Semi-physical Tire Model for Cornering Simulations of Vehicles

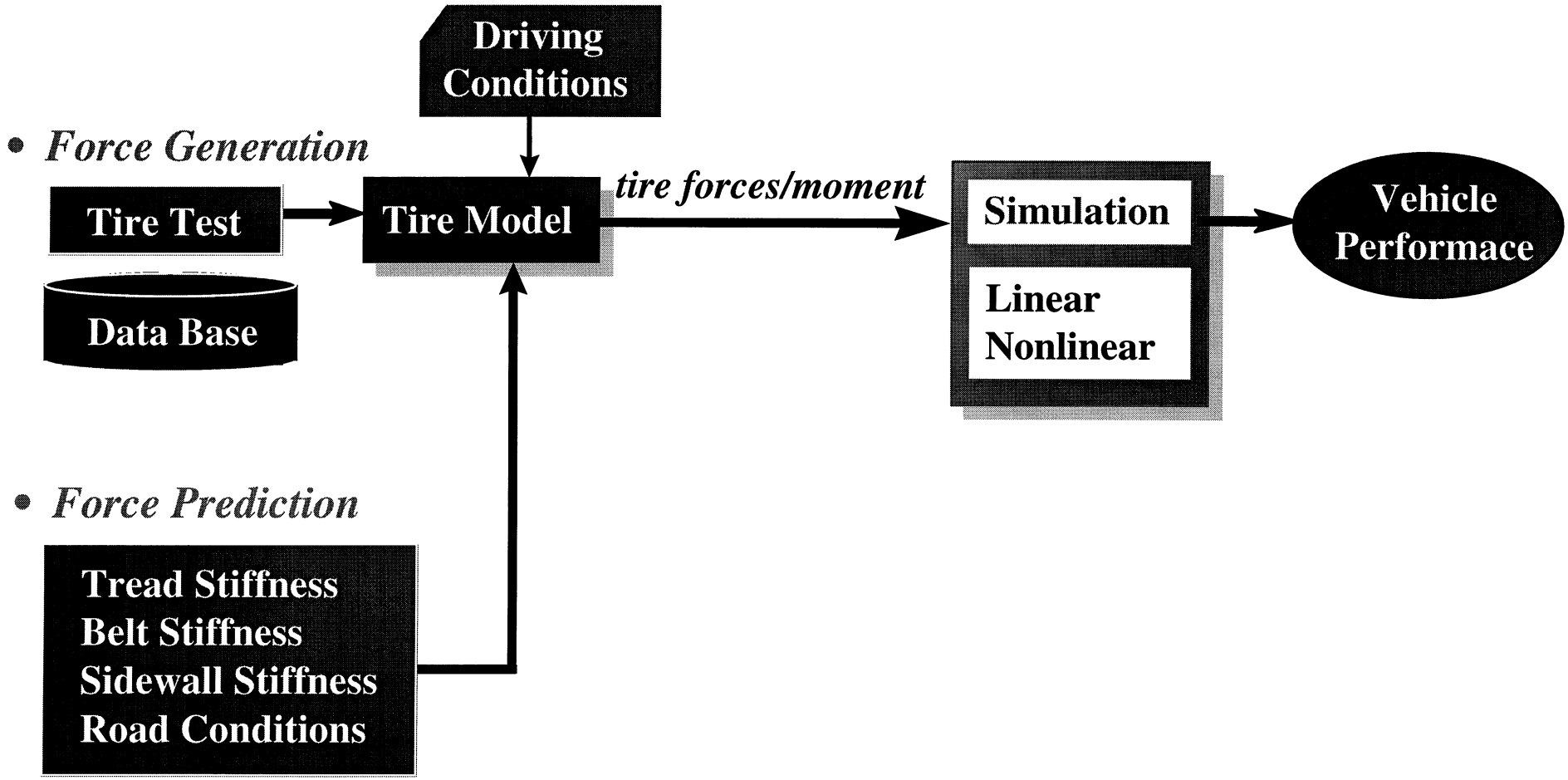
Seong Ho Kim

Gwanghun Gim

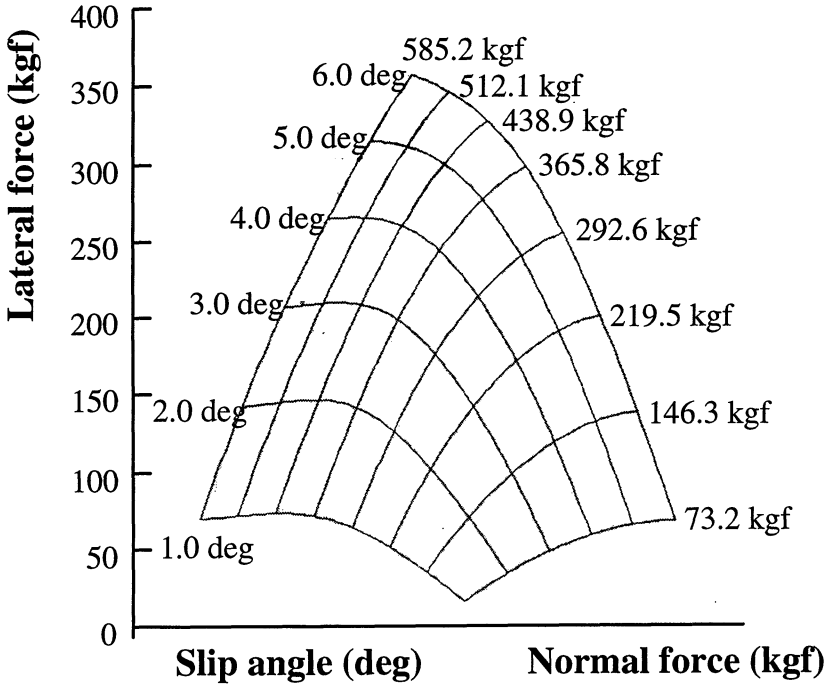
Hankook Tire Co. Ltd.

Contents

Role of Tire Model in Tire Design Process



Using the Raw Data



- **Carpet plot**
- **Interpolation**
- **Exact value at measured points**
- **A lot of time and cost for experiment**
- **Can not get the data beyond experiment**
- **Hard to get convergence in Simulation**

Previous Tire Model

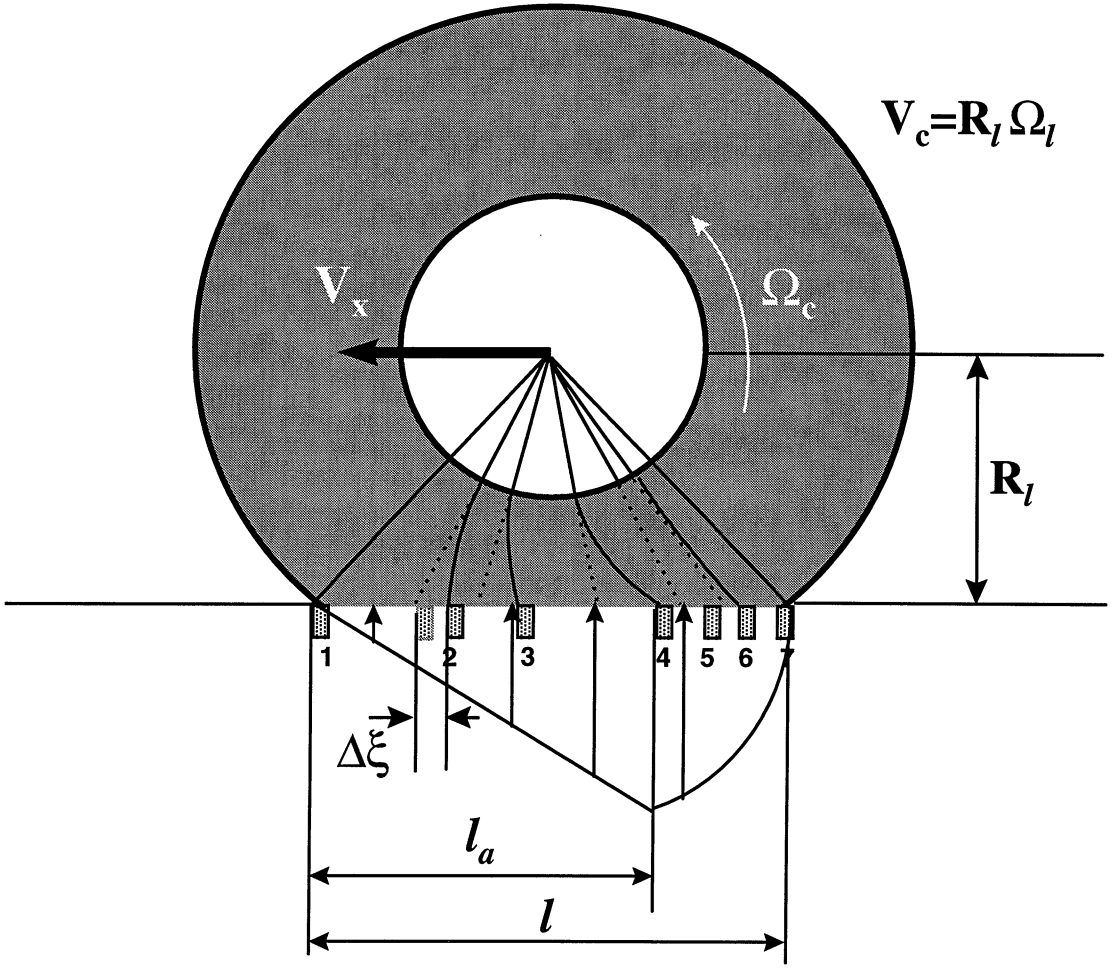
- **Analytical model**
  - Sakai model, UA-tire model
  - Based on physical concept
  - Small number of parameters
  - Not enough for practical simulations
- **Empirical model**
  - Magic formula, Polynomial model
  - Curve fitting the measured data using specific functions
  - More accurate than analytical models
  - Hard to use without experimental data

New Semi-physical Model

- **Analytical + empirical model**
- **Accurate tire forces/moment**
  - **For various driving conditions**
    - **slip ratio, slip angle, camber angle and load**
  - **Transient**
- **Based on physical concept**
  - **Tire component stiffness and pneumatic trail**
  - **Fewer parameters than empirical models**
  - **Provision of possibility that a designer can predict tire forces/moment for modified tire design**

→ **Paper Tire**

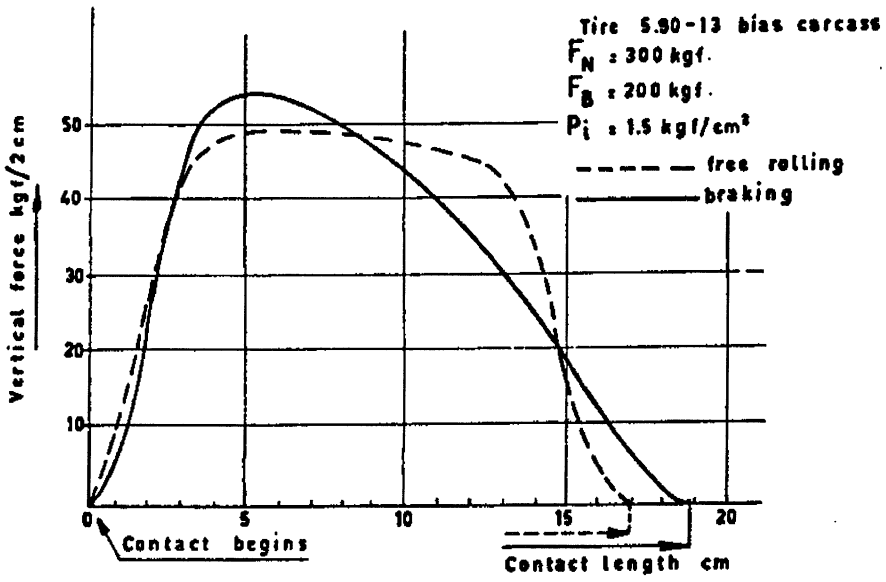
Generation of the Longitudinal Force



$$F_\xi = \int_0^w \int_0^{l_a} \sigma_\xi^{(a)} d\xi d\eta + \int_0^w \int_{l_a}^{l} \sigma_\xi^{(s)} d\xi d\eta$$

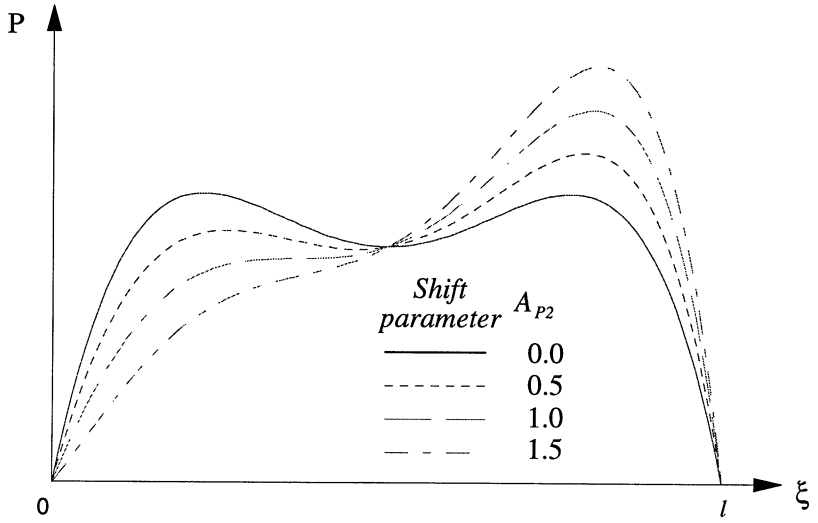
Contact Pressure Distribution

Contact pressure distribution for free rolling and braking



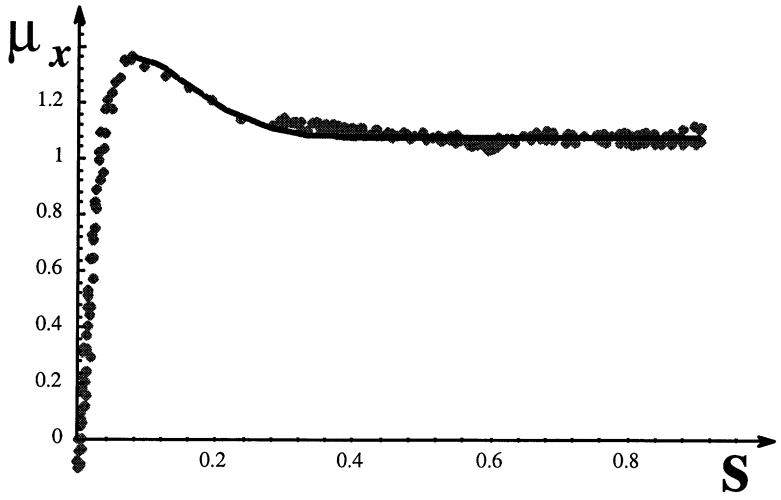
Generated by function

$$P = \frac{120F_z}{(20+A_{p1})\cdot w\cdot l}\cdot\frac{\xi}{l}\cdot\left(1-\frac{\xi}{l}\right)\cdot\left[1+A_{p1}\left(\frac{\xi}{l}-\frac{1}{2}\right)^2\right]\cdot\left[1+A_{p2}\left(\frac{\xi}{l}-\frac{1}{2}\right)\right]$$



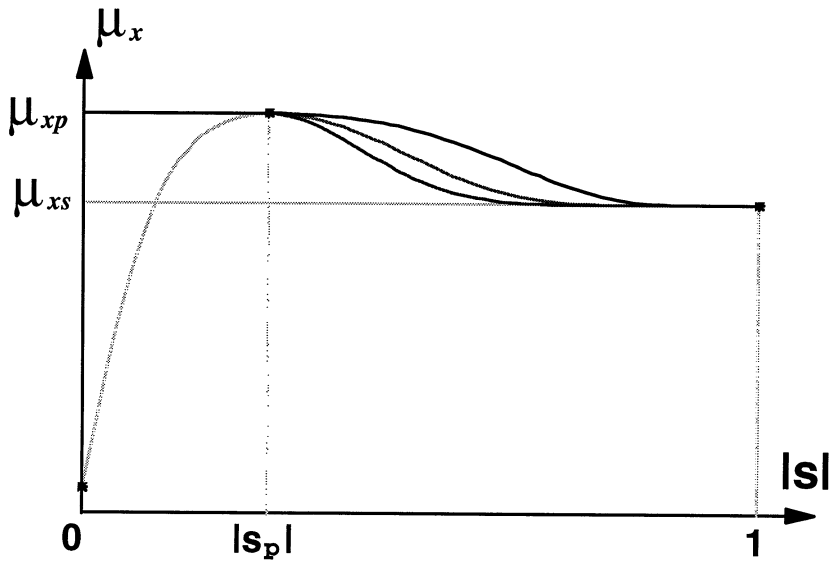
Friction Coefficient

Longitudinal friction force



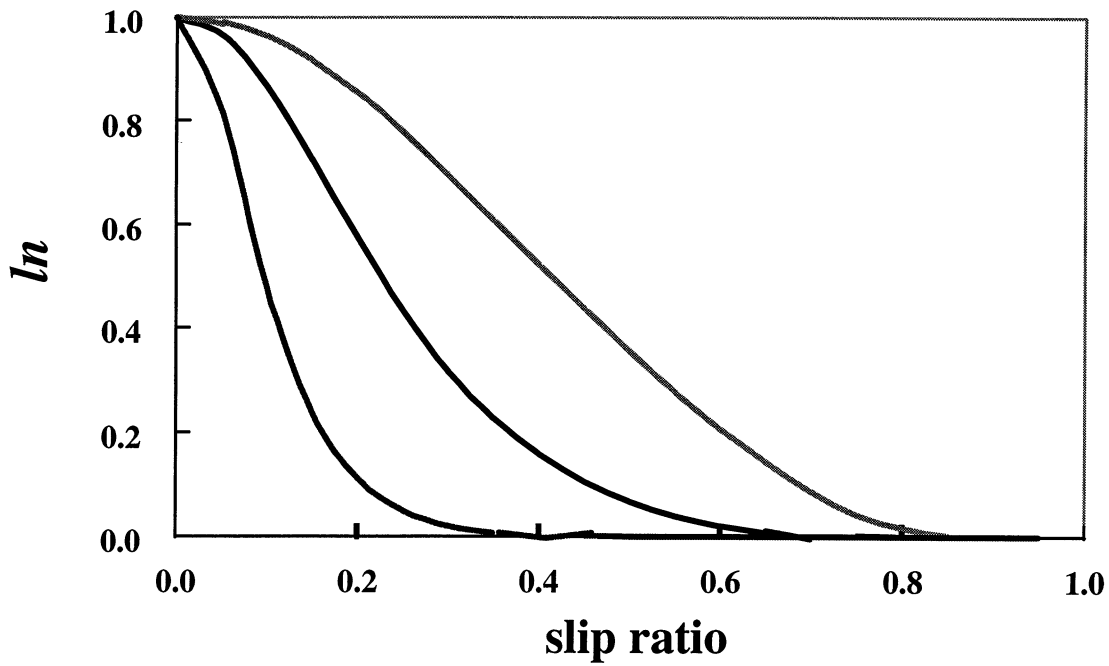
Generated by function

$$\mu_x = \mu_{xs} + \left(\mu_{xp} - \mu_{xs}\right) \operatorname{sech}\left(A_{\mu s1} \tanh\left(A_{\mu s2}\left(|s| - |s_p|\right)\right) \Big/ \left(1 - |s|\right)\right)$$



Adhesive Contact Length

$$l_n(s) = \mathrm{sech}\left[a \tanh\left(b\,|s|\right)/\left(1-|s|\right)\right]$$



$$l_n = \frac{\textit{adhesive length}}{\textit{contact length}}$$

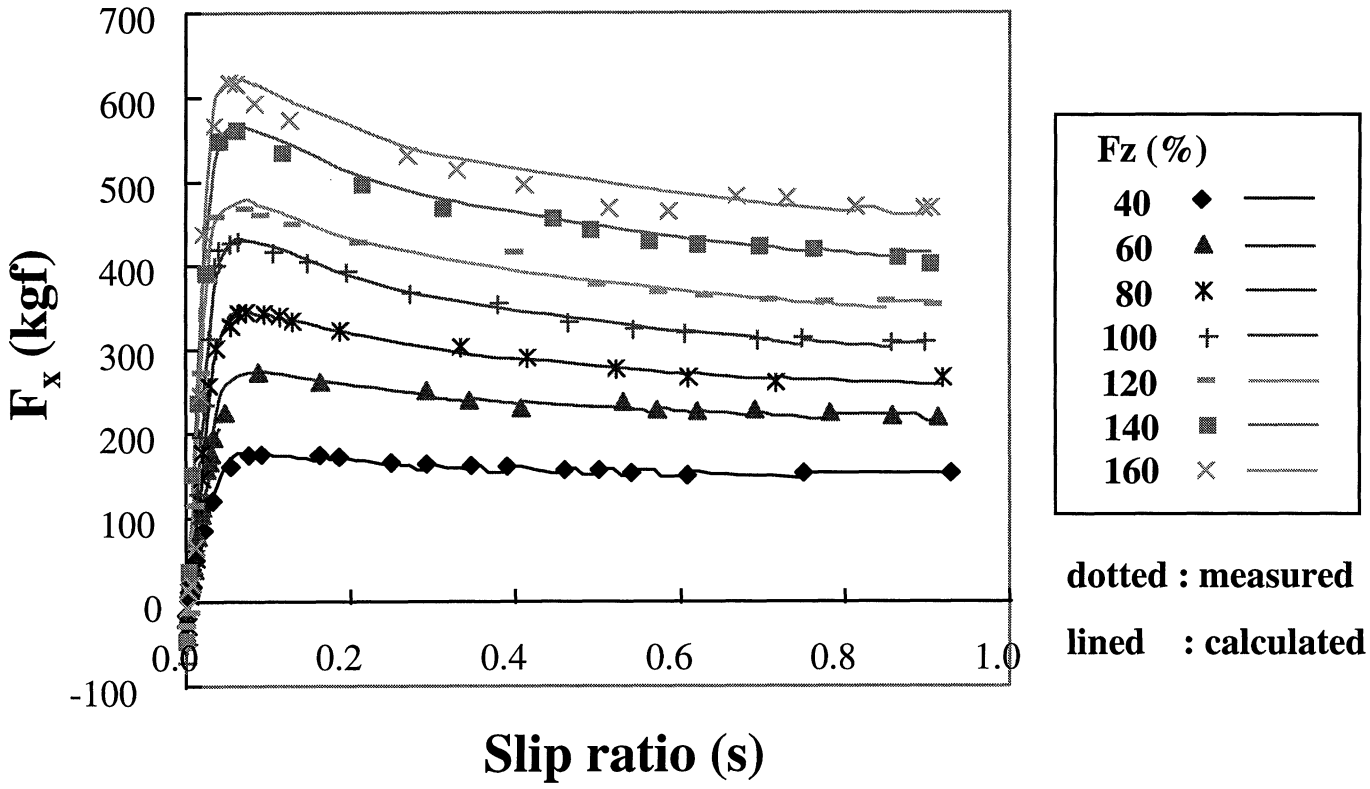
B.C

$$l_n\big|_{s=0} = 1$$

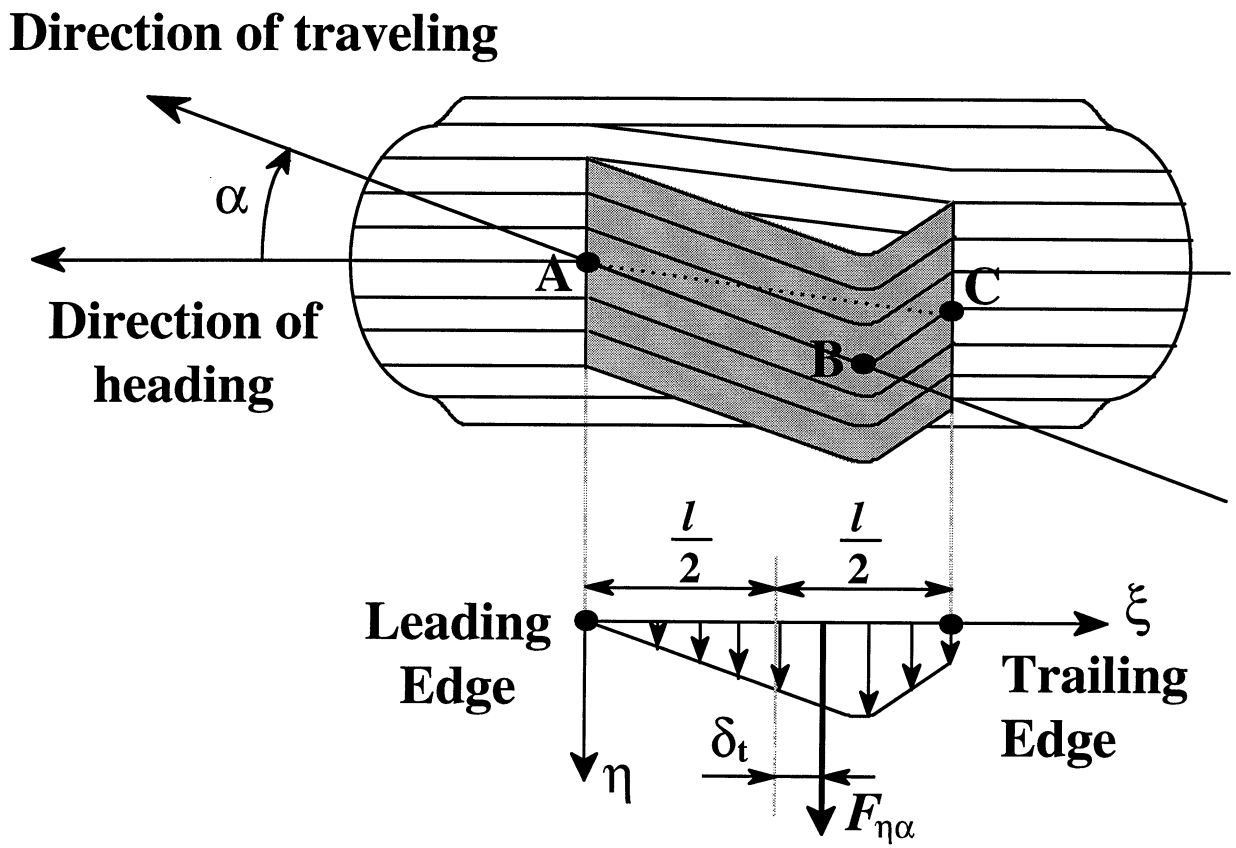
$$l_n\big|_{s=1} = 0$$

$$l_n \approx 1 \quad for\ s << 1$$

Longitudinal Force for various Loads



Generation of the Lateral Force

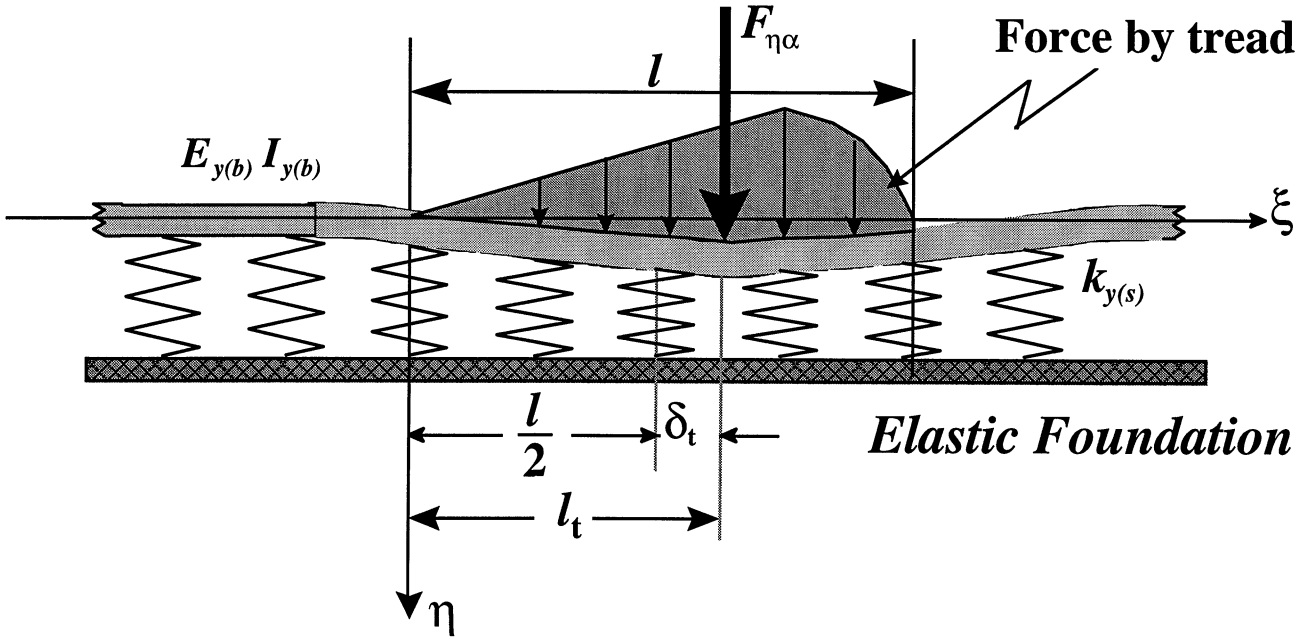


Elastic Founded Beam Model

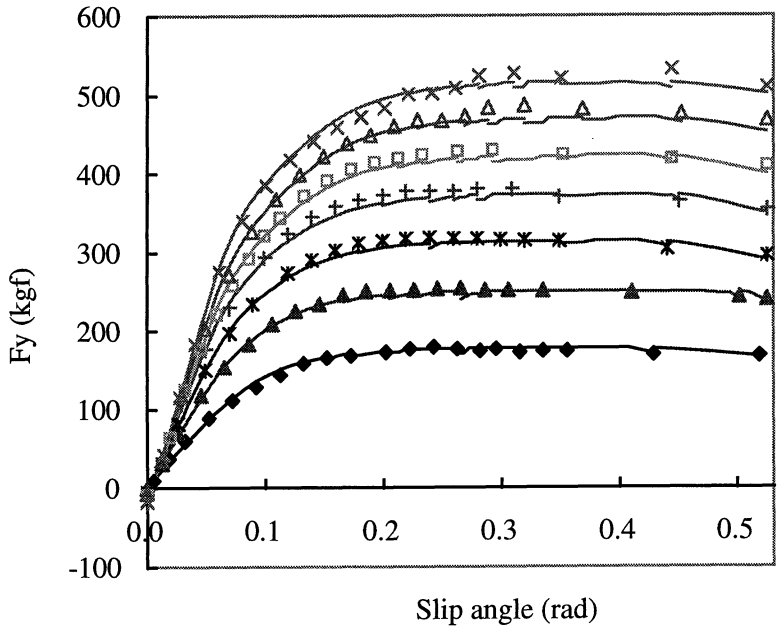
$$E_{y(b)} I_{y(b)} \frac{d^4 \eta}{d\xi^4} + k_{y(s)} \eta = F_{\eta\alpha} \cdot \delta(\xi - l_t)$$

$$F_\eta = \int_0^w \int_0^{l_a} \sigma_{\eta\alpha}^{(a)} d\xi dw + \int_0^w \int_{l_a}^{l} \sigma_{\eta\alpha}^{(s)} d\xi dw$$

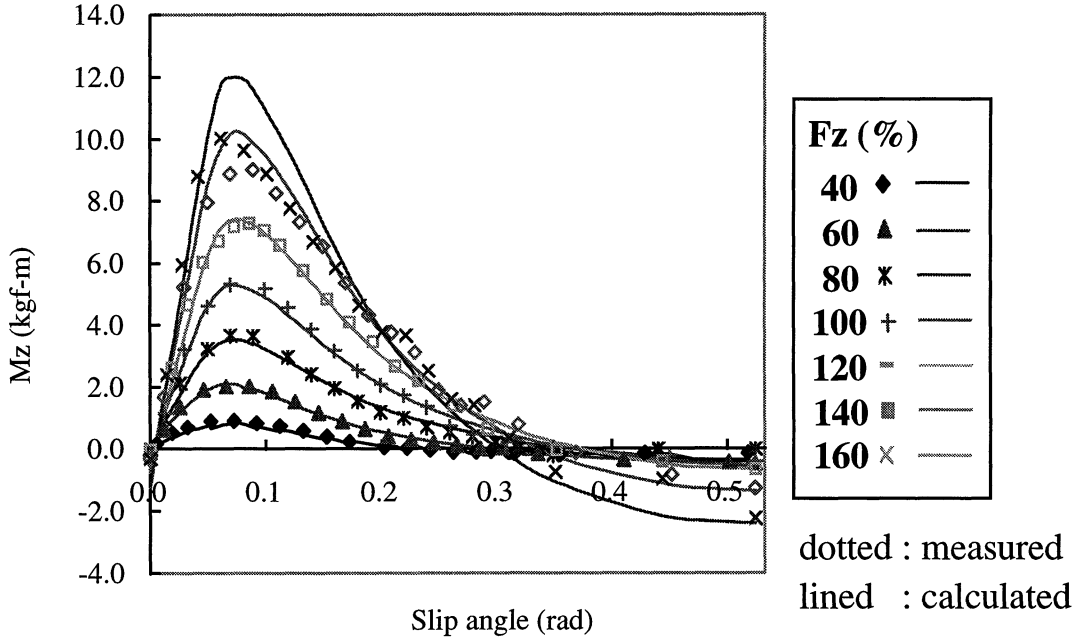
$$M_{z\alpha} = \int_0^w \int_0^{l_a} (\xi - l/2) \sigma_{\eta\alpha}^{(a)} d\xi dw + \int_0^w \int_{l_a}^{l} (\xi - l/2) \sigma_{\eta\alpha}^{(s)} d\xi dw$$



Lateral force/moment for Various Loads

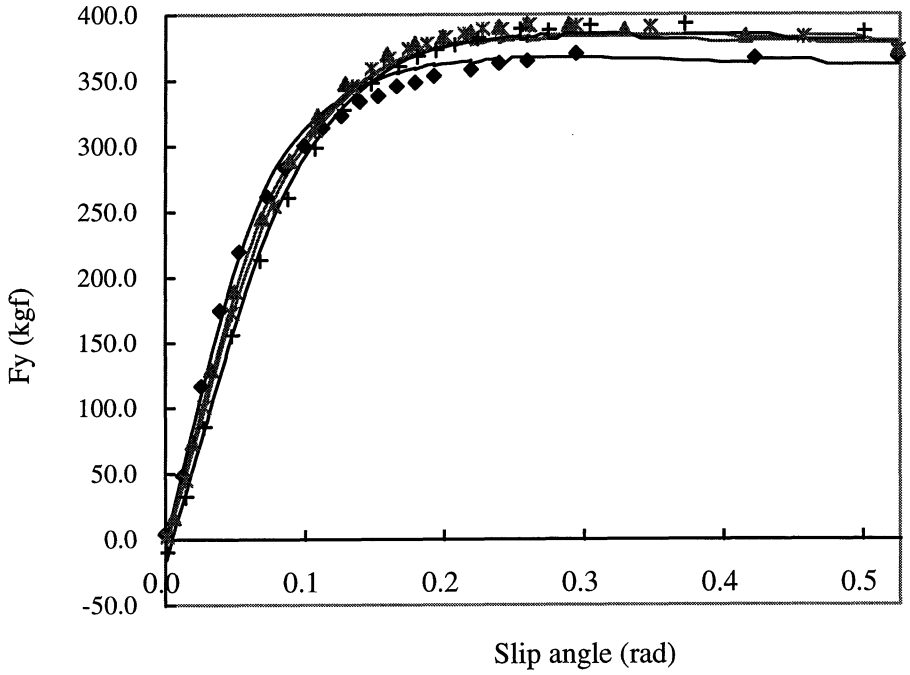


Lateral Force

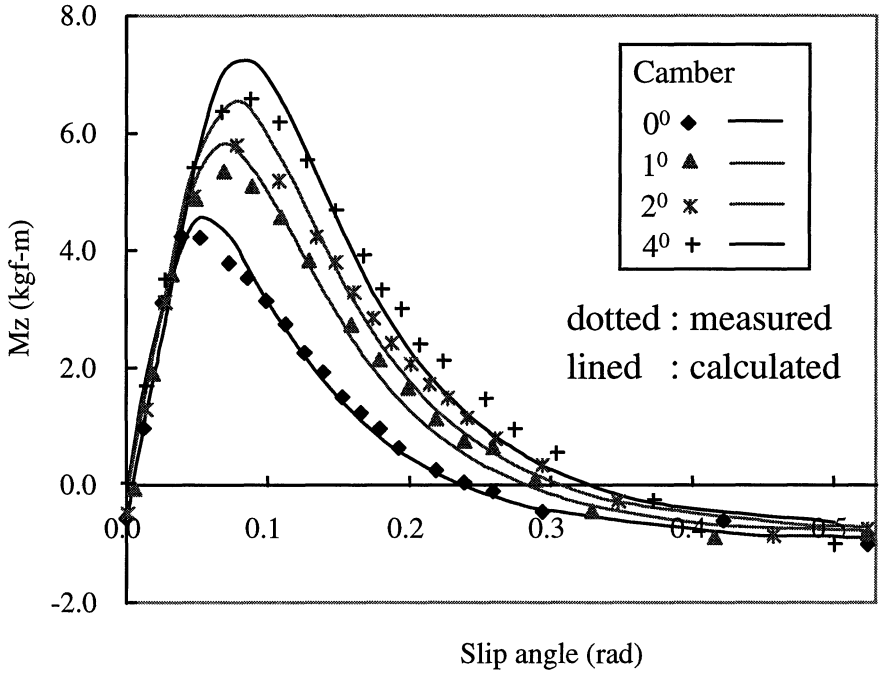


Self-aligning moment

Lateral Force/moment for Camber Angle

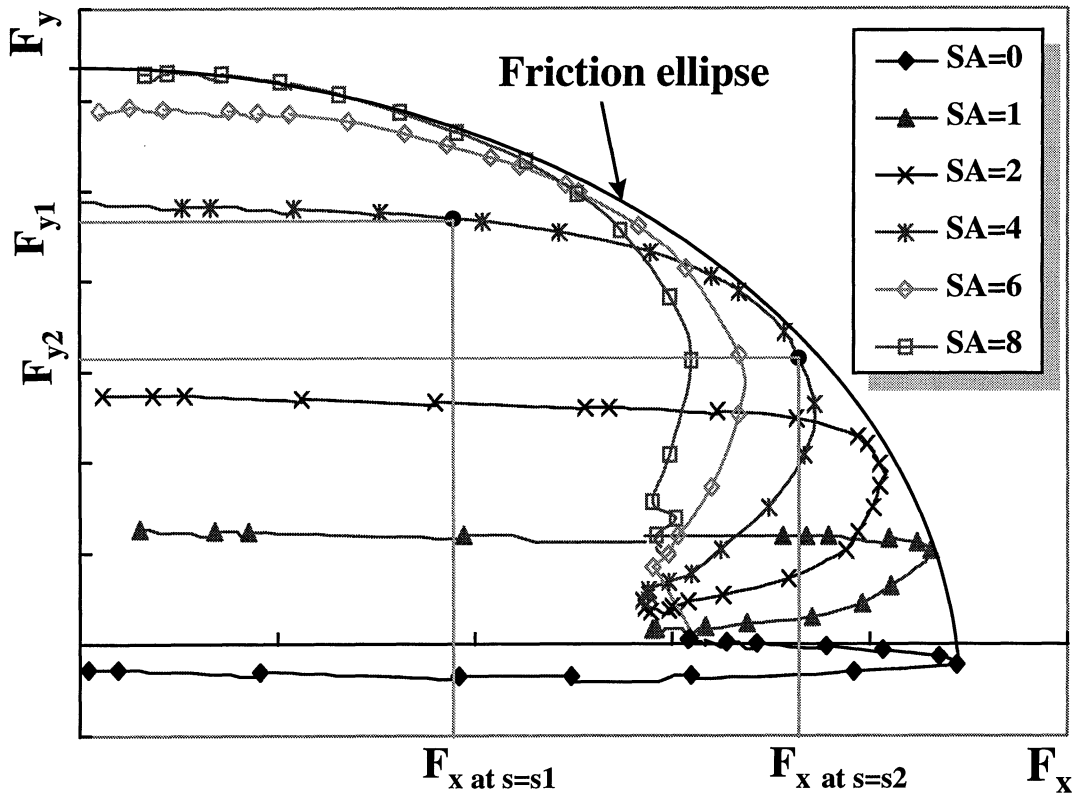


Lateral Force

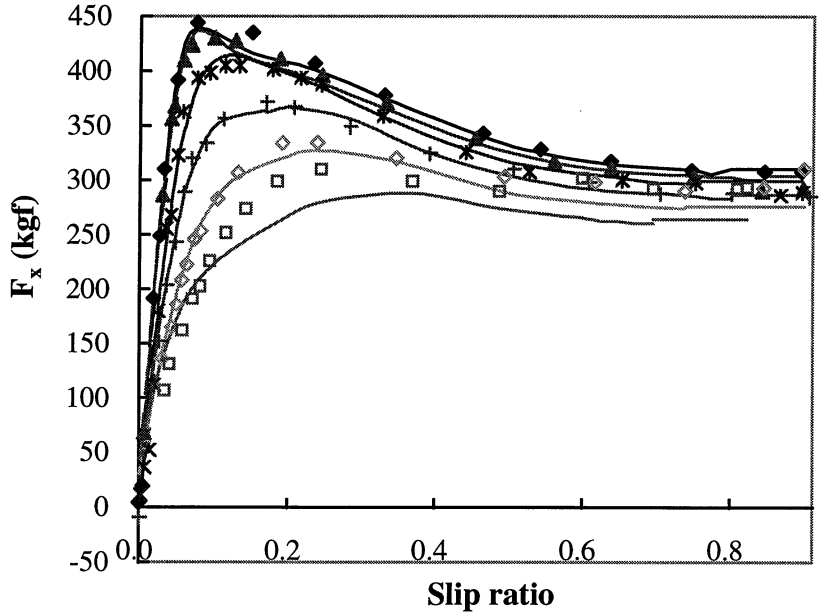


Self-aligning moment

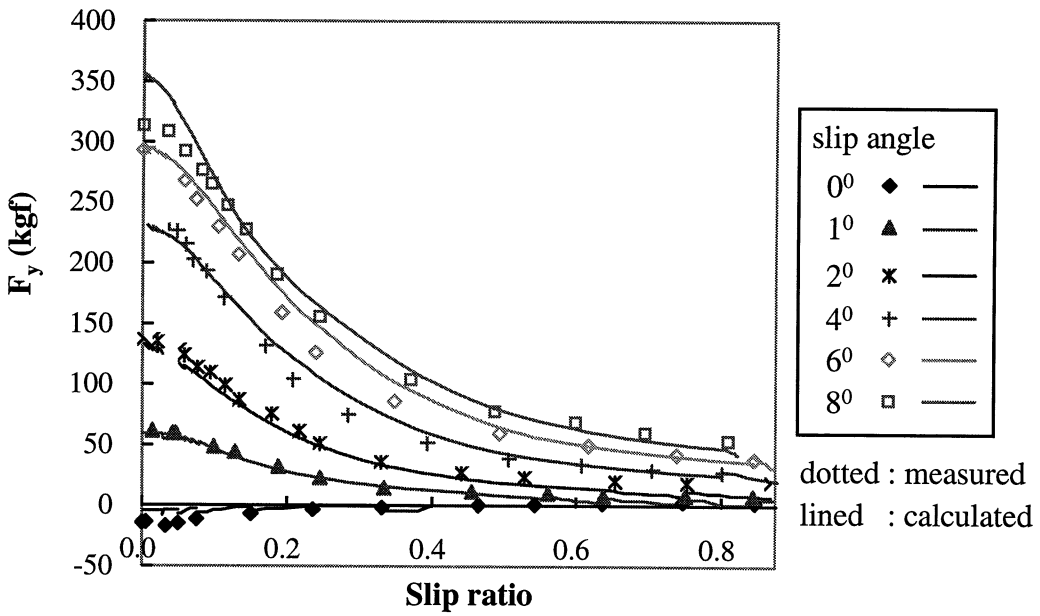
Longitudinal/Lateral Forces at Combined Slip



Longitudinal/Lateral Forces at Combined Slip

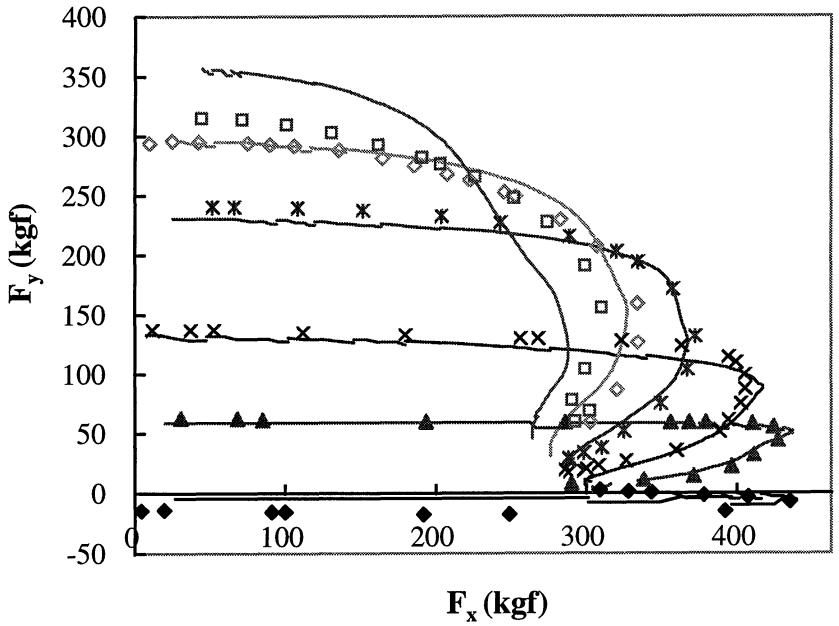


F_x vs. slip ratio for various slip angle

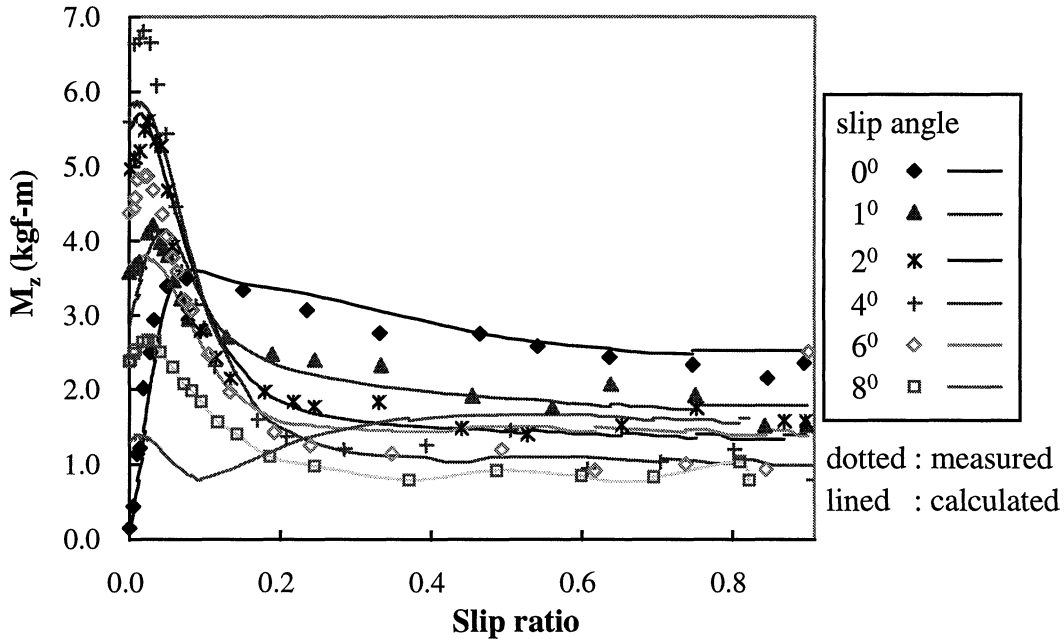


F_y vs. slip ratio for various slip angle

Forces/moment at Combined Slip

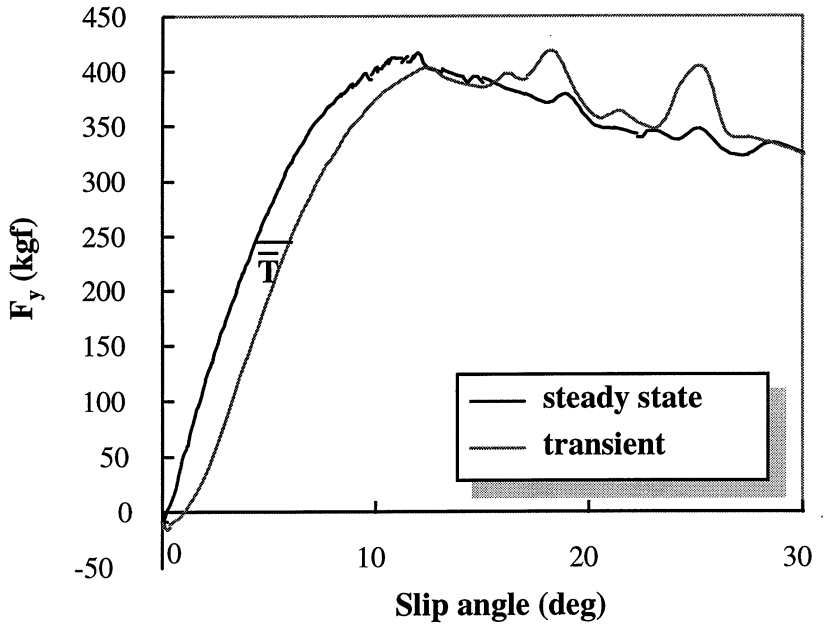


F_y vs. F_x for various slip angle



M_z vs. slip ratio for various slip angle

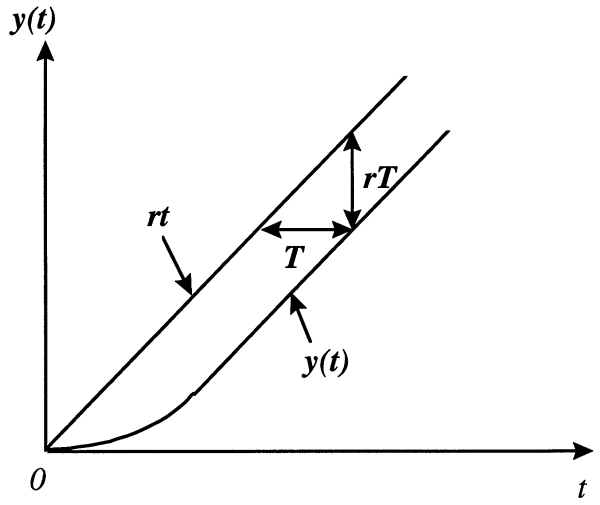
Transient Characteristics of Tire



Lateral force measured at transient and steady state

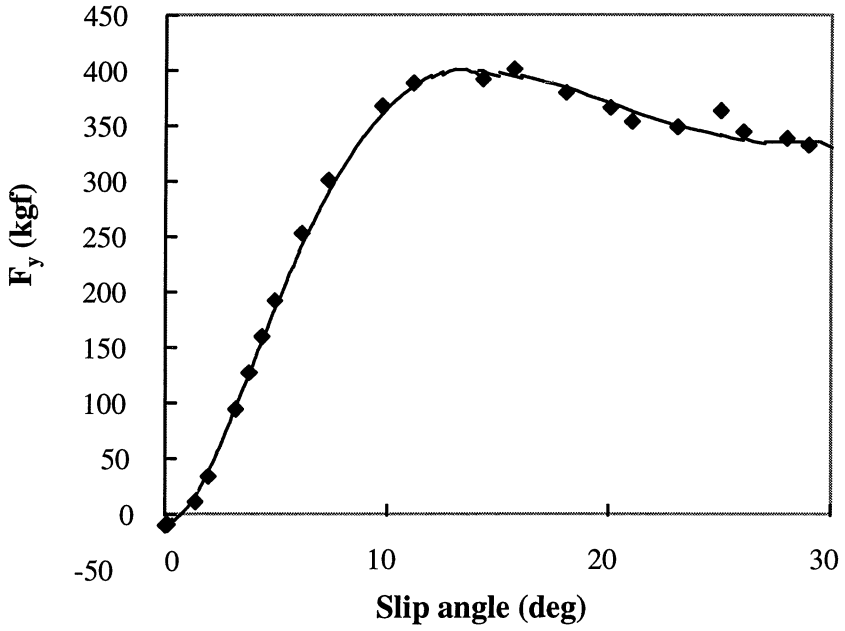
$$T\frac{dy(t)}{dt} + y(t) = f(t)$$

$$y(t) = r\left(t - T + Te^{-t/T}\right)$$

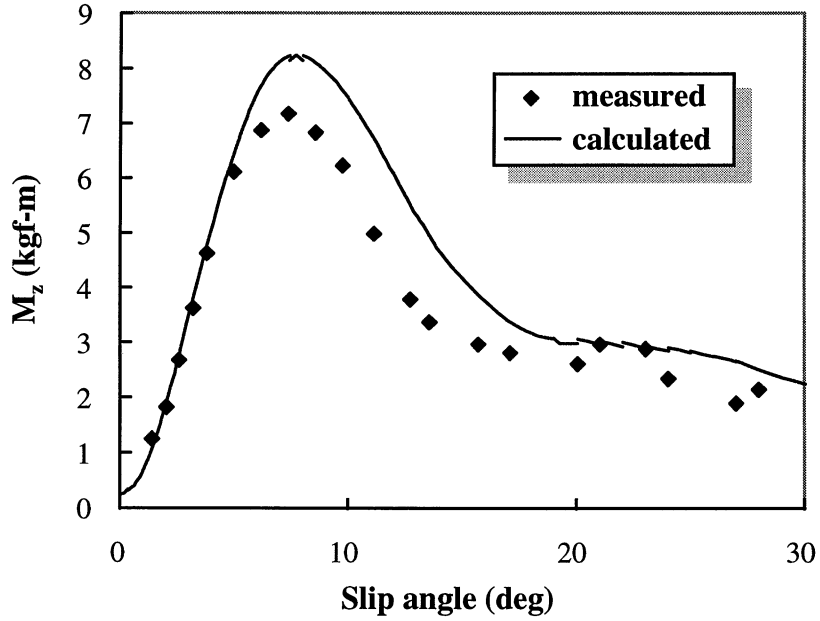


Response of 1st order system for ramp input

Lateral Force/moment at Transient



Lateral force at transient



Self-aligning moment at transient

Conclusions

- **Based on physical Concept**
  - Tire component stiffness
  - Pneumatic trail
  - Pressure distribution
  - Friction ellipse
  - Adhesive contact length
- **Accurate forces/moment for various driving conditions**
  - Load
  - Combined slip
  - Transient