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Impact Assessment of Speed Bump on Vehicle Suspension System on Selected Road in Benue State, Nigeria

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***Abstract* — Traffic safety is a critical aspect of road design and maintenance, with speed bumps playing a significant role in controlling vehicular speed in accident-prone areas. However, the indiscriminate installation of speed bumps in Benue State, Nigeria, often without adherence to engineering standards, has raised concerns about their adverse effects on vehicle performance and road infrastructure. This study evaluates the impact of speed bumps on vehicle suspension systems across five selected roads in Benue State, Nigeria. A comprehensive survey was conducted to document the dimensions, shapes, and locations of the speed bumps, as well as measurements of average vehicle speeds across these bumps. The dynamic behavior of vehicle suspension systems traversing these bumps was simulated using MATLAB to assess the impact of varying bump dimensions. The results reveal significant deviations from the Institute of Transportation Engineers standards, with bump heights ranging from 0.06 to 0.17 meters and widths ranging from 0.20 to 0.31 meters. Simulations were employed to analyze suspension stress, pitch angle, spring displacement, and settling time for cars, SUVs, and buses. The Gboko–Ugbema road exhibited the most severe dynamic responses, with SUVs experiencing stresses of up to 12.39 MPa and prolonged settling times exceeding 5 seconds. In contrast, the Makurdi–Aliade road, with bump dimensions closest to ITE standards, resulted in the least mechanical strain, with stress values for SUVs and buses at 3.79 and 4.67 MPa, respectively. Additionally, the results of the angle of inclination revealed discrepancies between the simulated and measured values. The study concludes that adherence to standard bump dimensions is necessary to minimize suspension damage and enhance vehicle durability.**

Keywords— Speed bumps, Traffic calming, Vehicle suspension system, MATLAB simulation and Road infrastructure.

I. INTRODUCTION

Traffic safety is a critical aspect of road design and maintenance, particularly in light of the increasing global population and the subsequent rise in road travel. Understanding road traffic safety is essential to ensuring efficient transportation systems. One of the primary indicators of road performance is vehicle speed, which is directly linked to the quality of service experienced by road users. In this context, speed bumps, or raised pavements spanning across roadways, play a significant role by forcing drivers to reduce speed, thus enhancing safety in accident-prone areas [1]. However, when installed improperly or unnecessarily, speed bumps can lead to discomfort, irritation, and even damage to vehicles [2].

In recent years, Nigeria has witnessed a growing trend in the installation of speed bumps across both rural and urban areas, often in locations where speed control is not essential due to low traffic volumes [3]. These speed bumps are frequently installed without standardized engineering assessments or design consistency, leading to concerns about their effectiveness in ensuring safety. Additionally, many of these bumps are installed without proper signage or road markings, increasing the risks to road users [4]. The improper design and placement of these bumps can also disrupt the natural water flow over the pavement, potentially affecting drainage systems and contributing to road surface degradation [1]. As a result, the installation of speed bumps can negatively impact the level of service on roads, increasing travel time, fuel consumption, and environmental pollution. Furthermore, the acceleration and deceleration required when crossing these bumps can cause damage to both vehicles and the road infrastructure, reducing the overall lifespan of the pavement [5–7]. Given these challenges, it becomes necessary to examine the impact of speed bump characteristics on vehicles, focusing on their potential consequences for vehicle suspension systems.

In Benue State, Nigeria, the unregulated installation of speed bumps has become a pressing issue. These bumps are often installed by local communities or organizations in an attempt to reduce traffic accidents but are frequently constructed without following standard engineering guidelines. This has led to poorly designed bumps that cause significant vehicle damage, discomfort for passengers, and, in some cases, accidents. The absence of proper signage further exacerbates the problem, as vehicles often approach these bumps at high speeds, unaware of their presence. The widespread nature of these issues calls for an in-depth investigation into the effects of speed bump characteristics on vehicles to establish appropriate design standards and ensure better road safety.

The aim of this study is to assess the impact of speed bumps on vehicle suspension systems by examining selected roads in Benue State, Nigeria. The specific objectives include surveying and measuring the dimensions and shapes of the bumps, determining the average vehicle speeds across these bumps, simulating the dynamic behavior of vehicle suspension systems using MATLAB, and analyzing the results to determine the effects of varying bump dimensions on vehicle suspension. The significance of the present research lies in its potential to provide crucial information about the impact of unprofessionally installed speed bumps on vehicles, particularly their effects on vehicle suspension systems. The study will also propose optimal bump dimensions that would minimize damage to vehicles, contributing to improved road safety and vehicle durability. By focusing on the dynamic behavior of vehicle suspensions, this research seeks to provide valuable insights that can guide the proper installation of speed bumps in Benue State and Nigeria as a whole. The present study is limited to investigating the effects of speed bumps on vehicle suspension systems using measured data and MATLAB simulations to model the dynamic loads experienced by vehicles when passing over speed bumps. These loads will be analyzed in conjunction with layered elastic analysis to assess the impact of different bump dimensions on vehicle suspension systems. Through this approach, the study aims to offer a comprehensive understanding of how speed bumps affect vehicles and contribute to road safety. Table I provides a summary of studies conducted on topics close to the present paper.

A. Speed Bump

Speed bumps are a widely utilized traffic calming measure designed to control vehicular speeds through vertical deflection, aiming to enhance road safety for both motorists and pedestrians. By compelling drivers to slow down as they approach and cross these raised structures, speed bumps help to reduce the likelihood and severity of accidents, particularly in areas where pedestrians are present or where speed control is crucial for safety [15].

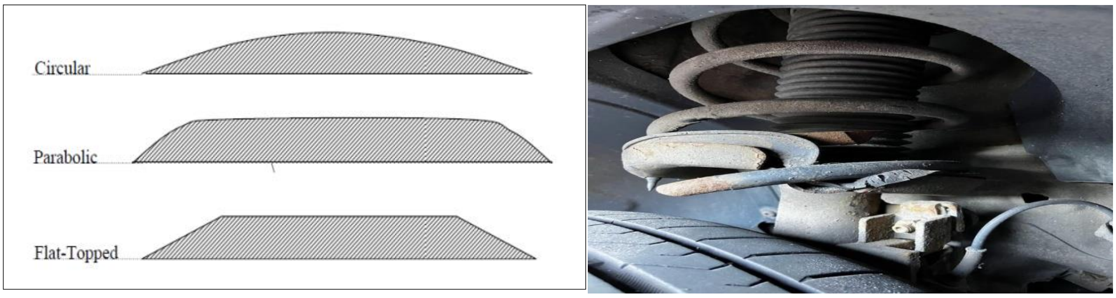
From a geometric perspective, speed bumps are defined by their distinct physical characteristics, including their base length, height, and width. These measurements create a protruding profile on the road surface that, depending on the dimensions, influences the degree of deceleration vehicles experience (see Fig. 1(a)). Typically, speed bumps range in height from 3 to 6 inches (approximately 76 to 152 mm) and extend across a base length of 1 to 3 feet (0.3 to 1 m) [5–7, 15]. The specific measurements used in any given speed bump installation can vary significantly, impacting their effectiveness and the level of discomfort experienced by drivers who do not reduce their speed.

In urban areas and on private roads within Nigeria, speed bumps are frequently found in parking lots, market areas, school zones, and estates. However, the inconsistency in their design often causes confusion for drivers, as there is no uniform standard dictating their height, shape, or spacing. This lack of standardization can cause vehicles to experience undue wear on suspension systems or result in abrupt stops, particularly when the speed bumps are poorly constructed or inadequately marked [16, 17]. The absence of uniform guidelines for speed bump construction on Nigerian roads means that, in many cases, the height and shape of speed bumps are left to the discretion of local authorities or private developers, leading to designs that vary significantly across different regions and road types.

Moreover, speed bumps in Nigeria are often installed in areas prone to high vehicle speeds where standard speed regulations might not be effectively enforced. Unfortunately, the haphazard installation of these speed bumps can sometimes lead to accidents or damage to vehicle suspension systems as shown in Fig 1(b), especially for vehicles traveling at speeds above the intended threshold. Consequently, the design inconsistency not only impacts vehicle comfort but also creates challenges in achieving optimal traffic control across Nigeria's varied road networks. Figure 1 describes the common profiles of speed bumps applications on roads and shows an example of a vehicle Suspension Failure.

Table I. Summary of Related Literature.

Authors (Year)	Title	Methodology	Findings	Research Gap
Fabra-Rodriguez (2024) [8]	Numerical model for vibro-acoustics analysis of tyre-road noise generation caused by speed bumps	Combining FEM and BEM methods, and performing dynamic analysis on the vehicle using a 3D tire model equipped with a suspension system	Increased noise level produced when driving on a speed bump compared to driving without a bump	Lack of appropriate finite element modeling of the actual conditions
Chiu *et al.* (2024) [9]	Design of sustainable energy harvesters using a 3D car suspension system model and half-width speed bump	Using simulated annealing algorithm and defining multiple objective parameters in the proposed functions	Increasing the vehicle's electrical power by up to 0.2 watts	Lack of appropriate mathematical formulas in defining the performance of engineering parameters in research
Audu and Odede (2023) [10]	Optimal Speed Bump Locations Based on Performance Indicators	Classical design of experiment, field tests on roads in Benue State, statistical analysis (ANOVA)	Speed bumps significantly affect passenger discomfort. Optimal design and placement minimize adverse suspension effects.	Study only established that poorly designed bumps cause discomfort; lacks comprehensive exploration of other potential factors.
Maftei *et al.* (2019) [11]	Influence of Speed Bumps on Braking Distance	Theoretical study using mathematical formulas, experimental study using real cars on dry roads with speed bumps	Speed bumps do not reduce braking distance. Induced forces from speed bumps affect car dynamics, especially on worn-out bumps with low adhesion.	Focused on braking distance; does not fully analyze long-term effects on vehicle suspension systems.
Deac *et al.* (2019) [12]	Vehicle Suspension Behavior Over Speed Bumps	Simulations to assess suspension response with different suspension designs, bump profiles, and vehicle dynamics	Suspension response varies with bump height and profile; optimizing suspension parameters improves handling and comfort.	Simulations based on simplified models; real-world testing and advanced modeling needed to capture complex dynamics and varying loads.
Purnomo *et al.* (2018) [13]	Correlation Between Speed Bump Dimensions and Motorcycle Speed	Field study on residential streets, regression analysis to correlate speed with bump dimensions	Height of speed bumps most significantly decreases vehicle speed.	Study only focused on motorcycles; does not consider the impact on other vehicle types or environmental factors.
Teja and Jyothi (2017) [14]	Speed Profile Analysis at Speed Breakers on An Urban Road	Field study at various locations in Hyderabad and Vijayawada, volume counts, video recording, speed reduction calculation	Speed reduction at bumps varies by location; significant reduction in speed, especially in urban areas.	Does not account for the impact of speed bump design variations or traffic density on speed reduction across different vehicle classes.



(a) (b)

Fig. 1. (a) Typical design profiles of speed bumps and (b) a vehicle suspension failure.

II. MATERIALS AND METHODS

A. Materials

The following materials and instruments were utilized in the present study to model and simulate the effects of speed bumps on vehicle suspension systems:

1) MATLAB™ Software 2020 Version,
2) Microsoft Excel 2019 version,
3) Measuring Tape,
4) Meter Rule,
5) A 0.1 RPM DT-2235B Digital-Handheld Speed Tachometer.

B. Site Selection

Five roads in Benue State, Nigeria, were selected for this study based on the presence of speed bumps as depicted in Fig. 3 and the roads are indicated in Fig. 2:

1) Makurdi – Gboko Road,

2) Makurdi – Aliade Road,
3) Gboko – Ugbema Road,
4) SRS Junction – JOSTUM Southcore,
5) Vandeikya – Tsar/Obudu Road.

These roads were chosen to ensure that each site experiences similar traffic conditions and is free from factors like merging or diverging lanes, which could alter vehicle dynamics. The site selection criteria followed [18] guidelines to ensure accurate assessments.

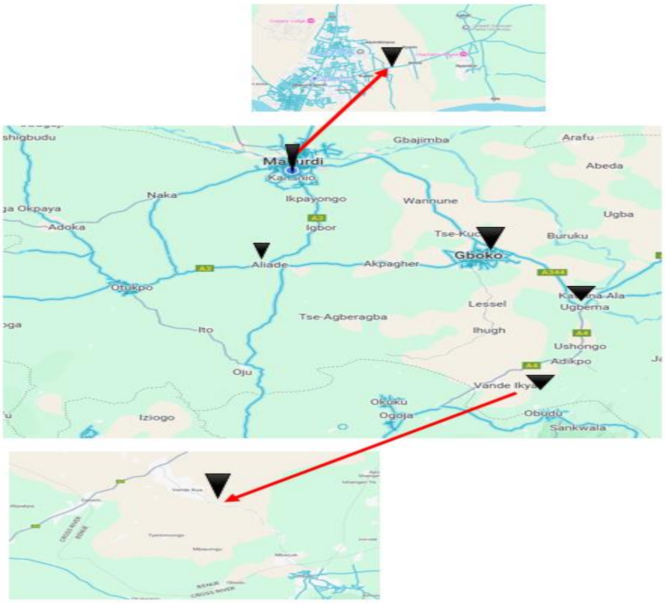


Fig. 2. A google map indicating the studied road.

C. Determination of Shape and Dimensions of Speed Bumps

The shape and dimensions of the speed bumps on the selected sites were measured using a measuring tape as shown in Fig. 3(b). Speed bumps were selected randomly per road, measurements taken and recorded. The geometry of these bumps plays a crucial role in how they affect vehicle suspension systems, and understanding their dimensions allows for a detailed simulation of their impact on vehicle dynamics.

(a) (b)

Fig. 3. (a) A Typical bump on the studied road and (b) taking measurement on a bump.

D. Determination of Average Speed of Various Vehicle Types

To determine the average speed of vehicles passing over speed bumps, a suitable location was chosen based on [18] guidelines. The digital handheld speed tachometer as shown in Fig. 4 was positioned strategically to capture vehicle speed at each site. Twenty vehicles were observed for each road, with their speeds measured as they crossed the speed bumps. The average speed for each vehicle type was calculated using Eq. (1) for each category.

$$\text{Average speed}(\bar{v}) = \frac{\text{sum of all speed}}{\text{total number of vehicles}} \quad (1)$$

Fig. 4. A digital handheld speed tachometer.

This measurement is vital for understanding how speed influences the vehicle suspensions and the forces applied to the road surface.

E. Impact Assessment of Speed Bumps on Vehicle Front Suspension System Using MATLAB

E1. Suspension System Overview

The vehicle suspension system consists of a spring-damper assembly that isolates the vehicle's body from road disturbances. In this study, we focus on a passive suspension system, where the system includes both sprung and unsprung masses connected via springs and dampers. The passive system's purpose is to absorb energy from road irregularities, providing a smoother ride and reducing wear on the vehicle.

E2. Mathematical Modelling of Speed Bump Geometry

To analyze the geometry of a vehicle moving over a circular speed bump, we start by defining key parameters and relationships involving the bump's height H, chord length L, and radius R with respect to the angle of inclination θ at the contact points on either side of the bump [15]. The bump is modeled as part of a circle, with the following relationships governing the bump's dimensions as depicted in Fig. 5.

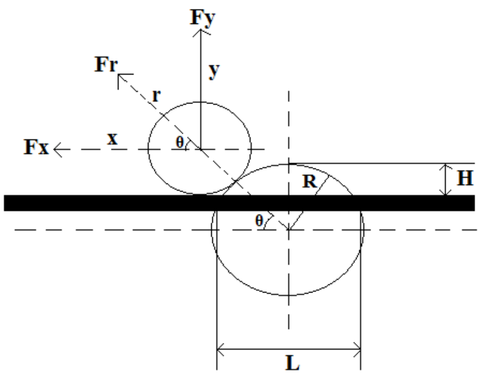


Fig. 5. The bump model.

From the geometry of the bump, the horizontal distance L relates to the angle θ and radius R as:

$$R.sin\theta = \frac{L}{2} \rightarrow R = \frac{L}{2.sin\theta} \quad (2)$$

Also the height H of the bump can also be derived from the radius and angle θ as:

$$H = R - R.cos\,\theta \rightarrow R = \frac{H}{1-cos\theta} \quad (3)$$

, where H: height of the bump (m), R: radius of the bump (m), L: chord length of the bump (m) and θ: Angle of inclination on the bump (degree).

From Eqs. (2) and (3), the following relationship is derived;

$$\frac{H}{1-cos\theta} = \frac{L}{2.sin\theta} \rightarrow \frac{H.sin\theta}{1-cos\theta} = \frac{L}{2} \quad (4)$$

Substituting sinθ, the expression becomes:

$$\frac{H.\sqrt{1-cos^2\theta}}{1-cos\theta} = \frac{L}{2} \quad (5)$$

Simplifying, this leads to the equation:

$$H.\sqrt{1-cos^2\theta} = \frac{L}{2} - \frac{L}{2}.cos\,\theta \quad (6)$$

Operating and reorganizing the terms,

$$\left(\frac{L^2}{4} + H^2\right).cos^2\theta - \frac{L^2}{2}.\cos\theta + \left(\frac{L^2}{4} - H^2\right) = 0 \quad (7)$$

Letting x = cos θ,the equation becomes:

$$\left(\frac{L^2}{4} + H^2\right).x^2 - \frac{L^2}{2}.x + \left(\frac{L^2}{4} - H^2\right) = 0 \quad (8)$$

Therefore, for a given height (*H*) and length (*L*) of the bump, angle θ used to define the bump geometry is obtained by solving Eq. (7). Once angle θ is found, the radius of the bump circle can be calculated either in terms of the bump length (*L*). Equation (8) is a quadratic equation in x = cos θ and can be solved using the quadratic formula as given in Eq. (9).

$$x = \frac{-b \pm \sqrt{b^2-4ac}}{2a} \quad (9)$$

, where, $a = \frac{L^2}{4} + H^2$: $\begin{cases} a = -\frac{L^2}{4} \\ c = \frac{L^2}{4} - H^2 \end{cases}$

So, once x = cos θ is determined, we calculate $\theta = \cos^{-1}(x)$.

E3. Vehicle Suspension Model

A quarter car model as shown in Fig. 6 is employed to simulate the behavior of a vehicle's suspension system traversing a speed bump. The model considers two degrees of freedom (2DOF), representing the sprung mass (vehicle body) and the unsprung mass (wheel assembly). The equations of motion are derived using Newton's second law of motion.

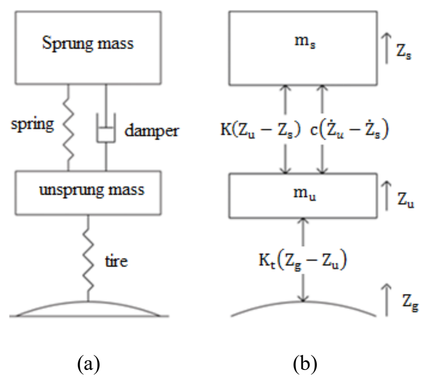


Fig. 6. Quarter car modeling.

The forces acting on the system are resolved using Eq. (10):

$$F = Kx \quad (10)$$

The equations of motion for system for both the masses are given as:

$$m_s\ddot{z}_s + c_s(\dot{z}_s - \dot{z}_u) + k_s(z_s - z_u) = 0 \quad (11)$$

$$m_u\ddot{z}_u + c_s(\dot{z}_u - \dot{z}_s) + k_s(z_u - z_s) + k_t(z_u - z_g) + c_t(\dot{z}_u - \dot{z}_g) = 0 \quad (12)$$

, where

m_s = Mass of the vehicle body supported by the suspension system

m_u = Mass wheel and other components not supported by the suspension system

k_s = Stiffness of the suspension spring

c_s = Damping coefficient of the suspension damper

k_t = Stiffness of the tire

z_s = Displacement of the sprung mass

z_u = Displacement of the unsprung mass

z_g = Road profile described by the bump

Considering the angle of inclination of the vehicle on the bump, the equations of motion are modified to account for the influence of θ:

$$m_s\ddot{z}_s + c_s\cos(\theta)(\dot{z}_s - \dot{z}_u) + k_s\cos(\theta)(z_s - z_u) = 0 \quad (13)$$

$$m_u\ddot{z}_u + c_s\cos(\theta)(\dot{z}_u - \dot{z}_s) + k_s\cos(\theta)(z_u - z_s) + k_t\cos(\theta)(z_u - z_r) + c_t\cos(\theta)(\dot{z}_u - \dot{z}_r) = 0 \quad (14)$$

The 4th-order Runge-Kutta method is applied to solve the equations of motion. The following state variables are used:

1) $y_1 = z_s$: sprung mass displacement
2) $y_2 = \dot{z}_s$: Velocity of the sprung mass
3) $y_3 = z_u$: Unsprung mass displacement
4) $y_4 = \dot{z}_u$: Velocity of the unsprung mass

These equations are solved numerically to determine the displacement and velocity of the sprung and unsprung masses over time.

$$\frac{dy_1}{dt} = y_2$$

$$\frac{dy_2}{dt} = \frac{c_s\cos\theta(y_2 - y_4) - k_s\cos\theta(y_1 - y_3)}{m_s}$$

$$\frac{dy_3}{dt} = y_4$$

$$\frac{dy_4}{dt} = \frac{c_s\cos\theta(y_2 - y_4) - k_s\cos\theta(y_1 - y_2) - k_t y_3}{m_u} \quad (15)$$

E4. Stress and strain Analysis

The stress in the suspension spring is calculated based on the forces acting on it. The force F in the spring is given by:

$$F = k_s\Delta_z \quad (16)$$

, where Δ_z is the relative displacement between the sprung and unsprung masses, the stress σ in the spring is calculated using Hooke's Law:

$$\sigma = F/A \quad (17)$$

, where A is the cross-sectional area of the spring and the strain is ϵ is calculated as:

$$\epsilon = \frac{\sigma}{E} \quad (18)$$

, where E is the Young's modulus of the spring material as described by [17]. This analysis allows for evaluating the forces, stress, and deformation experienced by the suspension system as the vehicle traverses the speed bump.

E5. Determination Forces Acting on the Suspension System

The forces exerted by the suspension spring, damper, and tire are determined through Eqs. (19), (20) and (21), respectively. These equations are derived based on the principles of linear momentum and Newton's second law of motion, which states that the rate of change of momentum of a body is directly proportional to the net external force acting on it. In this context, Newton's second law is applied to calculate the response of each component (spring, damper, and tire) to the forces exerted by the vehicle's mass and the varying loads encountered as it moves over speed bumps. By accounting for these forces, the suspension system's behavior under different road conditions is accurately modeled as stated by [18].

$$F_{spring} = k_s \cdot (z_u - z_s) \quad (19)$$

$$F_{damper} = c_s \cdot (v_u - v_s) \quad (20)$$

$$F_{tire} = k_t \cdot (z_g - z_u) \quad (21)$$

E6. MATLAB Program Development

According to [19], both linear and nonlinear ordinary differential equations can be solved using MATLAB's ODE45 solver. For the 2DOF quarter car model, a MATLAB program was developed to analyze the spring response of the suspension system as the vehicle passes over a speed bump. Input parameters for the analysis are detailed in Table II.

Using the ODE45 solver, the system's behavior over time is simulated based on the input road profile, specifically the speed bump geometry, and vehicle speed. The program calculates the displacements and forces in the suspension system, providing insights into how the system responds to varying bump geometries and speeds.

Table II. Values of different vehicles suspension parameters [15].

Parameters	Symbol	Values			Unit
		Car (Sedan)	SUV (Jeep)	Bus (Minivan)	
Vehicle Body Mass	m_b	300	2210	3645	Kg
Wheel Mass	m_w	60	120	140	Kg
Stiffness of First Spring	K_1	16000	30000	30000	N/m
Stiffness of Second Spring	K_2	190000	250000	270000	N/m
Damping factor of spring damper	b	1000	3500	5000	Ns/m
Wheel Base	W	2.69	2.85	8.50	M

III. RESULTS AND DISCUSSION

Figures 7-11 depict the dynamic behaviour of passenger car suspension systems negotiating speed bumps on various highways, while Table 3 presents the results of Bus and SUV simulations. The findings emphasise stress in the suspension spring, pitch angle, spring displacement, spring force, damper force, tyre force, and settling time.

The findings in Table III show that larger vehicles, such as buses, experience significantly higher stresses in their suspension systems, particularly on the Gboko-Ugbema road, where buses have a suspension spring stress of 11.52 MPa, pitch angle of 10.23 radians, and spring displacement of 0.22 m, indicating significant wear on suspension components over time. The settling time for buses on this road exceeds 5 seconds, indicating a slower return to equilibrium after over the bump. The SUVs also face significant stress and force, particularly on Gboko-Ugbema, where the stress reaches 12.39 MPa, with a spring force of 6.2 kN and a damper force of 12 kN, indicating greater strain on suspension components.

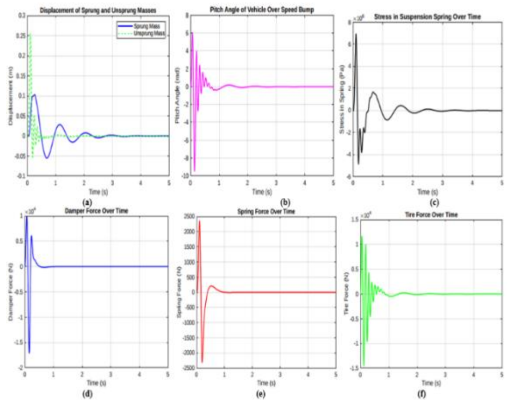


Fig. 7. Dynamic Behavior of a car suspension system over speed bump on Makurdi – Gboko Road:(a) Upward displacement of the sprung and unsprung masses vs time, (b) Pitch angle of the vehicle vs time, (c) Stress in the suspension vs time, (d) Damper force of the suspension vs time, (e) Spring force of the suspension vs time (f) Tire force of the suspension vs time.

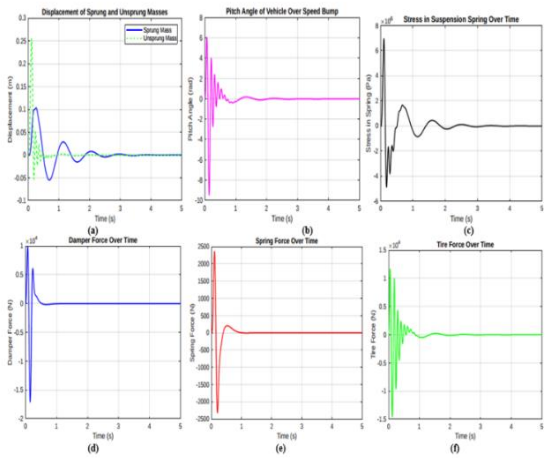


Fig. 8. Dynamic Behavior of a car suspension system over speed bump on Gboko-Ugbema Road: (a) Upward displacement of the sprung and unsprung masses vs time, (b) Pitch angle of the vehicle vs time, (c) Stress in the suspension vs time, (d) Damper force of the suspension vs time, (e) Spring Force of the suspension vs time (f) Tire force of the suspension vs time.

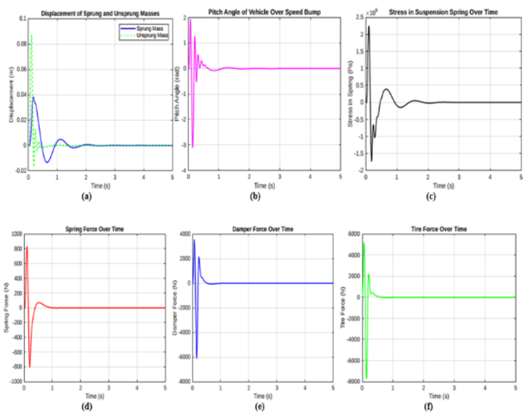


Fig. 9. Dynamic Behavior of a car suspension system over speed bump along Makurdi – Gboko Road: (a) Upward displacement of the sprung and unsprung masses vs time, (b) Pitch angle of the vehicle vs time, (c) Stress in the suspension vs time, (d) Spring force of the suspension vs time, (e) Damper force of the suspension vs time, (f) Tire force of the suspension vs time.

However, SUVs exhibit more moderate dynamic behaviour on the Makurdi-Gboko route, with a lower pitch angle of 2.71 radians and a shorter settling time of 4.2 seconds.

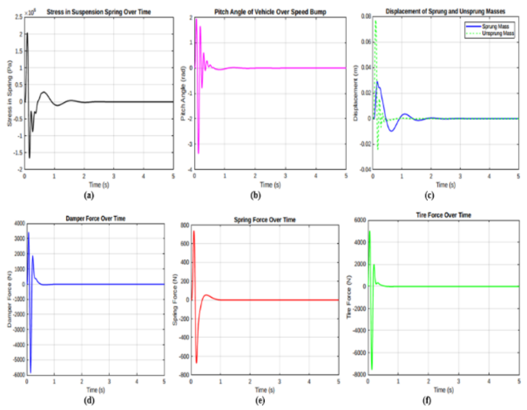


Fig. 10. Dynamic behavior of a car suspension system over speed bump on Makurdi – Aliade Road: (a) Stress in the suspension vs time, (b) Pitch angle of the vehicle vs time, (c) Upward displacement of the sprung and unsprung masses vs time, (d) Damper force of the suspension vs time, (e) Spring force of the suspension vs time (f) Tire force of the suspension vs time.

On highways such as Makurdi-Aliade and SRS-JOSTUM, cars typically exhibit gentler dynamic behaviour, with stress levels below 2.5 MPa and spring displacements less than 0.08 m. However, cars on Gboko-Ugbema have a spring displacement of 0.25 m and a pitch angle of 5.43 radians, indicating strong dynamic responses to greater bumps. Cars settle in around 2-3 seconds, with the exception of roads with severe bump geometry. These findings are consistent with [10, 20-22], who said that large overshoot and extended settling times are bad for suspension lifetime. The findings confirm that greater shocks have the greatest impact on buses and SUVs, but cars, while less affected, nevertheless exhibit significant dynamic responses.

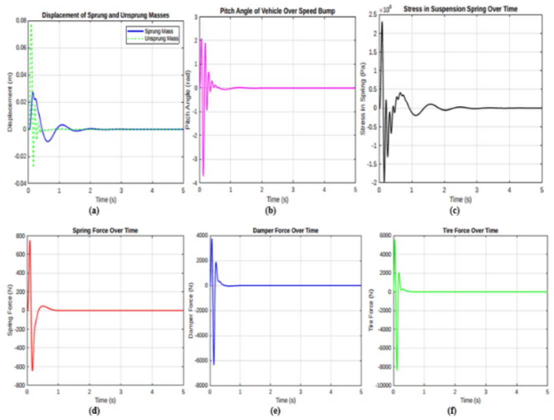


Fig. 11. Dynamic behavior of a car suspension system over speed bump on Vandeikya – Tsar/Obudu Road: (a) Upward displacement of the sprung and unsprung masses vs time, (b) Stress in the suspension vs time, (c) Pitch angle of the vehicle vs time, (d) Spring force of the suspension vs time, (e) Damper force of the suspension vs time, (f) Tire force of the suspension vs time.

Table III. Summary of simulation results.

Road	Vehicle Type	Stress in Suspension Spring (MPa)	Pitch Angle (rad)	Spring Displacement (m)	Spring Force (kN)	Damper Force (kN)	Tire Force (kN)	Settling Time of Spring (s)
Makurdi - Gboko	*Car*	2.85	3.29	0.11	0.8	6.0	8.0	2.0
	SUV	4.95	2.71	0.09	2.5	6.4	12.0	4.2
	Bus	5.81	6.79	0.09	2.6	5.8	10.0	5.0
Makurdi - Aliade	*Car*	2.04	1.93	0.08	0.72	3.4	4.5	2.0
	SUV	3.79	1.82	0.07	1.8	4.2	7.8	4..2
	Bus	4.67	6.24	0.06	2.0	4.2	7.0	5.0
SRS - JOSTUM	*Car*	2.08	2.08	0.08	0.75	3.8	5.8	2.5
	SUV	3.74	2.00	0.07	1.80	5.0	8.0	4.2
	Bus	3.94	4.75	0.07	1.90	3.9	6.8	5.0
Gboko - Ugbema	*Car*	6.34	5.43	0.25	2.4	1.0	11.0	2.8
	SUV	12.39	5.09	0.23	6.2	12.0	20.0	5.0
	Bus	11.52	10.23	0.22	5.8	8.2	14.0	>5
Vandeikya – Tsar/Obudu	*Car*	2.24	1.94	0.09	0.81	3.5	5.2	1.8
	SUV	4.31	1.73	0.08	2.20	4.1	7.0	4.3
	Bus	4.22	4.10	0.08	2.20	3.2	5.3	>5

Table IV. Average Bump Data of the Studied Roads.

Road/Location	Number of Speed Bumps Studied	Road length (m)	Average Bump Height (m)	Average Bump width (m)	Bump Shape
SRS – JOSTUM	11	6600	0.06	0.20	Circular
Makurdi-Gboko	10	88100	0.08	0.25	Circular
Makurdi - Aliade	14	59200	0.06	0.29	Circular
Gboko-Ugbema	7	45700	0.17	0.31	Circular
Vandeikya- Tsar	15	16200	0.07	0.32	Parabolic

Table IV compares the dimensions and shapes of speed bumps on the analysed highways to those reported in [15] and [23]. The findings revealed that all bumps investigated were circular, with the exception of those on the Vandeikya-Tsar/Obudu route, which were parabolic. According to [15], speed bumps should be 0.15 m high and 0.30 m long, with a suggested driving speed of 10-15 km/h. The bumps on Gboko-Ugbema exceed the height restriction by an average of 0.17 m and a width of 0.31 m, thereby increasing deceleration and stress on vehicle suspension systems, especially when vehicle speeds of 17.79 km/h for cars and 16.65 km/h for SUVs exceed the recommended limits. Bumps on SRS-JOSTUM South-core and Makurdi-Aliade roads, with heights of 0.06 m, fall short of the recommended dimensions, resulting in increased vehicle speeds of 19.67 km/h on Makurdi-Aliade, which exceeds safe limits. The bump on Makurdi-Gboko, which is closer to [15] with a height of 0.08 m and width of 0.25 m, results at higher average speeds of 24.20 km/h for automobiles and 21.20 km/h for SUVs, exceeding ITE's recommended speed range. These differences in bump diameters throughout the examined roads present issues in successfully managing vehicle speeds and may necessitate improvements for greater compliance with [15].

IV. CONCLUSION

The study found considerable differences in the dimensions and designs of speed bumps on selected roads in Benue State. While some bumps exceeded acceptable criteria, many had irregular geometries, with steeper heights and abrupt profiles, which contributed to poor vehicle dynamics. Field measurements revealed that vehicle speeds varied greatly depending on bump dimensions and placement, with larger and poorly designed bumps causing abrupt deceleration and increasing the risk of suspension damage for vehicles travelling at higher speeds, particularly on roads with inadequate signage.

MATLAB simulations effectively modeled the dynamic responses of various vehicle types traversing speed bumps, capturing critical parameters such as stress in the suspension spring, pitch angle, spring displacement, spring force, damper force, tire force, and settling time. The analysis highlighted that larger and steeper bumps, particularly on roads like Gboko-Ugbema, caused excessive stress and prolonged settling times, especially for heavier vehicles like buses and SUVs. In contrast, roads like Makurdi-Aliade, which have bump dimensions closer to standard guidelines, put little strain on vehicle suspension systems.

To address these findings, relevant bodies and government agencies should perform frequent checks to prevent the indiscriminate implementation of unauthorised speed bumps, particularly in Benue State. Road users should be taught about the economic benefits of speed bumps in controlling traffic flow, protecting car suspension systems, and improving ride comfort. Additionally, speed bumps should be maintained on a regular basis to ensure that their size remain within the approved safe limits. Finally, speed monitoring devices should be implemented, particularly on roads with small bumps, to improve traffic calming effectiveness.

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CONFLICT OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICS STATEMENTS

Our publication ethics follow The Committee of Publication Ethics (COPE) guideline. https://publicationethics.org/

DATA AVAILABILITY STATEMENT

The data are available from the corresponding author upon request. (If applicable provide the data link)

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