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Laboratory Evaluation of Frozen Soil Target Materials with a Fused Interface

Moo Y. Lee and David R. Bronowski

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185

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ABSTRACT

To investigate the performance of artificial frozen soil materials with a fused interface, split tension (or "Brazilian") tests and unconfined uniaxial compression tests were carried out in a low temperature environmental chamber. Intact and fused specimens were fabricated from four different soil mixtures (*962*: clay-rich soil with bentonite; *DNA1*: clay-poor soil; *DNA2:* clay-poor soil with vermiculite; and *DNA3*: clay-poor soil with perlite). Based on the "Brazilian" test results and density measurements, the *DNA3* mixture was selected to closely represent the mechanical properties of the Alaskan frozen soil. The healed-interface by the same soil layer sandwiched between two blocks of the same material yielded the highest "Brazilian" tensile strength of the interface. Based on unconfined uniaxial compression tests, the frictional strength of the fused *DNA3* specimens with the same soil appears to exceed the shear strength of the intact specimen.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Steve Heffelfinger and Laurence S. Costin for the managerial support. The final publication of the report was supported by C-6 project managed by Jaime L. Moya.

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1. Introduction

In order to estimate the performance of artificial frozen soil target materials with a fused interface, three phases of laboratory testing program have been developed. The objective for each phase of the laboratory experimental program is as follows:

1) Selection of an artificial mixture of a frozen soil which best represents the frozen soil from Alaska
2) Selection of a fused interface material which provides frictional strength close to the intact specimen
3) Evaluation of the frictional strength of the selected fused interface.

Four different soil compositions were under consideration: a clay-rich soil (CRS - for 962 mixture), and a clay-poor soil (CPS - for DNA 1, 2, and 3 mixtures). The clay-poor soil is assumed to be the principal soil of interest, with minimal properties developed for the clay-rich soil. All tests were conducted approximately at -25^{o}C in which brittle tensile fractures were observed under split tension (or “Brazilian”) tests in Alaskan frozen soil (Lee et. al., 2002).

Table 1. Different mixtures of artificial frozen soils proposed as the target material.

Specimen Designation	Soil Type	Ingredients
962	CRS	CRS, bentonite and water
DNA1	CPS	CPS and water
DNA2	CPS	CPS, water and vermiculite
DNA3	CPS	CPS, water and perlite

Note: CRS-clay rich soil
CPS-clay poor soil

The three-phase experimental program outlined in this report is designed to accomplish the objectives of eliminating unsuitable mixtures of soil and fusion methods for the future fabrication of the artificial target with several blocks. Upon completion of the testing program, not only will well-determined sets of right soil mixture for representing Alaskan frozen soil be established, but also the fusion method will be identified. Table 2 shows a list of test types, soil types, and the number of tests conducted. The test matrix assumes that the indirect tensile strength of the frozen soil, measured from “Brazilian” tests, is an indicator of shear strength of the specimen.

2. Sample Preparation and Test Methods

A block (approximately 30 × 30 × 30 cm^3) of frozen soil fabricated from each mixture was provided for testing. A modified drill bit mounted to a drill press was used to obtain a core (Figure 1) to be fabricated as specimens. The drill bit was cooled by liquid nitrogen. Drill bits used for hard rock coring had a tendency to get jammed when used in the fine-grained frozen soil due to lost circulation of coolant and accumulation of soil cuttings surrounding the bit. To provide circulation passages for the coolant and soil cuttings, tungsten carbide cutters were brazed into the drill bit as shown in Figure 1. The modified bit was similar to the cutting shoes used for the CREEL coring auger (Ueda et. al., 1975).

Table 2. Test-matrix for fused frozen soil specimens.

Phase	Type of Test	Specimen and Soil Type	No. of Tests
1	Indirect Tensile (or “Brazilian”) Test	Intact Specimen	16 (4 x 4 batches)
2	Indirect Tensile (or “Brazilian”) Test	Intact Specimen CPS	3
		Intact Specimen CRS	2
		Fused Specimen Technique A, CPS	3
		Fused Specimen Technique B, CPS	3
		Fused Specimen Technique C, CPS	3
		Fused Specimen Best Technique, CRS	3
3	Uniaxial Compression Test	Intact Specimen CPS	3
		Intact Specimen CRS	2
		Fused Specimen CPS	4
		Fused Specimen CRS	2

The extracted core was then cut perpendicular to the longitudinal axis of the core using a diamond saw. Specimens for “Brazilian” tests were prepared to have the following nominal dimensions: 85 mm in diameter (D) and 45 mm in thickness (t). The dimensions fell in the range of thickness-to-diameter ratio (0.2 to 0.75) recommended in ASTM D3967 (“Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens”. Samples were visually inspected for general straightness of circumferential surfaces and significant flaws. A diametrical line indicating the loading axis was marked on the specimen to align the specimen in the loading machine. The compressive line load was applied to the specimen at a constant displacement rate of 0.05 mm/s. For uniaxial compression tests, specimens were prepared to have nominal dimensions of 45 mm to 55 mm in diameter and 90 to 115 mm in length. Compressive load was applied along the long axis of the specimen using a constant displacement rate of 0.05 mm/s. The displacement control allows us to select the peak load at failure without overloading the specimen. The prepared specimens were tested in the environmental chamber shown in Figure 2. The temperature in the chamber was controlled by forced circulation of liquid nitrogen. The thermocouple inside the chamber constantly measured the air temperature in the chamber and provided feedback signal to the temperature controller. Two through-wall ports opened in the vertical direction of the chamber accommodated loading rods.

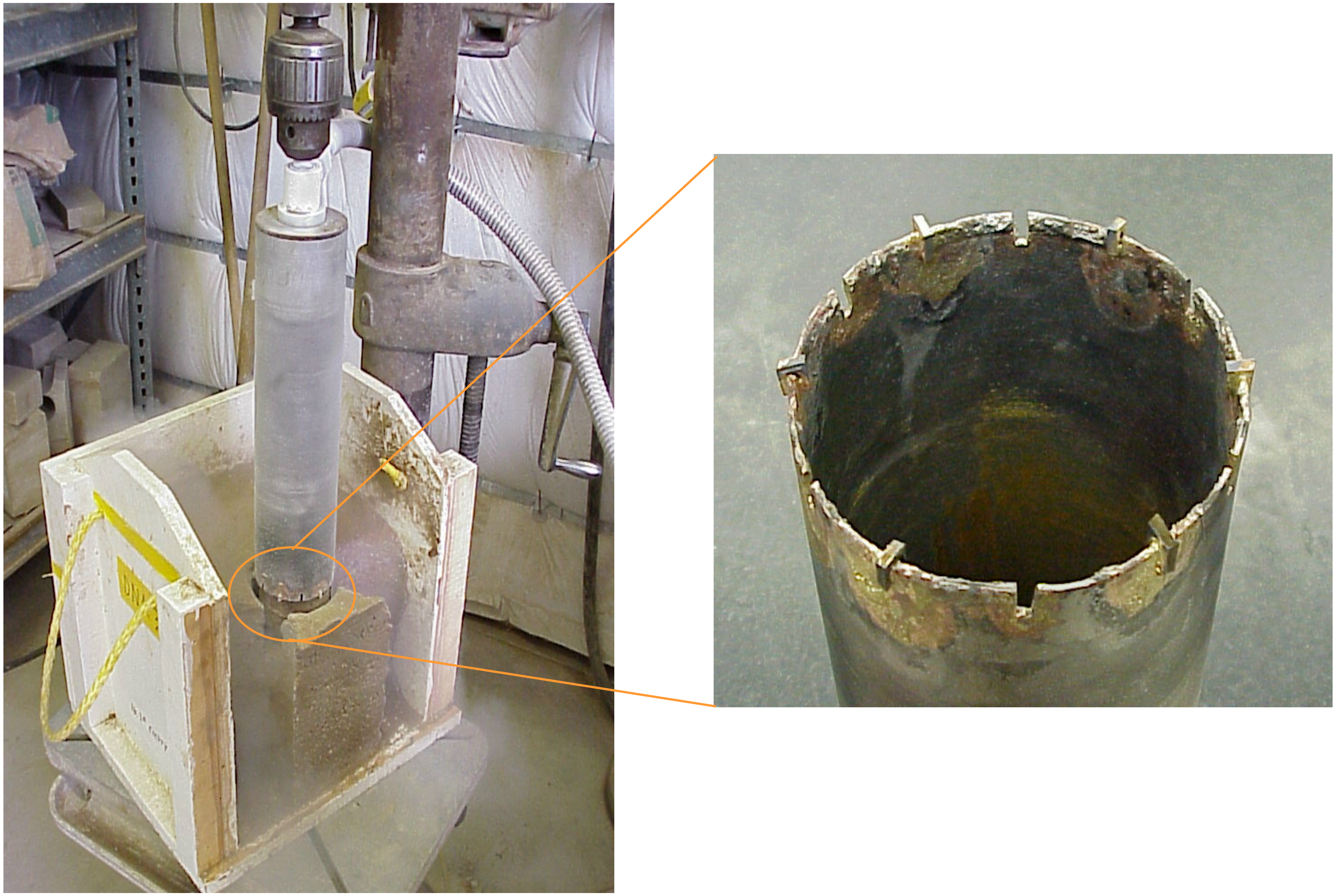

Figure 1. The modified drill bit with tungsten carbide cutters were used for coring a frozen soil specimen.

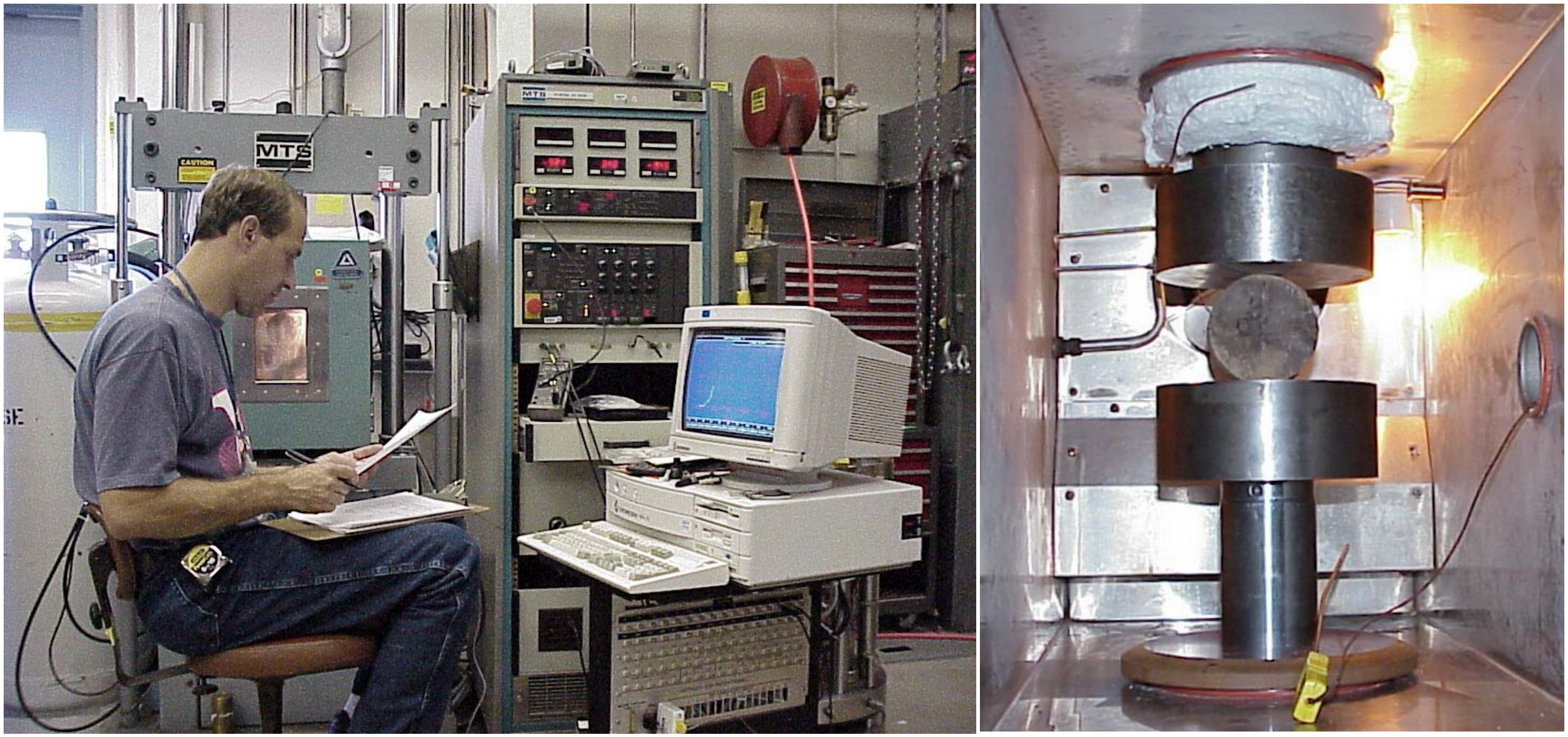

Figure 2. Low-temperature test facilities with an environmental chamber and a loading machine. A frozen soil disk is set to be loaded diametrically inside the chamber for “Brazilian test”.

The indirect tensile strength of the frozen soil was calculated from:

$$T_{br} = 2P_b / \pi tD$$

where T_{br} is the indirect "Brazilian" tensile strength in MPa; P_b is the peak load in N; t is the thickness of the circular core in mm; and D is the diameter of the specimen in mm.

The unconfined uniaxial compressive strength of the frozen soil was calculated from:

$$C_o = P_u / \pi r^2$$

where C_o is the unconfined uniaxial compressive strength of the frozen soil in MPa; P_u is the peak load in N; and r is the radius of the specimen in mm.

3. Laboratory Testing and Results

3.1 Phase 1-Selection of soil mixture

Four different mixtures of two different soil types (clay-rich and clay-poor) have been prepared as candidate materials for simulating Alaskan frozen soil. Each batch was composed of the following ingredients:

Soil used for mixture 962 was taken from piles of fill dumped north of building 962, Sandia National Laboratories around mid-January 1997. Mixture 962 consists of the clay-rich soil and silt as a base material with some rock debris as well (Furnish, 1998). Bentonite was mixed with the clay-rich soil base to have the dry density of the mixture approximately at 1.3 g/cm^3.

Soil used for DNA mixtures was a remnant from the 600 m sled track test. The DNA soil was light-brown clay-poor silty material sampled from the South 2nd street burrow stockpile. The dry density of the soil was approximately 1.7 g/cm^3. Mixture DNA1 consists of base DNA soil and water. To lower the density of the DNA specimens comparable to that of the Alaskan frozen soil, vermiculite and perlite were added to constitute DNA2 and DNA3 mixtures, respectively. Vermiculite and perlite are the lightweight and chemically inert aggregates which have been used as ingredients of potting soils in the horticulture industry.

For each batch, four intact specimens were prepared for Brazilian tests. The density of the specimen, γ, and the indirect "Brazilian" tensile strength of the specimen, T_{br}, were used as measures of selecting the artificial mixture of frozen soil which best fits the properties of the Alaskan frozen soil. Figure 3 shows a typical displacement vs. load plot for a frozen soil specimen subject to a diametral compressive stress condition. As shown in Table 3 and Figure 4, the *DNA3 (perlite+soil+water)* mixture appeared to best represent the mechanical properties of the Alaskan Frozen Soil. As a result we chose to use the DNA3 mixture for the following Phase 2 testing.

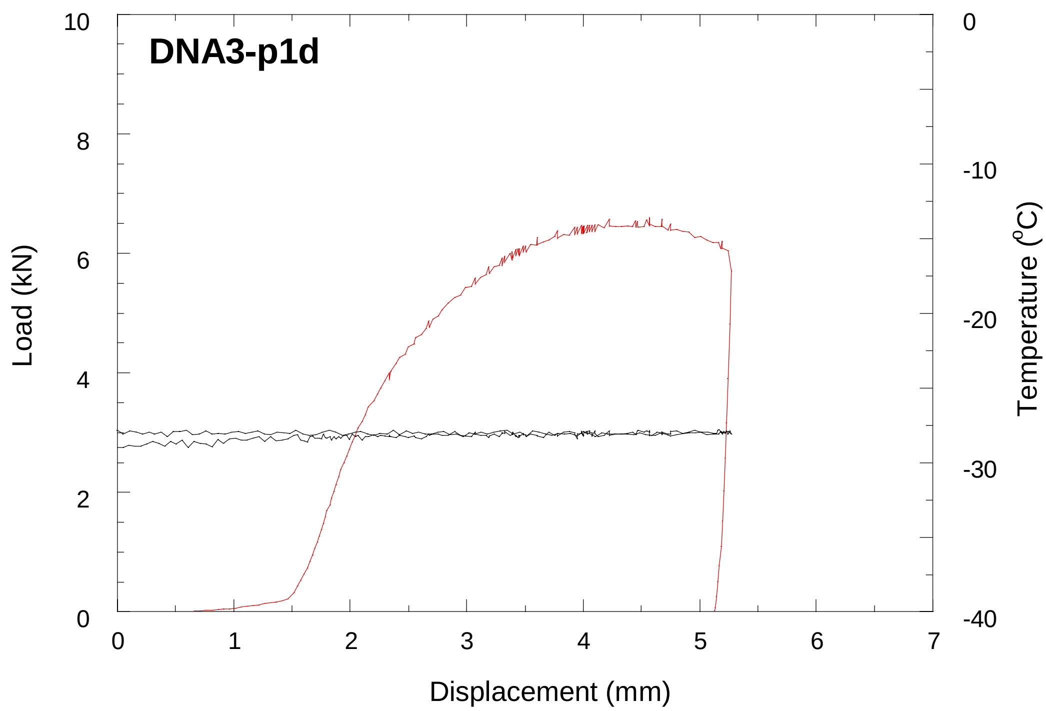

Figure 3. Typical displacement vs. load plot for an intact frozen soil specimen. Induced splitting tensile fracture is also shown on the specimen.

Table 3. Density and "Brazilian" tensile strength of frozen soil mixtures.

Specimen No.	Diameter **D** (mm)	Thickness **t** (mm)	Weight (g)	Peak Load **P** (kN)	Mean Temperature (°C)	Density γ (g/cm^3)	Tensile Strength $\mathbf{T_{br}}$ (MPa)
962-P1A	85	47	502	13.0	-28.3	1.85	2.04
962-P1B	85	47	495	10.7	-27.9	1.84	1.69
962-P1C	86	47	493	12.1	-28.3	1.82	1.92
962-P1D	85	47	486	12.3	-29.1	1.82	1.96
					Average	**1.83**	**1.90**
DNA1-P1A	83	46	510	11.4	-29.5	2.05	1.90
DNA1-P1B	83	45	509	14.0	-27.9	2.05	2.35
DNA1-P1C	84	48	549	8.0	-27.9	2.05	1.26
DNA1-P1D	84	47	543	10.6	-27.1	2.07	1.70
				10.6	**Average**	**2.06**	**1.80**
DNA2-P1A	84	45	500	10.6	-27.8	1.97	1.76
DNA2-P1B	85	45	482	10.6	-27.7	1.92	1.79
DNA2-P1C	85	46	512	11.2	-26.3	1.97	1.83
DNA2-P1D	85	45	503	11.8	-28.1	1.99	1.98
					Average	**1.96**	**1.84**
DNA3-P1A	85	42	419	6.5	-29.0	1.76	1.16
DNA3-P1B	85	45	484	11.4	-26.6	1.90	*1.90*
DNA3-P1C	85	46	492	8.1	-28.0	1.88	1.32
DNA3-P1D	85	47	483	6.6	-28.2	1.82	1.06
					Average	**1.84**	**1.36***

Note: *-average T_{br} for DNA3 without outlier 1.90 MPa from DNA3-P1B is 1.18 MPa.

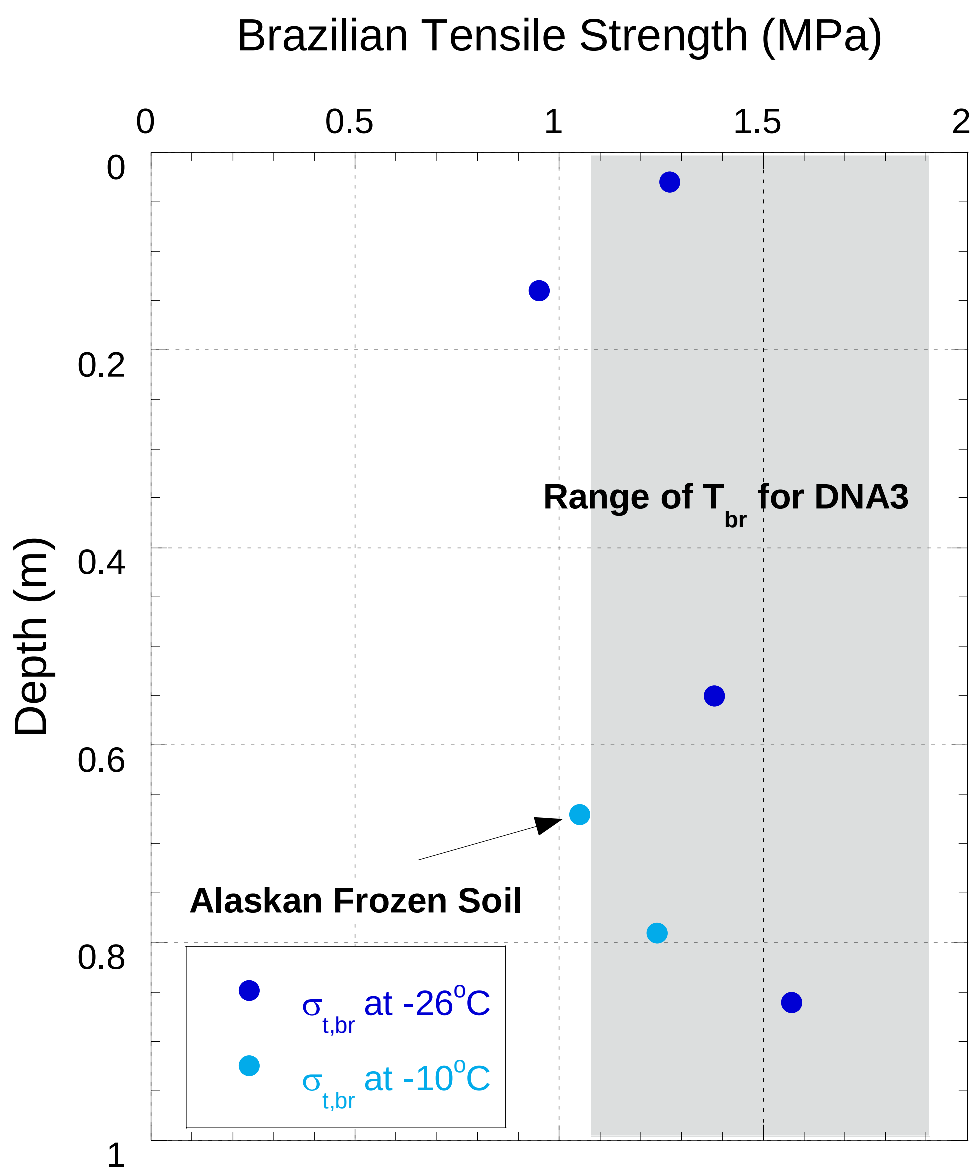

Figure 4. Comparison of the "Brazilian" tensile strength, T_{br}, for mixture DNA3 and the Alaskan Frozen Soil.

3.2 Phase 2-Selection of fusing method

To evaluate the feasibility of assembling several blocks of a frozen soil into a single target, fused interfaces filled with three different materials were tested under a laboratory condition. A disk of frozen soil, approximately 85 mm in diameter and 45 mm in thickness, was cut along the diameter of the specimen. The saw-cut surfaces were thawed using a heat gun until approximately 1 to 2 mm depth of the surface was softened. A sharp object such as the pencil tip was inserted into the softened surface to check the depth of the thawed layer. After both surfaces of the disk were thawed, we applied four different interface materials: 1) a thin layer of water brushed; 2) an approximately 2 mm thick layer of soil paste melted from the same frozen soil; 3) plastic mesh added to the soil paste; and 4) without any interface material. After the interface material was applied to the surface, the specimen was held together under approximately 5 kPa of normal stress to the fused surface for 10 seconds.

As a preliminary evaluation of the strength of fused interface, "Brazilian" tests were conducted on disks of fused frozen soil. The "Brazilian" test for the fused samples was conducted by applying diametral compression on the disk placed between the parallel steel platens along the fused interface. The compressive load induces a uniform tensile stress normal to the fused interface. Assuming that the tensile strength of the fused interface is positively correlated with the shear strength of the interface, the fusing technique, which yields the highest "Brazilian" tensile strength (T_{br}), was considered for the next phase of testing.

As shown in Figure 5 the fused specimens without any interface materials or with water interface showed brittle tensile fracture along the fused interface. In contrast, newly induced tensile fractures were observed for the fused specimens with the soil interface (Figure 6). Table 4 and Figure 7 show that the fused DNA3 specimens with melted soil paste yielded the highest T_{br} consistently. As shown in Figure 7, the tensile strength of the interface with plastic meshes added in the melted soil was in the similar range with the one without the meshes. The average tensile strength of the fused specimens with melted soil paste was practically same as that of the intact specimen (Table 3). Therefore, the thawed interface of the DNA3 specimens with layer of soil paste melted from the same frozen soil was selected as the preferred method of fusing for further analysis.

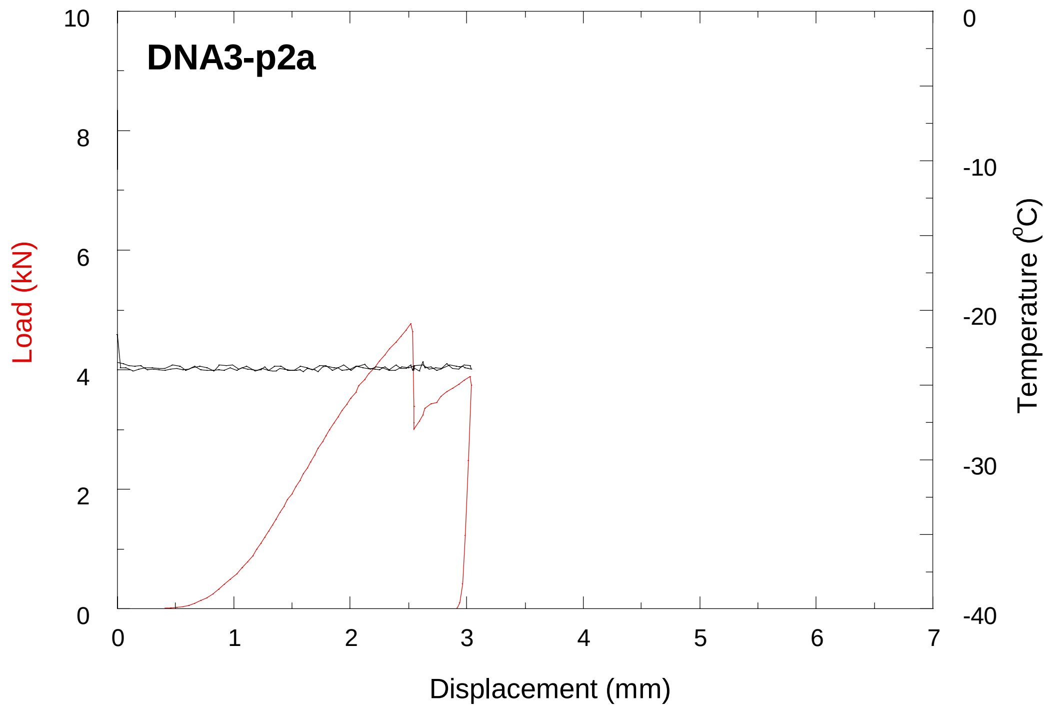

Figure 5. Typical displacement vs. load plot for fused frozen soil specimen with no (or water) interface material. Tensile fractures along the fused interface are shown on the specimen.

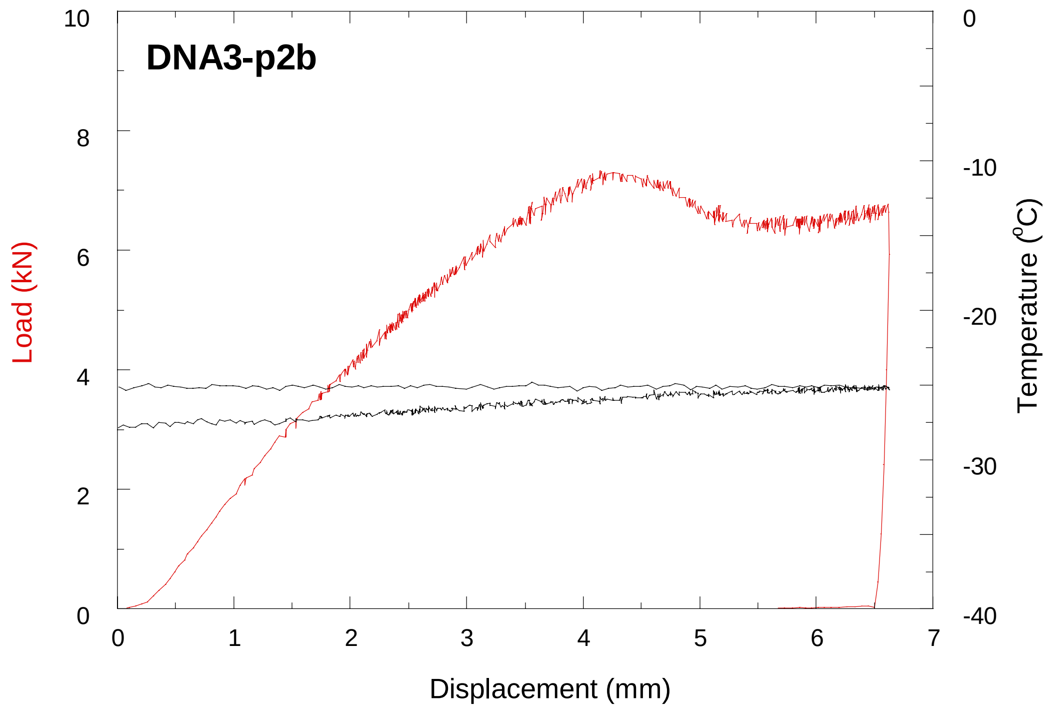

Figure 6. Typical displacement vs. load plot for fused frozen soil specimen with sol interface material. Induced tensile fractures independent from the fused interface are shown on the specimen.

Table 4. "Brazilian" tensile strength of the artificial soils with fused interface.

Specimen No.	Fusion Method	Diameter **D** (mm)	Thickness **t** (mm)	Peak Load **P** (kN)	Mean Temperature (°C)	Tensile Strength $\mathbf{T_{br}}$ (MPa)
962-P2A	N	85	47	8.3	-27.9	1.33
962-P2B	S	85	48	10.9	-24.9	1.69
962-P2C	N	85	46	11.3	-25.2	1.81
962-P2D	W	85	46	4.9	-25.4	0.80
DNA3-P2A	N	85	44	4.8	-23.9	0.82
DNA3-P2C	N	86	48	3.9	-23.5	0.61
DNA3-P2F	N	84	45	4.1	-26.0	0.69
DNA3-P2L	N	85	43	3.3	-24.7	0.57
					Average	**0.67**
DNA3-P2D	W	86	45	5.7	-24.7	0.94
DNA3-P2H	W	84	46	4.2	-28.6	0.69
DNA3-P2J	W	84	45	5.8	-26.2	0.98
					Average	**0.87**
DNA3-P2B	S	86	42	7.3	-26.0	1.30
DNA3-P2E	S	85	47	6.6	-27.1	1.06
DNA3-P2K	S	85	45	6.7	-27.3	1.12
DNA3-P2G	SM	84	45	8.2	-25.8	1.39
DNA3-P2I	SM	86	45	6.3	-23.9	1.04
					Average	**1.18**

Note: N-no interface material
W-thin layer of water brushed on both surfaces
S-approximately 2 mm of soil layer
SM- approximately 2 mm of soil layer with plastic mesh sandwiched between blocks.

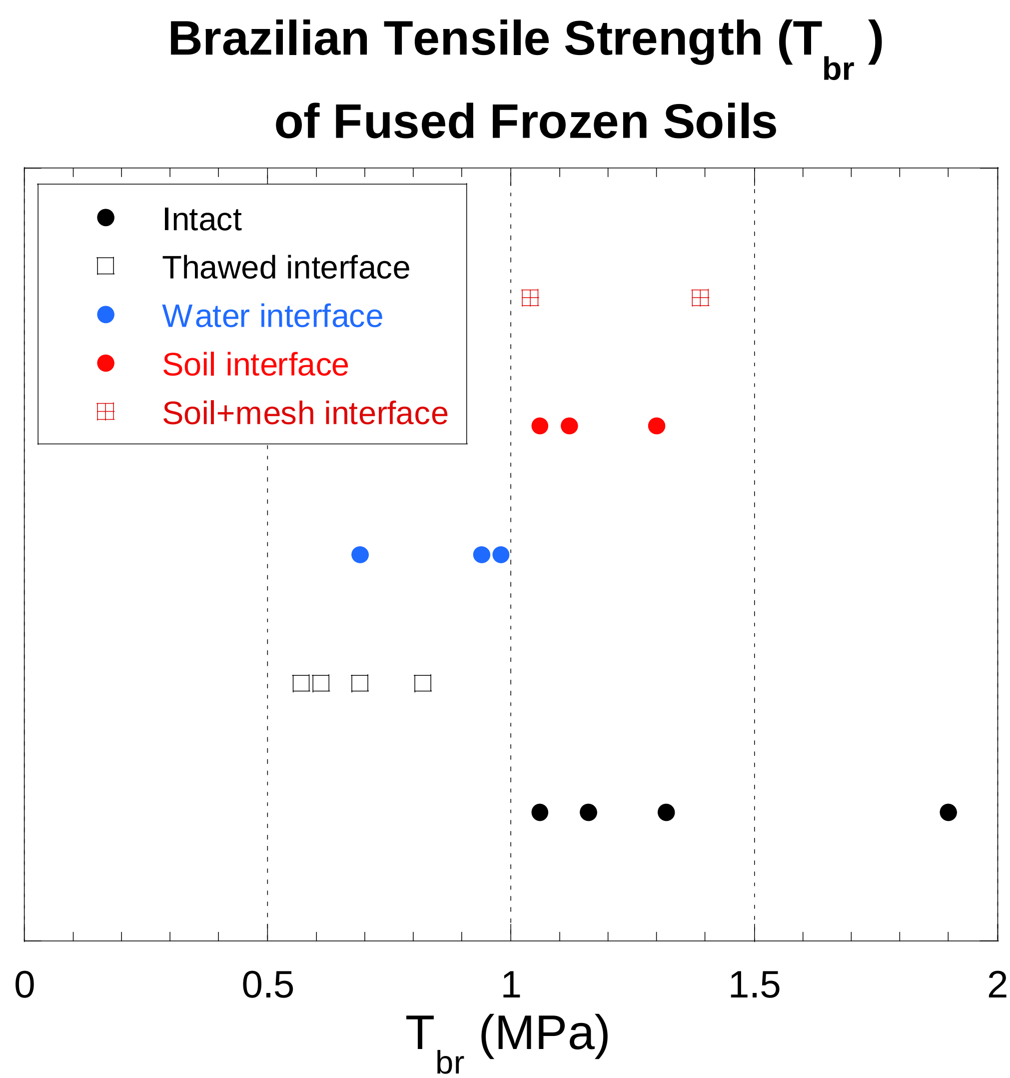

Figure 7. "Brazilian" tensile strength T_{br} of artificial frozen soil DNA3 with different interface materials

3.3 Phase 3-Evaluation of frictional strength of fused interface

The possible loss of frictional strength at the fused interface was investigated by comparison of the uniaxial unconfined strength of the frozen soil specimens with and without a fused interface. Right-circular cylindrical test specimens (45 to 55 mm in diameter and 90 to 125 mm in length) were cored using the modified bit shown in Figure 1.

The intact specimens without a fused interface were first tested in the environmental chamber under the nominal temperature of -25°C. Tests were conducted at a constant axial displacement rate of 0.05 mm/s using a servo-controlled hydraulic loading frame. The axial displacement of the specimen was measured by the LVDT mounted on the loading cylinder and the axial load was measured by the load-cell mounted on the frame (Figure 2). Figure 8 shows a typical displacement vs. load plot from uniaxial compression testing. The failed specimens are shown in Figure 9. Failure surface consisted of *en echelon* fractures coalesced together forming an inclined shear zone. Figure 10 shows unwrapped images of failure surfaces from the specimens. The angle θ measured between the normal to the plane of failure and the direction of the stress along the long axis of the specimen was approximately 50°. The angle of internal friction ϕ for the frozen soil was estimated as 10° based on the following relationship between θ and ϕ.

$$\theta = 45° + \phi/2$$

To investigate the frictional strength of the fused specimens, we created an artificial inclined failure surface in the specimen. The saw-cut specimens with θ = 50 and 60° were fused together using the selected interface material (paste made from the same soil) from Phase 2 experiments. Specimens with fused interfaces were tested in the environmental chamber under the nominal temperature (-25°C). Based on the average unconfined uniaxial compressive strength of the frozen soil (C_o=5.7 MPa), the critical shear stresses necessary for sliding along the saw-cut interface with θ = 50 and 60° are 2.8 and 2.5 MPa, respectively (see Figure 11). Figures 12 and 13 show the typical displacement vs. load plot and failed specimens with fused interface (θ = 50°), respectively. Figures 14 and 15 show the typical displacement vs. load plot and failed specimens with a fused interface (θ = 60°). As shown in Figures 13 and 15 none of the specimens were failed along the fused interfaces. Rather, new shear surfaces, either parallel or conjugate to the fused interface, were induced. Table 5 and Figure 16 show that uniaxial compressive strengths of the artificial frozen soils with or without fused interface are practically identical. This suggests that frictional strength of the fused interface with soil interface appears to at least same as that of the intact frozen soil.

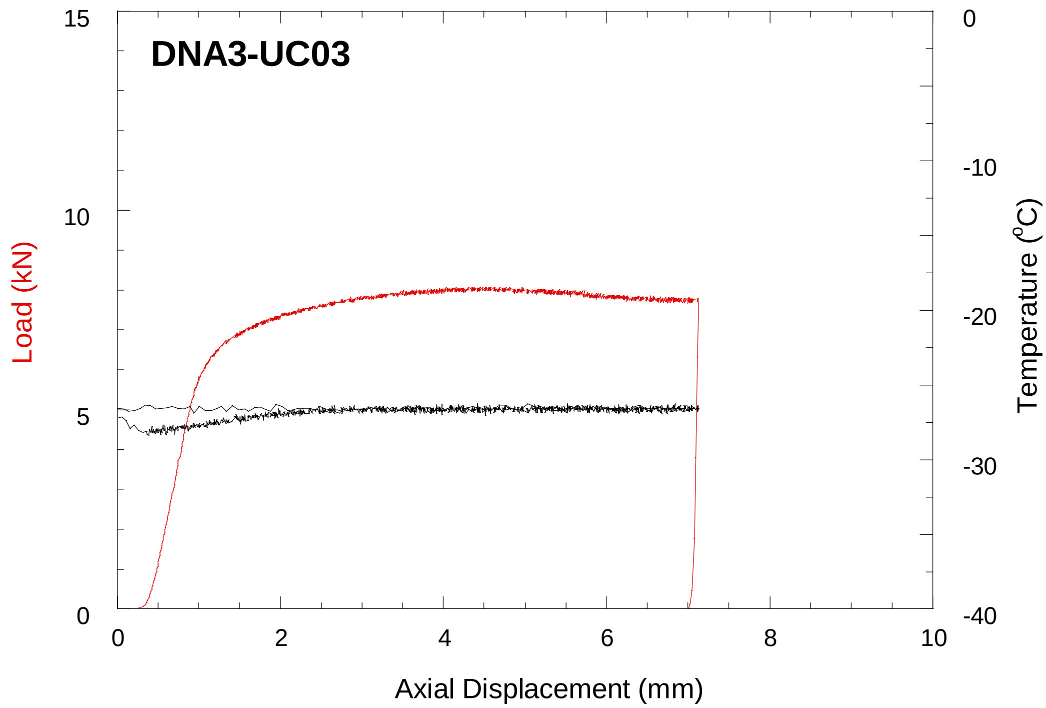

Figure 8. Typical displacement vs. load plot from unconfined uniaxial compression testing of an intact frozen soil specimen.

Figure 9. Frozen soil specimens loaded under unconfined uniaxial compressive stresses. En echelon fractures form an inclined fracture plane.

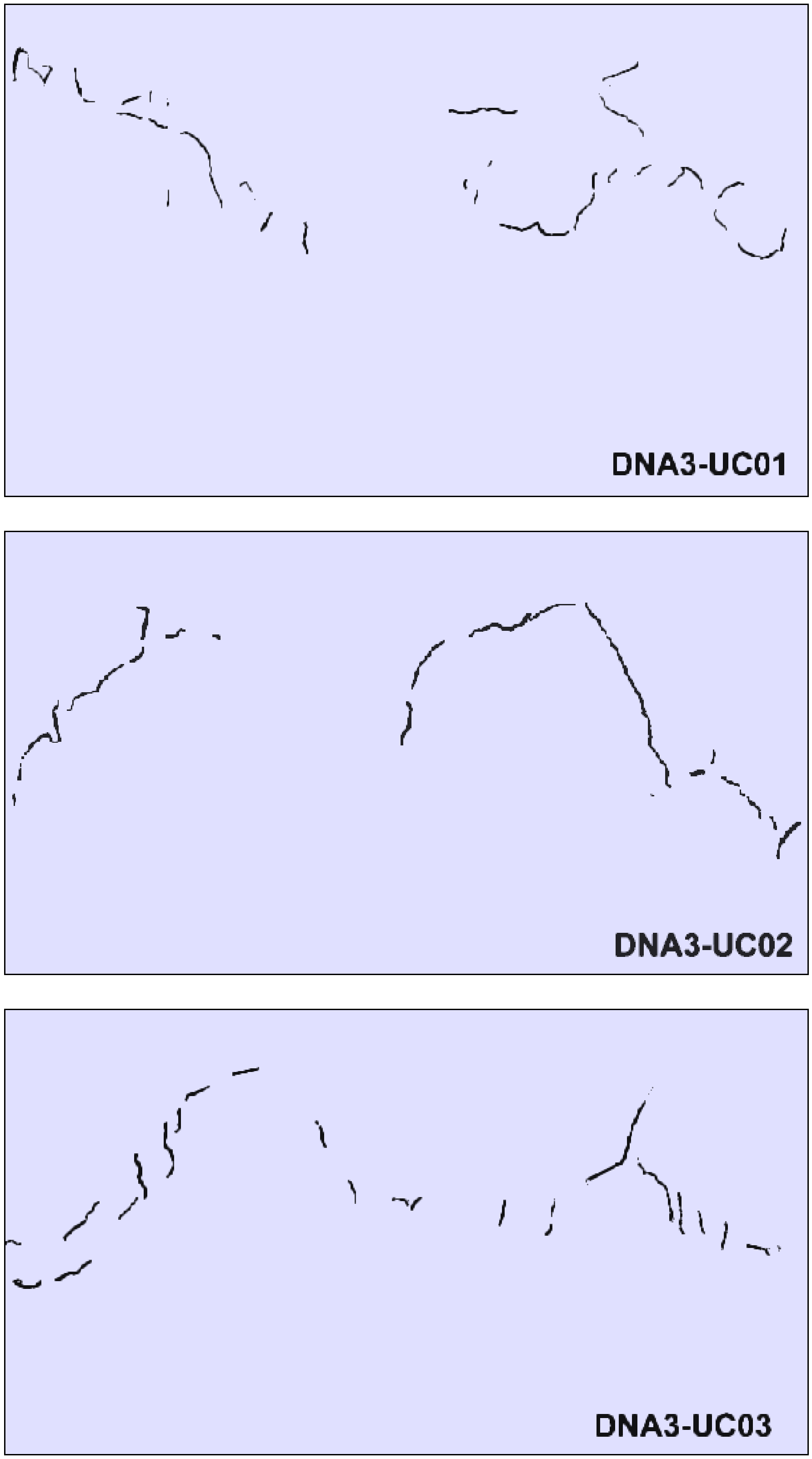

Figure 10. Unwrapped images of the induced fracture traces for frozen soil specimens subjected to unconfined uniaxial compressive stresses.

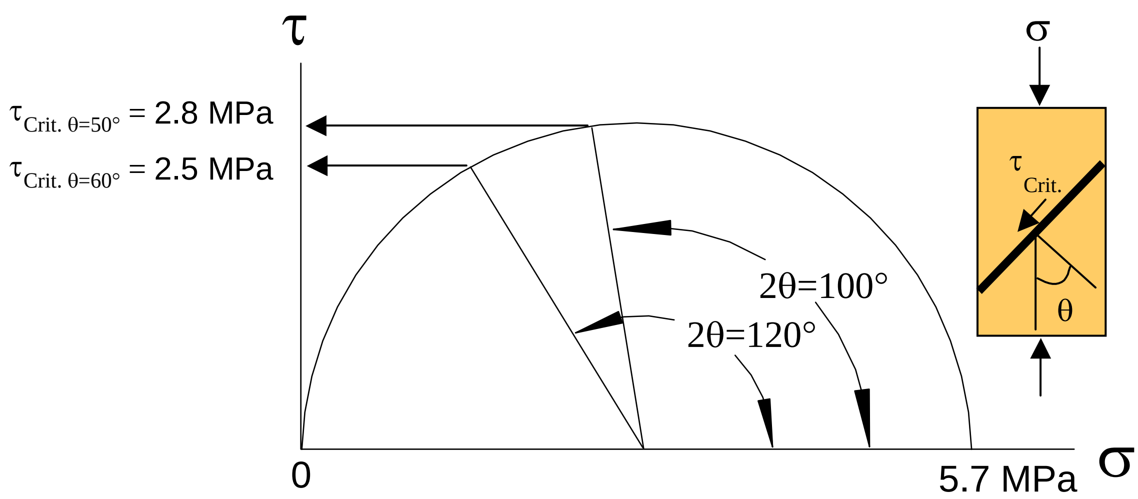

Figure 11. Mohr circle showing the critical shear stress necessary for sliding along the fused surface with θ=50 and 60°.

Table 5. Uniaxial compressive strength of the artificial frozen soil with or without fused interface.

Specimen No.	Specimen Type	Diameter **D** (mm)	Length **L** (mm)	Max. Load **P** (kN)	Mean Temperature (°C)	Uniaxial Compressive Strength C_o (MPa)
DNA3-UC01	Intact	54	113	14.4	-25.4	6.38
DNA3-UC02	Intact	43	93	7.8	-25.8	5.27
DNA3-UC03	Intact	43	93	8.1	-26.8	5.47
					Average	**5.71**
DNA3-UCF01	Fused (θ =50°)	54	96	11.8	-27.0	5.23
DNA3-UCF02	Fused (θ =50°)	54	97	16.1	-27.4	7.14
DNA3-UCF03	Fused (θ =50°)	53	124	11.9	-27.2	5.33
DNA3-UCF04	Fused (θ =50°)	44	88	9.3	-25.4	5.99
DNA3-UCF05	Fused (θ =50°)	44	89	9.4	-24.9	6.06
DNA3-UCF06	Fused (θ =50°)	44	90	6.8	-25.8	4.38
DNA3-UCF07	Fused (θ =60°)	44	95	8.8	-25.6	5.67
DNA3-UCF08	Fused (θ =60°)	44	90	8.0	-26.3	5.16
					Average	**5.62**

Note: θ is the angle between the axial load and the plane perpendicular to the fused surface
Stroke rate = 0.05 mm/s was used.

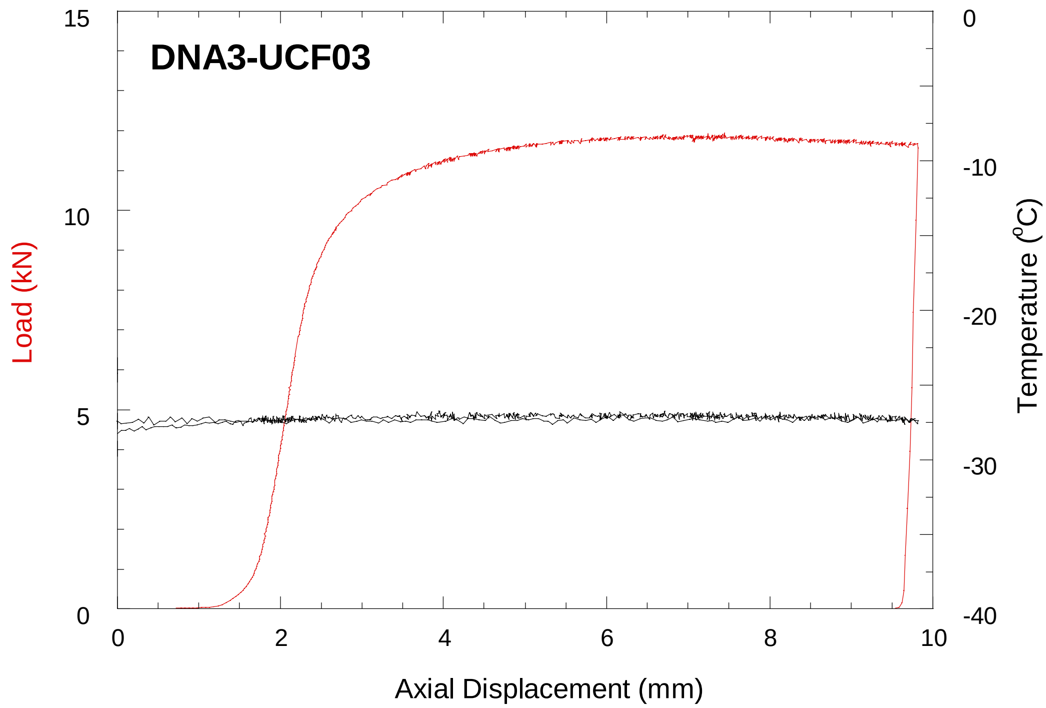

Figure 12. Typical displacement vs. load plot from unconfined uniaxial compression of fused frozen soil specimen with θ=50°.

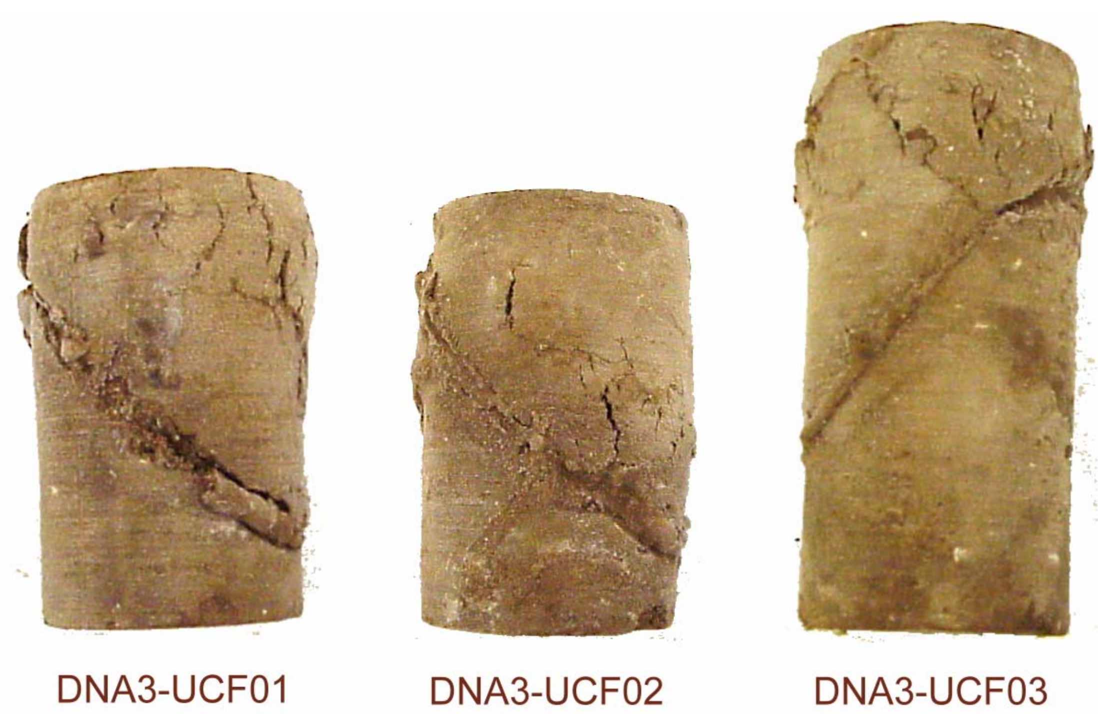

Figure 13. Fused frozen soil specimens (θ=50°) loaded under unconfined uniaxial compression. New fractures were formed either parallel or conjugate to the fused interface.

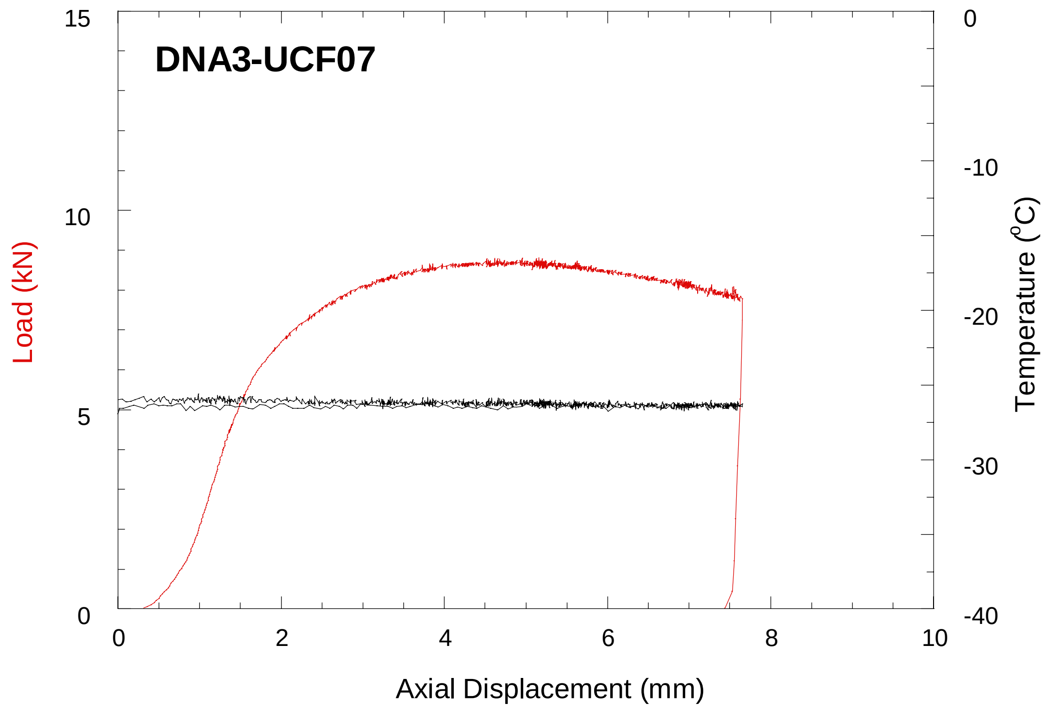

Figure 14. Typical displacement vs. load plot from unconfined uniaxial compression of fused frozen soil specimen with θ=60°.

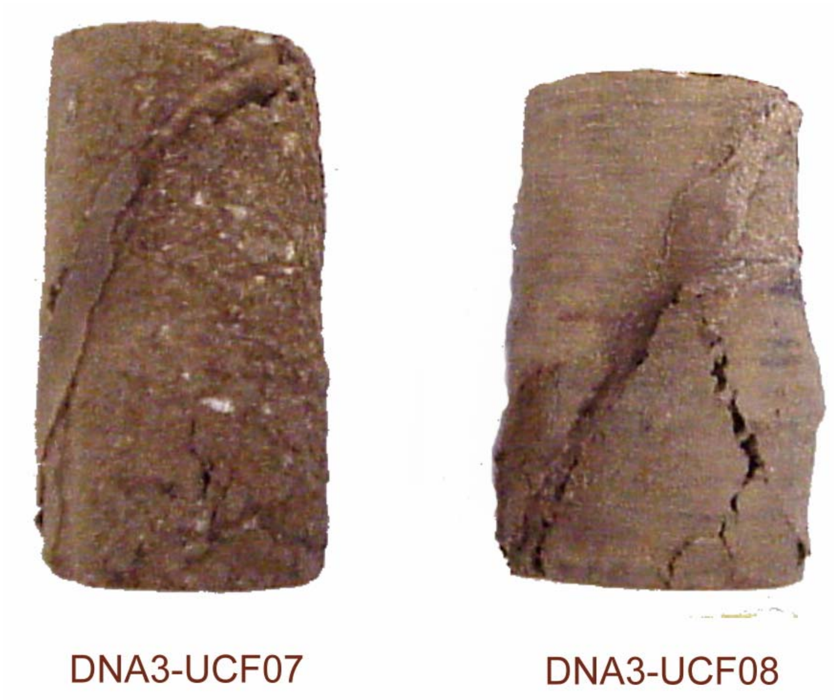

Figure 15. Fused frozen soil specimens (θ=60°) loaded under unconfined uniaxial compression. Fractures were formed conjugate to the fused interface.

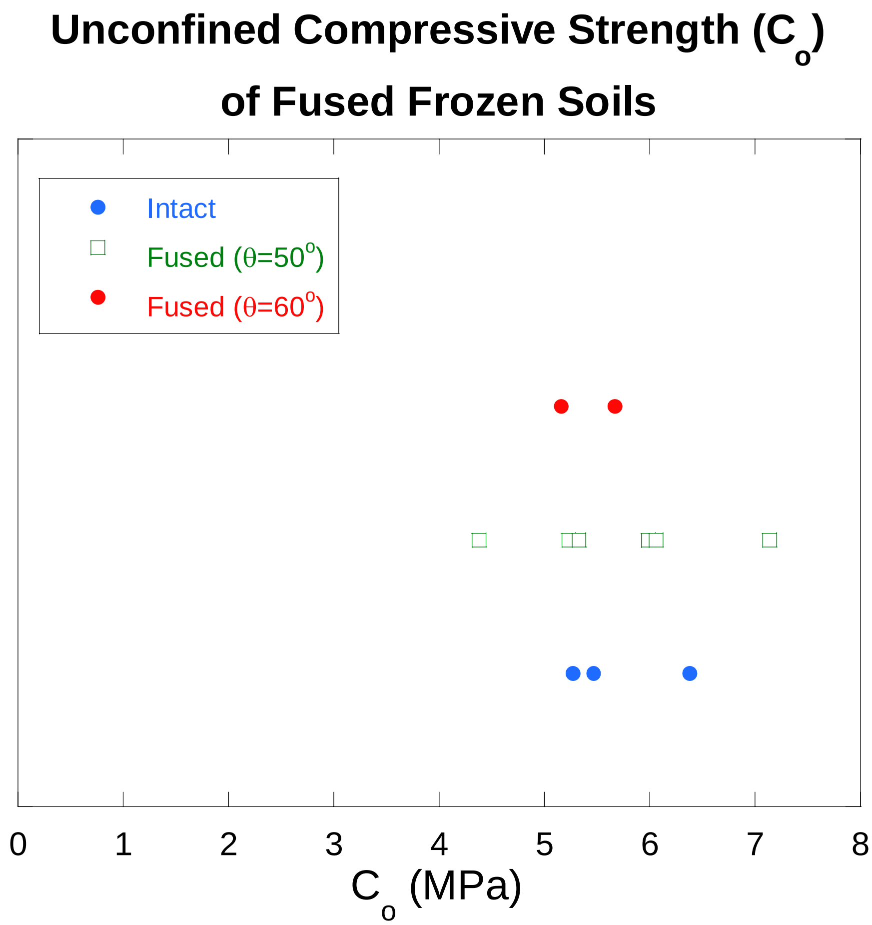

Figure 16. Unconfined compressive strength (C_o) of the intact and fused frozen soil specimens (θ=50 and 60°).

4. Conclusions

The three phase experimental program outlined in this report has been designed to investigate the performance of the artificial frozen soil with fused interface. The results from each phase of the experiments can be summarized as follows:

- Out of four tested mixtures, *DNA3 (perlite+soil+water)* best represents the mechanical properties of the Alaskan Frozen Soil.
- The healed-interface by the *same soil layer* sandwiched between two blocks of the same material yields the highest "Brazilian" tensile strength (T_{br}) of the interface consistently.
- The frictional strength of the healed-interface by the same soil layer appears to *exceed* the shear strength of the intact specimen.

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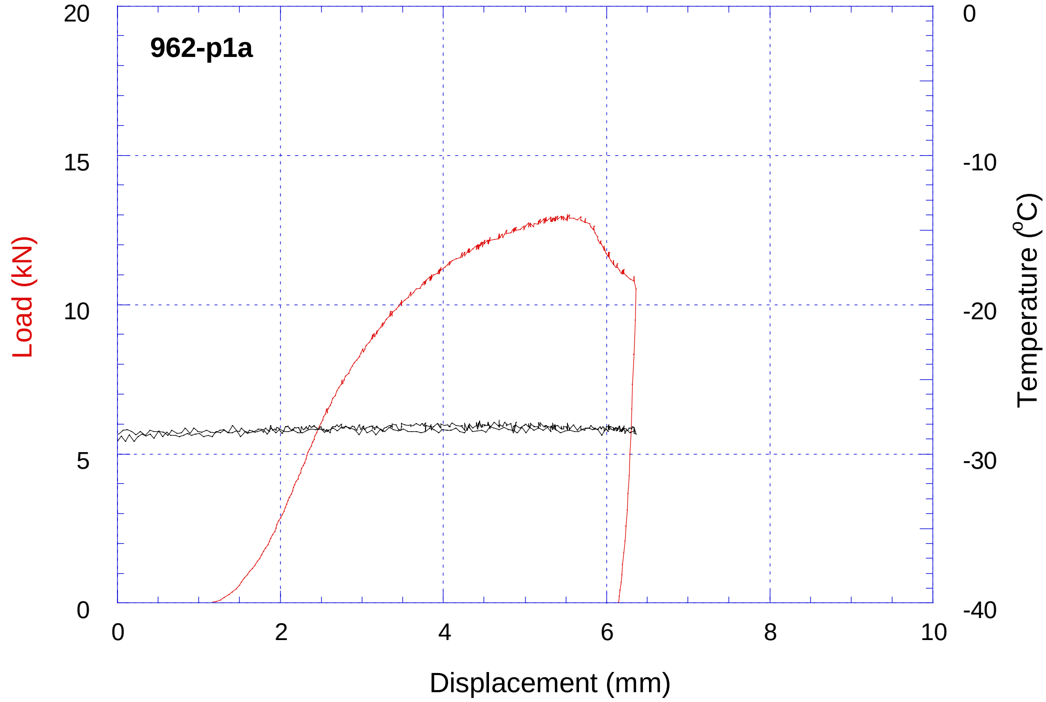
Appendix A

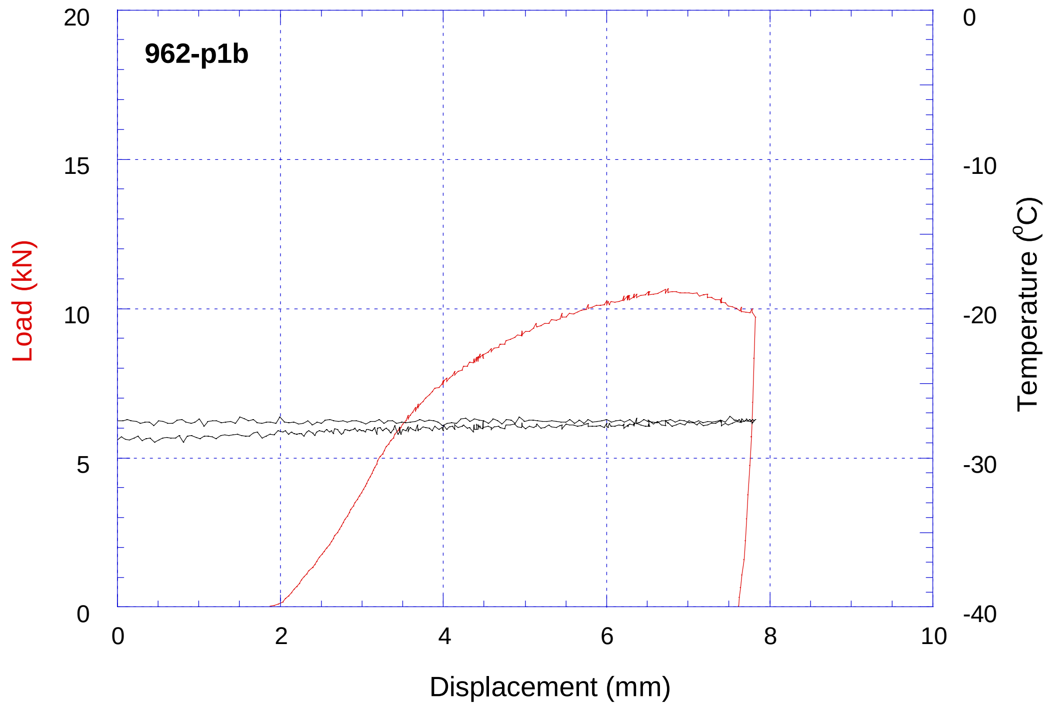
Load, Temperature vs. Displacement plots from "Brazilian" Indirect Tension Tests

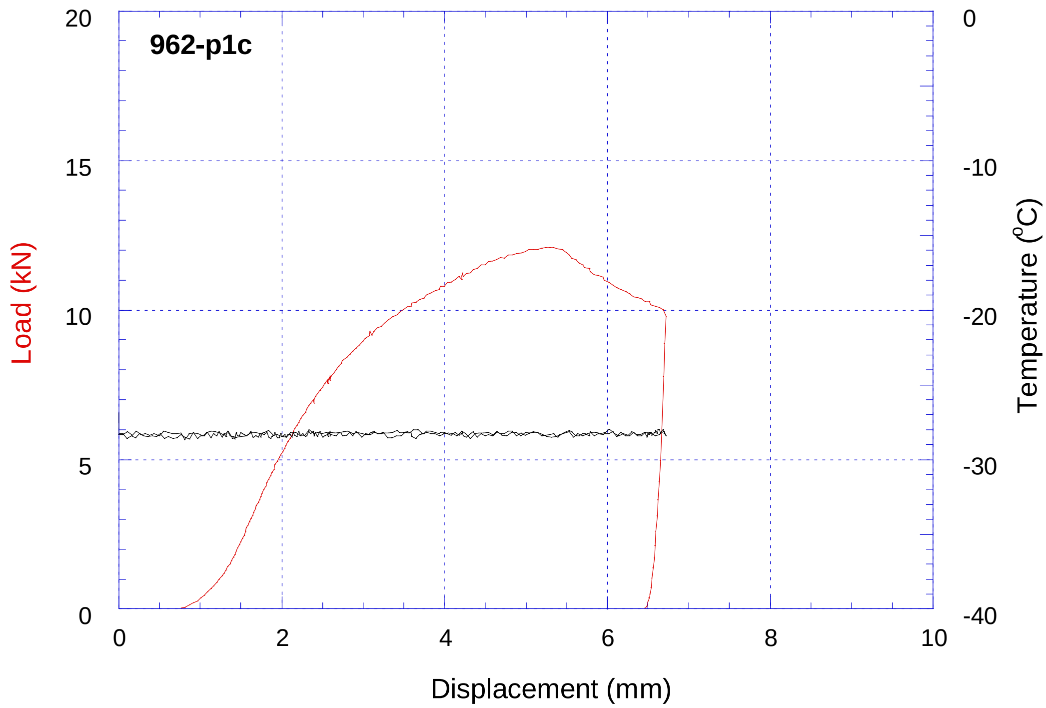
Phase 1-Selection of Soil Mixture

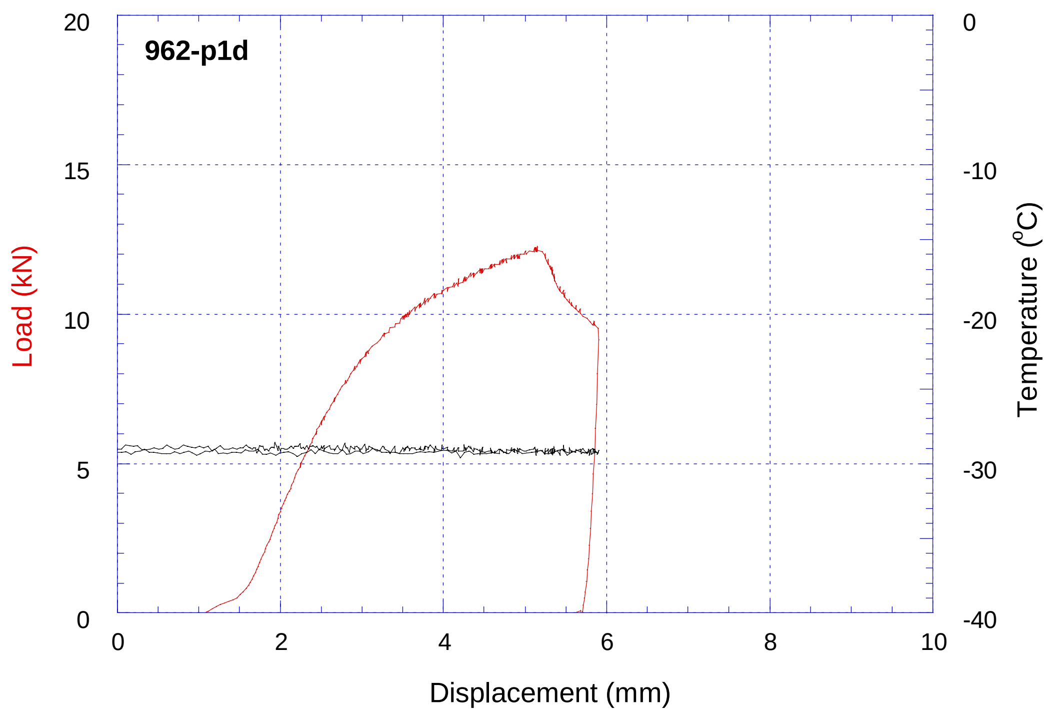
The title of the plot consists of three components:

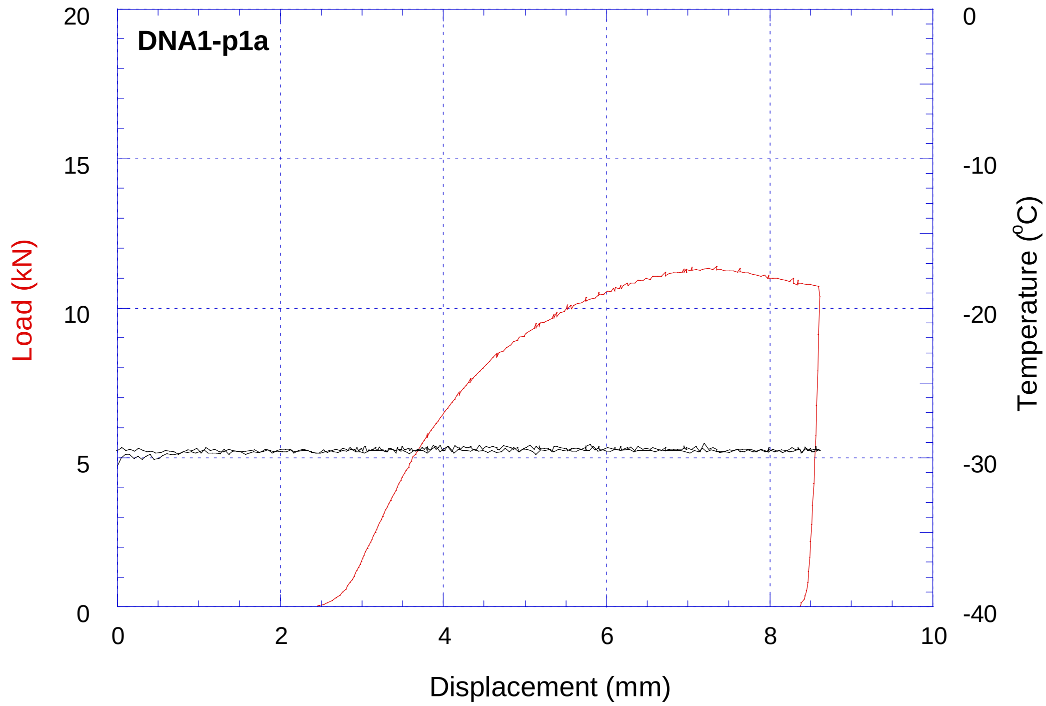
1. **Soil type**
   962, DNA1, DNA2, DNA3
2. **P1 for phase 1**
3. **Specimen designation**
   a,b,c… 01, 02…

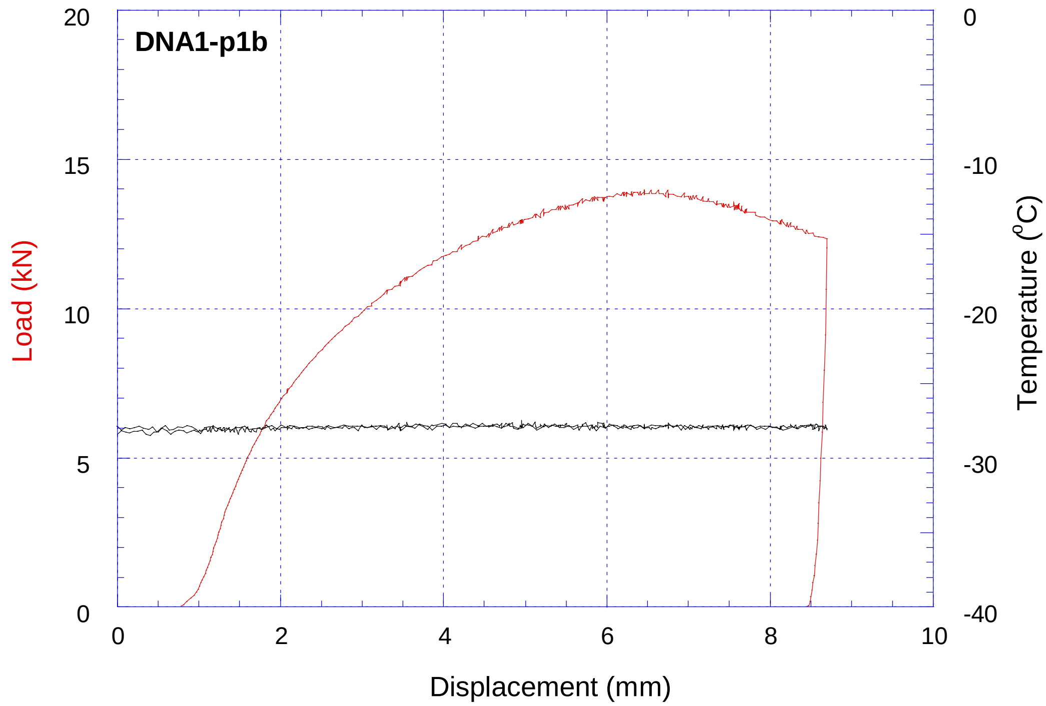

962-p1a
Load (kN)
Temperature (°C)
Displacement (mm)
0
2
4
6
8
10
0
5
10
15
20
-40
-30
-20
-10
0

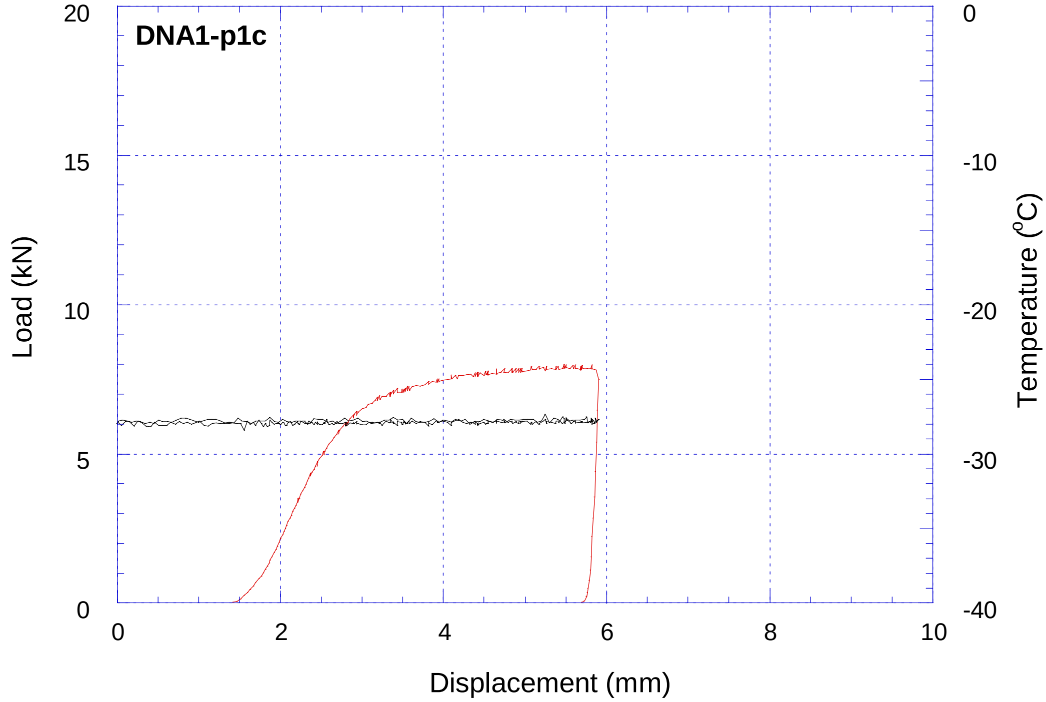

962-p1b
Load (kN)
Temperature (°C)
Displacement (mm)
0
2
4
6
8
10
0
5
10
15
20
-40
-30
-20
-10
0

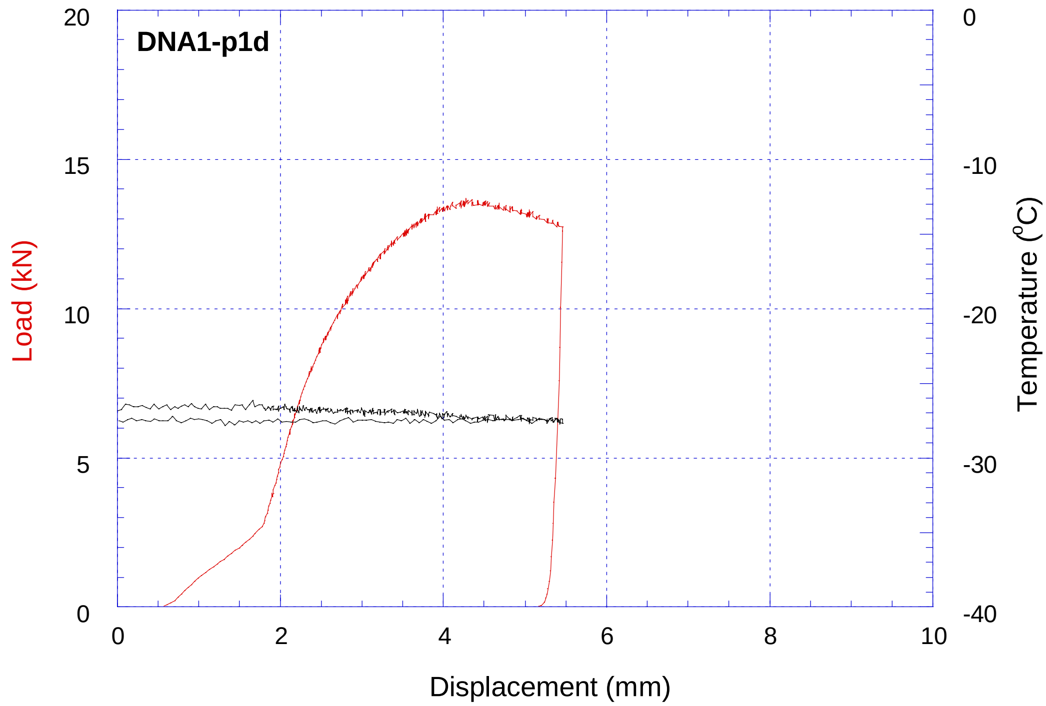

962-p1c
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

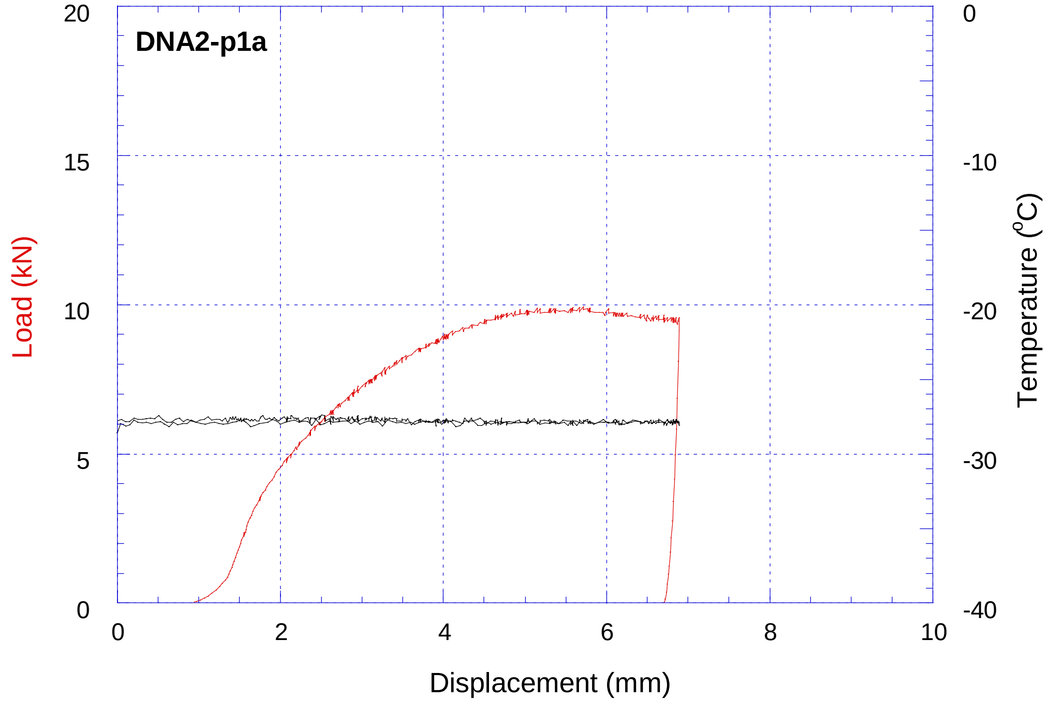

962-p1d
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

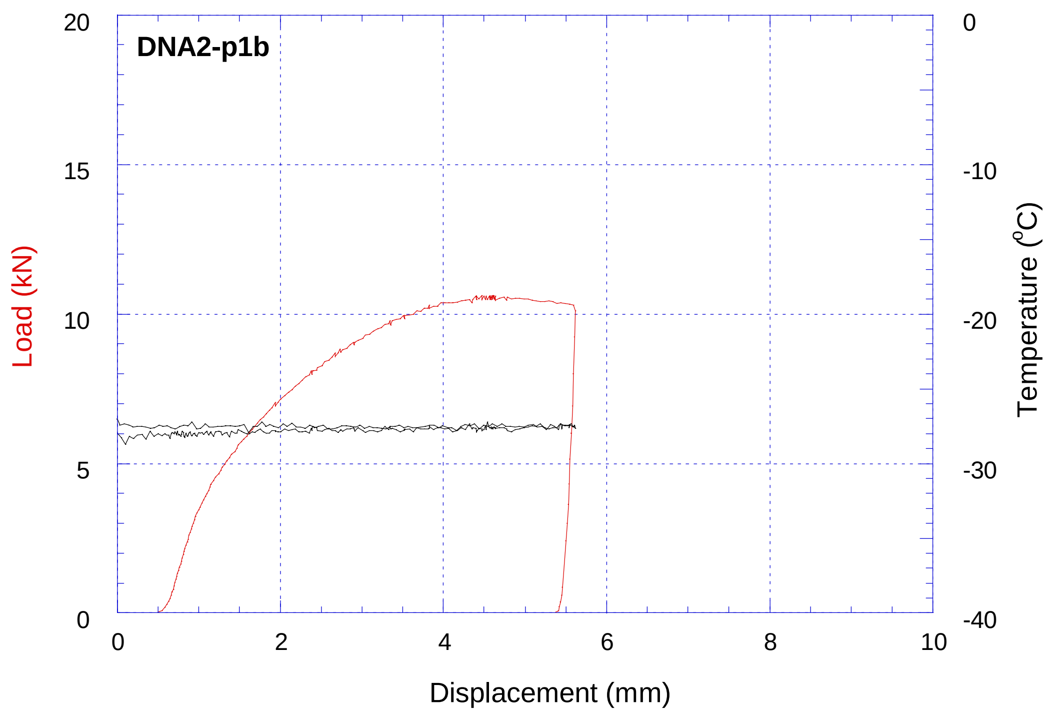

DNA1-p1a
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

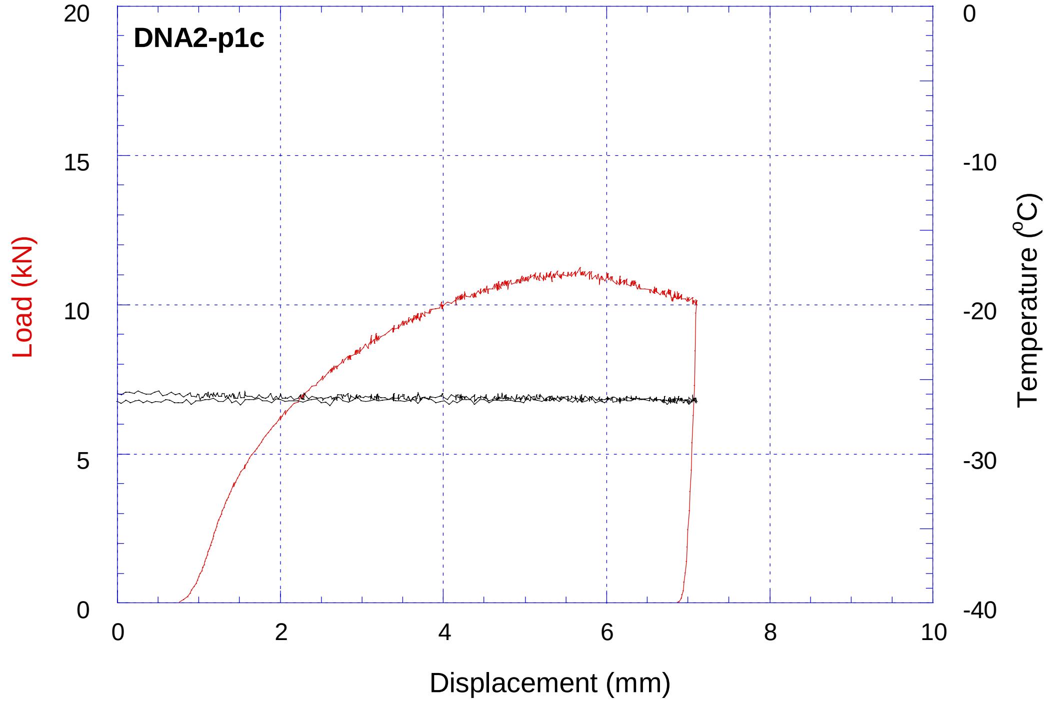

DNA1-p1b
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

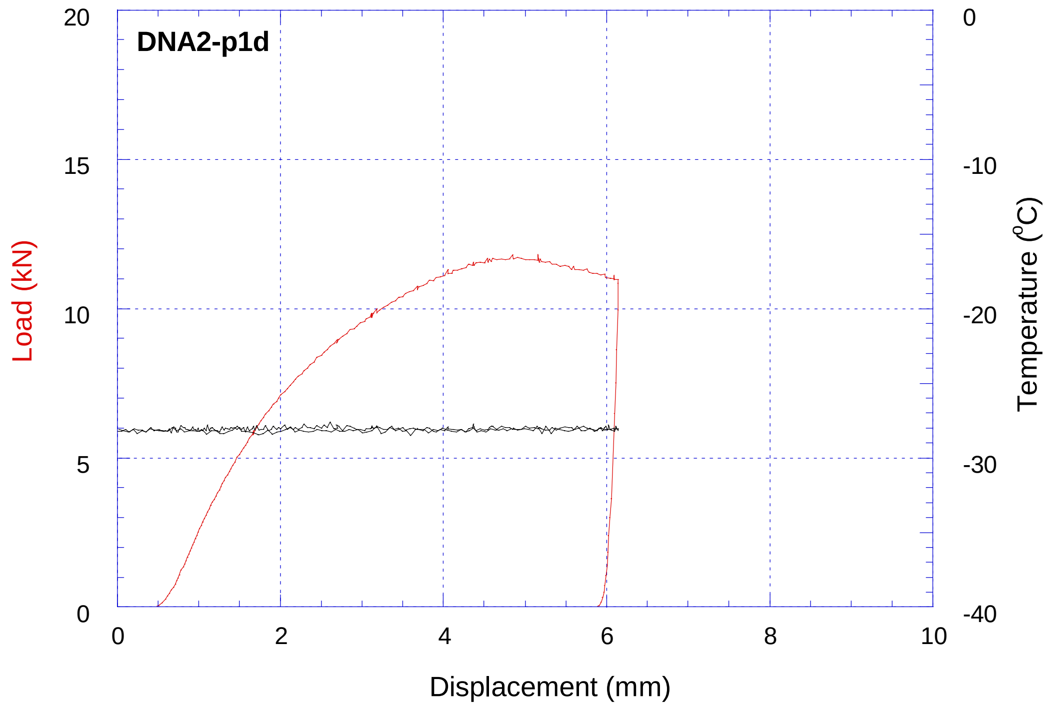

DNA1-p1c
Load (kN)
Temperature (oC)
Displacement (mm)
20
15
10
5
0
-10
-20
-30
-40
2
4
6
8
10

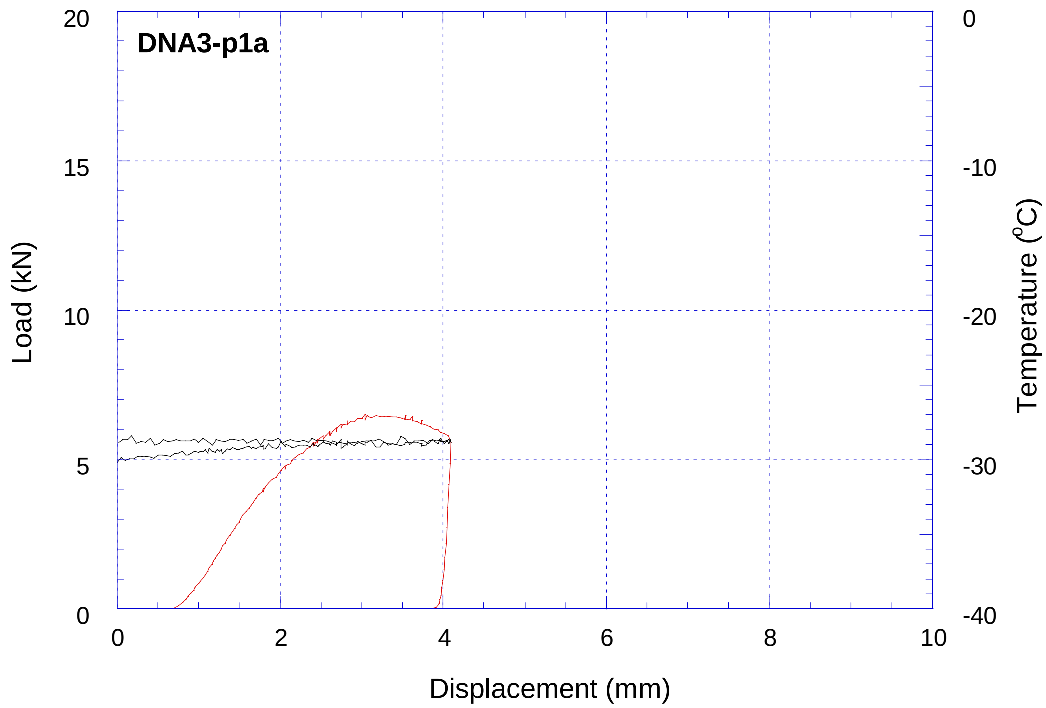

DNA1-p1d
Load (kN)
Temperature (oC)
Displacement (mm)
20
15
10
5
0
-10
-20
-30
-40
2
4
6
8
10

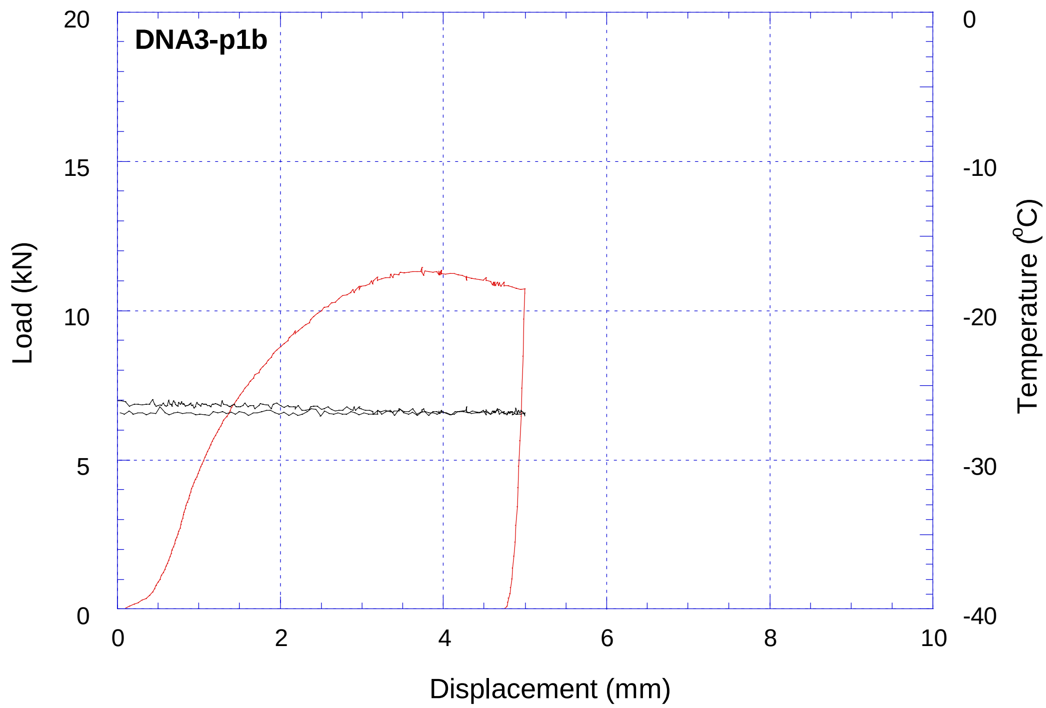

DNA2-p1a
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

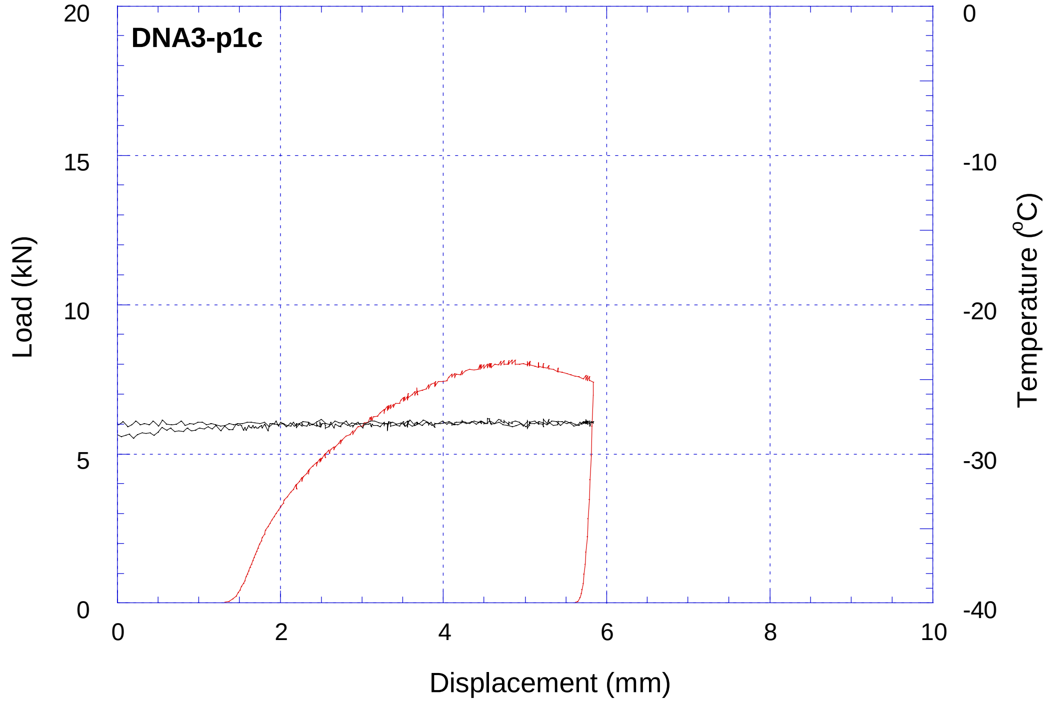

DNA2-p1b
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

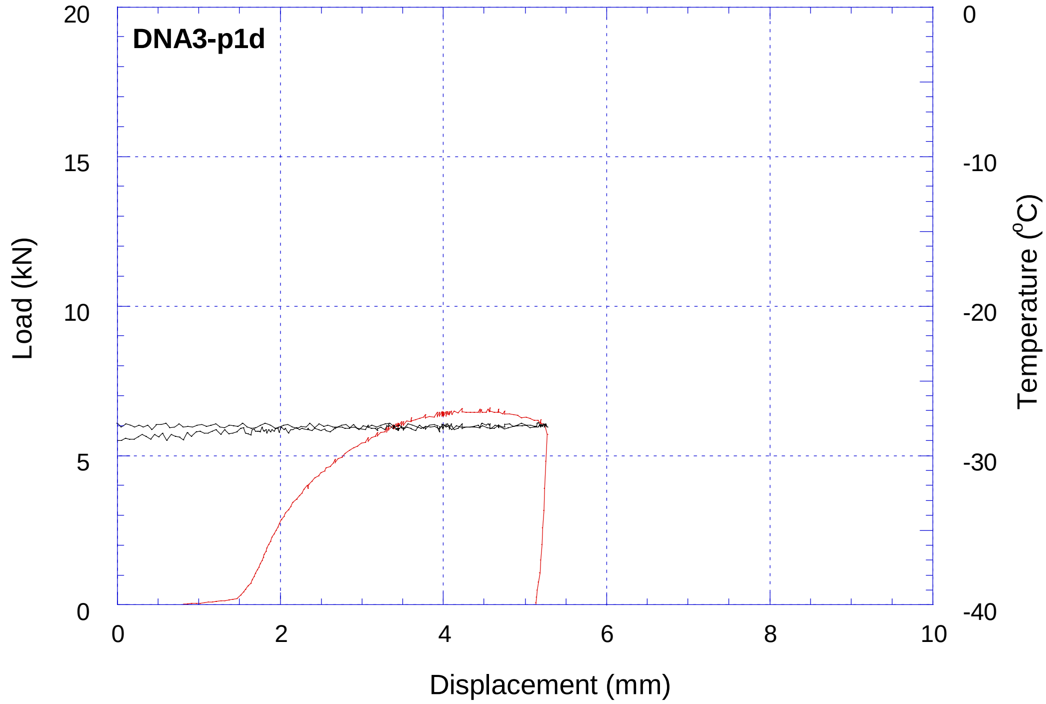

DNA2-p1c
Load (kN)
0
5
10
15
20
Temperature (°C)
0
-10
-20
-30
-40
0
2
4
6
8
10
Displacement (mm)


DNA2-p1d
Load (kN)
0
5
10
15
20
Temperature (°C)
0
-10
-20
-30
-40
0
2
4
6
8
10
Displacement (mm)


DNA3-p1a
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10


DNA3-p1b
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10


DNA3-p1c
Load (kN)
Temperature (oC)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10


DNA3-p1d
Load (kN)
Temperature (oC)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

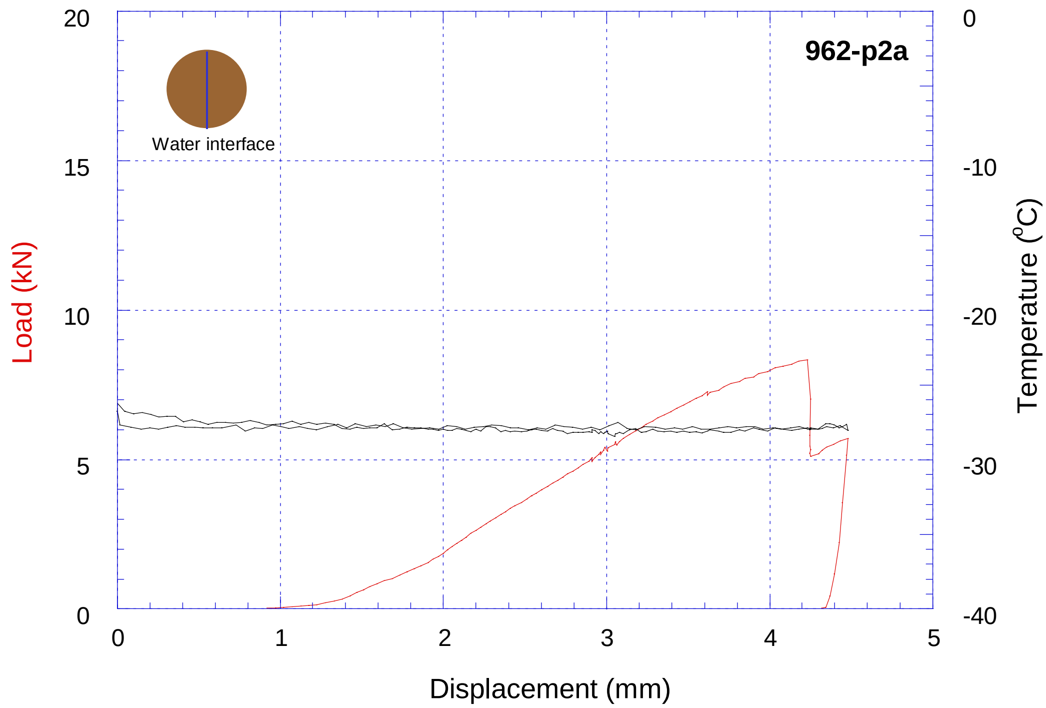
Appendix B

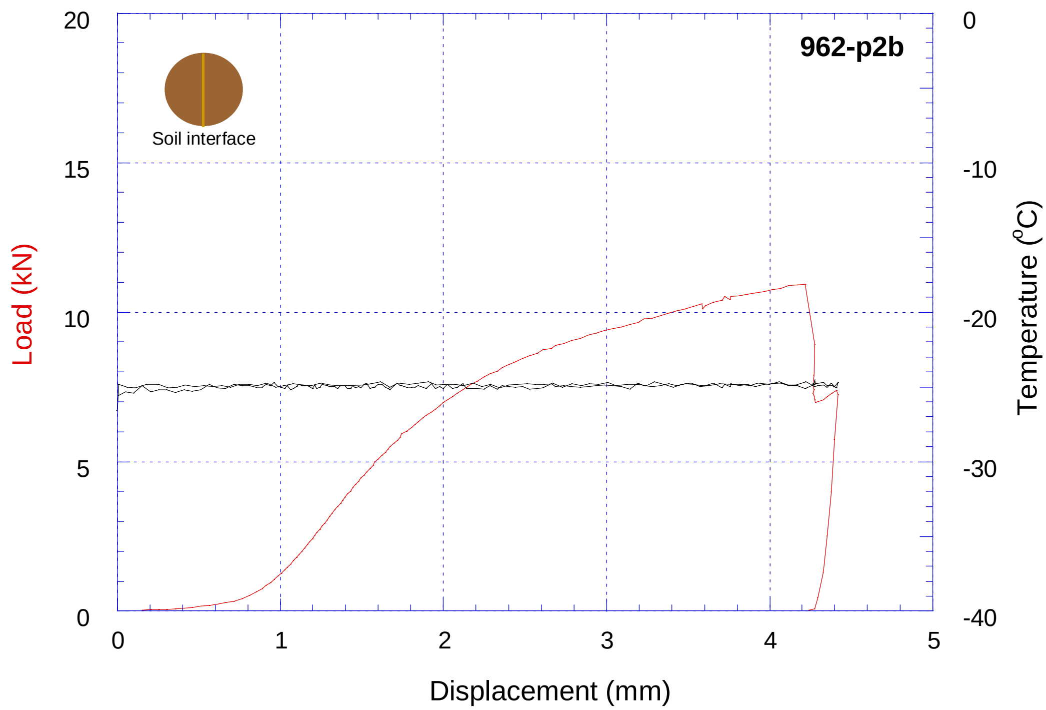
Load, Temperature vs. Displacement plots from "Brazilian" Indirect Tension Tests

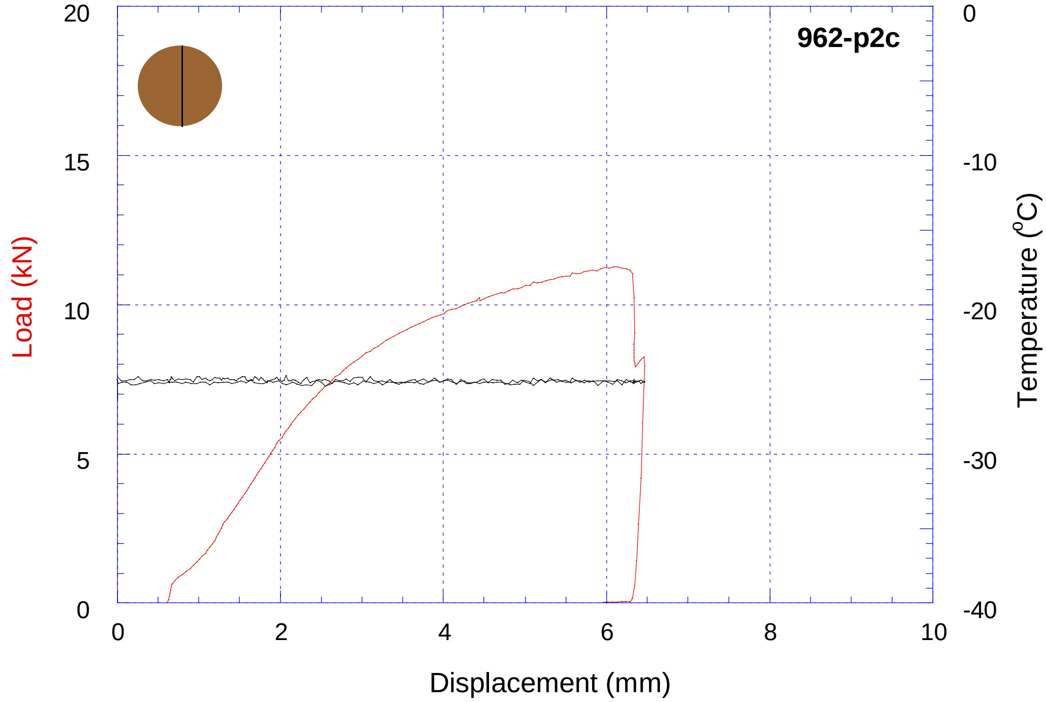
Phase 2-Selection of Fusing Method

The title of the plot consists of three components:

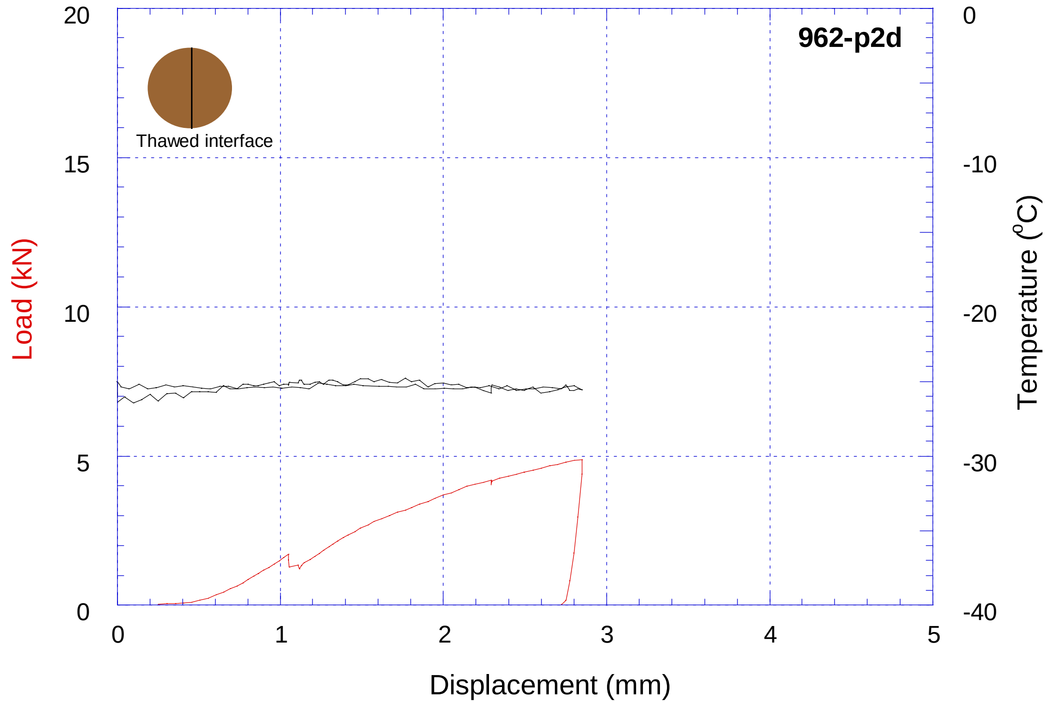
1. **Soil type**
   962, DNA1, DNA2, DNA3
2. **P2 for phase 2**
3. **Specimen designation**
   a,b,c… 01, 02…


962-p2a
Water interface
Load (kN)
Temperature (oC)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
1
2
3
4
5


962-p2b
Soil interface
Load (kN)
Temperature (oC)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
1
2
3
4
5



962-p2c
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10



962-p2d
Thawed interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
1
2
3
4
5

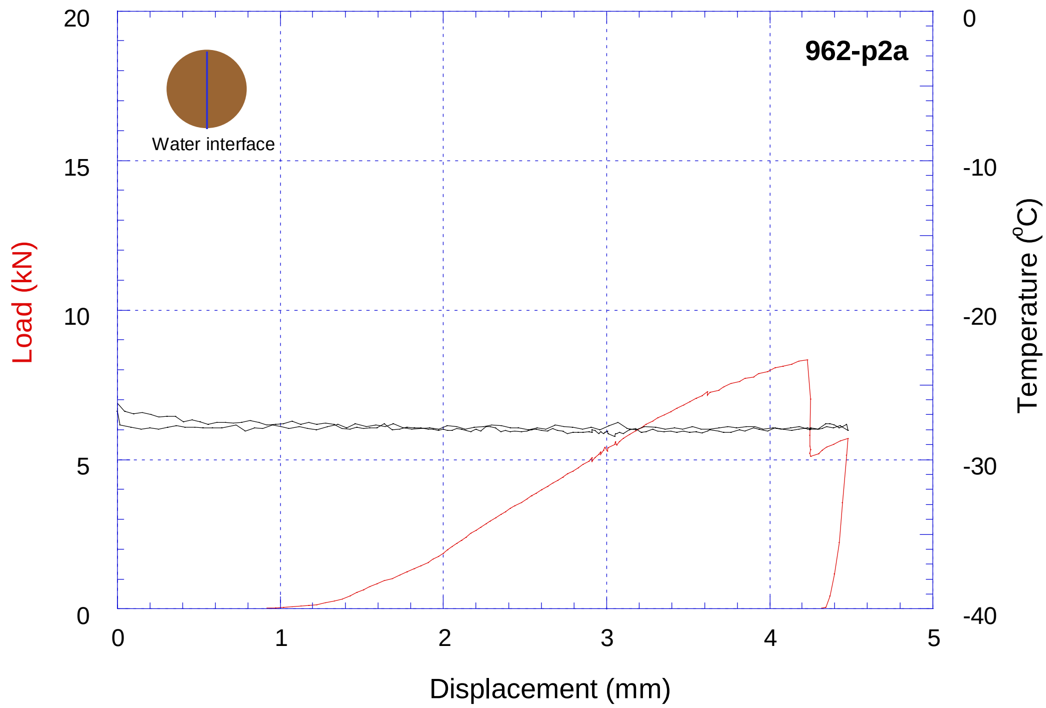
Appendix C

Load, Temperature vs. Displacement plots from "Brazilian" Indirect Tension Tests

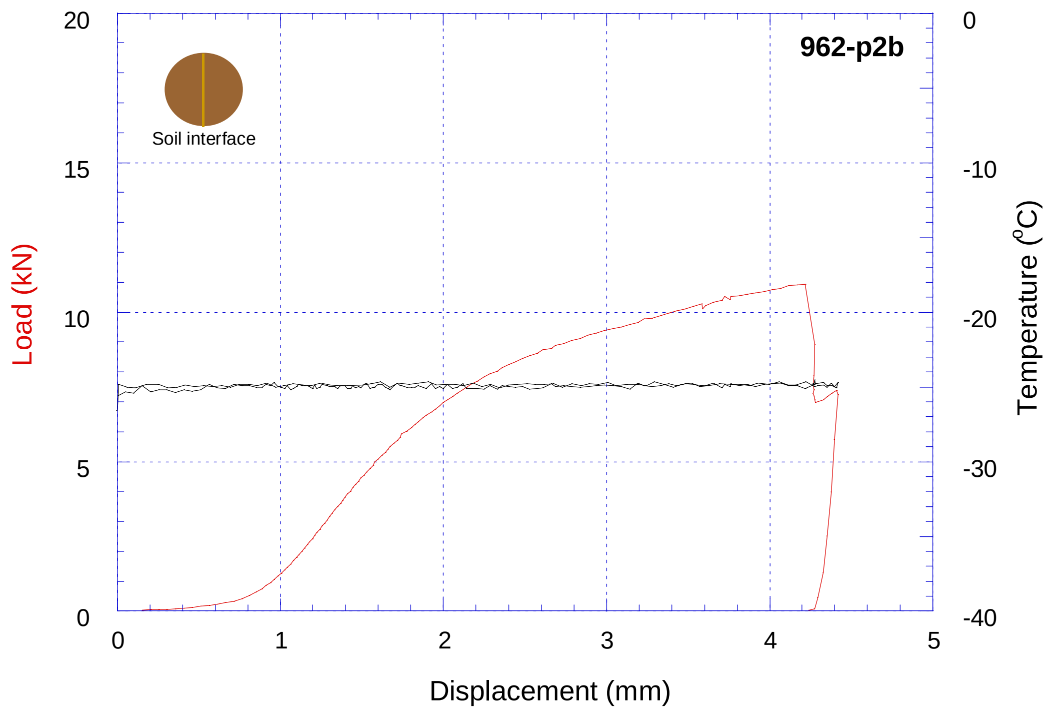
Phase 3-Evaluation of fused interface

The title of the plot consists of three components:

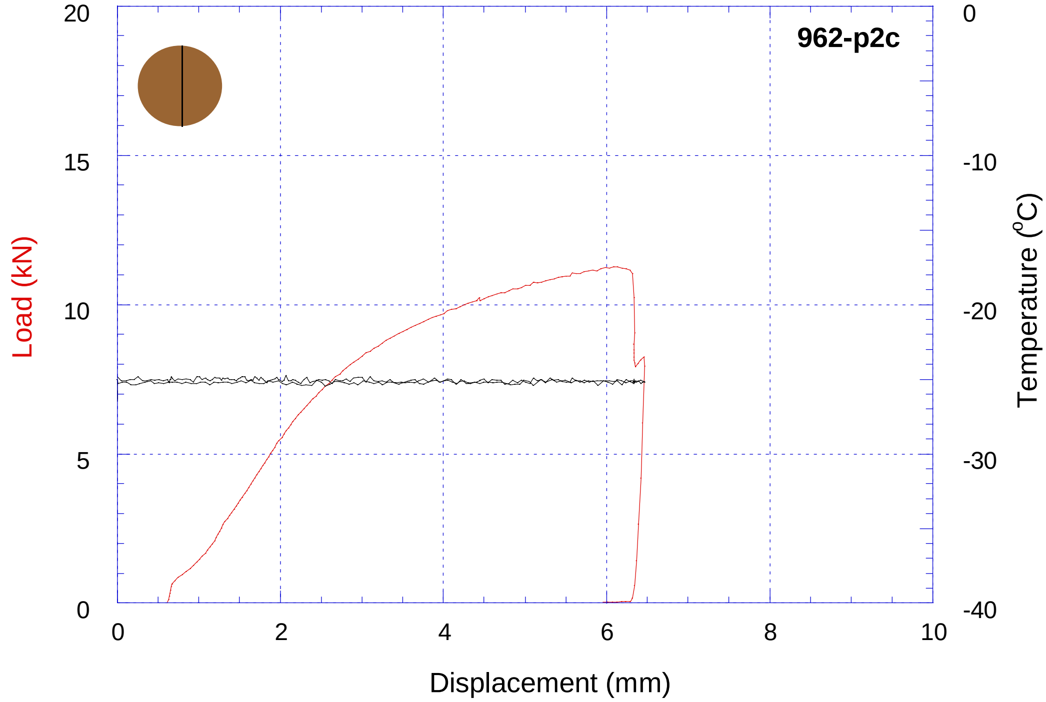
1. **Soil type**
   962, DNA1, DNA2, DNA3
2. **P3 for phase 3**
3. **Specimen designation**
   a,b,c… 01, 02…

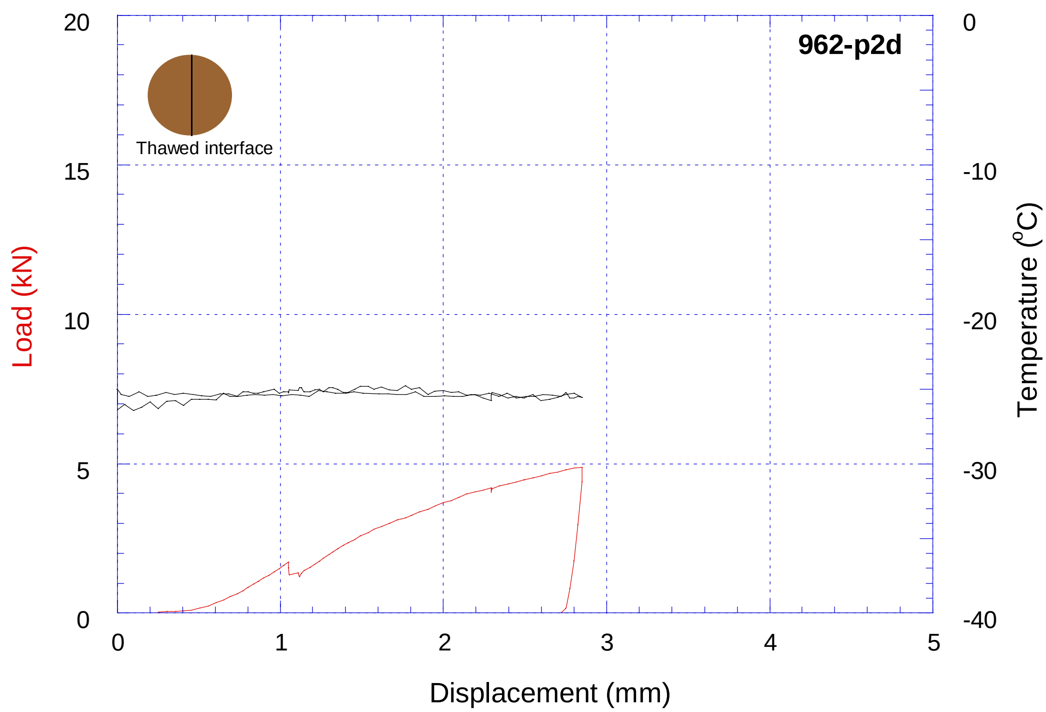


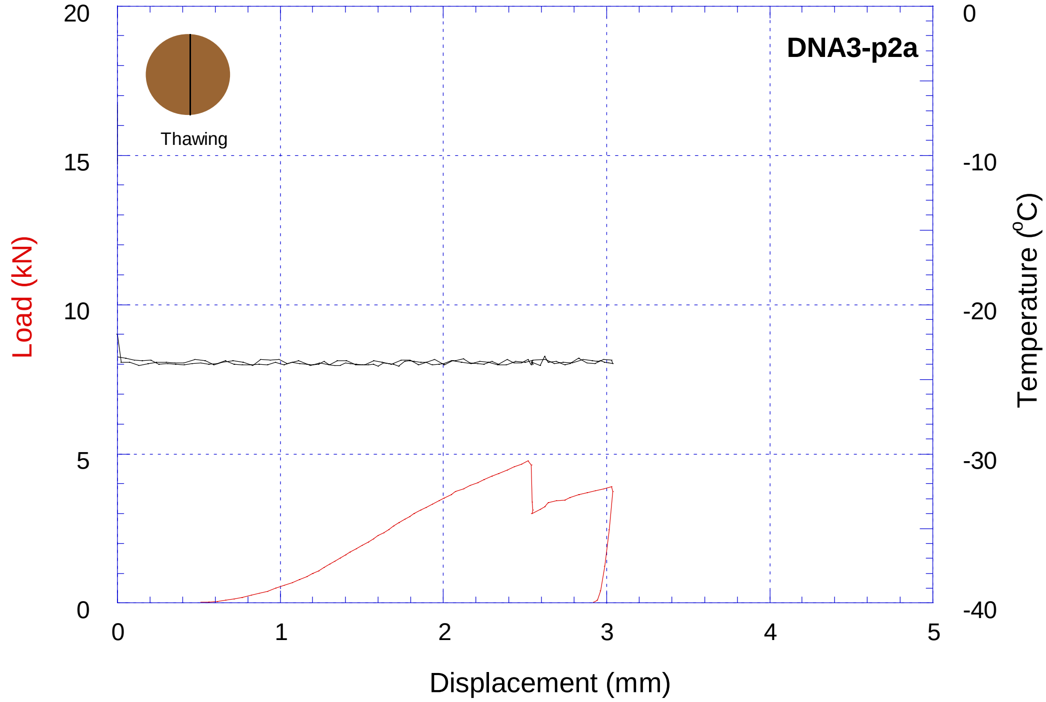
962-p2a
Water interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
1
2
3
4
5



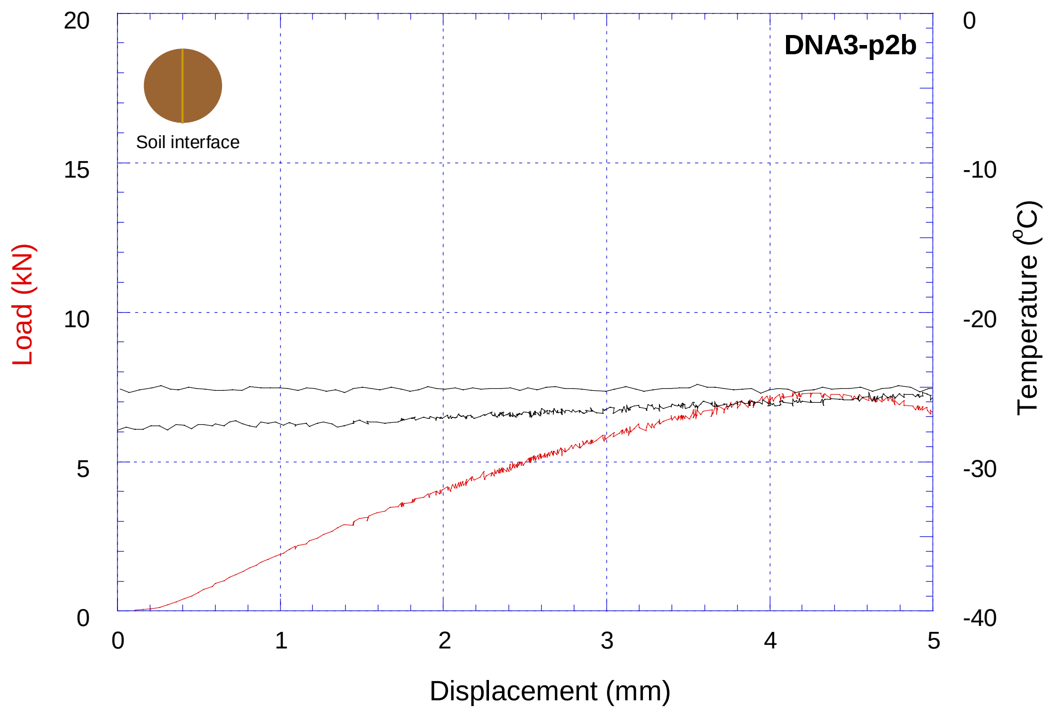
962-p2b
Soil interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
1
2
3
4
5


962-p2c
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

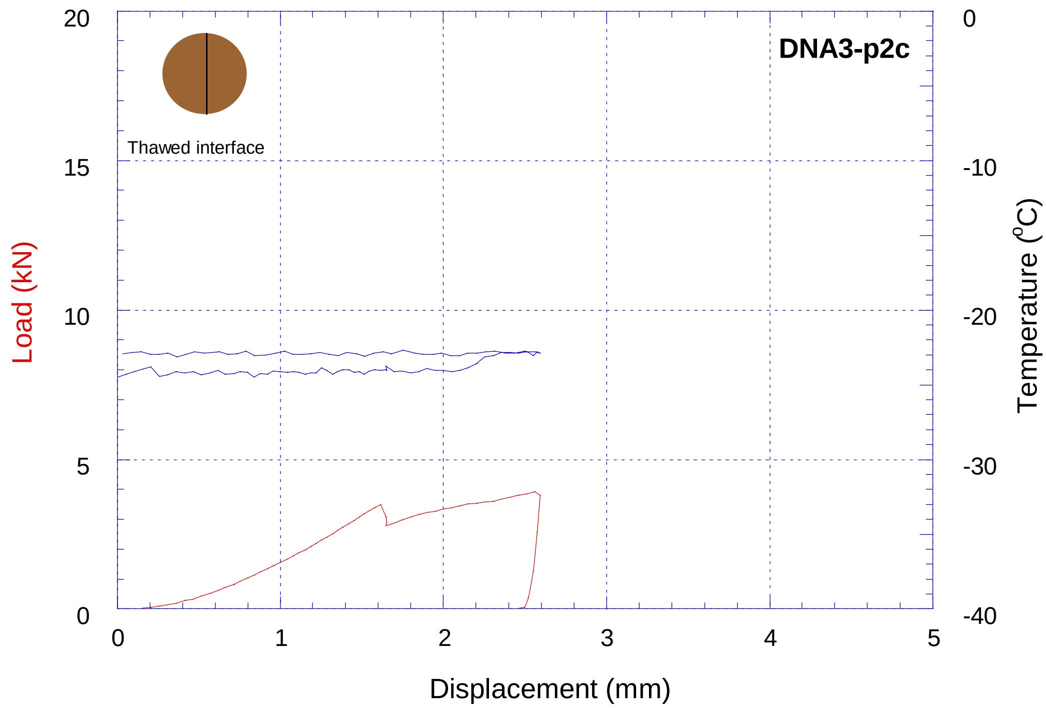

962-p2d
Thawed interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
1
2
3
4
5

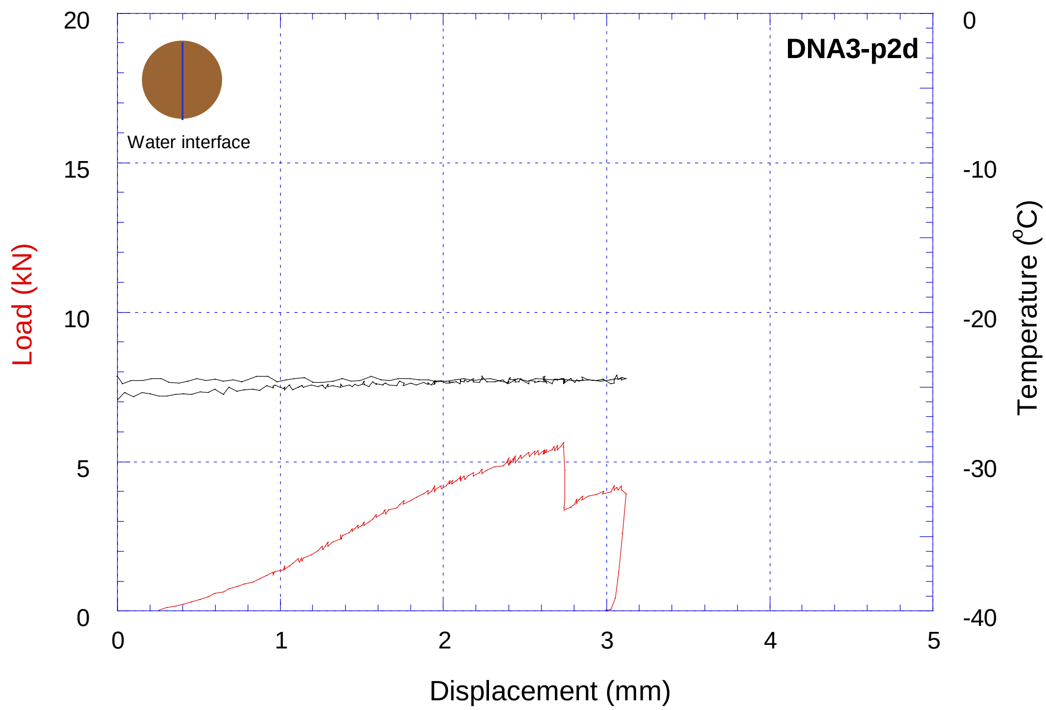


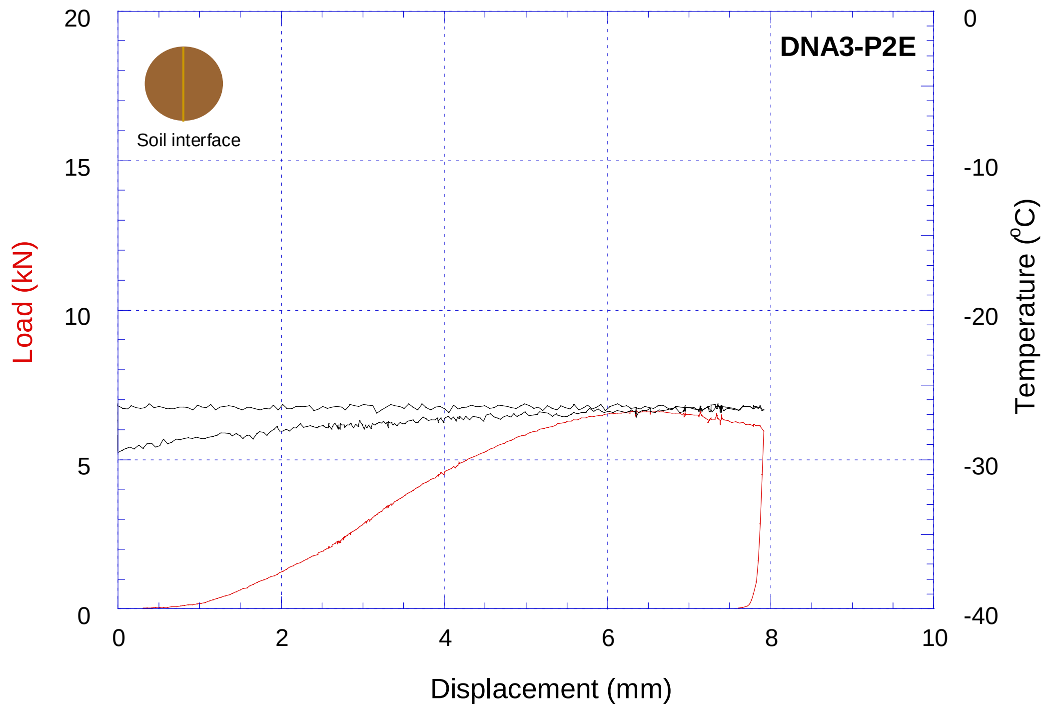
DNA3-p2a
Thawing
Load (kN)
Temperature (°C)
Displacement (mm)

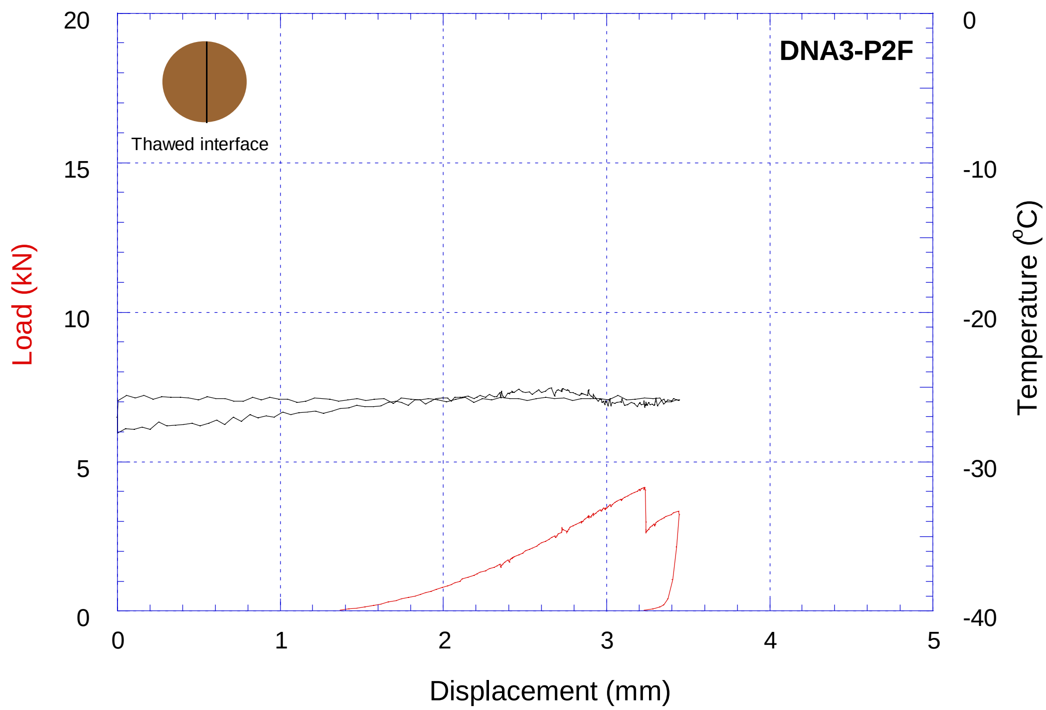


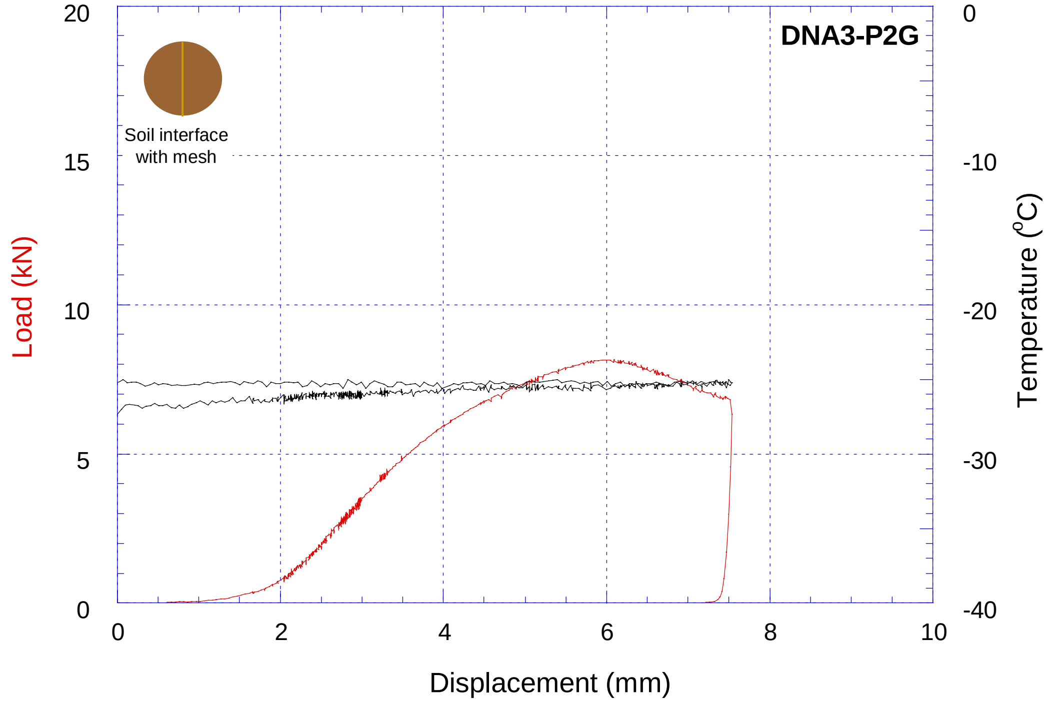
DNA3-p2b
Soil interface
Load (kN)
Temperature (°C)
Displacement (mm)


DNA3-p2c
Thawed interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
1
2
3
4
5

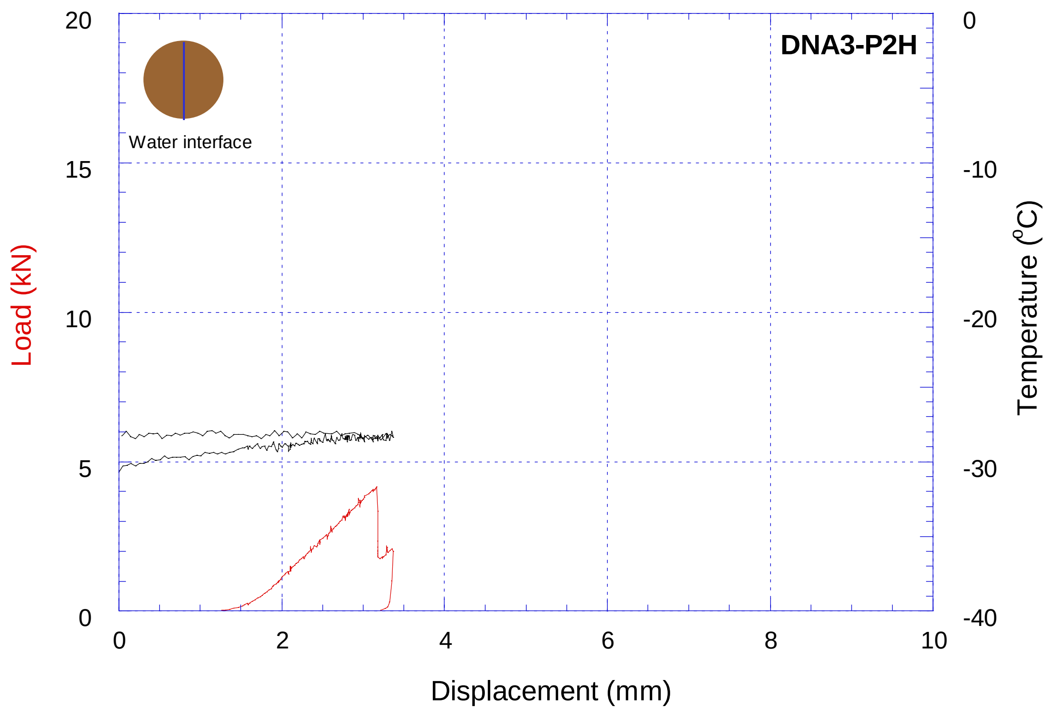

DNA3-p2d
Water interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
1
2
3
4
5


DNA3-P2E
Soil interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

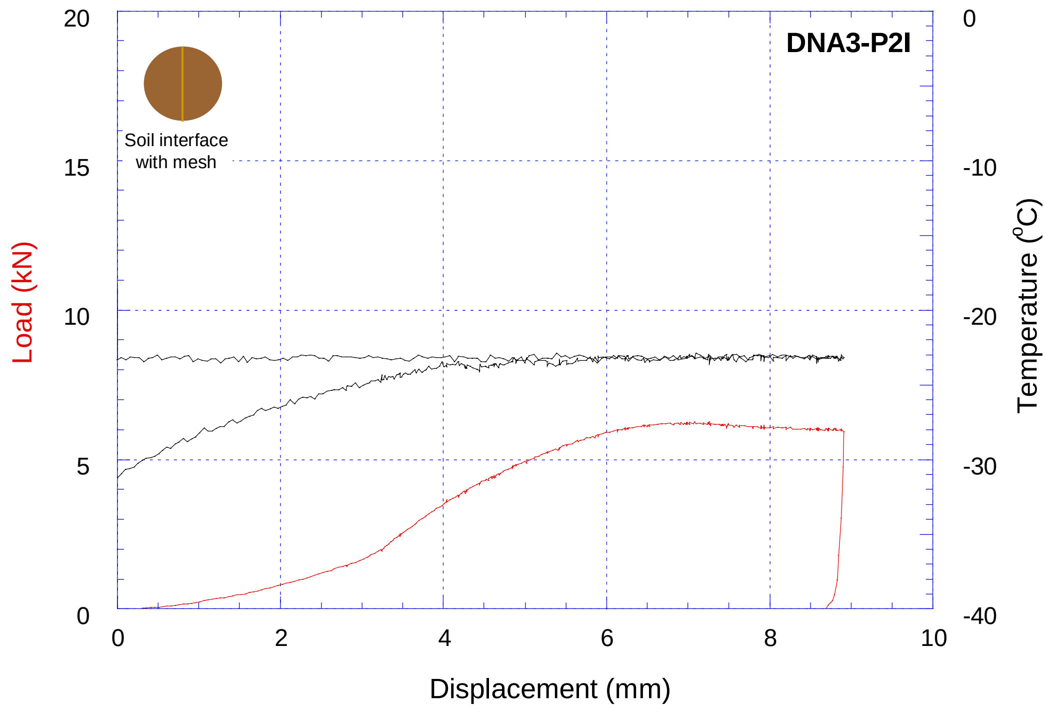

DNA3-P2F
Thawed interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
1
2
3
4
5

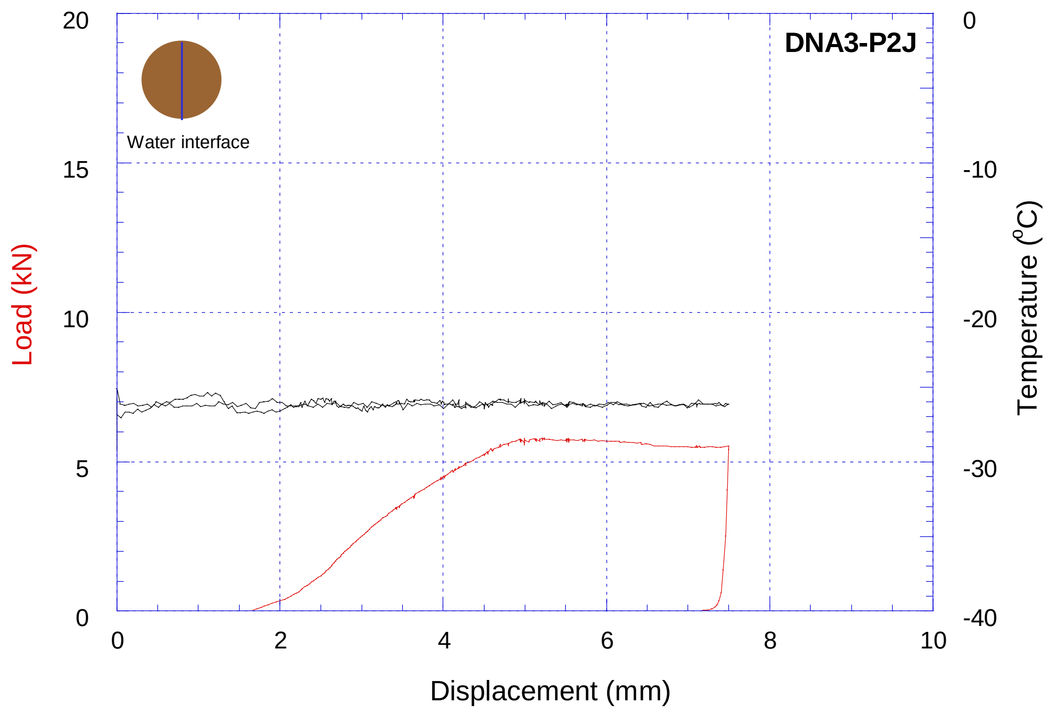


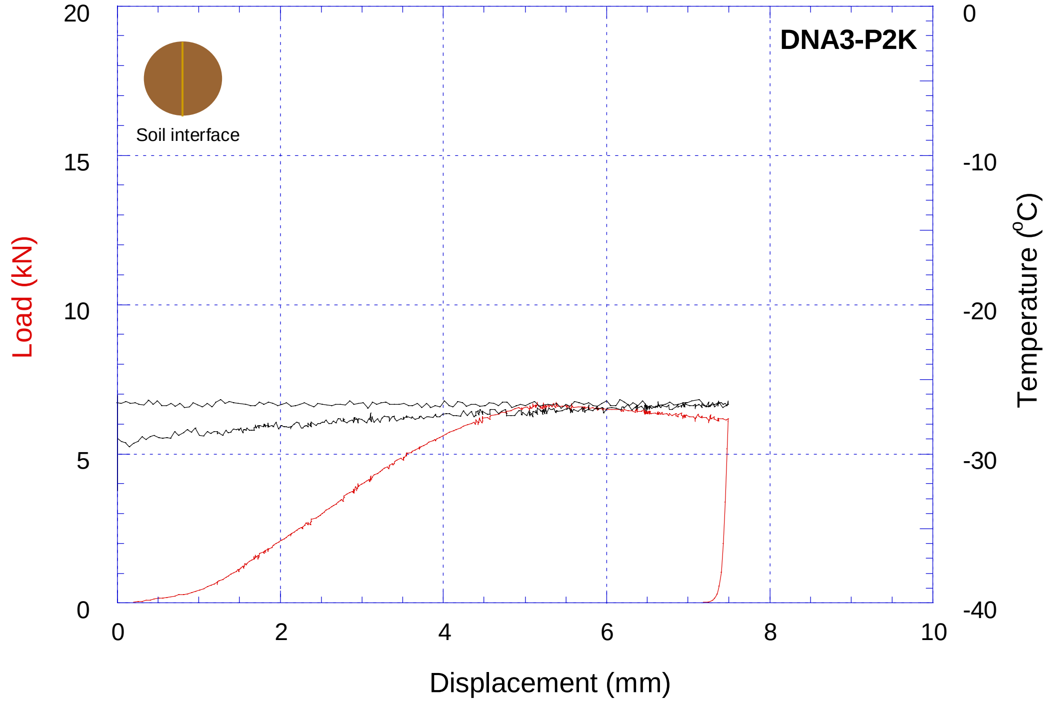
DNA3-P2G
Soil interface
with mesh
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

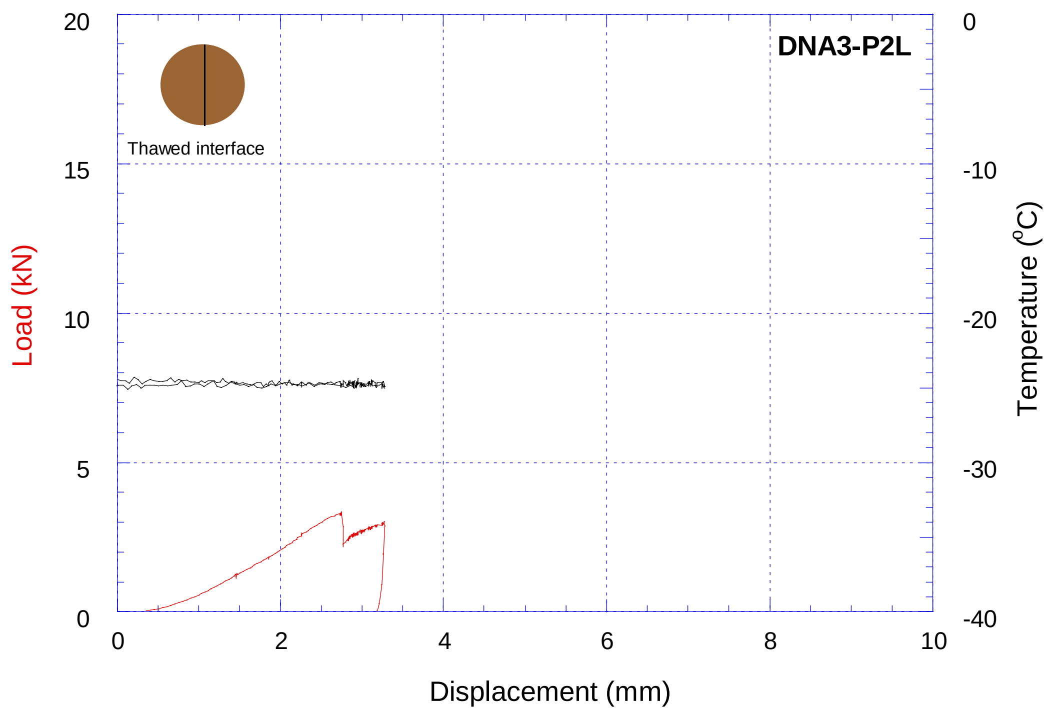


DNA3-P2H
Water interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10


DNA3-P2I
Soil interface
with mesh
Load (kN)
Temperature (°C)
Displacement (mm)
0
5
10
15
20
-40
-30
-20
-10
0
2
4
6
8
10


DNA3-P2J
Water interface
Load (kN)
Temperature (°C)
Displacement (mm)
0
5
10
15
20
-40
-30
-20
-10
0
2
4
6
8
10


DNA3-P2K
Soil interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

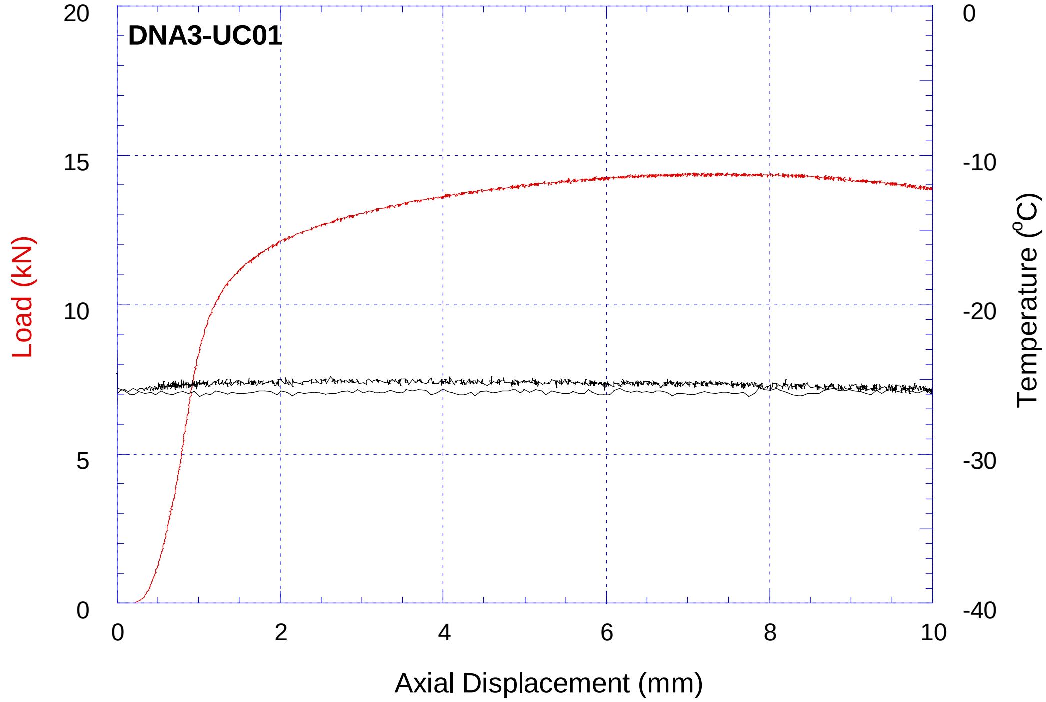

DNA3-P2L
Thawed interface
Load (kN)
Temperature (°C)
Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

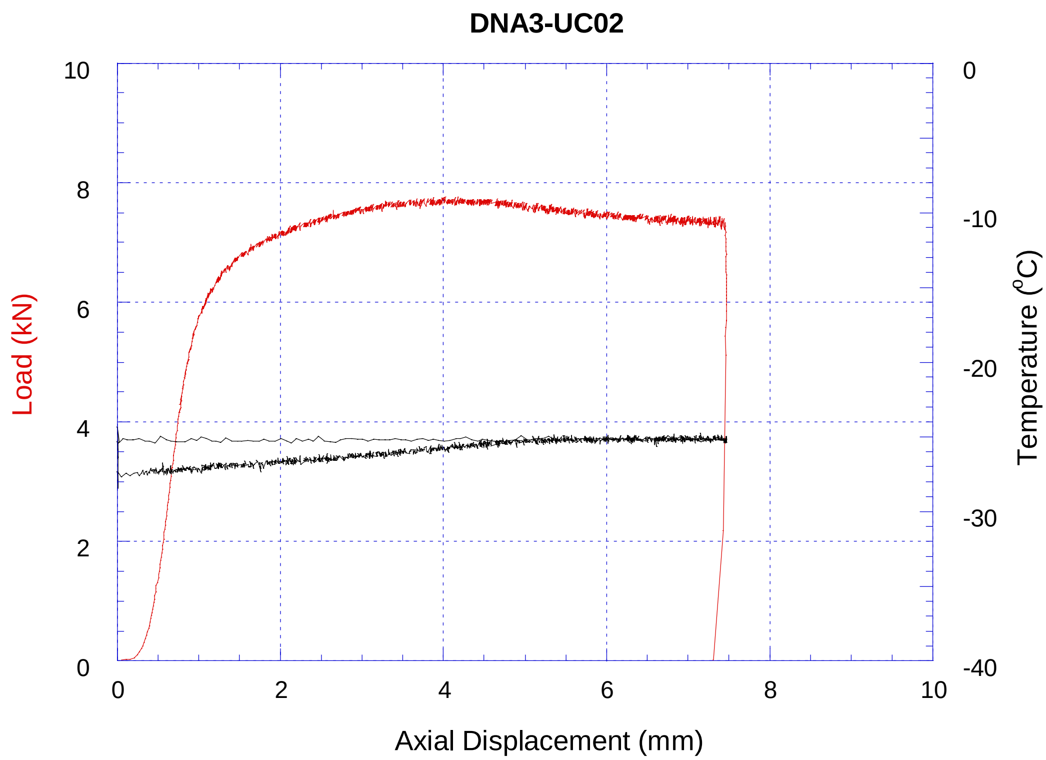
Appendix D

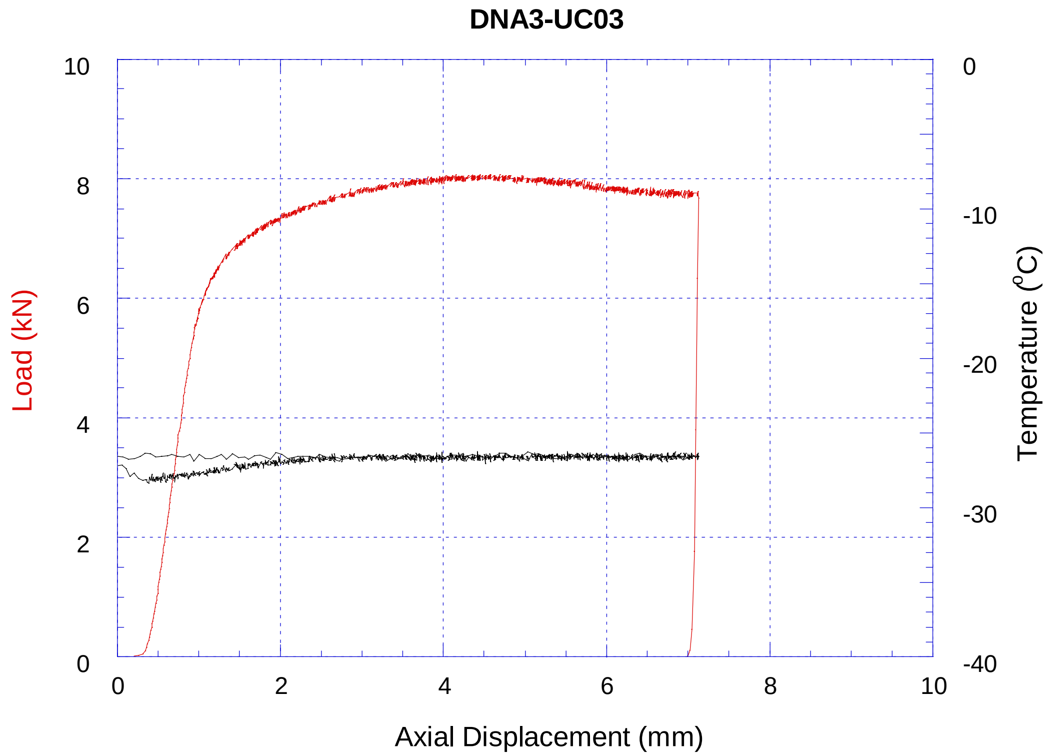
Load, Temperature vs. Displacement plots from Uniaxial Compression Tests for Intact and Fused Specimens

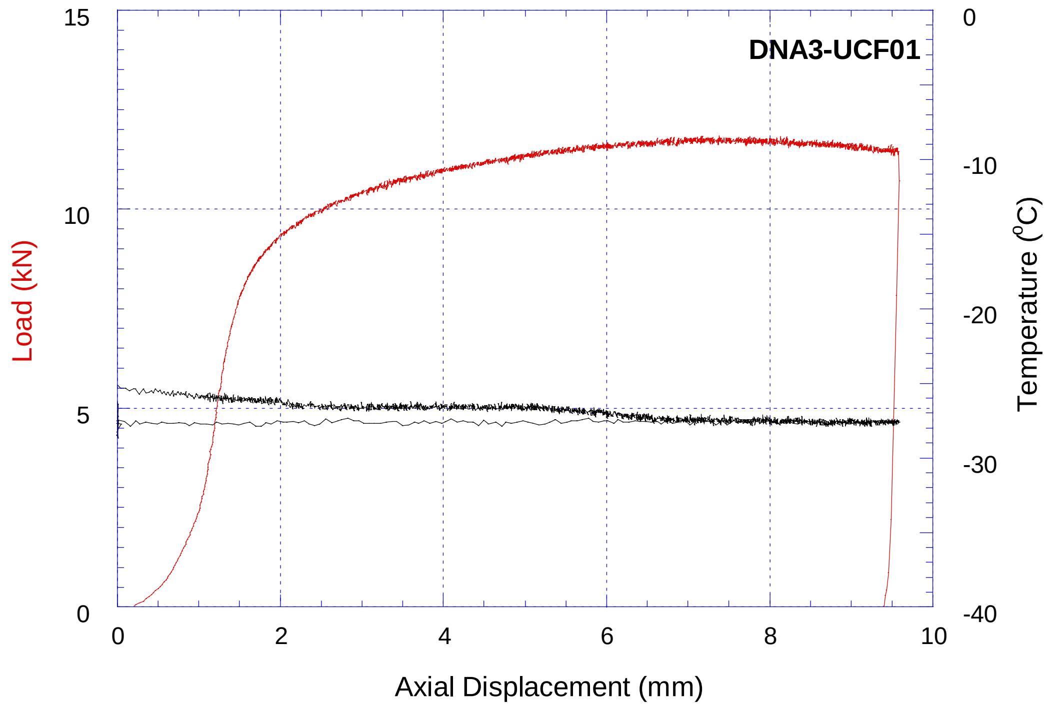
The title of the plot consists of three components:

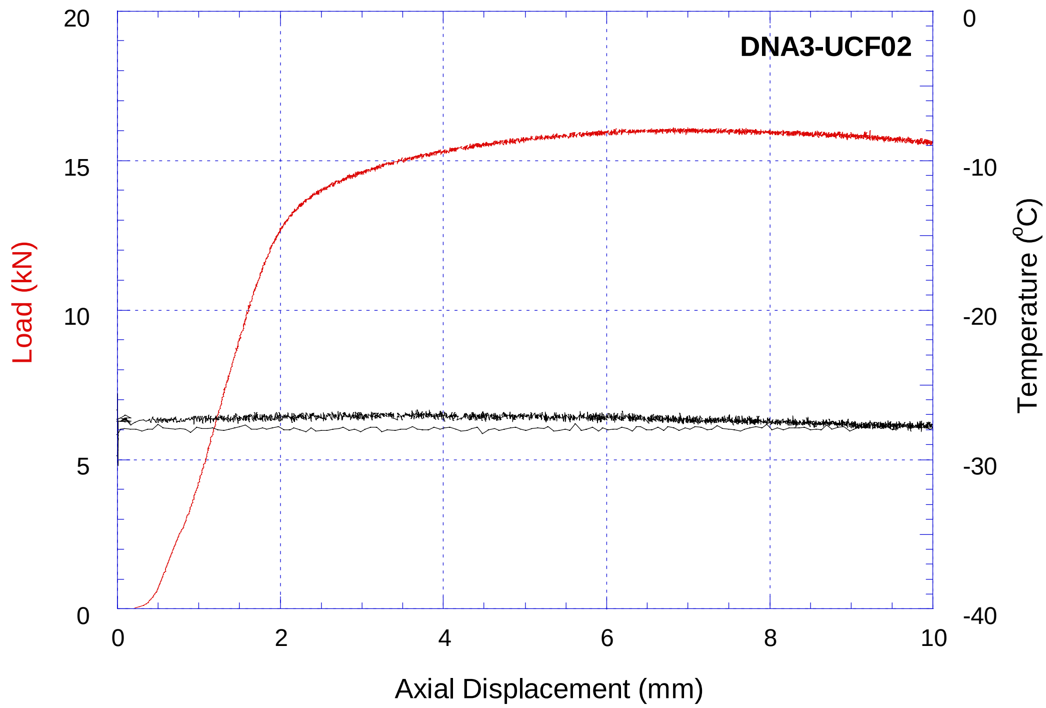
1. **Soil type**
   962, DNA1, DNA2, DNA3
2. **Test type**
   UC (uniaxial compression for intact specimen)
   UCF (uniaxial compression for fused specimen)
3. **Specimen designation**
   a,b,c… 01, 02…

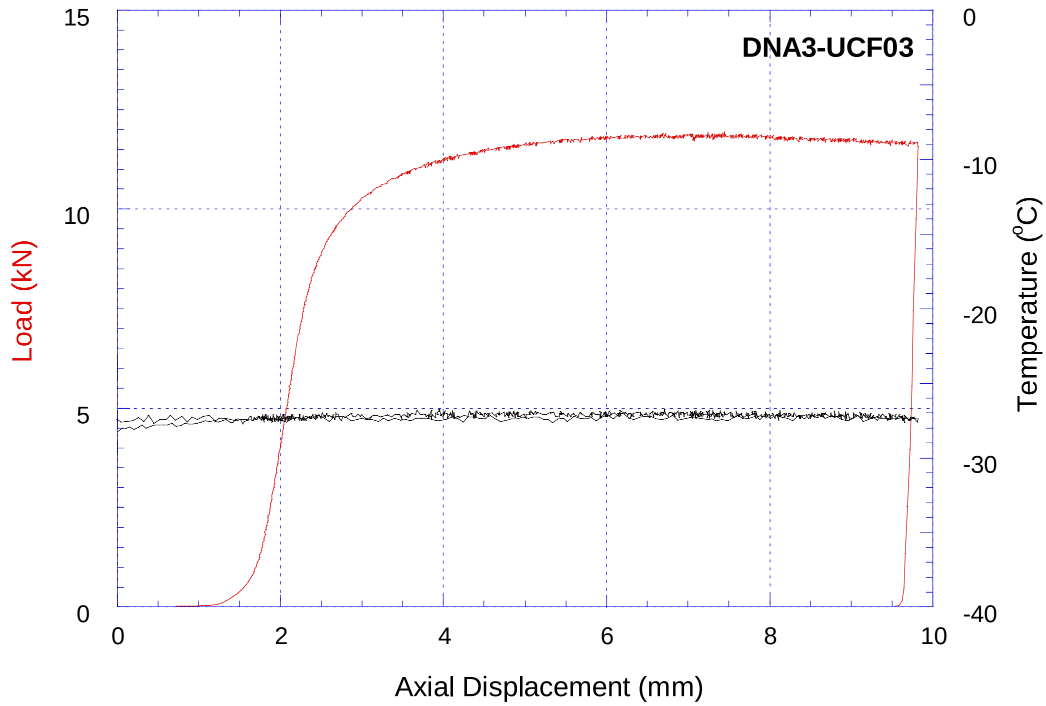

DNA3-UC01
Load (kN)
Temperature (°C)
Axial Displacement (mm)
0
5
10
15
20
0
-10
-20
-30
-40
0
2
4
6
8
10

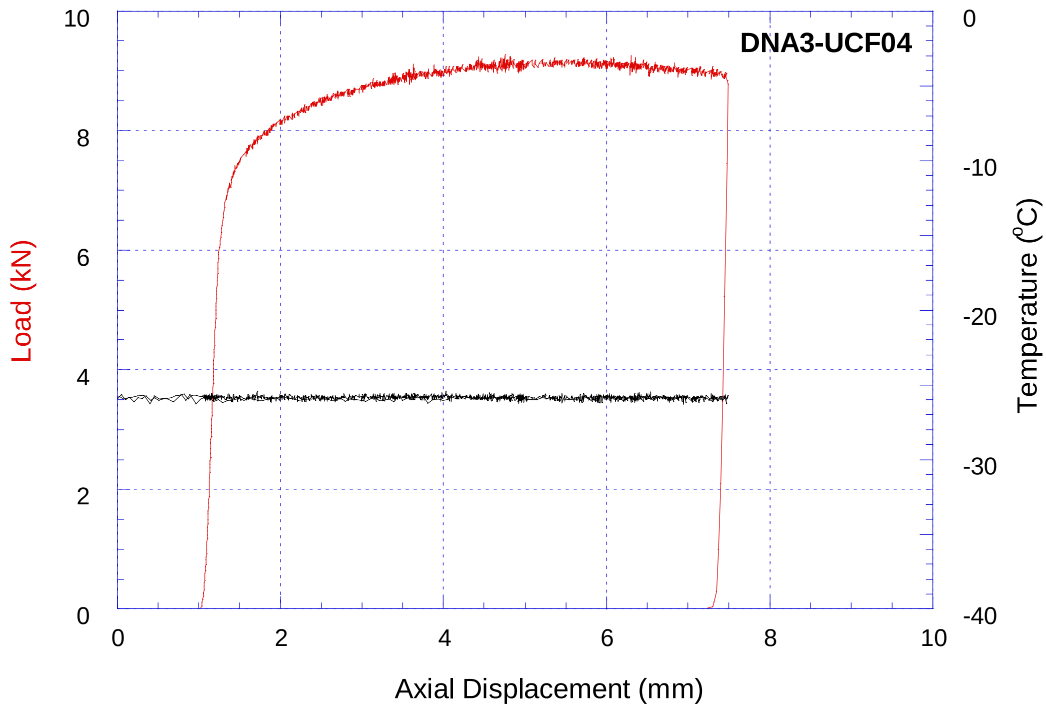

DNA3-UC02
Load (kN)
Temperature (°C)
Axial Displacement (mm)
0
2
4
6
8
10
0
-10
-20
-30
-40
0
2
4
6
8
10

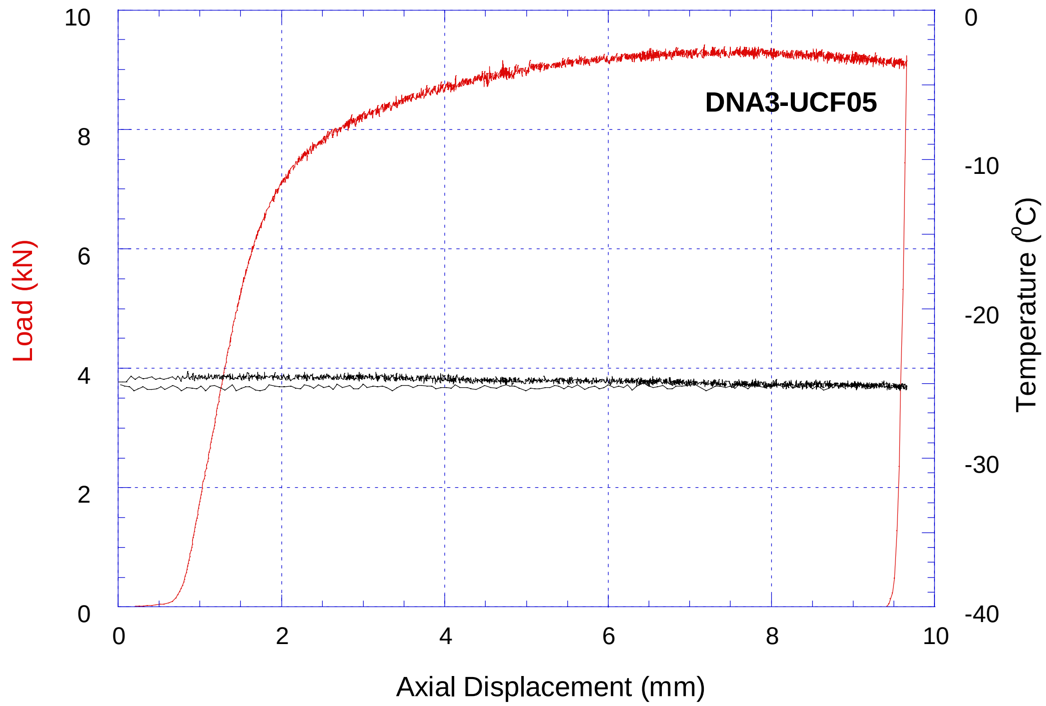

DNA3-UC03
Load (kN)
Temperature (°C)
Axial Displacement (mm)
0
2
4
6
8
10
-10
-20
-30
-40

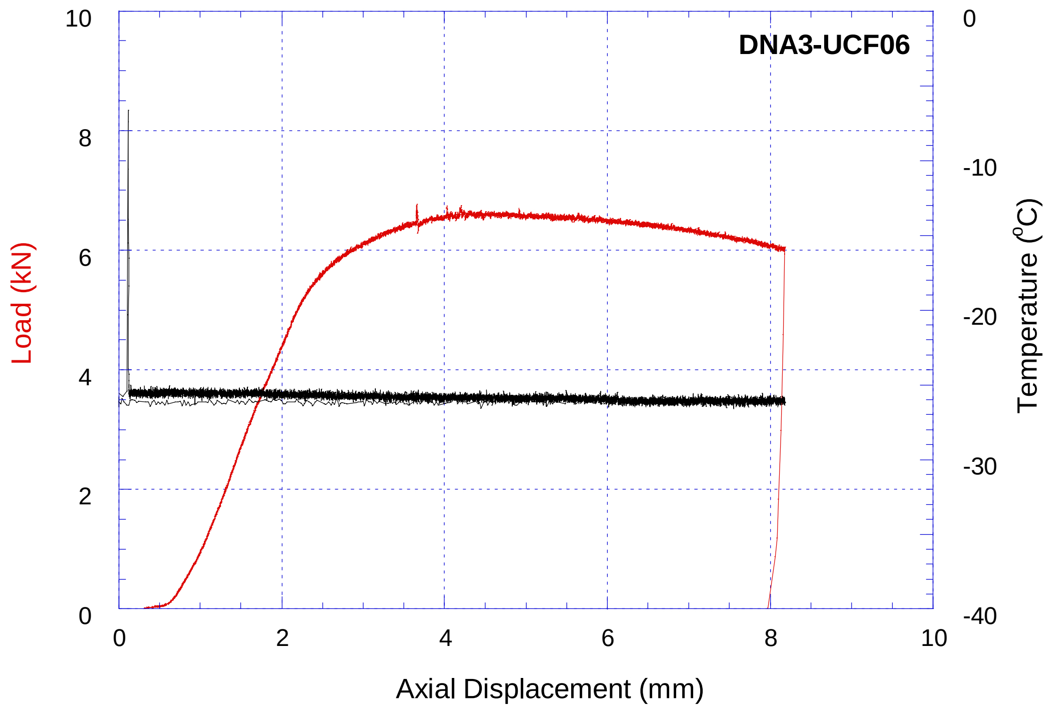

DNA3-UCF01
Load (kN)
Temperature (°C)
Axial Displacement (mm)
0
5
10
15
2
4
6
8
-10
-20
-30
-40

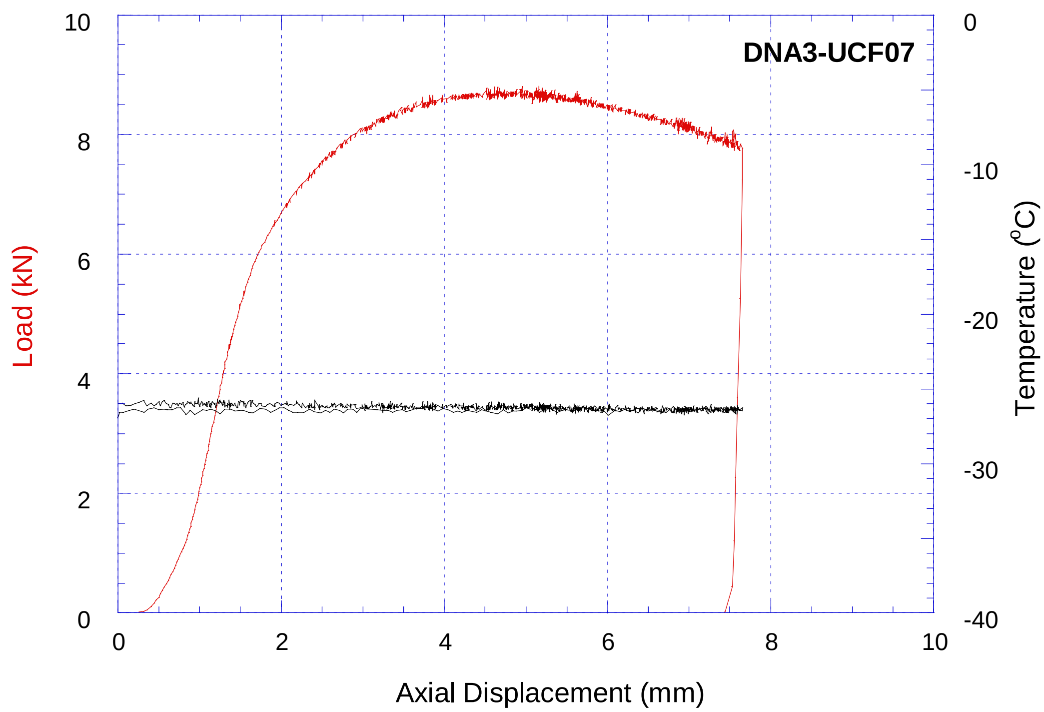

DNA3-UCF02
Load (kN)
Temperature (°C)
Axial Displacement (mm)
20
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10

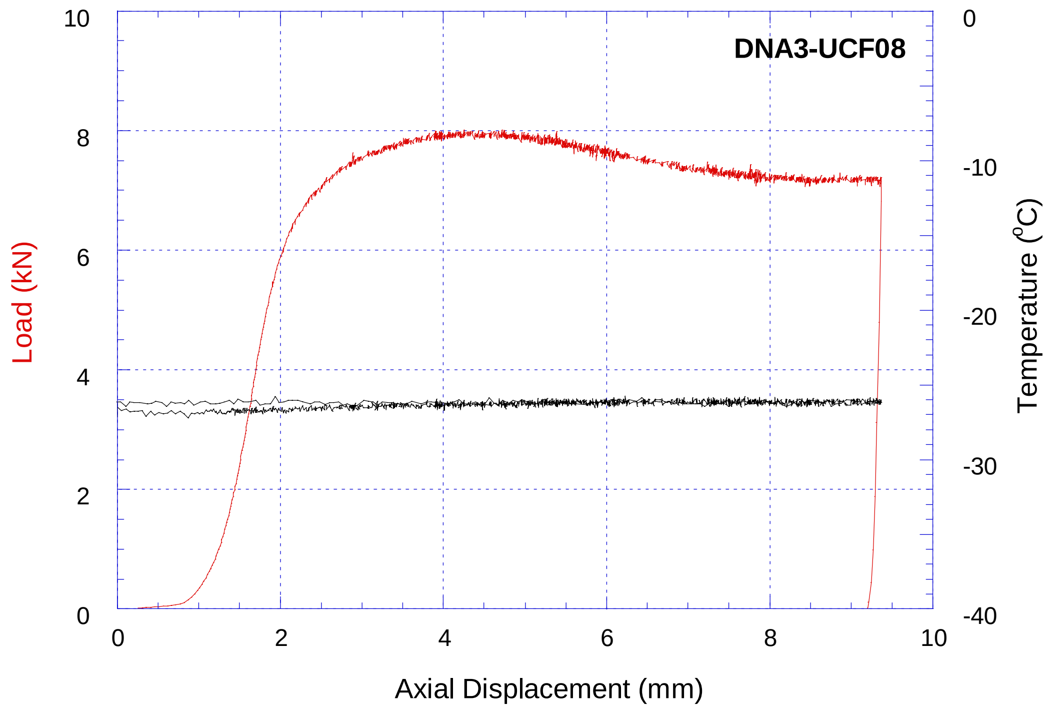

DNA3-UCF03
Load (kN)
Temperature (°C)
Axial Displacement (mm)
15
10
5
0
0
-10
-20
-30
-40
0
2
4
6
8
10


DNA3-UCF04
Load (kN)
Temperature (°C)
Axial Displacement (mm)
0
2
4
6
8
10
-10
-20
-30
-40


DNA3-UCF05
Load (kN)
Temperature (°C)
Axial Displacement (mm)
0
2
4
6
8
10
-10
-20
-30
-40


DNA3-UCF06
Load (kN)
Temperature (oC)
Axial Displacement (mm)
10
8
6
4
2
0
0
-10
-20
-30
-40
0
2
4
6
8
10


DNA3-UCF07
Load (kN)
Temperature (oC)
Axial Displacement (mm)
10
8
6
4
2
0
0
-10
-20
-30
-40
0
2
4
6
8
10


DNA3-UCF08
Load (kN)
Temperature (°C)
Axial Displacement (mm)
0
2
4
6
8
10
-10
-20
-30
-40

APPENDIX E

List of Data and Supplemental Files Archived in Webfileshare System

List of files archived in the WEBFILESHARE system (https://wfsprod01.sandia.gov).

Folder Name	File Name	Description
/TARGET/frozen soil interface	FS Interface-SAND.doc	This SAND report (SAND2004-5007)
/TARGET/ frozen soil interface	FS Interface-master.xls	Master data file consists of the following three worksheets: **Phase 1**: Test data for selection of soil mixture **Phase 2**: Test data for Selection of fusing method **Phase 3**: Test data for Evaluation of frictional strength of fused interface
/TARGET/frozen soil interface	FS Interface.ppt	Power-point presentation of the test results.

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