have much of an effect in the field. (See Statistical Sidebar.)

SUGGESTED DESIGNS

On non-bus routes the optimal speed-hump dimensions for automobiles are suggested. On bus routes, compromises between the optimal dimensions for automobiles and transit buses are suggested. For example, at a height of 100 mm and a speed of 25 km/h, the speed-hump length for bus routes was 6.1 m. The length was a compromise between 5.2 m and 7.9 m, biased towards automobiles to reflect their greater numbers on most streets. The suggested dimensions for bus routes and non-bus routes are listed in Table 4.

The suggested humps for bus routes will slow transit buses and other heavy vehicles to speeds slightly below those specified at the hump. Automobiles will be slowed to speeds slightly above those specified. Where it is not desirable to have *any* vehicles exceeding the desired speed, the humps designed solely for automobiles should be employed. While speed humps are not suggested specifically for buses at 45 km/h, they could be employed close to bus stops, where speeds are low.

Engineering judgment should be used to determine which speed-hump designs would make effective traffic calming measures under different conditions. Appropriate streets for traffic calming may have a higher percentage of buses and heavy vehicles or different desired speeds than those used in this study.

CONCLUSIONS

There was uncertainty associated with the suggested lengths because of small sample sizes used when establishing the discomfort criteria. Also, some of the optimal designs, such as the 5.2-m by 100-mm hump for automobiles at 25 km/h, had as much as a 3-m spread between the averaged lengths. This suggests that vehicle type is a significant parameter that needs to be tested further. On the other hand, the stepwise centered regression model turned out to be very precise.

In the fall of 1997, Public Works and Government Services Canada commissioned a traffic calming study to reduce motor-vehicle speeds in the Judicial Area and Parliament Hill, Ottawa, and make it safer for pedestrians.[11] Two 5.2-m long by 100-mm high humps were installed on Vittoria Way as per the suggested design for 30 km/h on non-bus routes. A recent study found that overall 85th percentile speeds have fallen from 51 to 29 km/h. Measured 85th percentile speeds were 24 km/h at the humps and 33 km/h between the humps.[12]

Table 4. Suggested speed-hump dimensions.

Street type	Desired speed (km/h)	Hump-crossing speed (km/h)	Speed-hump dimensions (m, mm)
Non-bus route	30	25	5.2 x 100
Non-bus route	40	35	7.9 x 100
Non-bus route	50	45	9.1 x 75
Bus route	30	25	6.1 x 100
Bus route	40	35	8.8 x 100
Bus route	50	45	See text

SUGGESTIONS FOR FURTHER RESEARCH

This study is by no means a comprehensive examination of all the parameters contributing to speed-hump design. More research should be done on the effects of vehicle type and how discomfort is interpreted by motor-vehicle occupants. Drivers of smaller automobiles, and passengers choosing to sit near the back of transit buses, may do so because they tolerate higher acceleration levels. More speed measurements are needed to refine discomfort criteria for motorists in North America, and different vehicles, including fire trucks and low-floor buses, should be tested.

Further experiments should be carried out on designs with different ramp slopes, since both Watts and Seminole Profile humps of the same height have the same ramp slopes. Speed humps with more gradual slopes, sinusoidal humps or speed cushions may be better suited for heavy vehicles.

Finally, additional speed measurements are needed to verify the suitability of the designs suggested in this study on actual streets and to determine the best compromises between transit-bus comfort and automobile effectiveness for speed humps on bus routes.

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References

1. ITE Technical Council Task Force on Speed Humps. *Guidelines for the Design and Application of Speed Humps*. Washington, D.C., USA: Institute of Transportation Engineers (ITE), 1993.

2. D.A. Nicodemus. "Safe and Effective Roadway Humps: The Seminole County Profile." *ITE 1991 Compendium of Technical Papers*. Washington, D.C., USA: ITE.

3. P. Moinat. *Étude et Simulation du Passage d'un Véhicule Sur un Dos d'Âne: Prédiction de l'Inconfort (A Study and Simulation of Vehicle Passage on Speed Humps: Prediction of Discomfort)*. Master of Engineering Thesis, Université de Sherbrooke, Canada, 1991.

4. J.R. Jarvis. *An Investigation of Road Humps for Use on Bus Routes*. Victoria, Australia: Research Report ARR No. 222, Australian Road Research Board Ltd., 1992.

5. Vejdirektoratet. *Road Standards Part 7—Speed Reducers*. Denmark: Ministry of Transport Urban Traffic Areas Report, Road Data Laboratory, Road Standards Division, 1991.

6. C. Hass-Klau, I. Nold, G. Böcker and G. Crampton. *Civilised Streets: A Guide to Traffic Calming*. Brighton, United Kingdom: Environmental and Transport Planning, 1992.

7. M.J. Griffin. *Handbook of Human Vibration*. London, United Kingdom: Academic Press, 1990.

8. G.R. Watts. *Road Humps for the Control of Vehicle Speeds*. Crowthorne, United Kingdom: Transport and Road Research Laboratory Report 597, Department of the Environment and Department of Transport, 1973.

9. T.F. Fwa and C.Y. Liaw. *A Rational Approach for Geometric Design of Speed-Control Road Humps*. Washington, D.C., USA: Paper presented at the 71st Transportation Research Board Annual Meeting, January 1992.

10. P.A. Weber. *Towards a Canadian Standard for the Geometric Design of Speed Humps*. Master of Engineering Thesis, Carleton University, Ottawa, Canada, 1998.

11. J.P. Braaksma & Associates Ltd. *Supreme Court of Canada Traffic Calming Study*. Ottawa, Canada: Public Works and Government Services Canada, Parliamentary Precinct Directorate, April 1998.

12. J.P. Braaksma & Associates Ltd. *Evaluation of Speed Humps on Vittoria Way*. Ottawa, Canada: Public Works and Government Services Canada, Parliamentary Precinct Directorate, December 1998.

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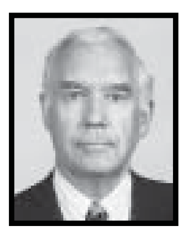

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