Analysis and Design for Comfort Ride of 4-Wheeled Vehicles Vibration on Rural Road Surface and To Reduce Climate Impact

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Abstract

Today all type of Transport Vehicles are need of hour for the movement from one place to other, on other hand introduction of advanced technologies of the automobiles are universal demand for improving its dynamic shape for comfort ride, safety majors, and environmental friendly. To fulfill this objective, continual improvements in automobile technologies are taking its pace. In this paper, authors' focus towards the suspension system to reduce considerably vibration of the vehicles for comfort ride and safety during its braking, acceleration or passes over irregular surfaces at higher speeds such as ramble strips / bumps and speed breakers or uneven road contours in the Indian Road Scenario. A mathematical model is prepared to consider these vibrations considering all four wheels running on irregular roads surface, ramble strips, speed breakers and simulated with software: Simulink / Matlab. Currently the research works are carried out for comfort ride up to 20-35 km per hour speed. In this paper, researches are carried out to improve the comfort zone at 50 km/hour and above for light vehicles at direct and indirect parameters such as: spring constants, damping coefficients, bumps etc. The simulation results were extensively and accurately evaluated on above factors impacting comfort ride of four wheeled vehicles. The result shows that comfort ride is found at speed 62.5 km/hr or above on rural roads when rear tire damping coefficient ($b_r$) is 4 kNs/m. Future researches can be done, on Ramble Strips / Speed Breakers at higher speeds for comfort ride.

Keywords: Automobile, comfort ride, suspension, ramble strips, technology

NOTATIONS

$m_c$ = Mass of the car body or sprung mass (kg)

$m_{rf}$ = Front mass of the wheel or unsprung mass (kg)

$m_{rr}$ = Rear mass of the wheel or unsprung mass (kg)

$I_p$ = Pitch moment of inertia (kgm$^2$)

$I_r$ = Roll moment of inertia (kgm$^2$)

$T_r$ = Front treat (m)

$T_{rr}$ = Rear treat (m)

$a$ = Distance from centre of sprung mass to front wheel (m)

$b$ = Distance from centre of sprung mass to rear wheel (m)

$b_r$ = Front tire damping coefficient (Ns/m)

$b_{rr}$ = Rear tire damping coefficient (Ns/m)

$k_c$ = Stiffness of car body spring for rear (N/m)

$k_{fr}$ = Front stiffness tire (N/m)

$k_{tr}$ = Rear stiffness tire (N/m)

1.0 INTRODUCTION

The research work is described to find out various aspects for comfort ride of a vehicle in heavy and rocking motion. The study was made to solve the problem with damping coefficient and vehicle speed in reducing the vibration. From recent literatures, Vivek Kumar et al. [1] present vertical dynamics of passenger car using Bond graph on eight degree of freedom full car model of passenger car considered spring, unsprung mass, pitching, rolling motion of sprung mass. Liqiang Jin et al. [2] study ride comfort of vehicle driven by in wheel motors, eleven degree of freedom mathematical model presented through MATLAB/Simulink. Galal Ali Hassaan et al.[3] reported mathematical model of quarter car evaluated in spring mass, displacement and acceleration. Simulation through MATLAB of comfort ride of quarter car speed not exceeds 6.75km/h. Yeqing Lu et al. [4] performed a full car model with seven degree of freedom a virtual prototype built. This paper consider complex behaviour of real vehicles through extended state observer (ESO).Simulation result obtain using ADRC controller for comfort ride. Yazan M. AL. Rawashad et al. [5] studied chassis of the car are considered and centre of gravity position is assumed to be fixed. Solving problem non convex particle swarm optimization technique used for PSO/LMI optimization. Sim Mechanism is used to build full car active suspension using the laws of motion for development of mathematical model. Radionova L.V et al. [6] presents for building mathematical model using Matlab/ Simulink. Development of model can be synthesizing direct torque control on each wheel. This paper present block diagram of mathematical model of vehicle helping of block control system, block transmission, block calculation of focus and block body. Arshad Mehmood et al.[7] studies suspension dynamics of vehicle with complete state analysis using Matlab. Simulation result obtains amplitude vs. time, frequency response for sprung mass for quarter car model root locus plot for quarter car model through Matlab not using vibration work. Galal Ali Hassaan et al. [8] present mathematical model of full car 3D with 10 degree of freedom taken suspension parameter stiffness and damping coefficient. Simulation result find through MATLAB of wheel bounce vs. time. Assyl Khan et al. [9] reported solving problem varying of form dynamic interactions of the system. Experimental results obtain vertical irregularities of the left rail thread, Horizontal irregularities of the right rail thread and horizontal irregularities of the left rail thread using MATLAB/Simulink. Cheng Cheng et al. [10] state the ride comfort and road holding performance enhancement of road for series active variable geometry suspension (SAVGS) concept. R.S. Sharp et al.[11] introduce potential road performance of active suspension.
limited control bandwidth is obtain with theoretically analysis. Linear quadratic Gaussian control theory used for control laws as a function of the operating condition. L. Dahil et al. [12] Investigate vehicle acceleration was passing over bumps at different speeds. The vehicle vibration determine at 20 km/h, 40 km/h and 60 km/h with HVM 100 device, not using sprung mass displacement vs. time using acceleration in different speed over bump. Vivek Kumar et al. [13] studies rail transport has demand high operation speed makes hunting problem. This is due to discomfort and physical damage of component such as wheel and rail etc. Modeling Bond Graph model of 31 degree of freedom railway vehicle. Vinyay R. Varude et al. [14] studies Suspension system provide a compromise between both ride comfort and road holding. This paper focuses on two degree of freedom passive suspension system model. Saayan Banerjee, et al. [15] deals with mathematical model of a full tracked with 17 degree of freedom trailing arm hydro-gas suspension. Sihem Dridi et al. [16] state that tubular permanent magnet linear synchronous actuator (TPMLSA) dynamic actuator modeled by bond graph formalism. Minimization of wheel vibration problem for comfort ride vehicle. Amar Majid et al.[17] states that modeling, simulation and control of linear half car suspension system with algorithm using Matlab/Simulink study of pitch, heave motion of sprung mass active suspension with fuzzy PID. Ashish R. Patil et al. [18] States that quarter car model s with non linear spring force property of Hyundai, Electra model suspension spring. Hamed et al. [19] suspension system has provided comfortable ride of full car seven degree of freedom using Matlab. The main function of suspension protects driver and passenger vibration. Fault of spring stiffness by 25%, 50% and 80% using simulation.

In this paper, research work presented new data which is systematically organized. We represented for a vehicle vibration of damping coefficient ≤ 8 kN/m, the highest sprung-mass displacement improved with an increased vehicle speed 62.5 km/h, then decreased for a vehicle speed > 62.5 km/h and ≤ 125 km/h. for the comfort ride on vehicle studies. The objective of the paper is to use Simulink/Symbolshakti simulation technology emerged for vehicle models to simulate varied response characteristics and alternative models vehicles for comfort ride are improved at higher speeds (even beyond 30 km/hr) at uneven road conditions. It is found that when ramble strips are replaced in place of higher bumps speed breakers, pitching of bumps are kept at higher distance with suitable spring’s stiffness and damper constants, it further improve the comfort ride at higher speeds.

2.0 DEVELOPMENT OF A VEHICLE REPRESENTATION

The development of a vehicle representation of sprung mass is complimentary in the direction of heave roll and pitch. They are complementary to rebound perpendicularly through the sprung mass and it directly converts inside Symbolshakti. $m_s$ is sprung mass, $m_u$ is unsprung mass of front wheel, $m_{sw}$ is unsprung mass of rear wheel, $I_p$ is moment of inertia of pitching, $I_r$ is moment of inertia of rolling, $Z$ displacement of vehicle representation, $Z_{s1}$, $Z_{s2}$, $Z_{s3}$ and $Z_{s4}$ displacement of vehicle representation for each corner, $Z_{f1}$, $Z_{f2}$, $Z_{f3}$ and $Z_{f4}$. Development of a vehicle representation suspension is established shown in Fig.3 and their parameter is shown in Table 1.

![Figure 2: Four wheeled car model having different load](image)

![Figure 3: Vehicle Representation](image)

2.1 Mathematical Model A Vehicle Representation

The mathematical model of a vehicle representative of the sprung mass and damper constant is given by:

\[ I_p \ddot{\theta} + b_1 T_f (\dot{Z}_{s3} - \dot{Z}_{s1}) + b_2 T_r (\dot{Z}_{s2} - \dot{Z}_{s2}) - b_2 T_r (\dot{Z}_{s3} - \dot{Z}_{s3}) + b_1 T_f (\dot{Z}_{s4} - \dot{Z}_{s4}) - k_1 T_f (Z_{s1} - Z_{s1}) + k_1 T_f (Z_{s2} - Z_{s2}) - k_1 T_f (Z_{s3} - Z_{s3}) + k_1 T_f (Z_{s4} - Z_{s4}) \]

(1)
b). For pitching motion

\[ \tau = \dot{\theta}_f + b_f (\dot{Z}_1 - \dot{Z}_3) + b_r (\dot{Z}_2 - \dot{Z}_4) + k_f (Z_1 - Z_3) - k_r (Z_2 - Z_4) \]

\[ + k_r (Z_3 - Z_5) + k_f (Z_4 - Z_6) \]

(2)

c). For bouncing

\[ m_r \ddot{Z}_1 = b_f (\dot{Z}_1 - \dot{Z}_3) - b_f (\dot{Z}_2 - \dot{Z}_4) - b_f (\dot{Z}_3 - \dot{Z}_5) \]

\[ - b_r (\dot{Z}_4 - \dot{Z}_6) - k_f (Z_1 - Z_3) - k_r (Z_2 - Z_4) \]

\[ - k_r (Z_3 - Z_5) - k_f (Z_4 - Z_6) \]

(3)

d). Every sides of wheel motion

\[ m_f \ddot{Z}_1 = b_f (\dot{Z}_1 - \dot{Z}_3) + k_f (Z_1 - Z_3) - k_f Z_1 + k_f Z_3 \]

(4)

\[ m_r \ddot{Z}_2 = b_f (Z_2 - Z_4) + k_r (Z_2 - Z_4) - k_r Z_2 + k_r Z_4 \]

(5)

\[ m_r \ddot{Z}_3 = b_r (Z_3 - Z_5) + k_f (Z_3 - Z_5) - k_f Z_3 + k_f Z_5 \]

(6)

\[ m_r \ddot{Z}_4 = b_r (Z_4 - Z_6) + k_r (Z_4 - Z_6) - k_r Z_4 + k_r Z_6 \]

(7)

Table 1: Parameters considered for 4-Wheeled vehicle representation

<table>
<thead>
<tr>
<th>SNo.</th>
<th>Description</th>
<th>Notations</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Sprung Mass of the vehicle</td>
<td>( m_s )</td>
<td>1125</td>
<td>kg</td>
</tr>
<tr>
<td>2.</td>
<td>Unsprung mass of front wheel</td>
<td>( m_{df} )</td>
<td>65</td>
<td>kg</td>
</tr>
<tr>
<td>3.</td>
<td>Unsprung mass of rear wheel</td>
<td>( m_{dr} )</td>
<td>69</td>
<td>kg</td>
</tr>
<tr>
<td>4.</td>
<td>Moment of Inertia of pitching</td>
<td>( I_p )</td>
<td>2500</td>
<td>kgm²</td>
</tr>
<tr>
<td>5.</td>
<td>Moment of Inertia of rolling</td>
<td>( I_r )</td>
<td>500</td>
<td>kgm²</td>
</tr>
<tr>
<td>6.</td>
<td>Stiffness of vehicle at front axle</td>
<td>( k_f )</td>
<td>36,000</td>
<td>N/m</td>
</tr>
<tr>
<td>7.</td>
<td>Stiffness of vehicle at rear axle</td>
<td>( k_r )</td>
<td>20,000</td>
<td>N/m</td>
</tr>
<tr>
<td>8.</td>
<td>Front treat</td>
<td>( T_f )</td>
<td>0.505</td>
<td>m</td>
</tr>
<tr>
<td>9.</td>
<td>Rear treat</td>
<td>( T_r )</td>
<td>0.557</td>
<td>m</td>
</tr>
<tr>
<td>10.</td>
<td>Front tire stiffness</td>
<td>( k_f )</td>
<td>182500</td>
<td>N/m</td>
</tr>
<tr>
<td>11.</td>
<td>Rear tire stiffness</td>
<td>( k_r )</td>
<td>182500</td>
<td>N/m</td>
</tr>
<tr>
<td>12.</td>
<td>Front tire coefficient</td>
<td>( b_f )</td>
<td>8 &amp; 16</td>
<td>kNs/m</td>
</tr>
<tr>
<td>13.</td>
<td>Rear tire coefficient</td>
<td>( b_r )</td>
<td>4 &amp; 12</td>
<td>kNs/m</td>
</tr>
<tr>
<td>14.</td>
<td>Distance from centre of sprung mass to front wheel</td>
<td>( a )</td>
<td>1.15</td>
<td>m</td>
</tr>
<tr>
<td>15.</td>
<td>Distance from centre of sprung mass to rear wheel</td>
<td>( b )</td>
<td>1.65</td>
<td>m</td>
</tr>
</tbody>
</table>

2.2 Vehicle Representation Simulation

Simulation results are presented in this paper. Results are also presenting in summarized and graphical form in Table 1 is obtained after simulating the development model. The different figures in the simulated results obtained at various speeds are 25 km/h to 125 km/h taken for simulation of parameter analyzed suspension displacement. The simulation results are presented easier to read and review and found to understand with logical order through Simulink.

3.0 SIMULATIONS RESULT

Considering the sprung-mass, un-sprung mass, damping coefficients at different bumps and speeds from 25 km/h, 50 km/h, 75 km/h, 100 km/h and 125 km/h etc. for:

- **First stage**: rear tire \( (b_r) \) 4 kNs/m and front tire \( (b_f) \) 8 kNs/m
- **Second stage**: rear tire \( (b_r) \) 12 kNs/m, and front tire \( (b_f) \) 16 kNs/m.

These simulation results are shown in the form of graphs as under:

3.1 When Rear Tire Damping Coefficient \( (b_r) = 4 \) kNs/m at different speeds (25 km/h, 50 km/h, 75 km/h, 100 km/h and 125 km/h), the time lag for establishing comfort zones are shown in Figure 5 to Figure 9.

![Fig. 3.1: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient \( (b_r) = 4 \) kNs/m and speed = 25 km/h.](image1)

![Fig. 3.2: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient \( (b_r) = 4 \) kNs/m and speed = 50 km/h.](image2)
3.2 Front Tire Damping Coefficient ($b_f$) = 8 kNs/m at different speeds (25 km/h, 50 km/hr, 75 km/hr, 100 km/hr and 125 km/h) are shown in Figs. 10 to 14.

Fig. 3.6: Sprung-mass displacement vs. Time lag for comfort zone, when front tire damping coefficient ($b_f$) = 8 kNs/m and Speed = 25 km/h.

Fig. 3.7: Sprung-mass displacement vs. Time lag for comfort zone, when front tire damping coefficient ($b_f$) = 8 kNs/m and Speed = 50 km/h.

Fig. 3.8: Sprung-mass displacement vs. Time lag for comfort zone, when front tire damping coefficient ($b_f$) = 8 kNs/m and Speed = 75 km/h.

Fig. 3.3: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient ($b_r$) = 4 kNs/m and speed = 75 km/h.

Fig. 3.4: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient ($b_r$) = 4 kNs/m and speed = 100 km/h.

Fig. 3.5: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient ($b_r$) = 4 kNs/m and speed = 125 km/h.
3.3 Rear Tire Damping Coefficient ($b_r = 12$ kNs/m) at different speeds (25 km/h, 50 km/h, 75 km/h, 100 km/h and 125 km/h) are shown in Figs. 15 to 19.

Fig. 3.11: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient ($b_r$) = 12 kNs/m and speed = 25 km/h.

Fig. 3.12: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient ($b_r$) = 12 kNs/m and speed = 50 km/h.

Fig. 3.13: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient ($b_r$) = 12 kNs/m and speed = 75 km/h.

Fig. 3.14: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient ($b_r$) = 12 kNs/m and speed = 100 km/h.
Fig. 3.15: Sprung-mass displacement vs. Time lag for comfort zone, when rear tire damping coefficient \( (b_r) = 12 \ \text{kN/s/m} \) and speed = 125 km/h.

3.4 Front Tire Damping Coefficient \( (b_f = 16 \ \text{kN/s/m}) \) at different speeds (25 km/h, 50 km/h, 75 km/h, 100 km/h and 125 km/h) are shown in Figs. 20 to 24.

Fig. 3.16: Sprung-mass displacement vs. Time lag for comfort zone, when front tire damping coefficient \( (b_f) = 16 \ \text{kN/s/m} \) and speed = 25 km/h.

Fig. 3.17: Sprung-mass displacement vs. Time lag for comfort zone, when front tire damping coefficient \( (b_f) = 16 \ \text{kN/s/m} \) and speed = 50 km/h.

Fig. 3.18: Sprung-mass displacement vs. Time lag for comfort zone, when front tire damping coefficient \( (b_f) = 16 \ \text{kN/s/m} \) and speed = 75 km/h.

Fig. 3.19: Sprung-mass displacement vs. Time lag for comfort zone, when front tire damping coefficient \( (b_f) = 16 \ \text{kN/s/m} \) and speed = 100 km/h.

Fig. 3.20: Sprung-mass displacement vs. Time lag for comfort zone, when front tire damping coefficient \( (b_f) = 16 \ \text{kN/s/m} \) and speed = 125 km/h.

4. RESULTS AND DISCUSSION

Sprung-mass Displacement and Speeds

Since vehicle passes through transient bumps, thus the comfort zone can be achieved by varying different tire coefficients and speeds. Figs. 5 to Fig. 24 show the various conditions of speeds and time of
discomforts considering front and rear tires damping coefficients.

a). When Rear Tire Damping Coefficient \((br)\) is kept 4 kNs/m at different speeds 25 km/h, 50 km/h, 75 km/h, 100 km/h and 125 km/h, then time lags for establishing into comfort zones are found as shown in Fig. 3.1 to Fig. 3.5.

- From Fig 3.1, when rear tire damping coefficient \((br)\) is kept 4 kNs/m at speed 25 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.080\) m within 2 sec, further gone down \(-0.015\) m at 4 sec and gone up \(+0.012\) m at 5 sec, further gone down \(-0.011\) m at 6 sec and gone up \(+0.001\) m at 7 sec, there after die out at 7 sec. Thus comfort zone is found within 7 seconds with zero vibration with peak upwards displacement of \(+0.080\) m.

- From Fig 3.2, when rear tire damping coefficient \((br)\) is kept 4 kNs/m at speed 50 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.008\) m at 2 sec, further gone down \(-0.011\) m at 4.1 sec and gone up \(+0.001\) m at 5.1 sec, there after die out at 6 sec. Thus comfort zone is found within 7 seconds with zero vibration with peak upwards displacement of \(+0.080\) m.

- From Fig 3.3, when rear tire damping coefficient \((br)\) is kept 4 kNs/m at speed 75 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.102\) m within 0.9 sec, further gone down \(-0.004\) m at 1.8 sec and gone up \(+0.016\) m at 2.7 sec, further gone down \(-0.008\) m at 3.7 sec and gone up \(+0.004\) m at 4.7 sec, there after die out at 5.5 sec. Thus comfort zone is found within \(5.5\) seconds with zero vibration with peak upwards displacement of \(+0.102\) m.

- From Fig 3.4, when rear tire damping coefficient \((br)\) is kept 4 kNs/m at speed 100 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.091\) m within 0.72 sec, further gone down \(-0.038\) m at 1.6 sec and gone up \(+0.015\) m at 2.6 sec, further gone down \(-0.038\) m at 1.6 sec and gone up \(+0.015\) m at 2.6 sec, further gone down \(-0.008\) m at 3.7 sec and thereafter die out 4.2 sec. Thus comfort zone is found within \(4.2\) seconds with zero vibration with peak upwards displacement of \(+0.091\) m.

- From Fig 3.5, when rear tire damping coefficient \((br)\) is kept 4 kNs/m at speed 125 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.085\) m within 0.6 sec, further gone down \(-0.035\) m at 1.6 sec and gone up \(+0.041\) m at 2.5 sec, further gone down and up 3.25 sec, there after die out at 3.5 sec. Thus comfort zone is found within \(3.5\) seconds with zero vibration with peak upwards displacement of \(+0.085\) m.

b). When Front Tire Damping Coefficient: \((bf) = \) 8 kNs/m at different speeds 25 km/h, 50 km/h, 75 km/h, 100 km/h and 125 km/h, then time lags for establishing into comfort zones are shown in Figs.3.6 to 3.10.

- From Fig 3.6, when front tire damping coefficient \((bf)\) is kept 8 kNs/m at speed 25 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.077\) m within 1.8 sec, further gone down \(-0.002\) m at 3.3 sec and gone up, there after die out at 5.5 sec. Thus it is found that peak upwards displacement has gone to \(+0.077\) m which becomes zero within \(5.5\) seconds, having only single spike that creates discomfort.

- From Fig 3.7, when front tire damping coefficient \((bf)\) is kept 8 kNs/m at speed 50 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.076\) m within 1.0 sec, further gone down \(-0.002\) m at 2.2 sec and gone up, there after die out at 3.0 sec. Thus it is found that peak upwards displacement has gone to \(+0.076\) m which becomes zero within \(3.0\) seconds, having only single spike that creates discomfort.

- From Fig 3.8, when front tire damping coefficient \((bf)\) is kept 8 kNs/m at speed 75 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.076\) m within 0.6 sec, further gone down \(-0.002\) m at 1.3 sec and gone up, there after die out at 2.5 sec. Thus it is found that peak upwards displacement has gone to \(+0.076\) m which becomes zero within \(2.5\) seconds, having only single spike that creates discomfort.

- From Fig 3.9, when front tire damping coefficient \((bf)\) is kept 8 kNs/m at speed 100 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.076\) m within 0.55 sec, further gone down \(-0.002\) m at 1.3 sec and gone up, there after die out at 2.4 sec. Thus it is found that peak upwards displacement has gone to \(+0.076\) m which becomes zero within \(2.4\) seconds, having only single spike that creates discomfort.

- From Fig 3.10, when front tire damping coefficient \((bf)\) is kept 8 kNs/m at speed 125 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.075\) m within 0.5 sec, further gone down \(-0.001\) m at 1.2 sec and gone up, there after die out at 2.0 sec. Thus it is found that peak upwards displacement has gone to \(+0.075\) m which becomes zero within \(2.0\) seconds, having only single spike that creates discomfort.

- From Fig 3.11, when rear tire damping coefficient \((br)\) is kept 12 kNs/m at speed 25 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.075\) m within 2 sec, further gone down to 0.0 m, within 4.0 sec. Thus it is found that peak upwards displacement has gone to \(+0.075\) m which becomes zero within \(4.0\) seconds, having only single spike that creates discomfort.

- From Fig 3.12, when rear tire damping coefficient \((br)\) is kept 12 kNs/m at speed 50 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \(+0.075\) m within 1 sec, further gone down to 0.0 m, within 2.1 sec. Thus it is found that peak upwards displacement has gone to \(+0.075\) m which becomes zero within \(2.1\) seconds, having only single spike that creates discomfort.
From Fig. 3.15, when rear tire damping coefficient \((b_r)\) is kept 12 kNs/m at speed 125 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \((+0.075)\) within 2.25sec, further gone down to 0.0m, within 1.75sec. Thus it is found that peak upwards displacement has gone to (+) 0.075m which becomes to zero within 2.2 seconds, having only single spike that creates severe discomfort.

From Fig. 3.16, when front tire damping coefficient \((b_f)\) is kept 16 kNs/m at speed 25 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \((+0.077)\) within 0.45sec, further gone down to 0.0m, within 0.6sec. Thus it is found that peak upwards displacement has gone to (+) 0.075m which becomes to zero within 0.4 seconds, having only single spike that creates severe discomfort.

From Fig. 3.17, when front tire damping coefficient \((b_f)\) is kept 16 kNs/m at speed 75 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \((+0.073)\) within 0.75sec, further gone down to 0.0m, within 1.75sec. Thus it is found that peak upwards displacement has gone to (+) 0.074m which becomes to zero within 1.75 seconds, having only single spike that creates higher degree of discomfort.

From Fig. 3.18, when front tire damping coefficient \((b_f)\) is kept 16 kNs/m at speed 100 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \((+0.073)\) within 0.6sec, further gone down to 0.0m, within 1.5sec. Thus it is found that peak upwards displacement has gone to (+) 0.074m which becomes to zero within 1.5 seconds, having only single spike that creates severe discomfort.

From Fig. 3.19, when front tire damping coefficient \((b_f)\) is kept 16 kNs/m at speed 125 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \((+0.073)\) within 0.5sec, further gone down to 0.0m, within 1.25sec. Thus it is found that peak upwards displacement has gone to (+) 0.073m which becomes to zero within 1.25 seconds, having only single spike that creates severe discomfort.

From Fig. 3.20, when front tire damping coefficient \((b_f)\) is kept 16 kNs/m at speed 125 km/h, then from the graph (displacement vs. time), it is observed that sprung-mass reached to its peak height of \((+0.073)\) within 0.5sec, further gone down to 0.0m, within 1.25sec. Thus it is found that peak upwards displacement has gone to (+) 0.073m which becomes to zero within 1.25 seconds, having only single spike that creates severe discomfort.

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