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# Finite Element Modelling of Bitumen Seals

27<sup>th</sup> Road Pavement Forum  
21 May 2014

Researcher: Johan Gerber  
Project Leader: Prof Kim Jenkins

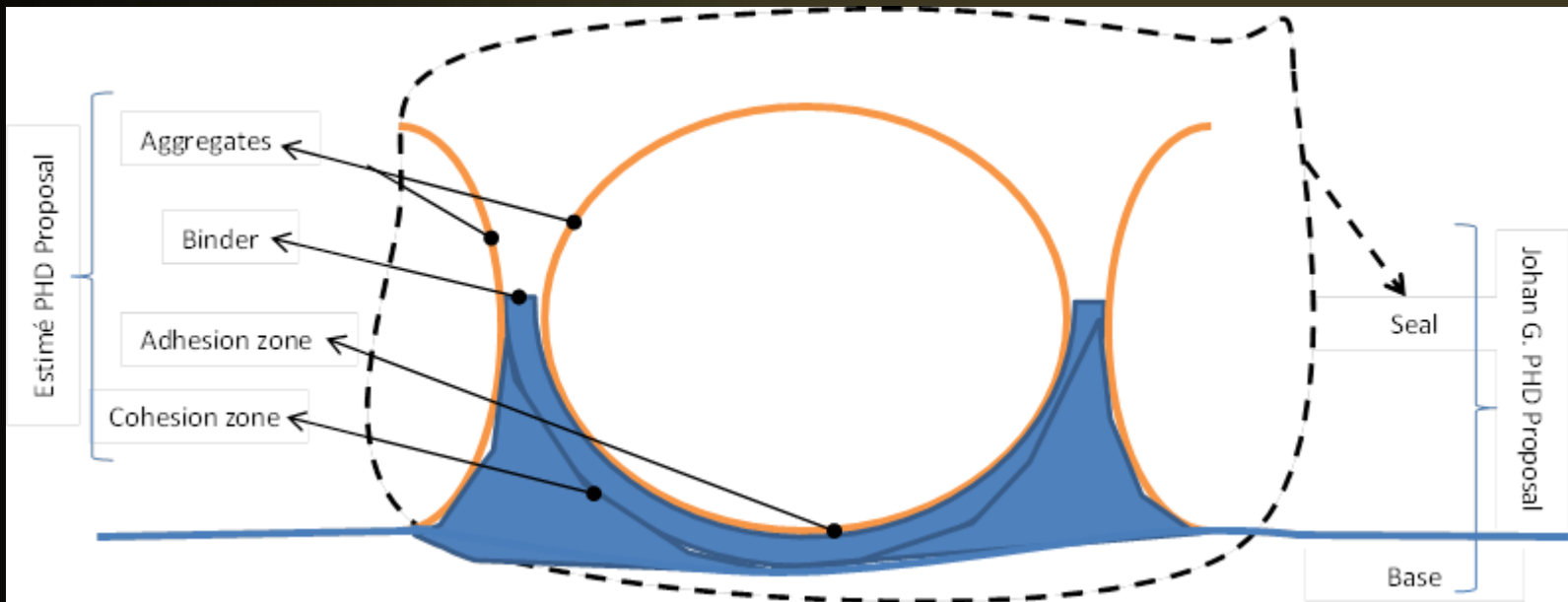
Researcher: Estime Mukandila  
Project Leader: Prof Wynand Steyn

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- FEM Model Structure
- FEM Model Components
- Failure Mechanisms
  - Embedment
  - Adhesive failure
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- Summary

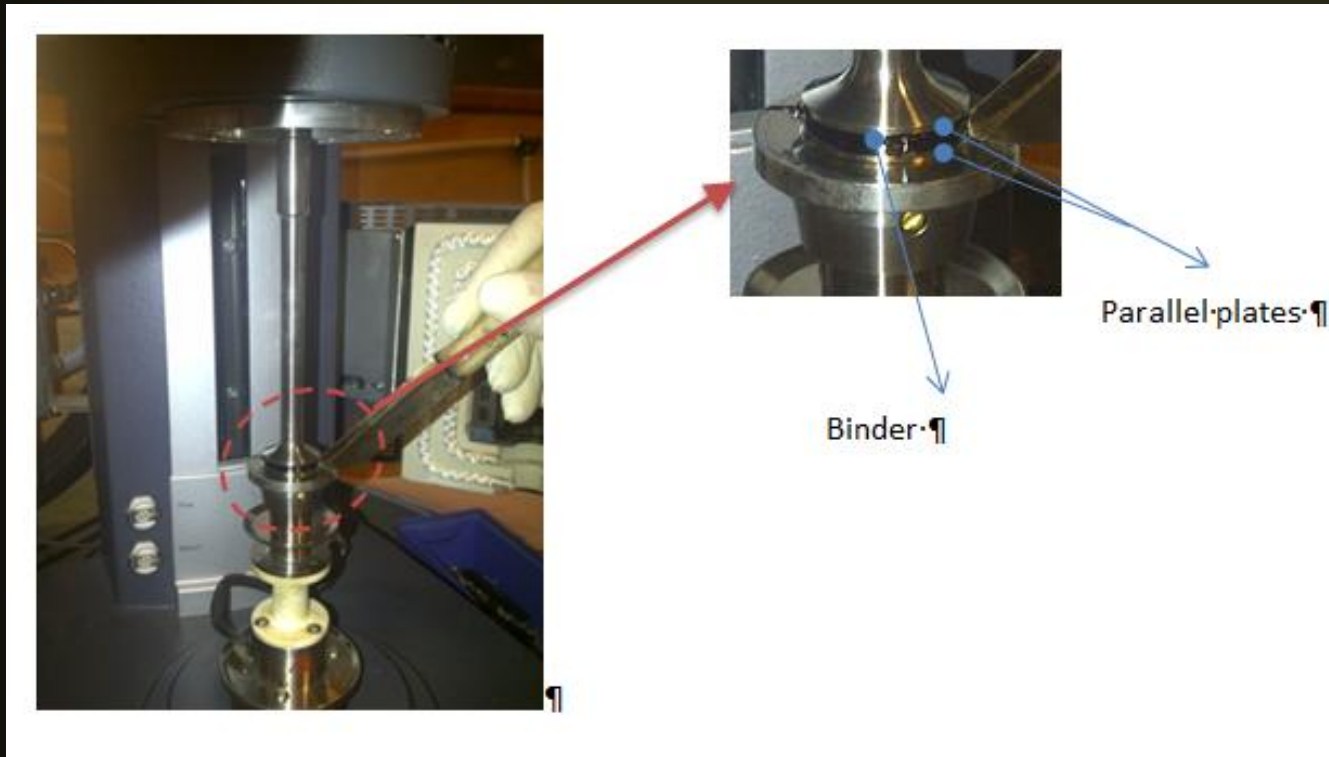
# Material Characterization

- Scope
  - » Binder response
  - » Adhesive damage
  - » Cohesive damage



# Material Characterization

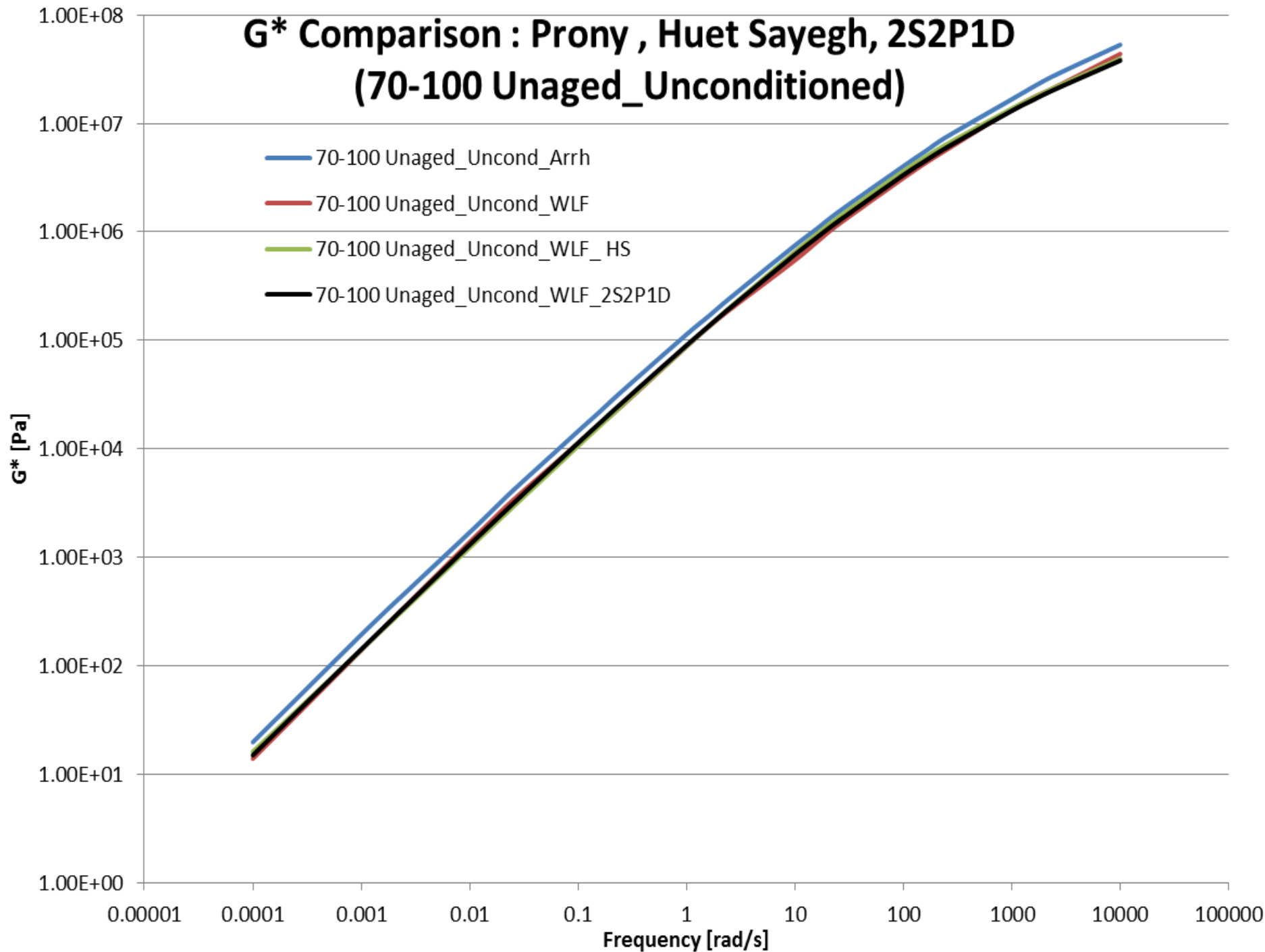
- Binder response (DSR parallel plates)



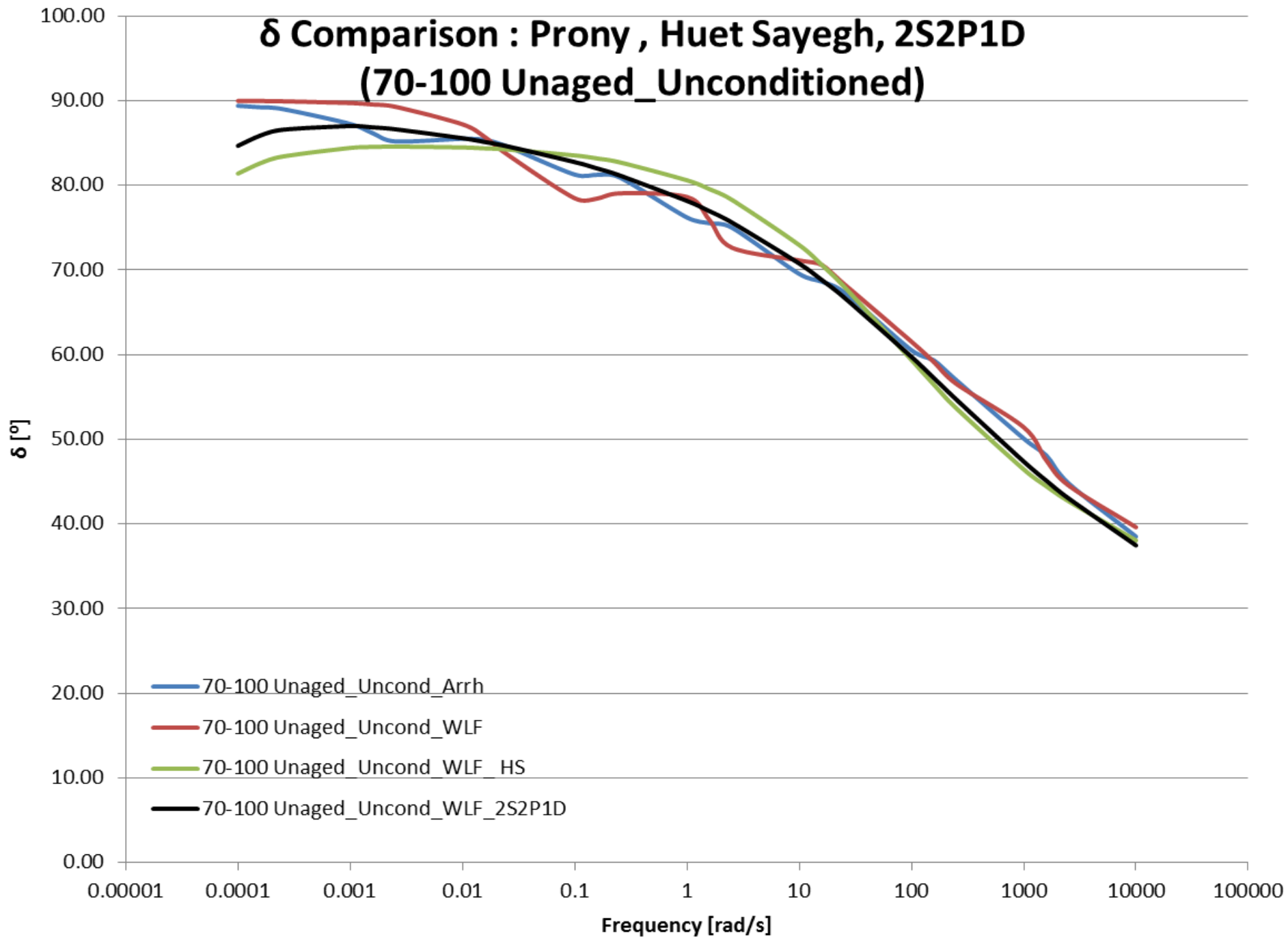
# Material Characterization

- Binder response
  - »  $G^*$
  - »  $\delta$

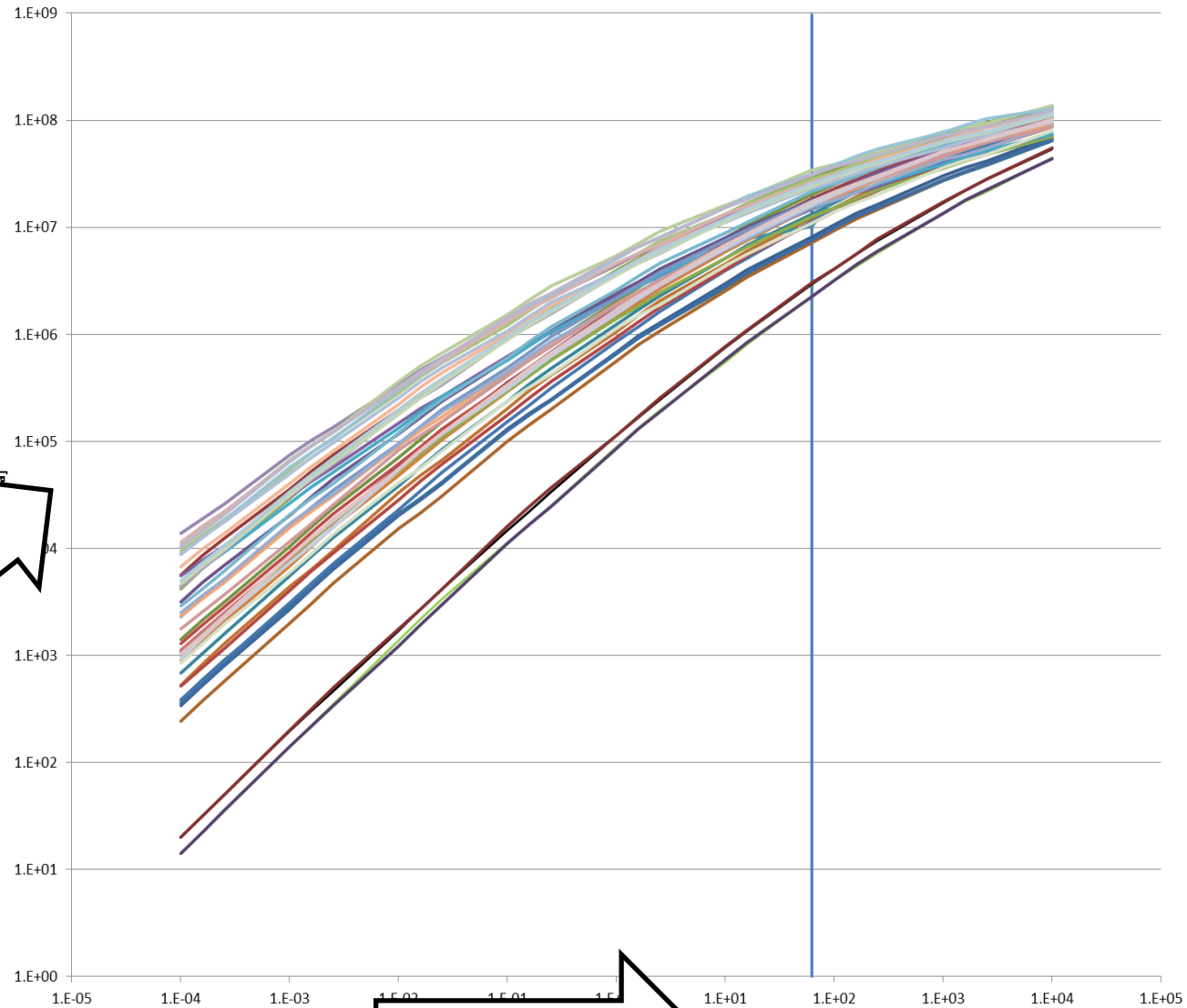
# G\* Comparison : Prony , Huet Sayegh, 2S2P1D (70-100 Unaged\_Unconditioned)



# $\delta$ Comparison : Prony , Huet Sayegh, 2S2P1D (70-100 Unaged\_Unconditioned)



Combined Prony G\* for 70-100 bitumen binder



- ref. Freq 62.83
- 70-100Unaged\_Uncond\_Arh
- 70-100Unaged\_Uncond\_WLF
- 70-100Unaged\_Cond\_Arh
- 70-100Unaged\_Cond\_WLF
- 70-100PAVaged\_Uncond\_Arh
- 70-100PAVaged\_Uncond\_WLF
- 70-100PAVaged\_Cond\_Arh
- 70-100PAVaged\_Cond\_WLF
- 70-100\_DR02175\_BWT\_3yrs\_Arh
- 70-100\_DR02175\_OWt\_3yrs\_Arh
- 70-100\_DR1298\_SHDR\_4yrs
- 70-100\_DR1298\_OWt\_4yrs
- 70-100\_MR23\_SHDR\_4yrs
- 70-100\_MR23\_OWt\_4yrs
- 70-100\_N10\_3\_SHDR\_4yrs
- 70-100\_N10\_3\_OWt\_4yrs
- 70-100\_DR1398\_BWT\_5yrs
- 70-100\_R61-5\_SHDR\_5yrs
- 70-100\_R61-5\_OWt\_5yrs
- 70-100\_DR2175-BWT\_6yrs
- 70-100\_DR2175-AWT\_6yrs
- 70-100\_N10-3BWT\_9yrs
- 70-100\_N10-3OWT\_9yrs
- 70-100\_N10-3AWT\_9yrs9
- 70-100\_MR174-SHDR\_10yrs
- 70-100\_MR174-OWT\_10yrs
- 70-100\_DR2216-BWT\_10yrs
- 70-100\_DR2216-AWT\_10yrs
- 70-100\_N6-5-SHDR\_11yrs
- 70-100\_N6-5-OWT\_11yrs
- 70-100\_DR1452-BWT\_12yrs
- 70-100\_DR1452-OWT\_12yrs
- 70-100\_N6-5-SHDR\_13yrs
- 70-100\_N6-5-OWT\_13yrs
- 70-100\_MR269-SHDR\_13yrs
- 70-100\_MR269-OWT\_13yrs
- 70-100\_12603\_MR188\_SHDR\_15yrs
- 70-100\_12603\_MR188-OWT\_15yrs
- 70-100\_12605\_MR188\_SHDR\_15yrs
- 70-100-DR1123\_IWT\_17yrs
- 70-100-MR563\_IWT\_19yrs
- 70-100-MR563\_BWT\_19yrs
- 70-100-P1398\_OWt\_22yrs
- 70-100-P1398\_SHDR\_22yrs
- 70-100-P1398\_OWt\_23yrs
- 70-100-P1398\_SHDR\_23yrs
- 70-100-TR2701\_OWt\_23yrs
- 70-100-TR2701\_SHDR\_23yrs
- 70-100\_1252\_QSun



# Material Characterization

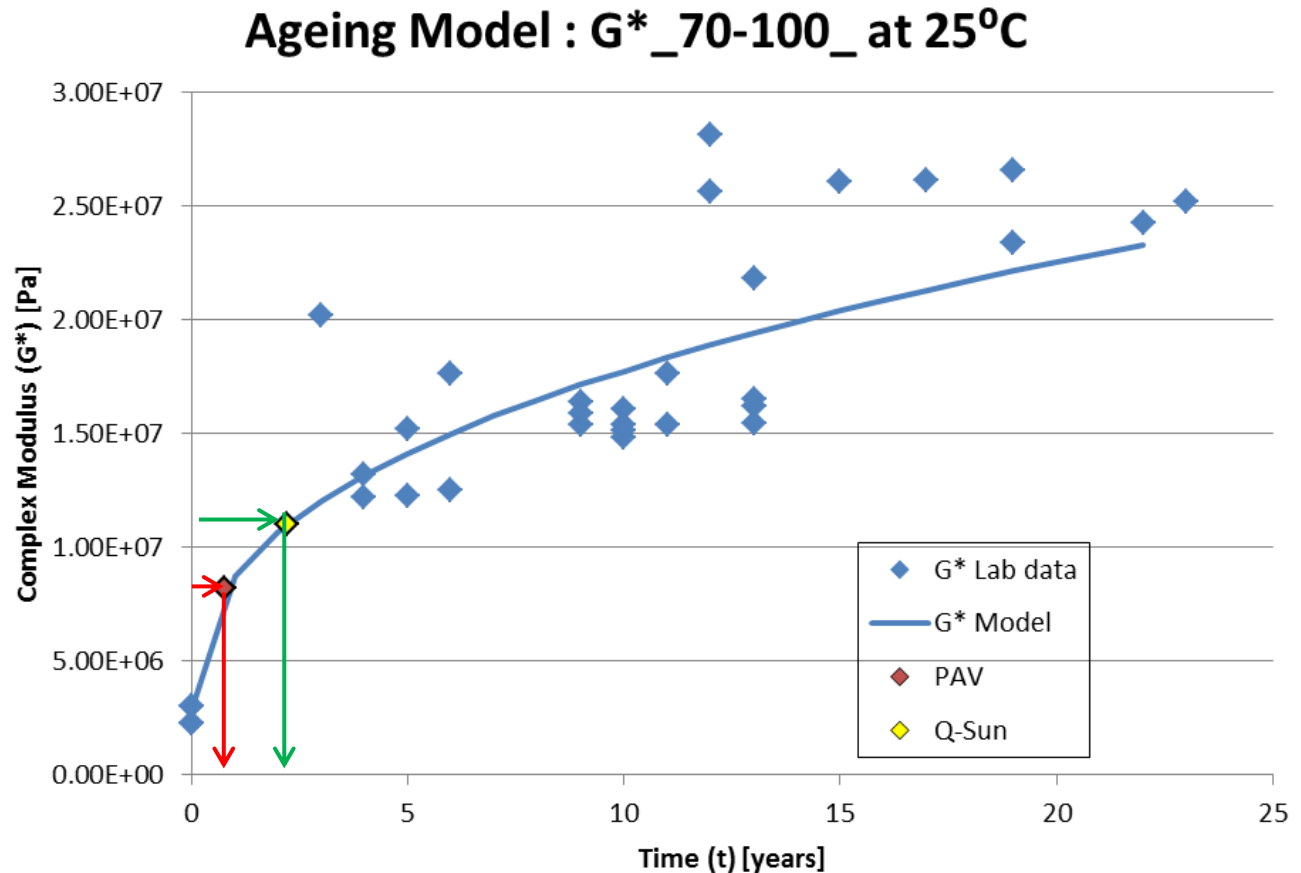
- Binder response -  $G^*$  aging

$$G^* = a + bt^c$$

a	b	c	R <sup>2</sup>
2.82E+06	5.93E+06	0.40127	0.76

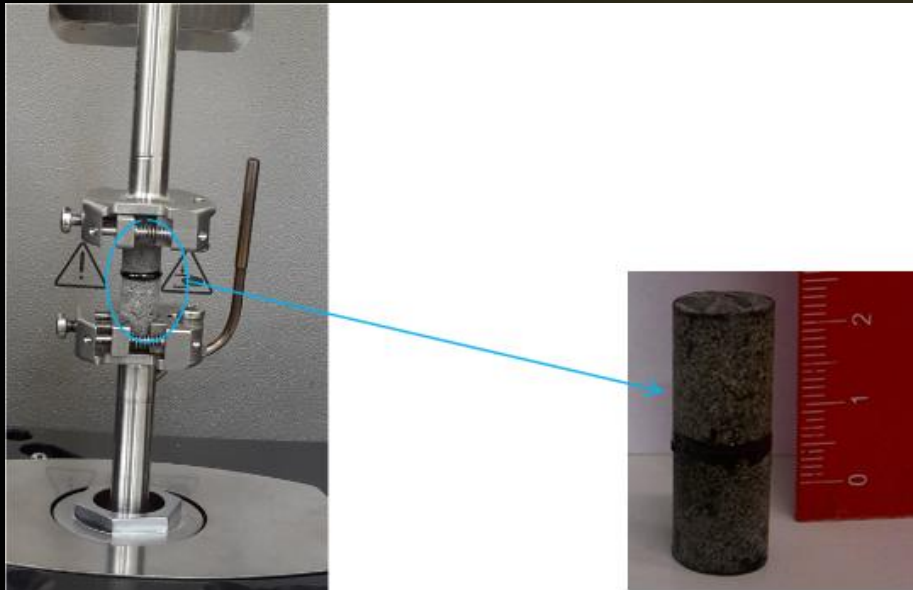
PAV Simulating = ±1 year

Q-sun Simulating = ±2 years



# Material Characterization

- Adhesion fatigue
- Cohesion fatigue



# Material Characterization

- Adhesion fatigue

- Transfer Function ( $N_F$ )

- End life fatigue

- » Stress controlled

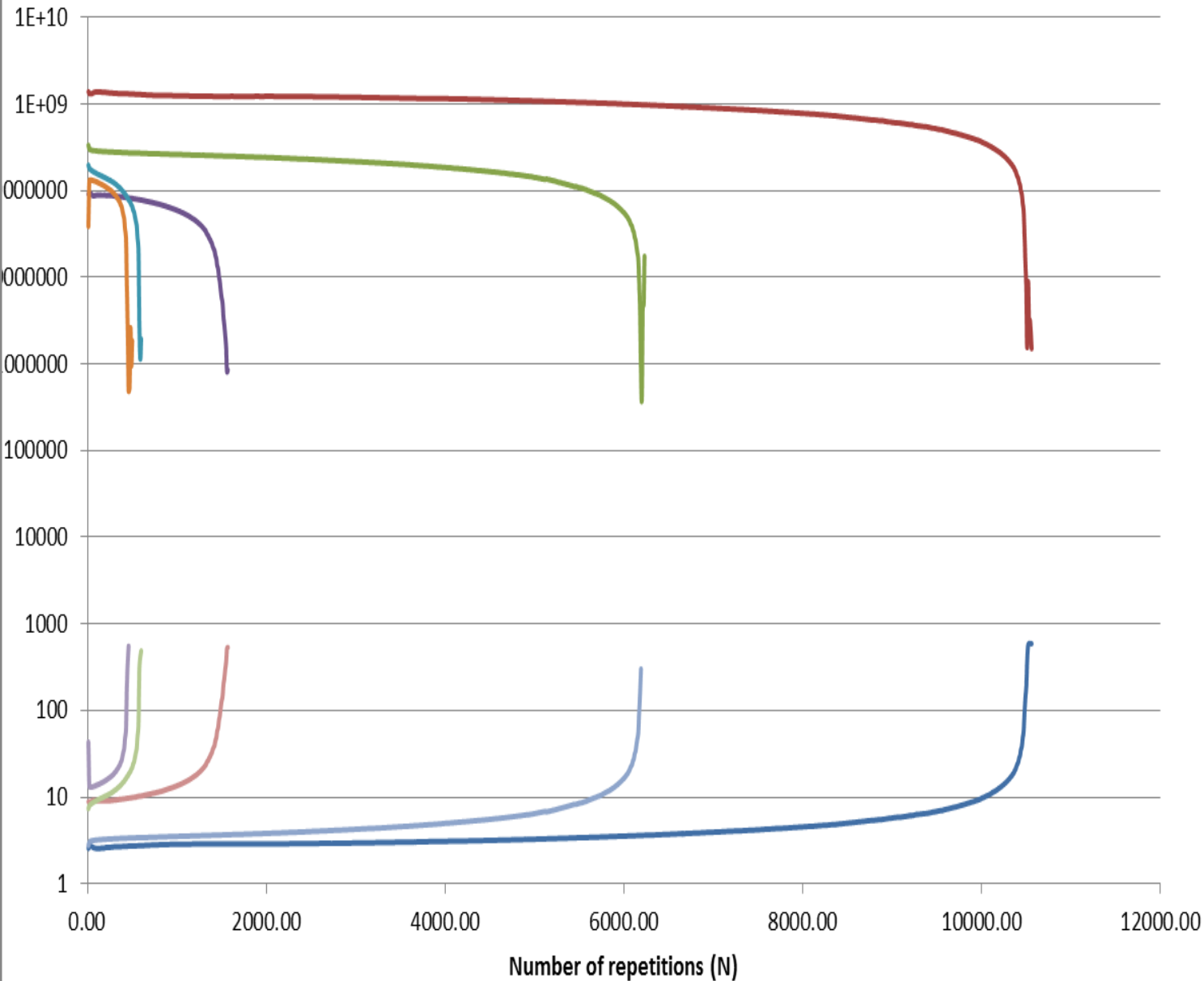
- » Normalization of  $G^*$  to  $G^*_n$

- »  $N_f$  as a function of  $G^*_n$

- Memory-less principle :

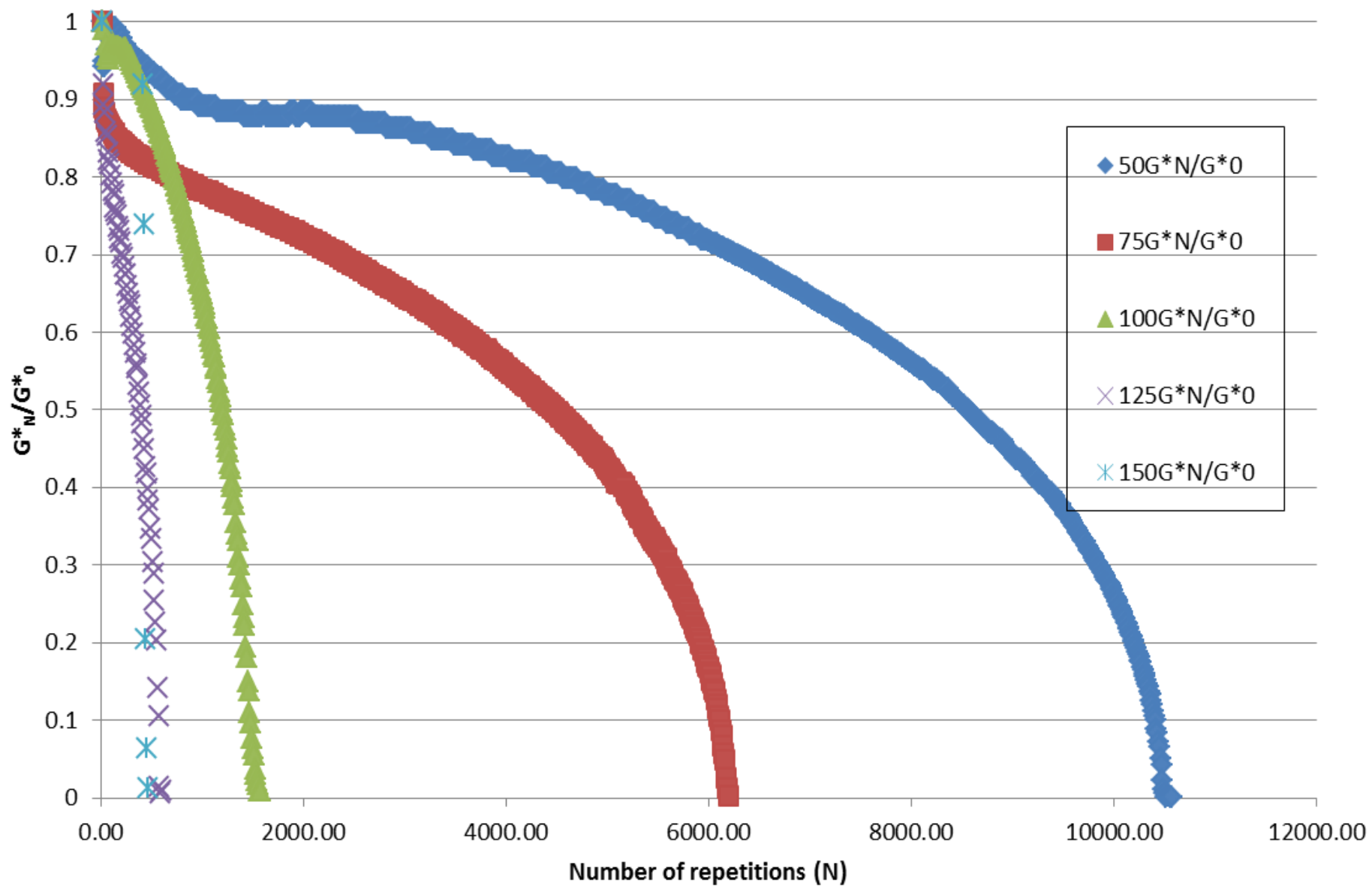
- fatigue during life period: rate of damage against damage

Dol\_70-100\_Fresh\_Uncond\_25C\_62.8\_10.9\_stress controlled



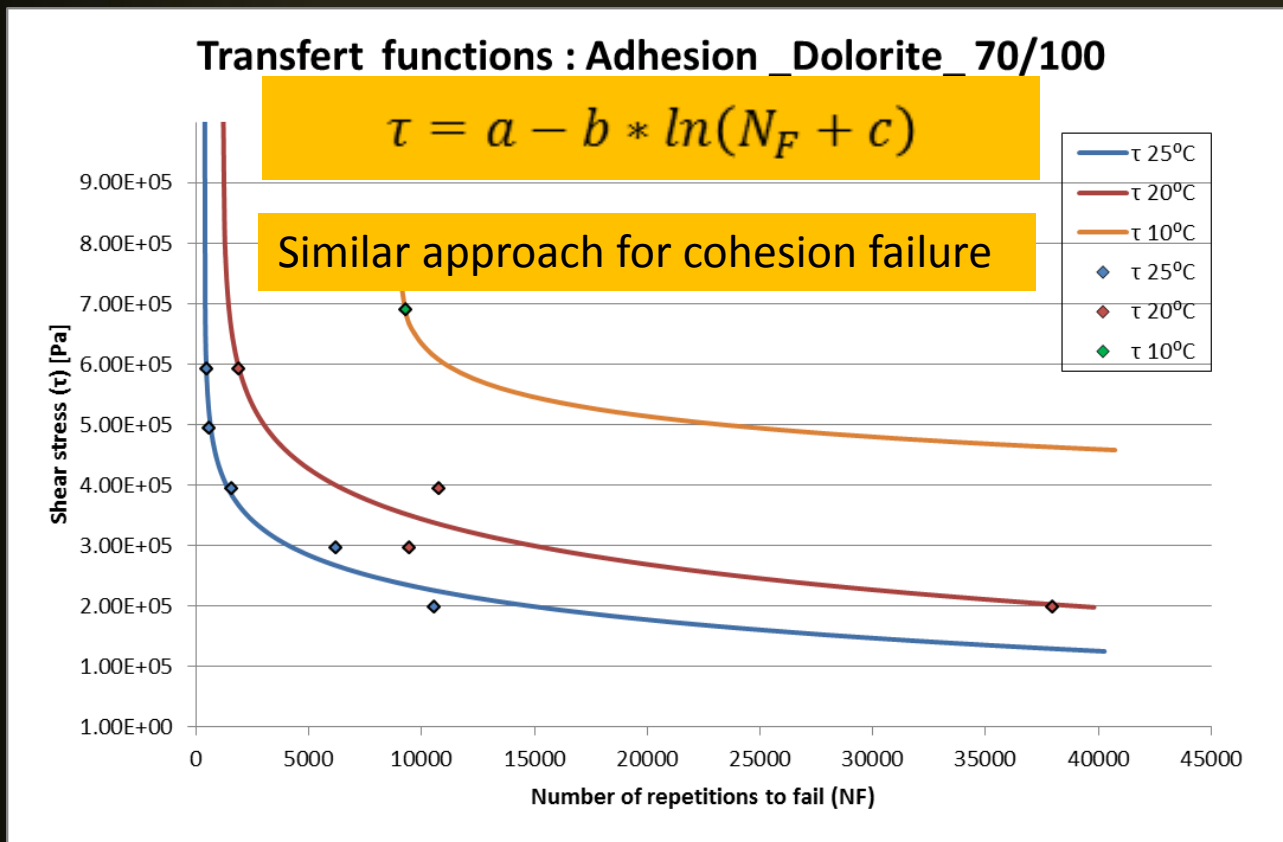
- Complex Modulus (50mNm)
- Complex Modulus (75mNm)
- Complex Modulus (100mNm)
- Complex Modulus (125mNm)
- Complex Modulus (150mNm)
- Deflection Angle (50mNm)
- Deflection Angle (75mNm)
- Deflection Angle (100mNm)
- Deflection Angle (125mNm)
- Deflection Angle (150mNm)

# Determination of Number of repetition to fail ( $N_F$ ) as function of Normalised Complex Modulus ( $G_N^*/G_0^*$ ) at 25°C



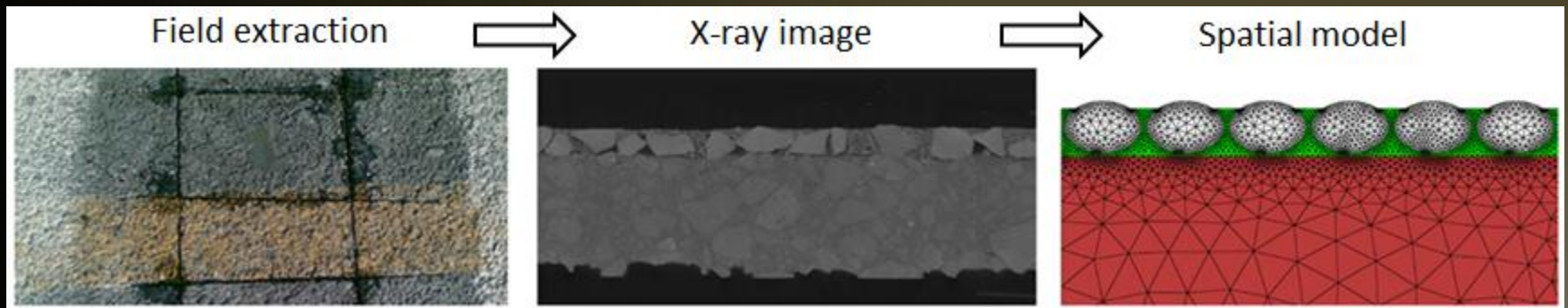
# Material Characterization

- Adhesion fatigue transfer function



# FEM Model Structure

- Geometry transformation
  - » Reality to spatial model
  - » Geometry components
    - Aggregates
    - Binder
    - Base



# FEM Model Components

Seal\_Generator

FE Seal Model Generator Version 1.0 Author: Johan Gerber Updated: 31 March 2014

Seals	Binder	Traffic
<input checked="" type="radio"/> Single seal <input type="radio"/> Double seal <input type="radio"/> Multiple seal <input type="radio"/> Cape seal	<b>Application</b> <input checked="" type="radio"/> Tack coat <input type="radio"/> Penetration coat <input type="radio"/> Fog spray <input type="radio"/> Slurry	Wheel size: 12R22.5 Vertical wheel load [kN]: 15 Tire inflation pressure [kPa]: 520 Tread rubber properties: Soft Travelling velocity [km/h]: 80 Wheel motion: Free rolling Tyre stress position: Center Road gradient [%]: 0 Road surface conditions: dry Analyses plane: Longitudinal
<b>Aggregate</b> Geometry: Ellipsoid Spread: 1.25, Open Aggregate regions of interest: 1 Number of first layer aggregates: 5 First layer: Type: Dolerite Nominal size: 13.2 ALD: 8.2 <input type="radio"/> Precoated Second layer: Type: Dolerite Nominal size: 6.7 ALD: 4.5 <input type="radio"/> Precoated	<b>Rate [l/m<sup>2</sup>]</b> : 1.0, 0.8, 1.0, max <b>Temp [°C]</b> : 25, 25, 25, 25 Film thickness [% of tack coat application]: 30 Film thickness [% of pen coat application]: 20 <b>Base</b> Type: Granular Elastic modulus [MPa]: 600 Expected construction embedment [mm]: 0.0 <b>Surface Deflection</b> Vertical deflection: 0.0 Radius of curvature: 0	

File name: Model\_name.inp

Directory: C:\Program Files\MATLAB 2012\R2012b\bin\SealGui2014



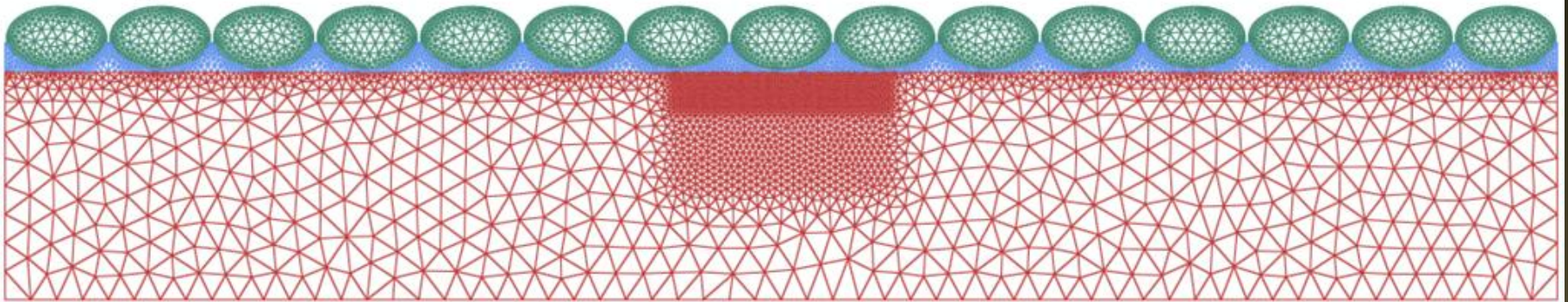
# FEM Model Components

- Seal structures
  - » Single seal
  - » Double (Multiple) seal
  - » Cape Seal
- Binder type
  - » 70-100 penetration grade
  - » SC-1 modified
  - » SR-1 rubber bitumen
  - » KRS-60 emulsion
  - » SC-E1 emulsion
- Traffic
  - » Heavy vehicle wheel loads (HV)
  - » Passenger (Light) vehicle wheel loads (LV)

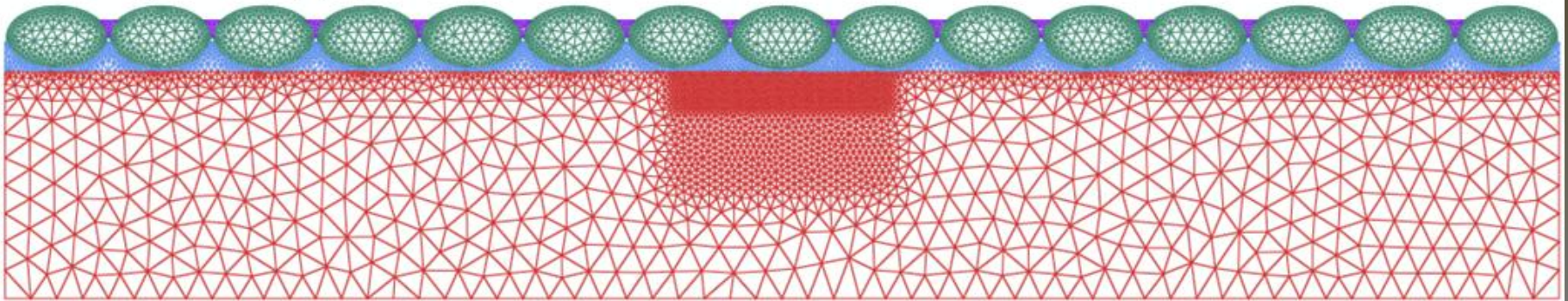
# FEM Model Components

- Seal structure - Single Seal

13.2mm Single seal



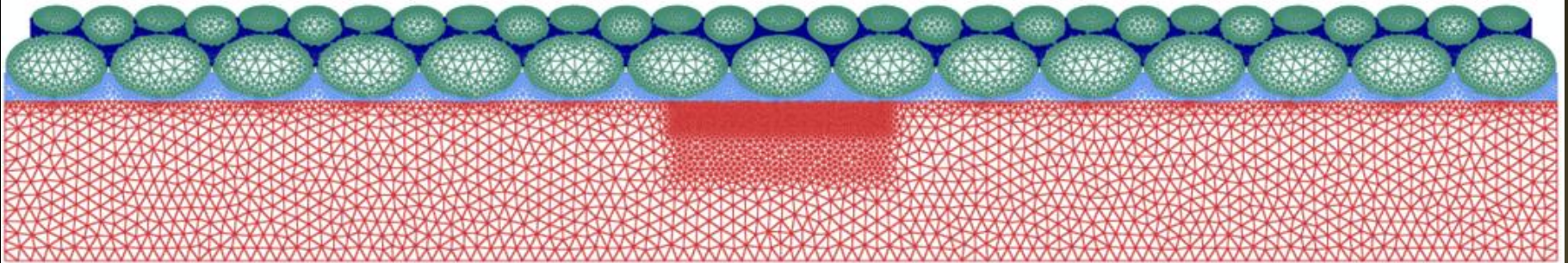
13.2mm Single seal with fog spray



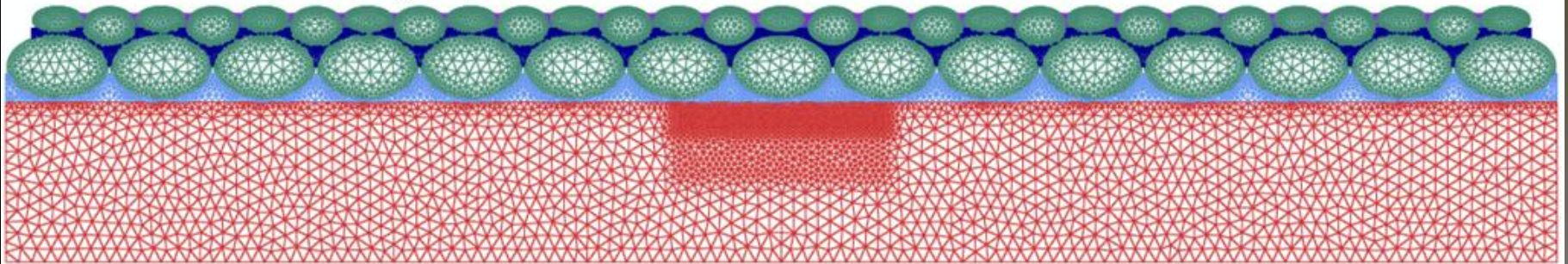
# FEM Model Components

- Seal structure - Double Seal

19.0mm + 9.5mm Double seal



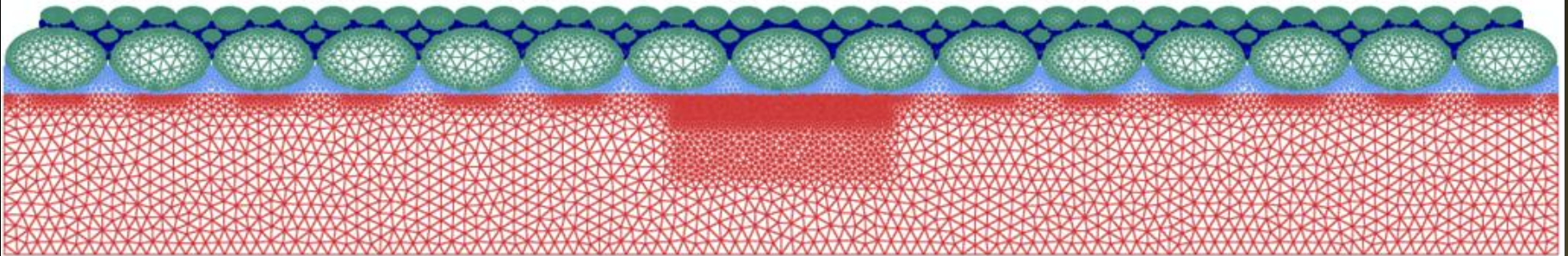
19.0mm + 9.5mm Double seal with fog spray



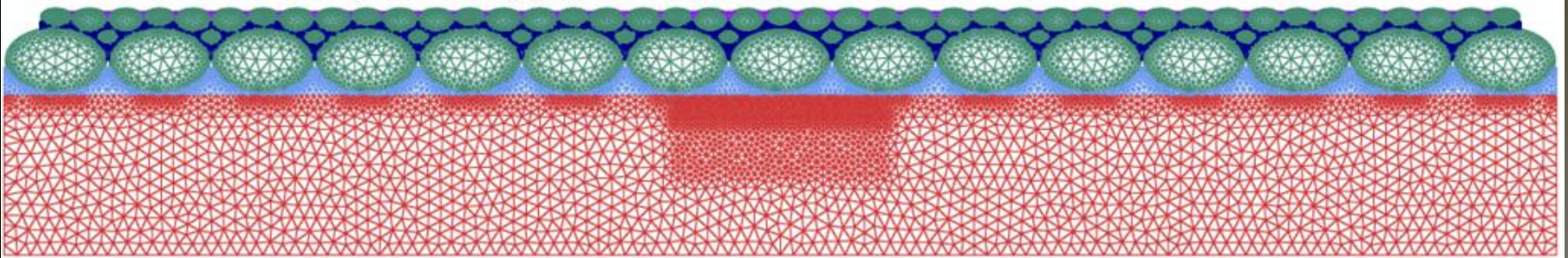
# FEM Model Components

- Seal structure - Multiple Seal

19.0mm + 6.7mm + 6.7mm Multiple seal



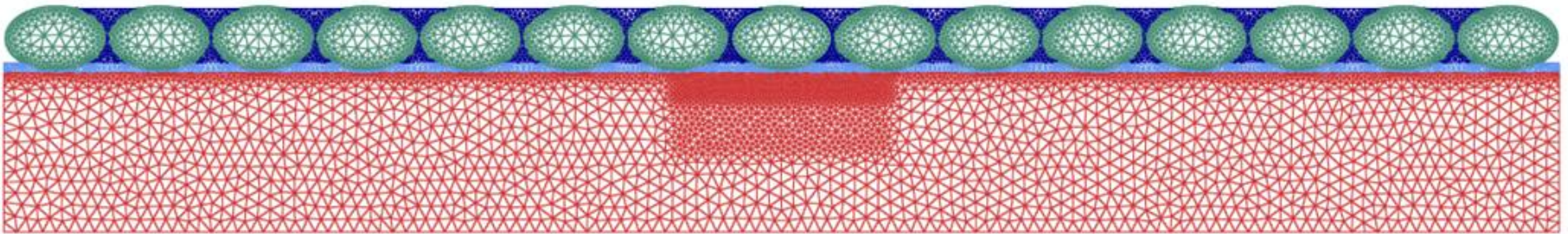
19.0mm + 6.7mm + 6.7mm Multiple seal with fog spray



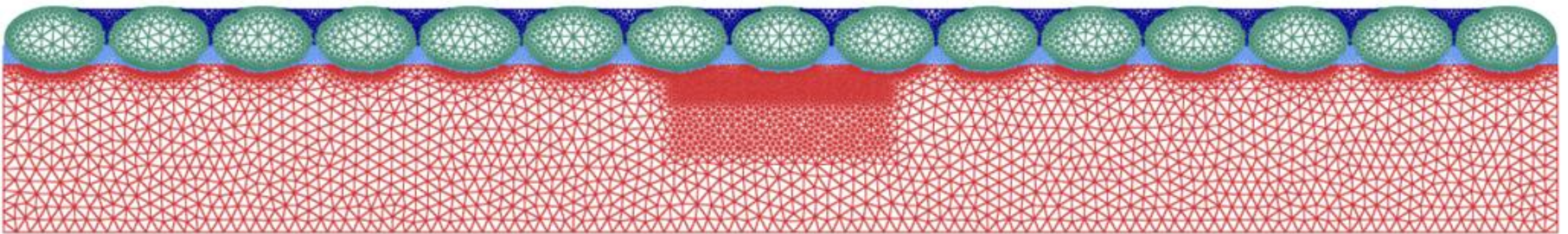
# FEM Model Components

- Seal structure - Cape Seal

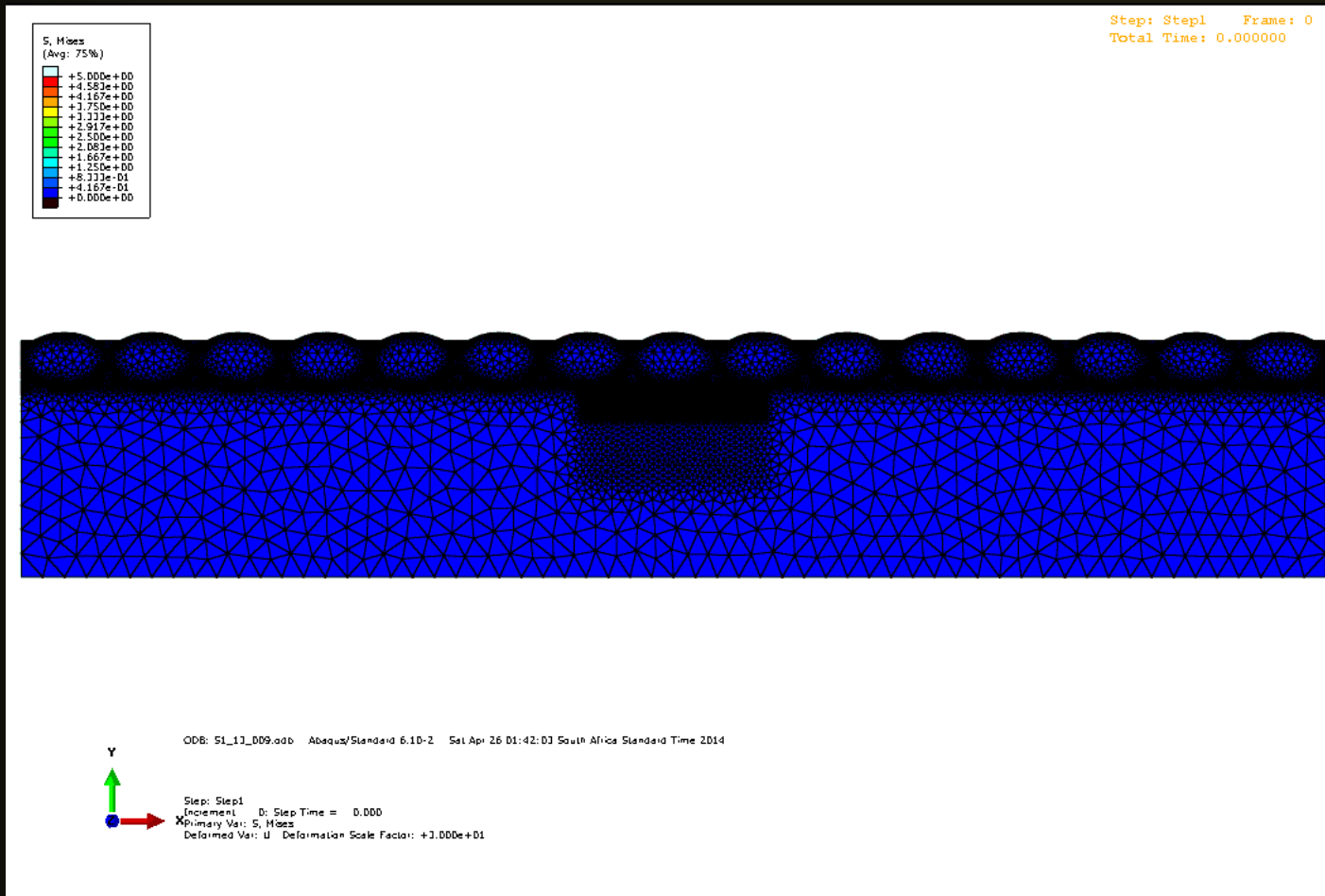
19.0mm Cape seal



19.0mm Cape seal with 1.5mm construction embedment



# Failure Mechanisms

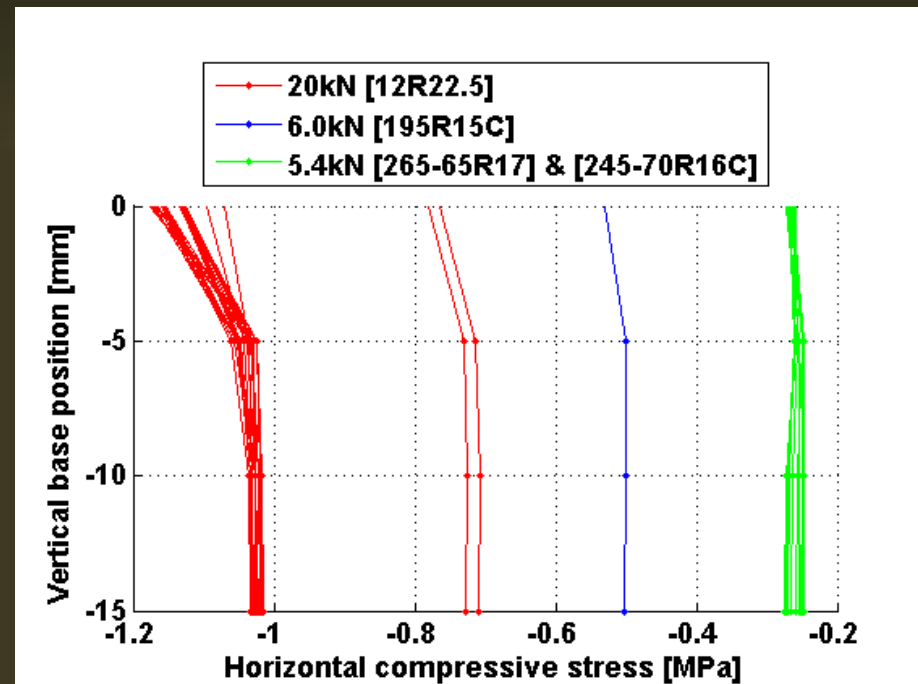
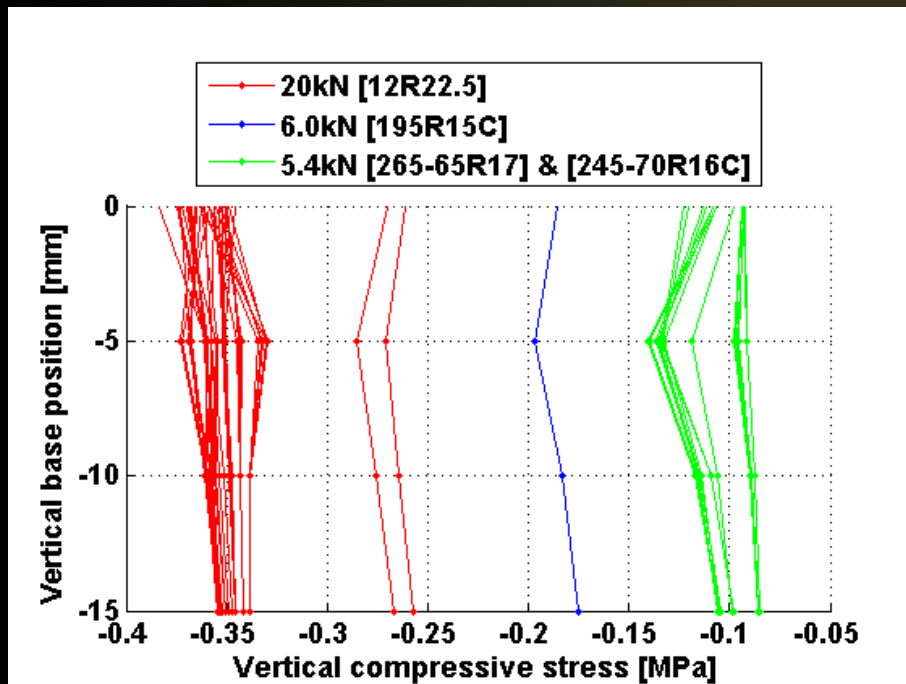


# Failure Mechanisms

- **Embedment (Texture loss)**
  - » Seal aggregate penetration into base
  - » Area of interest: Upper part of base
- **Adhesive failure (Stone loss)**
  - » Seal aggregate-bitumen bond loss
  - » Area of interest: Maximum tensile & shear bond stress
- **Cohesive failure (Binder fatigue)**
  - » Cracks in binder material
  - » Area of interest: Binder between aggregates

# Embedment

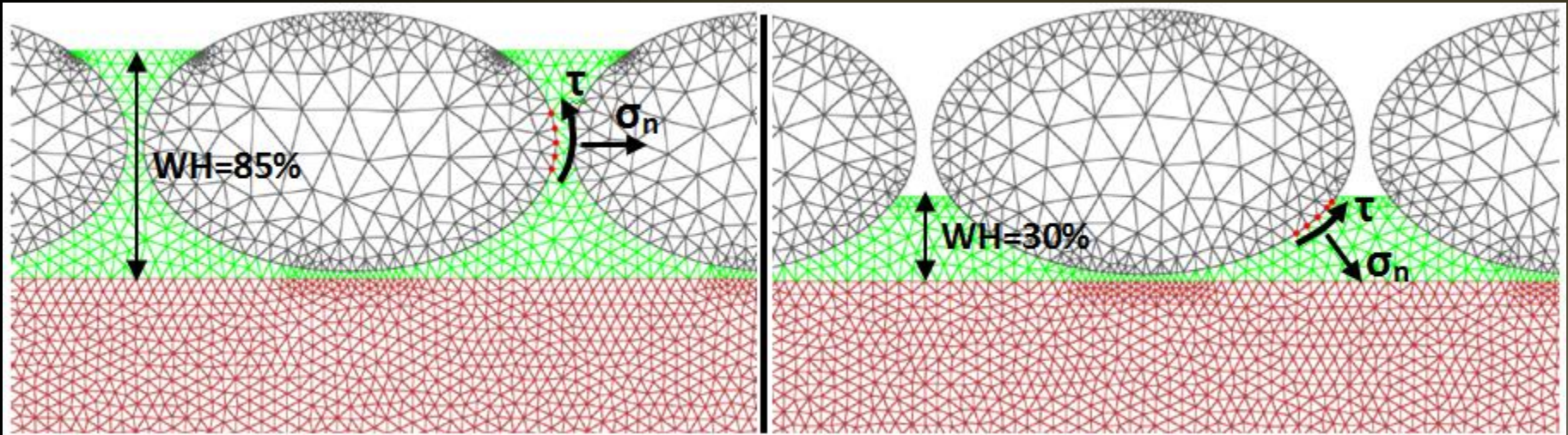
- Primary & secondary compression stresses
  - » Use stress in embedment damage model





# Adhesive Failure

- Area of interest
  - » Interface maximum normal and shear stresses
  - » Use stresses in adhesive damage model

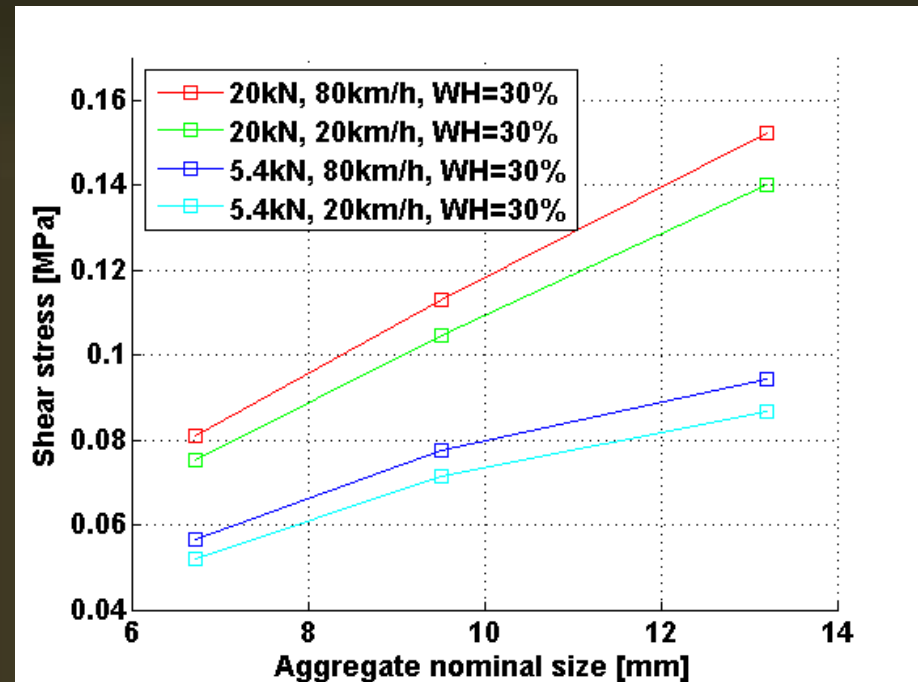
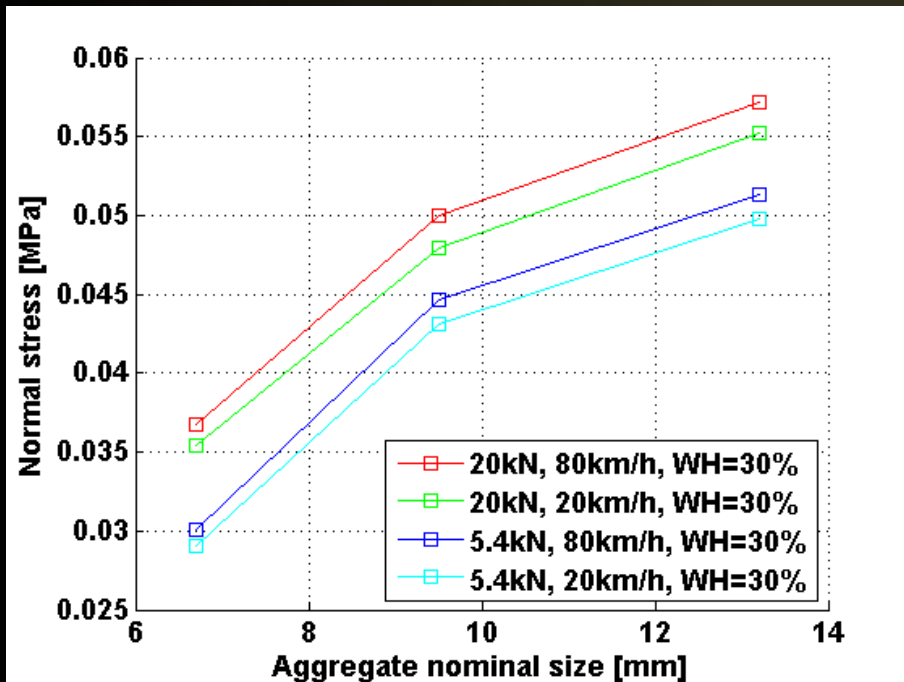


# Adhesive Failure

- Variations considered
  - » 3 x Single seal structures
  - » 4 x Binder types
  - » 2 x Aggregate wetted height (WH)
  - » 2 x wheel sizes
  - » 2 x speed
  - » 1 x fog spray
  - » 3 x base elastic modulus
  - » 3 x construction embedment
  - » 6 x Tyre inflation pressure (TiP)
  - » 3 x Radius of curvature (RoC)

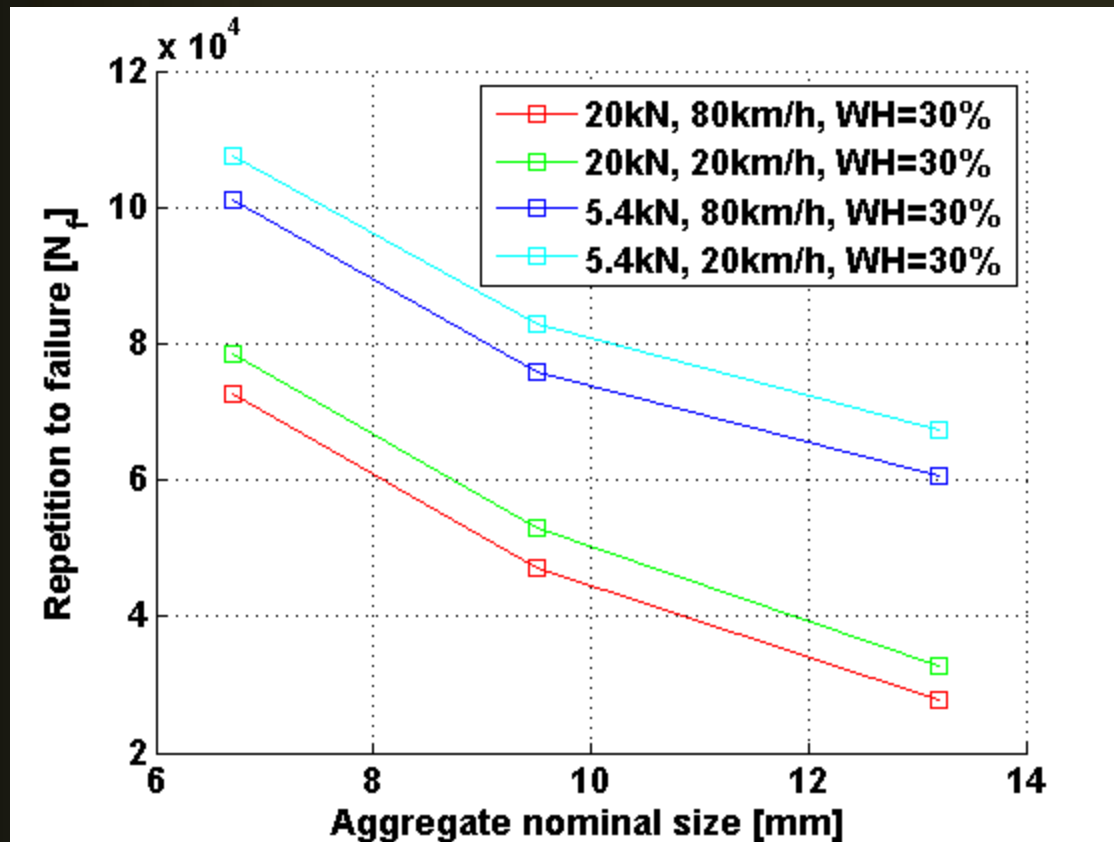
# Adhesive Failure

- Variables: Seal size, traffic & speed



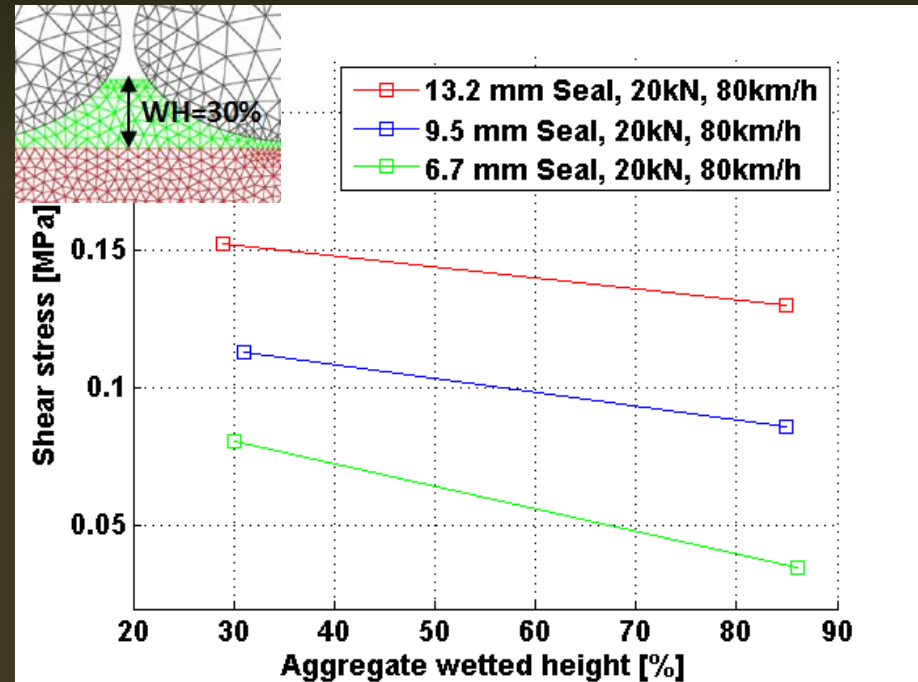
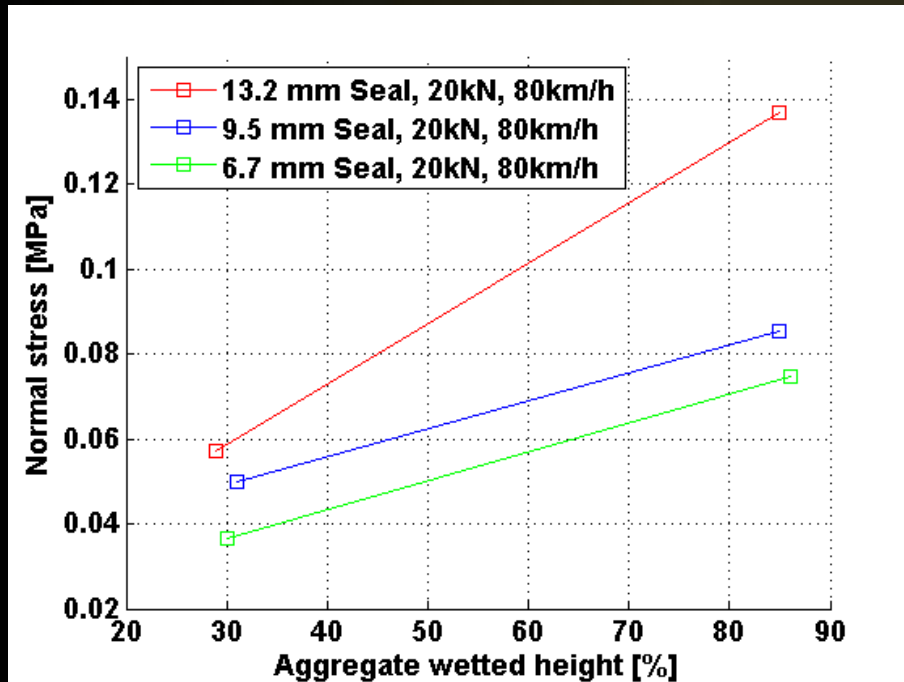
# Adhesive Failure

- Variables: Seal size, traffic & speed



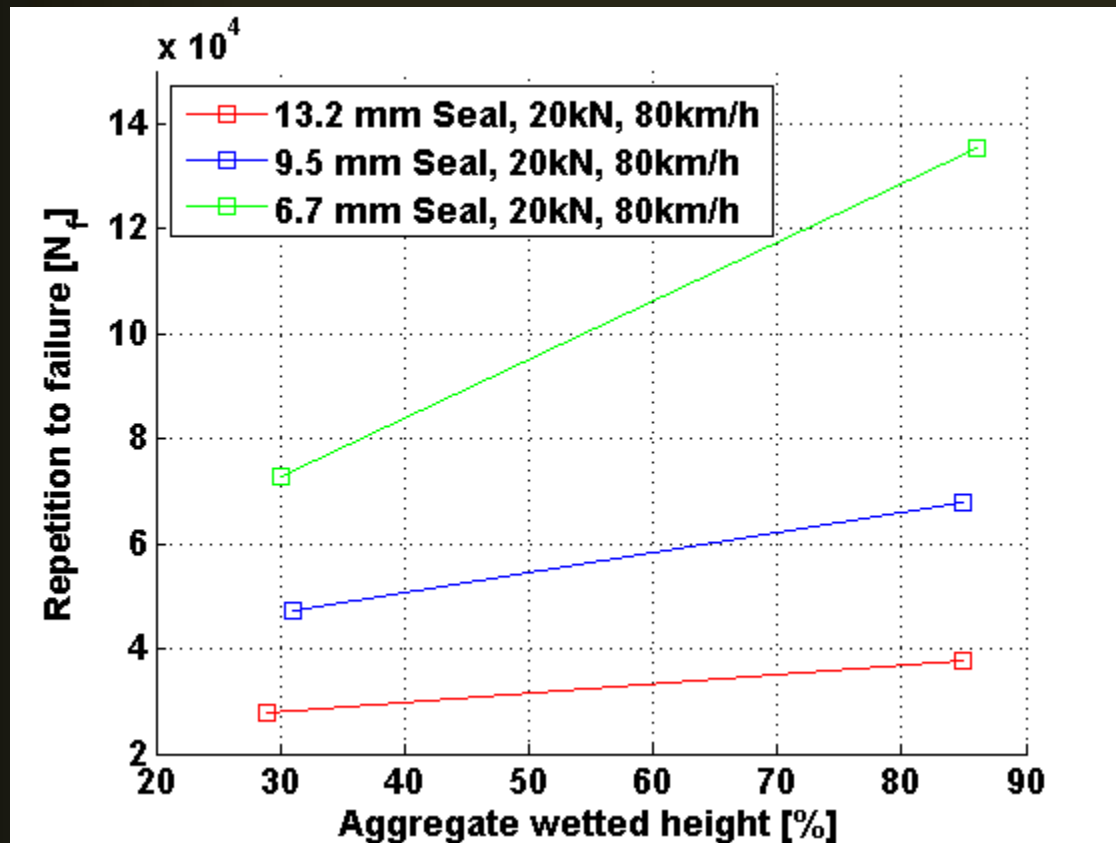
# Adhesive Failure

- Variables: Seal size & wetted height (WH)



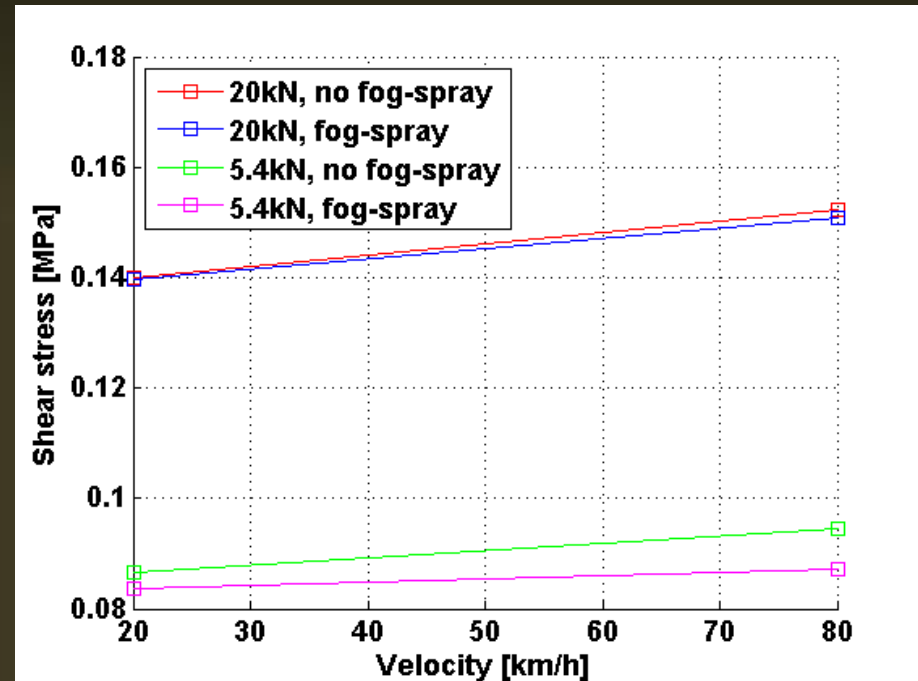
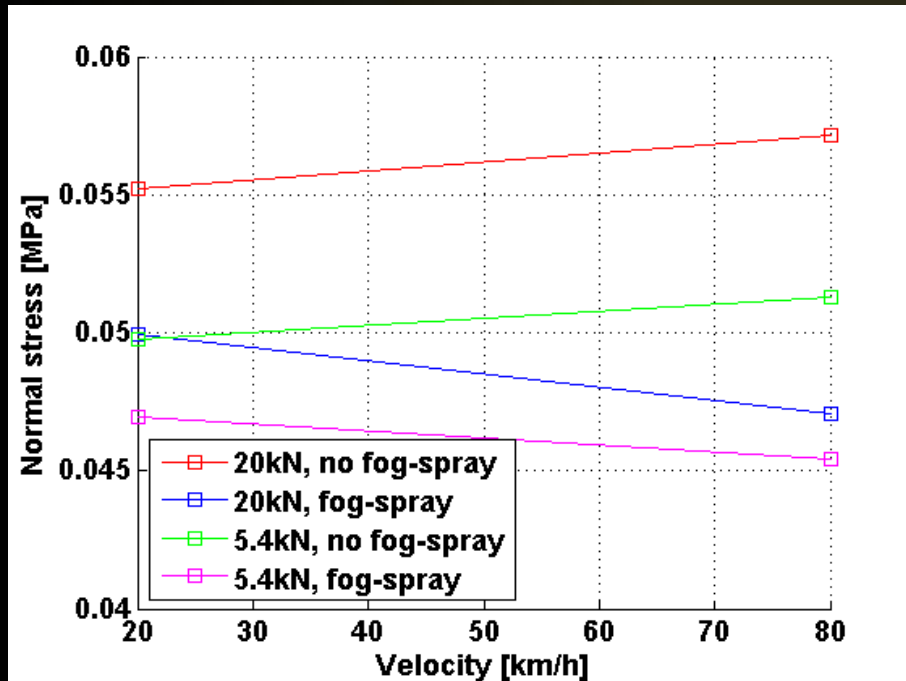
# Adhesive Failure

- Variables: Seal size & wetted height (WH)



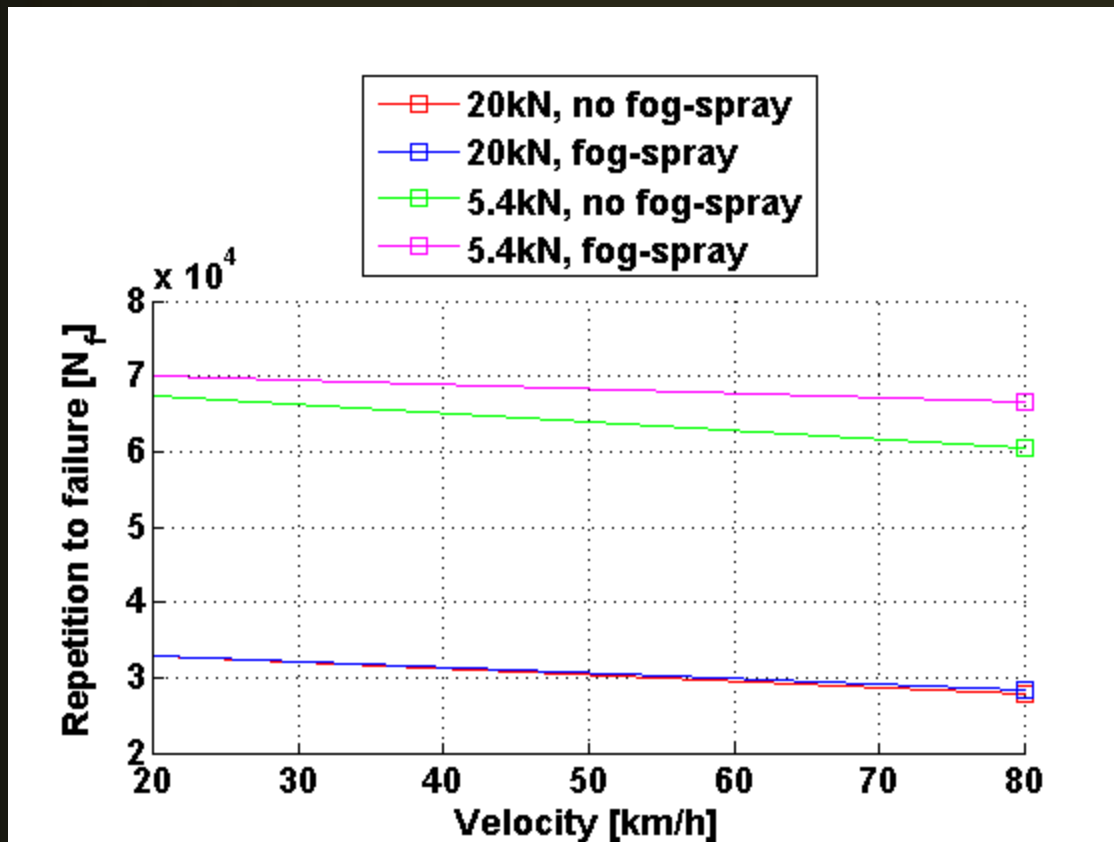
# Adhesive Failure

- Variable: Fog spray (KRS-60)



# Adhesive Failure

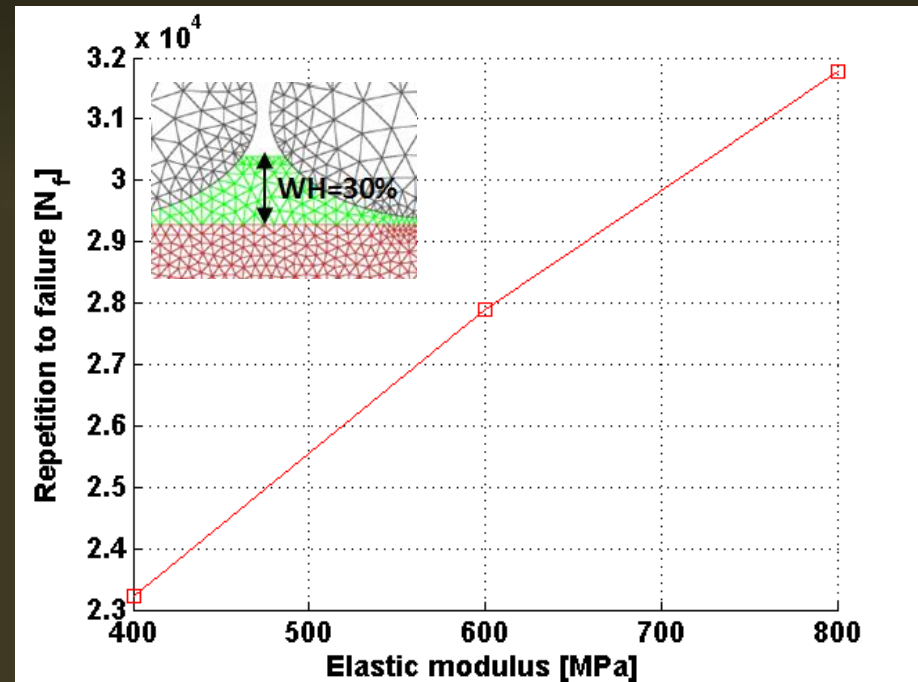
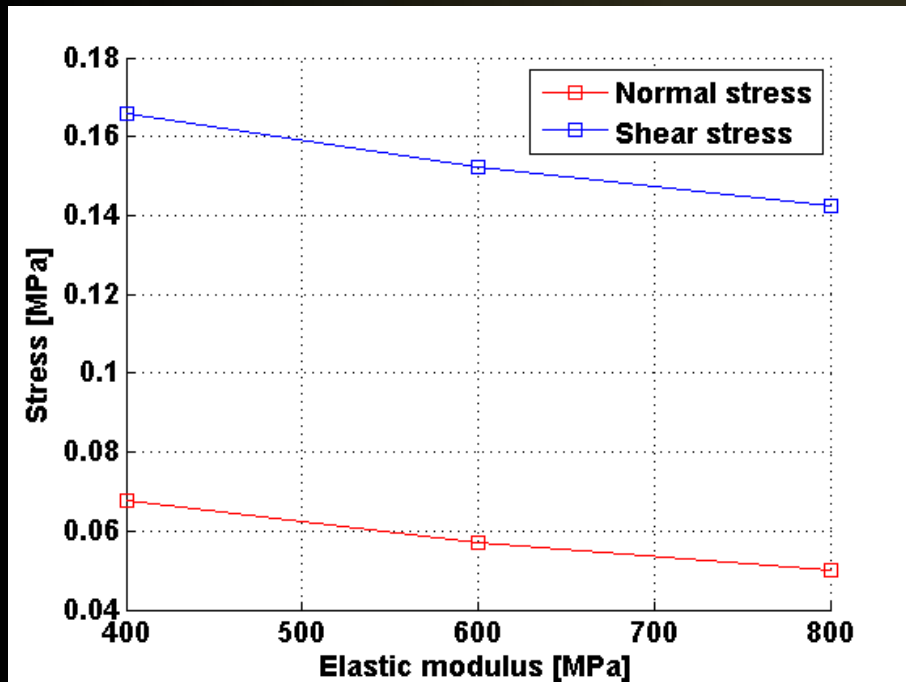
- Variable: Fog spray (KRS-60)





# Adhesive Failure

- Variable: Base elastic modulus



# Closure

- Research integration
  - » Material characterization feeds into FEM model
  - »  $N_f$  a FEM model output
  - » Similar approach for cohesive failure
- Way forward
  - » Calibrate FEM model  $N_f$  with empirical data
  - » Construct design trends

Thank you