Investigation of Effectiveness of Traffic Calming Measures on Urban Streets under Mixed Traffic Conditions

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Abstract: *Considering the increasing rate of fatal accidents on Indian roads (MoRTH Report, 2015), the need for considerable research aiming to reduce the conflicts is necessary. A speeding vehicle can be a menace to the other road users particularly for unsignalized intersections and the zones where motorized and non-motorized traffic interaction is high such as school proximities, residential streets etc. Static speed control devices like speed bumps and humps are one of the ways to keep vehicular speeds to a certain limit in such. Although the use of these measures becomes frequent all over the world, there are still controversies that they are not actually effective in reducing speeds. Hence, the present study aimed to evaluate the performance of the existing selected traffic calming measures such as Speed bump, speed hump, speed table and rumble strips from residential streets of Mumbai City. The speed profiles of the heavy, light commercial vehicles, cars, three wheelers and motor bikes, across the selected traffic calming measures are determined, examined and analyzed. It is observed that the speed bump has shown significant reduction in speed with 6-14kmph crossing speed. While Speed hump and speed table have recorded 25 to 30kmph. Almost over 85% of vehicles speed was reduction by 70% at the bump with respect to their approaching speed. The speed hump has recorded the highest percentage of vehicles crossing the hump above the speed limit with 55% which indicates that these are not much suitable for speed controlling measures.*
Keywords: Speed bump, streets, driving simulator, safety
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I. Introduction

The road space needs to be equally used by all the road users. In areas having high vehicular densities or speeds, the road is controlled or restricted in order to provide the equal use to all road users. Also, the traffic maneuvers at any of the parts of the transportation network needs to be controlled and restricted to specific movements in order to carry out the traffic operations safely. This will also result in the reduction of overall delay at intersections and avoids the blockage and jams at most of the urban roads. One of the best ways to ensure these regulations is by physical traffic calming measures. Traffic calming measures are the physical features that forces or encourages the drivers drive at a constant speed or to slow down.

II. Review

A speed breaker works primarily by transferring an upward force to the traversing vehicles with greater vertical accelerations. These are generally having 50mm to 150mm with varying lengths and profiles as per the requirements. For the bump design there has been several studies out of which Sahoo P.K. (2009) studied the speed bumps to develop a computer model to simulate the geometric characteristics of the speed bumps with respect to crossing speeds of the vehicles. The steps followed by the research were to select several speed bumps with different lengths and profiles, then for particular speed bump, find the 85th percentile crossing speeds of the automobiles at that location. A similar kind of study is done by Weber Philip A. (1998) in Canada by developing a multiple regression model to find the optimal design of the speed humps by using acceleration levels and discomfort criteria, shows different results. Streets, which carry only automobile traffic were recommended to have the speed humps

with 9.1m by 75mm, 7.9m by 100mm and 5.2m by 100mm for the desired speeds of 50, 40 and 30kmph respectively. Whereas on bus routes 8.8m by 100mm and 6.1m by 100mm humps are recommended for the desired speeds of 40 and 30kmph respectively.

Barbosa, H. et al. (2000) developed a speed profile model for the traffic calmed roads in York city, UK. They investigated the influence of traffic calming measures by evaluating the difference in speed profiles which are obtained from various combinations of the speed calming measures. Mainly focusing speed humps both round topped and flat topped (Speed table), speed cushions and chicanes which are implemented in sequence. The vehicles were tracked at 16 points simultaneously at each section for each individual vehicle to obtain the speed profiles. Based on the collected data an empirical model was developed using multiple regression analysis techniques which was calibrated and validated. The model describes the speeds along those lines as a function of input type measures, speed and distance between the measures. Validation results shown that the speed profiles are the good representation of the calibrated sites.

Speed bumps can be the devices that can create kiosks if they are installed at undesired locations or not installed with proper visible markings. There is always been a confusion that do the speed breakers really reducing the speeds and increasing the safety. Hence a study was done by W.Martin Bretherton (2003) to check that do speed tables improve safety. Speed tables are installed on 43 residential streets in Lawrenceville, Georgia in 1994 which are being monitored to check the improvement on the particular road. The results of the study states that a statistically significant reduction is observed in total crashes and injuries.

Similarly, Massimiliano Pau, SilvanoAngius (2001) have studied 23 speed bumps installed in Cagliari city, Italy for their effectiveness in speed reduction of vehicles. As the part of their aim they have performed the speed analysis at the selected speed bumps which were installed to protect the crosswalks and at the sections far from the crosswalks. Almost one third of the cases the 85th percentile speeds observed are more than the posted speed limit (50kmph).

An impact assessment study (Laura et al. ,2016) is done for traffic calming measures on road safety. The speed reduction and traffic calming measures are one of the influencing factors that effects accident rate and severity. Lithuanian city was chosen for this study where several speed calming measures were implemented from the last few years. Out of them the author chosen the vertical speed calming measures such as speed humps, speed bumps, raised crosswalks and safety islands and speed cameras. The results show that there is significant decrease in the fatal accidents on the road sections where vertical traffic calming is installed. A drop 60% in fatal and injury and a drop of 63% in injury accidents were observed. Which shows these measures are effective in reducing the accident rate and severity.

III. Methodology

The current study aims to find the effectiveness of the considered speed calming measures and to develop a model for the design of the speed breaker. In this concern, Speed bump, Speed hump, Speed table, Rumble strips are selected for data collection.

After the detailed review the following stepwise methodology has been adopted

1. Identifying different locations with the selected speed calming measures
2. Collect speed data using a radar gun without influencing driver behavior and without interrupting the traffic at different intervals of the road stretch as follows
   - 80m ahead of TCM,
   - 30m ahead of TCM
   - At TCM
   - 30m after TCM
   - 80m after TCM
   - At a location significantly far from TCM (150-250m) for free flow speeds
   - 250m, 100m, 40m and 0m for the study of rumble strips
3. Determining the Mean speed, 85 percentile speed and Maximum speed at each location.
4. Compare the following data using a statistical test
   - Derived parameters and Free flow speed to obtain the "effectiveness of the TCM"
   - Derived parameters and Speed limit of the corresponding locations to determine "Influence range"
5. Linear regression model development between A/W ratio and hump-crossing speed.
6.

Study Area

Two Different residential locations, Hiranandani and Chandivali in Mumbai city are selected where desirable traffic calming has been done. Hiranandani gardens is one of the well-planned residential areas of the city, which is also the hub of IT firms, shopping centers, international hotels and restaurants. Therefore, considerable non-motorized activities are being observed in the mix traffic flow conditions. Hence, the region required necessary traffic calming features. The streets are installed with traffic circles, speed tables and speed humps at all the required locations to hold the local traffic speed at 30kmph and below. While chandivali is dominated by residential characteristics and road side development. In most of the locations, vehicular speeds are controlled by speed bumps installed at regular intervals. Therefore, speed hump and speed table's locations are selected in hiranandani and speed bump locations are selected in chandivali. Rumble strips are not usually placed on residential or local streets since they are used on high speed corridors. Therefore, several locations from eastern express highway is selected for the study of rumble strips.

Data Collection

All streets are two-way two-lane roads except Eastern Express highway (EEH), which was selected for the study of rumble strips. EEH is a divided highway with 5 lanes in each direction. The following data is collected from each of the locations

1. Speed of different types of vehicles categorized as follows
    a. Two-wheeler
    b. Three-wheeler
    c. Sedan Car
    d. Sports Utility Vehicle (SUV)
    e. Light commercial Vehicle (LCV)
    f. Heavy commercial Vehicle (HCV)
2. Dimensions of the calming measures
3. Road width and road type
4. Volume

The spot speeds of different vehicles at specified distances are captured for each location in order to determine the speed profiles. The speed data acquisition includes spot speeds of above-mentioned vehicle categories which includes free flow speed of the street which is the speed obtained considerably far from the speed calming device.It is assumed that the spot speed at 150m from the device is free flow speed of the particular street. Therefore, for each of the speed calming device the vehicular speeds are captured at seven points which are at 0m, 30m, 80m and 150m from the speed bump on both upstream and downstream sides as shown in the Figure 1.
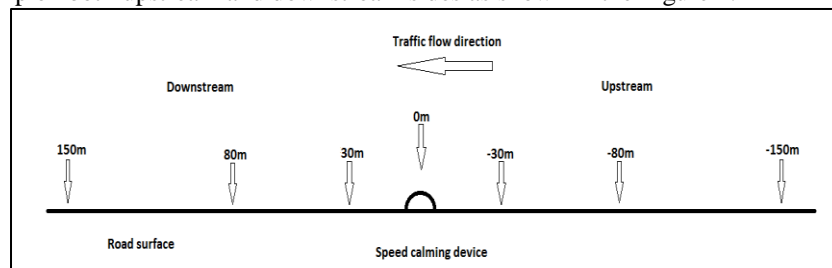

Figure 1 Data collection points at a Speed breaker

The speeds on the eastern express highway is observed to be high. Therefore, a minimum of 500m stretch is analyzed in case of rumble strips by collecting spot speeds at 250m, 100m, 40m of upstream & downstream and at the rumble strips. A total of 15 days was taken for the complete data collection in all the locations.

Two methods, Radar Gun method and Trap length method are adopted for the speed data acquisition. Radar gun gives the spot speeds of any vehicle which are moving above 10kmph. Whereas the crossing speeds of speed calming measures some times less than 10kmph. Especially for speed bump the traversing speed is less than 10kmph. Hence the trap length method is adopted to obtain the crossing speeds. A trap of 5m is marked from of the speed breaker on either side, which makes a total trap length of 10m, which is illustrated in Figure 2. Video data is collected for one hour at each location to extract the spot speeds at speed breakers.

All vehicle spot speeds are captured during the off-peak hour in 6am- 7am, 2pm – 4pm and 11pm- 1am time slots to get the free movement of vehicles and real response of drivers to the existing calming device. Speeds of 40% of the

volume is captured approximately using the above-mentioned methods. Spot speeds are captured during day and night conditions to obtain the effect night on drive behavior. A total of 16528 vehicle speeds were captured for all categories.

Figure 2 Filed data collection using Trap length method

Table:1 Number of vehicles captured

	Radar Gun	Trap length method
Day	8109	1740
Night	5787	892
Total: 16528 vehicles		

Hiranandani roads were designed to a speed limit of 30kmph since it comes under mix land use category. Whereas chandivali the speed limit assumed to have 30kmph. Eastern expressway, is posted with 80kmph speed limit. The summary of the data is given in the following tables.

IV. Analysis

Speed Reduction

Speed profiles are obtained individually from the speed data acquire from field for day and night conditions. Average 85th percentile speeds of all vehicles are calculated at various distances as indicated in Figure:1. as shown in Table: 2. The speed profiles obtained from the same are shown in Figure 3. Out of the selected traffic calming measures for the current study, speed bump has shown significant reduction in speed. A crossing speed of 25 to 30kmph is observed at Speed hump and speed table where as the speed bump is showing a maximum crossing speed of 15kmph which is only 30% of the approaching speed. The percentage reduction of speed at different calming measures for each type of vehicle category is shown Figure:4.
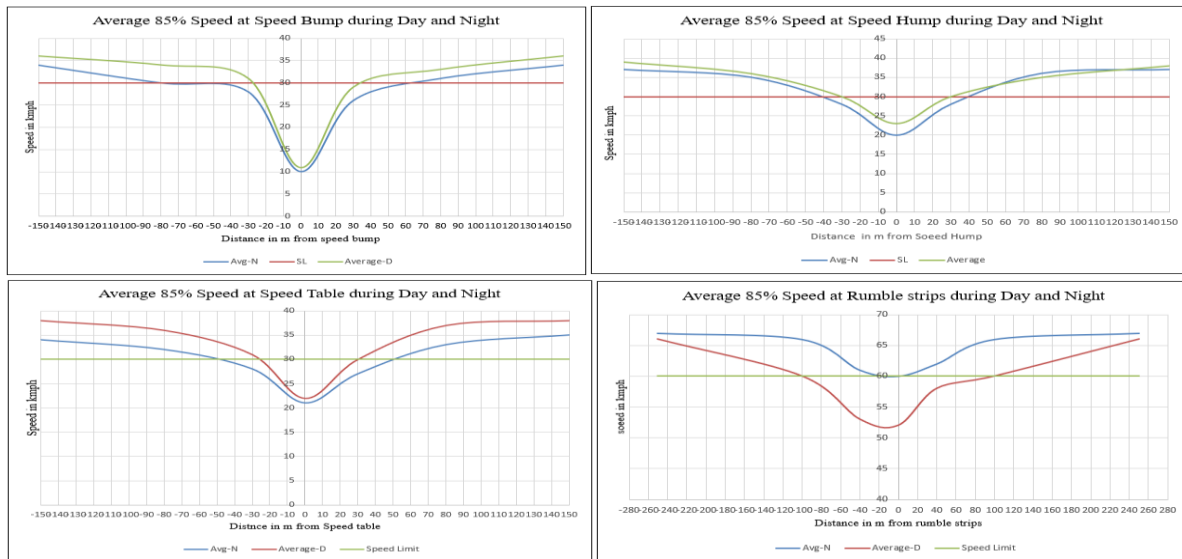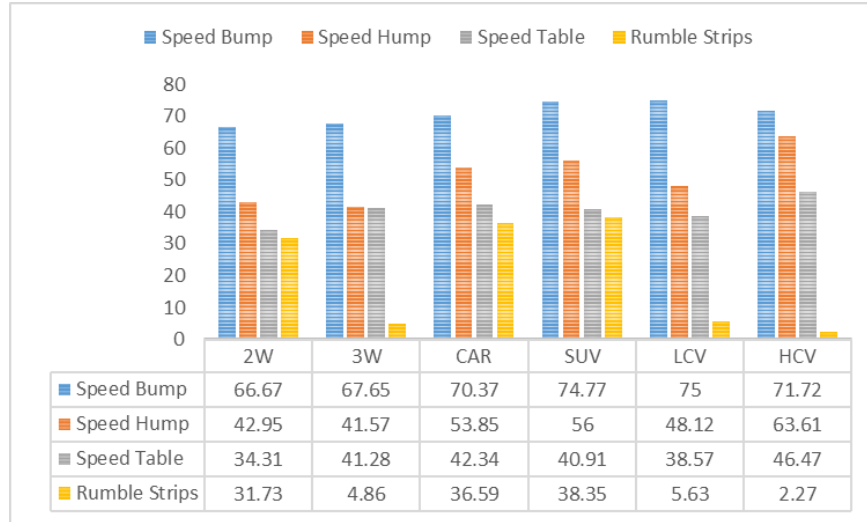

Figure 3 Speed profiles over speed bump, speed hump, speed table and rumble strips for day and night conditions

	2W	3W	CAR	SUV	LCV	HCV
■ Speed Bump	66.67	67.65	70.37	74.77	75	71.72
■ Speed Hump	42.95	41.57	53.85	56	48.12	63.61
■ Speed Table	34.31	41.28	42.34	40.91	38.57	46.47
■ Rumble Strips	31.73	4.86	36.59	38.35	5.63	2.27

Figure:4 Percentage reduction in speed by selected traffic calming measures

From each of the sample the outliers are removes using boxplot and the statistical analysis performed using Analysis of Variance (ANOVA) and t-test. A one-way ANOVA test performed at 0.05 significance level over the collected crossing speeds at three locations of speed bump resulted in 'no significance difference' for all types of vehicles. While the tests on speed hump, speed bump and rumble strips have shown at least one pair of samples is significantly different.

To understand the variation among the crossing speeds on speed bump, speed hump and speed table a multiple comparison is performed using t-test by considering two calming measures at a time with a sample of 125 to 150 at 0.05 significance level. Rumble strips are exempted from the test in view of its physical characteristics different from the rest. The results clearly stated that the crossing speeds of speed bump are different from speed table and speed hump with an average p-value of 0.048 and 0.081. Whereas the there is no significant difference observed in the crossing speeds between speed hump and speed table with p-value 0.175.

The speeds during night are observed to be higher than day time. Hence, the percentage hike in crossing speed during night time is calculated and listed in the Table 4. Where we can observe the rumble, strip has the highest hike and bump is having the least.

Table:4 Percentage of average 85thpercentile speed during night time over day time

SCM	Speed Hump	Speed Table	Speed Bump	Rumble strips
Percentage hike	6.8	4.5	9.1	15.4

Influence Range
The influence range of the speed calming measure is defined as the sum of upstream and downstream distances from the calming device in which the speeds are within the speed limit. Figure 5 is an illustration for influence range for one of the speed bumps from the present study.
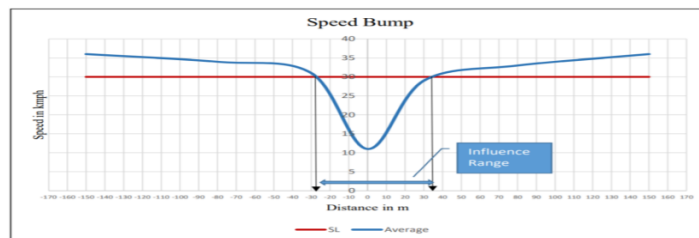
**Figure:5** Illustration of influence range

The locations selected for the present study are two-lane two-way road comes under distributary or local streets category surrounded by the built-up locations. Most of these locations are not posted with any speed limit, except some with 30kmph and the eastern express highway 60kmph speed limits. However, the remaining streets are distributary and collector roads, the speed limit of these roads is 30kmp for mixed traffic conditions with reference to IRC 70. Code of practice part-1 from Institute of urban transport also suggested to consider 30kmph as speed limit for distributary and collector roads. Anyhow, the speed limit for heavy vehicles are lower as per IRC 70-1977, which is 20kmph, present study is done assuming 30kmph for all category of vehicles.

Table 5 Influence ranges of selected calming measures during day and night

	Upstream (m)		Downstream(m)		Influence range (m)	
	Day	Night	Day	Night	Day	Night
Speed Hump	20-90	25-150	15-90	27-150	45-200	58-230
Speed Table	14-80	25-150	10-80	33-150	35-200	45-200
Speed Bump	23-110	22-78	24-90	34-110	55-180	60-200
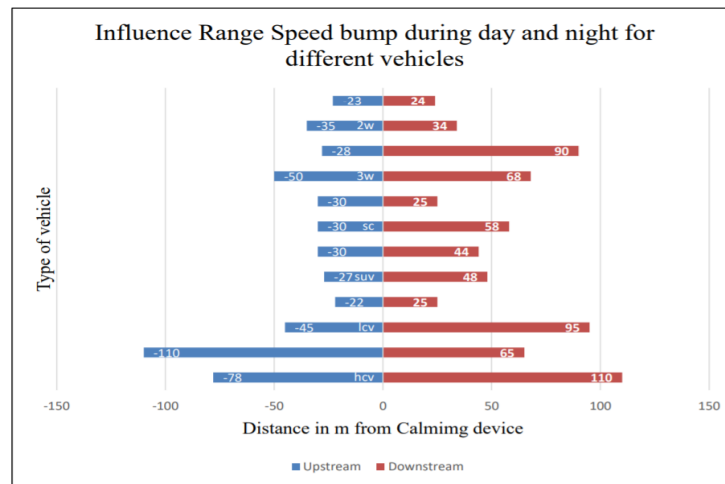
Figure:6 Influence Ranges of Speed Bump for various vehicle category
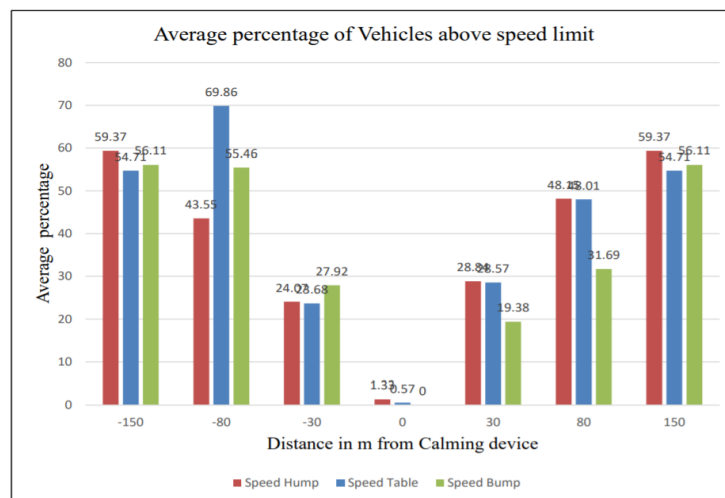
Figure:7 Average percentage of vehicles above the speed limit at the considered locations

The influence ranges of the speed breakers are determined for all selected traffic calming measures with respect to 30 kmph. The Table 5 indicates the Influence ranges of selected calming measures during day and night from field data. It varies for with respect to the category of vehicle, type of speed breaker and day and night conditions. which is illustrated in Figure 6. From the field observations, the influence range of during night is relatively high for all types of vehicle except LCVs.

It is observed from the field that most of the vehicles are moving above the safe speed. Hence the percentage of vehicles whose speeds are above speed limit is calculated on the entire stretch and shown in Figure 7

A model for Geometric Design of Speed Breaker

It is known that a universal design specifications and standard for speed control humps is not available.They are designed as per the local conditions and constraints of the respective country and later the performance is evaluation will be carried out. In order to ease the engineers to design the speed bump for local conditions of Indian cities, a statistical relationship between speeds of the automobiles and geometric characteristics of speed control humps should be developed. These models shall be suggested for the use of practicing engineers. This type of relationship can be used as a tool for designing the geometry of hump for a particular hump-crossing speed. The development of a simple procedure for the road hump design is considered as one of the important features of the study.

A linear regression modeling between the crossing speeds and geometric characteristics is suggested since, linear models are considered as simple for the designers as it involves less complexion. The aim here is to obtain a statistical relation between crossing speeds and geometric characteristics hence the profile of the calming measures is neglected. A ratio of hump area to width is considered asto represent the geometric characteristics of humps as shown in Figure:8.
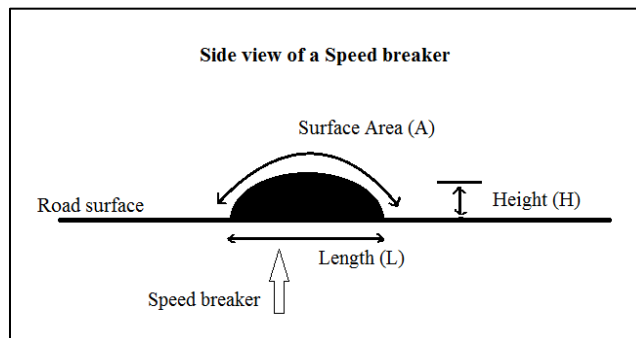
Figure: 8 Geometric parameters of the speed breaker

A total of nine calming measures, each of three, of the selected measures are used. The dimensions of the speed hump, speed table and speed bumps are measured during the data acquisition are used to fit model. The width of the bump is considered here since it is an indirect representation of the width of the road, which is also one of the important features of that influences the speed on the road. It is observed that the surface length is a better and effective representation than the area since, it depends on both height and length is the speed breaker.Also, the surface area is the product of surface length and width of the bump, and the bump width is already been used for ratio. Considering the 85th percentile crossing speeds, noted from field as independent variable a linear regression model is developed for surface area or length to width ratio for the data given in Table:6
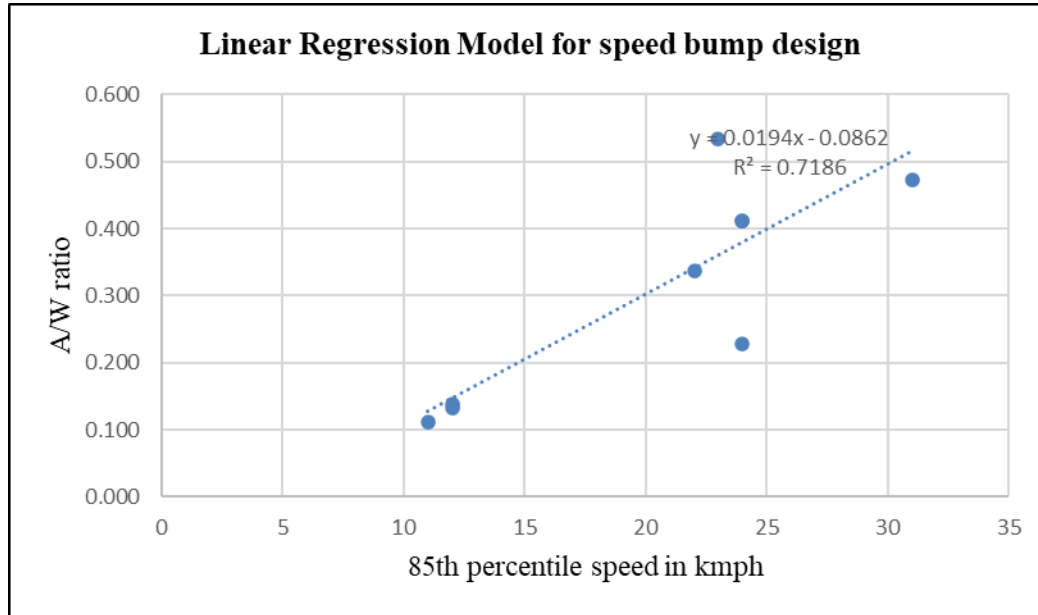
Table:6

Area/ Surface length (m)	1	1.2	1.25	2.5	3.7	3.7	3.7	4.8	5.2
Width in m	9	9	9	11	11	9	9	9	11
A/W	0.11	0.13	0.14	0.23	0.34	0.41	0.41	0.53	0.47
85th percentile crossing speed in kmph	11	12	12	24	22	24	24	23	31

From the above data a linear regression model is fitted by considering 85th percentile speed as independent variable and A/W ratio as dependent variable, which resulted in the following equation (1) with R^2 value 0.7186.

$$y = 0.0194x - 0.0862 \text{ ------------(1)}$$

Where y is the dependent variable which is Area to Width ratio (A/W) and x is the independent variable that is 85th percentile crossing speed. Based on the R-square value obtained which is considered as reasonable for a regression model, the equation can be used for the design of the speed breakers. Therefore the

$$V_{85\%} = 37.031(A/W) + 8.9145 \quad \text{------------}(2)$$

Linear Regression Model for speed bump design

$y = 0.0194x - 0.0862$
$R^2 = 0.7186$

A/W ratio (y-axis)
85th percentile speed in kmph (x-axis)

Figure: 9 linear regression model between 85th percentile crossing speed vs A/w ratio

This equation (2) obtained from the model shown in figure:9,helps the designers to design the speed breaker for a given road. Select the crossing speed of the speed breaker that is desired for the considered location. Determine the corresponding Area to Width ratio using above equation. Since width of the road is already known the surface length of the speed bump will be derives from the obtained ratio. Finally fix the profile the speed bump that is optimum for the design road stretch the height of the bump can be determined.

V. Summary and Conclusion

Urban streets are one of the vulnerable spots for motorised and non-motorised vehicle interaction. They are the potential locations for accidents, in the absence of sufficient safety measures. However, the various physical traffic calming measures are available to reduce the speeds of the vehicles, there is still ambiguity in defining their effectiveness. Hence, the present study is an to attempt to understand the effectiveness of the various geometrics of speed calming measures in reducing the speeds of vehicles on urban streets for mixed traffic conditions by field investigation.

The analysis of speeds 16528 samples for both day and night conditions have addressed several key aspects of the current scenario. The speed profiles drawn for various speed calming measures have shown that the speed bumps are the most effective in reducing the speeds to minimum level crossing speeds ranging from 5 to 12 kmph at all the three locations for all types of vehicles. However, Speed hump and speed table having relatively high crossing speeds still serving their purpose by reducing speeds less than 30 kmph. The t-test performed over speed bump speed hump and speed table considering 2 at a time resulted in same means for speed table and speed hump whereas the speed bump is not matching with any of the others for all types of vehicles. Also, the speed bump is showing no significant difference between day and night time speeds. The 85th percentile crossing speed of rumble strips during night is 15% greater than day time speeds, whereas for remaining calming measures it is below 10%.

70 to 80 % of cars are observed to be moving above speed limit at free flow conditions, which indicating the speed limits are not strictly followed by the drivers, Hence, an attempt is made to find out the influence range of speed calming measure. The speed bump has noted highest influence range among the selected traffic calming measures with 55to 200m from cars to heavy vehicles respectively. It has also shown the least percentage hike in

influence range during night with an average of 32%. Except for Light Commercial Vehicle all other categories have recorded higher influence ranges during nights compared to day time. Speed of cars are high throughout the stretch for all types of calming devices compared to other vehicle types. Up to 50% of the cars are moving above speed limit at 30m distance from the calming device, which indicates that the bumps also are not capable hold the speeds to long ranges. Except two wheelers, all other vehicles are traversing the calming measures at a speed lower than speed limit. Light commercial vehicles recorded lowest percentage of speeds above speed limit. Heavy vehicles show consistency in percentage of speeds above speed limit for all types of calming devices. Speed bumps and speed humps indicated almost same trend in percentage vehicles above speed limit, throughout the stretch.

Despite, various applications of different speed reduction measures, it is observed that the urban roads in India are vulnerable in road safety aspects. The speed of vehicles even in residential streets are observed to be higher than safe speeds except the premises of speed calming devices. Even the speed reduction techniques also have their influence to very short range of maximum 250m. Hence, the invention of new measures, techniques and policies to reduce the speeds on urban streets are at high importance considering the present situation

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