



Effects of Traffic Calming Measures on Mobility, Road Safety and Pavement Conditions on Abuakwa-Bibiani Highway

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Traffic calming measures (TCMs) have been widely adopted as the major speed control devices in Ghana. While initial evaluations have underscored their effectiveness, little research has been conducted to assess their characteristics relative to design guidelines as well as the negative externalities associated with their misapplications. The objectives of this research were to; (i) establish the characteristics of TCMs, and their implications on mobility; (ii) to establish essential speed parameters in communities where TCMs are deployed (iii) to establish pavement conditions abutting traffic calming measures and; (iv) to analyse the accident typology on the Abuakwa to Bibiani road. Firstly, a radar gun and android speed measuring device were used to unobtrusively measure vehicles' spot speeds and speed profiles, respectively, at different locations relative to the TCMs. Also, visual inspections were carried out to assess the pavement conditions surrounding the TCMs while a geodetic laser leveling instrument and a surveying staff were used to obtain the crown heights of the TCMs. Further, the accident typology on the candidate road were analyzed to establish how the TCMs are affecting road crashes. Vehicle speeds were generally lower than the posted speed limits in settlements which have TCMs. Nevertheless, the proportion of accident casualties being pedestrians despite lower speeds in settlements remains unacceptably high. Further, the collision typology on this highway were predominantly loss control and rear-end accidents suggesting that the TCMs are playing insidious roles in some of the crash types on this road. Pavement distresses such as depressions, cracks, rutting, raveling, potholes and deposit of debris were common in the vicinity of the TCMs. Our findings suggest that awareness creation among communities along the highway may be amenable to improving pedestrians' safety than relying on only engineering countermeasures. The predominant collision types; *loss control* and *rear-end* implies that the TCMs are inadvertently contributing to some accident types. For a long term and sustainable speed control, bypassing settlements, use of active dynamic speed bumps (smart or intelligent speed bumps); and a deterrence-based electronic enforcement such as the *Automatic Number Plate Recognition System* which uses the demerit points offer better alternatives on the highways.

Keywords: traffic calming measures, speeding, speed bumps, speed humps, speed tables, enforcement

BACKGROUND

Traffic calming is an important technique of speed control aimed to improve upon road safety. The term traffic calming may be defined as *the combination of physical measures that reduce the negative effects of motor vehicle use, alter motorists' behavior and improve conditions for non-motorized road users* (Hallmark et al., 2007, p. 3). Traffic calming devices such as speed bumps, speed humps and speed tables are common in Low-Middle Income Countries (LMICs) as well as many High Income Countries (HICs). For instance speed calming measures are used in the USA (Tester et al., 2004; Hallmark et al., 2007; Parkhill et al., 2007); Italy, (Galante et al., 2010); Lithuania (Jateikiene et al., 2016); Peru (Donroe et al., 2008); Egypt (Bekheet, 2014; Abdel-Wahed and Hashim, 2017); and Cameroun (Sobngwi-Tambekou et al., 2010). In many settings, traffic calming measures (TCMs) are predominantly used in residential streets. Conversely, these devices are used on highways, arterial roads and residential streets in Ghana, thereby presenting an ominous challenge to motorists and passengers.

The application of traffic calming procedures are necessitated in Ghana because of poor enforcement in a country where speeding is pervasive (Damsere-Derry et al., 2019). Along the inter-urban highways in settlements where traffic calming devices are absent, over 90% of vehicles exceed the posted speed limit of 50 km/h (Derry et al., 2007; Damsere-Derry et al., 2008). The situation has endangered pedestrians' life along inter-urban highways in Ghana, with pedestrian fatalities constituting over 40% of all road deaths in Ghana (Building Road Research Institute, 2018).

The predominant types of speed calming measures being used in Ghana include speed tables, speed humps and speed bumps. Unless otherwise stated, traffic or speed calming measures or devices in this context refer to speed bumps, speed humps and speed tables. A speed hump, table or bump is considered as a raised area in the road pavement extending transversely across the entire travel path (Parkhill et al., 2007). Characteristically, what distinguishes a speed bump from a hump or a table are their dimensions. Generally speed bumps, humps and tables have different designs and applicability. Speed tables are flat-topped with a height of 76–90 mm and a travel length (width) of 6.7 m (Parkhill et al., 2007). They are usually implemented on residential collectors and not used on emergency or bus transit routes. Marked speed tables for pedestrian crossing is referred to as "raised crosswalks." Though the Ghana Highway Authority (GHA) does not provide any guidelines for their implementation, speed tables are among the commonest traffic calming devices in Ghana. However, among the three devices being discussed here, speed bumps produce the most substantial discomfort to vehicle occupants when traversed upon at a higher speed and can cause damage to vehicle suspensions the most. Due to their abruptness, speed bumps use is restricted to parking lots and private roads (Parkhill et al., 2007).

The types of traffic calming measures used two decades ago in Ghana were characteristically smaller and shorter than what are being used today. They were made of asphaltic and thermoplastic materials and were respectively 10 and 5 cm high (Bawa, 2005).

These diminutive TCMs are called rumble strips rather than the current speed bumps, humps and tables being used in Ghana today. Ostensibly, the earlier TCMs built in the late 1990s and early 2000s did not pose much challenge to pavements, motorists and passengers yet they alleviated pedestrians' injury risks.

The Ghana Highway Authority's design guideline specifies that for a circular hump and desired speed of 50 km/h, a maximum crown height of 7.5 cm is ideal and that any height beyond 10 cm may cause damage to vehicles (Ministry of Transport, 2007). Speed humps are typically implemented on residential and local roads (Parkhill et al., 2007) but in Ghana, they are deployed everywhere. The guidelines are usually based on the speed limit, community request, functional classification or traffic volume of the road. For example, the Department of Transportation in Virginia, USA bases implementation of traffic calming measures on Average Daily Traffic (ADT) >4,000 vehicles per day. Non-physical traffic calming measures such as education and enforcement are recommended where ADT is between 600 and 4,000 vehicles per day (Hallmark et al., 2007). Further, the Delaware Department of Transportation do not recommend speed humps for expressways, freeways, principal and minor arterials, and major collectors. Speed tables (raised crosswalks) are not recommended for freeways and principal arterial roads in that state. On lower road hierarchy, speed tables may be used when the ADT is <10,000 vehicles per day and the posted speed limit is <60 km/h (Hallmark et al., 2007, p. 61). It is therefore, not proper to allow local communities to build their own speed calming devices without any reference to specifications and traffic conditions.

Evaluation of traffic calming devices in Ghana has shown that these devices have life-saving potentials on pedestrian safety as they reduce vehicular speeds significantly (Bawa, 2005; Afuakaar and Damsere-Derry, 2010; Damsere-Derry et al., 2019). People living in settlements without any traffic calming measures on the Ghanaian highways are two times more likely to die from vehicle-pedestrian collisions compared with people living in communities which have these devices (Damsere-Derry et al., 2019). Therefore, speed tables, humps and bumps are considered as *the crème de la crème* speed control countermeasures in Ghana. This is because perhaps, the road authorities have not tried other alternative speed calming measures. There has not also been any appraisal of the negative externalities of TCMs such as noise, platooning, safety for car occupants and health implications of vehicle occupants.

In view of their apparent effectiveness, every community along the highways in Ghana is clamoring for speed calming devices. When communities feel that their lives are endangered by speeding vehicles and their requests for traffic calming measures are not forthcoming, the people construct these devices by themselves (GNA, 2013, 2018; Anane-Amponsah, 2018; Ultimate FM, 2018).

In the wake of these challenges like platooning, noise, safety for vehicle occupants and damage to vehicles, some countries have developed alternative approaches of speed control. Firstly, active speed bump (Actibump) or smart traffic calming measures are being used as a better alternative to the traditional speed humps and tables. They are deployed on roads to contribute to

modern and sustainable urban development by using innovative traffic systems for human centered communities Endeve. (n.d). Actibump is an active dynamic speed bump which is activated only by vehicles exceeding the speed limit. Evaluation of these traffic calming devices indicated that not only are they capable of reducing speeds and pedestrian injuries but they also reduce noise and air pollution typically associated with traditional traffic calming measures (Nilsson, 2015; Al Haji et al., 2018). Secondly, deterrence-based countermeasures appears to bring about a more lasting behavior change (Ritchey and Nicholson-Crotty, 2011; Watson et al., 2013) than the physical devices that are merely perfunctory. However, in Ghana and many developing countries, enforcement by the police has failed to a large extent due to pervasive corruption (Starr FM, 2015; The Chronicle, 2015; Aburam Korankye, 2019). Mexico, which also records high level of corruption among the police has deployed smart speed bumps (Aburam Korankye, 2019).

Every road is built with a design life in mind. When the design life—the maximum number of years the road is expected to function elapses—the road is said to have reached its terminal condition. At this point, the road needs to be reconstructed or else deterioration will set in. However, certain natural, constructional and operational conditions like overloading, quality of the road pavements and environmental factors such as flood, poor drainage and temperature fluctuations can cause pavements to deteriorate prematurely (Hatmoko et al., 2019). In this research, it was assumed that conditions like overloading and environmental factors which can cause road pavements to deteriorate prematurely are constant for the entire road section investigated.

The objectives of this research were 4-fold: (i) Firstly, to establish the characteristics (i.e., density, spacing, heights, and traverse distances) of traffic calming devices relative to design guidelines and their suitability on trunk roads; (ii) secondly, to determine pavement conditions abutting traffic calming measures (iii) to establish speed parameters i.e., approach, speed on humps, speed between humps and operating speeds and; (iv) to establish the accident typology on the Abuakwa to Bibiani road in Ghana.

METHODOLOGY

Study Site and Period

The Abuakwa-Bibiani road is a section on the *Inter-Regional Road 5 (IR 5)*. It originates from Abuakwa in the Ashanti Region and stretches for 221 km to Osei-Kwadwokrom on the Ghana-Côte d'Ivoire border. The road section studied originates from Abuakwa (Km 0) to Bibiani roundabout (km 78.2). It is an important road linking one of the most important breadbaskets of Ghana, the Western North Region feeding a large marketing center, Kumasi and beyond. The road is a single carriageway for the entire length with an asphaltic pavement. It also has a lane width of about 3.5 m wide and an average shoulder width of 2.0 m. The road was constructed in 2004 and is in a fairly good motorable conditions except for a few localized potholes. Some of the road furniture is however damaged or missing in many places and require replacement. The road has many traffic

calming devices in the settled sections. During the period 2013–2018 for which accident records were retrieved and analyzed, the TCMs on this road were typically speed bumps, speed tables and speed humps. They were made of pavement bricks, asphaltic and concrete materials and were either used alone or in conjunction with others. There were also illegal Traffic calming measures in some communities composed of sand, stones and logs. Field data such as vehicle speeds, road distresses counts and characteristics of speed bumps were taken in June and July, 2018.

Approach

A 1-day reconnaissance survey was first carried out on the research road to familiarize researchers with prevailing conditions on site. The preliminary visit guided researchers on how to design the field sheets, identify the appropriate equipment and personnel that will be needed for the study. The initial site visit took place in May, 2018.

During the main site visit, visual inspection of pavement distresses and counts were carried out by the research team led by a Principal Highway Engineer. At each location, the team inspected the speed calming measures and their immediate surroundings to ascertain whether there were any visible pavement distresses such as rutting, raveling, evidence of patching, depressions, cracks, potholes etc. Also, the pavements surrounding the traffic calming measures were inspected to find out whether there were hazards like loose gravels and drainage problems evidenced by the accumulation of debris or water in the vicinity of the traffic calming devices. The differences between road distresses and hazards within the 1st and 10th m upstream and downstream within the TCMs vs. those within the 11th and 20th m upstream and downstream from the TCMs were determined.

In addition to visual inspections, field measurement was carried out to determine the basic characteristics of the speed calming devices. Physical measurements carried out included heights, widths, and intervening distances between speed calming measures within each settlement. Crown heights were measured with a geodetic laser leveling instrument and a surveying staff. Staff readings at the base and crowns of the speed calming devices were recorded from which the mean height was determined. These recordings were repeated at two (2) points along the devices and averaged. In relation to the widths (travel lengths), measurements were taken with a tape measure or a plumbed staff depending on convenience. A cyclometer was used to measure the intervening distances between the speed calming devices.

Where necessary (specifically, with the speed bumps) which were constructed in groups per location, an additional measurement representing the thickness, of each bump within the set was measured. The type, nature as well as the predominant materials of construction of each speed calming measure were also noted.

Three different types of spot speeds and the speed profile of each settlement were unobtrusively measured using radar speed guns and android speedometers, respectively. The procedure for the unobtrusive spot speed measurement have been described in detail in an earlier report (Derry et al., 2007) and summarized herein. By this procedure, the research vehicle was parked off

the traffic stream and researchers measured all the vehicles' spot speeds from within the research vehicle using handheld speed guns. This approach was adopted to prevent motorists from seeing that their speeds were being measured. The research vehicle also run through all the settlements as the lead vehicle and the android speedometer used to measure the speed profiles.

Firstly, spot speeds for various locations of the settlements i.e., approach speeds, speed on traffic calming devices and speed between the traffic calming devices were measured using radar guns. This was done to establish the impact of the devices on vehicle speeds, the manner motorists approach settlements as well as maneuver on the speed calming measures. Secondly, the operating speeds in the settlements, from gate to gate, were measured by an android supported speedometer.

Accident Analysis

Five most recent years' (2013–2018) road crash statistics were retrieved and analyzed for the Abuakwa-Bibiani Highway. This data are stored in a software called the Microcomputer Accident Analysis Package (MAAP) which was developed by Transport Research Laboratory, UK. The key variables analyzed were collision types and road environments stratified by casualty injury severity.

Settlements

The major settlements along the research route were Bibiani, Nkawie-Toase, and Nyinahin. These settlements are all district capitals. The remaining settlements were small villages; i.e., with population <5,000 inhabitants. Many of the vehicles which typically traverse the settlements are more likely to be inter-urban travelers rather than local traffic. Nkawie-Toase is about 11 km away from the start-point Abuakwa-Sunyani junction. It is a twain town which forms a conurbation with the Kumasi Metropolis. Nkawie-Toase and Nyinahin are both important farmers' markets where foodstuff vendors from Kumasi and neighboring cities buy their produce.

RESULTS

Observations

Generally, construction of the traffic calming measures was retrofitted into the existing pavement. It was observed that the construction materials were mainly asphaltic, concrete or pavement bricks or a combination of these. In total, 57% of the construction materials consisted of asphalt only, 33% concrete and pavement bricks, 7% concrete only, and 4% asphalt and concrete. Twenty-five illegally constructed speed bumps were present in some communities. The illegally constructed speed humps were usually made of lateritic and clay materials which lacked signage and posed hazard to motorists. The illegal devices also spread considerable amount of sand, gravels and stones on the roads. On some parts of the pavement, screws, bolts and nuts fallen off from vehicles were common near speed bumps. These parts are suspected to have dropped off from vehicles which have low ground clearances due to constant crouching with traffic calming measures too high for their passing. It was also observed that the speed

calming devices did not have reflective coating. Therefore, night-time travelers may not see them thereby posing danger to motorists.

Characteristics of Traffic Calming Measures

Density of Traffic Calming Measures on the Study Road

There were 75 "authorized" and 25 "unauthorized" speed calming measures along the 78.2 km stretch of road. Therefore, a density of 1.3 units of bumps per kilometer was typical on the research road.

Heights of Traffic Calming Measures on the Study Road

The mean crown height of the "legal" traffic calming measures along the Abuakwa-Bibiani road was 9.9 cm high with the means ranging between 5 and 18 cm depending on type. Generally, as shown in **Table 1**, the mean crown height of 5–6 cm was typical of speed bump predominated settlements like Sepaase, Afari, and Mim while mean crown height of 10–18 cm was typical of speed humps or table dominated towns like Nkawie-Toase, Bibiani, Kwanfifi, Akorabukrom, and Anyinamso. In Nkawie-Toase township, the heights of the speed humps range between 14 and 25 cm. A one-sample mean comparison *t*-test shows that the mean for all the "authorized" traffic calming measures ($M = 9.9\text{cm}$, $SD = 5.95$); was significantly higher than the Ghana Highway Authority's recommended height of 7.5 cm, $t_{(74)} = 3.5$, $p = 0.0004$. Also, a one-sample mean comparison *t*-test shows that the mean speed humps at Nkawie ($M = 18.2\text{cm}$, $SD = 3.22$) and that of Bibiani ($M = 16.80$, $SD = 7.46$) were significantly higher than the GHA's recommended height of 7.5 cm, $t_{(12)} = 11.98$, $p < 0.0001$, and $t_{(4)} = 2.79$, $p = 0.0255$, respectively. It is important to stress that speed bumps are not supposed to be deployed on public roads. Due to their steep slopes and the discomfort they bring about to motorists, bumps are mainly recommended for parking lots and private roads. The fact that speed bumps are being used on arterial roads and highways in Ghana leaves much to be desired. In many cases, speed bumps were in duplicates, triplicates or quadruplicates rendering maneuvers on them uncomfortable and dangerous.

Intervening Distances Between Traffic Calming Measures

The mean intervening distances between two successive speed calming measures along the research road was 222 m compared with 250 m as recommended by Ghana Highways Authority. There were however variations between settlements. For instance, the least intervening distance of 100 m was measured at Mpasatia Junction and the maximum spacing of 453 m was measured at Anyinamso as shown in **Table 1**.

Speed Distribution

Mean Speed

As illustrated in **Table 2**, the mean vehicular speeds at the outskirts were generally lower than the recommended speed of 80 km/h and the posted speed limit of 50 km/h in settlements.

TABLE 1 | Characteristics of speed calming measures on Abuakwa-Bibiani road.

| Location | Mean distances and heights | | |
|-------------------|----------------------------|-----------|-------------|
| | Spacing (m) | Width (m) | Height (cm) |
| Sepaase | 141.18 | 2.94 | 6.14 |
| Mim | 146.78 | 2.40 | 5.71 |
| Afari | 114.60 | 2.32 | 5.25 |
| Afari Hospital | 104.35 | 1.42 | 6.00 |
| Nkawie Toase | 163.69 | 3.75 | 18.19 |
| Mpasatia | 100.00 | 2.65 | 6.33 |
| Anyinamso | 453.00 | 3.75 | 14.00 |
| Serebuoso | 176.00 | 2.42 | 5.00 |
| Kentekyire | 247.00 | 2.73 | 5.50 |
| Kwanfinfi | 340.00 | 2.80 | 16.50 |
| Nkrumah Nkwanta | 177.00 | 2.75 | 5.00 |
| Agogoso | 340.67 | 3.29 | 10.75 |
| Akentenso Nkwanta | 166.00 | 2.83 | 6.50 |
| Nyinahin | 234.88 | 2.86 | 8.67 |
| Akorabourkrom | 208.00 | 3.75 | 16.50 |
| Otaakrom | 248.00 | 3.75 | 11.33 |
| Baniekrom | 260.00 | 3.75 | 14.50 |
| Bibiani | 377.75 | 6.06 | 16.80 |
| Overall average | 222.16 | 3.12 | 9.93 |

This is potentially due to the spill over effects from nearby TCMs. In all, 1,656 spot speeds of vehicles were unobtrusively measured 60% of which occurred in settlements and the remaining 40% took place at the approaches of settlements. The mean approach speeds ranged between 50 and 70 km/h at the outskirts precincts of settlements along the highway. Contiguous settlements such as Otaakrom, Baniekrom, and Bibiani registered much lower mean approach speeds of 25–40 km/h.

The main reasons accounting for lower mean speeds at these locations were that on the Kumasi approach, there was a police checkpoint while on the Bibiani city approach, there was a roundabout and the town center where human activities were dense. The Kumasi approach to Agogoso and the Bibiani to Nkrumah Nkwanta approaches had recorded mean speeds <10 km/h since they were both situated at police checkpoints where vehicles had to come to a complete stop for police checks before moving forward.

Speed on Traffic Calming Measures

Generally, many motorists came to a near or complete halt when they came upon traffic calming measures on the Abuakwa to Bibiani road. The mean speed on traffic calming measures generally range from 9 km/h to the highest of 27 km/h on speed calming measures. The predominant TCMs along the road corridor were speed bumps. Though speed bumps are smaller than humps and tables, their speed reducing capabilities are the most drastic. This is due to the unforgiving angles that speed bumps have on motorists compared to humps and tables, see **Table 2**.

Speed Between Traffic Calming Measures

As shown in **Table 2**, the mean speed in between the TCMs in the settlements ranged from 20 to 47 km/h. These speeds are notably lower than the posted speed limit of 50 km/h and signify that vehicles and pedestrians can safely interact. However, the jolts experienced by motorists and passengers implies comfortability in mobility is compromised.

Operating Speeds

Just like the spot speeds, the speed profiles along the settlements were considerably below 50 km/h, the speed limit specified for settlements along the research road. The only exception to this finding was Anyinamso where the operating speed was 55 km/h (see **Table 2**) because the spacing in that settlement was about half a kilometer apart.

Pavement Defects

There was at least, one type of pavement distress in the vicinity of the traffic calming measures or another. In many instances, multiple pavement distresses were found at one location. **Table 3** illustrates the net counts of pavement distresses near the TCMs relative to their immediate surroundings. Specifically, the net road distresses and hazards within the 1st and 10th meter upstream and downstream within the TCMs vs. those between the 11th and 20th meter upstream and downstream from the TCMs were determined. In all locations, the number of road distresses and hazards near the TCMs were higher than those further away. The net road distresses are illustrated in **Table 3**.

As shown in **Table 3**, the single most prevalent pavement distress identified was raveling which constitute about 29% of all the road deteriorations identified followed by depression 20%. There were evidence of poor drainage problem and accumulation of soil and debris which constitute 18% of the pavement problems identified.

Distribution of Accident Types and Severity Along Abuakwa-Bibiani Highway

As illustrated in **Table 4**, over 80% of all casualties emanated from rear end and ran off road collisions which all together resulted in over 43% of all fatalities during the period of research. Pedestrian collisions constituted over 14% of all injury related victims but 37% of all the road fatalities.

As shown in **Table 5**, over 90% of road accident casualties occurred in settlements; 82 and 11% occurring in village and urban settings, respectively. Further, 87 and 10% of all fatalities occurred in village and urban settings, respectively. It is important to stress here that these accidents occurred in settlements where the vehicle speeds were measured.

DISCUSSION

The use of TCMs on the Abuakwa-Bibiani road is very widespread. In Ghana, communities usually request or construct these devices when their kinsmen are knocked down by motorists (Anane-Amponsah, 2018; Ultimate FM, 2018). At Taviefe-Avenya community in the Volta Region for instance, the youth erected unauthorized speed humps with sand, stones

TABLE 2 | Distributions of vehicle speeds on Abuakwa-Bibiani Highway.

| Location | Predominant TCM | No. of TCM | Operating speed | Speed distribution | | | | |
|----------------------------|-----------------|------------|-----------------|--------------------|-----------------|---------|---------------|-------------------------|
| | | | | Bibiani approach | Kumasi approach | On hump | Between humps | 95% confidence interval |
| Sepaase (n = 107) | Bumps | 7 | 29.6 | 61.3 | 60.5 | 18.8 | 31.2 | 26.3–30.7 |
| Mim (n = 112) | Bumps | 7 | 21.2 | 64.1 | 63.0 | 16.2 | 26.9 | 16.2–24.0 |
| Afari (80) | Bumps | 4 | 25.2 | 57.0 | 69.8 | 20.8 | 29.0 | 22.3–26.1 |
| Afari Hospital (n = 150) | Bumps | 3 | 25.1 | 61.6 | 49.5 | 27.4 | 33.3 | 29.1–32.5 |
| Nkawie Toase (n = 158) | Humps | 13 | 28.7 | 51.0 | 54.7 | 17.8 | 31.6 | 23.5–27.9 |
| Mpasatia Junction (n = 68) | Bumps | 3 | 50.2 | 70.3 | 62.0 | 9.2 | 22.5 | 44.3–56.1 |
| Anyinamso (n = 90) | Humps | 3 | 54.5 | 59.3 | 52.8 | 10.1 | 40.8 | 43.0–50.6 |
| Serebuoso (n = 74) | Bumps | 3 | 28.7 | 61.8 | 60.3 | 11.2 | 46.0 | 49.0–57.0 |
| Kentenkyire (n = 60) | Bumps | 2 | 34.5 | 55.0 | 55.0 | 9.4 | 46.3 | 41.8–50.4 |
| Kwanfinfi (n = 57) | Bumps | 2 | 40.4 | 62.4 | 57.0 | 12.0 | 30.8 | 41.9–52.9 |
| Nkrumah Nkwanta (n = 58) | Bumps | 2 | 36.3 | – | 62.0 | 13.2 | 46.9 | 44.7–52.9 |
| Asibe Nkwanta (n = 54) | Bumps | 2 | 37.4 | 68.1 | 65.5 | 18.6 | 34.5 | 29.0–38.0 |
| Agogoso (n = 80) | Humps | 4 | 36.2 | 61.5 | – | 9.7 | 34.8 | 38.7–47.3 |
| Akentenso Nkwanta (n = 56) | Bumps | 2 | 36.2 | 68.5 | 68.7 | 14 | 31.7 | 43.6–50.0 |
| Nyinahin (n = 150) | Bumps | 9 | 37.8 | 57.5 | 67.5 | 11 | 37.2 | 43.6–50.0 |
| Akorabourkrom (n = 54) | Bumps | 2 | 48.9 | 47.6 | 48.3 | 9.6 | 35.1 | 37.9–45.9 |
| Otaakrom (n = 68) | Bumps | 3 | 48.2 | 51.6 | 37.3 | 9.4 | 38.4 | 37.1–43.3 |
| Baniekrom (n = 60) | Bumps | 2 | 29.1 | 39.5 | 33.8 | 13.2 | 19.8 | 16.2–24.0 |
| Bibiani (n = 120) | Speed tables | 5 | 28.5 | 25.5 | 25.3 | 9 | 35.6 | 26.3–30.7 |

TABLE 3 | Types of pavement distresses near traffic calming measures.

| Pavement defects | No. | Percentage |
|---------------------|-----|------------|
| Debris accumulation | 45 | 18 |
| Patching | 38 | 15 |
| Potholes | 18 | 7 |
| Rutting | 3 | 1 |
| Depression | 51 | 20 |
| Cracks | 24 | 10 |
| Raveling/weathering | 72 | 29 |
| Total | 251 | 100 |

and logs after six pedestrians had died from vehicle collisions within 2 years (Anane-Amponsah, 2018). This practice is illegal and definitely poses road safety danger and may prematurely destroy the road pavement. However, when they are not built, pedestrians’ life in the communities will be endangered. The question therefore is; why do the road authorities construct highways through settlements only for them to be interspersed with speed bumps, tables and humps? Bypassing settlements will ultimately reduce pedestrians’ exposure and improve the liveability of settlements along trunk roads (Damsere-Derry et al., 2008, 2019).

Despite the considerable low speeds and high density of TCMs in the communities on Abuakwa-Bibiani road, pedestrian fatalities still constitute 34% of all casualty deaths and 14% of total casualty injuries. This implies that engineering interventions

TABLE 4 | Distribution of casualty injury severity by collisions types on Abuakwa-Bibiani highway.

| Collision types | Casualty injury severity | | | | |
|--------------------|--------------------------|--------------|-------|-------|---------|
| | Fatal | Hospitalized | Minor | Total | Percent |
| Head On | 12 | 35 | 21 | 68 | 9.5 |
| Rear End | 22 | 66 | 57 | 145 | 20.3 |
| Ran Off Road | 18 | 117 | 308 | 443 | 62.0 |
| Hit Parked Vehicle | 2 | 6 | 13 | 21 | 2.9 |
| Hit Pedestrian | 34 | 45 | 18 | 97 | 13.6 |
| Side Swipe | 2 | 14 | 9 | 25 | 3.5 |
| Right Angle | 1 | 3 | 4 | 8 | 1.1 |
| Others | 2 | 2 | 3 | 7 | 1.0 |
| Total | 93 | 288 | 333 | 714 | 100.0 |

(TCMs) alone are not sufficient enough to improve pedestrians’ safety. Behavioral changes among pedestrians is imperative to complement and minimize pedestrian casualties. This calls for intensive road safety education. One common characteristics of settlements along the research road is that road reservations have not been adhered to. The duality of purpose of the road serving as a “local street” and a highway is very evident. Buildings that were exclusively residential near the highway have been gentrified into stalls, shops and offices. Roadside trading along the highway is a common phenomenon which brings hawkers and buyers alike unto the road thereby increasing their exposure to vehicular collisions. Any policy aimed to prohibit

TABLE 5 | Casualty distribution by road environment on Abuakwa-Bibiani Highway.

| Road environment | Casualty injury severity | | | | |
|------------------|--------------------------|--------------|-------|-------|---------|
| | Fatal | Hospitalized | Minor | Total | Percent |
| Urban | 9 | 19 | 50 | 78 | 10.9 |
| Village | 81 | 254 | 251 | 586 | 82.1 |
| Rural | 3 | 15 | 32 | 50 | 7.0 |
| Total | 93 | 288 | 333 | 714 | 100.0 |

trading along built-up areas along the highway will be a road safety benefit.

This research finds that the mean heights of the TCMs were significantly higher than the recommended GHA guidelines. In addition, other TCMs such as speed bumps were being misapplied on the highway. For, speed bumps are not recommended for highways (Parkhill et al., 2007). Nevertheless, the predominant type of TCMs on the Abuakwa-Bibiani Highway were speed bumps. This situation has exacerbated the safety of vehicle occupants as manifested in casualties from rear end and loss control collisions. There were also a number of unauthorized TCMs composing of sand, stones and logs along the highway. Many reports in Ghana have accentuated the impact of traffic calming measures (particularly unauthorized and inappropriate speed bumps) as the cause of road crashes in this country (GNA, 2013, 2018; David Kodjo, 2016; Aklobortu, 2018; Afavi, 2020; Ghanaweb, 2020). As shown in **Table 5**, over 90% of casualty injuries occurred in either large towns or villages, and **Table 2** shows that the operating speeds in these settlements are low due to the traffic calming measures. For, it has been established that over 90% of motorists exceed the posted speed limit in communities which have no speed calming measures in Ghana (Damsere-Derry et al., 2008). It is therefore plausible to deduce that these traffic calming measures are associated with many of the loss control and rear end collisions. For rear end-collisions, leading vehicles which accost these devices abruptly may be forced to break instantaneously thus creating a conducive environment for closely following vehicles to hit their rears and motorists who cannot stand the unexpected jolts may run off the road. Reflective paintings and proper signage are vital to alleviate these accident types. Importantly, these devices are not expected to be deployed on the highways though.

Another negative externality of TCMs on the road is the delays emanating from the slowing down effects from the speed bumps. Vehicles come to a complete or near halt when they come upon these devices. TCMs thus, impose two main constraints on transportation. Time dependent transportation services such as emergency responses are adversely affected by the slowing down effects of speed calming measures. Delays in the emergency response vehicles such as ambulances, or fire trucks to incidents may cause deaths, injuries and loss of property (Akowuah and Andoh, 2016; Radio Tamale, 2017; Al Haji et al., 2018; Anane-Amponsah, 2018). In fact, some of the negative impacts emanating from illegally constructed or poorly engineered speed

calming measures are the very things they purport to prevent. For example, illegally and improperly constructed TCMs are known to be causing serious spinal injuries among passengers and motorists (Myjoyonline.com, 2016), road injuries, road traffic crash fatalities (David Kodjo, 2016; Aklobortu, 2018; Afavi, 2020); and ailments such as waist pains, back pains and abdominal pains among drivers of emergency vehicles in Ghana (Akowuah and Andoh, 2016).

Various pavement distresses were also observed at the precincts of the traffic calming measures compared to their immediate surroundings. The construction and use of traffic calming measures appear to have initiated the road deteriorations. The practice of cutting the existing pavement to form the foundation of TCMs disturbs the pavements and set them forth for deterioration. Their construction (obviously not on a highway) should be considered when the road is being built to forestall the pavement destruction resulting from latter construction. Motorists' behaviors such as constant abrupt stops on the upstream and revving at the downstream of the traffic calming measures further weaken the pavement surfaces and accelerate their deteriorations. The rate of deterioration is aggravated when there is poor drainage near the calming devices thus leading to water and debris accumulation on the pavement. In particular, the dirt coating forces the asphalt binder to bond with dust rather than the aggregates thereby initiating raveling.

It is therefore recommended that better options of speed control that protect pedestrians as well as vehicle occupants and do not destroy the road pavement should be explored. Actibumps (active dynamic speed bump) or smart traffic calming measures are new innovations which have been tried and tested as better alternatives to conventional TCMs. Unlike the traditional TCMs which have no consideration for whether the driver is speeding or not, actibumps administer retributive justice to speed compliant motorists by punishing only those speeding. Actibumps' effectiveness has been reported in prior reports (Nilsson, 2015; Al Haji et al., 2018). Actibumps' use is recommended for Ghana as the types of TCMs currently being used are becoming a nuisance rather than road safety devices.

More importantly, deterrence-based countermeasures have been the best option to achieve a long lasting road safety compliance. The deterrence theory proposes that for enforcement practices to deter a proscribed behavior such as speeding, it should be a function of the perceived risk of detection, as well as the perceived certainty, severity and celerity of punishment (Watson et al., 2013). Deterrence-based enforcement has been the reason why speed control measures work effectively in High Income Countries (Ritchey and Nicholson-Crotty, 2011). Demerit points system which aims to disqualify motorists who incessantly violate traffic regulations is a deterrent-based enforcement which will improve motorists' speeding behavior in this country. Nevertheless, the current law enforcement particularly relating to road safety has been largely compromised due to the police overwhelming involvement in corrupt practices (Adu Gyamfi, 2015; Starr FM, 2015). This needs to be changed to ensure that deterrence-based countermeasures on speeding can be effective. The automatic number plate recognition method which uses the demerit point system of

speed enforcement will be a better alternative because this approach will forestall human interference and corrupt practices typically characterized with the manual police enforcement. In some developing countries where police enforcement is equally ridden with corruption, the non-Newtonian fluid speed bumps are used (Schwartz, 2009).

CONCLUSION

In conclusion, speeding in settlements along the Abuakwa-Bibiani Highway has been successfully ameliorated by using the TCMs. Therefore, pedestrians' collisions attributable to speeding is somewhat alleviated. However, the current proportion of pedestrians' fatality of 34% is unacceptable for a road section with 1.3 TCMs per kilometer. In order to complement the current engineering interventions, road safety education which will inform pedestrians to limit their exposure on the highway may be highly beneficial. Pedestrians should be made aware that the risk of death and injuries is still present even when hit by vehicles traveling at the barest minimum speed. Also, the fact that TCMs are deployed on the highway presents ominous hazards to vehicle occupants. Densities and heights of TCMs on road also reduces efficient mobility and pose safety challenges to vehicle occupants. Therefore, it is recommended that settlements should be bypassed, electronic monitoring using the Automatic Number Plate Recognition techniques will minimize human interference and corruption issues which has ridden manual enforcement in Ghana. Demerit-point based enforcement will instill deterrence into motorists and cause motorists to comply with speed limits. Smart speed bumps (Actibumps) offer better alternatives to traditional TCMs which destroy the road pavements and vehicles.

It is also recommended that this research should be expanded to cover representative road networks in the country to present a comprehensive characterization of the negative externalities associated with the misapplication of TCMs. This may elicit alternative solutions that will improve safety for all road users i.e., pedestrians, passengers and drivers as well as comfort for vehicle occupants and protect road pavement deterioration.

REFERENCES

- Abdel-Wahed, T. A., and Hashim, I. H. (2017). Effect of speed hump characteristics on pavement condition. *J. Traff. Transp. Eng.* 4, 103–110. doi: 10.1016/j.jtte.2016.09.011
- Aburam Korankye, K. (2019). *Police Top Corruption Perception Again*. President, GAF, Religious Leader Trusted-Afrobarometer Report. Accra: Daily Graphic.
- Adu Gyamfi, A. (2015). *IEA Research: Office of the Prez 2nd Most Corrupt Institution in Ghana*. Peace FM online. Available online at: <http://www.peacefmonline.com/pages/politics/politics/201502/233651.php> (accessed February 22, 2020).
- Afavi, S. B. (2020). *9 Die in Accident at Monkra*. Accra: Daily Graphic.
- Afukaar, F. K., and Damsere-Derry, J. (2010). Evaluation of speed humps on pedestrian injuries in Ghana. *Injury Prev.* 16, A205–A206. doi: 10.1136/ip.2010.029215.733

LIMITATIONS

This research was limited to only a 78.2 stretch out of 221 km long road. Therefore, findings reported herein may not necessarily reflect the entire road network or other roads in the country. Also, the study assumed that other factors such as overloading, pavement quality and environmental conditions which could cause roads to deteriorate prematurely were constant for the entire road segment investigated. This may not necessarily be true for the entire road segment. This limitation was somewhat mitigated as equal lengths of the road sections adjoining the TCMs were used as controls for comparison.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

JD-D designed the research methodology and study design, conducted data analysis and literature review and drafted manuscript. RL led the field data collection and took part in peer review. DT assisted in literature review, took part in the field data collection and analysis. SB assisted in designing the study and took part in reconnaissance survey. All authors contributed to the article and approved the submitted version.

- Aklorbortu, D. K. (2018). *Speed Hump-Induced Accident Claims Three Lives*. Available online at: <https://www.graphic.com.gh/news/general-news/speed-hump-induced-accident-claims-three-lives.html> (accessed February 22, 2020).
- Akowuah, E., and Andoh, P. Y. (2016). Effect of speed ramps on fire tender and service delivery: a case study of the Central Region, Ghana. *Afr. J. Appl. Res.* 2, 69–81.
- Al Haji, G., Fowler, S., and Andersson Granberg, T. (2018). *Smart Traffic Calming Measures for Smart Cities-A Pre-Study*. Linköping: Linköping University Electronic Press.
- Anane-Amponsah, M. (2018). *Illegal Speed Humps-Common Phenomenon on Volta Highways*. Available online at: <https://www.graphic.com.gh/features/features/illegal-speed-humps-common-phenomenon-on-volta-highways.html> (accessed February 22, 2020).
- Bawa, S. (2005). Assessment of the speed breaking ability of asphalt and thermosplastic rumble strips on the Kumasi-Accra road. *J. Ghana Inst. Eng.* 3, 93–97.

- Bekheet, W. (2014). Short term performance and effect of speed humps on pavement condition of Alexandria Governorate roads. *Alex. Eng. J.* 53, 855–861. doi: 10.1016/j.aej.2014.09.009
- Building and Road Research Institute (2018). *Road Traffic Crashes in Ghana, Statistics 2017* (Kumasi).
- Damsere-Derry, J., Afukaar, F. K., Donkor, P., and Mock, C. (2008). Assessment of vehicle speeds on different categories of roadways in Ghana. *Intern. J. Injury Cont. Saf. Prom.* 15, 83–91. doi: 10.1080/17457300802048096
- Damsere-Derry, J., Ebel, B. E., Mock, C., Afukaar, F. K., and Ojo, K. T. (2019). Evaluation of the effectiveness of traffic calming measures on vehicle speeds and pedestrian injury severity. *Traf. Injury Prev.* 20, 336–342. doi: 10.1080/15389588.2019.1581925
- David Kodjo (2016). *5 die, 53 Injured in Accident*.
- Derry, J. D., Afukaar, F. K., Donkor, P., and Mock, C. (2007). Study of vehicle speeds on a major highway in Ghana: implication for monitoring and control. *Traf. Injury Prev.* 8, 142–146. doi: 10.1080/15389580601100944
- Donroe, J., Tincopa, M., Gilman, R. H., Brugge, D., and Moore, D. A. (2008). Pedestrian road traffic injuries in urban Peruvian children and adolescents: case control analyses of personal and environmental risk factors. *PLoS ONE* 3:e3166. doi: 10.1371/journal.pone.0003166
- Endeva. (n.d). *Actibump, Traffic Systems for Liveable Cities*. Available online at: <https://www.edeva.se/en/> (accessed February 22, 2020).
- Galante, F., Mauriello, F., Montella, A., Perneti, M., Aria, M., and D'Ambrosio, A. (2010). Traffic calming along rural highways crossing small urban communities: driving simulator experiment. *Accid. Anal. Prev.* 42, 1585–1594. doi: 10.1016/j.aap.2010.03.017
- Ghanaweb (2020). *Unauthorized Speed Ramps Major Cause of Accidents-Long Distance Drivers*. Available online at: <https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Unauthorized-speed-ramps-major-cause-of-accident-Long-distance-drivers-844867> (accessed February 22, 2020).
- GNA (2013). *Unauthorized Speed Ramps are Causing Accidents*. Available online at: <http://www.ghananewsagency.org/features/unauthorized-speedramps-are-causing-accidents-67195> (accessed February 22, 2020).
- GNA (2018). *NRSC, NADMO to Clamp Down on Unauthorised Speed Ramps*. Available online at: <https://www.businessghana.com/site/news/general/177875/NRSC-NADMO-to-clamp-down-on-unauthorised-speed-ramps> (accessed February 22, 2020).
- Hallmark, S. L., Peterson, E., Fitzsimmons, E. J., Hawkins, N. R., Resler, J., and Welch, T. (2007). *Evaluation of Gateway and Low-Cost Traffic-Calming Treatments for Major Routes in Small Rural Communities*. Available online at: https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1030&context=intrans_reports (accessed February 22, 2020).
- Hatmoko, J. U. D., Setiadi, B. H., and Wibowo, M. A. (2019). “Investigating causal factors of road damage: a case study,” in *Paper Presented at the MATEC Web of Conferences*.
- Jateikiene, L., Andriejauskas, T., Lingyte, I., and Jasiuniene, V. (2016). Impact assessment of speed calming measures on road safety. *Transp. Res. Proc.* 14, 4228–4236. doi: 10.1016/j.trpro.2016.05.394
- Ministry of Transport. (2007). *Traffic Calming Measures Design Guideline. (Version 1)*. Available online at: https://www.ssatp.org/sites/ssatp/files/pdfs/Topics/RoadSafety/Traffic_Calming_Design_Guideline%5B1%5D.pdf (accessed February 22, 2020).
- Myjyonline.com (2016). *Speed Ramps to Cause Spinal Injury-Minister*. Available online at: <http://www.ghanaweb.com/GhanaHomePage/health/Speed-ramps-to-cause-spinal-problems-Minister-454311> (accessed February 22, 2020).
- Nilsson, A. (2015). Evaluation of Actibump in Uppsala, Sweden: effect on speed, yielding behaviour and noise level. *Rapport 2015:45*.
- Parkhill, M., Sooklall, R., and Bahar, G. (2007). “Updated guidelines for the design and application of speed humps,” in *Paper Presented at the ITE 2007 Annual Meeting and Exhibit* (Pittsburgh, PA: Institute of Transportation Engineers).
- Radio Tamale (2017). *Speed Ramps Impede Our Work-GNFS*. Available online at: <https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Speed-ramps-impede-our-work-GNFS-550438> (accessed February 22, 2020).
- Ritchey, M., and Nicholson-Crotty, S. (2011). Deterrence Theory and the implementation of speed limits in the American States. *Pol. Stud. J.* 39, 329–346. doi: 10.1111/j.1541-0072.2011.00410.x
- Schwartz, A. (Producer). (2009). *Smart Speed Bumps Punish you for Speeding*. Available online at: <https://www.fastcompany.com/90464459/this-map-shows-which-companies-have-lived-hundreds-and-even-thousands-of-years> (accessed February 22, 2020).
- Sobngwi-Tambekou, J., Bhatti, J., Kounga, G., Salmi, L.-R., and Lagarde, E. (2010). Road traffic crashes on the Yaoundé-Douala road section, Cameroon. *Accid. Anal. Prev.* 42, 422–426. doi: 10.1016/j.aap.2009.09.003
- Starr FM. (2015). *Image of Police at a Low ebb-Short*. Available online at: <http://www.ghanaweb.com/GhanaHomePage/NewsArchive/Image-of-Police-at-a-low-ebb-Short-349944> (accessed February 22, 2020).
- Tester, J. M., Rutherford, G. W., Wald, Z., and Rutherford, M. W. (2004). A matched case-control study evaluating the effectiveness of speed humps in reducing child pedestrian injuries. *Am. J. Public Health* 94, 646–650. doi: 10.2105/AJPH.94.4.646
- The Chronicle (2015). *MTTU Most Corrupt in Police Service: Commander*. Accra: General News Saturday.
- Ultimate FM. (2018). *Frustrated Kegyina Residents Construct Speed Ramps to Stop Deaths*. Available online at: <https://www.ghanaweb.com/GhanaHomePage/regional/Frustrated-Kegyina-residents-construct-speed-ramps-to-stop-deaths-623178> (accessed February 22, 2020).
- Watson, B., Leal, L. N., and Soole, D. (2013). “The impact of drink driving laws,” in *Interventions for Addiction: Comprehensive Addictive Behaviors and Disorders*, Vol. 3, ed P. M. Miller (San Diego, CA: Academic Press), 697–706.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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