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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

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World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Critical Analysis of Speed Hump, Speed Bump and Geometric Design of Curved Speed Hump

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Abstract

The motive of this study is to critically analyze speed humps and bumps on various accounts such as travel time delays, mileage reductions, exhaust emissions and propose a new traffic calming device, which can retain the positive impacts of speed humps and also reduce the disadvantages associated with them. The new traffic calming device, Curved Speed Hump (CSH), consists of a main speed hump which is a raised and curved area placed along a lane and a complementary speed hump, adjacent to it. Drivers can choose to adopt a curved path, thus moderating speeds and avoiding disadvantages of speed humps. The primary objective of CSH is to moderate the speed rather than locally reduce it, using both horizontal and vertical deflection concepts. Various geometric parameters are discussed, and their theoretical limits are proposed.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Curved Speed Hump; Speed Hump; Speed Bump; Mileage; Travel Time; Exhaust Emissions.

1. Introduction

Traffic calming, as defined by the Institute of Transportation Engineers (ITE) subcommittee on traffic Calming, 1997 is:

"The combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized commuters." (Lockwood, 1997)

The concept of traffic calming measures involves physical alterations to a road, which cause motorists to decrease driving speed and pay increased attention to the driving task. Some results include reduced speeds and volumes, reduced collision severity and improved safety for pedestrians and bicyclists.

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The main traffic calming measures are separated into two categories:

1. Horizontal Deflection (forces the driver to manoeuvre around the horizontal obstacle and create perception of narrower roads. E.g. Chicanes, roundabouts etc.

2. Vertical Deflection (creates a sudden change in height of the road. E.g. Speed humps, Speed table etc.)

A number of traffic calming programs have been successfully implemented in the developed countries and various traffic calming devices have been utilized in these programs including chicanes, traffic circles, roundabouts, speed humps, speed bumps, speed tables, speed cushions etc. and the concept has been made popular.

In India, Speed humps are the most widely used traffic calming measures. Speed humps are raised pavements spanning across or partly across a roadway, thus, forcing driver to reduce the speed of their vehicles in order to minimize uncomfortable bumping or vibrating sensations produced while traversing them. Many researchers reported speed reductions of about 18-20% (Hallmark et al., 2002; Zech et al., 2009) while using speed humps. It was also concluded that, speed reduction mainly depends upon spacing of the speed humps (Ewing et al., 1996; Garcia et al., 2010). The optimal spacing of speed humps as given by IRC is about 100-120m. Even though speed humps are effective in reducing vehicular speed and high cut-through traffic volume, there are considerable disadvantages associated with them which often overshadow its benefits.

Speed humps are known to increase the journey time, passenger discomfort, maintenance cost of vehicle, increase in environmental pollution and cause accidents. A study conducted revealed that speed hump causes a delay of 10sec per hump (Leslie w. Bunte, Jr., 2000). Even though in isolation this time seems short, the total delay increases considerably when speed humps are installed in series along a road. In our experimental study, it was found that there was a delay of 13.44 sec per hump installed. Moreover, speed hump also has adverse effect on mileage of the vehicles. In the study, the test car lost approximately 40% of fuel while traversing on a stretch with speed breaker density of 1.66/km. This can have substantial effect on environmental pollution.

The physical nature of traffic calming measures can result in increased environmental impact such as higher emissions of carbon dioxide (CO2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x) and particulate matter (PM). The increase in exhaust emissions results from speed adjustments (acceleration and deceleration) necessary to drive over an intervention. Also, vehicles driven at low average speeds provide increased levels of fuel consumption and emissions. In fact, low average speeds characterized by frequent vehicle stops and starts as well as accelerations and decelerations leading to speed variations are known to produce the highest values. In a study (Ahn and Rakha, 2009), it was found that there was an increase in 51% HC, 44% CO, 110% NO_x and 52% CO_2 emissions respectively while traversing on a stretch with speed hump when compared to an untreated stretch.

Even though there is evidence that speed-breakers (humps) reduce speed related accidents, they have also been known to cause accidents and injuries. When an automobile approaches a speed-breaker at a speed greater than a threshold velocity, the risk of accident or injury to the passenger becomes substantial (Hessling and Zhu, 2008). According to Ministry of Road Transport and Highways, speed breakers resulted in causing 11008 fatalities in 2014 and 11084 in 2015. This resulted in 3633 deaths in 2014 and 3409 deaths in 2015 respectively. It is to note that deaths due to speed breakers in India, is higher than the total road related deaths registered in UK and Australia combined (Dipak K Dash, *The Times of India 2017*).

Hence, in order to overcome the above-mentioned disadvantages of speed humps, a new traffic calming device named Curved Speed Hump will be introduced in India. The concept of curved speed hump was first mooted by the Highway Engineering Research Group of Polytechnic University of Valencia, Spain (Garcia et al., 2011). The major advantages of CSH when compared to other raised traffic-calming measures are: reduced effect on emergency vehicles, speed moderation of passenger cars and motorbikes with lower discomfort to passengers, bicycle friendly, minimal vehicle damage, and lower environmental impacts such as fuel consumption and exhaust emissions. The main objective of this project is to implement the concept in Indian conditions by modifying the design parameters according to the Indian road and traffic conditions.

2. Effects of speed humps on various parameters

In the introduction section, brief description of various disadvantages was postulated. Studies were conducted to evaluate the effect of speed humps and bumps on Travel time delays, 85th percentile speed, fuel consumption (mileage studies) and vehicular exhaust emissions. They are substantiated below.

2.1. Travel Time and Delay Studies

A travel time study determines the amount of time required to travel from one point to another on a given route. In conducting such a study, information may also be collected on the locations, durations, and causes of delays. Data obtained from travel time and delay studies give a good indication of the level of service on the study section.

The study stretch between Chandranyagutta and Shamshabad airport road in Hyderabad, India is adopted for the speed breaker stretch because of low traffic density, presence of well-designed speed breakers. Similarly, the stretch between Chandranyagutta and Srisailam highway in Hyderabad, India is adopted for studies involving free stretch. Now, three stretches were considered involving a speed hump, a speed bump and a double bump respectively. The description of the stretches is detailed in the Fig.1 The travel time and delay studies were conducted using license plate observation method. The travel time for a free stretch was calculated using the design speed and length of the stretch. The travel time on the speed breaker stretch was the average travel time of the vehicles traversing the test section, as recorded by the observers over a period of three days. The difference between the travel time on a speed breaker stretch and a free stretch gives the average delay due to the installation of the speed breaker.

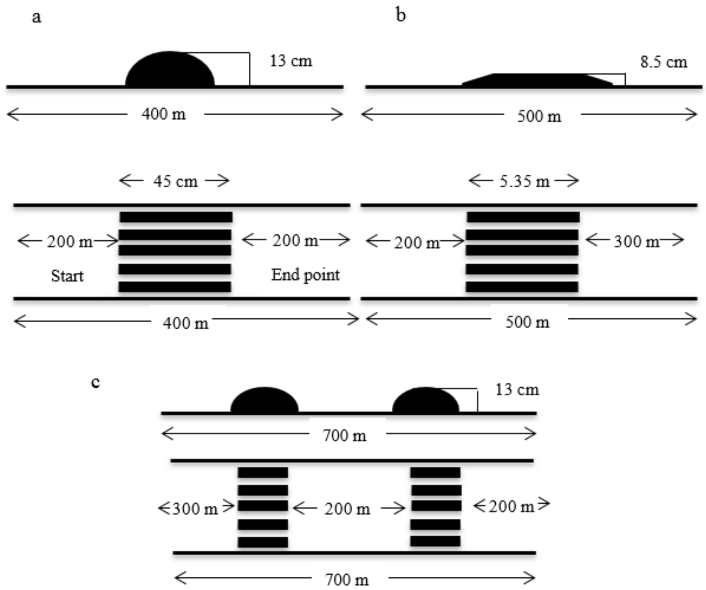


Fig. 1. Section view and plan view of (a) 400m stretch with speed bump; (b) 500m stretch with speed hump; (c) 700m stretch with two speed bumps

$$D_{avg} = \left[T_{fs} - T_{ss}\right] \quad (1)$$

Where,

D_{avg} = Average Delay,

T_{ss} = Travel Time for Speed Breaker Stretch,

T_{ss} = Travel Time for Free Stretch.

Table 1. Comparison of average travel time and average delay

	Avg. Travel Time (sec)		Avg. Delay (sec)
	Speed Breaker Stretch	Free Stretch	
Bump (400m)	38.88	21.92	17.46
Hump (500m)	39.20	25.76	13.44
Double Bump (700m)	65.33	34.01	31.32

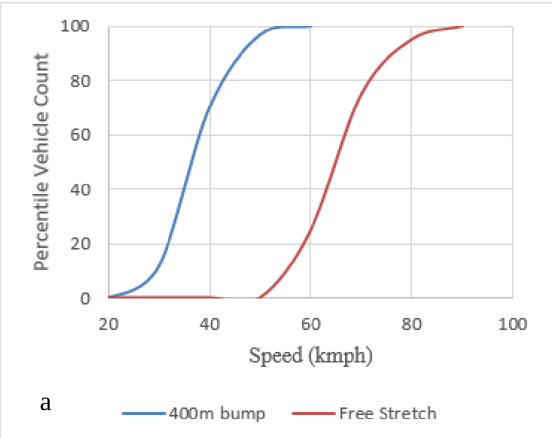
It is to conclude that there was an average delay 13.44 sec, 17.46 sec and 31.32 sec while traversing the stretches of a speed hump (500m stretch), speed bump (400m stretch) and double bump (700m stretch), respectively. Even though in isolation this time seems short, the total delay increases considerably when speed humps are installed in series along a road.

Moreover, the installation of traffic calming devices like speed humps and bumps can cause an increase in journey time of public transport. It also can lead to a string of other problems such as discomfort to passengers, increase in maintenance cost of vehicles, can cause shift in trips to other roads and thus increase the traffic congestion and can compromise passenger safety.

2.2. Effect on 85th Percentile Speed

The speed at or below which 85% of vehicles pass through under free flow condition is termed as 85th percentile speed. Many countries use 85th percentile speed for establishing regulatory speed zones and maximum safe speed for a given location.

To evaluate the effect of speed humps and bumps on the 85th percentile speed, a detailed study was conducted by selecting a free stretch and stretches with a speed hump, speed bump and a double bump, and the values of the 85th percentile speed were arrived at. The methodology adopted includes recording of travel time of the vehicle between two control points and measuring the distance of the stretch between the control points and subsequently plotting a graph between average speed of the vehicles on the stretch and the cumulative number of vehicles passing through the stretch over a given period of time. The graphs are shown below.



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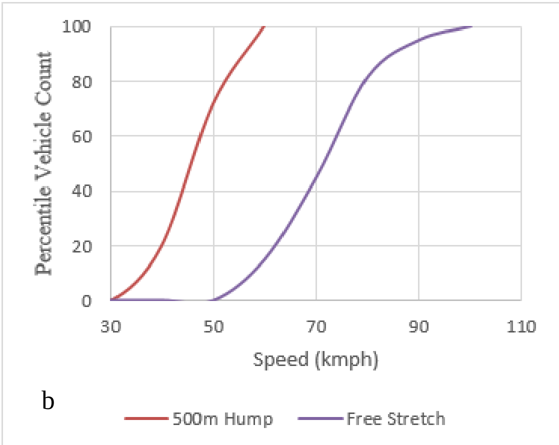

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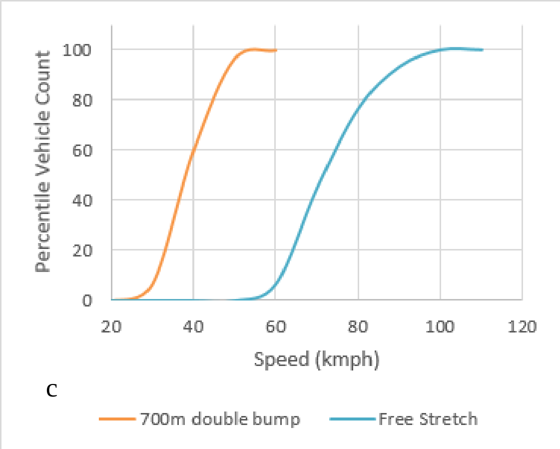

Fig. 2. Comparison of 85th percentile speed for (a) Bump; (b) Hump; (c) Double Bump

The 85th percentile speeds (calculated from the above graphs) was reduced from 81kmph on free stretch to 54kmph in case of a speed hump, from 74kmph on free stretch to 44kmph for a speed bump and from 84kmph on free stretch to 45kmph for double bumps. The percentage reduction in 85th percentile speed was 33.33%, 40.54% and 46.43% for a speed hump, bump and double bump respectively.

2.3. Effect on fuel consumption (Mileage)

Mileage is defined as the distance travelled by a vehicle per unit fuel. It can be expressed in KMPL (Kilometre per litre) or Miles per litre.

Mileage will be maximum for a given vehicle at a given speed. It depends on various factors such as power of the engine, thermal efficiency (mechanical output to chemical energy of fuel), design of the engine as a whole, usage patterns of the vehicle, age of the vehicle, condition of the roads on which the vehicle is being operated, traffic conditions etc. Vehicle speed and its variations are key factors of vehicles energy consumption and level of exhaust emissions. Aggressive driving, characterized by events of acceleration and braking have higher energy consumption and lead to higher emissions.

The effect of speed humps and bumps on the fuel consumption of the vehicle was arrived by studying the loss in travel distance of the vehicle while traversing on the speed breaker stretch. For this study, empty tank method was adopted i.e. the fuel tank is completely emptied and a predetermined quantity of fuel is added and then the vehicle is driven till the exhaustion of the fuel.

$$Mileage = \left[\frac{Distance\ Travelled}{Fuel\ Consumed} \right] \quad (2)$$

In the present study, two different stretches were selected i.e. a free stretch and a stretch with speed humps and speed bumps. Two different vehicles i.e. a 2-Wheeler and 4-Wheeler. The description of the vehicles is shown below:

- Two-Wheeler: Hero Honda CBZ Xtreme, 2014 Model, 149cc bike.
- Four-Wheeler: Maruthi Suzuki Swift Dezire, 2014 Model, 1200cc car.

The mileage is first obtained for a free stretch by approximately maintaining an average speed of 60kmph. Five trails were conducted and the data is shown below

Table 2. Average Mileage data for a Two-wheeler on free stretch

Trail	Distance (km)	Fuel (ml)	Mileage (km)
1	8.20	160	51.25
2	8.60	170	50.58
3	9.25	180	51.38
4	9.70	190	51.05
5	10.15	200	50.75

Table 3. Average Mileage data for a Four-wheeler on free stretch

Trail	Distance (km)	Fuel (ml)	Mileage (km)
1	17.20	1000	17.20
2	18.70	1100	17.00
3	20.10	1200	16.75

The average mileage for bike was found to be 51kmpl and car was 17kmpl.

After this two different speed breaker stretches for bike and car were selected. The speed breaker density in case of bike stretch was 1.85per kilometre or a speed breaker for every 540m. The speed breaker density in case of car was 1.66per kilometre or a speed breaker for every 600m. Various trails were conducted and the data is shown in Table below.

Table 4. Average Mileage data for a Two-Wheeler on speed breaker stretch

Trail	Distance (km)	Fuel (ml)	Mileage (kmpl)
1	7.4	160	46.25
2	7.7	170	45.30
3	8.1	180	45.00
4	8.5	190	44.70
5	8.9	200	44.50

Table 5. Average Mileage data for a Four-Wheeler on speed breaker stretch

Trail	Distance (km)	Fuel (ml)	Mileage (kmpl)
1	10.2	1000	10.20
2	11.1	1100	10.10
3	12.0	1200	10.01

The average mileage in speed breaker stretch was found to be 45kmpl for the bike and 10kmpl for the car.

Calculation of fuel wastage:

Two-Wheeler:
Mileage without speed breakers = 51kmpl
Mileage with speed breakers = 45.15kmpl
The loss in fuel in terms of kilometres per 100 kilometres is obtained by

$$F_w = 100 - \left[\frac{M_{ss}}{M_{fs}}\right] \times 100 \quad (3)$$

Where,

F_w = Fuel Wastage,

M_{ss} = Mileage on Speed Breaker Stretch,

M_{fs} = Mileage on Free Stretch.

So, the bike loses approximately 12km of fuel for every 100km of travel when the density of speed breaker is 1.85/km.

Four-wheeler:

Mileage without speed breakers = 17kmpl

Mileage with speed breakers = 10.1kmpl

So, the car loses approximately 40km of fuel for every 100km of travel when the density of speed breakers is 1.66/km.

$$Additional\ Fuel\ Consumption = \left[\frac{\frac{100}{M_{ss}} - \frac{100}{M_{fs}}}{\frac{100}{M_{fs}}} \right] \times 100 \tag{4}$$

Table 6. Loss in fuel and additional fuel consumption for car and bike

Type of Vehicle	Loss in Fuel (Km/100Km)	Additional Fuel Consumption (%)
Bike	11.47	12.96
Car	40.59	68.31

2.4. Graphical Representation of loss in Fuel

A graphical model containing the generalist overview of fuel consumption of the above-mentioned vehicles corresponding to an average speed has been proposed. This can be used to arrive at the escalated consumption of fuel because of installation of speed humps. This study has been conducted by recording the mileages of the vehicle on a free stretch, of 10km in length, at different average speeds varying from 30kmph to 100kmph. Consequently, prefabricated speed humps (according to IRC norms) were installed on a selected stretch of 2km, at densities varying from 1/km to 5/km and the vehicles were driven maintaining average speeds varying from 30kmph to 100kmph. The mileage of the vehicles was calculated using a Fuel Average Testing Machine. The tables presented below shows the variation of mileage of the vehicle corresponding to the average speeds.

Table 6. Two-Wheeler mileage data for different average speeds on free stretch

Average speed (kmph)	Mileage (kmpl)
30	42.00
40	45.20
50	48.00
56	54.00
60	51.00
70	27.00
80	20.00

Table 7. Four-Wheeler mileage data for different average speeds on free stretch

Average Speed (Kmph)	Mileage (kmpl)
30	13.00
40	14.50
50	15.50
60	17.00
64	17.40
70	16.00
80	14.50
90	11.00
100	7.60

The tables presented below shows the variation of mileage of the vehicle corresponding to varying average speeds and speed breaker densities.

Table 8. Two-Wheeler mileage data for different speed breaker densities and for different speeds

	Mileage (kmpl)				
Average Speed(kmph)	Speed breaker density (per km)				
	1	2	3	4	5
30	39	39	34	31	28
40	42	39.5	37	34.5	31
50	45	42	39.5	36.5	31.5
56	51	47.5	45	42	-
60	48	45	42	39	-
70	24	22	19.5	-	-
80	17.5	16	14	-	-

Table 9. Four-Wheeler mileage data for different speed breaker density's and for different speeds

	Mileage (kmpl)			
Average Speed (kmpl)	Speed breaker density (per km)			
	1	2	3	4
30	6.2	4.7	2.9	2.2
40	7.4	6.1	3.5	2.7
50	8.8	7.2	4.6	3.0
60	12.3	8.4	5.6	4.1
70	9.3	7.5	4.3	-
80	6.4	4.2	-	-

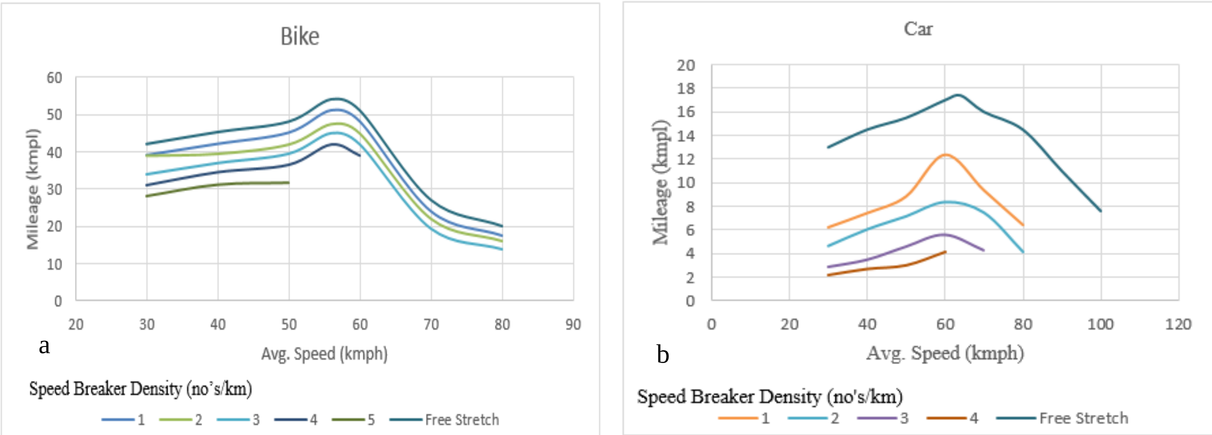

Fig. 3. Variation of mileage of on free stretch and speed breaker stretch (a) bike and (b) car

Further, the percentage reduction in mileage can be calculated using the values of mileage corresponding to an average speed on a free stretch and the mileage corresponding to the same average speed on a speed breaker stretch by varying the speed breaker density. The curves between the percentage reduction in mileage and average speed are plotted and presented below.

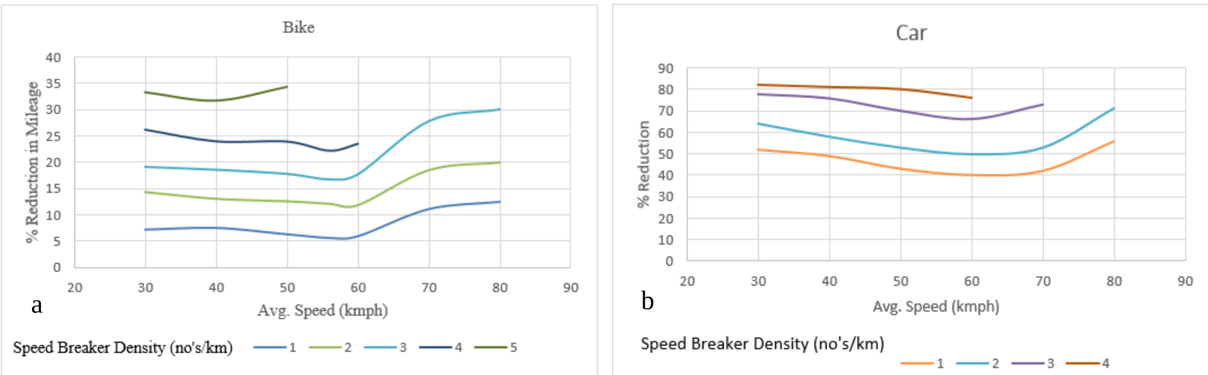

Fig 4. Percentage reduction in mileage for (a) Bike; (b) Car

These graphs can be utilised to estimate the fuel wastage and mileage for any general speed breaker density and average speed, by interpolating the above graphs. Moreover, these graphs can also be utilised to obtain a brief idea about how speed humps can affect the fuel consumption of a vehicle traversing the stretch and also an idea of the possible escalation of the cost of journey.

The problem of increased usage of fuel is particularly exaggerated in a country like India, which is a major fuel importer. Any reduction in mileage can impact the overall economy. So, improving the lacunae can help reduce the burden on the economy and also avoid additional expenditure due to loss in fuel efficiency from the pocket of the common man.

The above-mentioned results may not hold true for all vehicles. These results are highly subjective and depends on many factors like power of the engine, thermal efficiency (mechanical output to chemical energy of fuel), design of the engine as a whole, driver behaviour, age of the vehicle, condition of the roads on which the vehicle is being operated, traffic conditions etc. This effort is only a way forward to show the effect of speed breakers on mileage of the vehicle.

2.5. Effect on Exhaust Emissions

India's growing urbanisation and ever-increasing motor vehicles on road put a substantial pressure on the level of pollution and subsequently result in degraded health of its citizens and environment as a whole. Most of the cities of India are being suffered by extremely high level of urban air pollution particularly in the form of CO, SO_2, NO_2, PM (Particulate Matter) and RSPM (Respirable Suspended Particulate Matter). Transport sectors contributes a major share to the environmental pollution (around 70%). Among these pollutants Carbon Monoxide contributes about 90% of all emissions emanating from transport sector. A study conducted by Bahar et al., 2009 concludes that, the emission of CO and other pollutants are maximum when the vehicle travels at lower speeds i.e. 0-20kmph. This can be attributed to the fact that the vehicles tend to shift gears and reduce speeds while approaching a speed hump and thus increase the energy consumption. Moreover, the vehicles use lot of fuel when travelling at lower speeds and continued accelerations and decelerations resulting from a series of speed humps can affect the vehicular emissions adversely. The concentration of different pollutants as a function of vehicle speed was plotted and the graph is shown below.

It can be observed that the concentration of exhaust emissions is maximum when the vehicle travels at lower speeds and very high speeds.

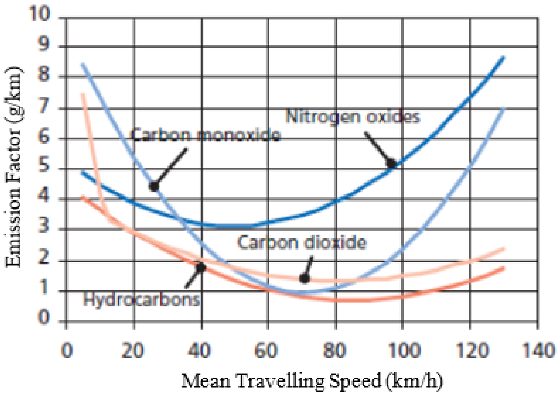

Fig 5. Effect of mean travelling speed on emission levels (Ntziachristos and Samaras, 2000)

A study was conducted to determine the speed profiles of different categories of vehicles while approaching a speed hump. A stretch of 200m, with a speed hump at the middle, is considered for the study. The spot speeds were recorded at every 20m interval on either side of the speed hump, using a Speed Radar Gun. Then the average of spot speeds of 100 approaching vehicles was calculated and graphs were drawn between the mean spot speed and approaching distance to the speed hump for different categories of vehicles. The graph is shown below.

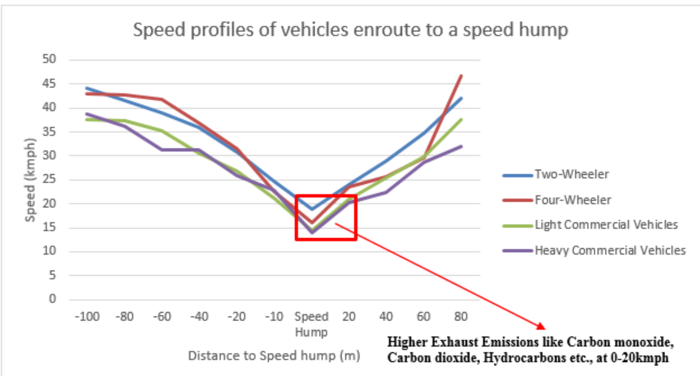

Fig 6. Speed profiles of vehicles en route to a speed hump

From the above graph, we can observe that speed hump reduced the speed of vehicle to about 10kmph to 20kmph. Moreover, according to the report by WHO cited above, we can infer that the exhaust emissions are maximum when the vehicular speeds are between 0-20kmph. So, we can effectively conclude that speed humps cause an increase in vehicular emissions.

3. A new Traffic Calming Device: Curved Speed Hump

The Curved Speed Hump (CSH) is a new traffic-calming device that consists of a raised and curved area placed along a lane. Drivers can choose to adopt a curved path, thus moderating speeds and avoiding disadvantages of speed humps. Moreover, it can potentially reduce the vehicular emissions when compared to speed humps and speed bumps.

The concept of curved speed hump was first mooted by the Highway Engineering Research Group of Polytechnic University of Valencia, Spain. The design parameters adopted were reflected from the road and traffic conditions of Spain. The objective is to implement the concept in Indian conditions by modifying the design parameters according to the Indian road and traffic conditions.

3.1. Description

The Curved Speed Hump (CSH) is composed of a main speed curve, as a speed hump, and a complementary speed hump (Fig. 7). The device offers drivers a chance to modify their path to avoid vertical discomfort. The optimal path is curved, following the main curved speed hump curvature. The vehicle straddles the device as it follows a slight and smooth chicane. Therefore, the vehicle's speed is moderated. Vehicles can continue straight ahead and pass the device with one or two wheels over the main speed hump. Speeding is discouraged by vertical forces and the consistent vertical discomfort. The Total width on road (W_T) is a key parameter. The parameter controls the minimum axle that straddles the device without changing the path and the wheels going up on the device. Vehicles with axles wider than the W_T will not be totally affected by the CSH. However, their speeds will be moderated as they centrally straddle the main speed hump. Consequently, the effect on emergency vehicles, such as fire trucks and ambulances, and to public transport vehicles, will be minimized, as the CSH acts as a speed cushion. The complementary speed hump, located between the two CSHs, functions as an additional speed hump so as to discourage passage of the vehicles between the CSHs without any effect. The width of the complementary speed hump is designed in such a way that the free space available between the CSH and complementary speed hump is lower than the minimum axle width of a vehicle that uses the road. The narrowing effect caused by the device can encourage a speed reduction for two-wheelers.

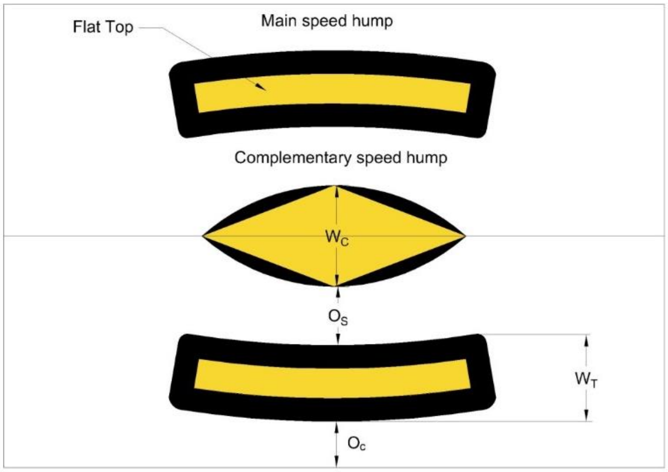

Fig 7. Plan view of a typical Curved Speed Hump on a Two-lane Road

The CSH is a TCM that involves a change on both horizontal and vertical alignment. The CSH allows drivers to choose between a straight path and a curved path. The drivers who adopt a straight path will suffer the discomforts associated with speed humps, though on a lower scale. Drivers adopting a curved path will have their speeds moderated, resulting in reduced discomfort and damage to their vehicles.

The geometric design shall be obtained through field trails and experimentation. Initially the relation between radius of the curve and objective speed shall be obtained through preliminary tests. Based on this relation, various other parameters shall be varied on test tracks and final results shall be obtained.

3.2. Geometric Design

The parameters adopted for the design are as follows:

Nomenclature

W	Uniform width of main Curved Speed Hump
W_T	Total width of main Curved Speed Hump on road
W_C	Width of Complementary Speed Hump
R	Radius of curvature of main Curved Speed Hump
L	Length of main Curved Speed Hump
r	Corner radius
O_C	Offset between main Curved Speed Hump and raised curb
O_S	Offset between main Curved Speed Hump and complementary Speed Hump

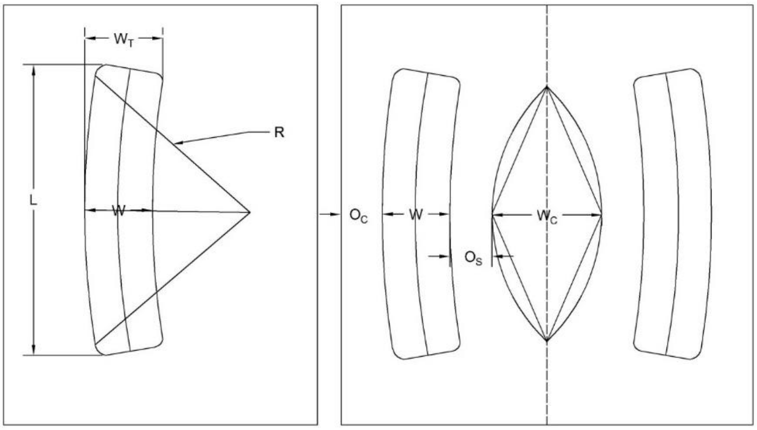

Fig 8. Various geometric parameters of a Curved Speed Hump

The uniform width (W) of the main CSH is arrived by considering the axle width (inner wheel to inner wheel of minimum axle) of vehicles traversing the path. For this, a survey was conducted by collecting the axle widths of various vehicles traversing on the roads. From the survey, it was concluded that more than 89% of vehicles had an axle width greater than 1.15m and 66% of vehicles greater than 1.20m. So, if W is taken more than 1.20m, more than 40% vehicles may experience discomforts of a speed hump and the main purpose of CSH may not be served. If the W is taken less than 1.15m, the W_T also reduces and vehicles can easily adopt a straight path totally avoiding the CSH. So, the optimum range of W is taken between 1.15m and 1.20m.

The radius of curvature of the main CSH can be arrived using experimental results. The R can be designed by deducing the relation between radius and objective speed (the speed at which the curve can be negotiated). This can be achieved by marking the contour of the CSH on the pavement by adopting different radii and quantifying the influence of the radius on the objective speed. The radii shall be varied by keeping the objective speed constant. Vehicles shall be made to pass through the marked contour at a predetermined speed (Objective speed) and the trajectory of the vehicle shall be evaluated using cameras and video recordings. The optimum radius can thus be obtained for a given objective speed.

Fig 9. Plotting Contour of Curved Speed Hump

The range of R adopted was fixed between 10m and 20m. It was found that, if R is less than 10m, negotiating the curve was found to be very difficult and if R is greater than 20m, negotiating the curve was very easy. The radii adopted were 10m, 15m and 20m. The length of the curve was varied between 4m and 9m and the curves with the radii and lengths were plotted in AutoCAD software. Based on the plotted curves, W_T was calculated and the results are tabulated below.

Table 10. Values of W_T for different lengths and radii of CSH

Radius (R)	10	15	20
Length (L)		Total width on road (W_T)	
4	1.32	1.27	1.24
5	1.43	1.34	1.30
6	1.55	1.42	1.36
7	1.71	1.53	1.44
8	1.89	1.65	1.53
9	2.10	1.78	1.63
All dimensions in 'm'			

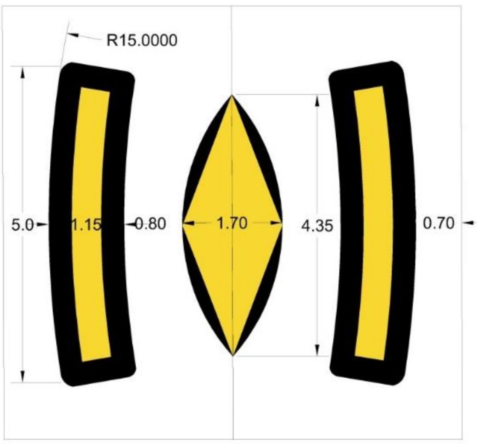

Fig 10. A sample Curved Speed Breaker on a two-lane road with a radius of 15m, length of 5m, W of 1.15m, W_C of 1.70m, O_C of 70cm and O_S of 80cm

Based on the above values, W_T shall be known for a given R & L. Further, W_T should be greater than the maximum axle width of the vehicles traversing the path, because if it is lesser, the vehicles can pass through the CSH in a straight path without any effect.

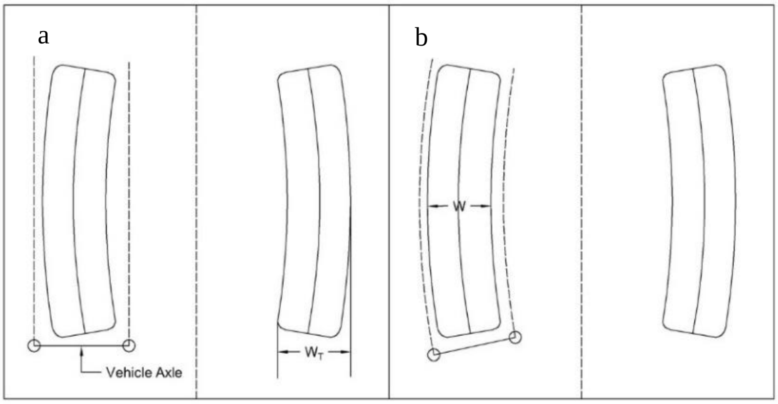

Fig 11. Critical conditions for total width on road (W_T) (a) When W_T is less than the vehicle axle (b) When W_T is greater than the vehicle axle.

The critical condition for calculating the width of the complementary speed hump (W_C) is that it should not allow vehicles to pass over it in a straight path without any effect. If W_C is just equal to W, then it allows maximum number of vehicles to traverse over it. To satisfy the above criteria, W_C is calculated as 40-60% greater than W. If W_C is very much greater than i.e. close to twice of W, then the available offset distances have to be compromised and spacing available for vehicles to adopt a curved path would be reduced. This can discourage vehicles to adopt a curved path.

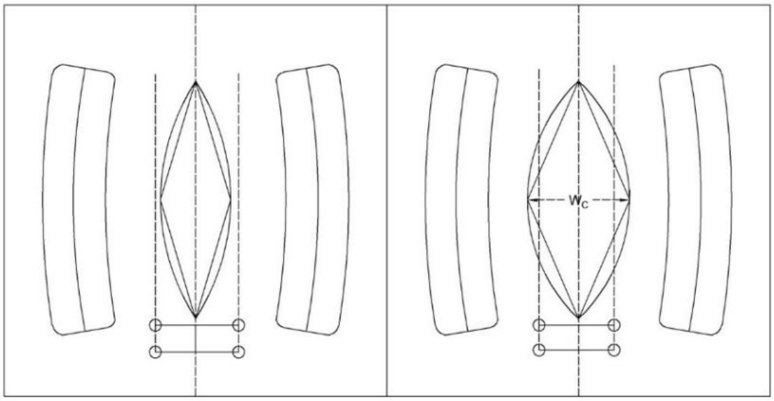

Fig 12. Critical conditions for W_C (a)When W_C is equal to W (b) When W_C is greater than W i.e. Min. vehicle axle

O_C is the offset between the main Curved Speed Hump and the raised curb. The offset should be in such a way that when the vehicle traverses on a curved path on the CSH, the vehicle should not collide with the raised kerb. The optimal range of O_C should be between 65-80cm.

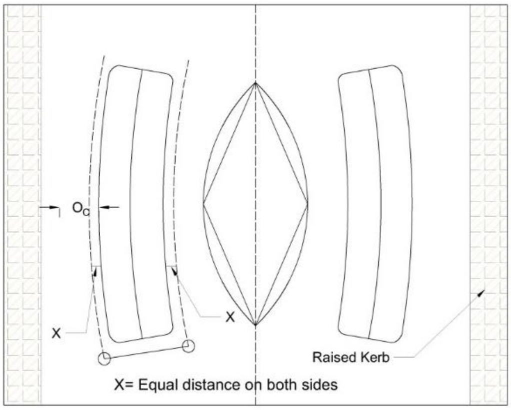

Fig 13. Critical condition for O_C i.e. when vehicle axle is spread equally across the curved speed hump, the vehicle should not collide with the raised kerb.

$$O_C \geq \frac{1}{2}\left[Vehicle\ Width - W\right] \tag{5}$$

O_S is the Offset between main Curved Speed Hump and complementary Speed Hump. The offset can be adopted according to the available lane width after the parameters adopted above. The optimal range of O_S should be between 70-90cm.

$$O_S = \frac{1}{2}\left[Total\ Lane\ Width - \left(2W + 2O_C + W_C\right)\right] \tag{6}$$

Based on the above criteria, many of the design parameters can be obtained. Other parameters such as Height of speed hump (H), corner radius (r), side slopes shall be defined after conducting various field trails.

4. Conclusions

Over the years, several countries have been using TCMs extensively and have given varying outcomes. Some widely used TCMs are speed humps, speed bumps, speed tables, speed cushions etc. However, these measures are centered on speed reduction and high cut through volume, ignoring the ill effects caused by them in terms of discomfort to the passengers, damage to vehicles, delays in travel times, higher reductions in mileages and can also exacerbate the situation of vehicular emissions.

The Curved Speed Hump, a new Traffic calming devise, is being introduced in the Indian conditions. This device can potentially reduce the negative effects caused by speed humps and bumps by using the technique of speed moderation rather than decreasing the spot speed. The optimum ranges of values of design parameters were theoretically obtained. The radius (R) was fixed between 10m and 20m, if R is less than 10m, negotiating the curve was difficult and if R is greater than 20m, negotiating the curve was very easy. In accordance to a vehicle survey conducted, the optimum range of W was found to be 1.15m to 1.20m. For the theoretical plotting of curves to evaluate W_T, W was taken as 1.15m. Various curves were plotted in AutoCAD using radii of 10m, 15m and 20m by varying the lengths of the curves and the values of W_T were obtained. The range of W_C was adopted 40% to 60% more than W, so that vehicles do not pass over the complementary speed hump nor affect the offsets. The O_C should be between 65cm to 80cm so that the largest vehicle negotiating the CSH does not collide with the raised kerb. O_S should range between 70cm and 90cm so as to fit in the available lane width.

The design of CSH shall be made in two stages: preliminary stage and experimentation stage. In the preliminary stage, various design contours shall be marked on the road surface by changing parameters like radius and length of the curve. The relation between objective speed and radius of the curve shall be obtained in the preliminary stage. In the experimentation stage, the CSH shall be laid and the effectiveness of the device shall be evaluated.

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