Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi

Afyon Kocatepe University Journal of Science and Engineering

AKÜ FEMÜBİD **22** (2022) 025602 (332-341)   AKU J. Sci. Eng. **22** (2022) 025602 (332-341)

DOI: 10.35414/akufemubid.1031891

Araştırma Makalesi / Research Article

Vibration Levels Exposed at Speed Bump and Speed Hump Transitions

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Received Date: 03.12.2021   Accepted Date: 12.04.2022

Abstract

The method used to eliminate the adverse effects of excessive vehicle speed in traffic operation is speed management. In the study, speed control undulations (SCUs), as one of the crucial tools of speed management in urban areas, have been evaluated in terms of their discomfort to the drivers and passengers in the passes over. In the evaluations, two narrow-type SCU (Bump) and two wide-type SCU (Hump) with 5 cm and 10 cm height were investigated. Whole-body vibration (WBV) values of the drivers were recorded by passing over the SCUs with passenger car type vehicles at the speeds of 20, 30, 40 and 50 km/h, and the discomfort levels were evaluated according to ISO 2631-1 standard. Vibration data were evaluated using the a_w parameter, which is considered to reflect the average effect of the vibration exposed, and the MTVV parameter, which is considered to be able to display instantaneous shock values with higher accuracy. The results were interpreted with the help of graphics, taking into account the comfort thresholds recommended by the standard. Contribution to the literature has been made on this subject, where there is only a limited number of studies.

Keywords

Speed bump;
Speed hump;
Traffic calming;
Whole-body vibration

Dar Hız Kesici Tümsek ve Geniş Hız Kesici Tümsek Geçişlerinde Maruz Kalınan Titreşim Seviyeleri

Öz

Trafik işletiminde aşırı hızın yarattığı olumsuz etkileri ortadan kaldırmaya yönelik kullanılan yöntemlerin tümü hız yönetimi olarak isimlendirilmektedir. Çalışmada, hız yönetiminin önemli araçlarından olan hız kesici tümsekler (HKT), üzerlerinden geçişlerde sürücü ve yolculara sağladığı konforsuzluk açısından değerlendirilmiştir. Değerlendirmelerde, 5 cm ve 10 cm yüksekliklerdeki iki adet dar tip HKT ve iki adet geniş tip HKT incelenmiştir. 20, 30, 40 ve 50 km/sa sürüş hızlarında yolcu otomobili türü taşıtlar ile HKT'ler üzerinden geçilerek sürücülerin maruz kaldığı Tüm Vücut Titreşimi (TVT) değerleri okunmuş ve ISO 2631-1 standardına göre konforsuzluk seviyeleri değerlendirilmiştir. Titreşim verileri, maruz kalınan titreşimin ortalama etkisini yansıttığı kabul edilen a_w parametresi ile anlık şok değerlerini daha yüksek hassasiyetle gösterebildiği kabul edilen MTVV parametresi kullanılarak değerlendirilmiştir. Sonuçlar, standardın önerdiği konfor eşiklerini dikkate alarak grafikler yardımıyla yorumlanmıştır. Yalnızca sınırlı sayıda araştırmanın bulunduğu bu konuda literatüre katkı sağlanmıştır.

Anahtar kelimeler

Dar hız kesici tümsek;
Geniş hız kesici tümsek;
Trafiği Sakinleştirme;
Tüm vücut titreşimi

1. Introduction

Nowadays, increasing vehicle speed as a result of the developments in technology is one of the most critical factors determining the severity of all accidents. More than 1.2 million people die each year from traffic accidents. In addition, injuries caused by traffic accidents are a leading cause of death worldwide (WHO 2015). Almost half of all deaths caused by traffic accidents happen among vulnerable road users, pedestrians, motorcycle drivers and bikers (WHO 2015). While the death rate of pedestrians in traffic accidents occurring worldwide is around 22%, it reaches up to 36% on urban roads (WHO 2015, Antić *et al.* 2013). However, according to WHO, in these accidents to which pedestrians were involved, death at 50 km/h speed is 80%, whereas the risk of death at 30 km/h speed decreases by up to 10%. Besides, the studies show that a 5% reduction in average speed provides a decrease of approximately 10% of all injury accidents and 20% of all fatal accidents (OECD 2006). Change of accidents according to mean speed change illustrated in Figure 1. Research shows that at least half of the drivers use their vehicles above the speed limit from time to time. In addition, researches have shown that drivers exceed the speed limit less than 20 km/h and rarely more than 20 km/h (OECD 2006). The further reduction of the relatively low speed of traffic operation in urban road networks is crucial in eliminating accidents in the frequently encountered form of 'pedestrian collision'.

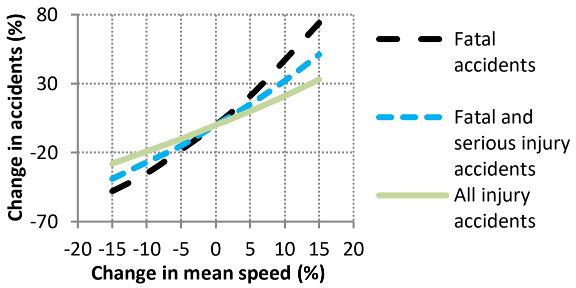

Figure 1. Change of accidents according to mean speed change (OECD 2006)

Traffic engineers have developed various methods to reduce the undesirable consequences of speed for vulnerable road users, especially on urban roads. Traffic control with electronic detectors, speed restrictions, warning and stop signs, lane channelization, diagonal diverters, road chokers, rumble strips and speed control undulations (SCU) are some of these methods. As a result of being easy to implement and economical, the SCUs are frequently preferred throughout the world for calming traffic purposes. SCUs developed to fulfil multiple tasks to regulate the traffic are named speed bumps (B), speed humps (H), speed tables (ST) and speed cushions (SC) according to their dimensions and cross-section geometries. Bs and Hs, which are frequently preferred worldwide for calming the traffic, are applied in constantly fixed sections as the platform width of the road. Bs have a rapidly rising section geometry from 0.3 m to 1 m wide, while Hs have a relatively gradual rising section geometry with a width of 1 m and above. They are manufactured in circular, parabolic or sinusoidal cross-section geometry in the direction of movement (Chadda and E. 1985, Parkhill *et al*. 2007, Cottrell *et al*. 2006). However, SCUs also have some unfavourable aspects similar to various methods being used to solve engineering problems. First and foremost among these is a prolongation of journey duration and a decrease in traffic mobility. It is generally known that traffic calming practices influence (either positively or negatively) the traffic volume (Cottrell *et al*. 2006). Therefore, traffic experts are concerned about the spread of the SCU practices as they are cheap and straightforward. On the other hand, reducing speed for all vehicle these practices cause delays in emergency vehicles such as fire brigades, ambulances and police vehicles. Among other problems are potential accidents that may occur due to the loss of control on vehicles as a result of failure to obey specified speed limits and diversion of traffic to alternative streets and avenues in an undesirable manner due to severe mechanical damage to the vehicles (Parkhill *et al*. 2007, Chadda and E. 1985, Cottrell *et al*. 2006). Undoubtedly, there can be avoided from many adverse effects of SCU applications with efficiency-oriented, well-planned and traffic circulation projects prepared.

Studies using comfort criteria to compare Bs and Hs are also included in the literature. In a limited number of studies in this regard, for comparing the comfort, there were used the vibrations to which the drivers and the vehicles exposed during SCU transitions. Whole-body vibration (WBV) exposure inside vehicles during transportation affects the driver and passengers adversely, particularly in comfort, human health, safety, etc. In the human body, well-known adverse effects of WBV can be listed as follows: gastrointestinal tract problems, spinal degeneration, lower-back pain, autonomic nervous system dysfunction, neck problems, and headaches (Eger *et al*. 2008). Many sectors are affected by the vibrations of motor vehicles while travelling. For example, 12% of the long-distance transportation sector, 14% of the wholesale and retail trade, cargo and motor courier sector are victims of the adverse effects of vibration (Bovenzi 2005).

Kırbaş and Karaşahin (2018) investigated the effects of vibration on human health at 5 and 10 cm high Bs and Hs transitions. Their study used vibration dose value (VDV), which explains the general adverse effects of vibration on human health, and the equivalent static compressive stress (S_e), which explains the impact on the lumbar spine in instant mechanical shocks. In the study, the number of SCU transitions that negatively affect human health was determined. Gedik *et al*. (2019) evaluated the seven different H types regarding the uncomfortably provided to the driver and passengers. Their study emphasised that H length and H geometry parameters are essential in addition to height. Khorshid *et al*. (2007) have planned an experimental study to determine the limit values that adversely affect human health in Hs with different cross-sections. The vibration data recorded as a result of the measurements were evaluated with the analysis approach proposed in the ISO 2631 standard, as in this study. As a result of the study, the researchers determined an H section with minimal adverse impact on human health. Patel and Vasudevan (2016) have determined that bicycle and motorized bicycles (scooters etc.) are pretty disadvantageous in SCU passages and have suggested that SCUs should not be used in urban roads where the proportion of two-wheeled vehicles in total traffic is high. Considering the driver's opinions regarding the use of SCU for traffic calming, it has been determined that users prefer Hs in terms of perceived comfort within the vehicle (Watts 1973, Hodge 1993, Bjarnason 2004, Webster and Layfield 1998). Vibration measurements also confirm this in the vertical direction to which drivers are exposed to (Watts 1973, Hodge 1993, Bjarnason 2004, Webster and Layfield 1998). Since the vibration occurring in the undulation transitions of the vehicles depends on the passed SCU profile, some studies plan to minimize the adverse effect by optimizing the cross-sections of the SCUs. For optimization, it is often seen that the vehicles are modelled as a quarter or half car. The solutions are made using optimization or simulation techniques. In various studies, the dynamic responses of the vehicles were evaluated by specifying the discomfort criteria in the range of 0.6 g - 0.9 g in polynomial or circle geometries (Molan and Kordani 2014, Khorshid and Alfares 2004, Fwa and Liaw 1992, Kanjanavapastit and Thitinaruemit 2013, Salau *et al*. 2004, Ansari Ardeh *et al*. 2008, Pedersen 1998, Aghazadeh *et al*. 28-30 August 2006). In general, studies show that the H sections suggested by Watts comply with ergonomics constraints (Watts 1973).

There are limited studies in the literature comparing SCUs in terms of both comfort and efficiency in reducing speed. In the study of Mak (1986), firstly, the SCUs compared as speed control devices and the ride (driving) speed was reduced by approximately 24% of Hs and 44% of Bs. Then, SCUs were compared in terms of comfort and, it was determined that vehicles are exposed to vibrations about twice as much vibration in B passages than in H passages. In the study, Bs and Hs with equal heights were not compared. As a result, the author has suggested that the use of Hs instead of Bs for speed management is more appropriate.

Speed management is defined as all methods that reduce adverse effects caused by over speed. Also referred to as “sleeping policemen”, SCUs, are one of the most economical and efficient ways to reduce vehicle speeds and thus reduce accidents. In this study, for passenger car type vehicles, Bs and Hs at 5 cm and 10 cm heights were evaluated comparatively in terms of comfort (or discomfort) that drivers will be exposed to during the transition at different speeds. The vibration data in the vertical direction exposed by the drivers are measured with three different types of passenger cars as station wagon (SW), sedan (S) and hatchback (HB) by passing through the SCUs at speeds of 20, 30, 40 and 50 km/h. These data were analysed according to the WBV evaluation methodology described in ISO 2631-1, and the discomfort levels of the SCUs on the drivers (also passengers (Watts 1973)) were determined using frequency-weighted root mean square (rms) acceleration, a_w, and maximum transient vibration value, MTVV, vibration components (ISO 1997).

2. Materials and Methods

2.1. SCU Profiles

The SCUs are the local elevation differences created by increasing the pavement up to 15 cm from the upper level. It is thought that the most critical factors affecting ride comfort in an SCU are peak accelerations, cognitive stimuli and rate of change of acceleration (Watts 1973). Despite the increase in the SCU height and speed and the increase in vertical vibration too much, the drivers cannot perceive much at altitudes above 76 mm, so it has been seen that this height is a significant distinction (Watts 1973). In light of this information, 5 and 10 cm heights were chosen for the measurements to remain above and below this value. All cross-sections of the Bs and Hs used in this study are a segment of a circle. Depending on this geometry, the widths of the SCUs used are different. Some agencies consider the SCUs as part of the road section, using the same material as pavement. In contrast, others use additional elements on the pavement such as composite, rubber, plastic, the concrete. In the study, the SCUs were manufactured as B1 plastic, B2 and H2 asphalt and H1 concrete, and the surface roughness was negligible. Geometric descriptions of examined SCU profiles are shown in Table 1.

Table 1. Geometric descriptions of SCUs used in the study

SCU	Width (cm)	Height (cm)	H/W Ratio
B1	40	5	0.125
B2	75	10	0.133
H1	210	5	0.024
H2	400	10	0.025

Apart from the devices applied for the traffic calming of the speeds of the vehicles in the traffic circulation, it is known that vehicle speeds are forced to decrease due to road geometry, traffic volume, driving habits. The examined SCUs were selected at distances as far as possible from intersections and at road sections not exceeding ± 3% longitudinal slope, mainly to avoid road geometry and traffic volume.

2.2. Vibration Measurement and Evaluation

Although it is possible to avoid many disadvantages of SCU applications with proper location selection and appropriate traffic operation projects, drivers and passengers are exposed to high vibrations in any case when they pass over them. The study's objective is to determine the differences between Bs and Hs at different heights in comfort or discomfort. For this purpose, the vibrations in the vertical direction were measured with passenger cars of SW, S and HB type at 20, 30, 40 and 50 km/h passage over each SCU. Therefore, as a general principle, during the vibration measurements, the principals of longitudinal profile measurement defined in the ASTM E 950 (ASTM 2009), E 1082 – 90 (ASTM 2007) and E 1926 – 08 (ASTM 2008) standards were accepted. The measurements were repeated many times, and the data that best matched the measurement method described by the standards were considered.

Human comfort perception can be explained accurately with the WBV assessment (Griffin 2007). The accelerometer in a particular elastic pad must be placed directly beneath the driver to ensure the entire interaction between the device and the driver and assess WBVs based on the definitions of the ISO 2631-1 standard. The principal factors for explaining the WBV, which are necessary to determine the acceptable level of exposure of the human body, are described in ISO 2631-1 standard (ISO 1997). Four possible effects of vibration on humans include degraded health, comfort, perception, and motion sickness. In ISO 2631-1, the frequency ranges of these effects are 0.5 - 80 Hz for degraded health, comfort and perception. Separated according to the 1/3 octave band frequencies, multiplying the acceleration frequency gain by the weights defined in the standard makes it possible to determine the frequency-weighted acceleration values (a_w) obtained for all directions separately by the following equations. According to the ISO 2631-1 standard, the a_w component is considered a reasonably suitable parameter to explain the acceleration transferred, as felt by the affected person (ISO 1997). The a_w is computed with equation (1).

$$a_w = \left[\sum_i (w_i a_i)^2\right]^{\frac{1}{2}} \tag{1}$$

Where a_w is configured frequency vertical acceleration, w_i is weight factor defined to the related factor and a_i vertical rms value for the 1/3 octave band interval. In some specific short periods, the random shock vibrations that are transferred to the passengers can be defined by evaluating all of the acceleration values recorded over a determined time interval. The MTVV parameter is produced by determining the maximum weighted squared average for a determined period ($a_w(t_0)$). The ISO 2631-1 standard advises "one second" be the time chosen for the period of the moving average, which leads to the calculation of the maximum transient vibration value as equation (2) (ISO 1997).

$$\text{MTVV}=\max\left[a_w(t_0)=\left[\frac{1}{\tau}\int_{t_0-\tau}^{t_0}\left(a_w(t)\right)^2 dt\right]^{\frac{1}{2}}\right] \quad (2)$$

Where $a_w(t)$ is the instant frequency weighted acceleration value, τ is the average moving period, t is the variable measurement, t_0 is the measurement period. The ranges of a_w and MTVV magnitudes are associated with varying degrees of discomfort according to ISO 2631-1, as shown in Table 2.

Table 2. Scale of vibration discomfort suggested in ISO 2631-1 (Griffin 2007)

Range (m/s²)	Discomfort level	
0 – 0.315	not uncomfortable	NU
0.315 – 0.63	a little uncomfortable	ALU
0.5 – 1	fairly uncomfortable	FU
0.8 – 1.6	uncomfortable	U
1.25 – 2.5	very uncomfortable	VU
> 2	extremely uncomfortable	EU

The driver is 36 years old, 172 cm in height and weighs 85 kg. All measurements were repeated with the same driver to eliminate the driver effect on the results. Measurements have been made to ensure that the driver travels in as upright a position as possible as recommended by the standards. It is known that the vibration caused by the mechanical structure of the vehicles is compelling, as well as the road effects in the vibration exposed in the car. For this reason, it was taken into attention to ensure that the measured vehicles are maintained, and the suspension systems are in the same technology. Vibration data were collected for three seconds while passing through each SCU during measurements. It was also taken into attention not to be any obstacle that can cause the vehicle's vibration in any way, except passing through the SCU. The technical specifications of the cars used in the measurements are shown in Table 3.

Table 3. Technical specifications of the vehicles used

	Length (m)	Width (m)	Weight (t)
SW	4.388	1.636	0.950
S	4.480	1.715	1.096
HB	4.065	1.687	1.105

2.3. Vibration Measurement Set

The vibration measurement set used in the study consists of an accelerometer (±4g measuring range, 500±15 mV/g sensitivity), a GPS antenna (< 3 m accuracy) and a data logger. Vibration data were recorded vertically to evaluate the relationship between the flexible pavement surface and the WBV. The acceleration measurement set works in conjunction with the computer and simultaneously collects vertical acceleration and GPS data. In the study, vertical vibration data were collected at intervals of 1000 per second and GPS data at 1 per second intervals and transferred to the computer instantly. The researchers evaluated the measured vibration values using the analysis method developed in the MATLAB® interface and the analysis method described in the ISO 2631-1 standard. The vibration measurement pad used for field surveys over the driver seat and the software developed to evaluate vibration data are shown in Figure 2.

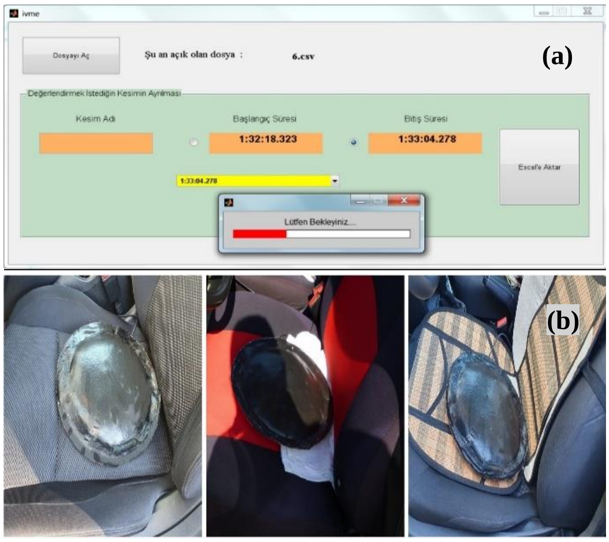

Figure 2. Analysis software (a) and vibration measurement pad (b) used in the study

3. Results

In this study, SCU in 4 different profiles, two of B and two of H, were evaluated for their performance for traffic calming in terms of discomfort to drivers when passes over them. The results of the measurements made in this section are explained with the aid of graphs.

Drivers need to reduce their speed due to the discomfort experienced during SCU passages. This is the result of increased safety by reducing the increased ride comfort along with the developing industry. The fact that one group of people tries to increase the comfort in vehicles while another group tries to decrease it makes one think that technology is in a vicious circle. Today, although various techniques have been developed to reduce the speed of vehicles, it is still a known fact that the most economical and efficient method is to make SCU on road surfaces (Pau and Angius 2001).

Therefore, the vehicle and the driver (or passengers) within it are exposed to a front-to-back pitching acceleration that increases with speed as they pass over the SCUs. In the study, the WBV to which the human body is exposed and comfort sense was explained with a_w and MTVV components. According to ISO 2631-1, a_w represents the approximate average of the vibration value being exposed, and the MTVV component is considered to represent the peak value (instantaneous shock) (ISO 1997). Vibration measurements were made with SW, S and HB type vehicles at different ride speeds and a_w and MTVV components were found for each SCU. The evaluation results are shown in Figure 3 and Figure 4. In addition, the evaluation scale limits adopted in ISO 2631-1 standard and shown in Table 2 are placed as background in the figures.

When the figures are examined, it is noted that the MTVV component, which is considered to represent the peak values of vibration, are higher than a_w. It is also observed that the vibration exposed by the increase in speed in all vehicle types increases for both components. For all vehicle types, both a_w and MTVV show that the most uncomfortable SCU is B2. Hence, discomfort for B1, H1 and H2 type SCUs are close to each other and relatively low.

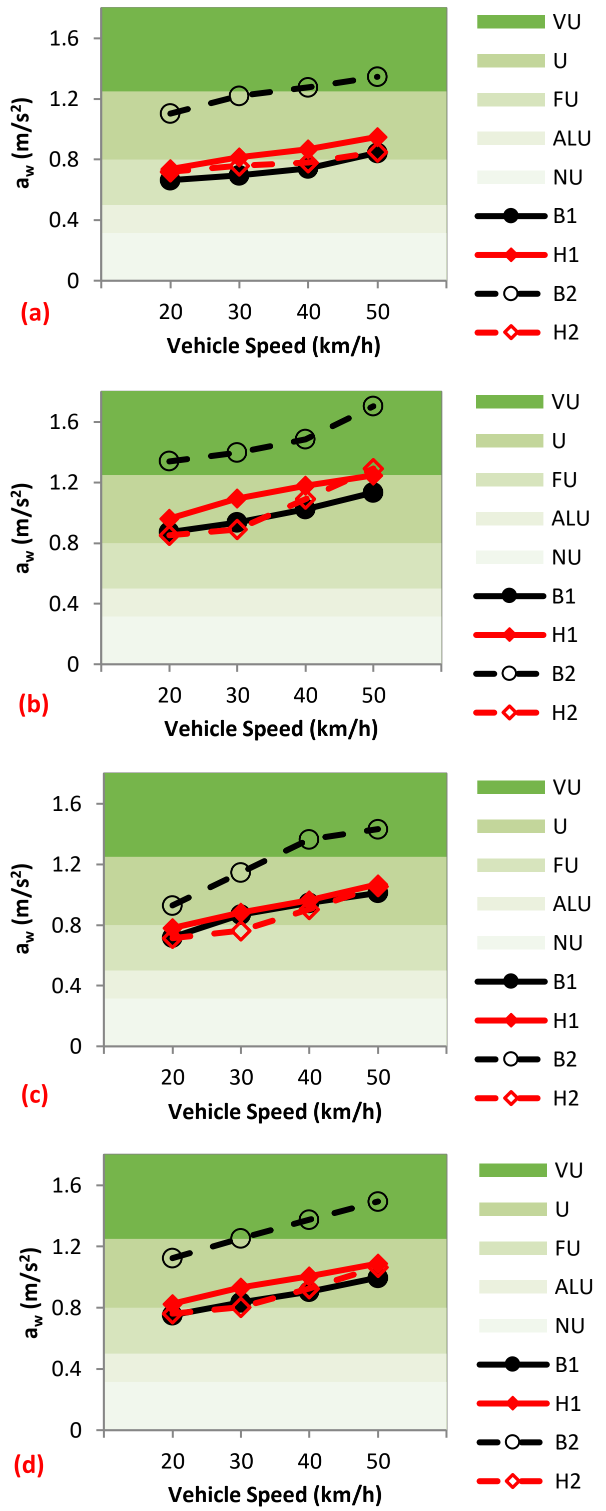

Figure 3. Changes in a_w that drivers are exposed to in SCU passages; (a) SW (b) S (c) HB (d) average of all

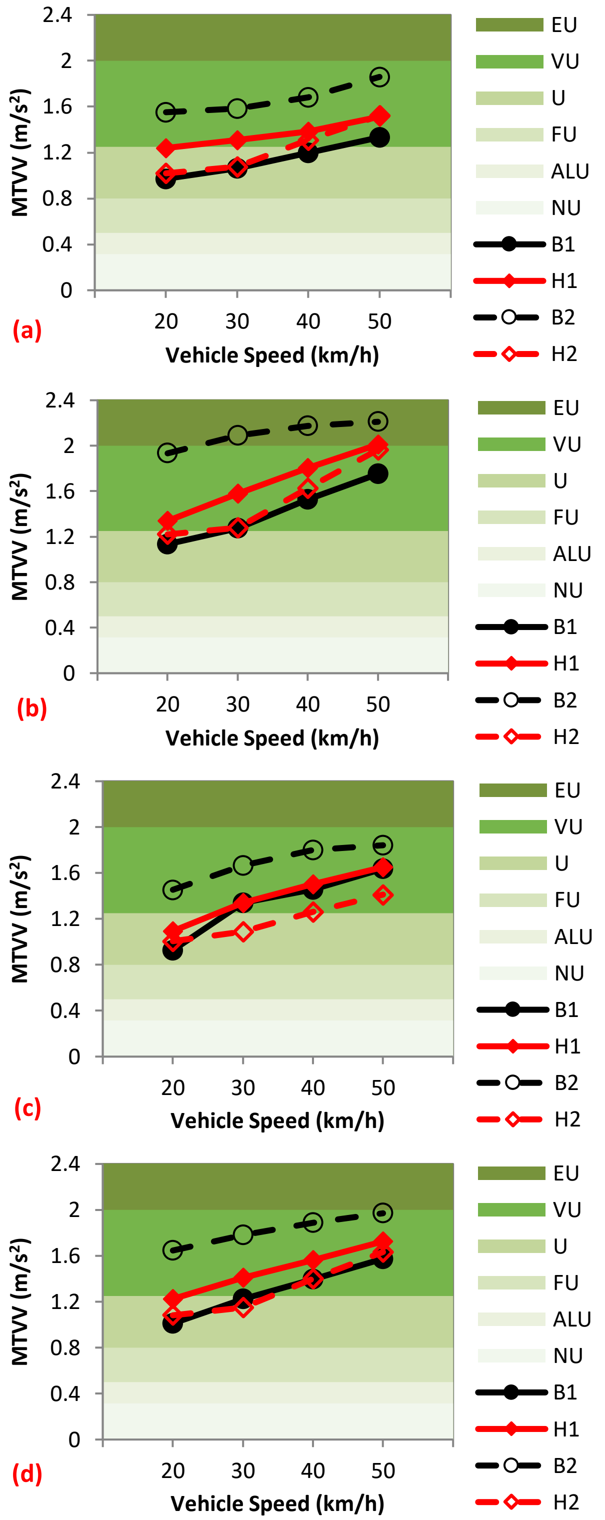

Figure 4. Changes in MTVV that drivers are exposed to in SCU passages; (a) SW (b) S (c) HB (d) average of all

4. Discussion

Since many authorities widely use it globally, this technique is thought to be a 'panacea' that can be used to solve any problem caused by speed (Pau and Angius 2001). This method, which is applied without considering the traffic characteristics, driving habits and road geometry of the region, should not be excluded from the mind that brings with it wrong and unnecessary usage. For example, it is recommended that Bs are only used on private roads and parking lots where traffic is under control (Parkhill *et al*. 2007, Pau 2002) . In contrast, it is also used frequently in calming urban traffic, especially in developing countries.

The comfort assessment made with three different passenger cars clearly shows that the B2 is the most uncomfortable SCU type compared to the a_w and MTVV vibration components. It is noteworthy that the discomfort is higher than B1, H1 and H2. It is seen that H1 follows B2 in terms of discomfort ability in the graphs (see Figures 3 and 4) obtained by taking the average of all vibration measured vehicle types. B1 and H2 provide approximately similar discomfort to the drivers when passing over them. As seen in the assessment of discomfort, it was observed that the H1 was less comfortable than B1.

Considering the average values of the vibration parameters for all three vehicle types, according to the a_w vibration parameter, SCUs with B1, H1, and H2 profiles experience an "uncomfortable" level of discomfort at speeds slightly above 20 km/h. In the B2 profile SCU, on the other hand, from 30 km/h, the discomfort at the "very uncomfortable" level is exposed. According to the MTVV parameter, B1 and H2 cross-section SCUs are exposed to "very uncomfortable" level discomfort at approximately 30 km/h ride speed and above. Besides, H1 and B2 section SCUs are exposed to "very uncomfortable" level discomfort at all speeds in the 20 - 50 km/h speed range.

The changes were examined by taking the average of the vibration parameter values found by the measurements made with three different types of vehicles. According to the a_w parameter, as the vehicle speed increases in the 20-50 km/h speed range, the discomfort in B1, H1 and B2 profile SCUs increases by 10% on average. In the H2 profile, it increases by 14% on average. Another evaluation was made according to the MTVV parameter, expressing sudden acceleration changes with higher precision. According to this, discomfort increases by an average of 16% in the B1 profile, 12% in the H1 profile, 6% in the B2 profile and 18% in the H2 profile. As per both parameters, the highest increase is seen in the H2 section SCU. This shows that while large-type SCUs does not negatively affect comfort at low speeds, the rotational acceleration spreading from front to rear strongly affects comfort as the speed increases. Therefore, the SCU section B2, where the discomfort changes the least depending on the speed, is encountered. While B2 causes discomfort increase at the same rate as B1 and H1 according to the a_w parameter with the increase in speed, the lowest discomfort increase according to the MTVV parameter is seen in the B2 profile SCU. This is clear evidence that narrow and high cross-section SCUs cause significant discomfort, even at very low speeds. Considering that sudden changes in discomfort while driving unexpected cause reactions in drivers, it justifies the recommendation that type B undulations should only be used in facility areas such as parking lots.

The evaluations were also made according to vehicle types. It can be said that the weight of the vehicle is more effective than the length of the car in the factor of increasing the discomfort with the increase in ride speed. With the increase in speed, an average of 7% increase is observed in the discomfort of the H2 section SCU in the SW type vehicle, while an average of 18% increase is observed in the S and HB type vehicle. In S and SW type long vehicles, while the discomfort increases by an average of 9% with the increase in speed in B1, H1 and B2 cross-section SCUs, the discomfort increases by 13% in HB type vehicles. All these changes are seen in Table 4.

Table 4. The rate of increase in the discomfort levels of vehicle types in each speed range

		a_w				MTVV			
	Speed Range	B1	H1	B2	H2	B1	H1	B2	H2
SW	20 km/h - 30 km/h (%)	5	11	11	7	9	6	2	7
	30 km/h - 40 km/h (%)	6	7	5	3	13	6	6	27
	40 km/h - 50 km/h (%)	14	9	5	11	11	9	11	19
	Mean (%)	8	9	7	7	11	7	6	18
S	20 km/h - 30 km/h (%)	7	14	4	6	12	18	8	6
	30 km/h - 40 km/h (%)	9	8	6	28	20	14	4	33
	40 km/h - 50 km/h (%)	11	6	15	22	15	11	2	24
	Mean (%)	9	9	8	19	16	15	5	21
HB	20 km/h - 30 km/h (%)	21	13	23	8	45	23	15	10
	30 km/h - 40 km/h (%)	9	9	19	22	9	12	8	19
	40 km/h - 50 km/h (%)	7	11	5	19	12	10	2	14
	Mean (%)	12	11	16	17	22	15	8	15
Average (SW, S, HB)	20 km/h - 30 km/h (%)	11	13	12	7	21	15	8	8
	30 km/h - 40 km/h (%)	8	8	10	18	14	11	6	27
	40 km/h - 50 km/h (%)	10	8	9	18	13	10	4	20
	Mean (%)	10	10	10	14	16	12	6	18

5. Conclusions

Although many devices have been developed for traffic calming by the authorities responsible for the operation of the roads, it is known that one of the most efficient methods is an undulation in the vertical direction of the road. That is why it is understood that the SCUs will continue to be used to reduce speed in urban road networks as they are economical. It is emphasized by researchers that SCUs used for traffic calming are mostly used without on-site determination of their suitability. The study examined the Bs frequently used in urban roads in developing countries, and the Hs recommended by internationally recognized standards to help some of the departments responsible for traffic management. For this purpose, the performance of two B and H units of 5 and 10 cm high with circular geometry was evaluated comparatively with the discomfort caused by the drivers travelling in different types of vehicles. The following findings were obtained in the light of these evaluations.

- It is seen that the discomfort increases with the increase in speed while passing through all the evaluated SCUs.
- For both vibration parameters, it has been determined that the most uncomfortable SCU is B2, and the discomfort for B1, H1, H2 type SCUs are close to each other and relatively low.
- According to the a_w and MTVV vibration parameters, in the measurements made with different vehicle types in the range of 20 – 50 km/h ride speed in the evaluated SCU profiles, discomfort is exposed at the levels of "uncomfortable" and "very uncomfortable".
- According to the a_w parameter, as the vehicle speed increases in the 20-50 km/h speed range, the discomfort in B1, H1 and B2 profile SCUs increases by 10% on average. In the H2 profile, it increases by 14% on average.
- As per the MTVV parameter, discomfort increases by an average of 16% in the B1 profile, 12% in the H1 profile, 6% in the B2 profile and 18% in the H2 shape.
- Considering that sudden changes in discomfort while driving unexpected cause reactions in drivers, it justifies the recommendation that type B undulations should only be used in facility areas such as parking lots.

In the next stage of the study, it is thought that similar evaluations should be repeated, especially with other types of vehicles used in public transport. This and similar studies will facilitate the decision making of the authorities that regulate urban traffic.

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