FINITE ELEMENT MODELLING OF OFF-ROAD TYRES

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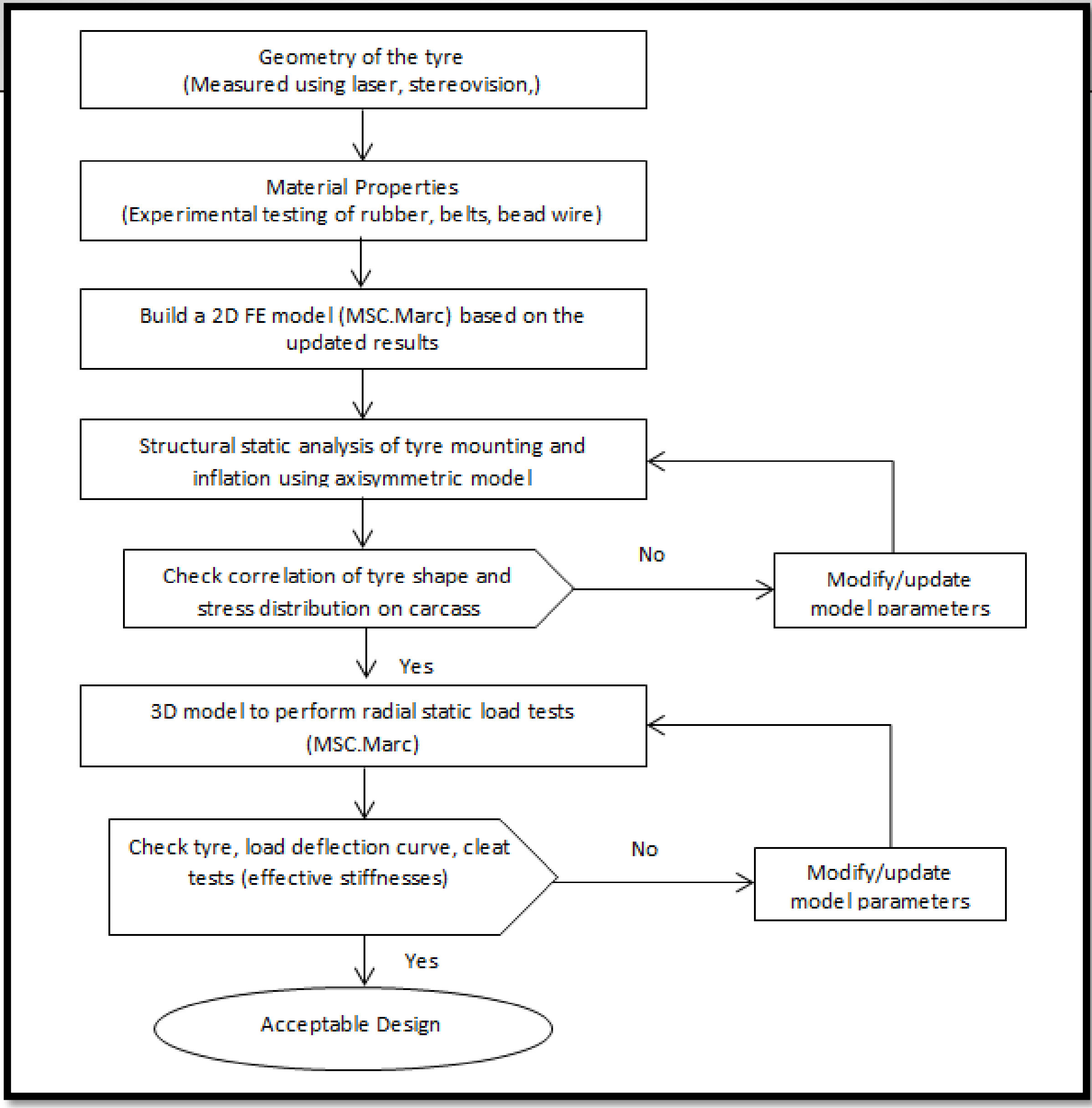
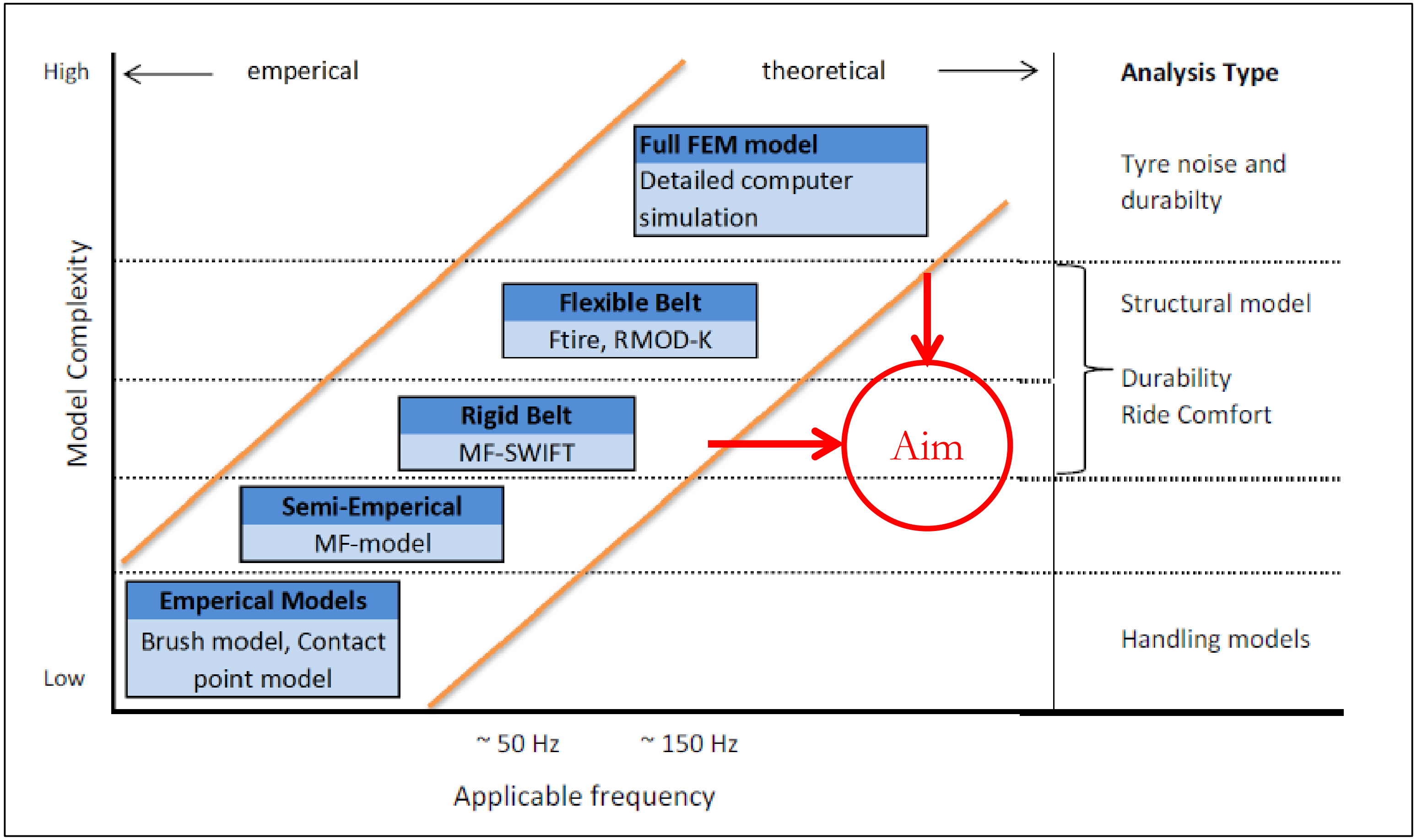
OBJECTIVES

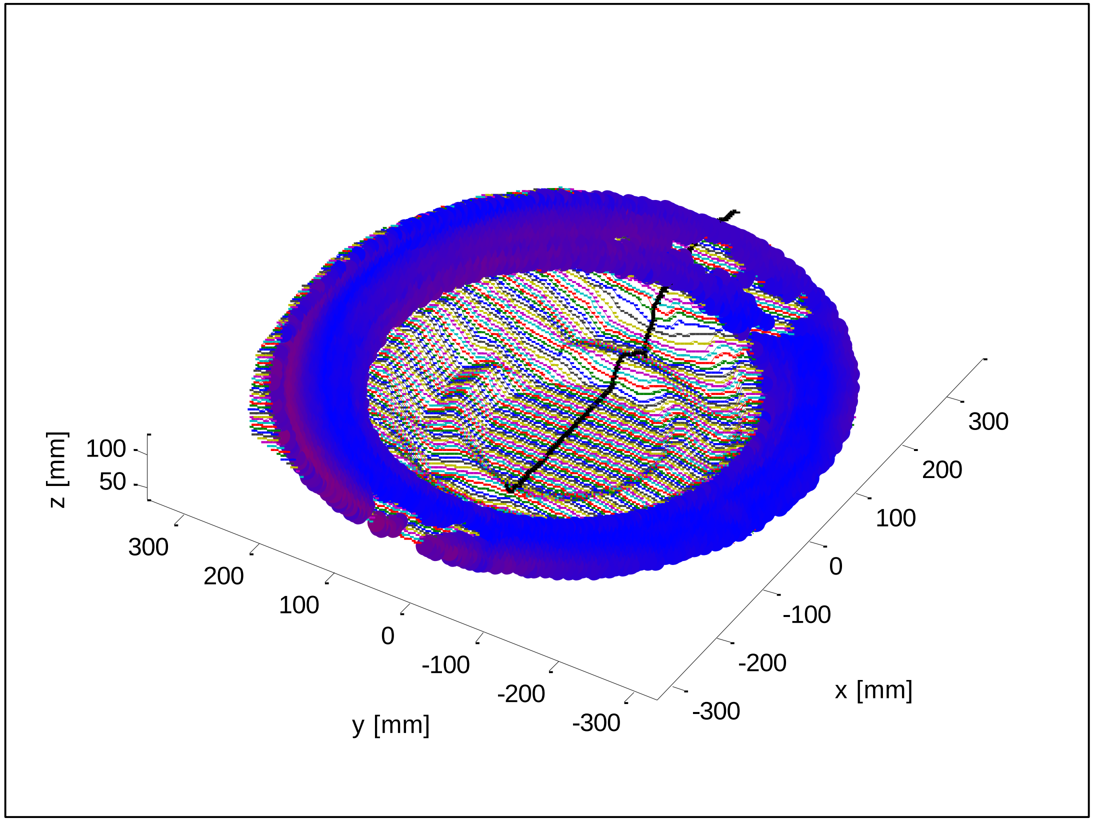
- Explore the most recent developments in tyre modelling.
- Parameterize the properties of an "off-road" tyre through a range of simple experiments.
- Develop a tyre model that can solve fast enough to be used in multibody dynamic vehicle simulations. (The use of elements with equivalent homogeneous properties is investigated)
- Ensure that the tyre model can accurately simulate tyre behaviour. The tyre model will be validated and updated through the use of deformation profiles of the sidewall and radial load-vs.-displacement curves obtained from experiments.


Geometry of the tyre
(Measured using laser, stereovision,)
Material Properties
(Experimental testing of rubber, belts, bead wire)
Build a 2D FE model (MSC.Marc) based on the updated results
Structural static analysis of tyre mounting and inflation using axisymmetric model
Check correlation of tyre shape and stress distribution on carcass
No
Modify/update model parameters
Yes
3D model to perform radial static load tests (MSC.Marc)
Check tyre, load deflection curve, cleat tests (effective stiffnesses)
No
Modify/update model parameters
Yes
Acceptable Design

EXISTING TYRE MODELS

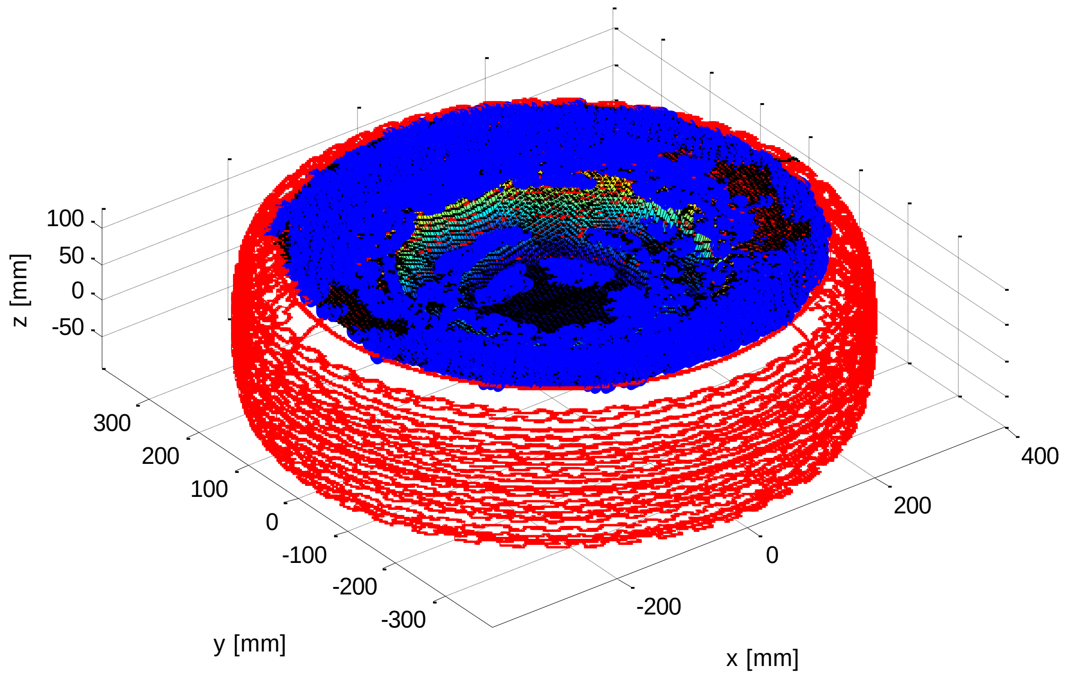


OPTICAL MEASURING TECHNIQUES



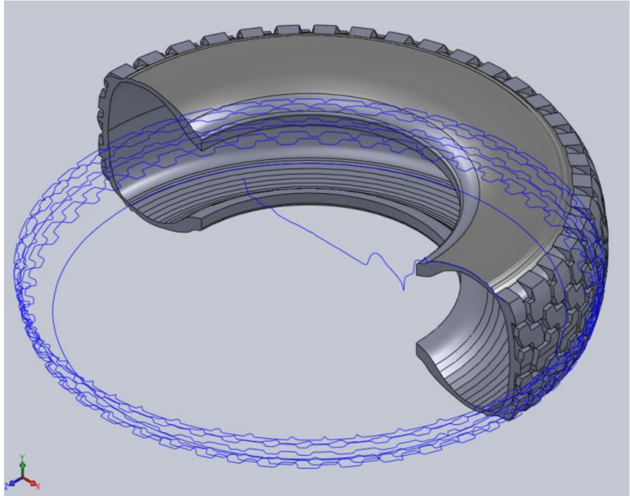
- Fairly good results
- Most deviations between laser profile and photogrammetry points are smaller than 4mm
- Larger deviations are found at the shoulder, tread blocks.

TYRE GEOMETRY

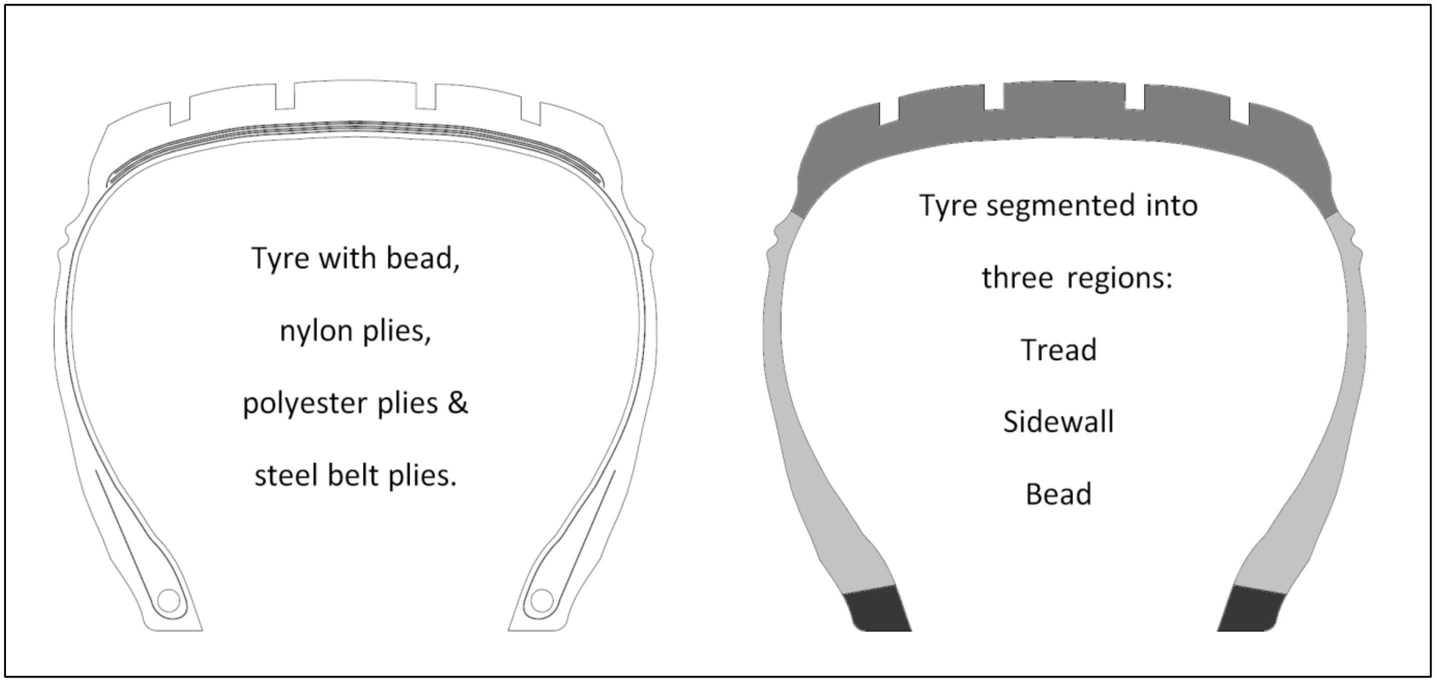


Solid Works Model

Section view of the tyre with some imported profiles shown



TYRE STUDIED – MATERIAL PROPERTIES



Tyre segmenting

Shore hardness tests

MATERIAL PROPERTIES - BACKGROUND

Hyper elastic constitutive models

The Neo-Hookean model:

$$W = C_{10}(I_1 - 3)$$

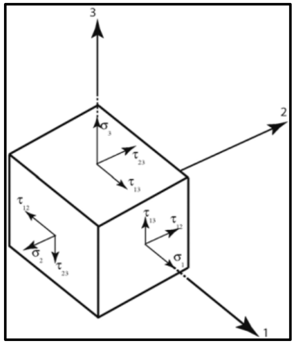
which is a special case of the Mooney-Rivlin form, with $C_{01} = 0$

The Ogden Model:

$$W = \sum_{n=1}^{N} \frac{\mu_n}{\alpha_n} ({\lambda_1}^{\alpha_n} + {\lambda_2}^{\alpha_n} + {\lambda_3}^{\alpha_n} - 3)$$

MATERIAL PROPERTIES - BACKGROUND

Orthotropic material properties



$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{13} \\ \gamma_{12} \end{Bmatrix} = \begin{bmatrix} 1/E_1 & -\nu_{21}/E_2 & -\nu_{31}/E_3 & 0 & 0 & 0 \\ -\nu_{12}/E_1 & 1/E_2 & -\nu_{32}/E_3 & 0 & 0 & 0 \\ -\nu_{13}/E_1 & -\nu_{23}/E_2 & 1/E_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/G_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G_{13} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G_{12} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{13} \\ \tau_{12} \end{Bmatrix}$$

The following equations relate the material constants:

$$\frac{\nu_{12}}{E_1} = \frac{\nu_{21}}{E_2}$$

$$\frac{\nu_{13}}{E_1} = \frac{\nu_{31}}{E_3}$$

$$\frac{\nu_{23}}{E_2} = \frac{\nu_{32}}{E_3}$$

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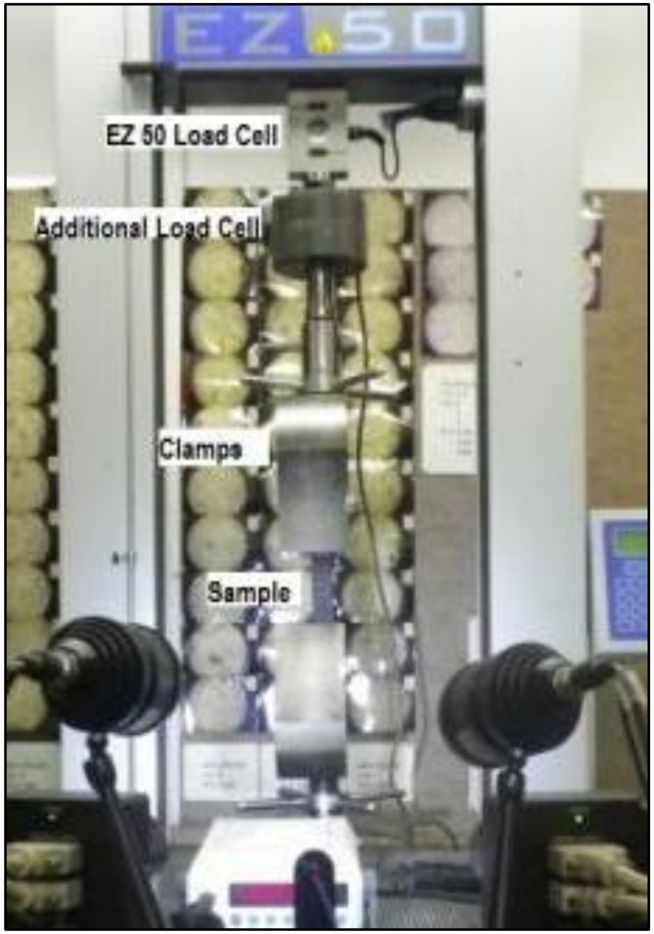
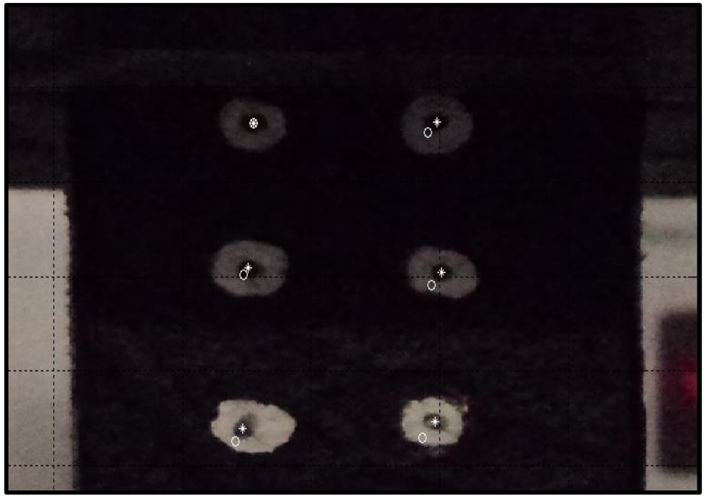
TYRE STUDIED – MATERIAL PROPERTIES

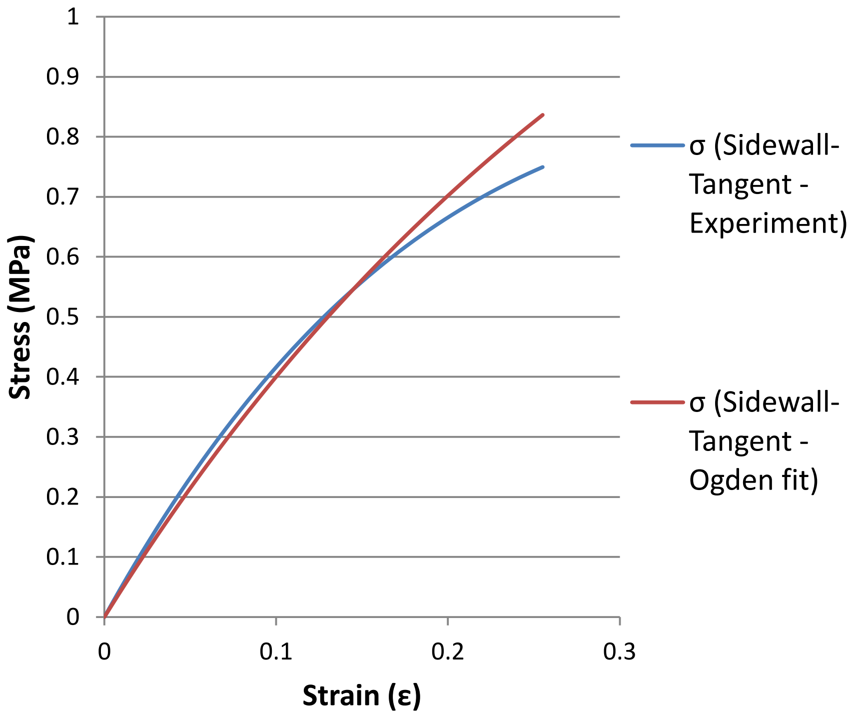




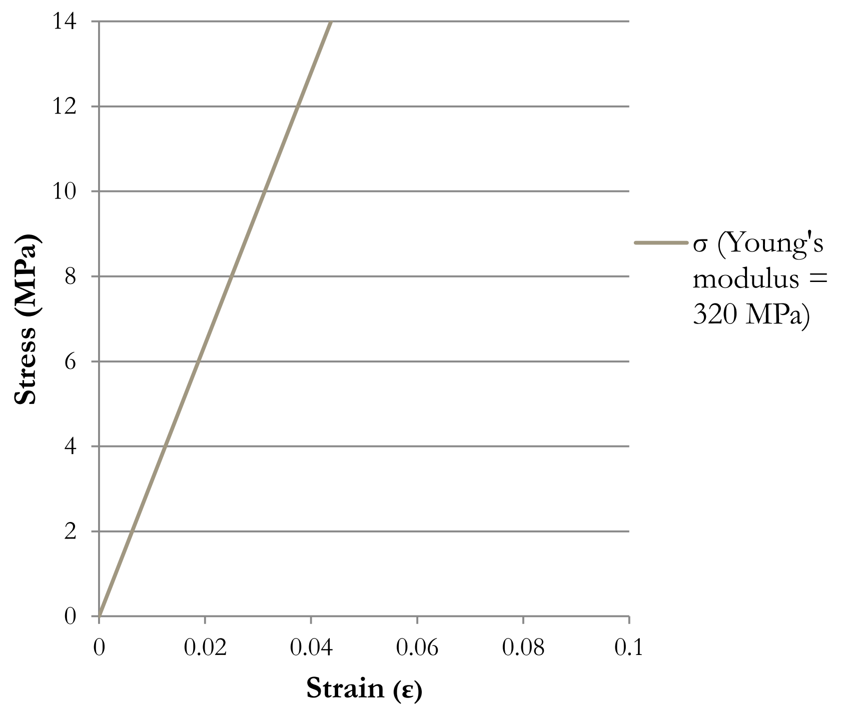
- Experimental tests for material properties
- Tensile tests on each orthogonal direction
- Digital image correlation

TYRE STUDIED – MATERIAL PROPERTIES

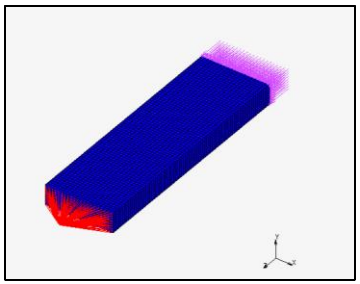
Ogden fit for tangential sidewall stiffness

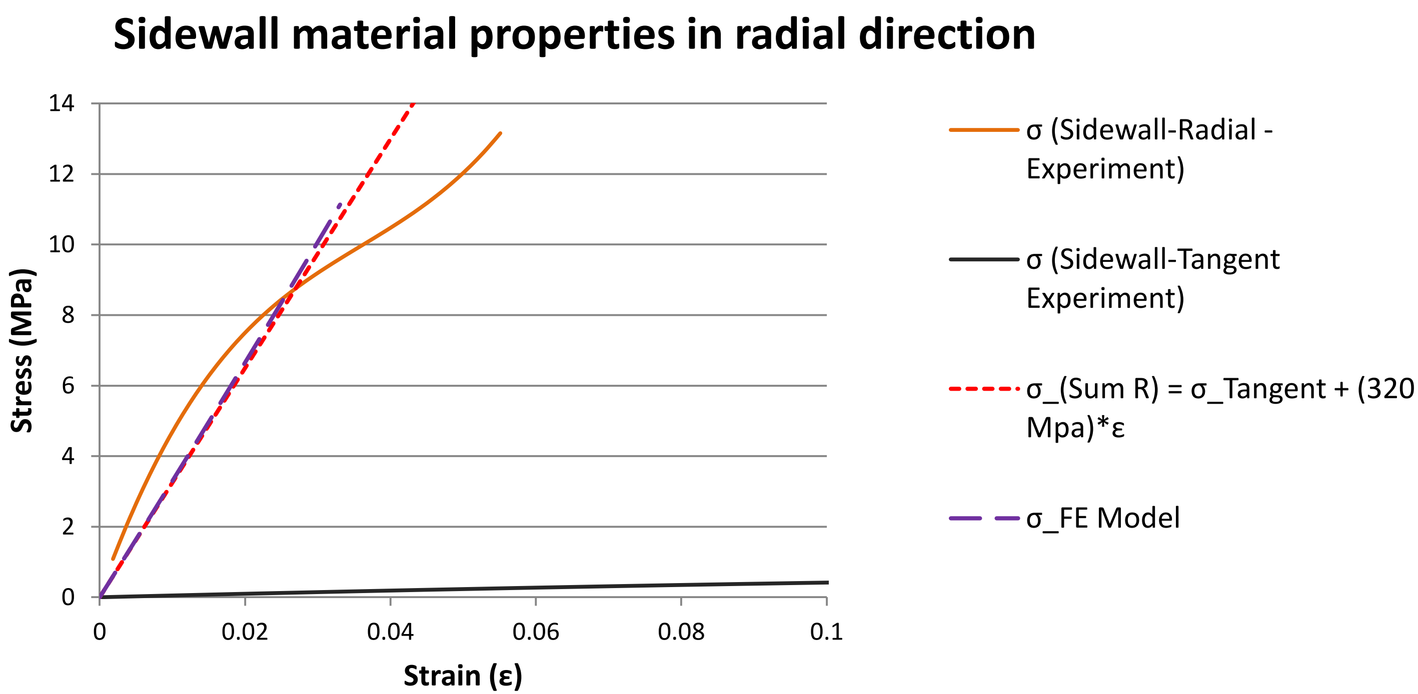


Orthotropic stiffness component in sidewall



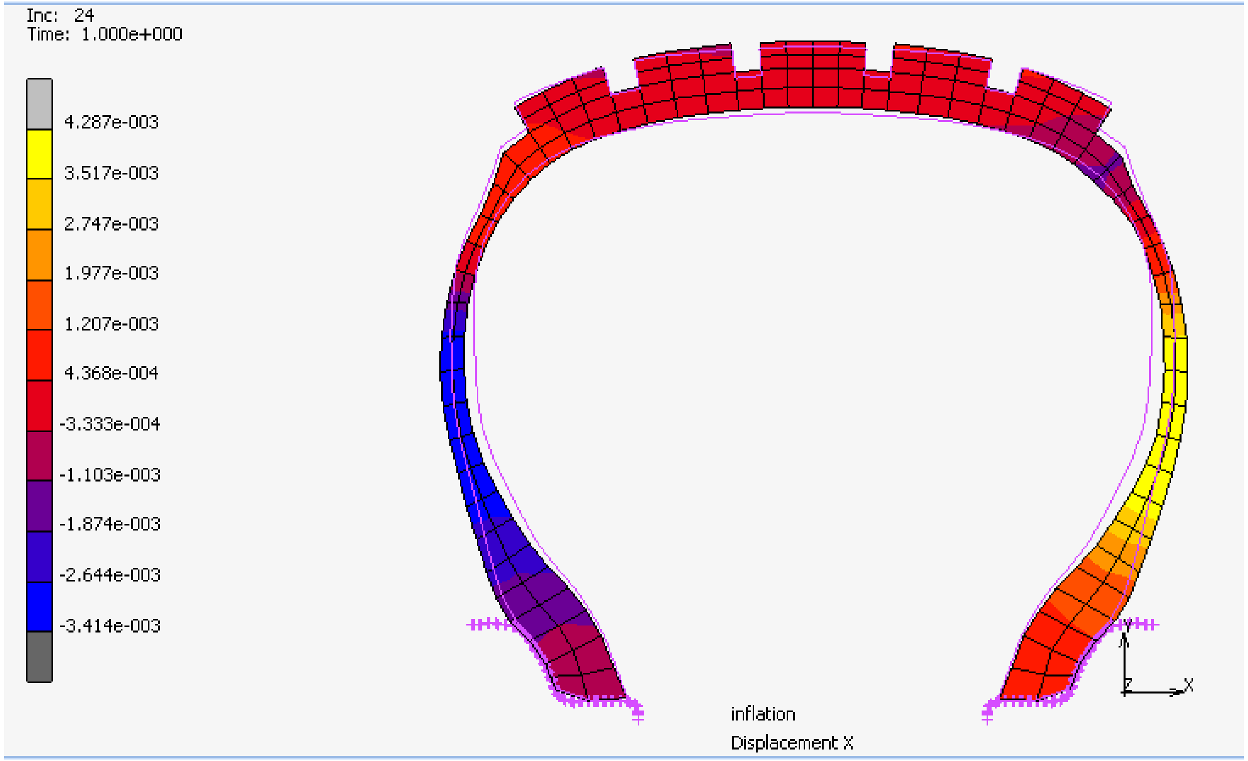
TYRE STUDIED – MATERIAL PROPERTIES





$$\sigma_{\substack{sidewall,radial\\experimental}} \approx \sigma_{\substack{sidewall,tangential\\experimental}} + \sigma_{\substack{Orthotropic\\Young'sModulus=320MPa}} = \sigma_{\substack{sidewall,radial\\approximation}}$$

FE MODEL (2-D INFLATION)



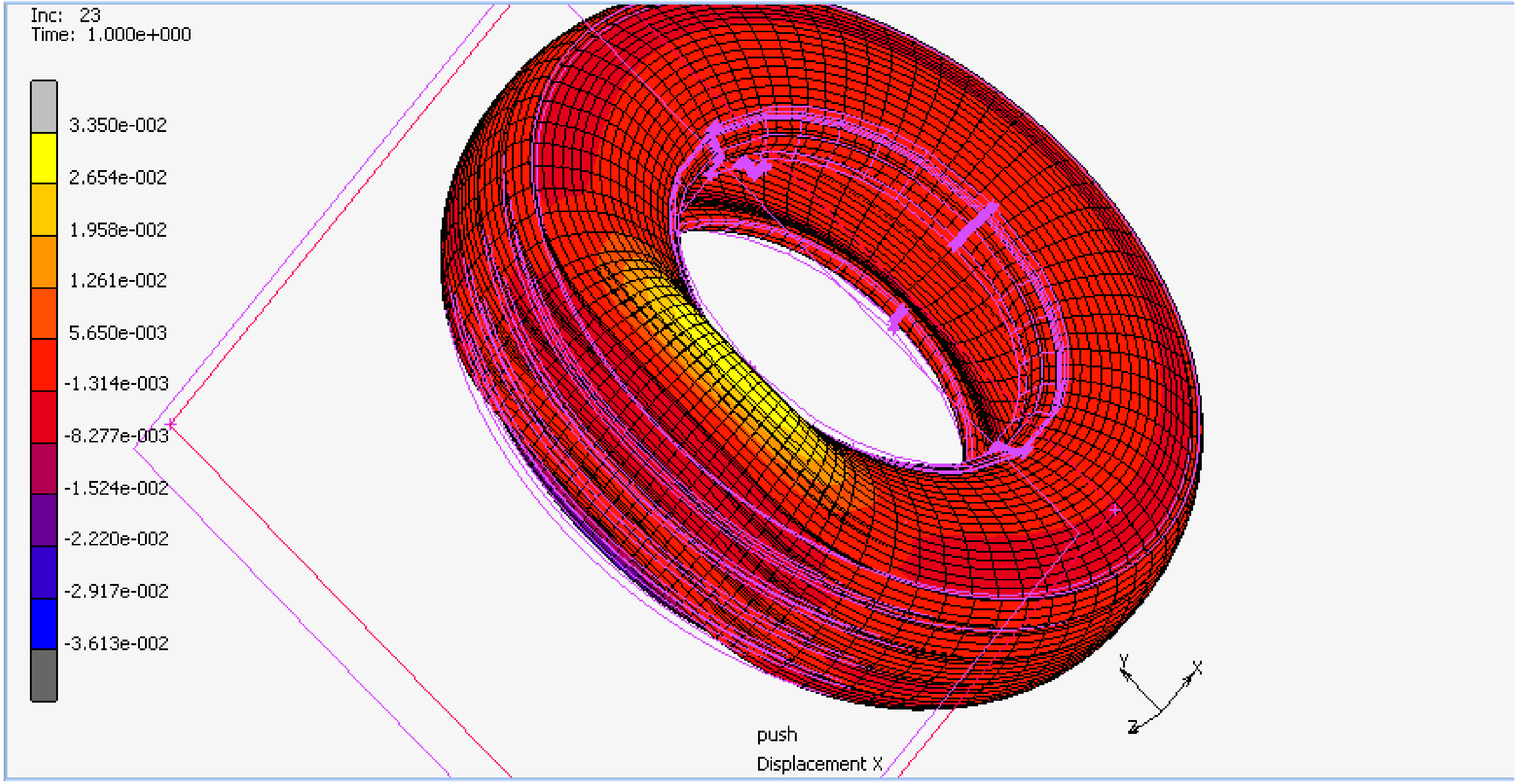
Displacement X

GLOBAL STIFFNESS AND CLEAT TESTS

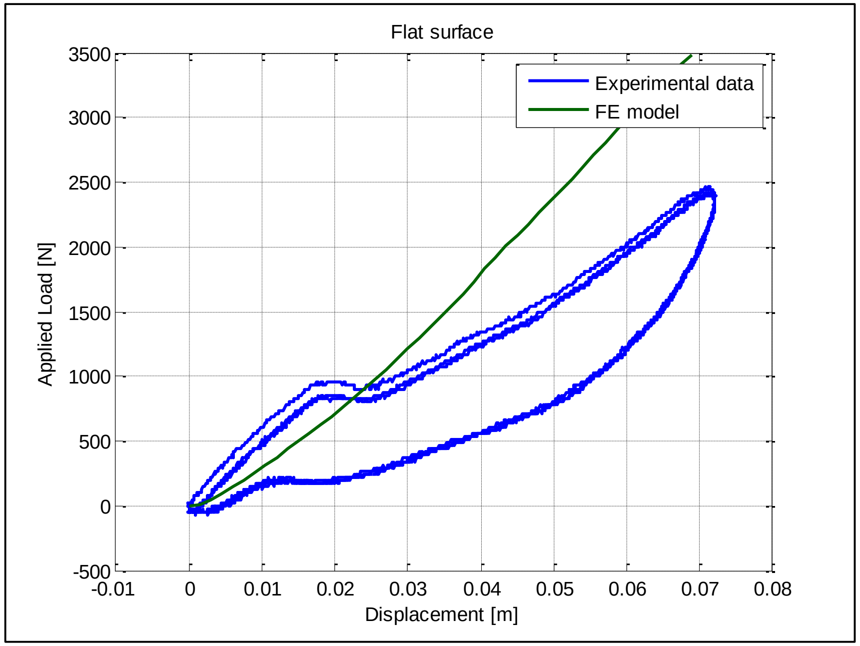
The displacement and output from the actuator was measured and recorded during tests. The equipment used in the experimental measurements was as follow:

- Schenck PL100 Actuator
- 100 kN load cell
- Laser displacement sensor (Acuity AR700)
- eDaq data acquisitioning system
- K7500 Servo controller
- Solid frame for mounting of tyre
- Flatbed for mounting the lasers
- **Cleats**

FE MODEL (MARC)

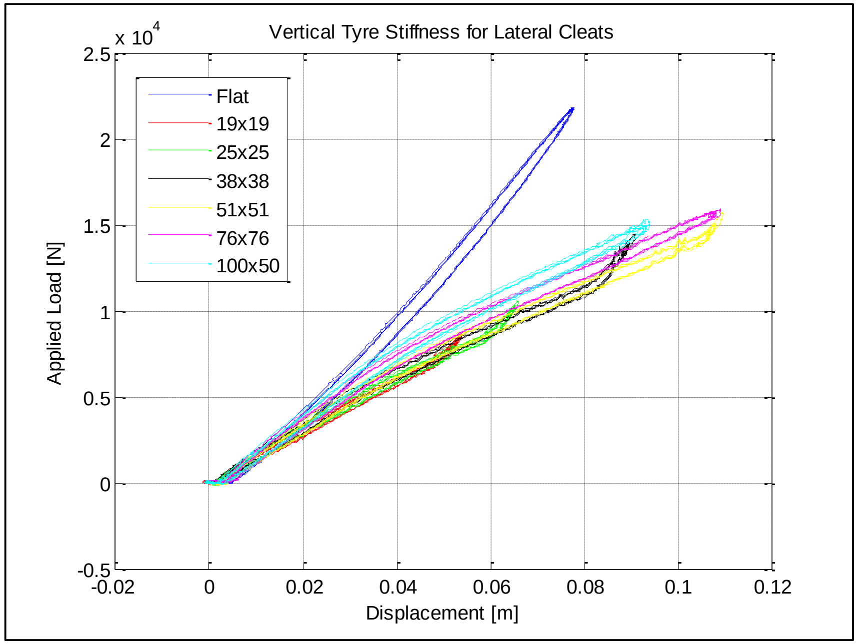


FE MODEL

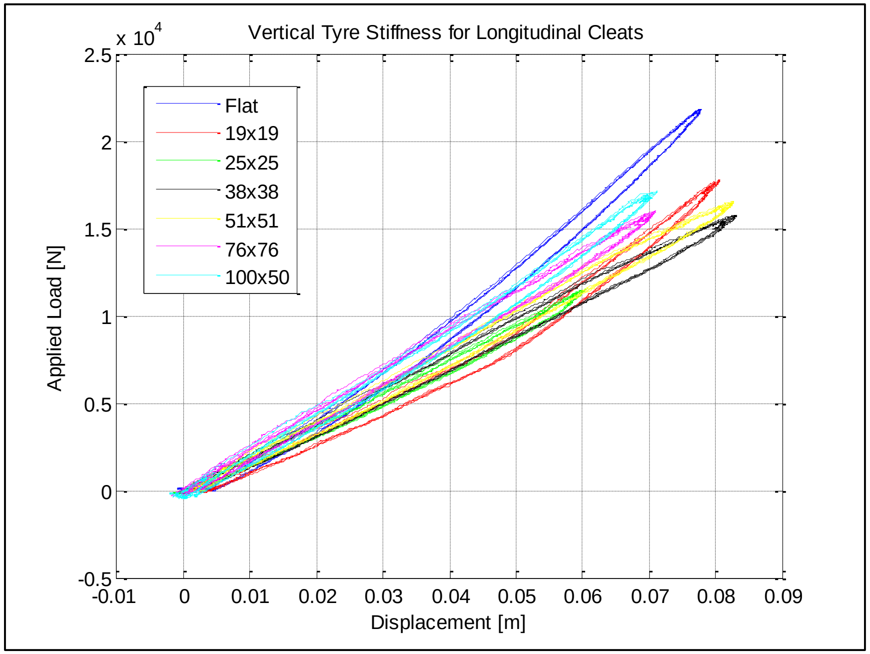


The validity of the material properties in the three dimensional tyre model was first checked by analysing the model with no internal pressure (simulating the deflated tyre).

GLOBAL STIFFNESS AND CLEAT TESTS

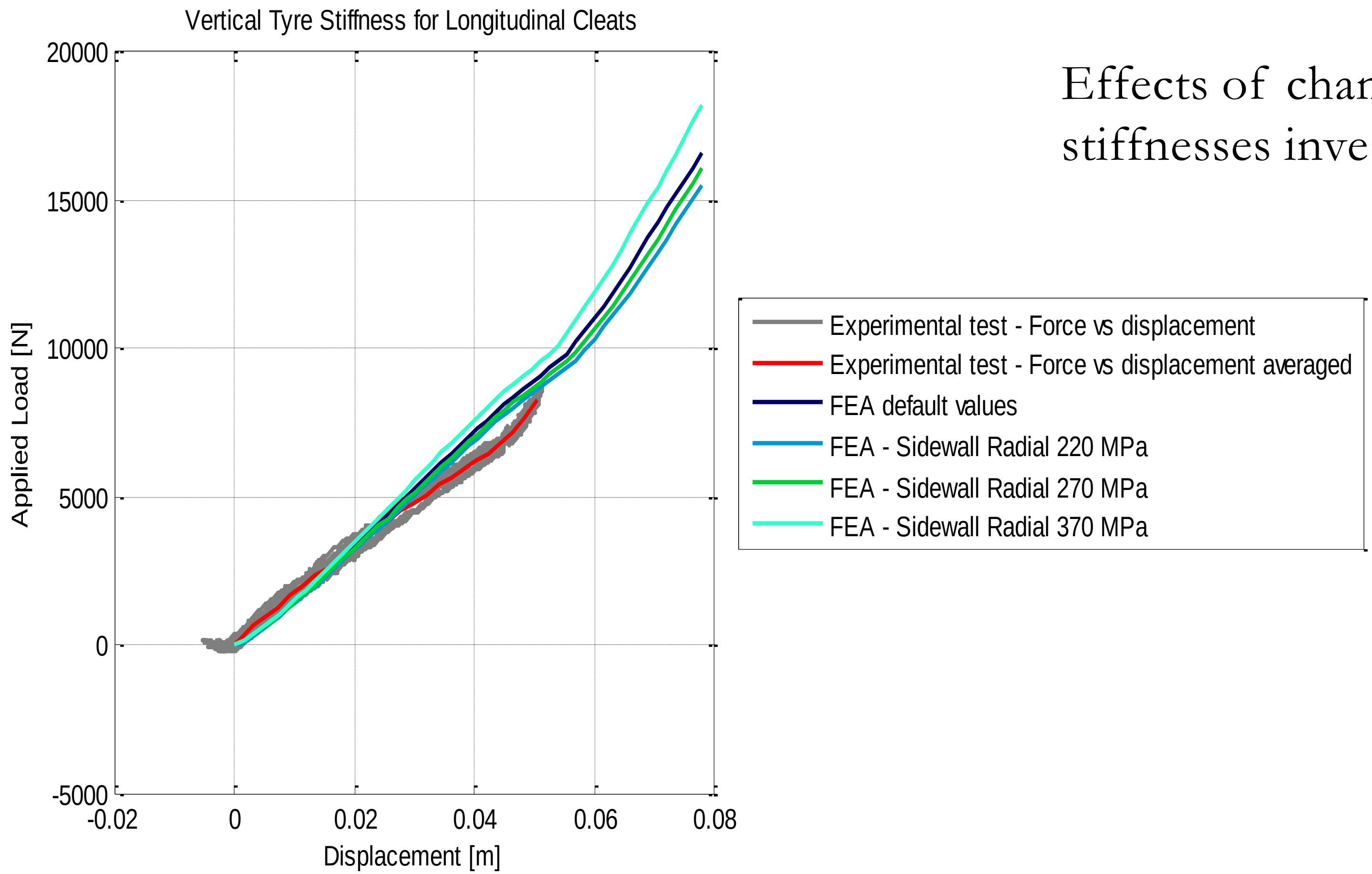


Load vs. Displacement (lateral cleats)



Load vs. Displacement (longitudinal cleats)

LOAD CASES ANALYSED



Effects of changing stiffnesses investigated

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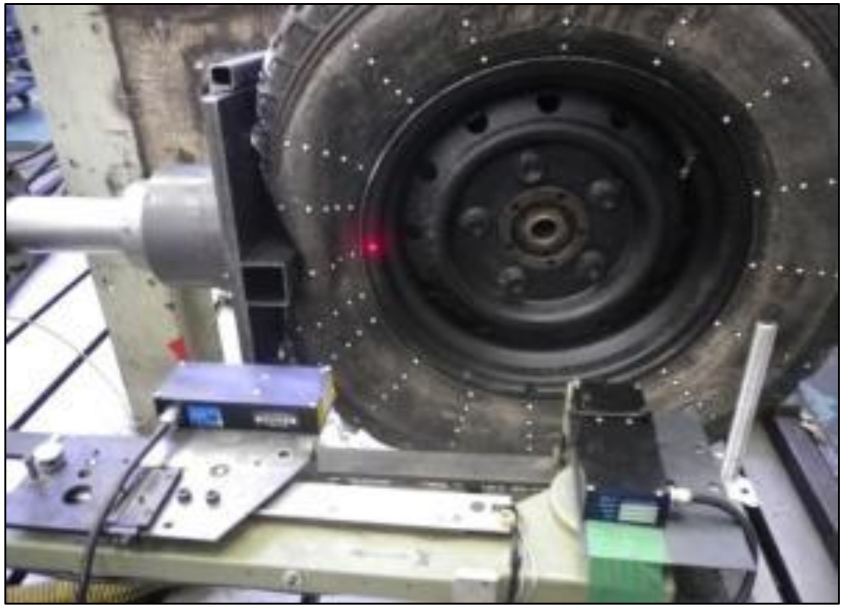
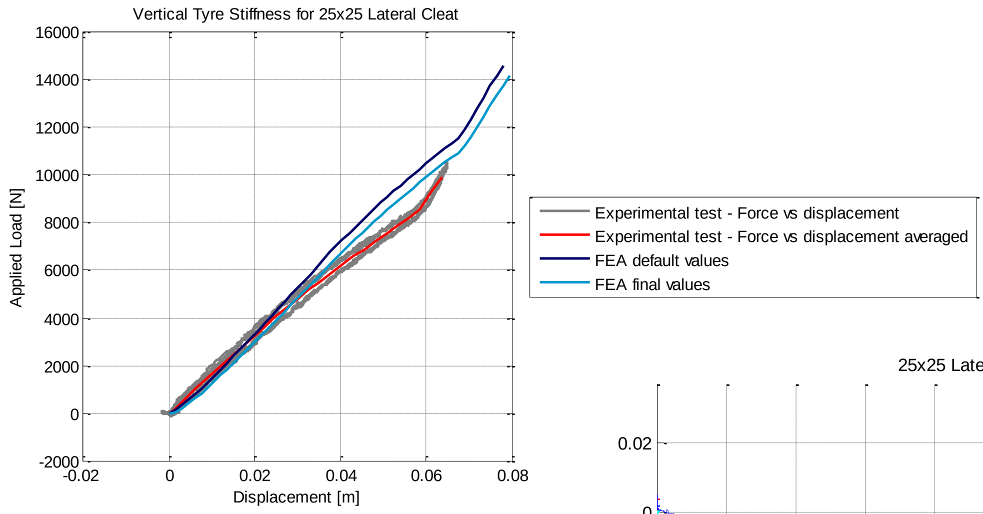
SIDEWALL PROFILES

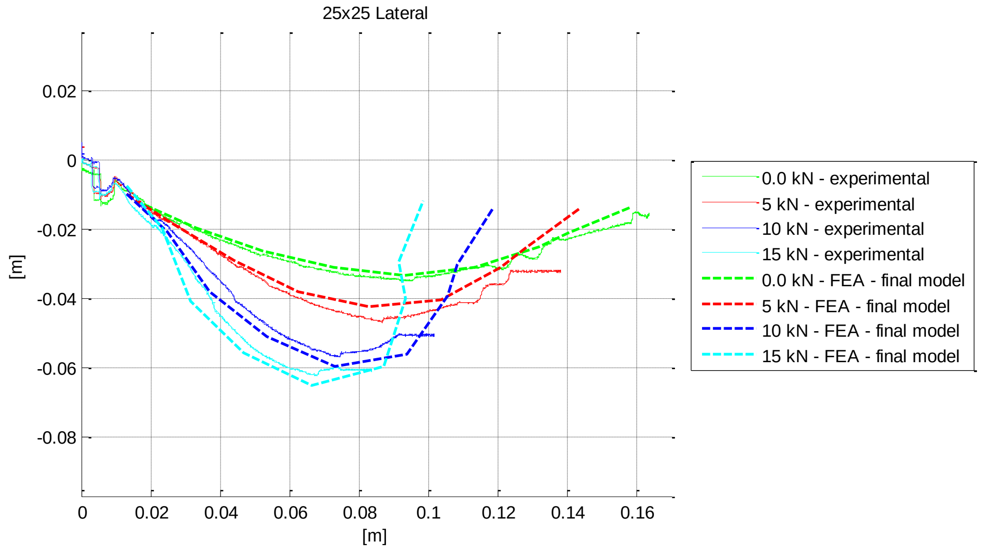


Using the same experimental setup, with the same cleats, the tyre profile was measured at the centre of indentation at different loading conditions, using two Acuity AR700 lasers.

LOAD VS. DISPLACEMENT & SIDEWALL PROFILES

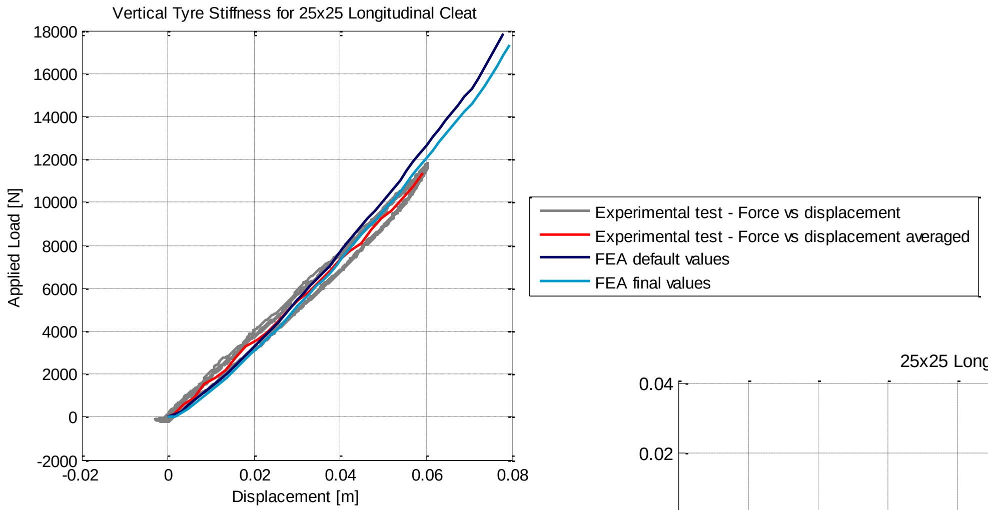
25mm x 25mm Lateral cleat

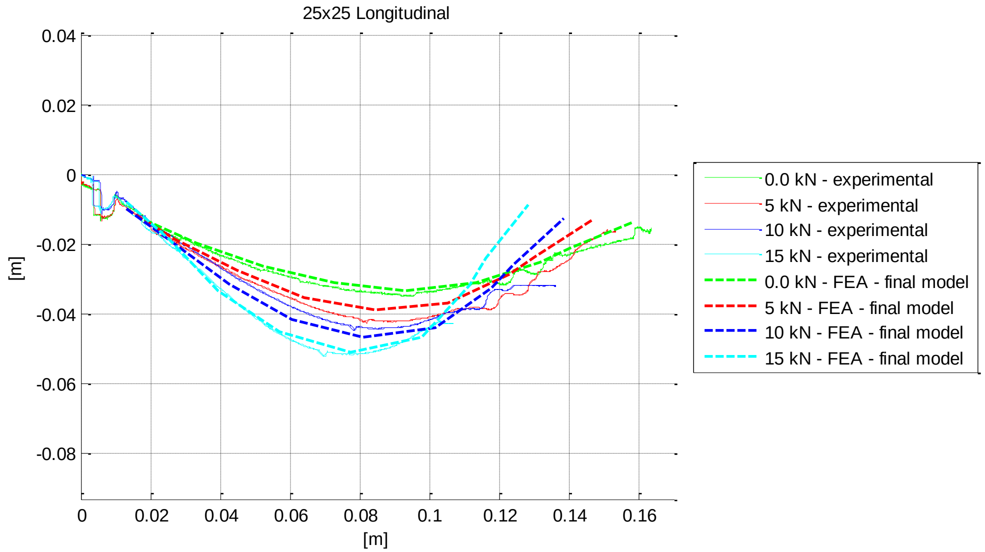




LOAD VS. DISPLACEMENT & SIDEWALL PROFILES

25mm x 25mm Longitudinal cleat





CONCLUSIONS & ACHIEVEMENTS

- Established experimental methods for testing.
- Used accurately measured deformation profiles of the tyre to verify the tyre models behaviour.
- A simple FE model was developed using the global material properties of sidewall, tread.
- Developed a finite element tyre model that can solve fairly fast.
- Investigate the use of two subsets of elements were superimposed onto each other to compensate for different stiffnesses caused by the steel wires, polyester and nylon threads.

The final FE model can successfully predict the vertical force vs. displacement, as well as side wall deformation of the tyre under static loading conditions on both a flat surface and various different cleats.