INDIAN INSTITUTE OF TECHNOLOGY, HYDERABAD

Department Of Mechanical And Aerospace Engineering

Numerical and Analytical model of Tire Forces and Moments

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INTRODUCTION

- Modeling of tires covers everything from simple models, aiming for understanding the physics, to advanced finite-element models that can predict the behavior precisely.
- What we have strived to do as part of this project is to unravel the complexities involved in tire forces and moments by numerical analysis as well as simulation results.

भारतीय प्रौद्योगिकी संस्थान हैदराबाद
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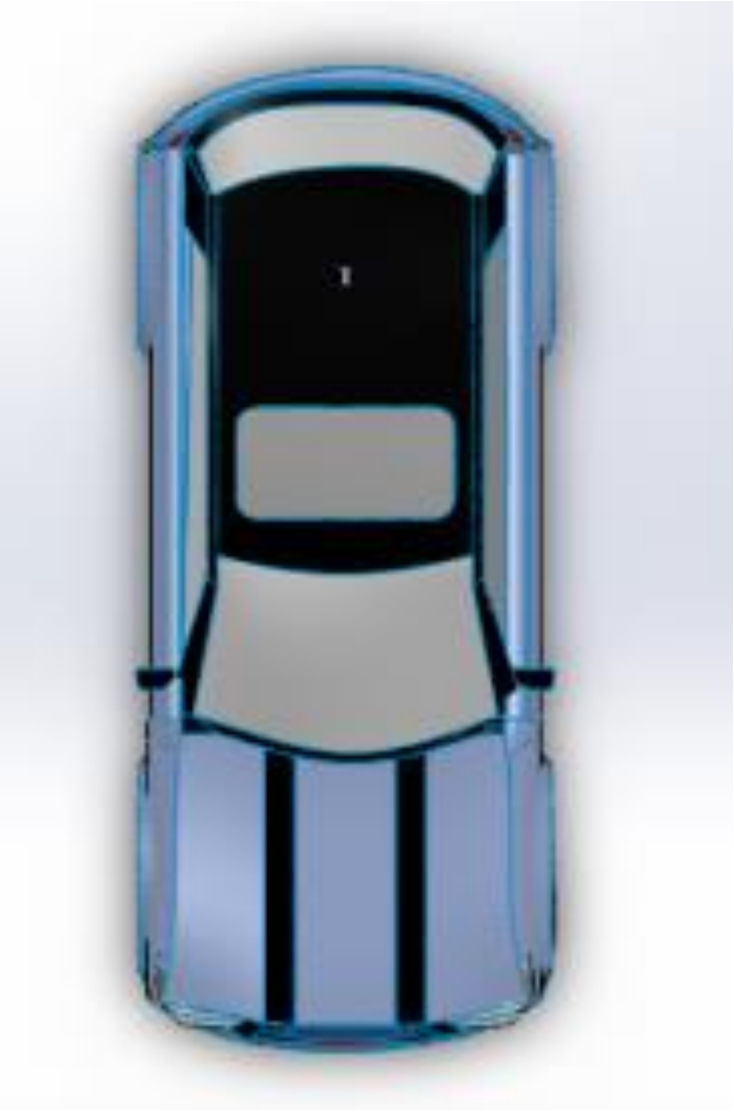
CAR MODEL

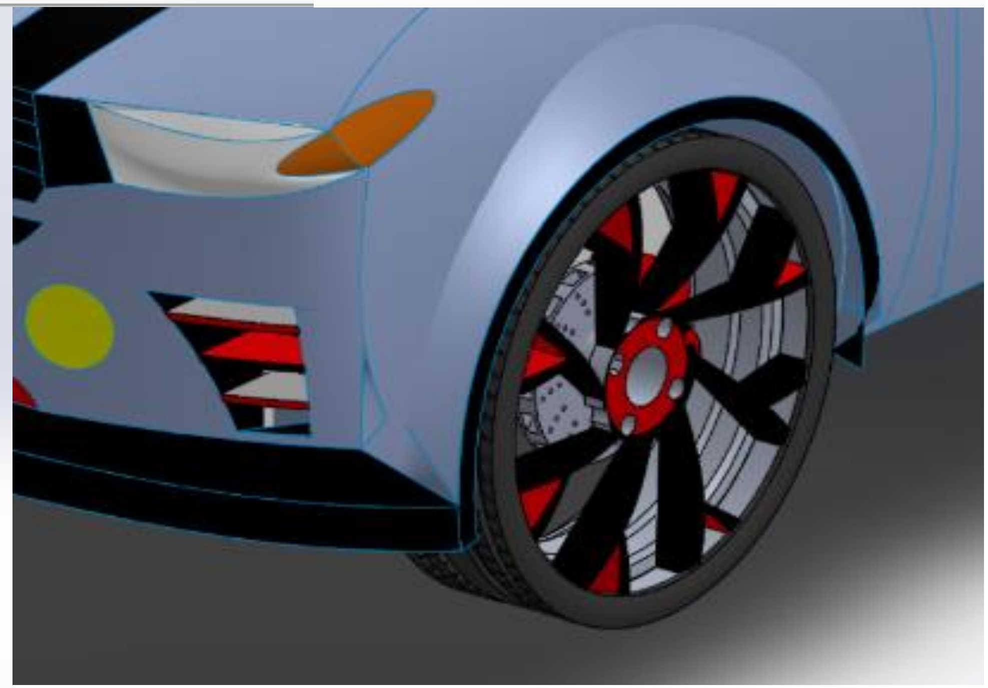
- **COMPACT SPORTS UTILITY VEHICLE**
- **TOOL USED – SOLIDWORKS**

DIMENSIONS

- Length : 3998mm
- Wheelbase : 2700mm
- Height : 1650mm
- Width : 1800mm
- Track width: 1680mm
- Ground Clearance : 210 mm

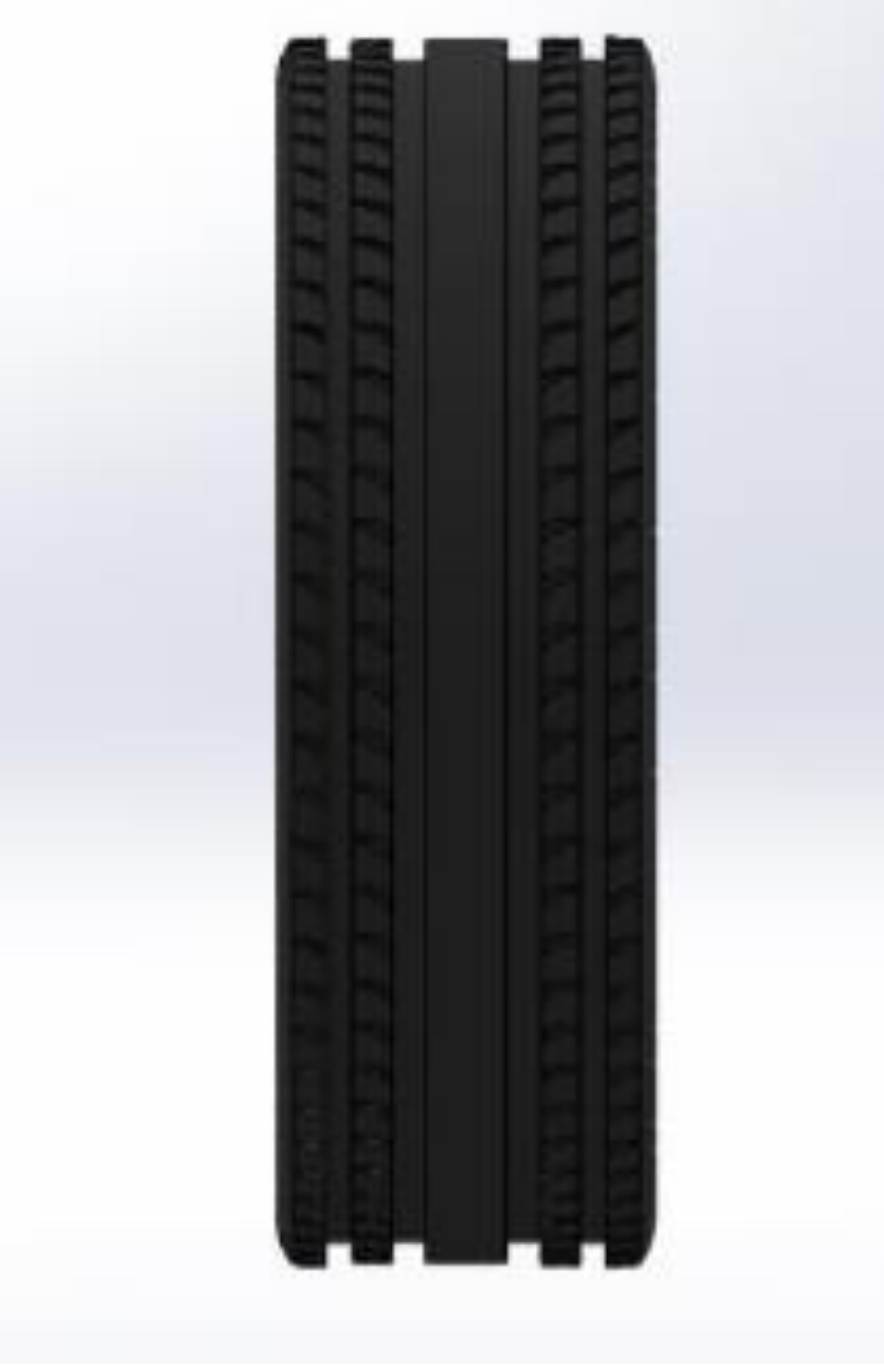



Y
Z
*Right



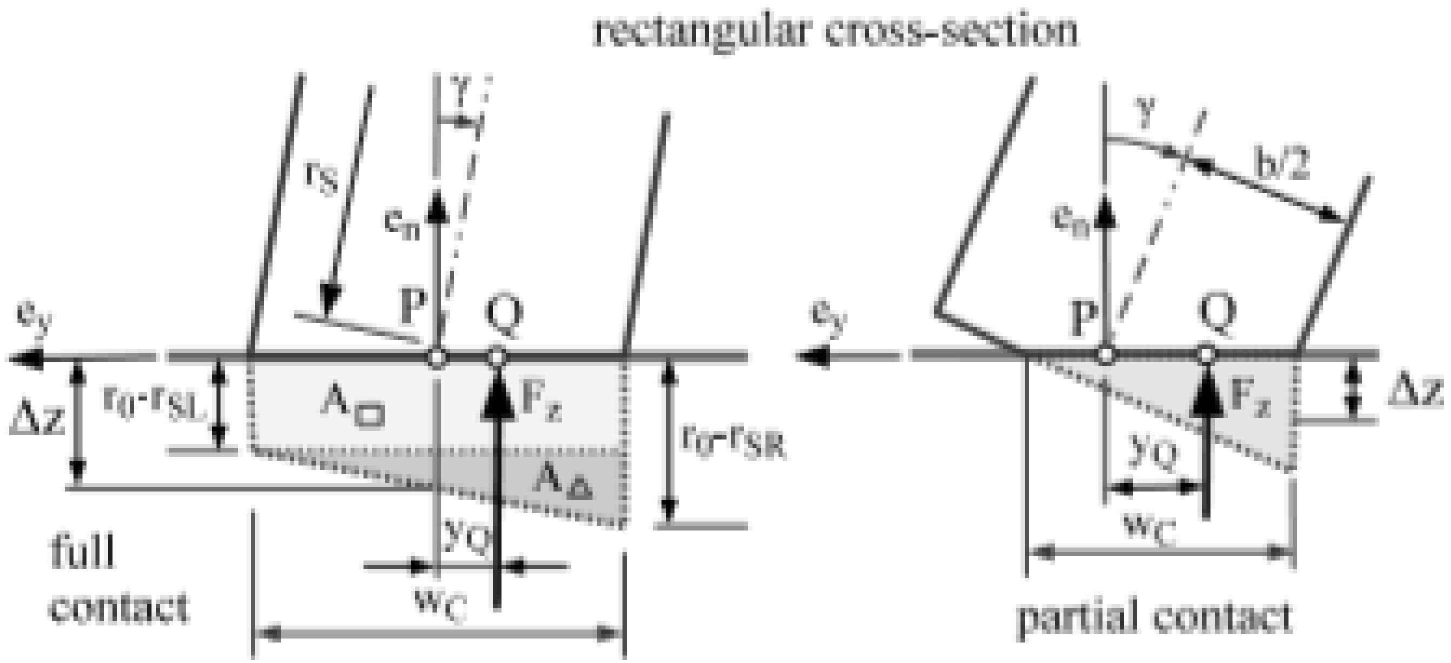
TIRE MODEL

In vehicle dynamics, tires are one of the most important factors that govern the behavior of a moving vehicle. They are the only link between the vehicle chassis and the road and have to transmit vertical, longitudinal and lateral forces.




LATERAL DEVIATION OF CONTACT POINT

- $T_x = F_z \, y_Q$

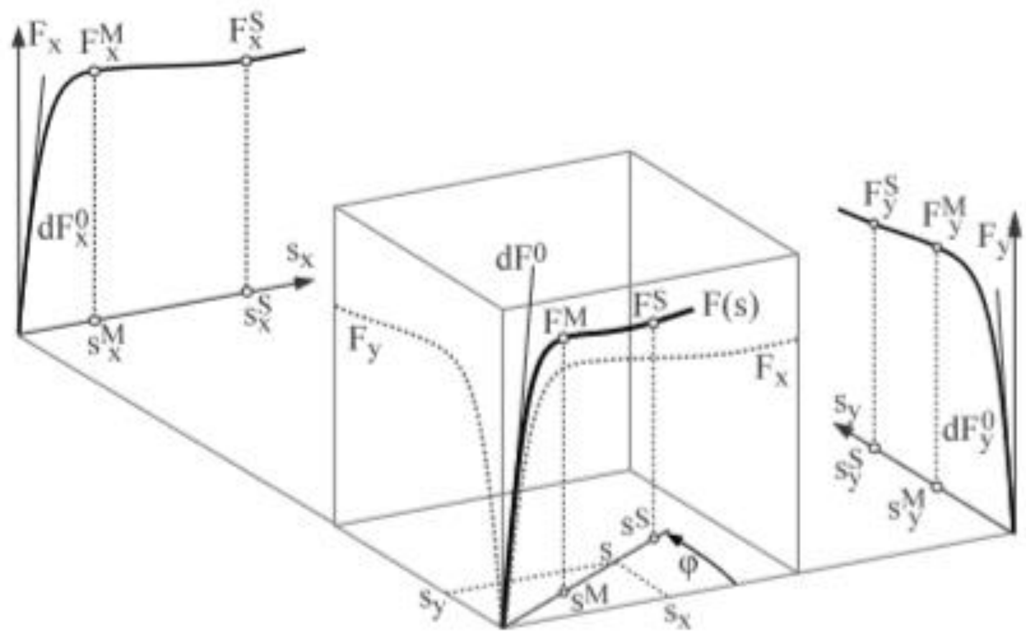


- Wheel load : $F_z = F_z^{st} + F_z^{D} = a_1 \Delta z + a_2 (\Delta z)^2 + d_T \Delta \dot{z}$,
- Longitudinal and lateral forces :

The longitudinal and the lateral forces are described as functions of the longitudinal and the lateral slips

Fx = Fx(sx)

Fy = Fy(sy)



- Combined slip :

$$s_x^N = \frac{s_x}{\hat{s}_x} = \frac{-(v_x - r_D\,\Omega)}{r_D\,|\Omega|\,\hat{s}_x} \quad \Rightarrow \quad s_x^N = \frac{-(v_x - r_D\,\Omega)}{r_D\,|\Omega|\,\hat{s}_x + v_N}$$

$$s_y^N = \frac{s_y}{\hat{s}_y} = \frac{-v_y}{r_D\,|\Omega|\,\hat{s}_y} \quad \Rightarrow \quad s_y^N = \frac{-v_y}{r_D\,|\Omega|\,\hat{s}_y + v_N},$$

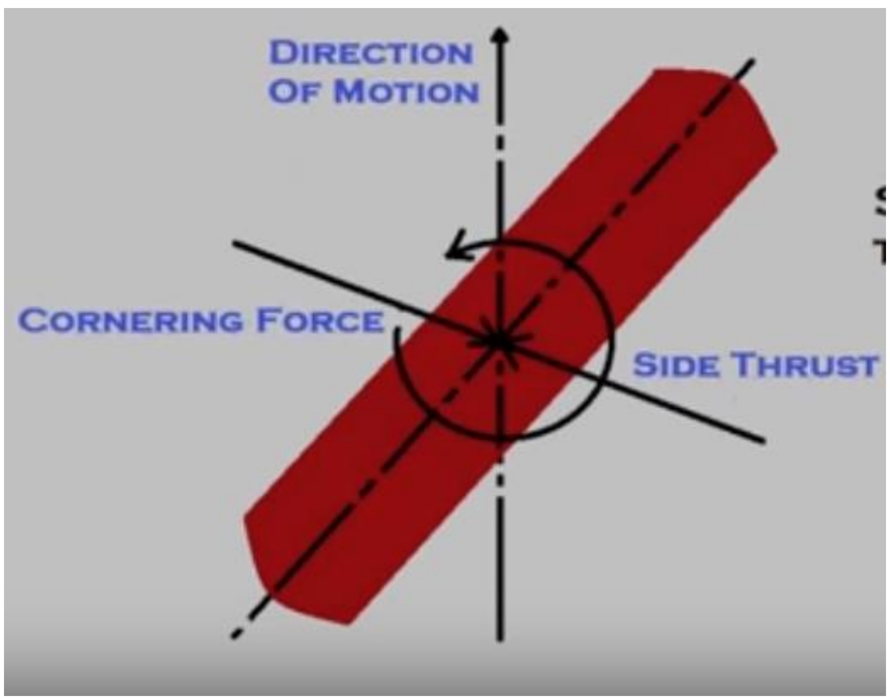
- Total slip , $s = \sqrt{\left(s_x^N\right)^2 + \left(s_y^N\right)^2}$
- Combined Forces

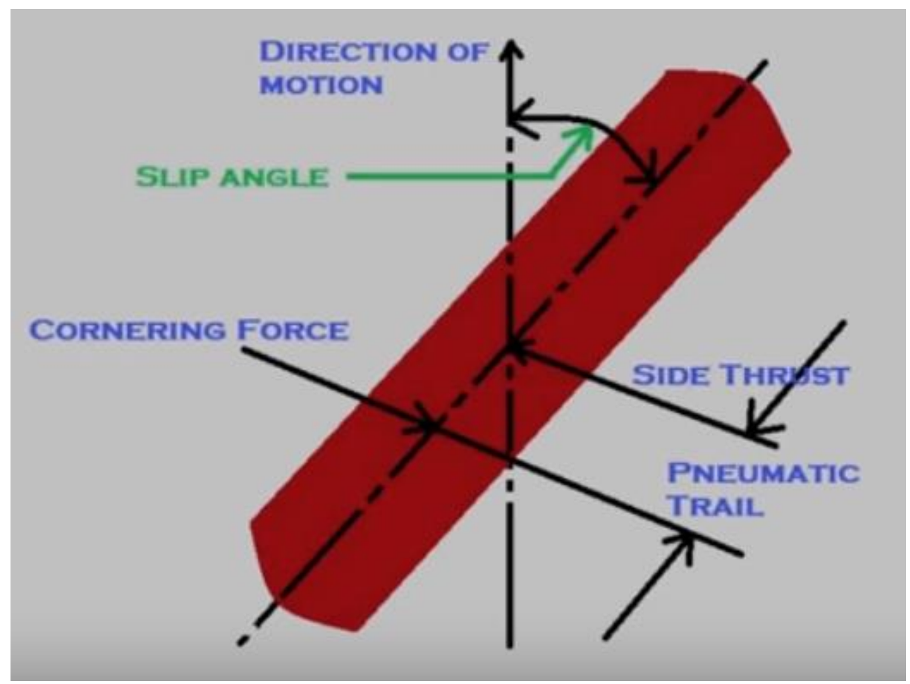
$$F_x = F\,\frac{s_x^N}{s} = \frac{F}{s}\,s_x^N = f\,s_x^N \qquad F_y = F\,\frac{s_y^N}{s} = \frac{F}{s}\,s_y^N = f\,s_y^N$$

SELF ALIGNING TORQUE

$TS = -nFy$

where n is the dynamic offset of pneumatic trail





THREE DIMENSIONAL SLIP

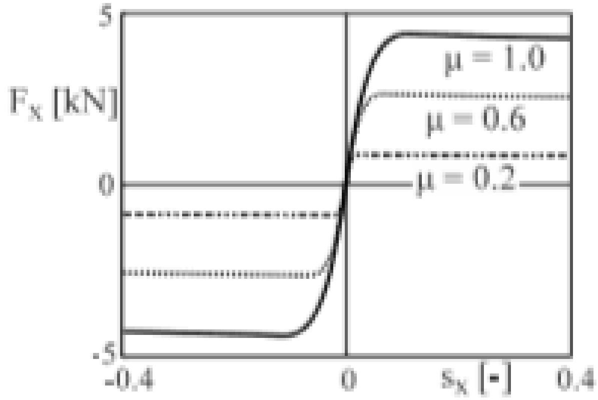
- On steering maneuvers at standstill, a longitudinal, a lateral, and a bore slip will occur simultaneously.
- Generalized slip, $$s_G = \sqrt{s^2 + s_B^2}$$

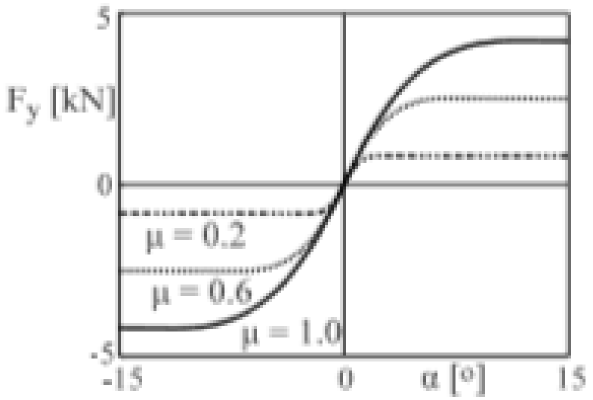
$$F = F_G \frac{s}{s_G}$$

- Bore torque , $$T_B = R_B F_G \frac{s_B}{s_G}$$

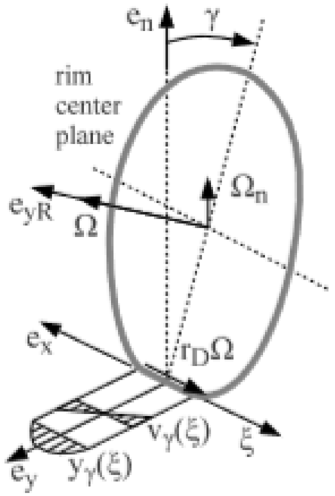
DIFFERENT INFLUENCES ON TIRE FORCES AND TORQUES

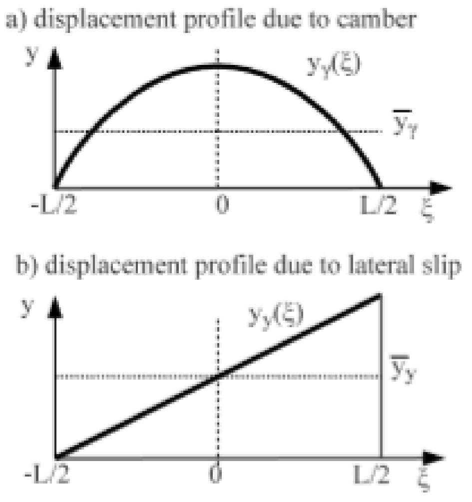
- Friction





- Camber Angle





FIRST ORDER TIRE DYNAMICS

- Modelling aspects

$$\underbrace{F_x(v_x + \dot{x}_e)}_{F_x^D} \approx \underbrace{F_x(v_x)}_{F_x^{st}} + \frac{\partial F_x}{\partial v_x}\dot{x}_e \quad \text{and} \quad \underbrace{F_y\left(v_y + \dot{y}_e\right)}_{F_y^D} \approx \underbrace{F_y\left(v_y\right)}_{F_y^{st}} + \frac{\partial F_y}{\partial v_y}\dot{y}_e\,,$$

$$F_x^{st} = F\frac{s_x^N}{s} = F_G\frac{s}{s_G}\frac{s_x^N}{s} = \frac{F_G}{s_G}s_x^N = f_G\,s_x^N$$

$$F_y^{st} = F\frac{s_y^N}{s} = F_G\frac{s}{s_G}\frac{s_y^N}{s} = \frac{F_G}{s_G}s_y^N = f_G\,s_y^N$$

- The derivatives of steady-state forces can be approximated by global derivatives.

$$\frac{\partial F_x^{st}}{\partial s_x^N} \approx \frac{F_x^{st}}{s_x^N} = \frac{f_G\, s_x^N}{s_x^N} = f_G$$

$$\frac{\partial F_y^{st}}{\partial s_y^N} \approx \frac{F_y^{st}}{s_y^N} = \frac{f_G\, s_y^N}{s_y^N} = f_G$$

$$F_x^D \approx f_G\, s_x^N + f_G \frac{-1}{r_D|\Omega|\hat{s}_x + v_N}\, \dot{x}_e \quad \text{and} \quad F_y^D \approx f_G\, s_y^N + f_G \frac{-1}{r_D|\Omega|\hat{s}_y + v_N}\, \dot{y}_e\,, \tag{24}$$

dynamic tire forces can be derived from

$$F_x^D = c_x\, x_e + d_x\, \dot{x}_e\,, \quad \text{and} \quad F_y^D = c_y\, y_e + d_y\, \dot{y}_e\,, \tag{25}$$

Inserting the normalized slips defined by Eqs. (3) and (4) into Eq. (24) and combining them with Eq. (25) yields first-order differential equations for the longitudinal and lateral tire deflection,

$$\left(v_{Tx}^{*}\, d_x + f_G\right) \dot{x}_e = -\,v_{Tx}^{*}\, c_x\, x_e - f_G\left(v_x - r_D\,\Omega\right) \quad \text{and} \quad \left(v_{Ty}^{*}\, d_y + f_G\right) \dot{y}_e = -\,v_{Ty}^{*}\, c_y\, y_e - f_G\, v_y\,, \tag{26}$$

Transition to stand still

- At stand still: angular velocity of the wheel is zero $\Omega = 0.$

- Then the differential equation is defined by

$$\begin{aligned}
(v_N d_x + f_G)\, \dot{x}_e &= -v_N c_x x_e - f_G v_x\,, \\
\left(v_N d_y + f_G\right) \dot{y}_e &= -v_N c_y y_e - f_G v_y\,, \\
(v_N d + f_G)\, \dot{\psi} &= -v_N c \psi - f_G \Omega_n\,.
\end{aligned}$$

$v_N d_x \ll f_G, v_N d_y \ll f_G$, and $v_N d \ll f_G$.

which describes the tire dynamics

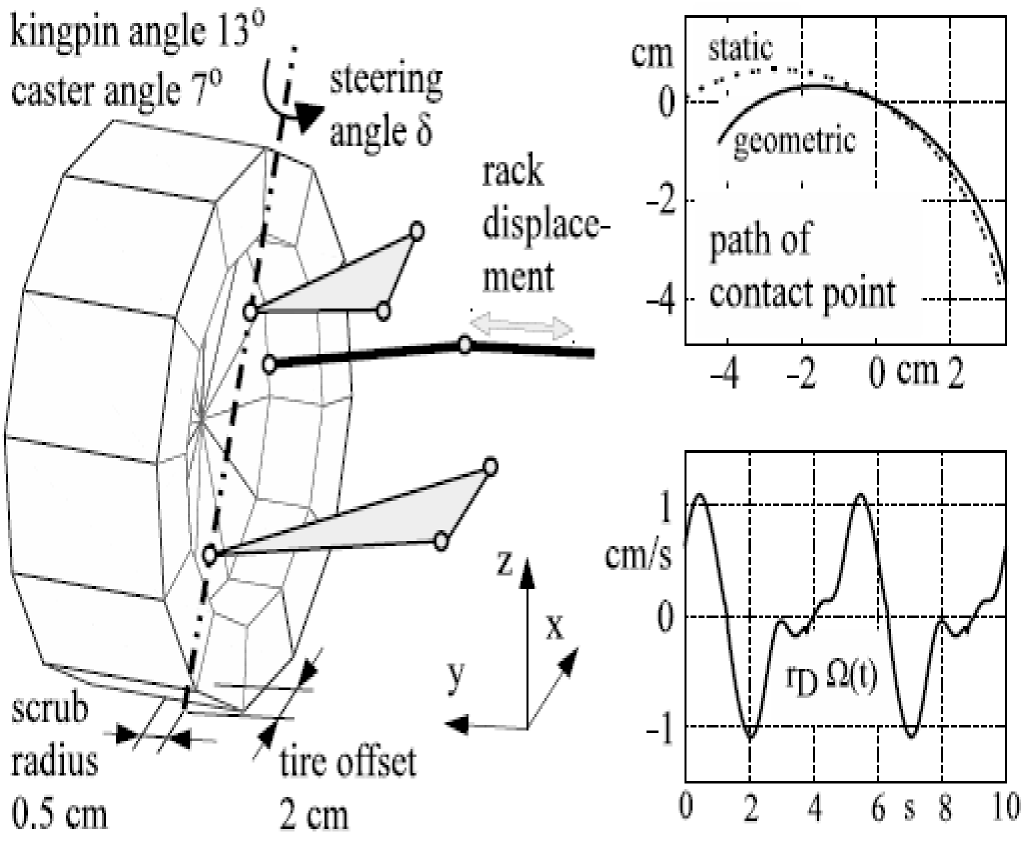
- At vanishing tire deflections,

$$x_e = 0, y_e = 0, \quad \psi = 0;$$

- Above differential Equation finally merges into

$$\dot{x}_e = -v_x , \qquad \dot{y}_e = -v_y , \qquad \dot{\psi} = -\Omega_n .$$

PARKING AT STANDSTILL

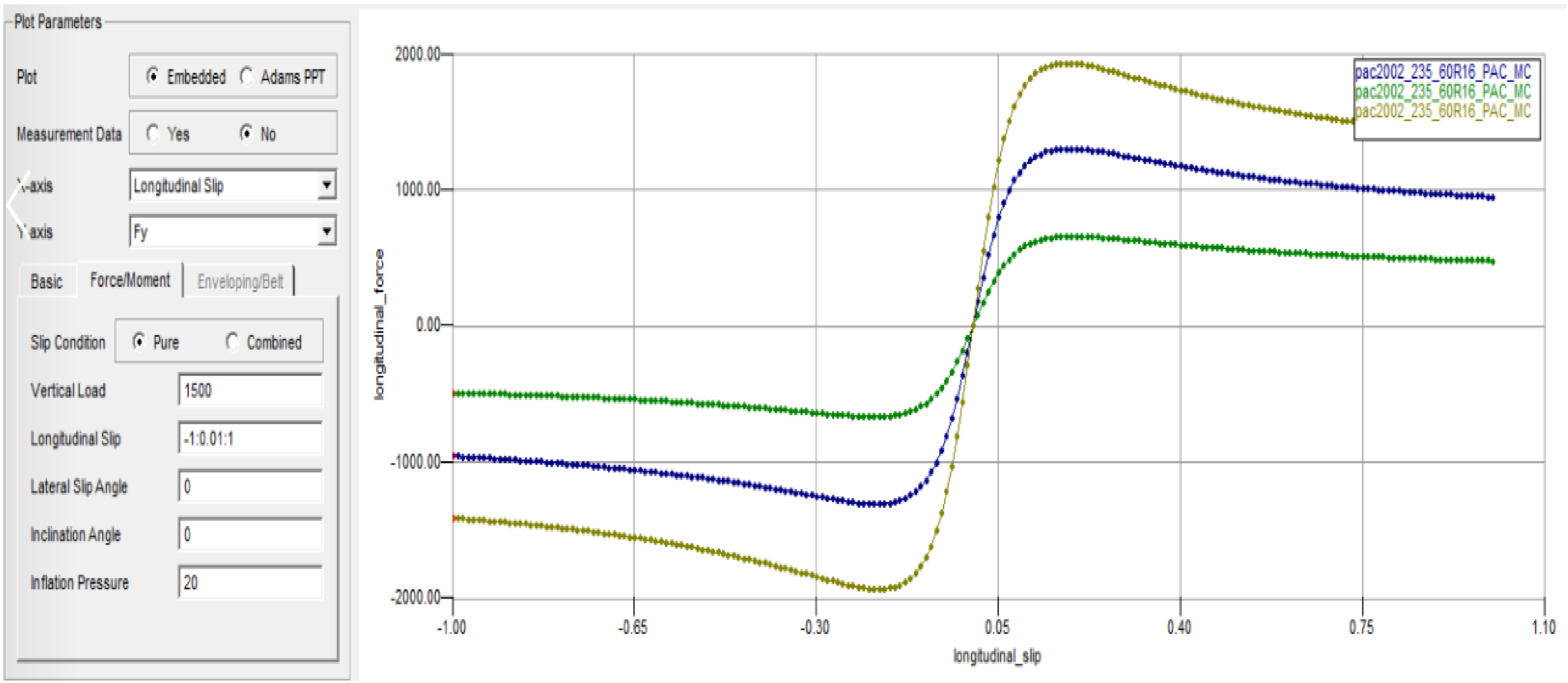


APPLICATION

The tire model TMeasy can handle complex parking maneuvers which are often performed close to or in standstill situations. In a standard layout of a front axle suspension, wheel body and wheel rotate about the inclined kingpin axis. In addition, tire off-set and scrub radius force the contact point to move in longitudinal and lateral direction during the steering motion.

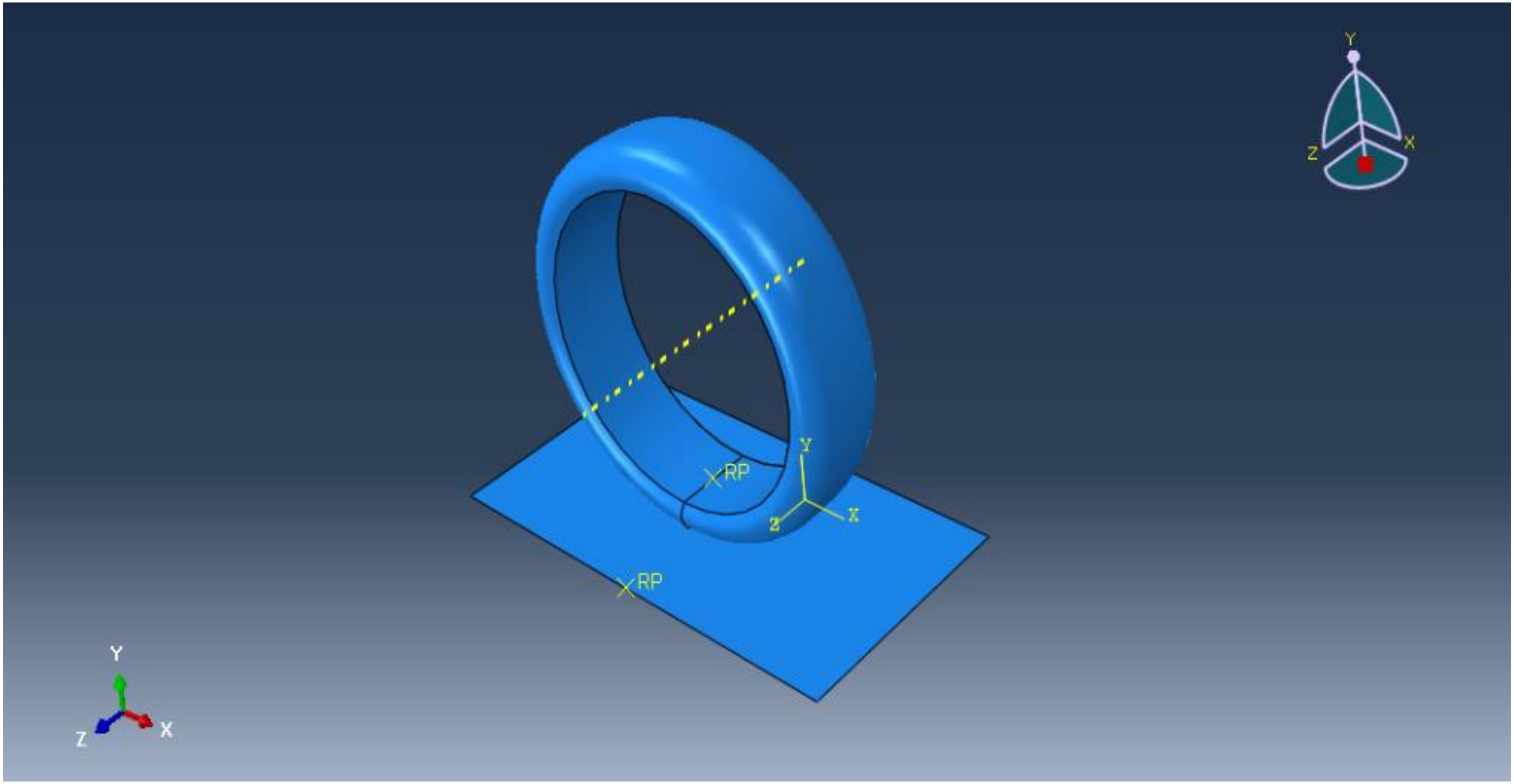
Plot between longitudinal force and longitudinal slip

- Tool used : ADAMS

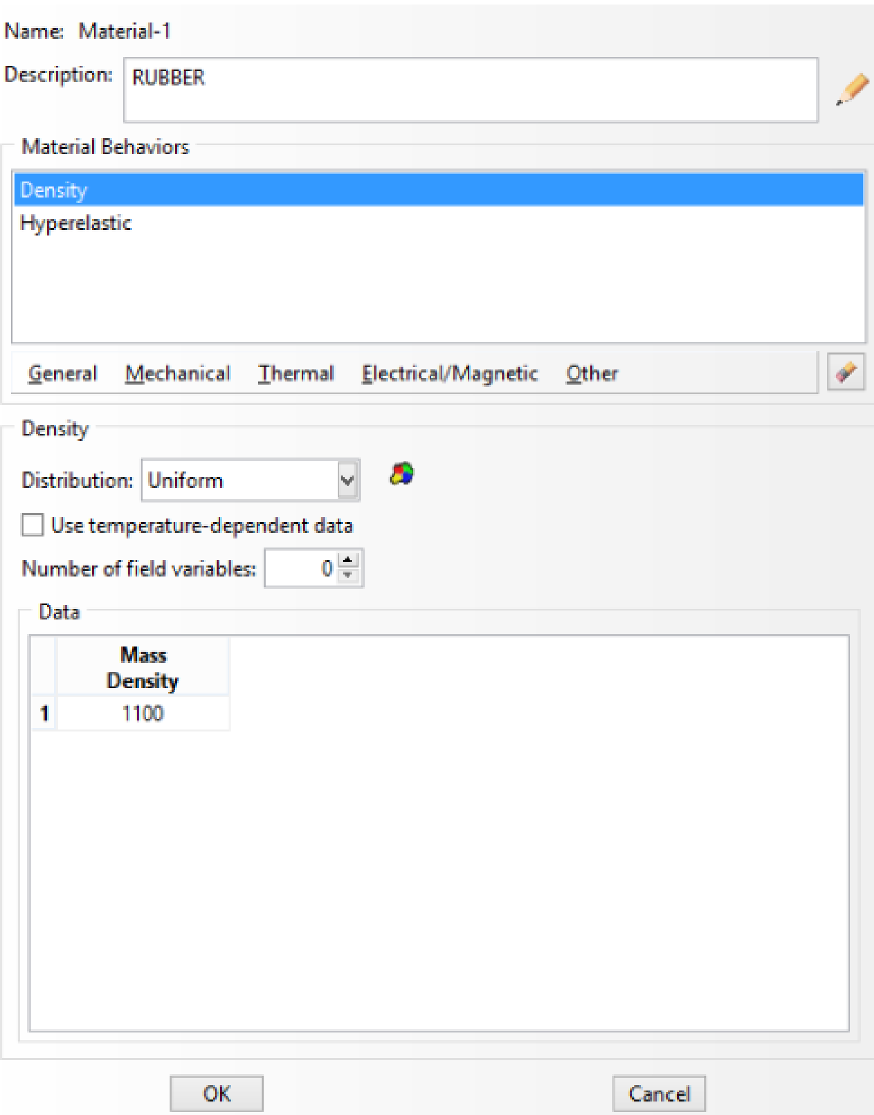


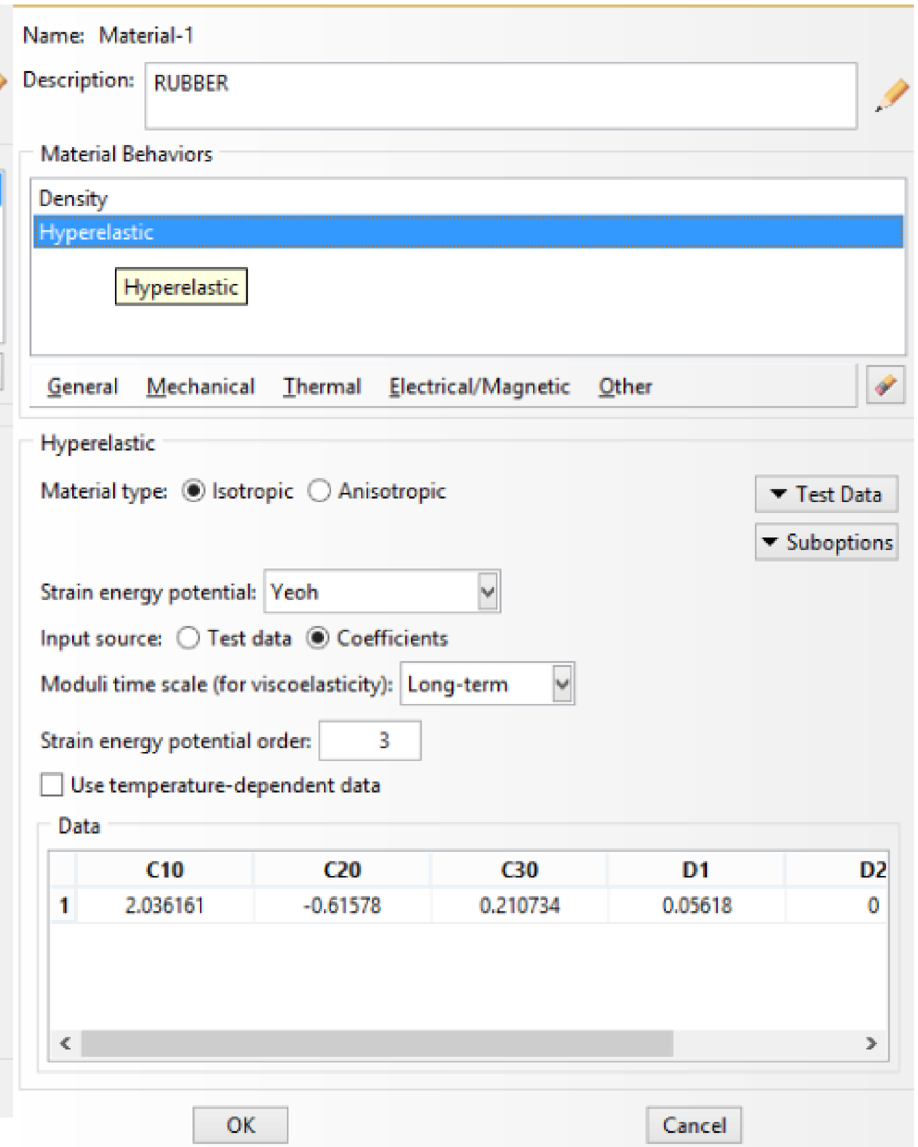
ASSEMBLY OF TIRE AND ROAD MODEL

- Tool used : Abaqus



PROPERTIES

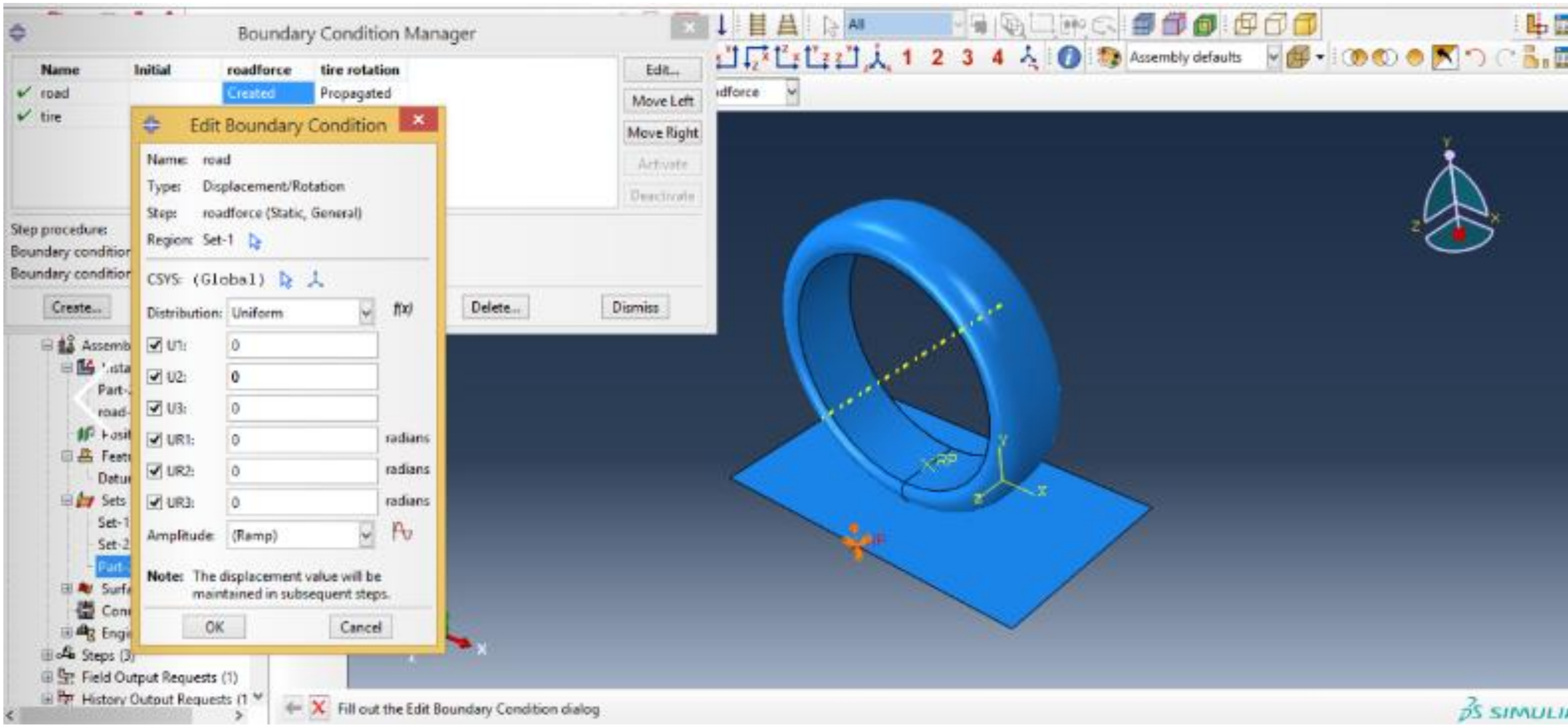

Name: Material-1
Description: RUBBER
Material Behaviors
Density
Hyperelastic
General Mechanical Thermal Electrical/Magnetic Other
Density
Distribution: Uniform
Use temperature-dependent data
Number of field variables: 0
Data
Mass Density
1 1100
OK
Cancel


Name: Material-1
Description: RUBBER
Material Behaviors
Density
Hyperelastic
Hyperelastic
General Mechanical Thermal Electrical/Magnetic Other
Hyperelastic
Material type: Isotropic Anisotropic
Test Data
Suboptions
Strain energy potential: Yeoh
Input source: Test data Coefficients
Moduli time scale (for viscoelasticity): Long-term
Strain energy potential order: 3
Use temperature-dependent data
Data
C10 C20 C30 D1 D2
1 2.036161 -0.61578 0.210734 0.05618 0
OK
Cancel

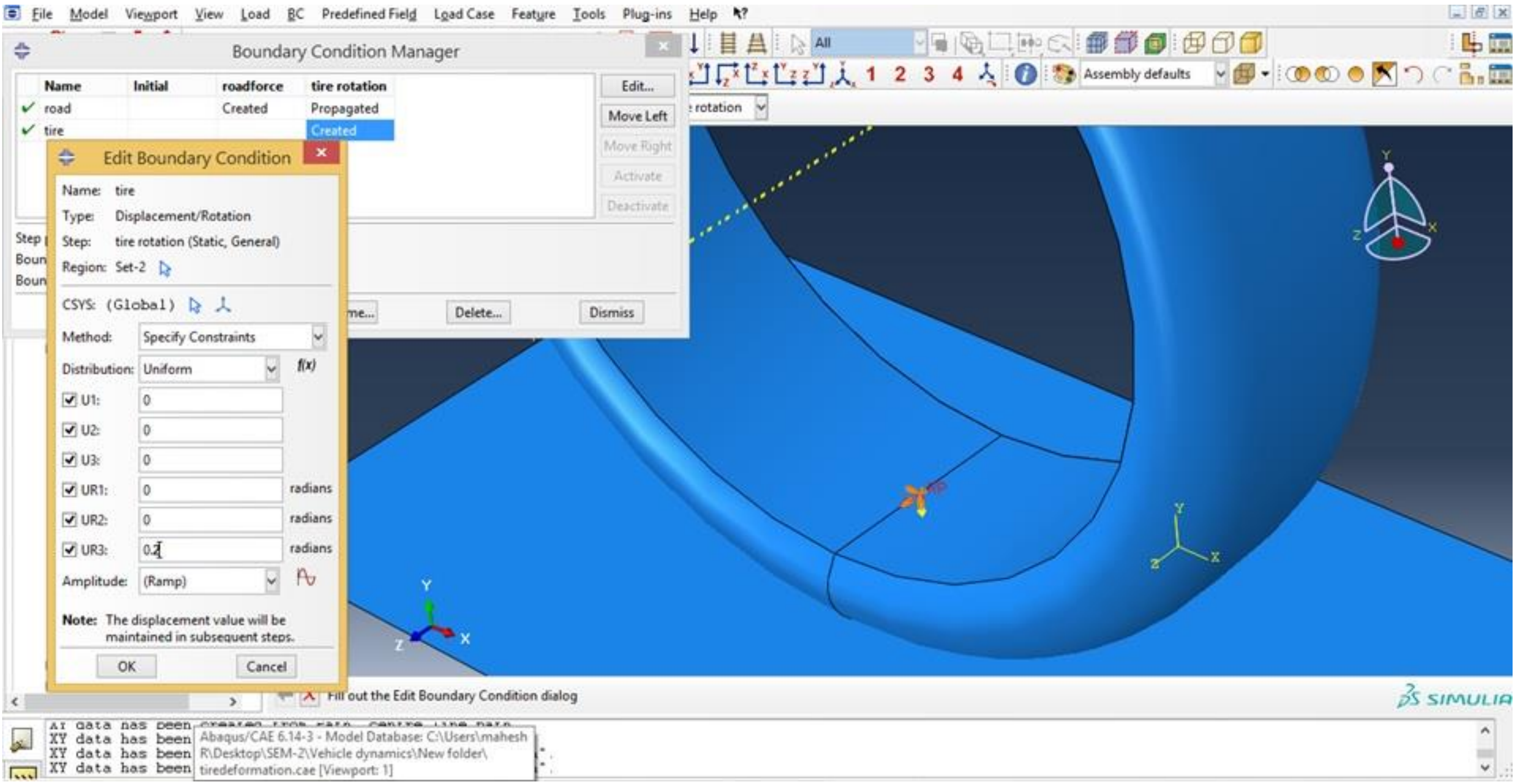
Hyper-Elastic Material

- The material properties investigation was conducted to determine material properties for use in the tire FEM.
- Tire construction materials consist of several different rubbers and reinforcement materials including polyamide, polyester and steel.
- Rubber is known to exhibit highly non-linear elastic behavior.
- Hyper-elasticity is by definition time independent, and therefore it is suitable for use in static finite analysis.

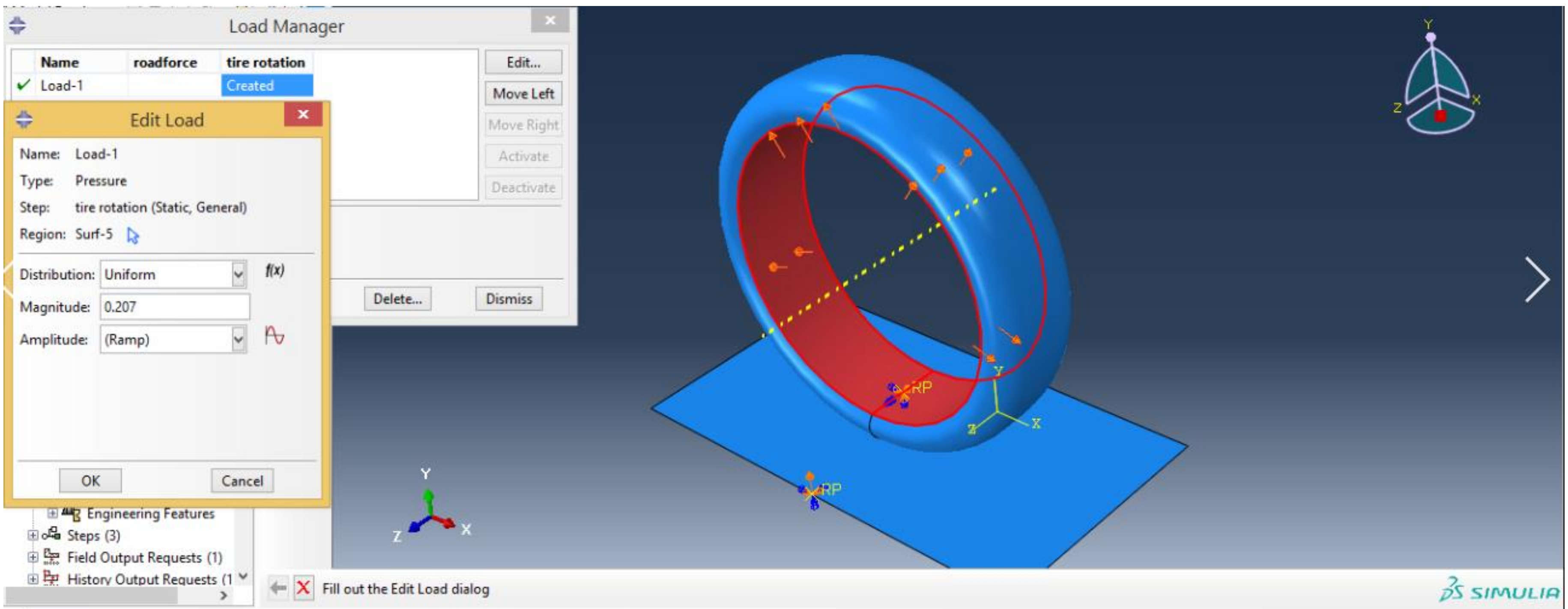
BOUNDARY CONDITIONS - ROAD



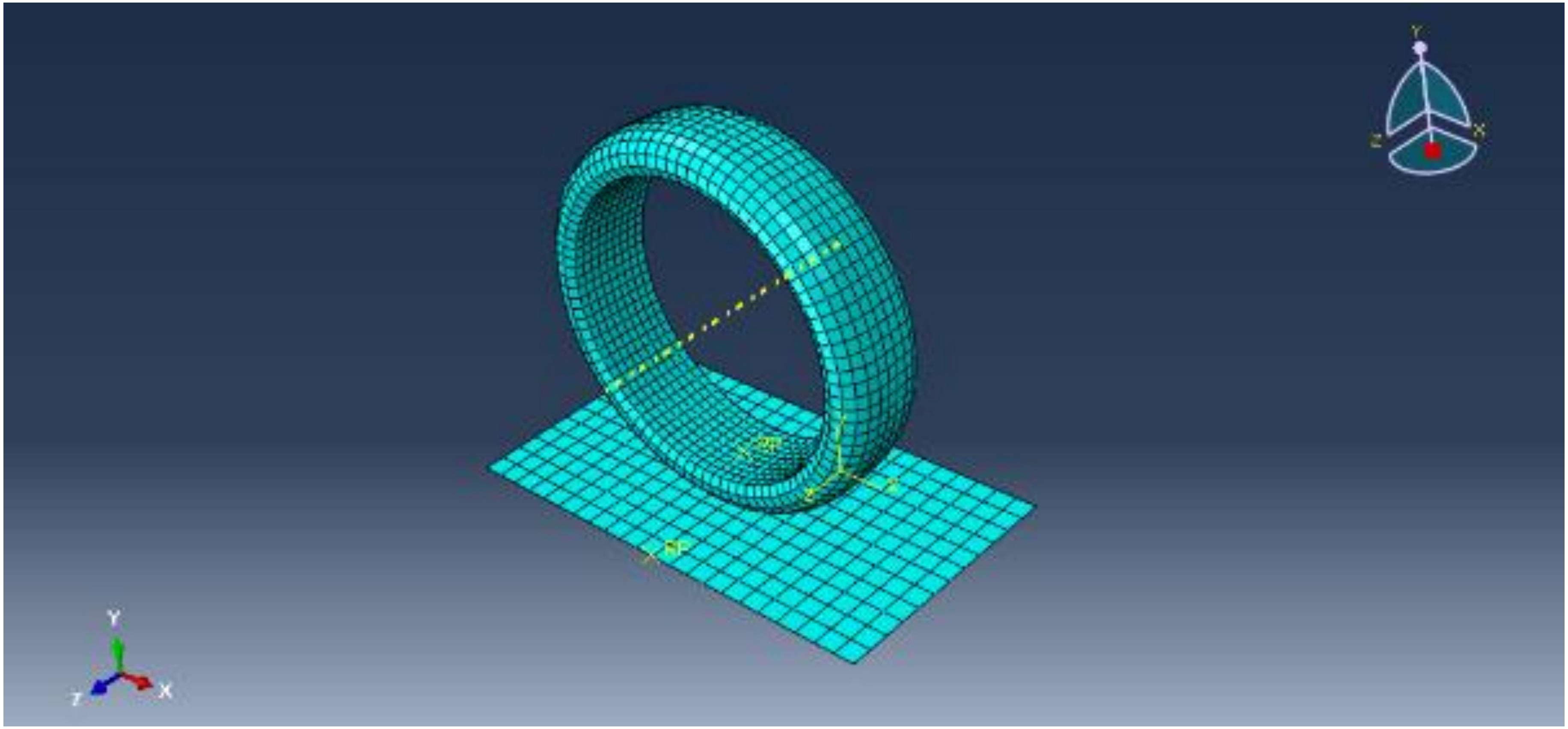
BOUNDARY CONDITIONS - TIRE



PRESSURE APPLIED

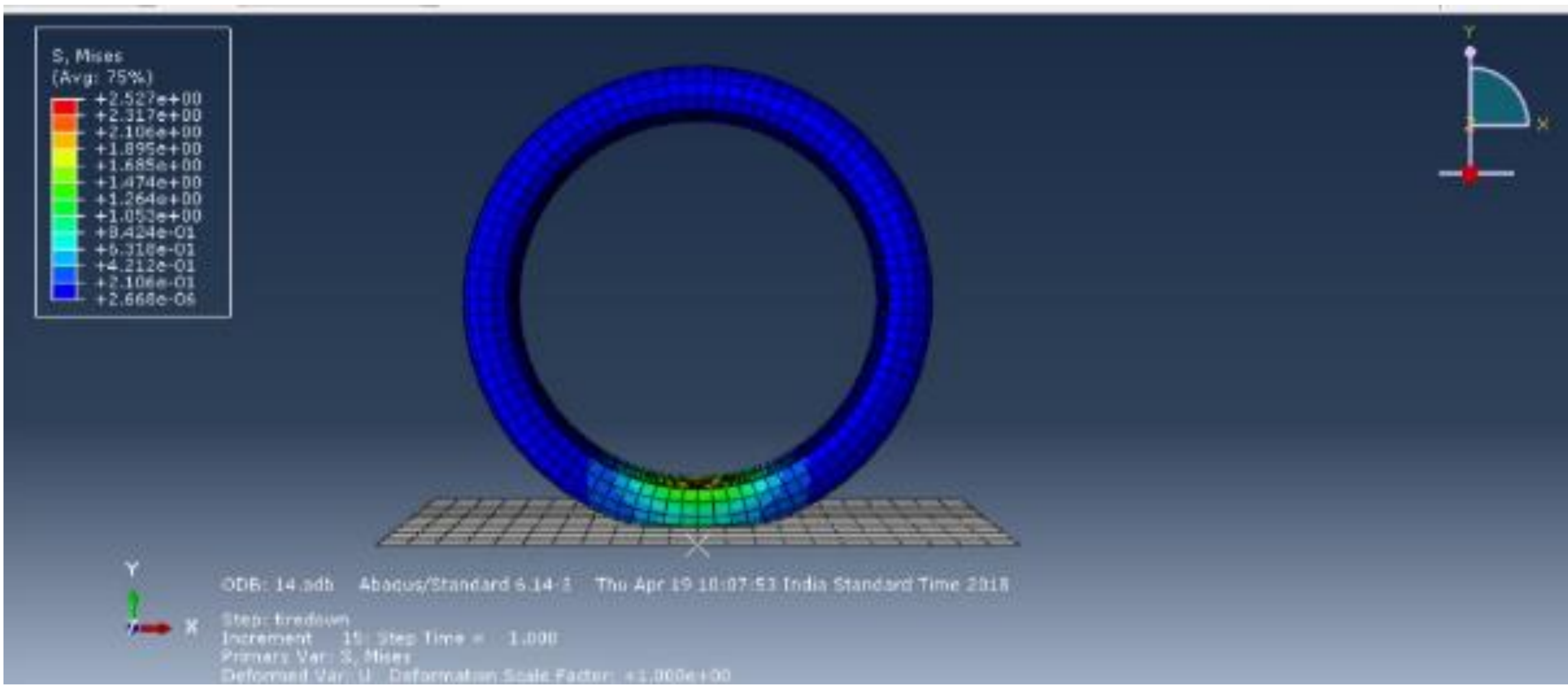


MESH GENERATION

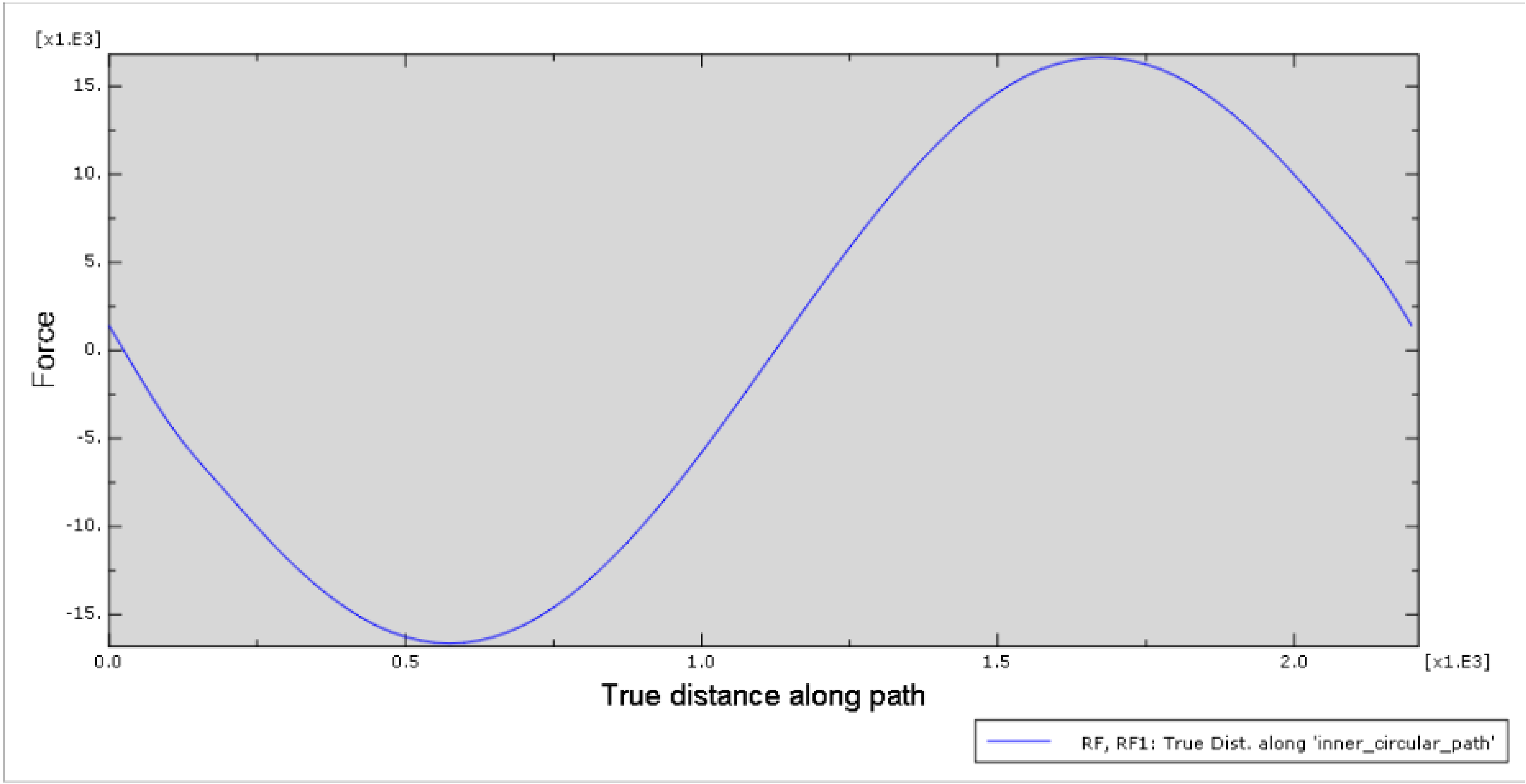


RESULT

STRESS ANALYSIS

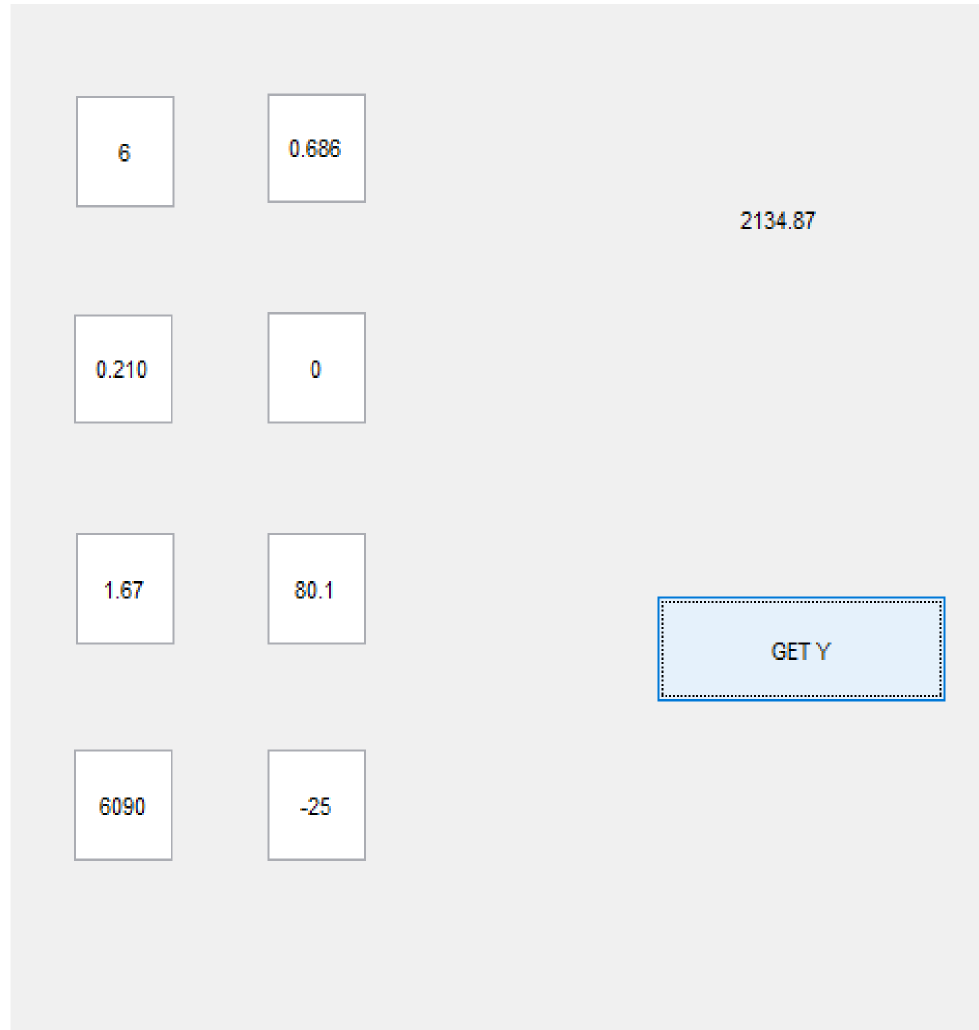


REACTION FORCE V/S OUTER CURVE LENGTH



GRAPHIC USER INTERFACE

- TOOL USED : MATLAB



FUTURE SCOPE

- Instead of using solid rubber tire model, tire construction can be done by part wise modelling.
- Different material properties may be assigned and optimum values can be obtained.
- Research on SMART tires.

CONCLUSION

- In static tire analysis (before starting), the load present on a tire is that of normal load (300-250)N.
- In Zero parking condition, the load on tire will be more as along with normal load, lateral force (opposing the turning motion) will also come into play.

REFERENCES

- Egbert Bakker, Lars Nyborg and Hans. B. Pacejka, "Tyre Modelling for use in Vehicle Dynamics”
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