THE USE OF RUMBLE STRIPS AS A SPEED - REDUCING MEASURE ON THE KASOA - WINNEBA ROAD

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DECLARATION

I hereby declare that this submission is my own work towards the MSC and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in text.

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ABSTRACT

The installation of rumble strips on the Kasoa-Winneba road is aimed at reducing speed, especially within settlements along the road to improve traffic safety. Thus, this research attempted to determine the effectiveness of the installation of rumble strips as a speed reducing measure. An inventory of rumble strips was conducted and spot speed data were recorded on sections with rumble strips and sections without the rumble strips. Speeds were recorded for all the classified vehicle types. The analysis of the spot speed data indicated that vehicles reduce speed at sections with rumble strips. Again the percentage of speed reduction at locations where strips were preceded by speed humps was significant compared to locations without speed humps. It was also revealed that small vehicles recorded the least reduction in speed of 23%, followed by medium vehicle represented by minibus with 28% reduction in speed. Heavy vehicle represented by a heavy truck recorded the highest speed reduction of 33% in speed .The overall speed reduction for all the three categories of vehicles was estimated as 26%. Considering the percentage reduction in speeds for categories of vehicles, it can be concluded that, the installation of rumble strips is an effective speed reducing measure in the light of pedestrians’ fatalities especially within settlements on highways.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1:

INTRODUCTION

1.1 Problem Statement

Most road accidents in Ghana involve pedestrian fatalities in semi-urban areas and on road sections through settlements along highways. Speed has been identified as one of the main causes of these problems. One way of dealing with the problem is to use physical measures to reduce speeds to an appropriate level at such locations. On the Kasoa -Winneba road among others, rumble strips and speed humps have been installed on sections of the road crossing settlements. The purpose of such installation is to alert vehicles to slow down on such sections in order to avoid potential accidents involving pedestrians. Reductions in accidents and pedestrian casualties can only materialize if the rumble strip installation actually causes significant speed reduction along the section where the devices have been placed. Speed reduction, therefore, provides a basis for evaluating the effectiveness of rumble strips and to justify their installation.

1.2 Objectives

The objectives of the research were the following:

- To establish the average speeds on sections of the road with rumble strips and on sections without rumble strips.
- To determine the extent of speed reduction achieved by rumble strips; and
- To inform policy direction on the use of rumble strips

1.3 Justification

The installation of rumble strips costs money and if the device is not effective, further installation on other roads implies waste of public funds. Moreover, they generate noise which sometimes becomes a nuisance to the public. Therefore, the purpose for installing rumble strips is worth considering and especially its effectiveness justified to warrant continuous application. The study will also inform Road Authorities whether this system of traffic calming is effective and necessary. Following the findings, Road Authorities will be adequately informed in deciding on whether installation of rumble strips is an effective strategy for dealing with vehicular speeds on road sections passing through settlements.

1.4 Scope of Work

The research work covered the following:

1. Literature Review
2. Selection of Study Locations
3. Speed Measurements
4. Collection of Road and Environmental Data
5. Data Analyses and Discussions

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A sleeping operator makes no discrimination. Only having rumble strips on half of the roadway is only fixing half of the problem of waking up drivers, making sure they stay on the roadway and allowing them to get to their ultimate destination safely (Arnebeck 2008).

Rumble strips as described by Finely et al (2005) are grooved or raised patterns that provide an audible and vibratory warning to drivers as the tires of the drivers' vehicle traverse the rumble strips. Rumble strips are designed to alert inattentive drivers through noise and vibration and reduce the number of accidents. Rumble strips are usually applied in the direction of travel along the edge or centerline to alert drivers when they are drifting from their lane or in series across the direction of travel to warn drivers of a stop ahead or nearby danger spot. Rumble strips in effect have reduced accidents caused by drivers' inattentiveness (Finely et al, 2005). Usually, after rumble strips are installed, white or yellow lines are marked right over them. The advantage of the marking is to make the rumble strip much more visible in the rain.

Although rumble strips do not convey information on the appropriate driving behaviour, the correct driving action is easily identified by the visual information collected by the driver, on the road environment and signs. Rumble strips may be applied on the road surface to alert drivers to changes in road design that may be dangerous. In this case, they are usually applied near intersections, toll booths, horizontal curves, lane reductions, work zones, etc. Rumble strips may also be applied on the edge of the carriageway, to alert drivers to the fact that they have left the road. In some countries, shoulder rumble strips are also used to diminish shoulder use by slow vehicles. Rumble strip application must take into account important negative side effects, normally associated with noise generation, improper use of opposite lane and maintenance issues.

2.2 History of rumble strips

The first rumble strips in North America appeared on New Jersey's Garden State Parkway when a 25-mile (40 km) section in Middlesex and Monmouth counties was retrofitted in 1955 (FHWA, 2001). The system consisted of strips of corrugated concrete. In the 1970s rolled-in rumble strips were created (Chen et al., 2003). Conversely, installation was non-uniform, had to be installed at the same time as the pavement and lacked a defined shape, all major limitations for their implementation (FHWA, 2011). Beginning in the 1980s a new method of rumble strip installation was developed by the Pennsylvania Department of Transportation (PennDOT) to allow rumble strips to be installed well after the pavement is placed. This milled-in rumble strip was the development of the Sonic Nap Alert Pattern (SNAP) design.

Implemented on a trial basis in June 1989, SNAP was introduced to help combat "Drifted –Off -Road" (DOR) crashes which at the time were the largest contributor to overall accidents on the Pennsylvania Turnpike (Wood, 1994). In April of 1986, the FHWA, recommended rumble strips on long tangents or monotonous sections of rural highways with high ROR crashes (FHWA, 1998). Rumble strips quickly gained acceptance by North American transportation agencies (Zein and Montufar, 2003). Through 1993, 18 to 21 states were incorporating rumble strips on their rural highways (Harwood 1993) and by the end of 1997, 85% of U.S. state transportation agencies used rumble strips on some sections of their highways as part of their highway improvement programs (FHWA, 1998). In general, previous research has shown that rumble strips reduce ran-off-road (ROR) crashes up to 76% (Transport Canada 2011). The NCHRP has concluded that at least a *20percent* reduction of ROR crashes system-wide can be expected with the installation of centre line and shoulder rumble strips (CSRS). The report also noted that a reduction rate of up to 70% for

ROR crashes could be expected on long isolated stretches of highway (Harwood, 1993). The American Association of State Highway and Transportation Officials (AASHTO) estimates a reduction of 16% of all collisions after the installation of rumble strips (Kenny, 2011).

Wood (1994) reported that run-off-the-road accidents decreased by 70% on the section of installation. Chen (1994) reported that milled strips generate 12.6 times the vibration and 3.4 times the noise of rolled strips. Many other states started to employ milled strips after the Virginia DOT introduced them. Perrillo (1998) reported that installation of 5,071 km of milled rumble strips at the shoulders of freeways in New York State from

1993 to 1998 reduced run-off-the-road accidents by 65%. The high cost-effectiveness reported in some studies and the development of a milling method for installation on existing pavements promoted the spread of rumble strips in the early 1990s. The facility was quickly employed against run-off-the-road accidents on freeways. Outcalt (2001) reported on milled rumble strips installed at the centerline of a 27-km two-lane section of State Highway 119 in Colorado. He found that the rumble strips reduced accidents per million vehicles by 34% for head-on collisions and 36% for sideswipe accidents.

2.3 Effectiveness and performance of rumble strips

Rumble strips can act as a navigational aid in inclement weather. The grooved edges serve as an effective means of locating the end of the travel lane in poor visibility.

The vibration the rumble strip provides can aid drivers in staying on the travel way. In the case of a rumble stripe, the pavement markings visibility is increased in unfavorable conditions. Even if there is no recovery area it is still beneficial to install rumble strips especially continuous shoulder rumble strips to give the driver more reaction time to avoid striking a fixed object (FHWA, 2011). Most importantly, it is advised that CSRS be installed on both sides of a roadway because vibrations acting on the driver side tires produce more noise in the vehicle at the critical driver position than when struck only on the right (FHWA, 2011). In a comprehensive analysis of the effectiveness of the rumble strips in Maine, crashes were broken down into three categories: Run-off-the Road (ROR) with the driver reported sleepy or fatigued, all ROR during dry pavement conditions and all ROR crashes. The results revealed that rumble strips (RS) had reduced sleep related ROR crashes by 58% with a 27% reduction in all ROR crashes. Statistical analysis showed with 99.9% certainty that there was at least a 41% reduction in sleep related ROR crashes.

It was estimated that milled-in rumble strips on rural interstates in Virginia, saved one life for every 17 miles (27 km) of installation over a 3-year implementation period (Chen et al., 2003). An estimated 22 crashes were eradicated per the same distance of roadway.

Using data from NYSDOT and the New York State Thruway Authority (NYSTA) to perform a before and after analysis, it was shown that milled RS provided at least a 65% to 70% reduction in ROR crashes on rural interstates and parkways within the state (Perrillo, 1998). Despite the continuous decrease in crashes, injuries and fatalities during and after rumble strips were installed, for every year throughout the study there was an increase of the number of vehicle miles traveled. Single vehicle accidents in Utah accounted for roughly thirty percent of all accidents each year (Cheng et al., 2001). A before and after analysis of Utah's freeways found that the rate of ROR crashes fell from 33.4% to 26.9% (nearly a 20% decrease) after rumble strips were installed (Carrasco et al., 2004). The study noted that the decrease was more pronounced with SRS that were continuous and located closer to the travel lane (Cheng et al., 2001). In Michigan, drift-off-the road (DOR) crashes were reduced 38 percent after the installation of milled-in rumble strips (FHWA, 2011).

Conversely, it was shown that rolled-in rumble strips reduced DOR crashes by only 20 percent over the same timeframe (Morena, 2003).

2.4 Placement of rumble strips

Rumble strips are placed at different locations along the roadway to alert drivers to various changes in the roadway environment (Finely et al, 2005). Rumble strips are divided into transverse rumble strips, shoulder rumble strips, and centerline rumble strips, depending on where they are placed. They include the following:

- **Transverse rumble strips** - are used to alert drivers of an upcoming change or hazard in the roadway. Additionally, they are used to warn drivers of needed lane changes, the need to slow down or stop, or change in the roadway alignment. Typical locations for these rumble strips are on approaches to intersections, toll plazas, horizontal curves, and work zones (Perrillo, 1998). They are most effective where drivers have been travelling at sustained high speed for long periods
- **Shoulder rumble strips** - also known as edge line rumble strips, are used primarily to reduce run-off-road collisions. The intent of shoulder rumble strips is to notify inattentive drivers that they are leaving the roadway - with the goal of reducing run-off-the-road crashes. They are also useful during snowy conditions to help the driver keep the vehicle on the road (Minnesota Department of Transportation).
- **Centerline rumble strips** - are used on undivided highways to reduce crossover incidents and resultant head-on collisions.

2.5 Types and size of rumble strips

There are several ways to apply rumble strips. They differ primarily in how they are installed, their shape and size, and the amount of noise and vibration produced (FHWA safety program). They include the following:

- Milled rumble strips - are cut into the road with a mechanical milling device that uses a rotary cutting head. These can be installed on both new and existing concrete and asphalt roadway. The cuts are typically 0.5 inches in depth (Finley, 2005).Tires passing over milled rumble strips drop roughly into the groove, which causes tire noise and vehicle vibration. In general, the wider and deeper the rumble strip, the more sound and vibration. Recent research suggests the length of the rumble strip is not as critical as once thought, largely due to the fact that the amount of vibration and noise in large trucks is not enough above the ambient levels to alert a drowsy driver (FHWA safety program).

- Raised rumble strips - are rounded or rectangular markers or strips bond to the roadway. This includes traffic buttons, profile markings, performed thermoplastic or raised sections of asphalt pavement. Raised rumble strips can be applied to any roadway. However, they are restricted to warmer climates, because cooler climate regions may require snowplowing that may damage the rumble strips and/or the snow plowing equipment. The heights of raised rumble strips vary from approximately 0.25 to 0.5 inches (Finley et al, 2005)
- Formed rumble strips - mirror the rolled type in shape but are made by pressing forms into concrete shoulders as they are being constructed (32-mmdeep, 40-mm-wide rounded or V-shaped grooves) (FHWA safety program).
- Rolled rumble strips- Rolled rumble strips are rounded or V-shaped grooves pressed into hot asphalt pavements and shoulders when the constructed or reconstructed surface course is compacted. The strips are made by a roller with steel pipes welded to drums, which make the depressions as they pass over the hot pavement. The sound and vibration of rolled rumble strips is typically much less noticeable than milled rumble strips, but varies based on width, depth, and spacing (FHWA safety program).

According to Finley et al (2005), rumble strips design do not only differ in type and application but also with respect to dimension. The width of a rumble strip is the dimension perpendicular to the direction of travel, while the length of a rumble strip is the dimension in the direction of travel. They further suggested that the spacing is the distance in the direction of travel from the leading edge of one rumble strip to the leading edge of the following rumble strip.

For milled and rolled rumble strips, the depth is measured from the roadway surface to the bottom of the rumble strip while for raised rumble strips; the height is measured from the roadway surface to the top of the rumble strip (Finley et al, 2005).

2.6 Forms of rumble strips

Rumble devices come in a variety of forms, which have been described as rumble strips, jiggle bars, and rumble areas. Rumble strips and jiggle bars are similar in concept and design, both comprising narrow strips of material laid transversely across the carriageway. Single rumble strips will seldom if ever be appropriate. However, a single group of rumble strips has been used, though to achieve any noticeable effect the group would need to have a large number of strips i.e. at least 10 strips per location(Jesse Bhullar et al, 2001) . Normally rumble strips will be laid in a series of groups consisting of between two to five strips per group. Spacing between the groups can vary. Rumble areas are generally constructed of coarse chippings, but can also be formed from block paving or gravel filled cellular blocks. Again they can be laid as a single area, or a series of areas, in advance of a hazard. Single areas unless accompanied by other measures are likely to have a very limited effect, not only with regard to speed reduction but also as an alerting device.

2.7 Noise generation by rumble strips

Rumble devices can generate considerable noise over a large area depending on the topography and ambient noise levels (Lori Swanson et al, 2012). Rumble areas tend to be less noisy than rumble strips, but a more expensive form of construction. To avoid complaints arising and the subsequent necessity to remove the device, the possible nuisance that might be caused by any noise generated should be considered at the outset. Noise generated will vary from location to location and depend on the pattern and type of device used. In general, siting of rumble strips close to residential properties should be avoided. Some authorities do not use rumble devices within 200m of residential properties. Where a conflict seems likely to arise between safety gains and increased noise levels, consideration should be given to whether the noise disbenefit outweighs the benefit of accident reduction. Additionally consideration could be given to using a lower height device, though this may be at the expense of overall effectiveness.

2.8 Rumble strips layouts

Choice of the most appropriate layout to adopt depends largely on local circumstances. The following should therefore only be considered as general advice, to be modified as the particular location dictates. Full or half width rumble strips can be constructed across part of a carriageway only, so that they only affect drivers approaching a hazard (Perrillo, 1998). Existing evidence suggests that, particularly where drivers can see a long way ahead, they may cross the centre line of the road to avoid the devices. This obviously can be dangerous but also lessens the effectiveness of the rumble strips. Extending the strips across the full width of the carriageway will prevent this. However, it will be necessary to consider whether the additional noise that might be generated could become a nuisance. Cycle and drainage provision to allow for drainage and help cyclists to avoid rumble devices, requires the provision of a gap, preferably in the range of 750mm to 1m, between the edge of carriageway and the strips (State Highway Administration, 2011).

2.9 Visibility of rumble strips

Rumble strips should be of a contrasting colour from the generality of the carriageway, so that drivers can see them. White must not be used, to avoid confusion with road markings. Rumble strips should also be clearly visible at night; where the colour of the construction is relied on, rather than signing, the use of a suitable reflective material may be feasible (Anund et al, 2005).

2.10 Rumble strips placement location

Rumble strips will be most appropriate in rural locations in advance of hazards such as bends and junctions (Finely et al, 2005). There is some evidence to suggest that rumble strips should not be used on bends with a radius less than 1,000m, because of possible danger to motorcyclists. Rumble devices used in urban areas will generally be limited because of the noise they can generate (Anund et al, 2005). If rumble areas are used to indicate the start of shared surface roads the overall height should be in the order of 5m in order to reduce noise levels, and make them friendlier for cyclists to cross (Karkle, 2011).

2.11 Signing at locations of rumble strips

Where rumble strips provided in accordance with the Traffic Calming Regulations do not stand out visually from the rest of the road surface, authorities should consider whether they should be signed. The Traffic Calming Regulations allow warning signs to be used. Where rumble strips are specially authorized, and have different dimensions to the regulations, specific signing may be required. Where rumble strips are used at the approach to a hazard such as a bend or junction they should, where possible, be sited in obvious relationship to signing warning of the hazard. Where this cannot be achieved, specific signing for the rumble strips should be considered (Carlson et al, 2003).

2.12 Characteristics of rumble strips

For normal use, a height of 13mm is adequate for providing both audible and vibratory warning, whilst achieving any speed reduction that might be obtainable. When used in combination with other features, such as at gateways, lower heights may yield acceptable results. In all cases, it is important to ensure that vertical faces do not exceed 6mm in height (Carlson et al, 2003). Figure 2.1 shows a typical cross section of a rumble strip.

Figure 2.1 Typical cross section of a Rumble Strip

- They are about 15–25 mm high and made of thermoplastic or concrete.
- They are usually laid in a pattern – typically 3 groups of 4 or 5 strips.
- The recommended width of rumble strips varies between 30cm and 50cm. The space between the rumble strips varies between 50 and 200cm (Kemeh, 2010).

2.13 Pattern of rumble strips

The pattern to be adopted will depend on physical features and driver behaviour at the particular location. Irregular spacing between groups or areas will help to break up the noise patterns generated, which may make them more acceptable to any nearby residents. Decreasing the space between groups or areas is generally the most effective. The number of groups/areas and strips per group should be kept to the minimum (Anund et al, 2005). In the case of rumble strips, about 50 strips divided into 2 to 4 groups will normally be sufficient. With regard to rumble areas 4 to 6 areas will normally be adequate, though where these take the form of narrow bands this number may need to be doubled. Normally, spacing between rumble strips in the individual groups will be between 300mm and 500mm. Spacing below 400mm are more suitable for roads having speed limits less than 40mph (60km/h). On roads with higher speeds, the closer spacing tends to allow vehicles to "float" over the strips (Carlson et al, 2003).

2.14 Maintenance of rumble strips

Rumble strips have been proven not to accelerate the deterioration of pavement, providing they are not placed along roadway joints (FHWA, 2011c). There is no noticeable degradation of pavement due to the installation of (milled-in) rumble strips. CSRS require little to no maintenance over the life of the pavement. There were no reported problems with degradation of the strips or with debris, water, ice or snow retention in the SNAP designs (Volpe et al., 2000). No problems with New Brunswick's rumble strips have been reported yet, the oldest of which are approaching 12 years. It should be noted that pavement deterioration is a safety issue with or without the presence of rumble strips. Traffic driving near the rumble strip generally keeps water and ice from accumulating due to the vibration\of vehicles travelling over the rumble strips (Bahar, 2001).

2.15 Rumble strip installation

Due to the difficulty in determining where a driver will become distracted or drowsy, it is recommended that rumble strips be installed system wide (FHWA, 2011), where right side rumble strips are already in place. The installation of rumble strips should be done using a moving operation lane closure method. This installation process can cut 15 - 30 miles (24 – 48 km) of roadway rumble strips per day. Milled-in rumble strips uses a rotary cutting head to produce a predetermined consistent cut design (Perrillo, 1998). Since the expense of removing rumble strips is significantly higher than the installation cost, community outreach should be taken to inform the general public of the safety goals, explain how the treatment works, present historical success, and explain mitigation measures (FHWA, 2011d).

2.16 Development of installation methods in Japan

In Japan, it has been necessary to develop a machine for installing such strips. Many methods for continuously installing milled grooves were examined, to clarify the installation effectiveness and economic efficiency, an existing machine was modified by equipping it with a guide wheel of non-circular profile that translates rotational movement into up-down movement as the vehicle moves ahead. Bits on the milling drum are removable, which enables adjustment of the groove transverse width (length perpendicular to the roadway direction) at intervals of 6mm in the range between 15 cm and 35 cm. The groove depth is also easily adjustable.

2.17 Effects of rumble strips on speed reduction of vehicles

Traffic calming is a useful way of controlling speeds where it is unnecessarily excessive and inappropriate for the place and uses in the surroundings (Taylor et al, 2000).

Transverse (in-lane) rumble strips are traffic control devices used to alert drivers to the possible need for action. Their purpose is to provide motorists with an audible and tactile warning that their vehicle is approaching a decision point of critical importance to safety. According to synthesis Report 2002 – 07 by Minnesota Department of Transportation, research suggests that vehicle speed may or may not be impacted slightly with the installation of rumble strips. The synthesis report further explains that transverse rumble trips have been used for traffic calming purposes especially in residential areas where citizens are much concerned about the speed of motor vehicles.

However, in a research by Thompson et al (2005), the installation of rumble strips generally produced small but statistically significant ($P \leq 0.05$) changes in traffic speed. In another research by Sumner and Shippey (1977) also revealed that rumble strips had an effect on speed reduction.

2.18 Potential disadvantages of rumble strips

There are some drawbacks to rumble strips that would limit their installation, chiefly, the cost of installation, maintenance and the noise they produce (FHWA, 2007). Studies have shown that at a distance of 656 ft. (200 m) away, rumble strips produce a tolerable noise to nearby residents while at a distance of 1,640 ft. (500 m) the noise produced by rumble strips is negligible (Bihar, 2001). Roadway observations have shown that vehicles traversing on the rumble strips do not add much noise to the background noise of cars and trucks passing on a highway and the duration of most intrusions are less than 4 seconds (Gårder and Alexander, 1995). Rumble strips are designed to get the drivers attention and notably noise is a byproduct of this approach.

2.19 Costs and benefits of rumble strips

Relative to other proactive traffic measures, rumble strip installation costs are low, often leading to a high benefit cost ratio. The expected benefit-cost ratio with RS is in the range of 30 to 182 (Zein and Montufar, 2003). Rumble strip installation has increased and technology has made the cost of installing rumble strips decrease. The cost of rumble strip installation in New York was $0.15 per linear (FHWA, 2001) compared with $1.88 per linear foot ($6.18 per linear metre) in 1990.

Based on an assumed life of six years for the new rumble strips, New York State estimated a benefit-cost ratio of 182 installations of rumble strips (Perrillo, 1998). The more linear feet/metres installed at once, the lower the average bid price per linear foot/meter.

In all of the following cases the roadway was retrofitted with rumble strips. Rumble strips have been consistently identified as one of the most cost-effective safety feature available (NYSDOT, 2011). Specifically the NYSDOT mentions: "At approximately $0.30 per foot [$1 per meter] rumble strips are more cost effective than many other safety measures, including guardrails, culvert-end treatments and slope. Wyoming's prices at the time of installation [1997] were $0.194 per linear foot ($0.636 per linear meter) with a contract length of 2.95 million linear feet (900 linear km) (FHWA, 1998) and Virginia's [1997] was $0.125 per linear foot ($0.41 per linear meter) for a contract length of 2.5 million linear feet (760 linear km). These prices include the full contract bid price and take into account factors such as mobilization and traffic control. In Pennsylvania (1997), costs were $0.30 per foot ($0.984 per meter) of asphalt shoulder (Hickey Jr., 1997). The addition of rumble strips for the entire 506mile (815 km) length of the Pennsylvania turnpike system cost between $2 and $3 million. In California and Illinois research showed flattening" (NYSDOT, 2011).

2.20 Rumble strips and rumble stripes

Rumble strips should be installed as close to the travel lane as possible to provide the earliest warning possible by noise or vehicle vibration. The reaction time for unexpected information for the average driver is less than one second (AASHTO, 1990). The earlier a driver can receive a warning that something is wrong can make the difference whether a driver can take the appropriate action to avoid an accident and thus providing a slightly larger recovery area (Cheng et al., 2001). In areas where the shoulder is too narrow for a rumble strip, a rumble stripe, also known as edge line rumble strips, is an option. A rumble stripe is where the painted edge of the roadway is on top of the rumble strip. The closer the rumble strip is to the travel lane, the sooner the motorist receives warning that something is wrong. Every additional 1 ft. (0.3m) the rumble strip is offset from the travel lane adds an extra 0.03 sec delay for warnings (Spring, 2003). Edge line rumble strips do have the added step and cost of restriping the pavement, so it is recommended that these projects be performed in conjunction with regular maintenance.

The rumble stripe has the added safety benefit of increasing retro reflectivity of pavement markings in inclement weather and at night. This is achieved by the contour of the grooves of the strip allowing water to drain and providing a reflective back wall for the pavement markings. Having a rumble stripe will improve nighttime highways travels in the right lane at the moment, marking visibility, especially in wet conditions, because the marking optics are on the back side of the rumble strip which makes them better seen by the driver than a flat marking. This is because the vertical component of the pattern is less affected by rain and other weather conditions that make markings less visible.

2.21 Methods of determining Spot Speeds

Three different methods are normally used to determine spot speeds. They are; stopwatch method, pneumatic road tube method and radar meter method. For the purpose of this study, Radar meter method was used.

2.21.1 Stopwatch method

The stopwatch method can be used to successfully complete a spot speed study using a small sample size taken over a relatively short period of time. The stopwatch method is a quick and inexpensive method for collecting speed data.

2.21.2 Pneumatic road tube method

The pneumatic road tube method is normally used for longer data collection time periods than those of either the stopwatch or radar meter method. Pneumatic tubes are placed in the travel lanes and are connected to recorders located at the side of the road

2.21.3 Radar meter method

A radar meter is a commonly used device for directly measuring speeds in spot speed studies. This device may be hand-held, mounted in a vehicle, or mounted on a tripod. The effective measuring distance for radar meters ranges from 200 feet up to 2 miles (Parma, 2001). A radar meter requires line-of-sight to accurately measure speed and is easily operated by one person. If traffic is heavy or the sampling strategy is complex, two radar units may be needed. The figure below (Fig.2.2) indicates a typical Radar Meter.

Figure 2.2 Radar Meter

Different sized vehicles and the detection of the observation vehicle may affect radar readings (Currin, 2001). Large vehicles such as trucks and buses send the strongest return signal to the radar meters and as a result smaller vehicles may not be detected.

If there is a presence of large vehicles, the observer may need to record the speeds of vehicles that are alone. Also, some vehicles are equipped with radar detectors to warn them that a radar unit is operating in their vicinity. Drivers will slow down when warned by a detector. It is not unusual for other drivers to slow down also; this will affect the study results. The radar unit may be turned off while not in use so radar detectors cannot detect it. The following are the key steps to a radar meter spot speed study.

- Select proper location and placement of radar meter.
- Determine an appropriate selection strategy.
- Record observations on radar meter spot speed study data form.
- Generate frequency distribution table and determine speed percentiles

2.21.4 Speed percentiles

Speed percentiles are tools used to determine effective and adequate speed limits. The two speed percentiles most important to understand are the 50th and the 85th percentiles. The 50th percentile is the median speed of the observed data set. This percentile represents the speed at which half of the observed vehicles are below and half of the observed vehicles are above. The 50th percentile of speed represents the average speed of the traffic stream. The 85th percentile is the speed at which 85% of the observed vehicles are traveling at or below. This percentile is used in evaluating/recommending posted speed limits based on the assumption that 85% of the drivers are traveling at a speed they perceive to be safe (Homburger et al., 1996). In other words, the 85thPercentile of speed is normally assumed to be the highest safe speed for a roadway section.

Weather conditions may affect speed percentiles. For example, observed speeds may be slower in rainy or snowy conditions. A frequency distribution table is a convenient way to determine speed percentiles. The cumulative frequency is the total of each of the numbers (frequencies) added together row by row from lower to higher speed.

CHAPTER 3: METHODOLOGY

3.1 Selection and Description of Study Sites

The Kasoa - Winneba road is a major highway with several speed calming devices including rumble strips and features diverse land use (residential, industrial, commercial, educational, etc.) settings. The general purpose of the study was to assess the speed reduction achieved by the installation of rumble strips on the Kasoa - Winneba road. The assessment was based on travel speeds. Questionnaires were administered to pedestrians, passengers, drivers and other stakeholders along the corridor. Following a reconnaissance survey, twelve (12) test sites were identified for the study. The test sites were assessed for the “with” and “without” rumble strips locations. The features of these strips vary in terms of geographical location, number of strips per location, strip thickness and width. The detailed inventory information of the rumble strips are presented in Appendix A. Meanwhile, the road and
environmental related features of the study sections are briefly described.

3.1.1 Kasoa CP/Walantu Intersection

This location has a flat terrain and features a straight horizontal alignment. It is located in a built-up environment, mostly residential and commercial. Other activities within the area include a parking area for heavy machinery and a mechanic shop. It is located about 300m from the Kasoa Signalised Intersection.

3.1.2 Budumburam

The nature of terrain is rolling and hilly. It is located at the sag, but straight section of the road. It is within a built-up environment which is mostly residential.

3.1.3 Fete Kakraba

The nature of terrain is rolling and hilly. It is located on a crest, but straight section of the road. It is located within a built-up environment which is mostly residential and commercial.

3.1.4 Awutu Breku

The nature of terrain is rolling and hilly. It is located on a crest and a curve section of the road in a built-up environment which is mostly residential and commercial. This study section is close to a Taxi terminal and features a staggered intersection

3.1.5 Gomoa Akotsi

The nature of terrain is flat. It is located within straight section of the road, within a built up environment, which slightly residential and commercial. The study section features two fuel filling station (Goil and Radiance Filling Stations). Other commercial activities within the area include; washing bay, vulganizing shop and mini mechanic shop.

3.1.6 Gomoa Dabenyin

The nature of terrain is rolling and hilly. It is sited close to a junction and also features a sharp curve. It is located within a built-up environment, mostly residential.

3.1.7 Gomoa Dominase

The nature of terrain is rolling and hilly. It is located on a crest and a curve section of the road, within a built-up environment, which is mostly residential.

3.1.8 Gomoa Potsin

The nature of terrain is rolling and hilly. It is located on a crest and a gentle curvy section in a built-up environment, which is slightly residential.

3.1.9 Gomoa Okyereko

The nature of terrain is rolling and hilly. It is located in a sharp curve section in a built-up environment, which is slightly residential.

3.1.10 Gomoa Adwukwah

The nature of terrain is virtually flat, but close to a bridge. It is located within a slightly built-up residential area. There are no commercial activities in the area.

3.1.11 Gomoa Impota.

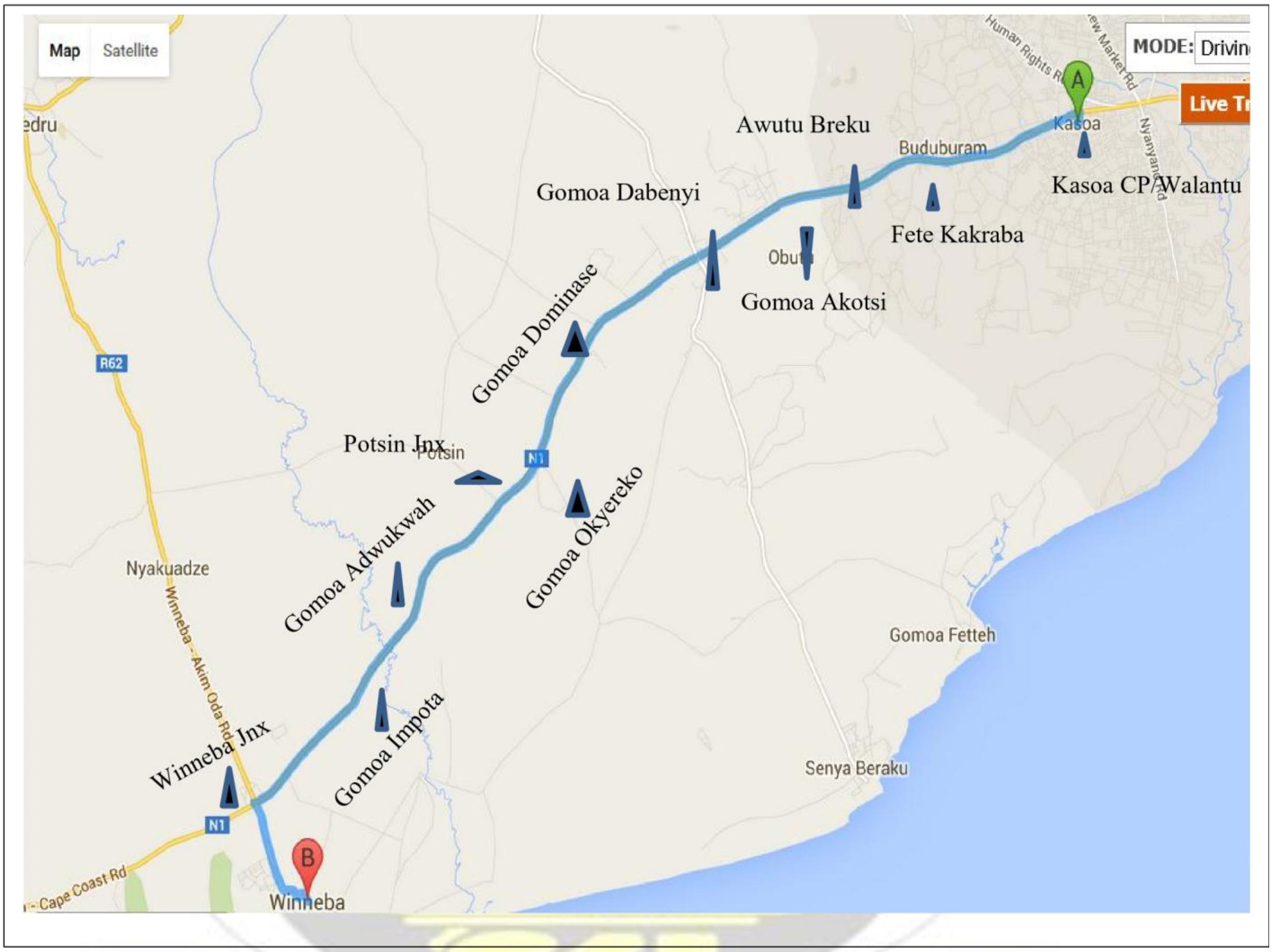
The nature of terrain is virtually flat, but located in a curve section in a slightly builtup residential area.

3.1.12 Winneba Junction

The nature of terrain is slightly hilly, and sited in a gentle curve section, located some few metres (about 350m) away from the Winneba Junction roundabout.

Figures 3.1 shows the route studied and the location map of Kasoa-Winneba road.

Figure 3.1: Location route showing Kasoa - Winneba



3.2 Data Collection

Feasibility studies were done for the two study locations "with" and "without" rumble strips to examine the condition of the rumble strips at their locations. After the feasibility study and reconnaissance survey, a total of 12 rumble strip locations were identified and used in the study.

3.2.1 Spot speed measurement

Radar speed gun equipment was used to measure the speed of free-flowing vehicles with cars, minibuses and heavy trucks as representative vehicles for small, medium and large vehicle categories respectively. The speed data were collected using handheld speed gun, which were used to compute the average speeds and 85th percentile speeds for the study locations.

3.2.2 Inventory and Condition Survey

Inventory and condition survey was conducted on the rumble strips to determine the material type, spacing, thickness, design width, length and number of strips per location. The survey was done to assess the condition of the installed rumble strips.

Detailed information has been summarized and included in Appendix A.

3.2.3 Land-Use Survey

Land-use survey was conducted to determine the land use types, that is, residential, commercial and educational facilities among others within the test sites environs. The survey was done to identify the activities within an installed rumble strip environ as well as within the settlement locations.

3.2.4 Spot Interviews

Spot interviews using pre-prepared questionnaires were conducted to solicit the views of passengers, drivers, pedestrians and other stakeholders on the performance of the rumble strips in their neighborhoods. The interviews covered passenger bus drivers at the Kasoa –Winneba terminals in Kasoa, Metro Mass terminal at Kaneshie and Winneba Junction.

3.3 Data Analysis Methodology

Speeds were recorded for the "with" and "without" rumble strips locations and the 50^{th} and 85^{th} percentile speeds determined to assess the rumble strips effectiveness. For the inventory data, direct measurements of distance such as length and width, and simple counts of number of strips were used to provide summaries for specific study locations. Using the Microsoft Excel software, the spot speed data was employed to determine the 85th percentile speeds for the study locations. The road and environmental setting of the study locations were described in terms of the most dominant activities that featured around specific study locations. The perception and opinions of passengers, drivers, pedestrians, and transport operators were synthesized from the various responses to assess the effectiveness of the installed rumble strips.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Spot Speeds of Study Locations

Spot speeds at sections with and without rumble strips for the three categories of vehicles at all the twelves (12) study locations were recorded. Speed data at sections with rumble strips were collected at three different points just before (B) the rumble strips, on (O) the rumble strips and just after (A) the rumble strips.

4.1.1 Spot Speeds at Kasoa Walantu/CP Intersection

Table 4.1 presents spot speeds recorded at sections with and without rumble strips at the Kasoa CP/Walantu intersection.

Table 4.1: Results of Speeds at Kasoa Walantu/CP Intersection

Vehicle Type	Description	Location	Mean Speed	85^{th} Percentile Speed

Car	Without Rumble Strip	-	78	85
	With Rumble Strip	B	71	83
		O	64	76
		A	54	69
Minibus	Without Rumble Strip	-	74	94
	With Rumble Strip	B	55	71
		O	51	66
		A	49	66
Heavy Truck	Without Rumble Strip	-	77	88
	With Rumble Strip	B	55	70
		O	52	68
		A	51	66

B = Before Rumble Strip O = On Rumble Strip A = After Rumble Strip

From Table 4.1, the average speed recorded for small vehicles (cars) at the location without rumble strips was 70km/h and that of rumble strips installation was 63km/h. This represents 11% reduction in speed on the rumble strip. For the 85th percentile speed, cars recorded 85km/h and 76km/h at the “without” and “with” rumble strip locations respectively. In the same way, the average speed recorded for medium vehicles (minibus) were 74km/h and 52km/h at locations without and with rumble strips installations respectively. This represents 42% reduction in speed. For the 85th percentile speed, minibus recorded 94km/h and 68km/h at the without and with rumble strips location respectively. For large vehicles (heavy truck), the average speeds recorded at the locations without and with the rumble strip were 77km/h and 53km/h respectively. This represents a reduction of 45% in speed. For the 85th percentile speed, heavy trucks recorded 94km/h and 68km/h on the without and with rumble strips location respectively. It is obvious that the installed rumble strips caused a significant reduction in the speeds of vehicles.

4.1.2 Budumburam

Table 4.2: Results of Speeds at Budumburam

Vehicle Type	Description	Location	Mean Speed	85^{th} Percentile Speed
Car	Without Rumble Strip	-	69	85
	With Rumble Strip	B	68	77
		O	63	72
		A	39	52
Minibus	Without Rumble Strip	-	71	85
	With Rumble Strip	B	41	60
		O	38	42
		A	40	35
Heavy Truck	Without Rumble Strip	-	75	87
	With Rumble Strip	B	43	51
		O	39	48
		A	39	48

The Table 4.2 above shows that, the average speed recorded for small vehicles (cars) at the location without rumble strips was 69km/h and that of installation was 57km/h. This represents 21% reduction in speed. For the 85^{th} percentile speed, cars recorded 85km/h and 67km/h at the without and with rumble strip locations respectively. In the same way, the average speed recorded for medium vehicles (minibus) were 71km/h and 40km/h at locations without and with rumble strips respectively. This represents 78% reduction in speed. For the 85^{th} percentile speed, minibuses recorded 85km/h and 46km/h at the without and with rumble strips location respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 75km/h and 40km/h respectively. This represents a reduction of 88% in speed. It is evident that the installed rumble strips caused a significant reduction in the speeds of vehicles. In the case of 85th percentile speed, heavy trucks recorded 87km/h and 49km/h on the without and with rumble strip locations respectively.

4.1.3 Fete Kakraba

Table 4.3: Results of Speeds at Fete Kakraba

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	70	80
	With Rumble Strip	B	45	68
		O	41	58
		A	41	60
Minibus	Without Rumble Strip	-	74	79
	With Rumble Strip	B	40	79
		O	36	73
		A	34	66
Heavy Truck	Without Rumble Strip	-	66	80
	With Rumble Strip	B	40	50
		O	38	48
		A	43	54

Table 4.3 shows the average speed recorded for small vehicles (cars) at the location without rumble strips was 70km/h and that at rumble strips installation was 42km/h. This represents 67% reduction in speed. For the 85th percentile speed, cars recorded 80km/h and 62km/h at the without and with rumble strip locations respectively. In the

same way, the average speed recorded for medium vehicles (minibus) were 74km/h and 45km/h at locations without and with rumble strips respectively. This represents 64% reduction in speed. For the 85th percentile speed, minibuses recorded 79km/h and 73km/h at the without and with rumble strips locations respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 66km/h and 40km/h respectively. This represents a reduction of 65% in speed. It is clear that the installed rumble strips caused a significant reduction in the speeds of vehicles. In the case of 85th percentile speed, heavy trucks recorded 80km/h and 51km/h at the without and with rumble strips locations respectively.

4.1.4 Awutu Breku

Table 4.4: Results of Speeds obtained at Awutu Breku

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	72	85
	With Rumble Strip	B	58	72
		O	53	70
		A	52	69
Minibus	Without Rumble Strip	-	69	85
	With Rumble Strip	B	54	69
		O	49	64
		A	69	65
Heavy Truck	Without Rumble Strip	-	71	86
	With Rumble Strip	B	40	67
		O	50	63
		A	50	66

Table 4.4 indicates the average speed recorded for small vehicles (cars) at the location without rumble strips was 72km/h and that of rumble strips installation was 54km/h. This represents 33% reduction in speed. For the 85th percentile speed, car recorded 85km/h and 70km/h at the without and with rumble strips locations respectively. In the

same way, the average speed recorded for medium vehicles (minibuses) were 69km/h and 57km/h at locations without and with rumble strips respectively. This represents 21% reduction in speed. For the 85th percentile speed, minibuses recorded 85km/h and 66km/h at the without and with rumble strips locations respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 71km/h and 47km/h respectively. This represents a reduction of 51% in speed. It is clear that the installed rumble strips resulted in a significant reduction in vehicular speeds. In the case of 85th percentile speed, heavy trucks recorded 86km/h and 65km/h at the without and with rumble strips locations respectively.

4.1.5 Gomoa Akotsi

Table 4.5: Results of Speeds at Gomoa Akotsi

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	76	86
	With Rumble Strip	B	65	78
		O	59	72
		A	55	70
Minibus	Without Rumble Strip	-	64	78
	With Rumble Strip	B	66	77
		O	58	72
		A	55	71
Heavy Truck	Without Rumble Strip	-	67	78
	With Rumble Strip	B	64	76
		O	56	70
		A	54	70

Table 4.5 shows speeds recorded for the vehicles at locations with and without rumble strips. A 27% reduction in average speeds was estimated for cars with the installation of the rumble strips. In the case of minibuses, 7% reduction in average speeds was determined. For heavy trucks, which represented the large vehicle category, a reduction

of 16% in speed was estimated. It is clear that the installed rumble strips caused appreciable reduction in speeds of vehicles. Regarding the 85th percentile speeds, it appears all the vehicles recorded speeds in the range of 86km/h and 72km/h.

4.1.6 Gomoa Dabenyin

Table 4.6: Results of Speeds at Gomoa Dabenyin

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	73	85
	With Rumble Strip	B	69	70
		O	61	70
		A	61	78
Minibus	Without Rumble Strip	-	74	86
	With Rumble Strip	B	65	70
		O	61	73
		A	59	83
Heavy Truck	Without Rumble Strip	-	72	84
	With Rumble Strip	B	61	79
		O	56	72
		A	54	77

Table 4.6 presents average speeds recorded for small vehicles (cars) at the location without rumble strips estimated as 73km/h and that of rumble strips installation as 64km/h. This represents 14% reduction in speed. For the 85th percentile speed, cars recorded 85km/h and 73km/h at the without and with rumble strips locations respectively. In the same way, the average speeds recorded for minibuses were 74km/h

and 62km/h at locations without and with rumble strips respectively. This represents 19% reduction in speed. For the 85th percentile speed, minibuses recorded 86km/h and 75km/h at the without and with rumble strip locations respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 72km/h and 57km/h respectively. This represents a reduction of 26% in speed. It is obvious that the installed rumble strips resulted in a significant reduction in vehicular speeds. In the case of 85th percentile speed, heavy trucks recorded 84km/h and 76km/h at the without and with rumble strip locations respectively.

4.1.7 Gomoa Dominase

Table 4.7: Results of Speeds at Gomoa Dominase

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	71	75
	With Rumble Strip	B	68	67
		O	62	62
		A	59	57
Minibus	Without Rumble Strip	-	70	85
	With Rumble Strip	B	71	81
		O	64	82
		A	66	81
Heavy Truck	Without Rumble Strip	-	76	86
	With Rumble Strip	B	66	83
		O	60	78
		A	60	72

Table 4.7 presents the average speeds recorded for small vehicles (cars) at the location without rumble strips as 71km/h and that of rumble strip installation as 63km/h. This represents 13% reduction in speed. For the 85th percentile speed, cars recorded 75km/h and 62km/h at the without and with rumble strip locations respectively. In the same

way, the average speed recorded for medium vehicles (minibuses) were 70km/h and 67km/h at locations without and with rumble strips respectively. This represents 4% reduction in speed. For the 85th percentile speed, minibuses recorded 85km/h and 81km/h at the without and with rumble strip locations respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 76km/h and 62km/h respectively. This represents a reduction of 23% in speed. It is obvious that the installed rumble strips significantly reduced vehicular speeds. In the case of 85th percentile speed, heavy trucks recorded 86km/h and 78km/h at the without and with rumble strip locations respectively.

4.1.8 Gomoa Potsin

Table 4.8: Results of Speeds at Gomoa Potsin

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	77	91
	With Rumble Strip	B	72	85
		O	68	56
		A	79	85
Minibus	Without Rumble Strip	-	75	86
	With Rumble Strip	B	71	86
		O	65	80
		A	59	74
Heavy Truck	Without Rumble Strip	-	74	89
	With Rumble Strip	B	68	81
		O	61	75
		A	53	65

Table 4.8 shows the average speed recorded for small vehicles (cars) at the location without rumble strips as 77km/h and that of rumble strips installation as 73km/h. This represents 6% reduction in speed. For the 85th percentile speed, cars recorded 91km/h

and 75km/h at the without and with rumble strip locations respectively. In the same way, the average speed recorded for medium vehicles (minibuses) were 75km/h and 65km/h at locations without and with rumble strips respectively. This represents 15% reduction in speed. For the 85th percentile speed, minibuses recorded 86km/h and 80km/h at the without and with rumble strip locations respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 74km/h and 61km/h respectively. This represents a reduction of 21% in speed. It is clear that the installed rumble strips resulted in a significant reduction in the speeds of vehicles. In the case of 85th percentile speed, heavy trucks recorded 89km/h and 74km/h at the without and with rumble strip locations

respectively.

4.1.9 Gomoa Okyereko

Table 4.9: Results of Speeds at Gomoa Okyereko

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	75	92
	With Rumble Strip	B	66	81
		O	59	74
		A	53	74
Minibus	Without Rumble Strip	-	75	88
	With Rumble Strip	B	66	79
		O	63	76
		A	55	70
Heavy Truck	Without Rumble Strip	-	78	92
	With Rumble Strip	B	72	83
		O	64	76
		A	57	66

From Table 4.9, the average speed recorded for small vehicles (cars) at the location without rumble strips was 75km/h and that for the installation was 59km/h. This represents 27% reduction in speed. For the 85th percentile speed, cars recorded 92km/h and 76km/h at the without and with rumble strip locations respectively. In the same way, the average speed recorded for medium vehicles (minibuses) were 75km/h and 61km/h at locations without and with rumble strips respectively. This represents 23% reduction in speed. For the 85th percentile speed, minibuses recorded 88km/h and 75km/h at the without and with rumble strip locations respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 78km/h and 64km/h respectively. This represents a reduction of 22% in speed. It is obvious that the installed rumble strips caused a significant reduction in the speeds of vehicles. In the case of 85th percentile speed, heavy trucks recorded 92km/h and 75km/h at the without and with rumble strip locations respectively.

4.1.10 Gomoa Adwukwah

Table 4.10: Results of Speeds at Gomoa Adwukwah

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	75	85
	With Rumble Strip	B	72	83
		O	66	81
		A	62	77
Minibus	Without Rumble Strip	-	73	79
	With Rumble Strip	B	71	87
		O	63	80
		A	55	70
Heavy Truck	Without Rumble Strip	-	78	78
	With Rumble Strip	B	69	69
		O	62	62

		A	54	54

Table 4.10 presents the average speed recorded for small vehicles (cars) at the location without rumble strips as 75km/h and that of rumble strips installation as 67km/h. This represents 12% reduction in speed. For the 85th percentile speed, cars recorded 85km/h and 80km/h at the without and with rumble strip locations respectively. In the same way, the average speed recorded for medium vehicles (minibuses) were 73km/h and 63km/h at locations without and with rumble strips respectively. This represents 16% reduction in speed. For the 85th percentile speed, minibuses recorded 79km/h and 78km/h at the without and with rumble strip locations respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 78km/h and 62km/h respectively. This represents a reduction of 26% in speed. It is obvious that the installed rumble strips caused a significant reduction in the speeds of vehicles. In the case of 85th percentile speed, heavy trucks recorded 78km/h and 62km/h at the without and with rumble strip locations respectively.

4.1.11 Gomoa Impota

Table 4.11: Results of Speeds at Gomoa Impota

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	70	82
	With Rumble Strip	B	65	67
		O	59	69
		A	60	75
Minibus	Without Rumble Strip	-	70	80
	With Rumble Strip	B	61	75
		O	59	66
		A	57	65
	Without Rumble Strip	-	78	83

Heavy Truck	With Rumble Strip	B	56	73
		O	59	70
		A	57	74

The Table 4.11 shows the average speed recorded for small vehicles (cars) at the location without rumble strips as 70km/h and that of rumble strips installation as 61km/h. This represents 15% reduction in speed. For the 85th percentile speed, cars recorded 82km/h and 70km/h at the without and with rumble strip location respectively. In the same way, the average speed recorded for medium vehicles (minibuses) were 70km/h and 59km/h at locations without and with rumble strips respectively. This represents 19% reduction in speed. For the 85th percentile speed, minibuses recorded 80km/h and 69km/h at the without and with rumble strip locations respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 78km/h and 57km/h respectively. This represents a reduction of 37% in speed. It is clear that the installed rumble strips caused a significant reduction in the speeds of vehicles. In the case of 85th percentile speed, heavy trucks recorded 83km/h and 72km/h at the without and with rumble strip location respectively.

4.1.12 Winneba Junction

Table 4.12: Results of Speeds at Winneba Junction

Vehicle Type	Description	Location	Mean Speed	85th Percentile Speed
Car	Without Rumble Strip	-	74	86
	With Rumble Strip	B	65	70
		O	61	73
		A	59	83
Minibus	Without Rumble Strip	-	70	86
	With Rumble Strip	B	67	72
		O	64	71

		A	61	73
Heavy Truck	Without Rumble Strip	-	75	93
	With Rumble Strip	B	67	72
		O	64	71
		A	60	93

Table 4.12 sows the average speed recorded for small vehicles (cars) at the location without rumble strips as 74km/h and that of rumble strips installation as 62km/h. This represents 19% reduction in speed. For the 85th percentile speed, cars recorded 86km/h and 75km/h at the without and with rumble strip locations respectively. In the same way, the average speed recorded for medium vehicles (minibuses) were 70km/h and 64km/h at locations without and with rumble strips respectively. This represents 9% reduction in speed. For the 85th percentile speed, minibuses recorded 86km/h and 72km/h at the without and with rumble strip locations respectively. For large vehicles (heavy trucks), the average speeds recorded at the locations without and with the rumble strip were 75km/h and 64km/h respectively. This represents a reduction of 17% in speed. It is obvious that the installed rumble strips caused a significant reduction in the speeds of vehicles. In the case of 85th percentile speed, heavy trucks recorded 93km/h and 79km/h at the without and with rumble strip locations respectively.

In general, the average speed reduction recorded by all the three categories of vehicles for the twelve (12) locations were 23%, 28% and 33% for cars, minibuses and heavy trucks respectively. This means that, cars recorded the least reduction in speeds whiles heavy trucks recorded the highest reduction in speed. Moreover the overall average speed reduction for the three categories of vehicles was recorded as 26%.

4.2 Rumble Strips Inventory details and their impact on Speeds

Table 4.13 shows the summary of the inventory information of all the twelve (12) rumble strips locations and their effect on average speeds.

Table 4.13: Detail information on Rumble Strips and their effect on speeds

Study Location	Spacing (m)	Design Width (m)	Thickness (mm)	No./Loc.	Set/Loc.	Speed Hump	Av. Speed (km/h)
Kasoa Walantu/CP Jct	2.5	0.3	15	4	2	No	56
Budumburam	5.0	0.3	10	10	1	Yes	46
Fete kakraba	5.0	0.3	10	10	2	Yes	42
Awutu Breku	5.0	0.3	10	10	2	Yes	50
Gomoa Akotsi	2.0	1.0	15	12	2	No	59
Gomoa. Dabayin	2.0	1.0	15	12	2	No	61
Gomoa. Dominase	2.0	1.0	12	12	2	No	64
Gomoa Potsin	2.0	1.0	10	10	2	No	66
Gomoa Okyereko	3.0	1.5	15	5	1	No	61
Gomoa Adawukwa	3.0	0.3	20	10	2	No	64
Gomoa Mpota	2.5	0.3	20	5	1	No	59
Winneba Junction	5.0	0.5	15	5	1	No	63

From Table 4.13 above, rumble strip locations at Budumburam, Fete Kakraba and Awutu Breku which are preceded by speed humps recorded an average speed of 46km/h, 42km/h and 50km/h respectively. The average speeds at these locations are far lower than those rumble strips locations not preceded by speed humps. Thus the average speeds of vehicles at rumble strips locations not preceded by speed humps was 66km/h and that of rumble strip locations preceded by speed humps was 46km/h. This represents 33% reduction in speed. It is evident that speed reduction achieved at installed rumble strips locations preceded by speed humps are more significant than at locations not preceded by speed hump

4.3 Rumble Strips Environmental features and their impact on speeds

Table 4.14 shows the environmental features of all the twelve rumble strips locations and their impact on speeds.

Table 4.14: Environmental features of Study Locations and their impact on speeds

Location	Characteristics	Avg Speed without Rumble Strips (km/h)	Avg. Speed with Rumble Strips (km/h)	Speed Reduction (%)
Kasoa CP/Walantu Jn.	Flat terrain, straight horizontal alignment, mostly residential and commercial	74	56	32
Budumburam	Terrain is rolling and hilly, and located in the sag but straight section of the road. It is within a built up environment which is mostly residential.	72	46	57
Fete Kakraba	The nature of terrain is rolling and hilly. It is located on a crest, but straight section of the road. Features a built up environment which is mostly residential and commercial.	70	42	67
Awutu Breku	The nature of terrain is rolling and hilly. It is located on a crest and a curve section of the road within a built up environment which is mostly residential and commercial. Study section is close to Taxi terminal and a staggered intersection	71	50	42
Gomoa Akotsi	The nature of terrain is flat. It is located in a straight section of the road within a built up environment, which is slightly residential and commercial. The study section features two filling station (Goil and Radiance filling station). Other commercial activities include; washing bay, vulganizing shop and mini mechanic shop.	69	59	17
Gomoa Dabenyi	The nature of terrain is rolling and hilly. It is sited close to a junction and also features a sharp curve. Features a built up environment, mostly residential.	73	61	20

Gomoa Dominase	The nature of terrain is rolling and hilly. It is located on a crest and a curve section of the road within a built up environment, which is mostly residential.	72	64	13

Table 4.14: Environmental features of Study Locations and their impact on speeds cont'd

Location	Characteristics	Avg. Speed without Rumble Strips (km/h)	Avg. Speed with Rumble Strips (km/h)	Speed Reduction (%)
Gomoa Potsin	The nature of terrain is rolling and hilly. It is located on a crest and a gentle curvy section of the road within a built up environment, which is slightly residential.	75	66	14
Gomoa Okyereko	The nature of terrain is rolling and hilly. It is located in a sharp curve section of the road within a built up environment, which is slightly residential.	76	61	25
Gomoa Adwukwah	The nature of terrain is virtually flat, but close to a bridge. It is located within a slightly built up residential area. There are no commercial activities in the area.	75	64	17
Gomoa Impota	The nature of terrain is virtually flat, but located in a curve section of the road within a slightly built up residential area.	73	59	24
Winneba Junction	The nature of terrain is slightly hilly, and sited in a gentle curve section of the road. It is located about 350m away from the Winneba Junction roundabout. It is slightly residential and commercial	73	63	16

From Table 4.14, the average speeds of rumble strips locations characterized by both residential and commercial activities such as Kasoa Walantu intersection, Budumburam, Fete Kakraba and Awutu Breku seem lower than those rumble strips locations characterized by residential alone such as Gomoa Akotsi, Gomoa Dabenyi, Gomoa Okyereko etc. The average speed reduction for rumble strips location characterized by residential and commercial activities was 43% and that of rumble strips location characterized by only residential was 18%. This means that rumble strip locations featuring both residential and commercial settings recorded significant reduction in speeds (25%) than those featuring only residential settings.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the results of this study, the following conclusions were drawn:

1. Vehicles experience significant reduction in speeds at installed rumble strips locations averaging 26% than locations without rumble strips.
2. Rumble strips sited close to residential and commercial areas tended to influence significant speed reduction than those sited in residential areas.
3. Speed reduction achieved at the rumble strips locations differed from one vehicle category to another with most significant reduction achieved by heavy vehicle of 33%.
4. Speed reduction at rumble strips locations preceded by speed humps are more significant than at locations not preceded by speed humps.
5. Some of the rumble strips thickness was not within the acceptable range of 15mm -25mm thickness.

5.2 Recommendations

1. Rumble strips may be constructed on our roads, but could be supported by other speed calming measures such as speed humps to improve their effectiveness at reducing speed significantly.
2. Road Authorities such as Ghana Highway Authority and the Department of Urban Roads should ensure that rumble strips constructed on highways are within the acceptable threshold of 15mm-25mm thickness.

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APPENDICES

Appendix A: Detailed information on the rumble strips on the Kasoa – Winneba Road

NO	LOCATION	MATERIAL TYPE	SPAC-ING	DESG. WIDTH	LENGTH	THICKN ESS	RUMBLE STRIPS PRECEDED BY SPEED HUMPS	NUM PER LOC.	SET PER LOC.	CONDITION
1	Kasoa Walantu/CP Junction	Asphaltic/ Painted surface	2.5m	0.3m	8m	15mm	No	4	2	good
2	Gomoa Budumburam	Asph/Painted surface	5m	3m	8.3m	10mm	No	5	1	old
3	Fete kakraba	Asph/Painted surface	5m	0.3m	8m	10mm	yes	10	2	old
4	Awutu Breku	Asph/Painted surface	5m	0.3m	8.1m	10mm	yes	10	2	old
5	Gomoa Akotsi	Asph/Painted surface	2m	1.0	8m	15mm	No	12	2	Very good
6	Gomoa. Dabayin	Asphaltic, not painted	2m	1.0m	8m	15mm	No	12	2	Good
7	Gomoa. Dominase	Asph/Painted surface	2m	1.0m	8m	12mm	No	12	2	average
8	Gomoa Potsin	Asph/Painted surface	2m	1.0m	8.1m	10mm	No	10	2	old
9	Gomoa Okyereko	Asph/Painted surface	3m	1.5m	8m	15mm	No	5	1	good
10	Gomoa Adawukwa	Asph/Painted surface	3m	0.3m	8m	20mm	No	10	2	fair
11	Gomoa Mpota	Asphaltic, not painted	2.5m	0.3	8m	20mm	yes	5	1	good

12	Wiinneba jct	Asph/Painted surface	5m	0.5m	8m	15mm	No	5	1	fair

Appendix B: Summary of Average and 85th percentile Speeds of Vehicle on the Rumble Strips of Study Locations

LOCATION	VEHICLE TYPE	AVERAGE SPEED(km/h)		85TH PERCENTILE SPEED	
		LOCATION WITHOUT RUMBLE STRIP (km/h)	LOCATION WITH RUMBLE STRIP (km/h)	LOCATION WITHOUT RUMBLE STRIP (km/h)	LOCATION WITH RUMBLE STRIP (km/
1. Kasoa CP/Walantu Junction	Car	70	63	85	76
	Van/Trotro	74	52	94	68
	Truck	77	53	88	68
2. Budumburam	Car	69	57	85	67
	Van/Trotro	71	40	85	46
	Truck	75	40	87	49
3.Fete Kakraba	Car	70	42	80	62
	Van/Trotro	74	45	79	73
	Truck	66	40	80	51
4. Awutu Breku	Car	72	54	85	70
	Van/Trotro	69	51	85	66
	Truck	71	47	86	65
5.Gomoa Akotsi	Car	76	60	86	73
	Van/Trotro	64	60	78	73
	Truck	67	58	78	72
6.Gomoa Dabenyin	Car	73	64	85	73
	Van/Trotro	74	62	86	75
	Truck	72	57	84	76
7.Gomoa Dominase	Car	71	63	75	62
	Van/Trotro	70	67	85	81
	Truck	76	62	86	78
8. Potsin Junction	Car	77	73	91	75
	Van/Trotro	75	65	86	80
	Truck	74	61	89	74
9.Gomoa Okyereko	Car	75	59	92	76
	Van/Trotro	75	61	88	75
	Truck	78	64	92	75
10.Gomoa Adwukwah	Car	75	67	85	80
	Van/Trotro	73	63	79	79
	Truck	78	62	78	62
11. Gomoa Impota	Car	70	61	82	70
	Van/Trotro	70	59	80	69
	Truck	78	57	83	72
12.Winneba Junction	Car	74	62	86	75
	Van/Trotro	70	64	86	72
	Truck	75	64	93	79

Appendix C: Generation of frequency distribution table for Truck at rumble strip location on Kasoa – Winneba Road.

Speed(mph)	Frequency of vehicles	Cumulative Frequency	Cumulative Percentage (%)	Speed Percentile	fx	X^2	Fx^2
21	1	1	1		21	441	441
22	2	3	3		44	484	968
23	3	6	6		69	529	1587
24	4	10	10		96	576	2304
30	8	18	18		240	900	7200
31	1	19	19		31	961	961
32	5	24	24		160	1024	5120
33	2	26	26		66	1089	2178
34	8	34	34		272	1156	9248
35	9	43	43	**50th**	315	1225	11025
37	8	51	51		296	1369	10952
38	2	53	53		76	1444	2888
39	7	60	60		273	1521	10647
40	7	67	67		280	1600	11200
41	17	84	84		697	1681	28577
42	1	85	85	85th	42	1764	1764
43	3	88	88		129	1849	5547
45	5	93	93		225	2025	10125
48	1	94	94		48	2304	2304
49	1	95	95		49	2401	2401
50	3	98	98		150	2500	7500
51	1	99	99		51	2601	2601
52	1	100	100		52	2704	2704
Total	100				3682	-	140242

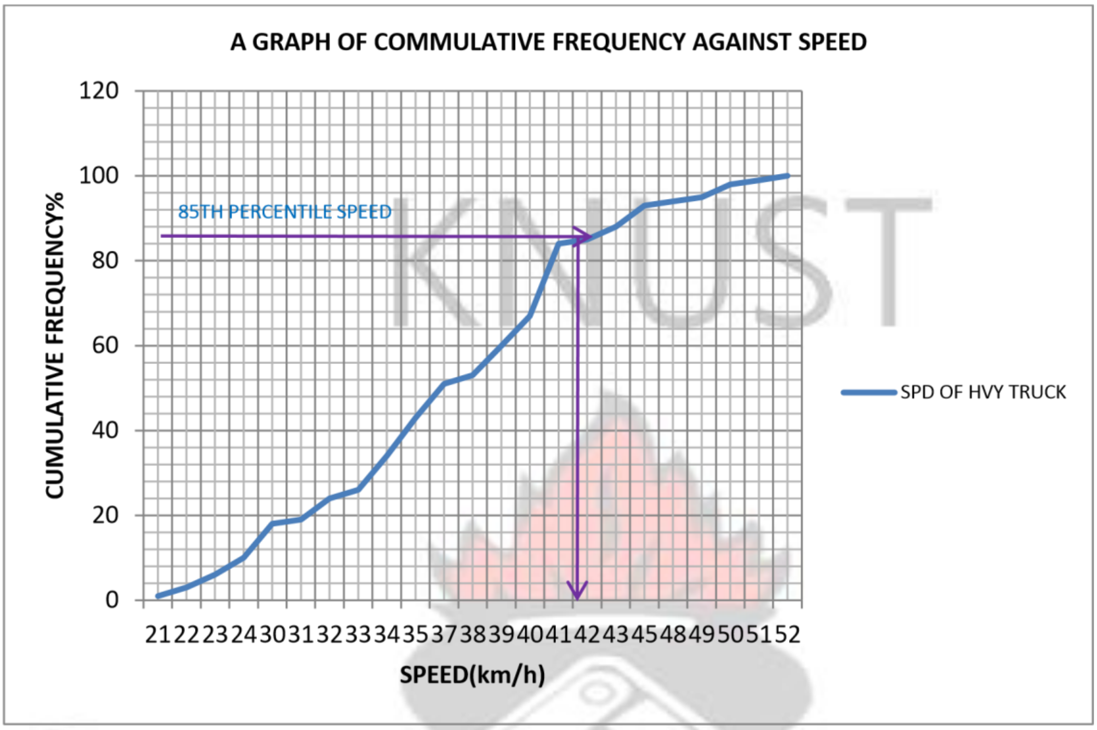
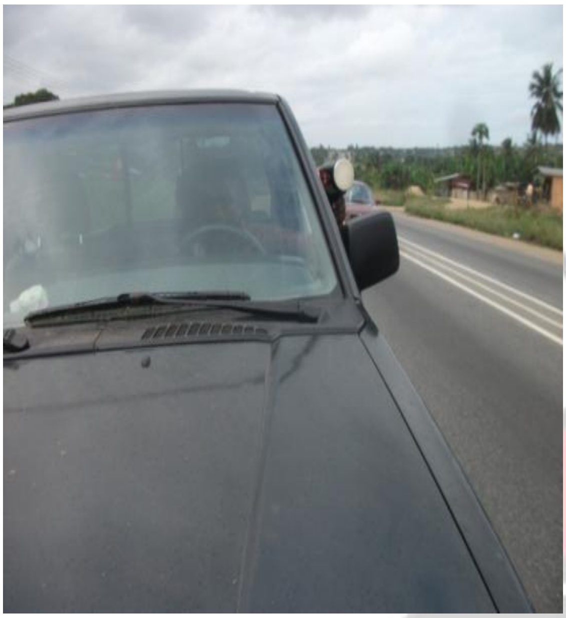


Fig C: Shows cumulative frequency of curve for Truck at a rumble strips location.

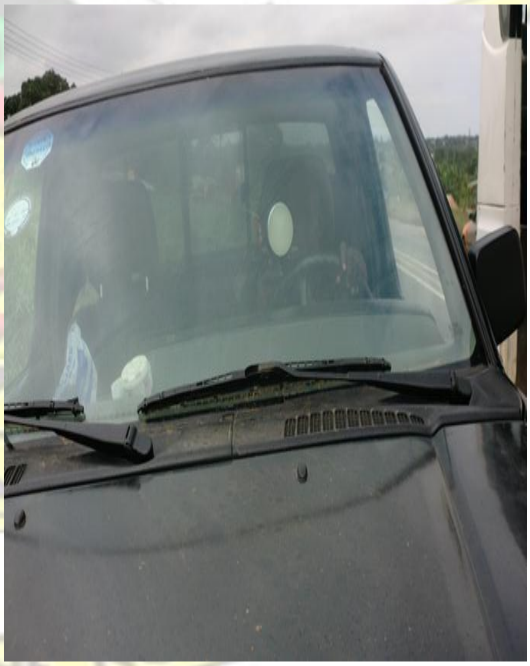
Appendix D: Photographs of features on Kasoa-Winneba Road



Shot 1: Spot speed measurement

Shot 2: Typical cross section of a rumble strip

Shot 3: deteriorated rumble strips



Shot 4: recording of spot speeds by observer

Shot 5: Vehicle approaching a strip location

Appendix E: Sample speed data collected at a location with rumble strips

Location: Gomoa Impota																	
Car			Light/ Medium Buses			Large Buses			Light/Medium Truck			Heavy Truck			Pick up		
Before	On	After	Before	On	After	Before	On	After	Before	On	After	Before	On	After	Before	On	After
85	80	77	80	77	74	87	78	70	74	70	55	77	70	65	84	77	62
70	55	45	72	69	61	27	22	21	69	60	55	60	55	45	92	78	69
71	68	55	77	70	56	30	24	27	80	75	70	77	71	68	77	70	62
69	60	57	84	75	68	32	27	31	84	80	74	69	62	54	84	80	74
79	77	66	78	60	47	28	26	27	59	50	45	65	61	57	81	75	70
77	70	55	75	70	68	30	21	20	68	65	59	77	70	65	63	60	58
50	45	38	70	58	48	26	25	20	55	50	47	88	84	80	74	70	55
69	60	57	66	60	45	67	53	51	67	60	54	74	70	65	68	66	61
79	70	61	55	50	58	41	43	37	70	65	54	70	68	65	68	55	42
77	70	66	80	67	60	28	34	25	85	70	65	60	55	50	88	80	71
50	41	39	88	84	80	49	55	35	79	68	55	50	48	40	92	78	70
69	60	51	77	58	51	77	56	50	76	66	65	60	55	50	77	69	65
85	77	70	94	90	82	68	49	32	78	75	70	77	71	68	84	59	41
65	60	55	68	57	47	37	42	33	80	66	56	74	71	60	81	78	68
52	48	42	60	58	41	32	25	21	71	60	45	60	57	50	63	58	48
92	88	70	85	70	69	70	55	52	90	88	78	78	65	54	74	70	59
68	69	55	65	63	59	23	37	30	77	70	65	84	74	58	68	60	57
57	50	47	54	47	41	80	71	52	79	74	68	79	77	66	69	61	55
87	80	77	92	89	86	58	49	35	84	78	70	77	70	55	80	77	70
66	60	45	72	70	71	25	22	27	71	68	57	50	45	38	77	72	68
50	45	39	67	54	39	60	51	40	82	78	75	69	60	57	66	55	51
72	70	69	84	70	67	59	48	42	70	65	55	58	51	47	84	80	74
66	60	55	66	65	63	27	32	34	62	58	47	64	61	48	82	77	66

69	60	54	58	51	53	75	71	50	75	70	68	81	75	65	56	50	46
85	65	60	72	69	55	34	25	20	82	74	65	68	57	51	55	45	38

Appendix F: Sample Speeds Recorded at locations without rumble strips.

(Gomoa Impota).

CAR	*LIGHT/M BUS*	*LARGE Bus*	*L/M TRUCK*	*HEAVY TRUCK*	*PICK UP*
86	60	53	47	69	35
81	51	63	53	79	49
74	58	71	95	70	80
75	78	65	84	45	54
84	45	78	75	78	42
75	84	45	95	87	51
81	75	62	74	74	75
71	84	31	81	84	84
41	75	51	62	75	95
45	95	65	85	95	86
96	62	95	74	86	53
95	42	75	85	51	62
81	51	84	95	42	78
75	74	95	42	62	74
74	84	86	35	53	58
84	75	62	41	65	95
40	96	42	75	45	76
82	85	51	84	78	95
52	74	78	95	95	74
62	64	95	86	86	84
32	35	45	51	59	75
42	75	51	42	88	65
51	84	42	74	77	42
754	74	60	85	74	51
85	95	51	95	55	62
19	52	84	86	65	53
55	41	75	51	75	95
95	74	95	42	85	75
85	85	86	62	74	84
74	96	65	43	96	95