Effects of speed hump on vehicle performance in the Sekondi-Takoradi Metropolis, Ghana

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Abstract: Upsurge in pedestrian-involved crashes, in the Sekondi-Takoradi Metropolis, has led to the installation of speed humps to ameliorate the situation. This has, however, attracted public complaints citing ride discomfort, vehicle damage and safety concerns. This study aims to explore the extent to which crossing speed and hump dimensions contribute to these concerns. Spot speeds at the humps, 30 metres upstream and downstream of the humps, alongside vehicles’ undercarriage contacts with humps were recorded. Logistic regression analysis was done to identify significant contributors to vehicle-hump contacts. Humps induced considerable speed reduction from 50–66 km/h (upstream) to 22–30 km/h at the humps. The reduction was, however, transient with speed of 41–56 km/h, downstream. A considerable number of non-standard humps were identified, with 1 in 3 vehicles making contact with the humps. The vehicle-contact was influenced by crossing speed, hump height and negatively correlated with hump length. This elevates ride discomfort, crash risk, long-term vehicle damage and maintenance cost. Humps should be modified into raised-pedestrian crossings, preceded by humps and advanced warning signs to enforce speed limit compliance and prevent sudden deceleration at pedestrian crossings. Additionally, non-standard humps should be replaced, alongside strict adherence to design-standard in the installation of future ones.

Subjects: Mathematics & Statistics for Engineers; Transport & Vehicle Engineering; Civil, Environmental and Geotechnical Engineering

Keywords: Pedestrians; speed hump; hump height; vehicle damage; Sekondi-Takoradi

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1. Introduction

Transportation provides immeasurable socio-economic benefits to every modern society. Road transportation, particularly, is the mainstay of most developing countries, as other transport modes are either non-existent or in their embryonic stage. In Africa, it accounts for 80% and 90% of goods and passenger traffic respectively (United Nations Economic and Social Council, 2009).

There are, however, downsides of road transportation. Road traffic crashes (RTCs), air pollution and traffic congestion are corollaries of road transportation. RTCs, for instance, are wrecking so much havoc on modern communities. According to the World Health Organization (2020), annually, RTCs account for 1.35 million fatalities, up to 50 million persons sustaining varying degrees of injuries globally, costing up to 3% of the gross domestic product (GDP) of most countries. While, developing countries have approximately 60% of the global vehicle population, these regions account for overwhelmingly 93% of the global fatalities.

Human error has been found to be the largest contributor to over 90% of RTCs (National Highway Transport Administration, 2008; Singh, 2015; Treat et al., 1979). While the safety literature is replete with several factors associated with RTCs, speeding (excessive or inappropriate) which is related to driver error, has been established to be inextricably linked to road RTC frequency and severity, regardless of the location. In the United States, for instance, speeding contributed to 31% of fatal RTCs, culminating in the loss of 11, 674 lives in 2008 (orbes, 2011). Similarly in Ghana, excessive speeding accounts for 65% of pedestrian fatalities annually (Damsere-Derry et al., 2010).

Transition from rural to urban areas, presents immense safety challenge to road users. A study in Australia revealed that injury-related crashes are common along transition zones compared to rural roads, largely due to speeding (Tziotis, 1992).

On rural-urban transition zones, motorists unconsciously over-speed, as they are unable to adjust their travelling speed, after travelling extended period on rural arterials at higher speed (Forbes, 2011). Besides, the structural properties of rural environment is less complex compared with those of the urban environment, inducing less mental arousal (Arien et al., 2014), consequently subduing the alertness required to handle the complexities of the urban setting. A combination of speeding, lack of alertness and other related factors elevate RTC risk in transition zones.

The growth of villages and towns along high-speed road corridors present safety concerns to both developed and developing countries. While these communities are sparsely located along rural landscape in developed countries (Forbes, 2011), there are high concentration of such communities along high-speed arterial roads, with speed limit exceeding 70 km/h in developing countries. It is impossible for vehicles to traverse these communities with such speed without leaving casualties in their wake. It is, thus, anticipated that vehicle speed is moderated to about 30 to 50 km/h to enhance safety, especially for vulnerable road users, whose activities are typically dominant in these communities. Oftentimes, however, this is violated with unsavoury consequences.

The concentration of communities along rural high-speed roads in most developing countries, is largely driven by socio-economic concerns. In these countries, communities living furthest from roads experience higher levels of poverty, lower levels of school attendance and worse health outcome (Watkins & Sridhar, 2009). While the proximity of communities to roads come with some socio-economic benefits, it is accompanied by enormous crash risk. For instance, in Ghana, 47% of the 3698 pedestrian fatalities recorded between 2014 and 2018, were amongst villages and towns located along high-speed arterial roads (Building and Road Research Institute (Building and Road Research Institute, 2019).
While RTCs may stem from a confluence of factors, speeding is a precursor to RTCs, and the introduction of an efficient speed management regime on the approaches to built-up areas, would significantly improve safety. Speed management strategies have typically focused on engineering, education and enforcement. Engineering measures are favoured amongst the three, as they are cost effective. For instance, physical modification to a road layout engenders lasting effects compared with education and enforcement, which are typically less effective and transient (Forbes, 2011). In this light, road safety management practice has focused on one or a combination of the following four enduring engineering-based speed reduction techniques: geometric design changes, traffic control devices, road surface treatment and road side features.

A combination of the aforementioned traffic calming measures are typically implemented to reduce vehicle speed, in developed countries, to curb the frequency and severity of crashes at rural-urban transition zones (Arien et al., 2014; Charlton & Boas, 2006; Forbes, 2006). In developing countries, in contrast, road surface treatment such as speed humps and speed tables christened “sleeping policeman,” are commonly used. This is because speed limit compliance is a major concern in developing countries, and speed humps/tables are effective at handling this routine blatant disregard for traffic regulations. Besides, the easy installation process and the low construction cost have made these calming measures attractive in developing countries.

Speed humps come in different design shapes: sinusoidal, circular and parabolic (Abdel-Wahed & Hashim, 2017), and are typically 76 to 100 mm high, 3.7 to 4.3 m in length (Federal Highway Administration, 2020). The speed at which a vehicle traverses a speed hump is influenced by its height and length. They can reduce the speed of vehicles up to 30 km/h, so that vehicles can safely and comfortably traverse the hump (Afukaar & Damsere-Derry, 2010; Federal Highway Administration, 2020; Yaacob & Hamso, 2013). Such considerable reduction in speed favours vulnerable road users, as they have a higher probability of surviving at 30 km/h crash speed (Wegman & Aarts, 2006), and also reduces crashes by 22%-43% (Arbogast et al., 2018; Rothman et al., 2015).

There are, however, downsides of speed humps such as, frequent rear-end collisions in heavy traffic, vehicle damage and passenger discomfort (District Department of Transport, 2010; Mohanty et al., 2021; Sayer et al., 1999). Efforts have been directed at optimising their use, though scant. In a study to evaluate the performance of speed humps, Sayer et al. (1999) revealed that crossing speeds of over 32 km/h and 25 km/h contribute to vehicle damage and ride discomfort respectively. Gedik et al. (2019) on their part, indicated that crossing speed and hump height are the most important factors influencing ride comfort and driving safety. In a recent study, Mohanty et al. (2021) realised that shorter hump length contributes to frequent rear-end crashes, wear and tear of vehicle parts and passenger discomfort.

Pedestrians are physically vulnerable in traffic. With approximately 40% pedestrian deaths of 2000 annual traffic fatalities (Building and Road Research Institute, 2019), Ghana has embarked on an ambitious road safety programme with the installation of speed humps on arterial routes traversing villages, towns and urban areas, to improve the situation. The widespread use has, however, attracted public complaints citing passenger discomfort, upsurge in vehicle damage and maintenance cost, and safety concerns. While concurrent evaluation of crossing speed, hump height and length, may help to fully assess their relative impact, to optimise vehicle performance, earlier studies considered them separately. This study, therefore, seeks to add to the existing literature by pursuing the following twin objectives: 1) To determine the extent to which installed speed humps satisfy existing design standard, 2) To explore the effects of crossing speed and geometric characteristics (height and length) of speed humps on vehicle performance. This would allow stakeholders make data-led decision regarding the appropriate application of speed humps for sustainable mobility. Besides, it would serve as an invaluable resource for other studies related to speed hump performance.
2. Literature review

Traffic crashes are major concerns that transportation agencies in both developed and developing countries are grappling with, particularly, on approaches to villages, towns and urban areas. Both developed and developing countries are confronted with the growth of built-up areas along high-speed arterials. There are, however, high pedestrian and cyclist activities in these locations, which raises safety concerns, because of the potential traffic conflicts between these vulnerable road users and vehicles traversing these communities at high-speeds. Given that speeding is inextricably linked to crashes, speed management strategies have focused on engineering, education and enforcement, on approaches to villages, towns and urban areas, with engineering measures favoured amongst the three (Forbes, 2011).

2.1. Traffic calming measures

The commonly applied engineering-based speed reduction techniques are:

- geometric design changes (e.g., Central island/raised median, roundabout, chicanes)
- traffic control devices (e.g., Variable message signs, speed cameras)
- road surface treatment (e.g., Speed humps, speed tables, speed cushions)
- road side features (e.g., Gateway/entrance features, street furniture, landscaping).

A combination of the aforementioned traffic calming measures are typically implemented to reduce vehicle speed, in developed countries, to curb the frequency and severity of crashes at rural-urban transition zones (Arien et al., 2014; Charlton & Baas, 2006; Forbes, 2006).

2.1.1. Effectiveness of traffic calming measures

These traffic calming measures, have proven to be very effective in significantly reducing the operating speed of vehicles in rural-urban transition zones or crash risk. For instance, the Department for Transport (2005) conducted a study to assess the effect of rumble-wave surfaces on traffic crashes at seven locations, including a high-to-low speed transition zones, in the United Kingdom. The results revealed on average a 55% reduction in casualty crashes.

In Canada, Forbes (2006) conducted a retrospective, observational before-after study of the safety effect of various traffic calming measures on rural settlements at 12 treatment sites, on rural arterial roads in, Ontario. The results indicated marked reduction in all traffic crash occurrence by 22% and casualty crashes by 28%. In addition, Andersson et al. (2008), assessed the safety performance of two gates between rural-urban transition zones, in Denmark. The gates were categorised into three: gates consisting of physical measures only, gates consisting of visual measures only, and gates consisting of a combination of the two (physical and visual measures). In all, 251 town gates were analysed. A combination of the physical and visual measures yielded the best safety performance, with a 28% decrease in injury crashes and a 36% increase in property damage only crashes.

Last but not least, the safety performance of speed cushions and speed humps in transition zones were investigated in the New Zealand by Charlton and Baas (2006). The study reported a 9% and 21% reduction in speed respectively.

2.1.2. Speed humps

Speed humps are raised sections of the road pavement that extend across the pavement width (District Department of Transport, 2010; Figure 1). They come in different design shapes: sinusoidal, circular and parabolic (Abdel-Wahed & Hashim, 2017), and are typically 76 to 100 mm high, 3.7 to 4.3 m in length, along the vehicle travel path axis (Federal Highway Administration, 2020). The speed at which a vehicle traverses a speed hump is influenced by its height and length. They can reduce the speed of vehicles up to 30 km/h, so that vehicles can safely and comfortably traverse the hump (Afukaar & Damsere-Derry, 2010; Federal Highway Administration, 2020;
Yaacob & Hamsa, 2013). Such a substantial reduction in speed enhances the safety of vulnerable road users (i.e., pedestrians and cyclists) as they have a higher probability of surviving at 30 km/h crash speed (Wegman & Aarts, 2006).

A combination of traffic calming techniques are typically employed in developed countries to enhance safety. In developing countries, on the contrary, speed humps and speed tables, christened “sleeping policeman,” are commonly used. This is because speed limit compliance is a major concern in developing countries like Ghana, and speed humps and speed tables are able to handle this routine blatant disregard for traffic regulations effectively. Additionally, the ease of installation and the low construction cost have made these traffic calming devices attractive in developing countries.

2.1.2.1. Speed reducing effect of speed humps. The traffic safety literature is replete with studies on the effectiveness of speed humps, in terms of speed and crash rates reduction. Some of these studies evaluated the impact of speed humps using vehicle speeds. For instance, Yaacob and Hamsa (2013) conducted a study to assess the effect of road hump on vehicle operating speed in Taman Setapak residential area in Kuala Lumpur (Malaysia). Using field observation and spot speed survey, data was collected on the roadway geometry and design characteristics of the humps, and vehicles speeds at different points near the humps. It was observed that design characteristics of the humps significantly contributed to speed reduction, with vehicle speed of about 30 km/h on approaching the humps and up to 10 km/h at the humps. In Serbia, Antic et al. (2013) on their part, conducted a before-after study to evaluate the effect of speed bumps on vehicle operating speed at locations of high pedestrian presence, using varying heights (3, 5 and 7 cm) in Belgrade. Speed measurements were done a day before the installation of the bumps and a month afterwards. The 50th and 85th percentile speeds were determined, indicating significant reduction in speeds after the bumps installation. Based on the results, it was suggested that speed bumps height of 5 and 7 cm should be installed at locations where vulnerable road users are highly at risk. It is palpable that, speed humps have speed reducing effect. In a recent study, Mohanty et al. (2021) investigated the effect of speed humps on vehicle operating speed. The study involved twelve (12) speed humps located on arterial roads in Bhubaneswar, a smart city in India. The study reported a reduction in vehicle approach speed from 33 km/h at 20 m to the speed hump and 9.8 km/h at the speed hump.

While some studies employed speed as the only performance measure for speed humps, others have employed both vehicle speed and crash data, to explore the link between speed reducing characteristics of humps and safety. Two separate studies in Ghana, reported significant reduction in speed and pedestrian crashes on selected calmed roads. Afukaar and Damsere-Derry (2010) evaluated the effectiveness of speed humps in reducing vehicle speeds and pedestrian crashes at selected settlements along the Kumasi-Konongo Highway,
a before-after study approach. Police reported crash data alongside measured vehicle speeds at six treated sites were collected before and after the installation. The installation of the speed humps accounted for an annual reduction in pedestrian casualties of 63%, and marked reduction in vehicles speeds ranging from 71 to 87 km/h before, and 32 to 36 km/h after installation. In a similar study, Damsere-Derry et al. (2019) examined the effects of traffic calming measures on vehicle speeds and pedestrian injury severity in 38 selected settlements, comprising 19 “with”, and 19 “without” traffic calming schemes, in Ghana. The study realised that, the proportion of vehicles exceeding the 50 km/h speed limit was 30% or less in settlements with traffic calming measures, with 60% or more speed limit violations in settlements without traffic calming measures. It was further revealed that, the odds of pedestrian fatality was approximately two-fold in settlements without traffic calming measures compared settlements with the safety measures.

Additionally, Yeo et al. (2020) examined the effects of speed humps on both vehicle speeds and pedestrian safety in South Korea. In the study, speeds of vehicles were recorded as they were driven along roadway sections with multiple speed humps. Pedestrian crash data along the entire roadway sections was also analysed. Speed reduction was observed at 30 m upstream of the speed humps, with substantial reduction at the speed humps. The speed reduction was, however, not sustained with vehicles regaining their original speeds after traversing the speed humps. Substantial speed reduction of 18.4% and 24.0% were reported on local and arterial roads respectively, with fewer pedestrian crashes and less injury severities registered at the speed humps within the 30 m analysis zone.

The performance of speed humps have also been investigated in combination with a variety of traffic calming measures, such as chicanes and raised pedestrian crossings. Gitelman et al. (2017) examined the impact of raised pedestrian crosswalks with preceding speed humps installed at non-signalised midblock pedestrian crosswalks on urban arterial and collector roads in Israel. Using a before-after study technique, the speed pattern before and after the installation of the raised pedestrian were compared, resulting in an overall safety improvement of the pedestrian crossings with marked reduction in 85th speed percentile of vehicles up to 29 km/h, which was sustained with time.

Agerholm et al. (2017) evaluated the effects of speed humps and chicanes on vehicle speeds on urban streets, in a small town of Skørping in northern Denmark, using Global Navigation Satellite System (GNSS) data loggers installed on vehicles travelling on such streets. A before-after analysis revealed that, while both speed humps and chicanes have considerable speed-reducing effect, speed humps have superior safety performance due to greater reduction in speed variation.

2.1.2.2. Crash reducing effect of speed humps. A plethora of successes have been reported in the safety literature, regarding crash reducing effect of speed humps. These studies have largely focused on pedestrian-involved crashes.

Tester et al. (2004) conducted a matched case-control over a five-year period among children at paediatric emergency department after a traffic crash, in Oakland, California, to evaluate the protective effectiveness of speed humps, in reducing child pedestrian injuries in residential neighbourhoods. A multivariate conditional logistic regression analysis revealed that, speed humps are related with lower odds of children sustaining injuries within their neighbourhoods and in front of their homes after a road traffic crash. In a similar study, Arbogast et al. (2018) conducted a before-after studies after the installation of speed humps around a middle school, in response to frequent crashes between child-and-adolescent pedestrians and motor vehicles within that vicinity. The analysis was done using crash data collected 2.5 years before and 2.5 years after the installation of the speed humps. The installation of the speed humps resulted in 37.5% reduction in pedestrian-involved crashes.
Additionally, Rothman et al. (2015) explored the effectiveness of speed humps on reducing pedestrian-motor vehicle crashes in Canada. In the study, speed hump locations were mapped along with a twelve-year police-reported pedestrian crash data (2000–2011). Using Poisson regression, stratified analyses were done by age group and injury severity. In all, the installation of the speed hump was associated with 22% reduction in pedestrian-vehicle crashes; children (i.e. 0–15 years) experienced the most protective effective, with 43% reduction in crashes.

In a recent study, Shahdah and Azam (2021) evaluated the effect of speed humps on the safety and mobility of unconventional median U-turn. In the study, speed humps were placed at distances of 50 m and 20 m upstream from the U-turn intersections. VISSIM microscopic traffic simulation model was used to simulate and extract trajectories of vehicles. Surrogate safety assessment model (SSAM) was then applied to extract traffic conflicts based on the time-to-collision (ITC) surrogate safety measure. Delays and safety concerns were significantly observed at speed humps placed 20 m from the intersections compared with speed humps at the 50 m locations.

While the aforementioned studies were solely based on speed humps, the impact of speed humps on crash frequency and severity have been evaluated alongside other traffic measures such as safety islands and speed cameras. Jateikienė et al. (2016) analysed the impact of speed bumps/humps along with raised pedestrian crossings, safety islands and speed cameras on road safety, on Lithuanian roads. A before-after analysis indicated significant improvement in road safety due to the combination of these traffic calming measures. While there have been reported crash-reduction benefits of speed humps, a handful of studies have reported no significant effect of the traffic calming measure. For instance, in New York City, 391 streets were calmed with speed humps between 1996 and 2003, essentially to improve pedestrian safety. Using crash data 5 years before and 5 years after the treatment, Ewing et al. (2013) conducted a large scale rigorous evaluation of the treatment based on quasi-experimental before-after technique to assess the impacts of the speed humps on the frequency crashes. The outcome of the analysis, however, did not reveal any statistically significant reduction in crashes.

2.1.2.3. Downsides of speed humps. It is evident that speed humps are pivotal in traffic safety management. There are, however, reported downsides of these traffic calming devices. Speed hump elevates air pollution and fuel consumption, stemming from frequent use of a vehicle’s brakes and accelerator (Janusevicius & Grubliauskas, 2019). Besides, speed humps have been established to negatively influence the response time of emergency vehicles (District Department of Transport, 2010; Jaeger, n.d) and delays to traffic (Al-Omari & Al-Massaieid, 2002).

Speed humps installation have been found to be associated with early pavement deterioration. Bekheet (2014) investigated the effect of speed humps on pavement deterioration patterns in Alexandria, Egypt. A representative sample of pavement projects was selected and Pavement Condition Index (PCI) developed to assess the overall pavement condition, alongside the effects of traffic loading and quality control measures adopted during the construction of the pavement. Raveling was the commonest distress observed, with load-induced distresses the least prevalent. The study concluded that improper speed hump installation is associated with pavement deterioration. Abdel-Wahed and Hoshim (2017) also evaluated the effect of speed humps on pavement condition based on PCI in Tahta and Gerga, in Upper Egypt. The study sampled 52 speed humps in the study area. PCI near speed humps were calculated based on visual pavement condition evaluation. Additionally, speed hump characteristics such as the width, height and distance from the preceding hump were measured. A regression analysis was done to model a relationship between the PCI and hump characteristics. It was revealed that, pavement conditions are significantly influenced by the presence of speed humps and characteristics.
Additionally, severe passenger discomfort and vehicle damage have been reported to be linked to speed hump installation. Sayer et al. (1999) in a trial field study using various categories of vehicles, passenger discomfort levels were gauged by measuring vertical acceleration at varied vehicle crossing speeds in the United Kingdom. Severe passenger discomfort was experienced with crossing speed over 15 mph (25 km/h), with greatest level of discomfort when a vehicle was coming off the ramp, while vehicle damage and temporary grounding was observed with a higher crossing speed of over 20 mph (32 km/h) among cars and buses. In a similar study, Gedik et al. (2019) evaluated the effect of parabolic speed hump profiles on ride comfort and driving safety under variable vehicle speeds. The study was based on evaluation and comparison of vertical acceleration data obtained through both in-situ and simulation tests. These tests revealed that both vehicle speed and hump height are the most important factors influencing ride comfort and driving safety.

Patel and Vasudevan (2016) on their part, investigated the effect of speed humps on cyclists. Vibrations were recorded by accelerometers attached to the handle bar, seat and neck of the cyclists, as they traverse speed humps at varying speeds. The same procedure was applied to motorised two-wheelers. The vibrations were converted to vibration dose values for evaluation. The study concluded that, bicyclists experienced the same level of discomfort as motorised two-wheelers. Since this level of discomfort could harm bicyclists and discourage bicycling, a special regime was advocated for bicyclists in the application of speed humps.

In a recent study, Mohanty et al. (2021) explored the operational effect of speed humps in India. The study involved twelve (12) speed humps located on arterial roads in Bhubaneswar, a smart city in India. The study revealed that, the installed speed humps fell short by the length. Shorter hump length does not provide smooth transition and elevates safety concerns. The authors suggested that the short hump length leads to sudden deceleration before the humps and elevates rear-end collision risk. Additionally, the sudden brakes also contributes to wear and tear, and passenger discomfort.

It is evident from the foregoing discussion that, while there are immeasurable safety benefits associative with speed humps, there are, however, legitimate concerns that need to be addressed. The widespread application of speed humps to address vulnerable road user safety, in most developing countries, requires an in-depth scrutiny to help maximise the safety benefits of these traffic calming measures.

3. Materials and methods

The Western Region is one of the sixteen regions (16) in Ghana, with the Sekondi-Takoradi Metropolis as the regional capital. The region has thirteen (13) districts and an estimated population of 2, 060, 585 with majority of the population, 33.6% (692, 356), concentrated in the Sekondi-Takoradi Metropolis (Ghana Statistical Service, 2020). The region is endowed with abundant natural resources. With the discovery of oil and gas in commercial quantities in 2010, the Western Region is now home to Ghana’s burgeoning Oil and Gas industry.

Lying wholly along the Trans-Regional route (N1-Highway), the Western Region is well connected to the southern part of Ghana and most part of West-Africa. Home to Ghana’s emerging Oil and Gas economy, the Sekondi-Takoradi is inundated with vehicular traffic on daily basis, stemming from a boost in economic activities in the metropolis.

In the Sekondi-Takoradi Metropolis, the regional thoroughfare (N1-Highway) traverses an urbanised road corridor, elevating traffic crash risk, especially for non-motorised users. For instance, between 2014 and 2018, 335 pedestrian fatalities were recorded (Building and Road Research Institute (Building and Road Research Institute, 2019). This is partly the culmination of increased interactions between vehicles and pedestrians, driven by increased traffic and pedestrian volumes, along with poor urban transport planning policy for the metropolis.
In order to ameliorate the situation, speed humps have been installed along routes noted for traffic crashes, in the metropolis. The widespread use of speed humps has, however, attracted incessant road user complaints regarding severe passenger discomfort and health concerns, frequent vehicle damage and increased maintenance cost, alongside traffic crash risk.

Previous studies have investigated the effects of vehicle crossing speed on passenger discomfort and vehicle damage (Sayer et al., 1999), hump length on rider safety (Mohanty et al., 2021), and crossing speed and hump height on passenger discomfort and driver safety (Gedik et al., 2019). No study has yet explored the combined effects of crossing speed and hump’s geometric characteristics (i.e., height and length) on vehicle performance.

Frequent contact between the undercarriage of a vehicle and a speed hump (i.e., vehicle-hump contact) would result in gradual tear and wear of the vehicle’s parts, and consequently long-term vehicle damage and increased maintenance cost. This study, therefore, primarily aims to explore the extent to which the crossing speed and geometric characteristics of speed humps contribute to possible frequent vehicle-hump contact. This would help optimise the safety benefit of speed humps.

A detailed road map of the Sekondi-Takoradi Metropolis was obtained and reconnaissance done to identify the locations of speed hump in the study area (Figure 2). In all, 20 speed humps were selected for the study on 50 km/h speed limit roads (Figure 3). A distance of 30 metres was marked out upstream and downstream to each speed hump location, and spot speed measurements conducted using a speed gun. Covert, but unobstructed random speed measurements were made during the off-peak period, under free-flow traffic condition. Speed measurements were made 30 metres upstream of the humps, at the humps and 30 metres downstream. This was done for 120 minutes, between Monday and Friday.

In traversing a speed hump, if a vehicle (i.e. front bumper, undercarriage and rear bumper) hits a speed hump (i.e., vehicle-hump contact), it is recorded along with the vehicle type involved.
Further, speed hump’s dimensions (i.e. height, length and width) were physically measured in the field using a measuring tape.

### 3.1. Data analysis

#### 3.1.1. Speed estimation

Using the observed spot speeds data, the 50th and 85th speed percentiles were determined by employing Equation (1; Duane et al., 2002):

$$S_D = \frac{P_D - P_{\text{min}}}{P_{\text{max}} - P_{\text{min}}} (S_{\text{max}} - S_{\text{min}}) + S_{\text{min}}$$  (1)

Where:

- $S_D$ = Speed at $P_D$; $P_D$ = Percentile Desired; $P_{\text{max}}$ = Higher cumulative percent
- $P_{\text{min}}$ = Lower cumulative percent; $S_{\text{max}}$ = Higher speed; $S_{\text{min}}$ = Lower speed

#### 3.1.2. Model building

The study seeks to model the occurrence of a vehicle speed hump contact or otherwise with respect to certain variables. Logistics regression was used in this study, as it is more suitable for modelling the probability of an event involving dichotomous (binary) dependent variable and a set of independent variables (predictors). The logistic model is mathematically represented as:

$$\ln(\text{ODDS}) = \ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m = \beta_0 + \sum \beta_i x_i, 0<p<1$$  (2)

$$p = \frac{1}{1 + e^{(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m)}}$$  (3)

Where $p$ and $\beta_i$ represent the probability of success and model parameters respectively. The regression coefficients ($\beta_i$) are estimated using the maximum likelihood estimation (MLE).
The IBM SPSS Statistics (version 24) was employed in the logistic regression. Three (3) independent variables (predictors), hump height, hump length and vehicle crossing speed were used to determine the likelihood of a vehicle-hump contact or otherwise (dichotomous dependent variable). A 95% confidence interval (C.I.) and p-values were used to assess the significance of the predictors to the resulting model.

4. Results

4.1. Characteristics of the field study

In the field study, 872 vehicles were randomly observed at 20 speed hump locations in the Sekondi-Takoradi Metropolis, for spot speeds measurements and potential vehicle-hump contact. Cars constitute the greater proportion with 45.8% of the observed vehicles, followed by small buses 25.1%. Details are indicated in Table 1.

4.2. Frequency of hump-vehicle contact

In the study, 872 vehicles were observed for potential contact with speed humps. In all, 32.3% of the vehicles observed made contact with speed humps (Table 1). Hump height greater than 0.10 m, contributed more to vehicle contacts (98.6%) compared with height up to 0.10 m (1.4%).

4.3. Effect of speed hump on vehicle crossing speed

Spot speeds measurements were made during the 40-hour field observation period at 30 metres upstream and downstream of speed humps, as well as at the speed humps in the Sekondi-Takoradi Metropolis. The 85th speed percentiles were then determined. This culminated in 85th percentile speeds of 50–66 km/h, 30 metres upstream of the humps; 41–56 km/h downstream of the humps; and 22–30 km/h at the humps (Table 2) on local roads with speed limits of 50 km/h.

| Descriptor | Number of Vehicles | Percent (%) |
|------------|--------------------|--------------|
| Vehicle Types |                    |              |
| Car        | 399                | 45.8         |
| 4WD/Wagon  | 74                 | 8.5          |
| Pickup     | 57                 | 6.5          |
| Small Bus  | 220                | 25.1         |
| Medium Bus | 4                  | 0.5          |
| Large Bus  | 4                  | 0.5          |
| Light Truck| 16                 | 1.8          |
| Medium Truck| 19               | 2.2          |
| Heavy Truck| 45                 | 5.2          |
| Truck Trailer| 34              | 3.9          |
| Total      | 872                | 100          |

| Vehicle-Hump observed Contact | Number | Percent (%) |
|-------------------------------|--------|-------------|
| Yes                           | 282    | 32.3        |
| No                            | 590    | 67.6        |

| Speed Hump Height | Number of Contacts | Number of vehicles | Percent of Vehicle-Hump Contact (%) |
|-------------------|--------------------|--------------------|-------------------------------------|
| Height up to 0.10 m | 4                  | 282                | 1.4                                 |
| Height greater than 0.10 m | 278               | 282                | 98.6                                |

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### Table 2. Speed hump dimension and spot speed distribution

| Hump  | Location          | Geometric Characteristics of Speed Hump | 85th Percentile Speed, 30 metres Upstream of Hump | 85th Percentile Speed at the Hump | 85th Percentile Speed, 30 metres Downstream of Hump |
|-------|-------------------|----------------------------------------|---------------------------------------------------|----------------------------------|--------------------------------------------------|
| Hump 1 | Inchaban-Aboadze | Height (m) 0.1, Length (m) 4.5, Width (m) 7.8 | 53.6                                              | 23.5                             | 47.4                                             |
| Hump 2 | Inchaban-Aboadze | Height (m) 0.1, Length (m) 4.8, Width (m) 7.8 | 56.4                                              | 24.7                             | 49.2                                             |
| Hump 3 | Inchaban-Aboadze | Height (m) 0.1, Length (m) 4.5, Width (m) 7.9 | 53.7                                              | 23.5                             | 49.5                                             |
| Hump 4 | Inchaban-Aboadze | Height (m) 0.1, Length (m) 4.5, Width (m) 7.7 | 57.4                                              | 25.2                             | 50.1                                             |
| Hump 5 | Inchaban-Aboadze | Height (m) 0.1, Length (m) 4.6, Width (m) 7.5 | 56.9                                              | 24.8                             | 47.7                                             |
| Hump 6 | Inchaban-Aboadze | Height (m) 0.1, Length (m) 4.4, Width (m) 7.1 | 50.8                                              | 22.3                             | 41.7                                             |
| Hump 7 | Inchaban-Aboadze | Height (m) 0.2, Length (m) 4.4, Width (m) 7.4 | 50.0                                              | 21.9                             | 45.1                                             |
| Hump 8 | Inchaban-Aboadze | Height (m) 0.2, Length (m) 4.4, Width (m) 7.4 | 55.5                                              | 24.3                             | 48.9                                             |
| Hump 9 | Inchaban-Aboadze | Height (m) 0.1, Length (m) 4.4, Width (m) 7.4 | 63.3                                              | 27.7                             | 51.3                                             |
| Hump 10 | Inchaban-Aboadze | Height (m) 0.1, Length (m) 4.6, Width (m) 7.5 | 53.3                                              | 23.2                             | 44.6                                             |
| Hump 11 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 6.4, Width (m) 9.5 | 50.9                                              | 22.3                             | 41.2                                             |
| Hump 12 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 6.2, Width (m) 9.5 | 55.7                                              | 24.4                             | 51.8                                             |
| Hump 13 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 4.5, Width (m) 6.1 | 57.2                                              | 25.4                             | 46.9                                             |
| Hump 14 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 4.5, Width (m) 6.2 | 57.6                                              | 25.2                             | 47.4                                             |
| Hump 15 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 6.0, Width (m) 9.0 | 67.1                                              | 29.5                             | 56.1                                             |
| Hump 16 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 6.0, Width (m) 8.8 | 63.2                                              | 27.9                             | 53.5                                             |
| Hump 17 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 6.0, Width (m) 9.0 | 58.9                                              | 25.8                             | 53.0                                             |
| Hump 18 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 6.0, Width (m) 9.1 | 57.8                                              | 25.5                             | 53.4                                             |
| Hump 19 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 6.0, Width (m) 8.8 | 63.5                                              | 28.0                             | 49.2                                             |
| Hump 20 | SECK Jn-Asoko    | Height (m) 0.1, Length (m) 6.0, Width (m) 8.8 | 66.6                                              | 28.8                             | 55.5                                             |

Source: From Authors' field study, 2020
4.4. Effect of vehicle crossing speed on vehicle-hump contact

From the logistic regression result (Table 3), every 1 km/h increase in vehicle crossing speed, is associated with a 4.4% (OR = 1.044; p-value = 0.001) increase in the odds of a vehicle-hump contact.

4.5. Relationship between vehicle-hump contact and geometry of speed hump

Height and length of speed humps were used as predictors in the logistic regression. All these variables are significant at 0.05% level (Table 3). A unit increase in hump height, increases the likelihood of a vehicle making contact with a hump by 19.2% (OR = 1.192; p-value = 0.001). However, a unit increase in hump length, is associated with a 0.4% (OR = 0.996; p-value = 0.001) reduction in the odds of a vehicle-hump contact.

5. Discussion

Pedestrians and cyclists are integral part of Ghana’s transport system. Increased pedestrian-involved crashes coupled with flagrant speed limit violations, has led to the deployment of speed humps at locations that are notorious for RTCs, to improve pedestrian safety in urban and settlement areas, including the Sekondi-Takoradi Metropolis. The widespread use of speed humps has, however, attracted incessant complaints from the public, citing severe passenger discomfort, vehicle damage and increase vehicle maintenance cost, and safety concerns. This study sought to explore, among others, the extent to which the crossing speed and geometric characteristics of humps contributes to these concerns.

The results showed 85th speed percentile of 50–66 km/h, 30 metres upstream of the humps, with considerable reduction in 85th speed percentile of 22–30 km/h at the humps. Higher vehicle speeds preceding the humps, indicates flagrant speed limit violation on 50 km/h speed limit roads, posing threats to other road users, particularly pedestrians. The magnitude of the speed reduction at the humps, on the contrary, reflects the speed reducing effect of humps and this favours traffic safety. This result is consistent with previous studies (Afukaar & Damsere-Derry, Antic et al., 2013; Gitelman et al., 2017; Mohanty et al., 2021; Shahdah & Azam, 2021; Yeo et al., 2020).

Walking and cycling are sustainable transport modes. They are one of the dominant modes of transport in most developing countries. In most African cities, walking accounts for 99% of all non-motorised trips, and makes up between 50% and 90% of daily trips (Mitullah et al., 2017). RTCs, however, deters walking and cycling and measures that reduce vehicle speed below 30 km/h guarantee the survival of vulnerable road users in the event of a crash (Wegman & Aarts, 2006), as the probability of fatal and severe injury crashes are substantially reduced at this speed. Clearly, the marked reduction in the 85th speed percentile at the humps fulfills the safe speed requirement for vulnerable road users. This undoubtedly would facilitate the downward trend in pedestrian-involved crashes, and encourage walking in the Sekondi-Takoradi Metropolis.

The speed reduction experienced at the humps was, however, transient as motorists accelerated at a higher rate after crossing the hump, almost regaining their original speeds with 85th speed percentile of 41–56 km/h, 30 metres downstream of the humps. This unsafe motorist behaviour is a compensatory mechanism to regain the time lost in traversing the humps. This phenomenon is called the “kangaroo” effect and has also been observed in previous studies (Arien et al., 2014; Yeo et al., 2020). In order to extend the speed reducing effect beyond the hump’s location, a slight modification would suffice. The humps should be modified into raised pedestrian crossings, preceded by speed humps and advanced warning signs to enforce speed limit compliance and prevent sudden deceleration at the pedestrian crossings.

Regardless of the potential safety benefit of speed humps on local roads in the Sekondi-Takoradi Metropolis, motorists risk long-term vehicle damage. Approximately 1 in 3 of the vehicles observed made contact with the speed humps. This result is influenced by vehicle crossing speed and hump height.
The Federal Highway Administration (2020), recommends a threshold hump height of 0.1 metres, for safe and comfortable vehicle operation. The results, however, revealed that substantial proportion of humps’ heights are beyond this threshold and contributed to 98.6% of the observed vehicle-hump contact. At this height, most vehicles do not have enough ground clearance to negotiate the humps without interference. The height differential stems from laxity in adhering to design standards. This suggests that, while, hump height is pivotal in speed reduction, it may have long-term damaging effect on vehicles, if design standards are overlooked.

Vehicle crossing speed was also found to be associated with vehicle-hump contact. With crossing speed up to 29.5 km/h at the speed humps, at such low speed it was anticipated that vehicles can safely and conveniently surmount the speed humps unhindered. However, significant vehicle-hump contacts were recorded. This may stem from the following twin reasons. Firstly, a considerable lower crossing speed may be required for vehicles to safely traverse the speed hump. Driver education is, therefore, needed to address this concern. Secondly, the inability of the low vehicle crossing speed to compensate for the impact of the excessive hump height, resulting in substantial proportion of vehicles hitting their chassis against the humps. These non-standard speed humps needs replacement to optimise the performance of the traffic calming measure. Besides, there should strict adherence to design standards and adoption of best construction practices for the installation of future ones.

A negative relationship was observed between hump length and hump-vehicle contact. This follows that an increase in hump length minimises potential vehicle-hump contact. In speed hump design, adequate hump length is provided to support a threshold hump height, for safe transition. However, significant proportion of the humps observed had excessive heights with shorter lengths. A combination of shorter hump length and excessive hump height, on the contrary, do not provide smooth transition, but encourages frequent hitting of a vehicle’s chassis against the hump. Besides, shorter hump length and excessive hump height brings about abrupt deceleration at the humps, which is associated with wear and tear, rear-end collisions and ride discomfort (Gedik et al., 2019; Mohanty et al., 2021). Shorter hump length and excessive hump height, therefore, degrades ride comfort and driving safety, which partly explains the complaints among road users in the Sekondi-Takoradi Metropolis.

From the foregoing discussion, this study has confirmed the speed reducing effect of speed humps. However, there are concerns related to riding safety and comfort, and long-term vehicle damage, due to the prevalence of non-standard speed humps and driver behaviour. In order to optimise the performance of speed humps for efficient vehicle operation, there should strict adherence to design standards in the installation of future speed humps.

6. Conclusions and recommendations
Speed humps were effective at significantly reducing vehicles speed for safe use by road users, from 85th speed percentile of 50–66 km/h (30 metres upstream of the humps) to 85th speed percentile of 22–30 km/h at the humps. The speed reduction was associated with hump height.

| Variable | B     | S.E. | df | p-value | OR     | 95% C.I. for OR |
|----------|-------|------|----|---------|--------|----------------|
| Length   | −0.004| 0.000| 1  | 0.001   | 0.996  | 0.995 − 0.997  |
| Speed    | 0.043 | 0.007| 1  | 0.001   | 1.044  | 1.031 − 1.058  |
| Height   | 0.176 | 0.018| 1  | 0.001   | 1.192  | 1.150 − 1.236  |
| constant | −1.911| 0.422| 1  | 0.001   | 0.148  |                |

S.E. = Standard Error, df = degree of freedom, OR = Odds Ratio, C.I. = Confidence Interval
The speed reduction was, however, transient as motorists accelerated at a higher rate after crossing the hump to 85th speed percentile of 41–56 km/h, 30 metres downstream of the humps.

A considerable number of the humps were found to be non-standard, as their geometric characteristics (height and length) failed to satisfy the existing specifications. This may due to laxity in the adherence to design standards and best construction practices.

The undercarriage of considerable proportion of vehicles made contact with the humps. This was directly influenced by crossing speed and height, and indirectly related with hump length. The prevalence of non-standard speed humps along with unsafe motorist behaviour, elevates long-term vehicle damage and maintenance cost, ride safety and comfort concerns.

In order to optimise the performance of speed humps for efficient vehicle operation, speed humps should be modified into raised pedestrian crossings, preceded by speed humps and advanced warning signs to enforce speed limit compliance and prevent sudden deceleration at the pedestrian crossings. Non-standard speed humps should be replaced, alongside strict adherence to design-standards in the installation of future ones.

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