SIMULATION STUDY OF ABS BRAKE SYSTEM USING CARSIM SOFTWARE

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ABSTRACT

The brake system is an active safety mechanism of vehicles, used to reduce speed or stop and park the vehicle when necessary. It is one of the main integral components and plays a crucial role in controlling vehicles on the road. In this study, the group utilized the CarSim software to conduct simulations on curved roads with varying speeds, establishing sample databases to the basic simulation problem-solving approach. The simulation results can be outputted in the form of motion videos and graphs, facilitating the analysis of the brake system's performance.

Keywords: *Simulation, Carsim software, ABS brakes.*

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1. INTRODUCTION

The braking system is a critical component of automobiles, ensuring safety by reducing speed or bringing the vehicle to a stop. The alarming traffic accident statistics, with 11,779 cases recorded in the first 11 months of the year exceeding the total for 2022 [1] highlight the importance of braking systems, particularly Anti-lock Braking Systems (ABS). Recognizing this, numerous studies have focused on enhancing ABS efficiency.

Mokarram et al. [2] proposed a fuzzy ABS controller using CMOS circuits, enabling the system to operate quickly, conserve energy, and adapt effectively to sensors. For commercial vehicles, Li et al. [3] analyzed a pneumatic ABS model and validated its effectiveness using AMESim and Simulink simulations, demonstrating a maximum deceleration error of only 13.51%. For hybrid vehicles, Xu et al. [4] introduced new braking modes combining regenerative braking with ABS, reducing energy losses and improving efficiency. In Vietnam, Duc et al. [5] used Matlab to simulate ABS systems, providing a theoretical foundation for evaluating braking performance. Ho Huu Hung’s dissertation [6] focused on pneumatic ABS, building a simulation model and proposing a control algorithm based on wheel angular acceleration to determine the control threshold for ABS. Similarly, Tran Van Hoang and Tran Vu Lam [7] simulated ABS control thresholds for pneumatic braking systems using Matlab, comparing control methods based on slip ratio and wheel angular acceleration.

These studies have significantly contributed to optimizing ABS systems and enhancing traffic safety. While investigating the body of scientific work on ABS systems, we found that although numerous studies have been conducted domestically and internationally, research on ABS systems using CarSim software remains limited. Therefore, this study focuses on simulating ABS performance on curved roads at various speeds, using CarSim to analyze and compare condition parameters. The objective is to provide deeper insights into system performance and propose solutions to improve vehicle safety during operation.

2. THEORETICAL BASIS

2.1. Vehicle Kinematic Equation

The fundamental equation describing the kinematics of a vehicle can be expressed as follows [8]:

$$F_{\Sigma} = m.a$$

Where: F_{Σ}: the total force acting on the vehicle; m: the mass of the vehicle; a: the acceleration of the vehicle.

2.2. Braking Torque

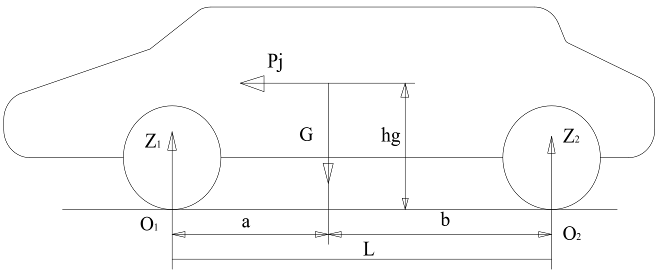


Fig. 1. Orces and dimensions acting on the vehicle

In this section, we determine the forces and braking torques acting on the vehicle's wheels. The key factors include the vehicle's weight G, the vertical reactions at the wheels (Z_1, Z_2), and the inertial force P_j.

To calculate Z_1, the moment equilibrium of forces about the rear tire-ground contact point is considered [8]:

$$Z_1L - Gb - P_jh_g = 0$$

$$=> \quad Z_1 = \frac{Gb + P_jh_g}{L}$$

Similarly: $Z_2 = \frac{Ga + P_jh_g}{L}$

2.3. Braking Torque on Axles

For brake mechanisms directly applied to the wheels, the required braking torque at each axle can be calculated as follows [8]:

For the front axle:

$$M_{p_1} = \varphi G_1^p r_{bx} = \varphi Z_1 r_{bx} = \frac{Gb}{2L}\left(1 + \frac{j_{max}h_g}{gb}\right)\varphi r_{bx}$$

For the rear axle:

$$M_{p_2} = \varphi G_2^p r_{bx} = \varphi Z_2 r_{bx} = \frac{Ga}{2L}\left(1 - \frac{j_{max}h_g}{gb}\right)\varphi r_{bx}$$

2.4. Wheel Rotational Equation

The equation describing the rotational motion of the wheel is expressed as follows [9]:

$$I \cdot \alpha = M_p - M_{\Sigma k}$$

Where: I: the moment of inertia of the wheel; α: the angular acceleration of the wheel; M_p: the braking torque; $M_{\Sigma k}$: the total resistive torque.

2.5. Operating Principle of ABS

The Anti-lock Braking System (ABS) is a critical technology used to improve vehicle braking safety and performance. ABS functions by controlling brake pressure to prevent wheel lock-up during braking, which helps maintain vehicle steerability and stability.

The control mechanism of ABS relies on measuring the wheel rotational velocity (V_ω) and the vehicle velocity (V). To determine the locking condition, the slip ratio (S) is calculated using the formula::

$$S = \frac{V - V_\omega}{V}$$

The ABS operation proceeds through the following steps:

1. Speed Measurement: Sensors measure the speed of the wheels and the vehicle.

2. Slip Calculation: Wheel slip is determined and compared against threshold values S_max and S_min. If S exceeds S_max, the system reduces brake pressure to prevent wheel lock. Conversely, if S falls below S_min, brake pressure is increased to maintain braking effectiveness.

3. Pressure Modulation: The applied brake pressure (Pa) is adjusted based on the required pressure (Pr) via solenoid valves. Specifically, when reducing brake pressure:

$$P_a = P_a - K_d * (P_a - P_r) * T_s$$

And when increasing pressure:

$$P_a = P_a + K_i * (P_r - P_a) * T_s$$

Where K_d and K_i are gain constants, and Ts is the sampling time. (Note: This represents a discrete-time control logic, likely P or PI based)

4. Process Repetition: This entire process is continuously repeated to optimize brake pressure in real-time, ensuring wheel slip control and thereby enhancing vehicle safety. The real-time monitoring of wheel angular velocity and timely response through pressure modulation constitute the core principle of ABS and form the basis for the control algorithm within CarSim, even though the specific source code is proprietary.

3. RESEARCH CONTENT

3.1. Algorithm Flowchart

The algorithm is constructed based on the structural parameters and operational principles of the ABS braking system, utilizing Carsim software to simulate various operating conditions. The flowchart is designed to determine the ABS slip ratio threshold, analyze braking distance, angular velocity, and theoretical angular acceleration, and subsequently identify the optimal speed threshold.

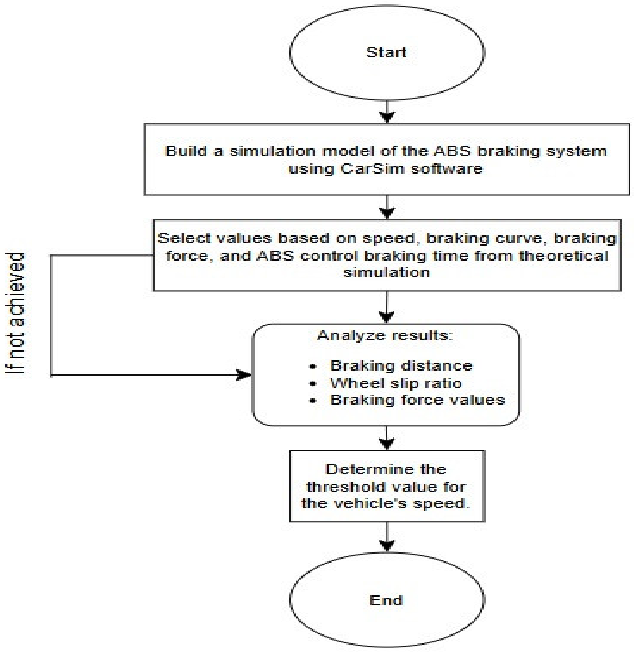


Fig. 2. Simulation algorithm flowchart

3.2. Simulation Using CarSim Software

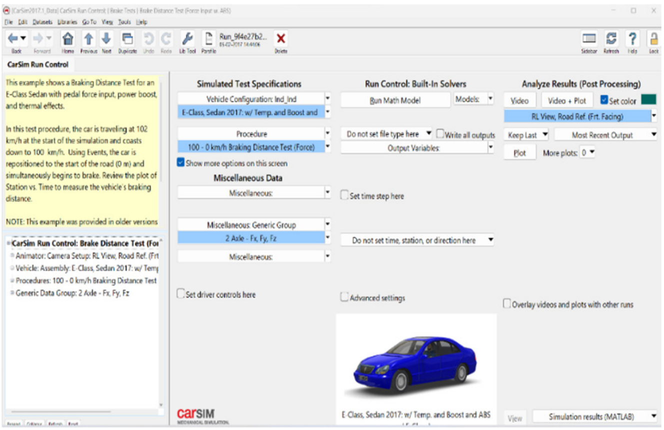


Fig. 3. CarSim software interface

The CarSim software is employed to simulate the vehicle dynamics of various types of automobiles, including racing cars, passenger cars, and light trucks. Traditionally, automotive system testing required numerous stakeholders, specialized equipment, and complex processes, which often introduced errors and reduced the accuracy of results [10].

Using CarSim helps save time and resources while ensuring accuracy. It provides comprehensive simulation results to support the efficient development of automotive systems.

3.3. ABS System Simulation on Curved Roads

The study focuses on simulating the performance of the ABS system at different speeds on curved roads, comparing the results to scenarios without ABS. The objective is to analyze the motion trajectory and numerical outcomes of the system to propose safety solutions, especially for speed braking limits. The simulation process includes the following main steps:

Input Data:

Dataset Setup: Create a dataset named “ABS Curved Road” and configure parameters such as Vehicle Configuration (e.g., “B-class, Hatchback 2017”) and Procedure (“Split Mu from XY km/h”).

Table 1. Vehicle Parameters

Parameter	Value / Description	Notes
Base Model	CarSim "B-class, Hatchback 2017"	B-Segment Passenger Car
Gross Vehicle Mass	~1350kg	Incl. nominal driver payload
Wheelbase	2.60m	
CG Height (Sprung)	~0.55m (Above ground)	
Tire Model	CarSim Default (Pacejka-based)	Standard passenger car tires
ABS System	- Enabled: CarSim Standard ABS (ABS runs)	Individual wheel control
	- Disabled: (Non-ABS runs)	

Road Configuration: Use the “Alt 3 from FHWA” in the 3D Road menu to simulate the curved road. Preview the setup using the "Video Preview" option.

Table 2. Road Conditions

Parameter	Value / Description	Notes
Road Type	CarSim "Alt 3 from FHWA" (3D Road)	Standard curved test track
Surface	Dry, Clean Asphalt	
Friction Coeff. (Peak)	$\mu \approx 0.9$	Nominal tire-road friction

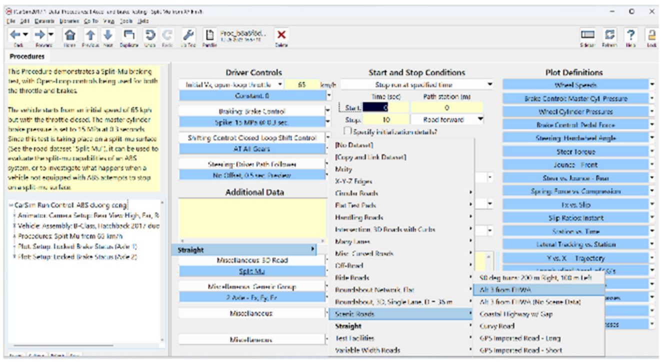


Fig. 4. Curved Road Setup in CarSim using 'Alt 3 from FHWA

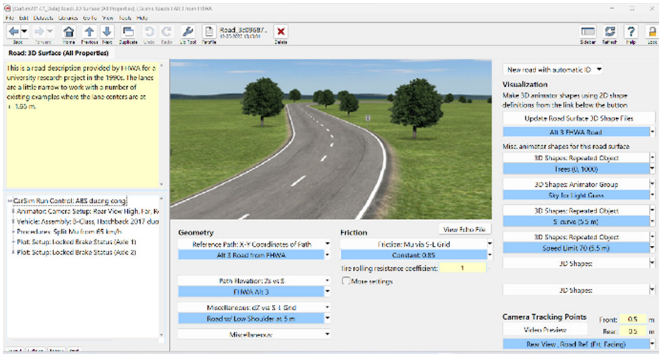


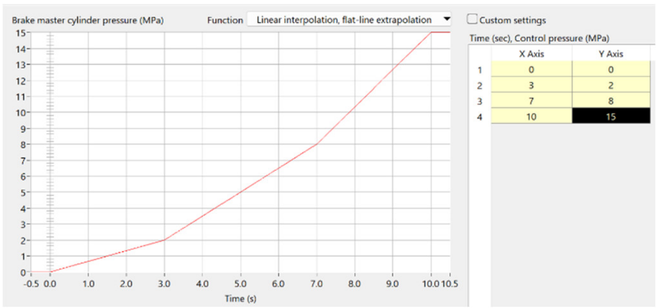
Fig. 5. Curved road setup

Brake Timing Adjustments:

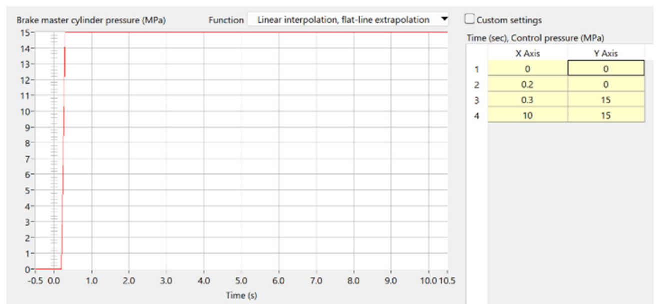
- Modify brake timing and pressure through "Braking - Brake Control" in two cases: gradual braking and sudden braking.

Table 3. Braking Parameters

Parameter	Gradual Braking	Sudden Braking	Notes
Control Method	Master Cylinder Pressure vs. Time	Master Cylinder Pressure vs. Time	Normalized pressure input (0-1)
Braking Start Time	1.0s	1.0s	Relative to simulation start
Time to Max Pressure	2.5s (from 1.0s to 3.5s)	0.3s (from 1.0s to 1.3s)	Ramp-up time from 0 to 1
Input Data (Time, Press.)	(0,0), (1,0), (3.5,1), (15,1)	(0,0), (1,0), (1.3,1), (15,1)	



Case 1: Gradual Braking



Case 2: Sudden Braking

Fig. 6. Brake parameter adjustments

- Further customize parameters such as speed, simulation time, and starting position.

Table 4. Other Simulation Parameters

Parameter	Value	Notes
Initial Speed	65, 120, 150, 170km/h	Constant before braking
Simulation Time	15.0s	Sufficient for most stops
Comparison Method	CarSim "Overlay" feature	Visual comparison (ABS Green, Non-ABS Blue)
Solver Settings	CarSim 2017.1 Default	

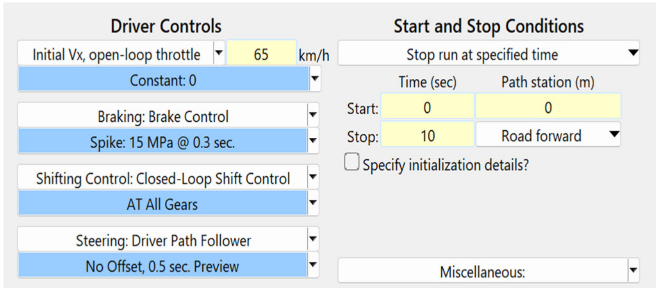


Fig. 7. Driver Controls, Start and Stop Conditions

Comparative Dataset Creation: Create a "NoABS Curved Road" dataset with similar configurations to provide a visual comparison between vehicles with and without ABS.

Simulation Execution.

Convention: The green vehicle represents ABS-enabled, and the blue vehicle represents non-ABS.

Process: Run the simulation using "Run Math Model." When changing speed or parameters, ensure both datasets are executed simultaneously for accurate analysis.

4. RESULTS AND DISCUSSION

4.1. Results at 65km/h

Gradual Braking:

- Braking Distance: ABS: 24.8m; Non-ABS: 29.5m. (15.9% reduction by ABS).
- Wheel Slip (Avg/Peak): ABS: ~12% / 16%; Non-ABS: Peak ~55% near stop.
- Avg Deceleration: ABS: ~6.6m/s^2 (0.67g); Non-ABS: ~5.5m/s^2 (0.56g).

Under gradual braking conditions, both vehicles (with and without ABS) can stop safely on curved roads. However, the non-ABS vehicle has a significantly longer braking distance compared to the ABS-equipped vehicle, highlighting the effectiveness of ABS in reducing braking distance.

Fig. 8. Gradual braking at 65km/h

Sudden Braking:

• Braking Distance: ABS: 21.5m; Non-ABS: 27.2m. (21.0% reduction by ABS).

• Wheel Slip (Avg/Peak): ABS: ~15% / ~20%; Non-ABS: Reaches 100% (lock-up), causing slight instability.

• Avg Deceleration: ABS: ~7.5m/s^2 (0.77g); Non-ABS: ~6.1m/s^2 (0.62g) before lock-up.

When sudden braking is applied, the non-ABS vehicle begins to experience wheel slippage and slight instability, whereas the ABS-equipped vehicle remains stable. The Slip Ratios (Instant) graph shows higher oscillations for the non-ABS vehicle compared to the ABS vehicle.

Conclusion: "The ABS system improves vehicle stability and safety during sudden braking at 65km/h".

Fig. 9. Sudden braking at 65km/h

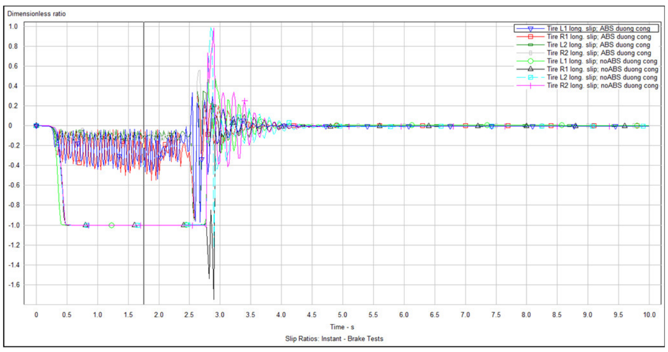


Fig. 10. Slip Ratios graph

4.2. Results at 120km/h

Gradual Braking:

• Braking Distance: ABS: 82.1m; Non-ABS: 108.5m. (24.3% reduction by ABS).

• Wheel Slip (Avg/Peak): ABS: ~14% / 19%; Non-ABS: Peak ~70 - 80%, signs of lock-up.

• Avg Deceleration: ABS: ~6.7m/s^2 (0.68g); Non-ABS: ~5.1m/s^2 (0.52g).

At 120km/h, both vehicles can stop without severe issues. However, the non-ABS vehicle exhibits a longer braking distance and experiences noticeable vibrations upon stopping, which can affect driver comfort. Higher wheel slip ratios in the non-ABS vehicle increase the risk of unsafe conditions under adverse weather.

Fig. 11. Gradual braking at 120km/h

Sudden Braking:

• Braking Distance: ABS: 76.5m (stable stop). Non-ABS: Loss of control, veered off road after ~60m, final stopping distance not applicable on lane.

• Wheel Slip (Avg/Peak): ABS: ~18% / ~22%; Non-ABS: Immediate 100% lock-up leading to loss of directional control.

• Avg Deceleration: ABS: ~7.2m/s^2 (0.73g); Non-ABS: Low effective deceleration (~4.8m/s^2 or 0.49g) due to full skid before losing control.

Fig. 12. Sudden braking at 120km/h

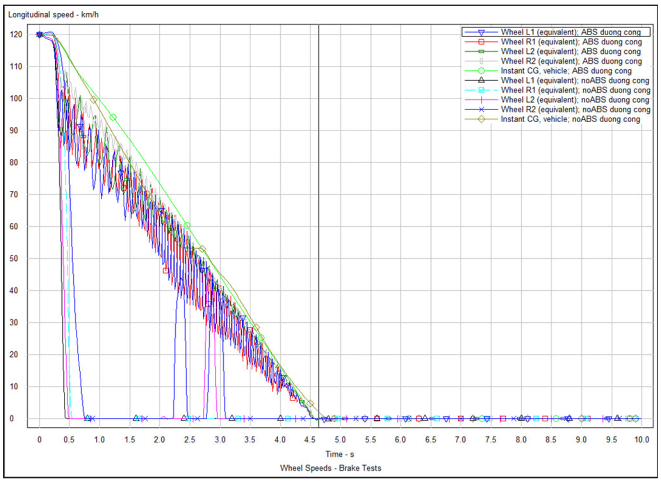


Fig. 13. Wheel speed and brake cylinder pressure graphs at 120km/h

Sudden braking at 120km/h causes the non-ABS vehicle to skid and veer off the road, creating a hazardous situation. Conversely, the ABS-equipped vehicle stops safely and maintains high stability. The wheel speed and brake cylinder pressure graphs clearly illustrate this distinction.

4.3. Results at 150km/h and 170km/h

Braking at 150km/h

Gradual Braking:

ABS stable stop ~128m (peak slip ~25%). Non-ABS loss of control. ABS Avg Decel: ~6.7m/s^2 (0.68g).

The ABS-equipped vehicle maintains stability with slight slippage, while the non-ABS vehicle skids and veers off the curved road.

Sudden Braking:

ABS controlled stop ~118m. Higher peak slip ~28 - 30% (near limit). ABS Avg Decel: ~7.3m/s^2 (0.74g). Non-ABS immediate loss of control.

The ABS-equipped vehicle continues to demonstrate superior control, significantly reducing the risk of losing control despite minor slippage.

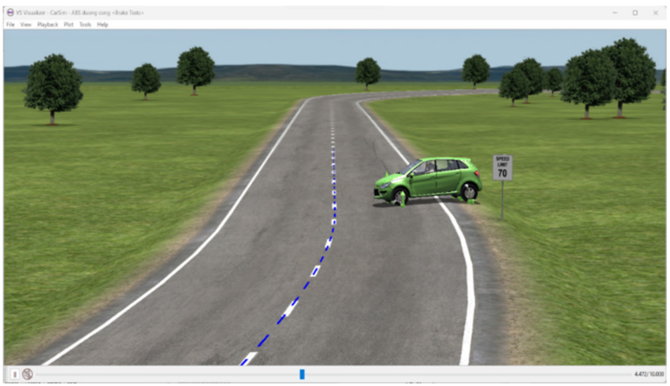


Fig. 14. Gradual braking at 150 km/h on a curve

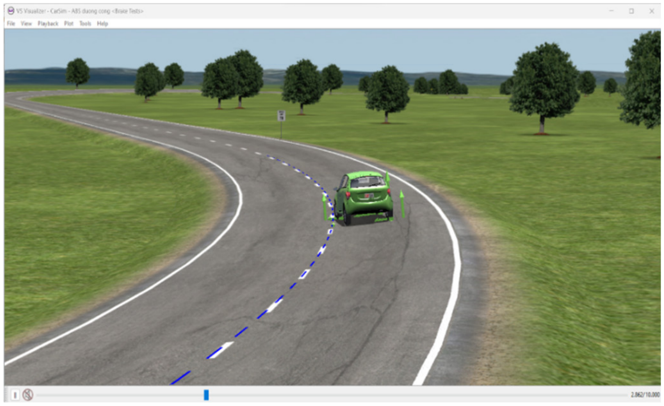


Fig. 15. Sudden braking at 150km/h

Braking at 170km/h

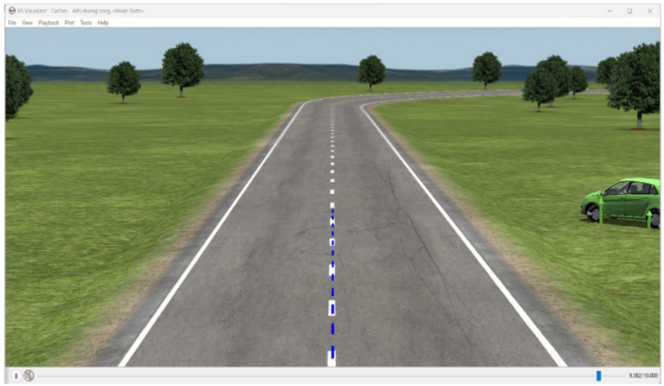


Fig. 16. Sudden braking at 170km/h

ABS shows significant difficulty, estimated stopping distance ~**160m** (if stays on road). High peak slip **>35%**, significant instability. Avg Decel reduced to **~6.6m/s^2 (0.67g)**. Non-ABS immediate loss of control.

At this speed, even the ABS-equipped vehicle begins to experience significant wheel slippage, indicating the system's control limits. The non-ABS vehicle completely loses control and veers off the road during sudden braking.

Table 5. Summary of ABS Effectiveness (Illustrative Results)

Speed (km/h)	Braking Type	ABS Dist. (m)	Non-ABS Dist. (m)	Dist. Reduction (%)	ABS Avg Decel (g)	Non-ABS Avg Decel (g)	ABS Peak Slip (%)	Non-ABS Peak Slip (%)
65	Gradual	24.8	29.5	15.90	0.67	0.56	16	~55
65	Sudden	21.5	27.2	21.00	0.77	0.62	~20	100
120	Gradual	82.1	108.5	24.30	0.68	0.52	19	~80
120	Sudden	76.5	Loss of Control	N/A	0.73	~0.49 (pre-LoC)	~22	100

Research Outcomes: The study confirms the exceptional effectiveness of the ABS system in enhancing vehicle safety and stability, particularly at high speeds. ABS reduces wheel slip and mitigates the risk of losing control in emergency scenarios. However, even with ABS, excessive driving speeds pose substantial risks.

5. CONCLUSION

This simulation study has clearly demonstrated the effectiveness and critical role of the Anti-lock Braking System (ABS) in enhancing vehicle safety and stability during braking on curved roads.

The results indicate that under gradual braking at speeds of 65km/h and 120km/h, both vehicles (with and without ABS) stopped safely; however, the non-ABS vehicle consistently required a significantly longer braking distance. The differences become particularly pronounced under sudden braking conditions: at 65km/h, the non-ABS vehicle began to exhibit slight skidding, while at 120km/h, it completely lost control, skidding off the lane, posing a severe real-world crash risk. Conversely, the ABS-equipped vehicle maintained safety and stability in all surveyed cases. This direct benefit of ABS translates into reduced collision risk due to shorter braking distances and, crucially, the preservation of steering control during emergency maneuvers, as evidenced by the more stable Yaw Angle and less fluctuating Steering Torque compared to the non-ABS vehicle.

However, simulations conducted at higher speeds (150 - 170km/h) also revealed the system's limitations. Even with ABS equipped, significant wheel slippage and instability could occur, especially during abrupt braking at these high velocities. This underscores a critical real-world lesson: while ABS significantly enhances the safety envelope, it cannot defy the laws of physics. Adherence to speed limits and cautious driving appropriate for the road conditions remain paramount for ensuring safety, regardless of the presence of advanced safety systems like ABS.

In summary, these findings validate the indispensable role of ABS in improving safety and stability during braking on curved roads. Furthermore, the detailed simulation methodology developed in this study (Section 3.3) proves valuable not only for analyzing ABS performance but also holds potential as a tool for preliminary evaluations of different ABS control strategies and as a compelling visual aid in driver safety training programs to foster a better understanding of both the capabilities and limitations of ABS technology.

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