



VEHICLE SPEED CONTROL USING ROAD BUMPS

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Abstract. Road bumps play a crucial role in enforcing speed limits, thereby preventing overspeeding of vehicles. It significantly contributes to the overall road safety objective through the prevention of accidents that lead to deaths of pedestrians and damage of vehicles. Despite the importance of road bumps, very little research has been done to investigate into their design. While documentation exists on quantitative descriptions of road bumps, they offer little guidance to decision making. This work presents a unique approach to solving road bumps design problems. The results of our study reveal three important road bumps variables that influence the control of vehicle speeds. The key variables are bump height, bump width, and effective distance between two consecutive road bumps. Since vehicle speed control is the ultimate aim of this study the relationship between vehicle speed and other variables earlier mentioned is established. Vehicle speed is defined as the product of frequency at which a vehicle is moving over road bumps and the sum of effective distance between two consecutive road bumps. In the determination of bump height we assume a conical shaped curve for analysis as a matter of research strategy. Based on this, two stages of motion were analysed. The first concerns the motion over the bump itself while the second relates to the motion between two consecutive road bumps. Fourier series was then used to formulate a holistic equation that combines these two stages. We used trigonometric functions to model the behaviour of the first stage while with the second stage giving a functional value of zero since no changes in height are observed. We carried out vibration analysis to determine the effect of road bumps on a vehicular system. Arising from this a model component is referred to as an isolation factor. This offers guidance to the safe frequency at which vehicles could travel over road bumps. The work appears to contribute to knowledge in road bump research through the development of a novel approach to the control of vehicle speeds. Significant research progress could be made if engineering and academic communities at large appreciate our viewpoints. With this work it is apparent that varying of the assumptions made in terms of bump shape may produce high proliferation of beneficial research studies. Although this work may reveal a new way of investigation into road bump research, no claim is made for the work comprehensiveness. We expect experts to challenge some of our thoughts and ideas presented in this work.

Keywords: vehicle system dynamics, vehicle technology, human safety, effective distance, road bumps, speed limit.

1. Introduction

Research into traffic safety has steadily increased over the past several decades (see[1–4]). Work in the field during the last century has evolved from three basic forms: critical reviews (articles which survey the field), theoretical frameworks (articles which propose a theory), and application-based articles (which emphasize the practical significance of a theory). Traffic safety is an important phenomenon with a wide range of studies in land, water, and air transportation. Land transportation covers two main means: road and rail. Water transportation refers to movements on seas or oceans. On the other hand, air transportation refers to airline operations. Each of these means of transportation has a distinguished heritage.

With an increasing significant proportion of the world population travelling by road, a more vigorous understanding of road traffic safety becomes critical. Consequently, road traffic safety research has assumed strategic importance in the safety literature. Research documentation on road traffic safety has therefore assumed an increasing dimension in the last three decades, particularly in the developing countries. Governments, research institutions, and some international research agencies have contributed an immense amount of human intelligence and research resources in traffic issues. Traffic engineering studies, enforcing existing laws and ordinances regarding speed limits, educating drivers and residents on causes and solutions of traffic problems, installing traffic control devices, all form a

part of the daily investments of human efforts and research resources into road traffic research.

In all parts of the world vehicle accidents present a very serious threat to human lives and survival. In the developed countries of the world where safety rules and policies are made and enforced, the problem of risks of human lives to the vehicle accidents and death is controlled. Unfortunately, the case for developing countries appears different. There is, therefore, the need for a closer look at the ways of controlling pedestrian injury and fatalities due to vehicle accidents on our roads [5, 6]. One of the solutions to this problem is presented in the work.

The need to control excessive speeds of motorists has been stressed and treated in the world safety literature. Numerous control measures are usually imposed on motorists with the aim of preventing accidents on our roads. One traditional approach is the use of well-trained personnel to monitor roads. Trained traffic officers and government agencies on traffic monitoring roads usually stay by the roadsides to control vehicle over-speeding [7, 8]. Unfortunately, the cost associated with maintaining this level of manpower and the relevant resources utilised by the monitoring crew is usually prohibitive. Apart, human beings are difficult to control and may therefore constitute a nuisance towards this goal achievement [9].

A second alternative is the use of rumble bars across the carriageways to alert motorists on the change in driving conditions over a distance of say, 200 metres prior to the danger site. While rumble bars can be effective, the noise produced limits their usage to locations outside areas that are sensitive to sound [10, 11].

A third, perhaps, the most attractive option is the use of road bumps. It is one very effective way of ensuring that desired speed limits are not exceeded. Road bumps therefore present an interesting research area that has attracted the attention of many scholars in various disciplines worldwide. Scholars in civil engineering, highway, and safety engineering have contributed a wealth of knowledge and data concerning road bumps. Despite the immense contribution of professionals and scholars in road bump research, a missing gap is the scientific design of road bumps. This work attempts to fill the gap. Specifically, the following research questions are answered: (i) guided by theory, what are the effective distances between road bumps for different speed limits? (ii) how can practitioners establish improvements of road bump research? To address these problems, the focus of this paper was to develop a mathematical model for determining the effective distance between road bumps for different speed limits in such a way as to have low transmissibility ratio between road and vehicular system. The model is based on the con-

cept of isolation factor (*I.F.*) against frequency Ratio (*F.R.*).

2. Literature review

The literature review on road bumps encompasses a wide array of enquiries on the development of speed bump systems that can respond instantaneously to traffic conditions. Another viewpoint is the construction of full or partial scale prototype remote-controlled speed humps and the assess of their abilities to meet specifications. Research attention has also been focused on effective use of speed humps for traffic control with specific minimum criteria that must be met before installation [12].

In this paper, *bumps* and *humps* are interchangeably used. Speed humps have geometric roadway design features with the purpose of slowing traffic in residential neighbourhoods. (They are self-forcing and often called *sleeping police officers*). Speed humps are three to four inches high and 12–22 feet long. They are found on public residential roadways. To be effective, speed humps should be placed in series at 200–600 foot intervals. Speed humps will reduce vehicle speed to 15–20 mph at the humps and 25–30 mph between humps in a series.

Afukaar [13] takes an exploratory view of speed control in developing countries. The issues, challenges, and opportunities of reducing road traffic injuries are explored. Vehicle speed is considered as a factor in the causation of road traffic crashes using Ghana as a case study. The effectiveness of various speed control measures was examined on speed control crashes in Ghana and published works on speed control measures in both industrialised and developing countries were examined. The results show that pedestrians were the main victims of road traffic injuries. The dominant driver error assigned by traffic police includes the loss of control as a result of excessive reckless speeds. The *speed factor* alone counted for more than 50 % of all Ghanaian road traffic accidents between 1998 and 2000. While the enforcement of speed limits by traffic police may not be affordable for most developing countries, rumble stripe and speed humps were found to be useful alternatives.

Hallmark and Smith [14] evaluated the impact of temporary speed humps and speed tables on vehicle speeds, vehicle speed profiles, and traffic volumes along local and/or collector streets in the USA. Speed volume and resident opinion data were then collected and evaluated. In general, the devices were shown to be effective with the temporary speed table performing as well or better than the speed hump. Both the speed hump and the speed table were effective in reducing mean speeds at the device and immediately downstream, while speeds immediately upstream and farther downstream were less

likely to be affected. The speed hump and speed table also reduced the number of vehicles exceeding the speed limit in the immediate vicinity of the devices. However, the analysis of the volume data collected did not indicate any reduction in traffic.

The results of the resident surveyed in this study were consistent with those reported in other jurisdictions. Overall more respondents were supportive of the use of the temporary speed hump/table than opposed. However the responses from the resident survey related to the preference of temporary device were not conclusive. The temporary speed hump and temporary speed table used in the study were easily installed and removed with little damage to the existing pavement. These temporary devices may also be ideal for jurisdictions that have concerns of snow removal or those that experience unwanted traffic characteristics during certain time of a year only (e.g. recreational areas).

Smith and Giese [15] studied the impacts of high traffic volumes on the quality of life in residential neighbourhoods. Speed humps are designed for residential roadways that have two lanes or less at a posted speed limit of 30 mph or less, and 85th percentile speed of 31–34 mph. Roadways that carry traffic volumes of 600–5000 vehicles per day are good candidates for speed hump after installation.

In a study by the Las Vegas Neighbourhood community in 2003, a traffic management policy on speed bumps was discussed. The aim was to successfully manage the minimisation of non-essential vehicular traffic on residential streets and ensure that vehicles use the streets at an appropriate rate of speed. The documentation discussed administrative procedure, minimum criteria, placement of speed hump monitoring and evaluation, as well as liability concerns.

The paper by Beckman and Kuch [16] investigated how the effects of road bumps vary with speed. Research questions that define their study include (1) could bump be the limiting factor in concerning speed? (2) in an aerodynamic car, could a bump cause sudden and catastrophic loss of downforce and adhesion? To analyse these questions the researchers explored the variation of bump violence with speed.

Fishman [17] introduced the concept of traffic calming employed to improve the conditions on a roadway for pedestrians, bicyclists, and neighbourhood. Traffic calming techniques alter the appearance or geometry of a roadway to reduce traffic volume or speed. The technique is self-enforcing making drivers seek alternate routes. Other by creating a sense of shared space between the driver and resident, make drivers want to slow down on local roads.

The conclusions from the literature are highlighted in the following points. There is a significant interest in

finding highly effective means of controlling traffic speeds in order to improve the conditions on roadways for pedestrians, a major accident controlling factor on our road. A number of other control measures emerged from research investigations and practice. These are the use of traffic calming, fibre reinforced plastic (FRP) showcases, and e t c. There is a body of research emerging on the control of road bumps installation. Critics have defected road bumps in the following points (i) speed bumps slow down emergency vehicles (ii) speed bumps increase air pollution and fuel usage (iii) speed bumps harm the disabled and those with physical ailments (iv) speed bumps increase vehicle wear and tear, and (v) speed bumps increase noise.

3. Road bumps modelling

Road bumps theory usually reflects important parameters, including an effective distance between bumps for different speed limits, shape, and aesthetic characteristic of bumps. To design road bumps, consideration must be given to the parameters of road bumps - height, length, width, and distance apart. Here, the width of a bump is also the width of a road. As a matter of research strategy and for computational ease, the road bump design considered here is of semi-circular shape. (Fig 1). A close observation of Fig 1 suggests the possibility of modelling the problem using any periodic function that can be represented by a series of sinusoids of suitable frequencies, amplitudes, and phases. A useful function that could be used for these is Fourier series.

3.1. Assumptions

The following assumptions are made in the modelling of road bumps discussed in this paper: (1) vehicles have variable speed with maximum speed between road bumps (when approaching road bumps, the vehicle needs to slow down and after crossing it accelerates). (2) road bumps angle of inclination with the road should be less than 90° (to prevent impact due to collision or to low uneasy ride over road bumps). (3) road bumps angel of inclination with road should not be equal to zero. (if it is equal to zero, no road bump again). (4) vehicle is assumed not to decelerate in between road bumps beyond recommended values (to prevent accident due to over speeding). (5) there is an indication for awareness of road bumps ahead (to prevent sudden application of brake due to late awareness of road bumps ahead). (6) vehicles have self-suspension system (provision of both smooth ride and good handling characteristics). (7) its entire wheel is in contact with road all the time (to prevent resonance of a vehicle). (8) the weight of a vehicle is stored on all its wheels (so, when a vehicle hits a bump, the effect on its wheels will be the same).

3.2. Notations

The following notations used in the paper

A, B, R	constants
v	maximum constant speed over bumps (m/s)
p _n	forced amplitude (N)
t	time (s)
Ψ, φ, α, θ, μ	phase angle or phase difference (rad.)
m	vehicle mass (kg)
γ	damping factor
t	time to travel over a bumps (m)
λ	distance between two successive points on road with bumps
x ₀	amplitude of vibration of vehicle (m)
I.F	Isolation factor
f	forced frequency (m)
h(t)	bumps height with respect to time (m)
a ₀ , a _n , b _n	Fourier's series constants
s	length of bump in road direction (m)
p	forced circular frequency (Hz)
β	damping ratio
a	frequency ratio
T	period of vehicle motion (s)
c	damping co-efficient (Ns/m)
ω	natural circular frequency of suspension spring (rad/s)
L	effective distance between road bumps (m)
k	suspension spring stiffness constant (N/m)
x _n	amplitude of vibration of supporting part (m)
n	no of series in the Fourier's series
f _{ns}	natural frequency of spring

3.3. The road bump model

The conceptual modelling of the road bump problem (shown in Fig 1) reveals some interesting variables on the road bump problem that are the tools for modelling and empirical investigations. Analysing Fig 1 below, the principles embedded in Fourier series were adopted to understand the mathematical relationship between various component variables of the road bump problem. The motivation for applying Fourier's series lies in its characteristic repeated series of events. Fourier analysis is based on the fact that any periodic function can be represented by a series of sinusoids of suitable frequencies, amplitude, and phases.

We consider the function y(t) which is periodic in time T, and representing the motion of vehicle over the road bumps. If t represents the time taken to complete each cycle of movement on the road bump, and v is the uniform velocity at which vehicles are travelling over road bumps, then:

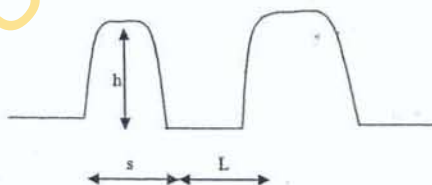


Fig 1. Conical-shaped road bump

$$y(t) = a_0 + \sum_{n=0}^{\infty} (a_n \cos(pnt) + b_n \sin(pnt)). \quad (1)$$

Where

$$p = \frac{2\pi}{T}, \quad (2)$$

$$a_n = \frac{2}{T} \int h(t) \cos(pnt) dt, \quad (3)$$

$$b_n = \frac{2}{T} \int h(t) \sin(pnt) dt. \quad (4)$$

It should be noted that a₀, a_n, and b_n are Fourier series constants. But recall that

$$h(t) = Q \sin\left(\frac{\pi t}{t_1}\right). \quad (5)$$

If the value of h(t) is substituted in the equations containing a₀, a_n, and b_n, then we have new values for a₀, a_n, and b_n as follows:

$$a_0 = \frac{2Qt_1}{\pi T}, \quad (6)$$

$$a_n = \frac{Q}{T} \left(\frac{1}{A} + \frac{1}{B} \right) (1 + \cos(pnt_1)), \quad (7)$$

$$b_n = \frac{Q}{T} \left(\frac{1}{A} + \frac{1}{B} \right) \sin(pnt_1). \quad (8)$$

Where

$$A = \left(\frac{\pi}{t_1} + pn \right) \text{ and } B = \left(\frac{\pi}{t_1} - pn \right). \quad (9)$$

Having obtained expressions that indicate the time taken to complete each cycle of movement on the road bump, the conceptual framework of vibration analysis could be incorporated into the road bump modelling problem. Fig 2 represents the analytical model based on vibration analysis.

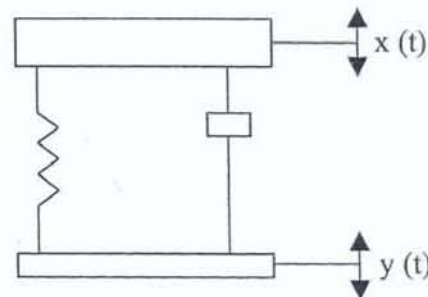


Fig 2. Analytical model of road bump-vehicle interaction

Free-body diagram of Fig 2 is illustrated in Fig 3.

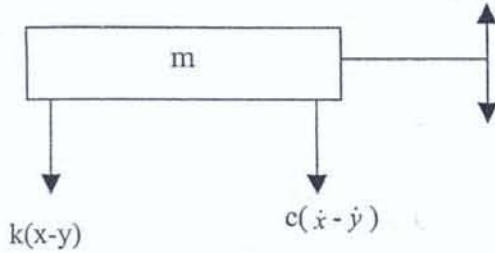


Fig 3. Free-body diagram of the road bump-vehicle interaction

From Fig 3, a new expression, referred to as equation (10) evolves

$$m\ddot{x} + c\dot{x} + kx = c\dot{y} + ky, \tag{10}$$

but

$$\dot{y}(t) = \sum_{n=0}^{\infty} H_n [(1 + \cos(pnt_1)) \cos(pnt) + \sin(pnt)] \tag{11}$$

by substituting the value of $\dot{y}(t)$ in equation (12) above, we have a new expression that reduces to

$$\ddot{x} + 2\gamma\dot{x} + \omega^2 x = \sum_{n=0}^{\infty} \frac{Pn}{m} \cos(pnt + \theta). \tag{12}$$

The equation above is a second order differential equation with a constant co-efficient. The solution of the equation is the addition of the complementary and particular solutions. The complementary aspect of the equation is obtained as:

$$X_c = Re^{-n} \cos(qt - \alpha). \tag{13}$$

Where

$$R = \sqrt{A^2 + B^2} \text{ and } \alpha = \tan^{-1}(B/A). \tag{14}$$

The particular solution which was determined by superposition principle is:

$$x_p = x_o \cos(p_n t + \mu). \tag{15}$$

The general solution for this particular equation then becomes:

$$x(t) = Re^{-n} \cos(qt - \alpha) + x_o \cos(p_n t + \mu). \tag{16}$$

Now, to derive an expression for isolation factor, we consider the ratio of system displacement to that of the support.

$$I.F = \frac{\text{system displacement}}{\text{displacement of support}} = \frac{x(t)}{y(t)} = \sum_{n=0}^{\infty} \left[\frac{1 + 4\beta^2 n^2}{(1-n^2)^2 + 4\beta^2 n^2} \right]^{1/2} \tag{17}$$

Our analysis from the above equation finally led us to the expression for Isolation factor. The graph of Isolation factor can be plotted against frequency by getting values for other variables in the isolation factor equation from boundary conditions with initial conditions of the model incorporated. A Fortran program was written (see appendix) for isolation factor equation and the result is then plotted to show graphic variations between isolation factor and other parameters as indicated in the graphs displayed in the appendix.

Another area of interest could be the determination of the effective distance between two road bumps. As such the wave equation may be adopted. Fig 4 shows the diagram representing the effective distance between two road bumps.

Where:

$$v = f\lambda, \tag{18}$$

$$\lambda = v/f, \tag{19}$$

f can be determined from the safe frequency obtained from the graph of isolation factor against frequency (see Fig 3).

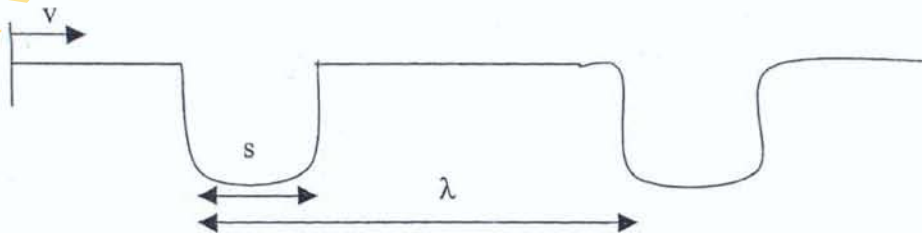


Fig 4. Effective distance between two consecutive road bumps

Thus, effective distance = $\lambda - s = v/f - s$. (20)

4. Results and discussions

The mathematical analysis of the road bump problem using Fourier series shows that the motion of a vehicle can be represented in a sinusoidal form with the expression of amplitude of the motion, X_n , and that phase angle is using a second order derivative equation with a constant coefficient. The solution, having both complementing and particular aspects, was also obtained. The roots of the auxiliary equation, r , may be real and distinct, real and equal, or complex conjugates depending on the magnitude of w and r . If w is less, the values of r are real and negative. Therefore, no oscillatory motion is possible from the complementary solution of the equation of motion regardless of the initial conditions imposed on the system. If w is equal to g , the motion is again not oscillatory, and its amplitude will eventually diminish to zero. If w is greater than g , the values r are complex conjugates.

An automobile suspension system is meant to provide both safety and comfort for the occupants.

When a vehicle encounters road surface irregularity, the tyre deforms and suspension system displaces. Tyres, suspension springs, suspension bushings, and friction damping in the suspension systems absorb these vibrations. Ride harshness isolation above 30 % is considered good, between 41 % and 60 % is considered fair, and under 40 % is considered to be poor. Lower numbers indicate stiffer tyres and/or excessive friction in the suspension system, and smaller sprung mass.

Graphically the results are presented in Fig 5. and Fig 6.

5. Summary and conclusions

The focus of this paper was to develop a mathematical model for determining the effective distances between road bumps for different maximum speed limits in such a way as to have a low transmissibility ratio between a road and a vehicular system. With this, the passenger's sensation of discomfort does not exceed a certain level

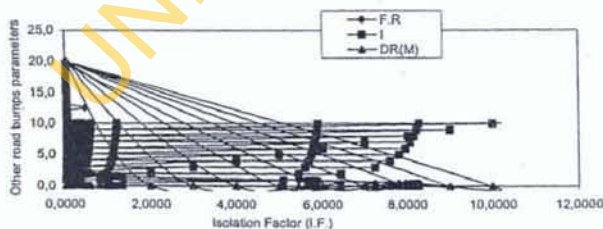


Fig 5. Relationship chart between road bump parameters (Isolation Factor on the x - axis)

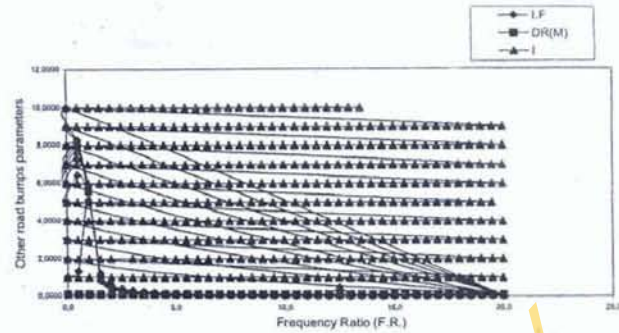


Fig 6. Relationship chart between road bump parameters (Frequency Ratio on the x - axis)

corresponding effective height and bump height. The paper furthered our better understanding of the various parameters inherent in bump design and implementations.

To this end, the study focused on important variables of bump height, width and effective minimum distance between two bumps. As it can be observed, high frequency input ratio can be effectively isolated through the action of the suspension spring due to the low natural frequency of the spring mass. Low frequency excitation can however be transmitted to the vehicle body.

The graph of effective distance is directly proportional to the maximum speed. It can be observed that the graph of bumps maximum height against maximum speed limit is parabolic in nature. It is therefore recommended that the frequency ratio to choose must be greater than the crossover frequency ratio thereby making excitation frequency to be greater than the suspension natural frequency. In no case should the maximum posted speed on any road exceed the design speed of the road. To make road bumps visible to a motorist especially at night, it should be painted with white road paint or mastic asphalt and sprinkled with white glass beads. Also, road construction companies are advised to involve experts in the design of road bumps.

The position taken in this paper is that traffic safety research is an established function in most developing countries, yet it is an area that suffers from key research. Instead, some toy problems are investigated with toy research methodologies. For the present study, the important question of what appropriate distance between bumps needs to be considered for various bump shapes and designs. It is a candidate for future research.

Some other directions for further synthesising future research include: (1) evaluating alternative designs of bumps that cause the least negative effects on a motor vehicle; thus, optimisation studies on the road bump modelling problem presents an important area of immense benefits to researchers and practitioners, (2) developing a mathematical relationship on the distance between bumps and the forces generated as a result of the speed of a motor vehicle on roads; and (3) alternative research

methodologies need to be explored regarding integration of our model with established concepts in road bump research in order to have a new wave of researchable topics.

The study calls for the replicability of the present study under different environmental conditions to study the effect of environmental changes on the results of some key variables in the system. Given the popularity of prior research along the minimum distance dimension, the future holds much promises in terms of great improvements in the quality of research into road bump research.

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