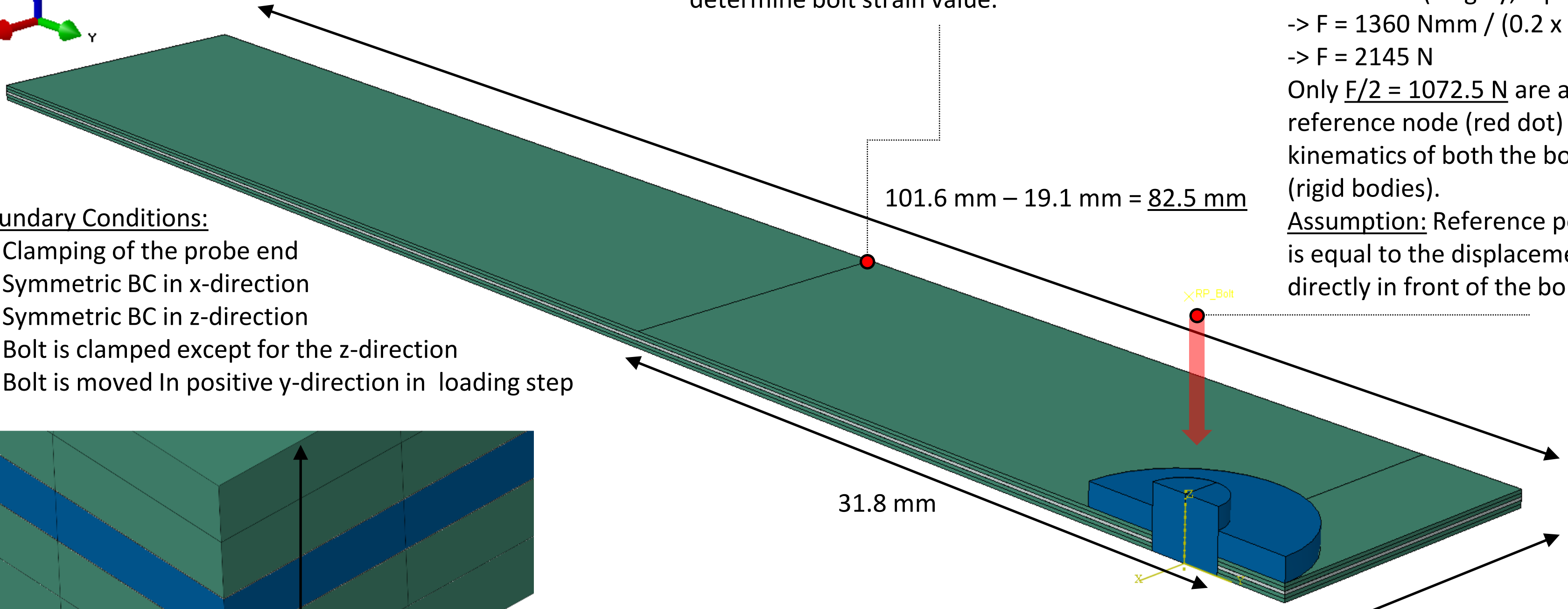
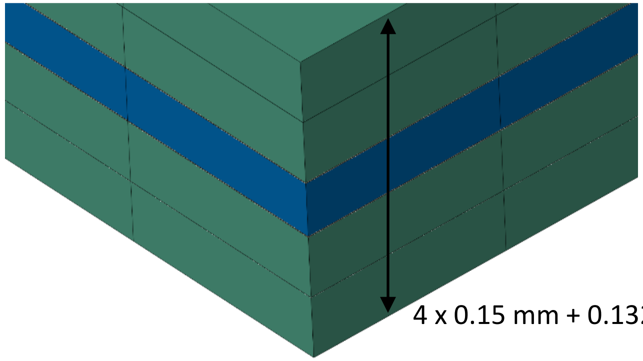
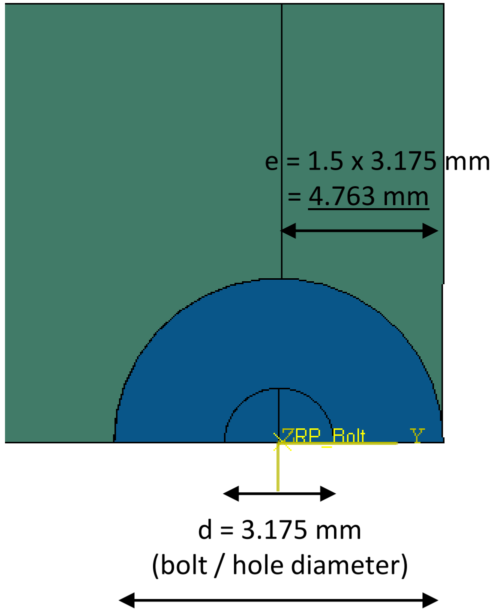






Virtual LVDT:
Second node defined on the laminate to determine bolt strain value.

Relating bolt torque to bolt tension:
T = K x F x d (Shigley, Eq. 8.27) with K ≈ 0.2
-> F = 1360 Nmm / (0.2 x 3.175 mm)
-> F = 2145 N
Only F/2 = 1072.5 N are applied to the reference node (red dot) that governs the kinematics of both the bolt and the washer (rigid bodies).
Assumption: Reference point displacement is equal to the displacement of the nodes directly in front of the bolt.

Boundary Conditions:
- Clamping of the probe end
- Symmetric BC in x-direction
- Symmetric BC in z-direction
- Bolt is clamped except for the z-direction
- Bolt is moved In positive y-direction in loading step

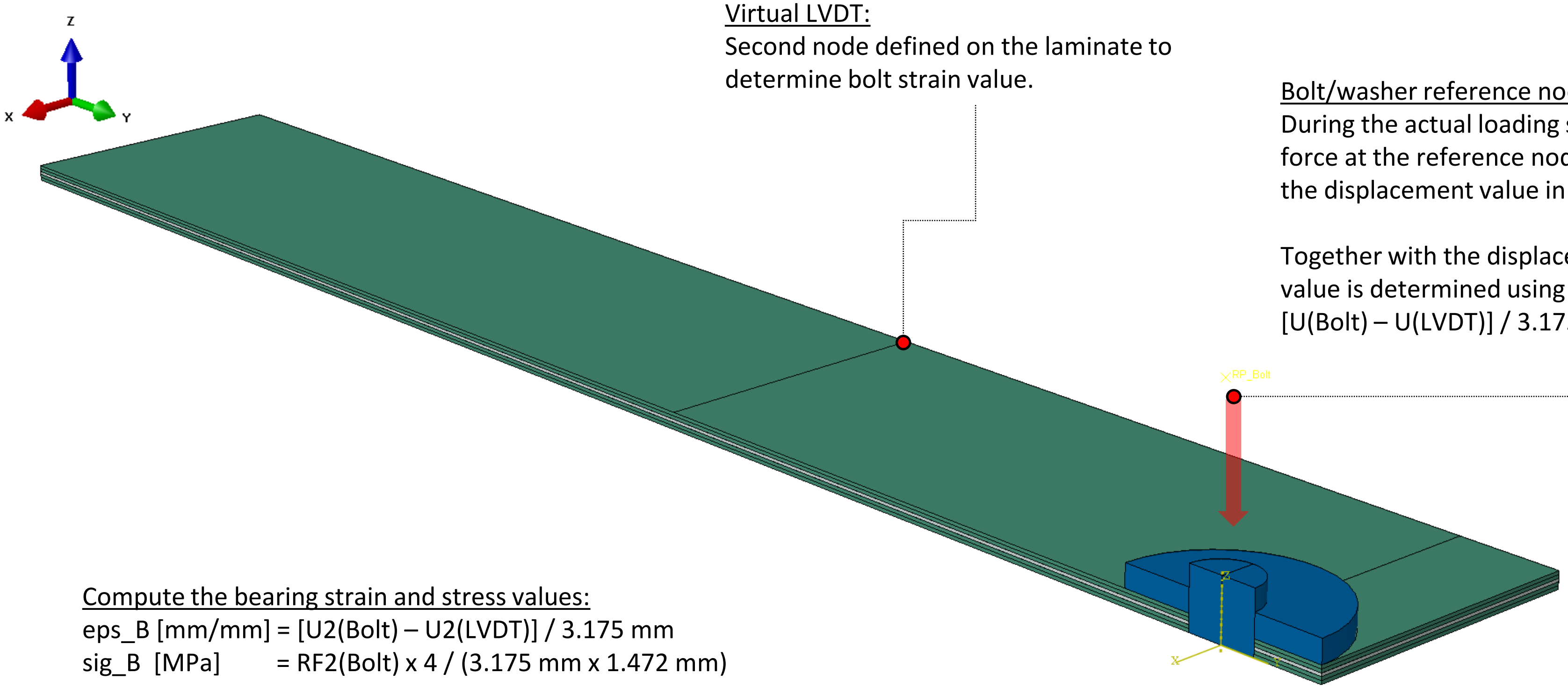
Laminate composition from top to bottom:

CFRP	0°
CFRP	+45°
CZM	(0°)
Titanium	(0°)
CZM	(0°)
CFRP	-45°
CFRP	90°

Material Properties CFRP (Elastic -> Engineering Constants):
E11 = 151690 MPa | E22 = E33 = 6900 MPa | v12 = v13 = 0.3 | v23 = 0.41
G12 = G13 = 2410 MPa | G23 = 2450 MPa

Material Properties Titanum (Elastic / Isotropic Plasticity):
E = 146930 MPa | v = 0.3 | Sig_y = 268.05 MPa
Sig_max = 382.34 MPa at a plastic strain value of 0.0844

Material Properties CZM (Traction Separation / Initiation / Evolution):
Elastic values divided by t = 0.002 mm: E/Enn = 1855000 Mpa/mm | G1/Ess = G2/Ett = 2060000 Mpa/mm
Quads Damage: R33 = 22.08 MPa | R13 = R23 = 26.32 MPa
Evolution (linear, energy): Gc = 0.68 N/mm

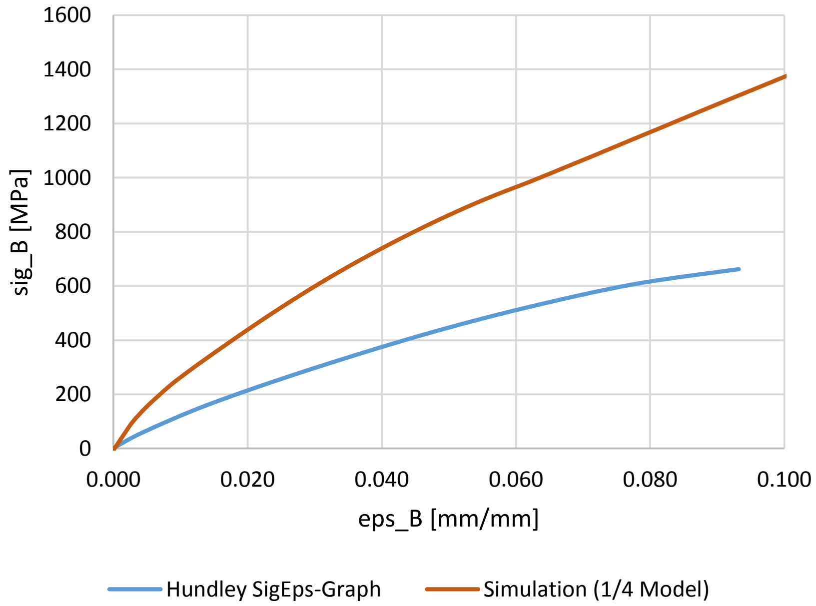


Virtual LVDT:
Second node defined on the laminate to determine bolt strain value.

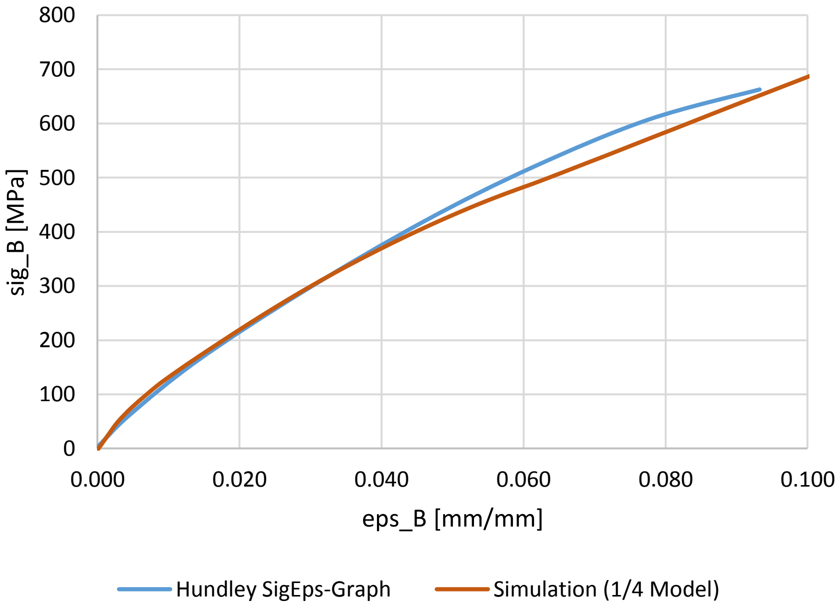
Bolt/washer reference node:
During the actual loading step (bolt/washer movement in y-direction) the bolt reaction force at the reference node of the rigid body in y-direction is monitored together with the displacement value in y-direction.

Together with the displacement in y-direction of the virtual LVDT node the bearing strain value is determined using
[U(Bolt) – U(LVDT)] / 3.175 mm.

Compute the bearing strain and stress values:
eps_B [mm/mm] = [U2(Bolt) – U2(LVDT)] / 3.175 mm
sig_B [MPa] = RF2(Bolt) x 4 / (3.175 mm x 1.472 mm)



sig_B x 1/2



Discussion of the results:
Comparing the obtained results for the e/D = 1.5 model with the results presented by Mr. Hundley shows that my model is approximately twice as stiff as it should be according to the Hundley results (numerically and also experimentally).

The effect of twice the stiffness can be demonstrated by dividing the obtained bearing stress values by factor 2 (see right graph).

What went wrong?