On Tread Patterns

Parameterisation and Inverse Design

John Sebastian

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Image Credit: Pirelli PZERO

Tread Patterns

As the component of the tyre in direct contact with the road, made entirely out of typical rubber compounds, the Patterned Tyre Tread affects the following parameters

Aesthetics

Manoeuvring
- **Rolling**
- **Traction/ Braking**
- **Cornering**

Aquaplaning

Modelling

Structural models assume the belt + cap package to be a single entity.

Tread is considered as a spacer (Radials)

As a matrix of springs

Interaction between tyre body and tread pattern can be idealised by a spring model connected in series

Important since the weakest spring determines the overall stiffness in a series configuration

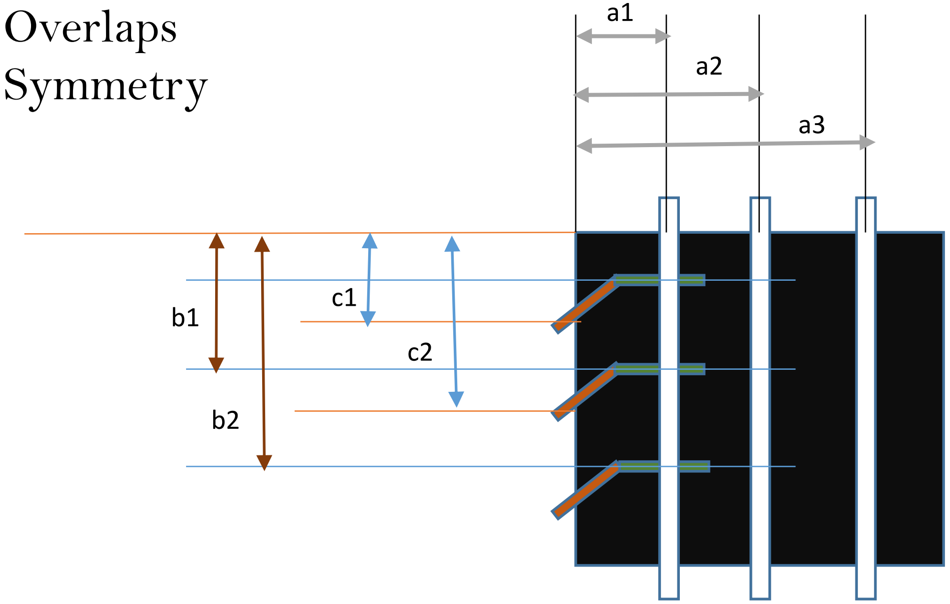
- Cornering stiffness is influenced primarily by tread at low loads
- by tyre body at high loads

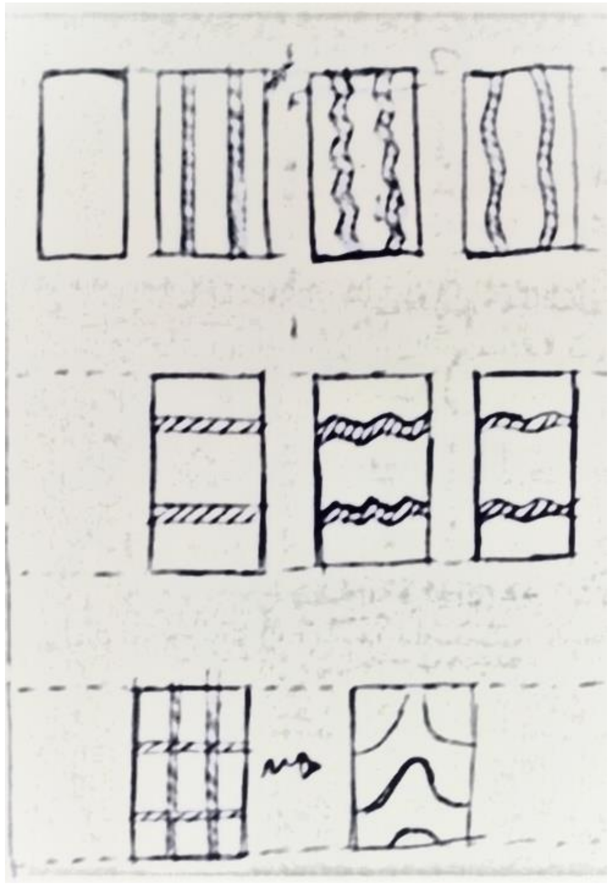
An Inverse Design Problem

1. Parameterization

Identification and assigning of variable names to prominent features such as

- Ribs
- Lateral Grooves
- Fillets
- Offsets
- Overlaps
- Symmetry

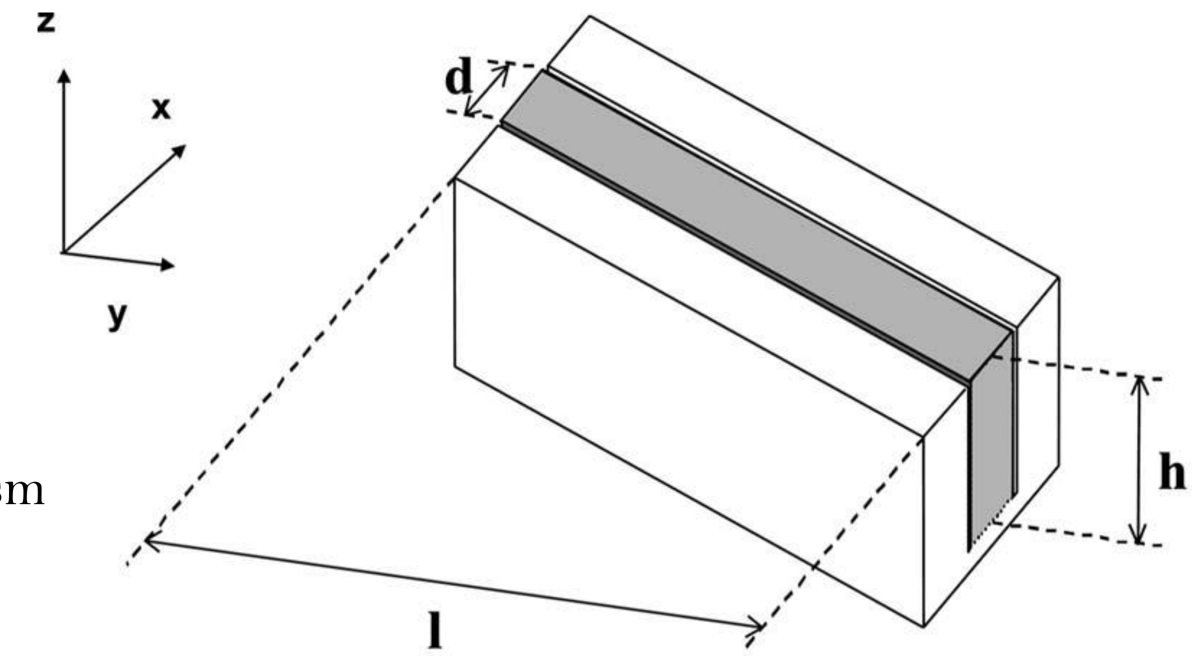




An Inverse Design Problem

Importance of parameterisation

$$\text{Criff Index} = \sum_{footprint} I_i \cdot \frac{h_i}{d_i}$$



- 3 geometric variables are grouped together
- Performance graphs are plotted against this parameter
- Finally gives some insight into the actual mechanism

- Case: Development of snow tyres

Ref: 3

An Inverse Design Problem

2. Performance Parameters

After each iteration a scheme to calculate the following parameters is to be developed:

- K_x
- K_y
- K_{xy}

K_{xy} is the stiffness in x direction due to an applied force in the y direction. It is dependent on the geometry

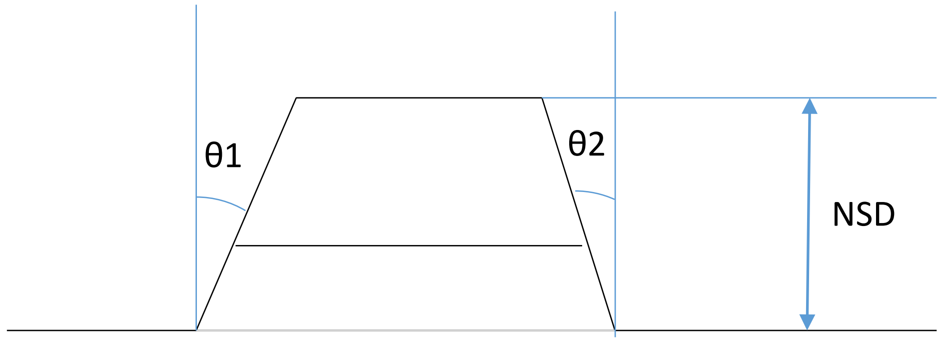
These are the geometric stiffness constants. K_{xy} is to be evaluated from K_x and K_y. The stiffness along any direction may be evaluation thence.

$$K_\alpha = K_x \cos^2\alpha + K_y \sin^2 \alpha + K_{xy} \sin 2\alpha$$

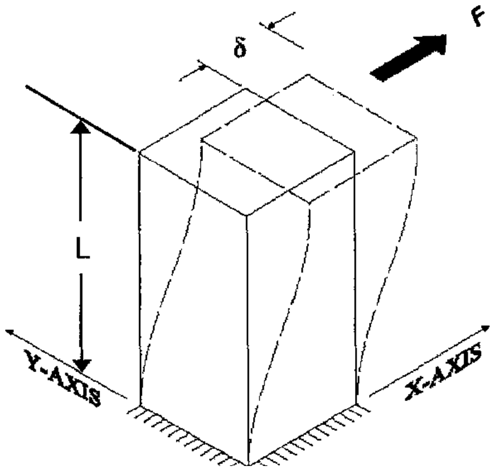
This equation is written assuming a single block of material. Hence each tread block needs to be modelled as a cantilever beam for applicability.

An Inverse Design Problem

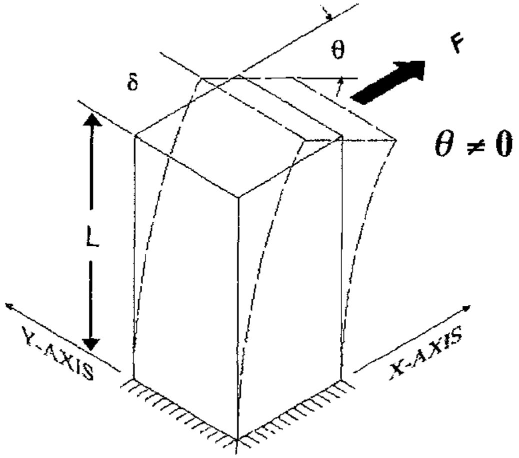
Modelling as beams



These beams behave differently across the contact patch



Mid Patch

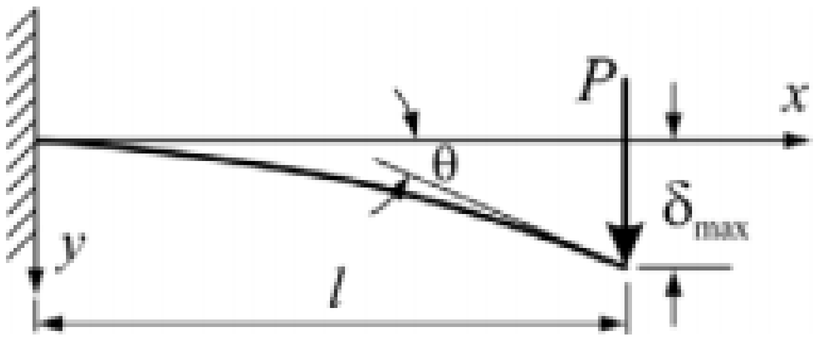


Entry and Exit

An Inverse Design Problem

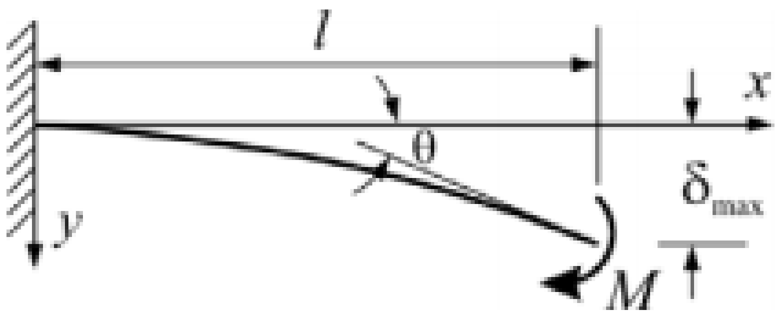
Conventional Assumptions:

- Beams are of uniform cross sections
- Single material
- More complex shapes are attached combinations of basic cross sections (solved for separately)



$$\theta = \frac{P \cdot l^2}{2 \cdot E \cdot I}$$

Mid Patch



$$\theta = \frac{M \cdot l}{E \cdot I}$$

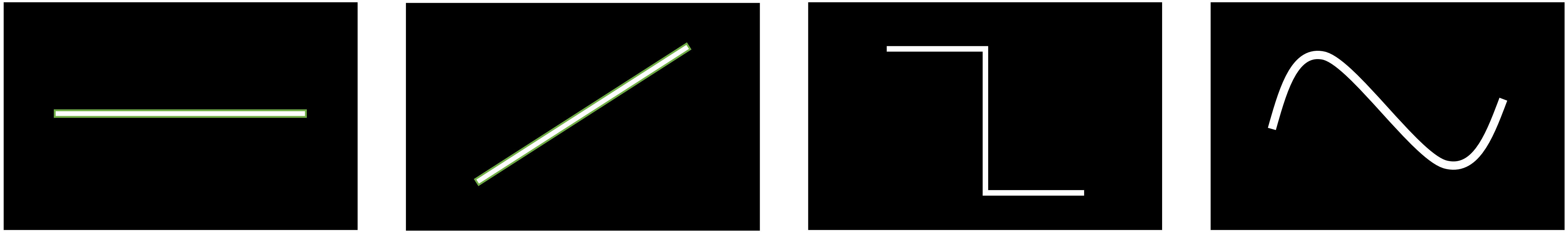
Entry and Exit

Equations for tapered beams are included in the appendix

Designer's Call

The mathematical solution can yield an advanced layout for the designer to work with. Relevant features to be added:

1. Sipes (How to Model?)
2. Tie Bars
3. Fillets
4. Padding angles

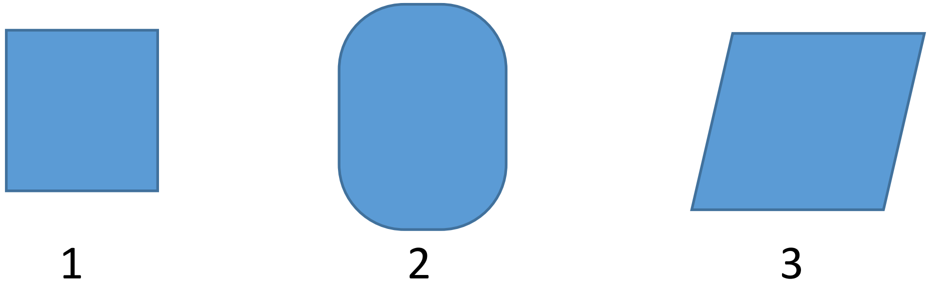


Sipes - functions: Directional stiffness, Water suction, Heat Conduction (in moulding), Control over Edge Density

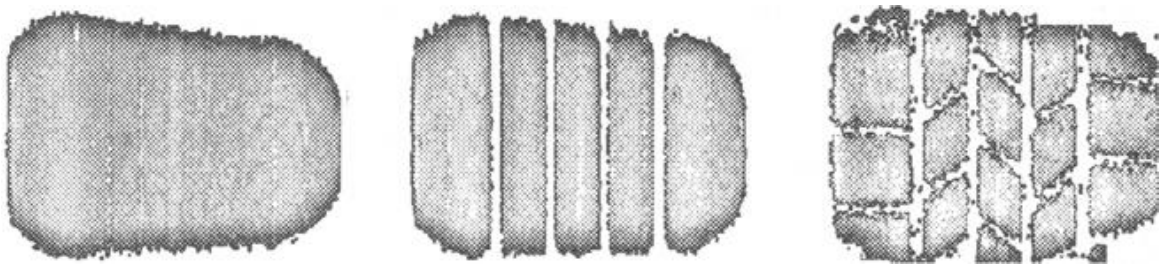
Proposed Procedure

Input:

1. Contact Patch boundary



2. Pressure distribution based on proposed architecture
3. Compensation for Ply Steer
4. Designing for Cornering (Race tyres)
5. Initial Stiffness for patch regions (optional)



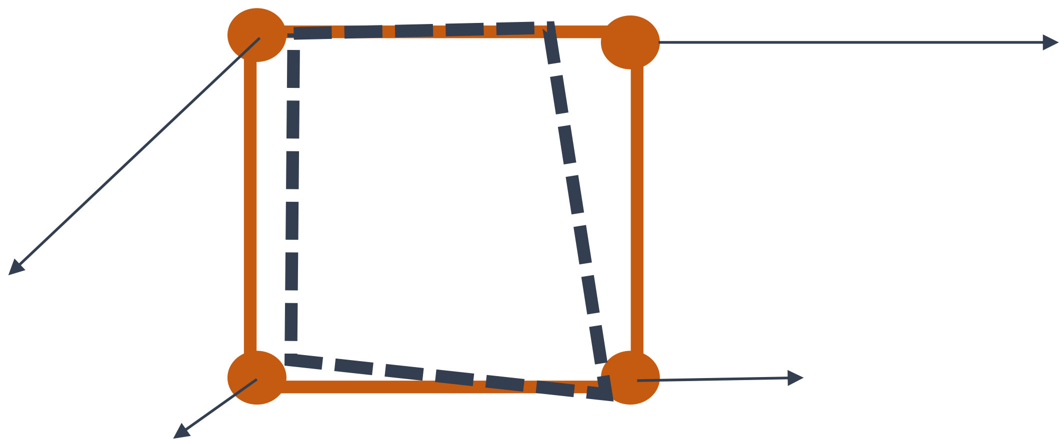
Footprint of Rolling Tire: Smooth, Ribbed, Patterned – Dynamic Conicity reduced by pattern design

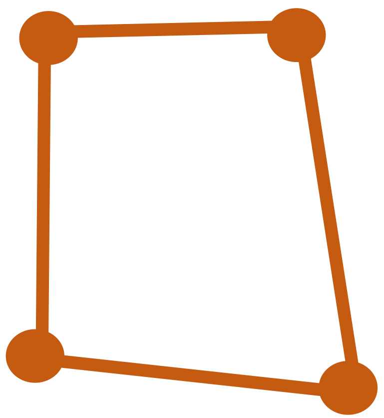
Proposed Procedure

Solution:

1. Moment of Inertia is solved for
   - Principal Axis is determined first
   - Quadrilaterals are fitted into the returned I value
2. Siping, tying, etc

- The Feature based parameterization cannot be implemented here directly.
- The following (Lagrangian inspired) method of definition of geometry and boundary conditions have to be evaluated:





Hydroplaning

Hydroplaning

- The moving tyre contacts and displaces the stationary runway fluid the resulting change in momentum of the fluid creates hydrodynamic pressures that react on the runway and tyre surfaces.

- The resulting hydrodynamic pressure force, acting on the tyres tends to build up as the square of the vehicle speed.

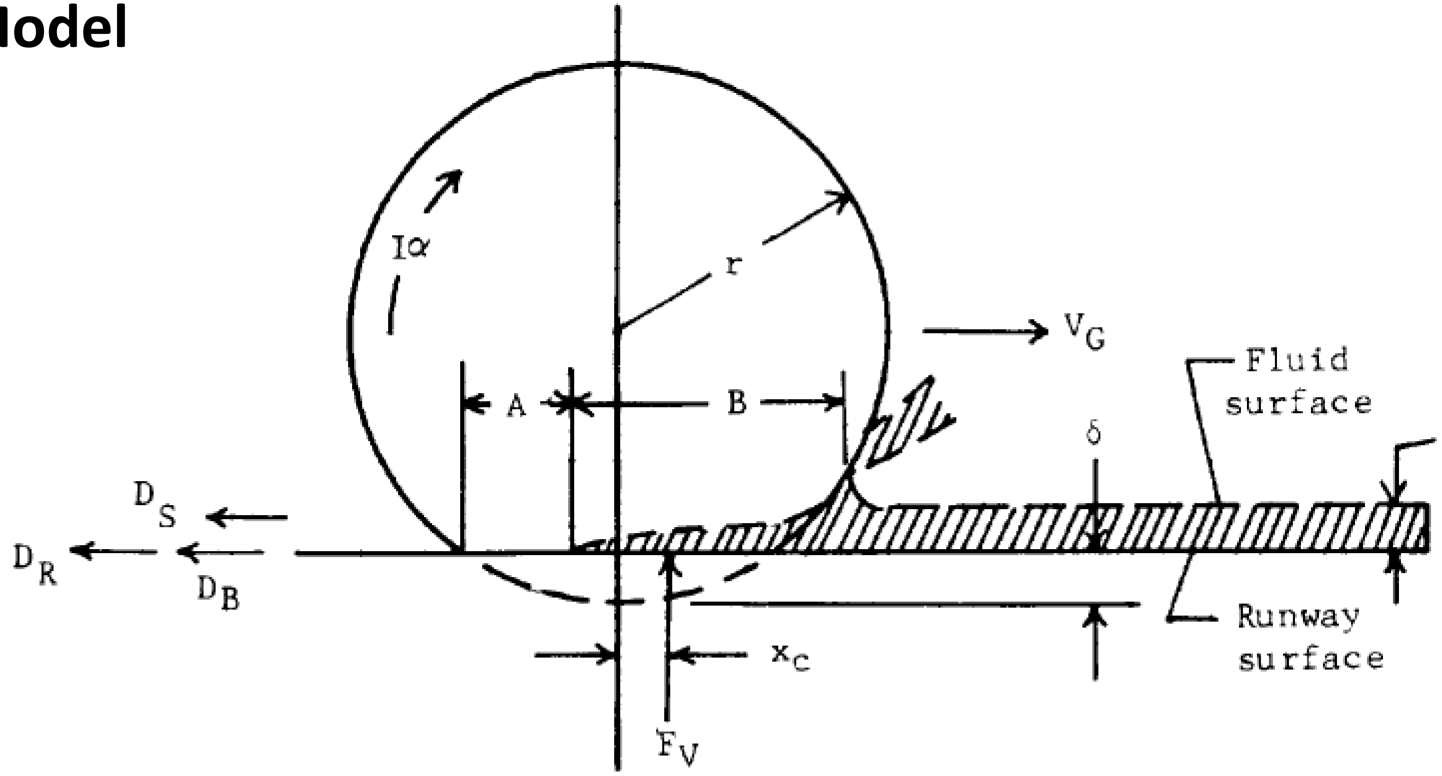
- Fluid escape is retarded in the tire-ground contact region and the fluid wedge formed would tend to detach the tire from the ground.

- At some high ground speed, the hydrodynamic lift developed under the tyre equals the total load of the vehicle acting on the tire forces the tyre to lift completely off the surface.

Ref: 4

Hydroplaning

Model



D_S = Hydrodynamic drag due to slush
D_R = Tyre Rolling Resistance
D_B = Drag due to slip

Dynamic Equilibrium Equation: $I \cdot \alpha = F_V(x_C) - [D_R + D_S + (F_V - F_{V,S})\mu](r - \delta)$

References

1. Okonieski, R. E., Moseley, D. J., and Cai, K. Y., "Simplified Approach to Calculating Geometric Stiffness Properties of Tread Pattern Elements," Tire Science and Technology, TSTCA, Vol. 31, No. 3, 2003, pp. 132–158.

2. Köhne, St., Matute, B., and Mundl, R., "Evaluation of Tire Tread and Body Interactions in the Contact Patch," Tire Science and Technology, TSCTA, Vol. 31, No. 3, 2003, pp. 159–172.

3. Mundl, R., M. Fischer, W. Strache, K. Wiese, B. Wies, and K. H. Zinken., "Virtual Pattern Optimization Based on Performance Prediction Tools4," Tire Science and Technology, TSTCA, Vol. 25, No. 4, 1997, pp. 319–338.

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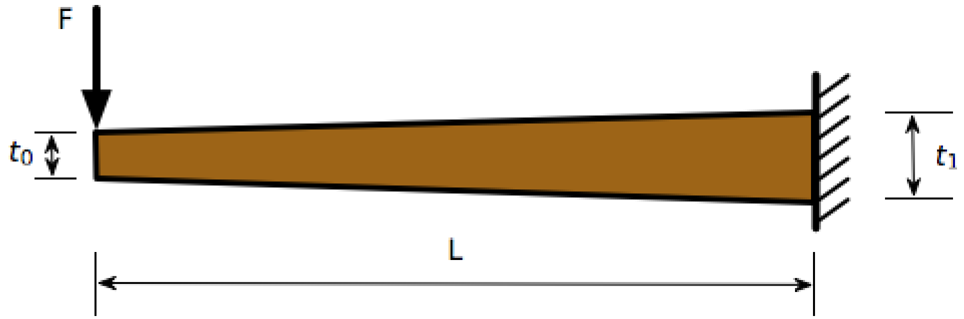
6. Phenomena Of Pneumatic Tire Hydroplaning- Walter B. Horne And Robert C. Dreher, Langley Research Center, Nasa

Appendix



$$U^* = \int_0^L \frac{M^2}{2EI} dx$$

Complimentary Strain Energy

$$I = \frac{b(t_0 + \alpha x)^3}{12}$$

Moment of Inertia

$$\alpha = (t_1 - t_0)/L$$

Gradient

$$\Delta = \frac{dU^*}{dF} = \frac{F}{E} \int_0^L \frac{x^2}{I} dx = \frac{12F}{Eb} \int_0^L \frac{x^2}{(t_0 + \alpha x)^3} dx$$

Castigliano Derivative

$$k = \frac{F}{\Delta} = \frac{E}{\int_0^L \frac{x^2}{I} dx} = \frac{Eb}{12 \int_0^L \frac{x^2}{(t_0+\alpha x)^3} dx}$$

Stiffness