

Theoretical Analysis and Experimental Verification using Test Bench of Jacking Characteristics during Cornering

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First, jacking characteristics during steady-state cornering are analyzed theoretically, including the differences in the mechanisms between independent suspension systems and (semi) rigid suspension systems, such as torsion beam suspension. Based on the equilibrium of internal forces in the suspension during steady-state cornering, the jacking displacement of independent suspension system is expressed as a system of equations involving the roll angle and load transfer distribution, as shown in Equation (1). Assuming that the roll angle is proportional to lateral acceleration and the load transfer distribution is a constant value, this yields the approximate solution given by Equation (2). The jacking changes more rapidly than a quadratic parabola characteristic with respect to the lateral acceleration. Since the roll center height change rate for most independent suspension systems is such that $e > 1$, jack up tendency increases when the roll angle decreases due to higher stabilizer stiffness. On the other hand, the system of equations for jacking in rigid and semi-rigid suspensions is given by Equation (3), and the approximate solution is given by Equation (4). The jacking exhibits a quadratic parabola characteristic with respect to lateral acceleration. Since the roll center height change rate for rigid and semi-rigid suspensions is $e < 1$ (torsion beam suspension is $e \approx 0$, rigid suspension with lateral rod is $e \approx 0.5$), the behavior becomes jack-up characteristics proportional to the roll angle. In contrast to independent suspensions, an increase in stabilizer stiffness reduces jack-up behavior.

$$Z_i = \left[\frac{\frac{2}{w} h_i \lambda_i + (1 - e_i) \phi}{1 - \frac{\lambda_i e_i d_i m a_y}{w k_i}} \right] \frac{d_i m}{2 k_i} a_y \quad (1) \quad \text{where } \lambda_i = \frac{\Delta F_i}{F_i} = \varepsilon_i \frac{\Delta W_i}{W_i} = \varepsilon_i \frac{\left(\frac{H}{w}\right) D_i m a_y}{d_i m g / 2} = 2 \varepsilon_i \frac{H D_i a_y}{w d_i g}$$

$$Z_i \approx \left[\frac{4 \varepsilon_i \frac{D_{i0} H}{d_i g w^2} h_i + (1 - e_i) G_\phi}{1 - 2 \varepsilon_i \frac{e_i D_{i0} m H}{g w^2 k_i} a_y^2} \right] \frac{d_i m}{2 k_i} a_y^2 \quad (2)$$

$$Z_i = (1 - e_i) \phi \frac{d_i m}{2 k_i} a_y \quad (3)$$

$$Z_i \approx (1 - e_i) G_\phi \frac{d_i m}{2 k_i} a_y^2 \quad (4)$$

Z_i : jacking displacement, ϕ : roll angle, m : vehicle mass, H : center of gravity height, w : tread, d_i : weight distribution ratio, k_i : wheel rate, g : gravitational acceleration, a_y : lateral acceleration, G_ϕ : roll angle gain, D_i : load transfer distribution ratio, D_{i0} : initial D_i , ε_i : sensitivity of lateral force to vertical load, h_i : initial roll center height, e_i : roll center height change rate, subscript i : $i=f$ (front), $i=r$ (rear).

Next, experimental method using a test bench that is unaffected by road surface conditions are devised to verify the relationship between suspension type and jacking characteristics. Using the K&C suspension characteristics measurement system, the vehicle body attitude—including the front and rear jacking—can be measured by controlling the lateral force and vertical load acting on each wheel so that the external forces acting on the vehicle during steady-state cornering are balanced. Figure 1 shows the jacking characteristics for a vehicle with front strut suspension and rear multi-link suspension. Figure 2 shows the jacking characteristics for a vehicle with front strut suspension and rear torsion beam suspension. Without the bump stopper, the experimental results show good agreement with the theoretical calculations. Furthermore, this experimental method also can evaluate the effect of bump stopper characteristics on jacking.

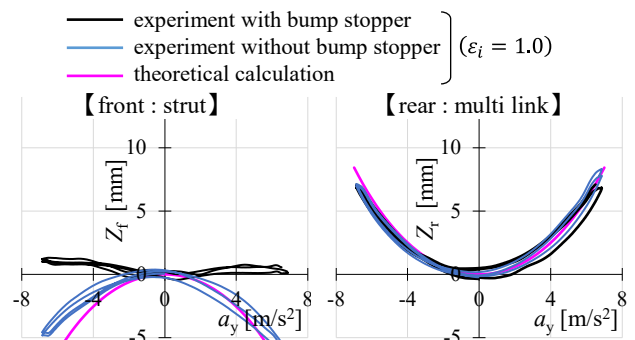


Fig.1 Jacking characteristics of vehicle I

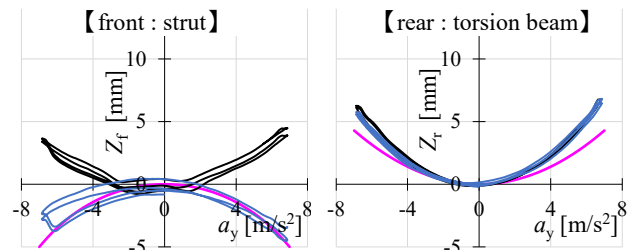


Fig.2 Jacking characteristics of vehicle II