# Dynamic Analysis of Half-Car Suspension Systems Using MATLAB Simulink and ANSYS

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**Abstract**

This study presents the dynamic modelling, simulation and analysis of a half-car suspension system using both passive and active suspension configurations. A vertical half-car 4-DOF (degree of freedom) model is developed to analyse pitch and bounce motions. The project integrates MATLAB Simulink for time-domain analytical simulations and ANSYS finite element analysis (FEA) for numerical validation. The objective is to evaluate suspension behaviour under road disturbances at speeds ranging from 10 to 45 km/h. The analysis demonstrates that active suspensions significantly improve ride comfort and handling compared to passive systems, although they involve higher complexity and cost.

## 1. Introduction

Modern vehicle suspension systems are critical to ensure both ride comfort and handling stability. The suspension separates the car body from the wheels, managing the forces generated during driving and isolating the passengers from road irregularities. Traditionally, passive suspension systems have dominated the automotive industry due to their simplicity and cost-effectiveness. However, these systems have limitations, particularly in adapting to varying road and speed conditions. Advances in technology have led to the development of active suspension systems, where actuators and control strategies dynamically adjust suspension parameters in real time. This study models both passive and active suspension systems for a half-car configuration and evaluates their performance using analytical and numerical methods.

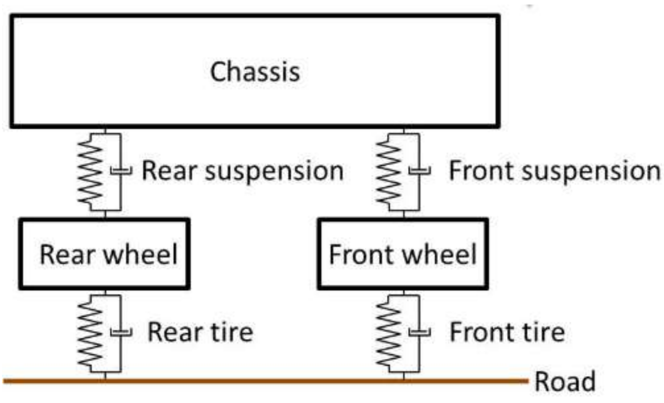



**Fig 1:** Half-car model schematic

## 2. Methodology

A 4-DOF half-car model was created with vertical displacement and pitch motion for the sprung mass, and vertical motion for front and rear unsprung masses. Road input was modelled as a 0.05 m high, 2 m long bump. Simulink solved the system dynamics, while ANSYS validated stresses and displacements in suspension components under transient loading.

### 2.1 Half-Car Model

The half-car model chosen for this study is based on a **2023 Swift Dzire** vehicle. It includes independent front and rear suspensions and represents pitch and bounce dynamics using 4-DOF.

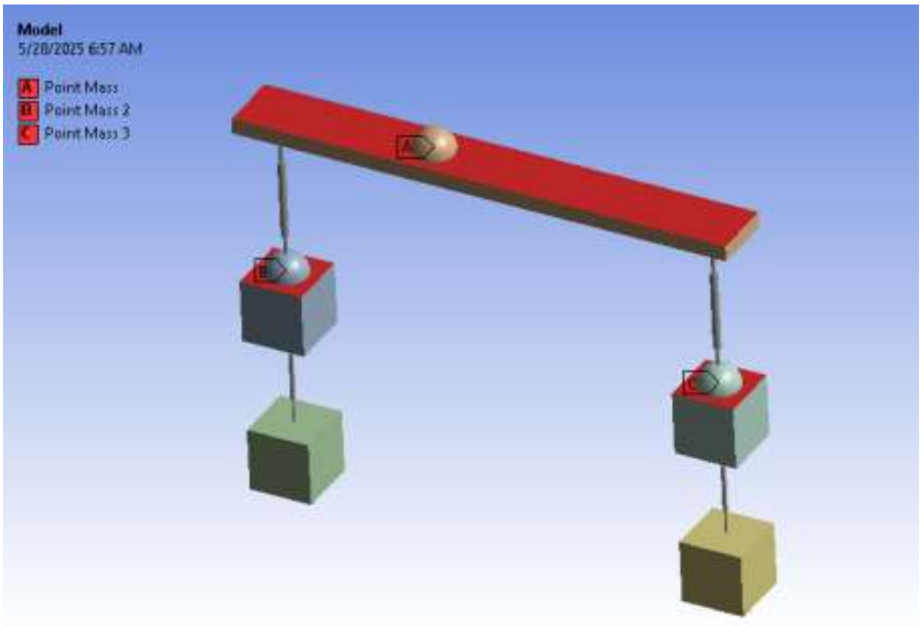



**Fig 2:** Geometry model of half car model.

### 2.2 Simulation Tools

- **MATLAB Simulink**: Used for dynamic simulation, solving the equations of motion derived from Newtonian mechanics.
- **ANSYS FEA**: Employed for numerical validation of structural response, including stress and displacement analysis.

### 2.3 Road Input

A road bump with height 0.05 m and length 2 m serves as the disturbance input, simulating real-world driving scenarios across different speeds.

### 3. Mathematical Model

The half-car model equations include vertical bounce and pitch for the sprung mass and vertical motion for front and rear unsprung masses. The suspension consists of springs and dampers (passive) or hydraulic actuators (active).

The model equations describe forces on the sprung and unsprung masses due to spring stiffness, damping, and tire-road interactions. In active suspension, an LQR controller minimizes a quadratic cost function to reduce body acceleration, suspension deflection, and control effort. The state-space form enabled optimal control design.

The **state-space representation** is used for active suspension design:

$$\dot{x} = Ax + Bu + D\omega$$

Where:

x = state variables (displacement, velocity)

u = control input

ω = disturbance input

An **LQR controller** optimizes the active suspension by minimizing a quadratic cost function of the form:

$J=\int(x^TQx+u^TRu)dt$

**4. Finite Element Analysis**

The **ANSYS workbench** model includes:

- ✶ Mass blocks for sprung and unsprung components.
- ✶ Spring-damper elements for suspension properties.
- ✶ Mesh with 864 elements and 4736 nodes.

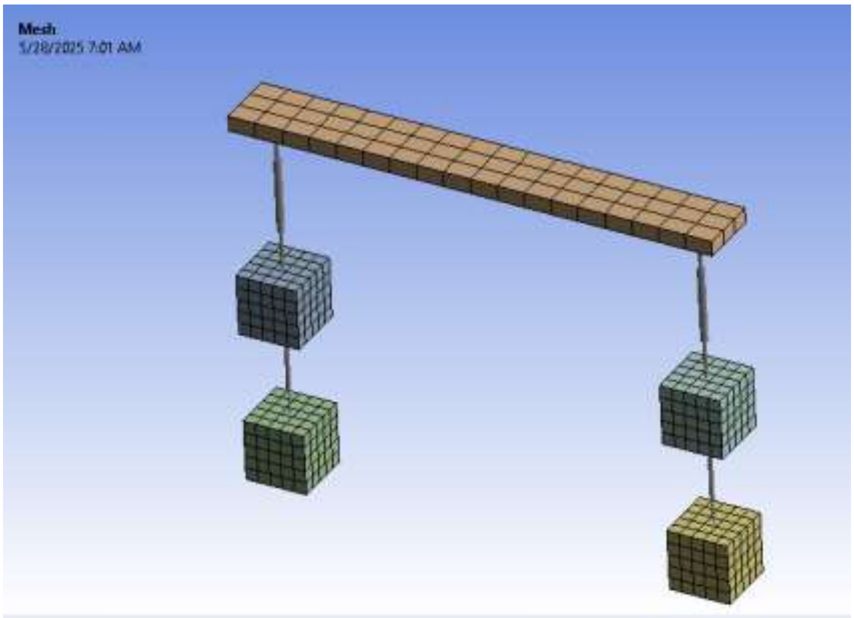



**Fig 3:** Meshing view of half car model.

FEA is used to observe displacement under transient loading. Results align with analytical predictions, validating the model.

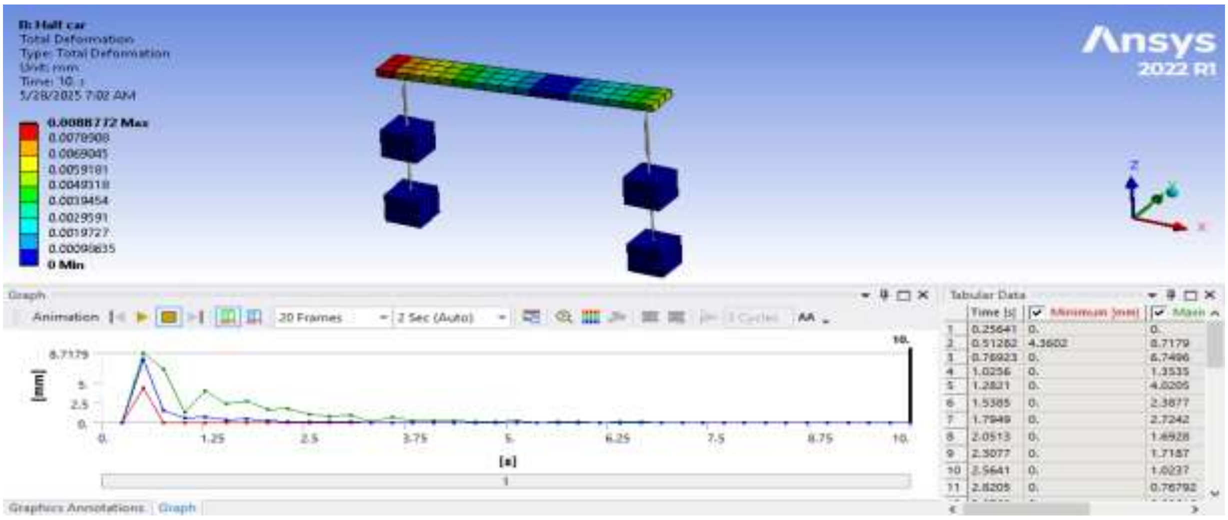



**Fig 4:** Displacement due to transient loading.

**5. Simulink Modeling for Half Car Model**

In optimal control, the attempts to find controller that can provide the best possible performance. Control strategy is a very importance part for the active suspension system. With the correct control strategy, it will give better compromise between ride comfort and vehicle handling.

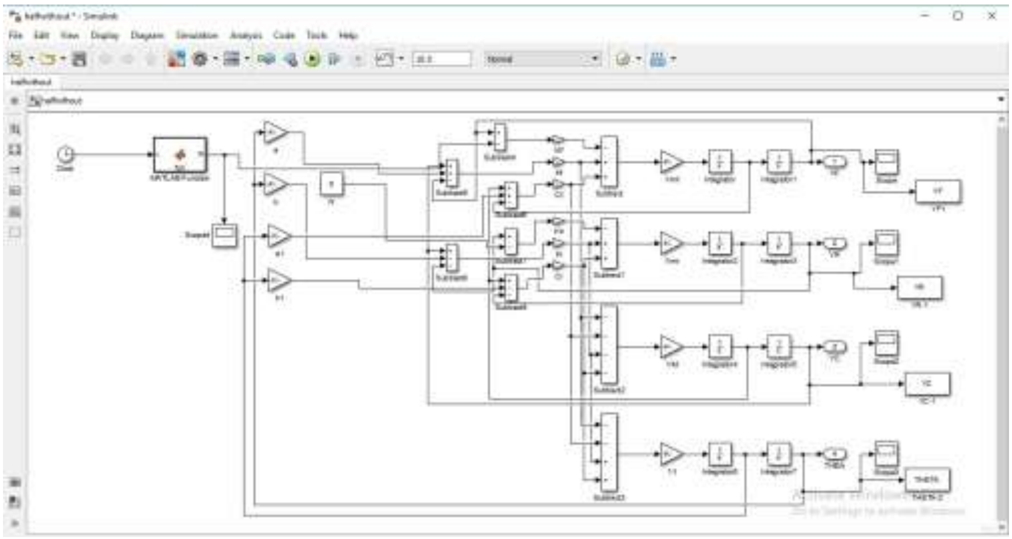


**Fig 5:** Passive half car modeling.

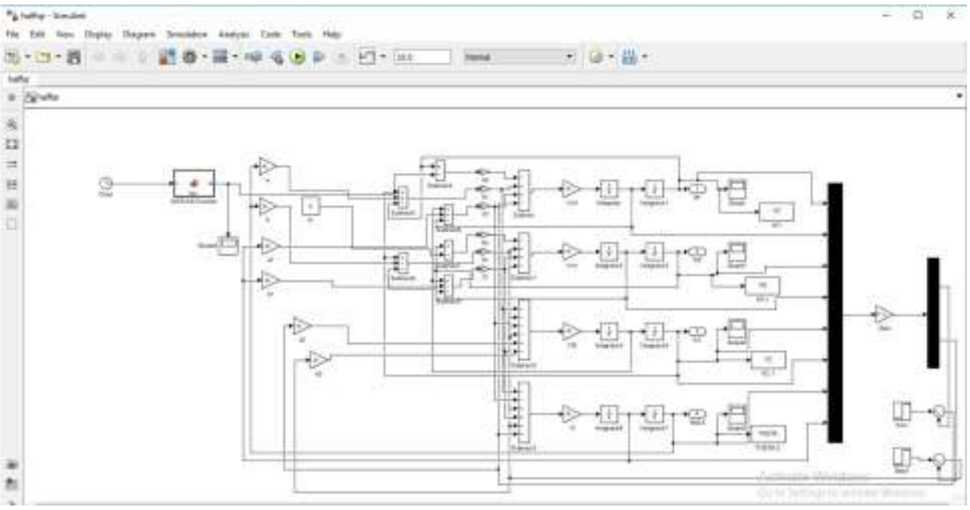


**Fig 6:** Simulink model for LQR controller.

Nowadays there a lot of researches have been done to improve the performance of active suspension by introducing various control strategies. In this chapter LQR controller developed for the design of active suspension system to improve the vehicle dynamics

**6. Results**

Simulations showed that passive suspension systems resulted in larger body displacements, prolonged oscillations, and greater pitch angles, especially at low speeds. Active suspension reduced body displacement by about 42%, pitch by 46% and wheel deflection by over 35%. ANSYS analysis confirmed reduced stress levels in suspension components under active control, indicating both performance and durability benefits.

### 6.1 Passive vs. Active Suspension

MATLAB Simulink simulations show:

- **Passive system:** Larger, longer-lasting oscillations.
- **Active system:** Reduced oscillations, faster stabilization.

ANSYS results confirm:

- Maximum displacement under load: ~0.087 m at peak.
- Active system reduced pitch by ~46%, body displacement by ~42% and wheel displacement by ~35% compared to passive.

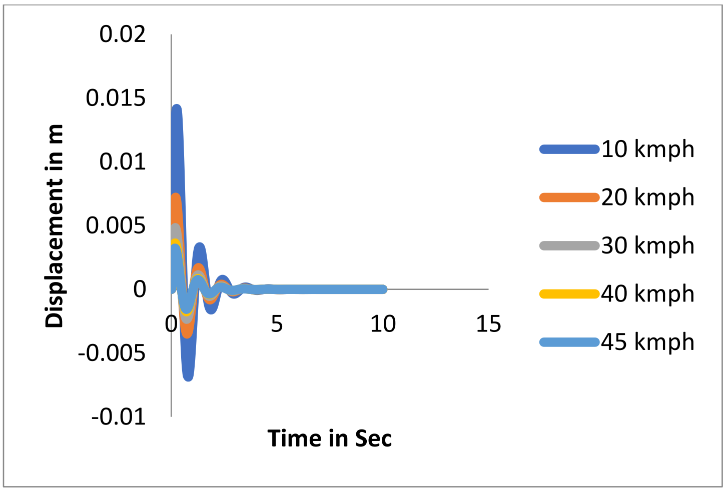
### 6.2 Key Graph Insights

- **Vehicle displacement**: Active system dampens vibrations 60% faster.
- **Front/rear wheel displacement**: Active system halves settling time.
- **Pitch response**: Active control reduces amplitude and duration of pitch.

## 7. Discussion

The comparative study highlights the trade-offs:

- **Passive suspension**: Reliable and cost-efficient but limited in adaptability.
- **Active suspension**: Superior ride comfort, better handling, but higher complexity and energy demand.




**Graph :** vehicle displacement at different velocities.

Active systems prove essential for future high-performance and autonomous vehicles where dynamic adaptability is critical.

## 8. Conclusion

This study confirms that active suspension systems substantially outperform passive systems in managing pitch, bounce, and overall ride comfort. The integration of MATLAB and ANSYS provides a robust analysis framework, ensuring both dynamic accuracy and mechanical reliability. Future work could extend to full-car models, lateral dynamics, and real-time controller implementation.

Active suspension systems significantly enhance ride comfort, stability, and component life compared to passive systems. While passive designs are cost-effective, active systems provide superior vibration isolation and handling, making them suitable for modern and high-performance vehicles.

**References**

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