Finite Element Modelling of Bitumen Seals

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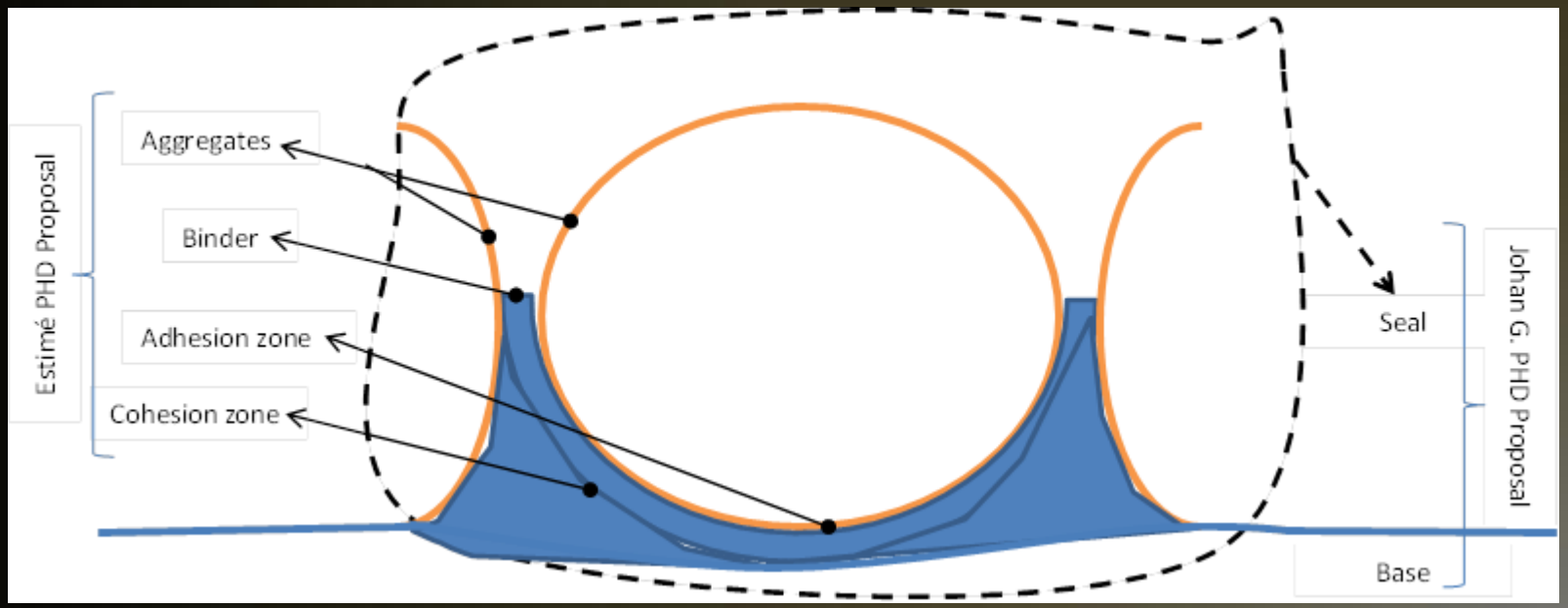
- FEM Model Structure
- FEM Model Components
- Failure Mechanisms
  - Embedment
  - Adhesive failure
  - Cohesive failure
- Summary

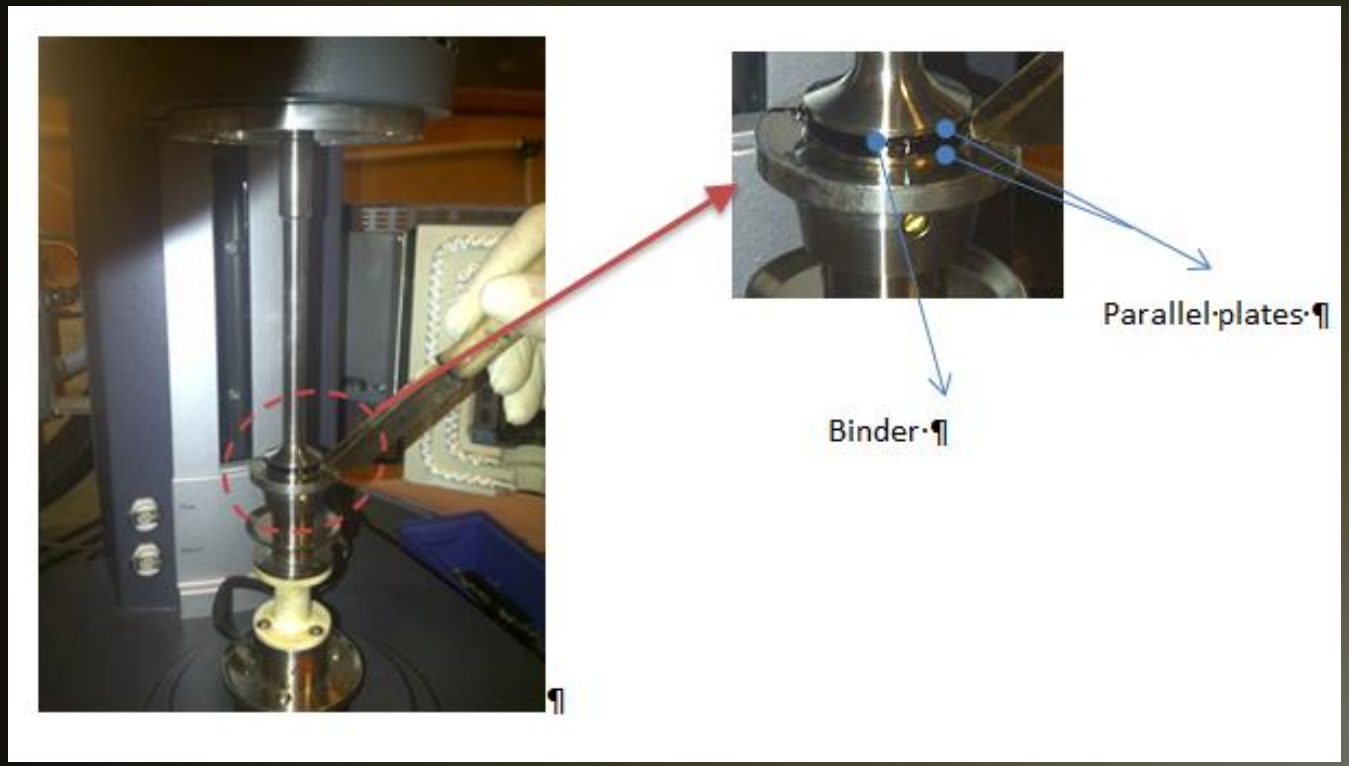
Material Characterization

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



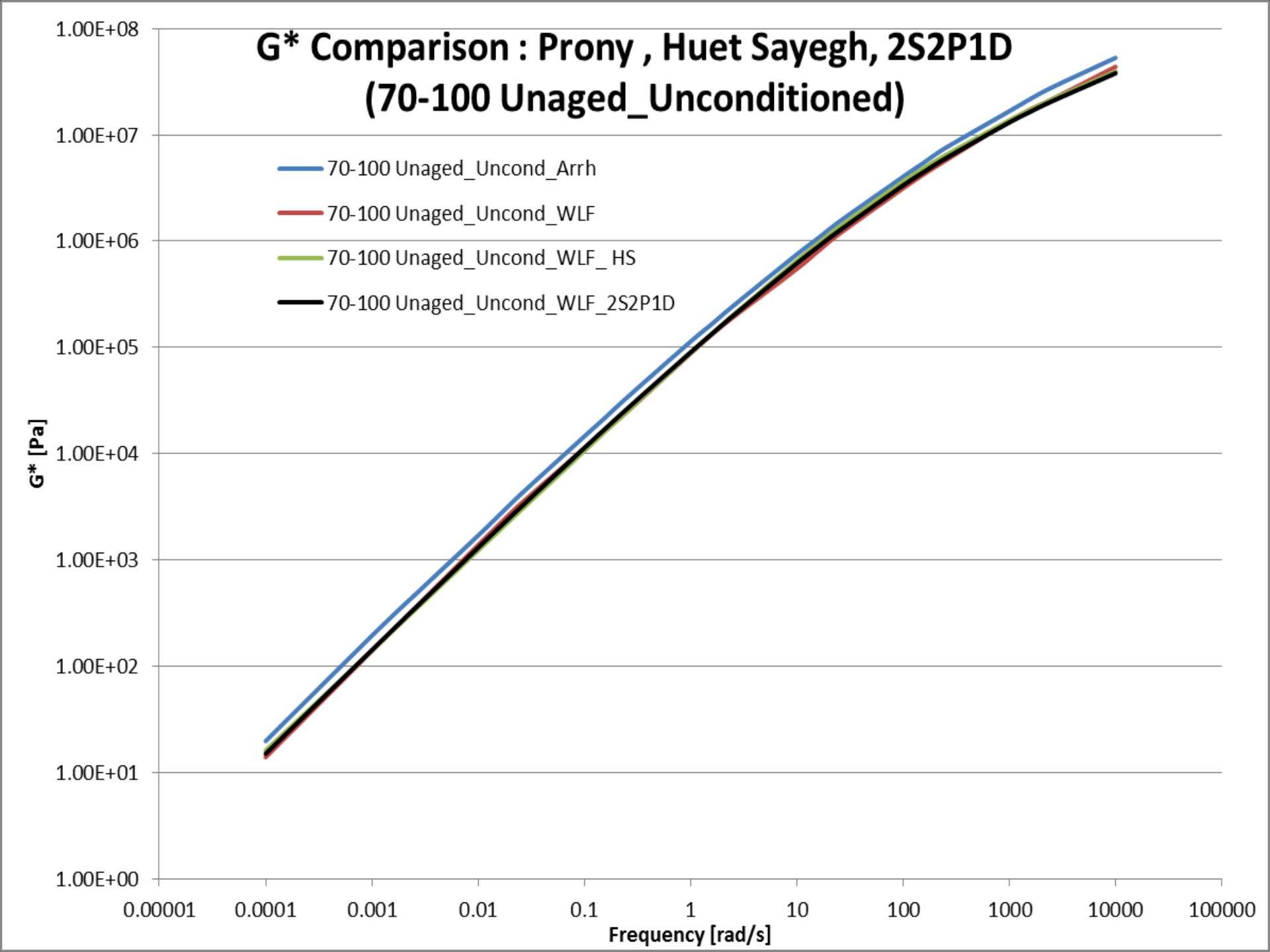
Material Characterization

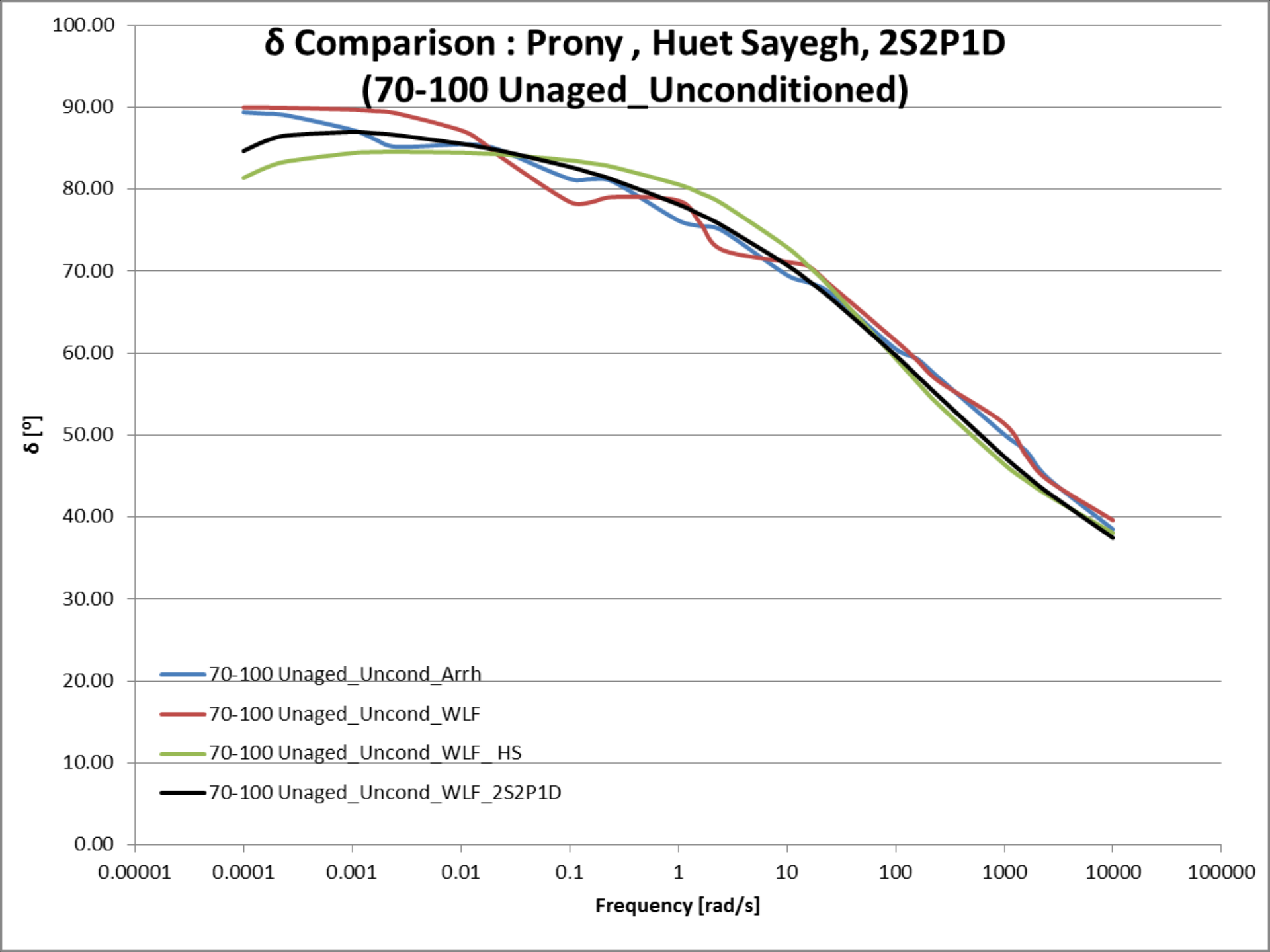
- Binder response (DSR parallel plates)



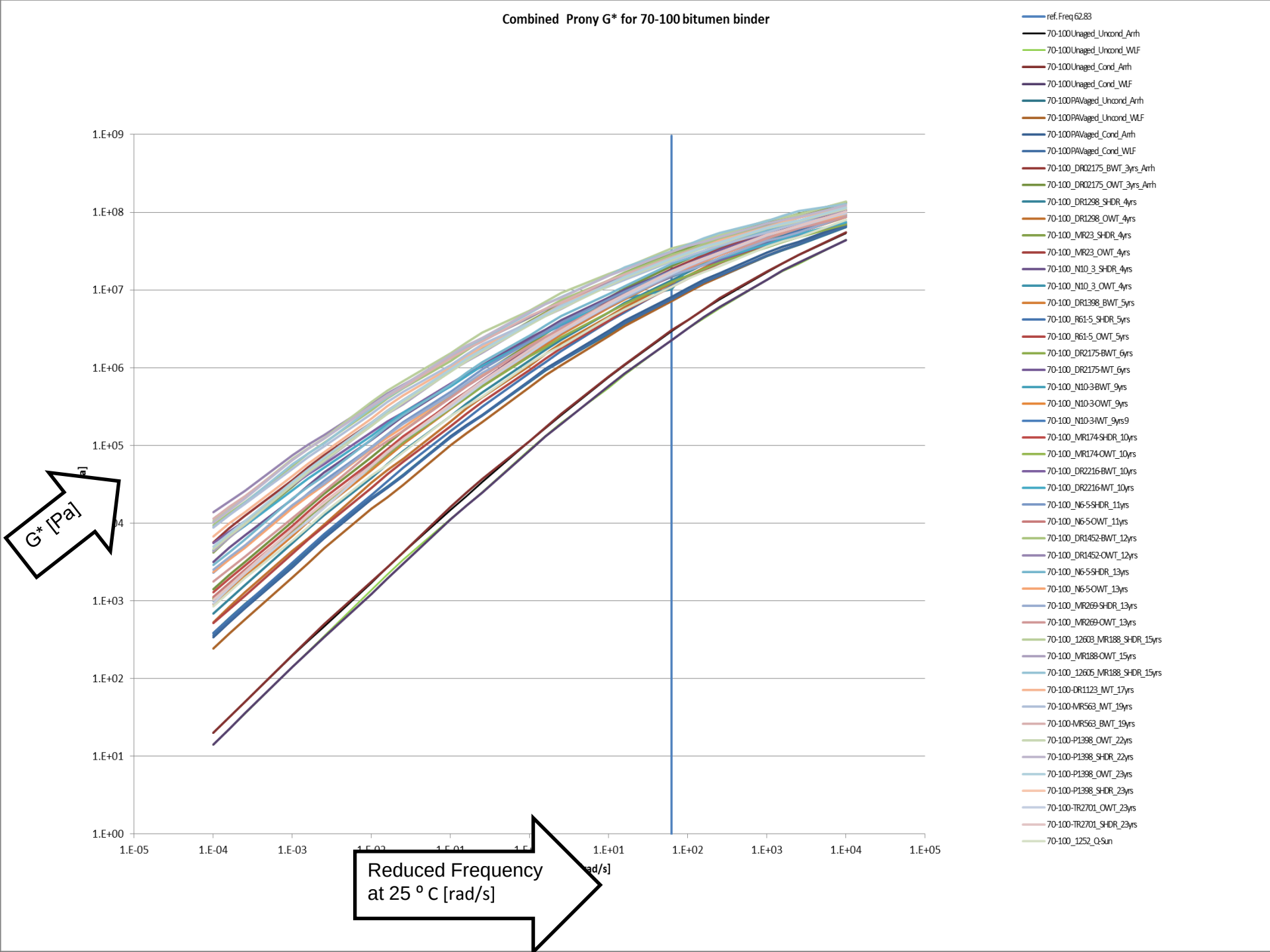
Material Characterization

- Binder response
  - » G*
  - » δ


G* Comparison : Prony , Huet Sayegh, 2S2P1D
(70-100 Unaged_Unconditioned)
70-100 Unaged_Uncond_Arrh
70-100 Unaged_Uncond_WLF
70-100 Unaged_Uncond_WLF_ HS
70-100 Unaged_Uncond_WLF_2S2P1D
G* [Pa]
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
0.00001
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
100000
Frequency [rad/s]


δ Comparison : Prony , Huet Sayegh, 2S2P1D
(70-100 Unaged_Unconditioned)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
δ [°]
0.00001
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
100000
Frequency [rad/s]
70-100 Unaged_Uncond_Arrh
70-100 Unaged_Uncond_WLF
70-100 Unaged_Uncond_WLF_ HS
70-100 Unaged_Uncond_WLF_2S2P1D

Combined Prony G* for 70-100 bitumen binder



Material Characterization

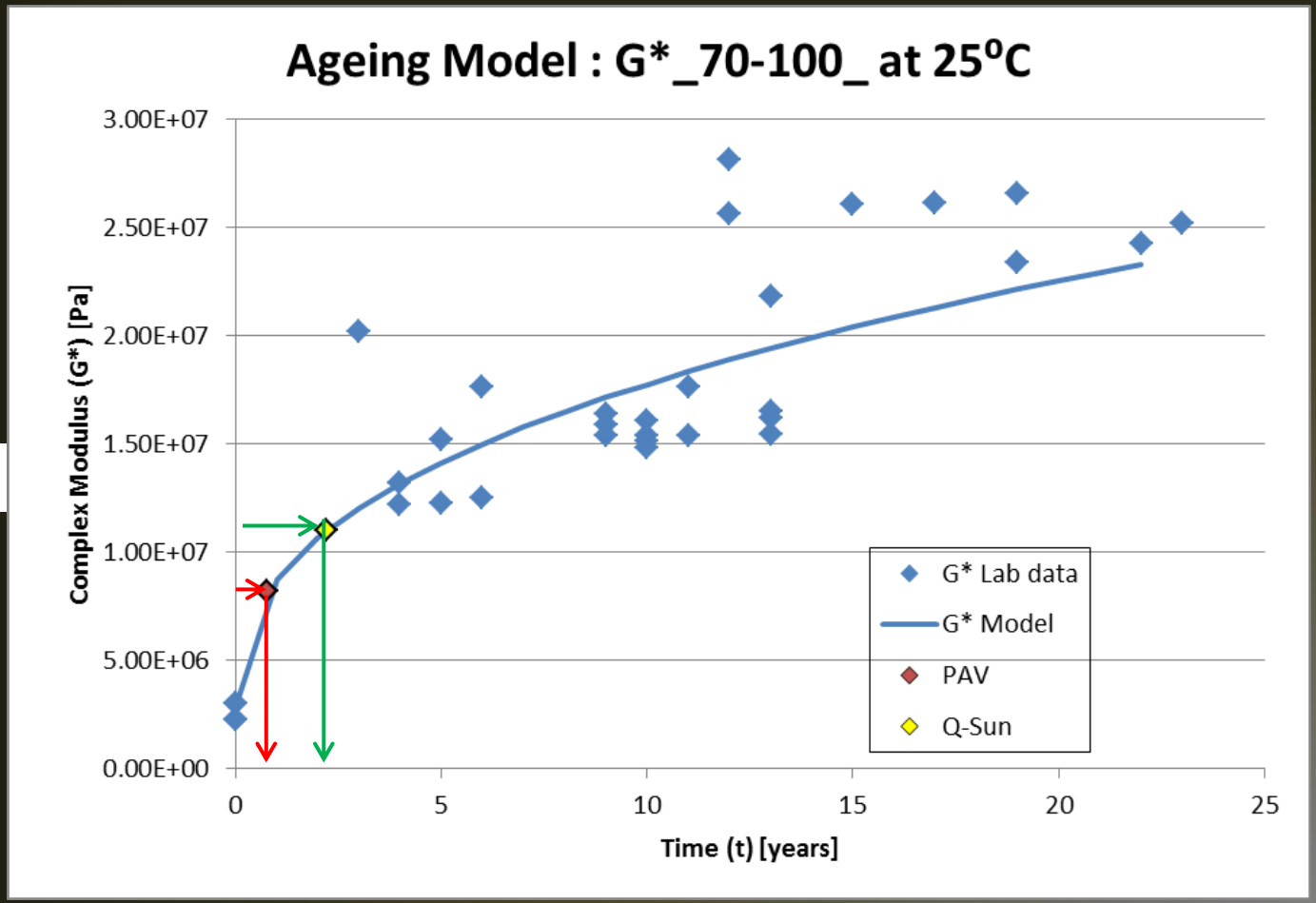
- Binder response - G* aging

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

a	b	c	R^2
2.82E+06	5.93E+06	0.40127	0.76

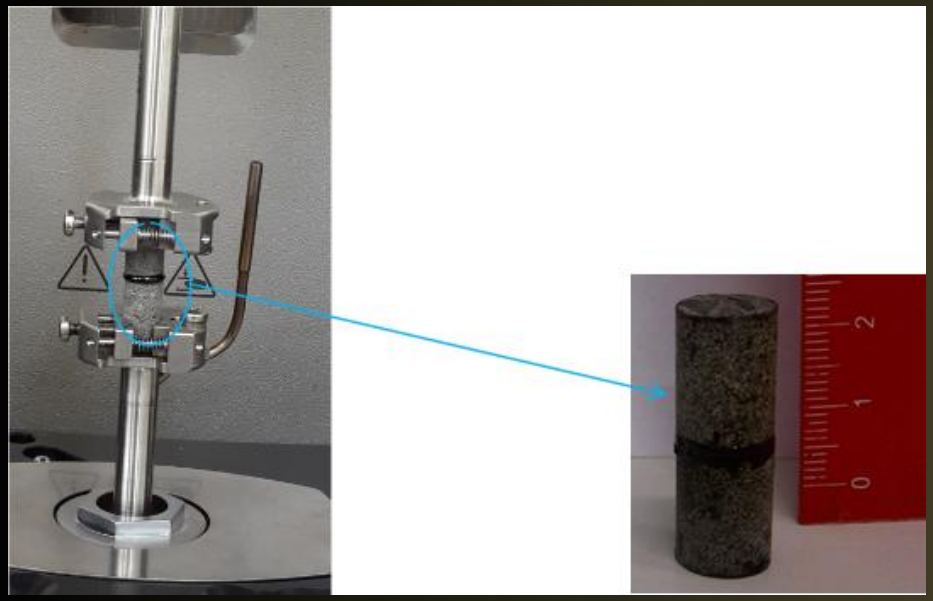
PAV Simulating = ±1 year

Q-sun Simulating = ±2 years



Material Characterization

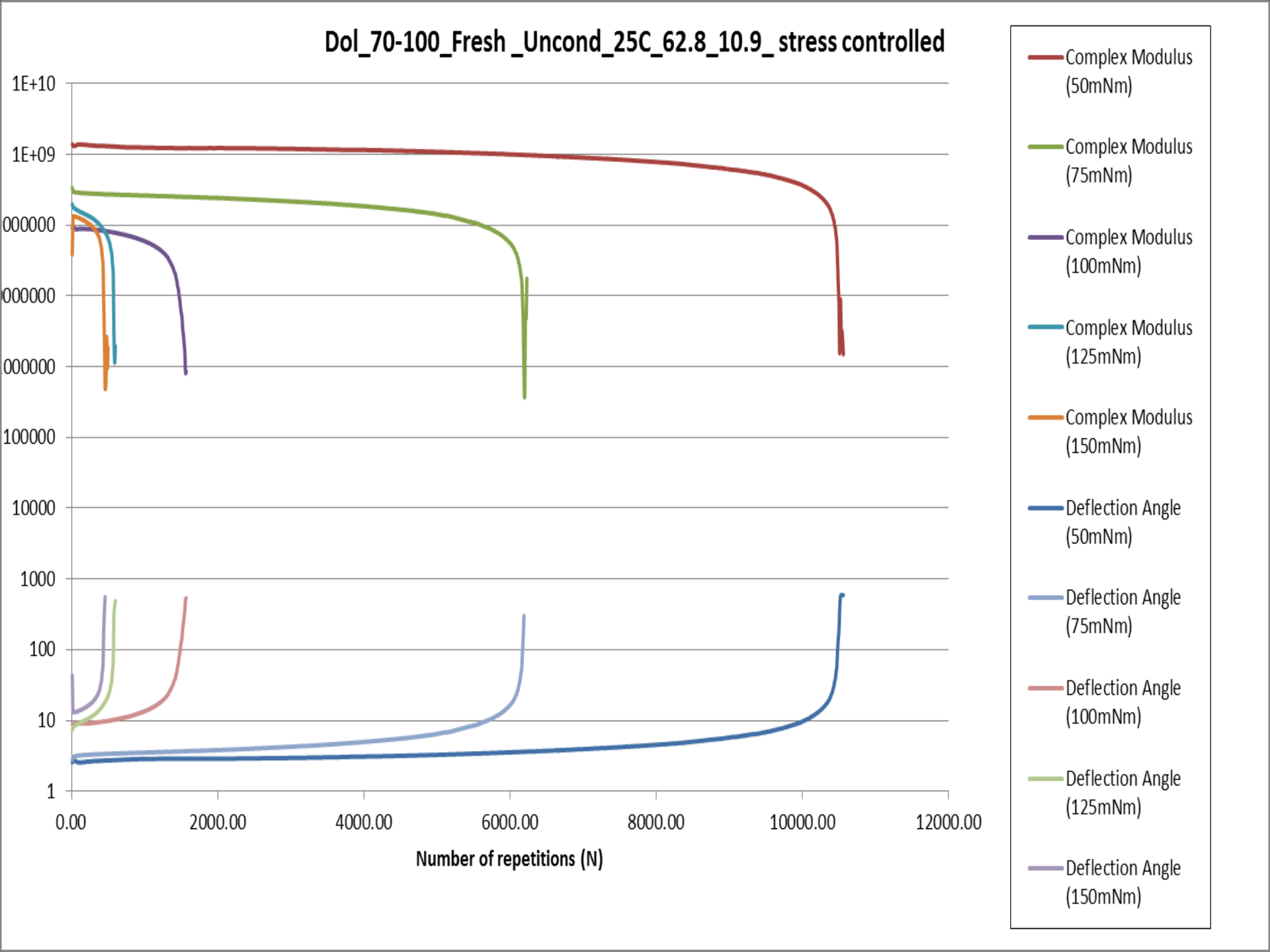
- Adhesion fatigue

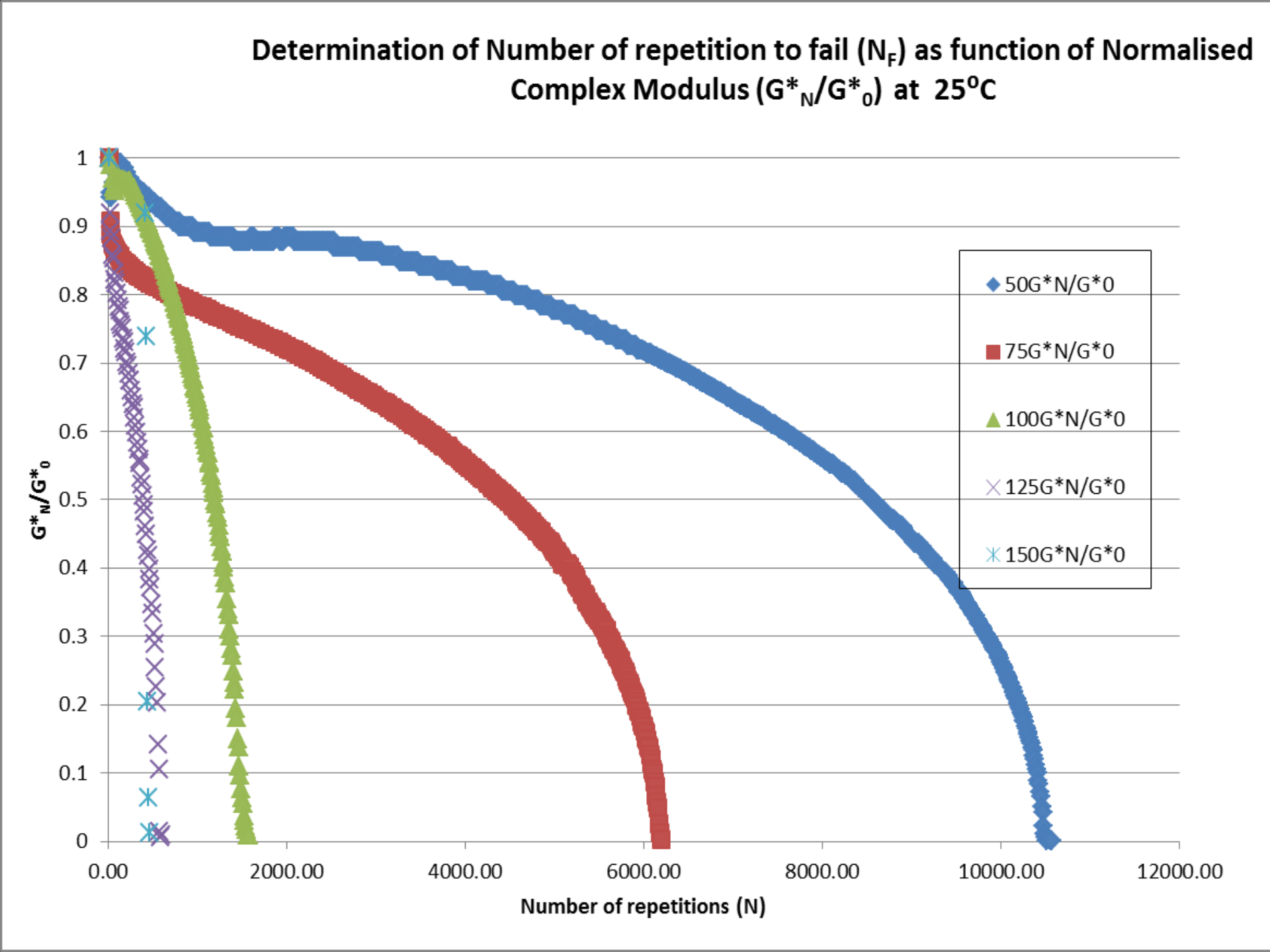


- Cohesion fatigue

Material Characterization

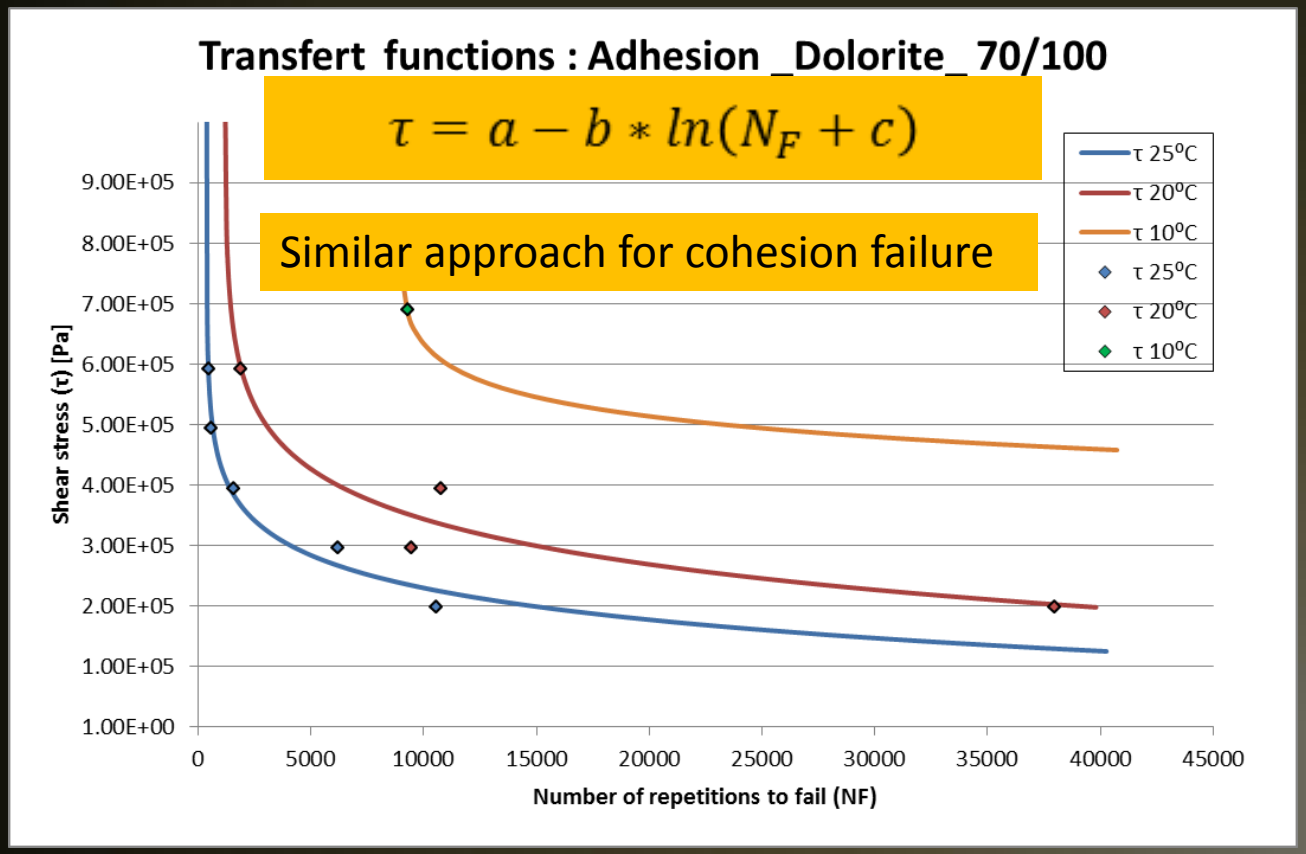
- Adhesion fatigue
  - Transfer Function (N_F)
    - End life fatigue
      - » Stress controlled
      - » Normalization of G* to G^*_n
      - » N_f as a function of G^*_n
  - Memory-less principle :
    - fatigue during life period: rate of damage against damage


Dol_70-100_Fresh _Uncond_25C_62.8_10.9_ stress controlled
1E+10
1E+09
000000
000000
000000
100000
10000
1000
100
10
1
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
Number of repetitions (N)
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
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
G^*_N/G^*_0
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
Number of repetitions (N)
50G*N/G*0
75G*N/G*0
100G*N/G*0
125G*N/G*0
150G*N/G*0

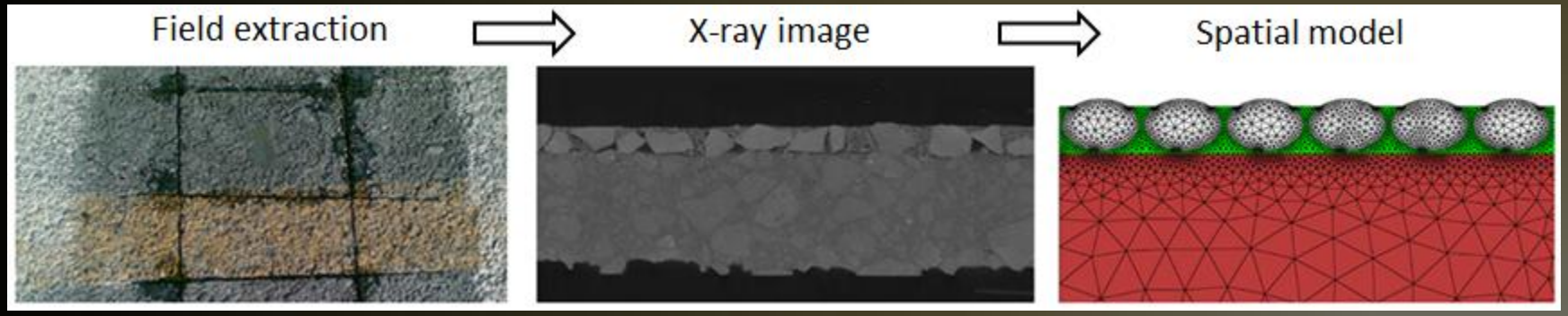
Material Characterization

- Adhesion fatigue transfer function

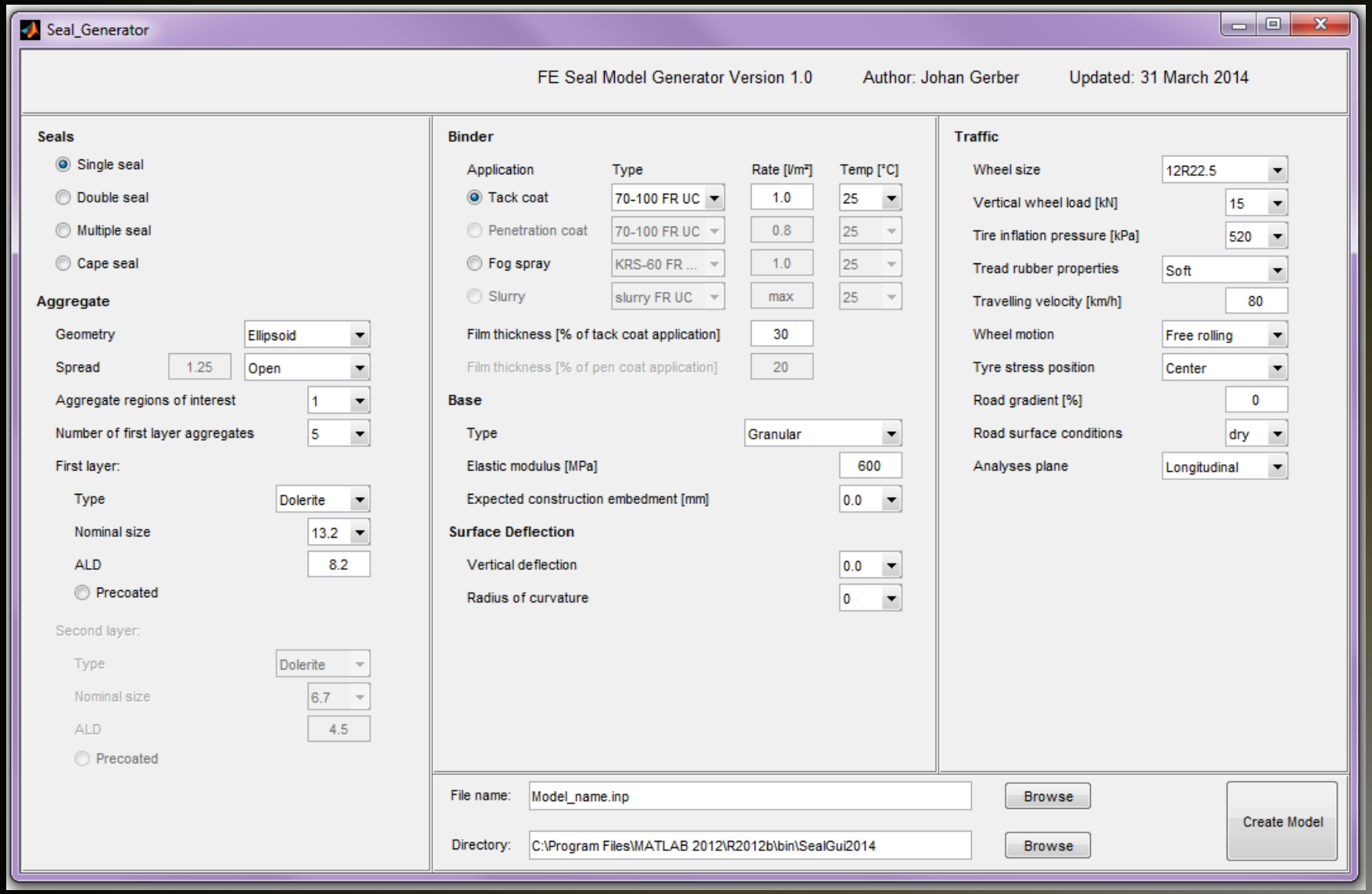


FEM Model Structure

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



FEM Model Components

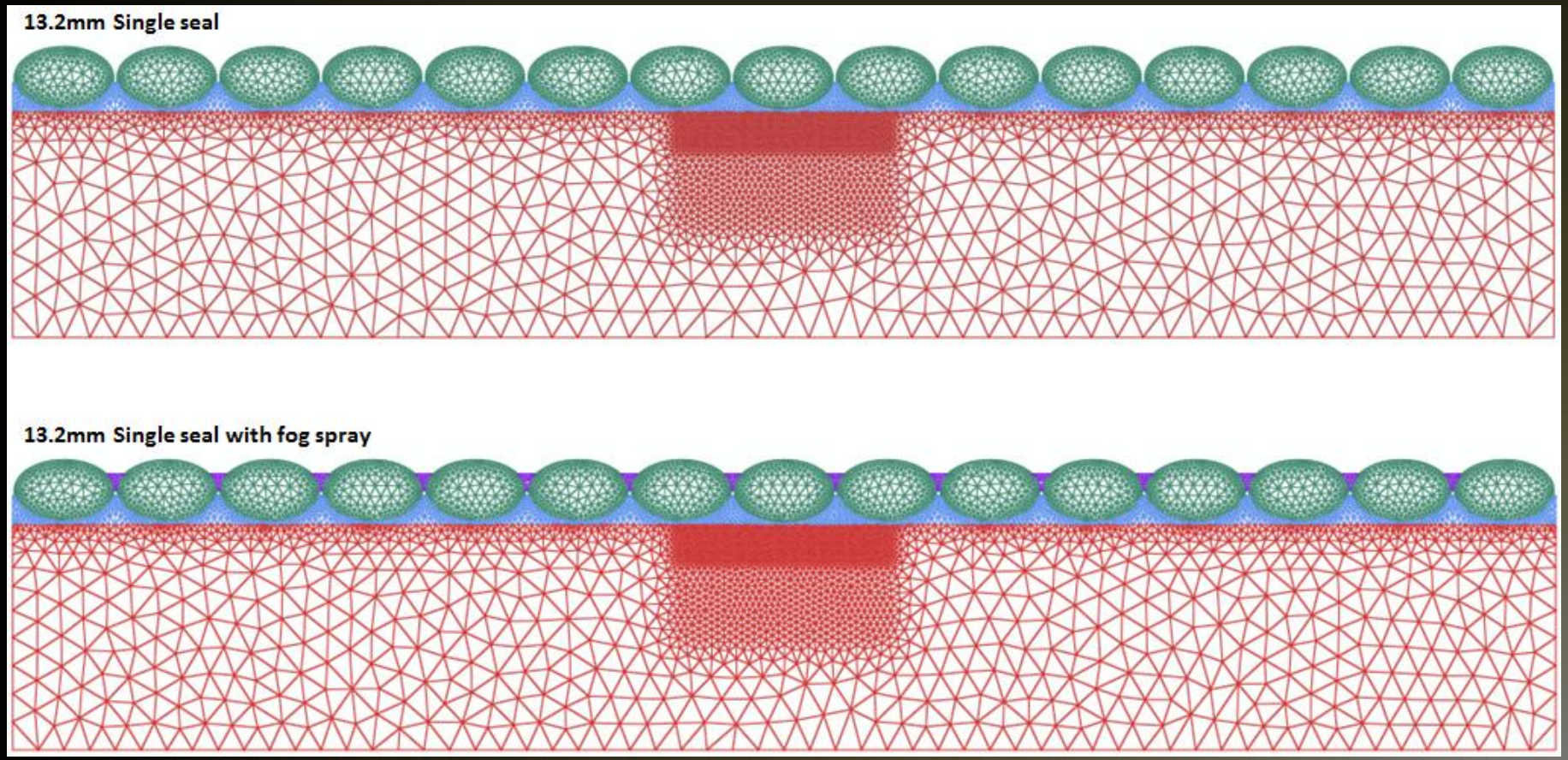


FEM Model Components

- 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)

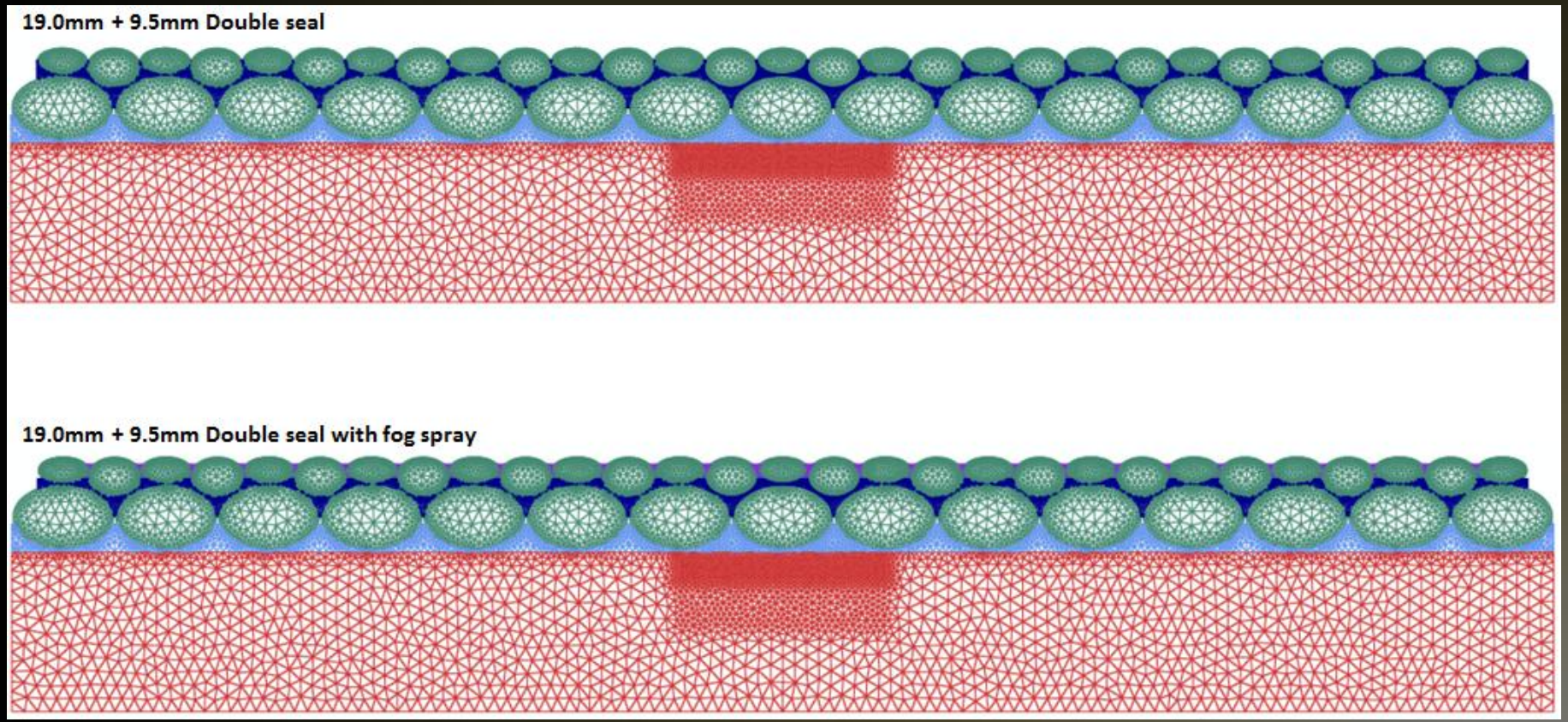
FEM Model Components

- Seal structure - Single Seal



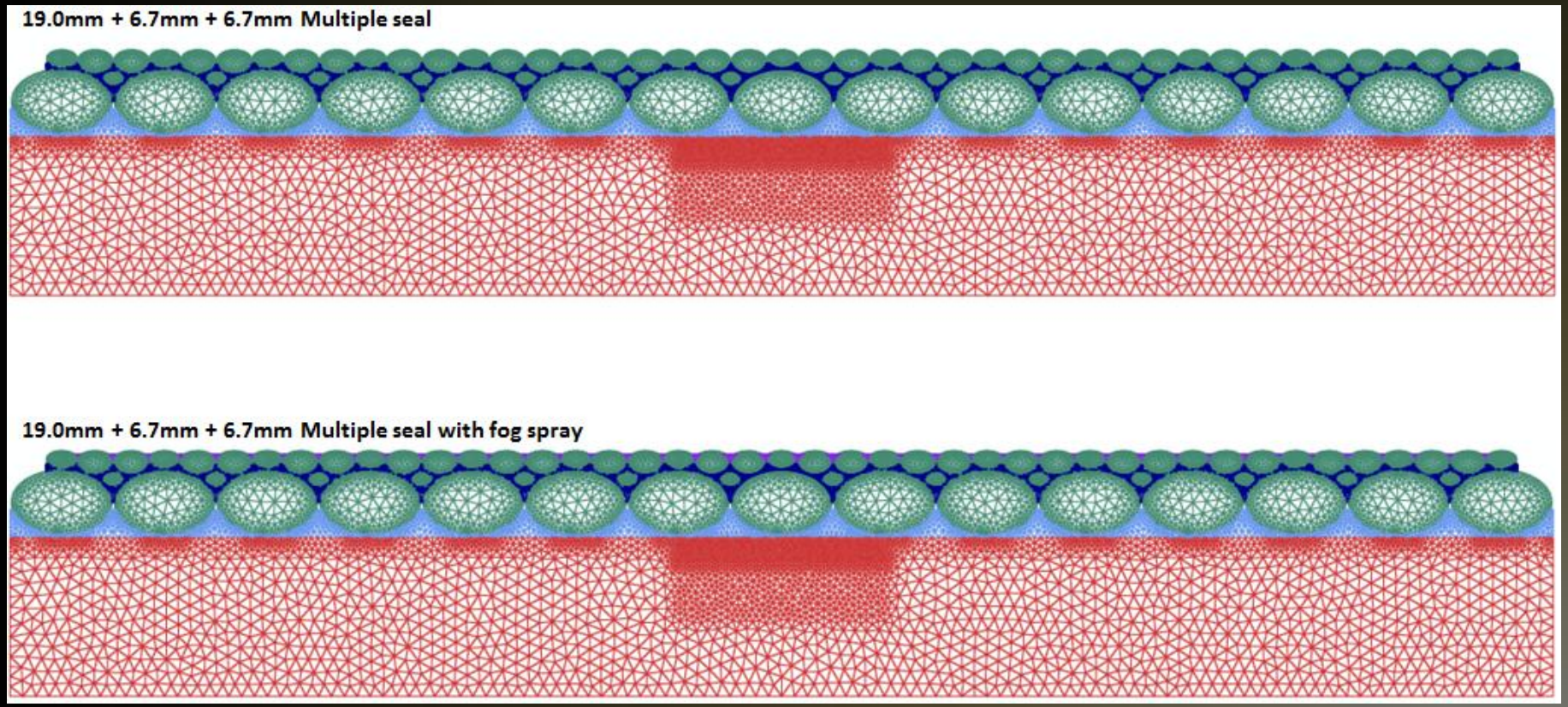
FEM Model Components

- Seal structure - Double Seal



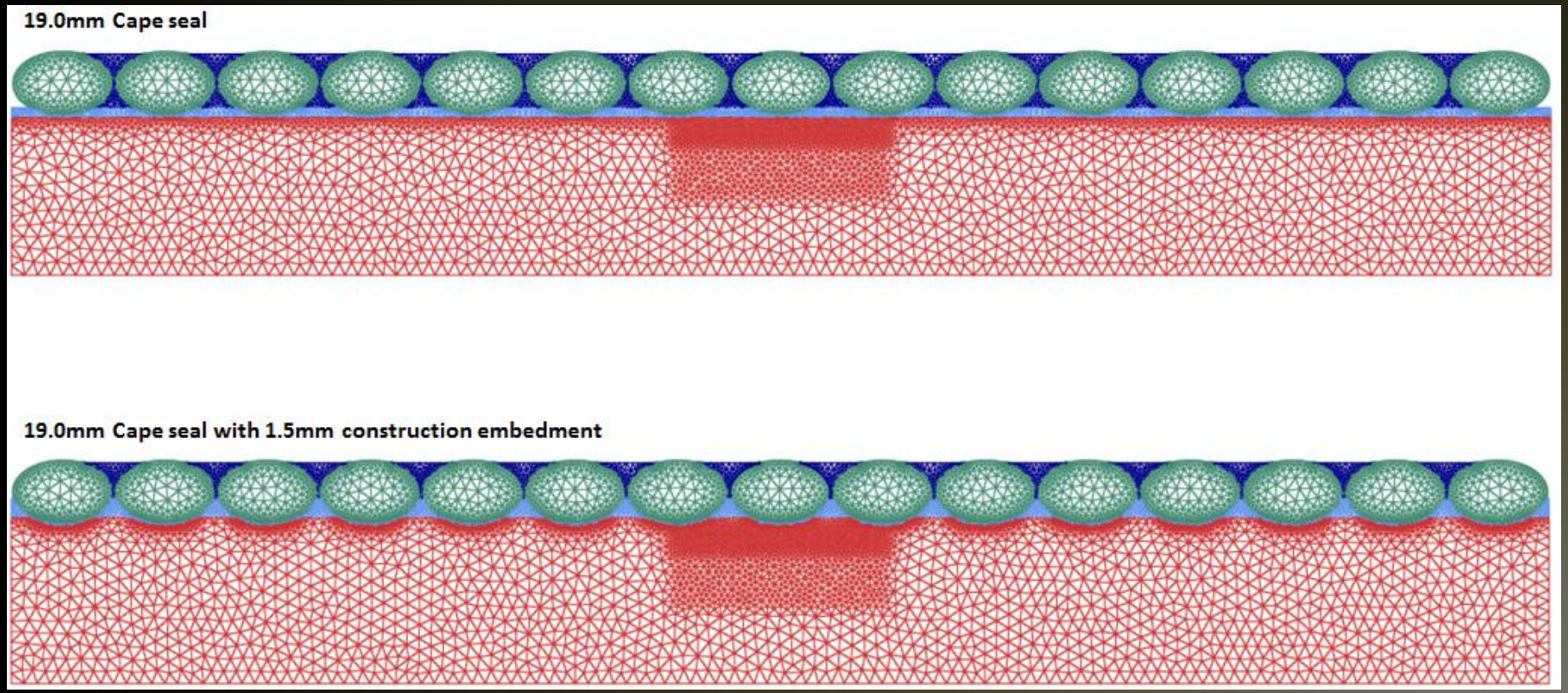
FEM Model Components

- Seal structure - Multiple Seal

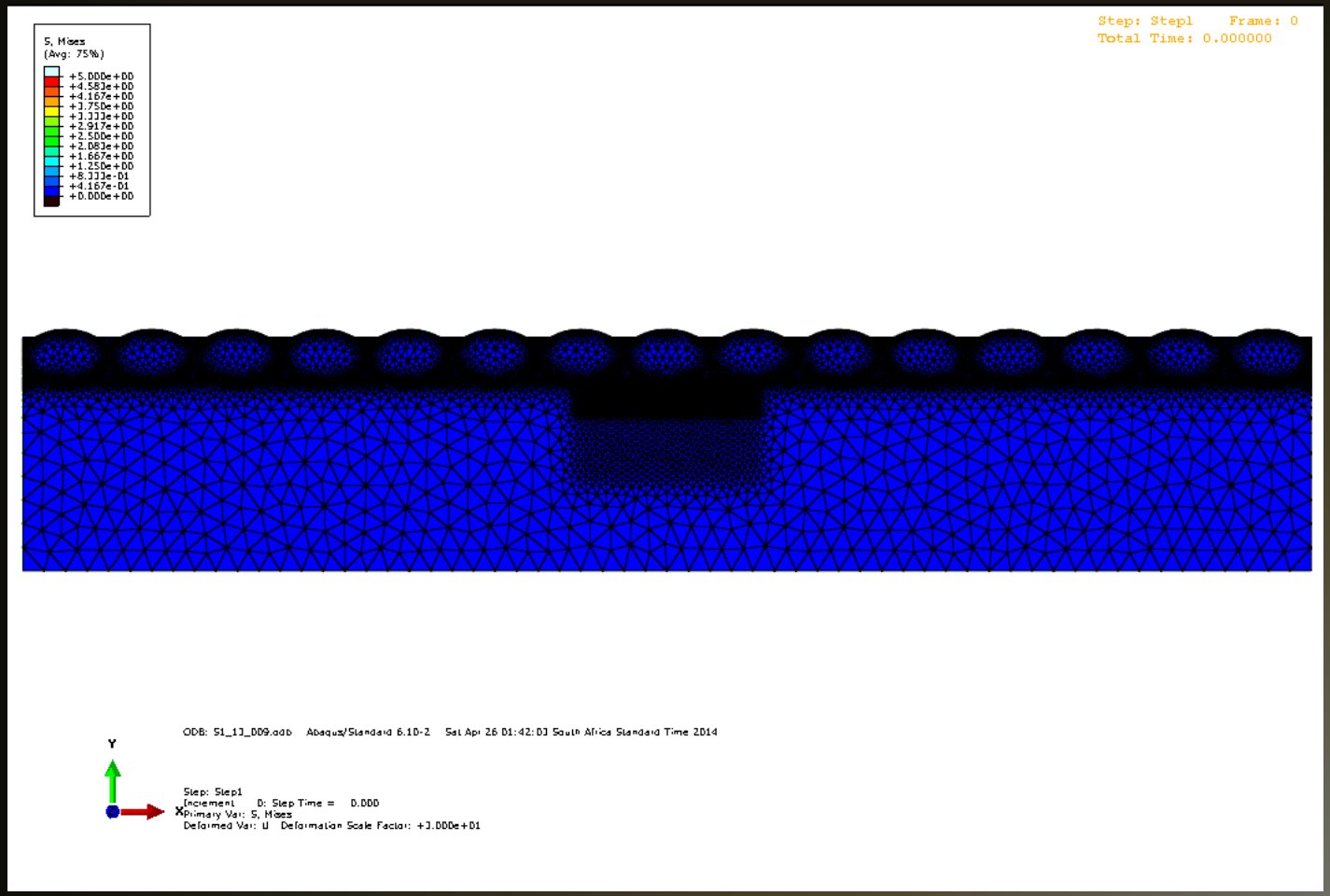


FEM Model Components

- Seal structure - Cape Seal



Failure Mechanisms

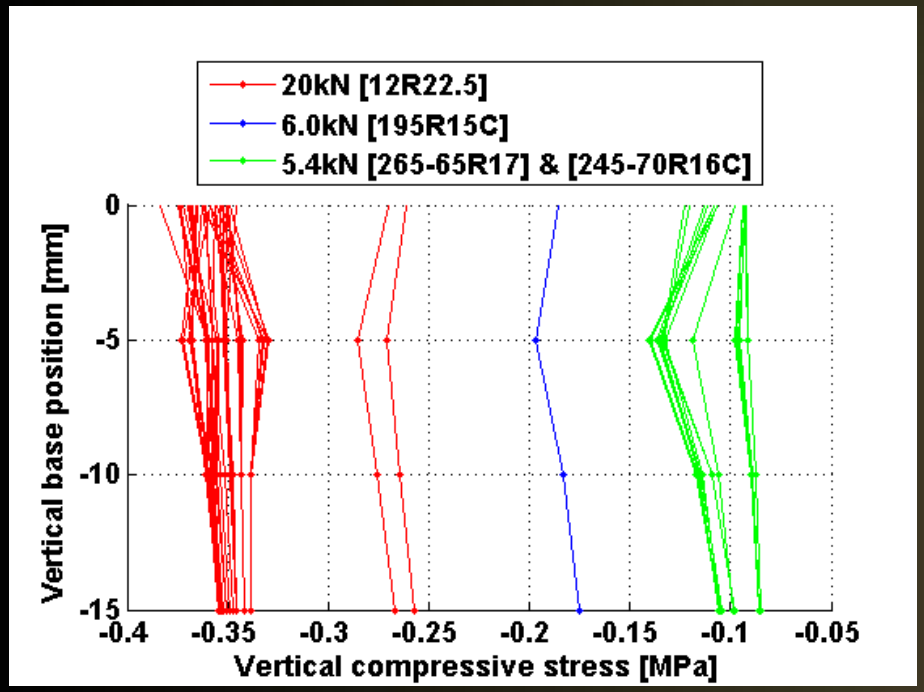


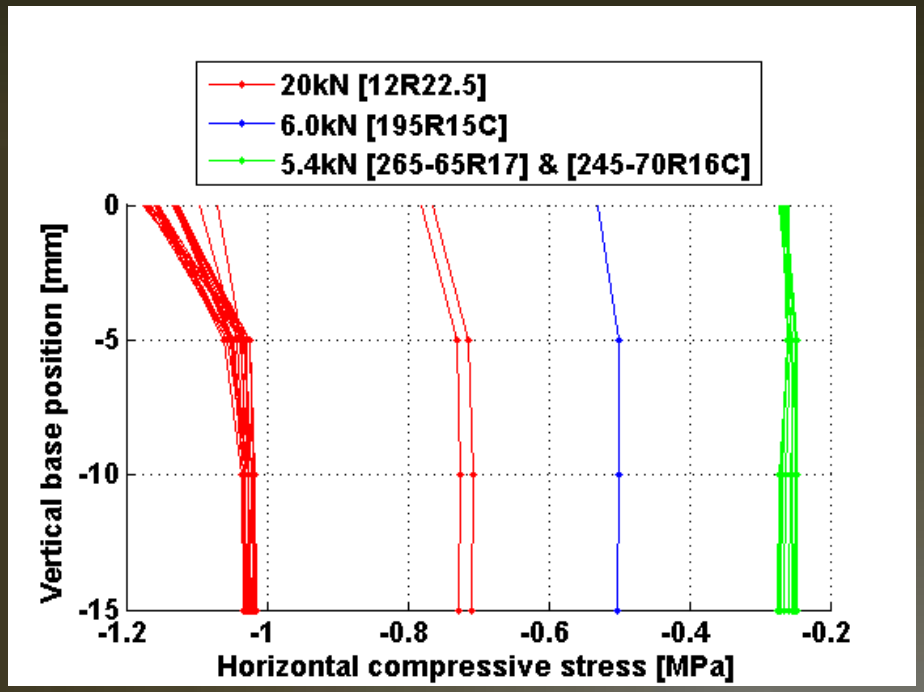
Failure Mechanisms

- 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

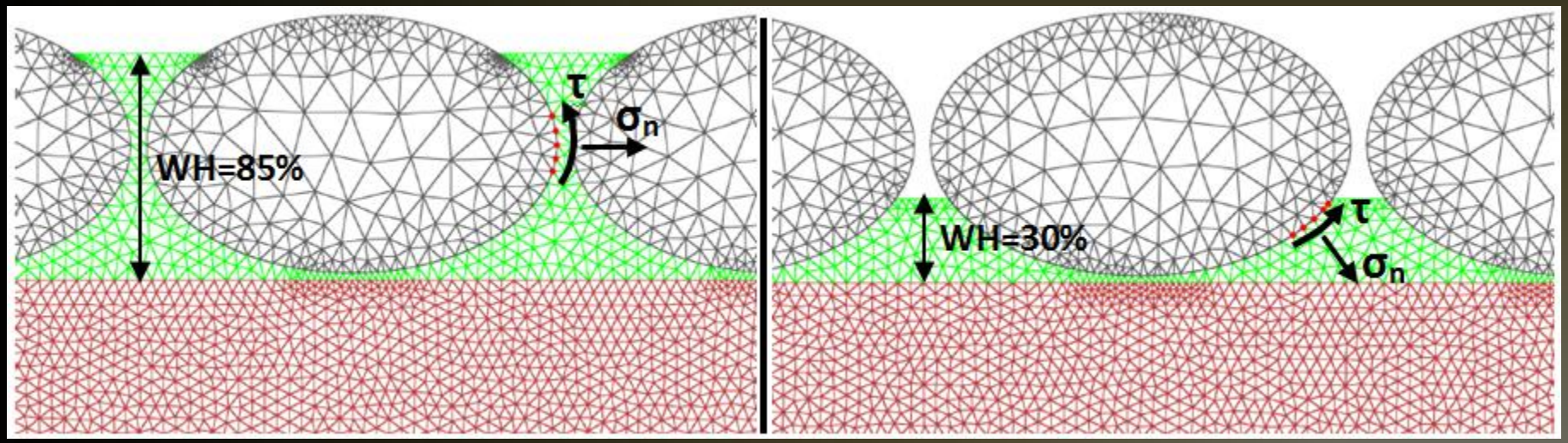
- Primary & secondary compression stresses
  - » Use stress in embedment damage model





Adhesive Failure

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

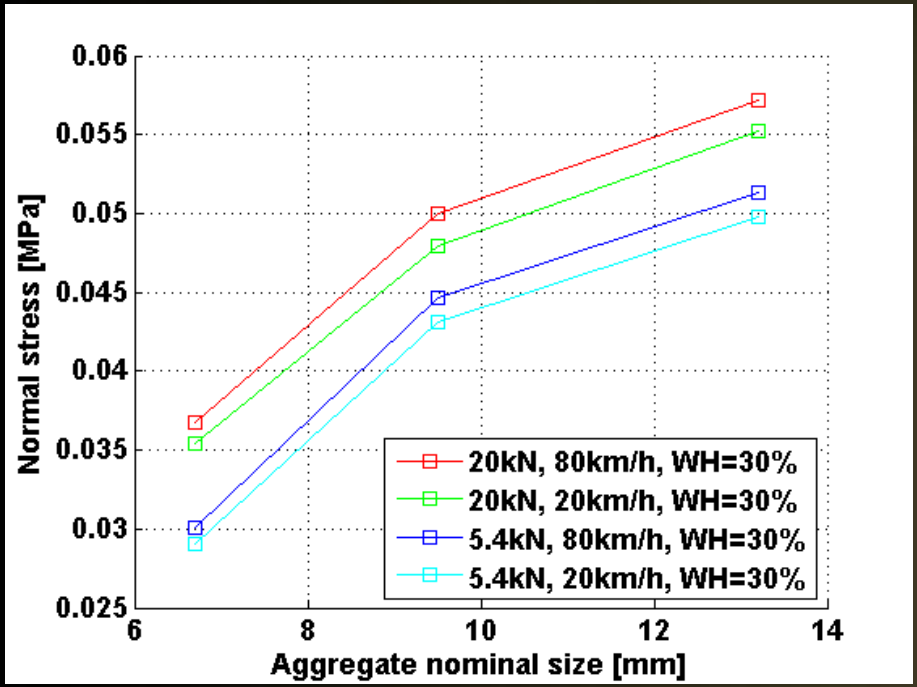


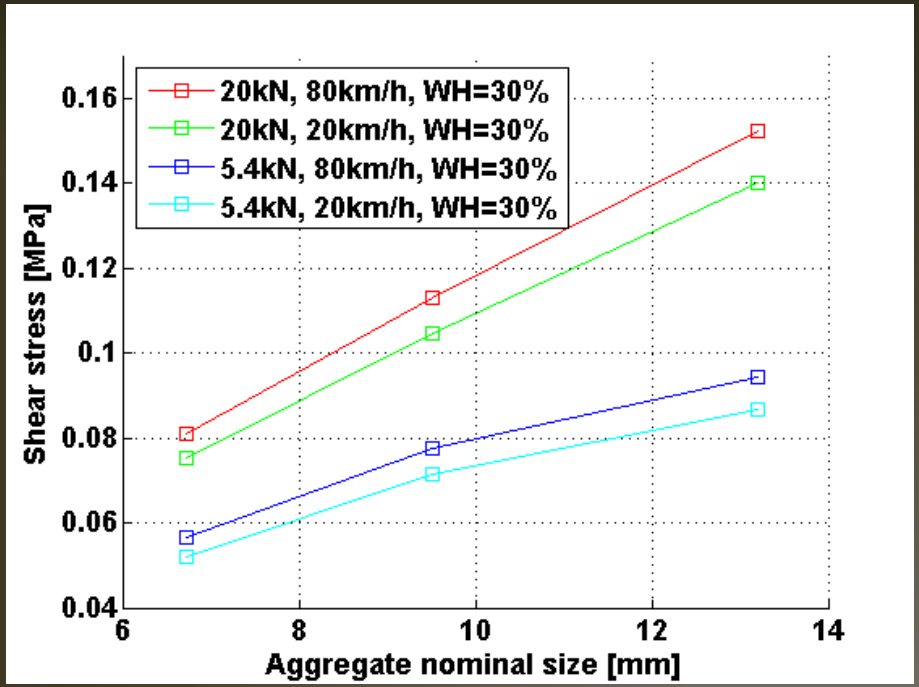
Adhesive Failure

- Variations considered
  - » 3 x Singe 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

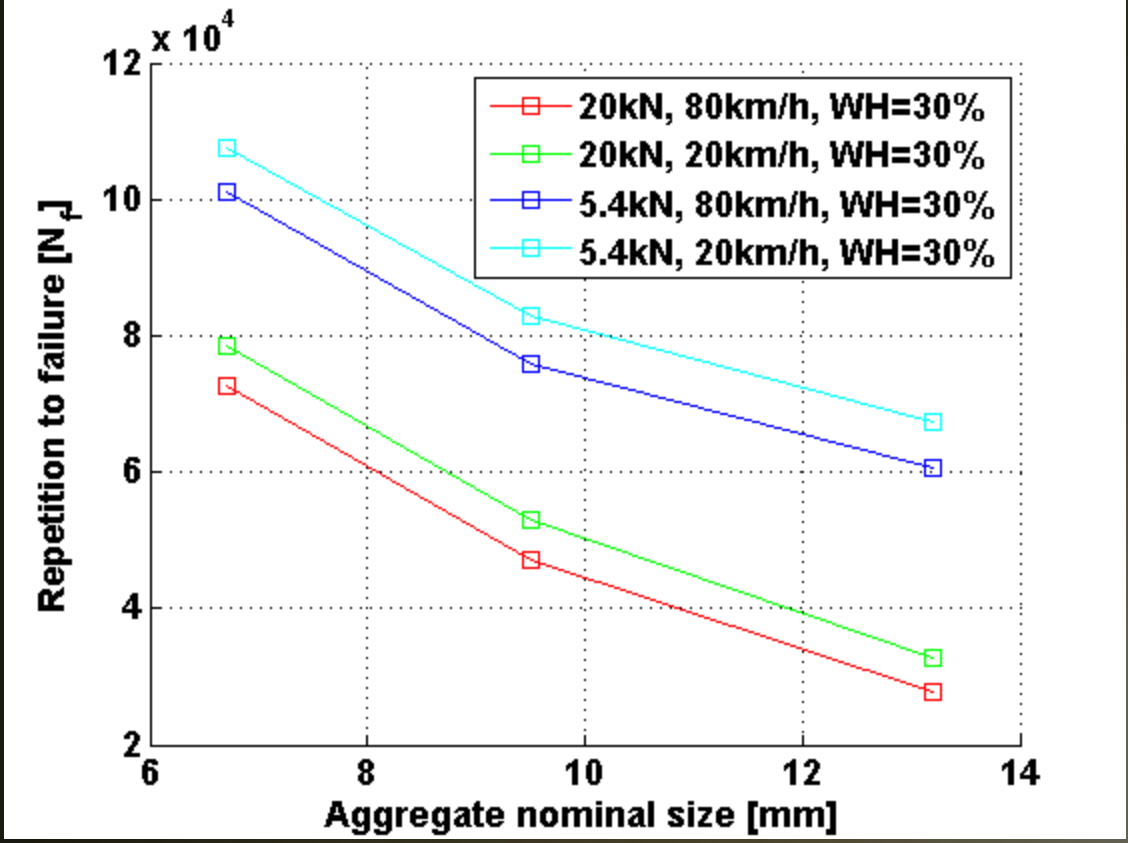
- Variables: Seal size, traffic & speed





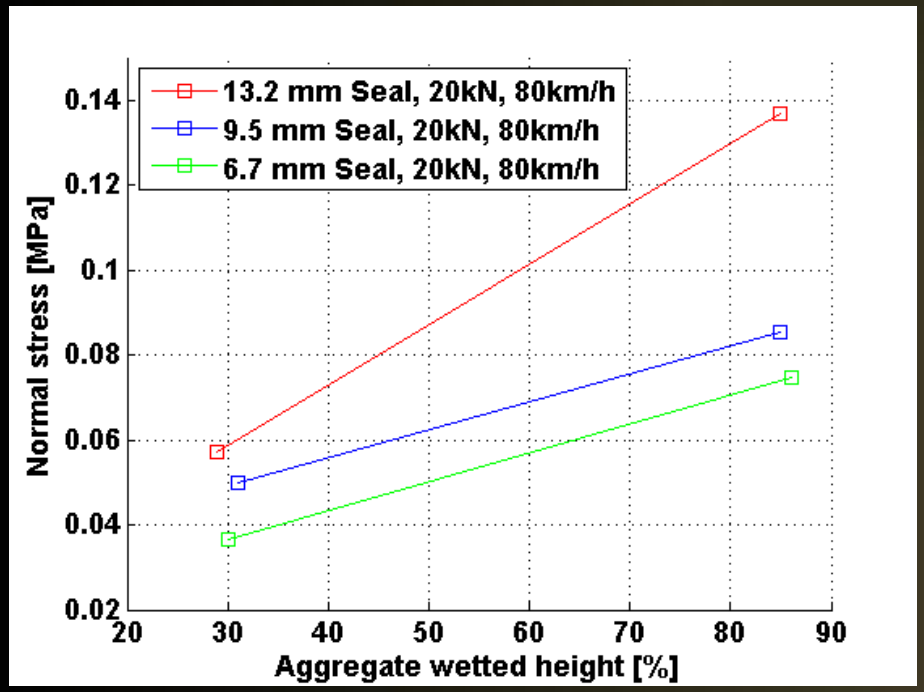
Adhesive Failure

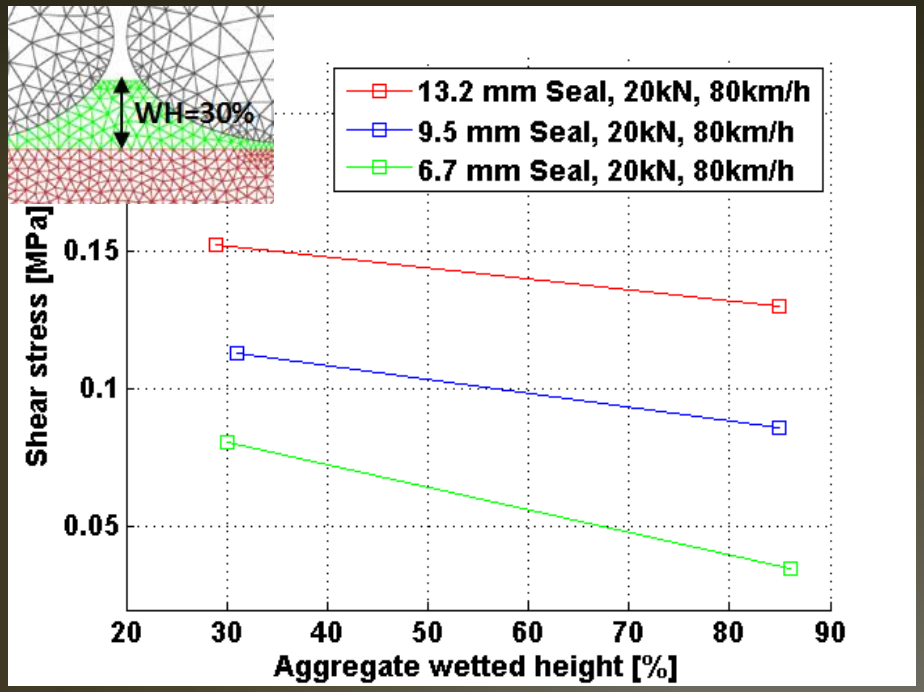
- Variables: Seal size, traffic & speed



Adhesive Failure

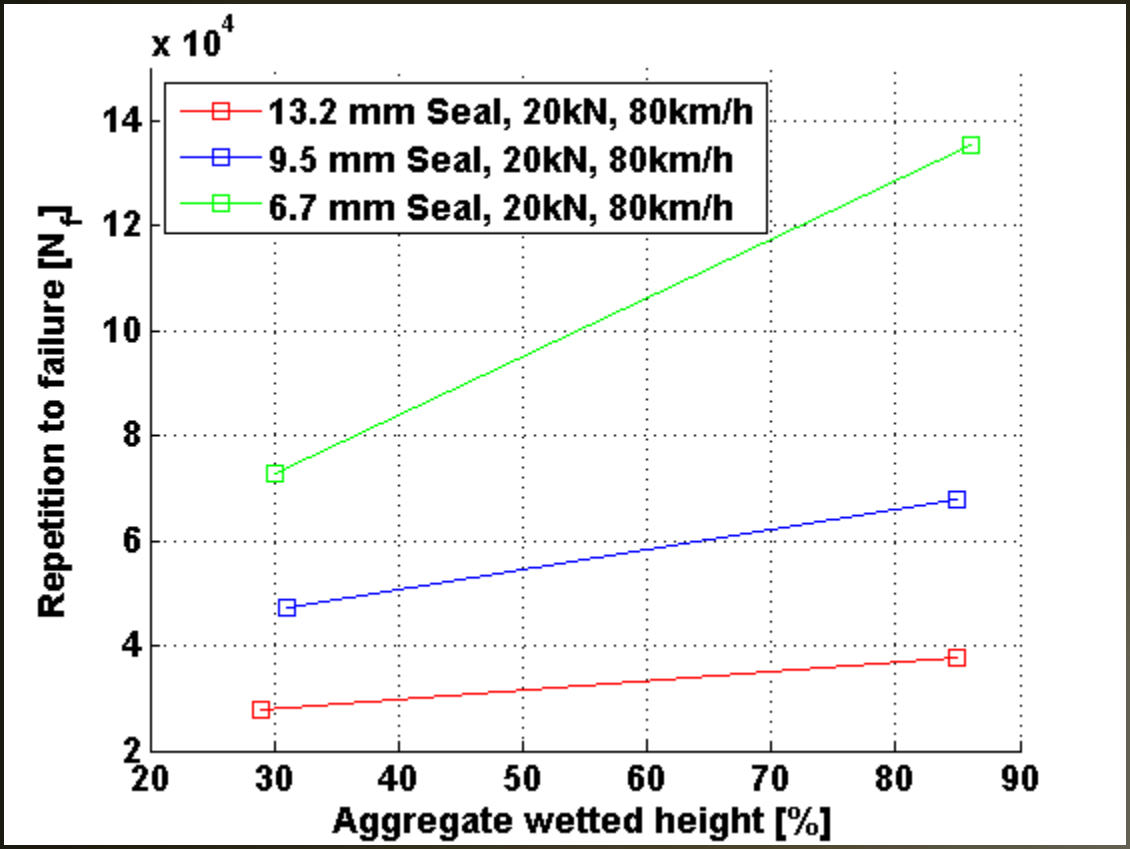
- Variables: Seal size & wetted height (WH)





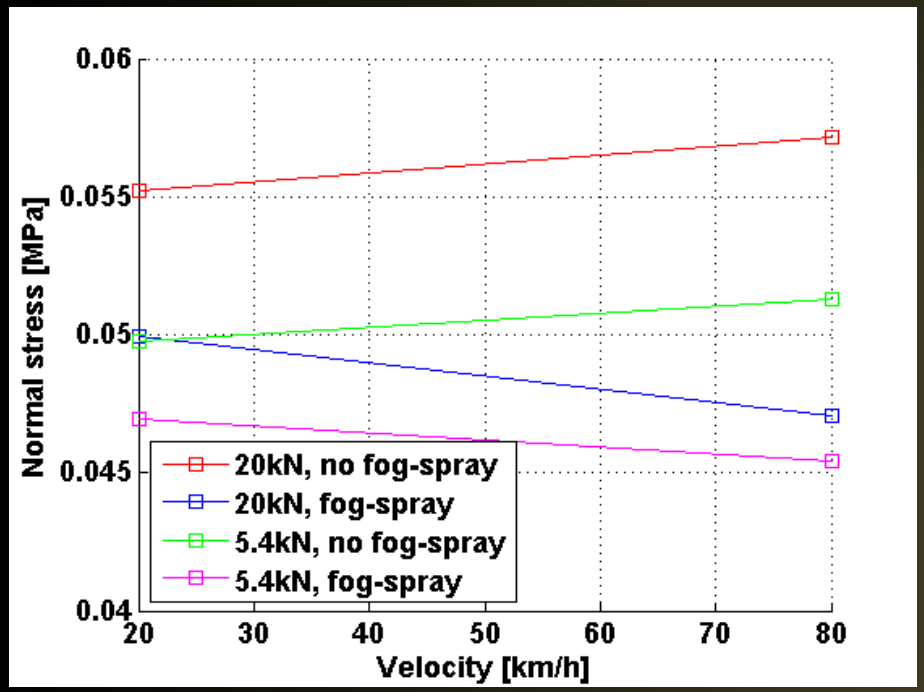
Adhesive Failure

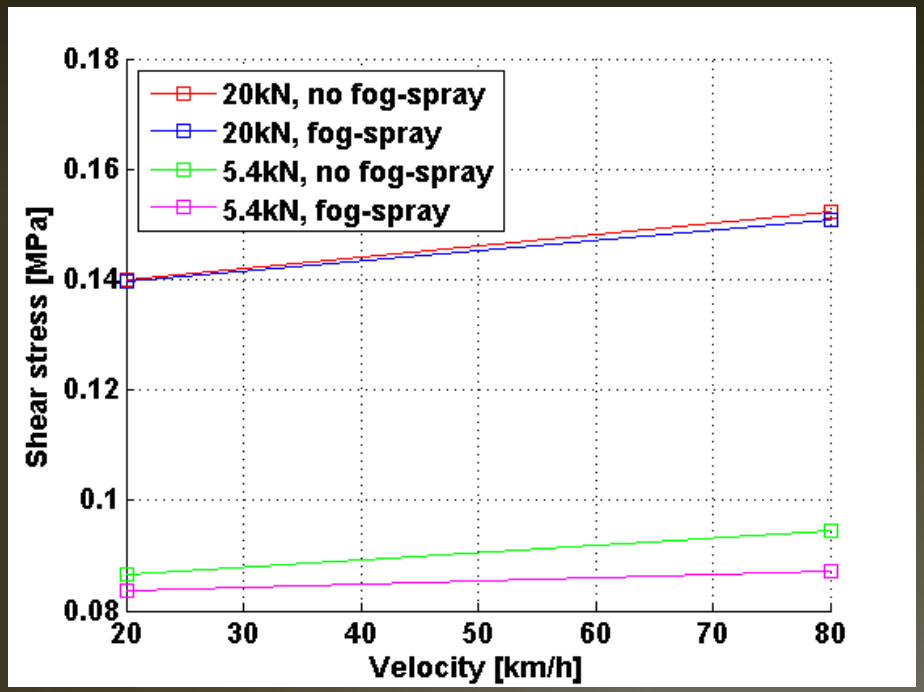
- Variables: Seal size & wetted height (WH)



Adhesive Failure

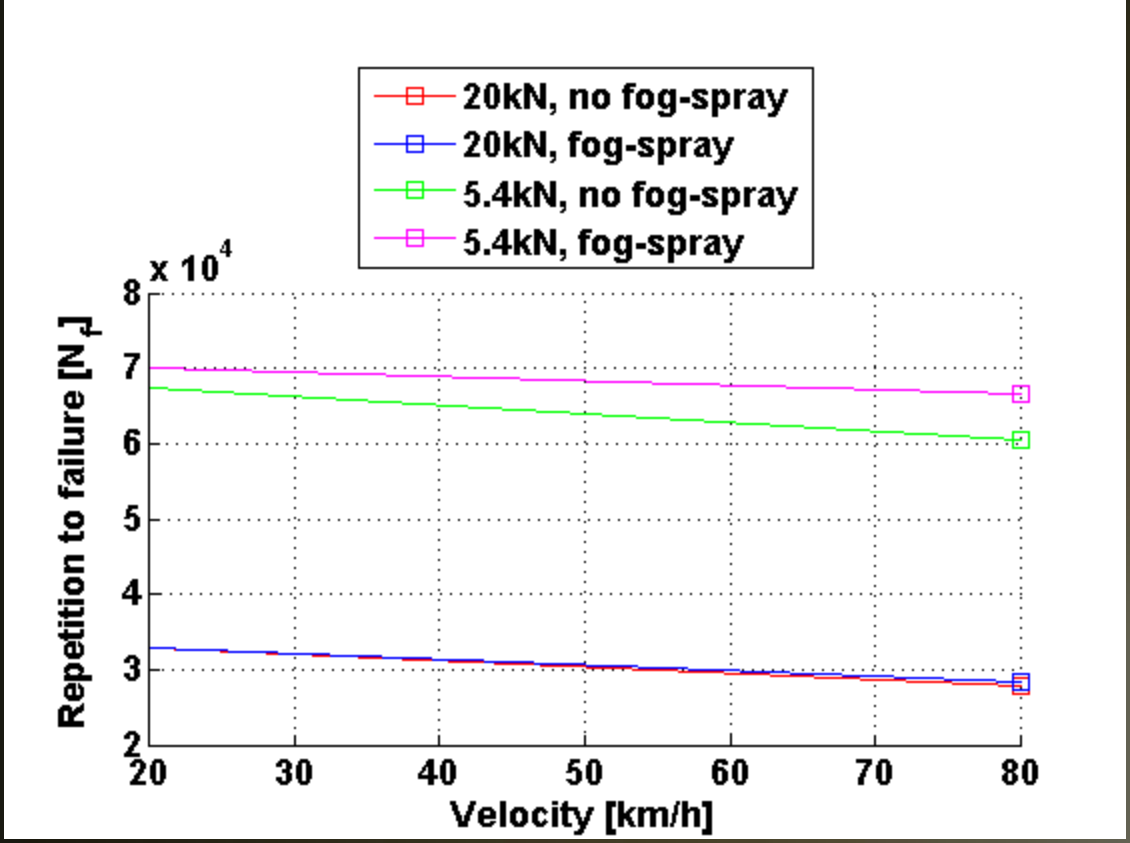
- Variable: Fog spray (KRS-60)





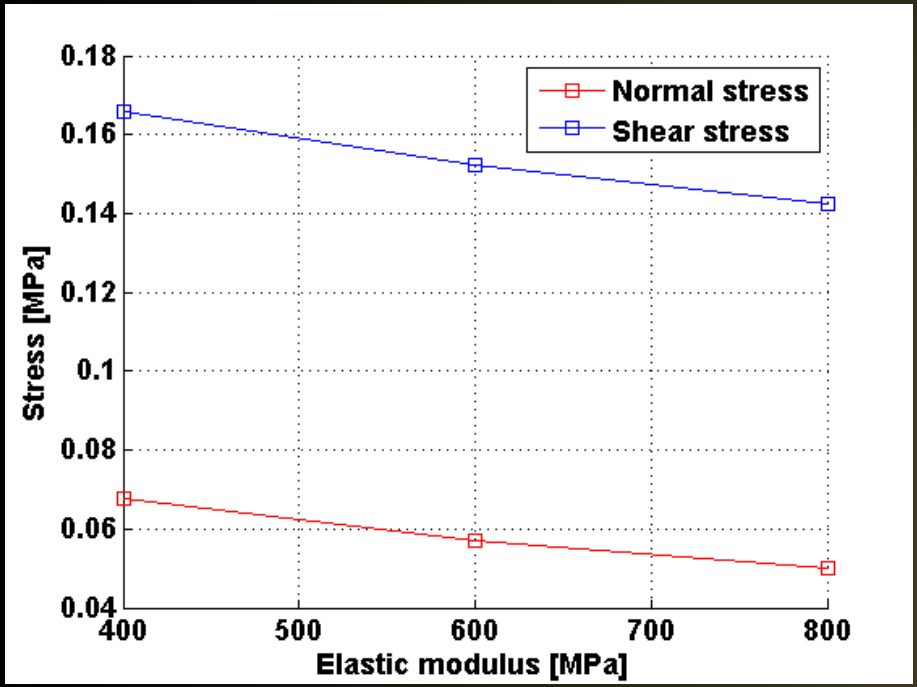
Adhesive Failure

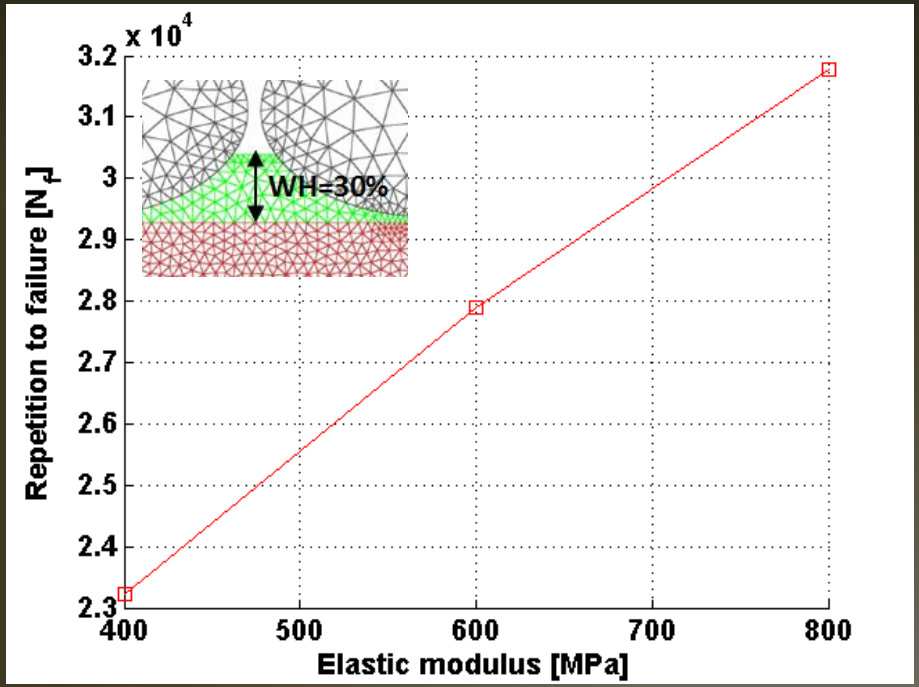
- Variable: Fog spray (KRS-60)



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