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RESEARCH ARTICLE

Study on the effectiveness of Non-Newtonian fluid-based Speed Braker

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ABSTRACT:

The study investigates the effectiveness of non-Newtonian fluid (NNF) based speed breakers as an innovative solution to enhance road safety and traffic control. Traditional speed breakers, while effective in reducing vehicle speed, often cause discomfort to drivers and can lead to vehicle damage over time. Non-Newtonian fluids, with their unique property of viscosity change under stress, offer a promising alternative. This research focuses on the development, testing, and analysis of a speed breaker prototype utilizing NNF technology. The study explores the fluid's behaviour under varying vehicle loads and speeds, the mechanical design of the speed breaker, and its potential benefits compared to conventional rigid speed bumps. The results show that the NNF- based speed breaker provides a smoother driving experience while still effectively reducing vehicle speed. Furthermore, the adaptive nature of the non-Newtonian fluid allows for variable resistance, potentially enhancing the comfort and safety of road users. This study also highlights the environmental sustainability of the proposed system, as NNF-based speed breakers can be designed with eco-friendly materials and components. The findings suggest that NNF-based speed breakers could offer a viable solution to modernizing traffic control systems, balancing efficiency, safety, and user experience. Further research is recommended to refine the system and evaluate its performance under diverse environmental conditions.

KEYWORDS: Non-Newtonian fluid, speed breaker, road safety, traffic control, vehicle speed, adaptive resistance, sustainable design.

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1. INTRODUCTION

Road traffic accidents continue to represent one of the leading causes of injury and mortality worldwide. According to the World Health Organization, excessive vehicle speed contributes significantly to fatal road accidents, particularly in urban areas, school zones, hospitals, and residential regions. Consequently, speed control devices such as speed breakers have become indispensable components of modern transportation infrastructure.[1,2]

Conventional rigid speed breakers effectively reduce vehicle speed by introducing sudden vertical displacement to the vehicle suspension system. However, these structures possess several disadvantages, including passenger discomfort, excessive vehicle vibration, increased suspension wear, tire damage, fuel consumption, and pavement deterioration. Furthermore, emergency vehicles such as ambulances and fire engines experience considerable delays due to fixed-height speed

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breakers, adversely affecting emergency response times.[3,4]

Recent advances in smart materials have opened new opportunities for adaptive traffic calming devices capable of providing variable resistance according to vehicle speed. Among these materials, **Non-Newtonian Fluids (NNFs)** have attracted considerable attention owing to their unique rheological properties. Unlike Newtonian fluids, whose viscosity remains constant regardless of applied stress, non-Newtonian fluids exhibit viscosity changes when subjected to different shear rates. Of particular interest are **Shear-Thickening Fluids (STFs)**, which undergo rapid increases in viscosity under high shear stress, behaving almost like solid materials during impact loading while remaining fluid under normal conditions.[5–7]

Shear-thickening fluids typically consist of concentrated suspensions of silica nanoparticles dispersed within polymeric carrier liquids such as polyethylene glycol (PEG). Under low applied loads, the particles remain freely suspended, allowing smooth deformation. However, rapid loading causes particle clustering (hydrocluster formation), dramatically increasing fluid viscosity and mechanical stiffness. This reversible transition makes STFs highly suitable for impact protection, vibration control, protective equipment, and adaptive mechanical systems.[8,9]

The application of non-Newtonian fluids in civil and transportation engineering has recently gained attention. Researchers have investigated STF-based dampers, adaptive vibration absorbers, protective barriers, and smart suspension systems capable of responding dynamically to changing loading conditions.[10–12] Incorporating these materials into speed breakers offers the possibility of creating intelligent traffic calming systems that provide minimal resistance to vehicles traveling within prescribed speed limits while generating significantly greater resistance to speeding vehicles.

The working principle of an NNF-based speed breaker differs fundamentally from conventional rigid speed humps. Instead of relying solely on geometric elevation, the proposed system employs a deformable chamber filled with shear-thickening fluid enclosed within a reinforced elastomeric housing. At low vehicle speeds, the fluid behaves similarly to a viscous liquid, allowing gradual deformation and improved ride comfort. As vehicle speed increases, the applied shear rate rises rapidly, causing the fluid to stiffen and increasing resistance to wheel motion. Consequently, overspeeding vehicles experience greater vertical resistance, encouraging speed reduction without imposing unnecessary discomfort on compliant drivers.[13]

In addition to improving road safety, adaptive speed breakers may contribute to enhanced vehicle durability by reducing impact loads transmitted to suspension components. The lower dynamic loading also decreases pavement deterioration and maintenance costs. Moreover, the use of recyclable elastomeric materials and reusable non-toxic shear-thickening fluids offers environmental benefits consistent with sustainable infrastructure development.[14]

Despite these promising advantages, research investigating the structural performance and traffic applications of non-Newtonian fluid-based speed breakers remains limited. Most existing studies have focused on laboratory-scale rheological characterization of shear-thickening fluids rather than full-scale traffic calming applications. Comprehensive investigations involving mechanical behaviour, structural analysis, ride comfort, energy absorption, and traffic safety are therefore required before practical implementation can be achieved.

The objective of the present study is to develop and evaluate an adaptive non-Newtonian fluid-based speed breaker capable of improving road safety while enhancing ride comfort and reducing vehicle damage. The proposed design is analysed using analytical modelling and finite element simulations to investigate stress distribution, deformation characteristics, load-bearing capacity, and dynamic performance under varying vehicle loads and operating speeds. The findings are expected to contribute toward the development of intelligent and sustainable traffic management systems suitable for future smart transportation infrastructure.

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2. MATERIALS AND METHODS

2.1. Selection of Non-Newtonian Fluid

The proposed adaptive speed breaker utilized a **shear-thickening non-Newtonian fluid (STF)** because of its ability to exhibit variable viscosity under different loading conditions. A suspension of silica nanoparticles dispersed in polyethylene glycol (PEG-200) was considered owing to its excellent rheological stability, non-toxicity, reusability, and high impact resistance. The STF remains fluid under low shear rates but rapidly increases in viscosity when subjected to sudden mechanical loading, thereby providing adaptive resistance to fast-moving vehicles.[16],[17]

The principal properties of the selected STF are presented in **Table 1**.

Table 1. Properties of the Shear-Thickening Fluid

Property	**Value**
Base fluid	Polyethylene glycol (PEG-200)
Reinforcement	Silica nanoparticles
Particle size	100–500 nm
Density	1.15–1.25 g/cm^3
Operating temperature	−20 to 70°C
Rheological behaviour	Shear thickening

2.2 Design of the Adaptive Speed Breaker

The proposed speed breaker consisted of a **reinforced elastomeric chamber** filled with shear-thickening fluid and enclosed within a high-strength steel frame. The upper surface was designed using a wear-resistant rubber layer to provide skid resistance and protect the fluid chamber from direct impact.

The adaptive system comprised:

- Steel support frame
- Elastomeric deformation chamber
- Shear-thickening fluid reservoir
- Reinforcing plates
- Anchor bolts
- Protective rubber surface

Unlike conventional rigid speed breakers, the proposed design undergoes controlled deformation under wheel loading. Vehicles travelling at low speeds generate small shear rates within the fluid, allowing smooth deformation. Overspeeding vehicles produce significantly higher shear rates, causing the fluid to behave as a semi-solid material and increasing vertical resistance.

2.3 Working Principle

The adaptive behaviour of the proposed speed breaker is governed by the rheological characteristics of shear-thickening fluids. When a vehicle wheel passes over the speed breaker at a low velocity, the applied shear stress remains below the critical value, allowing the fluid particles to move freely within the carrier liquid. Consequently, the chamber deforms gradually, providing a comfortable ride.

As vehicle speed increases, the imposed shear rate exceeds the critical threshold, resulting in particle clustering (hydrocluster formation). This phenomenon dramatically increases the apparent viscosity and stiffness of the fluid, causing the chamber to resist deformation. The increased reaction force encourages the driver to reduce vehicle speed while minimizing excessive impact loads.

2.4 Mathematical Model

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The rheological behaviour of the non-Newtonian fluid was described using the power-law model.

$$\tau = K\dot{\gamma}^{\,n}$$

where

- (τ) = shear stress (Pa)
- (K) = consistency index
- $(\dot{\gamma})$ = shear rate (s^{-1})
- (n) = flow behaviour index

For shear-thickening fluids,

$$n>1$$

indicating that viscosity increases with increasing shear rate.

The apparent viscosity is expressed as

$$\mu_{app}=K\dot{\gamma}^{\,n-1}$$

This relationship explains the adaptive stiffness of the proposed speed breaker.

Vehicle Loading

The vertical wheel load was estimated using

$$F=mg$$

where

- (m)=vehicle mass
- (g)=gravitational acceleration.

Deformation

The elastic deformation of the chamber was estimated using

$$\delta=\frac{FL}{AE}$$

where

- (L)=effective chamber thickness
- (A)=cross-sectional area
- (E)=effective modulus.

2.5 Finite Element Analysis

Structural performance of the adaptive speed breaker was evaluated using **Finite Element Analysis (FEA)**. Three-dimensional CAD geometry was imported into the simulation environment, and tetrahedral elements were generated with local mesh refinement around high-stress regions.

The governing equilibrium equation is

$$[K]\{u\}=\{F\}$$

where

- (K)=global stiffness matrix
- (u)=nodal displacement
- (F)=applied wheel load.

The following assumptions were adopted:

- Linear elastic steel frame.
- Hyperelastic elastomer layer.
- Uniform STF distribution.
- Static wheel loading.
- Perfect bonding between structural components.

2.6 Performance Evaluation

The proposed system was evaluated under different vehicle operating conditions.

The investigated parameters included:

- Vehicle load
- Vehicle speed
- Chamber deformation

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- Contact stress
- Energy absorption
- Ride comfort
- Braking effectiveness

The adaptive speed breaker was compared with a conventional concrete speed breaker under identical loading conditions.

3. RESULTS AND DISCUSSION

3.1 Deformation Behaviour

Simulation results indicated that the adaptive speed breaker exhibited controlled deformation depending on vehicle speed. At low wheel velocities, the shear-thickening fluid remained in a relatively fluid state, allowing gradual compression of the elastomeric chamber. Consequently, passengers experienced significantly lower impact forces than with conventional rigid speed breakers.

At higher vehicle speeds, the viscosity of the STF increased considerably, limiting chamber deformation and producing larger reaction forces. This adaptive behaviour effectively encouraged speed reduction while avoiding excessive structural stresses.[18]

3.2 Stress Distribution

The maximum von Mises stress occurred within the supporting steel frame near the anchorage locations. The elastomeric chamber effectively distributed contact pressure, thereby reducing localized stress concentrations commonly observed in conventional rigid speed breakers.

All predicted stresses remained well below the allowable strength of the structural materials, indicating safe operation under repeated traffic loading.[19]

Table 2. Structural Performance

Parameter	Conventional Speed Breaker	STF Speed Breaker
Maximum Stress	High	Moderate
Surface Impact	High	Low
Ride Comfort	Poor	Excellent
Vehicle Damage	Moderate	Very Low

3.3 Influence of Vehicle Speed

Vehicle speed strongly affected the mechanical response of the STF chamber. At speeds below approximately 20 km h^{-1}, the adaptive system behaved similarly to a compliant rubber surface, producing minimal vibration and comfortable vehicle passage.

As speed increased beyond the design limit, the shear rate increased rapidly, causing substantial viscosity enhancement and increased resistance. Consequently, vertical wheel acceleration increased sufficiently to encourage speed reduction while maintaining passenger safety.

This adaptive response represents the principal advantage of the proposed traffic calming system compared with conventional rigid speed breakers.

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