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Modal Analysis on Vehicle Transient Behavior

Kaoru Kusaka [1)] **Takahiro Yuhara** [1)] **Shingo Koakutsu** [1)]

1) Honda R&D Co.,Ltd.
Shimotakanezawa 4630, Haga machi, Haga gun, Tochigi, 321-3393, Japan (E-mail: Kaoru_Kusaka@jp.honda)

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This study presents a new analysis method that applies modal analysis technique to vehicle dynamics model considering roll and pitch motion. The approach decomposes key vehicle responses such as yaw rate, lateral acceleration, roll angle, and pitch angle into three fundamental vibration modes, clarifying how each mode contributes to each state variables. The influence of design parameters—especially suspension geometry—on these vibration modes is examined as an example and the results demonstrate that pitch-dominant mode is dynamically independent from planar and roll modes, and that enhancing the pitch mode through suspension design can emphasize a nose-down turning posture improving subjective evaluation at turn-in maneuver without compromising stability or handling performance. This modal perspective provides a theoretical basis for optimizing fundamental chassis design in the early stages of vehicle development, reducing reliance on trial-and-error design a nd enabling more efficient, targeted performance tuning.

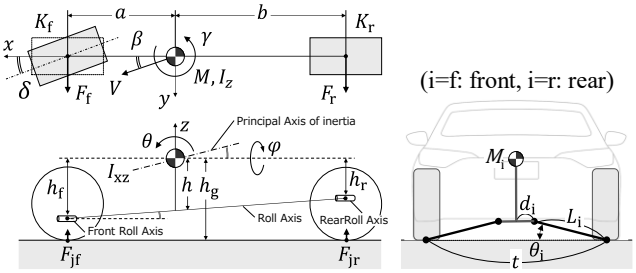

Fig. 1 Bicycle Model with roll and pitch

Pitch dynamics

$$|sE - A| = (I_y s^2 + C_\theta s + K_\theta)$$

Yaw rate, body slip and roll dynamics

$$\begin{bmatrix} MVs + (K_f + K_r) & MV + \frac{aK_f - bK_r}{V} & \frac{h_f K_f + h_r K_r}{V} & 0 \\ aK_f - bK_r & I_z s + \frac{a^2 K_f + b^2 K_r}{V} & -I_{xz} s + \frac{ah_f K_f - bh_r K_r}{V} & 0 \\ (h_f K_f + h_r K_r) & -I_{xz} s + \frac{ah_f K_f - bh_r K_r}{V} & I_x s + (C_\varphi + \frac{h_f^2 K_f + h_r^2 K_r}{V}) & K_\varphi - mgh \\ 0 & 0 & -1 & s \end{bmatrix} = 0$$

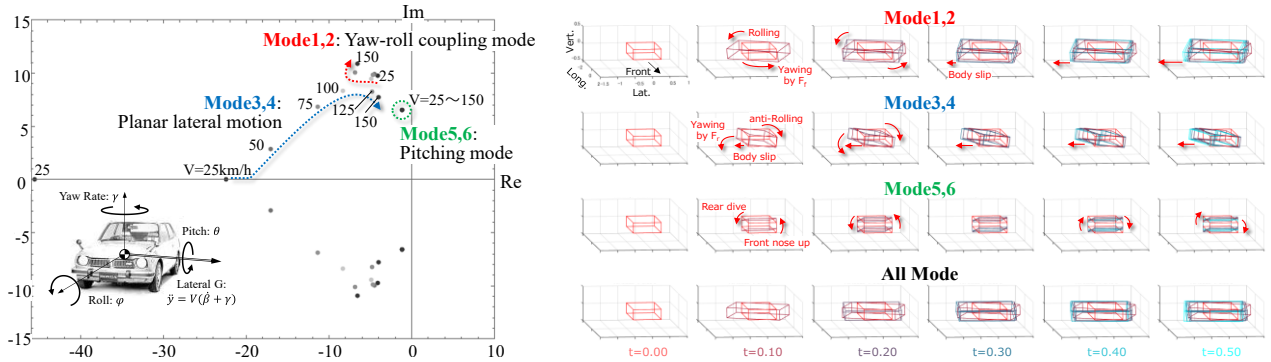

Fig.2 Animated visualization of individual modal responses to a step steer input of 15[deg] at V=100 [km/h].
Note: The amplitude of each mode is independently scaled for clarity. (yaw and roll: ×20, pitch: ×4000)

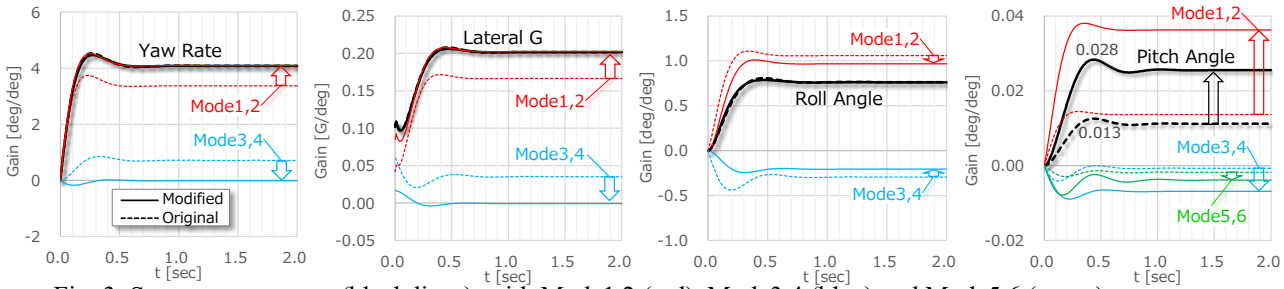

Fig. 3 Step steer response (black lines), with Mode1,2 (red), Mode3,4 (blue) and Mode5,6 (green) component, from Modified(solid line) compared with Original(broken line) roll center height configulation, V=100[km/h]

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